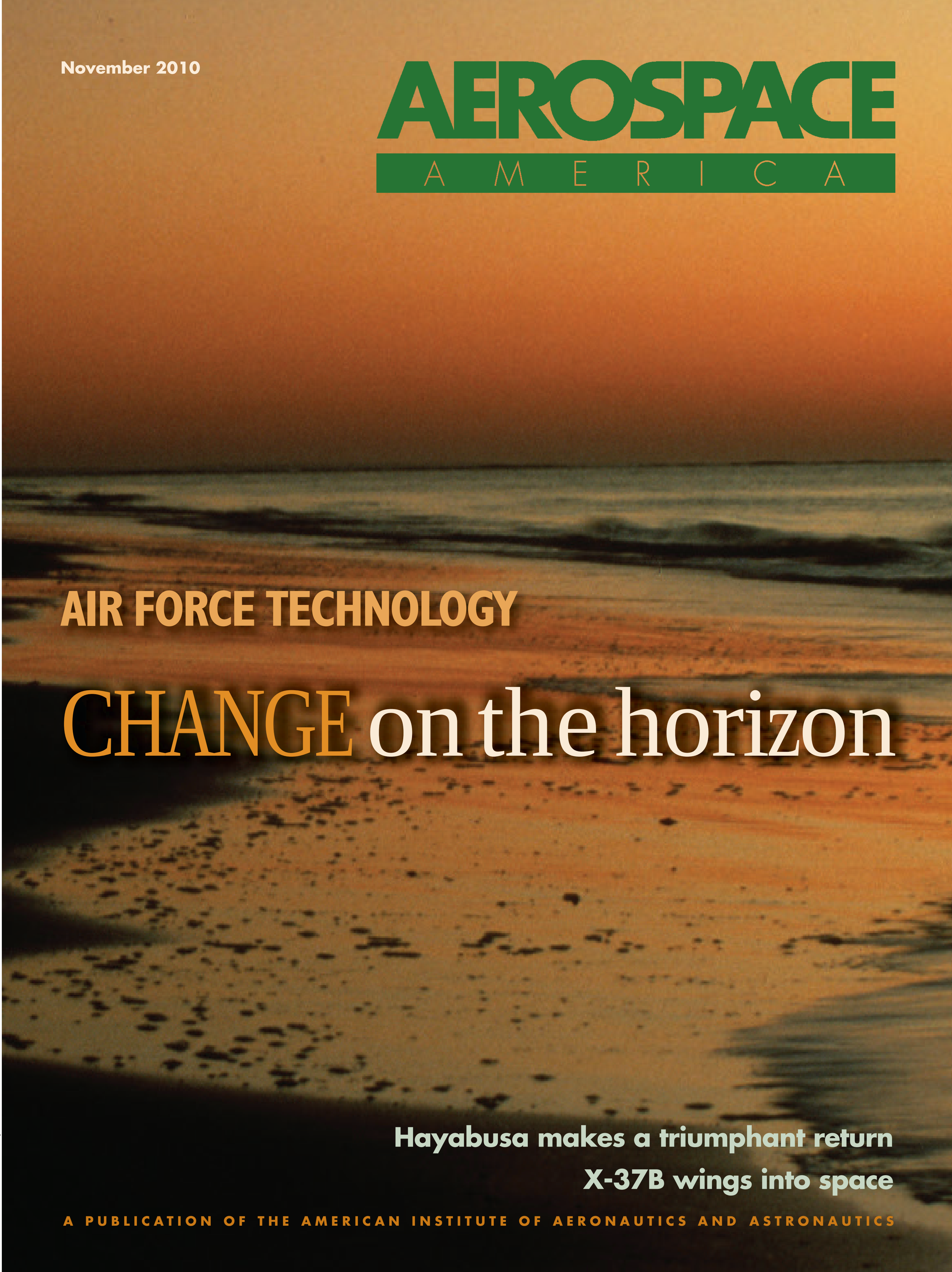
November 2010

AEROSPACE AMERICA



AIR FORCE TECHNOLOGY

CHANGE on the horizon

Hayabusa makes a triumphant return

X-37B wings into space

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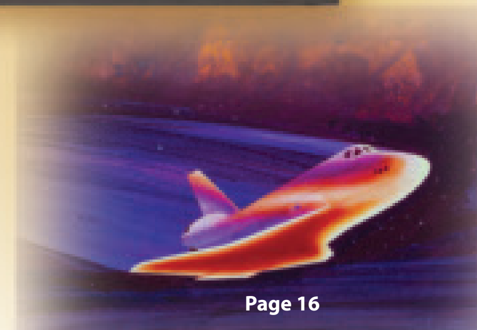
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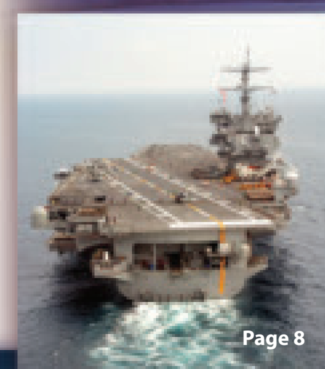
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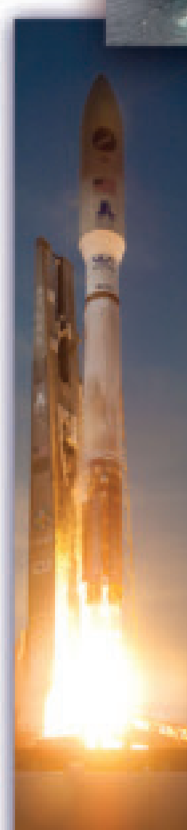
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COVER
The USAF report *Technology Horizons* describes an Air Force transformed by new technologies. For a look at what those changes may be, turn to the story on page 28. Copyright© University Corporation for Atmospheric Research. Photo by Carlye Calvin.

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When Did You Know?
"I launched an Estes Astron Scout – I saw the smoke trail go up in the air and thought it was cool. Suddenly for the first time I could see how fins were angles, nose cones were parabolas. Geometry had value now and I loved it."
David Newill
AIAA Associate Fellow

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Commentary

The greening of aviation: Another context

Much emphasis has been placed in recent years on the greening of aviation. The primary focus has been on reducing greenhouse-gas emissions, most notably carbon dioxide. But the burgeoning efforts in this direction have another "greening" effect: the saving of "greenbacks."

In July 1999, I wrote what might be viewed as an obituary for governmental support of aeronautics R&D: "In FY99, both high-speed research (HSR) and advanced subsonic technology (AST) were essentially zeroed, leaving a yawning gap in the technologies they supported. Then the DOD closed out its efforts in hypersonic research. These actions, along with the now-decimated research and technology (R&T) base, leave virtually no support for advanced U.S. aeronautics technology development."

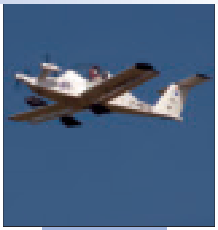
But now the new focus on environmental impacts has revitalized aeronautics R&D. NASA's Environmentally Responsible Aviation (ERA) program, aimed at technologies and designs that could be implemented during the next 25 years, is developing advanced aeronautical technologies and novel designs that go well beyond those envisioned by the old HSR and AST programs. These include new aircraft configurations such as the hybrid wing-body for Boeing-777-class aircraft, highly integrated airframe-propulsion concepts, advanced engine concepts such as a three-shaft turbofan and a turbine-electric hybrid, integrated composite structures, active aeroservoelastic controls, and especially the long-sought holy grail of drag reduction, laminar flow control (LFC). Under the ERA program LFC has finally been brought within reach in practical aircraft hardware. Combinations of these technologies are projected to produce not only marked reductions in emissions, but fuel-burn savings of up to 70%. And the ERA program's aggressive environmental goals have even spurred two designs for 100-seat supersonic airliners, circa 2030-2035.

The NextGen air traffic management system being implemented by the FAA represents another avenue—aircraft operations—for improving aviation economics, along with big environmental benefits. "Tailored arrivals" and 4D trajectory operations (three spatial dimensions plus time) can achieve huge fuel savings. Finally, the substantial replacement of petroleum-based fuels by alternative fuels derived from agricultural and municipal wastes and crops that do not impinge on food production (such as algae, camelina, salicornia, and jatropha) is finally imminent: Approval of blends using up to 50% of these fuels is expected shortly. The benefits of alternative fuels go well beyond that of fuel-burn cost reduction, by reducing U.S. dependence on foreign oil imports.

Europe too is moving aggressively in cost-reduction measures that derive from reducing environmental impact. The Smart Fixed Wing Aircraft program will fly a "smart" wing with passive and active laminar flow and load control and will demonstrate propulsion-empennage integration with open-rotor engines. Future European thrusts include liquid-crystal polymer fibers (strength/weight ratios tenfold higher than steel), the "Claire Liner," whose box wing-empennage integration and "dolphin" body shape substantially increase lift-to-drag ratios, hypersonics, and solar-powered aircraft.

Many have argued that since aviation generates only 2% of anthropometric greenhouse gas emissions worldwide, efforts to reduce that small contribution even further are not really necessary. But the ancillary benefits—both the significant cost savings that can be realized and especially the revitalization of government research in aeronautics—are very good reasons for pursuing the greening of aviation.

Jerry Grey
Editor-at-Large



New batteries, fuel cells energize electric aviation

On September 2, the four-engined all-electric Cri-Cri aerobatic flying testbed took to the skies for the first time above Paris Le Bourget Airport. The project is part of a joint effort by EADS Innovation Works, Aero Composites Saintonge, and the Green Cri-Cri Association.

For EADS, Cri-Cri is an important testbed for emerging electric propulsion technologies such as unmanned aircraft engines, auxiliary power units, and hybrid (half electric/half diesel) helicopter propulsion. These concepts are being researched as part of the company's Eco2-Avia program.

In the initial stage of the trials, the key issue will be to understand the thermal management issues of all-electric propulsion. Says Emmanuel Joubert, who heads the project, "We need to check during the entire mission the temperature of all-electrical components. For that we have developed specific software and panel instruments....For example, we can follow in real time the temperature of batteries, with the LED switch on orange when the temperature is at its limits, and red when it is critical."

Over the next few months, the team will test new battery management systems to see how they can be integrated with other electrical components in ways that keep them at optimal temperatures during all phases of flight.

At Paris Le Bourget on September 2, the Cri-Cri all-electric flying testbed took to the skies for the first time.

A different breed

What makes the Cri-Cri slightly different from other electric aircraft concepts is its performance in the air: 30 min of autonomous cruise flight at 110 km/hr, 15 min of autonomous aerobatics at speeds reaching 250 km/hr, and a climb rate of approximately 5.3 m/sec. Until now, most electrically powered aircraft have been motorized gliders, but the Cri-Cri will allow its designers to test whether an electric aircraft can perform maneuvers and operations that a conventional aircraft cannot.

The Cri-Cri's unusual design will also enable researchers to see how distributing the mass of the propulsion and energy storage units around the airframe might obviate the need for a single large, heavy engine and battery—with the attendant weight, balance, and drag issues it brings. This research has also been undertaken by Cambridge University.

"This aircraft flies very smoothly, much more quietly than a plane with conventional propulsion," notes Didier Esteyne, who piloted the all-electric Cri-Cri. "But we are still at the beginning and have a lot to learn. We are allowed to start aerobatic maneuvers only after 5 hr of flight and 15 landings."

Long evolution

Electrically powered piloted aircraft have been around for some time. On April 29, 1979, the Solar Riser, designed by Larry Mauro, made the world's first official flight in a solar-powered, fully controlled man-carrying flying machine, an ultralight hang-glider. The craft rose to 40 ft and flew for about half a mile. The impetus for much of the early design and development work on electrically driven aircraft has come from the light and experimental aircraft community in the U.S. In recent years, however, European designers have also been investing heavily in this area.

The past few years have seen a slow but steady evolution of electrically powered sport aircraft, from ultralights to powered gliders, from powered gliders to light sport aircraft (LSA)—where we are now—with another evolutionary move to Cessna 172-size aircraft expected during the next 10 years.

Further accelerating the technology boost into electrically powered aircraft is the involvement of companies such as EADS and Boeing, whose focus is on something very different from the light aircraft enthusiast market: Apart from virtually zero carbon dioxide emissions, electrically propelled aircraft have two other key benefits, with obvious military implications—very low noise levels and insignificant infrared signatures.

There are, broadly, three means of providing electric propulsion: battery power, solar power, and fuel cells, often used in combination. Boeing Research & Technology Europe in Madrid flew its first electrically powered aircraft, which had both hydrogen fuel cells and batteries, in April 2003. During the climb, the aircraft used a combination of battery and fuel-cell power but cruised on fuel-cell power alone. Flight time was generally about 30 min, with 20 min devoted to the fuel-cell demonstration. The fuel cell had approximately 10 min of margin beyond the 20 min planned for the tests, which have been completed.

Technological improvements in all three areas of fuel storage/generation are accelerating.

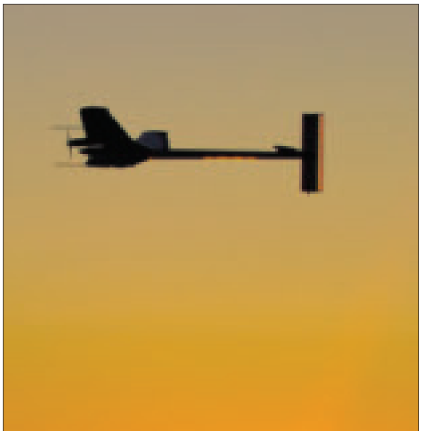
Solar flight at night

In September, the solar-powered, Switzerland-based Solar Impulse HB-SIA completed a 26-hr flight powered only by solar energy. According to the company, "The success of this first night flight by a solar-powered plane is crucial for the further course of the Solar Impulse project. Now that the HB-SIA's ability to remain flying at night using solar energy stored during the day has been proved, we can start pushing the human and technological limits further. The next important milestones for Solar Impulse will be the crossing of the Atlantic and the around-the-world flight, using the second prototype, which goes into construction this summer."

The aircraft comprises 12,000 photovoltaic cells, covering 200 m^2, with 12% total efficiency for the propulsion chain. The HB-SIA's motors generate just 8 hp, or 6 kW, of power (around the same output as that of the Wright brothers' first flyer in 1903). Generated electricity is stored in batteries weighing 400 kg, more than a quarter of the aircraft's mass. Motors and batteries are fitted in four pods under the wings. The batteries are polymer lithium units consisting of 70 accumulators, with a management system controlling the charge threshold and temperature.

A long way to go

It will, however, be a huge leap from a motorized glider to an electric four-seat aircraft that performs like a conventional Cessna or Piper.



The experimental aircraft Solar Impulse, with pilot Andre Borschberg onboard, flies at sunrise above Payerne's Swiss airbase on July 8 during the historic first round-the-clock flight fueled only by solar power. AFP photo/Fabrice Coffrini.

"Today's technology allows a realistic one hour of flying only," according to Oliver Reinhardt, technical director of advanced general aviation engine manufacturers at Flight Design, based in Stuttgart. "The bottleneck is the battery mass. Today the maximum is around 200 Wh per kilogram; we would need in theory around 5,200 Wh per kilogram."

Further issues that need to be addressed are the expense of high-density batteries, the requirement for complex controllers to ensure they remain cool, and a complex charging cycle. One solution is to develop hybrid engine versions, and the company is working on a lithium-ion battery-powered electric motor in combination with a Rotax 914 engine, with the battery and electric motor boosting the power of the Rotax engine on takeoff.

A lift for lithium-based batteries

Driven by billions of dollars' worth of funding for research into environmentally friendly automobile performance, battery efficiencies are improving every year. In particular, the development of a new generation of lithium-ion batteries, which can increase energy and power densities by a factor of two to four, will open the way to units with greatly improved performance. Lithium-based batteries are lighter than conventional units because they have no anodes and have a much higher energy density.

In Asia, work on advanced battery technologies is well under way. This contrasts with the U.S., which accounts for just 1% of the total global lithium-ion battery production, according to the U.S. National Alliance for Advanced Transportation Batteries, or NAATBatt. This recently formed group worries that U.S. industry is falling behind its global competitors in this arena.

The demand for new, advanced batteries is growing. The High Altitude Airship under development by Lockheed Martin for DARPA in the U.S. will feature a 40-kWh lithium-ion battery to store power from 15-kW thin-film solar arrays. These will generate all power required on-station and store it for use by the payload (up to 50 lb) and the 2-kW lightweight all-electric propulsion units.

Lithium-ion batteries are also at the heart of Sikorsky's electrically powered S-300C Project Firefly technology demonstrator, announced at this year's Oshkosh AirVenture. The aircraft has a 190-hp electric motor replacing the standard piston-engine and lithium-ion battery packs. The energy storage system from German manufacturer GAIA consists of 300 cells with an energy density of 0.13 kW/kg, added to either side of the cabin. Sikorsky says initially the Firefly's flight time range will be just 15 min, compared to over 3 hr for the conventional equivalent. But as battery capacities increase and weights decline, this will improve exponentially.

At current rates of progress, lithium-based battery technology is doubling in efficiency every seven years, according to some industry experts.

Fast track for fuel cells

Fuel cell storage/generation is also improving. According to researchers at Boeing, PEM (polymer electrolyte membrane) fuel cell technology could eventually power small manned and unmanned aircraft, while solid oxide fuel cells could be applied to secondary power-generating systems such as auxiliary power units

DIESEL AND ELECTRICITY ROTORCRAFT POWER

EADS Innovation Works is developing a diesel-electric hybrid proof-of-concept helicopter propulsion system. Electrical motors in combination with OPOC (opposed piston, opposed cylinder) diesel engines drive the rotors and have shown reduced fuel consumption and emission rates of up to 50%, according to the company. Takeoffs and landings are possible on electrical power alone, resulting in lower noise levels and improved flight safety.

Says EADS, "The main components of this hybrid system are multiple diesel-electric motor-generator units, a pair of high-performance batteries, and a power electronics unit controlling the energy flows for best efficiency. The OPOC diesel engines, designed and built by EcoMotors International in the U.S., offer a fuel economy improvement of up to 30% compared to today's helicopter turbine engines.

"The OPOC engine's power output shafts are fitted with advanced, weight-optimized generators delivering electrical current to a power electronics unit, which manages the distribution of the electricity to the electrical motors driving the main rotor and the tail rotor as well as the other user systems on the helicopter. High-performance batteries can store sufficient energy to enable the helicopter to take off and climb or approach and land on electrical power alone."

MAJOR CURRENT ELECTRICALLY DRIVEN PILOTED AIRCRAFT PROGRAMS

Aerola Alatus-ME
On January 10, 2009, the Aerola electrically powered Alatus-ME glider flew for the first time. The company is based in Ukraine. Its Electravia engine delivers 26 hp and is powered by a lithium-polymer battery.

APAME Electra
APAME (Association pour la Promotion des Aéronefs à Motorisation Électrique), based in St. Pierre d'Argençon, France, flew its Electra F-WMDJ on December 23, 2007. It has an electrical engine of 25 cv (capacitance voltage) and lithium-polymer batteries.

Bye Energy/Cessna
In July, Cessna Aircraft announced that it is collaborating with Bye Energy (Englewood, Colo.) to design and develop an electric propulsion system for a Cessna 172 proof-of-concept aircraft.

Flightstar e-Spyder
The e-Spyder ultralight features a Yuneec power system that is available in 10, 20, 40, and 60 kW, allowing it to fly 40 min on two lithium-polymer batteries. The company is based in South Woodstock, Conn.

ElectraFlyer-X
The ElectraFlyer-X is a two-seater based on the Electraflyer-C ultralight. The first -X will have a 20-hp (15-kW) engine and two lithium-polymer batteries. ElectraFlyer-C is a converted Monnet Moni motor glider; the company is based in Cliffside Park, N.J.

Lange Aviation Antares 20E
The Antares 20E motor glider (Zweibrücken, Germany) electric engine has been certificated by the European Aviation Safety Agency for the very light aircraft class, which covers vehicles that have a maximum mass of 750 kg and can carry two people. The engine, a 42-kW DC/DC brushless motor called EM42, is powered by lithium-ion batteries.

PC-Aero Elektra One
The single-pilot Elektra One ultralight is being built to fly for 3 hr. The company, based in Landsberg am Lech, Germany, has two- and four-seat versions in development.

Sonex Aircraft
The Sonex (Oshkosh, Wis.) e-flight program is to develop a practical and affordable aircraft based on a proof-of-concept craft positioned between the company's Xenos electrically driven motor-glider and conventionally powered sport aircraft, based on a 55-kW (74-hp) brushless motor engine powerplant.

SkySpark Alpi 300
The Italian two-seat SkySpark Alpi 300 flew with a 75-kW (101-hp) brushless electric motor powered by lithium-polymer batteries, achieving a world record of 250 kph (155 mph) for a human-carrying electric aircraft on June 2009. The team of researchers is now working on an engine powered by hydrogen fuel cells.

Yuneec E430
The E430, announced in 2009, has flown extensively. This all-battery electric two-seater uses three lithium-polymer battery packs to fly for 2 hr. It is regarded by many as the market leader for electric aircraft. Yuneec, based in Shanghai, China, is aiming to sell its E430 from mid-2011.

for large commercial airplanes.

A fuel cell is an electrochemical energy converter that mixes fuel and oxygen from air to produce electricity. When the fuel is hydrogen, the only byproducts are water and heat. In Europe, the drive for cleaner transport solutions has sparked massive investment in fuel cell research.

The Fuel Cells and Hydrogen Joint Technology initiative will see national governments, the EU, and industry partners plan for an investment of nearly €1 billion in new fuel cell concepts over six years. Although this research aims mainly at the automotive and stationary electricity storage markets, it is highly likely there will be aerospace applications. "The activities of the JU [joint undertaking] will help to reduce time to market for hydrogen and fuel cell technologies by between two and five years and will therefore have a faster impact on improving energy efficiency, security of supply, and reducing greenhouse gases and pollution," according to the JU objectives.

This year Lange Research Aircraft and the DLR (German Aerospace Center) began test flight work on aviation fuel cell performance using the Antares DLR-H2 flying testbed, which demonstrated a range of 700 km and a duration of 5 hr.

The next stage of work will be to fly a new, more capable aircraft in 2011, the Antares H3, to a range of up to 6,000 km, for an endurance of more than 50 hr, with payloads of up to 200 kg. The aircraft will use four external pods to house fuel cells and fuel. The aim is to develop an aircraft capable of both piloted and unmanned operations.

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Slowly but steadily, improvements in electric propulsion are feeding into the mainstream aerospace industry—from below, via the light sports aircraft enthusiast community, and above, via advanced, long-endurance UAS research. The speed with which these aircraft mature will depend to a large extent on improvements in fuel cell and battery technology—areas of major investment for Europe and Asia.

Philip Butterworth-Hayes
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The waiting game

When FY11 arrived on October 1, Congress had passed only one of the 13 authorization bills that establish funding for more than one-third of the government, including most executive branch agencies, for the next year. The rather surprising exception was NASA, which began the fiscal year with its funding priorities enacted into law—albeit via a compromise measure that is not without controversy.

Although lawmakers are often late fulfilling their core duty of financing government, never before have they entered a new fiscal year without approving funds for so many branches of government. To prevent government from shutting down completely, lawmakers enacted, and President Barack Obama signed, a last-minute continuing resolution that provides temporary FY11 funding through December 3 for all agencies that receive appropriations funding. The measure holds most agencies to FY10 levels of funding for most programs, and even lower levels for the remainder.

Democrats in Congress say they will enact FY11 appropriations bills, but not before the November 2 elections. Many in Washington believe that key legislation—even, it appears, for defense—may be stalled until the post-election, "lame duck" 111th Congress gives way to the 112th on January 3. The delay would require a second continuing resolution. This is viewed as especially likely if the elections bring about dramatic change in Congress, where it is possible that Republicans will wrest control of the House from the Democrats, say many Washington observers.

Inaction on Capitol Hill is having an impact on aerospace, especially in the Dept. of Defense. For the Pentagon, as with other Washington agencies including NASA, each year's budget requires two items of legislation: a policy measure called an authorization bill, followed by a spending measure called an appropriations bill.

In most years, the first half of this two-pronged effort for the DOD is resolved by late summer. This year, a defense authorization bill failed to pass the Senate because Democrats tried unsuccessfully to insert two measures that doomed the bill—language ending the "don't ask, don't tell" law, known as DADT, which prohibits gays from serving openly in the military, and the DREAM Act (Development, Relief and Education for Alien Minors) Act, providing a path to citizenship for young illegal aliens of military age. Critics saw the latter as a backhanded way of providing the Pentagon with a new pool of young people to sign up as service members; Dept. of Defense spokesman Eileen Lainez confirmed that the department supports the DREAM Act as a recruiting tool.

The vote broke down almost along party lines, with two Democrats breaking ranks to help Republicans filibuster the defense authorization bill. Emotions were high: Sen. John McCain (R-Ariz.), who opposes repealing DADT now, argued testily with a reporter over the issue. Repeal had easily passed the House of Representatives, but observers now say even that cannot happen again, assuming that the next House will have a very different composition.

The tally on the defense authorization is a defeat for the administration. Still, the White House and Defense Secretary Robert Gates are expected to get their way in the recurring debate on the C-17 Globemaster III airlifter. The administration may even prevail on the F136 alternate engine for the F-35 Lightning II Joint Strike Fighter.

Over several years, two successive administrations—with Gates as secretary of defense in both—sought to end C-17 production for U.S. forces. Even so, Congress appropriated funds for 43 of the planes that the Air Force did not request and said it did not need. Last year, pushed by the late Rep. John P. Murtha (D-Pa.), lawmakers added 10 Air Force C-17s to the budget at a cost of $2.5 billion. The service will eventually have 223 planes instead of the 180 it wanted.

Two successive administrations have sought to end C-17 production for U.S. forces.

This year, no lawmaker announced a plan to insert C-17s into defense legislation. None was included in the Senate measure that was defeated. Even Rep. Norm Dicks (D-Wash.), disparaged by critics as "the congressman from Boeing," announced he would seek no more C-17s. Dicks replaced Murtha as chairman of the House defense appropriations subcommittee.

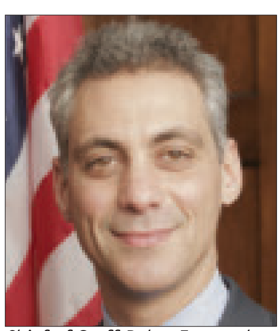
Cuts and changes

Many in Congress—across party lines—oppose efforts to cancel work on the second engine for the JSF, the F136, built by General Electric and its partner, Britain's Rolls-Royce. The administration wants a single JSF engine, the F135 from Pratt & Whitney. The House voted again this year to maintain funding for both engines in FY11. The Senate Appropriations Committee, while paradoxically calling for a cut in JSF purchases, issued this statement: "The incongruence of the [administration's] insistence on canceling the second engine program, which is a near model program and which most analysts expect would curtail long-term costs of the entire JSF program, with equal [administration] insistence on the need to fully fund the JSF program, is hard to rationalize."

Having succeeded in canceling or cutting back the F-22 Raptor fighter, the C-17, the Army's Future Combat Systems, and four Navy DDG-1000 destroyers, Gates has his eye on the F136 as part of a new program that he says will save $100 billion over five years. Gates also emphasizes that he wants to redirect, rather than reduce, some military spending. He has ordered a 30% reduction in the Pentagon's use of contractors, elimination of the Joint Forces Command in Norfolk, Va. (an issue on which congressional hearings were pending when we went to press), a reduction of 50 flag-rank officers, and a cut of 150 senior executive positions. Gates has also announced that he would like to step down next year. Those in Washington who do not support his policies are openly talking about waiting him out.

About half a dozen other key Obama advisors have left or are leaving soon. One is White House Chief of Staff Rahm Emanuel, who is running for mayor of Chicago. He was replaced by Pete Rouse, who played a major role in Obama's presidential campaign and transition. Another is retired Marine Gen. James Jones, who resigned as national security advisor. Jones had strained relations with other war leaders such as Adm. Michael Mullen and Gen. David Petraeus, commander of U.S. forces in Afghanistan. Jones' replacement is Deputy National Security Adviser Tom Donilon


Defense Secretary William Gates


Chief of Staff Rahm Emanuel

Funding legislation may be in limbo, but lawmakers' concerns about aerospace issues are still on the table, and some are still being debated. The Senate Appropriations Committee, while urging a second JSF engine, nonetheless wants to curtail the JSF program until technical and cost issues can be resolved. The committee considered scrapping all JSF funding for FY11 but recognized what it called the nation's "urgent" need for the new fighter. It recommended a purchase this year of 10 fewer JSFs than the 42 requested by the Pentagon, claiming a saving of $1.5 billion.

Some lawmakers' concerns over JSF are assuaged by a September 21 "fixed-price" agreement with prime contractor Lockheed Martin for this batch—the fourth—of the fighters. The agreement ends months of negotiations. Pentagon spokesman Bryan Whitman says the deal includes 30 JSF fighters for the U.S., one for Britain, and an option for one more for the Netherlands.

These are not the same 32 airframes covered by the Senate Appropriations Committee's funding proposal, but rather constitute "low-rate initial production" (LRIP) Lot 4, which precedes them. The planemaker had wanted to delay the fixed-cost agreement until even later, for a batch of planes called LRIP Lot 5. Whitman says the contract provides a "fair and reasonable" basis for the fourth lot of production jets and "sets the appropriate foundation for future production lots." The deal was initially expected in May, but took longer to negotiate given a shift to a "fixed-price, incentive fee" contract structure.

Previous JSF contracts were on more traditional "cost-plus" contract terms, which make the government responsible in the event of cost overruns—a method now opposed both by Pentagon acquisitions boss Ashton Carter and Defense Secretary Gates.

In another area of defense issues, the Navy says it has too many pilots. In September at the Tailhook Association convention in Reno, Nev., Capt. Bret Batchelder of the Navy Personnel Command said the sea service has 743 more naval aviators than its plans call for. At the same time, the Navy has a shortage of officers in other fields. The Air Force is currently seeing the largest proportion of its pilots remaining in uniform for a career since the 1980s and currently has about 400 more pilots than it has cockpits for them to occupy.


Lockheed Martin agreed to a fixed-price contract for the latest batch of F-35s.

In the late 1990s, the military service branches experienced a significant pilot shortage. Today, say observers, declining airline salaries are no longer a lure, airline work no longer guarantees glamour or even respect, and too many pilots are remaining in uniform.

A familiar sight in the Navy, the one-of-a-kind nuclear aircraft carrier USS Enterprise (CVN 65) will be retired when it completes its current combat tour in waters off South Asia. September 24 marked the 50th anniversary of the launch of the giant aircraft carrier. The "Big E" was the first nuclear carrier, a pioneer in a largely nuclear Navy, and a key participant in conflicts from Vietnam onward. But because it differs from every other carrier in the fleet, Enterprise is now costly to operate.

Capt. O.H. Honors, the ship's skipper, estimates that a quarter of a million sailors served aboard the warship. But, said Honors in the *Navy Times*, "The people who designed and built the equipment for this ship—they've been dead for 25 years. When this ship was commissioned, I was three months old. Think of a car that was built 49 years ago, you've been driving it the whole time, and they only built one of them, and it was a technology demonstrator. There's no store that we can go to. There's no Pep Boys for the Enterprise."

NASA spending issues

The NASA authorization bill enacted on September 29 amounted to reluctant House acquiescence to a Senate version. The policy measure does not give the Obama administration everything it sought in the realm of human spaceflight, but it does require the agency to

The USS Enterprise will be retired when it completes its current combat tour.

rely on private companies to launch astronauts into space while it starts work on a larger booster able to launch a payload of at least 70 tons for travel to more distant destinations—an asteroid, perhaps, and eventually Mars. The measure eliminates the Moon as a destination and, except for the new booster rocket, wipes away most of the ingredients of the earlier "Vision"; thus, the Ares I, for example, is rendered defunct.

The bill "helps put the U.S. space program on a more sustainable trajectory," says Lori B. Garver, NASA's deputy administrator.

NASA Administrator Maj. Gen. Charles Bolden quietly called the FY11 NASA authorization bill a "historic vote" but appeared to be maintaining a low profile in Washington—the agency's inspector general (IG) had charged him with an ethical misstep after he consulted Marathon Oil on whether NASA should participate in a biofuels project. Bolden, who sat on Marathon's board, denied wrongdoing, and many observers saw the IG overreacting to a single, short phone conversation Bolden had held with a Marathon official. Still, while he appeared at the National Press Club in September to tout privatized space travel, Bolden was less visible than Garver in commenting on funding issues.

On the other hand, Sen. Bill Nelson (D-Fla.)—who chairs the Senate Commerce, Science and Transportation Committee's subcommittee on science and space—was the driving force behind the NASA authorization bill and apparently persuaded Rep. Bart Gordon (D-Tenn.), Science Committee chairman, to go further than Gordon originally wanted toward eliminating the Bush-era Constellation program (except for its large booster rocket) in favor of commercial carriers for both astronauts and cargo.

Sen. Bill Nelson

The measure had strong support from Sen. Kay Bailey Hutchison (R-Texas), who said it will "safeguard America's human spaceflight capabilities while balancing commercial space investment with a robust mission for NASA." Even though the agency may no longer be the prime moving force in the design and development of a next-generation spacecraft, NASA will receive slightly more money in FY11 than it did in FY10—some $19 billion, a modest increase over last year's $18.7 billion, and in line with Obama's budget request.

Eventual passage of a NASA appropriations bill—needed before space agency employees can actually work on their new mission—is expected to be routine. In the meantime, however, the continuing resolution keeps NASA's spending levels—and programs, including Constellation—unchanged until passage of further legislation.

Shuttle missions

The Washington actions that set NASA's future policy came after September 20, when the agency trundled the space shuttle Discovery to Launch Pad 39A at the Kennedy Space Center for its last journey into orbit, the mission scheduled to go to the ISS on November 1. Led by Air Force Col. Steven W. Lindsey, the six-member STS-133 crew will deliver and install the permanent multipurpose module and the express logistics carrier 4, and will provide critical spare components to the ISS. This will be the 35th shuttle mission to the station. Two space-walks are part of the plan.

There will be just one more shuttle mission thereafter, unless NASA modifies a longstanding flight schedule—as it has the authority to do—and many in Washington believe it will. The schedule was already changed to arrange for the last two flights after the start of FY11, which was once intended to mark the end of the program. As now scheduled, the final mission will be STS-134, to be flown by Endeavour, also with six astronauts, and commanded by Navy Capt. Mark E. Kelly. Endeavour will deliver spare parts, including two S-band communications antennas, a high-pressure gas tank, additional parts for the robotic device Dextre, and micrometeoroid debris shields. The launch date for the 36th and final shuttle journey to the ISS is now February 26.

Discovery was delivered to the launch pad on September 20 for its final flight.

NASA has also named four astronauts who might become the final Americans to fly a shuttle, if one additional, last mission is assigned to Atlantis. The NASA authorization calls for one more flight to take supplies to the ISS in the second half of 2011.

If it happens, the not-yet-scheduled mission will probably be christened STS-135, the number reflecting a final total of 135 shuttle journeys into space. Whether this "final, final" flight will happen is as uncertain as the rest of NASA's future, but the agency is planning for it. "Normal training template for a shuttle crew is about one year prior to launch, so we need to begin training now in order to maintain the flexibility of flying a rescue mission if needed, or alter course and fly an additional shuttle mission if that decision is made," said Bill Gerstenmaier, NASA associate administrator for space operations, in a statement.

A U.S. astronaut and two Russian cosmonauts returned from the ISS on September 25. After an initial technical glitch, American Tracy Caldwell-Dyson and Russians Mikhail Kornienko and Alexander Skvortsov, who had lived aboard the ISS for six months, landed safely in Kazakhstan in a Russian Soyuz capsule.

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Mark Clough

Interview by Philip Butterworth-Hayes

Why does it take so long for World Trade Organization (WTO) trade dispute decisions to come through?

That's the result of panel members who need the time to peruse these matters. Often the parties will ask for more time to submit their briefs and request the opportunity to submit further briefs. This will delay the process.

If you take a summary of the outcome of the two cases concerning Boeing and Airbus at the WTO, who won and who lost?

I don't think either of them has actually won it. Airbus says it can rectify the situation by simply changing the language of the contract on launch aid, but there are other situations of financing agreements relating to the Airbus A380 that are subject to scrutiny. Boeing has always had a significant mixture of civil and military business, which makes it very difficult. Boeing is supposed to have enjoyed $22 billion of tax breaks from defense and research contracts, and those have never been repaid at all—Airbus has repaid [its launch aid]. I would have thought it was one black mark against both of them.

It is stalemate. Though of course there is still the appeals process to go through, and it is interesting to note that there is no implementation timetable for the recommendations.

Given the outcome, then, does this case really matter? Is this important?

I think it's important in that it appears that the U.S. has decided it does not want to go on any longer with the bilateral arrangement, so in a sense it is testing the WTO rules on what the legalities really are on the subsidies issue between Boeing and Airbus. It is also testing the strength of the U.S. and the EU on whether they really will remarry, and whether this process of having a free-for-all actually allows them to get something out of the system. Or should they go back and say, "We agree to limit our subsidies in a respectable way," which will mean developing a further bilateral agreement. This is especially important now as there are a lot more competitive pressures in the market, new players who will start outmaneuvering them if they are not careful.

Going back to the question of why this process has taken so long, I imagine that both sides, the governments of the EU and the U.S., have told the panelists that they would like to try to settle this issue through the WTO disputes process—though obviously this hasn't happened.

So what are the implications, if any, of the WTO dispute rulings for the worldwide aerospace industry—and for other industries, for that matter? Or is this simply a Boeing vs. Airbus dispute?

I think it does have further implications in that it shows what the panel's interpretation of the subsidies agreement is in the context of aircraft manufacturing. It has set a precedent. If somebody else tries to do the same thing, there will now be an easier and faster way to reach a settlement—because agreements on subsidies and countervailing measures have been reached for this market. It's obviously not terribly tidy, but in areas where subsidies have been condemned, there is a precedent, at least for negotiations between newcomers to these issues—for the new countries who are subsidizing their industries.

Mark Clough QC (Queen's Counsel) is a partner in the competition and trade practice of U.K.-based international lawyers Addleshaw Goddard. He leads the European Union and international trade law practice covering antidumping, subsidies and countervailing duties, safeguards, and World Trade Organization dispute resolution. In addition, he specializes in customs advice and litigation as well as export controls.

He represents clients before national trade administrations, the European Commission in Brussels, the WTO in Geneva, and the European Courts in Luxembourg. His work involves countries ranging from the U.S. to China, and Azerbaijan to Ukraine. Recent antidumping cases concerned ethanol-amines, shoes, and chemicals, as well as WTO dispute procedures and issues relating to WTO accession.

Clough has also advised on the Energy Charter Treaty in the context of energy projects. In his capacity as legal advisor to the EU Ukraine Business Council, he recently made representations at the public hearing of the European Commission on its Green Paper on EU trade defense instruments.

A member of the editorial board of the International Trade Law and Regulation Journal, *Clough has written many articles on EU and WTO issues and has published a book on the WTO and telecoms,* Trade and Telecommunications. *He has participated in numerous international trade conferences and governmental training events in different countries, and belongs to the International Chamber of Commerce and the International Bar Association's international trade committees.*

Most industry experts seem to believe that no one in China, Brazil, or Russia will be particularly concerned about the results of this dispute. Most aerospace manufacturers outside North America and Europe see this as just an Airbus and Boeing issue. But if a newcomer, building an aircraft industry financed mainly through its own government, attempts to flood the market with cheap airliners, will these findings have some relevance?

I quite understand why people say it's just a bilateral tiff, because that's exactly what it is. But once you have gone to the WTO for a panel ruling—and indeed an appellate body ruling—that adds to the body of law at the WTO level. It's not a binding precedent, but it is very helpful for those who want to criticize or defend a position.

Aerospace is a global industry, with aircraft manufacturers contracting out large parts of production work to other countries, where government-owned industries undertake all the work. Are these contracts covered by the WTO trade rules or not? It seems to me it is possible for manufacturers to circumnavigate the rules by getting governments in other parts of the world to subsidize the cost of building new aircraft. Isn't one of the key challenges the fact that the industry is just so complex and international trading laws so difficult to understand? In the context of outsourcing, what constitutes fair and unfair subsidies when the work is carried out by a third country?

It's obviously quite difficult, in this context, to deal with a state-owned business. A government that delegates the work to a private enterprise that gives it subsidies is subject to the [WTO] subsidies agreement. If it's a genuinely government-owned aircraft manufacturer employing people to do the work, that's one thing. But if they don't employ people but effectively just pay a private body to do the work, then I would have thought that was subject to international agreement. In China I suspect they tend to do the latter rather than the former.

"Maybe that is the motive for these lengthy exchanges, to have a multilateral agreement that will bring in the other relevant countries. It would be nice to think that."

Isn't the best solution for the U.S. and Europe to create a new civil aircraft manufacturing agreement alongside the WTO? That should surely be the next step.

One solution would be to do that and then try to make it a multinational agreement, to get everyone to sign up to it. The two sides could fall back on a plurilateral agreement—such as the already famous agreement on trade in civil aircraft—for those who might want to sign up to it. Maybe that is the motive for these lengthy exchanges, to have a multilateral agreement that will bring in the other relevant countries. It would be nice to think that.

What it a plurilateral agreement?

A multilateral agreement is one which all members of the WTO have to sign up to; a plurilateral agreement is where all those governments who *want* to sign it do so.

What's the latest on the Doha round [the current series of trade negotiations aimed at lowering trade barriers around the world]? Is there any sign of progress?

Doha is very difficult at the moment in that keeping negotiations going at all is an achievement in itself. The Indians for a long time blocked Doha—though there are recent signs of a change of mind. Of course one would have thought that the last few years of bilateral trade agreements which the large countries have embarked upon would have persuaded the developing countries that it would be in their interest to move ahead on the Doha round, no matter how little they may get from it, rather than trying to undo what they see as the disadvantages of the previous arrangements.

I don't understand why there isn't more progress. But of course the current economic climate is not exactly useful, with the prospect of politicians in the larger countries having to tell their domestic electorate that they are going to be giving away trade concessions.

When it comes to the question of subsidies, developing countries are not subject to the same subsidy rulings as the larger trading nations. There's a let-out for them.

Does that mean it's easier, for example, under present international WTO trade rules, for India to obtain a government subsidy in an international competitive industry than someone in the U.S., Canada, or the U.K.?

India is a developing country, but it is the "least-developed countries" which benefit from "special and differential treatment," primarily.

How would you define a developing country in this case?

These are states which are listed as developing countries within the WTO membership. India is listed, as are Brazil and China—though that sounds quite bizarre.

"When it comes to the question of subsidies, developing countries are not subject to the same subsidy rulings as the larger trading nations."

As part of the issue of developing countries receiving "special and differential treatment" within the WTO, the prohibition of subsidies for exports is qualified for developing countries under annex seven. This covers the least developed countries as designated by the United Nations.

This means there is some recognition that subsidies can play a part in important economic development for general issues and not just aircraft manufacturing.

Although the WTO ruling has a significance for Airbus and Boeing, what does it mean for smaller, medium enterprise [SME] manufacturers in the West—is this important for them too?

The only way it would be significant is if they were receiving aid in a direct way, which would then be stopped if either the EU or the U.S. decided they were going to comply with the WTO rulings by stopping subsidies as they had agreed. The main remedy is to stop the subsidy. I suppose smaller companies could suffer if either party agreed to withdraw the subsidies that had previously been agreed with each particular SME.

So would European companies, for example, have to repay the subsidy—or would it simply be stopped?

I don't know whether they would necessarily have to repay the money, because the subsidies agreement is different to the EU law on state aid, which would require a government to recover unlawfully paid aid. The WTO arrangement doesn't seem to require that; it seems to require that the subsidy be stopped. There are other questions as to whether the harmed member of the WTO would require compensation—I don't think that compensation necessarily has to come from the beneficiaries of the subsidy.

Do you know whether anyone has, or could request, compensation?

It often does arise—but there again, there would be another tit for tat.

In considering whether aid is fairly or unfairly distributed by governments, how are governments exactly defined? For example, if a regional or state authority agrees to subsidize the manufacture of an aircraft production plant, would that grant be covered by a WTO agreement? How far down does the remit of the WTO go?

I think if the aid were given by a governmental body and it had an impact on exports, it would normally be covered by the agreement. The designation of a subsidy can be defined as a financial contribution by a government or any public body in the territory of the member referred to in the agreement.

Spool forward five years, at a time when the Airbus A320 and the Boeing 737 replacement programs are just about to be getting under way. Do you think, by then, there will be clear rules and a clear understanding about what is allowable? Or do you think these arguments will just carry on forever?

I think there are three considerations here. The first concerns how well respected the WTO will be and how well its rules will be applied. I would like to think they will be respected, because it is in everyone's interest if they are. After all, with the arrival of China and India on the aircraft manufacturing market, the U.S. and Europe will want to have something in place.

Second, there is the question of how these newcomers are going to get their share of the overall market. One view, though a very cynical one, is that this is all about sharing out the market and making sure that you keep your share. I think it would be too much for either Airbus or Boeing to expect to block the other one out of the market.

The third issue is, should the U.S. and the EU keep using the WTO trades dispute procedures, since these are now under way, as a means to bolster their market positions? At some stage they will have to share some of their market with some of the newcomers.

It's true that Boeing and Airbus are going to have to share the market with new competitors, but the issue is surely one of fairness. After all, China has a huge domestic market on which it can base demand for its new aircraft manufacturing sector. It would be very difficult for Airbus or Boeing to prove that Chinese airlines have been made to buy Chinese aircraft even though they would prefer U.S. or European models.

I agree—it would be very difficult. On a positive note, if the market overall improves, there may be enough room for new Chinese aircraft without diminishing the sales volume of Boeing or Airbus. That I would have thought was the best outcome—and a fairly realistic one. One result of the Chinese economic revolution is that there is going to be a more prosperous society.

And they will be using the U.S. dollar to buy and sell aircraft.

Yes—I don't see why the United States should miss out. They are, after all, highly competitive.

Finally, are you optimistic that the U.S. and the EU have now agreed what fair play, a level playing field, actually looks like in the market for large aircraft manufacturing?

I think both the U.S. and Europe should recognize that a single level playing field is in their interest, especially because of the way the market is expanding now. If they don't effectively plan to have other players in their market, they will not ultimately succeed, because they won't be the cheapest—which is always a deciding factor in purchasing policies.

"I think both the U.S. and Europe should recognize that a single level playing field is in their interest, especially because of the way the market is expanding now."

Futuristic aircraft: Old-fashioned look is only skin deep

An 18-month NASA research effort to visualize the passenger airplanes of the future has produced some ideas that at first glance may appear old fashioned. Instead of exotic new designs seemingly borrowed from science fiction, familiar shapes dominate the pages of advanced concept studies that four industry teams completed for NASA's Fundamental Aeronautics Program in April.

But look more closely at these concepts for airplanes that may enter service 20-25 years from now and you will see features that are quite different from those of today's aircraft. Just beneath the skin of these ideas lie breakthrough airframe and propulsion technologies designed to enable significantly quieter, cleaner, more fuel-efficient flight that offers greater passenger comfort and access to more of America's airports.

You may see ultramodern shape memory alloys, ceramic or fiber composites, carbon-nanotube or fiber-optic cabling, self-healing skin, hybrid electric engines, folding wings, double fuselages, and virtual reality windows.

"Standing next to the airplane, you may not be able to tell the difference, but the improvements will be revolutionary," says Richard Wahls, project scientist for the Fundamental Aeronautics Program's Subsonic Fixed Wing project at NASA in Hampton, Va. "Technological beauty is more than skin deep."

Goals for 2030 and beyond

In October 2008, NASA asked industry and academia to imagine what the future might bring and develop advanced concepts for aircraft that can satisfy anticipated commercial air transportation needs while meeting specific energy efficiency, environmental, and operational goals in 2030 and beyond. The studies were intended to identify key technology development needs to enable the envisioned advanced airframes and propulsion systems.

NASA's goals for 2030-era aircraft, compared with aircraft entering service today, are:

- A 71-dB reduction below current FAA noise standards, which aim to contain objectionable noise within airport boundaries.
- More than a 75% reduction on the International Civil Aviation Organization's CAEP 6 (Committee on Aviation Environmental Protection Sixth Meeting) standard for nitrogen oxide emissions, which aims to improve air quality around airports.
- A greater than 70% reduction in fuel burn performance, a reduction that could lower greenhouse gas emissions and the cost of air travel.
- The ability to exploit metroplex concepts that enable optimal use of runways at multiple airports within metropolitan areas, as a means of reducing air traffic congestion and delays.

Leading the teams were General Electric, MIT, Northrop Grumman, and Boeing.

The **GE Aviation** team conceptualizes a 20-passenger aircraft that could reduce congestion at major metropolitan hubs by using community airports for point-to-point travel. The aircraft has an oval-shaped fuselage that seats four across in full-sized seats. Other features include an aircraft shape that smoothes the flow of air over all surfaces, and electricity-generating fuel cells to power advanced electrical systems. The aircraft's advanced turboprop engines sport low-noise propellers and further mitigate noise by providing thrust sufficient for short takeoffs and quick climbs.

With its 180-passenger "double bubble" configuration, the **MIT** team strays farthest from the familiar, fusing two aircraft bodies together lengthwise and mounting three turbofan jet engines on the tail. Important components of the D8 concept are the use of composite materials for lower weight and turbofan engines with an ultra-high-bypass ratio (meaning airflow through the engine core is even smaller, and airflow through the duct surrounding the core is substantially larger, than in a conventional engine) for more efficient thrust.

In a reversal of current design trends, the MIT concept increases the bypass ratio by minimizing expansion of the overall diameter of the engine and shrinking the diameter of the jet exhaust instead. The team said it designed the D8 to do the same work as a Boeing 737-800, but its unusual shape gives it a roomier coach cabin.

The **Northrop Grumman** team foresees the greatest need for a smaller 120-passenger aircraft that is tailored for shorter runways to help expand capacity and reduce delays. The team describes its Silent Efficient Low Emissions Commercial Transport, or SELECT, concept as "revolutionary in its performance, if not in its appearance." Ceramic composites, nanotechnology, and shape memory alloys figure prominently in the airframe and ultra-high-bypass-ratio propulsion system construction. The aircraft delivers on environmental and operational goals in large part by using smaller airports, with runways as short as 5,000 ft, for a wider geographic distribution of air traffic.

Boeing's Subsonic Ultra Green Aircraft Research, or SUGAR, team examined five concepts. Its preferred choice, the SUGAR Volt, is a twin-engine aircraft with hybrid propulsion technology, a tube-shaped body, and a truss-braced wing mounted to the top. Compared to the typical wing used today, the SUGAR Volt wing is longer from tip to tip and shorter from leading edge to trailing edge, with less sweep. It also may include hinges to fold the wings while planes are parked close together at airport gates.

Projected advances in battery technology enable a unique hybrid turboelectric propulsion system. The engines could use both fuel (to burn in the engine's core) and electricity (to turn the turbofan when the core is powered down).

NASA did not specify future commercial air transportation needs as domestic or global. All four teams focused on aircraft sized for travel within a single continent, because their business cases showed that small and medium-sized planes will continue to account for the largest percentage of the overall fleet in the future. One team, however, did present a large hybrid wing concept for intercontinental transport.

Recurring themes

All of the teams provided "clear paths" for future technology R&D, says Ruben Del Rosario, principal investigator for the Subsonic Fixed Wing Project at NASA Glenn in Cleveland, Ohio. "Their reports will make a difference in planning our research portfolio. We will identify the common themes in these studies and use them to build a more effective strategy for the future," he says.

Common themes from the four reports included:

•Slower cruising, at about Mach 0.7—which is 5-10% slower than today's aircraft—at higher altitudes, to save fuel.

•Engines that require less power on takeoff, for quieter flight.

•Shorter runways—about 5,000 ft long, on average—to increase operating capacity and efficiency.

•Smaller aircraft—in the medium-size class of a Boeing 737, with cabin accommodations for no more than 180 passengers—flying shorter and more direct routes, for cost efficiency.

•Reliance on promised advances in air traffic management, such as the use of automated decision-making tools, for merging and spacing en route and during departure climbs and arrival descents.

The teams recommended a variety of improvements that can help bring their ideas into reality, in areas including lightweight composite structures, heat- and stress-tolerant engine materials, and aerodynamic modeling. NASA is weighing the recommendations against its objective of developing aeronautics technologies that can be applied to a broad range of aircraft and operating scenarios for the greatest public benefit.

"This input from our customers has provided us with well-thought-out scenarios for our vision of the future, and it will help us place our research investment decisions squarely in the mainstream," says Jaiwon Shin, associate administrator for aeronautics research at NASA Headquarters.

"Identifying those necessary technologies will help us establish a research roadmap to follow in bringing these innovations to life during the coming years," Shin says.

Next steps

The next step in NASA's effort to design the aircraft of 2030 is a second phase of studies. These will seek to begin developing the new technologies that will be necessary to meet the national goals related to an improved air transportation system with increased energy efficiency and reduced environmental impact. The agency received proposals from the four teams in late April and expects to award one or two research contracts for work starting in 2011.

NASA managers also will reassess the goals for 2030 aircraft to determine whether some of the crucial technologies will need additional time to move from laboratory and field testing into operational use. With their concepts the four teams managed to meet either the fuel burn or the noise goal, not both.

A companion research effort looked at ideas for a new generation of supersonic transport aircraft capable of meeting NASA's noise, emissions, and fuel efficiency goals for 2030. NASA envisions a broader market for supersonic travel, with aircraft carrying more passengers to improve economic viability while meeting increasingly stringent environmental requirements.

Teams led by Boeing and Lockheed Martin evaluated market conditions, design goals and constraints, conventional and unconventional configurations, and enabling technologies to create proposed road maps for R&D activities. Both teams produced concepts for aircraft that can carry 100 passengers up to 5,000 mi. at cruise speeds greater than Mach 1.6.

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COMBINING SAFETY and

Human spaceflight is a risky business. Spacecraft undergo very large acceleration forces during launch; travel through the atmosphere at great speeds; and, in the harsh environment of space, either connect with the international space station, remain in low Earth orbit trying to avoid orbital debris and meteors, or continue farther into outer space. Then, after what could be weeks or months, crew and passengers return to Earth, again traveling at very high speeds and under very high deceleration loads.

As difficult as this process is, it has been completed many times, thanks to the efforts of the NASA/industry human spaceflight community. One spacecraft, the space shuttle, has been launched 133 times since 1981. Unfortunately, two shuttles and their crews have been lost, Challenger during launch in 1986 and Columbia during reentry in 2003. These tragedies have resulted in a 'loss of vehicle and crew' rate of 1.5 per 100 launches, which is approximately the same as the combat loss rate of the B-17 bomber in WW II. This very high loss rate must be reduced if human spaceflight is to grow.

THE MILITARY AIRCRAFT MODEL

One way to lower the loss rate of spacecraft is to adopt some of the design processes and technology used to increase the survivability of military aircraft in combat. An aircraft takes off toward the target, which may be defended by one or more weapons or threats. As it approaches, it may be detected by enemy air defense sensors, tracked, engaged, and hit and possibly killed by ballistic projectiles, warhead fragments, or high explosive blasts. A large number of U.S. military aircraft have been downed, lost, or killed in this man-made hostile environment since the early 20th century. For example, approximately 5,000 U.S. fixed- and rotary-wing aircraft were killed in combat during the Southeast Asia (SEA) conflict from 1964 to 1973, with an overall loss rate of approximately one per 1,000 sorties. That's a lot of aircraft.

As a result of those losses, a new aircraft

As we move to the next generation of manned spacecraft, new initiatives would benefit from combining the survivability concepts of military aircraft design with the safety discipline of the spaceflight community.

SURVIVABILITY *for future spacefaring*

design discipline called aircraft combat survivability (ACS) was developed, starting in the early 1970s. Fundamentals have been established for this discipline, including a viable, cost-effective technology for enhancing survivability and a methodology for assessing it. Live-fire testing for survivability is congressionally mandated, top-level survivability design guidance is prescribed, and quantified survivability requirements are now routinely specified by the Dept. of Defense.

The goal is the early identification and successful incorporation of those specific survivability enhancement features that increase the combat cost-effectiveness of the aircraft as a weapon system. In situations where the damage would lead to an aircraft kill, those survivability enhancement features should enable a gradual degradation of system capabilities, giving the crew a chance to eject over friendly territory.

As a consequence of this emphasis on increasing survivability, the number of U.S. military aircraft killed in combat since the SEA conflict has dropped dramatically, and loss rates have been significantly lowered.

Although manned spacecraft are not currently threatened by weapons in space, this

Flak damage completely destroyed the nose section of this Boeing B-17G, a 398th Bomb Group aircraft flown by 1Lt. Lawrence M. Delancey over Cologne, Germany. USAF photo.

Robert E. Ball is a distinguished professor emeritus in the Department of Mechanical and Aerospace Engineering, Naval Postgraduate School, Monterey, California. He is the author of the AIAA Education Series textbook The Fundamentals of Aircraft Combat Survivability Analysis and Design, *First (1985) and Second (2003) Editions. He started the first-ever graduate-level course in Aircraft Combat Survivability at NPS in 1978, and 19 of the 33 astronauts who graduated from NPS have taken one of his courses. He currently is working with the NPS Center for Survivability and Lethality on several survivability projects, including the merging of the safety and survivability disciplines for spacecraft.*

During Operation Iraqi Freedom, A-10 maintenance members from the 392 Air Expeditionary Wing inspect their aircraft for any additional damage after it was hit by an Iraqi missile in the right engine. The A-10 made it back to the base safely. USAF photo/Staff Sgt. Shane A. Cuomo.

relatively new discipline could contribute to the needed improvement in the naturally hostile space environment.

AIRCRAFT SURVIVABILITY VS. SPACECRAFT SAFETY

Aircraft combat survivability is applicable to flight in a man-made hostile environment, but survivability can be more broadly applicable to flying in any hostile environment, including severe turbulence, lightning, birds, or crashes. Aircraft survive either by avoiding being hit by a damage mechanism—known as susceptibility reduction—or by withstanding any hit that does occur—vulnerability reduction. Stealth and electronic countermeasures reduce susceptibility because they make it less likely an aircraft will be hit; fuel system fire and explosion protection and redundant and separated flight control components reduce vulnerability because they make it less likely the aircraft will be killed given a hit.

The spaceflight community has a similar discipline devoted to safe travel. It is part of a package of disciplines known as safety, reliability, and mission assurance, or just safety

During STS-115, micrometeoroid orbital debris struck the shuttle Atlantis and left a 0.108-in. ding in its right-hand payload bay door radiator. Credit: NASA.

and mission assurance. One of the major activities within NASA's Office of Safety and Mission Assurance is "improving methodologies for risk identification and assessment, and providing recommendations for risk mitigation and acceptance."

Risks are associated with hazards or conditions that can cause injury to a spacecraft's occupants or damage to the vehicle. For example, a piece of foam insulation could break away from the surface of a spacecraft and impact a critical portion of the craft's thermally protected exterior, a phenomenon known in combat survivability as cascading damage. The impact damage could cause a loss of the spacecraft upon reentry. If the hazard occurs, and people are injured or killed and the vehicle damaged or lost, as happened to Columbia, the result is known as a mishap.

Any potential hazard can pose a threat to the safety or mission capability of a spacecraft. In any safety program, risks or hazards are identified and then assessed, first by determining the severity of the subsequent mishap, possibly using a failure mode and effects analysis (FMEA), and then by estimating the probability the mishap will occur.

Risks, hazards, or mishaps deemed unacceptable because of their combination of severity and probability of occurrence must be avoided, mitigated, or, as a last resort, accepted if no satisfactory avoidance or mitigation technique can be found. Avoidance and mitigation techniques include eliminating the hazards through design selection, incorporating safety devices, providing warning systems, and developing procedures and training.

Comparing the two disciplines, safety is achieved by avoiding hazards, survivability by avoiding hits and thus reducing the likelihood a hazard or hit will occur. Safety is also achieved by mitigating hazards, survivability by withstanding hits, reducing the severity of the subsequent mishap or damage.

One difference between the two disciplines is the operational environment. The threats to the survival of a military aircraft are external and man-made. The current threats to the safety of a spacecraft are not man-made (except for orbital debris) and are both external (micrometeorites, orbital debris, radiation) and internal (such as mechanical or electrical breakdown).

When considering external threats, the survivability fundamentals can be applied to spacecraft as well as aircraft: Avoid being hit by the damage mechanisms, if possible, and withstand any hits that do occur. (One could consider the external threat to spacecraft as a threat to its survival rather than a safety issue.)

When considering internal threats, the safety discipline relies on the traditional approach of hazard avoidance and mitigation. The survivability discipline, although developed for external threats, can also be used for internal threats if the definition of a hostile environment is expanded to include them. A leak, a fire, or a burst pressure vessel on board a spacecraft creates an internal hostile environment that must be withstood if the spacecraft is to survive. (Again, one could consider the internal threats as threats to the survival of the spacecraft rather than a safety issue.)

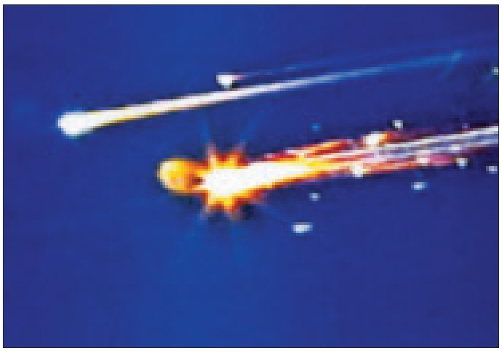
The difference in the nature of the threats to survival in combat and to safety in spaceflight influences how they are dealt with by the two disciplines. For example, the primary emphasis in system safety is the avoidance of hazards, particularly by preventing component failures through improvements in reliability. Similarly, the primary emphasis in survivability is to reduce the likelihood a hit occurs. Preventing a hit on a component is conceptually the same as preventing its failure—the component continues to function as needed.

The difference between the two disciplines shows up in safety's mitigation of hazards versus survivability's withstanding hits. In safety, if a pump fails, an adjacent back-up pump can be used. The severity of the mishap associated with the hazard occurrence is mitigated by the use of redundant pumps, and the resultant two-pump design is failure tolerant.

This is not the situation in survivability. When an aircraft is hit, damage can cascade. This cascading damage must be withstood if the aircraft is to survive. If a pump is hit and killed, an adjacent back-up pump could also be killed by the same hit or by cascading damage from the hit pump, and the functions provided by both are lost. Survivability requires redundancy with separation. As a consequence of this difference between safety's component failures and survivability's component damage, the combat survivability discipline conducts a damage mode and effects analysis (DMEA) after the FMEA when identifying the consequences of a hit.

The DMEA can also be used to analyze the survivability of a spacecraft design. In this situation, although the components are not hit by a damage mechanism, more energetic component failures are assumed, such as a liquid oxygen tank that bursts. This particular damage mode occurred on Apollo 13 when one of the two O_2 tanks in the service module burst. Cascading damage caused a loss of the adjacent O_2 tank and a subsequent loss of electrical power and air in the command module. In a more survivable design, the two tanks would have been separated so that a rupture of one tank would not cause the loss of both.

In short, the safety discipline focuses on hazard elimination and mitigation, whereas the survivability discipline focuses on avoiding hits and withstanding the subsequent damage when hits do occur. Safety is an a priori condition where hazards are avoided or mitigated during design; survival is a beneficial outcome of an undesired event. When safety fails, survivability is there to save the vehicle.



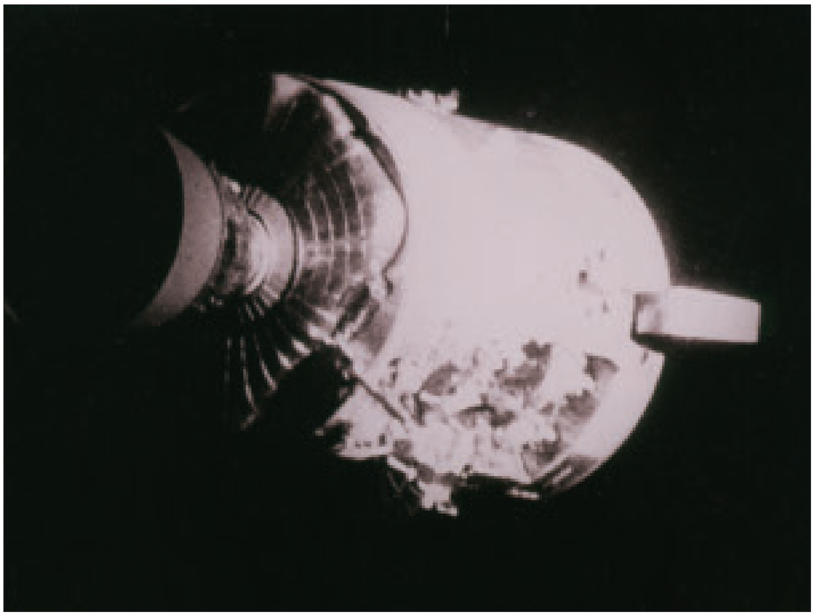
The loss of the shuttle Columbia and its crew of seven was a stark reminder that human spaceflight, though now viewed as routine, is still a high-risk undertaking.

Among the larger pieces of debris recovered from the crash of Columbia was its nose gear, shown here with its tires still intact.

COMBINING SAFETY AND SURVIVABILITY

Because the fundamentals of the aircraft combat survivability discipline have direct applicability to the design of spacecraft, a merger or combination of both could be beneficial for future human spaceflight. The merger could

"When safety fails, survivability is there to save the vehicle."



An entire panel of the Apollo 13 service module was blown away by the apparent explosion of oxygen tank number two, located in sector 4 of the SM. Two of the three fuel cells are visible just forward of the heavily damaged area.

take the form of a combined discipline known as safety and survivability, or a separate discipline could be developed known as spacecraft survivability.

If a combined discipline is chosen, NASA Procedural Requirements 8705.2B, Human-Rating Requirements for Space Systems, should be expanded to include the fundamentals of survivability enhancement developed for military aircraft. (“The human factor,” page 3, and “Human rating for future spaceflight, A Roundtable Discussion,” page 26, July-August, examine the ramifications of rating systems for human spaceflight.) If a separate spacecraft survivability discipline is chosen, a new process and requirements document should be developed.

This proposed combination has already begun for internal threats to the Orion crew exploration vehicle, originally part of NASA’s Constellation program. Michael Saemisch, former safety and mission assurance manager for Project Orion on the Lockheed Martin contract, and Meghan Buchanan, lead engineer for the company’s spacecraft survivability innovation for Orion, in collaboration with the Naval Postgraduate School Center for Survivability and Lethality, are developing a spacecraft survivability program based upon the fundamentals of the ACS discipline. Several design changes to Orion were made using this new approach. In June, the NASA/Lockheed Martin Orion team completed the Phase 1 Safety Review, making Orion the only spacecraft in development that meets all of NASA’s human-rating criteria for missions beyond low Earth orbit.

Now is an opportune time to formalize the merger. NASA’s Commercial Crew Development Program is currently working on a standardized integrated safety and design analysis process for the NASA commercial crew initiative that will be used for risk assessment during design, development, and demonstration of vehicles for human spaceflight. This work will focus on the integrated analysis process instead of prescriptive failure tolerance requirements to generate a safety-optimized solution. The DMEA and other design and analysis processes developed for enhancing the survivability of military aircraft should be incorporated into this new analysis, to ensure safer and more survivable spacecraft.

A production assembly crew lowers a full-scale Orion mockup onto the crew module holding structure during an assembly pathfinding maneuver at the Operations & Checkout Facility at NASA Kennedy.

RECOMMENDATIONS

As the shuttle era draws to an end, new commercial initiatives are under way for human spaceflight. They can all benefit from the following recommendations, drawn from experience during the development of the aircraft combat survivability discipline:

•Safety and survivability should be merged or combined to form a new discipline for space systems, leading to improvements in both the safety and the survivability of human spaceflight in all environments. They should be essential elements, just as they are in military aircraft. This does not mean there will be no more losses—as long as there are flights, there will be losses. It does mean that any mishap will not be the result of a lack of foresight, insight, or oversight.

•Safety and survivability should be considered from the inception of any program, whether for military aircraft or a human-rated space vehicle. Any changes that have to be made well into the program because of postponed or neglected safety and survivability concerns will most likely be very costly in weight and dollars and may result in cancellation of the program, or even loss of life.

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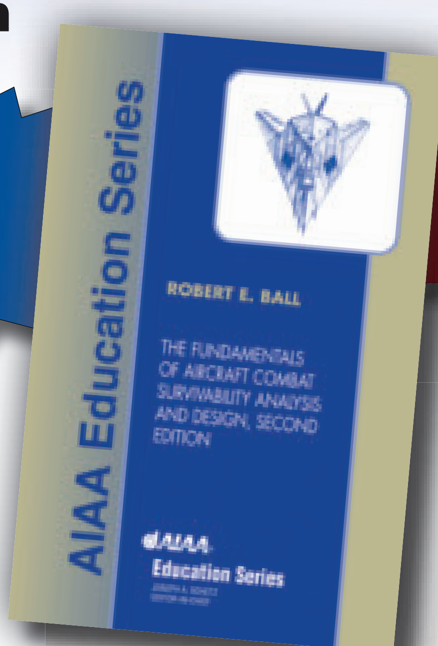

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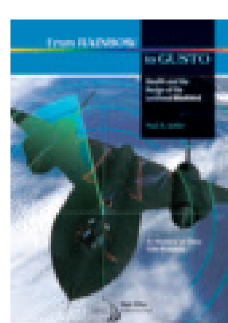

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Hayabusa makes a triumphant return

On its mission to an asteroid, Japan's Hayabusa spacecraft was plagued with malfunctions and delays. But the creativity and persistence of the program's science team brought the crippled vehicle back to a flawless reentry, including the successful delivery of a payload that may yet hold major surprises.

On June 13, the Japan Aerospace Exploration Agency's (JAXA) Hayabusa spacecraft completed its 6-billion-km round-trip mission to an asteroid. In many ways, its journey could be viewed as a robotic equivalent of Apollo 13: In both cases, ground control teams and onboard intelligence triumphed over seemingly insurmountable odds, overcoming a multitude of technical snafus to return a crippled spacecraft to Earth.

The Japanese probe truly became the little interplanetary spacecraft that could…and dutifully did. During its long voyage through deep space, reaction wheels used to stabilize its attitude failed; its chemical engine suffered a fuel leak; communications with Earth were lost for weeks; and repeated problems plagued its ion engine propulsion system.

A few months after Hayabusa's 2003 launch, even its solar panels were degraded slightly by a solar flare, reducing the amount of electricity received by the craft's ion engine.

At a cost of $200 million, the Hayabusa program focused on wringing out new hardware and testing ion propulsion, autonomous navigation, sampler, and reentry capsule concepts. But the craft was much more than a flying testbed. When its return sample canister parachuted down into the Australian Outback after its seven-year journey, Hayabusa was hailed as an icon of scientific curiosity and sheer persistence.

Sampling a rock of ages

The asteroid mission began to take shape in the mid-1980s, spurred by studies at Japan's Institute of Space and Astronautical Science (ISAS), now part of JAXA.

JAXA launched Hayabusa from Kagoshima Space Center aboard an M-V rocket on May 9, 2003. A swing-by of the Earth in May 2004 accelerated the craft, which reached its target—asteroid 25143 Itokawa—on Sept. 12, 2005, after traveling about 2 billion km. In September and October of that year, Hayabusa completed its remote sensing tasks and measurements of the asteroid. The following month it made back-to-back touchdowns in an effort to sample the rock and deliver the specimens to Earth.

Itokawa was discovered in 1998 by the LINEAR (Lincoln near-Earth asteroid research) program, an effort conducted by MIT's Lincoln Laboratory with funding from the Air Force and NASA. The asteroid received the provisional designation 1998 SF36. In 2000, it was officially named after Hideo Itokawa, a professor who had died the previous year. Af-

Sharp-shooting cameras on Hayabusa provided impressive close-up views of asteroid Itokawa. Credit: JAXA/ISAS.

fectionately known as "Dr. Rocket" in Japan, he had played a seminal role in the early stages of the country's space program.

Asteroid Itokawa is a potato-shaped object about 600 m long, classed as an S-type—of siliceous, or stony, composition. Asteroids are believed to be celestial time capsules that retain information from the beginning of the solar system's formation. Bringing a sample of the space rock back to Earth for laboratory study could yield precious clues for piecing together information on the origin and evolution of the solar system.

After liftoff the mission's name was changed from MUSES-C to Hayabusa, Japanese for "peregrine falcon." Propelling the craft were four xenon-fed ion engines. The xenon ions were generated by microwave electron cyclotron resonance and accelerated in an electric field. For its acceleration grid, the unique system used a carbon/carbon composite material resistant to erosion.

The ion engine array also featured neutralizers designed to turn the high-speed jetted ions into electrically neutral plasmas. If the spacecraft were to keep injecting positively charged ions, it would become negatively charged and attract positive ions. That would prevent Hayabusa from being propelled forward; hence the need for neutralizers.

"The Hayabusa can be called a 'high-tech spaceship,' as its key technologies—a plasma reactor that supports cutting-edge industries, robot technology with visibility, development of heat resistance, and power-saving technology—are expected to be applied to various other fields," says Hayabusa project manager Junichiro Kawaguchi.

Hayabusa's September reentry was celebrated at Operations Center 2. Credit: JAXA/ISAS.

Touchdown!

Asteroid rendezvous took place in September 2005. When Hayabusa arrived at a point 20 km from Itokawa, a reflective target marker was dispatched to the surface to assist in the spacecraft's descent. Although Hayabusa had an autonomous navigation system, the marker was used to gauge the speed of the spacecraft's horizontal movement as it landed.

Later that year, Hayabusa succeeded in making two touchdowns on the asteroid, one on November 20 and another on November 26, in efforts to use the sampling gear.

by Leonard David
Contributing writer

On that first landing, the craft touched the asteroid's surface, bounced twice, and came to rest in one place for 30 min. On the second touchdown, the tip of the craft's sampling unit was able to contact the asteroid's surface for about one second, after which the spacecraft made an immediate ascent. Experts believe that in both cases the sampling equipment, which involved firing pellets into the asteroid's surface, did not function as planned. However, it is possible that the speed of the spacecraft's contact with Itokawa stirred up the scene, with particles of the asteroid perhaps finding their way into the collection unit.

Although trouble-plagued, Hayabusa did chalk up a milestone, performing the first ascent from any other solar system body except the Moon.

Overall, the road to and from asteroid Itokawa was fraught with difficulty, says Hitoshi Kuninaka, group leader for spacecraft systems at JAXA's Space Exploration Center. Because of Hayabusa's equipment failures, its return to Earth was deferred by three years from the original date of 2007.

The craft had innumerable problems with its solar arrays, ion engines, lithium-ion battery cells, and attitude-controlling reaction wheels, encountering several delays and losses of communication. For example, in departing the asteroid after its second landing, Hayabusa suffered a fuel leak from its reaction control system. As the escaping fuel turned to gas and shot out into space, the spacecraft lost attitude and its antenna lock on Earth. The resulting communications link loss, although temporary, lasted more than seven weeks.

Homeward bound

Hayabusa literally limped back to Earth, with the very weak pressure of sunlight helping it to regain attitude control. Adding to the misery of ground operators, the probe's ion engines made an irregular stop in late 2009. A final workaround involved the "cross-operation" of previously separate pairs of neutralizers and thrusters. "By using this method, we generated thrust and managed to guide Hayabusa to Earth," Kuninaka says.

This cobbled-together attitude stabilization method—using a single reaction wheel, the ion beam jets, and photon pressure—enabled Hayabusa to struggle homeward.

"Hayabusa had enough redundancy, but some of that redundancy was developed after the malfunction," says Kuninaka, "including the improvement of onboard software and the ground support system."

In April and early June of this year, Hayabusa performed delicate trajectory correction maneuvers to prepare for receiving precision guidance into the designated Australian landing zone. A team of Japanese and U.S. navigators directed the spacecraft on the last leg of its expedition. They calculated the final trajectory correction maneuvers the ion propulsion system would have to perform to ensure a triumphant homecoming.

Import from outer space

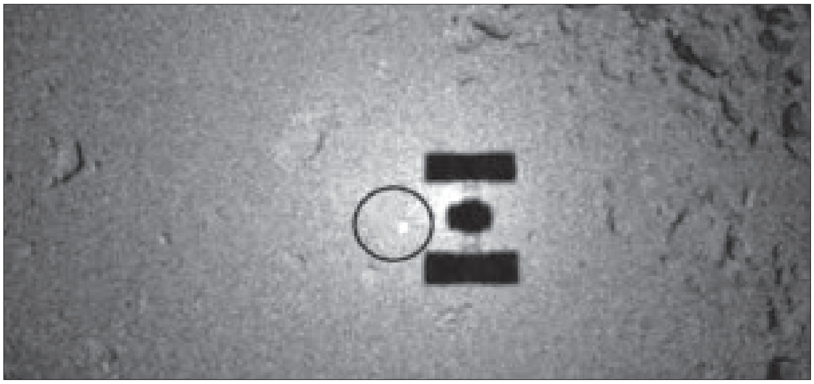
Three hours before Hayabusa's reentry into the Earth's atmosphere, the sample return capsule was to separate from the mothership. A specially developed heat shield protected the 40-cm capsule from blistering temperatures of 10,000-20,000 C. The shield, fabricated in-house, used two main ingredients: carbon-fiber-reinforced plastic and carbon phenolic resin.

At an altitude of roughly 10 km, a pyrotechnic mechanism in the capsule triggered the jettisoning of both the heat shield and a lid from the sample return capsule. The two pieces of the heat shield then fell to Earth separately as a parachute was deployed by the capsule to slow its plummet into the Woomera Prohibited Area test range. The capsule's location was tracked using radar and a radio beacon onboard the returning canister.

JAXA had to do some legal paperwork to enable its foreign-made hardware to drop in on Australia. Hayabusa was an import, not just from Japan but from outer space as well. Furthermore, the Australian government had concerns about introducing possible contaminants reminiscent of the fictional "andromeda strain" of book and movie fame.

Japan obtained import consent via the Authorized Return of Overseas Launched Space Object from the Space Licensing and Safety Office of the Australian government.

Hovering above Itokawa, Hayabusa casts a shadow on the asteroid. The bright dot is a deployed marker to aid the probe's landing on the space rock's surface. Credit: JAXA/ISAS.



Hayabusa's June 13 reentry was closely watched by a NASA-sponsored Hayabusa Reentry Airborne Observing Campaign. An international lineup of scientists on board the agency's instrument-packed DC-8 Airborne Laboratory recorded the entry of the spacecraft bus and capsule.

Flying at 39,000 ft in a race-track pattern some distance from the capsule's anticipated touchdown ellipse, researchers used a clutch of gear and instruments mounted to aircraft windows—spectrographs and several types of cameras: high-definition TV, high-frame-rate, intensified, and near-infrared-sensitive—to snare the light from the capsule, now a speeding fireball, during its swift reentry.

"It couldn't have been better," notes SETI Institute's Peter Jenniskens, principal investigator of the Hayabusa observing campaign. "Everyone had put so much energy and effort into pulling it all together. It was nerve-wracking—there were so many worries."

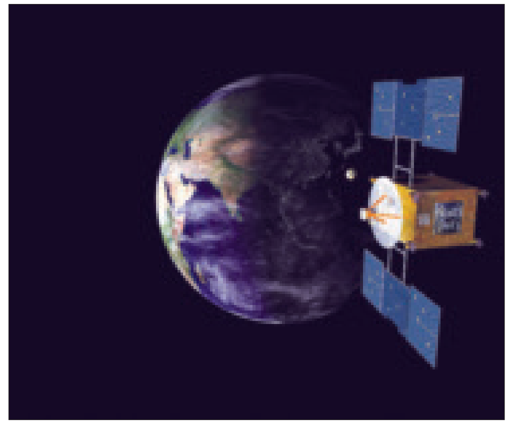
"Awe-inspiring and jaw-dropping"

Jenniskens has a habit of being in the right place at the right time for watching human-made meteors. He ran a similar airborne campaign for NASA's Stardust sample return capsule entry in January 2006 and took part in observing the September 2004 Genesis spacecraft reentry. In September 2008 he was a principal investigator for the joint ESA/NASA multiinstrument aircraft campaign that monitored the controlled destructive reentry of Europe's 13-ton automated transfer vehicle, the Jules Verne, over the South Pacific.

More than a year of planning for Hayabusa's nosedive to Earth came down to just 40 seconds, Jenniskens recalls. There were many uncertainties: Would the capsule be isolated from the main spacecraft's breakup? How bright were things going to be? Would the intense light from the spacecraft bus demolition swamp the return capsule itself?

At the appointed time, Hayabusa sped its way toward terra firma at well over 26,000 mph. "When the event actually happened, we immediately recognized that the thing moving ahead of everything, and a little bit below it, must be the capsule," Jenniskens says. "It was just phenomenal. It was awe-inspiring and jaw-dropping…just to see this whole capsule sitting there and seeing all this stuff going on around it—and then it survives."

The airborne campaign gathered a beautiful set of data, says Jenniskens. The reentry was rich in phenomena, with numerous bus pieces ejected at very high speeds and surprisingly high angles. Spectroscopic features were identified, including the moment when the lithium batteries were destroyed.



An artist's view depicts the return of Hayabusa and the release of its sample capsule toward Earth. Credit: C. Waste and T. Thompson, courtesy NASA/JPL-Caltech.

"We're using the colors of the flares, the types of signatures, to potentially reconstruct the breakup process. Of course, all this is going to take time. We have a whole mountain of data to face," Jenniskens notes. The information is potentially a bonanza, particularly for understanding the intense breakup process, to ensure safety on the ground in the case of a deliberate reentry. Similarly, studies of the high-speed fall of the 18-kg return capsule might lead to lighter thermal protection systems or aid in validating computer models.

Hopeful signs

In early October, there was heightened excitement by officials at JAXA. Analysis of the tiny contents within the Hayabusa sample capsule may indeed be particles of the visited space rock. According to researchers, some 100 rocky particles have been detected, apparently diverse in composition.

While JAXA officials remain cautiously optimistic, more analysis of the materials is needed. The extremely tiny bits will undergo further inspection at SPring-8, a large synchrotron radiation facility located in Harima Science Park City, Hyogo Prefecture, Japan. SPring-8 derives its name from super photon ring-8 GeV, with 8 giga-electron volts, being the power output of the ring.

Given this powerful tool, scientists hope to determine whether microbits of the asteroid were captured by Hayabusa—or if they are bits of Earthly contamination.

"It's surprising how difficult it is to predict how the mechanical and thermal stresses actually work out on these breakups. Our observations, in a way, give ground truth to what really goes on," he concludes.

Right on time, right on target

Shooting ahead of the debris field in the tumultuous breakup of the Hayabusa bus, the thermally protected return capsule continued on its path toward the target ellipse.

Ground observation equipment was set up to record Hayabusa's plunge. Three opti-

Hayabusa's scientific sleuthing

Hayabusa weighed 510 kg at launch, toting into space a tightly packaged suite of scientific instruments:

•A wide-view and a telescopic camera for imaging Itokawa in multiple spectral bands to determine its shape and surface features and to map mineral distributions.

•A near-infrared spectrometer to determine the distribution and abundance of the asteroid's surface minerals.

•A laser altimeter for measuring the range to the asteroid's surface, to build up high-resolution topographic profiles and provide both an accurate spacecraft position and a global shape model.

•An X-ray fluorescence spectrometer to determine the chemical composition of surface materials.

Hayabusa also contained a small surface hopper called MINERVA, short for micro/nano experimental robot vehicle for asteroid. Japan's first planetary exploration rover, MINERVA was built to move around on the asteroid autonomously, hopping about from spot to spot taking surface temperature measurements and churning out high-resolution images with each of its three miniature cameras.

In addition, Hayabusa carried a deployable target marker covered with a reflective coating. When illuminated by a flash of light from Hayabusa, the marker served as a lighthouse to guide the vehicle's descent onto the asteroid. To prevent the marker from bouncing off the asteroid because of the low gravity there, the device was filled with beads of polyimide resin—bean bag style—to dissipate energy as it contacted Itokawa's surface. The marker also contained 880,000 names from 149 countries around the world.

The "business end" of Hayabusa was essentially a sampler horn, a 1-m-long cylindrical tube projecting from underneath the spacecraft. When a sampler mechanism makes contact with an asteroid, a pellet is fired to fracture the object's surface. The anticipated result is that bits and pieces of the asteroid spew up into the sampler horn's interior. The sample-catcher is then inserted into the recovery capsule, followed by a lid-closure operation that includes latching and sealing the lid.

All in all, a creative way to snag specimens, given the gravity on asteroid Itokawa: less than 1/100,000th that on Earth.

cal stations were installed near the prohibited area to profile the capsule's ablating thermal protection system. Infrasound and seismic sensors were installed on four stations to detect atmospheric shock waves emitted from the incoming capsule. The return capsule itself deployed a parachute that provided high reflectivity for radar signals and a radio responder to locate it within desert brush.

"It's kind of weird. You've worked on this mission for so long. Then all of a sudden you realize, holy cow, this thing is coming back," says Paul Abell, a planetary scientist from NASA Johnson and a member of the Hayabusa science team. Abell was one of four individuals who served on a contingency ground recovery team. "We were there in case there was an off-nominal return, the parachute didn't work…[or] the beacon didn't activate," he explains.

As they traipsed to a nighttime position in the Australian Outback at around 10:30 p.m., Abell recalls, the skies were perfect, with no Moon and no clouds. "The atmosphere was electric. Then, right on target, right on time, we saw it come in…both the mothership and the capsule. We knew we were in a recovery situation. The fireworks were spectacular.… like Roman candles," he says.

Lessons learned

The Hayabusa mission, Abell believes, offers important lessons: Never give up on a situation, and always come up with innovative ideas for handling certain failures. "The Japanese have shown that, if you are flexible and resilient, you can do a lot of things with a modest spacecraft—even in dire situations," he points out.

Abell stresses the huge importance of international cooperation by Japan, Australia, and the U.S. in bringing about Hayabusa's success. Having those lines of communication open early in a program is vital. Being flexible and preparing for just-in-case contingencies is an important take-home message, he says.

"Yes, Hayabusa was a technology demonstration, but the science it returned is absolutely huge, everything we learned about

The recovery team in Woomera, Australia, inspects Hayabusa's sample return capsule after its-seven year voyage to and from asteroid Itokawa. Credit: JAXA/ISAS.

the asteroid....It has changed our whole way of thinking about these small objects...how they are put together, their internal structure, the nature of rubble-pile asteroids," Abell says. "It was the experience of a lifetime. The Japanese should be absolutely thrilled."

Tiny specks in a big container

Recovery teams located not only the reentry capsule but also the two parts of the heat shield cast off during the descent. The capsule, with its parachute, landed less than 1 km from the predicted touchdown point.

In early July, JAXA announced that tiny particles had been found in the sample container. This was confirmed by specialists at the agency's Sagamihara Campus, where Hayabusa's collection hardware was brought and opened. But they could not be certain whether the particles were from Itokawa or from Earth. Detailed and painstaking scrutiny would be needed to discern the true origin of the specks.

The curation center at the Sagamihara Campus was built to provide tremendous flexibility in handling extraterrestrial samples. There the capsule was first inspected in detail; it was then opened in a laboratory clean room. Specialists at the JAXA sample curatorial facility are performing a preliminary cataloging and analysis of the capsule's contents. Assisting the Japanese astromaterials experts are scientists from NASA and Australia.

"They've done their homework," says Carlton Allen, head of the Astromaterials Acquisition and Curation Office at NASA Johnson's ARES (Astromaterials Research and Exploration Science) Directorate.

Allen visited the Hayabusa curatorial lab about a month before the capsule's return to Earth. He and other NASA officials had interacted with the Hayabusa curatorial team for years as they built the facility and honed their skills in using it. "They had a spacecraft in unknown condition, possibly damaged, but they wanted to preserve as much science as they possibly could," Allen tells *Aerospace America*. "So they wanted to build a lab where they could work with something that might be damaged, dented, partially broken...and if everything worked, they could responsibly test and curate the samples."

Early indications are that the sample container seals held. "If they cleaned it well before launch and the seals held, whatever is in there should be from the asteroid," Allen says.

At Sagamihara, scientists are dealing with microscopic dust grains in a big container. To study the material, they have developed a very imaginative and novel system that uses electrostatic forces to pick up and transfer individual dust grains, he says.

"We're going to buy a copy of that system and test it out in our labs," adds Allen, who sees it as another tool for handling extraterrestrial samples in the future.

How daunting is the study of ultrasmall particles such as those possibly brought back to Earth by Hayabusa?

"We've known from our cosmic dust collection—and more recently from the Stardust mission—how to deal with particles of this size, to subdivide them, and then slice them up into lots of different samples that can be sent all around the world," Allen says. "Small particles are not a problem. [Working with] them is not easy, but we know how to do it."

Follow-on activities

Michael Zolensky is one of two NASA scientists engaged in examining the specimens. He is the agency's curator of stratospheric dust and also works in the ARES directorate at NASA Johnson.

Zolensky believes that, despite the spacecraft's sampling difficulties, the landing itself may well have coated the inside of the collection equipment with dust from Itokawa. If so, the captured microscopic grains of asteroidal material would, indeed, speak volumes.

"Hayabusa is probably going to return less than a gram of sample, at the most a few grams...possibly much less than that," Zolensky says. Nevertheless, an incredible number of things can be done with even a sample that tiny, he adds.

A team of scientists, most of them from Japan, will study the samples for a year and then release them to "anyone on the planet who is qualified to study them," says Zolensky.

Because of Hayabusa's success, JAXA has received a thumbs-up to conduct preliminary design work on Hayabusa 2. This time the target will be 1999 JU3, a C-type (carbonaceous) asteroid.

Hayabusa's achievement has also resulted in a collaboration by Japan's NEC and U.S.-based Aerojet-General. The two companies will work together on a new ion engine technology aimed at the lucrative communication and broadcast satellite market.

In summing up Hayabusa's mission, NASA's Abell says, "It was just amazing how everything came together. [The team] should be very proud of their accomplishments. It was a tremendous effort on their part...absolutely stunning."

The spacecraft reached asteroid Itokawa on September 12, 2005, after a journey of roughly 2 billion km. The asteroid is about 600 m long and of siliceous, or stony, composition.

AIR FORCE TECHNOLOGY Change

In an Air Force transformed by the next two decades of technological progress, autonomous systems will have vastly greater capabilities than those of today, says an exhaustive new USAF study. Cyber systems, already changing rapidly, will gain even more power and speed. The human operators of these and other systems will themselves need enhanced capabilities to avoid becoming the weakest link in a chain of continuing advances.

Over the next 20 years, technological change will make the USAF look very different from the way it looks today. Aircraft and other systems will become increasingly autonomous, and the people involved in their operations will have to use performance-enhancing technologies to keep up with the changes.

This is the main thrust of *Technology Horizons*, a voluminous report on the outlook for Air Force science and technology (S&T). Published earlier this year and based on an exhaustive study, the report highlights the key areas of R&D that the service should stress between now and 2030 to meet its warfighting and fiscal requirements.

Orchestrated by Air Force Chief Scientist

on the horizon

Modernization of the ISC² (Integrated Space Command and Control) program will provide warfighters with a common operational picture of the global battlefield derived from shared, real-time data. (Source: Integrated Space Situational Awareness Brochure.)

by **James W. Canan**
Contributing writer

Werner J.A. Dahm, the study involved briefings and discussions held throughout the Air Force S&T community and at the Air Combat, Air Force Special Operations, Air Force Space, and Air Mobility Commands. Other parts of the Air Force also provided inputs, as did the Dept. of Defense, federal agencies, federally funded R&D centers, national laboratories, industry, and academia.

The resulting report is “visionary” but “not a prediction of the future,” notes Dahm. Instead, he says, it is “an assessment of what is credibly achievable from a technical perspective” through the next two decades, and is intended as guidance for Air Force leadership. “We are not looking five years out or 50 years out. This is not science fiction,” he stresses.

The chief scientist notes that strategic and budgetary considerations will make the next 20 years “different from the past.” The Air Force, he says, “is now at a pivotal time in its history; it needs a clear vision for S&T to [produce] capabilities that align with future needs.”

Technology Horizons is the latest in a succession of reports produced since WW II, each aimed at refining and redirecting the Air Force’s S&T outlook 10-20 years ahead. The service’s top two officials, Secretary Michael Donley and Chief of Staff Gen. Norton Schwartz, initiated the study to give Air Force leaders an updated S&T perspective.

“The far-reaching strategic changes, rapid global technological changes, and growing resource constraints that we face over the

Stealth technology such as that used by the B-2 Spirit bomber will continue to play a major role through the next 20 years.

next decade make this an especially timely document,” Dahm says. “It will serve as a guide for Air Force S&T efforts that can maximize our ability to maintain technological superiority over potential adversaries.”

Challenges abound

The Air Force will be challenged in many ways and on many fronts to maintain such superiority, the report concludes. Among other things, the service must focus on developing technologies for air and space systems that enable it to maintain air dominance in hostile territory. Three research areas are deemed particularly important in this regard: precise navigation and timing in GPS-denied environments, electromagnetic-spectrum warfare, and “cyber resilience,” including the introduction of “massive virtualization” and “polymorphic networks.”

Low-observable, or stealth, technologies and the systems that use them will continue to play a major role through the next 20 years, the report notes. Because stealthy systems provide long-range penetration of enemy airspace and persistent striking power, they are among “the most distinguishing elements of the Air Force,” says the report. They will face an increasingly challenging environment, but “will remain essential for the ability they give to penetrate defended airspace, for the sensitivities they demand in the air defense systems of potential adversaries, and for the potential secondary benefits that this can create for other technology-based capabilities.”

Technology Horizons puts its S&T priorities into strategic perspective. It warns that “the immense strategic advantage” provided by the Air Force’s superior technical capabilities through the years may well be eroded or eliminated by the development and proliferation of high-tech weapon systems around the globe, including integrated air defenses, long-range ballistic missiles, and advanced air combat capabilities.

In many nations, “there have been equally important advances in counter-space technologies, in cyber warfare technologies, and in understanding the cross-domain effects that these technologies can produce on the U.S. ability to conduct effective air, space, and cyber domain operations,” the document states.

Intrusion resilience

In recent years, no other technologies have grown in importance as rapidly as those pertaining to offensive and defensive cyber warfare, the study found. “The electromagnetic spectrum is becoming fundamental to everything that we do,” Dahm declares. “Being able to develop technologies to enable dominant electromagnetic-spectrum warfare is very important—everything from protecting our own use of the spectrum to making direct use of the spectrum for our own purposes.”

This is why “intrusion-resilient cyber systems” rank high among the technology-spawned capabilities the report projects for the Air Force in years to come. Such systems represent “a fundamental shift in emphasis from cyber protection” to “maintaining mission effectiveness in the presence of cyber threats,” using such techniques as frequency hopping, “network polymorphing, massive virtualization, and rapid network recomposition,” says the report. It also spotlights technologies for automating the assessment of, and reaction to, cyber threats, and for improving electronic warfare (EW) capabilities.

The X-48 blended wing body design promises lower fuel costs, which will continue to receive high priority.

Investment priorities

The report identifies key areas of priority for S&T investment through the next decade, including "intelligent" sensors/processors; directed energy, including high-power microwaves and lasers for tactical strike missions, aircraft defense, and airbase defense; persistent situational awareness of space; "rapidly composable small satellites"; and next-generation high-efficiency gas turbine engines.

The study also puts a premium on technologies for systems that lower fuel costs while improving performance. Prime examples of such systems are hybrid wing/body aircraft, high-altitude long-endurance airships, and partially buoyant cargo airlifters.

Another top priority will be technologies for rapid-response, globe-spanning airbreathing hypersonic vehicles designed for long-range strike and ISR (intelligence, surveillance, and reconnaissance). These technologies are vital to the creation of "future airbreathing, two-stage access-to-space systems."

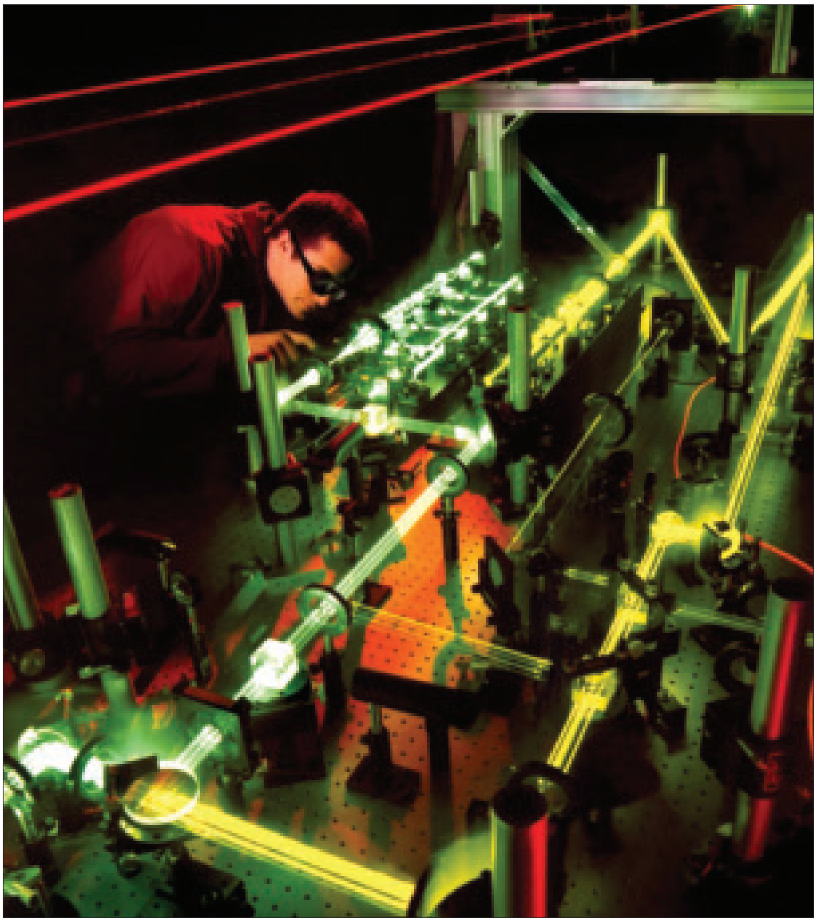
The major finding

Withal, the S&T study's "single greatest finding" involves "decision-making" autonomous systems: Expanding their use will address the Air Force's "need, opportunity, and potential" for greatly improving efficiency, increasing capabilities, reducing manpower, and lowering costs. Calling them "autonomous systems writ large," Dahm explains that their levels of autonomy far surpass those of current applications such as remote-piloted aircraft and operational flight programs.

The newer, "flexibly autonomous" decision-making systems would be able to collect, analyze, and decide how to act on information about the environments in which they fly, and about their own performance and effectiveness during missions.

A remote-piloted aircraft, for example, "might measure its own battle damage and autonomously decide how to execute its operator's intent—maybe as part of a much larger mission package—to adjust the way its mission will be executed in order to maximize its effectiveness," Dahm explains.

Technology Horizons predicts that "highly adaptable autonomous systems will be used in entirely new remote-piloted aircraft, but will also be implemented widely in Air Force systems and processes." These applications "can create massive time-domain operational advantages over adversaries [who are] limited to human planning and decision speeds." Another benefit will be a heightened operational tempo for combat units, which is "in itself a major capability advantage."



Military laser technology will be an area of significant investment during the next decade.

The study foresees pervasive autonomy not only in air and space platforms, but also in a wide variety of cyber management applications, including regional and theater air operations and multifaceted ISR activities.

The human factor

As highly or wholly autonomous systems gain ascendancy in the Air Force, the performance

The study also puts a premium on high-altitude, long-endurance airships, which lower savings while increasing performance.

TECHNOLOGY HORIZONS: MAJOR FINDINGS

According to the study, "Key technology areas are those that support the following key capability areas":

- *Highly adaptive autonomous systems*
- *Human performance augmentation*
- *Increased cyber resilience*
- *PNT (precision navigation timing) in GPS-denied environments*
- *Electromagnetic spectrum warfare*
- *Processing-enabled intelligent sensors*
- *Directed energy for tactical strike/defense*
- *Next-generation, high-efficiency gas turbine engines*
- *Persistent space situational awareness*
- *Rapidly composable small satellites*

of the people who operate them must be enhanced, states the study. The report's "second key finding" is that "natural human capacities are becoming increasingly mismatched to the enormous data volumes, processing capabilities, and decision speeds" of the rapidly improving intelligent processors and sensors that control autonomous systems.

"Although humans today remain more capable than machines for many tasks, by 2030, machine capabilities will have increased to the point that humans will have become the weakest component in a wide array of systems and processes," the report asserts. "Humans and machines will need to become far more closely coupled, through improved human-machine interfaces and by direct augmentation of human performance."

Developing ways of augmenting human performance "will become increasingly essential for gaining the benefits that many [other] technologies can bring," the S&T study says. Such augmentation could take the form of drugs or implants to improve human memory, cognition, alertness, and sensory capabilities.

It also could involve screening humans for brainwave patterns, "or even genetic modification itself," the report says. "While some such methods may appear inherently distasteful, potential adversaries may be entirely willing to make use of them," it says.

Human-machine interfaces are already being explored, using techniques such as "brain wave coupling." For this, humans would wear brain-sensitive skull caps to establish and enhance their brain-wave connections with intelligent machines.

Performance augmentation is an area where "tremendous progress has already been made," says Dahm. It "will find routine use in the cockpit, on the flight line, by ISR operators, and by commanders," says the report. "Data may be fused and delivered to humans" in ways that will speed up and improve their innate ability to make decisions, it says. "Human senses, reasoning, and physical performance will be augmented using sensors, biotechnology, robotics, and computing power."

In years to come, humans and machines will become "very tightly coupled" in many venues, and "the Air Force will be a major beneficiary of that," Dahm predicts.

Developing ways of augmenting human performance in areas such as cognition will be essential for taking advantage of rapidly advancing technologies.

A major obstacle

The report warns that there could be a major impediment ahead for the development of autonomous systems: certification of the voluminous and highly complex computer-generated software they require. Verification and validation (V&V) of such software is currently out of the question, says the study, and still requires the standard human-driven methods of seeking and finding errors in software codes.

"It is possible to develop systems having high levels of autonomy, but it is the lack of suitable V&V methods that prevents all but relatively low levels of autonomy from being certified for use," the document asserts. This lack, it says, precludes the "trust in autonomy" that the Air Force must develop before it puts highly autonomous systems into operation.

"Potential adversaries, however, may be willing to field systems with far higher levels of autonomy without any need for certifiable V&V, and could gain significant capability advantages over the Air Force by doing so," the report notes. "Countering this asymmetric advantage will require as-yet-undeveloped methods for achieving certifiably reliable V&V."

Fractionated architectures

Technology Horizons also looks ahead to partially or fully autonomous, "fractionated" systems supplanting or augmenting totally integrated systems. The latter would include the current fighter aircraft and other complex aerial platforms that the Air Force has been bent on developing and deploying in recent years.

Fractionation may also be the hallmark of future Air Force space systems, the study says. Constellations of small satellites, each with a particular function, could operate as a single, distributed system. It would be more survivable, less costly, more readily upgraded, and more capable than the large, complex, expensive satellites long in fashion, it says.

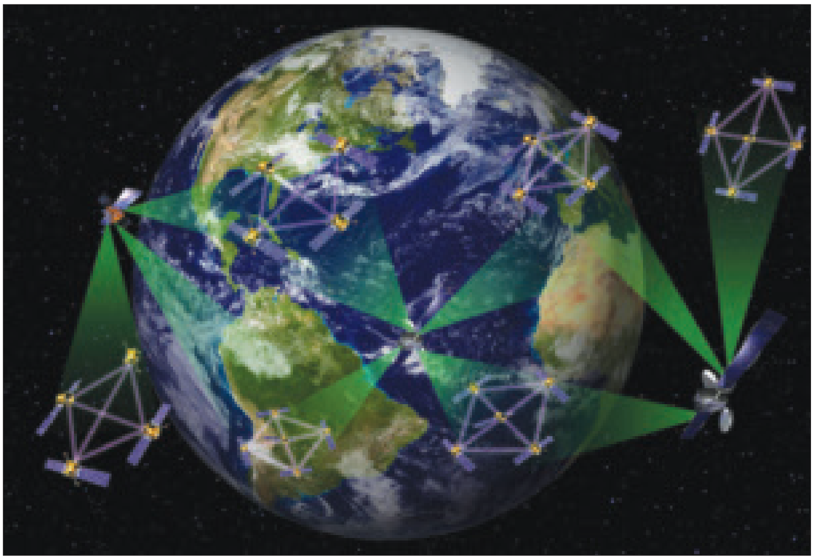
In most modern system architectures, the report observes, various subsystems and their mission functions—such as communications, EW, strike, and ISR—are physically integrated within a single platform. These platforms, it says, tend to become too big and too heavy, which limits their range and functioning. They also have relatively high unit production and operating costs. Moreover, the loss of any one subsystem can cause the whole system and its mission to fail, the report notes.

In fractionated systems, the subsystems and their functions would be spatially dispersed among various smaller, simpler platforms capable of communicating with each other, and of operating, in effect, as a coherent whole. The S&T report spells out the distinction between fractionation and modularity, which applies to the individual subsystems of integrated platforms.

"Most important, when a fractionated architecture is augmented by even low levels of redundancy among the dispersed elements, survivability can increase dramatically [over that of integrated systems]," the document contends. "Fractionated architectures are the key to the development of low-cost autonomous systems that can survive in anti-access, area-denial environments."

The "standardized, remote-piloted" airframes in such architectures would be small to medium sized, with compact, efficient turbojet engines. They would be capable of fully autonomous takeoff, flight, landing, and "collaborative control among elements of the mission package," says the report. They would carry standard-sized modular payloads such as those for ISR, EW, strike, and communications. And they would use "secure, burst-mode, frequency-agile RF [radio frequency] or laser communication."

Technologies that allow for jam-resistant, ultrasecure communications make fractionated systems feasible, says the report, adding that such communications are in the offing or already coming into play.



Constellations of small satellites, each with a particular function, could operate as a single distributed system that would be more survivable, less costly, and easier to upgrade than today's large, complex satellites.

Improving navigation and timing

The report attaches high priority to technologies that will enable the Air Force to augment or supplant GPS precision navigation and timing capabilities in GPS-denied operational environments. These technologies foster development of chip-scale inertial measurement units and atomic clocks, and of "cold-atom" inertial navigation systems and timing systems "based on compact matter-wave interferometry approaches," says the document.

The study recommends that the Air Force explore and develop technologies that will "enable single-pass, extremely precise, autonomously guided aerial delivery of equipment and supplies under GPS-denied conditions" and at altitudes required for aerial operations in steep mountainous terrain.

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A major premise of *Technology Horizons* is that, given the rapidly increasing globalization of up-to-the-minute science and technology, potential adversaries will likely have the same access that the Air Force has to advances in S&T in the years ahead. Thus they will be able to develop capabilities that the Air Force must be prepared to counter.

All things considered, the report seems upbeat about the Air Force's prospects for prevailing against all comers in future years, but with this qualification: "If we invest in the right technology areas, we can have unbeatable capabilities."

Air Force X-37B wings into

After 50 years of study, the Air Force finally has its own military spaceplane, the X-37B. Built by Boeing's Phantom Works and launched in April, the reusable craft has gone through many iterations under three different agencies. On this first orbital flight it is seeking to demonstrate several new technologies and systems—the most important of which, managers say, is the spaceplane itself.

by Craig Covault
Contributing writer

In a historic milestone, the Air Force finally has a winged space vehicle—the X-37B—to demonstrate the diverse missions that can be carried out by a robotic reusable military spaceplane.

The first flight of the 5.5-ton Boeing Phantom Works X-37B, under way since April, is a major step forward as the Air Force begins building a new, more responsive space system infrastructure. An additional vehicle, now nearing completion, is to fly the second USAF spaceplane mission in 2011.

The challenge for the Air Force in exploiting the new fleet's capabilities will be to develop a new "concept of operations" for the military spaceplane, said Gary Payton, then-deputy undersecretary of the Air Force for space at a briefing. These new concepts must transcend the USAF's traditional "wild blue yonder" mindset and provide truly higher, faster operations where that blue sky turns to black in the vacuum of space.

Launched April 22 from Cape Canaveral, Fla., on board a United Launch Alliance Atlas V rocket, the X-37B carries enough hydrazine propellant to remain aloft for nine months, though it will likely return earlier.

As part of a move by NASA and the Air Force to take greater advantage of commercial facilities, the craft underwent final assembly and checkout several miles outside the launch site, at the Astrotech commercial spacecraft processing facility. "As a first-of-its-kind vehicle, it was remarkably easy to work with," says Lt. Col. Erik Bowman, commander of the Launch Support Squadron for the 45th Space Wing, which manages Cape Canaveral launch operations.

The vehicle is testing second-generation reusable spacecraft technologies, especially a greatly improved reentry thermal protection system, says Payton, who flew in 1985 as a military payload specialist astronaut on shuttle Mission 51C. His flight launched a top-secret eavesdropping satellite into geosynchronous orbit. Payton provided a detailed media briefing on the X-37B.

Tougher, lighter, smaller

The new spaceplane's most notable thermal space

protection advance is at the wing leading edge, which on the shuttle is covered with reinforced carbon carbon (RCC). The ceramic-type material is relatively fragile, as the loss of the orbiter Columbia and her crew tragically demonstrated in 2003, after a piece of external tank insulation pierced the leading edge of the left wing RCC.

The X-37B, however, is using a different material, called toughened unipiece fibrous reinforced oxidation-resistant composite, or TUFROC. Developed by NASA Ames, it is thicker than RCC and heats at a slower rate, which makes it stronger and less susceptible to degradation from oxidation. TUFROC is also lighter than RCC, which improves vehicle payload performance. Thermal engineers are eager to see how the new material holds up to quick-turnaround ground processing.

On its belly the X-37B is carrying tough-

The X-37B spaceplane sits on its Atlas V interface mount as a booster nose shroud is placed around it at Astrotech facilities near Cape Canaveral. USAF photos.

ened unipiece fibrous insulation, or TUFI, tiles similar to those flown on the space shuttle for 15 years. TUFI is more durable and provides a better barrier against water absorption when rained on.

Instead of a human crew, redundant autonomous flight control systems are being used to maneuver the vehicle in orbit. These feature computers that are much smaller but more powerful than those of the shuttle.

The spaceplane, which can carry 500 lb, is 29 ft 3 in. long with a wingspan of just under 15 ft and a tail height of 9 ft 6 in. Its payload bay measures 7 ft x 4 ft.

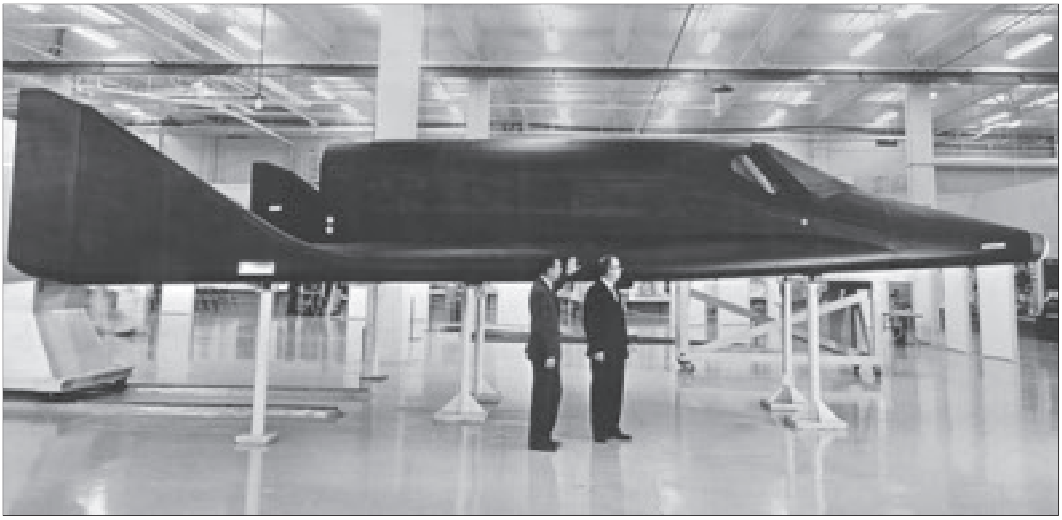
Like the shuttle, the X-37B has two clamshell doors that are kept closed during reentry and launch. At this size, the new vehicle can carry any two of several small satellites currently under development by the Air Force and the other military and intelligence services, says Payton.

spacecraft routinely fly unclassified missions with elements of their payloads kept secret.

In fact, the X-37B's current mission is like those of nonrecoverable Air Force Space Test Program satellites, which since 1965 have flown over 450 space sensor and other hardware tests on more than 175 space missions.

The Air Force kept the X-37B's orbit classified, but a skilled group of civilian space trackers based around the world eventually sighted the spacecraft in a 255-mi. circular orbit inclined 40 deg to the equator. The ground track of this orbit repeats every four days.

The NRO's imaging reconnaissance satellites often use the altitude and inclination of this orbit, says Canadian-based tracker Ted Molczan, who helps coordinate the observations. This makes it likely that the X-37B is testing reconnaissance sensors, perhaps related to advanced technologies such as hyperspectral imaging, he says.



The USAF/Boeing X-20 Dyna-Soar spaceplane was approved for development in 1957 but later canceled. USAF photo.

Element of secrecy

The X-37B and its technologies are not classified, but on this mission it carries a classified payload. The first flight, however, does not involve the deployment or retrieval of other spacecraft, nor will it entail any rendezvous or proximity operations with other satellites. The mission is demonstrating one of the primary uses planned for the X-37B: flying attached sensor payloads so that their performance can be assessed before they are integrated with much more costly free-flying systems.

The existence of a new winged military spaceplane carrying a secret payload has intrigued the media considerably. This interest is overblown and unwarranted, say military managers, who point out that U.S. military

With a double delta wing that duplicates space shuttle aerodynamics, the X-37B will perform a fully automatic reentry and steep 20-deg final approach to land on the 15,000-ft space shuttle runway at Vandenberg AFB. NASA and the Air Force adopted the shuttle design when they were developing the X-37B so the same complex reentry flight algorithms could be used to fly the spaceplane. Edwards AFB will be the backup landing site.

Origin and goals

The X-37B comes 50 years after cancellation of the X-20 Dyna-Soar program, the first Air Force initiative for a winged space vehicle. Test pilot Neil Armstrong, who nine years later would command Apollo 11 on the first manned lunar landing, was among several pilots secretly selected as X-20 military astronauts in 1960, before Armstrong transferred to NASA.

The Air Force proposed other winged space vehicles but, in decisions made 40 years ago by the Nixon administration, had to compromise with NASA for military use of the manned shuttle. That proved to be a costly and unhappy marriage for both parties.

The X-37B itself grew out of a NASA program, but as a dedicated robotic military spaceplane it will benefit from lessons learned on the manned shuttle.

Instead of serving only as a launch vehicle, however, the X-37B will be more responsive to rapidly changing mission needs that place greater emphasis on small spacecraft well suited to launch and recovery by a spaceplane this size.

The primary goal of this first mission is to demonstrate the performance of specific X-37B technologies. Most, including thermal protection and electromechanical systems, represent second-generation reusable spacecraft hardware that was proven initially on the space shuttle.

"If the technologies on the vehicle prove to be as good as we currently estimate," notes Payton, "it will make our access to space more responsive, perhaps cheaper, and push us toward being able to react to warfighter needs more quickly."

Not your father's STS

The new spaceplane, which has redundant and fault-tolerant robotics, is just one-fourth the size of the space shuttle. The other major difference between the two vehicles is that the X-37B uses a several-foot-long gallium arsenide solar array panel that extends from its payload bay to feed power into lithium-ion batteries. The shuttle instead uses liquid oxygen and hydrogen fuel cells for electricity and auxiliary power units to generate hydraulic pressure and move its large control surfaces.

The X-37B is an all-electric vehicle that will use the battery power to move its control surfaces during reentry. It uses hydrazine propellant in its attitude control thrusters and in its single 6,000-lb-thrust maneuvering engine. It carries no manipulator arm.

Unlike the shuttle, whose large vertical tail/rudder splits open as a speed brake, the X-37B uses twin tails for better yaw control and an aft-fuselage top-mounted speed-brake panel somewhat like that of the F-15 fighter.

Smaller twin tails also keep the X-37B's height to under 10 ft so it can fit under a launch vehicle nose shroud. An initial plan calling for the spaceplane to be exposed to the airflow atop a Delta II during launch was dropped when analysis showed there would be excessive aerodynamic loads without a nose shroud to cover the vehicle.

In this NASA graphic, the X-37B flies in space with its payload bay open and solar array extended. NASA graphic.

New missions

The flight kicks off a twin vehicle effort to forge—at Mach 25 and 250-mi. altitude—the same multirole space capability inherent in many military aircraft operations.

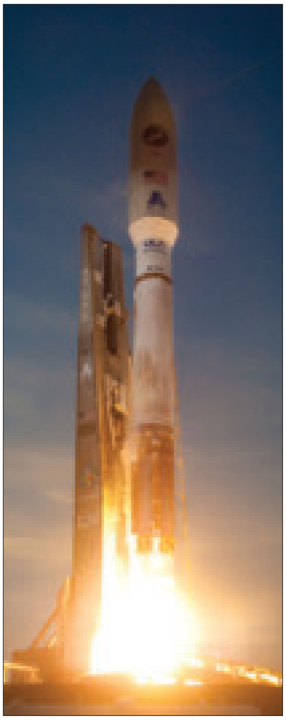
While proving new technologies such as advanced thermal protection materials, the two X-37s will also demonstrate entirely new missions, including the emergency surge-launch of small critical satellites. The spaceplane's payload bay provides a standard interface for user satellites, and the X-37B itself has a standard user interface with the Atlas V, Delta IV, and possibly other launchers such as the SpaceX Falcon 9.

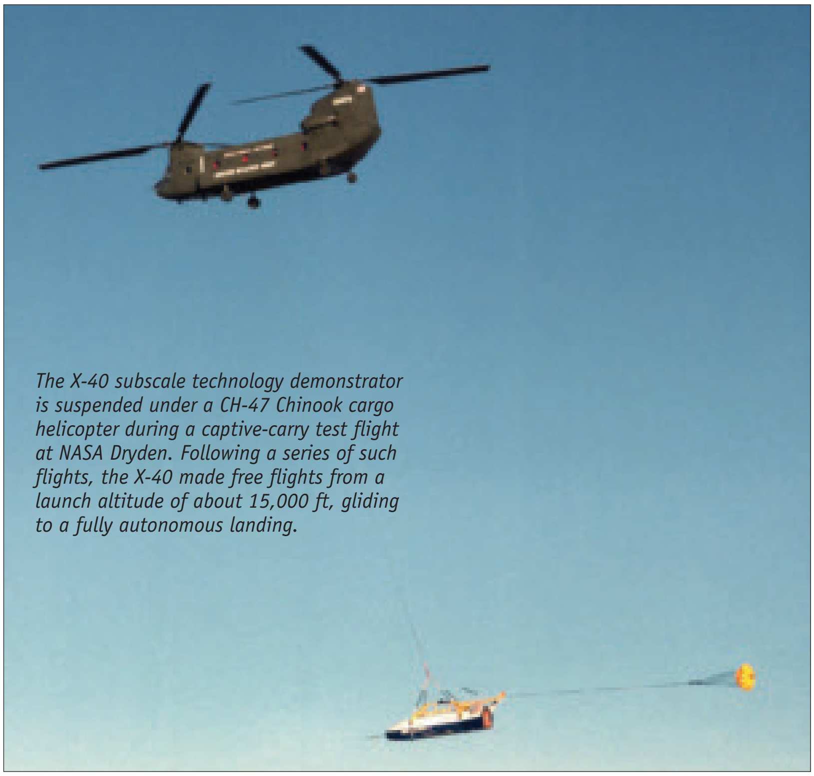
Payton points out that, in an emergency, launchers already in their processing flows at the Cape or Vandenberg would be used for quick-reaction spaceplane flights. A decision would be made on which payloads are more important; if those capable of X-37B launch are needed, the previously planned payload for the Atlas or Delta would be bumped to open a slot for the X-37B mission.

Unlike the shuttle orbiter, however, the unmanned X-37B carries a destruct system that allows safety officers to destroy the vehicle over the Pacific should it stray from its reentry corridor enroute to Vandenberg.

Landing at Vandenberg will position the spacecraft at the Air Force's west coast launch site—only a few thousand feet from processing facilities and launch pads for any of four different rockets that could be used to launch it into polar orbit, in contrast to its current equatorial mission.

On April 22 an Atlas V lifted off from Space Launch Complex 41 carrying the X-37B on its first spaceflight.





The X-40 subscale technology demonstrator is suspended under a CH-47 Chinook cargo helicopter during a captive-carry test flight at NASA Dryden. Following a series of such flights, the X-40 made free flights from a launch altitude of about 15,000 ft, gliding to a fully autonomous landing.

Research conducted at the Air Force Institute of Technology at Wright-Patterson AFB, Ohio, shows that an operational X-37B-type spaceplane will support the Air Force Space Command Strategic Master Plan. The research found that it would have a “direct and substantial” effect on several goals. Key among them are:

•Intelligence, surveillance, and reconnaissance of ground targets with either integrated sensors or deployed surveillance satellites.

•Deployment of space control micro satellites for key surveillance and intelligence missions in a crisis.

•Rapid replenishment of constellations by the small satellites that can be carried in the X-37B payload bay.

The X-37B test vehicle is readied for ground testing. USAF photo.

Top priority

Payton stresses that obtaining cost and work-flow data once the vehicle is back on the ground will be especially important.

”The top-priority technology demonstration is, on this first flight, the vehicle itself. Getting it into orbit, getting the payload bay doors open, solar array deployed, learning about on-orbit attitude control, and then bringing it all back.

”But probably the most important demonstration will be on the ground, once we get the bird back: to see what it really takes...how much it really costs to do this turnaround on the ground with these new technologies,” he says. “So it’s as much a ground experiment in low-cost operations and maintenance as it is an on-orbit experiment with the vehicle itself.”

Managers hope that processing of the spaceplane will be more like that of the SR-71, with perhaps one or two weeks between flights instead of the months it takes to process existing spacecraft, says David Hamilton of the Air Force Rapid Capabilities Office, which is overseeing X-37B operations. Managing the actual flight operations will be the Air Force Space Command’s 3rd Space Experimental Squadron and Space Command at Colorado Springs, Colo.

X-37B development has gone through so many iterations at NASA, DARPA, and now the Air Force that Payton says he has no idea what the program’s total costs have been since its inception in 1996.

That fits well with the Rapid Capabilities Office that handles the X-37B. The motto on the organization’s insignia reads, “Opus Dei cum pecunia alienum efficemus,” which is Latin for “Doing God’s work with other people’s money.”

Evolutionary steps

The vehicle that became the X-37B is derived from the Air Force X-40 Space Maneuver Vehicle project and NASA’s Future-X reusable launch vehicle concept. Key steps in the evolution of the vehicle were:

•1996: The Air Force awards a contract to Boeing for a Space Maneuver Vehicle demonstrator that could be launched by the shuttle or atop an expendable booster. A year later it is designated the X-40. At the same time NASA is evolving concepts for its Future-X program, aimed at developing future reusable launch vehicles. NASA reserves the X-37 designation for use later as it does conceptual work on its X-34, which will later be turned over to industry for possible commercial development.

•1998: Initial X-40 auto-land drop tests from a UH-60 helicopter at 9,000 ft take place at Holloman AFB, N.M.

•1999: NASA selects a Boeing proposal to use the X-40 as the basis for its Future-X pathfinder program, with the vehicle redesignated the X-37A. Built by Boeing, the X-37A is a 20% larger version of the X-40 design begun with the Air Force.

•2000: The Air Force agrees to participate in the X-37A program and gives NASA the X-40 for ambitious drop tests from 15,000 ft. The tests, which employ air data and software developed by Boeing and

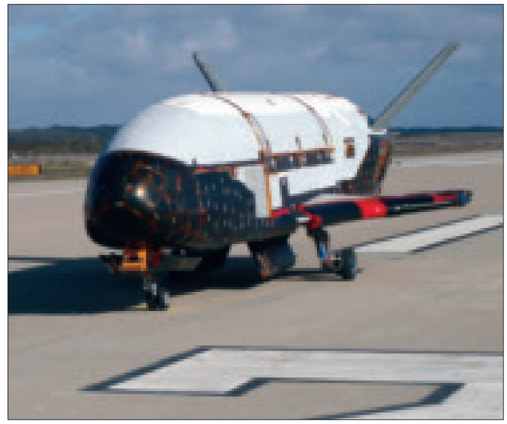
NASA, use a CH-47D helicopter to drop the X-40 seven times.

•2001: More drop tests are completed, but cost factors compel the Air Force to pull out of the program. NASA continues to plan for an X-37A orbital test mission that could be deployed from the space shuttle as early as 2002. A plan is also drawn up to launch the vehicle in 2006 atop a Delta II booster, then later on an Atlas V with a nose shroud covering the spaceplane.

•2003-2004: NASA, facing cost issues, is reevaluating the need for any space test of the X-37A. But in late 2004, DARPA agrees to take the craft.

•2006: After adding more avionics to the X-37A, DARPA begins its own series of tests on the Scaled Composites White Knight carrier aircraft that has dropped the SpaceShipOne commercial manned suborbital vehicle. In April 2006 it makes its first drop test from the White Knight.

•2007: By early 2007 the Air Force is moving ahead with a new plan to develop a variant of the drop test vehicle, to be flown in space and designated the X-37B orbital test vehicle. A USAF statement says the OTV's objectives will be "risk reduction, experimentation, and operational concept development for reusable space vehicle technologies, in support of long-term developmental space objectives." Aspects of the project are also classified. The vehicle then enters preparation for launch into space, and a second vehicle is also procured to give the USAF an initial robotic spaceplane fleet.



The X-37B completes its rollout on the runway after a drop test. USAF photo.

Out of the

25 Years Ago, November 1985

Nov. 27 Payload specialist Rudolfo Neri Vela, the first Mexican astronaut, flies on board the shuttle Atlantis. The mission, STS 61-B, launches Morelos B, Mexico's second satellite. NASA, *Astronautics and Aeronautics*, 1985, pp. 329, 339-340.

50 Years Ago, November 1960

Nov. 3 Explorer VIII is successfully launched by a Juno II. Shaped like a spinning top, the satellite is designed to investigate the radio-reflecting layers of the Earth's ionosphere and to observe the effects of solar flares and other cosmic disturbances that affect radio communications. *The Aeroplane*, Nov. 11, 1960, p. 640.

Nov. 6 The USSR publishes the world's first atlas of the far side of the Moon, based on photos taken by the Soviet Lunik, or Luna III, launched on Oct. 4, 1959. E. Emme, ed., *Aeronautics and Astronautics 1915-60*, p. 130; D. Baker, *Spaceflight and Rocketry*, p. 95.

Nov. 10 The first extended-range A2 model of the Polaris missile lifts off from Cape Canaveral, Fla., and travels 300 mi. in a test flight. *The Aeroplane*, Nov. 18, 1960, p. 694.

Nov. 11 The first successful transmission of a letter through space takes place when a "Speed Mail" letter is sent via the Echo satellite. The letter is scanned by a facsimile transmitter in Washington, D.C., and the signals are sent by wire to the Naval Research Laboratories at Stump Neck, Md. From there they are transmitted by microwave to the passive Echo balloon satellite nearly 1,000 mi. above Earth. The signals are then bounced off the satellite and picked up by the tracking antenna of Bell Telephone at Holmdel, N.J. *The Aeroplane*, Dec. 2, 1960, p. 744.

Nov. 12 The Discoverer XVII reconnaissance satellite is launched into a polar orbit from Vandenberg AFB by a restartable Agena-B second stage. It is the first flight for this upper stage. E. Emme, ed., *Aeronautics and Astronautics 1915-60*, p. 130.

Nov. 14 Discoverer XVII's capsule is successfully ejected after 31 orbits and is captured at 9,000 ft by an Air Force Fairchild C-119 Flying Boxcar carrier plane. This is the second recovery of this type from space. E. Emme, ed., *Aeronautics and Astronautics 1915-60*, p. 130.

Nov. 14 Umbaugh Aircraft of Ocala, Florida, demonstrates its Umbaugh 18 two-seat Gyrocopter at Los Angeles. *The Aeroplane*, Nov. 25, 1960, p. 703.

Nov. 15 A North American X-15 hypersonic rocket research plane (No. 2) is flown for the first time with its Reaction Motors Division, Thiokol Chemical, XLR-99 rocket engine, which provides 57,000 lb of thrust. The plane reaches an altitude of 80,000 ft and a speed of Mach 2.9 as flown by A. Scott Crossfield. E. Emme, ed., *Aeronautics and Astronautics 1915-60*, p. 130; *The Aeroplane*, Oct. 21, 1960, p. 552; D. Baker, *Flight and Flying*, p. 373.

Nov. 15 The solid-fuel Polaris fleet ballistic missile becomes operational when the USS George Washington leaves Charleston, S.C., with a load of 16 A-1-type Polaris intermediate-range ballistic missiles. *U.S. Naval Aviation 1910-1980*, pp. 240-241.

Nov. 21 During preparations for a test of the unmanned Mercury-Redstone (MR-1) space capsule at Cape Canaveral, the pylon-mounted escape rocket inadvertently fires and tears loose from the capsule while the Redstone launch rocket, with the capsule, remains in place. *The Aeroplane*, Dec. 2, 1960, p. 745.

Nov. 23 The Tiros II weather satellite is sent aloft by a Thor-Delta rocket. The 14th satellite launched by the U.S., it transmits nearly 1,000 pictures within five days. The photos are successfully sent to receiving stations at Fort Monmouth, N.J., and San Nicolas Island, Calif. E. Emme, ed., *Aeronautics and Astronautics 1915-60*, pp. 130, 132.

Nov. 30 A cow is reportedly killed in Eastern Cuba by space debris, a fragment of a Thor-Able Star rocket that went out of control after its launch from Cape Canaveral. The rocket was to have launched a new Transit navigational satellite and a smaller research satellite but was blown up by the range safety officer. *The Aeroplane*, Dec. 9, 1960, p. 783.

Past

An Aerospace Chronology
by **Frank H. Winter, Ret.**
and **Robert van der Linden**
National Air and Space Museum

75 Years Ago, November 1935

Nov. 3 President Franklin D. Roosevelt awards the Air Mail Flyer's Medal of Honor to seven U.S. air mail pilots. Medals go to Edward A. Bellande, TWA, for landing a burning plane safely; James H. Carmichael Jr., Central Airlines, for safely landing his plane in the dark after one engine had dropped off with part of the undercarriage; Gordon H. Darnell, Braniff, for safely landing his burning plane and retrieving the mail before the plane exploded; and Wellington P. MacFail, American Airlines, for bailing out with the mail after the aircraft's single engine came off. Three other pilots who performed similar acts of heroism are also honored. *The Aeroplane*, Nov. 27, 1935, p. 652.

Nov. 11 Capts. Albert W. Stevens and Orvil A. Anderson, both of the Army Air Corps, reach the highest altitude ever attained by humans as they take their stratospheric balloon, Explorer 11, to 74,000 ft. The 3.5-million-ft^3-capacity balloon is inflated with helium.Taking off near Rapid City, S.D., they fly for 8 hr 12 min, landing about 340 mi. away at White Lake, near Aurora, Neb. *The Aeroplane*, Nov. 20, 1935, p. 645.

Nov. 13 Jean Batten becomes the first woman to make a solo flight across the South Atlantic, landing her De Havilland Gypsy Moth at Natal, Brazil, after a 13-hr, 5-min flight from Dakar, Senegal. *Aero Digest*, Dec. 1935, p. 58.

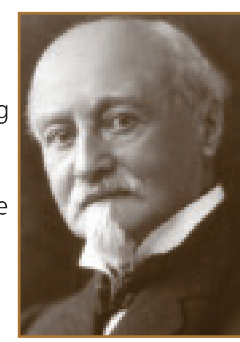
Nov. 21 The USSR claims the world altitude record by an airplane as Vladimir Kokkinaki, a 31-year-old former stevedore, flies a single-seat, single-engine biplane to a height of 47,806 ft. The aircraft flies 62 min and lands with empty fuel tanks. Kokkinaki sets a dozen aviation records in his lifetime and dies, in 1985, as one of the most decorated Soviet airmen. *The Aeroplane*, Dec. 4, 1935, p. 701; *The New York Times*, Jan. 21, 1985.

Nov. 22 The Martin C-130 China Clipper flying boat of Pan American Airways leaves San Francisco on the first of its scheduled mail and passenger services across 7,000 mi. of the Pacific Ocean to Manila. Capt. Edwin Musick commands a crew of seven. Two tons of mail are aboard the flight, which stops at Honolulu, Midway, Wake Island, and Guam. The run takes six days, with 60 hr of actual flying time. Passenger service will begin in the autumn of 1936. *The Aeroplane*, Nov. 27, 1935, p. 671; R. Bilstein, *Flight in America 1900-1983*, pp. 92-93.

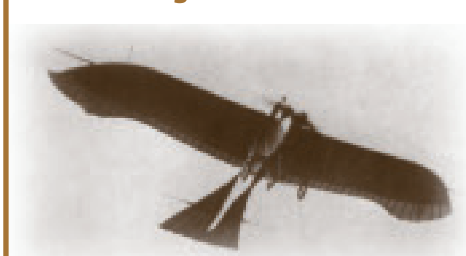
100 Years Ago, November 1910

Nov. 14 The birth of the aircraft carrier is said to start with the first flight of Eugene B. Ely in a Curtiss from the deck of the modified cruiser USS Birmingham at Hampton Roads, Va. For this experiment the Birmingham is fitted with an 83-ft-long platform. The experiments continue, and on January 18, 1911, Ely completes the first landing and takeoff from a ship, the USS Pennsylvania, which is some 13 mi. out to sea from San Francisco. C.H. Gibbs-Smith, *Aviation*, p. 156; *Flight*, Jan. 28, 1911, p. 67.

Nov. 23 Octave Chanute, one of the great aviation pioneers who influenced the Wright brothers, dies at age 72. In 1894 the French-born Chanute published his classic *Progress in Flying Machines,* earning him the title of first aviation historian. He undertook gliding experiments and contributed greatly to the development of control systems, having invented the wire wing braced structure that was later adopted in biplanes and became the nucleus of wing warping. Chanute became a special mentor of the Wrights. *Aero* (St. Louis), Nov. 23, 1910, p. 3.



And During November 1910



The German military purchases five or six aircraft and then, in December, orders 20 Etrich monoplanes from Austria. France also begins acquiring military aircraft in the summer of 1910 and by December has 35. *The Aeroplane in War*, pp. 27, 42-47.

University of Michigan
Aerospace Engineering
Tenure-track Faculty Position

The Department of Aerospace Engineering at The University of Michigan invites applicants for a tenure-track faculty position in an area of aerospace engineering that is complementary to the principal research interests pursued in the department. Applicants must have extensive experience with disciplines relating to aerospace engineering. The Department presently has 26 full time faculty members. Both its undergraduate and graduate programs are highly ranked nationally. Research interests of the faculty cover a broad spectrum of aerospace engineering including gas dynamics, propulsion, structural mechanics, aeroelasticity and flight dynamics and control. Information about the department can be found at: www.engin.umich.edu/dept/aero/.

Applicants should have an earned doctoral degree in aerospace engineering or a closely related field. The successful candidate will be expected to participate in all aspects of the department's mission, including the development of a strong and relevant externally funded research program, the teaching of undergraduate and graduate courses and the supervision of graduate students. Appointments at all ranks will be considered.

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UC SAN DIEGO - DEPARTMENT OF STRUCTURAL ENGINEERING
Position Title: Associate/Full Professor
Job Number: JPF00055

Description: The Department of Structural Engineering (http://structures.ucsd.edu) is seeking outstanding candidates in the area of Aviation Safety of Composite Structures to fill a tenured faculty position. Particular emphasis should be on the full-scale behavior and failure of composite structures, structure design, composites processing, crashworthiness and survivability, static and dynamic large-scale testing, bonded and bolted connections, buckling and stability, and damage tolerance. The successful candidate must hold a doctorate or equivalent degree, demonstrate high-quality research and teaching potential, and is expected to develop a strong externally funded research program. Major large-scale experimentation resources are available via the Structural Engineering Department's Charles Lee Powell Laboratories and Englekirk Center. Additional facility space for fabrication, characterization, and testing of full-scale composite aircraft structures is expected via the new Structural and Materials Engineering Building, currently under construction.

The Department of Structural Engineering offers undergraduate and graduate degrees in structural engineering and emphasizes cross-disciplinary research in aerospace, civil, mechanical, and marine structures. Current related research activities include impact damage of large composite structures, full-scale FAA-certified qualification testing, aircraft ground vibration testing, development of long-range unmanned air vehicles (UAV's), NDE, structural health monitoring and damage prognosis in next-generation aircraft, composite ducted fan blade research, computational mechanics, advanced material structural rehabilitation, explosive blast loading, and innovative nano-materials.

The Department of Structural Engineering is committed to building an excellent and diverse faculty, staff, and student body. In addition to having demonstrated the highest standards of scholarship and professional activity, the preferred candidates will have experience or demonstrated contributions to a climate that supports equity, inclusion and diversity. Applicants are asked to submit a summary of their past or potential contributions to diversity in their personal statement. The University of California, San Diego, is an Equal Opportunity/Affirmative Action Employer with a strong institutional commitment to excellence through diversity. For applicants with interest in spousal/partner employment, please see the website for the UCSD Partner Opportunities Program: (http://academicaffairs.ucsd.edu/offices/partneropp/default.htm)

Salary: Level of appointment and salary will be commensurate with qualifications within the University of California published pay scales.

Closing Date: The review of applications will begin on November 1, 2010, and will continue until the position is filled.

To Apply: Please include: 1) a personal statement summarizing teaching experience and interests, leadership efforts and contributions to diversity; and 2) a resume and names/addresses of four professional references to: https://apol-recruit.ucsd.edu/

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Tenure Track
Aerospace Engineering
Daytona Beach, Florida

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Referencing IRC34907, please submit a cover letter, curriculum vitae, and the names of at least three references to: online at http://www.erau.edu/jobs, email to Karen.Jacobs@erau.edu or US mail to: AE Faculty Search, C/O Human Resources, Embry-Riddle Aeronautical University, 600 S. Clyde Morris Blvd., Daytona Beach, FL 32114. EEO.

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Dr. Raman P. Singh, Chair
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School of Mech & Aero Engineering
218 Engineering North
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