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Final Technical Report for AFOSR Grant F49620-94-1-0326, for 1 July 1994 to 30 June 1997. FY94 AASERT Grant titled 'Laminar-Turbulent Transition in High-Speed Compressible Boundary Layers with Curvature: Non-Zero Angle of Attack Experiments'

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1 Abstract

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in use at zero angle of attack (AOA). Instead, a high-sensitivity laser differential interferometer is being developed, for non-intrusive high-bandwidth measurements of instability waves. Work towards the larger wind tunnel discussed in the proposal was also advanced, through measurements of the effect of elevated driver-tube temperature on the extent of quiet flow. Apparatus for placement of the elliptic cone at a 3-degree AOA has been designed; these measurements will commence on completion of the zero AOA measurements, late this summer.

2 Introduction

This grant funded the work of 2 additional graduate students, in our program on high-speed boundary-layer transition. In the original proposal, most of their efforts were to go towards measurements of receptivity and extent-of-transition on an elliptic cone at angle of attack. Part of the work of one of the students was to go towards development of a larger quiet-flow test section which would allow the use of larger models at higher angles of attack. This plan was a natural extension of the work funded under the parent grant, which involved measurements of instability and transition processes on an elliptic cross-section cone at Mach 4, at zero angle of attack (AOA). However, the hot-film and glow-perturber instrumentation developed for the zero AOA work was more extensive and delicate than originally envisioned. Also, measurements of extent-of-transition proved to be impossible under quiet-flow conditions, for the elliptic-cone boundary layer was much more stable than expected. Thus, after consultation with the technical monitor, Len Sakell, the non-zero AOA work was delayed until completion of the zero AOA work, to reduce the risk of damage to the model.

The original parent grant for this AASERT grant was F49620-94-1-0067. The final report for the parent grant summarizes the elliptic-cone work, along with the work of the AASERT students [8], through January 1997. This parent-grant final report also references the 17 papers and reports produced between 1994 and 1997. This report will therefore discuss only the work produced by the 3 students while funded under the AASERT grant (see references [7, 6, 9, 4, 2, 5]). The work continues to be funded by AFOSR, under grant F49620-97-1-0037.

Mr. Terry Salyer has been pursuing his PhD with support from this grant. His work has been in the area of high-sensitivity laser differential interferometry, which is being developed to enable better measurements of the receptivity and extent-of-transition processes. He was funded under this grant for the full duration, from 1 June 1994 through 30 June 1997. Mr. Scott Munro was supported during his pursuit of an M.S. degree, which he received in Sept. 1996; he was funded from August 1994 through Sept. 1996. He worked on the effect of elevated driver-tube temperature on the extent of quiet-flow. The work of these two students will be discussed further in the following two sections.

Miss Laura Randall was supported from October 1996 through May 1997, while pursuing her PhD degree. She passed her qualifying examination in Spring 1997, and has designed a 3-degree AOA mount for the elliptic cone. She has also been continuing work on two other projects commenced in 1993-95: the receptivity of a blunt-nose body at Mach 4 [3], and the instability and transition of a scramjet-vehicle forebody [9]. She will bring these three projects to some completion; this must be done before the existing 4-inch Mach-4 test-section is replaced by the new 9-inch Mach-6 test section, sometime in late 1998.

3 Effect of Elevated Driver-Tube Temperature on the Extent of Quiet Flow in the Purdue Ludwieg Tube

A larger test section was desired, in order to make measurements with larger models at higher quiet Reynolds numbers, and at angles of attack. A Mach number must be selected for the new test section. Discussions with the technical monitor, Len Sakell, drove interest towards hypersonic Mach numbers, where most Air Force interest lies. To reach Mach 6, where second-mode instability and roughness Reynolds numbers are in the range of Air Force interest, it is necessary to heat the air in the driver tube. Potential for thermal instabilities then exists in the driver tube, and any such buoyancy-driven motions would be convected into the test section, which could destroy quiet flow. To address this risk, apparatus for heating the driver tube was installed, and the effect of heating on the quiet-flow Reynolds number was measured. The results show a small adverse effect of running hot gas past a cold nozzle [2].

This is entirely consistent with the observed favorable effect of running cooler gas past a hotter wall [1]. No significant problems with thermal instabilities were observed, although paint dust from the carbon-steel driver tube was a major problem when the driver tube was heated. A stainless-steel driver tube will have to be used for the Mach-6 work.

4 High-Sensitivity Laser Differential Interferometer

The high-sensitivity laser differential interferometer (LDI) was technology new to Purdue at the inception of this grant. The duration of the grant has seen the development and refinement of the LDI, at first on the bench-top. The LDI is now in regular use in the Purdue Mach 4 Quiet-Flow Ludwieg Tube. Coordination with Wright Labs and EOARD personnel led to Purdue access to two Window-of-Science visitors to Wright Labs who are the inventors and leading practitioners of the LDI. The LDI has now been used in the Purdue Mach 4 Quiet-Flow Ludwieg Tube for detection of turbulent spots on the wind-tunnel walls, for examining the nose-region boundary layer flow on a blunt body, and for improved characterization of the thermal spot produced by the laser perturber.

The immediate purpose of using the LDI is to achieve non-intrusive, high-sensitivity, off-body measurements of a fluctuating fluid property (density changes) at a bandwidth exceeding that of hot-wire anemometers. This has been achieved: data acquired by Mr. Salyer shows well-resolved passage of the weak shock waves prior to, and after, the passage of the thermal spot from the laser perturber used in our experiments[7]. The hot-wire data shows only one object; hence the hot-wire is either missing the weak shock because of lack of sensitivity, or blurring it into the thermal spot response for lack of bandwidth[6]. A longer-term benefit of this LDI work can be the ability to make multiple-streamwise point measurements, which is impractical with hot-wires because of blockage.

Work by Mr. Salyer to implement the LDI for operation with the Purdue Mach 4 Quiet-Flow Ludwieg Tube was a critical part of the success of this effort. Vibration and acoustic perturbations produce noise in the LDI data, so minimization of these effects has been an important part of the implementation efforts. The noise in the signal is now approximately 1/15,000 of a wavelength phase delay between beams. There is no other instrument we can find or conceive of which has this high sensitivity and works in the low-density flow. Noise-reduction efforts continue as we become increasingly familiar with the LDI and it's sensitivity to various effects. Furthermore, the low-power and highly-sensitive LDI probes the flow through the same windows as the high-power laser-perturber operates, which required Salyer to design the system to eliminate obstructions for both systems.

5 Acknowledgements

This work has also been supported by a gift from the Boeing Company, and a gift in memory of K.H. Hobbie. Laura Randall's earlier work was supported by NASA Langley and a NASA Space Grant Fellowship; she is currently supported under a fellowship from the Purdue Research Foundation. The craftsmanship of the Purdue Aeronautics Shop has been essential to the effort.

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