Lewis Research Center
Cleveland, Ohio 44135

Technical Support Package

Probes for Measuring Pressures in Flowing Gases

NASA Tech Briefs
LEW-16348

National Aeronautics and
Space Administration

Technical Support Package

for

PROBES FOR MEASURING PRESSURES IN FLOWING GASES

LEW-16348

NASA Tech Briefs

The information in this Technical Support Package comprises the documentation referenced in **LEW-16348** of *NASA Tech Briefs.* It is provided under the Technology Transfer Program of the National Aeronautics and Space Administration to make available the results of aerospace-related developments considered to have wider technological, scientific, or commercial applications. Further assistance is available from sources listed in *NASA Tech Briefs* on the page entitled “NASA Commercial Technology Team.”

Additional information regarding research and technology in this general area may be found in Scientific and Technical Aerospace Reports (STAR), which is a comprehensive abstracting and indexing journal covering worldwide report literature on the science and technology of space and aeronautics. STAR is available to the public on subscription from

Registration Services
NASA Center for AeroSpace Information
800 Elkridge Landing Road
Linthicum Heights, MD 21090-2934

Telephone: (301) 621-0390, Fax: (301) 621-0134, E-mail: help@sti.nasa.gov

Probes for Measuring Pressures in Flowing Gases

A. OBJECTS OF THE INVENTION

The present invention relates to an improved static pressure probe which is capable of providing a near-instantaneous (dynamic) static pressure measurement in a fluid flow field. A primary object of the invention is to provide a flow field static pressure measurement assembly comprising of the following elements: (1) A probe mounting stem, (2) A cartridge insert which contains both a commercially-available, fast-acting, electronic pressure-sensing transducer and conventional pneumatic pressure-sensing passages, and (3) Two static pressure probe tips which screw on to the probe stem. Each probe tip is optimized for flow field static pressure measurements in two separate flow regimes. The cone/cylinder probe tip is optimized for static pressure measurements in supersonic flow fields while the sphere/cylinder probe tip is used for the same measurements in subsonic flow fields. Another objective of the invention is to exploit the high frequency measurement capability of the electronic pressure transducer so that the static probe assembly is optimized to acquire multiple individual pressure measurements per second. A limitation of the invention is that the probe is suited for use in gaseous fluid flows only, not liquids.

B. COMMERCIAL APPLICATIONS

The present invention relates to an improved static pressure probe which is capable of providing a near-instantaneous (dynamic) static pressure measurement in a fluid flow field. Two areas where we see a commercial application of this invention is the aircraft industry and the natural gas pipeline transmission industry.

With the advent of digital flight controls, modern production aircraft now have the capability of efficiently monitoring highly sophisticated in-flight instrumentation to better assess the flow field in which the plane is flying. In particular, these flight control systems attempt to determine when detrimental atmospheric conditions such as wind shear and increased turbulence are present so that corrective flight control measures can be implemented immediately to avert a mishap. Our invention is well-suited as a piece of instrumentation intended to augment an aircraft digital flight control system. The main advantage of this dynamic static pressure probe over the current art is that this probe can provide the digital flight control system an instantaneous, time-varying trace of flow field static pressure which can be used to assess the aircraft's immediate flow field conditions. Also, the physical dimensions of the prototype probes are an appropriate scale for use as an aircraft pressure-sensing probe.

This probe may also see some potential use as a static pressure sensor in the natural gas pipeline transmission industry. In this application, the probe (or an array of probes) can be installed in a gas transmission pipeline segment. As with the aircraft application, the probe will provide an instantaneous, time-varying trace of the local flow field static pressure. The static pressure probe can be used to augment a transmission pipeline mass flow control system.

C. DISCLOSURE OF INVENTION

1. Purpose

The present invention relates to an improved static pressure probe which is capable of providing a near-instantaneous (dynamic) static pressure measurement in a fluid flow field.

2. Prior Art and Disadvantages of the Prior Art

Conventional flow field static pressure measurement probes typically are manufactured with pneumatic pressure passages and use tubing to transmit the sensed static pressure to measurement transducers located some distance away from the actual sensor point. Because the pressure-measuring transducer is located so far from the sensing point, a significant volume of fluid between the measurement and sensing location tends to damp out any rapid fluctuation in static pressure at the probe sensing point. Hence, the transducer tends to measure a time-averaged static pressure rather than an instantaneous static pressure. In addition, there can be a significant time lag present between when the pressure is sensed and when it is actually measured by the transducer.

3. Description of the Invention

A primary object of the invention is to provide a flow field static pressure measurement assembly comprising of the following elements shown in the engineering assembly drawing number 27146XXXX101: (1) A probe mounting stem (Part 102), (2) A cartridge insert which contains both a commercially-available, fast-acting, electronic pressure-sensing transducer (dynamic pressure transducer) and conventional pneumatic pressure-sensing passages (Part 103), and (3) a static pressure probe tip which screws on to the probe stem (Part 104). The probe tip shown in the drawing is a cone/cylinder geometry which is optimized for static pressure measurements in supersonic flow fields. Alternatively, a sphere/cylinder probe tip geometry, which is not illustrated in the drawing, can be used for static pressure measurements in subsonic flow fields.

As shown in the assembly drawing, the pressure measurement cartridge insert subassembly (Part 103) mounts within the probe stem (Part 102). The appropriate static pressure probe tip (Part 104) screws onto the threaded portion of the probe stem to form the complete flow field static pressure probe assembly.

The pressure measurement cartridge details are shown in engineering drawing number 27146XXXX103. There are two methods of pressure measurement incorporated into this cartridge: (1) A dynamic pressure measurement capability provided by a commercially-available fast-acting, electronic pressure-sensing transducer, and (2) A time-averaged (steady-state) pressure measurement capability provided by a pneumatic-sensing approach which consists of a series of machined fluid flow passages.

The dynamic pressure transducer is not shown in the drawing. However, the transducer mounts within the 0.067 in diameter passage at the centerline of the cartridge, and the sensing portion of the transducer is flush with the cartridge front face (Surface B). This pressure transducer is a self-contained unit; only a wire is used to transmit the electronic pressure measurement signal.

The pneumatic pressure-sensing apparatus consists of four 0.020 in passages spaced 90 degrees apart that duct the sensed pressure to a plenum. The plenum is actually a 0.025 in wide slot milled into the cartridge. At the rear of the plenum is a single 0.020 in diameter channel which has provisions to attach tubing which transmits the pressure measurement to the steady-state pressure transducer.

Two O-rings are used on the outer surface of the pressure sensing cartridge to seal the air passages and also to hold the cartridge in the probe stem. These O-rings mount in the two milled slots just downstream of the plenum slot.

The detailed drawing of the static pressure measurement tip is shown in engineering drawing number 27146XXXX104. The external shape and locations of the static pressure measurement ports are a standard design that has been proven to successfully measure flow field static pressures in supersonic flow. Alternatively, a different external design would be specified if the probe assembly were used to obtain flow field static pressure measurements in subsonic flow. The internal passages of these probe tips are unique to this invention and are optimized to integrate with the above-mentioned cartridge assembly so that accurate dynamic and steady-state static pressure measurements can be acquired simultaneously. The major features of these internal passages would be similar in each probe (supersonic or subsonic).

A significant portion of the probe tip internal passage acts as a sleeve to house the pressure measurement cartridge. Just upstream of this sleeve, another passage is machined in the probe tip which is intersected by eight 0.020 in radial holes. These radial holes are the actual pressure sensing mechanism for the entire static probe assembly and are typically referred to as static pressure measurement ports. That is, when this static pressure probe is used to acquire pressure measurements in a gaseous flow field, the measurements are actually made by these eight ports. The passage that these static pressure ports intersect acts as a plenum. It is the pressure in this plenum that is actually measured by both the dynamic pressure transducer and the steady-state pneumatic system.

This pressure sensing tip screws onto a hollow probe stem which is depicted in the engineering drawing number 27146XXXX102. This stem serves the following purposes for the static probe assembly:

a. It serves as a holder for the pressure sensing cartridge.

b. It is used as a mounting platform for the static pressure measurement tip.

c. It is used to attach the entire probe assembly to a facility mounting apparatus.

d. It shields the tubing and electronic wire that is attached to the pressure sensing cartridge.

One concern of the probe assembly is that the probe tip may tend to unscrew during actual use due to factors such as vibration, pressure loadings, and thermal gradient effects. For this reason we chose an extremely fine thread pitch (40 TPI) for the prototype probes coupled with the application of a mild thread locking compound when assembling the two parts. We experienced no instances of the probe unscrewing at all during our development testing program.

4. Operation of the Invention

In actual use, the static probe assembly is immersed in a flow field in which a static pressure measurement is desired. In the Figure 1 photograph, a pair of these probes are installed in a small supersonic wind tunnel for development testing. At the exit of each probe stem, a pneumatic tube and electronic wire must be routed to the measurement apparatus. The probe measures the local flow field static pressure in the following manner:

a. The external aerodynamic shape of the probe tip ensures that the local pressure at the eight measurement taps on the surface is equal to the static pressure of the flow field in which the probe is immersed.

b. The pressure within the probe measurement ports and the plenum adjust to this external pressure.

c. The dynamic pressure transducer located in the cartridge assembly immediately senses this pressure via electronic means and sends the signal through the transmission wire to the external signal processing equipment. Depending on how well this electronic transducer is integrated into the probe measurement tip, accurate static pressure measurements will be obtained on the order of 10 to 500 measurements per second. This results in a near-instantaneous static pressure measurement capability which can respond to measure a change in pressure on the order of milliseconds.

d. Concurrently, the same pressure in the plenum is measured by the pneumatic system. However, the volume of fluid in the pneumatic passages upstream of the pressure transducer results in a steady-state pressure measurement similar to what is measured with a conventional pneumatic static pressure probe.

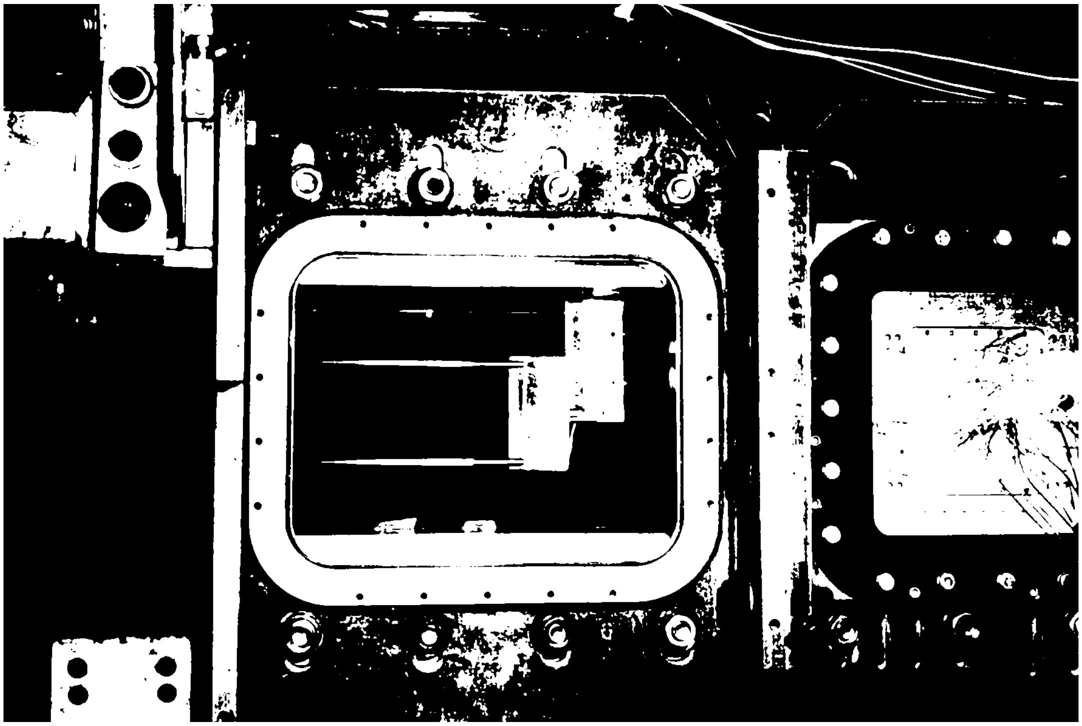

Figure 1
Prototype Dynamic Static Pressure Probes Installed in a Supersonic Wind Tunnel

5. Validation Testing

From the results of the conceptual study of this flow field static pressure measurement concept, a number of prototype probes are fabricated to the specifications shown in the engineering drawings. A series of developmental tests are proposed to validate the measurement concept:

a. Tests where the probes are immersed in a steady-state supersonic flow field with some transient pressure fluctuations. Objectives of this testing is to determine whether both measurement methods in the probe are measuring the correct steady-state flow field static pressure. Begin to evaluate the dynamic measurement capability of the probe by acquiring some transient data with the high-response transducer.

b. Tests where the probes are immersed in a transient flow field. A shock tube is used to provide a step change in static pressure at the probe measuring station. Objectives of this testing is to characterize the near-instantaneous (dynamic) pressure measurement capability of the probe.

In the present development study, the electronic transducer/data acquisition system is capable of obtaining 250,000 measurements per second. This rapid sampling rate coupled with the transducer’s near proximity to the measurement location results in a near-instantaneous pressure measurement. Although the transducer is capable of providing 250,000 measurements per second, the actual pressure measurement rate by the probe assembly is much less due to measurement damping effects caused by the measurement taps/plenum portion of the probe. For the prototype testing, the plenum chamber in the probe tip is deliberately oversized as shown in the engineering drawing (number 27146XXXX104). Various plenum volumes are chosen as a means of optimizing the dynamic pressure capability of the probe.

From the phase one testing, we determined the following:

a. The static pressure probe did measure the correct free stream static pressures at supersonic flow conditions. Testing was conducted at free stream nominal Mach numbers of 1.6, 2.0, and 2.5.

b. Both pressure measurement techniques incorporated in the static pressure probe measured static pressures within 0.02 psia of each other (worst case). This amounts to a one to two percent discrepancy in static pressure measurement based on the static pressures measured in this investigation. The rms value of the dynamic pressure transducer signal is compared to the time-averaged pneumatic pressure measurement for these comparisons.

c. Different probe plenum chamber volumes did not affect the steady-state measurement capability of the probes.

d. The unsteady pressure measurement with the electronic transducer did react to changes in static pressure due to transients in the flow field. In particular, the probe did sense the change in static pressure due to shock waves passing through the flow field.

The phase 2 portion of the validation testing will be conducted later in the calendar year. The focus of this testing will be to optimize the frequency response (sampling rate) of the static pressure probe assembly.

6. Advantages Over Prior Art

The advantages of this flow field static pressure probe over the prior art are listed below:

a. Probe is capable of responding to a transient change of a flow field static pressure much quicker than the prior art. Prior art response times are on the order of seconds while this invention is capable of responding and measuring a pressure transient on the order of milliseconds.

b. Probe is capable of simultaneously measuring static pressure via two methods: (1) A dynamic pressure transducer to capture transient effects, and (2) Pneumatic pressure sensing system to capture steady-state effects.

c. Modular nature of probe assembly allows probe to be used in various flow fields such as subsonic and supersonic airflow by changing the probe tip. Prior art fabricated complete probes for use in one type of flow field only.

7. Features Believed to be New

The following features of the invention are believed to be new:

a. Dynamic pressure measurement capability of static pressure by placing a dynamic pressure transducer within a flow field static pressure probe.

b. Novel design of removable cartridge assembly that allows simultaneous measurement of transient and steady-state static pressure via two independent measurement systems.

c. Modular design of probe allows a variety of probe tips to easily reconfigure the probe assembly for use in different flow fields.

8. Contribution of Inventors

The contributions of each inventor to this invention are listed below:

a. A. Robert Porro

1. Envisioned mounting a dynamic pressure transducer within a static pressure probe to improve measurement response times.

2. Conceptual design of probe cartridge insert that simultaneously measures transient and steady-state static pressure.

b. Michael A. Ernst

1. Envisioned that the static pressure probe assembly be designed and assembled in a modular fashion so that a variety of static pressure measurement tips could be easily adapted to the probe assembly.

2. Detailed engineering design of all parts of probe assembly.