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RESEARCH SENSORS

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ABSTRACT

The program described here covers development of sensors and sensing techniques for research applications on aeropropulsion systems. In general, the sensors are used in situ to measure the environment at a given location within a turbine engine, or to measure the response of an engine component to the imposed environment. Locations of concern are generally in the gas path and, for the most part, are within the hot section. Specific parameters of concern are dynamic gas temperature, heat flux, airfoil surface temperature, and strain on airfoils and combustor liners. In order to minimize the intrusiveness of surface-mounted sensors, a considerable effort has been expended to develop thin-film sensors for surface temperature, strain, and heat flux measurements. Most of the work described is sufficiently advanced that sensors have been used and useful data have been obtained. The notable exception is the work to develop a high-temperature static strain measuring capability; this work is still in progress. The work described here has been done in-house at the Lewis Research Center and via contracts and grants.

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RESEARCH SENSORS

The program described here covers development of sensors and sensing techniques for research applications on aeropropulsion systems. In general, the sensors are used in situ to either measure the environment at a given location within a turbine engine or to measure the response of an engine component to the imposed environment. Locations of concern are generally in the gas path and, for the most part, are within the hot section of the engine. Since these sensors are used for research testing as opposed to operational use, a sensor lifetime of the order of 50 hours is considered sufficient.

RESEARCH SENSORS

MINIATURE DISCRETE SENSORS FOR IN SITU RESEARCH MEASUREMENTS IN AEROPROPULSION SYSTEMS:

- DYNAMIC GAS TEMPERATURE MEASURING SYSTEM
- TOTAL HEAT FLUX SENSORS
- THIN-FILM SENSORS
- HIGH-TEMPERATURE STRAIN MEASURING SYSTEMS

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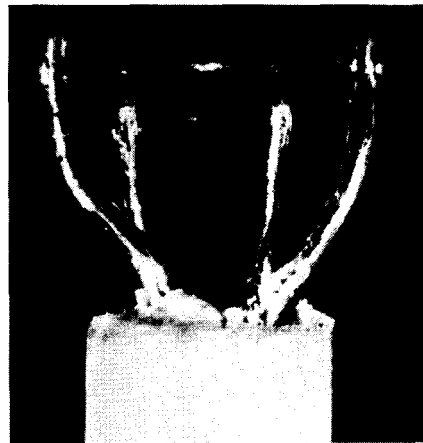
DYNAMIC GAS TEMPERATURE MEASURING SYSTEM

One of the most important environmental parameters in a turbine engine hot section is gas temperature. Normally only time-average temperature is measured. Fluctuations in gas temperatures are, however, of great concern for hot section durability and combustor modeling activities. In this measuring system, a probe with two wire thermocouples with different diameters provides dynamic signals with limited frequency response. By comparing these signals over a range of frequencies, we can generate a compensation spectrum sufficient to provide compensated temperature data at frequencies up to 1000 Hz.

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DYNAMIC GAS TEMPERATURE MEASURING SYSTEM

- **MEASURES GAS TEMPERATURE FLUCTUATIONS AT THE EXIT OF A TURBINE ENGINE COMBUSTOR**
- **A TWO-ELEMENT PROBE PROVIDES DATA TO PERMIT ACCURATE FREQUENCY COMPENSATION**



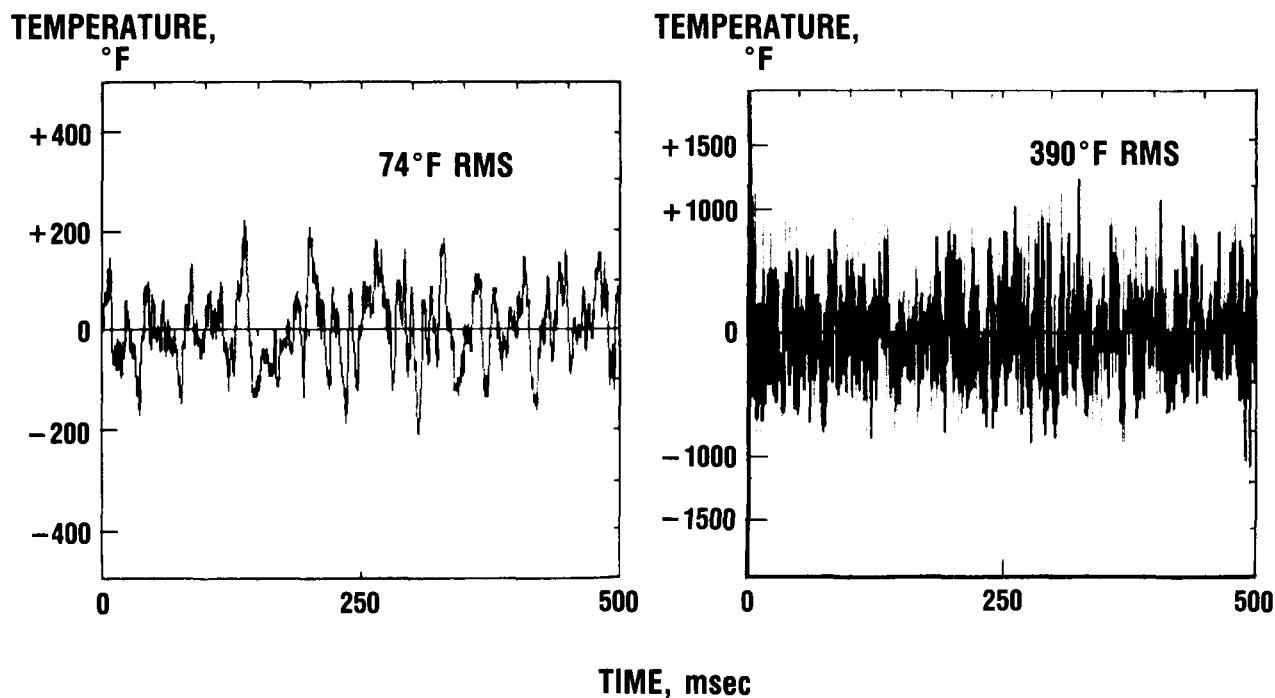
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DYNAMIC GAS TEMPERATURE MEASUREMENT

This figure shows dynamic temperature data obtained from a probe at the turbine inlet of a PWA F-100 engine operating at an intermediate power setting. The plot on the left is the dynamic signal from a 0.003-in.-diameter wire thermocouple with no frequency compensation. The rms value of the temperature fluctuation is 74 °F. The plot on the right is the compensated signal from the same thermocouple. The rms value of the temperature fluctuation is 390 °F and the peak-to-peak fluctuation is ± 900 °F. Such a large temperature fluctuation implies that there are filaments of primary combustion gas and dilution gas within the combustor exhaust stream.

DYNAMIC GAS TEMPERATURE MEASUREMENT

TEMPERATURE AT TURBINE INLET



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TOTAL HEAT FLUX SENSORS

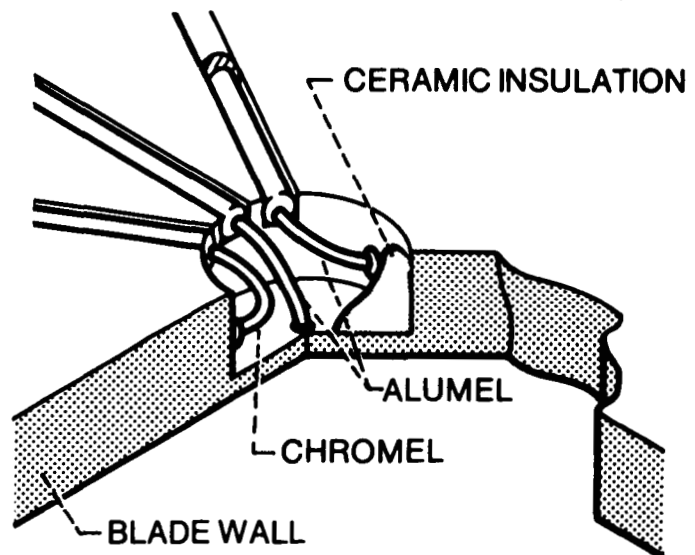
Another environmental parameter of interest for hot section durability is total heat flux. We have developed miniature total heat flux sensors which can be welded into combustor liners and built into cooled turbine airfoils. This figure shows one sensor configuration based on the Gardon Gage design. An innovation in these sensors is the use of the burner liner or airfoil material as part of a differential thermocouple circuit. Calibration tests on these materials showed that this technique could provide acceptable signals. The differential thermocouple simplifies construction and permits a direct measurement of the differential temperature proportional to heat flux. These miniature heat flux sensors must be calibrated over the temperature range in which they will be used.

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TOTAL HEAT FLUX SENSORS

- MEASURE TOTAL HEAT FLUX ON BURNER LINERS AND TURBINE AIRFOILS
- MINIATURE WIRE THERMOCOUPLE SENSOR:
 - WELD INTO BURNER LINERS
 - BUILD INTO AIRFOILS
- SENSOR BODY PART OF THERMOCOUPLE CIRCUIT
- CALIBRATION SYSTEM REQUIRED

HIGH TEMPERATURE HEAT FLUX SENSOR

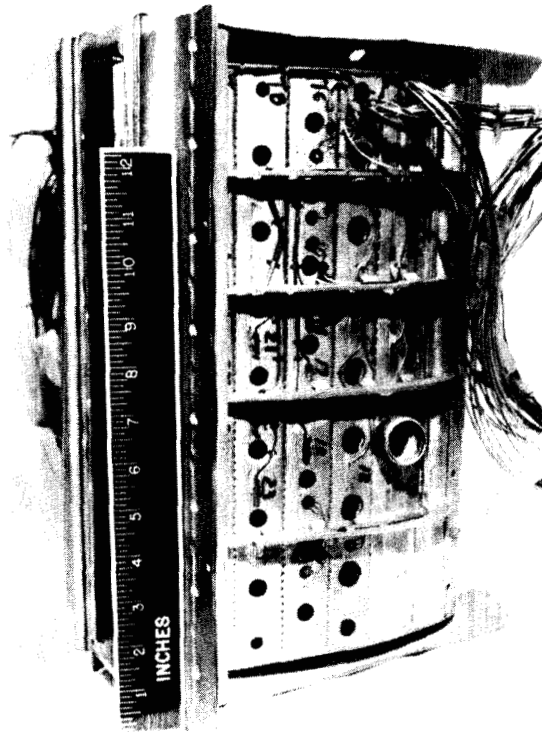


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COMBUSTOR SEGMENT INSTRUMENTED WITH HEAT FLUX SENSORS

This photograph shows a segment of a combustor liner which has been instrumented with six total heat flux sensors. The sensors are 0.3-in.-diameter disks with thermocouple leads radiating from the edge of the disk. The actual sensor part of the unit is at the center of the disk and is only 0.06 in. in diameter. The sensors are individually calibrated and then welded into holes cut in the liner. Tests on combustors such as this one have produced useful heat flux data over a range of combustor operating conditions. Similar sensors built into turbine airfoils have been less successful because of the sensitivity of these sensors to temperature and/or heat flux gradients which are more prevalent in turbine airfoils. Sensor designs which are less sensitive to gradients have been examined but have not yet been put into use.

COMBUSTOR SEGMENT INSTRUMENTED WITH HEAT FLUX SENSORS



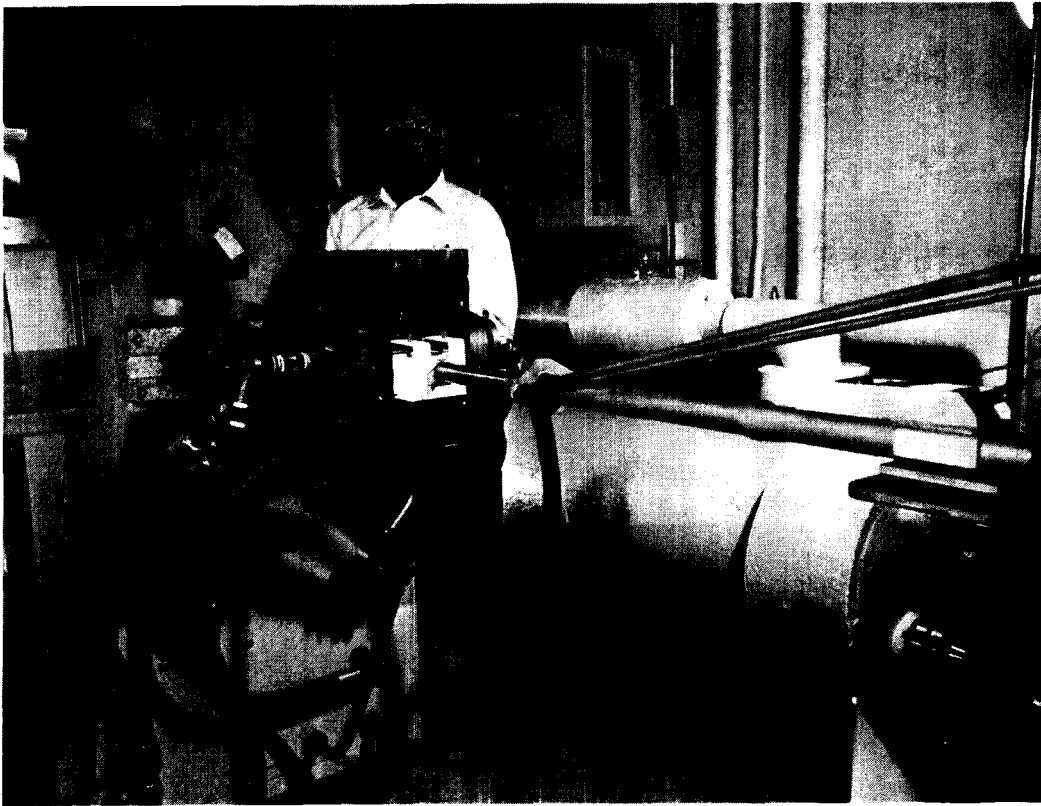
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HEAT FLUX SENSOR CALIBRATION SYSTEM

This photograph shows a heat flux sensor calibration system developed at Lewis. The heat source is a 400-kW arc lamp. A reflector is used to focus the energy from the arc onto a ceramic sensor holder. This system can supply a maximum flux of 6 MW/m^2 , which is higher than the heat fluxes in present-day turbine engines. The system can operate in both steady-state and transient modes. Two other roughly comparable calibration facilities exist in this country; efforts have been started to cross-compare calibration of test sensors. This is especially important since a national standard for heat flux sensor calibration does not exist.



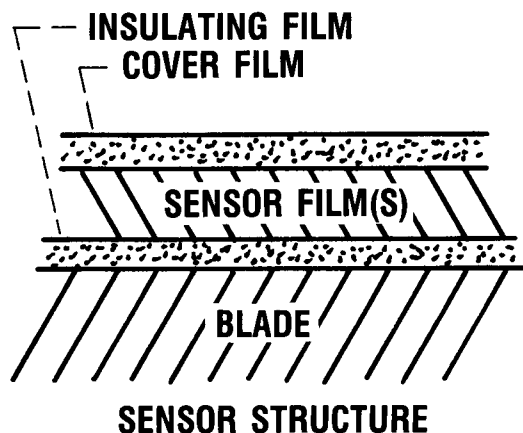
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THIN-FILM SENSORS

Lewis has been the major advocate and sponsor for development of thin-film sensors for turbine engine applications. Thin-film sensors applicable to turbine engines include temperature sensors, strain gages, and heat flux sensors. Thin-film sensors are formed directly on the component to be instrumented by first depositing a suitable insulating film and then depositing sensor and protective films as required.

THIN-FILM SENSORS

- TEMPERATURE SENSORS
- STRAIN GAGES:
DYNAMIC
STATIC
- HEAT FLUX SENSORS



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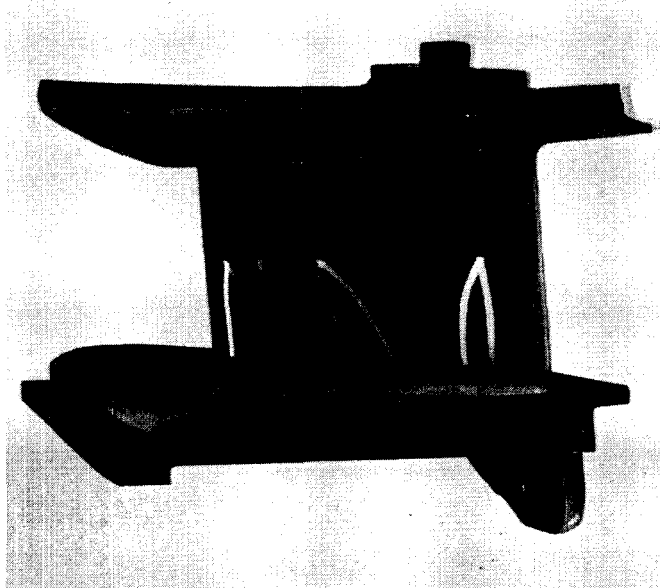
THIN-FILM THERMOCOUPLES

An excellent application for thin-film thermocouples is the measurement of the surface temperature of a cooled turbine airfoil such as shown here. The surface of the vane is covered with Al_2O_3 thermally grown from an anticorrosion coating and augmented with sputtered Al_2O_3 . Pt and Pt-Rh films are sputter deposited with thermocouple junctions formed by overlapping the two films at the desired spot. The films extend to the base of the vane where leadwires are connected. The sensor is less than 0.001 in. thick. This technique has considerable advantages over the previous technology, which required swaged thermocouple wires to be buried in grooves cut in the surface.

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THIN-FILM THERMOCOUPLES

- **MEASURE SURFACE TEMPERATURE OF COOLED TURBINE AIRFOILS**
- **FABRICATION: SPUTTER ALLOY FILM LEADS OVER INSULATING COATING ON AIRFOIL SURFACE**
- **SENSOR THICKNESS, < 0.001 in.**



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APPLICATIONS OF THIN-FILM SENSORS

Two types of thin-film sensors have been used in regularly scheduled test operations at some turbine engine facilities in the United States. Dynamic strain gages have been used on compressor blades, and thermocouples have been used to measure turbine airfoil surface temperatures. A thin-film, high-temperature static strain gage system and thin-film heat flux sensors are still under development. One of our goals is to make the thin-film sensor technology available to the entire United States turbine engine community. Impediments to wider use of this technology are many. One problem is that sensor fabrication is material specific; technology has not been established for a wide variety of materials. Another problem is that the investment required to establish a thin-film sensor fabrication capability is considerable; commercial services for custom fabrication of thin-film sensors are not yet available.

APPLICATIONS OF THIN-FILM SENSORS

- **DYNAMIC STRAIN GAGES IN USE ON COMPRESSOR BLADES AT SOME FACILITIES**
- **THERMOCOUPLES IN USE ON TURBINE AIRFOILS AT SOME FACILITIES**
- **STATIC STRAIN GAGES AND HEAT FLUX SENSORS STILL UNDER DEVELOPMENT**
- **IMPEDIMENTS TO WIDER USAGE:**
 - TECHNOLOGY NOT ESTABLISHED FOR ALL MATERIALS**
 - LARGE INVESTMENT REQUIRED**
 - COMMERCIAL SERVICES FOR FABRICATING SENSORS NOT YET AVAILABLE**

HIGH-TEMPERATURE STRAIN MEASURING SYSTEMS

The most ambitious goal of the research sensor program is the development of high-temperature (1800 °F) strain measuring systems. Approaches being followed in this work include both wire and thin-film resistance strain gages and remote measuring systems. Our resistance strain gage work has included work on new strain gage materials and testing of available strain gages, including the Chinese 700 °C gages. Work on remote strain measuring systems has involved three different system concepts based on laser speckle patterns.

HIGH-TEMPERATURE STRAIN MEASURING SYSTEMS

- **GOAL:**

MEASURE STATIC STRAIN ON TEST SAMPLES AND TURBINE ENGINE COMPONENTS AT TEMPERATURES UP TO 1800 °F

- **APPROACHES:**

RESISTANCE STRAIN GAGES—

WIRE GAGES

THIN-FILM GAGES

REMOTE STRAIN MEASURING SYSTEM—

LASER SPECKLE BASED SYSTEM

FUTURE THRUSTS IN RESEARCH SENSORS

Future work in research sensors will be strongly influenced by new materials being developed for turbine engine components. These materials are expected to be in the forms of metal- and ceramic-matrix composites. Both the nature of the materials and the significantly higher hot section temperatures that these materials are expected to make possible will influence our sensor work. If thin-film sensors are to be applied to these materials, methods for producing suitable insulating films must be developed. As surface temperatures rise, the temperature limits of available sensor materials will force more emphasis on remote noncontact sensing techniques. In addition, we will continue to search for new sensor materials with higher temperature capabilities. Work has already started in these directions relative to surface temperature, strain, and heat flux measurements on ceramic and ceramic-matrix composite materials.

FUTURE THRUSTS IN RESEARCH SENSORS

- **PROGRAM TO DEVELOP MATERIALS TO OPERATE AT SIGNIFICANTLY HIGHER HOT SECTION TEMPERATURES—METAL-AND CERAMIC-MATRIX COMPOSITES**

EFFECT ON SENSOR PROGRAMS:

- **DEVELOP TECHNOLOGY FOR THIN-FILM SENSORS ON NEW SUBSTRATE MATERIALS**
- **DEVELOP SENSOR MATERIALS FOR HIGHER TEMPERATURE RANGES**
- **IMPROVE REMOTE SENSING TECHNIQUES**