interceptors that defend against a variety of threats at all levels of the atmosphere. For these hypervelocity intercepts, highly accurate systems are required. Lessons learned on earlier interceptor flight tests identified the need for flight duplication during ground testing. Issues with missile shroud separation, Reynolds number scaling, aero/thermal effects on sensor window heating, jet interaction effects, and aero/optics are dependent on true flight duplication of important flight parameters, including long run times consistent with endgame scenarios. The need for highly reliable, realistic T&E is paramount.

During the 1980s there was also a renewed interest in hypersonic flight vehicle development. NASP, the primary program during this time, used Tunnel 9 extensively for high Mach number aerodynamic and scramjet inlet testing. High Mach number testing is critical to the development of such a vehicle because the extrapolation of data to higher Mach numbers is not reliable for these complex, high lift-to-drag ratio (L/D) configurations. Engine inlet design and testing provides a significant challenge for NASP due to the engine/airframe integration necessary for hypersonic cruise scramjet operation. The entire flowfield ahead of the scramjet affects the engine inlet flowpath, thereby coupling the engine development with the aerodynamic flowfield. Tunnel 9's high Mach number capability, long run times, and large test cell provided the high data rates necessary to meet the NASP ground test needs.

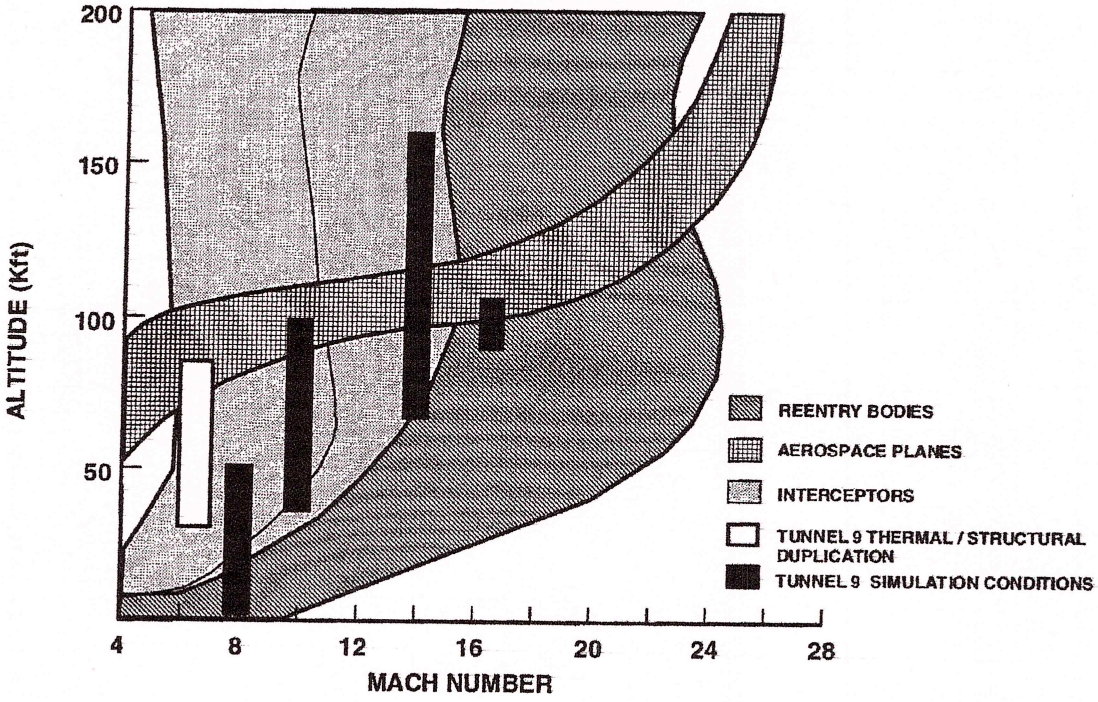

Figure 3—Tunnel 9 Operating Conditions

Mission: Hold Strategic Targets at Risk Via Safe, Reliable, and Accurate Warhead Delivery and Detonation At Intercontinental Ranges Within 30 Minutes and After 15 Years Dormancy

Requirements:

- High Leakage Against Terminal Defense
- High-Kill Probability, Accuracy, and Reliability
- Severe Weight and Mass Property Control
- Dormant for 15 Years (Design), 23 Years to Date on Mk 12
- Operational Readiness in Less Than 30 Seconds
- Nuclear Safety: Inadvertent Detonation Probability $< 1.0 \times 10^{-9}$

Environments:

- Ascent Heating And Dust/Debris Erosion
- Nuclear Encounters (Hundreds Of Encounters)
- Endo- And Exo-Atmospheric Mechanical and Electrical Effects 10 to 20 Times Higher Than Booster Levels
- Shock Loads Boost, Deployment and Reentry up to 200 G's in Reentry 34 G (RMS) Internal Component Vibration
- Reentry Thermal Loads 185 Atmospheres Pressure
- Temperatures Would Melt Unprotected Aluminum in Less Than 1 Msec

Figure 3—Unique Reentry Requirements

as given in Figure 3, mandate the focusing of supporting technologies to the extent that leveraging of other weapons technology for reentry applications is not possible. This also explains the need for a stand-alone reentry systems advanced technology demonstration program as called for by both the SAG Industrial Base Study and the NPR.

RSAP was implemented in FY 95. Three programmatic tasks were to be completed and reported to congressional staff before the initiation of technical program activity. These tasks included a Reentry System Industrial Base Assessment, to provide a detailed report on the erosion of the reentry system industrial base; a Reentry System Technology State-of-the-Art Assessment, to identify any emerging technologies that would support the life extension of reentry systems; and a Technical Program Plan, to provide details of the technical tasks that would be accomplished under RSAP.

Reentry System Industrial Base Assessment

The objective of the Reentry System Industrial Base Assessment was to evaluate existing and far-term capabilities of the reentry industrial base to support reentry system design, development, manufacturing, and in-service operations. The approach to conducting the assessment included identifying all prime contractors, suppliers, test facilities, etc., that make up the reentry system industrial base; ranking the criticality of the particular expertise that was so identified; and defining critical areas in which technical tasks must be performed to prevent further erosion of critical elements of the reentry system industrial base. The identification of the critical elements of the reentry system industrial base was accomplished by constructing detailed "technical task trees" for the design, development, manufacture, and in-service support of each reentry system component. Output from the Reentry System Industrial Base Assessment included lists of

During the early stages of the NASP program, multiple aerospace contractor teams were in competition. Each team provided a different configuration. Multiple full-body aerodynamic configurations and engine flowpath/scramjet inlet tests were performed in Tunnel 9.[7,8] Full-body aerodynamic and inlet configuration testing at Tunnel 9 was enhanced by the ability to test large, heavily instrumented models. Inlet models are the largest nonpitching models tested to date in Tunnel 9, reaching lengths exceeding 10 feet. Long run times allowed inlet models to be started, unstarted, and restarted during a single run to assess the dynamic nature of the process.

Most of the testing described in the preceding sections required upgrades in instrumentation and tunnel capability or both to meet the data collection requirements specified by the sponsors. A discussion of some of the most important facility upgrades follows.

UPGRADES TO TUNNEL 9 TO SUPPORT STRATEGIC SYSTEMS

Mach 10 High Reynolds Number

In order to obtain natural boundary layer transition on full-scale reentry body frustra and oversized reentry body nosetips, very high Reynolds numbers are required. To accurately predict the aerodynamic characteristics of an RB, it is necessary to know when and where on the body the boundary layer transitions from laminar flow to turbulent flow. Only in a facility that can simulate full-flight Mach and Reynolds numbers concurrently can this type of data be generated. To achieve these flow parameters, the Mach 10 leg of Tunnel 9 was significantly redesigned.[9] The nozzle supply pressure was increased to 15,000 psi, resulting in a tenfold increase in the mass flow rate through the test cell. The pressure and mass flow increases resulted in a fourfold increase of Reynolds number from 5.4×10^6 to 20×10^6. This Mach 10 high Reynolds number capability allowed boundary layer transition studies to be completed on Navy reentry systems.

Mach 14 High Altitude

As a reentry body descends through the atmosphere, the aerodynamic stability of the vehicle drives any angle of attack towards zero. This phenomena is known as angle-of-attack convergence. During the testing of the Navy's Mk-4 reentry system, the predicted angle-of-attack convergence was not observed. If any aerodynamic parameter cannot be accurately predicted, it will be not be properly modeled in fire control, resulting in an uncertainty that decreases a weapon system's accuracy. Heatshield outgassing was postulated as a possible culprit, but there was no way to test the theory.

Heatshield outgassing occurs at high altitudes when the friction created by the air begins to heat the heatshield. As the temperatures on the heatshield increase, volatiles begin to percolate to the heatshield surface and are injected into the boundary layer. This mass injection into the boundary layer changes the nominal boundary layer characteristics, creating a local change in all of the aerodynamic parameters in the area of the mass injection. The question to be answered was, "Were the aerodynamic changes observed in flight caused by heatshield outgassing?"

In order to test this theory, a technique for simulating mass addition to the boundary layer using porous models was designed, developed, and characterized at NSWCDD White Oak.[10] This technique, combined with the ability to simulate very high altitudes, was developed for the Mach 14 leg of Tunnel 9. The resultant test series verified the theory that heatshield outgassing at high altitudes could generate the aerodynamic forces necessary to recreate an observed flight test anomaly.[6] The data from these tests were used to adjust aerodynamic models and SLBM fire control.