DYNAMIC GAS TEMPERATURE MEASUREMENT SYSTEM

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INTRODUCTION

The objective of this effort is to develop an advanced measuring system which is capable of measuring the rapidly varying gas temperature at the exit of an aircraft jet engine combustor during ground based testing of hot section components. The following presentation gives a brief review of the contract objectives/sensor guidelines, the technical approach/program schedule, and the accomplishments to date.

The Sensor must be designed for installation in an annular jet engine combustor operating with jet A fuel and air, and must have a compensated frequency response up to 1 K Hz. The environment of present-generation combustors is detailed in Table I. The program goals for measurement uncertainty are 5% or less for frequencies up to 200 Hz and 10% or less from 200 Hz to 1000 Hz.

The Program is organized into eight tasks with the technical effort concentrated into the following six tasks:

Task 1 - Study and Selection of Methods

Task 2 - Analysis of Methods and Selection of the Most Promising Method

Task 3 - Review

Task 4 - System Design and Test Plan Formulation

Task 5 - Fabrication and Tests

Task 6 - Analysis of Results

The contract was initiated on 10 August 1981 and will run for an 18 month period. Tasks 1 through 4 have been completed and Task 5 is currently in process. The results of these efforts are briefly discussed in the following paragraphs.

PROGRESS

Task 1 consisted of identifying and evaluating candidate measurement concepts. The effort included performing a literature survey using the Lockheed Dialog, the NASA Recon and the Defense Technical Information Center information retrieval systems. A list of candidate measurement methods is shown in Table II. These candidates were evaluated against contract technical criteria and rated either acceptable or unacceptable. Results of the evaluation revealed that only two concepts meet all contract requirements: a) The dual-wire passive thermocouple and b) single-wire pulse heated thermocouple.

The dual-wire passive thermocouple concept uses two different diameter, beadless-junction thermocouples to measure heat transfer coefficient in-situ and thereby compensate thermocouple response. The single-wire pulse heated thermocouple concept uses an electrically-pulsed over-temperature condition to determine the time constant from the pulse decay rate. Construction techniques are very similar for both designs. Both approaches use type B wire elements with beadless welded junctions to provide a uniform cylinder in cross flow geometry which is easily analyzed. Both are mounted similarily in high temperature ceramic insulators. The length to diameter ratio for thermocouple elements of both designs is less than 20 to 1.

The two concepts were further analyzed in Task 2. Each concept was analyzed for structural, thermal, and data acquisition/reduction requirements. Both concepts were rated acceptable structurally and thermally. The single pulse-heated concept would have to be pulsed near the melting temperature of the thermocouple material. In addition, the pulse-heating amplitude was not large enough to obtain the contract accuracy requirements using a reasonable number of decay pulses and sampling times. Based on these results, the dual passive thermocouple concept was selected for use in the remaining tasks involving detailed design, fabrication and testing.

The analyses also revealed that both concepts had end conduction losses which could not be ignored and would have to be corrected during the data analyses.

Task 4 efforts consisted of: 1) design of a temperature measuring system based on the dual-wire passive thermocouple approach, including sensor detailed design and design of the data acquisition/reduction system; and 2) the definition of the test plans.

The sensor design effort was based on the thermal and structural analyses of Task 2. The final probe configuration was designed for installation in an F100 engine borescope plug location at turbine inlet. The probe was designed structurally to P&WA design criteria and the final thermocouple wire element lengths were reduced from preliminary designs due to higher aerodynamic loading in the full scale engine.

The final data acquisition/reduction system design was also based on results of Task 2. The computer software was modified from a simple first order system to a program using a finite element model which accounts for sensor wire end conduction losses. The data acquisition system records each thermocouple signal on FM tape through AC coupling and low noise differential amplifiers (Preston DX-A3). Data reduction system consists of an FM tape reproduce and a Hewlett Packard Model 5451 C Fourier Analyzer.

The data reduction process consists of computing the theoretical response (gain and phase) of each thermocouple over a range of discrete frequency points (generally between 2 Hz to 40 Hz) as a function of heat transfer coefficient using the finite element analysis. The range of heat transfer coefficient is selected to cover the anticipated value for the engine test conditions. From these theoretical data, the transfer function (ratio of gains) of the two thermocouples for the same discrete frequency points as a function of heat transfer coefficient is derived.

Engine test data for both T/C's is digitized (4 Khz sampling rate) into the Fourier system and converted to temperature using an NBS curve fit. From these data the transfer function of the two thermocouples is computed vs. frequency using FFT techniques. This measured transfer function data is used to determine the in-situ value of heat transfer coefficient from the theoretically derived relationships of the transfer function of the two thermocouples as a function of heat transfer coefficient.

The in-situ value of heat transfer coefficient is then used to compute the theoretical response of the 76μm T/C to the gas stream temperature fluctuations using the finite element analysis. Gain and phase response is computed at discrete frequencies from 2 Hz to 2Khz. This response curve is then used to compensate the 76μm thermocouple engine data to yield a compensated frequency spectrum. The compensated frequency spectrum can be Fourier transformed to yield the compensated temperature time wave form.

The test plans consist of three test series: 1) System shakedown laboratory tests; 2) Laboratory burner tests; and 3) An engine test.

A summary of environmental conditions for each of these tests is shown in Table III.

The system shakedown lab tests will verify system function. The testing will be done in a laboratory using an electrically heated air blower. The accuracy of the compensation will be verified using an electrical analog of the thermocouple finite element array using first order low pass RC filters which correspond to the individual time constants of each node. These filters will then be substituted for the thermocouple and a random noise signal will be input to simulate the thermocouple signal levels.

The second test series will be conducted using a laboratory burner test rig. These tests will allow evaluation of the sensor and measurement system in an elevated temperature combustor environment.

The third test series will be performed by installing and evaluating on a non-interference basis in an experimental F100 engine test. The sensor will be installed in the turbine-inlet borescope plug. These tests will provide the final evaluation of the sensor at the required environmental conditions.

The program status as of the first of October 1982 was that Tasks 1 through 4 has been completed and Task 5 was in process. The sensor fabrication and software program were completed.

FUTURE WORK

Future work will complete the three test series described above and process the data taken. The test program is a stepwise, iterative approach which allows for necessary problem-solving and technical flexibility. At the present rate, data acquisition should be complete by the end of 1982 and final data reduction/analysis should be well underway.

SUMMARY

An approach to dynamic temperature measurement has been identified. The method uses two beadless junction Type B thermocouples to measure heat transfer coefficient in-situ. Heat conduction effects are accounted for using a finite element model of the thermocouple. Fabrication of thermocouples is complete. A test program which verifies measurement system function will be accomplished in the next few months.

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DYNAMIC GAS TEMPERATURE MEASUREMENT SYSTEM

Overview

- Contract objectives and sensor guidelines
- Technical approach/program schedule
- Program status

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DYNAMIC GAS TEMPERATURE MEASUREMENT SYSTEM

Objectives

To develop an advanced measuring system capable of measuring the rapidly varying gas temperature at the exit of an aircraft jet engine combustor during ground-based testing of hot section components

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Table I sensor design and environment guidelines

Geometry: Annular combustor, $2 \text{ cm} < H < 8 \text{ cm}$
Temperature: $\bar{T} \sim 1400^\circ K$ (2060°F); $T' \sim 500^\circ K$ (900°F)
Frequency response: 1 kHz
Pressure: $10 < P < 20$ ATM
Flow: $\bar{v} \sim 150$ m/s; $v' \sim 50$ m/s
Gas composition: Fuel (nominal jet A) and air
Sensor life: 5 hr minimum
Accuracy: Temperature uncertainty $\leq 5\%$ for $f \leq 200$ Hz
Temperature uncertainty 10% for $200 \text{ Hz} < f < 1 \text{ kHz}$
Spatial resolution: $D \leq 0.5$ cm
Vibration 10g

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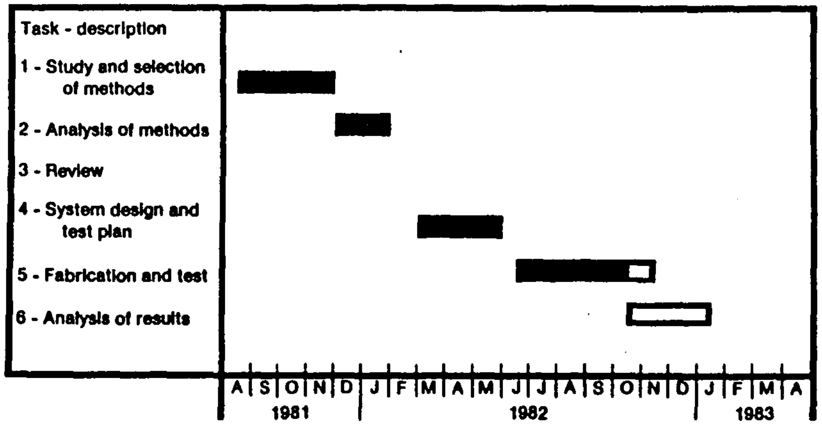
Technical approach/program shcedule



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Task 1 - Study and selection of methods

Literature survey

- Concepts identified

Evaluation/screening

- Selected - dual passive thermocouple
  - single pulse-heated thermocouple

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Table II concepts evaluated

Single wire thermocouple
- Passive
- Pulse-heated

Dual wire thermocouple
- Passive
- Pulse-heated

Resistance thermometer
- Wire
- Film

Ultrasonic thermometer

Fluidic resonator

Gas sampling

Johnson noise thermometer

Piezoelectric resonator

Vibrating wire

Radiation pyrometry

High speed photography

Coherent anti-stokes raman spectroscopy

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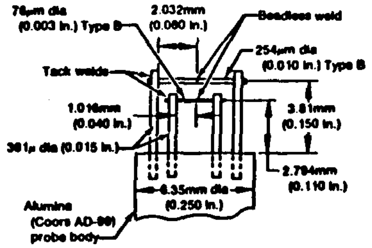
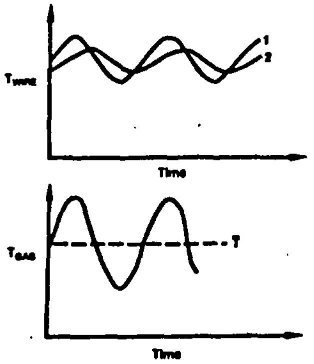
Dual passive thermocouple concept





$$\frac{\tau_1}{\tau_2} = \left(\frac{D_1}{D_2}\right)^{1.5}$$

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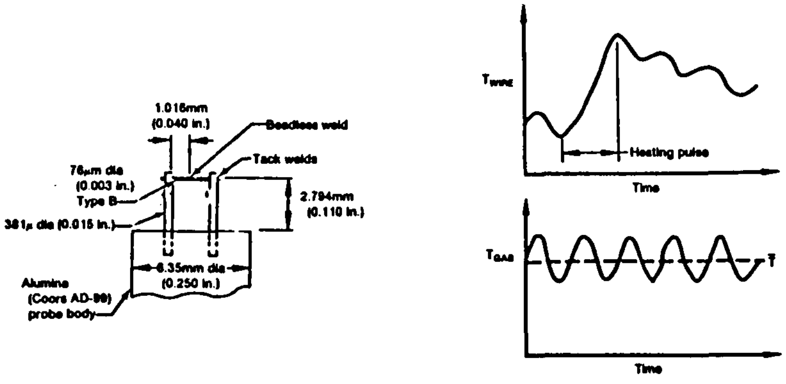
Single pulse-heated thermocouple concept



$$\tau = (T_w - T_G) / \frac{\delta T_w}{\delta t}$$

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Task 2 - Analysis of methods and selection of the most promising method

- Structural analysis
- Thermal analysis
- Data acquisition/reduction analysis

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Task 2 analysis results

	Single-wire pulse-heated	Dual-wire passive
Structural	Acceptable: d>0.008CM(0.003 in) L/D<20	Acceptable: d>0.008CM(0.003 in) L/D<20
Thermal	Acceptable: end-conduction correction necessary (pulse approaches wire melting point)	Acceptable: end-conduction correction necessary
Data acquisition and reduction	Unacceptable: pulse-heating amplitude required is too large for required accuracy and conditions	Acceptable:

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Task 4 - System design and test plan formulation

Sensor design

- Mechanical
- Structural
- Thermal

Data acquisition and data reduction system

Test plan

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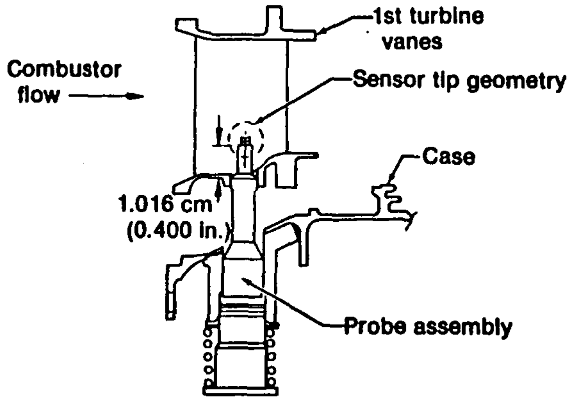
Probe designed for F100 turbine installation



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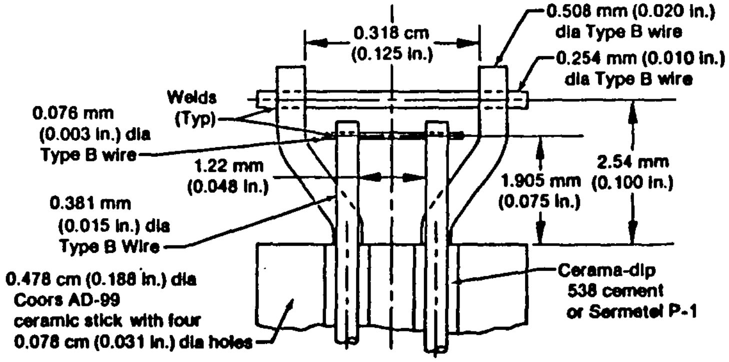
Sensor tip geometry



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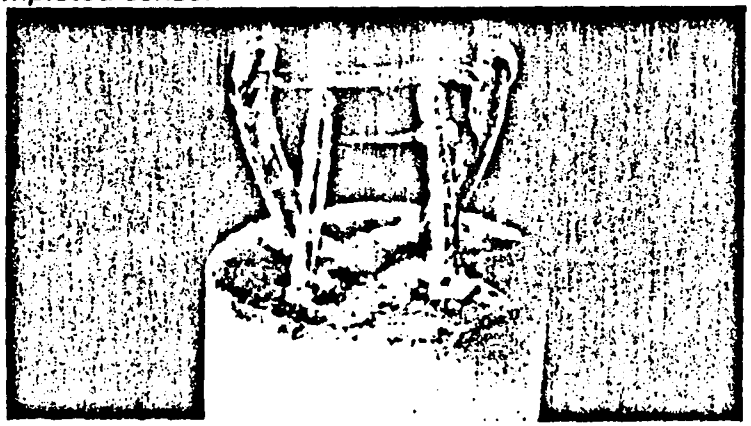
Completed sensor



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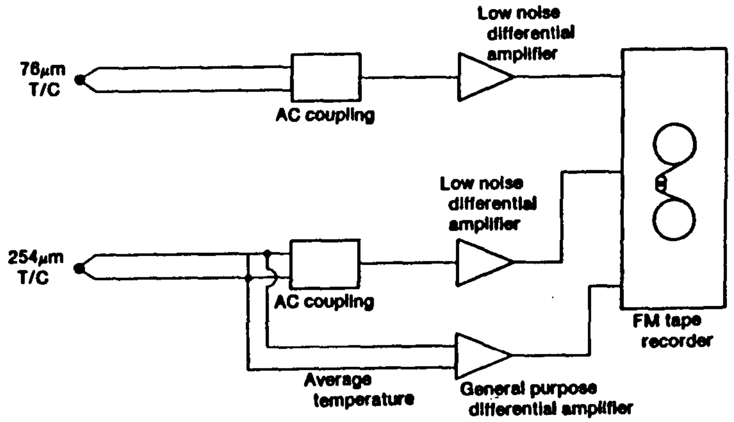
Data acquistion system



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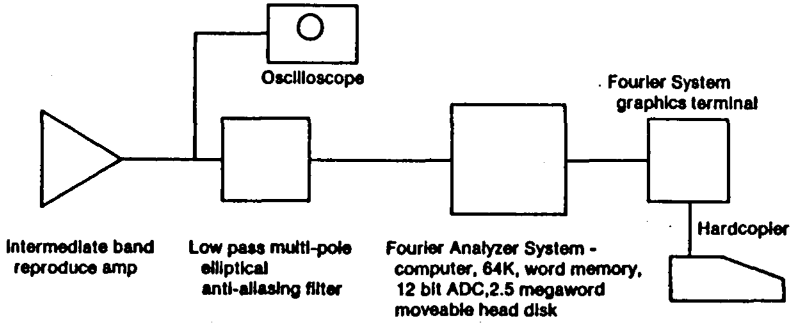
Data playback system



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Compensation method

- Compute theoretical response (76μm and 254μm T/C's) vs heat transfer coefficient (finite element conduction effects included) over frequency range
- Measure (data) response of 76μm and 254μm T/C's over frequency range (using FFT techniques)
- Determine actual heat transfer coefficient from computed and measured response
- Generate theoretical response of 76μm T/C for actual heat transfer coefficient for frequency range
- Compensate 76μm T/C data in frequency domain
- Inverse fourier transform to time domain

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Table III test plan summary

Criteria	System shakedown and compensation verification	Lab burner rig	Full-scle engine tests
Temperature (1900°K peak; ±500°K fluctuations)			X
Frequency response (1000Hz compensated)	X	X	X
Pressure (10 to 20 atm)			X
Flow (150m/s with ±50m/s fluctuations)			X
Gas composition (products of combustion and air)		X	X
Sensor lifetime (5 hr minimum)		X	X
Accuracy	X		
Vibration (10g loading up to 500Hz)			X

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Program status

Completed Tasks 1 through 4

Task 5 in process

- Hardware fabrication
- Software programming
- Testing