EIR Science & Technology

Open the Age of Hypersonic Flight!

For more than 60 years, scientists and engineers have worked to combine aircraft and rocket technology. NASA's Hyper-X program is designed to finally meet the challenge. Marsha Freeman reports.

Ever since man began to fly, he has aimed to reach higher and higher into the atmosphere, to finally fly into space. As early as the 1920s and the first rocket experiments, space pioneers were designing aircraft that would be equipped with rockets to fly through the atmosphere into space, and return to the Earth like an airplane. In this way, the airplane frame would use its wings for aerodynamic lift, and the rocket engine would allow it to travel faster than would any aircraft engine, and fast enough to go into orbit. Today's Space Shuttle is an approximation of this concept, using rockets to orbit the Earth, and using its wings to aerodynamically glide back. But, because it is launched vertically into the atmosphere using its rockets, the Space Shuttle plows through the atmosphere, fighting against it.

But what if technology could be developed to make use of the atmosphere for the oxygen needed for propulsion, rather than having to carry it along in weighty tanks, the way a rocket does? If engines could be developed that could extract oxygen from the atmosphere and attain hypersonic speeds, only a minimal amount of rocket power would be needed to take the last step into space.

Such a hybrid system would substantially reduce the weight of a space vehicle, making it more efficient and economical. Today, for rocket-propelled vehicles, 88% of the take-off weight is propellant. The Space Shuttle carries 1.3 million pounds of liquid oxygen in its 15-story-tall external tank, along with 223,000 pounds of liquid hydrogen fuel, to feed its main engines. Rocket-powered vehicles have to be designed in stages to go into orbit, disgarding excess weight when the fuel is exhausted, which is why the Shuttle drops its external tank.

If the Shuttle could use the air in the atmosphere on its way to space, instead of carrying its oxygen and tank along with it, the vehicle could carry more than a million pounds more payload. Or, the vehicle could be much smaller, hauling the same amount of cargo.

If the space vehicle also took off horizontally, like an airplane, rather than vertically, like a rocket, it could potentially be "launched" from a runway at an airport, rather than a special space center, further cutting cost. Safety is greatly increased, because the launch stage would be based on aviation, not rocket technology. Were there a problem with an engine, the plane could fly back to the runway, rather than "drop out of the sky," as if it were attached to a rocket.

Every space agency in the world has been interested in lowering the cost of its access to space, because that cost determines what activities can be carried out. If the cost of orbiting a pound of payload could be one or, better, two orders of magnitude less than what it is today (about $5,000 per pound on the Shuttle), space would be opened to scientific institutions, industry, and even tourists. The cost reduction would ripple through every space activity, from launching satellites to establishing manned settlements on the Moon, enabling whole new missions.

The National Aeronautics and Space Administration (NASA) is embarked on the Hyper-X program to develop and test the revolutionary technologies that can make the dream of "flying" into space a reality. Under development is a scramjet

An artist's concept of the Hyper-X during its hypersonic cruise.

engine that can take a vehicle to hypersonic speeds, i.e., higher than Mach 5 (Mach 1 equals the speed of sound, about 760 miles per hour at sea level), using the oxygen in the atmosphere. If the scramjet engine could bring the vehicle to a speed of Mach 18, only a modest amount of rocket power would be needed to get it to the orbital speed of Mach 25. Hyper-X will be the first flight test of a scramjet engine, and will lay the basis for designing tomorrow's vehicles, that can fly into space.

There have been numerous starts to this space plane project, over the past 50 years. What is needed now, is a crash program commitment to overcoming the very real obstacles in fundamental physical principles—such as hypersonic fluid flow and aerodynamics—and the associated engineering challenges in materials, structures, combustion, and the like. This will require the mobilization of a near-moribund aerospace and aeronautics industry, to rebuild basic research and development resources, enabling the breakthroughs for hypersonic flight.

Rockets on Airplanes

The first proposal for a spaceplane consisted of merely physically joining the two technologies. In 1923, at the dawn of serious rocket engine experiments, Latvian engineer Fridrikh Tsander described an airplane with a "high-pressure" aviation engine, attached to a rocket. At an altitude of 28 kilometers, he proposed, the aviation engine would be cut off and a rocket engine would take over.

Inside the aircraft would be a smaller, winged spaceship that would be launched into space, and later glide back to land. With aviation itself still in its infancy, and airplanes being made out of wood, it would be decades before technology could catch up to this innovative design. Tsander died in 1933, a decade before even the first rocket took flight.

In 1914, a young man born in Bohemia built his first model rocket plane, powered with a fireworks rocket. Eugen Sänger, who was nine years old at the time, went on to read the works of Hermann Oberth and other rocket scientists, and submitted a doctoral thesis at the Technical High School in Vienna in 1928, on high-altitude rocket plane flights. The thesis was rejected by his teacher, who advised that he would be an "old man with a long beard before you succeed in obtaining your doctorate." But this did not discourage the young enthusiast.

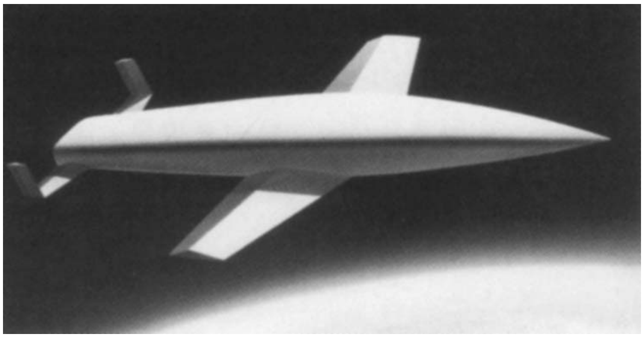
The space plane designs of the 1920s had followed an approach of taking a rocket engine and building an airplane around it. Sänger realized that this idea was obvious, but unworkable; that the airplane and propulsion design had to be integrated, to optimize the performance of each.

During the 1930s, Sänger carried out rocket motor experiments at Vienna University, but, according to German-American science writer Willy Ley, he "felt certain then—and future development, has, of course, borne him out—that the practical problems of larger motors would certainly be solvable." Sänger, therefore, left rocket experiments to others, and concentrated on the next step—of marrying the new rocket technology to the airplane.

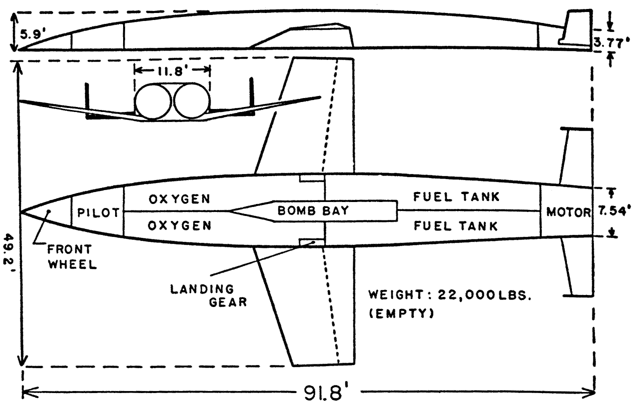
To Sänger, the logical progression from air to space was through a series of ever-more-capable rocket-powered planes, each of which could fly faster and higher than its predecessor. Through successive approximations, the technologies would be developed and the design matured, leading to airplanes in space.

In 1933, when serious rocket engine development work was under way in Germany, Sänger published his book, *Rocket Flight Technique,* in which he presented the design of a rocket plane that could travel for more than an hour at an average speed of 1,600 miles per hour, with an engine burn time of 20 minutes. He called the vehicle the Silver Bird.

In the introduction, Sänger wrote: "In particular, that type of rocket flight shall be treated which takes place in the upper



A model of the Sänger-Bredt rocket spaceplan, the Silver Bird.



A diagram of Eugen Sänger's anti-podal bomber, which would be capable of travelling halfway around the world and landing at an airport.

layers of the stratosphere with such velocity that the inertial forces due to the curvature of the flight path contribute essentially to the lift. This type of rocket flight is the next basic development step beyond the tropospheric flight, accomplished during the last 30 years, and it is the prelude to space flight, the greatest technical problem of our time."

Sänger submitted the proposal for development of his Silver Bird to the Austrian Ministry of Defense in 1933. As Robert Goddard was told by the military establishment in the United States, and Hermann Oberth was told in Germany, Sänger was told that rockets wouldn't work.

Two years later, the German Air force, the Luftwaffe, established a rocket research center in Trauen, Germany, in competition with the Army rocket research program, later at Peenemünde, to investigate rocket motors. Sänger was invited to join. In 1938, Sänger and mathematician Irene Bredt (later to become his wife) created a steel model of Sänger's Silver Bird, and applied for a patent.

During World War II, Sänger and Bredt worked on a 400-page report titled, "A Rocket Drive for Long-Range Bombers." This concept, based on the earlier Silver Bird, would orbit the Earth using a single-stage vehicle, at a maximum altitude of 186 miles, carrying four tons of payload. A ground-based, liquid-fuelled rocket sled would be used to accelerate the space plane to a speed of 1,640 feet per second, to provide the lift for take-off.

Sänger knew that if the rocket plane were launched vertically, like a rocket, or steeply into the dense layers of the atmosphere too quickly, once its engine were stopped, it would ricochet, dropping back to a denser layer, bouncing off it to an upper thinner layer, repeating this roller coaster trajectory as it lost altitude. He realized that such a sinusoidal, or "skip" path, would increase the range of the plane, which led to his concept of the anti-podal bomber. (This concept is being used today for flights to Mars, where the drag in the atmosphere "aerobrakes" the spacecraft over a series of orbits, until it lands.)

The single-stage plane Sänger designed is 92 feet long, with a wing span of 50 feet. It would weigh 20 metric tons empty, and carry 80 metric tons, including fuel, a pilot, and 660 pounds of bombs. A two-mile-long straight take-off track on the ground would be used, with the plane seated on a rocket sled. The rocket would operate for 11 seconds to accelerate the plane to a speed of 1,640 feet per second, producing enough lift for take-off. The plane's rocket stage would then be ignited, and accelerate it to a speed of 3.73 miles per second.

Sänger calculated that this vehicle would be able to travel more than 14,000 miles before it landed, going halfway around the world (or to its anti-pode), and could set down at an airport. The propulsion period would be about five minutes, and the total trip duration, two and a half hours.

The war ended before such a design could even be considered.

Rocket Planes Begin To Fly

Following the end of World War II, and the demonstration of the reality of rocket technology by the team under the leadership of Wernher von Braun at Peenemünde, the American National Advisory Committee on Aeronautics and the United States Air Force embarked on a program to test a rocket-propelled hypersonic space plane. This was a path parallel to the pure rocket development program, proceeding under the U.S. Army and von Braun, which was also designed to put man into space.

The purpose of the X-plane program was to develop the technologies and test the flight regimes in the atmosphere, that would be required for manned, orbital rocket plane vehicles.

On Oct. 14, 1947, Air Force pilot Chuck Yeager, sitting in his X-1 rocket plane, was taken aloft by a B-29 airplane to an altitude of 37,000 feet. The X-1 was released from the plane, and ignited its rockets. It was the first aircraft to exceed Mach 1, the speed of sound. That, and the subsequent flights of the X vehicles, provided scientists and engineers with their first test data on the aerodynamics of supersonic flight, the stability of a vehicle in that flight regime, and other information that would be crucial 25 years later in the design of the Space Shuttle. The speed record for manned rocket plane vehicles was set by the X-15 at Mach 6.7, during its 199th flight, in 1968.

While the initial testing of supersonic vehicles was under way, ideas abounded on how to apply what was sure to be the next revolution in flight. In 1949, working at the California Institute of Technology, Dr. Tsien Hsue-shen, who would later lead the Chinese space program, designed a suborbital rocket plane to travel from Los Angeles to New York. Rocket burnout would take place after 150 seconds, at 100 miles altitude, and the plane would glide for 10,000 miles, over about an hour.

Similarly, while working for Bell Aircraft, which built the X-1, former Peenemünde rocketeers Walter Dornberger and Krafft Ehricke designed an intercontinental passenger transport consisting of two winged airplanes, both stages boosted by rocket engines. One hundred thirty seconds after launch, the stages would separate. The manned booster would be flown back to a landing site, and the smaller second stage, with its passengers, would continue on its journey. The plane could be able to cross the Atlantic in 75 minutes, reaching a maximum velocity of 8,560 miles per hour.

The Air Force planned to continue development of hypersonic planes with speeds faster than that possible with the X-15, in the Dyna Soar (Dynamic Ascent and Soaring Flight), or X-20 program, which began in 1958. But the technical challenges were severe, requiring the development of higher-temperature materials, the mastery of fluid- and aerodynamic properties of the upper layers of the atmosphere, and new propulsion systems. Politically, Dyna Soar was seen as unnecessary, because NASA was already developing a manned space program, to lead up to the lunar landing. President John Kennedy had given NASA less than nine years to land a man on the Moon. Ballistic rocket flight was seen as the solution with the lowest risk, and the only way such a timetable could be met. The Dyna Soar program was cancelled in 1963.

As the United States decided to develop ballistic rocket vehicles for manned space flight, Sänger saw a window of opportunity for Europe to exert technological leadership in the space field, and develop the advanced and efficient space plane he had been designing for 30 years.

In 1962, Sänger pointed out that the United States and the Soviet Union were concentrating on their race to the Moon. "There is, therefore, at the moment, a unique, but short-lived opportunity for Europe, with its great intellectual and material resources, to become active in a sector of spaceflight in which the major space powers have not yet achieved an insuperable lead," he said. But, in postwar Germany, rocket, space, and military technologies could not be pursued, and, at the time, there was no European-wide space organization to carry through on such a proposal.

In 1961, Sänger working at the German aircraft giant Junkers, and then at Dornier, began a study of space transportation systems, which was completed in 1964. Similar to the Dornberger-Ehricke design, he proposed a two-stage design for a one-man spacecraft for either anti-podal flights, or a transport plane, to a 186-mile orbit. Both the booster vehicle and the space vehicle, which would ride piggyback, would be manned and recoverable. The initial lift would be provided by a horizontal catapult, or track, with a pair of rockets. Sänger thought that such a vehicle could be realized within 15 years.

It would be another 20 years before Europe, or at least Germany, would take up Sänger's challenge, but Sänger did not live to guide that effort. He died on Jan. 23, 1964 of a heart attack, while lecturing at the Technical University in Berlin.

On the Other Side of the Curtain

The United States and Europe were not the only places where hypersonic rocket planes were being designed. In an article in *EIR* in 1996, Russian space engineer Oleg Sokolov reported on previously secret Soviet aerospace plane projects, dating back to the 1960s.

Similar to the situation in the United States, the Soviet space program was focussed on using rocket technology, such as the Soyuz, borrowed from intercontinental ballistic missiles. This was the quickest, and then-cheapest way to achieve Earth orbit.

But the Soviet aviation industry was pursuing the "Spiral" project, initiated in 1965, building on 1950s design experience that had been carried out as the counterpart to the U.S. Dyna Soar program. Spiral was to include a hypersonic airplane-booster, an orbital plane, and an additional booster to take the plane into orbit.

Spiral would have a total mass of 140 tons, and inject the orbiter, with a three-man crew aboard, into low-Earth orbit. The orbiter could carry out two or three revolutions of the Earth, and land at an airfield. The entire system would be reusable.

Although the Spiral program was shelved in 1969, and abandoned in 1978, the Russians carried out flight tests of a scale model of the orbital plane in order to study aerodynamic braking, thermal properties, and landing. Tests continued into the 1970s with a variety of analogue vehicles, until the work was shifted to support the development of the Soviet space shuttle, the Buran.

Interest in hypersonic flight reawakened in the mid-1980s, with the focus on using already-existing hardware and what had already been learned. The new design, designated the Multi-Purpose Aviation Space System (MAKS), used the Ukrainian conventional super-heavy cargo aircraft Mria as an air carrier. The orbiter would be dropped from the airplane at a designated altitude and then use its rocket engines to enter orbit. As political and economic chaos engulfed the former Soviet Union, and the Buran shuttle was mothballed because of lack of funds, the MAKS concept went through various iterations, but never came to fruition.

But resident today in Russia and the former Soviet republics is some of the world's finest expertise, not only in rocket plane design, but also in hands-on experience in designing and testing some of the most advanced engines for the future.

The Soviet "Spiral" aerospace plane, which included a hypersonic airplane booster and small orbital plane on top.

That expertise is ready to be re-engaged in an aerospace plane project.

The 1980s Sänger II

In the mid-1980s, President Ronald Reagan committed the United States, and invited international partners, to help develop a space station in low-Earth orbit. This initiative opened up the possibility of new missions for relatively small manned spacecraft that could be used to deliver crew members, and service the permanent space facility. In addition, the 1986 Challenger explosion prompted nations involved in the station to have second thoughts about the policy of relying solely on the Space Shuttle to take astronauts into space. (Russia did not join the project until early 1990s.)

German aeronautics and space engineers resurrected the project for an aerospace plane, and honored the originator of the concept by naming it the Sänger II.

The Sänger program, begun in 1986, had the goal of developing hypersonic engine technology (above Mach 5), including developing a vehicle that would take off from an airport, release a second, orbital vehicle to visit the space station—or provide a ride to a transfer orbit for payloads, such as a communications satellite, headed for geosynchronous orbit, 24,000 miles above the Earth—and then fly back to land.

The German program was designed to make use of available, or near-term technology, by employing a two-stage configuration. The first stage, a large booster plane, used a conventional jet turbine engine, and then switched to a ramjet, fuelled by liquid hydrogen, which would obtain speeds up to Mach 7. At that point, the second, smaller space plane would separate, and ignite its rocket engine to obtain orbit.

Ramjets had been under development for nearly 40 years. In 1946, Sänger went to France, to advise the government on rocket technology. While there, he carried out research and tests on ramjet engines towed by an airplane.

The ramjet concept had been originally explained by René Lorin in 1913, and was patented in 1941 in Germany. Preliminary tests were conducted in Germany between 1942 and 1944. In his 1965 book, *Space Flight,* Sänger pointed out that rocket vehicles consume 60% of their propellants in altitudes less then 30 kilometers, in the densest part of the atmosphere, on their way to space. Tremendous savings could be won by replacing rockets that carry along their oxygen, with turbojet and ramjet engines that use air from the atmosphere, up to that altitude.

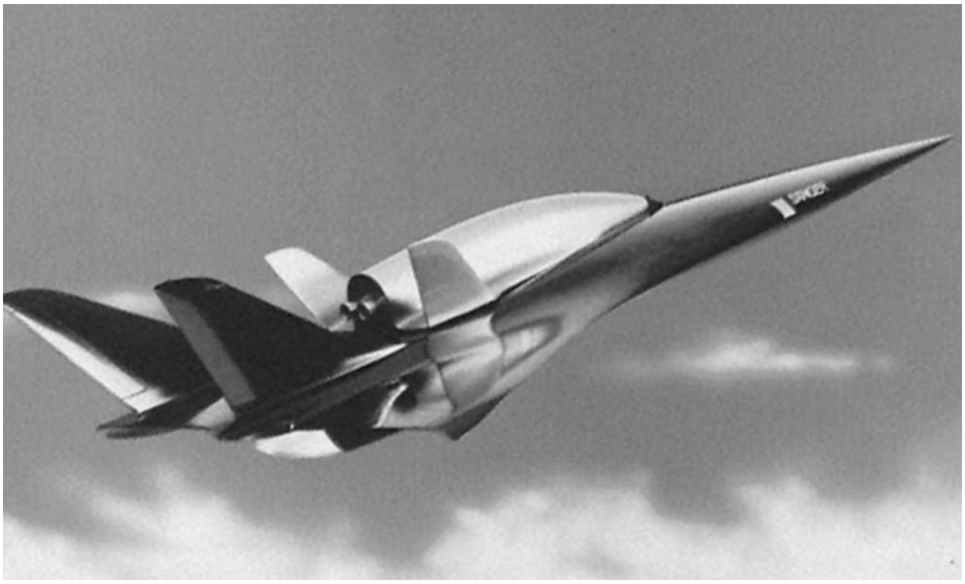
Sänger explained that three different propulsion systems would be needed in his spaceplane design. Because ramjets are only efficient at about Mach 2 and above, conventional turbojet engines are needed for the first leg of the flight. And, because ramjets have been shown to operate effectively up to a speed of about Mach 6, rockets would be needed for the last leg into space, at Mach 25.

Sänger stated that the goal is to increase the payload weight of a space vehicle to 15-20% of the total weight, similar to a commercial airliner. Ballistic space vehicles represent "a primitive, uneconomical, and unreliable initial stage of the development program," he said.

Today's jet aircraft, commercial and military, use turbojet engines that compress the air in the atmosphere, combine it with fuel, burn the mixture, and expand the combustion products to produce forward thrust. But these engines are limited to speeds of about Mach 3. Above that speed, the turbine blades used to compress the air, overheat. Unlike turbojets, ramjets have no moving parts.

In ramjets, the air is channeled into the engine through an in-take duct pointing in the direction of flight. It requires no moving parts, because the air is compressed by the forward speed of the aircraft itself. The air enters a combustion chamber where it slowed down as it is rammed into the chamber. As it slows, the pressure increases and the gas expands. Even without combustion, the air is heated to 1,100°C for flights at a speed of Mach 5.

The Sänger II design included an air-breathing hypersonic ramjet for the first stage, which could, by itself, be an intercon-



An artist's drawing of the two-stage Sänger II, with its hypersonic ramjet first stage and space plane.

tinental transport plane. Carrying 130 passengers, it would have a range of 13,000 km, a 33-foot wingspan, six ramjet engines, and would reach a maximum speed of Mach 6.8 and a crusing speed of Mach 4.5.

The smaller, second-stage rocket-powered plane could be designed for either a crew of two, or for cargo. The Horizontal Upper Stage (Horus) was the manned version, and the Cargus, for up to 15,400 pounds of freight. Preliminary models of the ramjet engine were tested in wind tunnels at a speed of Mach 4.7.

Because of both technical and financial difficulties, the Sänger II project, entirely funded by the German government and industry, was stretched out, with the first, technology development phase extended from 1992 to 1995. This technically challenging phase required the development of air-breathing propulsion, advances in aerothermodynamics, propulsion integration with an airframe, and new materials and structures. It was estimated that the last phase, a flight-ready vehicle, would cost $20 billion.

From the beginning of the program, Germany made clear that to advance to the second stage of building scale models for testing and, eventually, a full-scale test vehicle, international collaboration would be required. While partners for the program were being sought, the German space budget was reduced 20% in 1993, other necessary parts of the program were dropped, and only research on air-breathing engines continued. The European Space Agency, contending with competing concepts from France and England, and in the end unwilling to fund any one of them, did not approve the program. Foolishly, Sänger II was cancelled in 1994.

From Ramjets to Scramjets

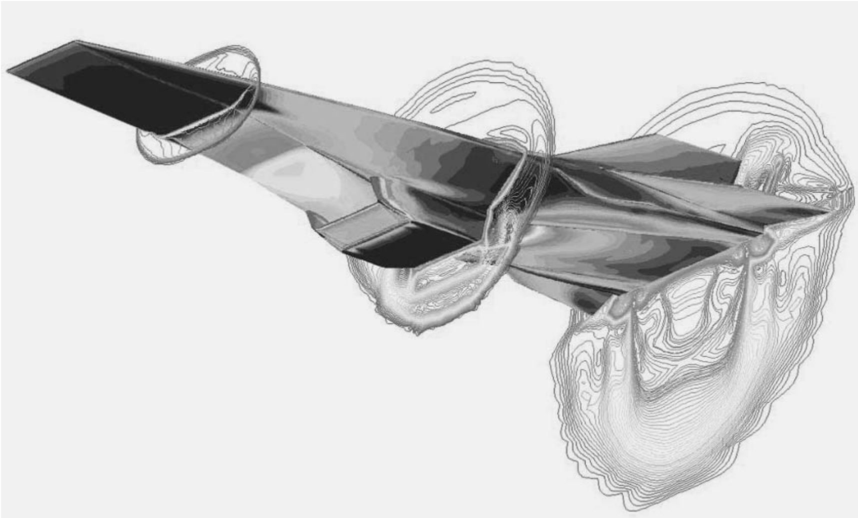
In the mid-1980s, the United States began the National Aerospace Plane program, dubbed the "Orient Express." It had been announced as a national initiative by President Reagan in his 1986 State of the Union address. The goal of NASP, or the X-30, was to demonstrate the feasibility of "sustained hypersonic cruise," in a most difficult single-stage-to-orbit configuration. This would mean that subsonic aircraft propulsion, and air-breathing hypersonic ramjet and scramjet propulsion, would all be integrated into one vehicle. This had never been attempted before. The program was to culminate in a full-scale flight-ready vehicle. The estimated cost was $10-15 billion.

It was known from previous tests that at six times the speed of sound, the combustion chamber in a ramjet engine becomes so hot that the combustion products needed for thrust, decompose. At that point, a more advanced propulsion system is needed to take over.

Scramjets, or supersonic ramjets, were the invention of Antonio Ferri, working at New York University in the late 1950s. In the United States, his work led to the 1960s Hypersonic Research Engine program at NASA's Langley Research Center in Virginia. Unlike the ramjet, the air coming into the engine is not "rammed," or slowed down, but stays at supersonic speeds throughout the engine. This prevents the air flow from heating up, keeping it relatively cool. But, it reduces the time the air spends in the chamber to one-thousandth of a second, or less. A very quick chemical reaction is required in the chamber, with hydrogen the most effective candidate. It was well known that this would be a challenging technology to understand and engineer.

As the National Aerospace Plane program proceeded, it became clear that technical challenges in developing a hypersonic scramjet engine—which could only be flight tested, because no wind tunnel exists that can test anything higher than Mach 8—was more difficult, and much more expensive, than originally calculated.

The program also ran into political problems in Washington. With Defense Department budget cuts in 1989, Defense



Beyond a speed of Mach 8, where the ability to test in wind tunnels is lost, scientists use computational fluid dynamics to analyze air flow and shock fronts around hypersonic aircraft. This is such a diagram of the Hyper-X.

Secretary Dick Cheney tried to cancel the X-30 program during his first week in office. The program limped along from year to year, tossed back and forth between the Air Force and NASA, never receiving enough political support, or funding.

By 1993, it was clear that only (expensive) test flights could accurately characterize the shock wave transition point for the X-30; provide test data on scramjet performance at high Mach numbers, prior to manned X-30 flights; and overcome the lack of data to support the claims that hypersonic vehicle stability and control were manageable. The program was behind schedule and over budget. Members of the technical community felt that NASA and the Air Force had bitten off more than they could chew, and that substantially more research and development was necessary before development of test flight vehicles could be entertained.

While progress was made in a number of areas, and scramjet wind tunnel tests were successfully conducted, the program was essentially ended in 1994. Although it was intriguing to propose flying from New York to Toyko in one hour, a well-funded, longer-term R&D effort, with the stable political backing of Washington policymakers, was lacking.

A similar situation existed in the Soviet Union, where work on hypersonic engines had been under way. There, on Nov. 28, 1991, for the first time in history, an air-breathing ramjet/scramjet engine was tested in flight. The engine, launched on a missile, operated for 20 seconds, and attained a speed of Mach 8. A second test took place the following year, prepared by the Central Institute of Aviation Motors, the Tupolev aircraft design bureau, and the famed Central Aero-Hydrodynamics Institute (TsAGI). At a speed of Mach 6.6 the ramjet engine converted to a scramjet. Scale models of potential airframe designs were tested in the wind tunnel at TsAGI, up to speeds of Mach 20, for two minutes.

The resources have not existed in Russia to complete the development that is possible on the ground, and then to move to test-flight articles to verify the revolutionary new propulsion technology. As early as 1993, Russian scientists proposed that their extensive, ground-based hypersonic test facilities be combined with the American capabilities in fields such as computational fluid dynamics, in a joint program to develop hypersonic flight. Now that NASA has initiated such a program here, this proposal should be implemented.

When the National Aerospace Plane program was ended in 1994, it did not diminish NASA's interest in completing development of the technology. Within the next 10-20 years, the Space Shuttle fleet will reach the end of its productive lifetime. The challenge is not only to replace the Shuttle, but also to radically reduce the cost of manned access to space. In 1995, NASA began Hyper-X, a more modest, $185 million five-year technology development effort, starting from the progress made in the NASP program.

Hyper-X: From Earth to Space

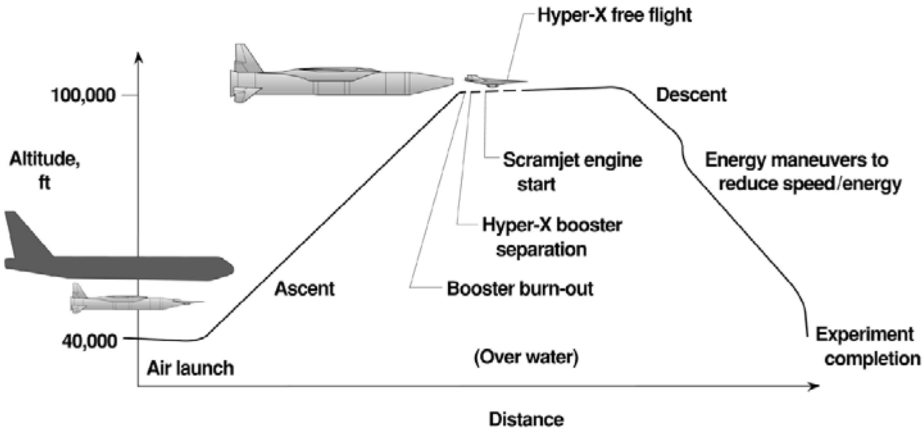
The goal of the Hyper-X program is to design and test scramjet propulsion systems in wind tunnels and on a small-scale vehicle. If these are successful, a decision will be made to proceed with a full-scale flight vehicle.

Conceptual design work began in 1995, and wind tunnel tests of engine models followed early in 1996. Fifteen experimental aerodynamic test programs, on 11 different models, were tested during more than 1,000 runs, to validate a scramjet design. In 1977, NASA chose MicroCraft, Inc. of Tullahoma, Tennessee to develop the X-43 test vehicle, in order to integrate the scramjet engine with an airframe. Three vehicles have been built, each approximately 12 feet long, with a wing span of about five feet.

In order to test the scramjet engine, the X-43 is carried aloft attached to a Pegasus rocket booster, under the wing of a B-52. At a speed of Mach 7, when the B-52 reaches a height of about 40,000 feet, the Pegasus, carrying the X-43, is released from the plane. At an altitude of 100,000 feet, the X-43 is released from the Pegasus, and turns on its engine for ten-plus seconds. In its unpowered, six-minute glide phase, it is to perform a number of "S" curves to slow itself down aerodynamically, and finally ditch in the Pacific Ocean.

The three X-43 aircraft, while appearing identical, will be engineered with slight differences to simulate variable air inlet scramjet geometry, which changes with Mach number. Two vehicles were designed to fly at Mach 7, and the last at

HYPER-X FLIGHT TRAJECTORY



During a flight test of the Hyper-X, or X-43, a B-52 flies to 40,000 feet, where it releases the X-43, which is attached to a Pegasus rocket. The rocket ascends to 100,000 feet, and the X-43 flies using its scramjet engine after release from the Pegasus.

Mach 10, or 7,200 miles per hour.

The first such flight test took place on June 2. But after separation from the B-52, the Pegasus rocket booster went out of control 5-8 seconds after igniting, and range safety officers ordered the rocket, with the attached X-43, to self-destruct. While NASA is investigating the cause of the test failure, the schedule for the next two test flights, which were supposed to proceed at six-month intervals, has been put on hold.

The second phase of the Hyper-X program will use a slightly larger X-43 vehicle, for follow-on tests in the Mach 5 through Mach 7 regime. These tests will actually be more difficult than tests at Mach 7 or 10, because they will take place in the transition region between supersonic and hypersonic speeds, and the engine will have to transition from a ramjet to the scramjet. That program will be centered around a hydrocarbon-fuelled scramjet, which is being developed by the Air Force Research Laboratory. The project, led by NASA's Marshall Space Flight Center, is planned to start in October 2001.

Each mode of air transportation has a regime in which it operates most efficiently. Today's turbojet engines are designed to operate at relatively slow speeds, in the densest part of the atmosphere, using mechanical means to provide air compression for forward thrust and lift. At the temperature and speed limit beyond which rotating turbines become operable, ramjets, with no moving parts, can accelerate a plane to up to six times the speed of sound.

Beyond the reach of the ramjet, where air and combustion temperatures extend beyond the limits of today's heat-resistant materials, and combustion becomes inefficient, supersonic ramjets, operating at cooler temperatures, can bring a plane to the edge of space.

Up to now, scramjet engines have been tested in the United States only in wind tunnels. Because of the complexity and nonlinear character of hypersonic aerodynamics, only *in situ* tests will prove any particular design. The Hyper-X program will be the first to take the step to integrate advanced air-breathing engines with an airframe, and it will ultimately have to house and be an integral part of them.

Considering all of the theoretical and experimental work that has also been done, particularly in the former Soviet Union and in Europe, NASA's Hyper-X program would certainly benefit from an international effort.

Nearly 80 years after the first rocket plane concept, and more than 50 years since research began on revolutionary air-breathing engines, it is time to open the age of hypersonic flight.

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