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COMPUTER ASSISTED THERMAL-VACUUM TESTING

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ABSTRACT

In testing complex systems and components under dynamic thermal-vacuum environments, it is desirable to optimize the environment control sequence in order to reduce test duration and cost. Additionally, it is necessary to maintain cognizance of critical trends during the test in order to assure safety of the equipment. This paper describes an approach where a computer is utilized as part of the test control operation in order to achieve these aims. Real time test data is made available to the computer through a time-sharing terminal at appropriate time intervals. A mathematical model of the test article and environmental control equipment is then operated on using the real time data to yield current thermal status, temperature analysis, trend prediction and recommended thermal control setting changes to arrive at the required thermal condition. The program logic flow is developed in relation to facility equipment capabilities, the need to keep a person in the control loop, and the need for real time update of program constants in order to provide successful application on first use. The data acquisition interface and the time-sharing hook-up to an IBM-370 computer is described along with a typical control program and data demonstrating its use.

INTRODUCTION

The objective of thermal-vacuum testing is to expose systems and their components to representative thermal and vacuum environments in order to verify design performance, reliability and proper manufacturing. Typically, this is done by placing the system in a vacuum chamber, outfitted with heat sinks and heat sources. A thermal balance is obtained, controlling the system to the desired temperature levels and distribution defined by predetermined criteria. Test monitoring involves select data reduction, temperature averages of specific areas of the test article, and a visual history of the test progress by plotting of selected temperatures.

Although practical and workable, this type of approach results in variations from test to test and operator to operator. The approach does not provide any firm basis for trend prediction and relies on the operator to accurately anticipate and respond to temperature changes as they occur. Therefore, a method of real time test data analysis and trend prediction was devised to optimize the environmental control sequence and to assure

proper safety of the equipment. The method is based on utilization of a computer and a mathematical thermal model of the test article as a decision tool in controlling the test.

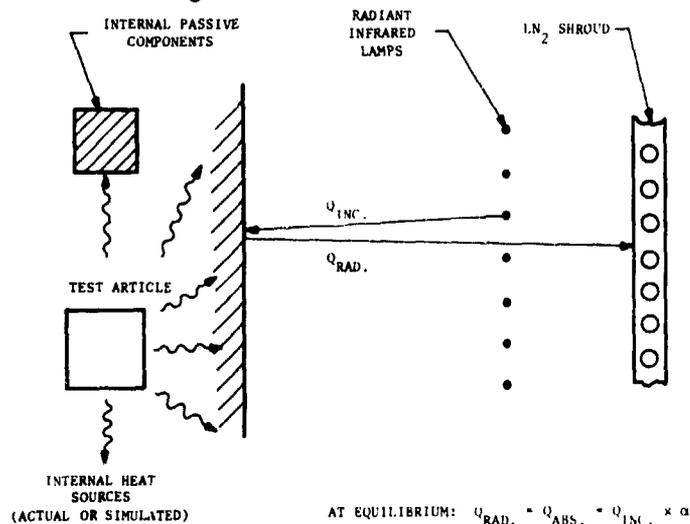


Fig. 1-Typical test setup

A typical test setup is shown schematically in Figure 1. The test is primarily controlled by controlling the incident heat flux on the test article surface from zoned arrays of infrared lamps. The flux level is set to establish a heat balance between energy absorbed by the surface from the lamps and that radiated by the surface to the cold sink, normally a liquid nitrogen cooled shroud, to yield and maintain a predetermined test article surface temperature. Additional heat control zones are employed to simulate internal heat sources and to control other thermal interfaces, such as test mounts and other specialized areas where lamp heat input is not practical.

Typically, servo controls are used to control lamp and heater power supplies, and real time temperature and alarming indicators provide first order test performance information and safety control.

This paper will first discuss the approach for utilizing the computer in the test control process. The program logic flow will then be developed. Finally, sample programs will be discussed for specific test setups to demonstrate the program approach.

DISCUSSION

In order to integrate the computer into the test control loop, it is necessary to first develop an approach which will make this practical and reliable. Among the parameters to consider, the most important are the methods of interfacing to the computer, the data reduction necessary, and a thermal model and its use of the reduced data, including trend analysis/prediction. An additional consideration is the requirement to maintain the capability to revert to simple, operator-based evaluation and control methods in case of computer problems, emergencies such as power failures, or obvious failures of the actual test to respond as predicted by modeling.

Making data available to the computer entails taking data generated by the data system and converting it to a form which is compatible with the computer. Generally, this will require that the data be recorded on some intermediate medium, such as punched paper tape or magnetic tape, since thermal data loggers are generally too slow to input directly to the computer. This will be especially true if the computer is a time-sharing system rather than a dedicated device. The subsequent discussions will be based on interfacing to a time-sharing system.

The introduction of an intermediate data storage medium will, however, make the system near-real time rather than real time in that data would be processed in "batches" at discrete intervals rather than continuously. Thus, the frequency of need to look at temperature progression during the test will dictate the quantity of data points that must be handled for each evaluation and will thus influence the design of the thermal model to be employed.

To be really effective in utilizing the computer, the thermal model should be as simple as possible. This is desirable so that the run time is reasonable. As will be developed later on, the use of the thermal model may require its solution for more than one case in carrying out the trend analysis/prediction. Nevertheless, while simplicity is desirable, it must not be achieved at the expense of maintaining a reasonable degree of faithfulness to the true thermal response of the system. Experience in thermal-vacuum testing indicates that even highly complex test articles can be modeled using simple models of less than 10 nodes. In some cases, thermal modeling may be adequately accomplished by simply utilizing the data in a temperature map, the temperature map itself being the thermal model.

Once a thermal model has been decided on, the information that it generates will dictate how it might be used in analyzing trends and providing predictions. Models that permit computation of temperature changes can realistically provide a basis for predicting where temperatures are likely to go for given boundary conditions. By varying the boundary conditions, it is possible to determine what changes should be made in these boundary conditions for optimum thermal control. In this case, the program can be made truly predictive, providing the operator with a recommendation for changing the environment and showing where the current trends will lead.

If the model is simply a temperature map, then the visual display can be utilized by the operator to evaluate his current status. In conjunction with the maps generated from earlier data, it is possible for the operator to see current trends and deduce where these trends will lead. More reliance is placed on the operator's judgment in this instance, but sufficient data is supplied in a timely fashion to permit him to intelligently make these assessments.

In order to implement the test performance calculations by means of the thermal model, a set of programs for the computer are prepared. These programs are generally grouped into two categories: i.e., the executive program and the performance calculation program. These programs are normally resident in the computer memory during the period that they are needed for test use.

The executive program controls the computer operation. It performs such functions as identifying the storage locations for the input and output data. It also organizes various output data in temporary storage,

making it available in proper sequence to future needs of the program, either for this run or subsequent runs of the program. It will also specify the order of execution of the performance programs. The actual form of this program is determined by the particular operating system used by the computer.

The performance program or programs (often, more than one performance program is executed) would normally be written in a language such as FORTRAN. The thermal model, whether it be the temperature map or true mathematical model, is executed in these programs. Trend data is generated using the model, and if predictions, including instructions to the operator, are to be made, this program is the one which would generate them.

These programs must be prepared so as to provide the operator with the required information in a timely manner. They must further be conceived in such a manner that the operator remains personally aware of what is happening from point to point so that in an emergency, a return to pure operator data evaluation and control action can occur immediately, or in less severe cases, the operator will intervene when it becomes obviously necessary to ignore computer-generated recommendations.

A very definite additional benefit of employing the computer in test control operations in this manner is in the area of test data handling, storage, and future use. Since all data, calculations, and control recommendations can be stored on a medium such as magnetic tape, additional post-test analysis and evaluation can be carried out easily because the data is already available in a form suitable for ready recall and further analysis.

To illustrate an actual implementation of computer use as described above, representative test programs are described.

Illustrative Examples of Representative Test Programs

To demonstrate the use of the computer during a test program, two specific examples will be considered. The first case uses a simple mathematical model to compute changes for given changes in the boundary conditions, i.e., the controlling environment, while the second case uses the temperature map as its thermal model. These examples will demonstrate the range of sophistication that can be achieved using the computer.

Mathematical/Thermal Model in Test Control--To demonstrate the successful use of the simple mathematical model with the computer, a test program involving a test article/test environment control system shown schematically in Figure 2 will be discussed. The objective of this test program is to change the mean temperature of the test article from a start temperature of +70°F (21.1°C) to a stabilized test temperature of approximately +90°F (32.2°C). To carry out such a test efficiently and cost effectively, it must be accomplished in a minimum amount of time.

The thermal model of the test article is simply three nodes coupled to the environment as shown schematically in Figure 2. The three nodes represent key internal elements of the test article, and it will be the stability of these elements that will determine the final stability of the test article. This is a uniform temperature condition that is to be achieved and, therefore, the environmental control surfaces will all be set to the same uniform temperature levels.

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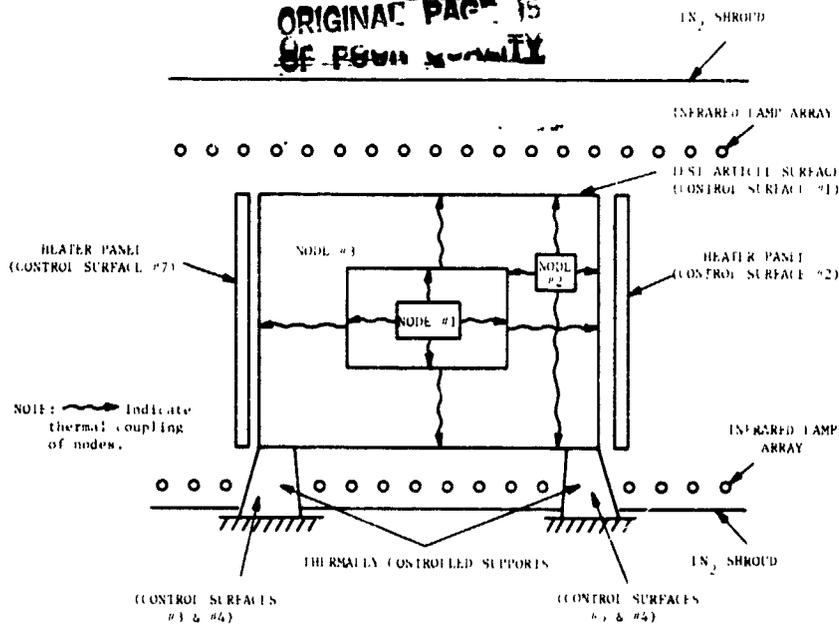


Fig. 2-Mathematical model test setup

Figure 3 shows the electrical analog for this model. The equations covering this model are:

$$m_1 C p_1 \frac{dT_1}{dt} = \epsilon \sigma A_1 F_{1-3} (T_3^4 - T_1^4) \quad (1)$$

$$m_2 C p_2 \frac{dT_2}{dt} = \epsilon \sigma A_2 F_{2-CS} (T_{CS}^4 - T_2^4) + \epsilon \sigma A_2 F_{2-3} (T_3^4 - T_2^4) \quad (2)$$

$$m_3 C p_3 \frac{dT_3}{dt} = \epsilon \sigma A_3 F_{3-CS} (T_{CS}^4 - T_3^4) + \epsilon \sigma A_1 F_{1-3} (T_1^4 - T_3^4) + \epsilon \sigma A_2 F_{2-3} (T_2^4 - T_3^4) \quad (3)$$

where:

- m = mass of node
- Cp = specific heat
- T = temperature
- ϵ = emissivity
- σ = Stefan-Boltzmann Constant
- A = area
- F = view factor
- dt = time increment
- dT = temperature increment

$$\begin{aligned}
R_{1-3} &= 1/\epsilon\sigma A_1 F_{1-3} \\
R_{2-3} &= 1/\epsilon\sigma A_2 F_{2-3} \\
R_{3-CS} &= 1/\epsilon\sigma A_3 F_{3-CS} \\
R_{2-CS} &= 1/\epsilon\sigma A_2 F_{2-CS} \\
C_1 &= mCp_1 \\
C_2 &= mCp_2 \\
C_3 &= mCp_3
\end{aligned}$$

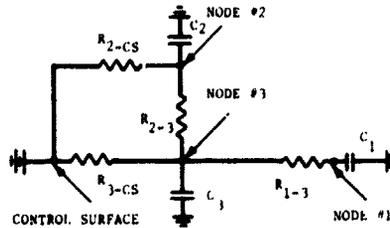


Fig. 3-Electrical analog of thermal model

Rearranging gives:

$$dT_1 = \left[\frac{\epsilon\sigma A_1 F_{1-3}}{m_1 Cp_1} (T_3^4 - T_1^4) \right] dt \quad (4)$$

$$dT_2 = \left[\frac{\epsilon\sigma A_2 F_{2-CS}}{m_2 Cp_2} (T_{CS}^4 - T_2^4) + \frac{\epsilon\sigma A_2 F_{2-3}}{m_2 Cp_2} (T_3^4 - T_2^4) \right] dt \quad (5)$$

$$\begin{aligned}
dT_3 = & \left[\frac{\epsilon\sigma A_3 F_{3-CS}}{m_3 Cp_3} (T_{CS}^4 - T_3^4) + \frac{\epsilon\sigma A_1 F_{1-3}}{m_3 Cp_3} (T_1^4 - T_3^4) \right. \\
& \left. + \frac{\epsilon\sigma A_2 F_{2-3}}{m_3 Cp_3} (T_2^4 - T_3^4) \right] dt \quad (6)
\end{aligned}$$

This set of equations can now be solved for change in temperature by substituting in present values for the temperatures on the right-hand side. By making the time increments small enough, good approximations can be obtained for this change in temperature. By adding the temperature to the current value, the new temperature for the given time increment is obtained. As a result, predicted temperature-time plots can be generated.

The key to making this model work is to obtain the correct values for the heat transfer coefficients. If there is sufficient knowledge of the test article, these coefficients may be calculated beforehand. However, the simplification involved in this modeling usually will preclude this. Instead, the model will have to generate its own corrections to these coefficients early in the test, based on the temperature history to that point.

Having now obtained the appropriate thermal model, the programs may now be developed. The control program consists of the executive program and the averaging and trend/prediction programs it executes. Figure 4 shows the logic flow of the executive programs for the two samples.



Fig. 4-Executive program logic flow

They are structured so that the data locations for use by the FORTRAN programs are defined prior to execution of the programs. After the data averaging program is run, the input and output data are stored for later transfer to magnetic tape. The trend/prediction program is run and its data is similarly stored. Interspersed throughout the program are a number of data file manipulations which cause the data to be arranged in the proper sequence in data files which will be accessed by subsequent execution of the control program. Note that return of the output data to the terminal is commanded by the executive program.

The data logger which generates the data used in the working programs is a Leeds and Northrup digital data system. It has a capacity for handling 576 channels of data in 24 banks of 24 points each. Individual banks can be selected for readout so that only those banks with the necessary data need be scanned. The data logger records its output on punched paper tape in ASCII code which is compatible with the computer terminal interface. The format of the output data on the paper tape was specially tailored so that it would be compatible with the time-sharing system. This included the use of appropriate character sequences to terminate data

records and the avoidance of characters which would cause unwanted reactions from the computer, e.g., characters such as "@" and "null character" are given special interpretations by the computer and cause unwanted responses from the system ("@" causes erasure of the previous character, and the "null character" causes the computer to ignore all remaining input on the record).

The punched paper tape produced by the data logger is then read into the computer via a time-sharing terminal. In this instance, the terminal was an RCA Teletype with a paper tape reader. This terminal gives a printout of the input data as it is read into the computer.

Additionally, the terminal serves the all-important function as the communications link with the computer. The commands which initiate data input and program execution are given via the terminal keyboard and the program output data is returned via the terminal printout.

The computer system is an IBM 370-158 with a Memorex 1270 time-sharing interface unit. The IBM 370 operating system is the VM/370 CMS. Each user is assigned disk storage on the system. User programs and data files reside on the disk storage. Since this disk storage is limited, permanent data storage is accomplished by transferring all desired data from temporary storage on the disk to permanent storage on magnetic tape. The temporary storage areas can then be reused for new data.

The VM/370 CMS operating system provides the means for program writing, compiling and execution, data file creation and manipulation, and the basic elements for executive programming. In addition, all other aspects of the time sharing operation are handled via this operating system.

The program input data is shown in Figure 5. This data is input to the computer prior to running the control program. It contains all the temperature data required by the programs. It is loaded into the computer utilizing the input mode of VM/370 CMS operating system. Once it is stored into its assigned location, the FORTRAN program will then be able to access it when the control program is executed.

The program output data is shown in Figure 6. The first grouping of data consists of the temperature averages of the specified control areas and the critical areas of the test article. The next grouping includes the computer-generated instructions for the operator and a prediction of the temperature trends for the next eight hours (assuming that the instructions are followed).

The slope computations use the results of the previous three hours. The sloping is based on a straight line approximation for the curve connecting the data points.

The instructions are based on the execution of the thermal model for values of the environment which are in the range of $\pm 5^{\circ}\text{F}$ ($\pm 2.8^{\circ}\text{C}$) on either side of the current setting in 0.5°F (0.28°C) increments. A weighting system is applied to evaluating the results of holding each of the environmental values for eight hours and scoring its effects on proper trend and the ability of the setting to achieve stability. The environmental setting with the best score is then selected as the proper setting to be given in the instructions to the operator. It is assumed that a uniform environment is the ideal and that all the control areas should be set to the same temperature level. This process is repeated for a total of eight hours with the exception that after the first hour, no further inputs are made to the instructions. This results in the eight hour prediction.

THERMAL TEST DATA

TEST CODE 100000

TIME: 237:11:00

01 01	+6.006 V	01 02	+6.933 V	01 03	+7.049 V	01 04	+6.812 V
01 05	+7.045 V	01 06	+6.819 V	01 07	+7.107 V	01 08	+6.930 V
01 09	+6.728 V	01 10	+1.398 V	01 11	+7.604 V	01 12	+5.373 V
01 13	+5.521 V	01 14	+5.376 V	01 15	+5.507 V	01 16	+6.869 V
01 17	+6.727 V	01 18	+6.928 V	01 19	+7.099 V	01 20	+5.117 V
01 21	+5.116 V	01 22	+6.911 V	01 23	+5.006 V	01 24	+6.609 V
02 01	+6.781 V	02 02	+5.853 V	02 03	+6.142 V	02 04	+6.573 V
02 05	+6.739 V	02 06	+6.874 V	02 07	+6.847 V	02 08	+6.709 V
02 09	+6.706 V	02 10	+6.316 V	02 11	+6.930 V	02 12	+6.821 V
02 13	-0.001 V	02 14	0.002 V	02 15	0.002 V	02 16	0.001 V
02 17	+5.378 V	02 18	+5.374 V	02 19	+5.507 V	02 20	+5.520 V
02 21	-3.706 V	02 22	-3.706 V	02 23	3.706 V	02 24	-3.705 V
08 01	T+239.1 C	08 02	T+239.1 C	08 03	T+239.1 C	08 04	T+239.1 C
08 05	T+239.1 C	08 06	T+239.1 C	08 07	T+239.1 C	08 08	T+239.1 C
08 09	T+239.1 C	08 10	T+239.1 C	08 11	T+239.1 C	08 12	T+239.1 C
08 13	+021.8 C	08 14	+022.5 C	08 15	+019.3 C	08 16	+020.4 C
08 17	+018.2 C	08 18	+016.3 C	08 19	+017.5 C	08 20	+017.0 C
08 21	+017.4 C	08 22	+018.5 C	08 23	+017.5 C	08 24	+019.3 C
09 01	+019.3 C	09 02	+019.3 C	09 03	+019.1 C	09 04	+016.3 C
09 05	+042.5 C	09 06	+038.4 C	09 07	+020.4 C	09 08	+021.4 C
09 09	T+082.6 C	09 10	+021.4 C	09 11	+026.4 C	09 12	+026.1 C
09 13	T+022.6 C	09 14	+026.9 C	09 15	+026.8 C	09 16	+024.4 C
09 17	+024.4 C	09 18	T+000.3 C	09 19	T+046.3 C	09 20	09 20 C
09 21	+020.5 C	09 22	+000.6 C	09 23	+000.3 C	09 24	+000.3 C
10 01	+021.2 C	10 02	+021.5 C	10 03	+021.1 C	10 04	+021.2 C
10 05	+021.0 C	10 06	+021.2 C	10 07	+020.2 C	10 08	+021.3 C
10 09	+021.4 C	10 10	+021.7 C	10 11	+021.1 C	10 12	T+018.4 C
10 13	+021.3 C	10 14	+021.4 C	10 15	+020.7 C	10 16	T+025.9 C
10 17	+020.3 C	10 18	+020.8 C	10 19	+020.1 C	10 20	+021.3 C
10 21	+021.6 C	10 22	+021.4 C	10 23	+020.9 C	10 24	T+007.8 C
11 01	+021.0 C	11 02	+021.4 C	11 03	+021.1 C	11 04	+020.8 C
11 05	+019.0 C	11 06	+021.3 C	11 07	+020.7 C	11 08	+022.6 C
11 09	+022.7 C	11 10	+023.0 C	11 11	+021.6 C	11 12	T+024.9 C
11 13	+023.6 C	11 14	+023.1 C	11 15	+020.8 C	11 16	+017.6 C
11 17	+013.1 C	11 18	+013.3 C	11 19	+014.7 C	11 20	+018.3 C
11 21	+020.3 C	11 22	+024.1 C	11 23	+024.0 C	11 24	+012.3 C
12 01	+023.1 C	12 02	+019.2 C	12 03	+021.1 C	12 04	+019.3 C
12 05	+020.4 C	12 06	+021.3 C	12 07	+026.1 C	12 08	+016.7 C
12 09	+019.0 C	12 10	+024.6 C	12 11	+021.1 C	12 12	+018.2 C
12 13	+018.5 C	12 14	+021.3 C	12 15	+018.5 C	12 16	+024.1 C
12 17	T+007.1 C	12 18	T+070.6 C	12 19	+018.0 C	12 20	+012.9 C
12 21	+011.3 C	12 22	T+013.0 C	12 23	+012.9 C	12 24	+012.7 C

END OF SCAN

137:31:12

Fig. 5-Program input data

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VM/CMS

09:04:00 >tdata
EXECUTION:
IHCOO2I STOP 1265
EXECUTION:
IHCOO2I STOP 1265

TEST CODE 100000
TIME: 237:11:00
NODE 1 = 21.1C
NODE 2 = 21.1C
NODE 3 = 20.9C
CONTROL SURFACE 1= 21.4C HIGH= 23.0C LOW= 19.0C
CONTROL SURFACE 2= 19.4C HIGH= 22.3C LOW= 16.3C
CONTROL SURFACE 3= 20.7C
CONTROL SURFACE 4= 21.1C
CONTROL SURFACE 5= 20.7C
CONTROL SURFACE 6= 20.6C
CONTROL SURFACE 7= 22.1C HIGH= 22.8C LOW= 21.2C
RJS ARE IN SPEC.

NODE 1 SLOPE= 0.5 C/24 HRS
NODE 2 SLOPE= 0.2 C/24 HRS
NODE 3 SLOPE= 0.2 C/24 HRS

INSTRUCTIONS:

CHANGE CONTROL SURFACE 1 -0.3C TO 21.2C
CHANGE CONTROL SURFACE 2 1.8C TO 21.2C
CHANGE CONTROL SURFACE 3 0.5C TO 21.2C
CHANGE CONTROL SURFACE 4 0.1C TO 21.2C
CHANGE CONTROL SURFACE 5 0.4C TO 21.2C
CHANGE CONTROL SURFACE 6 0.6C TO 21.2C
CHANGE CONTROL SURFACE 7 -0.9C TO 21.2C

PREDICTIONS:

TEMP r HR	1	2	3	4	5	6	7	8
NODE 1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1
NODE 2	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1
NODE 3	21.0	21.0	21.0	21.0	21.0	21.1	21.1	21.1
CONTROL SURFACE	21.2	21.2	21.2	21.2	21.2	21.2	21.2	21.2

QUERY DISK

A (191): 120 FILES; 680 REC IN USE, 912 LEFT (of 1592), 43% FULL (6 CYL)
. 3330, R/W

CONWAIT

LOG

CON= .185H VIRT= 3.318 CP= 2.56S ACCESS: D/T= 581 UR = 101
LOGOFF AT 09:05:00 EST FRIDAY 10/15/76

Fig. 6-Mathematical model program data output

To illustrate the effectiveness of this thermal model in practice, consider the test objective which is to change the mean temperature of the test article from $+70^{\circ}\text{F}$ to $+90^{\circ}\text{F}$ (21.1°C to 32.2°C). Figure 7 shows the temperature history for the test. Note that the technique used is to overtemperature the environment by 20°F (11°C) to accelerate the transition. An undercooling of the environment is then used to accelerate the stabilization at 90°F (32.2°C). The transition and stabilization can be accomplished in less than half the time it would ordinarily take if the desired test level, $+90^{\circ}\text{F}$ (32.2°C) were merely set into the environment and the test article was allowed to coast into stability at the new level with only this driving force.

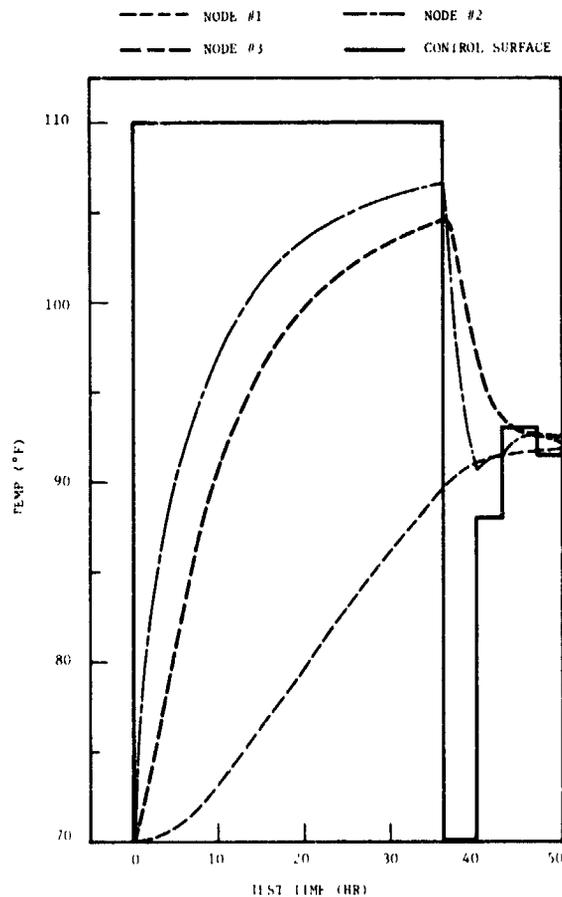


Fig. 7-Temperature history for $+70^{\circ}\text{F}$ to $+90^{\circ}\text{F}$ test

Figure 8 shows comparison of the actual temperature trends early in the transition to that predicted. The agreement here is poor. Correction of the heat transfer coefficients by the program yields a predicted curve that now closely tracks the actual data. With an accurate prediction, the computer can now give accurate instructions to the operator as the transition and stabilization progress.

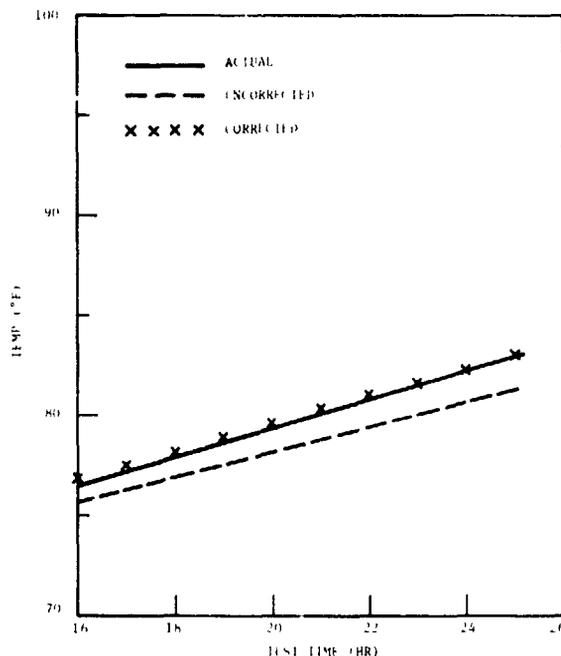


Fig. 8-Comparison of predicted temperature using corrected and uncorrected heat transfer coefficients

Temperature Map as a Thermal Model--A temperature map as a thermal model for computerized test control was successfully employed in the cryogenic testing of a beryllium mirror. The test program is described in detail in Reference 1. Briefly, the objective of this test was to test a beryllium mirror at various temperature levels from 300°K to 150°K in vacuum. Thermal and optical data was obtained after stabilization at the specified levels.

Thermal control of the beryllium mirror was achieved by surrounding the mirror with an 80°K, LN₂ shroud and using a matrix of heater wires to buck the heat transfer from the mirror to the shroud. The heater matrix was divided into five individually controlled zones. See Figure 9 for the test setup.

The temperature map used for the thermal model was based on mapping all the available temperature data from the mirror itself. In instrumenting the mirror, sensor placement was selected so that as complete a map as possible would be given with a reasonable number of sensors. Figure 10 shows the sensor locations on the mirror.

The program output is shown in Figure 11. The first grouping of data is the temperature map. This is followed by the temperature averages of critical areas of the beryllium mirror and of the controlling environment. The final grouping gives the scope of critical areas of the mirror.

Review of this output data allows the operator to see the test progress and to readily evaluate the trends. By comparing the current results with those from previous hours, it is possible to make intelligent evaluation of the current environmental settings and decide on the necessary changes. Also, the slope data gives a ready means for tracking stability.



Fig. 9-Beryllium mirror test setup

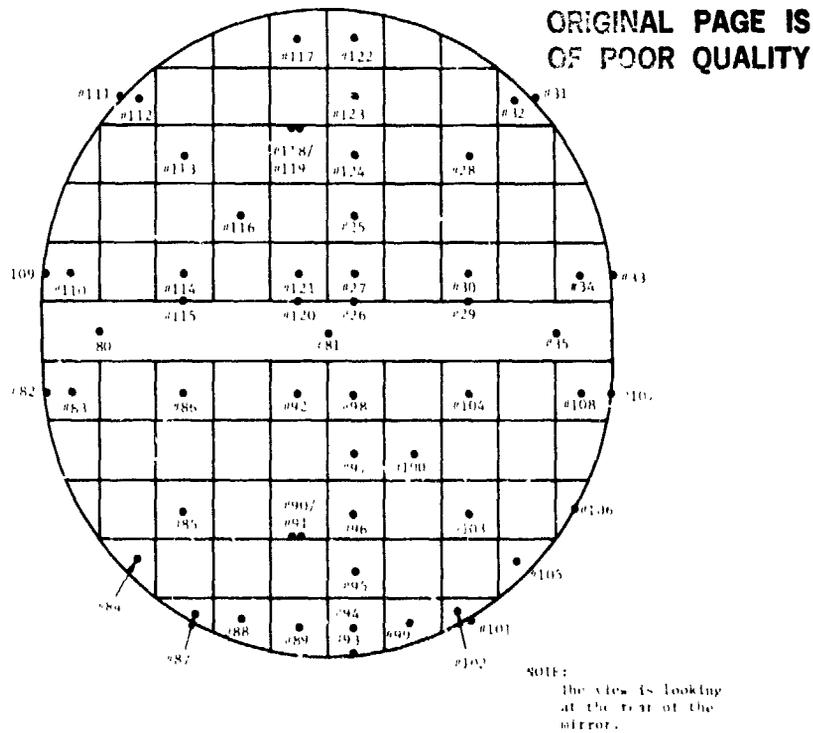


Fig. 10-Thermocouple locations flat beryllium mirror

08:38:09 LOAD LDATA (XEQ)
 EXECUTION:
 TYPE IN CHAMBER PRESSURE
 >4.8E-03,
 TIME:207:12:87

```

                                -78.0 -76.8
                                -77.1
                                -77.1
                                -76.8
                                -77.1
                                -77.9
                                -78.0
                                -77.9
                                -78.4
                                -77.3
                                -76.5
                                -77.0
                                -76.6 -77.2
                                -77.7
                                -76.3
                                -76.6
                                -76.3
                                1001.0
                                -77.7
                                -79.0
                                -77.1 -77.2
                                -78.7
                                -76.8
                                1001.0 -76.6
                                -77.7
                                -76.8
                                -77.8
                                -77.5
                                -79.8
                                -77.9
                                -76.9
                                -77.0
                                -79.4 -77.01001.0 -78.3
  
```

MIRROR AVE= -77.50 HIGH= -76.30 LOW= 79.80
 TUBE AVE = -77.20
 VERT GRAD = 1.70
 HORIZ GRAD= 0.80
 SHROUD AVE=-184.80 INLET=-182.60 OUTLET=-184.90
 CHAMBER PRESSURE= 0.480E-02
 IHCOO21 STOP 1265
 !!! E(01265) !!!
 TYPE IN PLS1 HOUR
 >37
 08:40:59 LOAD LDATA1 (XEQ)
 EXECUTION:
 MIRROR SLOPE= 3.00
 TUBE SLOPE = 3.00
 IHCOO21 STOP 1265
 !!! E(01265) !!!
 08:41:26 STAT
 P (191): 43 FILES; 306 REC IN USE, 486 LEFT (OF 792), 39% FULL (3 CYL)
 08:41:26 ^LOG
 CON= .176H VIRT= .99S CP= 1.62S ACCESS: D/T= 309 UR= 0
 LOGOFF AT 08:41:45 EDT SATURDAY 07/26/75

Fig. 11-Program output for beryllium mirror

SUMMARY

This paper has described a practical approach which can bring the computer into the thermal-vacuum test control loop, resulting in savings of both time and cost for running such a test. In addition, the use of the computer will tend to reduce variations in the efficient execution of a test from operator to operator and the errors which can accompany this type of testing.

For the future, improvements and expansion of capabilities is possible. This approach can be made even more efficient with an improvement in the computer interface by utilizing magnetic tape and a high speed video terminal in place of the punched paper tape and slower teletype.

The current uses of the computer discussed do not begin to fully utilize the capabilities of the computer. For example, time plots of the type shown in Figure 7 could be routinely generated as part of the data reduction, adding to the operator's bank of data for tracking the progress of the test.

Although not necessary in every application, data reduction and analysis for design purposes is often needed. Usually, this is done after the fact with these necessary results normally appearing days or even weeks after the test is completed. However, by integrating these data reduction and analysis requirements into the test control programs, the complete test results can be available as the test is completed.

The integration of the computer into the thermal-vacuum test control loop is practical and desirable. A significant improvement in the quality of testing has resulted for the applications discussed above and the future will see even greater improvements in the test quality.

REFERENCES

1. Mikk, G., "Cryogenic Testing of a Beryllium Mirror", presented at the SPIE Proceeding, August 1975.