Europe speeds up hypersonics

Flying from Brussels to Sydney in two to four hours may seem like a fantasy, but European organizations and companies are now collaborating on research aimed establishing the concept's feasibility. Early work has also evaluated proposed design ideas and sought to identify challenges and solutions. Efforts in several countries are now under way, and one major program will begin a new phase soon. Leading researchers are optimistic that these projects will bring the dream closer to reality.

by Philip Butterworth-Hayes
Contributing writer

Toward the end of this year the second stage of research is due to begin on the LAPCAT (Long-term Advanced Propulsion Concepts and Technologies) program, a study coordinated by ESA for a hypersonic, cruising civil transport to connect Brussels and Sydney in two to four hours.

LAPCAT II will be partly funded under the European Commission's Seventh Framework research program; the EC will invest around €7.4 million of the €10-million project, which will last around four years. During the first LAPCAT work (completed in April and funded as part of the EC's Sixth Framework program), ESA researchers and their industry partners examined the core technical challenges to developing two types of hypersonic transports powered by TBCC (turbine-based combined cycle) and RBCC (rocket-based combined cycle) engines: a vehicle in the Mach 3-4 range and another in the Mach 5-8 range.

research

To complement the Scimitar engine, Reaction Engines has proposed the A2, which attains the necessary subsonic and supersonic lift/drag ratio for efficient commercial operation. The airframe is designed to have adequate control authority about all axes to handle engine-out and to achieve pitch trim over the full Mach range.

The LAPCAT research partners include ESA, CIRA (Italian Aerospace Research Center), Reaction Engines, DLR, VKI, Cenaero, Snecma, and EADS, as well as the universities of Stuttgart, Rome, and Oxford. LAPCAT II also includes ONERA, MBDA, GDL, and the University of Brussels.

"The object of the program has been to examine whether such concepts are technically feasible," says LAPCAT project coordinator Johan Steelant, of ESA's European Space Research and Technology Centre (ESTEC) in the Netherlands. "What are the hurdles? And if they can be overcome, what are the solutions?"

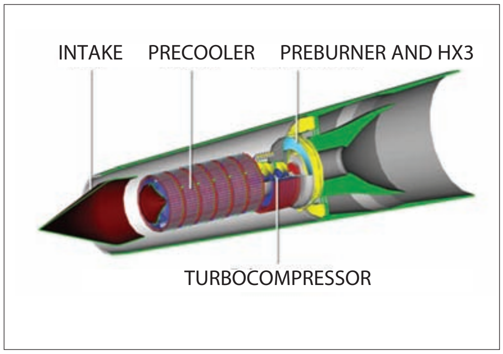
Propulsion choice

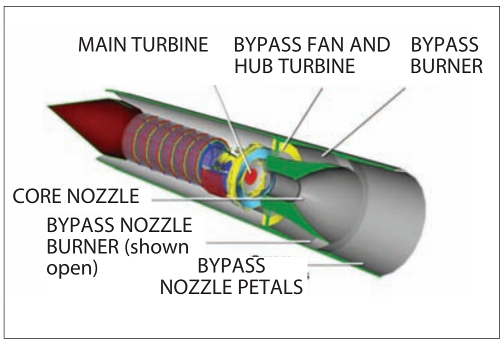
"For the Mach 5 vehicle, we have been looking at two propulsion concepts, the Deutsche Zentrum für Luft- und Raumfahrt's (DLR) Mach 4 kerosene-powered concept, and a hydrogen-powered engine concept developed by Reaction Engines of the U.K." says Steelant. "For the Mach 8 vehicle, DLR and ESTEC have investigated two different concepts that are based on scramjet propulsion for cruise flight with hydrogen fuel. After careful consideration, we have decided that in the next LAPCAT study work, the Mach 5 vehicle will focus more fully on the Reaction Engine concept."

Although the DLR kerosene alternative was a viable design, the hydrogen-powered concept looked to provide a longer range; the DLR's engine would have made Brussels-Tokyo routes possible, but not Brussels-Sydney, according to Steelant. Criteria for evaluation included safety, the ability to reach diversion airports, adaptability to different sonic boom restrictions, and technological maturation.

The DLR's active compression design used a variable-cycle propulsion system to accelerate the vehicle up to its cruise speed. Reaction Engine's concept was built around a turbocom-

The Scimitar engine is a derivative of the Sabre spaceplane engine intended for SSTO launcher application. It is designed around existing gas turbine, rocket, and subsonic ramjet technology; however, the incorporation of lightweight heat exchangers in the main thermodynamic cycles of these engines is a new feature to aerospace propulsion.





pression design, which enables a single propulsion system to accelerate the aircraft from rest to Mach 5. Some key objectives of the LAPCAT project were the design of air-breathing engines for trajectory points; dedicated combustion experiments for supersonic and high-pressure combustion, including potential fuels and interaction with flowfield turbulence; and aerodynamic experiments for major engine components and establishment of data on interaction of vehicle and propulsion aerodynamics.

Scimitar and Sabre

Reaction Engine's Scimitar engine and the corresponding LAPCAT A2 vehicle will now be the focus for further research.

"The Scimitar engine is based on conventional engine technology," according to Reaction Engine's managing director and chief technical analyst Alan Bond. "It is a derivative of the Sabre spaceplane engine intended for single-stage-to-orbit launcher application."

According to Reaction Engines, the Sabre engine is essentially a closed-cycle rocket engine with an additional precooled turbocompressor to provide a high-pressure air supply to the combustion chamber. "This allows operation from zero forward speed on the runway, and up to Mach 5.5 in air-breathing mode during ascent. As the air density falls with altitude, the engine eventually switches to a pure rocket propelling the spaceplane to orbital velocity—around Mach 25," says Bond.

The engine has been designed to power the Skylon, a remotely piloted reusable spaceplane currently in the proof-of-concept phase. The vehicle, which will take approximately 10 years to develop, will be capable of transporting 12 tonnes of cargo into space.

Both Scimitar and Sabre engines are designed around existing gas turbine, rocket and subsonic ramjet technology. One of the main features of the Scimitar engine is the extensive use of lightweight heat exchangers, required to precool the air and transfer heat within the thermodynamic cycle. This allows the use of a relatively conventional turbocompressor.

"One of our major challenges has been the design of the heat exchangers; we've had to design them to transfer around 400 MW in the precooling stage. In a conventional power station that would take up 200 tonnes of equipment, but we've had to compress that to 1.25 tonnes. By and large we're there."

The solution has been to design an assembly of large heat exchanger modules, incorporating thousands of tubes built in Inconel 718 nickel chromium alloy, as the main heat-exchange material.

"But that hasn't been the only technical challenge," says Bond. "The original design was aimed at powering a spaceplane with perhaps a life expectancy of 50 hr. In the Scimitar engine we are looking at a design life of around 18,000 hours, and that means we have to take into account issues such as fatigue and creep. This is a particular issue when it comes to examining the lifetime of the precooler."

"We're looking at a 4:1 bypass ratio and a subsonic exhaust speed for takeoff," says Bond. "This gives us a quite reasonable performance and means we will be able to fly over populated areas at Mach 0.9 before accelerating to Mach 5 once over the sea." Weight of the aircraft on takeoff will be around 400 tonnes, of which 200 tonnes will be the liquid hydrogen." Others areas of further research will be the integration of the engine and the airframe—and especially the air intakes—and methods to cut the amount of nitrous oxide (NOx) emissions.

The other concept pursued in LAPCAT II is the LAPCAT Mach 8 vehicle. The focus here will be the vehicle-propulsion integration, operation in multiple points, and verification by various experimental facilities and detailed numerical simulations. A strong coordination is put into place to enhance the synergy of the existing hypersonic facilities within Europe.

ATLLAS

Another EC-funded hypersonic research program, focusing on materials for hypersonic operations, is being developed in parallel to the LAPCAT work. The ATLLAS (Aerodynamic and Thermal Load Interactions with Lightweight Advanced Materials for High-Speed Flight) program is examining the development of lightweight, high-temperature composite materials for structure and engine applications, to reduce weight, fuel consumption, and direct operating costs (http://www.esa.int/techresources/atllas).

Also coordinating ATLLAS research is ESA-ESTEC with DLR, ONERA (Office National d'Etudes et Recherches Aérospatiales), the Swedish Defence Research Agency, MBDA, EADS, CRC, GDL, ALTA, and four universities as partners. The current focus is on examining the overall design for high-speed transports to increase the lift/drag ratio and volumetric efficiency through the "compression lift" and "waverider" principles, taking into account sonic boom reduction. A second strand of work is research into materials and cooling techniques and their interaction with aerothermal loads for both airframe and propulsion components.

According to ESA, "The former will focus

Europe's major hypersonics research programs 1988-2008

HOTOL (mid-1980s)
Partners: *British Aerospace, Rolls-Royce*
Concept: *Future reusable launch vehicle.*

PREPHA (1992-1998)
Partners: *Aerospatiale, Dassault Aviation, Sep, and Snecma*
Concept: *French-based program for research into a scramjet-powered reusable spacecraft launcher.*

JAPHAR (1997-2003)
Partners: *DLR, ONERA*
Concept: *A fixed dual-mode ramjet using gaseous hydrogen, with an experimental scramjet concept also developed. Simulated flight tests achieved at Mach 4.9, 5.8, and 7.5.*

PROMETHEE (1999-2002)
Partners: *MBDA, ONERA*
Concept: *Development of a variable-geometry dual-mode ramjet for long-range air-to-ground missiles.*

Hypersonic missile (2000-2003)
Partners: *EADS/LFK, Bayern-Chemie (EADS), Federal Office for Defense Technology and Procurement (Koblenz/Germany), Bundeswehr Technical Centers WTD 71 and WTD 91, ISL*
Concept: *An "integral concept" powerplant tested successfully at speeds of over Mach 6.5 along with aerodynamic control system.*

Phoenix (2002-2006)
Partners: *EADS-Astrium, DLR, Swedish Space*
Concept: *Reusable vehicle for space transport to demonstrate the guidance, navigation, and landing systems and to clarify the vehicle's aerodynamic characteristics and validate wind tunnel data. The prototype scale model is 6.9 m long, has a wingspan of 3.9 m, and weighs 1,200 kg. A number of successful flight tests carried out.*

Castor and Pollux (2002-ongoing)
Partners: *Italian Space Agency, CNR (National Research Council), Italian air force, Italian navy, ENAC (Italian Civil Aviation Authority), ENAV (Italian Company for Air Navigation Services), ESA, Thales Alenia Space Italia, Carlo Gavazzi Space, Vitrociset, Space Software Italia, Techno System Dev., ISL, DEMA, and Marotta*
Concept: *€179-million program of unmanned space vehicle research flights, part funded by PRORA (National Aerospace Research Program)/PASN (National AeroSpace Plan), to investigate hypersonic flight on reentry and in the atmosphere.*

Project Enterprise (2006-ongoing)
Partners: *Talis Institute (Germany), Vega, and Swiss Propulsion Laboratory*
Concept: *Development of a horizontal takeoff and landing vehicle for space tourism; initial concept is a two- to five-passenger vehicle powered by three liquid oxygen/kerosene rocket engines. SPL also developing low-cost launcher called X-Bow.*

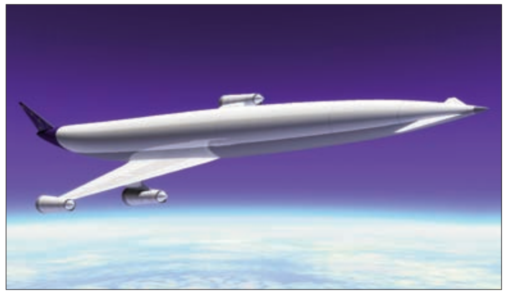
LEA (2003-2012)
Partners: *MBDA, ONERA*
Concept: *Development of an experimental hypersonic vehicle equipped with a dual-mode ramjet to fly at speeds up to Mach 10 or 12. Flight tests in the Mach 4-8 range envisaged, using a methane/hydrogen-fueled dual-mode ramjet/scramjet. Tests understood to be coordinated with Russian research institutes.*

Sustained hypersonic flight experiment (2002-ongoing)
Partners: *QinetiQ, U.K. Ministry of Defence*
Concept: *Research to demonstrate upper limit of ramjet performance through the use of high-temperature materials; experimental vehicle to be launched at Mach 4 and 15-km altitude intended to climb and accelerate to Mach 6 and 32-km altitude.*

Skylon (ongoing)
Partner: *Reaction Engines*
Concept: *An unpiloted, reusable spaceplane intended to provide inexpensive and reliable access to space. Currently in proof-of-concept phase, the vehicle will take approximately 10 years to develop and will be capable of transporting 12 tonnes of cargo into space.*

SpaceLiner (ongoing)
Partner: *DLR*
Concept: *A rocket-propelled, fully reusable spacecraft capable of flying from Europe to Australia in under 90 min with 50 passengers*

SHEFEX (ongoing)
Partner: *DLR*
Concept: *Research into actively controlled hypersonic flight (at Mach 12) of movable canards for missile control system. Flight test scheduled for 2010.*



The next phase of research on the A2 should begin by the end of the year.

on sharp leading edges, intakes, and skin materials coping with different aerothermal loads, the latter on combustion chamber liners and cooling strategies. After material characterization and shape definition at specific aerothermal loadings, dedicated on-ground experiments will be conducted. Both ceramic matrix composites and heat-resistant metals will be tested to evaluate their thermal and oxidizer resistance."

From the work done so far, Steelant is confident that the research will show viable high-speed transport concepts at different Mach numbers in the years ahead.

"From our current perspective we try to overcome the technical hurdles—and some of the concepts we have been examining, such as contrarotating fans or materials for combustion chambers, are applicable to classic engine technology," he tells *Aerospace America*.

"But Mach 8 is much more difficult than Mach 5—especially the airframe-engine integration area and the design of intakes. And we think that scramjet propulsion for Mach 8 operations will be feasible, judging from the results of research programs such as the Hyper-X (X-43A) study in the U.S. We are sure that at the end of the next stage of LAPCAT research we will have a clear road map to developing an air transport vehicle capable of sustained hypersonic flight."

The A2 would dwarf the Airbus A380.

Other studies

Although LAPCAT and ATLLAS research has concentrated European hypersonic research efforts in the air transport sector, other work, mainly in France and Germany, has also examined a wide range of hypersonic activities for missiles, space launchers, and space station crew transfer vehicles.

In particular, France's PREPHA (French National Research and Technology Program for Advanced Hypersonic Propulsion) laid the foundation for ONERA and MBDA to collaborate on scramjet and dual-mode ramjet component designs in the 1990s—in particular inlet, combustor, injection struts, and nozzles—and air-breathing hypersonic vehicle technologies. MBDA, owned by BAE Systems (37.5%), EADS (37.5%), and Finmeccanica (25%), was created in 2001 following the merger of Europe's major missile manufacturers, Matra BAe Dynamics in the U.K. and France, Aerospatiale Missiles in France, Alenia Marconi Systems (U.K. and Italy), and EADS/LFK in Germany.

French research has concentrated over the past 10 years or so on developing mature dual-mode ramjet technologies. Between 1997 and 2001 the ONERA-DLR JAPHAR program focused on studies of a hydrogen-fueled dual-mode ramjet, to operate in the Mach 4-8 range, while PROMETHEE (a joint ONERA-MBDA study) looked at overcoming the difficulties associated with the use of hydrocarbon-powered dual-fuel ramjets for hypersonic cruise missiles.

Meanwhile, MBDA has also been working on dual-mode ramjet designs with full variable geometry, based on kerosene and hydrogen propulsion. Extensive ground tests have taken place in collaboration with the Moscow Aviation Institute. The company has collaborated with EADS Space Transportation in the development of fuel-cooled composite structures.

✈✈✈

As a result of this and related work, ramjet technology is now becoming an increasingly mature science within Europe. However, moving beyond Mach 5 into the hypersonic domain will involve a much greater collaborative effort as the engine-airframe integration issues and the physics of managing supersonic flows within the engine need to be much better understood.

In the area of scramjet technology at least, U.S. research appears to be far in advance of European collaborative efforts. In contrast to the U.S. and Russia, Europe lacks a major network of hypersonic-compatible wind tunnel facilities to test high mass flow rates.

Programs such as LAPCAT and ATLLAS will take Europe quite a long way along the path to developing hypersonic air transport concepts, but for Mach 8+ research—driven mainly by military demands for new generations of high-speed, long-range missiles—a more coordinated research initiative will be needed throughout the continent.