HEAT FLUX MEASUREMENTS IN ROCKET LAUNCH ACCIDENTS

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Introduction

When aluminized, solid rocket propellant burns at ambient pressure, temperatures can exceed 3000 K and heat fluxes of over 1 MW / m^2 have been measured. To support safety assessments, temperature and heat flux measurements are needed in fire plumes produced by burning large chunks of propellants. To provide a more complete definition of the thermal environment in such fires, NASA's Jet Propulsion Laboratory has funded a detailed experimental program and supported the development of a CFD fire model.

Sensor Development

Two graphite calorimeters have been developed for heat flux measurements in plumes generated by approximately one-dimensional, end burning of propellant cylinders up to 0.5 meters in diameter. A Rod Calorimeter has been developed for when the propellant burn surface faces upward; this calorimeter is a 10 cm diameter cylinder. A Plate Calorimeter has been developed for when the propellant burn surface faces downward; the circular plate has a 60 cm diameter.

Multi-dimensional heat transfer in the calorimeters is unavoidable. As a result, the calorimeter development process includes analytical and experimental performance characterizations. This characterization process will be used to evaluate how multi-dimensional heat transfer, measurement noise (or errors), and loss of sensors affects the uncertainty of the heat flux estimates.

The thermal network analysis code, SINDA, is being used to predict calorimeter response to a best estimate of the heat flux history. For the surface being impacted by the flame plume, the total heat transfer components are deposition, radiation, and some convection. The deposition heat transfer is due to the impact and solidification of molten aluminum / aluminum oxide particles. In SINDA, the heat transfer is simulated by a time varying, heat flux input.

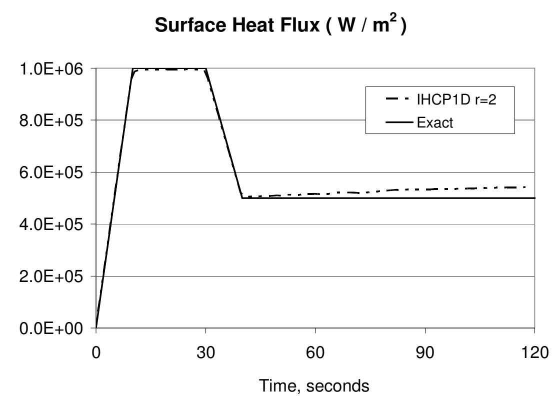
There are four thermocouples in the central instrumented core of the Rod Calorimeter. One is at the surface and the others are 6.3 mm, 12.7 mm, and 25.4 mm below the surface. One of several heat flux exposure scenarios is:

Impact (End) Face – ramp from 0 to 1 MW / m^2 over 10 seconds, hold for 20 seconds, drop to 0.5 MW / m^2 over 10 seconds, hold for 80 seconds

Side Wall – hold at 0.3 MW / m^2 for 120 seconds

Uncertainty - Preliminary

The code IHCP1D from Beck Engineering Consultants is used for the inverse heat conduction analysis. Using SINDA results as perfect thermocouple data, the inverse analysis showed the estimated heat flux closely tracked the input heat flux (within ±5%) for the first 35-40 seconds. As shown below, there was some rounding of sharp corners and the estimated flux drifted slowly above the input due to multi-dimensional heat transfer. At 120 seconds, the estimated value was 10-12% above the input. Loss of the surface thermocouple degraded the heat flux estimates. Adding noise had a lesser effect.



Inverse Analysis of 3-D SINDA Model Data

Experimental Characterization

The next step in the development is experimental characterization of the calorimeters. This will be done in the Thermal Test Complex at Sandia National Laboratories. A quartz lamp array will be used to provide radiant heating that matches the SINDA input levels as closely as possible. Experimental data analysis will use measured thermal properties to better estimate as-built uncertainty.