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This grant supported fabrication of the 9.5-inch Mach-6 quiet-flow Ludwieg tube at Purdue University. Due to delays in fabrication, the facility is not yet complete. Fabrication continues under AFOSR Grant F49620-00-1-0016 and other funds. Fabrication status is reported in several open-literature publications, here cited. Most parts of the tunnel have been completed and tested. The critical quiet-flow nozzle is nearly complete, with the last parts scheduled for shipment during early March 2000.

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Final Report for DURIP Grant F49620-99-1-0278, 1 June 1999 to 30 Nov. 2000. Grant titled 'Completion of the 9.5-inch Mach-6 Ludwieg Tube: Enabling Low-Cost Hypersonic Quiet-Flow Experiments'

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1 Summary

This grant supported fabrication of the 9.5-inch Mach-6 quiet-flow Ludwieg tube at Purdue University. Due to delays in fabrication, the facility is not yet complete. Fabrication continues under AFOSR Grant F49620-00-1-0016 and other funds. Fabrication status is reported in several open-literature publications, here cited. Most parts of the tunnel have been completed and tested. The critical quiet-flow nozzle is nearly complete, with the last parts scheduled for shipment during early March 2001.

2 Introduction

This grant supported fabrication of the tunnel cited. The progress of the design, fabrication, and testing is reported in References [1], [2], [3], [4], [5], [6], [7], and [8]. Early results, following completion, are to be presented in Ref. [9]. Cost information was reported in Ref. [10]. The finite-element stress-analysis for the large plexiglas window is to be reported in Ref. [11]. Work continues under AFOSR Grant F49620-00-1-0016 and Sandia contract BG-7114. These two grants support labor for facility completion and testing, as well as research into transition on scramjet forebodies (AFOSR) and blunt round cones (Sandia). Completion is currently scheduled for March 2001.

3 Brief Summary of Fabrication Status

The most critical element of a hypersonic quiet tunnel is the nozzle. The purchase order for fabrication of the present nozzle was awarded in Jan. 1999, about 2 years ago. Completion was delayed due to difficulties in fabricating the mandrel for the electroformed throat. The throat must have very high accuracy, very low waviness, and the tunnel performance is limited by the largest microscopic flaw in the mirror-finished throat. If a surface finish flaw develops during fabrication, the part must be discarded, and the process must start over. Three mandrels were fabricated in order to get a good one. Fortunately, the results shown in Ref. [6] show that the electroformed throat generated using the third mandrel looks good.

The remainder of the nozzle must also meet tight specifications for accuracy, low waviness, and the size of small steps near the joints in the nozzle. Seven of the 8 nozzle sections have been completed; the third is to be completed by early March. While the entire nozzle has not met the 0.001 inch accuracy specification and the 0.001 inch/inch waviness specification, the largest flaws are so far within 0.0015-in. in accuracy and the waviness remains generally within 0.0015 inch/inch. The electroformed nickel apparently became slightly elliptical during formation, with stress-relieving causing the cross-sections to become asymmetrical by about 1000 ppm. This left a step or steep wave of about 0.002 inches at the end of the electroform. Although this is within the $Re_k = 12$ roughness specification, it remains a waviness concern.

The rest of the tunnel pieces have been completed, installed, and tested, as described in the references cited.

4 Acknowledgements

Design and fabrication of a complex and specialized wind tunnel requires the conscientious and skilled assistance of many persons, too numerous to mention here. The work has benefited from continued advice from the NASA Langley quiet tunnel group, especially Dr. Steve Wilkinson. The AFOSR program manager is Dr. Steven Walker, whose interest and patience is appreciated. The program manager for the nozzle fabrication is Mr. Larry DeMeno, of Dynamic Engineering Inc.; his conscientious attention to the many critical fabrication details is also appreciated. Mr. Terry Kubly, recently of Monticello Exchanger, Indiana, cooperated in the design of the aerodynamic pressure-vessel elements of the tunnel; this involved many tradeoffs between aerodynamics, operability, manufacturability, and the ASME pressure-vessel code.

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[10] Steven P. Schneider. Laminar-turbulent transition in hypersonic boundary layers: Development of a high-Reynolds number Mach-6 quiet-flow testing capability. Final Report AFRL-SR-BL-TR-00-0025, AFOSR, February 2000. Citation AD-B251202 in DTIC. Distribution restricted to U.S. government agencies, due to proprietary cost information.

[11] S.W. Kwon and Steven P. Schneider. Stress analysis for the window of the Purdue Mach-6 quiet-flow Ludwieg tube. Technical Report 2002-XXXX, AIAA, January 2002. To be submitted to the Jan. 2002 AIAA Aerospace Sciences Meeting.