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SUMMARY

Limited flight testing of a laser transit velocimeter has provided insight into the problems associated with the use of such instruments for flight research. Although the device tested was not designed for flight application, it had certain features such as fiber optics and low laser power which are attractive in the airborne environment. During these tests, operation of the velocimeter was limited by insufficient concentrations of light-scattering particles and background light interference. Normal operation was observed when these conditions were corrected by utilizing cloud particles and flying at night. A comparison between the laser flow velocity measurements and corresponding pressure measurements is presented and shows a coarse correlation. Statistical bias due to turbulence in the flow is suspected to have affected the laser measurements.

INTRODUCTION

The advantages of laser velocimetry over conventional direct-contact instrumentation have begun to be realized for certain local flow measurements in wind-tunnel research. In particular, optical systems can provide flow-velocity and direction measurements without disturbing the flow being measured — a significant advantage when unstable flow fields, such as boundary layers, are being studied. In some instances, lasers may be used to measure flows that are inaccessible or that are otherwise unsuitable for the use of conventional instrumentation. However, these benefits must justify the greater complexity and cost of the optical systems. Similar laser velocimeter systems may also be desirable for specific flight-test applications, but additional operational problems associated with the flight environment must be considered.

For several reasons, ground-based laser velocimeters are generally not practical for direct installation on aircraft: (1) laser systems used for wind-tunnel testing are not severely constrained by size, weight, or electrical power requirements — factors that are significant in the flight-test environment; (2) high-powered lasers, used in many laser velocimeters, can be hazardous in flight; and (3) vibration, temperature, and pressure changes must also be considered in the design of flight equipment.

In addition, the performance of laser systems in flight may be limited by the concentration of aerosols in the atmosphere. Laser velocimeters rely on particles embedded in the airflow to scatter the laser light, but the natural distribution of particles in the atmosphere varies considerably with altitude and weather conditions. Unlike wind-tunnel applications, in which artificial particles can be inserted into the flow, it is difficult to control the particle concentration in flight.

The objective of this limited study was to use a laser velocimeter system to make a flight flow measurement and to evaluate the system relative to its basic operational considerations. An existing ground-based system was used to make flow-velocity measurements near the fuselage of an airplane in flight. This paper presents and discusses the results that were obtained. It should be noted that some common flight-test instrumentation constraints, such as size and weight, were not of prime importance in this study.

The laser system used in this study was designed and built by the Boeing Commercial Airplane Company, Seattle, Washington, and loaned to NASA for the duration of the flight tests. Dr. J. C. Erdmann of the Boeing Company helped in the design and interpretation of the experiment.

GENERAL SYSTEM DESCRIPTION

A laser transit velocimeter (LTV) uses scattered light from particles embedded in a flow field to determine the velocity of the flow. Two focused beams of laser light are projected into the flow so that the focal regions, or beam "waists," are closely spaced a known distance apart in the direction of the flow. As particles intersect the beam waists, or probe volume, light is scattered from each beam. If a single particle intersects both beams, the times of the beam disturbances can be used to determine the transit time between the two beams, and therefore, the speed of the particle.

In the interest of safety, system simplicity, and power limitations, it is desirable to work with low-power lasers in flight. Laser transit velocimeter systems can operate with relatively low-power light signals since the data are processed through digital correlation. Also, LTV systems are less sensitive to particle size. The trade-offs between LTVs and other laser velocimetry techniques are discussed in more detail in references 1-3.

An LTV that had been developed for wind-tunnel research was used in this experiment (fig. 1). Relative to many ground-based LTV systems, it is compact, low-power, and easy to align and operate. Fiber optics were included in the design to make installation easier under difficult conditions. A detailed description of the components and operational procedures of the device are given in reference 4.

The transceiver component (fig. 1) houses the transmitting and receiving optics in a single unit which can be remotely located from the rest of the system. Fiber optics are used to transmit laser light to the transceiver and to transmit the received light signal to the data processing equipment. The outside dimensions of the transceiver are 22 × 13 × 24 cm. The probe volume is projected at a fixed distance of 15.2 cm from the transmitting telescope aperture.

The light source in this system is a Class IIIb helium-neon laser. For safety reasons, the laser light is enclosed within the hardware except at the transmitting telescope, where it is directed into the flow field being studied. The optical power intensity is greatest at the probe volume and drops off rapidly with distance.

Separate photomultiplier tubes and a pulse shaper are used to convert the light signals from each beam waist into trains of consistent electrical pulses suitable for input into the digital correlater. The sensitivity of the tubes is controlled by the input voltage supplied to them. The threshold signal level for pulse generation is controlled at the pulse shaper.

The results of the correlation process are displayed on an oscilloscope in the form of a correlogram. The oscilloscope displays the number of pulse correlations at each of 96 discrete transit-time values. The range of transit times was usually 0 to 4800 nsec in these tests although the range could be varied.

This LTV device can also be used to indicate flow direction and turbulence intensity (ref. 4). These options were not exercised in order to reduce the scope of the experiment.

EQUIPMENT INSTALLATION AND INSTRUMENTATION

For flight testing, the LTV system was installed in the cabin of a Lockheed JetStar airplane. The JetStar was chosen because it could accommodate the LTV system in terms of space and electrical power requirements. Moreover, the cabin was pressurized and temperature-controlled, thus making it possible to use laboratory equipment in flight. The transceiver was mounted on a modified emergency escape hatch (fig. 2), so that flow measurements could be made near the fuselage surface. The laser, photomultiplier tubes, and power supplies were installed on the seat rails of the cabin floor. The data processing equipment was installed in such a way that an on-board operator could monitor the system and hand-record the results. A boundary-layer pressure rake was also installed so that local air velocity near the escape hatch could be calculated and compared with the LTV measurements.

A 7.6-cm-diam window of optical glass was installed so that the light beams could be focused near the fuselage surface. This window, which was 6.0 mm thick, affected the separation of the beam "waists" in the probe volume; however, a determination of the actual separation distance was not necessary for this experiment. The distance was assumed to be constant during the tests and, therefore, the consistency of the data could be evaluated. The probe volume itself was projected about 110 mm from the fuselage surface.

The laser system required 60 cycle electrical power which was supplied from the on-board, dc generator using three 250-W inverters. The total weight of the system with the inverters was about 110 kg. During the flight tests, the data processing equipment was manually operated in order to manually control the system and record data (fig. 3). The photomultiplier tube sensitivity, pulse shaper threshold levels, and correlator sample time were adjusted in flight. Data were recorded from the correlogram displayed on the oscilloscope.

Because the laser light emitted from the transciever is an eye hazard at close range, a nonreflective screen was used to attenuate the beams during ground testing. The laser was operated without the screen only in flight.

A total-pressure probe and static orifices were installed on the rescue hatch of the JetStar to provide an independent measurement of local flow velocity. The tip of the impact probe was 31 cm below the laser probe volume and 12.9 cm from the fuselage surface. Three flush orifices near the base of the probe provided a static pressure source, and the differential pressure (impact minus static) was displayed on a dial gage in the cabin. Pressure altitude from the cockpit instrument and current weather balloon data were used to calculate velocity and mean sea level altitude from the pressure data. This local velocity measurement was satisfactory for obtaining a coarse comparison with the laser velocimeter data.

TEST CONDITIONS AND DATA

The laser velocimeter was installed on the airplane for a series of five test flights and was operated during steady-state flight conditions at various airspeeds and altitudes. Data were recorded whenever adequate correlograms were observed on the oscilloscope. Only 15 measurements were obtained because of low concentrations of suitable particles in clear air (see table 1). Some of the correlograms that were observed in flight (figs. 4-6) were recorded by hand-fairing of the discrete points displayed on the oscilloscope. The correlograms shown in this report have been normalized to the peak number of occurrences at a realistic transit time. These results and the operation of the laser during each flight will be briefly discussed.

RESULTS AND DISCUSSION

The first flight was made in clear air during daylight hours and the laser was operated for about 20 min. Only two distinct cross-correlation peaks were observed in that time; they were similar to that shown in figure 4. An insufficient concentration of suitable particles made further measurements impossible. The unusual shape of these correlograms is attributed to interference from background light. The levels of ambient light accepted by the laser system were greater than anticipated and changed rapidly because of the motion of the airplane. The steady-state level of ambient light tended to produce random cross-correlation at all possible transit times. Transients in the light caused autocorrelation. In figure 4, the cross-correlation peak is seen superimposed on these effects. This ambient light interference could not be eliminated from the input to the digital correlator without greatly reducing the velocimeter's sensitivity to scattered laser light as well. The second flight, on which only one measurement was made, was flown under similar conditions and the same problems were noted.

The third flight was made at night in order to minimize the effects of background light. It was successful in that regard, although the particulate concentrations in clear air were again insufficient for continuous measurements. In an effort to find greater particle concentrations, several passes were flown through cirrus clouds at an altitude of about 9.3 km. Cross-correlation peaks were observed whenever cloud particles were used. A representative correlogram is shown in figure 5. The random correlation and autocorrelation associated with daylight background light in the first two flights are not seen in this figure. Along with the distinct cross-correlation peak, the correlogram shown in figure 5 also contains two other local maximums. This phenomenon was observed on three of the correlograms obtained from cloud particles and has not been accounted for. For the measurements made in this study, the largest peak was assumed to correspond to the transit velocity.

The fourth and fifth flights were made in daylight and more measurements were made during cloud passes. Because the cloud particles were relatively large, the sensitivity of the photomultiplier tubes could be reduced, therefore reducing background light interference. On the last flight, the JetStar was flown through clouds at lower altitudes (2.3 and 3 km), in which the levels of atmospheric turbulence were relatively higher; a representative correlogram (fig. 6) was observed.

Although flying through clouds provided adequate particle concentrations for the laser measurements in these tests, this is not a reliable and practical technique for laser flight-test applications. Aside from the obvious operational difficulties of conducting flight research in clouds, the particles found in these clouds were relatively large and in regions of accelerated flow may not accurately represent the flow velocity. Increasing the laser power or the diameter of the receiving optical components would allow smaller and more numerous particles to be detected by the system, but these modifications would also increase the size and complexity of the instrument, as well as the hazards associated with its use in flight. Adding particles to the flow is another possible solution, but the flow being measured would thereby be perturbed to some extent. Also, the flow would have to be seeded far enough upstream to ensure that the particles would have time to accelerate to the local flow velocity at the measurement location.

In these flight tests, the level of background light during daylight flights could not be controlled. Sky brightness and cloud cover affected these levels, as well as changes in the heading or bank angle of the airplane. Flying at night eliminated this interference from the observed correlograms. Precise spectral filtering of the received light may solve this problem in future designs.

In figure 7, laser measurements obtained in flight are plotted as a function of the corresponding pressure-probe velocity measurements. Because the actual beam separation distance of the laser velocimeter was not determined for this particular installation, velocity values cannot be computed from the transit-time measurements. By assuming a spot separation of 500 μm, perfect correlation between laser and pressure measurements is shown (solid line in fig. 7). The data generally reflect this trend, although there is a considerable amount of scatter. The pressure probe was located 31 cm from the laser probe volume which may account for some difference in velocity between the two measurements. Another explanation for this scatter is the statistical bias associated with particle arrivals in turbulent flow.

If the flow field that was measured was turbulent and if the concentration of particles was uniform, more particles would pass through the probe volume at a higher-than-average velocity than at a lower-than-average velocity. As a result, the mean laser velocity measurement in turbulent flow will be greater than the actual mean velocity. This bias, which is described in references 5-7, is reflected in the shape of the correlogram obtained from an LTV.

CONCLUDING REMARKS

The operation of an LTV was investigated on a limited basis in flight. Although the system was not optimized for flight testing, it had certain features that made it desirable for this application. These included fiber optic links between components of the system and low laser power. Some aspects of the airborne environment that affected system performance were addressed.

Operation of the device was limited primarily by insufficient particle concentrations and daylight interference. When these problems were remedied by utilizing atmospheric cloud particles and testing after daylight hours, normal operation was observed. Further research may provide satisfactory solutions to these problems as a step toward developing practical laser velocimeters for flight-test applications.

Laser velocimetry may be a solution for certain flight research measurements in situations for which current techniques are unsatisfactory; however, operational and environmental problems, some of which have been addressed in this study, must be resolved.

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TABLE 1.- SUMMARY OF FLIGHT DATA

Flight No.	Transit time, m/sec	Local velocity, pressure probe, m/sec	Altitude mean sea level, km	Conditions
1	3.30	193	5.6	Clear air
1	2.80	196	5.6	Clear air
2	1.60	259	6.3	Clear air
3	2.55	180	1.3	Clear air, night
3	3.51	179	6.4	Clear air, night
3	1.90	211	9.3	Cloud, night
3	1.99	210	9.3	Cloud, night
4	1.70	256	9.4	Cloud
4	1.60	255	9.4	Cloud
4	1.50	247	9.4	Cloud
5	4.39	108	2.3	Cloud
5	3.15	156	3.1	Clear air
5	3.74	157	3.1	Clear air
5	1.94	192	3.0	Cloud
5	2.10	189	3.0	Cloud

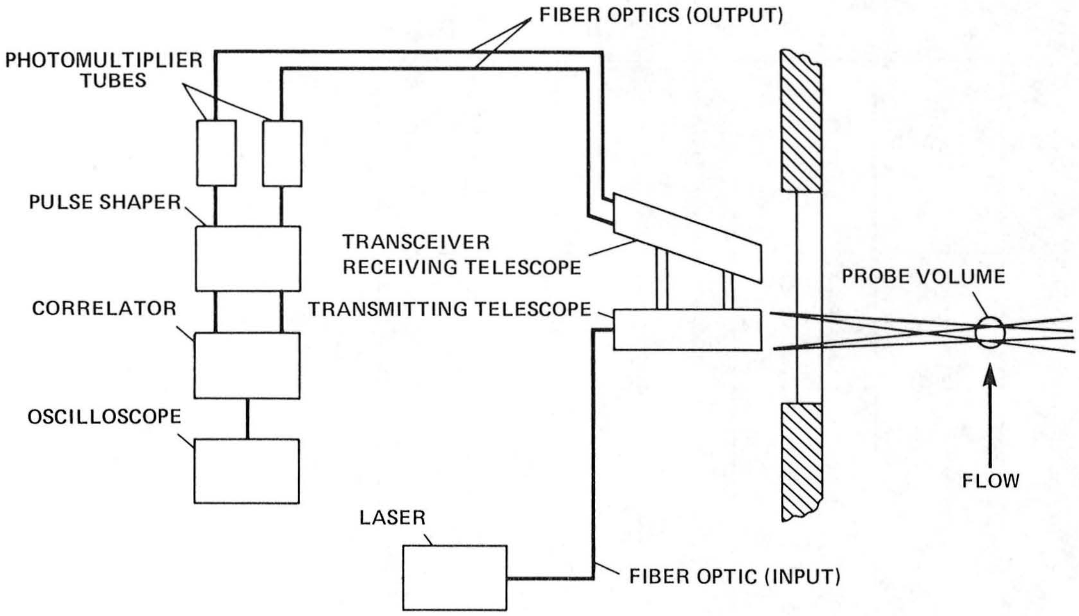

Figure 1.- Schematic of laser system.

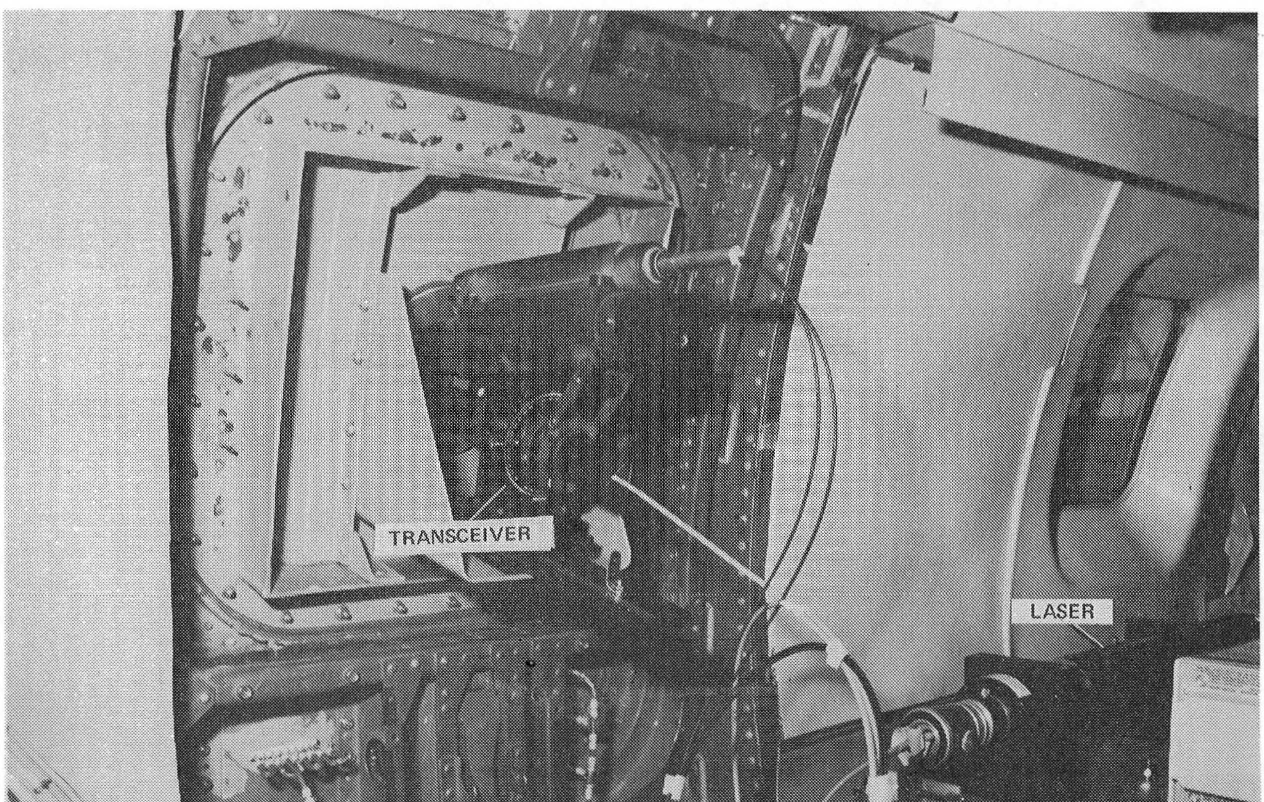

Figure 2.- Transceiver installation in airplane. (ECN 17831)

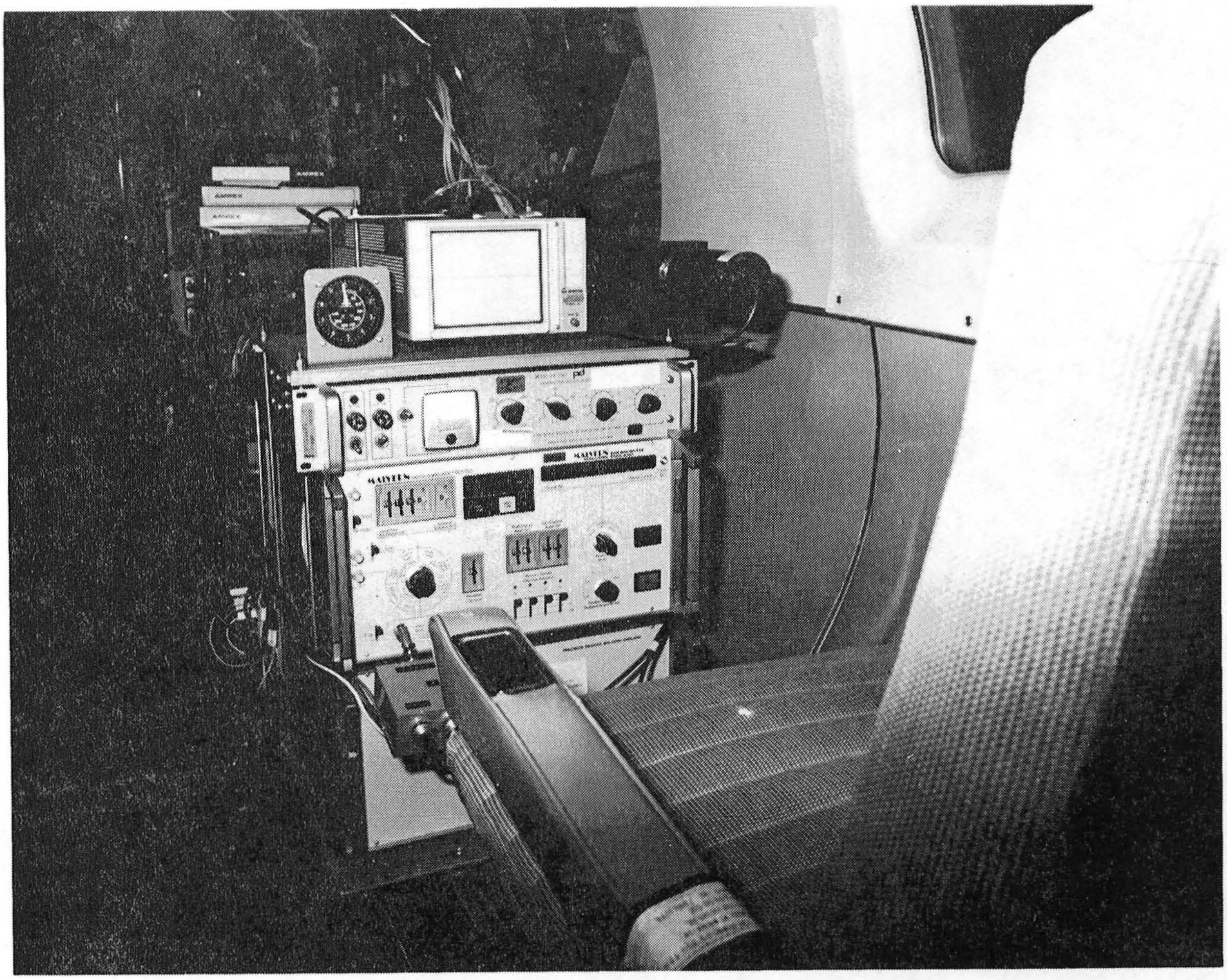

Figure 3.- Operator's console in airplane. (ECN 17826)

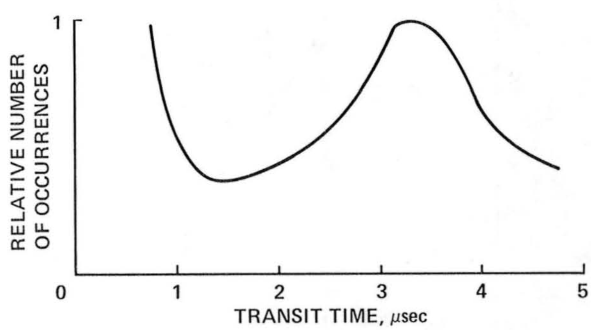

Figure 4.- Correlogram with background light interference.

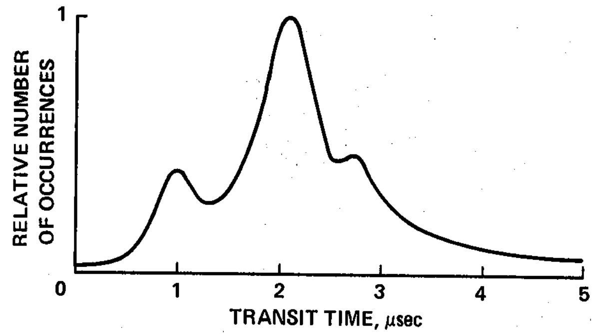

Figure 5.- Correlogram obtained from cloud particles at night.

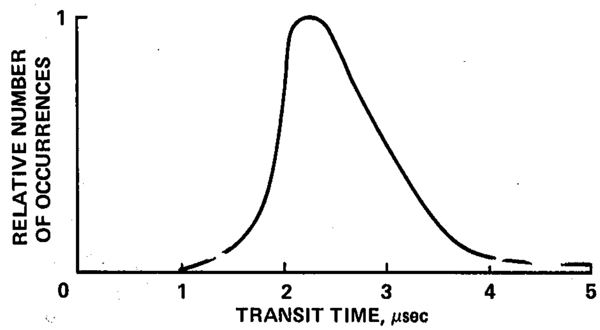

Figure 6.- Correlogram obtained in a low altitude turbulent cloud.

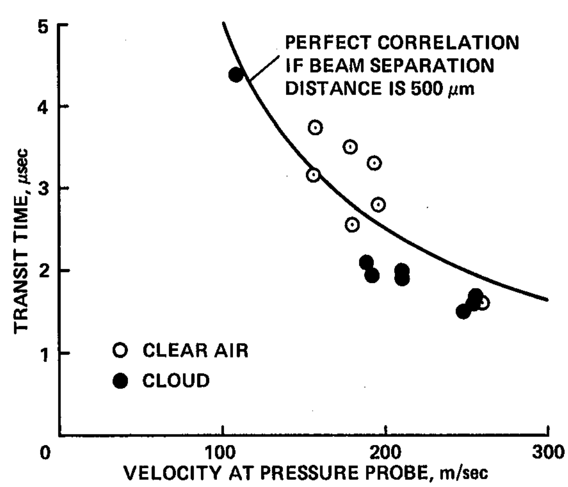

Figure 7.- Comparison of laser velocimeter and pressure probe measurements.

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16. Abstract

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