March 2011

AEROSPACE AMERICA

UAV roundup 2011

Quieter flight: A balancing act

China's military space surge

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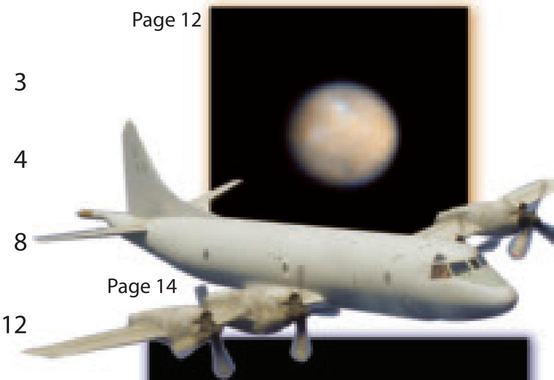

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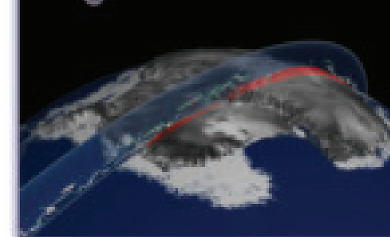

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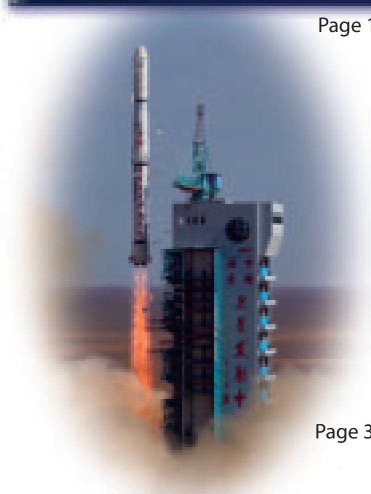

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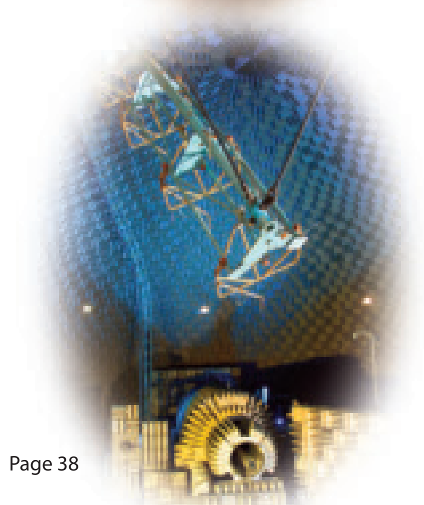

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COVER

An MQ-1 Predator armed with AGM-114 Hellfire missiles flies a combat mission over southern Afghanistan. See the latest on UAVs beginning on page 22. (USAF photo by Lt. Col. Leslie Pratt.)

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Send materials to Craig Byl, AIAA, 1801 Alexander Bell Drive, Suite 500, Reston, VA 20191-4344. Changes of address should be sent to Customer Service at the same address, by e-mail at custserv@aiaa.org, or by fax at 703.264.7606.
Send Letters to the Editor to Elaine Camhi at the same address or elainec@aiaa.org.

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Commentary

How far can you see?

Much has been written about the apparent decline of science, technology, engineering, and math (STEM) education in the U.S. and, to varying degrees, other Western countries. Four years ago, the National Academy's oft-cited "Rising Above the Gathering Storm" study, chaired by former Lockheed Martin Chairman and CEO Norm Augustine, sounded the alarm on challenges facing the nation, with recommendations to bolster STEM disciplines to improve American competitiveness. Other studies see American science and engineering being surpassed by nations that are more actively investing in infrastructure and stressing education.

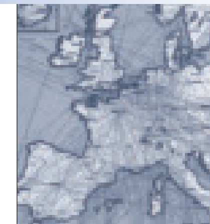
Key among these concerns is the relatively sparse percentage of U.S. students seeking advanced degrees in science and engineering, especially compared with their counterparts overseas. While some concrete steps have been taken to reverse this trend, recent economic concerns, coupled with inevitable cutbacks, pose a threat to this progress. And nowhere do those threats seem as alarming as in the aerospace community. Present uncertainty in NASA's direction and budget, calls for "efficiencies" in the DOD, and even funding threats to national test and evaluation infrastructure all suggest that aerospace will not fare well.

However, the situation is not as bleak for aerospace as it is for other STEM fields. Researchers at the National Institute of Aerospace have been compiling data on aerospace student enrollments dating back over two decades, and the results are encouraging. In 1989, the various aerospace undergraduate programs enrolled roughly 350 students per program; by 1996 that number had fallen to about 130. But since 1997, these enrollments have shown a steady rise, such that by 2008 they had returned almost to the late 1980s levels and continue to grow. Graduate enrollments are even more encouraging, with U.S. programs now reporting 50% more students than in the late 1980s. Last year, the 57 aerospace programs participating in the survey reported total enrollments of over 20,000 students. Think we're not attracting top students from around the globe? A recent National Academy study suggests the opposite. The quality of aerospace students across the board remains second to none.

Our biggest challenge is not one of *supplying* the next generation of aerospace engineers; rather, it is in having sufficient *demand*. Program cancellations, starts and stops, and facility closures all mean fewer opportunities for our graduates. Students come to aerospace seeking the chance to contribute to meaningful progress in air and space transportation and exploration. If our society does not provide those, they will eventually go elsewhere.

The benefits of educational outreach hardly require justification—we will always want to recruit the best and the brightest. To do so, we must convince decision makers to create *lasting* opportunities, so that we don't lose this generation's talents and enthusiasm. In securing the future, the greatest contribution we can make to education is to provide inspiration. Then we can all look with pride at the many ways aerospace technology has already transformed our world, and extrapolate to a future where it continues to bring value to our lives while opening new avenues of knowledge and understanding.

Mark Lewis
Willis Young Professor, University of Maryland



Europe confronts intel capability shortfalls

EUROPEAN MILITARY ALLIES WILL HAVE to dramatically increase their levels of cooperation if they are to make up for a potential shortfall in intelligence, surveillance and reconnaissance (ISR), signals intelligence (SIGINT) and electronic intelligence (ELINT) capabilities as a result of increasing pressures on defense budgets. Given the complexities of the tasks and the multitude of platforms European nations use to meet their requirements for intelligence gathering, it is highly likely they will become increasingly reliant on mature U.S. technologies.

The cancellation last October of the U.K.'s BAE Systems Nimrod MRA4 program and the planned phase out of the Sentinel Airborne Stand-Off Reconnaissance (ASTOR) system once U.K. troops leave Afghanistan are just two recent examples of the removal of special-mission platform capabilities. The Sentinel incorporates a Raytheon dual-mode synthetic aperture/moving target indication (SAR/MTI) radar mounted on a Bombardier Global Express long-range business jet,

Yet most service chiefs acknowledge that these capabilities will play an increasing role in future conflicts and that new ways will have to be sought to share intelligence-gathering assets. New ways will also have to be found to finance and develop new capabilities in these areas—improved sensors, more accurate analysis capabilities, and better sharing of information.

"The main capability drivers of RF sensor research and technology activities include a great diversity and unpredictable circumstances of military missions, changing threats, a changing operational environment, and a need for more precise and reliable information," said Attila Simon, research and technology project manager within the European Defense Agency (EDA), at a September 2010 Paris conference. The drivers for improved sensor technology also include increased levels of RF interference and increased pressure for commercial use of the spectrum, according to Simon.

France leads technology push

During the 1991 gulf war, Europe had to rely on U.S. assets for many of their intelligence-gathering and SIGINT/ELINT operations. France, in particular, was at the forefront of a push for Europe to develop its own capabilities not just in ISR but SIGINT and ELINT as well. That country has been the driving force in Europe behind several generations of military satellites and airborne SIGINT/ELINT programs.

Along with a network of satellite and UAS platforms, France has also developed considerable fixed-wing intelligence-gathering capabilities, including the operation of C-160 Gabriel aircraft with recently upgraded Thales electronic surveillance systems. In September 2008, Thales was awarded a contract to upgrade the aircraft's ELINT system, to enter service in 2011. The C-160 Gabriel is due to be replaced by an A400M version when the new aircraft type becomes available.

France remains committed to developing its capabilities in these areas; the country's June 2008 strategic defense review included a doubling of expenditures to approximately $1 billion a year on space-based ISR capabilities by 2012.

Sharing rather than gathering

Elsewhere in Europe, however, the focus has been on developing new ways of sharing, rather than gathering, intelligence. For example, back in May 1991, Western European Union (WEU) ministers agreed to create the European Union Satellite Center in Torrejón de Ardoz, to share imagery intelligence from satellite operators. Over the last few years, the center's acitivies

France's considerable fixed-wing intelligence-gathering capabilities include the C-160 Gabriel.

have grown considerably in support of EU missions, providing images to EU security operations in the Congo, Chad, Georgia, Rafah, Kosovo, Guinea Bissau, and most recently to EU naval assets targeting Somali pirates.

But because of the complexities of the technologies involved, the different views by national governments on the priority for such assets, and diminishing defense budgets, European cooperation in this area has been a challenge. In general, it is only the larger countries such as France, the U.K., and Germany that have identified these intelligence-gathering technologies as a priority, which has led to further complications in sharing the costs of developing pan-European capabilities.

The other major issue is, which is the best forum for sharing capabilities—there has been a danger of duplicating efforts for intelligence gathering already under way within NATO, the European Defence Agency, and the WEU, and between individual states. Sharing accurate intelligence—especially in the sensitive areas of SIGINT, human intelligence, and measurement and signature intelligence—is fraught with political complexities.

But there is considerable political will to improve intelligence sharing. The 1998 St. Malo agreement between France and the U.K. announced a need for Europe to improve its intelligence-gathering capabilities, which opened the door to new cooperative agreements within the continent.

"In order for the European Union to take decisions and approve military action where the Alliance as a whole is not engaged, the Union must be given appropriate structures and a capacity for analysis of situations, sources of intelligence and a capability for relevant strategic planning, without unnecessary duplication, taking account of the existing assets of the WEU and the evolution of its relations with the EU," ran the words of the agreement.

St. Malo was followed by the 1999 Cologne agreement to support the EU's new common foreign and security policy with the development of autonomous intelligence capabilities, "without prejudice to actions by NATO."

Institutional and fiscal challenges

However, this political will has been undermined by technical and institutional obstacles on the ground. So although Europe's ISR capabilities, in particular, increased in the early years of the last decade, even when they were operating in-theater, valuable intelligence has not always been available to coalition partners.

"Although German land-based SIGINT was present in the Area of Operations, the system was not under operational control of COMISAF [Commander of ISAF, the International Security Assistance Force]," according to Lt. Col. Mark Exterkate of the Royal Netherlands Air Force, writing in NATO's *Joint Air Power Competence Centre Journal* in 2006 of the ISAF operation in Afghanistan the previous year. "It was embedded into the German Kabul Multi-National Brigade contingent for German force protection purposes and not integrated into ISAF's Command, Control and Communication infrastructure."

According to Adam Sowa, deputy chief executive of the EDA, speaking in June 2010, "The problem with EU-NATO relations [is that it] is, as we all know, of a highly political nature. Unfortunately, it does also affect the relations between EDA and its NATO counterparts. The fact is that we cannot exchange information formally. Clearly, this is hampering work on concepts, doctrine, and standards where 'copy and paste' should be the line to take and not reinventing the wheel."

Joint intelligence surveillance and reconnaissance have been targeted by the EDA as a priority for improved EDA and NATO cooperation. But this will require individual European nations to rethink their capability priorities, according to the EDA. "Member States will have to further reform their armed forces," explained Alexander Weis, EDA chief executive, in a July 2010 speech. "They will have to shift the capability focus even more than in the past to areas such as deployability; particularly strategic and in-theatre transport; intelligence, surveillance and reconnaissance; force protection, and command and control."

The complexities of developing strategic cooperative arrangements and robust international technology programs which, when delayed, will withstand fluctuating economic pressures have made it difficult to develop pan-European intelligence gathering programs.

For example, the Multinational Space-based Imaging System for Surveillance, Reconnaissance and Obser-

Europe's military surveillance satellite programs

France launched its Helios-1 imagery intelligence satellites in 1995 and 1999, in cooperation with Italy and Spain, providing 1-m optical imaging resolution but with no infrared capability. For the second-generation Helios program, Helios-2, which included an infrared capability, France tried to form a partnership with Germany, to no avail. Instead, it partnered with Belgium. Helios-2A, built by EADS-Astrium, was launched in December 2004; Helios-2B was orbited in December 2009.

According to CNES, Helios-2 "will operate in the visible and infrared portions of the spectrum to deliver imagery to the French military night and day. France also has an agreement to exchange some of Helios-2's optical observing capacity for future radar observation capacity now under development in Germany and Italy, thus affording it an all-weather imaging capability. Enhancements provided by Helios 2 include significantly improved resolution, more imaging capacity, and faster access to imagery."

The German and Italian programs referred to are Germany's SAR-Lupe and Italy's Cosmo-SkyMed systems. SAR-Lupe comprises a constellation of five X-band SAR satellites in three polar orbits that became operational in 2008. Cosmo-SkyMed is a constellation of four satellites with X-band SAR capabilities. The first satellite was launched in June 2007 and the full constellation was reported to be operational early this year.

France also launched four Essaim (Swarm) experimental ELINT satellites in December 2004. The country plans to launch the first of two very-high-resolution civil/military observation satellites called Pleiades at the end of this year, with the second satellite planned for launch in mid-2012.

vation—an international program including France, Italy, Belgium, Greece, Germany, and Spain to share imagery from various military satellites—was cancelled last May.

Last June Denmark pulled out of the NATO Alliance Ground Surveillance (AGS) program to provide an ISR capability based on the Northrop Grumman RQ-4B Block 20 Global Hawk that would enable NATO to perform persistent surveillance over wide areas from high-altitude, long-endurance, unmanned air platforms operating at considerable stand-off distances and in any weather or light condition.

The program began in 1995 and was originally developed as a broad network of manned and unmanned platforms—including an Airbus A321—with both national and shared assets. However, in November 2007, "due to declining European defense budgets, NATO chose to move forward with a UAV-only solution based on an off-the-shelf Global Hawk RQ-4B and the multiplatform radar technology insertion program (MP-RTIP)," according to NATO. In January 2009, the North Atlantic Council selected Sigonella Naval Air Station in Italy to host the UAVs and the ground segment (flight control capabilities and necessary command and control systems).

As of early 2011, the program was continuing to progress. A key project milestone was reached in December 2010 when Northrop Grumman delivered the first production multiplatform radar technologyinsertion program sensor to Edwards AFB for integration on the initial USAF Block 40 Global Hawk, one of the key technologies on which AGS will be based.

Transatlantic solutions

Where European technology providers have developed mature ISR, SIGINT, and ELINT technologies, there have been problems in finding a suitable platform. Where a platform has been found, the appropriate European technologies have been lacking.

As a result, European nations have looked increasingly across the Atlantic for solutions to their short-term requirements. This year, for example, Germany should take delivery of its first Euro Hawk UAV from Northrop Grumman equipped with a SIGINT mission built by EADS. The program is a transatlantic one—Northrop Grumman and EADS have established a 50-50 joint venture company in order to pursue it. The political framework for the program was laid back in May 2006, when the German ministry of defense and the U.S. Dept. of Defense signed a memorandum of understanding establishing conditions for cooperation on Euro Hawk.

The U.K.'s Royal Air Force will operate three RC-135V/W Rivet Joint sig-

The RAF will operate Rivet Joints provided by the USAF.

The Northrop Grumman-built Euro Hawk to be delivered to Germany will be equipped with a SIGINT suite built by EADS.

nals intelligence aircraft supplied under a Foreign Military Sales deal with the U.S. government. The aircraft are based on KC-135 airframes, which form part of the USAF tanker fleet. The first copy is to be delivered in 2014. L-3 Communications, which handles airframe and mission-system modifications on the Rivet Joints, will modify, refurbish, and install mission systems for the U.K. aircraft.

Looking ahead

To meet future intelligence needs, European nations will seek to increase cooperative efforts in new long-term technology programs. The EDA has helped pioneer a number of ISR programs recently, including the SPACE-BaSAR project2 to research high-resolution, wide-area angle-of-coverage research for a next generation of military SAR satellites, and the Tactical Imagery Exploitation Station study to investigate joint capabilities for tactical imagery exploitation. A key component of this will be the development of dual-use satellite imaging concepts, to help the spread of cost of implementing very-high-resolution imaging techniques.

As well as developing strategic intelligence gathering programs, there will likely be closer collaboration between the armed forces of individual states for tactical surveillance and SIGNIT/ELINT operations, especially in the coordination of UAV operations. This will probably mean that smaller European nations will develop more data-sharing agreements with countries such as Spain, France, Italy, Germany, Sweden, and the U.K. with the appropriate airborne and space-based ISR, SIGNIT, and ELINT capabilities. While some of these countries have been able to delay the upgrade of airborne platforms carrying this equipment, the age of some of the airframes and engines involved makes further delays difficult to contemplate.

There will also be a much closer realignment of intelligence gathering and dissemination agreements among NATO, the EU, and individual states. In the meantime, Europe still risks the technology gap between the continent and the U.S. growing if the appropriate agreements are not reached soon.

Philip Butterworth-Hayes
Brighton, U.K.
phayes@mistral.co.uk

Events Calendar

MARCH 5-12
2011 IEEE Aerospace Conference, Big Sky, Mont.
Contact: David Woerner, dwoerner@ieee.org; www.aeroconf.org

MARCH 15-16
2011 AIAA Congressional Visits Day, Washington, D.C.
Contact: Duane Hyland, 703/264-7558; duaneh@aiaa.org

MARCH 21-23
Ninth Annual U.S. Missile Defense Conference and Exhibit (SECRET/U.S. only), Washington, D.C.
Contact: 703/264-7500

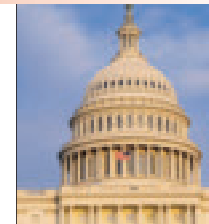
MARCH 28-30
3AF 46th Symposium of Applied Aerodynamics, Orleans, France.
Contact: Anne Venables, secr.exec@aaaf.asso.fr; www.aaaf.asso.fr

MARCH 29-31
Infotech@Aerospace 2011 Conference, St. Louis, Mo.
Contact: 703/264-7500

APRIL 4-7
Fifty-second AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference; 19th AIAA/ASME/AHS Adaptive Structures Conference; 13th AIAA Nondeterministic Approaches Conferences; 12th AIAA Gossamer Systems Forum; Seventh AIAA Multidisciplinary Design Optimization Specialist Conference; including AIAA Dynamics Specialists Conference. Denver, Colo.
Contact: 703/264-7500

APRIL 11-14
Seventeenth AIAA International Space Planes and Hypersonic Systems and Technologies Conference, San Francisco, Calif.
Contact: 703/264-7500

APRIL 13-15
First CEAS Specialist Conference on Guidance, Navigation, and Control, Munich, Germany.
Contact: DGLR, +49 228 30 80 5-0; gnc@dglr.de



Space, stealth, and Spartans

"WITH MIXED SIGNALS AND MICRO-managing, Congress is making a mess of the U.S. space program," reads an editorial in the January 20 *Orlando Sentinel*. Observers of the aerospace scene fear that NASA is imprisoned in a kind of limbo; but the administration is as likely as Congress to catch the heat for what one NASA scientist calls "confusion in terms of projects and priorities, and where we're heading."

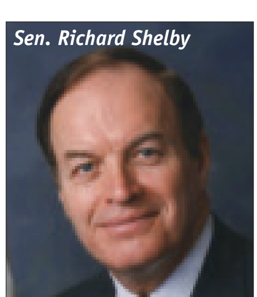
Across the globe, China was making headlines as well, as it introduced a new fighter, just when the U.S. secretary of defense was paying a visit.

The space shuttle Discovery's final flight was originally scheduled for last October. It was on the launch pad when the first of its problems was detected.

NASA faces fiscal woes

Like most of the U.S. government, NASA has been operating under a continuing resolution (CR) since October 1, without an appropriations law that covers FY11. But NASA is under greater constraints than other government agencies. The administration announced it would abandon Constellation, the Bush administration's Moon-Mars program, and develop a new rocket for human space exploration. But Congress—prompted by Sen. Richard Shelby (R-Ala.), who has many Constellation jobs in his home state—inserted into the FY10 budget a sentence requiring the agency to continue spending on the program.

Because the FY10 budget still applies as long as a CR remains in effect, NASA would be allowed to spend as much as $215 million on Constellation by the end of February, even though the program had been officially canceled and the term 'Constellation' banished from the agency's Washington, D.C., headquarters.



Sen. Richard Shelby

Sen. Bill Nelson (D-Fla.), who will face a difficult reelection campaign next year, is introducing legislation to repeal the 2010 requirement. Nelson's measure would, in effect, drive the final nail into Constellation's coffin. Meanwhile, NASA has had to publicly acknowledge that its goal of fielding a new heavy-lift launch vehicle (HLV) by 2016 is now out of reach.

A NASA document, *Preliminary Report Regarding NASA's Space Launch System and Multi-Purpose Crew Vehicle,* delivered to Congress on January 11, asserts that because of budget constraints, a first flight by the HLV "this early" does not "realistically appear to be possible." With respect to a crew vehicle to replace the canceled Orion, the report says, "none of the design options studied thus far appeared to be affordable in our present fiscal conditions."

Republicans, who took control of the House of Representatives last November in part by promising to rein in spending, are now saying they will seek to trim as much as $1.4 billion from NASA's budget before an overdue appropriations bill is passed. A cut this size would take the agency below FY10 levels and would roughly equal the entire cost of the HLV. Such cuts probably would not survive in the Democratic-controlled Senate, but a standoff could mean that no spending bill is enacted at all. That, too, would threaten the HLV.

Critics in Washington see a disconnect between spaceflight goals and hometown jobs, with lawmakers focused more on the latter than the former. Some critics accuse NASA's administrator, Charles Bolden, of not playing a large enough role in representing his agency on Capitol Hill, and even of failing to enunciate a vision for the agency's future.

While struggling to look ahead, NASA workers are also looking toward the end of the spectacularly successful shuttle program. The first of three final shuttle flights, the STS-133 mission by Discovery to the ISS, has experienced significant delays. The mission, as of this writing, was scheduled for February 24, to deliver the permanent multipurpose module, an external platform that holds large equipment and critical spare components for the station, as well as Robonaut 2, the first human-like robot in space.

For the penultimate launch, NASA named Marine Col. Frederick W. 'Rick' Sturckow as backup to Navy Capt. Mark Kelly to command the planned April 19 Endeavour STS-134 mission. Kelly's wife, Rep. Gabrielle Giffords (D-Ariz.) was gravely wounded in a Tucson shooting that killed six and injured 14. However, after several days of discussion and deliberation, Capt. Kelly decided to carry out his mission. Kelly's twin brother, Scott, was serving on the space station as commander at the time of the shooting.

For the "really, truly very last shuttle flight," as one observer put it—but with no FY11 budget yet, and hence no way to fund the mission—NASA announced in January that it has set a target launch date of June 28 for the shuttle Atlantis to embark on the final mission of the program. The newly scheduled Atlantis STS-135 flight, led by Navy Capt. Christopher Ferguson and with a crew of just four, will carry the Raffaello multipurpose logistics module, supplies, and spare parts to the ISS and return a faulty pump.

The prototype of the Chengdu J-XX made its first flight on January 11.

Chinese technology

Two high-profile January visits—by U.S. Defense Secretary Robert Gates to Beijing and Chinese President Hu Jintao to Washington—have prompted many in the nation's capital to take a closer look at China's trade advantages, technological competitiveness, and aerospace progress. Always the beneficiary of a distorted trade balance, China until recently was hugely dependent on the outside world when developing and producing aircraft.

Now, however, the U.S. may be losing the influence it was able to wield on Chinese activities in the aerospace field. Already widely seen by the outside world in controlled 'leaks' of still photography, the prototype of the Chengdu J-XX or J-20 Black Eagle very-low-observable superfighter made its first flight on January 11 during the secretary's visit to China.

Secretary of Defense Robert M. Gates shakes hands with Chinese President and Chairman of the Central Military Commission Hu Jintao at the Hall of the People in Beijing, China, on January. 11. DOD photo by Master Sgt. Jerry Morrison, USAF.

A Chinese Internet source reported that the J-XX "combines the innovative harmonization of 'extreme plus' agility, supersonic cruise, long range and persistence, and stealth." Hu assured Gates that the maiden flight of the fifth-generation competitor to the F-22 Raptor during his visit was "coincidence." Some U.S. officials hastened to play down both the timing and capabilities of the J-XX, although Gates acknowledged that the Chinese "may be somewhat further along" than U.S. intelligence previously believed.

Several China experts wrote that there are no coincidences in that country, dismissing the notion that the timing of the flight resulted from miscommunication between Beijing's civilian and military leaders. "The Chinese wanted that plane to fly while Gates was in town," said a former State Dept. China analyst.

Although the C919 has so far been purchased only by domestic carriers, it is expected to do well on the world market.

Some defense analysts dismissed the J-XX by saying the Chinese superfighter is using heisted U.S. technology. China, they wrote, gained access to the U.S. F-117 Nighthawk stealth fighter that was shot down in Serbia during fighting over Kosovo in 1999. But the kind of stealth used by the F-117 was entirely different from that of the J-XX and F-22. House Armed Services Committee chairman Buck McKeon (R-Calif.) charged the Chinese with copying foreign technology but said it was Russian rather than U.S. know-how they had lifted.

A C-27J Spartan Joint Cargo Aircraft waits at the 179th Airlift Wing at Mansfield Lahm Airport in Ohio. Credit: Ohio ANG/SrA Joseph D. Harwood.

The charge that China lacks the engineering and scientific skills to develop its own stealth fighter reminded some observers of a popular myth: that Japanese aircraft designer Jiro Horikoshi had stolen from the U.S. when he created the incomparable Mitsubishi A6M Zero fighter in the late 1930s. Very much homegrown, the Zero outperformed even the best U.S. fighters in the early part of the Pacific war. A Communist Party newspaper in China insisted the J-XX is an indigenous design and quoted test pilot Xu Yongling as calling it "a masterpiece of China's technological innovation."

Long dependent on U.S. and European industry in the commercial aerospace field, China is now developing its own domestically built large passenger jet. The Commercial Aircraft Corporation of China (COMAC) C919 will compete head-to-head with the Boeing 737 and Airbus A320/321—the two most successful and numerous airliners in the world. The Chinese planemaker announced last November that it has signed orders to sell more than 100 C919s to three domestic carriers—Air China, China Southern Airlines, and China Eastern Airlines. No one in Washington expects much time to pass before the company sells C919s overseas.

"China's grand ambitions extend literally to the Moon," wrote Keith Richburg in the *Washington Post* on January 23. At the time of Hu's Washington trip—again, say observers, there was no coincidence—Chinese news media reported a new program to train astronauts, or 'taikonauts,' for missions to an orbiting Chinese space station planned for 2015. China is also actively working toward its first manned Moon landing.

Joint cargo aircraft

The Pentagon continues to confront problems with the C-27J Spartan Joint Cargo Aircraft (JCA), the twin-turboprop airlifter meant to supply troops near the front lines by carrying small payloads to unprepared airstrips.

Col. Gary McCue

The JCA, originally known as the Future Cargo Aircraft, began as an all-Army program to replace that service branch's fleet of aging C-23 Sherpa transports. Following interservice debate and, ultimately, agreement, the Air Force took over the program in 2007. At that time, the plan was to acquire 78 airframes. Italian manufacturer Alenia pledged to build an assembly plant in Jacksonville, Florida.

The buy of JCAs has since been cut to 38 aircraft, and the Florida facility is no longer part of the plan. The Air National Guard will operate the planes, the first time guardsmen have flown an aircraft not used by the active-duty force. An operational Guard unit will have just four C-27Js, a total some critics say is too small to justify keeping a squadron in service. Hometown Guard units enjoy tremendous support on Capitol Hill, and many legislators have sought to get C-27Js in their constituencies.

The C-27J fleet was grounded at the end of December 2010 after maintainers discovered metal shavings inside the fuel cells of all eight aircraft currently in inventory. The on-line trade journal *airforce-magazine.com* reported that officials believe the problem was caused during manufacture. Following the grounding, three C-27Js at a temporary joint Army/Air Force training facility at Warner Robins, Georgia, were returned to flight. But three at the Guard's 179th Airlift Wing at Mansfield Lahm Airport in Ohio and two aircraft undergoing predelivery modifications in Waco, Texas, remained grounded while workers waited for spare parts.

The commander of the 179th, Col. Gary McCue, said in an interview last fall that he was being tasked, paradoxically, to achieve initial operating capability in 2012 but to deploy C-27Js to Afghanistan this year. McCue and other officials say they are still planning to take the C-27J to the war zone in March, but the grounding clearly delayed much-needed training time for the Air National Guard crews. Changes in the JCA program have occurred so rapidly that many of the C-27Js now in inventory are still painted in obsolete Army colors.

Robert F. Dorr
robert.f.dorr@cox.net

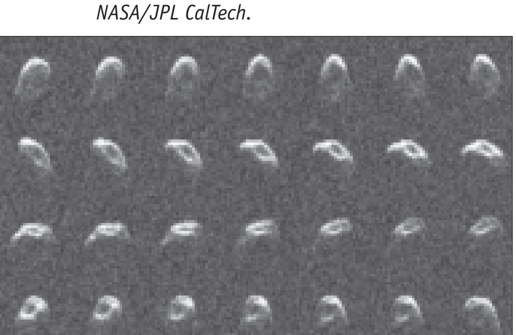
Robert F. Dorr's book Mission to Berlin, *about B-17 Flying Fortress crews in WW II, will be published this month by Zenith Press.*

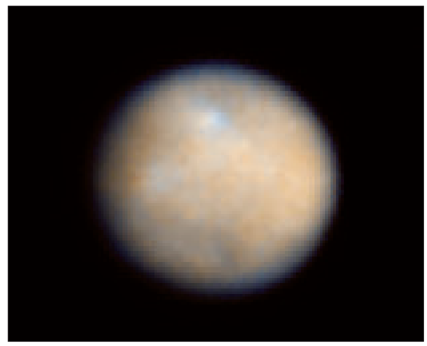
Mapping a course to the asteroids

LAST DECEMBER, TUMBLING SILENTLY in its endless fall around the Sun, asteroid 2010 JL33 swept to within 8.5 million km of Earth, about 22 times the Moon's orbital distance. Discovered by the Catalina Sky Survey in Tucson on May 6, 2010, the 1.8-km-wide JL33 is one of millions of small asteroids and comets that cruise the inner solar system. During its close approach, JL33 came within range of the Goldstone solar system radar, which bounced a tightly focused radar beam off the asteroid. A JPL team recorded a series of images covering nearly a full, 9-hr rotation of JL33's impact-scarred surface, revealing its irregular topography, precise orbit, and axis of rotation.

Ghostly JPL/Goldstone images reveal a prominent impact crater gouged from the pebble-shaped asteroid. The portrait adds to our small but growing body of knowledge of these ancient, enigmatic near-Earth objects (NEOs). Comprised of near-Earth asteroids (NEAs) and the much rarer near-Earth comets, they represent a long-term hazard to Earth, a rich source of scientific information on the solar system's formation, and a source of potentially valuable space materials. And last year they rose to prominence in NASA's plans for future human exploration.

NASA's Goldstone solar system radar captured these images of asteroid 2010 JL33, obtained on December 11 and 12, 2010. The Goldstone and Arecibo radars perform important follow-up investigations of NEOs discovered by other ground-based facilities. Image courtesy NASA/JPL CalTech.





This 2003-2004 Hubble image of asteroid 1 Ceres suggests surface material variations on this 980-km-wide NEO. Ceres probably has a layered interior of rocky inner core, an icy mantle, and a thin, dusty outer crust.

Budget barriers

President Obama declared last April that the U.S. would launch an astronaut expedition toward a near-Earth asteroid by 2025. Specifics were few, however. Now, with the Constellation program effectively ended by the president and Congress, asteroid exploration appears to be the only long-range human deep-space activity NASA has approval to pursue. Yet with the FY11 budget still in limbo, and talk circulating that NASA's exploration office will soon merge with its space operations mission directorate, an 'asteroid program' has yet to take shape.

Although last October's authorization bill terminated Constellation, release of funds to other exploration activities, such as NEA missions, awaits final appropriation action by the Congress. The authorization also directed NASA to develop and fly a heavy-lift rocket by 2016. Such a booster, based on shuttle and Constellation heritage, is a key requirement for human exploration beyond the space station.

The heavy lifter will presumably carry an Orion spacecraft, but neither the White House nor Congress has approved any hardware architecture or schedule for a true deep-space mission capability.

To propose a way forward, NASA's Exploration Systems Mission Directorate (ESMD) has for nearly a year been evaluating possible combinations of technologies, schedules, and budgets that might produce a national capability to reach the asteroids, Moon, and eventually Mars. HEFT, the Human Exploration Framework Team, issued a status report in January, to be followed by a full report this spring.

The January HEFT results were not encouraging, with the NASA team noting that no combination of heavy-lift boosters, deep-space craft, in-space propulsion, and projected technologies enabling beyond-LEO exploration could be produced by the 2016 congressional deadline or within long-term budget projections. At best, NASA could achieve a solution that satisfied only two of the three specified high-level constraints, traded among performance, schedule, or budget.

The agency's sobering assessment echoes the Augustine committee's 2009 conclusion that relatively static funding levels and traditional procurement practices would doom Constellation's lunar return plans.

Senators Bill Nelson (D-Fla.) and Kay Bailey Hutchison (R-Texas) responded quickly that NASA should get on with producing both the heavy lifter and Orion. Nelson told Administrator Charles F. Bolden that "he has to follow the law, which requires a new rocket by 2016," adding, "and NASA has to do it within the budget the law requires." The HEFT stated it will continue to study combinations of vehicle architecture, systems, propulsion, and technology that can deliver a human deep space exploration capability.

Asteroid recon

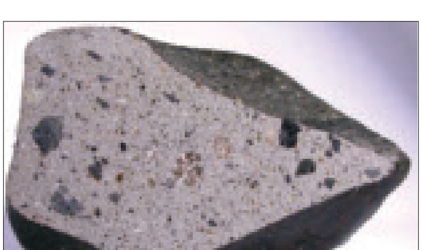
If NASA aims for a human NEA capability, it will need much more information about possible asteroid destinations. To date, just two spacecraft have explored NEAs in detail: NASA's NEAR-

Shoemaker probe landed on 433 Eros in 2001, and Japan's Hayabusa mission returned a microsample of asteroid 25143 Itokawa to Earth last June.

New asteroid data should arrive this summer from NASA's Dawn mission. The ion-driven Dawn spacecraft will visit the two most massive 'protoplanets' in the main asteroid belt between Mars and Jupiter, the source of the Earth-approaching population. The spacecraft will thrust into orbit around asteroid 4 Vesta this August, map its surface in detail, then depart for a rendezvous with the largest asteroid, 1 Ceres, in February 2015.

Spectroscopic observations and meteorite studies suggest that 580-km-wide Vesta is a dry, differentiated body surfaced with lava flows. Mineral composition varies across Vesta's surface, suggesting interior layers are exposed; an apparent impact crater 460 km in diameter lies near the south pole. Fragments excavated by that impact may have arrived on Earth in the form of once-molten igneous meteorites called HED achondrites. Dawn's orbital survey should yield clues about what heat source and style of volcanism produced these impact-welded assemblages of lavas.

Ceres, some 980 km across and only slightly farther from the Sun than Vesta, appears radically different. Its surface exhibits the spectroscopic signature of water-bearing clays. Ceres' north pole may host a thin cap of water frost, fed from a subsurface reservoir of ice incorporated during its formation 4.5 billion years ago.



The Sioux City eucrite meteorite, an amalgam of pulverized silicate fragments and dark basalt lava, is linked to melting, differentiation, and impact processes experienced on Vesta. Image courtesy Arizona State University, J. Kurtzmen.

Large asteroids like Ceres and Vesta are probably the parent bodies of many smaller objects fed into the inner solar system by collisions and gravitational nudges from massive Jupiter. NEAs are objects whose perihelion distances are less than 1.3 AU; a subset with Earth-approaching orbits are potential targets for robotic and human exploration.

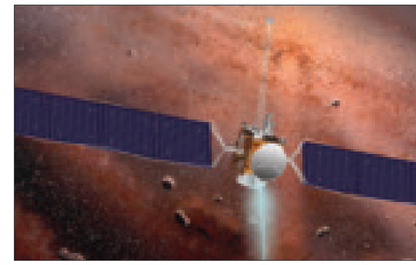
Both NASA's Science Mission Directorate (SMD) and ESMD may pursue missions to NEAs in the coming decade, to learn more about their varied properties, compositions, and origins. NASA is studying the Osiris Regolith Explorer, aimed at returning a 150-g sample from the volatile-rich NEA 1999 RQ36. JAXA's Hayabusa II sample return mission, just approved, will complement NASA efforts.

I serve as principal investigator on a new NEA mission concept called Amor, currently under evaluation for NASA's Discovery robotic exploration program. The Amor mission is designed to address NASA's solar system science priorities and obtain physical measurements vital to human exploration plans and future efforts to deflect a rogue asteroid.

Amor will rendezvous with, land on, and explore a remarkable triple asteroid system. The C-type (carbonaceous) NEA 2001 SN263 is accompanied by two small moonlets. The primary object, Alpha, is 2.8 km wide. Satellites Beta and Gamma are 1.1 and 0.4 km across, respectively. Beta is outermost, its orbit around Alpha spanning some 30-35 km.

The SN263 system's elliptical orbit circles the Sun once every 2.8 years, inclined about 7 deg from the ecliptic. The orbit crosses that of Mars and swings deep into the main asteroid belt. At its inward reach, the system comes as close as 0.06 AU to Earth.

Ground-based spectra classify SN-263 as a C-type asteroid, the dominant type in the main belt; the C-types are thought to be volatile and organic-rich objects relatively unaltered since formation 4.5 billion years ago. Their low



NASA's Dawn will orbit around asteroid 4 Vesta, then depart for a rendezvous with 1 Ceres.

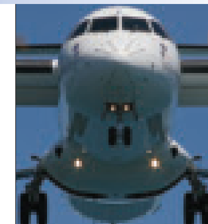
albedo (about 5% reflectivity) makes them difficult to study from Earth, and spacecraft have provided only distant glimpses of two main belt C-types. The Amor spacecraft is designed to study this enigmatic C-type system at extremely close range, taking science to the surface.

Amor will launch aboard an Atlas V booster in January 2017 to begin its nearly five-year journey to SN263. Following an Earth gravity assist and several asteroid flybys, the spacecraft arrives at the triple system in November 2021. Eight months of detailed study follow, including high-resolution mapping and landings on at least two of the asteroid components. Amor will return answers to questions high on NASA's list of science priorities:

- What are C-type asteroids?
- Are these asteroids truly linked to the primitive, carbonaceous chondrite meteorites?
- Are C-types truly rich in water and organic compounds?
- How do multiple asteroid systems form?
- How could we avert an impact from a C-type NEA?
- What resources do C-types offer to future human exploration?

As it stationkeeps with the SN263 system, Amor will use the NEOCam color imager to map the three components, develop a detailed shape model of each body, and choose landing sites on Alpha and one of the two satellites. After several practice approaches enabling a detailed look at the landing terrain, Amor will maneuver onto a trajectory that matches asteroid rotation

(Continued on page 17)



MPAs: Statements of global power

In the U.S. and elsewhere, the fixed-wing maritime patrol aircraft (MPA) market has recently made a comeback. Spurred by the availability of new equipment and a growing awareness of MPA utility in projecting force in contested waters, the market has returned to life. Until India's early 2009 P-8 buy, the high-end MPA market had seen no new orders in almost two decades.

Yet while the P-8 represents a new catalyst for market growth, the two biggest markets outside the U.S. have taken widely divergent paths. And China's minimal MPA force represents the biggest mystery on the market.

The U.S. finally gets it right

During the Cold War, the U.S. Navy acknowledged that Lockheed Martin's P-3 Orion was indeed the optimal MPA design. In fact, the long-range air anti-submarine warfare (ASW)-capable aircraft P-3 replacement program resulted in Lockheed's P-7, which, in effect, was a rejuvenated P-3. Unfortunately, serious technical problems and the end of the Cold War resulted in a decision to cancel the P-7 in July of 1990.

This led to a multidecade MPA procurement hiatus and a badly aging P-3 fleet. But Boeing's P-8 Poseidon, chosen in June 2004 as the P-3's second replacement under the MMA (Multimission Maritime Aircraft) program, has had a relatively successful development. The P-8 made its first flight in April 2009; the first test plane arrived at Patuxent River in April 2010.

Current plans call for the Navy to purchase 117 P-8As, to be used for ASW, anti-surface warfare, intelligence, surveillance, and reconnaissance missions. Initial operational capability is planned for 2013.

Notably, the Navy's MMA Analysis of Alternatives clearly ruled out a UAV-based approach; however, it did state that UAVs should be part of a long-term MMA architecture. This has led to the BAMS (Broad Area Maritime Surveillance) effort, a P-8 adjunct. Northrop Grumman's Global Hawk won this contract in April 2008. The first two BAMS test aircraft and a ground station will be delivered in 2012. The Navy has plans to procure about 40 aircraft.

P3

Emerging powers

The P-8 program received a major boost in December 2008, when the Indian navy placed the first export order—eight P-8s for delivery by 2016. Cost of the deal was estimated at $2.13 billion. In December 2010, Boeing began fabricating parts for the first Indian P-8.

After the P-8 order established India's intention to create a robust MPA force, the country abandoned plans to buy a select adjunct force of small turboprop MPAs. Instead, in October 2010 the country announced plans to buy four more P-8s. Clearly, India has made blue water MPA capability a key part of its strategic ambitions.

Y-8X

In contrast with India's blue water MPA ambitions, China, Asia's other key emerging power, fields a remarkably small fixed-wing patrol force. The People's Liberation Army Naval Air Force (PLANAF) uses the Shaanxi Y-8X MPA (X is for Xun—surveillance). A Chinese copy of the Soviet/Russian Antonov An-12 transport, the Y-8 is a four-turboprop design. In its MPA in-

P-8

carnation it is unarmed, but carries a capable array of avionics and sensors. Some of this equipment is Western, including a Litton Canada AN/APS-504 search radar. It has been in service with the PLANAF since 1985.

The PLANAF also uses the Harbin SH-5 maritime bomber, an amphibious design capable of ASW and search and rescue operations. It, too, has been in service for about 25 years. China's only other MPA is Harbin's Y-12, a small twin turboprop with minimal sensors and no weaponry. It is primarily used for observation duties.

China's MPA fleet has received remarkably scant resources. The two primary fixed-wing aircraft have certainly been in service long enough to be described as 'mature' systems, yet just a handful have been deployed. Just four Y-8s and another four SH-5s constitute the entire MPA fleet, and one of the SH-5s has been fitted as an aerial firefighter.

There are also no new Chinese MPA programs currently in development. While there have been rumors over the past decade of a PLANAF deal to buy 20 Beriev Be-200 amphibious jets for search and rescue duties, nothing firm has materialized. Fewer than 10 Be-200s have been built since the type made its first flight in September 1998.

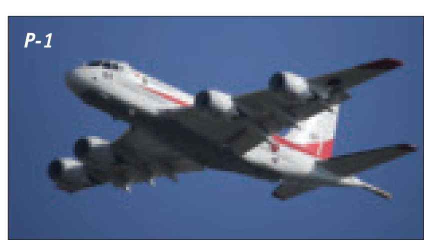
In short, for all the chatter about China's intentions to become a serious maritime power, there is no evidence of this in its MPA force. The 2001 Hainan Island incident, which saw the collision between a U.S. EP-3 surveillance plane flying near several key Chinese military bases and a Chinese fighter jet highlighted a significant difference between the two countries in terms of global reach. Notably, South Korea and Taiwan both field P-3C fleets that are considerably more capable than China's MPAs.

Japan goes it alone

The Japan Maritime Self-Defense Force (JMSDF) is historically the second largest MPA fleet operator, after the U.S. The country procured 110 P-3s and P-3 variants, with most of these still in service with the JMSDF.

Sh-5

As a follow-on to the P-3, the JMSDF plans to procure Kawasaki's P-1 (formerly P-X), a four-engine jet using new Ishikawajima-Harima F7-10 engines and a Japanese mission control system. Kawasaki Heavy Industries was selected to lead the program in December 2001, and the airplane made its first flight in September 2007, with flight tests scheduled through 2015. The Japanese military wants to buy 80 P-1s, plus 40 C-2s (formerly C-Xs), a Kawasaki-built transport airplane that will be designed with some commonality with the P-1. Development costs are estimated at $3 billion in 2007 dollars.

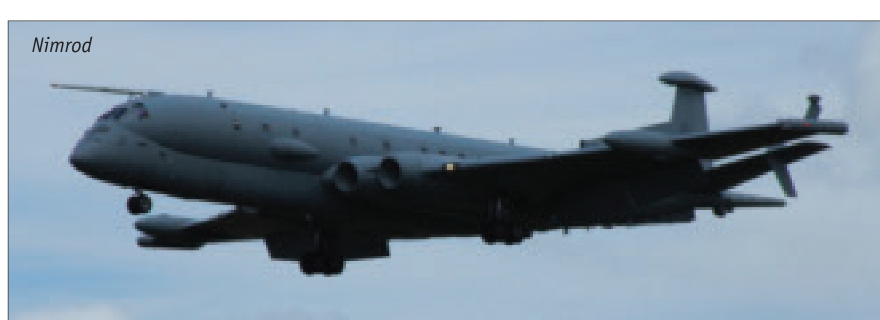


P-1

Four XP-1 test aircraft were built through late 2009, with another two built in 2010. There has been a relative absence of news about the flight test program, and there is no denying that this is a very ambitious effort. Not only is it one of the largest aircraft ever built in Japan, but it also has a high level of concurrency, with all-new engines and a new mission control system being developed alongside an all-new airframe. There are a number of technologically advanced new features being developed for the plane, including a Toshiba active electronically scanned array radar and a fly-by-light control system, the first such control system for a production aircraft. All of this adds a great deal of technical risk to the program.

Still, the FY11 Japan defense budget provides ¥5.5 billion for three P-1s, up from the one aircraft funded in FY10. That first plane is scheduled to be delivered in March 2012.

Japan's FY11 budget also calls for a life extension program for the current P-3 fleet, with ¥600 million in funding for the first aircraft modification. This reflects a commitment to maintaining a strong MPA fleet, as well as a hedge against a P-1 program failure or any program delays. Since the Japanese constitution prohibits defense exports, all P-1 program expenses will be borne by the Japanese government.



Nimrod

The U.K.'s shortfall

By contrast with Japan's decision to prioritize maritime patrol, the U.K., historically the third biggest MPA market, has basically announced plans to eliminate its fixed-wing MPA force. There is considerable uncertainty surrounding this move, and no way of telling whether it represents a permanent decision or merely a temporary deferral of fleet recapitalization needs.

In October, the U.K.'s Strategic Defence and Security Review (SDSR) killed the Nimrod MRA4 MPA project. This rather extraordinary decision capped a long and unpleasant effort to develop a follow-on to the original Nimrod MPA, which had served in the Royal Air Force since the late 1960s.

BAE Systems won this contract in July 1996 with its Nimrod 2000 design, using new Rolls-Royce engines, new systems, and a new Boeing-designed mission control system. This locally created alternative won against a new version of Lockheed's P-3. The U.K. planned to remanufacture 21 older Nimrods to this modern configuration, designated MRA4.

Due to problems with the existing airframes and the need to maintain commonality, this quickly became a largely new-build program. By the time the SDSR killed it, the MRA4 was 10 years late. Also, there was about $1.5 billion in projected cost overruns, and the procurement objective had been slashed to just nine production aircraft, plus three prototypes.

Immediately after the SDSR decision, the existing MRA4s were destroyed, removing any hope of a reversal. Also, the decision was not accompanied by any discussion of an alternative for the MPA future force. SDSR also scrapped the RAF's airborne stand-off radar (ASTOR) force, a fleet of five Bombardier Global Express business jets used for surveillance. Since these had just entered service in June 2007, the clear implication has been that intelligence and surveillance aircraft of all kinds will receive a very low priority in the U.K. budget.


ATR-72

Other markets, other possibilities

Most other countries have a more coherent vision for their MPA fleet future. For example, France has announced a new upgrade program for its fleet of Dassault Atlantique 2 MPAs, and a plan to procure a force of Dassault Falcon 2000 business jets modified for MPA duties as an adjunct force. Since the SDSR was announced in conjunction with a U.K. government plan to cooperate on certain defense missions and roles with France as an austerity measure, it is conceivable that the Atlantique/Falcon force may become a shared fleet.


Atlantique

The other key MPA markets will likely wind up procuring P-8s. Even New Zealand, a small power but one with a key maritime role, has discussed procurement of four P-8s, and the country is upgrading its present P-3C fleet. Australia is leaning toward a P-8/BAMS solution under its AIR 7000 program, with likely procurement of 8-9 P-8s. Canada, too, will likely replace its P-3s with P-8s. Italy has also expressed strong interest in a P-8 acquisition, but budget cuts mean this will likely need to wait a few years, at least.

For countries without an Atlantique or a P-8, there are many less capable choices. UAVs and adaptations of twin turboprop aircraft and smaller regional jets (such as Embraer's ERJ 145) have a strong utility for adjunct MPA duties, such as search and rescue, fisheries protection, and maritime zone surveillance. They are also useful for operations in the shallower coastal regions that do not need the deep water sensors and long range of a P-8 or its equivalent. And of course they are useful for countries that cannot afford a high-end blue water MPA fleet. In late 2008 the Italian government approved the purchase of four firm and one option ATR 72 MPAs. These might be an interim force until funds become available for the P-8, or they might become an adjunct force.

But because of the MPA4 cancellation, we cannot rule out the prospect of the U.K. winding up with a force of these smaller planes. Compared with the Royal Navy and RAF's historically strong naval presence, that would be the saddest MPA market change of all.

Richard Aboulafia
Teal Group
raboulafia@tealgroup.com

Asteroids

(Continued from page 13)

and brings the spacecraft to a point just 10 m above the surface. The 3-axis-stabilized vehicle, built by Orbital Sciences, then free falls to the surface under the few micro-*g*s of local gravitational acceleration.

Once on the surface, held fast by a set of auger-like anchors, Amor begins a week of intensive surface investigation. Operations and science teams at NASA Ames deploy both the NEONS (neo spectrometer package) for major element composition and the CHAMP (camera hand-lens and microscopic probe) macro/microscopic imager. The articulating, 2-m-long robot arm carries CHAMP into close contact with the surface to characterize surface mineral texture and structure down to submillimeter scales. CHAMP's strobe-lit color images, along with bulk elemental composition from NEONS, will test the suspected link between the C-type surface and carbonaceous chondrite meteorites. If confirmed, the link will enable us to use terrestrial meteorite samples to assess the mineralogy, thermal history, and practical resources of C-type asteroids.

Astronauts to asteroids

Missions like Amor, Hayabusa II, and others would scout the properties of a variety of NEAs and assess techniques for proximity operations, resource prospecting, and anchoring to varied asteroid surfaces. A series of robotic missions over a decade should be sufficient to inform the details of an astronaut expedition. Constellation program studies and industry concepts like Lockheed Martin's Plymouth Rock have outlined how an early NEO mission might be conducted.

A piloted asteroid mission capability would have at its core a heavy launch system and a beyond-LEO spacecraft (Orion). Following a flexible path toward deep space, NASA could add the hardware components needed to enable visits to asteroids, Lagrange points, or the Moon's surface, depending on national priorities.

Asteroid missions could do without the expensive lander or habitats sited on the lunar surface, but they do require more crew consumables and habitation space than sortie-class lunar missions lasting just a few weeks. A hab module, either derived from ISS experience or a TransHab-style inflatable design, would be added to propulsion and crew reentry modules assembled in LEO or at a Lagrange point. Together the reentry, propulsion, and hab components would form a spacecraft capable of multimonth asteroid expeditions.

Lockheed Martin's Plymouth Rock mission concept would use a pair of Orion spacecraft to take an astronaut crew to a nearby asteroid. The vehicle would support a crew for about 6 months, including a two-week exploration phase at the asteroid. Image courtesy Lockheed Martin.

A few known asteroids offer round-trip delta-V requirements equal to or less than a lunar expedition, but propulsion for a crewed NEA mission might call for refueling from an orbital depot or multiple propellant tank launches. Minimizing required propellant costs creates a large incentive to start a thorough search for accessible asteroids as soon as possible.

Last fall, a NASA Advisory Council task force on planetary defense recommended that NASA launch a space-based search telescope into a Venus-like orbit to catalog NEOs. The hundreds of thousands of asteroids and comets discovered would greatly aid NASA's science, exploration, and planetary defense programs.

Encounter

The hab module would house consumables, radiation shielding, exercise gear, and docking ports for EVA suits or small exploration craft. Following Earth departure and several months of cruise, a three- or four-person crew would rendezvous with the chosen asteroid, already scouted by a robotic explorer. Following a few days of surface reconnaissance using a small teleoperated probe, a pair of astronauts would translate to the asteroid surface in personal spacecraft whose handling qualities had been checked out years earlier at the ISS.

These 'multimission exploration vehicles,' or MMEVs, would ease the jobs of surface anchoring and asteroid sampling. Should science requirements or problems on the surface demand it, astronauts could conduct space-suited EVAs, but mobility, productivity, and reduced fatigue favor use of the MMEV, with its shirt-sleeve environment and stationkeeping autopilot. ESMD has been studying MMEV concepts derived from work on its lunar electric rover.

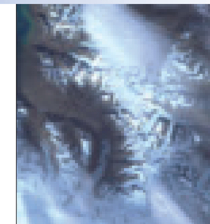
During a two-week exploration phase, the MMEVs should enable more wide-ranging, sustained surface investigations than spacesuits alone. A major activity would be physical properties measurements aimed at developing deflection techniques. After stowing NEA samples totaling tens of kilograms aboard the reentry vehicle, and deploying science packages and resource extraction demonstrators, the crew would prepare the cruise vehicle for Earth return.

Sustained exploration

After a multimonth cruise to Earth, the astronauts would undock their reentry module for a direct entry into the atmosphere, while the deep space vehicle maneuvers into a high Earth orbit for refueling and refurbishment. This concept preserves the hab, personal exploration craft, and propulsion modules for reuse. Later asteroid explorers might return with their cruise vehicle to a Lagrange point, transferring with their samples to a waiting reentry transport.

Although more costly initially than a minimalist approach using, for example, coupled Orion spacecraft, reusable exploration vehicles can be adapted for repeated use throughout the Earth-Moon system, to nearby asteroids, and eventually to the Martian moons. Addition of a lander for lunar surface sorties or descent to Mars itself is a natural evolution of this sustained approach to exploring deep space.

Thomas D. Jones
Skywalking1@gmail.com
www.AstronautTomJones.com



ICESat 2: Laser eyes on Earth's changing ice

When climate scientists began using the laser-equipped ICESat spacecraft to measure the thickness of the Earth's ice sheets in 2003, they encountered a series of technical and scientific problems. Engineers hope to overcome these by shifting to a completely new design for ICESat 2.

That mission is now in its definition phase for a January 2016 launch and is one of NASA's top Earth science priorities.

ICESat was equipped with three lasers that were turned on in succession as each wore out. Forty times a second, ICESat bounced lasers off the ice, received the reflections through its telescope, and used the transit time to calculate the height of ice sheets in Greenland, the Arctic, and Antarctica. Formally known as the Ice, Cloud, and Land Elevation Satellite, it took atmospheric readings and studied forests. But its primary mission was to help determine whether the planet is in fact losing ice due to global warming, information that could improve predictions of sea level rise.

With ICESat, scientists knew that they would need about 12 passes over a location to assure themselves they were measuring actual changes caused by melting or accumulating ice. Ice sheets are often sloped, and when the lasers landed a few meters uphill or downhill on subsequent passes—as is inevitable when a laser is pointed earthward from 600 km in orbit—readings could look like changes in thickness. The only way to subtract the changes would be to determine the slope first by making multiple passes.

Accomplishing the required passes turned out to be harder than expected. The first ICESat laser fizzled in just 37 days because of what engineers suspect was electronic erosion caused by solder. Because ICESat's goal was to look for changes over time, NASA was forced to conserve ICESat's laser power by turning the instrument on just three times a year—typically February, June, and October. The device was operated on 33-day collection campaigns and at lower temperatures to slow the erosion.

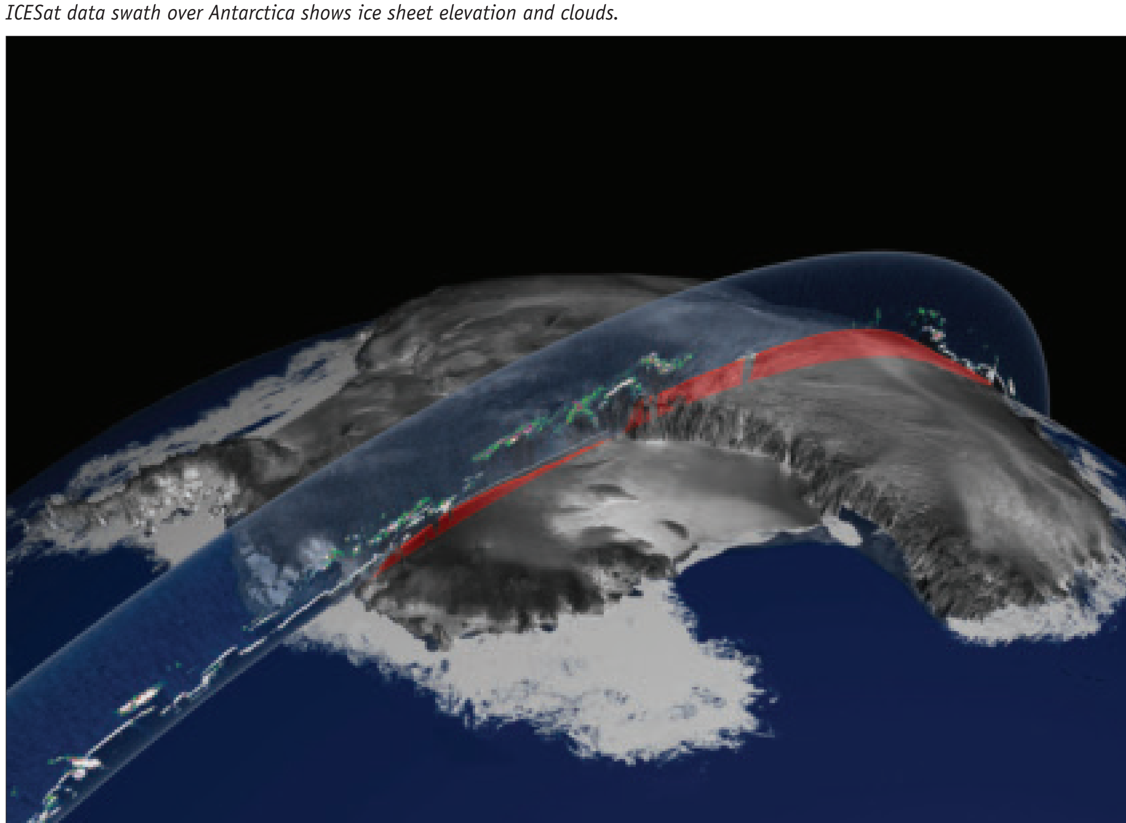
"We had to collect five years of data to get good solutions," laments NASA glaciologist Jay Zwally, who came up with the basic concept behind ICESat in the 1980s. Even with its shortcomings, ICESat delivered valuable data before losing laser power in 2009 and reentering the atmosphere in August 2010. ICESat depicted the subsidence and uplift that occurs when water flows beneath glaciers, and it measured sea ice freeboard, the distance between the surface of the ice and the water.

Fresh start

At an instrument science requirements review in December 2010, NASA engineers finalized the basic outline of their plan to avoid the pitfalls encountered during the first ICESat effort. Just about everything will be different on the follow-on mission, from the frequency of the laser signals to the number of beams.

"We're using a completely different kind of laser," says NASA Goddard systems engineer Tony Martino, the

ICESat data swath over Antarctica shows ice sheet elevation and clouds.



architect for ICESat 2's advanced topographic laser altimeter system, or ATLAS. "The big challenge is, we've never flown an instrument like this in space before," he says.

The original ICESat made altimetry measurements by transmitting pulses of laser energy 40 times a second in a single beam, with a power of 75 mJ for each pulse. For ICESat 2, engineers plan to transmit not one but six beams. The pulses will be rapid-fire, bouncing off Earth at a rate of 10,000/sec, which is what makes the effort unique for a space mission, Martino says. To make the overall power demands achievable, the pulses will be 1,000 times weaker than ICESat's altimetry pulses, creating a need for highly sensitive detectors in the craft's telescope. Three of the six beams will have an energy of 150 µJ per pulse, and the others about a quarter of that energy, "with the exact value to be determined," he says .

Engineers are banking that sending thousands of lower energy pulses every second will be less taxing on the laser system than sending dozens of more powerful ones.

"Since there's less stress on the components, these lasers should last longer," explains Tom Neumann, the ICESat 2 deputy project scientist.

Although the measurement approach is new for a space instrument, the technologies behind it are not considered to be particularly risky. "There is very little that is incredibly new," says Matthew McGill, the principal investigator for the ICESat 2's ATLAS instrument. Using all the components together may be new (or not)," he adds by e-mail. He says the Dept. of Defense has used the approach.

Multiple beams

Primarily, the switch to six beams is meant to improve the science readings. When a new measurement lands from a single beam, "you don't know whether it's because you hit a different place, or whether the ice has grown or shrunk," Martino says.

In the new approach, six beams will land perpendicular to the orbital path and track along the surface like a push broom. Originally, the scientists wanted 16 beams, but in 2009 they reduced the number to nine, then to six last year. "In order to get cost down, we had to do a number of descopes, and that was one of them—reducing the number of beams," Neumann says.

The mission's $650-million target cost includes three years of operation. It far exceeds the $300-million "rough cost estimate" envisioned for ICESat 2 in 2007 by NASA's first decadal survey of Earth science priorities. "The decadal survey numbers were a challenge to a lot of folks because they didn't include things like launch vehicle costs, which are large and growing," he adds.

Even with the six-beam compromise, scientists expect ICESat 2 to deliver more and better readings. With the original satellite, measuring the slope of an area took years, but "with ICESat 2, we'll be able to measure the slope on each pass," says Neumann. Scientists would be able to devote more time to looking for changes in ice cover.

"We are hoping from this approach we can take care of the problems on ICESat," adds laser physicist Anthony Yu, a member of the laser team at Goddard.

Technical solutions

As for workmanship issues, NASA engineers plan to build the instrument themselves with lasers procured commercially. In the case of ICESat, investigators concluded that excessive indium solder was used to attach the laser's heat sink, the device that was supposed to protect the laser electronics by absorbing excess heat. The indium caused a metallurgic reaction that eroded the gold wires that fed current to the laser diodes. Those diodes were critical, because they pumped energy to the laser source known as yttrium aluminum garnet, or YAG. After the first laser failed, engineers theorized that the gold would erode faster at higher temperatures, so ICESat managers lowered the operating temperature.

To avoid something like that on ICESat 2, engineers plan to capitalize on improvements made in the telecommunications industry, which uses diodes to help transmit data through fiber optic cables. "The telecommunications industry is helping out here because they have developed highly reliable pump modules that have essentially zero failure rate in the field," Yu says. "The workmanship and quality are much better."

Engineers also think they have a solution to a separate problem that cropped up when scientists began running ICESat's second laser. The engineers suspect this laser lost power rapidly, because hydrocarbons in adhesives vaporized in the vacuum of space and accumulated on the laser crystal, darkening it.

On ICESat 2, "that module is going to be pressurized with clean, dry air to mitigate that problem," Yu says.

New challenges

The decision to turn to a rapid-rate, low-energy approach solves some engineering issues but creates others. On ICESat 2, the detectors that receive the reflected energy via the spacecraft's telescope must be extremely sensitive because of the low energy.

The problem is, the most sensitive detector materials are designed for the green portion of the spectrum, but laser light is easiest to generate in the infrared. "You end up with this mismatch between what the lasers are good at and what the detectors are good at," Neumann explains.

The solution will be to generate infrared laser energy but use a set of optics called a frequency doubler that will shift the 1,064-nm IR wavelengths to higher frequency 532-nm green wavelengths. The first ICESat spacecraft's signals were strong enough that engineers had the luxury of making the altimetry readings in the infrared. The main purpose of that satellite's frequency doubler was to create green light for atmospheric measurements, Yu says.

With 10,000 pulses arriving at the detectors every second, the detector material will have little time for electromagnetic recovery between pulses. The light arrives so quickly that ICESat 2 must measure the transit time of individual photons. By contrast, the original ICESat received lots of photons measured as voltage.

“The detection system gets a little more complicated because we're responding to individual photons rather than the higher light levels,” Martino says. The bottom line is that ICESat 2 will require detectors that are “sensitive, with a short dead time. That was most of the trade right there.”

Mike Kapitzke, ER-2 lead engineer, inspects the MABEL installation in preparation for the initial flight.

The rapid-fire speed-of-light pulses also create a data-handling issue for the instrument's processor. “Because of the 4-msec transit time, you will have 40 pulses in flight at any given time. So you have to keep track of that many.” This will be a major hardware and software challenge. “It's not like it's intrinsically hard, but it is new,” Martino says.

As for the multiple beams, the basic approach is nothing new for a space instrument. The Lunar Reconnaissance Orbiter is equipped with a five-beam instrument called the lunar orbiter laser altimeter, or LOLA, whose data are turned into 3D maps of the Moon. A single beam is transmitted through a diffractive optical element consisting of a flat piece of glass with a hologram. The hologram divides the light into separate beams.

LOLA is far from a precursor to ICESat 2, however. It sends pulses 28 times a second, each with an energy of 3 mJ. Engineers also do not have to cope with atmospheric distortions.

A more accurate pointing mechanism for the laser was not considered a viable option. The original ICESat had a 30-m control accuracy, and so will ICESat 2. That is about the best that can be done for a reasonable cost, Yu says. Martino cautions that control accuracy is not the same as knowing where the laser landed. The knowledge accuracy will be about 6 m for ICESat 2, he says.

One planned improvement will be the ability to adjust the direction of the outgoing beam after launch to ensure the telescope catches the reflected light. ICESat did not have that capability. “We're looking at a smaller spot,” a 10-m footprint compared to 70 m for the original ICESat, “so adjustment is more critical for us,” Martino says.

Looking ahead

To test ICESat 2's multibeam concept, NASA has put together an airborne instrument called the multiple altimeter beam experimental lidar, or MABEL. It is not a prototype of ICESat 2, Martino cautions, but “it's going to be very useful for characterizing what the surface and atmosphere look like when we're using this technique.”

In December, NASA installed the instrument in the nose of its high-flying ER-2 and flew it over five targets in the Southwest to collect elevation data similar to what they expect to receive from ICESat 2.

With the instrument science review behind them and the MABEL flights under way, ICESat 2 engineers have plenty of work ahead. Size, power, and mass are extremely important on any satellite, but at the moment, engineers do not know how big to make ICESat 2 because they do not yet know which rocket will launch the satellite. “We have made some allocations, but they're somewhat arbitrary because we don't have a launch vehicle,” Martino says.

Few Delta 2 rockets are left in the inventory, and NASA's satellite builders do not yet have permission from the agency to consider a SpaceX Falcon 9 or an Orbital Sciences Taurus 2. Atlas-class rockets would be too large to launch ICESat 2 alone, so engineers are discussing the possibility of launching it into orbit in tandem with another satellite.

Scientists expect today's engineering work to pay off in the years after 2016. “With ICESat 2, knock on wood, all will go well, and we'll run it continuously. We won't turn it off for half the year,” says Neumann.

Ben Iannotta
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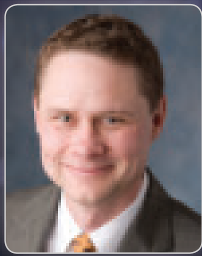

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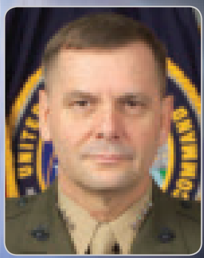

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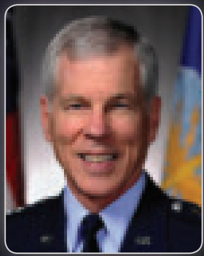

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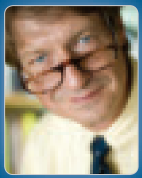

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Roundup 2011

Today, companies in nations around the globe are building—or at least designing—some type of UAV, both for their own militaries and for a fast-growing worldwide market. Their many benefits—multiple suppliers, relatively low cost, and demonstrated abilities for widely varying applications (persistent ISR, command and control, communications relay, and 'hunter-killer')—have made most nations eager to add UAVs to their military fleets.

Technology

Operational experience and tighter defense budgets have reduced warfighter and service chief wish lists to what is most needed, most quickly attainable, affordable, most versatile, able to use an integrated ground control station (one that can control multiple UAVs and/or types of aircraft), and able to be easily integrated into a multiservice, multination networked battlespace.

The past two decades have seen almost every conceivable type of craft and propulsion system thrown into the air in hopes of being ordered. UAVs have gained enough technological maturity and user acceptance to move from revolutionary concept to evolutionary development.

This is not to say that DARPA and its counterparts around the world will not continue to push the envelope on every aspect of UAVs—materials, shape, propulsion sys-

Because UAVs are inexpensive, easy to maintain and, most important, eliminate risk to human pilots, they are now on the wish lists of many nations. Although many countries are building their own systems or seeking such capability, some find it more efficient to buy UAVs from the world's leading manufacturers. Either way, the growth in sales of these aircraft is projected to continue at a brisk pace worldwide.

J.R. Wilson
Contributing writer

tems, sensors, artificial intelligence, scalable lethality (including the ability to change in mid-mission), guidance, operating environment), and size.

The past two years, for example, have seen new efforts in the development of unmanned helicopters. These aim at meeting a Marine Corps requirement for a system to resupply forward units (especially with water) while relieving manned rotorcraft for other missions, without increasing the demand on—and dangers to—ground convoys. At the same time, the MQ-1 Predator has seen its last procurement, with future acquisition going to the MQ-9 Reaper. It has a strong Predator lineage (it was once called Predator B), but was designed from scratch to be a true hunter-killer, using an expanded weapons set and advanced sensors.

Some consider the Reaper the first true UCAV (unmanned combat air vehicle), because its size, flight envelope, and weapons capability—including GPS-guided joint direct attack munitions, Paveway laser-guided bombs, and Sidewinder air-to-air/air-to-ground missiles—give it precision-strike and ground-support capabilities far exceeding those of the Predator.

Designated UCAV projects now include the Northrop Grumman/USN X-47B naval unmanned combat air system, which made its first test flight on February 4, BAE Systems/U.K. Taranis, the six-nation European nEUROn, Russia's MiG Skat, and multiple (but unverified) Chinese programs.

Interest in UCAVs has grown as the likelihood of a non-U.S. near-term fifth-generation manned fighter remains remote, despite Russian and Chinese claims to be on the verge of producing such aircraft. A fleet of UCAVs would be far easier—and less expensive—to acquire. But they also have grown more important to the U.S., especially given predictions the combined U.S. air fleet will fall short of requirements because of delays in the F-35 and a significantly reduced buy of F-22s. The Navy, for example, sees UCAVs as a way to put more strike aircraft with longer range and endurance to sea in less time.

Manufacturers

The numbers in the accompanying chart have changed significantly with each biennial edition. The last one, in 2009, showed far more companies in far more countries

MQ-9 Reaper (USAF photo by Tech. Sgt. Efren Lopez.)

The X-47B is expected to demonstrate carrier-based launches and landings in the 2013 timeframe.

working on many more UAVs than did its predecessor.

But it also reflected the beginning of a consolidation of design and development efforts, a new concentration on specific mission types and capabilities, and a falling away of those 'manufacturers' who were offering little more than remote-controlled hobby airplanes carrying new small cameras and data transmission systems based on commercial technology (primarily advances in smartphones).

That consolidation has continued, at all levels. And although this report reveals as much information as we could gather—surprisingly little in response to direct requests to more than 500 companies, universities, labs, and so on—the discussion will focus on the legitimate major players, both nations and companies

These will be UAVs built for their own militaries, for allies and alliances, and for general sale. It also will include as much information as possible on 'black' programs—the DARPA-level efforts that continue the UAV revolution. In some cases, little more than a name is known—and, often, even that may not be real. In this category, special care has been taken to verify, validate, and confirm the information presented.

We will also look at end users—nations that plan to buy and use one or more types of UAV, or have already done so, rather than attempting to develop an indigenous manufacturing capability. Even the most prolific manufacturers fall into this category, as do some nations that have sufficiently advanced infrastructure to develop their own UAVs but have decided not to 'reinvent the wheel,' instead spending their scarce defense R&D funds on other projects.

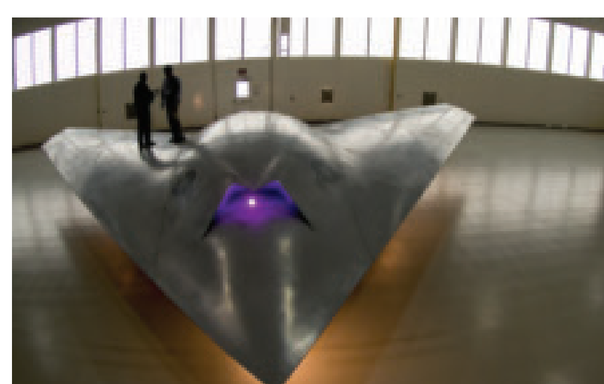
Even so, the Teal Group's 2010 UAV market study predicts a worldwide demand of more than $80 billion for UAVs and related systems through the coming decade, with expenditures more than doubling from a current worldwide level of about $4.9 billion per annum to more than $11.5 billion. And despite increasing global interest in the technology, the report also predicts the U.S. will be responsible for 76% of all RDT&E spending on UAV technology and about 58% of all procurement through 2020.

United States

While Israel was the first to send UAVs into situations where it was unwise to risk a human pilot, the U.S. has become—after a decidedly slow and reluctant start—the most prolific developer, producer, and user of UAVs of all types and sizes.

Although budget constraints have sent some early concepts back to the drawing board and many companies have dropped away, the number of manufacturers and UAVs remains high. Perhaps more important for the future is the continued growth in academic involvement, not only in training the next generation of scientists and engineers, but also in pushing the envelope on such areas as nano- and pico-UAVs.

One area that has progressed far more slowly than some had expected is UCAV programs, although RDT&E continues. The most public of those—and black programs in this area are a given—is the X-47B. Boeing and Lockheed Martin also continue to pursue the technology, while companies such as Predator/Reaper prime contractor General Atomics can be expected to build on existing hunter-killer platforms.



Boeing took the basic design of the X-45A and B to produce the X-45C Phantom Ray.

The Global Hawk can fly halfway around the world without refueling.

While the USAF has an official lock on all current, and presumably future, large UAVs, the Navy is back in the hunt for a carrier-based UCAV. Cancellation of J-UCAS temporarily stalled Navy efforts, but, as with 'joint' programs in the past, the withdrawal of one service revealed the real desire of the other to push forward.

From the ashes of J-UCAS rose UCAS-D (demonstration), with an ultimate downselect to the X-47B, which the Navy sees as precursor to a strike-fighter-sized, carrier-capable, transformational UAV capable of ISR, target acquisition, and strike missions.

The need for a carrier-based UCAV has grown even greater with the decrease in U.S. aircraft carriers and fully equipped air wings. Also spurring Navy efforts is China's public stance that, in any future armed conflict with the U.S., its goal would be to destroy U.S. military airfields and carriers before they could launch manned aircraft toward China. Having a fleet of long-range, preferably stealthy UCAVs that could be airborne long before any such attack—and possibly help thwart it—is rapidly becoming a Navy 'urgent need.'

The Air Force, while less public in its pursuit of UCAVs than the Navy, nonetheless did not abandon interest in them with the end of the J-UCAS. With that in mind, Boeing took the basic design of the X-45A (J-UCAS) and X-45B (its UCAS-D effort) and pushed forward with internal development of the X-45C—which came out of Boeing's Phantom Works in 2010 as the Phantom Ray. In response to one major UCAV concern—aerial refueling for extended range and endurance—Boeing is under contract on several key R&D programs.

The service also plans to take delivery of its last Predator this year. While it will continue to fly both armed and unarmed Predators for some time—as will several other operators, from allied militaries to the U.S. Border Patrol—the emphasis for this decade will be on the Reaper. The Reaper was built by General Atomics from scratch to be a hunter-killer; to some, that makes it the first true UCAV.

The Reaper can fly twice as fast and twice as high as the Predator, carries 10 times the payload (including a far wider range of weapons), and has enough additional on-board power to handle a broader array of new or improved sensors. The first USAF Reapers entered service in 2007 and have been flying combat missions in Southwest Asia, piloted (as is Predator) by crews based near Las Vegas, Nevada.

Reaper already has an upgrade—the jet-powered Predator C Avenger. With significant weight, payload, speed, and other advantages, the Avenger—which also boasts a version of the F-35's electrooptical targeting system—also has been proposed by General Atomics to meet the Navy's requirement for an "unmanned carrier-launched airborne surveillance and strike (UCLASS) system."

A brief history

Advances in military aviation technology historically follow a two-war development phase. The first heavier-than-air combat aircraft were introduced in WW I, but their varieties and massive use during WW II earned that conflict the title of the world's first 'air war.'

A handful of helicopters saw use in WW II, but their first real application was during the Korean conflict, primarily for medical evacuation and resupply. But the next major U.S. war, in Vietnam, saw thousands of combat helicopter sorties by gunships, as well as their medevac and logistics missions, making Vietnam the first true 'helicopter war.'

Israel introduced the concept of UAVs for intelligence, surveillance, and reconnaissance applications in the 1980s, but these planes did not earn worldwide attention until the first gulf war. The primitive (by today's standards) Pioneer UAV became so closely attached to attacks by ship guns and rockets, as well as air strikes, that Iraqi soldiers eventually tried to surrender to the flying robot.

But it is the second gulf conflict that has become known as the 'UAV war,' because of the vast numbers and varieties involved, including the centerpiece of the conflict, the MQ-1 Predator. This was the first UAV to be armed, its Hellfire air-to-ground missile originally designed for helicopters. The skies over Iraq and Afghanistan have been filled with UAVs operated by multiple nations. They range from the tiny hand-launched Wasp to the massive Global Hawk.

UAVs became so numerous that pilots of manned combat aircraft flying through the same battlespace sometimes referred to them as 'aerial FOD' (foreign object debris).

UAVs now come in multiple sizes, carry varied payloads, and use different propulsion systems. Launch methods range from slingshot-style hand-launched to rocket-launched and long-range, from home basing to target zone—Global Hawks can fly halfway around the world without refueling, while Predators routinely are 'flown' by pilots at air bases near Las Vegas while performing missions over Southwest Asia.

Although they require highly skilled, well-trained pilots and sensor operators, UAVs typically are less manpower-intensive than manned aircraft. But most important, they do not put these operators at risk of death or capture. Thus, they can be flown into situations that might otherwise be considered too dangerous. Depending on the type of aircraft and mission, they also can be 'swarmed' against a well-defended target, increasing the likelihood that at least one will get through.

Future UAVs may replace most of the manned fighters in an attack formation, with one piloted aircraft controlling multiple UAVs. A mixed formation of unmanned combat air vehicles and F-35 Lightning II stealth ground attack fighters could significantly enhance the survivability and mission capability of the JSF, which has only marginal stealth attributes.

Meanwhile, the Army has a variety of new and upgraded unmanned aircraft systems (UAS—which include both the aircraft and its ground control station) in development and testing. A major demonstration—the manned/unmanned systems integration concept, or MUSIC—is scheduled at Dugway Proving Ground, Utah, in September.

An MQ-1C Grey Eagle/Sky Warrior, RQ-11 Raven, MQ-5B Hunter, and RQ-7B Shadow UAVs will exchange information with AH-64D Apache Block III attack helicopters, with the Apache crew taking control of the UAVs in flight.

That level of manned/unmanned interoperability is considered crucial to the future integration of both ISR and hunter-killer UAVs in the network-centric battlespace now being implemented in Southwest Asia and planned as the future centerpiece of allied military operations.

Another major factor in the future of UAVs will be the ability of U.S. allies and coalition partners to share useful information in real time. Ongoing efforts to integrate NATO and other allies into a distributed common ground system for UAVs enhance their capabilities for dealing with regional threats and mitigating the risks to all involved. A key to achieving that will be the 2012-2014 delivery and implementation of the NATO Alliance Ground Surveillance system, jointly developed by 21 nations since 2007.

Europe

Although a number of European Union nations have their own, often robust, UAV R&D and production programs, defense manufacturing is one of the primary areas in which EU cooperation is a reality.

A leading example of that is nEUROn, a B-2 lookalike designed to be a European UCAV technological demonstrator. While France's Dassault Aviation is prime, the craft gains its EU label from Dassault's five partners: Alenia (Italy), SAAB (Sweden), Hellenic Aerospace Industry, or HAI (Greece), EADS (in Spain), and RUAG (Switzerland).

EADS has recently led the charge to get Europe to focus on specific UAV programs rather than allowing many competing programs to drain scarce government and corporate resources. For example, CEO Louis Gallois, while vowing EADS would continue developing the French/German/Spanish Talarion MALE (medium altitude/low endurance) UAV with its own funds, demanded that Europe "make a choice" about its MALE UAV requirements. Gallois was referring to the competing BAE Systems Mantis UAV, claiming that continuing both developments was a 'risk' to BAE and EADS.

EADS has offered the Talarion to meet the U.K.'s Scavenger ISTAR UAV requirement, which also is being competed by two U.S. firms—General Atomics (Avenger) and Northrop Grumman (Global Hawk). Published reports have indicated the U.K. Ministry of Defence's ultimate decision will be based as much on politics as military requirements—a not uncommon occurrence with military acquisitions, especially those involving international competitors.

But the U.K. is not alone in trying to make such choices. The French government is weighing competing offers on the Dassault/Thales Systeme de Drone MALE and Sagem's Patroller UAV.

Gallois has suggested that the various EU nations considering future UAV requirements come together with a multinational industry effort to design and develop a single system—an 'Airbus for UAVs.'

"We have to avoid having two MALE programs," Gallois says, adding that EADS plans to jump-start the multinational approach by forming associations with some of its competitors to market UAVs around the world. "We are going to partnership. If we want to sell in Brazil or India, we need

The Talarion is being developed by EADS to meet Future European needs for a UAV for reconnaissance and surveillance.

to have a partner. We are discussing with a lot of them," he says, while declining to reveal any details of what he calls a "three pillars" approach to dealing with the UAV market and competition in Europe, the U.S., and emerging nations.

At the same time, France and the U.K. are going head-to-head in developing a European UCAV despite similar warnings from Dassault that within two decades European industry could 'compete' itself out of existence while the U.S.—already ahead in UAV technologies—dominates the market.

Mirroring EADS' position, Dassault is calling for a pan-European 'combat aircraft program' to replace the continent's existing manned combat fleet. In the absence of such a program, the firm is pushing acceptance of the nEUROn as a way to keep multiple European companies involved and pushing UAV technologies.

The nEUROn technology demonstrator is scheduled to begin flight tests in 2012, almost a decade after its launch. While drawing heavily on commercial off-the-shelf avionics and computers, it was intended to be the first major stealth platform designed entirely in Europe. However, it now faces a British competitor: the Taranis.

As with Germany, France, and other members of the EU, it is sometimes difficult to separate British UAV developments from those of the EU as a whole. One distinct exception, however, is the Taranis UCAV concept demonstrator, on which the MOD has invested over $227 million with a British industry team (BAE Systems, Rolls-Royce, GE Aviation, and QinetiQ).

"Taranis has been three-and-a-half years in the making and is the product of more than a million man-hours. It represents a significant step forward in this country's fast-jet capability," according to Nigel Whitehead, managing director of BAE Systems' Programmes & Support Group. "This technology is key to sustaining a strong industrial base and to maintain the U.K.'s leading position as a center for engineering excellence and innovation."

The initial Watchkeeper platform is based on Elbit Systems' Hermes 450 UAV platform.

Iinitial flight testing for Taranis, another B-2 look-alike about the size of the BAE Hawk, is planned for this year. It is intended to validate technologies needed to develop an intercontinental stealthy UCAV by the end of the decade. It has two internal weapons bays for bombs and missiles, and is expected to be capable of using future directed-energy weapons, either high-power microwave- or laser-based.

Other European nations are striving to develop indigenous capabilities within one or another UAV niche. Most of these involve small, comparatively basic aircraft for ISR applications, often centered on border patrol or sales to less industrially developed markets in Asia, Africa, and Latin America.

China

In the past two decades, this communist giant has emerged as one of the world's most successful capitalist nations, in many ways returning to its mercantile roots. Because of its massive economy, manufacturing base, and status as both a nuclear power and just the third nation to launch its citizens into space, China has earned its place as a regional superpower and global great power.

However, some things remain unchanged, including a 21st-century 'Great Wall' China maintains around its military technologies and capabilities. Aside from still photos, static airshow displays, and an occasional video of an aircraft 'taxiing,' there is little to prove—or disprove—any claims China makes about its aviation capabilities, including UAVs.

China has proudly displayed models that bear a striking resemblance to the most advanced U.S., European, and Israeli UAVs, but there is little evidence to prove any of their claimed capabilities. However, given the country's known prowess in other areas of high tech—from nuclear weapons to microchips, spacecraft to consumer electronics—it would be foolish to dismiss their UAVs as pure fiction.

Israel

Israel was the first nation to put UAVs into actual military use, telling the world in the 1980s it was far more reasonable to use flying robots for ISR missions than to risk Israeli Defense Forces (IDF) human pilots being killed or captured.

In over 30 years of use and development, Israel has continued to maintain a leadership role in both capabilities and global sales. As with many nations, however, analysts can only speculate about what may exist within the IDF's 'black' programs.

Israel's Hunter UAV is exported worldwide.

What is widely known, however, is that Israel is not only one of the world's leading marketers of UAVs, but also perhaps the most sought-after partner for those nations wanting to develop an indigenous manufacturing capability.

Russia

Since the collapse of the Soviet Union—with at least a decade of decay in its technological infrastructure and the loss of senior scientists to other countries—Russia has struggled to regain its status as a technology leader. In some ways, it has moved back ahead of the U.S.—shortly only Russia will have the ability to carry humans to the international space station. It also has seen some success in resurrecting its fighter aircraft industry, although the actual performance capabilities of its latest jets—despite Prime Minister Putin's claims of fifth-generation status—are questionable.

In terms of UAVs, however, Russia had expected to rely heavily on assistance from Israel. But that relationship appeared to fall apart in the fall of 2010 because of Israeli anger at a Russian decision to supply Yakhont naval missiles to Syria. However, the director general of Vega, Russia's leading UAV manufacturer, claimed Israeli assistance was not necessary.

The Russian military has already purchased several Israeli UAVs, including the Searcher Mk II.

"In the next two or three years, there will be a breakthrough in the Russian UAV market regardless of the Israeli position on this issue," Vladimir Verba told reporters last fall during an international exhibition, adding that the government had approved his company's "comprehensive development program," set to run through 2025.

Verba also claimed Russia's Federal Security Service (FSB) is "quite happy with the quality of our equipment. The FSB is giving us new orders and we are cooperating successfully." Even if the defense ministry did decide to buy UAVs abroad, he said, "there is nothing terrible about that."

His confident remarks, however, did not mesh with the words and actions of the government. Apparently dissatisfied with the progress of Russian industry, and having seen the need for UAVs during recent conflicts with Georgia and Chechnya, the military already has bought a few Israeli Bird Eye 400 reconnaissance, I-View MK-150 tactical, and Searcher Mk II multimission UAVs, with follow-on contracts for three times as many.

More to the point, in April 2010, Russian Deputy Defense Minister Vladimir Popovkin admitted that indigenous UAVs the government had spent about $172 million to develop had failed in testing. And in November 2010, the head of the Russian air force, Col. Gen. Alexander Zelin, said Russian UAVs had failed to meet the military's speed and altitude requirements, among other shortfalls.

The agreement jeopardized by the missile sale had called for a UAV joint production effort, with Israel helping Russia upgrade its domestic capability. The nation also reportedly is looking to France for a similar joint venture.

India and Pakistan

It is difficult to discuss military developments in one of these nations without including the other. While India has by far the larger economy and industrial infrastructure, as well as a more stable government, Pakistan has managed to maintain a degree of equilibrium with its neighbor.

Although primarily a buyer of military technology, Pakistan has put considerable effort in recent years into building an indigenous UAV capability. But with India announcing plans to field a fifth-generation manned fighter (coproduced with Russia) by 2015, Pakistan will face technological and numerical challenges it cannot match.

As a result, the Pakistani government is pushing industry to develop a UCAV capable of reducing any new advantage India may gain in the realm of air combat. Indeed, some in Pakistan seem convinced any future sixth-generation fighter will be a stealth UCAV, such as Boeing already has proposed to the USAF. But rather than rely on foreign suppliers, Pakistan wants to develop its own capabilities, not just for UCAVs, but also all other levels of UAVs.

Most nations pursuing UCAV development are working on aircraft that can fight their way into a target zone and back out. However, Pakistan appears to be embracing the concept of a suicide aircraft that, if necessary, would simply crash into its target. Even in air-to-air engagements against a fifth-generation fighter, Pakistani researchers believe a reasonably capable UCAV, operating in a 'swarm,' could overpower and defeat the manned aircraft.

While not claiming to be the technological equal of Europe or the U.S., Pakistan believes it can avoid the political and interservice conflicts that have slowed western development of both UAVs and future UCAVs. The result, they agree, may be more akin to an F-4 than an F-35, but it should also be less expensive and thus easier to field quickly and in large numbers.

In a December 2010 paper on UCAVs and the future of Pakistani-Indian conflict, Malaysian defense analyst Meinhaj Hussain called unmanned aircraft the "golden opportunity to pull ahead" for Pakistan and many other nations.

"If the Pakistan air force can do better and avoid institutional and political barriers that the West is plagued with, they can make a relative leap in capabilities and meet their goals and objectives far better than a linear and asymmetric solution could," he wrote. "Pakistan's aircraft manufacturing industry would remain relevant rather than become outdated and relegated to obsolescence.

"Pakistan does not have the technology or the resources to build an expensive and complex fifth-generation plane. A UCAV, however, is a far more achievable goal. The technologies involved allow far greater flexibility and can be said almost ideally suited to Pakistan's military-industrial complex's strengths."

Such an effort would not necessarily fall entirely to native industry, Hussain added. A UCAV adequate to counter India's larger and more advanced manned air fleet could be built in partnership with China, Turkey, Malaysia, South Africa, Brazil, Iran, Italy, or any combination of those or other nations.

For Pakistan, UCAVs could "become the foot soldier of the skies, lightly armed and yet overwhelming in their numbers," said Hussain. "UCAVs are an emerging technology that has the potential to revolutionize air warfare....[they] provide an interesting paradigm shift that cannot be ignored by those entrusted with the defense of their nations and peoples."

India is not ignoring the value of UAVs, either, but is pursuing that element alongside advanced manned aircraft and missiles. Along with increased purchases—primarily from Israel and Europe—India has spent part of its defense budget increases in recent years on development of such platforms as the Autonomous Unmanned Research Aircraft, a flying-wing design with alleged stealth capabilities developed by the Aeronautical Development Establishment.

In April 2010, a contract to build the Rustom MALE UAV—in the same class as the U.S. Predator and U.K. Watchkeeper—was

Jasoos is designed and manufactured by SATUMA of Pakistan. The Jasoos II Bravo+ variant is currently operational with the Pakistan air force.

A contract to build the Rustom was awarded to state-run corporations rather than private industry.

awarded to state-run Hindustan Aeronautics and Bharat Electronics. The decision marked another in a long line of lost programs India's civil industry has suffered at the hands of government-run competitors.

The Defence Research and Development Organisation (DRDO), India's premier defense research agency, also has been working on a number of new platforms, including the 1.5-kg Netra, intended for antiterrorist and counterinsurgency operations. Although well-equipped by foreign suppliers, India is looking to DRDO and both its government and civil infrastructure to provide an independent advanced UAV capability before the end of the decade.

Iran

While everything that happens inside Iran is cloaked in secrecy and subject to speculation—often started by the government in what might be considered a smoke-and-mirrors campaign—its technological capabilities cannot be denied. It is the reality of deployable systems that remains in doubt.

In 2010, for example, the commander of Iran's air force announced large-scale production would soon begin on the new Pehpad UAV, which Brig. Gen. Amir-Ali Hajizadeh said was undergoing field tests and training. Pehpad has been called a stealth craft, a claim Iran has made about numerous UAVs for several years. But some reports claim the 'stealth' aspect of the Pehpad consists of USAF markings on a platform designed to look like a Predator.

Iran also has claimed it soon will be able to control UAVs from submarines, will equip all border stations with a variety of such aircraft, has developed long-range UAVs that could sink the U.S. fleet in the Persian Gulf, and so on. The U.S. reportedly did shoot down an Iranian UAV in Iraqi airspace in 2009, although details remain sketchy.

South Korea, Taiwan, and Singapore

Across Asia's broad expanse, nations large and small are seeking to purchase the latest UAV technology available from Israel, the U.S., Europe, Russia, and elsewhere. But in most cases these countries are also developing at least a minimal indigenous manufacturing capability.

High on that list is South Korea. A major share of increases in its defense budget, a reflection of increasingly belligerent acts and statements by its neighbor to the north, has gone toward the purchase of UAVs. At the same time, added emphasis has been placed on becoming at least partially self-reliant in what is seen as a top priority.

Similar concerns about potentially aggressive neighbors have made Taiwan and Singapore active import markets as well.

Recently, however, Taiwan has begun pushing development of its own systems, led by the military's Chung-Shan Institute of Science and Technology (CSIST). Both industry and academia have been working on UAV prototypes for several years, and it now appears CSIST has been tasked with providing the Taiwanese air force with advanced systems it had been expected to buy from Israel or the U.S.

In Singapore, the air force UAV command—actually a joint command staffed by personnel from all three services—is responsible for overseeing both domestic development efforts and the use of existing UAV assets, purchased primarily from Israel. Singapore also is working hard to develop an indigenous capability. In August 2010, Singapore raised its profile by deploying a UAV task force to Afghanistan as part of its contribution to the effort there.

Africa and Latin America

The nations of these two continents run the gamut from the poorest to (potentially, at least) some of the richest. They also host a wide range of technological infrastructure, with some countries capable of producing competitive ISR UAVs—and nearly all in the market for such devices. Applications range from counterdrug and counterinsurgency ISR to border patrol and antipiracy efforts.

In Africa, the lead in UAV development and manufacturing has belonged to South Africa. But what had appeared a promising area of development has now faded. A lack of interest in UAV acquisition by that nation's military has led programs at leading companies, such as Advanced Technologies & Engineering and Denel Dynamics, to stall. Nor have efforts by Russia to boost its own sagging UAV capability by partnering with South Africa led to any improvement in the status of either.

As a result, Israel has found a solid sales opportunity in Africa (and South America), and China is working hard to break into both markets. But the biggest owner/user of UAVs in Africa for now may be the newly created U.S. African Command.

While Africa's interest is waning, several Latin American nations are using their growing fleets of UAVs as a weapon in the war on drugs. Mexico, Chile, Brazil, and others are now flying Israeli UAVs on such missions, while Brazil has formed a joint venture with Israel in an effort to develop a native infrastructure.

With technological capability growing in the region, there have also been efforts to combine internal capabilities, such as a joint program by Chile and Argentina.

The Air Force will take delivery of its last Predator this year, as the UAV gives way to the Reaper and Avenger upgrades.

Every nation is a potential buyer when it comes to UAVs, including the U.S. and Israel. UAVs, and someday, perhaps UCAVs, are far less expensive to acquire and maintain than manned aircraft or satellites for ISR, while offering the added potential of weaponization at no risk to human pilots.

Wars may be won by superior technology, tactics, numbers, or money. UAVs can be an equalizer, even for a small, relatively poor nation with limited technological infrastructure facing a larger, more powerful, and more advanced adversary. For such nations, cheap and plentiful UAVs have been referred to as 'aerial IEDs' (improvised explosive devices), the inexpensive, low-tech weapons of choice for Iraqi and Afghani insurgents and the primary cause of deaths and injuries to U.S. and coalition forces.

What the future may hold for UAVs and UCAVs remains to be seen. What is certain, however, is that the demand for unmanned systems will continue to grow, whether natively produced or purchased from others.

China's
MILITARY SPACE SURGE

China's surging military space program is poised to challenge U.S. aircraft carrier operations in the Pacific, as Chinese military spacecraft already gather significant new radar, electro-optical imaging, and signal intelligence data globally.

During 2010, China more than doubled its military satellite launch rate to 12. This compares with three to five military missions launched each year between 2006 and 2009. Since 2006, China has launched about 30 military related spacecraft. Its total of 15 launches in 2010 set a new record for China and for the first time equaled the U.S. flight rate for a given year.

Most U.S. public and media attention has focused on China's occasional manned flights and its maturing unmanned lunar program. But China's military space surge reveals a program where more than half of its spacecraft are like 'wolves in sheep's clothing,' posing a growing threat to U.S. Navy operations in the Pacific. India's navy is also concerned.

Expert analysts say China is accelerating its military space program to target U.S. aircraft carriers. The surge in development and launch activities has caught the attention of the U.S. secretary of defense and has begun to affect DOD planning. Yet very little U.S. or political and media attention has focused on this trend, which some are calling "a new space race with only one participant."

First liftoff from Jiuquan Gobi Desert launch site of the Long March 4C with restartable third stage in late 2010 also marked first launch of three co-orbital Yaogan spacecraft, 9A/B/C, that maneuvered into an ocean surveillance constellation to track U.S. carrier battle groups. Credit: U.S. Naval Institute.

"This is a really big deal. These military spacecraft are being launched at a very rapid pace" says Andrew S. Erickson, a Naval War College expert on China's naval and space forces. China is becoming a military space power within a global context."

At least three or four different Chinese military satellite systems are being networked to support China's 1,500 km+ range DF-21D antiship ballistic missile (ASBM) program, say U.S. analysts. The DF-21D is being designed to force U.S. Navy aircraft carrier battle groups and other large U.S. allied warships to operate hundreds of miles farther away from China or North Korea than they do today.

The ASBM "has undergone repeated tests and has reached initial operational capability," Adm. Robert Willard, commander of the U.S. Pacific Command said recently in Tokyo. The new Chinese space capabilities, combined with development of the DF-21D, are already having an effect on the planning of future operations in the Pacific, says Secretary of Defense Robert Gates.

"I'm trying to get people to think about how do we use aircraft carriers in a world environment where other countries [China specifically] will have the capability, between their missile and satellite capabilities, to knock out a carrier," Gates said recently at Duke University. "How do you use carriers differently in the future than we've used them in the past?" he asked.

The space arena

Some analysts say the basic DF-21 two-stage solid propellant ballistic missile could also play a role in Chinese antisatellite development. As former Director of National Intelligence Adm. Dennis Blair testified before Congress in 2009, "counter command, control, and sensor systems, to include communications satellite jammers, are among Beijing's highest military priorities. China continues to pursue a long-term program to develop a capability to disrupt and damage critical foreign space systems. Counterspace systems, including antisatellite weapons, also rank among the country's highest military priorities."

Detailed analyses of China's military space program have been done by Erickson at Harvard University, where he is com-

by Craig Covault
Contributing writer

A mobile version of the DF-21 missile is being tested as a fixed DF-21D version of aircraft carrier killer ballistic missile, linked to multiple Chinese military satellites to track and target U.S. carriers hundreds of miles farther away from China than in the past.

pleting a book entitled *Great Power Aerospace Development, China's Quest for the Highest High Ground*.

Grandson of the late Joe Gavin, who led Apollo lunar module development at Grumman, Erickson has also written for the U.S. Naval Institute at Annapolis, where his piece "Eyes in the Sky" in the institute's *Proceedings* lays out a detailed picture of China's growing military space program. Work from Erickson's research is included in this analysis, as are his findings from another major research project on Chinese military small satellites and microsats.

"An emerging network of space-based sensors promises to radically improve the targeting capabilities of China's Navy and other services," says Erickson. This is also giving the country a major new capability to image and eavesdrop on U.S. aircraft and ships basing at key Pacific locations like Guam and Japan.

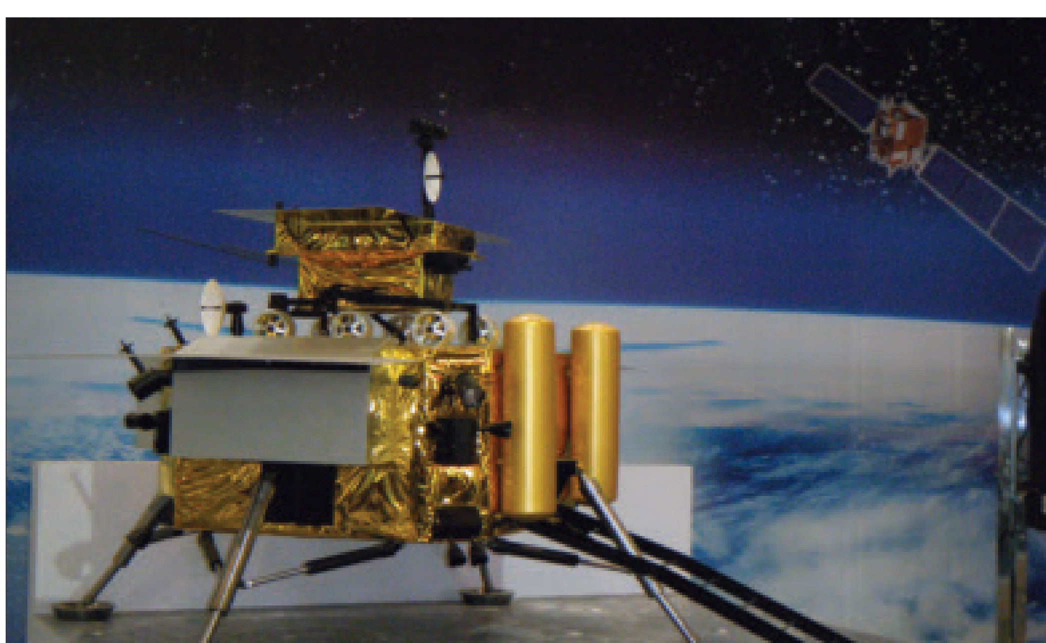
Racing alone

China is accelerating its military satellite launch and networking operations so rapidly that personnel at U.S. Strategic Command (STRATCOM), Offutt AFB, Neb., refer to "the new space race that seems to have only one participant." Sources say that is not a criticism of U.S. space capabilities, but rather a comment by Air Force officers on how little media and political attention there is about China's military space surge. STRATCOM oversees U.S. military space operations as well as its strategic deterrent.

"China's military space program is moving at a rapid pace and has to be taken very seriously," says Erickson.

Yaogan spacecraft form the core of Chinese military space operations. But this designation is a cover to maintain secrecy for at least four different military designs, including satellites with electrooptical digital imaging cameras, a totally different spacecraft with synthetic aperture radar imaging, a third type with signal intercept, and a fourth with electronic eavesdropping capability. A fifth version is for formation flight and has ocean surveillance sensors.

Thirteen Yaogan satellites launched since 2006 are engaged in military space activity, and most remain operational, says Erickson. Only Yaogan 1 has expired. This first Chinese imaging radar satellite appears to have exploded in orbit in February 2010 after four years of service. Four digital imaging Yaogans and four imaging radar satellites have been launched.



By mid-decade, China plans to launch a small nuclear-powered lander carrying a 'pathfinder' Moon rover that will descend to the surface, then periodically plug in to recharge, along with also using a small solar array. Missions like this are showing other countries China's growing high-technology leadership.

"This is the most rapid launch sequence of anything I have yet seen. It is particularly significant because [although they clearly have military missions] they are officially billed as satellites for civilian applications like crop monitoring."

Analysts ask which People's Liberation Army entity is managing the multimillion-dollar military satellite development and launch capability and the daily operation of these spacecraft. One says "there is an ongoing struggle for control of the new military space assets, with perhaps the PLA air force in the lead." He muses that there appears to be "a big food fight" in the PLA over the new military space capability.

Most Yaogans fly in 400-mi. orbits inclined about 98.8 deg. These high inclination orbits involve ground tracks that fly from south to north. The orbits have been used since the cold war by the U.S. and Soviet Union because spacecraft eventually pass over every point on Earth as the planet rotates east to west under the polar orbit satellites' ground tracks.

Quality and quantity

China appears to have very advanced capabilities in both electrooptical and radar imaging, with very high resolution," Erickson points out. "These seem to be exactly the type of capabilities for which to further develop space-based information, surveillance and reconnaissance to support precision weapons."

Two large spacecraft developed by China and Brazil under the China Brazil Earth Resources Satellite (CBERS) program also provide a diverse array of imaging products for both military and civil applications. Two spacecraft are operational and a third is planned. All have advanced cameras and other imaging scanners. Erickson says that, as a whole, China has about 15 reconnaissance-relevant imaging spacecraft, spread between the Yaogans, CBERS, and numerous small satellites. In fact, China has launched some 40 small satellites (weighing 500 kg or less) to date, he says.

Coorbital choreography

Such satellites have been involved in coorbital spacecraft formations like triangles or echelons that can detect ships and calculate location, speed, and direction of travel. Acquisition of such constantly updated positions can give the Chinese navy extremely accurate information as to the actions and intensions of U.S. warships and allied ships.

A small man-tended Salyut-type spacecraft will be used to explore Chinese military space technologies, as well as minor science projects. They will lead to a larger station, and are being used to inspire China's youth to pursue math and science for space-related careers.

Ian Easton, a research fellow at the Arlington, Va.-based Project 2049 Institute, has studied these coorbital missions. The institute is a think tank dedicated to studying Chinese national security issues. Easton writes in the "Asia Eye" blog that the first (and perhaps most strategically significant) of the coorbital satellite constellations to form in 2010 was launched in March. One constellation makes use of three Yaogan radar and eavesdropping spacecraft.

"Unlike previous electrooptical and radar imagery satellites deployed in the series, the Yaogan 9 launch positioned three satellites [A/B/C] orbiting in a highly choreographed triangular formation, suggesting that China had deployed a dedicated Naval Ocean Surveillance Satellite system to bolster the ASBM program. Space-based surveillance and cueing capabilities represent an essential (and previously underdeveloped) element of the ASBM program," Easton writes.

The next coorbital development came in August 2010 when China's Shi Jian-12 satellite conducted a series of sophisticated maneuvers to rendezvous with Shi Jian 6F, one of several suspected electronic intelligence satellites. But the rendezvous ended in a collision. Whether deliberate or accidental, the Chinese remained mum on the incident," Easton says. However, the dean of China satellite analysts, Joan Johnson Freese at the Naval War College, does not believe it was an ASAT test.

"More recently, the September 2010 launch of the three-satellite Yaogan 11 constellation and the October 2010 launch of the two-satellite Shi Jian-6 Group-04 constellation have expanded China's coorbital portfolio," Easton says. His sources believe that Yaogan-11A/B/C are radar imagery satellites with all-weather, day/night capability and can play a role in tracking carrier strike groups. Likewise, the Shi Jian-6 group launched in October were reported to be intended for an electronic intelligence role, also perhaps as part of China's ASBM program," he says. Easton says key personnel like Li Yandong have been involved in several of the coorbital flights.

"Ultimately, it appears that these coorbital programs, when viewed in the context of their underlying military missions, have worrisome security implications for both the space and the maritime segments of the global commons in the coming years," he points out.

Ocean monitoring

In addition to intelligence and targeting formations, China is also moving aggressively with ocean monitoring satellites that provide militarily important coastal and sea condition data.

Among the spacecraft planned are 15 additional Haiyang satellites, in three sets, over the next decade. The initial HY-1 series will monitor ocean color using an optical radiometer and sea-surface temperature with a medium spatial-resolution optical sensor. Erickson says a total of eight satellites, designated HY-1C-J, will be launched every three years, in pairs, between 2010 and 2019. The HY-2 series will then introduce a Ku/C dual-frequency radar altimeter, a tri-frequency radiometer, a Ku-band scan radar scatterometer, and a microwave imager to monitor sea surface wave field, height, and temperature.

Four additional satellites, HY-2A-D, will be launched every three years over the same period. In addition, the coming HY-3 series will use SAR sensors with 1-10-m resolution and X-band radar to monitor maritime resources, pollution, and coastal zones.

The Hope 1 communications relay satellite also has an imaging system. Such spacecraft are becoming a key element of the China military space program.

Three satellites will be launched in 2012, 2017, and 2022, according to an analysis by Eric Hagt and Matthew Durnin, "China's Antiship Ballistic Missile: Developments and Missing Links."

And an analysis published by Taiwan's navy says the Haiyang satellites are part of an "ocean monitoring system that has strengthened the PRC military's knowledge of a potential Pacific Ocean battlefield."

Also relevant to maritime surveillance will be the eight-satellite Huanjing disaster/environmental-monitoring constellation. It is envisioned to contain satellites capable of visible, infrared, multispectral, and SAR imaging. Two initial satellites in the series, Huanjing-1A and -1B, will provide real-time multi- and hyperspectral imaging, respectively, at 30-m resolution.

Small size, big payoff

China is especially pursuing constellations of relatively small but high-resolution electrooptical and imaging radar spacecraft, as well as electronic intelligence constellations, says Easton. Erickson has also conducted a detailed study of Chinese military small sats and microsats, both of which may aid China's intelligence gathering.

"What is especially intriguing is that by employing diverse small satellite designs based on common buses, or standardized platforms, China may not need to develop superior heavy spacecraft technologies, but end up with military space capabilities greater than the sum of its parts," Erickson says. "That may suit their purposes quite effectively, although quite differently from the U.S. military space program, which uses larger individual spacecraft."

China may have discovered very sweet 'knees on the curve' (points of maximum benefit) in terms of capability versus cost. Looking forward, if they are able to continue to develop and succeed with reasonably priced satellites updated with the latest off-the-shelf technologies, they may have a potent modular, affordable, adaptable, and replenishable military satellite nucleus the U.S. will not have, Erickson says.

"With this strategy, China may be able to come up with something that is increasingly more than the sum of its parts," Erickson says. He points out that Chinese specialists almost uniformly view microsatellite technology as essential for 21st century military development.

In the assessment of one major Chinese aerospace journal, "The successful development of reconnaissance, monitoring, surveying and mapping, communications, and other satellite systems can provide comprehensive, accurate and timely strategic and tactical information for high technology warfare." Another argues that "microsatellites will play an indispensable role in future information warfare," which reflects a view widespread in China's defense industrial sector. Having recognized that "space control provides the key to military victories in modern warfare, Chinese defense analysts are focusing on developing improved methods for entering space, using space, and controlling space."

They already credit indigenously developed satellites for substantially improving the nation's military communications. Erickson points out that "Chinese researchers are studying not only how to attack other nations' satellites, but also how to defend their own." He says a detailed study of satellite defense methods by researchers at the Shijiazuang School of Ordnance Engineering predicts that, "As microsatellite technology advances, small high-energy lasers or high-power microwave systems may be incorporated for self-defense or satellite protection."

Protecting assets

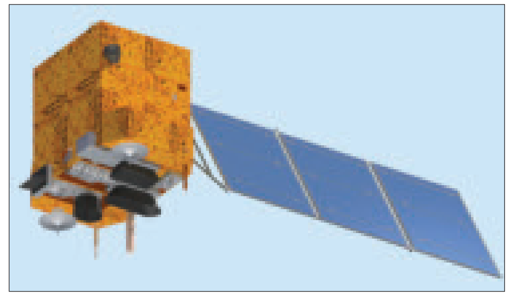
The study further noted that, "at the present moment, we should significantly reinforce the top level design of satellite protection to address specifically the status of satellite protection in China. By combining countermeasures against 'soft kill' and 'hard destruction,' the concept of 'system-based countermeasures' should be practiced by taking a variety of measures. We should actively engage in the development of all kinds of protection technology and initiate preliminary research on low cost, novel protection technology.

"On the other hand, we also must closely monitor progress made by foreign militaries in satellite protection technology in order to adjust and alter our focus and direction of our countermeasure technology correspondingly.

"We have to know ourselves as well as our enemy in order to win every battle," says the Chinese internal assessment.

Navigation and communications

In satellite navigation, China's 2007-era Beidou 1 four-satellite constellation has its capability limited by its latitude and longitude area of service. To improve on that, China is deploying a 35-satellite Beidou 2/compass navigation satellite system that will have five spacecraft in geosynchronous orbit and 30 medium-altitude spacecraft. It should achieve global coverage capability in 2015-2020, Erickson predicts.



Spacecraft developed by China and Brazil under the China Brazil Earth Resources Satellite [CBERS] program provide imaging products for both military and civil applications.

Chinese military satellite communications has been hampered in recent years with failures in the DFH-4 bus. But overall, several other geosynchronous orbit designs are providing China with reliable encrypted communications. According to the authoritative Global Security.org, China's most advanced military satcom series is the Feng Huo-1 (FH-1) satellite, the country's first space-based communications platform to provide military units with both C-band and UHF communications.

First launched in 2000, it is the first of several military communications satellites for the Qu Dian C4I system, China's first integrated command, control, communications, computer, and intelligence system. The new system gives the PLA new capabilities for coordinating and supporting its growing terrestrial forces. The PLA describes the new Tactical Information System as similar to the American Joint Tactical Information Distribution System, or JTIDS. When fully deployed, the Qu Dian system will allow theater commanders to communicate with and share data with all forces under a joint Chinese command.

China launched a smaller military comsat in November 2010. A Long March 3A launched the Zhongxing-20A military communications satellite from Xichang. A new navigation satellite followed in mid-December as the 15th and final mission of the year and the 12th with military capability.

As China continues to keep its three existing launch sites busy, huge construction crews continue to work at the giant new Wenchang Satellite Launch Center on Hainan Island, scheduled for completion in 2013. It will launch the new oxygen/hydrogen-powered Long March 5, similar to the American Delta IV.

PART ONE

Quieter flight: A balancing act

Equipped with an ever-expanding suite of new developmental tools, NASA's aeronautical researchers are exploring innovative concepts in jet engine and airframe technology, all to help achieve specific 'green aviation' goals related to fuel burn efficiency, noxious emissions, and nuisance noise.

Integrating these efforts into the Next Generation Air Transportation System, or NextGen, will follow as ideas are refined, proven, certified, and then adopted into the commercial marketplace during the next 10-30 years.

NASA's direction toward these goals comes from the National Aeronautics Research and Development Plan, a White House Office of Science and Technology Policy document most recently updated in February 2010. It clearly sees the federal government's role as one that "advances aeronautics research to improve aviation safety [and] air transportation, and reduce the environmental impacts of aviation." Another requirement demands that the aviation research community promote "the advancement of fuel efficiency."

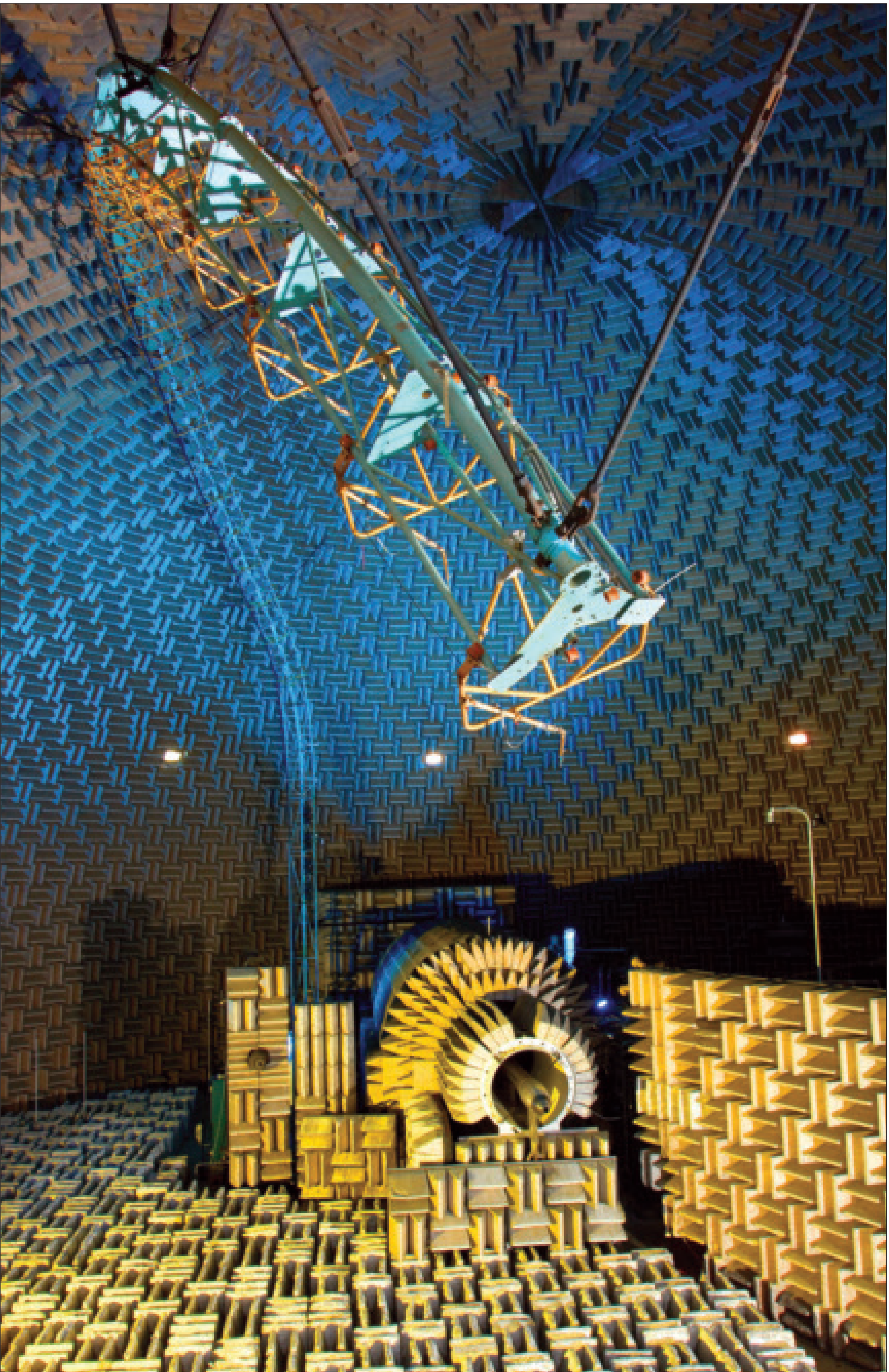
Achieving these national goals will require adequate and sustained funding for NASA's Aeronautics Research Mission Directorate and for other relevant government agencies, including the FAA. In recognition of the need to meet these goals, the Obama administration requested FY11 funding of $580 million, an increase of $83 million from the FY10 request. As of this writing, Congress had not yet approved NASA's funding package.

NASA is working to achieve aeronautical engineering breakthroughs that will enable development of technologies that make airplanes better for the environment. Among the most challenging problems researchers face is reducing aircraft noise, from both engines and airframes. Design features that successfully lower noise in one area, however, can raise it in another, making the task an extremely delicate balancing act.

"During these tough economic times, when difficult choices have to be made, it is gratifying to see NASA's aeronautics program will receive more funding this year," says Winston Scott, a former astronaut who is now dean of the College of Aeronautics at the Florida Institute of Technology. "At the same time, when you consider the importance of aviation research to making airplanes safer and more environmentally friendly, you wonder sometimes why aeronautics doesn't receive even more."

Aircraft should be seen and not heard

It was not until commercial jet operations began in 1958 that complaints about noise really started to become a problem for the aviation community. The combination of urban sprawl and expanding suburbs shrank the distance between residential neighborhoods and airport property. A Boeing 707 on final approach was an impressive sight, but if it flew over your house, even while still a mile high, you would be



A fisheye view of the anechoic AeroAcoustic Propulsion Lab at NASA Glenn highlights the overhead microphone array that encircles the Nozzle Acoustic Test Rig in the center of the chamber.

by Jim Banke
Public Affairs writer,
NASA Ïdquarters;
President, MILA Solutions,
a NASA subcontractor

Gold-colored foam wedges shield test subjects from outside noises during an acoustics test at NASA Langley. NASA researchers study people's perception of aircraft sounds in an indoor setting and investigate the role of rattle noises and vibration. They use this information to help design quieter aircraft. Credit: NASA Langley/Sean Smith.

subjected to 106 dB of noise—approximately the same level as a jackhammer.

Since then, NASA has worked with other government agencies and industry to significantly reduce the level of nuisance noise made by aircraft, especially during takeoff and landing. Now the bar is set even higher: Confine objectionable noise within the airport perimeter. That means quieting all sources of airframe and engine noise enough that people living or working near an airport in 2035 would not hear any noise they might consider a nuisance.

Eliminating the noise problem is a tall order by itself. But noise, emissions, and fuel-burn reduction technologies are not mutually exclusive. A concept that mitigates one problem might exacerbate another. For instance, one good solution for fuel burn and emissions problems is to equip jet engines with a dual-propeller system known as an open rotor to generate thrust. But then, as Ruben Del Rosario, manager of NASA's Subsonic Fixed Wing Project, notes, "You have the challenge of noise, because these blades are spinning in the open air."

So NASA's biggest hurdle is in developing technologies that can strike the right balance among multiple performance goals and meet them simultaneously. "At the end, the ultimate challenge is to find solutions that significantly reduce the airplane's fuel consumption, thus decreasing carbon dioxide emissions, while minimizing the objectionable noise and mitigating negative effects on air quality around the airports," says Del Rosario.

When it comes to what produces noise on airliners and how to suppress it, NASA researchers are considering everything, not just engines. Landing gear, flaps, the aircraft shape, the kinds of materials used, engine types and placement, the flight paths used during takeoff and landing—even the problems associated with eliminating the nuisance factor of sonic booms from supersonic aircraft—are all on the table. Each noise source could have its own quieting solution, so the trick is to find the best way to balance all of those considerations.

"There's a lot of work to do on all fronts to get the objectionable noise within the airport boundary," says Brian Fite, chief of the Acoustics Branch in the Aeropropulsion Division of NASA Glenn. "We've probably harvested all the low-hanging fruit to quiet a number of noise sources independently. And now we've really started to look at it in an integrated way. We're able to work on a few key areas and make progress, but eventually you have to start addressing interactions between components, including the airframe."

Testing for the right blend

One of those integrated solution approaches is to consider how best to bring together the airframe and the propulsion system. Will the overall noise be reduced the most by placing the engines on top of the aircraft, under the wings, in the tail, or in some other place that results in an airframe shape very different from the standard tube and wing used today? If a different airframe is the choice, how will the wings and tail be blended into the design? And will the resulting improvements in engine noise now worsen the noise made by the aircraft body itself, or add drag and weight issues that hamper fuel efficiency?

To help determine the ultimate answer, NASA researchers are preparing a series of wind tunnel tests to learn more about acoustic shielding, a design approach that uses parts of the airplane to prevent engine noise from reaching the ground.

Charlotte Whitfield, head of the Aeroacoustics Branch at NASA Langley, says one of these tests will involve Langley's 14x22-ft wind tunnel. This activity is funded by NASA's Environmentally Responsible Aviation Project. A generic hybrid-wing aircraft body, scaled to fit into the test stand, will be outfitted with a pair of propane-powered jet engine simulators. Cameras, sensors, and other instrumentation wired throughout the test area of the wind tunnel will record data about the interaction of the engines and airframe.

Beginning in 2012, several runs will be made with the jet engine simulators moved to different positions, and all the data will be fed into NASA's publicly available Aircraft Noise Prediction Program (ANOPP) software to see how accurately ANOPP can predict the noise of these advanced, highly integrated propulsion and airframe configurations. Validating the accuracy of ANOPP is an important prerequisite for its use in guiding the design of new low-noise aircraft concepts.

"I don't expect we'll wind up with one solution here. We're still going to have to look at our multiple options and try to understand their relative strengths and weaknesses," Whitfield says. "It's very simple to say that we should all go to blended wing bodies, but that's not going to happen. So we need to do more than just look at the effects of shielding from a blended wing body. We need to see what we can do with a conventional tube-and-wing design."

A look at the airframe

While discussion continues on the best way to bring propulsion and the airframe together, the airframe itself as a source of noise is also being studied. "We've reduced the noise from jet engines so much through the years that now we find airframe noise holds a greater potential for further noise reduction than we have had to think about before," Whitfield says.

Moving a body as large as an airframe though the air sets up any number of air currents that result in turbulence and the creation of noise.

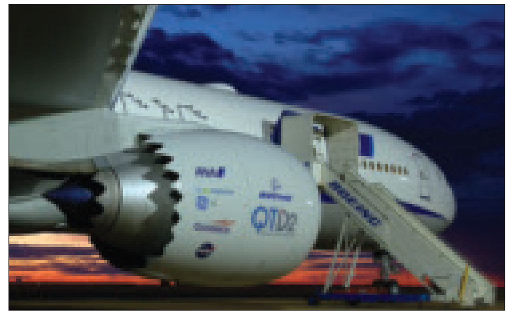
"We understand a great deal, not absolutely everything, but a great deal about how airframe noise is generated. What we end up with is a problem to a certain extent in practicality," says Whitfield. "We know how it is generated, but we also know that it takes a remarkably small amount of energy to create a remarkably large amount of noise. You work on streamlining, especially for landing gear. You have to work on it very carefully, because you can end up with something you think is going to be great flying, but while it reduces one noise source it introduces another."

Giving teeth to engine efforts

Like airframes, jet engines also are under study for additional noise suppression technology. Further improvements are expected even for one of NASA's more recent noise reduction success stories, chevrons.

Boeing recently introduced chevrons on its 787 and 747-8 aircraft, whose jet engine nozzles sport a distinctive saw-tooth pattern on their trailing edges. The teeth help to enhance the mixing of hot air from the engine core and cooler air blowing through the engine bypass fan, thus reducing turbulence that creates noise.

"Successes like chevrons are the result of a lot of different, hard-working people



NASA has partnered with industry many times during years of chevron testing, including these tests of nozzles on a specially adapted GE engine mounted on a Boeing 777. Chevron nozzles will be seen on more engines in the coming years. Credit: Boeing/Bob Ferguson.

and...a lot of very small efforts that all come together, often across many scientific disciplines," says James Bridges, an associate principal investigator responsible for coordinating NASA's aircraft noise research.

One type of propulsion system requiring big advances in noise reduction is that used on airplanes capable of vertical takeoffs and landings. NASA is looking hard at rotorcraft for civil transport, because systems studies have shown this configuration can improve air capacity by 30-60%, says Susan Gorton, manager of NASA's Subsonic Rotary Wing Project at Langley. Improving air capacity is a key feature of NextGen.

Gorton says the type of civil tilt-rotor envisioned would be able to haul 90 passengers at speeds of 300-350 kt with a range of 1,000 n.mi. A rotor wing aircraft would have to hover in the terminal area only a short time, would avoid delays caused by waiting on a taxiway for a runway to be available, and could land directly on the spot where it unloads.

"There's nothing in the industry's current inventory that has that kind of passenger capacity. To make that kind of vehicle a reality, we have to address certain technologies," Gorton explains. Approaches to making the rotor blades quieter include modifying the shape of the blade, employing technologies that would allow it to change shape during flight, or slowing

NASA and its industry and government partners used a modified F-5E jet to show that changing the shape of an aircraft's nose can reduce the intensity of a sonic boom. The 2003 flight test done was a precursor to current Fundamental Aeronautics supersonics technology low-boom research. Credit: NASA/Northrop Grumman.

down the blade. Slowing it could be done by simply reducing power, redesigning the blade to provide more lift at slower speeds, or shortening the blade, which would slow the tip speeds. Blade tip speed is a major variable for rotor noise.

"Right now the NASA research is targeting technologies for large civil tilt-rotor development. But at the same time we realize the nation currently has a helicopter fleet that will certainly continue for many years to come," Gorton points out. She notes that NASA's objective is to have any technology advances and breakthroughs apply to both tilt-rotor and helicopter applications.

Sonic whisper?

NASA is also exploring the fundamentals of how noise is made in the first place, as well as its impacts. "Our research concentrates in the physics of the source of the noise," Gorton says. "How do you model where the noise is generated? How do the blades interact with the wake? How does the noise propagate through the air? What does it sound like when it hits the ground? How do you minimize the footprint of the noise when it hits the ground?"

The rotorcraft story—improving an older technology to better fit an evolving aircraft—is similar to that told by NASA researchers working on technology to enable the FAA to change current policy prohibiting commercial supersonic flight over the U.S. because of worries about sonic booms.

Those laws are left over from the days when the nation first attempted to build its own supersonic transport and then abandoned the project. That left Great Britain and France to field the Concorde, which could fly only to cities along the U.S. coast, and only at subsonic speed when flying overhead. Now U.S. business jet manufacturers are asking for a supersonic option, and NASA may soon come up with a design in which the sonic aftereffect is more whisper than boom.

"From a technologist's viewpoint, I would say there are a great many of us who have always dreamed of having an economically viable supersonic airplane. And in order to do that we have to be able to fly it over land, which means reducing the sound level of a sonic boom so it is not annoying," says Peter Coen, manager of NASA's supersonics project. "It's a real challenge for us moving forward to clearly identify and explain to the public that the sonic boom we're talking about now is completely different from what has ever been heard in the past."

Whether made by an X-1 rocket plane, an F-22, or the space shuttle, a sonic boom results when supersonic shockwaves are produced by the aircraft's nose, then its canopy, then its tail, and even the handle to open the cargo hatch. Just about any change in the aircraft's geometry will set off a shockwave. Because all of these are produced at different times by different shapes and under minutely different air temperatures and pressures, the shockwaves travel away at different speeds. But within a few thousand feet, those independent shockwaves coalesce, creating two pressure spikes. When these spikes pass over the ground, you hear a sonic boom. (There are always two booms, but usually the aircraft is so small that both booms arrive at the same time. The space shuttle, at 120 ft long, is big enough that the ear can clearly pick up a double boom.)

As Coen explains, "the theory of sonic boom reduction says if those waves, those independent shocks, are approximately the same strength, they will not coalesce. They will travel to the ground as separate waves. And all the way through the atmosphere the magnitude of them attenuates. So if you can design an airplane such that the shocks are relatively the same strength, and relatively equally spaced, instead of getting two pressure pulses on the ground, you will get something else." Some have called it a 'sonic puff,' but Coen says he does not like that term and is open to other ideas.

To get an ideal shockwave signature that would not be noticed on the ground, the aircraft would have a long, slender nose and tail. But with the need for control surfaces on the tail, and possibly for a pair of engines hanging on or jutting out somewhere, this design becomes impossible.

"We're coming to the conclusion that

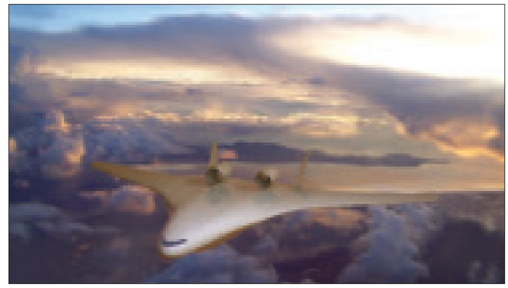
A view upstream looks into the NASA/Rolls-Royce variable-cycle nozzle with a lobed mixer, mounted on the jet rig in the Nozzle Acoustic Test Rig during acoustic testing in the AeroAcoustic Propulsion Lab at NASA Glenn.

the best thing to do is really not try to get that completely smooth pressure rise on the back end, but break the shock on the back end up into several pieces so you get the attenuation without the coalescing," Coen says. "So we know what needs to be done to shape the airplane to mitigate the boom. But we also need to reduce drag, we need to reduce takeoff noise, so it's really about understanding how to manipulate the shape of the airplane in three dimensions to produce the design that achieves multiple, hard performance goals.

"The real challenge has been integrating all the pieces of the sonic boom with all the components of the aircraft and coming up with a robust approach to reducing the aft signature to acceptable levels. We've made some improvement but we've had to go back and look at other approaches."

With nearly 100 years of experience in bringing innovative solutions to the skies, aeronautics is now faced with its biggest engineering challenges ever. The prospect of meeting the goals of simultaneous reductions in noise, fuel burn, and emissions, along with safely integrating the resulting aircraft into an ever-expanding air transportation system, is daunting, to say the least. Some aeronautics researchers have compared this challenge to NASA's 1960s-era effort to land humans on the Moon.

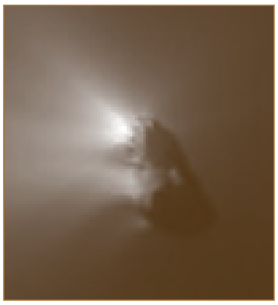
But unlike the historic Apollo goal, this one will not be achievable by the end of the decade—in part because of the time and effort industry must now invest in adopting green technologies and certifying their safety for flight.



This hybrid wing body concept (N2A HWB) has the engines mounted on top of a body that deflects noise upward instead of toward the ground. The concept was generated by Boeing under a Subsonic Fixed Wing Project study and is planned for testing in 2012 by NASA's Environmentally Responsible Aviation Project. Credit: NASA.

Editor's note: This is the first of four features that will describe the challenges associated with trying to invent a truly 'green' airplane. Future articles will cover work on technology to curb emissions, boost fuel efficiency, and enable the nation's air traffic management system to handle aircraft in a more environmentally responsible manner.

25 Years Ago, March 1986



March 8-28 During its closest approach to Earth since 1910, Halley's Comet is observed from space at various distances by ESA's Giotto spacecraft, the USSR's two Vega craft, and Japan's MS-T5 and Planet-A spacecraft. Nothing is sent by the U.S., although the ICE, launched in 1978 as the ISEE-3 (International Sun-Earth Explorer 3), is repositioned in its solar orbit to make observations. Planet-A approaches closest at 120,000 mi., but Giotto passes through Halley's tail. Vega-1 takes the first close-up photos of the famous comet, revealing it to be peanut-shaped and 3-4 mi. across. ICE also becomes the first spacecraft to intercept a comet, passing through the tail of Giacobini-Zinner on its way to Halley. NASA, *Astronautics and Aeronautics, 1986-90*, pp. 4-5, 21, 23; F. Winter, *Comet Watch*, pp. 47, 56-57.

50 Years Ago, March 1961

March 1 NASA announces the Saturn vehicle configuration known as the Saturn C-1. The first stage has eight H-1 engines with 1.5 million lb of thrust. The second stage has four LR-119 engines with 30,000 lb of thrust. The third stage has two LR-119 engines with 35,000 lb of thrust. Eventually, the Saturn evolves into the much larger, more powerful Saturn V vehicle that takes men to the Moon. *The Apollo Spacecraft: A Chronology, Vol. I*, p. 76.

March 1 The first Russian-built Antonov An-12 four-engine turboprop transport aircraft (the military version of the An-10 airliner) arrives at New Delhi for delivery to the Indian air force. Eight planes have been ordered, and there are reports that 100 Indian pilots are in training in the USSR. The An-12 is to be used for supplying construction projects in North India. *The Aeroplane*, March 17, 1961, p. 278.

March 3 Cessna Aircraft announces that its new light twin-engine, twin-boom, four-seat Skymaster, Model 336, has achieved its first flight at Wichita, Kansas. *Aerospace Year Book, 1962*, p. 470; *The Aeroplane*, March 10, 1961, p. 265.

March 6 Boeing's B-52H strategic bomber, developed to carry a Douglas Skybolt air-to-surface missile, makes its first flight. The Skybolt is later canceled, and the B-52H instead carries Hound Dog missiles, among other weapons. D. Baker, *Flight and Flying*, p. 374.

March 6 The British two-stage solid-fuel Skylark sounding rocket is fired from Woomera, Australia. In an experiment, it emits a sodium cloud to determine winds and temperatures in the upper atmosphere. The cloud appears about 50 times the size of the Moon. *The Aeroplane*, March 17, 1961, p. 300.

March 7 North American X-15 rocket research plane No. 2 becomes the first plane to fly faster than Mach 4. This is also the aircraft's first flight with its XLR-99 Pioneer engine, with 59,000 lb of thrust. The pilot is Capt. Robert M. White, who reaches a speed of 2,905 mph at an altitude of 77,450 ft, or Mach 4.4. D. Baker, *Flight and Flying*, p. 374; *The Aeroplane*, March 17, 1961, p. 277.

March 8 A new around-the-world record is set by Max Conrad when he lands his light plane in Miami, Florida, after completing a 25,527-mi. global flight of 8 days 18 hr 40 min in his specially equipped Piper Aztec light twin aircraft. The flight, which also carries NBC reporter Richard Jennings, began on Feb. 27. *Aerospace Year Book, 1962*, p. 470; *The Aeroplane*, March 1, 1961, p. 275.

March 13 Britain's Hawker P 1127 VTOL strike fighter makes its first conventional flight in a test at the

Royal Aircraft Establishment at Bedford, England. Flying the plane is Hawker's chief test pilot A.W. ('Bill') Bedford, who had flown it in tethered and untethered hovering trials. Powering the aircraft is a single Bristol Siddeley BS.53 lift-thrust turbofan of 15,000 lb thrust. *The Aeroplane*, March 17, 1961, p. 276.

March 23 The Saunders-Roe SRN.1 Hovercraft makes its longest nonstop journey to date, a 70-mi. circuit of the Isle of Wight, in 1 hr 30 min. *The Aeroplane*, March 30, 1961, p. 335.

Past

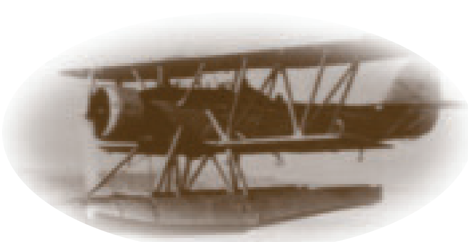
An Aerospace Chronology
by **Frank H. Winter**
and **Robert van der Linden**

March 25 From Cape Canaveral, a Delta vehicle launches Explorer X, a satellite designed to make the first detailed measurements of Earth's outer radiation belts. Some measurements are made, revealing higher radiation levels than expected, but signals cease on March 28. D. Baker, *Spaceflight and Rocketry*, p. 115.

And During March 1961

—Astrometrics develops a new sound reproducing system for transmitting the human voice from space. *Aircraft & Missiles*, March 1961, p. 158.

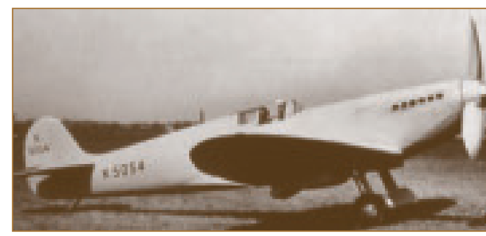
—The Israel Astronautical Society establishes an optical satellite tracking system on the roof of the Aeronautical Engineering Building at the Technion-Israel Institute of Technology at Haifa. The society will operate the tracking system in conjunction with the Astrophysical Observatory of the Smithsonian Institution at Cambridge, Massachusetts. *The Aeroplane*, March 23, 1961, p. 322.



75 Years Ago, March 1936

March 3 Six Blackburn Shark float planes are demonstrated in acceptance trials before the Portuguese mission at Blackburn's factory at Brough, England. Portugal is acquiring the planes as torpedo-bombers. They will also serve as reconnaissance aircraft. *The Aeroplane*, March 11, 1936, pp. 324-325.

March 4 Germany's newest zeppelin, the LZ 129—to be named the Hindenburg on March 25—is launched successfully from Friedrichshafen after removal from its 650-yard-long hangar. Hugo Eckner, father of the zeppelin, takes command and completes a 3-hr flight over Lake Constance. Cmdr. Ernest Peck, USN, is among the guests on board during the maiden flight. Powering the Hindenburg are four Daimler-Benz diesel motors with cruise ratings at 800-900 hp each. *The Aeroplane*, March 11, 1936, p. 310, and April 29, 1936, pp. 525-531.



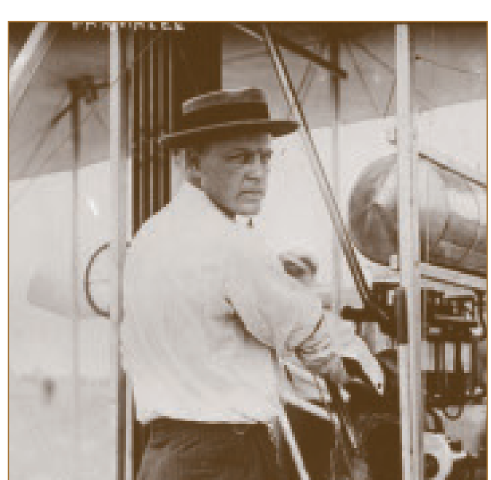
March 5 Spitfire prototype K5054 makes its first flight, with 'Mutt' Summers as test pilot. The plane proves to be a superb machine with great growth potential. During WW II the Spitfire becomes Britain's fastest and best fighter airplane and the backbone of the RAF's Fighter Command. *Supermarine Aircraft Since 1914*, pp. 216-217.

March 9 Flight Lt. Thomas Rose beats the Capetown-to-England flight record by 5 hr 12 min when he flies the 7,904-mi. trip in 6 days 7 hr 5 min in his Miles Falcon. This was slower, however, than his outbound trip to Capetown in February, accomplished in 3 days 17 hr 37 min. Nonetheless, Rose also sets a record for a two-way flight between Capetown and England, beating Amy Mollison's outward record by 13 hr 16 min. *Aero Digest*, April 1936, p. 156; *Flight*, March 22, 1936, p. 278.

March 12 Soviet pilot P.M. Stephanofsky claims a record for the greatest height reached by a glider. On the flight, started at Moscow, his glider is towed by a propeller-driven airplane to 34,989 ft and is then cut loose and makes a successful landing. Edgar Premen pilots the tow plane. *Aero Digest*, April 1936, p. 156.

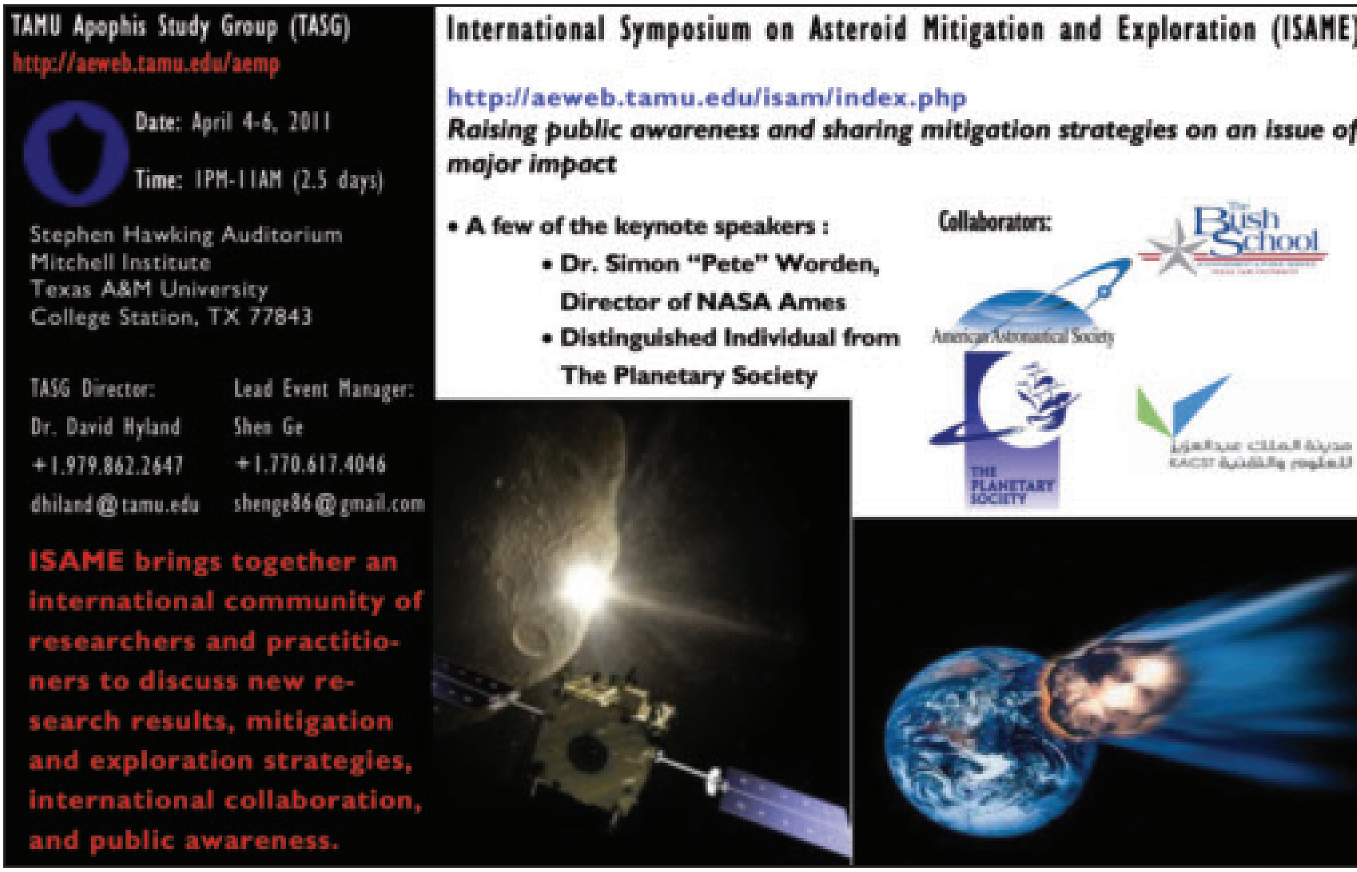
March 14 Weekly airmail service between Hong Kong and London begins. *Flight*, March 19, 1936, p. 314.

March 16 The Smithsonian Institution publishes Robert H. Goddard's classic report, "Liquid-Propellant Rocket Development," which covers his work from 1920. Perhaps not coincidentally, this date also marks the 10th anniversary of Goddard's first flight with a liquid-propellant rocket. The report contains his first public mention of that 1926 flight. E. Emme, ed., *Aeronautics and Astronautics 1915-60*, p. 34.



100 Years Ago, March 1911

March 3 Flown by Philip Parmelee and navigated by Capt. Benjamin Foulois, the Wright Type B aircraft sets an official U.S. cross-country record, flying from Laredo to Eagle Pass, Texas, in 2 hr 10 min. U.S. Centennial of Flight Commission Web site.



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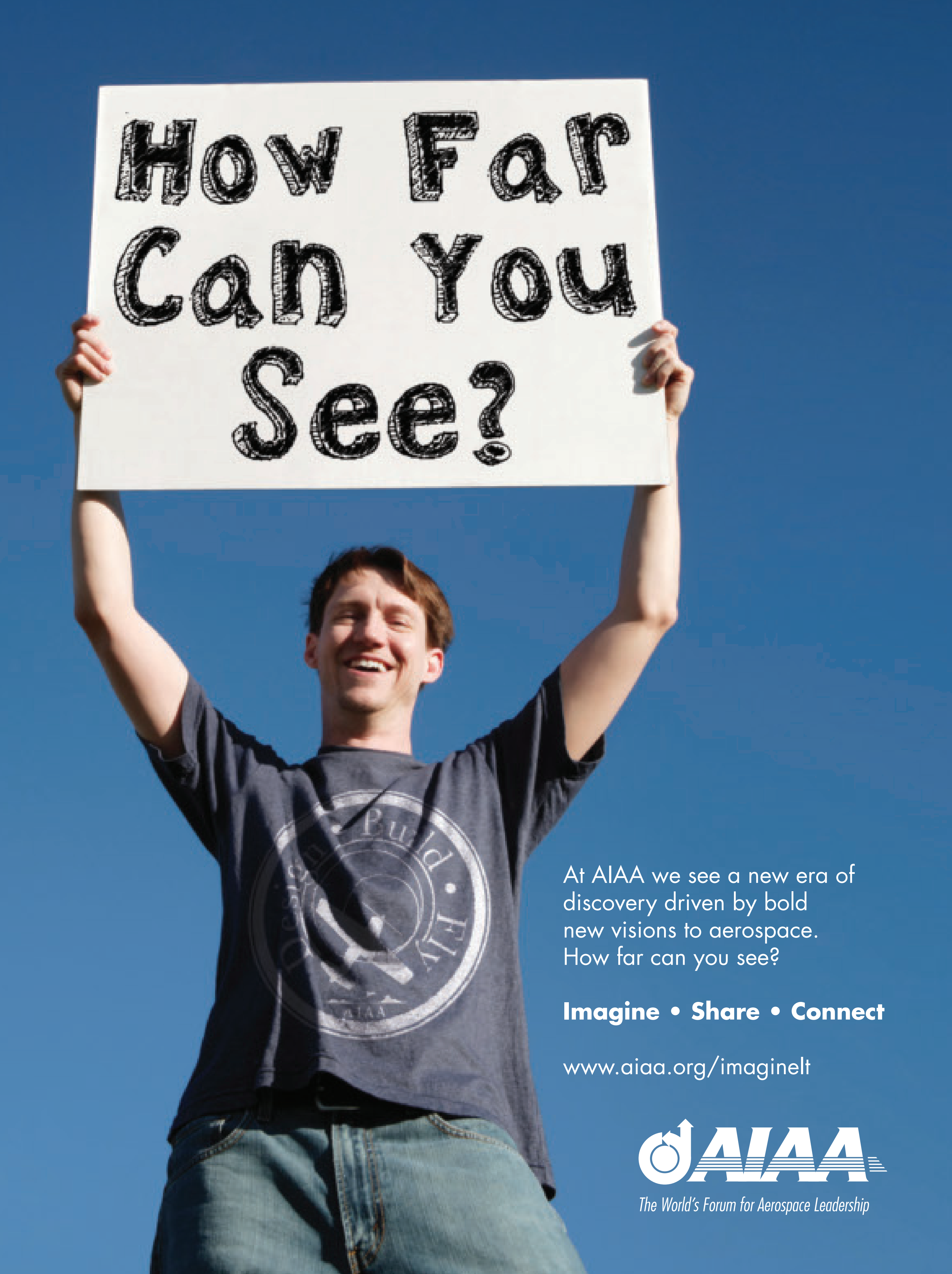
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