NASA TM-88851

NASA-TM-88851 19860023230

A Reproduced Copy

OF

NASA TM-88851

Reproduced for NASA

by the

NASA Scientific and Technical Information Facility

FFNo 672 Aug 65

NASA Technical Memorandum 88851

Research Instrumentation for Hot Section Components of Turbine Engines

David R. Englund
Lewis Research Center
Cleveland, Ohio

(NASA-TM-88851) RESEARCH INSTRUMENTATION FOR HOT SECTION COMPONENTS OF TURBINE ENGINES (NASA) 22 p CSCL 82B N86-32702
Unclas
G3/35 44453

Prepared for the
Symposium on Propulsion Instrumentation
cosponsored by the National Aeronautics and Space Administration and
the Chinese Aeronautical Establishment
Jiangyou, People's Republic of China, October 6–10, 1986

NASA

N86-32702 #

E-3241

RESEARCH INSTRUMENTATION FOR HOT SECTION COMPONENTS OF TURBINE ENGINES

David R. Englund
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

SUMMARY

Programs to develop research instrumentation for use on hot section components of turbine engines are discussed. These programs can be separated into two categories: one category includes instruments which can measure the environment within the combustor and turbine components, the other includes instruments which measure the response of engine components to the imposed environment. Included in the first category are instruments to measure total heat flux and fluctuating gas temperature. High temperature strain measuring systems, thin film sensors (e.g., turbine blade thermocouples) and a system to view the interior of a combustor during engine operation are programs which compose the second category. The paper will describe the state of development of these sensors and measuring systems and, in some cases, show examples of measurements made with this instrumentation. The discussion will cover work done at the NASA Lewis Research Center and at various contractor facilities.

INTRODUCTION

In the late 1970's, NASA and the turbine engine community in the United States became aware of a need to be able to design more durable hot sections (i.e., combustors and turbines) for new generations of engines. This concern was prompted by an upward trend in the percentage of maintenance costs attributed to the hot sections of engines in commercial service. A multidisciplinary program was started to work on this problem (ref. 1) which included instrumentation developments to (1) better define the environment to which hot section components were exposed, and (2) measure the response of hot section components to that environment. Specifically, these instrumentation development projects include the following:

(1) Development of sensors for measuring total heat flux on combustor liners and turbine airfoils.

(2) Development of a system to measure the fluctuating component of combustor exit temperature with a frequency response to 1000 Hz.

(3) Improvement in the capability to measure high temperature structural strain.

(4) Development of thin film sensor technology suitable for operating thin film thermocouples and other sensors on hot section surfaces.

(5) Development of an optical system for recording visual images from the interior of a combustor during operation.

This work has been done both at NASA Lewis and at contractor facilities.

This paper will describe the state of development of these projects and in some cases will show examples of data obtained with this advanced instrumentation.

HEAT FLUX SENSORS

One of the important parameters of the environment imposed on hot section components of a turbine engine is the total heat flux. The total heat flux is one of the input variables in the heat balance equation which establishes the cooling requirements and the anticipated surface temperature for the component in question. There is not sufficient knowledge of heat transfer coefficient under engine operating conditions to permit prediction of hot section component surface temperatures with acceptable accuracy. This is especially true as incident heat fluxes approach 1 MW/m^2. Initial development work on total heat flux sensors was directed at developing sensors for use in combustor liners (ref. 2). Later work involved mounting heat flux sensors into air cooled turbine blades and vanes.

We used conventional sensor concepts in this work; we measured the temperature difference generated by the heat conducted through the sensor body. The unconventional features of the sensors are that they operate at temperatures up to 1250 K, that they are small (approximately 1.5 mm in diameter), and that we made differential thermocouples to measure the temperature differences, using the sensor body material as part of the thermocouple circuit. This means that we also calibrated a number of engineering alloys such as Hastelloy X and nickel- and cobalt-based superalloys to determine if their thermoelectric potential was suitable for use.

Figures 1 and 2 show the sensors that were developed for measurements in a combustor liner. The sensors were built in a disk of material 0.8 cm in diameter and of the same thickness as the liner. After calibration the sensors were to be welded into holes cut in the liner so that the sensor assemblies became part of the combustor liner. Figure 1 shows the embedded thermocouple sensor. In this case the sensor body is Hastelloy X and the body is grooved so that 0.25 mm outside diameter sheathed, single conductor thermocouple wire can be laid into the grooves and covered with weld material. The thermocouple wires are ISA type K, Chromel-Alumel, and single conductor leads are used so as to maximize the insulation resistance between the wire and the external metal sheath. Grounded Alumel junctions are located on the hot and cold sides of the sensor body and a Chromel junction is added to the cold side. A voltage measurement between the two Alumel leads (i.e., using the Alumel-to-Hastelloy X-to-Alumel differential thermocouple) provides the hot-to-cold side temperature difference proportional to the one-dimension heat flow through the combustor liner at that point. A measurement using the conventional Chromel-Alumel thermocouple provides the temperature of the cold side of the liner.

Figure 2 shows a Gardon gauge sensor. In this case the Hastelloy X body has a 1.5 mm diameter cylindrical cavity on the cold side so that a thin membrane of material is left at the hot side. Alumel thermocouple wires are positioned so that junctions with the Hastelloy X material are formed at the center of the membrane and halfway up the sidewall of the cavity. A Chromel junction is also made on the sidewall of the cavity. After the thermocouples are installed, the cavity is filled with ceramic cement.

Sensors of both types have been successfully fabricated, calibrated, and used in combustor test rigs. Information on sensor calibration and a sample of experimental results will be presented later in this section.

Sensors of the embedded thermocouple and Gardon gauge types have also been built into air cooled turbine blades and vanes. In the case of turbine blades, two piece blades were used and the sensors were installed from the cooling passage side of the blade. The two half-blades were then joined by brazing. In the case of the vanes, sections of the vane wall opposite to the desired sensor site were removed and the sensors were installed from the cold side through this "window." Figure 3 depicts the installation process in a turbine vane.

The heat flux sensors were experimentally calibrated over a heat flux range up to 1.7 MW/m^2 and a temperature range up to 1250 K. The calibrations were accomplished by imposing a known radiant heat flux on the hot side surface of the sensor and flowing cooling air over the cold side surface. The hot side surface was coated with a high temperature black paint with a measured absorptance and emittance of 0.89 over the test temperature range. In all cases the reference temperature was measured and used to estimate a hot side surface temperature from which the energy being radiated away from the hot side surface was calculated. Estimates were also made of the convective heat flow away from the hot side surface and used as a correction to determine the heat flux being conducted through the body of the sensor.

The calibration systems used banks of tungsten filament lamps enclosed in quartz tubes as heat flux sources; the most powerful rig provided maximum heat fluxes as high as 1.7 MW/m^2. The quartz lamp rigs were capable of long time and cyclic operation at reduced heat fluxes. Thermal cycling and drift tests were run on the heat flux sensors using this capability.

Calibration and performance tests on total heat flux sensors have indicated that measurements can be achieved fairly readily on combustor liners, but that measurements on airfoils are difficult to achieve. Combustor liner measurements have been made both at a contractor facility and at NASA Lewis. Figure 4 shows an instrumented combustor segment. Figure 5 compares measured values of total heat flux conducted through the liner and radiant heat flux incident on the liner at different combustor pressure levels. The lower total heat flux compared to the radiant flux indicates that there is significant convective cooling of the hot side surface.

Tests on sensors mounted in turbine airfoils indicate that these sensors are sufficiently sensitive to transverse gradients in heat flux and/or temperature that applications in blades and vanes must be carefully evaluated. The greater complexity of blades and vanes (e.g., high curvatures and cooling passage structure) causes more severe gradients than were encountered in combustor liners. Sensitivity to transverse gradients is especially critical in the Gardon gauge sensor because of its lack of symmetry.

DYNAMIC GAS TEMPERATURE MEASURING SYSTEM

Another important parameter defining the environment in the hot section of a turbine engine is the gas temperature. In general, however, most attention has been directed at the time average value of the gas temperature rather than the fluctuating component of the gas temperature. It is generally agreed that there may be significant temperature fluctuations in the gas exiting a combustor due to incomplete mixing of the combustion and dilution gas streams. It is also agreed that thermal cycling of the surfaces of vanes and blades can result in accelerated spalling of oxide films used for corrosion protection and thus shorten the life of the blades or vanes (ref. 1). As a result, one of the instrumentation development efforts was a system to measure the fluctuating component of combustor exit gas temperature to a frequency of 1000 Hz (ref. 3).

The approach used in this work was to devise a way to determine in situ the compensation spectrum required to correct the signal from a thermocouple probe located in the gas stream. Frequency compensation has often been used, especially with hot wire anemometers, in the measurement of dynamic flow phenomena. The classical problem with this technique when applied to a thermal element such as a thermocouple in a flow stream is that the required compensation spectrum is a function of both the thermal mass of the thermocouple and the heat transfer coefficient between the gas and the thermocouple surface. The heat transfer coefficient depends on the gas properties and velocity. This means that each time the flow conditions change, a new compensation spectrum must be determined. In some cases estimates of the compensation spectrum may be sufficient; in this case it was important to be able to determine the compensation spectrum in situ.

The system that was developed uses a dual element thermocouple probe such as shown in figure 6. Thermocouples are formed with carefully butt welded junctions so that there is no enlargement in the region of the junction. These thermocouples are each supported across a pair of support posts so that they are parallel cylinders in cross flow, in close enough proximity (approximately 1 mm) so that they are measuring the same gas temperature. The thermocouple junctions are midway between the support posts. The two thermocouples have different diameters, commonly 75 and 250 μm. The dynamic signals from these two thermocouples of different diameter can be used to determine the compensation spectrum. The technique is based on the use of the ratio of the Fourier coefficients of the dynamic signals for frequencies in the region where the signals become attenuated. In the system which has been developed, the thermocouple signals are recorded on magnetic tape and processed in a general purpose digital computer at a later time. The data reduction process takes approximately 5 min for each flow condition for which a new compensation spectrum must be developed.

This system has been used to measure fluctuating temperatures in both turbine engines and in combustor test rigs. A sample of data from a turbine engine test is shown in figure 7. In this test the thermocouple was located between first stage turbine vanes; the thermocouple was made from ISA Type B (Pt70-Rh30/Pt94-Rh6) wire. Figure 7 shows four plots of temperature fluctuation versus time. Figure 7(a) and (b) show the uncompensated signals from the 75 and 250 μm thermocouples. Note that the temperature scales on these plots have been adjusted so as to display the waveforms. Also note that the rms temperature is listed on each plot. Figure 7(c) shows the compensated signal from the 75 μm thermocouple and figure 7(d) shows an expanded time segment of that signal. The rms value of the compensated signal is 218 K.

HIGH TEMPERATURE STRAIN MEASURING SYSTEMS

The most ambitious instrumentation development effort in this program is the development of strain measuring systems. The target goal for high temperature structural strain measurement is to measure strain (approximately 2000 microstrain, maximum) at temperatures up to 1250 K with an uncertainty of ±10 percent. This requirement is for relatively short term testing; a 50 hr life is considered sufficient. Spatial resolution of the order of 3 mm is desired and where measurements are required on blades and vanes, large temperature gradients are anticipated. In general, the requirement is for steady state measurements as differentiated from dynamic (fluctuating component only) measurements.

The principal candidate for making strain measurements under similar but lower temperature conditions (less than approximately 700 K) is the electrical resistance strain gauge. However, at the higher temperatures, strain measurements become increasingly difficult and the commonly used strain gauges are marginal at best. As the required temperature range increases, the magnitude of the correction for apparent strain becomes substantially larger than the strain signal and the uncertainty of the correction becomes excessive. To meet the measurement goals listed above, the uncertainty of the apparent strain correction must be less than ±200 microstrain. Assuming a gauge factor of two, this requirement translates to a repeatability of the resistance versus temperature for the mounted strain gauge to well within ±400 parts per million (ppm).

The approaches we are taking to improve our high temperature strain measuring capability consists of:

(1) developing improved high temperature strain gauges

(2) learning how to better use available strain gauges

(3) developing optical strain measuring systems as alternatives to resistance strain gauges.

The following sections will discuss these three areas of work.

Development of Improved High Temperature Strain Gauges

In attempting to develop improved high temperature resistance strain gauges, we are emphasizing development of alloys with very repeatable resistance versus temperature characteristics. We tested a number of alloy compositions from five alloy families. These alloy families are FeCrAl, NiCrSi (Nicrosil), PtPdMo, PdCr, and PtW. In all cases, except for the thermocouple alloy Nicrosil, we looked at a range of alloy compositions. Alloy samples were prepared in the form of cast rods which were then machined into suitable test samples. Measurements were made of resistance versus temperature over a number of temperature cycles in which cooling rates were varied from 50 to 250 K/min. Additional tests included oxidation (weight gain method) and resistance drift for up to 3 hr in air at 1250 K. The results of these tests indicated that two alloys, one in the FeCrAl family and one in the PdCr family, had the best potential for high temperature strain gauge applications.

The FeCrAl alloy was designated as "Mod. 3". The apparent strain for this alloy at temperatures up to 1250 K is compared with the apparent strain of the commercial Kanthal A-1 alloy in figure 8. In this case both samples were annealed for 2 hr at 1150 K prior to testing. The apparent strain of the Mod. 3 alloy is much less than that of the Kanthal A-1 and shows comparatively little change for different cooling rates. This alloy does, however, exhibit different resistance versus temperature characteristics, depending on previous thermal history. Figure 9 illustrates this effect for exposures to 1250 K in air for times ranging from 10 to 105 hr. Because of this effect, work on this alloy has been deemphasized in favor of the PdCr alloy.

The PdCr alloy has a resistance versus temperature curve which is characteristic of a binary solid solution alloy with no phase or internal structure changes being evident. The resistance is essentially linear with temperature and not affected by changes in cooling rate or previous thermal history. Cycle-to-cycle repeatability of the fractional change in resistance with temperature for four thermal cycles to 1250 K was excellent; the average (over the temperature range) standard deviation was 130 ppm and the worst deviations were at approximately 700 K with a standard deviation of 245 ppm. The long term drift of cast samples of this alloy at 1100 and 1250 K in air and in argon is shown in figure 10. It should be noted that these data imply a repeatability in resistance measurement to the order of a hundred ppm; it is likely that some of the fluctuations in these curves is attributable to the measuring system rather than the resistance of the alloy samples.

The repeatability of the PdCr alloy is the characteristic that we feel is essential for high temperature strain gauge work. However, there are other properties required for good strain gauges and the PdCr alloy may not necessarily be ideal in these other considerations. The temperature coefficient of resistance is high enough that active compensation will be required; the added complication and larger gauge size required for this will have to be accommodated. Other potential problems such as oxidation resistance of high surface-to-volume ratio thin films and fine wires, gauge factor changes with temperature, and the elastic/plastic strain properties are still under investigation.

Work with Available Strain Gauges

Learning how best to use available strain gauges in high temperature applications requires that considerable experimental work be done to explore strain gauge characteristics and devise optimum procedures for specific applications. Such work is very time consuming, especially when tests at many different temperatures are required. Consequently one of our objectives in this work was to establish a computer controlled testing capability at NASA Lewis so that testing could be accomplished with minimal operator attention.

The automated strain gauge test laboratory has the capability to measure apparent strain and gauge factor over a range of temperatures from 300 to 1370 K. The laboratory has two ovens (one of which contains a test fixture for a constant strain beam), a computer controlled actuator for deflecting the beam, strain gauge and temperature instrumentation, and a computer based controller and data collection system. An IBM PC XT is used as the system controller and data system. Communication between various parts of the system is accomplished on an IEEE-488 data bus and an RS-232 serial interface. A microcomputer system was custom built to interface a ten channel strain gauge indicator system to the IEEE-488 data bus. A test profile is constructed by typing a series of time and command statements into a data set. Figure 11 shows a block diagram of the system.

One approach to better utilization of available strain gauges is outlined in reference 4. In this work, using Kanthal A-1 FeCrAl alloy, it was determined that the apparent strain of the gauge was affected by the rate at which the alloy is cooled from the highest use temperature. Further, the apparent strain versus temperature for the next heating cycle followed that established by the cooling part of the previous cycle. A repeatable apparent strain versus temperature could be obtained if the rate of the cooling could be reproduced each time. This implies that a repeatable apparent strain correction term can be obtained by matching the cooling rate during apparent strain calibration to the cooling rate impressed on the strain gauge during use. It is necessary, of course, that the cooling rates during use must be controllable, and this is not always the case. But for the work of reference 4, the cooling rates could be matched and the result was usable static strain measurement at temperatures up to 950 K.

Work following this approach has been undertaken at NASA Lewis. Hastelloy X plates 13 by 20 cm were instrumented with Kanthal Al and Chinese FeCrAl 700 °C (ref. 5) strain gauges, and a plate holding fixture was made that permitted cooling gas to flow over the plate uniformly so as to get controlled cooling rates. The Kanthal A-1 gauges were mounted using a flame sprayed aluminum oxide and ceramic cement process and the Chinese gauges were mounted with ceramic cement following the procedure supplied with the gauges. The plates were also instrumented with 10 thermocouples so as to provide the temperature distribution in the area of the strain gauges. Apparent strain measurements were made over the temperature range from 300 to 950 K with cooling rates controlled at 0.1 K/sec, 1.0 K/sec, and 5.6 K/sec. A sample of the resulting resistance change versus temperature data is shown in figure 12. Plotted here are fractional changes in resistance versus temperature for one of the Kanthal A-1 and Chinese strain gauges, for the three different cooling rates. The data for the Kanthal A-1 gauge show that there is a large dependence on cooling rate and that the resistance of the gauge is repeatable at the maximum test temperature. The resistance change for the Chinese gauge is independent of cooling rate at 300 and 950 K, but at intermediate temperatures the curves deviate depending on cooling rate. The maximum deviations in these curves are in the temperature range from 650 to 800 K, roughly the same temperature region in which high drift rates have been reported for the Chinese alloy (ref. 6).

Optical Strain Measurement

Optical systems may not provide exact alternatives to resistance strain gauges for all turbine engine applications, but they appear to have excellent potential for providing high temperature, noncontact, two-dimensional strain measuring systems with virtually unlimited strain range. An optical technique that requires no modification to the surface under test uses laser speckle patterns. These patterns are formed by constructive and destructive interference of laser light reflected from a diffuse surface. The source of the pattern is the irregularities in the surface; when the surface is distorted, for example, by strain in the plane of the surface, the speckle pattern changes. Precise measurements of changes in recorded speckle patterns can provide information on the strain imposed on the surface. A practical implementation of this technique is a laser speckle photogrammetric system in which speckle patterns are recorded on photographic film (ref. 7). Speckle pattern photographs (called specklegrams) are made at different increments of loading of the test sample and then pairs of specklegrams are examined in an automated interferometric photocomparator which uses heterodyne techniques to provide acceptable resolution for the measuring system. No attempt will be made here to describe this system in detail; it has been thoroughly described in the open literature.

The laser speckle photogrammetric system has successfully measured high temperature surface deformation. Reference 7 describes an experiment to measure the thermal expansion of an unrestrained plate of Hastelloy X at temperatures up to 1150 K. The plate was heated in a laboratory furnace to 1150 K and then allowed to cool to 500 K over a period of several hours. Specklegrams were recorded at roughly 200 K intervals during the heating and cooling and succeeding specklegram pairs were used to determine the thermal expansion of the plate. Measured thermal expansion agreed with values calculated from the temperature and the thermal expansion coefficient to within 3 percent.

We have attempted to use the laser speckle photogrammetric system in test cell environments. In one attempt we recorded specklegrams of a combustor liner in a high pressure, high temperature combustor test rig (ref. 4). In this test, speckle pattern photographs were taken through a viewing port in the pressure vessel of the test rig as combustor temperature and pressure were varied. A potential problem in this application is that the high pressure cooling air flowing over the exterior surface of the combustor liner is in the optical viewing path, and turbulence in the gas flow may cause sufficient optical distortion to prevent correlation of succeeding pairs of specklegrams. Examples of distorted and undistorted specklegrams are shown in figures 13(a) and (b). This effect proved to be a fundamental limitation for the measuring system in this application when combustor pressure was higher than approximately three atmospheres. We intend to explore further high-temperature applications of optical strain measuring systems.

THIN FILM SENSORS

One of the fundamental concepts of experimentation is that the sensors used to get the experimental data must not perturb the subject of the experiment from its condition prior to the introduction of the sensors. In turbine engine testing there are many situations in which this concept may be violated. A prime example of this problem is the measurement of turbine blade or vane surface temperature. Previous technology involved laying sheathed thermocouple wire into groves cut into the surface of the blade or vane, then covering the installation and smoothing the airfoil contour. Although the airfoil contour is restored, the thermocouple disturbs the temperature distribution, does not give a true measure of outside surface temperature, and threatens the integrity of the structure of thin walled blades and vanes.

The thin film thermocouple shown in figure 14 appears to be an ideal solution for blade and vane surface temperature measurement (refs. 8 to 10). As seen in the cross-sectional sketch of the sensor in figure 15, the sensor has minimal intrusiveness. In this case the blade or vane, coated with an MCrAlY anticorrosion coating, is polished and then oxidized to form an adherent surface coating of aluminum oxide. Additional aluminum oxide is deposited over this film to form an electrically insulating film of roughly 2 μm thickness. Films of thermocouple alloy (Pt and Pt-10 Rh) are sputter deposited through appropriate masks so that the twc films overlap at one point to form the measuring junction. The thermocouple films extend to the root of the vane where connections to leadwires are made. The complete installation of insulating film and thermocouple alloy films has a maximum thickness of less than 20 μm. The installation has not changed the contour or the strength of the component and the greatest thermal changes apparent are the different absorptance and emittance of the thermocouple films compared to the oxidized MCrAlY. The technology for thin film thermocouples on turbine blades and vanes has been developed to the extent that instrumented blades and vanes are being used in turbine engine tests at temperatures of approximately 1000 °C.

Thin film strain gauges on compressor blades are also in use in turbine engine tests for measuring blade vibration (refs. 11 and 12). In these sensors the strain gauges are NiCr alloy and the insulating films are either Si_3N_4 or Al_2O_3 deposited directly on the polished blade surface.

Thin film sensor development work is going on both at contractor facilities and at NASA Lewis. The thin film sensor laboratory at NASA Lewis is shown in figure 16. The laboratory is housed in a clean room in which both temperature and humidity are controlled. On the left in the photograph are three vacuum sputtering systems for deposition of both insulator and sensor films. In the right-hand corner of the room is equipment used for photolithography of sensors; conventional photo-resist techniques are used. At the far right edge of the photograph is a welder for connecting lead wire to the sensor films.

COMBUSTOR VIEWING SYSTEM

Another way to determine the response of a component to the hot section environment is to monitor visual images of that component during operation. This is not likely to produce quantitative data, but in some cases, qualitative data are sufficient or even preferable. A case in point is the Combustor Viewing System (ref. 13). This system was designed to provide recorded images of the interior of a combustor during operation; the objective was to produce a visual record of some of the causes of premature hot section failures.

The Combustor Viewing System consists of a water cooled optical probe, a probe actuator, an optical interface unit that couples the probe to cameras and an illumination source, and system controls. This system has been developed and has been used in both combustor and engine tests. Subsequent to the initial development program, additional systems were built and put into service in aircraft engine development work and in testing turbine engines used to generate electrical power.

The probe with its actuator is designed to mount directly on an engine or combustor. The probe is 12.7 mm in diameter, small enough to fit into an igniter port. The actuator provides a rotational motion of ±180° and radial insertion to a maximum depth of 7.6 cm. Two probes were built to use with the system. The wide field of view probe can be fitted with lenses for 90° and 60° fields of view, with the viewing axis oriented 45° to the axis of the probe.

The narrow field of view probe has lenses for 35° and 13° fields of view that are oriented 60° relative to the probe axis. Both probes are water cooled and gas purged and are capable of operating within the primary zone of a combustor.

Figure 17(a) and (b) shows cross section views of the ends of the wide and narrow fields of view probes. In each case an image conduit is used to transfer the image through the length of the probe. The image conduit is a fused bundle of fibers 3 mm in diameter and consists of about 75 000 fibers of 10 μm diameter. Each of these fibers corresponds to a picture element. The image conduit is 33 cm long and is coupled to a flexible fiber bundle which connects the probe to the optical interface unit. Each probe is also equipped with two 1 mm diameter plastic clad fused quartz fibers used for illumination when required.

The optical interface unit contains cameras, filters, and an illumination source. Either film or video cameras can be remotely selected and up to eight filters can be inserted into the viewing path. The illumination source is a mercury arc lamp which is focused on the ends of the illumination fibers.

CONCLUDING REMARKS

This paper has reviewed the state of development of a number of advanced instrumentation projects applicable to the hot sections of turbine engines. From the context of the discussion presented it should be clear that most of these projects are complete and the instrumentation is in use. This is the case for the Combustor Viewing System, the Dynamic Gas Temperature Measuring System, total heat flux sensors, and thin film thermocouples. Work in the general area of thin film sensors is continuing in order to further improve the technology and expand sensor types and applications. The work to improve our high temperature strain measuring capability is still in progress.

REFERENCES

1. Sokolowski, D.E.; and Ensign, R.E.: Toward Improved Durability in Advanced Combustors and Turbines - Progress in the Prediction of Thermomechanical Loads. ASME Paper 86-GT-172, June 1986.

2. Atkinson, W.H.; Hobart, H.F.; and Strange, R.R.: Advanced High-Temperature Heat-Flux Sensors. Advances in Instrumentation, Vol. 38, Part 2, Instrument Society of America, 1983, pp. 1457-1479.

3. Elmore, D.L.; Robinson, W.W.; and Watkins, W.B.: Dynamic Gas Temperature Measurement System. Instrumentation in the Aerospace Industry, Vol. 30, Advances in Test Measurement, Vol. 21, Instrument Society of America, 1984, pp. 289-302.

4. Stetson, K.A.: Demonstration Test of Burner Liner Strain Measuring System. (R84-926376-15, United Technologies Research Center; NASA Contract NAS3-23690) NASA CR-174743, 1984.

5. Wu. T.T.; Ma, L.-C.; and Zhao, L.-B.: Development of Temperature-Compensated Resistance Strain Gages for Use to 700 °C. Exp. Mech., vol. 21, no. 3, Mar. 1981, pp. 117-123.

6. Hobart, H.F.: Evaluation Results of the 700 °C Chinese Strain Gauges. NASA TM-86973, 1985.

7. Stetson, K.A.: The Use of Heterodyne Speckle Photogrammetry to Measure High-Temperature Strain Distributions. Holographic Data Nondestructive Testing, D. Vukicevic, ed., Proc. SPIE-370, SPIE, 1983, pp. 46-55.

8. Grant H.P.; and Przybyszewski, J.S.: Thin Film Temperature Sensor. (PWA-5526-31, Pratt and Whitney Aircraft; NASA Contract NAS3-20768) NASA CR-159782, 1980.

9. Grant, H.P.; Przybyszewski, J.S.; and Claing, R.G.: Turbine Blade Temperature Measurements Using Thin Film Temperature Sensors. (PWA-5604-31, Pratt and Whitney Aircraft; NASA Contract NAS3-20831) NASA CR-165201, 1981.

10. Grant, H.P., et al.: Thin Film Temperature Sensors, Phase III. (PWA-5708-26, Pratt and Whitney Aircraft; NASA Contract NAS3-22002) NASA CR-165476, 1982.

11. Grant, H.P., et al.: Thin Film Strain Gage Development Program. (PWA-5628-69, Pratt and Whitney Aircraft; NASA Contract NAS3-21262) NASA CR-174707, 1983.

12. Stowell, W.R.; and Weise, R.A.: Application of Thin Film Strain Gages and Thermocouples for Measurement on Aircraft Engine Parts. AIAA Paper 83-1292, June 1983.

13. Morey, W.W.: Jet Engine Combustor Viewing System. Conference on Lasers and Electro-Optics, IEEE, 1985, p. 298.

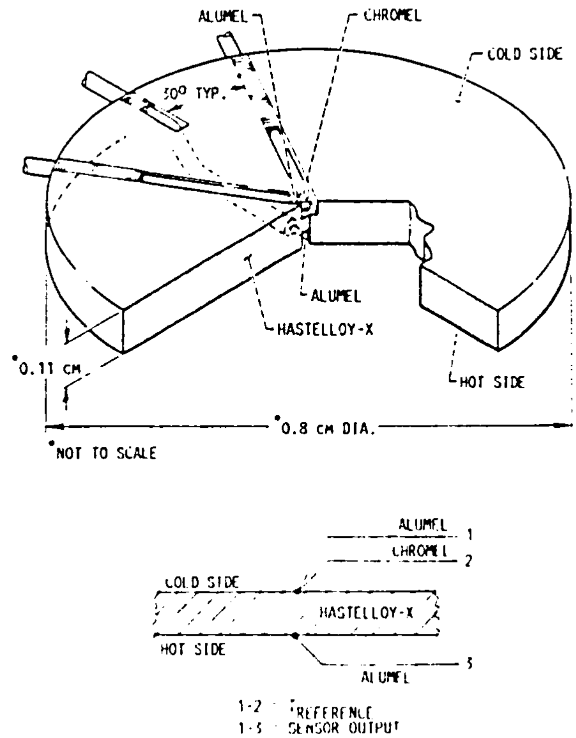


FIGURE 1. - EMBEDDED THERMOCOUPLE HEAT FLUX SENSOR.

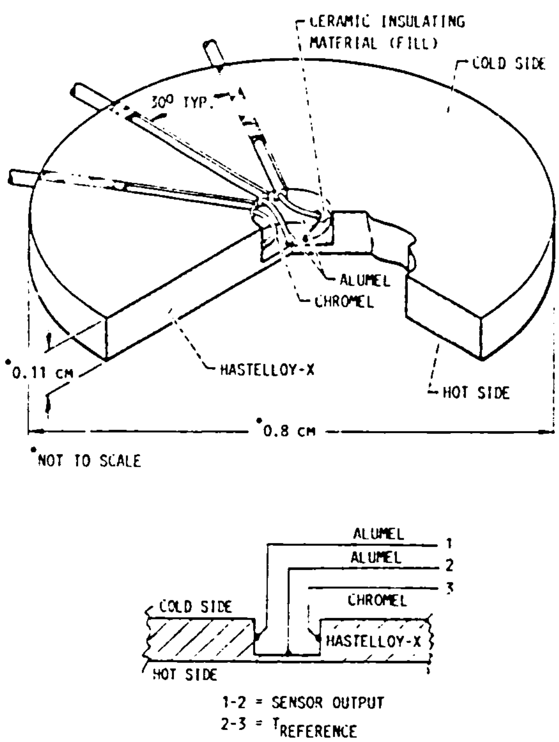


FIGURE 2. - GARDON GAUGE HEAT FLUX SENSOR.

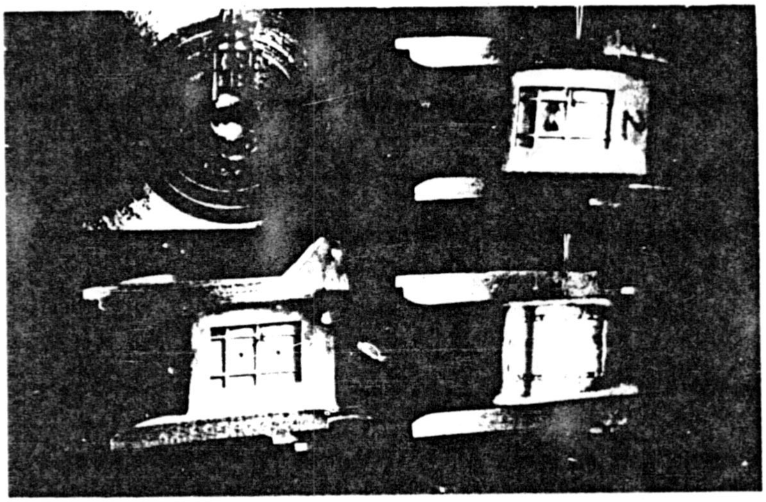


FIGURE 3. - HEAT FLUX SENSORS INSTALLED IN TURBINE VANE.

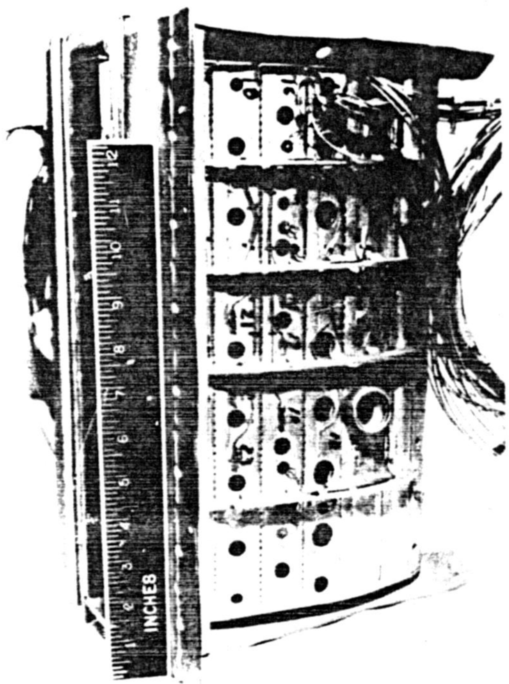


FIGURE 4. -COMBUSTOR SEGMENT INSTRUMENTED WITH HEAT FLUX SENSORS.

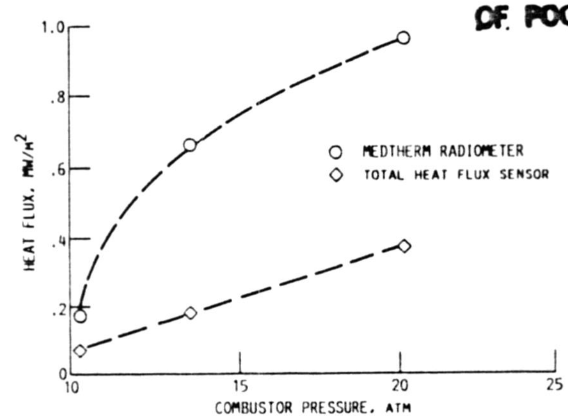


FIGURE 5. - COMPARISON OF TOTAL HEAT FLUX AND RADIANT HEAT FLUX FOR VARIOUS LEVELS OF COMBUSTOR PRESSURE. RADIANT HEAT FLUX WAS MEASURED WITH A COMMERCIAL RADIOMETER.

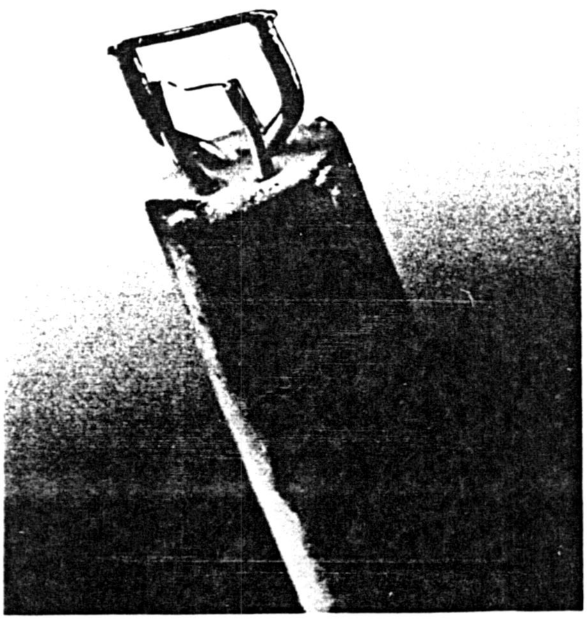


FIGURE 6. - DUAL ELEMENT THERMOCOUPLE PROBE FOR MEASURING FLUCTUATING GAS TEMPERATURE.

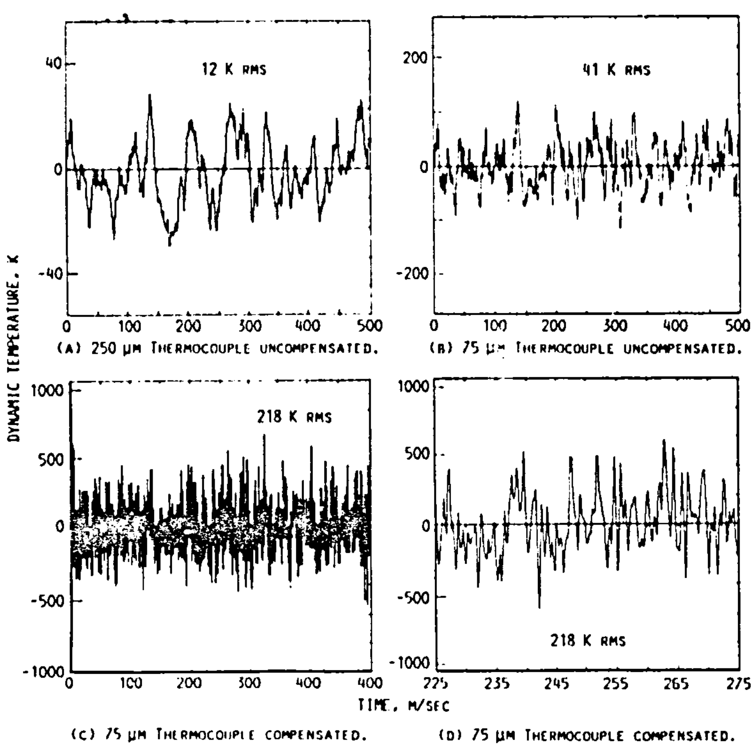


FIGURE 7. - DYNAMIC GAS TEMPERATURE SIGNALS FROM AN ENGINE TEST.

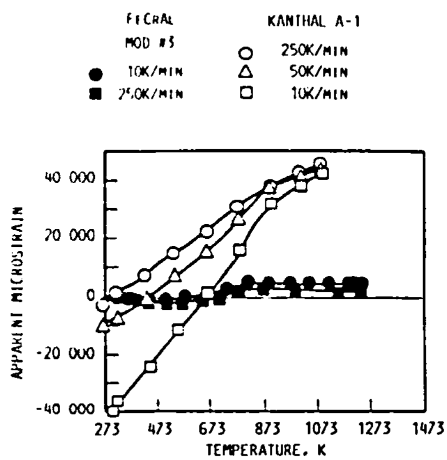


FIGURE 8. - APPARENT STRAIN OF KANTHAL A-1 AND FECRAL MOD #3 AS A FUNCTION OF TEMPERATURE. APPARENT STRAIN IS CALCULATED FROM FRACTIONAL RESISTANCE CHANGE ASSUMING A GAUGE FACTOR OF 2.0.

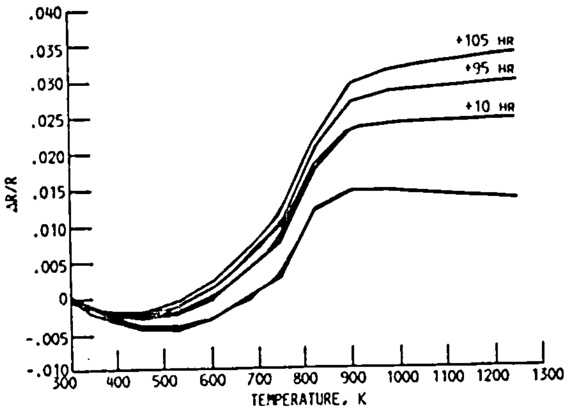


FIGURE 9. - EFFECT OF SOAK TIME AT 1250 K ON THE RESISTANCE VERSUS TEMPERATURE CHARACTERISTIC OF FECRAL MOD #3.

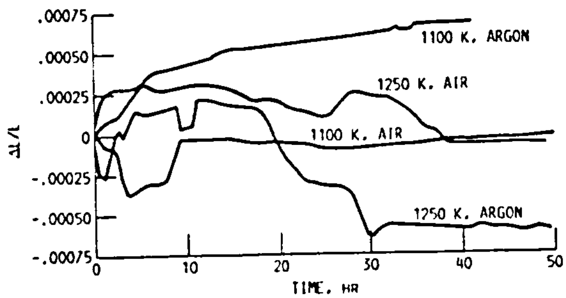


FIGURE 10. - LONG-TERM DRIFT OF PDCR ALLOY IN ARGON AND AIR. DRIFT IN TERMS OF STRAIN (ΔL/L) IS CALCULATED FROM FRACTIONAL RESISTANCE CHANGE ASSUMING A GAUGE FACTOR OF 2.0.

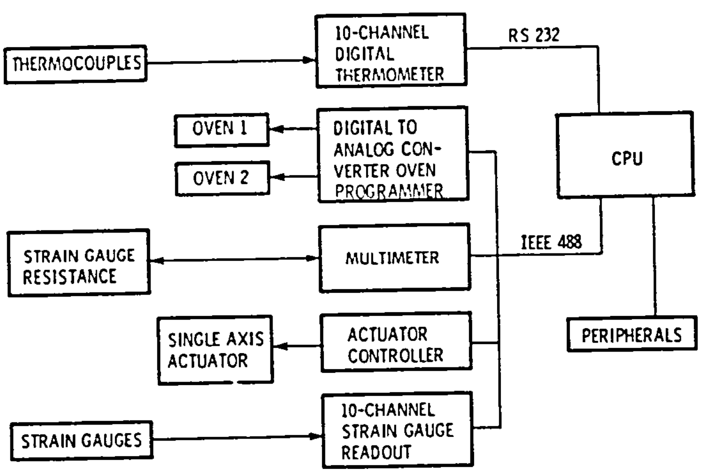


FIGURE 11. - BLOCK DIAGRAM OF THE HIGH TEMPERATURE STRAIN GAUGE TESTING SYSTEM.

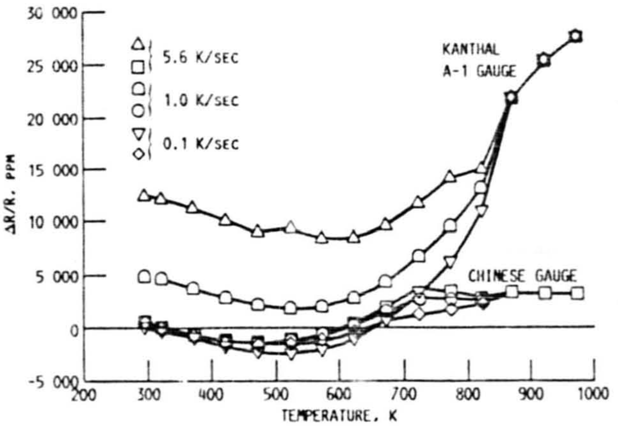


FIGURE 12. - FRACTIONAL RESISTANCE CHANGE VERSUS TEMPERATURE FOR KANTHAL A-1 AND 700 °C CHINESE GAUGES WITH THREE DIFFERENT COOLING RATES.

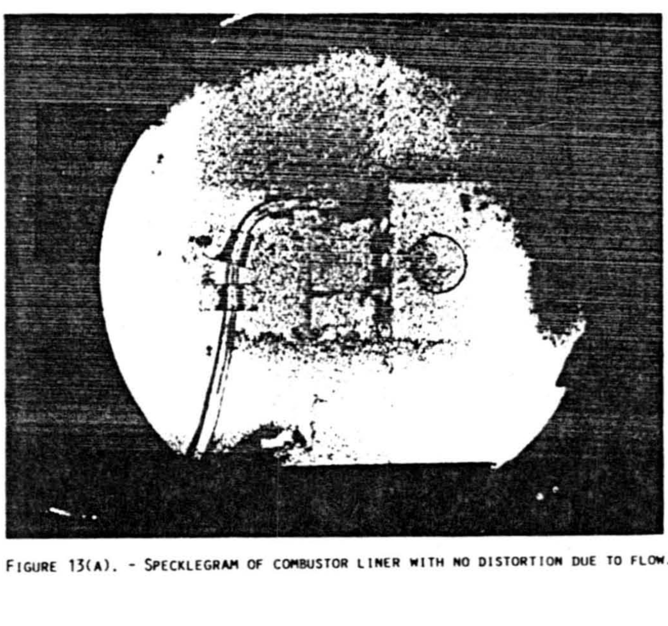


FIGURE 13(A). - SPECKLEGRAM OF COMBUSTOR LINER WITH NO DISTORTION DUE TO FLOW.

ORIGINAL PAGE IS
OF POOR QUALITY

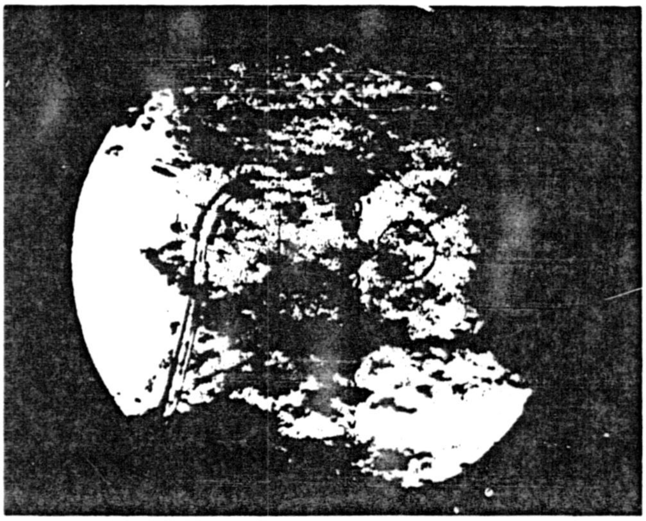
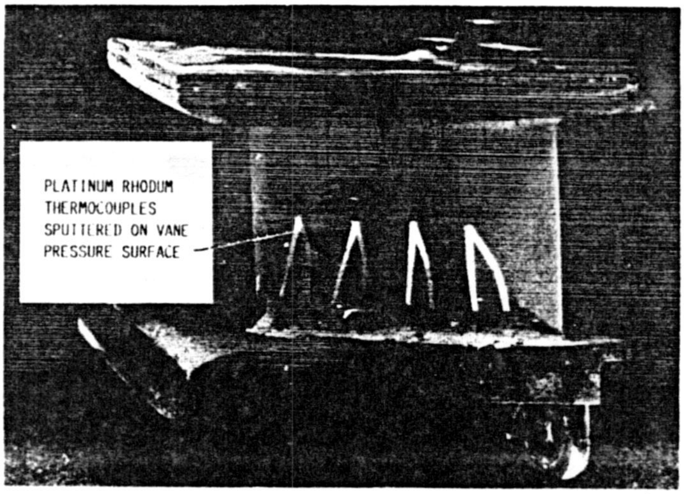


FIGURE 13(B). - SPECKLEGRAM OF COMBUSTOR LINER WITH DISTORTION FROM TURBULENT GAS FLOW.



V-2514

FIGURE 14. - A TURBINE VANE INSTRUMENTED WITH THIN FILM THERMOCOUPLES.

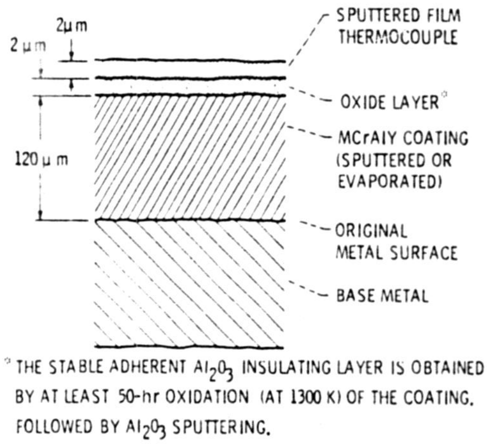


FIGURE 15. - THIN FILM THERMOCOUPLE CROSS SECTION.

FIGURE 16. - THIN FILM SENSOR LABORATORY AT THE LEWIS RESEACH CENTER.

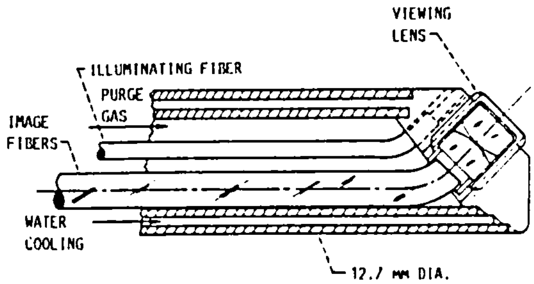


FIGURE 17A. - CROSS SECTION OF WIDE FIELD OF VIEW COMBUSTOR VIEWING PROBE.

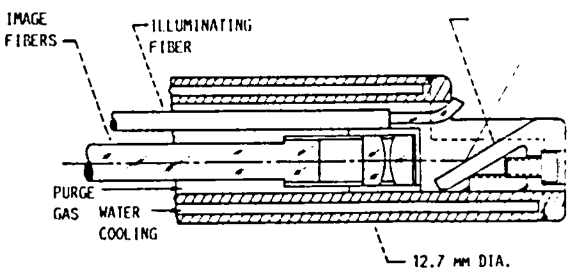


FIGURE 17B. - CROSS SECTION OF NARROW FIELD OF VIEW COMBUSTOR VIEWING PROBE.

1. Report No. NASA TM-88851	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Research Instrumentation for Hot Section Components of Turbine Engines		5. Report Date
		6. Performing Organization Code 533-04-12
7. Author(s) David R. Englund		8. Performing Organization Report No. E-3241
		10. Work Unit No.
9. Performing Organization Name and Address National Aeronautics and Space Administration Lewis Research Center Cleveland, Ohio 44135		11. Contract or Grant No.
		13. Type of Report and Period Covered Technical Memorandum
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		14. Sponsoring Agency Code

15. Supplementary Notes

Prepared for the Symposium on Propulsion Instrumentation, cosponsored by the National Aeronautics and Space Administration and the Chinese Aeronautical Establishment, Jiangyou, People's Republic of China, October 6-10, 1986.

16. Abstract

Programs to develop research instrumentation for use on hot section components of turbine engines are discussed. These programs can be separated into two categories: one category includes instruments which can measure the environment within the combustor and turbine components, the other includes instruments which measure the response of engine components to the imposed environment. Included in the first category are instruments to measure total heat flux and fluctuating gas temperature. High temperature strain measuring systems, thin film sensors (e.g., turbine blade thermocouples) and a system to view the interior of a combustor during engine operation are programs which compose the second category. The paper will describe the state of development of these sensors and measuring systems and, in some cases, show examples of measurements made with this instrumentation. The discussion will cover work done at NASA Lewis and at various contractor facilities.

17. Key Words (Suggested by Author(s)) Hot section instrumentation; Heat flux sensors; Dynamic gas temperature sensor; Strain measurement; Strain gage		18. Distribution Statement Unclassified - unlimited STAR Category 35	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of pages	22. Price*

*For sale by the National Technical Information Service, Springfield, Virginia 22161

END

DATE

FILMED

DEC 1 1986