Last Revised: February 3, 2020

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 boost-glide missiles such as the Conventional Prompt Strike glide vehicle, scramjet-powered vehicles such as the DARPA HAWC, and the Orion manned-entry capsule.

Many of the important scientific issues in this field remain to be worked out, but development and verification of theory is difficult, for most of the existing experimental data is contaminated by facility noise. Conventional hypersonic wind tunnels suffer from high levels of acoustic noise radiated from the turbulent boundary layers on the nozzle walls. No single ground test facility can simulate all aspects of transition in hypervelocity flight: Mach number, Reynolds number, enthalpy and chemistry effects, freestream fluctuations, surface temperature and ablation, roughness and so on. Computational simulations are very helpful, but all such simulations must make simplifying assumptions, including estimates for the input disturbance environments. Just as in the incompressible case, an understanding of tunnel noise effects is critical, and requires the use of 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 in 1989. NASA Langley had recently developed the only low-noise high-speed facilities in the world. 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.

Professor Schneider has spent much of the last three decades planning, designing, constructing, and using these new kinds of quiet-flow facilities. The Quiet-Flow Ludwieg 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 Ludwieg Tube was constructed at Purdue using a 4-inch Mach-4 nozzle provided by Langley. However, the quiet-flow Reynolds number of the Mach-4 facility was too low to permit development and validation of prediction methods that are of practical interest for engineering. Since studies that are only of scientific interest are difficult to fund, a higher Reynolds number quiet tunnel had to be completed.

The Boeing/AFOSR Mach-6 Quiet-Flow Ludwieg 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 largest hypersonic quiet tunnel that is operational at high Reynolds numbers, 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 quiet-flow stagnation pressure has since risen to about 170 psia, and then temporarily decreased to 155 psia. 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 in operation at Texas A&M. Two large hypersonic quiet tunnels have now been built in China, but their quiet-flow performance has not yet been well-documented in the open literature.

The design and construction of quiet-flow tunnels is an expensive research program in the control of hypersonic laminar-turbulent transition, the very problem the facilities are built to study. The successful development of the Mach-6 quiet-flow Ludwieg tube at Purdue is now making possible the study of natural transition under quiet-flow conditions, at least for some geometries. In most cases, the tunnel is being used to study instability waves that lead to transition. The website for the Mach-6 tunnel group contains many papers summarizing the various results that have been obtained in the facility.

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.

In the last few years, hypersonics has again become a national priority for defense purposes, providing new opportunities to build better facilities, and develop the next generation of quiet-tunnel experts. Purdue has received funding to begin development of a large Mach-8 quiet tunnel, led by Dr. Brandon Chynoweth. Large quiet tunnels are also in development at Notre Dame University, at Mach 6 and 10, as part of a cooperative effort between Purdue and Notre Dame. Purdue has also hired Prof. Joe Jewell to take over the 9.5-inch Mach-6 quiet tunnel. Prof. Schneider is moving into a senior technical expert role, supporting Drs. Chynoweth and Jewell. He also plans to spend more time serving as a subject matter expert.

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 Fellow and received the Ground Testing Award in 2012. To aid in understanding the vast literature in the field, and to inform the next generation, he has written nine review papers on hypersonic instability and transition. He is married, has two grown children and three grandchildren, and enjoys outdoor activities such as bicycling, hiking and backpacking. He also enjoys reading history books, especially the history of exploration, engineering, and technology. *Soli Deo Gloria.*