ramjet and a rocket. The operating modes are:

- **Ejector mode** during takeoff phase up to Mach 1-1.5, in which rocket performance is improved by mixing rocket exhaust gases with air that participate in the combustion process (air/rocket gas flow = 1:1.3, oxygen : hydrogen = 6:1);
- **Ramjet mode** up to transition velocity, in which combustion is stoichiometric, and because of the wide range of Mach numbers, very wide nozzle geometry variation (10 : 1) is required;
- **Rocket mode** with closed air intake, in the transfer into orbit trajectory.

Performance comparison of the three basic concepts, considered in terms of specific impulse and specific thrust, suggests turboramjets are to be preferred for those winged launcher concepts where a high specific impulse is more important than specific thrust, as in the case of TSTO vehicles, with cruise capability requirements. In contrast, a ramrocket solution is more interesting for applications in SSTO vehicles where the thrust/weight ratio is of greater importance. Turborockets offer intermediate performance characteristics and could be a good compromise, depending on the selected mission.

The technological effort on the propulsion system must be oriented according to which composite engine concept is chosen. This remains true even though the challenge can be generalized as an increased temperature capability inclusive of the installation features. In fact, high dynamic pressure and Mach number in the air-breathing phase lead to high internal pressures (about 10 bar at Mach 7, but varying with the intake geometry selected) and high stagnation temperatures (2,100° K at Mach 2) resulting in severe thermal and structural loads on engine components, especially air intakes and turbomachinery.

A fully reusable space plane

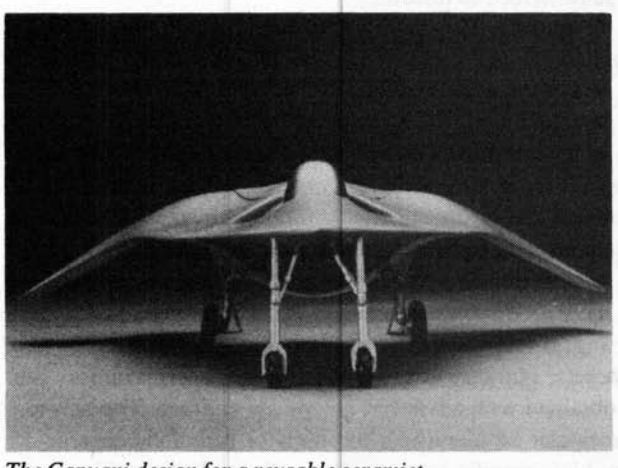
The goal of reusable space plane programs is to develop new propulsion systems, systems that will go from Earth's surface into space and back again.

In the 1930s, German aeronautical scientist Eugen Sänger designed the first horizontally launched spacecraft, which could take off from an airport-type runway. The Sänger project, led since the 1960s by German aerospace giant Messerschmitt-Bolkow-Blöhm (MBB), has been an effort to investigate novel ways of propelling a plane from the Earth's surface into supersonic and hypersonic regimes, all the way to the Mach 25 needed to go into orbit.

Sänger's key concept was to use the oxygen in the atmosphere to burn hydrogen fuel, rather than carrying along liquid oxygen, which has been done since the German V-2 of the 1940s. The MBB Sänger project envisions a turboramjet first stage which, carrying the second-stage orbiter, reaches a speed of Mach 7 at an altitude of about 110,000 feet.

At this point, the rocket engine on the orbiter is ignited and the second stage separates, carrying its payload into orbit, while the first stage lands horizontally. According to MBB, one advantage of this two-stage design is that the first stage produces, as a by-product, a hypersonic (Mach 7) airliner, similar to the U.S. concept for an "Orient Express."

Although most of the effort internationally in the various aerospace plane projects has necessarily been in the area of challenging and risky new propulsion systems, Dr. Alfredo Capuani in Italy has been testing new aerodynamic designs to minimize the drag and maximize the efficiency of the overall spaceplane design. Capuani's work takes its lead from the research in supersonic aerodynamics of Adolf Busemann, who solved the problem theoretically of destabilizing shock waves that form around aircraft as they approach the speed of sound.



The Capuani design for a reusable scramjet.

The unusual geometry of the Capuani spaceplane is derived from the formation of a "Busemann biplane" configuration, where the shock waves formed from the air flow around the wing of the plane are canceled by the use of two wings. In the Capuani design, it is the relationship between the wings on the spaceplane and on the carrier/first-stage vehicle that produce the Busemann biplane effect. The Capuani design also includes a high-powered lift design, which can make use of short airport runways.