Engineering Notes

ENGINEERING NOTES are short manuscripts describing new developments or important results of a preliminary nature. These Notes cannot exceed 6 manuscript pages and 3 figures; a page of text may be substituted for a figure or vice versa. After informal review by the editors, they may be published within a few months of the date of receipt. Style requirements are the same as for regular contributions (see inside back cover).

Miniature Low Range Differential Pressure Transducer with Time Constant for R/Vs

J. M. Cassanto* and C. R. Droms†
General Electric Company, Philadelphia, Pa.

Introduction

THE purpose of this note is to present the results of feasibility ground tests of a new miniaturized, low range differential pressure (ΔP) transducer modified with a time constant to measure low level ($P \leq 1.0$ psia) pressures for re-entry vehicle (R/V) flight test applications. This new sensor is an order of magnitude smaller and lighter than a standard conventional low range absolute pressure transducer. The ΔP sensor with a time constant is a previously developed concept[1] used in wind tunnels and shock tunnels[2-4] to produce a small compact flight package which has been applied to a commercially available miniaturized ΔP sensor. The concept consists of a differential pressure transducer with a time constant (lagged reference pressure/controlled leak rate) that vents to the vacuum of free space while "over the top" in an R/V ballistic trajectory and utilizes that vacuum as a reference pressure during re-entry.

R/V Flight Data Low Range Base Pressure Requirements

Low range ($P_b \leq 1.0$ psia) pressure measurements are made on the base of flight R/V's to provide a means of detecting the altitude of onset of boundary-layer transition from laminar to turbulent flow. It has been shown[5] from both ground tests and flight tests that the base pressure ratio altitude or Reynold's number history reaches a minimum at boundary-layer transition onset. The minimum in the base pressure ratio manifests itself in a repeatable discontinuity/slope change for the raw pressure data which always occurs at transition onset. Basically, the rate of change of base pressure (dp/dt) takes a sharp increase during transition from laminar to turbulent flow. This trend is illustrated by the typical flight data of Fig. 1 which shows an altitude/time history of both the raw pressure data (P_b) and the reduced base pressure ratio data (P_b/P_∞). The raw base pressure data clearly show transition by the slope change, and this technique will be utilized in the feasibility ground tests.

Concept Operating Principle/flight Simulation Test Results

Typical low range absolute pressure sensors ($P \leq 1.0$ psia) flown on GE R/V's to detect transition from base pressure measurements have operated on either the variable capacitance or reluctance principle. These sensors have provided highly accurate and reliable data on a multitude of R/V flight programs. However, these transducers have tended to be large, bulky, and heavy (~12 in.^{3} volume and ~9 oz weight) to meet stability and environmental test requirements. These sensors employ a large diaphragm area for low level pressure sensitivity and a hermetically sealed reference chamber, under vacuum, to sense the difference between the measured and reference pressures. Since vacuum leakage is present even with the best hermetic seals, a large reference chamber is required to insure calibration stability and a long shelf life. The advent of highly accurate miniaturized solid-state pressure transducers[6,7] in conjunction with the ΔP time lag sensor concept allows fabrication of a lightweight and compact flight package an order of magnitude smaller than the relatively large capacitance or reluctance low range absolute pressure transducers.

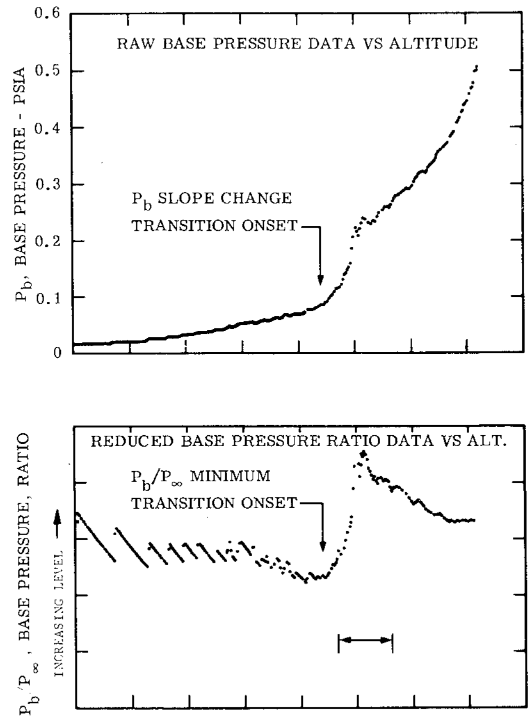

Fig. 1 Typical R/V base pressure flight data.

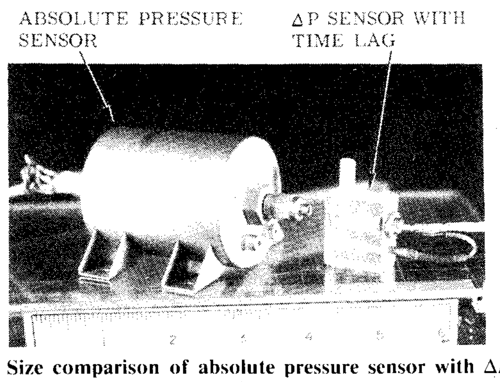

Fig. 2 Size comparison of absolute pressure sensor with ΔP time lag/time constant pressure sensor.

Received May 10, 1976; revision received Oct. 1, 1976. Presented as full paper at the Instrument Society of America (ISA) 22nd International Instrumentation Symposium, San Diego, Calif., 1976.

Index categories: LV/M Flight Testing; Boundary-Layer Stability and Transition; Jets, Wakes, and Viscid-Inviscid Flow Interactions.

*Project Engineer, Re-entry & Environmental Systems Division. Member AIAA.

†Group Leader, Re-entry & Environment Systems Division.

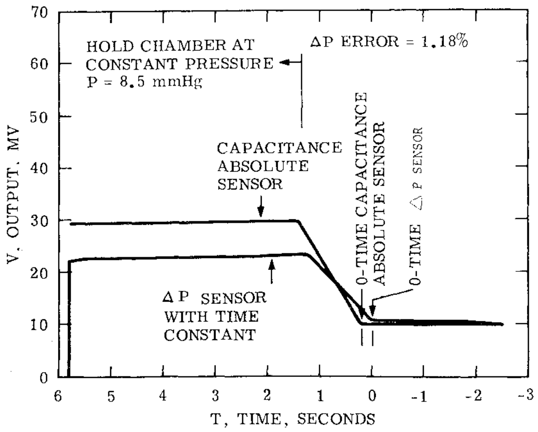

Fig. 3 Optimized time constant vent tube restrictor calibration.

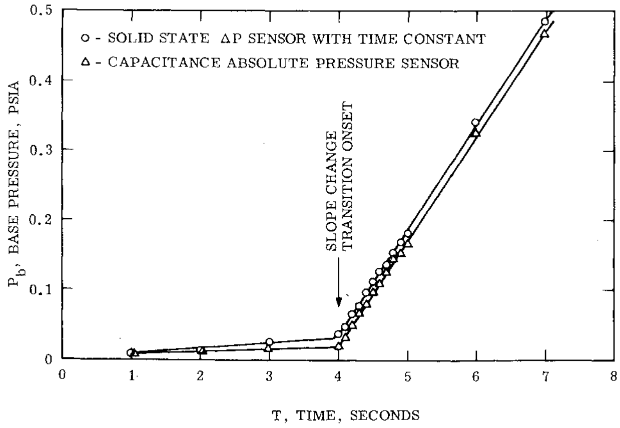

Fig. 5 Ground test re-entry base pressure simulation showing transition onset detection with ΔP sensor.

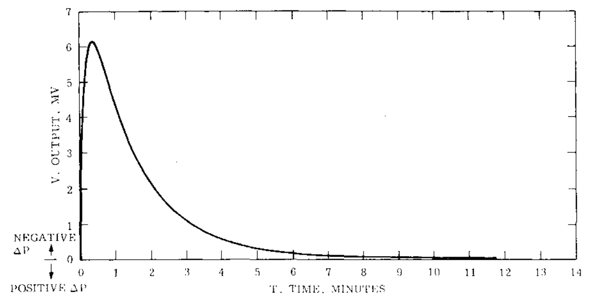

Fig. 4 Typical powered flight/over the top trajectory simulation (optimized time constant vent tube).

The miniaturized solid-state pressure transducer used for these tests operates on the strain gage principle, having a range of 0-0.2 psia. These type sensors have demonstrated capability to accurately measure pressures to within 0.1% of full scale.

The pressure sensor range of interest is 0 to 0.5 psia, and the base pressure level at transition onset for a typical R/V is ~0.05 to 0.10 psia. This represents 2.5 to 5.0% of the range of the transducer selected for the tests.

The sensor was modified with a vent tube restrictor flight test fixture to demonstrate feasibility. The test fixture would allow the pressure to be measured to flow directly into the sensor face while the reference or vent side of the sensor (low pressure side) was connected to the restrictor tube which caused a time lag in the re-entry flow to the reference side. Figure 2 is a photograph of the ΔP sensor with time lag compared to an absolute pressure sensor and demonstrates the obvious size advantage of the ΔP sensor concept.

Tests were conducted on an optimized time constant vent tube to determine the time lag required to keep the re-entry measurement error less than 5% at any test condition. The tests on the ΔP sensor with time constant were monitored with an absolute pressure transducer for comparison. Ramp/step function pressures were applied to both sensors in a vacuum chamber.The response of both sensors for a ΔP of 8.5 mmHg (Fig. 3) shows an error of only 1.2% for the ΔP sensor at the end of ~5 seconds. These results demonstrated that errors due to the time constant reference pressure lag are small during re-entry for a static pressure pulse.

The next test assessed whether the pressure transducer and vent tube restrictor could "vent" to a vacuum during the powered flight and "over the top" trajectory. It can be observed (Fig. 4) that the sensor vented the atmospheric pressure out of the sensor and equalized to a vacuum in approximately 10 minutes. This is more than enough time for most ICBM R/V trajectories to provide a vacuum reference pressure for re-entry measurements.

The final test was to perform re-entry pressure profile simulations by venting the bell jar from vacuum to atmospheric pressure in a time sequence that simulated re-entry base pressure during transition onset. The bell jar contained both the solid-state ΔP sensor (with time constant) and the absolute pressure sensor for comparison. Figure 5 shows the reduced data plotted as pressure time histories. Both the solid-state ΔP sensor and the absolute sensor clearly indicate transition onset at the same time, by the slope change. These data clearly show the feasibility of the time lag concept for providing valid re-entry flight pressure data.

Conclusions

The present results have demonstrated that a solid-state miniaturized ΔP pressure sensor with time constant (time lagged reference pressure) can accurately measure re-entry base pressure and successfully detect the onset of boundary-layer transition. This sensor is an order of magnitude smaller than a conventional low range absolute pressure transducer and can perform the same function. The ΔP time lag concept has another advantage in addition to the obvious size and weight advantages; namely, an extended shelf life since there are no calibration shifts due to reference chamber leakage as this concept eliminates the sealed reference chamber.

References

[1]Cassanto, J. M., "A New Concept for Low Range Pressure Measurements on Full Scale Flight Re-entry Vehicles," *Journal of Spacecraft and Rockets*, Vol. 6, Oct. 1969, pp. 1184-1186.

[2]Cassanto, J. M., "Base Pressure Results at M = 12 Utilizing Free Flight Telemetry Techniques in the GE-MSD Long Test Time Facility," General Electric, Philadelphia, Pa., GE-RESD ATDM No. 66-24, Dec. 1966.

[3]Ward, L. K. and Choate, R. H., "A Model Drop Technique for Free Flight Measurements in Hypersonic Wind Tunnels Using Telemetry," Arnold Engineering Development Center, Arnold AFB, Tenn., AEDC-TR-66-77, May 1966.

[4]Welton, J. T., "Free Flight Testing in the Jet Propulsion Laboratory Wind Tunnels," Jet Propulsion Lab., Pasadena, Calif., JPL TR No. 32-775, Sept. 1965.

[5]Cassanto, J. M., "A Method of Determining Onset of Boundary Layer Transition From Flight Test Base Pressure Data," General Electric, Philadelphia, Pa. GE-RESD AFTM 67-23, Oct. 1967.

[6]Cassanto, J. M., Rogers, D. A., Droms, C. R., and Robison, A. G., "Use of a Miniature Solid-State Pressure Transducer for R/V Flight Test Applications," Proceedings of ISA 20th International Instrumention Symposium, Albuquerque, New Mexico, May 1974; also see GE TIS 73SD251, Dec. 1973.

[7]Kicks, J., "Notes on Applications of Integrated Sensor (IS) Pressure Transducer," Application Note KPS AN11, Kulite Semiconductor Products, Inc., Ridgefield, N. J., 1973.