LOW-DISTURBANCE FLOW CHARACTERISTICS OF THE NASA-AMES LAMINAR FLOW SUPERSONIC WIND TUNNEL

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A unique, low-disturbance (quiet) supersonic wind tunnel has been commissioned at the NASA-Ames Fluid Mechanics Laboratory (FML) to support Supersonic Laminar Flow Control (SLFC) research. Known as the Laminar Flow Supersonic Wind Tunnel (LFSWT), this tunnel is designed to operate at potential cruise Mach numbers and unit Reynolds numbers (Re) of the High Speed Civil Transport (HSCT). The need to better understand the receptivity of the transition phenomena on swept (HSCT) wings to attachment-line contamination and cross-flows has provided the impetus for building the LFSWT.

Low-disturbance or "quiet" wind tunnels are known to be an essential part of any meaningful boundary layer transition research. In particular, the receptivity of supersonic boundary layers to wind tunnel disturbances can significantly alter the transition phenomena under investigation on a test model. Consequently, considerable effort has gone into the design of the LFSWT to provide quiet flow.[1]

The distinctive aerodynamic features of this new quiet tunnel are a low-disturbance settling chamber, laminar boundary layers on the nozzle and test section walls, vibration isolation of the test section/nozzle/settling chamber, and steady supersonic diffuser flow. Furthermore, the tunnel runs continuously at unusually low stagnation pressures, with uniquely low compression ratios (less than unity). The design is based on the Jet Propulsion Laboratory 20-inch supersonic tunnel because this facility was used as the first quiet supersonic tunnel by Laufer, for pioneering transition research[2] in the mid-1950s.

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The LFSWT has an 8 inch (20.32 cm) high, 16 inch (40.64 cm) wide and 32 inch (81.28 cm) long test section, designed with all-round optical access (as shown on Figure 1). The test section was originally sized for mass flows up to 21 lbs/sec (9.5 kg/sec). The LFSWT is the first purpose-built quiet wind tunnel for low supersonic testing. More details can be found in Reference 1. The quiet features for the LFSWT are different from those of the NASA-Langley quiet wind tunnels, which operate above Mach 3.5 and at much higher Re.[3]

The paper describes efforts to quantify the low-disturbance flows in the LFSWT operating at Mach 1.6, as a precursor to transition research on wing models. The definition of quiet flow, as we currently know it, is based on achievable and measurable levels of low disturbances. Ultimately, this definition will be linked to the range of actual atmospheric disturbances at HSCT supersonic cruise altitudes (47,000 to 60,000 feet), and a better understanding of transition receptivity to different levels and types of disturbances. Currently, the consensus is that flow is "quiet" if the free stream is spatially and temporally uniform with acoustic disturbances (the ratio of total pressure rms to total pressure - Prms/Pt) less than 0.1%. This requirement is met with laminar boundary layers on the supersonic nozzle and test section walls, and pressure (acoustic) disturbance levels in the settling chamber (Prms/Po) less than 0.2% and velocity (vortical) fluctuations (u'/U) less than 1%.[1] Additionally, the potential adverse effects of wall vibrations in the nozzle and test section, and shock movements in the supersonic diffuser need to be minimized, in the absence of acceptable levels.

Flow measurements have been made in both the test section and settling chamber of the LFSWT, using a full range of measurement techniques (miniature pressure transducers, hot-wires, thermocouples, a five-hole probe and Schlieren/shadowgraph flow visualization). We consider that the use of all available techniques is the best means of determining the quality of the tunnel test core. Preliminary measurements have confirmed the sensitivity of test section flow quality to free stream disturbances fed from the settling chamber at low supersonic speeds.[1] A traversable pitot probe, cantilevered from the test section sidewall, has been used to measure pressure fluctuations (as shown in the picture on Figure 2 viewed from the settling chamber). The spanwise distribution of pressure fluctuations, measured at three streamwise locations in the empty test section, is shown on Figure 3. The test section centerline is $Z = 0$ and the sidewalls are $Z = \pm 8$. There are some regions of non-quiet flow in the empty test section which are small and are not observed to grow downstream. The disturbances in these non-quiet regions appear to be shock induced. Overall these preliminary measurements indicate the existence of a quiet test core, but are insufficient to identify the size of the quiet test core or the source of disturbances (shocks, turbulent boundary layer noise etc.). Consequently, we plan to expand the scope of these measurements by using a purpose-built 3-axis traverse mechanism, shown in the general arrangement drawing on Figure 4. This computer controlled traverse will provide the opportunity for flow mapping, disturbance tracking and boundary layer traverses anywhere in the nozzle and the upstream half of the test section. The paper will contain unpublished data sets from this traverse system, which should provide a unique insight into the propagation of disturbances in a low supersonic flow field.

We have studied the state of the test section boundary layer so far by using a single hot-wire mounted above the floor centerline, with and without boundary layer trips fitted at the test section entrance. The hot-wire data is summarized on Figure 5 over a range of Po and hence unit Reynolds number. Raw signal rms is presented because the hot-wire cannot be calibrated in the LFSWT supersonic flows. Nevertheless, the raw hot-wire data has been shown to be useful in determining qualitatively the state of the boundary layer at Mach 1.6.[4] In normal operation, the hot-wire signal rms was order 60 milli-Volts. With the trips fitted, the hot-wire signal rms rose to 150 milli-Volts. Examination of the hot-wire signals and power spectra revealed known boundary layer characteristics. With the boundary layer tripped, the hot-wire measured random pressure surges, which increased the spectral power of the signal mostly at low frequencies. This situation is indicative of a turbulent boundary layer. With no trips, the signal spectra is relatively flat, which is indicative of a laminar boundary layer.

These measurements show that the floor boundary layer is laminar back at least to the mid-region of the test section, over the entire Po range. To achieve this feat, the run of laminar flow from the contraction is of the order 84 inches (2.13 m) in length. So far, the prediction of our CFD analyses[1] that transition will not occur along the LFSWT walls has not been contradicted on the tunnel vertical centerline. Sidewall boundary layer data will be presented and discussed in the paper. In fact, our flow studies, using the new traverse, will examine all the test section boundary layers of a quiet supersonic tunnel in detail, exceeding previous work.[5] Furthermore, our traverse will allow us to report on secondary flows in the nozzle corners which are a potential source of disturbances.[6]

The effect on flow quality of unsteady supersonic diffuser flow, joint steps and gaps, and wall vibration will also be discussed in the paper. With the LFSWT operational, we now have the opportunity to examine these potential sources of transition, and study means of delaying transition due to the combined effect of all the flow disturbance generators in the tunnel. These LFSWT studies will help identify those tunnel design parameters which are most important to achieving a quiet test environment at low supersonic speeds. Furthermore, the resulting maps of actual LFSWT disturbances fed into a model's boundary layers will be available to accompany the model data. In this way, transition research can be interpreted with a better understanding of the boundary conditions for each data set.

References

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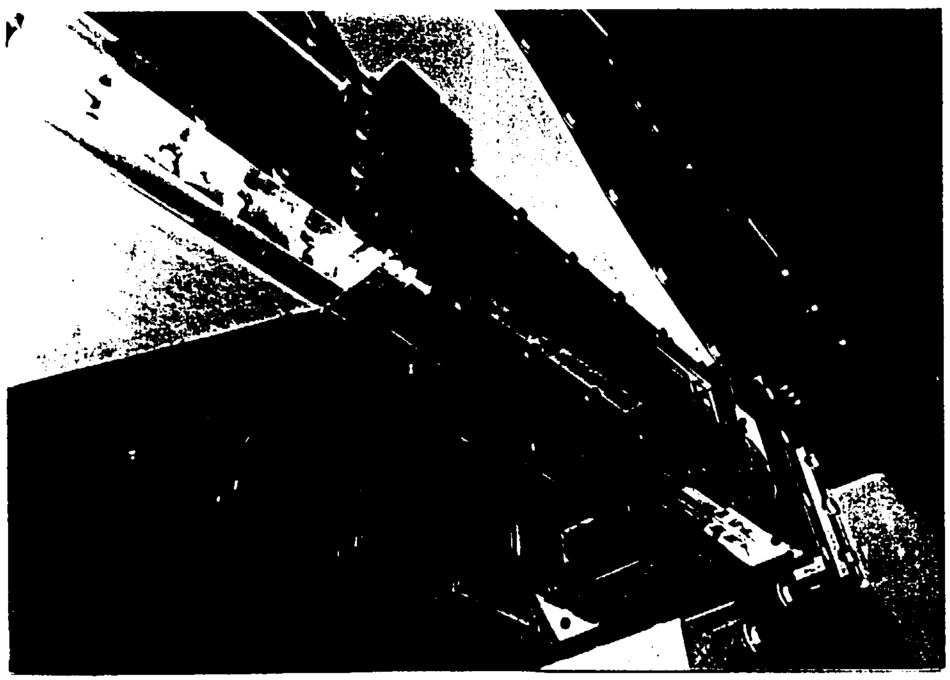
The material of the proposed presentation was reviewed and the technical content will not reveal any information not already in the public domain and will not give any foreign industry or government a competitive advantage.

NASA-Ames Laminar Flow Supersonic Wind Tunnel

Test Section and Nozzle



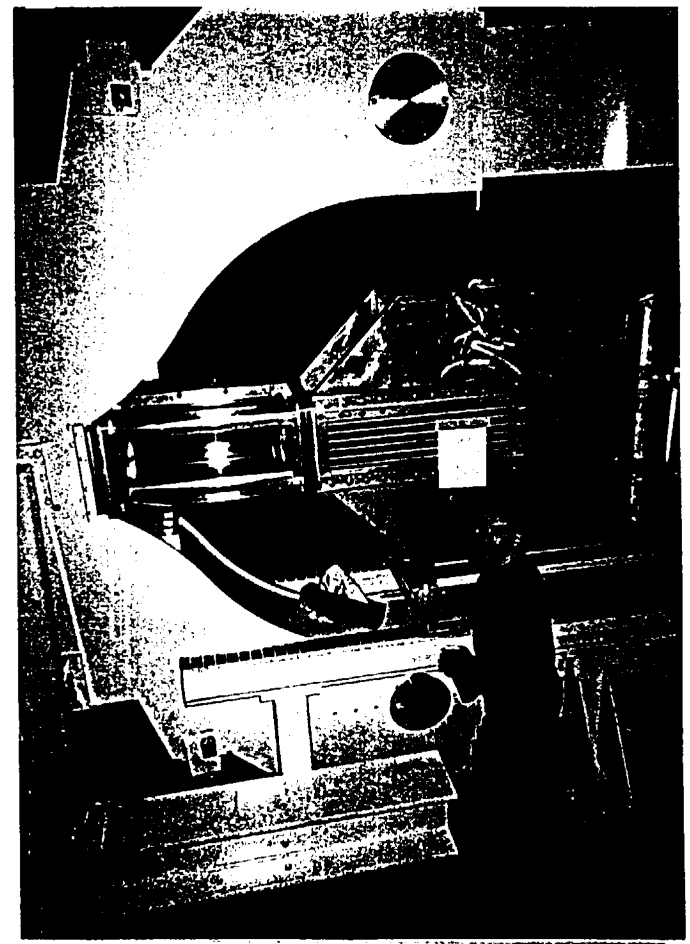
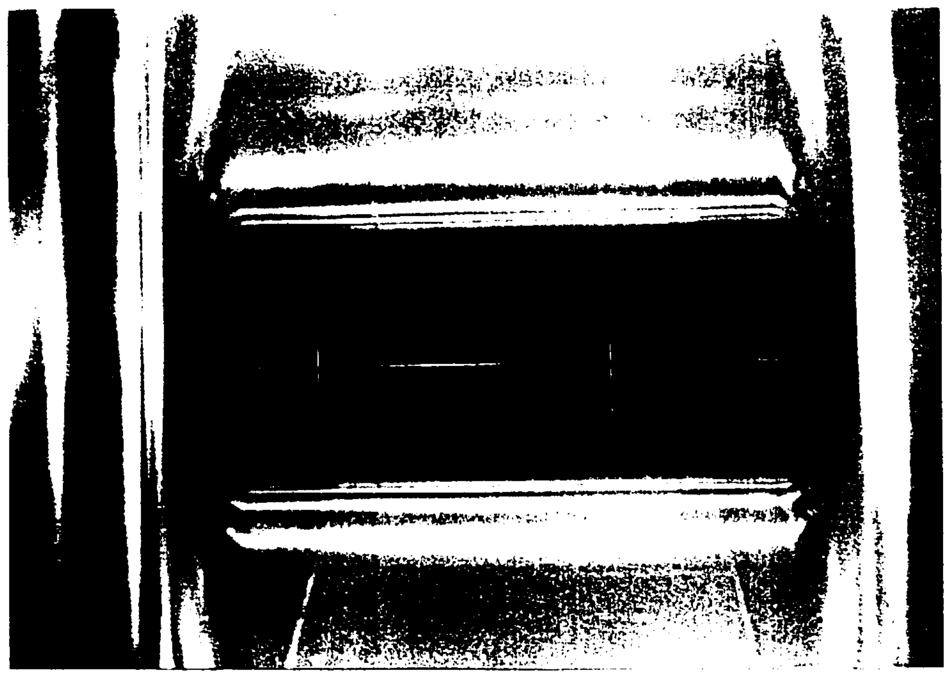


Fig. 1

View of the LFSWT Nozzle Throat



(Shown downstream of the nozzle is the pitot probe mounted in test section)

Fig. 2

LFSWT Test Section Pressure Fluctuation Data

250 - 50k Hz Range; Tunnel Vertical Centerline; Test Section 16 inches Wide

Re ≈ 2.8 million per foot   Po = 7.5 psia

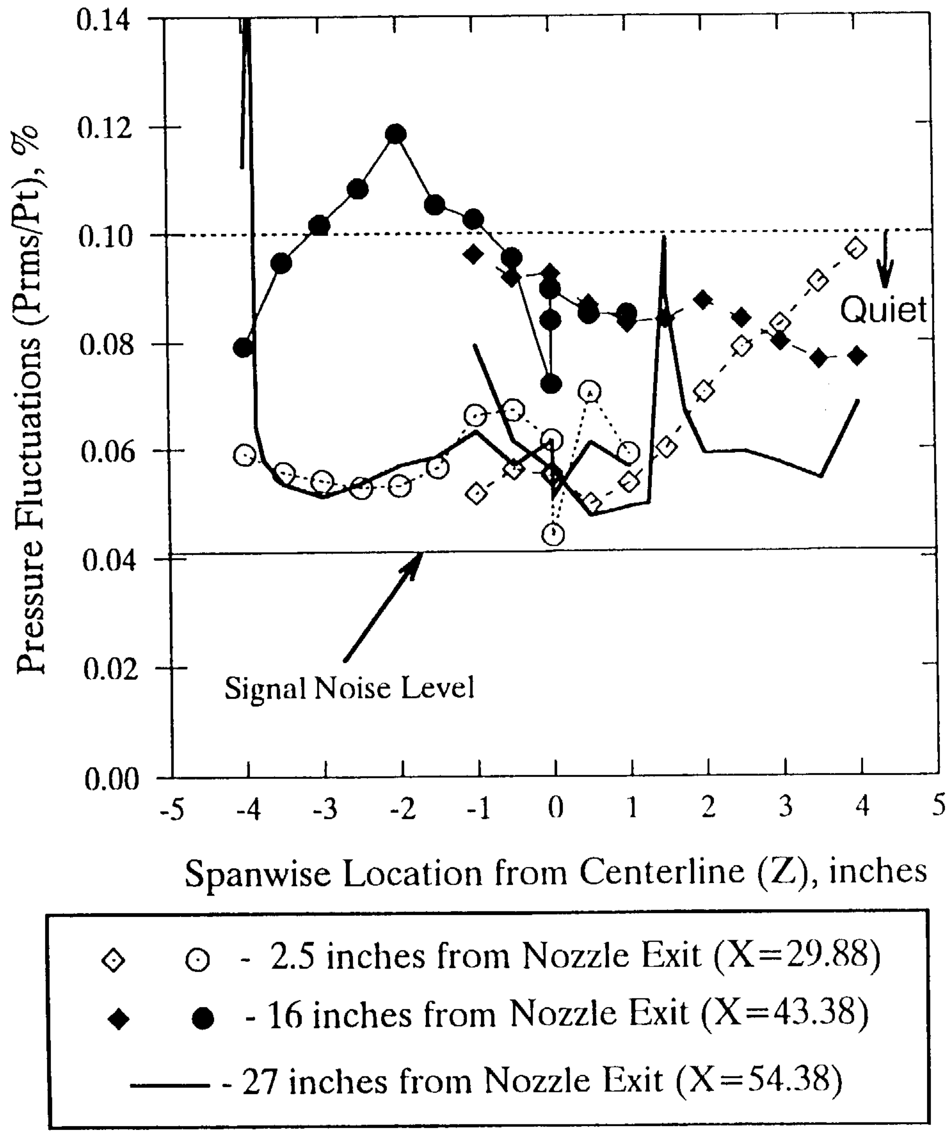


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Fig. 3

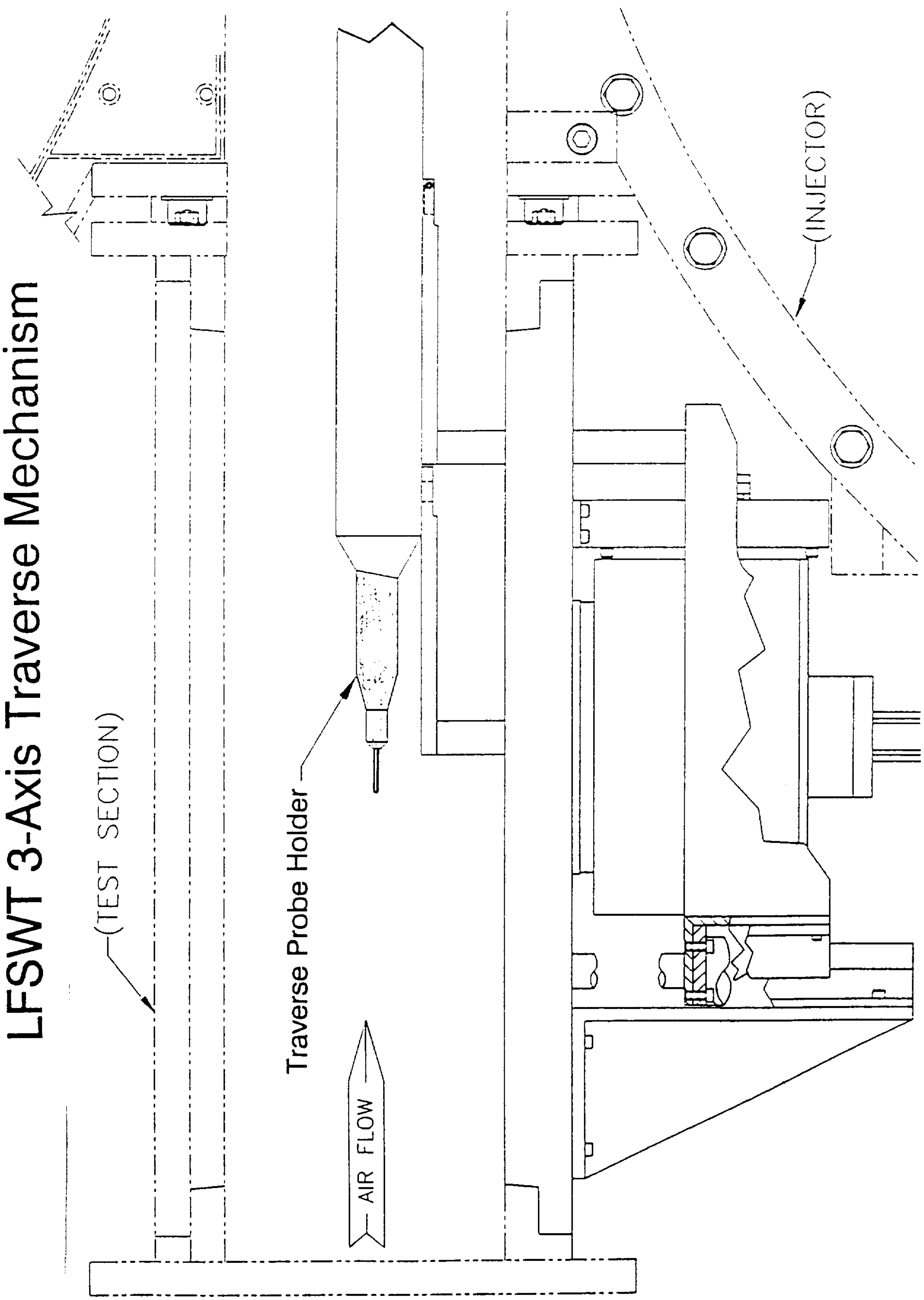
LFSWT 3-Axis Traverse Mechanism
(TEST SECTION)
Traverse Probe Holder
AIR FLOW
(INJECTOR)

Fig. 4

LFSWT Test Section Hot-Wire Data at Mach 1.6

0.025 inch Above Floor Centerline; 16 inches From Nozzle Exit (X=43.38); 5 micron Tungsten Wire

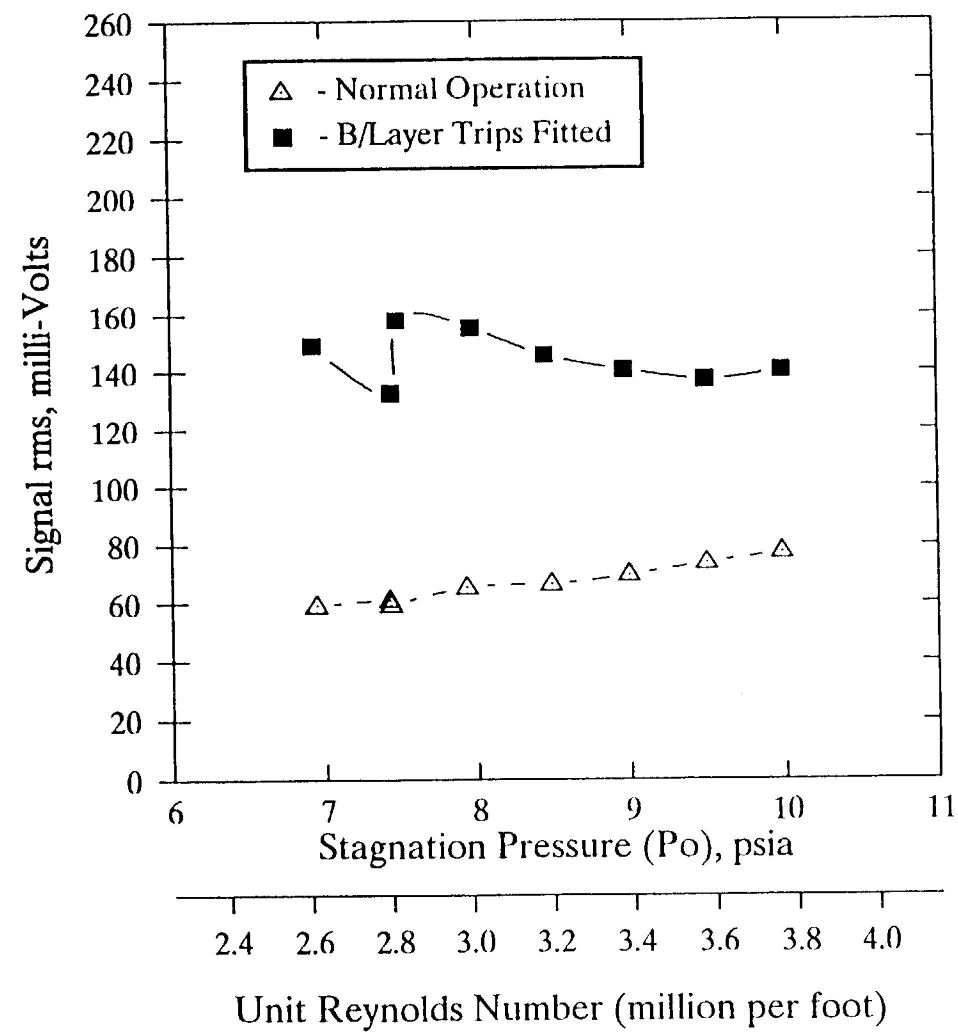

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Fig. 5