Purdue wind tunnel key for 'hypersonic vehicles,' future space planes

January 2 2008

Purdue doctoral student Matthew P. Borg holds a model of an advanced aircraft called the X-51A, which will be powered by engines called scramjets and capable of flying at Mach 6, or six times the speed of sound. Purdue engineers, using the only wind tunnel capable of running quietly at "hypersonic" speeds, have conducted experiments to yield data critical for the vehicle's design. The researchers, led by Steven Schneider, are reporting the first major findings from the quiet wind tunnel after about 18 years of research to perfect the facility, which will be used to analyze the performance of hypersonic vehicles. Credit: Purdue News Service photo/David Umberger

By using the only wind tunnel capable of running quietly at "hypersonic" speeds, Purdue University engineers have conducted experiments to yield critical data for designing an advanced aircraft called the X-51A, powered by engines called scramjets.

The X-51A test vehicle is expected to evolve into missiles capable of flying at Mach 6 - or six times the speed of sound - enabling them to hit mobile "time-critical" targets.

Scramjets also may propel future military and civilian space planes.

The quiet wind tunnel operation is critical for collecting data to show precisely how air flows over a vehicle's surface in flight. No other wind tunnel runs quietly while conducting experiments in airstreams traveling at Mach 6, said Steven Schneider, an aerospace engineer and professor in Purdue's School of Aeronautics and Astronautics.

"A quiet wind tunnel yields more accurate data because it more closely simulates flight," he said.

Specifically, engineers need detailed information about how airflow changes from "laminar," or smooth, to turbulent as it speeds over an aircraft's surfaces. The information is essential to properly design vehicles that fly at hypersonic speeds, or faster than Mach 5, nearly 4,000 mph, Schneider said.

The X-51 project is led by the Air Force Research Laboratory and the Defense Advanced Research Projects Agency, and the vehicle is being built by Pratt & Whitney and the Boeing Co. Purdue engineers are part of a national team of researchers from government, academia and industry handling different aspects of the vehicle.

The Purdue research focuses on the forebody, or front portion of the craft, using a foot-long model for wind-tunnel testing. Research findings are providing information in two vital areas: maintaining the turbulent flow of air into the engine's combustor to keep the scramjet running properly, and increasing the amount of smooth airflow over the vehicle's upper surface to reduce friction and heat that could damage or destroy the vehicle. The higher the Mach number, the greater the friction and heat generated in flight.

Findings are detailed in a research paper to be presented on Jan. 8 during the American Institute of Aeronautics and Astronautics' 46th Aerospace Sciences Meeting and Exhibit in Reno, Nev. The paper was written by Schneider and graduate research assistant Matthew P. Borg.

The X-51A is a wedge-shaped vehicle with a scooplike cowl on its underbelly, where air rushes into the inlet of the engine's combustor. It is critical for air entering the inlet to be turbulent at hypersonic speeds, or the engine could "unstart," causing it to crash, Schneider said.

For this reason, air has to be converted to a turbulent flow before entering the inlet. This conversion is accomplished using a raised strip of metal placed near the inlet to "trip" the air from smooth to turbulent. Wind tunnel tests are helping engineers better understand this "roughness-induced transition."

The research findings will enable engineers to determine precisely where to place the trips and how far they should be raised from the aircraft's skin, Schneider said.

Experiments under quiet conditions yielded more accurate findings compared with experiments under noisy conditions. The quiet data indicated the trips should be raised about twice as high.

At the same time, air flowing over the top of the vehicle should be as smooth as possible to reduce friction and heating, which increases drag and necessitates a heavier thermal protection system for the vehicle's thin metal skin. Data from the experiments will be used to assess the performance of that portion of the vehicle.

"Laminar airflows can have eight times less heating than turbulent ones," Schneider said.

The researchers used a temperature-sensitive paint to measure how hot the skin of the model gets during testing. The paint was coated on a nylon strip inserted into the model. Shining a blue light onto the strip during testing generates a temperature-dependent red light from the paint. The intensity of the red light shows how hot the surface is.

"The results of our work can be used to help determine the heating and the skin friction of the vehicle, which is important for the design of the X-51A," Schneider said.

The vehicle is scheduled to fly in a series of tests by 2009. The project is part of an effort to build future missiles six times faster than today's cruise missiles.

Scramjets, or supersonic combustion ramjets, could lead to the design of space planes that are far less expensive to operate than the current space shuttles, making it more affordable to haul payloads into orbit. The space planes would use a combination of scramjets and rockets. Because scramjets use air from the atmosphere as the "oxidizer" to combust fuel, they do not require the liquid oxygen needed for rockets. That means vehicles equipped with scramjets would carry less liquid oxygen - only enough needed to operate rockets at high altitude.

"And if you don't have to carry as much oxidizer, you can make the vehicle a lot lighter, or you could make the structure heavier and more robust," Schneider said.

The researchers are able to switch the wind tunnel back and forth from quiet to high-noise airflow, which allows them to compare the quality of data in the two modes.

To measure the airflow velocity and turbulence, the researchers use a heated wire about one-tenth the diameter of a human hair. The higher the speed of the airflow, the more the wire is cooled and the greater the electrical current needed to maintain the wire's hot temperature. Monitoring the changing current needed to maintain the wire's temperature reveals the changing air speed at fluctuations of up to 250,000 times per second.

"This enables us to see how it goes from laminar to turbulent," Schneider said.

The research paper details the first major findings from the quiet wind tunnel after about 18 years of research to perfect the facility, which will be used to analyze the performance of hypersonic vehicles.

"Purdue, the Air Force and private industry have invested about $1 million in this tunnel over that time, and it's finally working and getting results that are affecting the design of these vehicles," Schneider said.

Scramjet vehicles could be in use by 2015.

To obtain quiet flow, the throat of the Mach 6 nozzle must be polished to a near-perfect mirror finish, eliminating roughness that will trip the flow near the wall from laminar to turbulent. Then, for the wind tunnel to remain quiet, it must be entirely free of particles. Even a single speck of sand could cause turbulence inside the wind tunnel, damaging the finish and ruining the quiet effect.

The wind tunnel is not the first of its kind. The National Aeronautics and Space Administration previously operated a wind tunnel capable of similar performance, but that wind tunnel is not currently in operation.

Source: Purdue University