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Further Development of The Dynamic Gas Temperature Measurement System*

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SUMMARY

Two experiments for verifying the frequency response of a previously-developed dynamic gas temperature measurement system have been performed. The first involves a rotating wheel and gas manifolds alternately introducing heated and ambient air to the sensors. The second involves a high-temperature atmospheric pressure burner which produces a wide band temperature spectrum. In both experiments, fine-wire resistance temperature sensors were used as standards, and the compensated dynamic temperature sensor data will be compared with the standards to verify the compensation method. In the rotating wheel experiment, knowledge of the air supply temperatures and repetition frequency provides an additional check on the compensated data. In the burner experiment redundant sensors were employed, and uncompensated data from different combinations of sensors will be used in the compensation algorithm. The two experiments are described in detail. A short description of the numerical compensation method and software revisions in the past year are described.

INTRODUCTION

The measurement system developed in reference 1 uses a compensated two-element thermocouple probe. The compensation technique uses the ratio of signal amplitudes from the two thermocouples' passive responses to gas temperature variations. Comparisons with a numerical heat transfer model allow compensation of temperature fluctuations to above 1KHz. Two-element sensors were used in atmospheric pressure burners and gas turbine engines in reference 1, and demonstrated durability required for these test environments. In addition, compensated data were generated.

The objectives of the present program are to: 1) verify experimentally the frequency response of the dynamic gas temperature measurement system; 2) optimize the computer compensation method for execution speed; and 3)

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to implement the reference 1 computer code in Fortran IV for use on generally available computers.

The program is organized into four basic tasks including (1) frequency response experimental verification: (2) compensation code execution streamlining; (3) implementation of the compensation code in Fortran IV; and (4) data acquisition at NASA Lewis Research Center. This progress report will describe progress since the October 1984 HOST meeting (reference 2). Efforts in tasks 2 and 3 are complete. The experiments of task 1 have been performed and data analysis is underway. The numerical compensation method has been streamlined for execution on an IBM3081 computer in Fortran.

FREQUENCY RESPONSE VERIFICATION EXPERIMENTS

Reference 2 describes twelve conceptual experiments for verifying the measurement system compensation system. From the twelve, two were selected for detailed design, fabrication and execution. Both set-ups have capability to generate minimum peak-to-peak fluctuations of 278K (500°F) at Mach numbers greater than 0.1 and frequency content to 250Hz. The experiments are described in detail below.

Rotating Wheel

The rotating wheel experiment consists of a hot gas manifold supplying 568K (563°F) air, a cold gas manifold supplying ambient air at 291K (63°F), a wheel with eight holes in the periphery, a bifurcated collection manifold, and the dynamic temperature sensor (Figure 1). The wheel is driven by an electric motor at rotation rate N revolutions per second. The hot gas and adjacent ambient air manifolds exhaust into the plane of the wheel such that one opens into a hole on the wheel and the gas is collected by one leg of the collection duct as the other manifold and collection duct leg are blocked. Then, as the hole rotates beneath the adjacent manifold, its gas flows to the second leg of the bifurcation duct, and the first gas supply is blocked. The common leg of the collection duct in turn exhausts alternate hot and ambient air streams onto the dynamic temperature sensor. The resultant flow generated consists of an approximate square wave pulse train of frequencies from 20Hz to 250Hz and peak to peak amplitude of the hot air supply temperature minus the ambient air supply temperature.

The dynamic temperature sensor and a fine-wire anemometer resistance thermometer are mounted in the collection duct discharge stream. The fine wire anemometer is used as a temperature measurement standard. Uncompensated frequency response of the fine wire thermometer was computed from a theoretical model, the probe geometry, and the gas path parameters to be approximately 350Hz (1st order response). An existing Pratt and Whitney-designed analog compensation amplifier was set up to provide the inverse function (1st order RC high pass filter with Fc = 350Hz) for use in extending the frequency roll-off of the sensor. Dynamic temperature sensor and fine wire thermometer data were recorded on FM tape. The dynamic temperature sensor data will then be compensated using the method described in reference 1. Comparison between the fine wire resistance signals, known frequency and amplitude inputs generated by the apparatus, and the compensated dynamic temperature sensor signals will then be made.

Figures 2 through 4 show three views of the experiment. Figure 5 shows the two-wire dynamic temperature sensor used in these experiments. The two-wire sensor consists of two thermocouple elements constructed using Type K material. The junctions were formed using a technique that produces no bead and thus a uniform cylindrical cross section, which simplifies the analysis and compensation. The two elements were fabricated using 76 μm (.003 inch) and 254 μm (.010 inch) diameter wire. The support wires are 381 μm (.015 inch) and 508 μm (.020 inch) in diameter. The probe was inspected prior to testing to determine actual dimensions and the results are presented in Figure 6.

Atmospheric Pressure Burner

Measurements taken under the previous contract (reference 1) characterized the atmospheric burner flowfield as having large (> 500°F p-p) temperature fluctuations. Verification of the compensation algorithm using burner data by compensating both small (76 μm) and large (254 μm) thermocouple signals and comparing results was done. This comparison is to be extended under this effort by adding an intermediate size thermoelement (127 μm) and a fine-wire resistance thermometer. Compensations then may be done with three combinations of thermocouples: 76 μm-254 μm; 76 μm-127 μm; and 127 μm-254 μm. Compensated spectra for the three pairs may also be compared with the fine-wire resistance thermometer.

The dynamic temperature sensors shown in Figure 7 consist of one probe with 127 μm (.005 inch) and 254 μm (.010 inch) diameter elements and another probe with a single 76 μm (.003 inch) diameter element. The elements were constructed with Type B thermocouple material and have beadless junctions. The probes tested were inspected and the results are shown in Figure 8. The fine-wire resistance thermometer was fabricated using 8.3 μm (.00025 inch) and 12.7 μm (.0005 inch) diameter elements.

Figure 9 is a diagram of the burner setup. The dynamic temperature sensors, a fine wire resistance thermometer, and a total pressure impact tube were mounted together to obtain a close spatial relationship as shown in Figure 10. The sensors were then mounted downstream of the burner which was run at the minimum operating combustion temperature due to the structural limits of the fine-wire thermometer sensor. Figure 11 is a photograph of the experiment with approximately 1367K (2000°F) flowfield. The sensors were located approximately 28 cm (11 inches) from the burner nozzle exit plane.

COMPUTER CODE OPTIMIZATION

Task 2, involving compensation code execution streamlining, and Task 3, involving implementation of the compensation code in Fortran, are both complete. The reference 1 numerical method calculates thermocouple response at several frequencies, and the compensation spectrum is obtained by cumulating results of several calculations (Figure 12). This approach was originally implemented on a Hewlett-Packard 5451C Fourier Analyzer, and reprogramming into Fortran and optimization for execution time was required for practical, repeated use. The reference 1 approach was retained in the reprogramming software. Execution time for a typical data set was reduced to about 3 minutes of IBM 3081 computer time as compared with about 2 hours on the HP5451C. The upgraded compensation software is now in routine use, and will be used to compensate data from the previously described experiments.

DATA ANALYSIS

Data taken in the two experiments described above will be analyzed and results will be presented at the next HOST meeting.

REFERENCES

1. Elmore, D.L., Robinson, W.W., and Watkins, W.B., "Dynamic Gas Temperature Measurement System", NASA CR-168207 (May, 1983). This work is summarized in ISA Transactions 24, No. 2, P. 73-82.

2. Elmore, D.L., Robinson, W.W., and Watkins, W.B., "Further Development of the Dynamic Gas Temperature Measurement System", in Turbine Engine Hot Section Technology, NASA CP-2339 (October, 1984).

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ROTATING WHEEL EXPERIMENT

Test Configuration

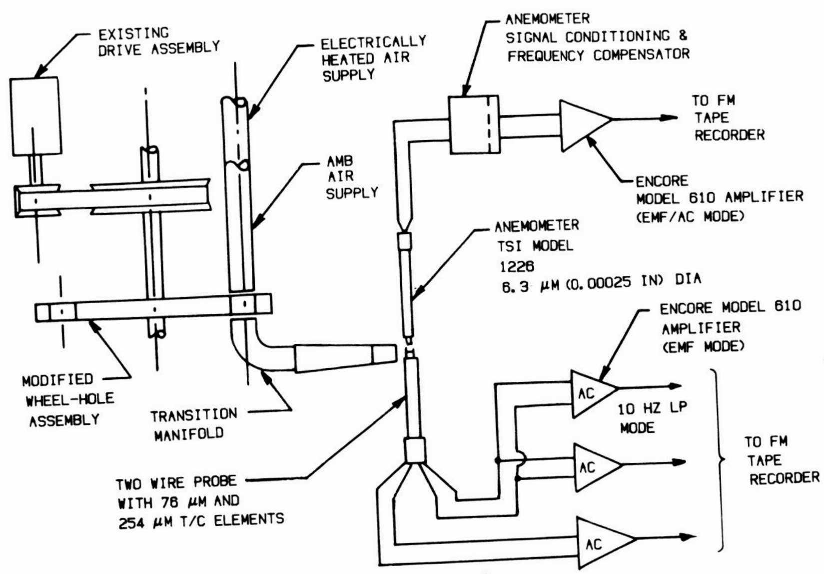


FIGURE 1

ROTATING WHEEL EXPERIMENT

Test Apparatus - Overall View

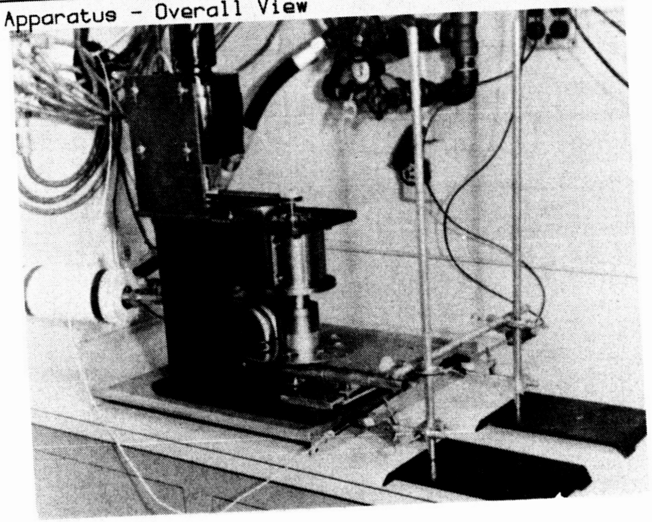


FIGURE 2

ROTATING WHEEL EXPERIMENT

Test Apparatus - Wheel/Manifold Detail

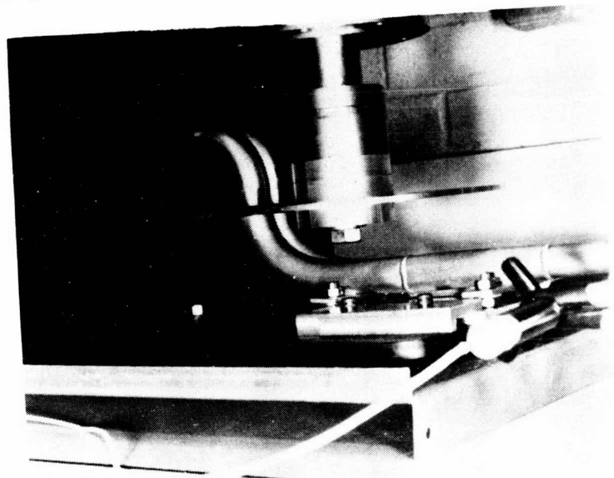


FIGURE 3

ROTATING WHEEL EXPERIMENT

Test Apparatus - Probe Detail

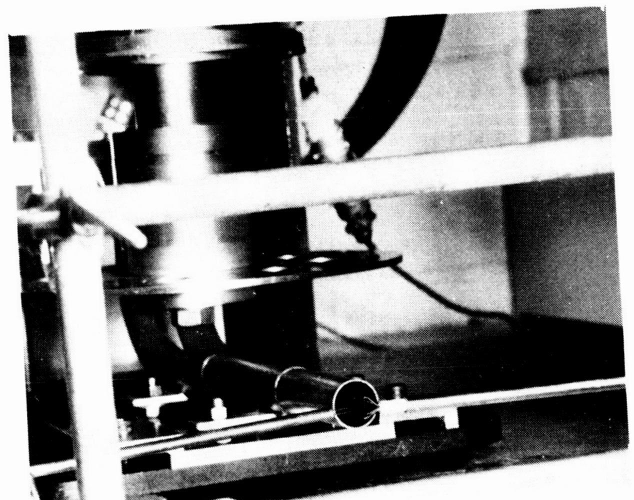


FIGURE 4

ROTATING WHEEL EXPERIMENT PROBE

As Fabricated

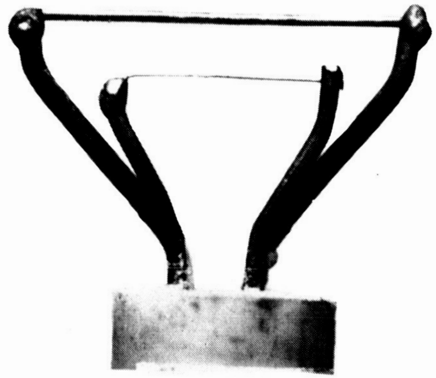
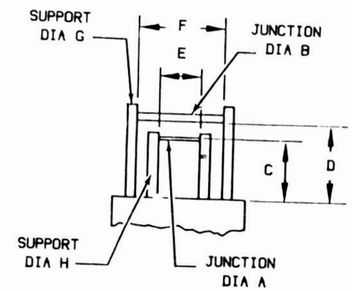


FIGURE 5

PROBE PRE-TEST INSPECTION SUMMARY

Rotating Wheel Experiment



DIM	PRINT µm (IN)	MEASURED µm (IN)
A	76.2 (0.003)	71.78 (0.0028260)
B	254 (0.010)	245.92 (0.0096425)
C	4572 (0.180)	4826 (0.190)
D	5842 (0.230)	6604 (0.260)
E	3810 (0.150)	3810 (0.150)
F	7620 (0.300)	7620 (0.300)
G	508 (0.020)	508 (0.020)
H	381 (0.015)	381 (0.015)

FIGURE 6

LABORATORY BURNER PROBE

SINGLE WIRE ASSEMBLY
AS FABRICATED

TWO WIRE ASSEMBLY
AS FABRICATED

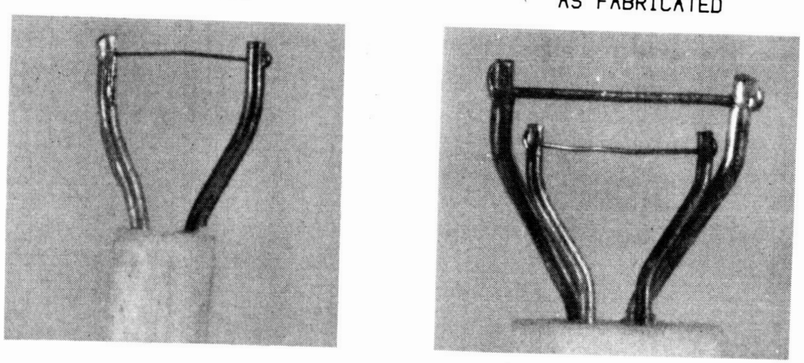
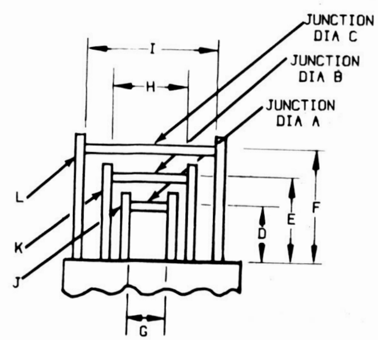


FIGURE 7

PROBE PRE-TEST INSPECTION SUMMARY

Laboratory Burner Experiment



DIM	PRINT µm (IN)	MEASURED µm (IN)
A	76.2 (0.003)	732 (0.0029)
B	127 (0.005)	1236 (0.0049)
C	254 (0.010)	2491 (0.0098)
D	2540 (0.100)	3574 (0.1407)
E	3810 (0.150)	3709 (0.146)
F	5080 (0.200)	5055 (0.199)
G	2286 (0.090)	2591 (0.102)
H	3556 (0.140)	3556 (0.140)
I	5080 (0.200)	5131 (0.202)
J	381 (0.015)	381 (0.015)
K	381 (0.015)	381 (0.015)
L	508 (0.020)	508 (0.020)

FIGURE 8

LABORATORY BURNER EXPERIMENT
Test Configuration

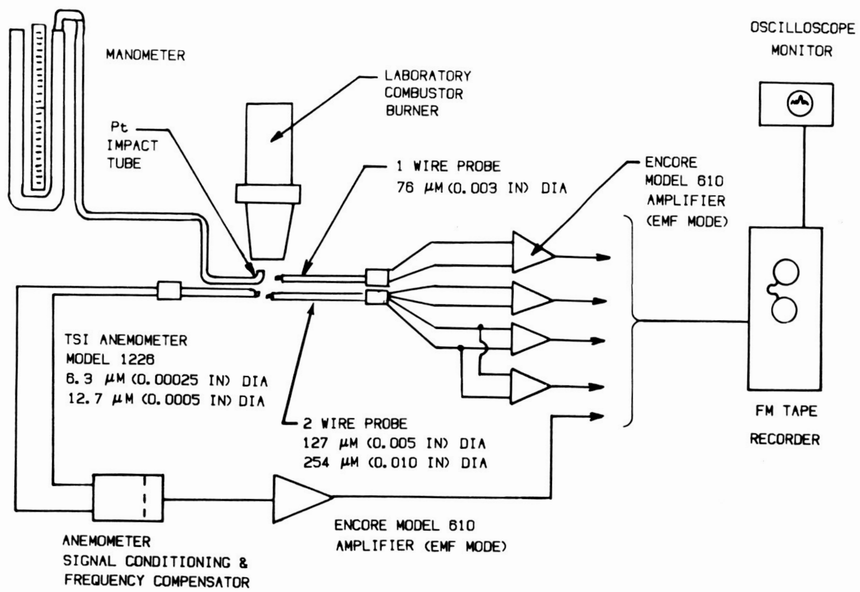


FIGURE 9

LABORATORY BURNER EXPERIMENT
Test Probe Set-Up

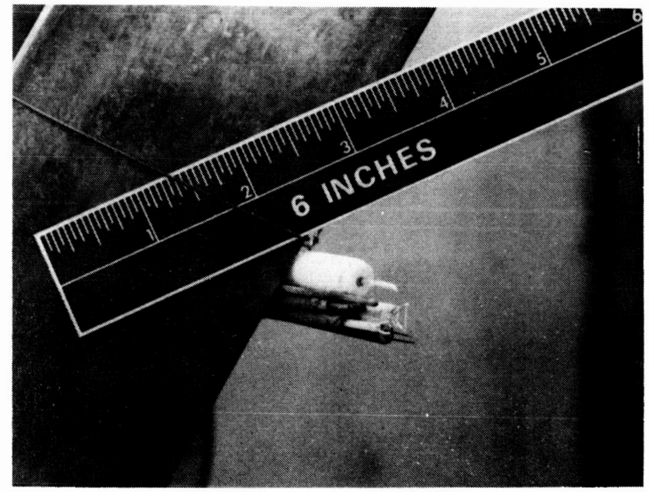


FIGURE 10

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LABORATORY BURNER EXPERIMENT
Test Firing

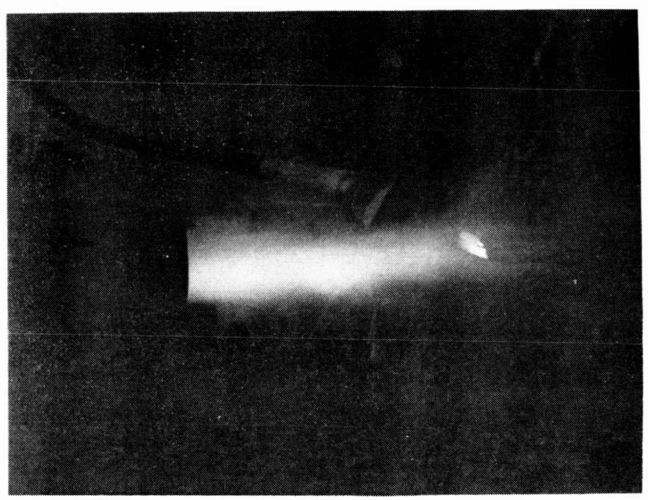
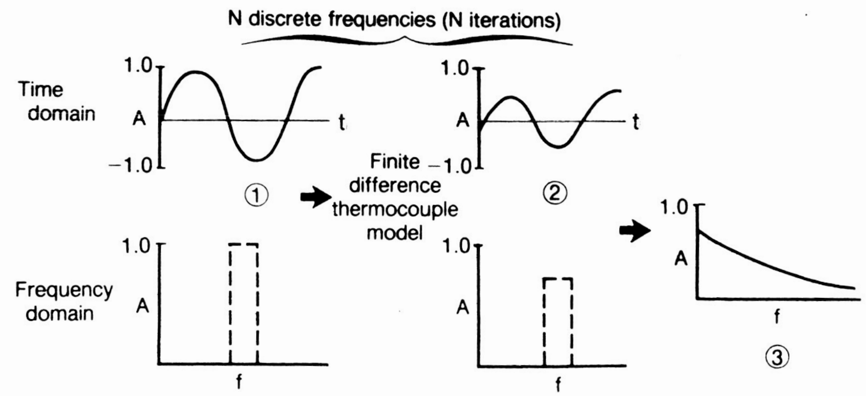


FIGURE 11

COMPUTER CODE OPTIMIZATION

Original numerical compensation method



- Individual frequencies input to finite difference T/C models
- Output from model complex added to yield compensation spectrum

FIGURE 12