

Brief Summary of the Boeing/AFOSR Mach-6 Quiet Tunnel and Prof. Schneider's Research

Professor Schneider's primary area of expertise is high-speed laminar-turbulent instability and transition. He focuses on hypersonic boundary-layer instability and transition, construction of quiet-flow wind tunnels, and instrumentation for study of high-speed flows.

High-speed laminar-turbulent transition is crucial to the design of hypersonic cruise vehicles such as hypersonic reconnaissance aircraft, hypersonic missiles, high-speed interceptor missiles, supersonic transports, many reentry vehicles, and trans-atmospheric vehicles. Current programs for which transition is important include the DARPA FALCON HTV-2 glide vehicle, scramjet-powered vehicles such as the X-51A, the Space Shuttle (e.g., the removal of gap fillers on STS-114), and the Orion.

Most of the important scientific issues in this field remain to be worked out, but development and verification of theory is difficult, for nearly all existing experimental data is contaminated by facility noise problems. Conventional hypersonic wind tunnels suffer from high levels of acoustic noise radiated from the turbulent boundary layers on the nozzle walls. Just as in the incompressible case, the acquisition of conclusive data for the instability process appears to require quiet flow facilities. Results obtained in noisy facilities often differ not only in amplitude but also in trends from those obtained in flight and in quiet facilities. At hypersonic speeds, quiet flow requires laminar nozzle-wall boundary layers, which are very difficult to achieve at high Reynolds numbers.

However, because construction of quiet facilities for high-speed transition is extremely difficult, and because instrumentation for high-speed work is also very difficult, no universities in the United States had experimental programs in this area when Professor Schneider arrived at Purdue. NASA Langley had recently developed the only transition-quality high-speed facilities in the world. No one had tackled the difficult task of constructing high-speed facilities at universities, since the cost and difficulty seemed insurmountable. Professor Schneider was able to develop new concepts for the design of a high-speed transition-quality facility that proved feasible on a university scale. These concepts were recognized with a grant from Langley for design and then construction of a Mach-4 facility at Purdue.

Professor Schneider has spent much of the last two decades planning, designing, constructing, and testing these new kind of quiet-flow facilities. The Quiet-Flow Ludwig Tube is capable of giving quiet flow for short run times in large test sections at relatively low cost. These short run times are an acceptable sacrifice, since high speed instrumentation for time-resolved measurements is required in any case. The development of the facilities has been discussed at technical meetings and documented in conference papers and technical reports. A Low Reynolds Number Quiet-Flow Ludwig Tube was constructed at Purdue using a 4-inch Mach-4 nozzle provided by Langley. The facility was first assembled in summer 1992 and underwent shakedown and testing. Results demonstrating that quiet operation was achieved at useful Reynolds numbers were presented in January 1994. Several thesis projects were carried out in the facility during 1994-1999, developing instrumentation and making low-Reynolds number receptivity and instability measurements. A number of theses and publications have resulted from this work.

However, the quiet-flow Reynolds number of the Mach-4 facility is too low to permit development and validation of prediction methods that are of practical interest for engineering. For example, the instability waves generated by Lagoon grew only by a factor of 2-3 within the quiet domain, while factors of about 4000 are expected prior to transition. Since studies that are only of scientific interest rarely attract funding, a higher Reynolds number quiet tunnel had to be completed.

The Boeing/AFOSR Mach-6 Quiet-Flow Ludwig Tube was constructed during 1995-2001, to raise our quiet-flow Reynolds number from 400,000 to about 13,000,000. It has a 9.5-inch nozzle that is driven from a 122-ft. pipe of 18-in. diameter; a downstream double-diaphragm valve starts the flow into the 4000 cubic foot vacuum tank. This \$1m facility is the only hypersonic quiet tunnel that is operational anywhere in the world. In September 2006, after five years of debugging, it began achieving quiet flow at 145 psia stagnation pressure, near the design Reynolds numbers. The tunnel is designed to have about twice the quiet Reynolds number of the NASA Langley Mach-6 quiet nozzle, which is the only previous hypersonic quiet tunnel, but which was disassembled due to a space conflict, and is now reassembled at Texas A&M.

The design and construction of the quiet-flow Ludwig tube is an expensive research program in the control of hypersonic laminar-turbulent transition, the very problem the facility is built to study. Success is making possible the study of natural transition under quiet-flow conditions, at least for some geometries. In most cases, the tunnel will be used to study instability waves that lead to transition. Instability-wave growth of a factor of 1000 or more, under quiet conditions, was predicted for some geometries of interest to Sandia National Labs. This performance should enable development and validation of prediction methods for problems where unambiguous results have been unsuccessfully sought for 40 years.

The facility development and the transition research have been funded by NASA Langley, the Air Force Office of Scientific Research, the Ballistic Missile Defense Organization, Sandia National Labs, TRW, and NASA Johnson. Fabrication of the Mach-6 quiet tunnel was made possibly primarily by a \$0.5m gift from the Boeing Company and about \$0.4m of equipment grants from AFOSR. Without the long-term sustained funding that has been provided by AFOSR, the facility and associated research would not exist.

Professor Schneider received his B.S. in 1981 in Engineering Science from Caltech. From 1981-1983 he was an Engineer-Scientist with the Naval Ocean Systems Center in San Diego. He returned to Caltech in 1983, receiving his M.S. in 1984 and Ph.D. in 1989, both in Aeronautics. His advisors were Hans Liepmann and also Anatol Roshko and Donald Coles. Prof. Schneider is an AIAA Associate Fellow. He is married, has two children, and enjoys outdoor activities such as bicycling, kayaking, hiking, backpacking, and camping. He also enjoys reading history books, especially the history of exploration, engineering, and technology. *Soli Deo Gloria.*