"Heat Flux Sensors for Burner Liners and Turbine Blades and Vanes"

W. G. Alwang
Pratt & Whitney Aircraft Group
Commercial Engineering

The major challenge to designers of advanced gas turbine engines continues to be: how does one make significant improvements in fuel efficiency without compromising the durability of hot section hardware? Although great strides are being made in efficiency improvement via better gas path clearance control and less lossy aerodynamic design, the principal approach to efficiency improvement is determined by the fundamental thermodynamics of the gas turbine cycle, that is, increased cycle temperature and pressure. Thus, hot section hardware durability must be maintained in an increasingly hostile environment.

The NASA HOST program is devoted to the development of design methodology which will allow these problems to be overcome. Early in the evolution of the program it was recognized that several formidable experimental difficulties existed with respect to obtaining suitable data in support of the desired analytical techniques for life prediction. These were principally difficulties in the measurement of critical hot section parameters such as gas temperature distribution, metal temperature, high temperature static and dynamic strain, and heat flux. Consequently, the program addressed development of measurements technology very early.

The particular programs which I will discuss cover the measurement of heat flux. This work is being carried out under two contracts as follows;

1) "Advanced High Temperature Heat Flux Sensor Development," NAS3-22133.

2) "Turbine Blade and Vane Heat Flux Sensor Development and Experiment," NAS3-23529.

The first, which was a precursor to the HOST program, covers the development of total heat flux sensors for burner liners and also the demonstration of total and radiant heat flux sensors in a combustor test. The second covers total heat flux sensors for turbine blades and vanes.

At the present time very little data is available on heat flux in realistic gas turbine environments. At lower combustor temperatures convective heat transfer dominates but with increases in pressure and temperature as well as use of more luminous broad spec fuels radiant heat transfer must also be accounted for.

A thorough review of potential approaches was conducted including both transient and steady state measurements. Measurement of total heat flux was emphasized rather than measurement of hot side or cold side heat transfer coefficients. Consequently, configurations were sought which produce minimum disturbance to the heat flux which would be present without the sensor in place. Three basic types of devices were selected for further study; the embedded thermocouple sensor, the laminated sensor and the Gardon gauge. These sensors were analytically modelled and detailed heat transfer calculations carried out to provide data for the design of non-perturbing sensor installations. This work also included an investigation of hot side boundary layer effects using the program STAN5. The experimental development program consisted of the fabrication of sensors which were then subjected to a series of thermal soak tests, thermal cycle tests and pre and post test calibrations. Calibration facilities were constructed using electrically heated filaments and quartz lamp banks. A major requirement of the program was the achievement of repeatable calibration with 5% uncertainty or less at realistic gas turbine temperature conditions. The results of this work and the sensor designs developed are contained in the contract final report which will be published shortly.

A follow on to this program was recently begun which will be completed in mid '83. In this work the total heat flux sensors developed in part 1 of the program will be run in a high pressure combustor environment as part of the NASA Broad Spec Fuels Combustor Technology Program (NAS3-23269). In addition, two types of radiant heat flux sensors will be run, a porous plug radiometer and an optical radiometer. The two radiometers are significantly different in principle and in their spectral and spatial sensitivity. On completion of this contract, HOST participants will have sensor design information and performance data available to provide the basis for total heat flux measurements on combustor liners and also performance data on two types of radiant heat flux sensors.

The turbine blade and vane heat flux sensor program, NAS3-23529, was recently begun and is planned to be completed in two years. It has two basic objectives. First, building on experience in the above programs, it will develop total heat flux sensor concepts which apply to the considerably more difficult geometry of cooled vanes and blades. In addition to wire thermocouple based approaches to the sensor design, sputtered thin film thermocouples, fiber optic and other alternative sensor designs will be considered. The most promising sensor designs will be run in a demonstration test employing a well known geometry in which the output of the sensors under development will be compared with alternative measurements of heat flux. This program will result in sensor design and performance data suitable for use by other HOST participants in blade and vane heat flux measurement.

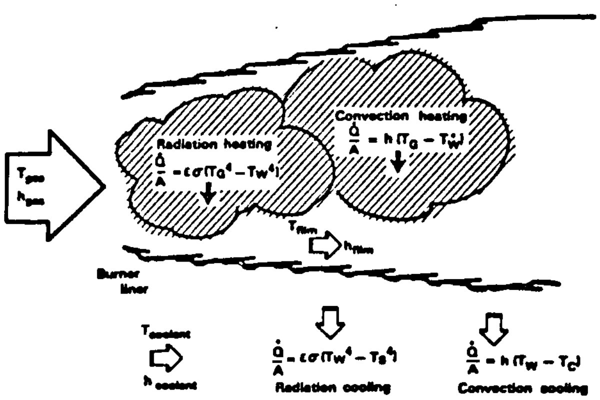
"HEAT FLUX SENSORS FOR BURNER LINERS AND TURBINE BLADES AND VANES"

W.G. Alwang
P&WA
Commercial Engineering

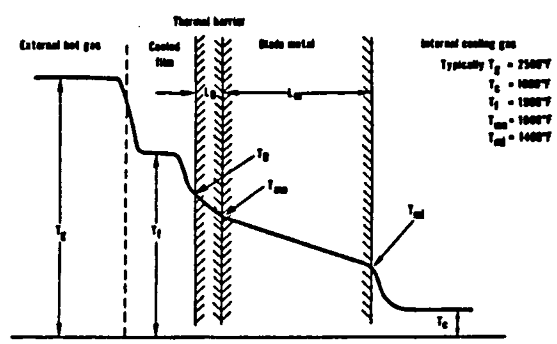
CRITICAL PARAMETERS IN TURBINE COOLING

- Metal temperature
- Heat flux:
  convective and radiative
- Gas temperature
- Strain

BURNER LINER HEAT TRANSFER



HEAT FLUX IN A COOLED AIRFOIL



$$Q_c = \frac{(1-\eta_f)(T_g - T_c)}{\left(\frac{1}{h_g} + \frac{K_B}{L_B} + \frac{K_m}{L_m} + \frac{1}{h_c}\right)} \qquad \eta_f = \frac{T_g - T_f}{T_g - T_c}$$

HOST HEAT FLUX SENSOR PROGRAMS

- "Advanced high temperature heat flux sensor development" (NAS3-22133)
  - Phase 1 — Develop sensor for burner liner good to 1 megawatt/m^2 (Final report October 1982)
  - Phase 2 — Demonstrate total and radiative heat flux measurement in NASA broad spec fuel program (Test schedule May 1983)
- "Turbine blade and vane heat flux sensor development and experiment" (NAS3-23529)
  - Phase 1 — develop sensor for cooled blades and vanes (complete August 1983)
  - Phase 2 — demonstrate in experiment at turbine conditions (complete August 1984)

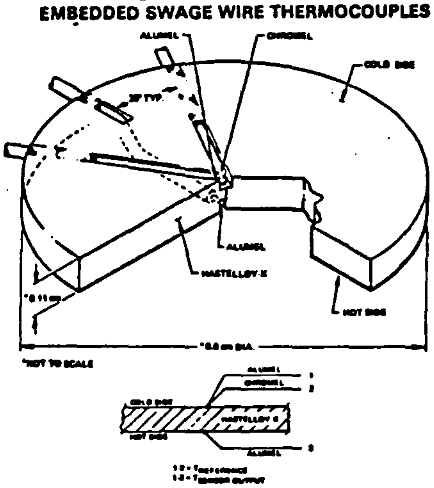
GENERAL METHODS OF MEASURING TOTAL HEAT LOADS

- Measurement of differential temperature across a thermal barrier caused by the heat flow
- Measurement of the temperature history of a known mass of material
- Measurement of input power required to maintain a constant surface temperature

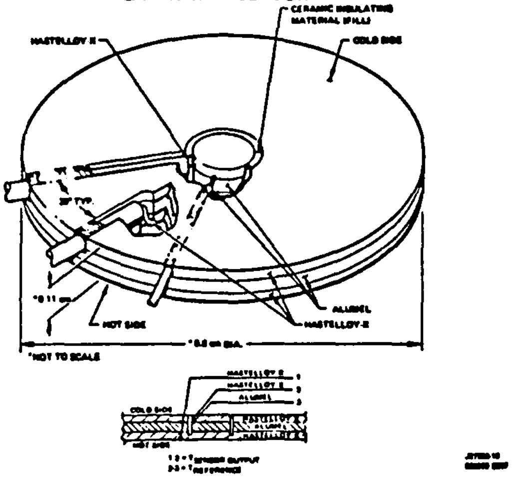
THREE APPROACHES SELECTED FOR BURNER LINERS (ALL STEADY STATE)

- Embedded thermocouple sensor
- Laminated sensor
- Gardon gauge

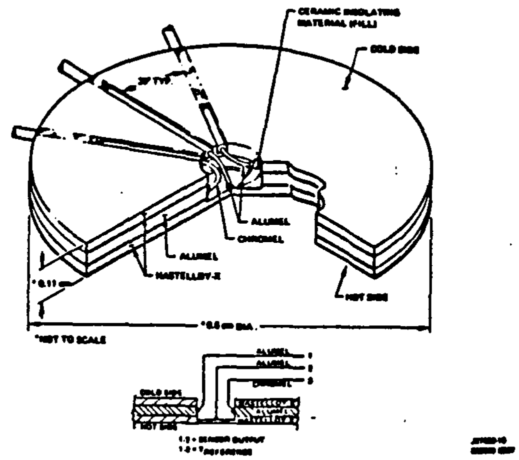
CONSTRUCTION DETAILS EMBEDDED SWAGE WIRE THERMOCOUPLES



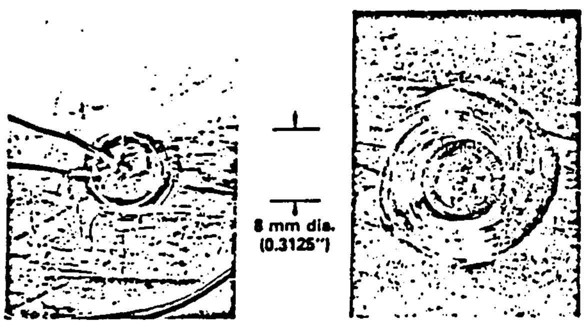
CONSTRUCTION DETAILS
LAMINATED SENSOR



CONSTRUCTION DETAILS
GARDON GAUGE



HIGH TEMPERATURE STEADY STATE HEAT FLUX SENSOR FOR COMBUSTOR LINER APPLICATIONS



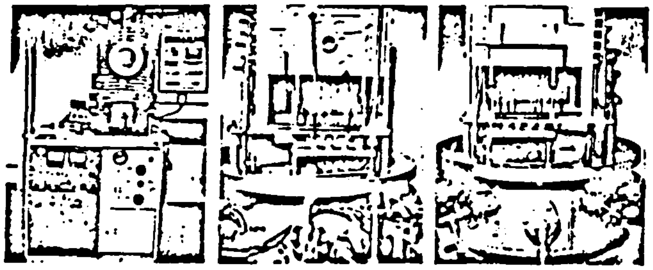
Cold side

Hot side

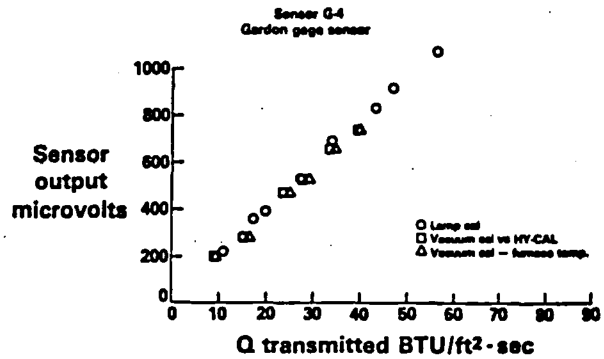
DEVELOPMENT TESTING OF SENSORS

- Thermal soak tests
- Thermal cycle tests
- Calibrations
  - Absolute
  - Comparative

THREE FILAMENT RADIATIVE CALIBRATION FACILITY



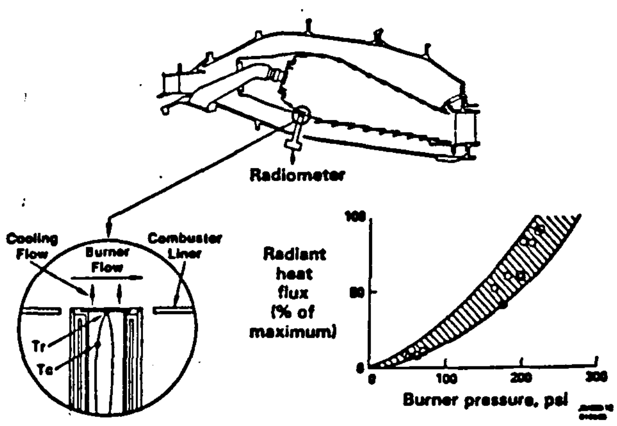
COMPARISON OF ABSOLUTE AND COMPARATIVE CALIBRATIONS

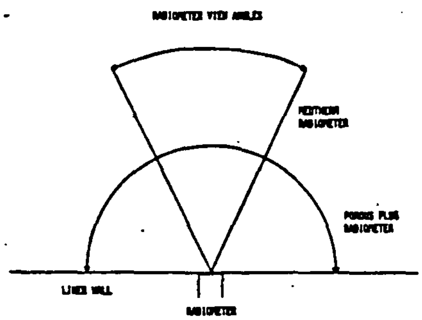


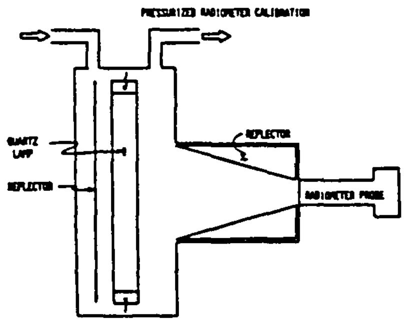
GENERAL METHODS OF MEASURING RADIATIVE HEAT TRANSFER

- Radiometers with windows
- Radiometers with gas purge
- Porous plug radiometers

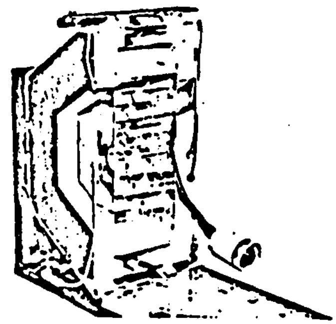
POROUS PLUG RADIOMETER



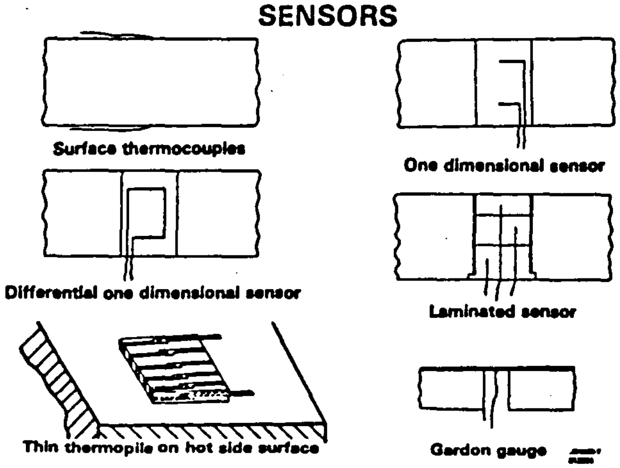




QUARTZ LAMP RADIATIVE CALIBRATION FACILITY



ONE DIMENSIONAL STEADY STATE SENSORS



THIN FOIL TRANSIENT HEAT FLUX SENSOR