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X-43: Mach 7 and Beyond

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On 27 March 2004 NASA's scramjet powered X-43 broke the world speed record for air breathing engine-powered aircraft. At 5,000 miles/hour, the X-43 covered about 13 miles in 10 seconds of powered flight. It then glided 450 miles to a controlled, pinpoint landing in the Pacific Ocean off southern California. The Hyper-X Program, a joint effort between NASA's Langley Research Center (LaRC) and Dryden Flight Research Center (DFRC) executed this record-breaking flight.

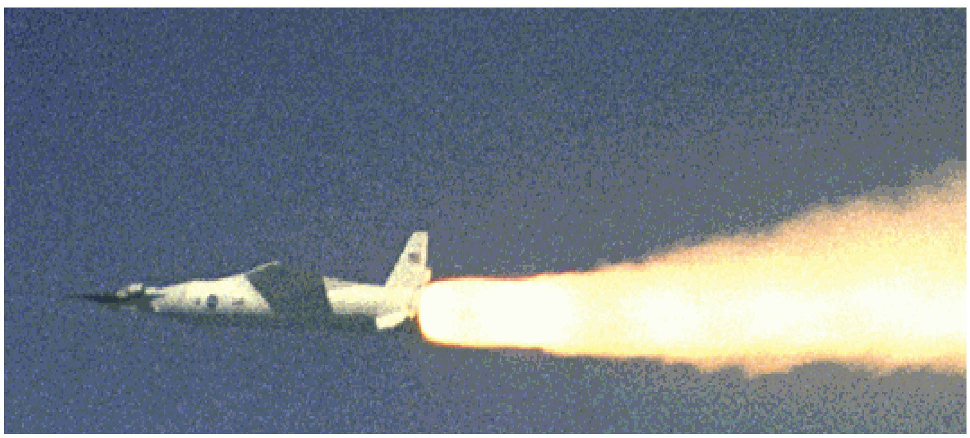

Figure 1. NASA X-43 Research Vehicle and Booster, 27 March 2004

Forty-four years ago NASA LaRC started research on Supersonic Combustion RAMJET (SCRAMJET) engines. These engines utilize oxygen from the air, and allow airplane-like operation at speeds faster than turbojets (Mach 3.5-4) or conventional ramjets (Mach 3-5). To date, flight operation above Mach 5 has been limited to rockets. One such application is earth-to-orbit space transportation. Scramjet engines provide an alternative. The German Professor Sanger first recognized this in the 1930's. Work toward realization of airbreathing engines for earth-to-orbit continued under Wernher von Braun in the 1940's and 50's. Today, designers estimate air breathing engines can increase safety and reliability by three orders of magnitude, and reduce operating costs by one order of magnitude, related to existing rocket-based systems.

Unlike turbine engines, scramjets have no moving parts. The scramjet uses the airplane's forward velocity to compress air. The air is first compressed by the airplane's nose, then through an inlet. This compressed air then flows through a small passage called the combustor, where fuel is injected, mixed and burned. This must happen rapidly, as the air only remains in the combustor for 1-2 milliseconds. Combustion further increases the pressure, and the high-pressure exhaust is expanded through a nozzle and over the back of the vehicle. Figure 2 illustrates a typical scramjet internal geometry – fuel is injected at different locations within the engine combustor, depending on the airplanes' speeds.

Scramjet-powered vehicles like the X-43 fly at very high altitudes, to avoid unbearable forces and temperatures associated with high speed at lower altitudes. The X-43 flight dynamic pressure was 1000 pounds-per-square foot (PSF), at about 95,000 ft. altitude. Because engine thrust is directly related to air mass flow through the engine, the vehicle and engine are carefully integrated so the engine captures most of the air disturbed and compressed by the vehicle. Engine air-capture needs lead, in part, to the shape of the X-43 (see figure 6). The wide, flat nose funnels additional air to the engine. The vehicle

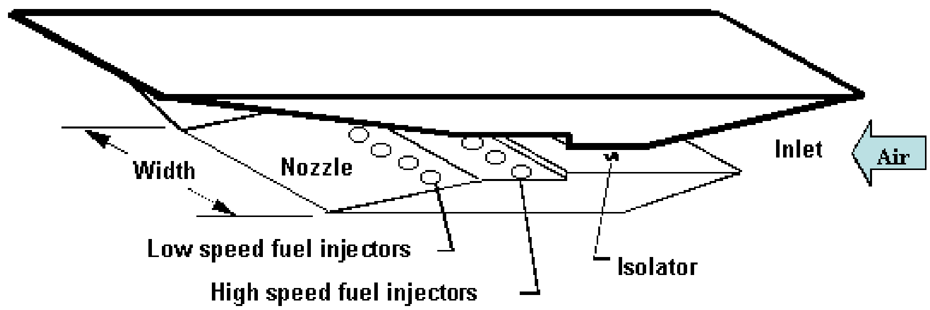

Figure 2. Typical scramjet engine internal geometry.

shape is also an effective lifting surface at supersonic and hypersonic speeds. High pressure on the lower front surfaces, simply caused by the vehicle shape and speed, is balanced by high pressure on the back lower surfaces, caused by the engine exhaust. The vehicle is trimmed for different flight conditions using the all-moving horizontal control surfaces, or "wings". Lateral/directional control is achieved with rudders at the rear of the twin vertical tails.

Design of these engines is based on wind tunnel test data. Previously, verification of these engines was limited to wind tunnel tests. Figure 3 illustrates a model of the X-43 vehicle lower surface, with a flight engine, installed in a Mach 7 wind tunnel at NASA LaRC. This is the most comprehensive integrated scramjet plus vehicle test in a wind tunnel ever performed. These tests confirmed that the flight vehicle should accelerate under its own power. (Flow visualization is enhanced by the cooling water exhaust – from the engine cowl leading edge, which highlights the engine's high-pressure exhaust – pushing the water stream away from the vehicle behind the engine module).

Figure 3. Test of the X-43A flight test engine in NASA LaRC 8' High Temperature Tunnel, Mach 7. Airflow is right to left.

To reduce costs, the X-43 is only 12 feet long. The X-43 research vehicle contains a flight control computer; wing/rudder electromechanical actuators; instrumentation and measurement system; power system (batteries); cooling water for the engine leading edges; and an ignition source for starting the scramjet engine. The remaining vehicle volume is for fuel. Due to the small vehicle scale and volume required for the other systems, only about 10 seconds of fuel was available for this flight. Therefore a rocket is used to boost the X-43 to the test condition. The flight test condition was Mach 7 at 95,000 feet. The test was performed in the "Western Flight Test Range", over the Pacific Ocean, west of Los Angeles, California. The rocket (a modified first stage of the Pegasus launch system) with the X-43 vehicle attached is carried to the range by NASA's B-52 (figure 4).

Figure 4. NASA B-52 ready to launch the X-43 Booster Stack.

The B-52 flew a "holding" pattern east of the launch point, at 40,000 ft altitude. As the B-52 crossed the launch point, it released the booster stack (booster, booster-to-research vehicle adapter, and the X-43 research vehicle) on a westerly heading. The booster stack dropped for 5 seconds, before the rocket ignited (figure 1). The rocket performs a pull-up climb to about 50,000 ft, and then starts a pushover as it accelerates to Mach 7 and 95,000 feet with a targeted burnout 1-2 degree climb angle.

Figure 5. Picture of X-43 from booster stage separation video camera.

A few seconds after burnout, the X-43 research vehicle separated from the booster (figure 5). Separation is accomplished using ejection pistons; one can be seen on the left side of figure 5. Following the piston push, the X-43 vehicle literally flies from the booster – to assure no contact with the booster. The wing has moved trailing edge down in figure 5, to lift the back of the vehicle over the adapter surface. Sunlight reflecting from the ocean surface is visible between the X-43 and the booster adapter in this picture.

Following stage separation, the engine cowl was opened for about 30 seconds. Vehicle performance without combustion was measured before and after the powered part of the flight using sensitive accelerometers in the Inertia Navigational Unit and a variety of pressure, temperature and strain sensors. During the powered flight, fuel was varied to determine performance over a large throttle range. The vehicle performance was very close to predicted – the X-43 accelerated as predicted, and cruised (thrust equals drag) at the expected throttle settings.

Following the powered part of the flight, the vehicle glided another 450 miles while descending to the ocean. During this part of the flight the vehicle control system commanded pre-programmed performance identification (PID) maneuvers to provide data required to validate the aerodynamics and stability of the vehicle. These maneuvers were performed at Mach 7, 6, 5, 4, 3, and 2. In addition, the X-43 performed a flare maneuver before impacting the water. The aerodynamic and stability data generated validated predicted performance.

Figure 6. Artist Concept of X-43 in flight.

The X-43 research vehicle successfully demonstrated hypersonic airbreathing vehicle performance. It also generated a huge archive of data from over 500 channels of measurement. This unique database will be used by engineers to validate design tools. The next flight, at Mach 10, is scheduled for late this year.