An Experiment to Determine Nose Tip Transition with Fluctuating Pressure Measurements

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Theme

AN accurate assessment of the altitude at which nose tip boundary-layer transition onset occurs is required to design and evaluate the heat protection system of high performance re-entry vehicles. Theoretical approaches to the transition phenomena are lacking, consequently the re-entry vehicle designer has relied almost exclusively on experimental data. Although transition onset has been determined on the frustum of R/V's in both ground and flight test experiments, and nose tip transition has been obtained and detected in ground tests with thermal instrumentation, there is a noticeable lack of transition detection techniques based on pressure measurements for the nose tip region.

The purpose of this paper is to present the results of an exploratory ground test program to assess possible flight pressure instrumentation concepts to detect nose tip transition for full scale R/V flight test applications.[1] Specific ground test objectives were: a) to determine the feasibility of detecting nose tip transition by fluctuating pressure measurements using a miniaturized solid-state pressure transducer,[2] and b) to demonstrate that the solid-state pressure sensor can make both steady-state and fluctuating pressure measurements simultaneously in a wind tunnel test for possible flight test application.

Simultaneous fluctuating and steady-state pressure measurements were made and transition could be detected on the nose tip frustum 3.3 nose radii aft of the stagnation point. Transition onset was not detected at more forward stations possibly due to a porous nose.

Content

The wind tunnel test was conducted at the Naval Ordnance Laboratory (NOL) hypersonic tunnel No. 8 at $M_\infty = 5$, $\alpha = 0$. The tunnel supply pressure (P_0) was varied from 17 atm to 45 atm which produced a Reynolds number variation from $Re\,/\text{ft} = 6.2 \times 10^6$ to 1.65×10^7. This Reynolds number range was sufficient to produce a laminar, transitional, and turbulent boundary layer on the model nose tip. Tests were conducted using two test procedures. The first procedure was to run the tunnel at several "fixed" steady-state Reynolds number conditions, obtain data, and then change the operating conditions.

The second procedure consisted of running the tunnel at the maximum condition for this test series (45 atm), inserting the model into the test stream, and continuously reducing the tunnel supply pressure (to 10 atm) which varied the Reynolds number and the transition front location on the model, thus simulating a re-entry trajectory in reverse. The total test time was on the order of 20 sec and allowed the transition front to move over the pressure ports and produce a pressure gage response similar to what would occur in the actual flight test case.

Figure 1 shows the blunt sphere cone porous nose/stainless steel model utilized in the test, the solid-state pressure sensor locations (Kulite sensors), and the heat transfer gage locations (Gardon gages). Also shown is the approximate transition front progression[3] for various Reynolds number conditions based on the Gardon gage data.

A compilation of raw fluctuating pressure data is presented in Fig. 2 for the flight port-gage (K5) at different Reynolds number conditions in which the gage experienced laminar, transitional, and turbulent flow. The first two photos represent laminar flow and consequently low $\tilde{P}_{rms}$ pressure levels. However, the third photo is indicative of pre-transition onset and "turbulent bursts" can be seen on the trace. The fourth photo represents transitional flow and the fluctuating pressure levels can be seen to be significantly larger ($\tilde{P}_{rms} =$ 0.012 psi). The fifth through seventh photos represent a turbulent boundary layer and have lower fluctuating pressure levels ($\tilde{P}_{rms}$ = 0.0058 - 0.0070 psi) even though the Reynolds number is increasing. The fluctuating pressure level does, of course, increase with increasing Reynolds number after the boundary layer becomes fully turbulent.

The previous trends of the fluctuating pressure data during transition are illustrated more clearly in Fig. 3 which presents $\tilde{P}_{rms}$ plotted vs Reynolds number for the two port geometries (short and long) located at ~3.3 nose radii aft of the stagnation point. The fluctuating pressure data can be seen to be maximum during transition.[4] This is precisely what would be observed inflight as the transition front moves over the port. The heat transfer data was also analyzed to correlate the transition front movement. Unfortunately, the closest Gardon gage was located one nose radii forward of the pressure port. However, the Gardon gage was clearly laminar prior to the peak in the $\tilde{P}_{rms}$ pressure data, and turbulent very near the peak. This would be the expected trend since the data of Ref. 5 has shown that the transition front consists of a wide-band rather than a definitive line. In addition, the peak in fluctuating pressure data indicative of transition onset actually occurs at the rear or end of the transition front band. A comparison of the data from the two port designs is also

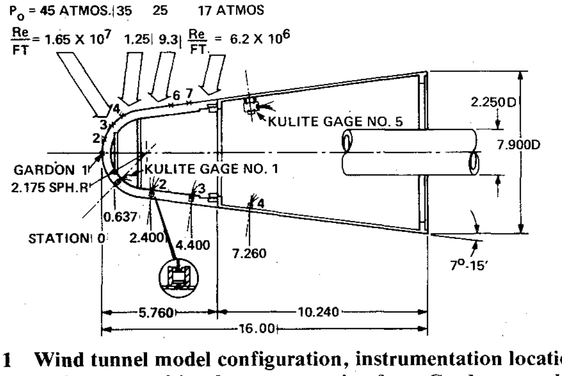

Fig. 1 Wind tunnel model configuration, instrumentation locations, and approximate transition front progression from Gardon gage data.

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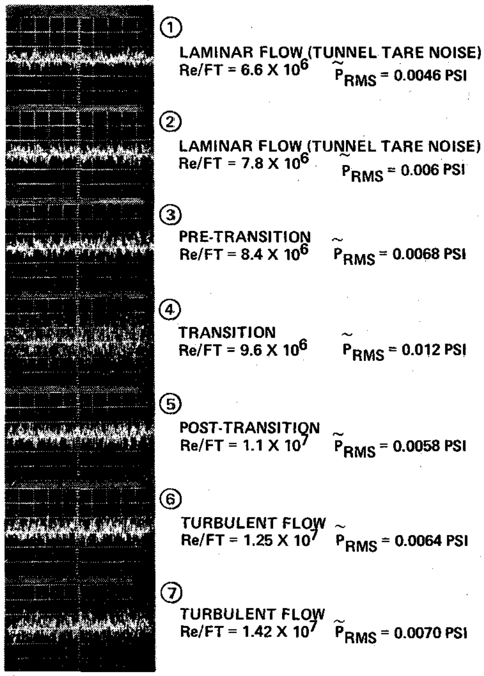

Fig. 2 Raw fluctuating pressure data time history from Kulite gage sensor no. 5 flight port ($\sim 3.3\ R_N$).

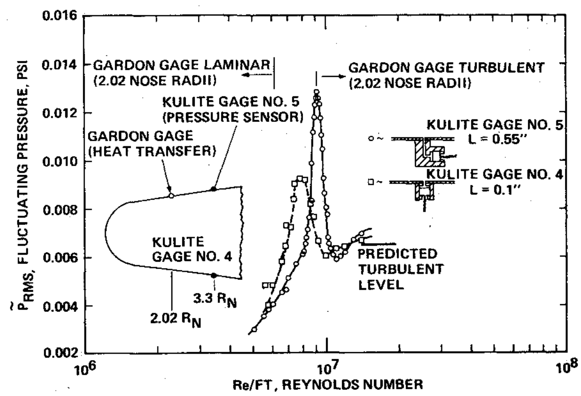

Fig. 3 Reduced fluctuating pressure data ($\tilde{P}_{rms}$) vs Reynolds number: comparison of fluctuating pressure data from the short and long port at 3.3 nose radii.

shown. The flight port measured a higher $\tilde{P}_{rms}$pressure level than the short port during transition, and the peaks in the data are displaced slightly. However, this may have been due to a slight angle of attack of the model which would produce the observed trends. Note, however, that the fluctuating pressure level from both ports are in good agreement with the turbulent prediction of Ref. 5.

It should be noted that the pronounced indication of transition observed on both aft gages ($\sim 3.3\ R_n$) was not present on the forward gages (Sonic point, $\sim$ 1.0 and 2.0 R_n,Fig. 1). It is believed that the forward gages did not detect a peak in the fluctuating pressures even though transition passed over the ports because all these forward ports were located on the porous section of the model, and it has been shown in Ref. 6 that porous material can attenuate fluctuating pressures. Both aft ports ($\sim 3.3 R_n$) which successfully detected transition were located on the stainless steel section of the model. The secondary purpose of the wind tunnel test was to demonstrate

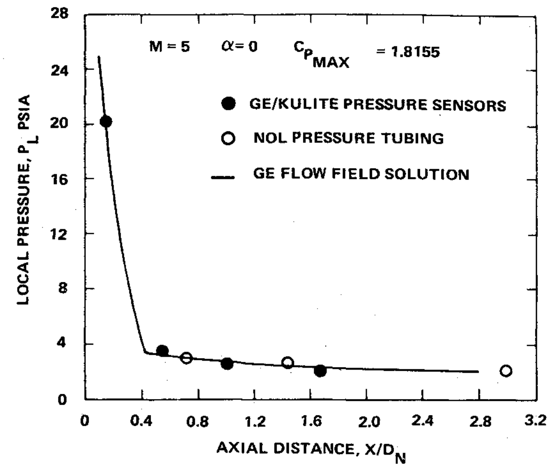

Fig. 4 Steady-state pressure data axial pressure distribution.

that the solid state pressure transducer could measure both steady-state and fluctuating pressures simultaneously. This capability represents a tremendous advantage over conventional piezoelectric acoustic transducers for flight test applications since the same sensor (solid state) can be used to: 1) detect nose tip transition with fluctuating pressures, and 2) determine the R/V nose loading with steady-state pressures.

The magnitude of the steady-state pressure levels recorded with the solid state sensor in the ground test are in excellent agreement with both theoretical predictions and with pressure measurements made with standard pressure ports monitored by pressure tubing and conventional transducers located exterior to the model/test section (Fig. 4).

The exploratory ground test wind tunnel program has 1) demonstrated that nose tip transition can be detected by fluctuating pressure measurements ~ 3 nose radii aft of the stagnation point, and 2) the solid-state pressure sensor has demonstrated the capability to measure both steady-state and fluctuating pressures simultaneously in a wind tunnel/flight test application.

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