Technology Focus: Test & Measurement

An "Inefficient Fin" Non-Dimensional Parameter to Measure Gas Temperatures Efficiently

This method provides a convenient sensing error guideline.

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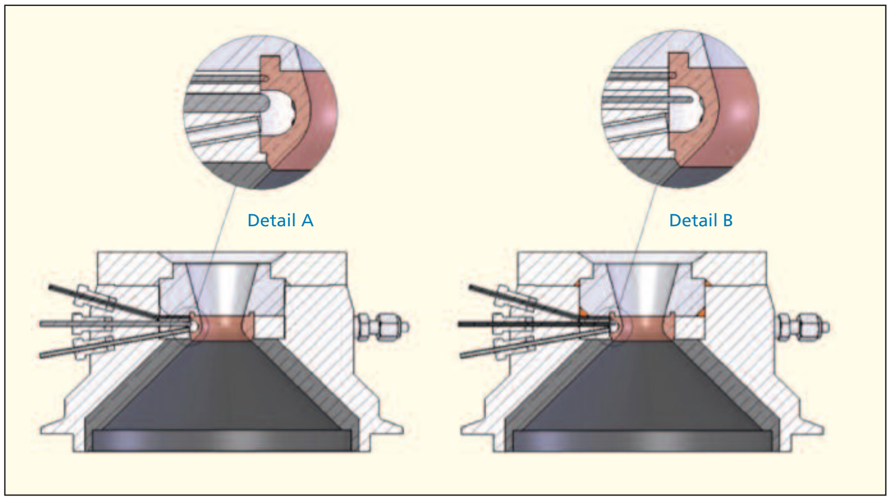
A gas containment vessel that is not in thermal equilibrium with the bulk gas can affect its temperature measurement. The physical nature of many gas dynamics experiments often makes the accurate measurement of temperature a challenge. The environment itself typically requires that the thermocouple be sheathed, both to protect the wires and hot junction of the instrument from their environment, and to provide a smooth, rigid surface for pressure sealing of the enclosure. However, that enclosure may also be much colder than the gas to be sensed, or vice-versa. Either way, the effect of such gradients is to potentially skew the temperature measurements themselves, since heat may then be conducted by the instrument.



A **Schematic of the Apparatus Used in the Rocket Throat Cooling Experiment**. The three instruments measure throat temperature, gas temperature, and gas pressure (top to bottom). At left, the gas-sensing probe is nearly flush with the inner surface of the throat, corresponding with a low inefficient fin non-dimensional number. At right, the *D* (probe diameter) and *L* (distance past the enclosure wall) were changed to correspond to a non-dimensional number of 4.60.

Thermocouple designers traditionally address this problem by insulating the sheath from the thermocouple leads and hot junction as much as possible. The thermocouple leads are typically packed in a ceramic powder inside the sheath, protecting them somewhat from temperature gradients along the sheath, but there is no effective mechanism to shield the sheath from the enclosure body itself. Standard practice dictates that thermocouples be used in installations that do not present large thermal gradients along the probe. If this conduction dominates heat transfer near the tip of the probe, then temperature measurements may be expected to be skewed. While the same problem may be experienced in the measurement of temperature at various points within a solid in a gradient, it tends to be aggravated in the measurements of gas temperature, since heat transfer dependent on convection is often less efficient than conduction along the thermocouple.

The proposed solution is an inefficient fin thermocouple probe. Conventional wisdom suggests that in many experiments where gas flows through an enclosure (e.g., flow in pipe, manifold, nozzle, etc.), the thermocouple be introduced flush to the surface, so as not to interfere with the flow. In practice, however, many such experiments take place where the flow is already turbulent, so that a protruding thermocouple probe has a negligible effect on the flow characteristics. The key question then becomes just how far into the flow should a thermocouple protrude in order to properly sense the gas temperature at that point. Modeling the thermocouple as an "inefficient fin" directly addresses this question. The appropriate assumptions in this case are: one-dimensional conduction along the fin; steady-state, constant, and homogeneous thermal conductivity; negligible radiation; and a uniform, constant heat transfer coefficient over the probe surface. It is noted that the nature of the ceramic-filled probe makes the key assumption of homogeneous thermal conductivity that much more conservative.

Normally a mathematical expression is used to assess fin efficiency, i.e., how far from the fin base heat can be carried. In this case, however, the thermocouple probe should be designed to be an inefficient fin; that is, parameters should be chosen such that the temperature of the wall does not affect the temperature sensed at the tip of the probe. This inefficient fin parameter is then numerically equal to $\ln(100/\%\text{ error})$, where % error is computed with respect to the temperature difference between the wall and the fluid. A one-to-one correspondence between this parameter and the error in sensed temperature may thus be established. For example, for a maximum error of 5%, the non-dimensional parameter value is 3.00. For an error of 1%, the target parameter value becomes 4.60. This parameter dictates the minimum distance for a given probe.

This simple method provides a convenient guideline to maintain flow temperature sensing error within a predefined range, given a temperature mismatch between a gas and its surrounding walls. This approach was put to practice in such an experiment, where a hot rocket nozzle was cooled using a two-phase fluid (where the fluid temperature may thus be verified, using the saturation pressure). The measured temperature in the cooling annulus showed good agreement with the method, and the thermocouple became essentially insulated from the wall by setting the hot junction at a distance corresponding to the parameter value of 4.60.

This work was done by Patrick Lemieux, William Murray, Terry Cooke, and James Gerhardt of California Polytechnic State University for Dryden Flight Research Center. Further information is contained in a TSP (see page 1). DRC-010-030

On-Wafer Measurement of a Multi-Stage MMIC Amplifier With 10 dB of Gain at 475 GHz

Imaging applications include hidden weapons detection, troop protection, and airport security.

NASA's Jet Propulsion Laboratory, Pasadena, California

JPL has measured and calibrated a WR2.2 waveguide wafer probe from GGB Industries in order to allow for measurement of circuits in the 325–500 GHz range. Circuits were measured, and one of the circuits exhibited 10 dB of gain at 475 GHz.

The MMIC circuit was fabricated at Northrop Grumman Corp. (NGC) as part of a NASA Innovative Partnerships Program, using NGC's 35-nm-gate-length InP HEMT process technology. The chip utilizes three stages of HEMT amplifiers, each having two gate fingers of 10 μm in width. The circuits use grounded coplanar waveguide topology on a 50-μm-thick substrate with through substrate vias. Broadband matching is achieved with coplanar waveguide transmission lines, on-chip capacitors, and open stubs. When tested with wafer probing, the chip exhibited 10 dB of gain at 475 GHz, with over 9 dB of gain from 445–490 GHz.

Low-noise amplifiers in the 400–500 GHz range are useful for astrophysics receivers and earth science remote sensing instruments. In particular, molecular lines in the 400–500 GHz range include the CO 4-3 line at 460 GHz, and the CI fine structure line at 492 GHz. Future astrophysics heterodyne instruments could make use of high-gain, low-noise amplifiers such as the one described here. In addition, earth science remote sensing instruments could also make use of low-noise receivers with MMIC amplifier front ends.

Present receiver technology typically employs mixers for frequency down-conversion in the 400–500 GHz band. Commercially available mixers have typical conversion loss in the range of 7–10 dB with noise figure of 1,000 K. A low-noise amplifier placed in front of such a mixer would have 10 dB of gain and lower noise figure, particularly if cooled to low temperature. Future work will involve measuring the noise figure of this amplifier.

This work was done by Lorene A. Samoska, King Man Fung, David M. Pukala, and Pekka P. Kangaslahti of Caltech; and Richard Lai and Linda Ferreira of Northrup Grumman Corp. for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-47541

Software to Control and Monitor Gas Streams

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This software package interfaces with various gas stream devices such as pressure transducers, flow meters, flow controllers, valves, and analyzers such as a mass spectrometer. The software provides excellent user interfacing with various windows that provide time-domain graphs, valve state buttons, priority-colored messages, and warning icons. The user can configure the software to save as much or as little data as needed to a comma-delimited file. The software also includes an intuitive scripting language for automated processing. The configuration allows for the assignment of measured values or calibration so that raw signals can be viewed as usable pressures, flows, or concentrations in real time. The software is based on those used in two safety systems for shuttle processing and one volcanic gas analysis system.

Mass analyzers typically have very unique applications and vary from job to job. As such, software available on the market is usually inadequate or targeted on a specific application (such as EPA methods). The goal was to develop powerful software that could be used with prototype systems. The key problem was to generalize the software to be easily and quickly reconfigurable.

At Kennedy Space Center (KSC), the prior art consists of two primary methods. The first method was to utilize LabVIEW and a commercial data acquisition system. This method required rewriting code for each different application and only provided raw data. To obtain data in engineering units, manual calculations were required. The second method was to utilize one of the embedded computer systems developed for another system. This second method had the benefit of providing data in engineering units, but was limited in the number of control parameters.

Other products allow the same end effect, except multiple computers would be required along with multiple software packages. This is compounded by the difficulty in timing the various software products. The software package described here is a combination of gas stream monitoring software products. It combines pressure monitoring and control, fluid flow monitoring and control, and many chemical analysis products, including, but not limited to, mass analyzers, turbo pumps, dew point sensors, oxygen sensors, temperature sensors, and the like. It allows for real-time display of raw data as well as reassigned cal-