March 2010

# AEROSPACE AMERICA

## Unmanned and airborne

## A NEW PLAN

ISR in today's war: A closer look

World tanker market: More than just KC-X

A PUBLICATION OF THE AMERICAN INSTITUTE OF AERONAUTICS AND ASTRONAUTICS

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*March 2010*

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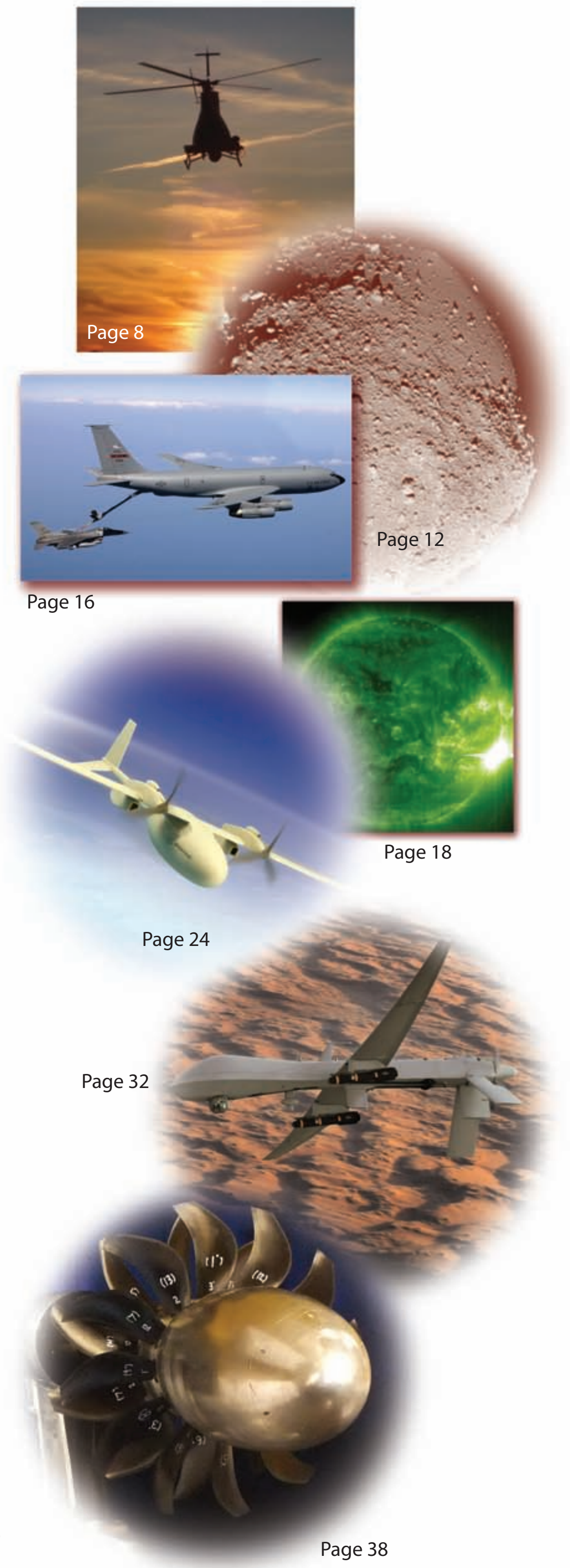


COVER
The Phantom Ray is the latest of Boeing's forays in the development of unmanned systems, a sector the company believes will continue to grow. Read all about their plans in the story beginning on page 24.


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# Editorial

## Space, safety—and risk

The FY11 NASA budget request represents a sea change for the agency—not just in terms of missions but, at least for human space operations, in the way it will bring those missions to fruition. It would bring the curtain down on the Constellation program, the agency's dominant program over the last five years.

The new budget supports extending the lifetime of the international space station beyond its current 2016 expiry out to at least 2020, funding programs to increase station capabilities and enhance ground support. It also commits funds to complete the space shuttle's current manifest, even if it must be stretched into another year.

But the mission to return humans to the Moon and then travel onward to Mars would be cancelled, replaced by robotic precursor missions to varied destinations in the solar system, followed by human exploration.

Gone as well are Ares I and Ares V, meant to launch crew and cargo, respectively, as well as the Orion crew vehicle. But what is more telling is what is meant to take their place. Building upon the "successful progress in the development of commercial cargo capabilities," the budget authorizes the investment of $6 billion over five years to "spur development of American commercial human spaceflight vehicles."

The passage of the president's budget request is by no means certain, and portions of the Constellation program such as the Orion, which has made considerable progress, might be redirected and survive in some guise, but the nation's future in space may well reside in the hands of commercial enterprise. Though they have often been partners with NASA, this new budget places the reins in their hands.

Many have argued since the decision was first reached to retire the space shuttle that human-rating the Atlas and Delta EELVs, which have excellent safety records, was a viable, lower cost alternative to reinventing the rocket yet again. It also would fall in line with the Augustine commission recommendations for a "flexible path" to space—albeit with lower funding.

But determining exactly what the criteria are for human-rating a launch vehicle is no easy task. Some argue that the directives laid down by the Columbia Accident Investigation Board are so rigorous that building a new vehicle under those strictures would be next to impossible.

Throughout the history of aviation in the U.S. there has always been the drive for the next generation—trying new vehicle shapes, new engines, even new fuels. Each new drawing, each new prototype was an effort to get us where we want to go more safely, more quickly, and as inexpensively as possible. Those criteria drove the development of a gamut of aircraft from the X-1 to the X-51, from the flying boat to the 787.

The pilots who sat in the cockpit of many of those experiments understood the risks they were taking—but were buoyed by the knowledge that some of the best minds in the nation were behind those aircraft. And so it went, and we did fly faster and further with each new effort. And though many were met with failure, and some with tragedy, we learned lessons from each and continued forward.

And so it should be now, with whatever the next launch vehicle turns out to be, that we put safety first, but not so much so that it keeps us Earthbound. The brave men and women who are the pioneers of this new century deserve nothing less—and, I believe, expect nothing more.

Elaine Camhi
Editor-in-Chief

# Environmental regulations fly high and wide

The failure of the Copenhagen United Nations Framework Convention on Climate Change (UNFCCC) in December 2009 to agree to global, binding targets for nations to lower their greenhouse gas emissions has both good and bad implications for the world's aerospace industry. But one immediate result will be a reevaluation of the way the industry will be regulated on this issue in the future.

Environmental pressure groups had been campaigning for conference delegates to set a cap on aviation emissions and introduce charges to airlines, based on their emission performance, to fund climate change management schemes in developing countries. The final agreement—which was not agreed to unanimously—committed developed countries to generate $100 billion a year by 2020 for poorer nations, but there was no mention of how aviation-generated emissions should be treated.

## Moving targets

The International Air Transport Association (IATA), perhaps fearful of a new wave of taxes and emission limits, welcomed the accord as "an important step in the right direction for climate change." According to IATA, which represents the world's largest scheduled airlines: "Aviation emissions were not addressed specifically in the accord, a reflection of the proactive measures the industry has taken to set challenging targets for itself, together with an aggressive strategy to achieve them."

IATA favors self-regulation, and before the conference had agreed with its airport, manufacturing and air navigation service provider partners on industry-wide targets to improve fuel efficiency by an average of 1.5% per year to 2020, stabilize carbon emissions from 2020 with carbon-neutral growth and work toward a net reduction in carbon emissions of 50% by 2050 compared to 2005.

These targets differed somewhat from limits agreed to by the International Civil Aviation Organization (ICAO), the Montreal-based U.N. global aviation regulator, at its High Level Meeting on International Aviation and Climate Change last October. Government delegates to that meeting agreed that the civil aviation industry will need to reduce its carbon footprint by 2% a year for the next 10 years. However, there were no sanctions or penalties outlined if these targets were missed.

The challenge of managing aviation emissions had been delegated to ICAO by the Kyoto UNFCCC meeting, held in December 1997, which set binding targets for 37 industrialized countries and the European Union to reduce greenhouse gas emissions by an average of 5% against 1990 levels over the five-year period 2008-2012. For environmental campaigners and some governments, one of the most important aspects of the Copenhagen meeting was to deal with aviation emissions from 2013, and the failure to do so has opened up important questions on how aviation emissions should be regulated in the future.

"With zero progress at Copenhagen we will continue to press for tough aviation emissions reduction target-setting to be given to UNFCCC itself," says Jeff Gazzard, board member of the Aviation Environment Federation, a U.K.-based environmental lobbying group.

"We simply cannot trust the global industry-dominated politics at ICAO to deliver meaningful limits—we will strongly encourage the European Union's 27 member states to press hard for the EU aviation emissions trading scheme to become the global model but with a tougher cap, 100% auctioning of carbon dioxide and inclusion of aviation's non-carbon dioxide impacts. We want the EU's New Year resolution to be to develop mutual effective ETS [Emission Trading System] schemes with like-minded states and blocs throughout 2010," Gazzard says.

Environmental campaigners are now targeting the next UNFCCC decision-making meeting in Mexico City in November 2010, rather than the ICAO assembly meeting in September, for the appearance of new global regulations capping aviation emissions.

One outcome of the last ICAO meeting was that its contracting states would "evaluate the possibility of more ambitious goals by the next ICAO assembly [2010], taking into consideration industry's collective commitments and the special needs of developing nations." And this is where a key structural problem in the current global environmental regulatory system appears.

## The regulatory conundrum

"The UNFCCC works on an understanding of common but differentiated obligations—a device developed at Kyoto for bridging developed and developing nations," says Andrew Charlton of the Geneva-based aviation government affairs firm Aviation Advocacy. "In the Kyoto protocol a two-track system was developed that created positive obligations on developed nations to achieve goals and aspirations for developing nations. One of the main issues in Copenhagen was whether to preserve the Kyoto arrangement—which would have excluded the U.S. from negotiations—or find a way to bring everyone on board. ICAO doesn't have the luxury of common but differentiated goals—all ICAO members are equal."

One possible outcome of this current impasse will be for the global regulation of environmental issues to be shared between ICAO and the UNFCCC, with the latter taking a more supervisory role.

Without a global agreement, the next few months will see the global aviation industry continue to pursue different directions. The most serious potential rift involves the inclusion of aviation within the European Union's ETS. EU representatives at the November ICAO meeting wanted this ETS to be adopted on a global scale, but the ICAO Assembly instead recommended it be adopted only as a voluntary measure.

## Cash or credit

Under the current timetable, beginning January 1, 2012, all flights landing in or departing from the EU will be covered by the ETS. Airlines will be given a free quota of carbon dioxide emission "credits"—but if they exceed this allowance they will have to start buying more credits from the market. Airlines have been obliged to provide precise data on their traffic and $CO_2$ emissions rates since January 1, 2010.

The quota is based on 97% of the total average annual levels of $CO_2$ emissions measured as having been sourced by aircraft operators between 2004 and 2006. This cap will be reduced to 95% at the start of 2013. Of the overall available carbon credits, 85% will be allocated on a free basis to aircraft operators and the remainder auctioned off, with the proceeds directed to climate change measures in European member states.

But the scheme is complex and, many aircraft operators argue, confusing. Over the last 12 months aircraft operators have had to register their plans with appropriate national authorities for monitoring, reporting and verification of $CO_2$ emissions from their fleet. Different countries set different deadlines for filing these plans.

According to the European Business Aviation Association (EBAA), of the 6,000 aircraft operators on the European Commission list for ETS, around 5,000 collectively account for less than 1% of total $CO_2$ emissions. For operators of small aircraft, the cost of joining the scheme is prohibitively high—the EBAA estimates it will cost a medium-size European business aircraft operator almost $100,000 in the first year of ETS. The threshold for joining the scheme is more than an average of 243 flights into and out of the EU over three consecutive four-month periods.

In December 2009, three U.S. airlines, American, Continental and United, and the U.S. Air Transport Association (ATA) brought a case in the U.K. courts challenging the inclusion of non-EU airlines in the ETS. The case was pending at press time.

## Sharing the pain

Aircraft operating companies are not the only aviation stakeholders who will be impacted by the EU ETS issue. "Our members are concerned about any new regulation that would increase their costs and potentially make them less profitable," notes Kevin Morris, environment and sustainability manager for ADS, the U.K.'s trade association of defense and aerospace manufacturing companies.

"In this respect they are concerned about the emissions trading scheme just as they are concerned about the other carbon management schemes put in place by the U.K. government, such as the climate change agreement (CCA) and carbon reduction commitment (CRC) schemes. This is because there is a significant opportunity for double charging and money being removed from the industry that could have been invested in new technology that would actually help reduce emissions."

Starting in April 2010, the CRC will be a U.K. mandatory carbon trading scheme that works in tandem with the EU ETS. The initial phase of the CRC is compulsory for organizations that consumed over 6,000 MWh of half-hourly metered electricity during the period from January to December 2008.

The aim is to reduce the level of carbon emissions currently produced by the larger "low-energy-intensive" organizations by about 1.2 million tonnes of $CO_2$ per year by 2020 and a 60% reduction in $CO_2$ emissions (over 2008) by 2050. In theory, where emissions have been captured by the EU ETS and CCA, they will not be captured by the CRC. In essence, the CRC is targeted at low-energy-intensive users.

U.K. companies, like most EU manufacturers, have had $CO_2$ emission reduction plans in place for some time. But these efforts will have to be intensified over the next few years to meet more stringent national and international limits beyond the ETS. For example, in January 2008 the European Commission released its Climate Action and Renewable Energy Package which, when it comes into operation in March 2011, will include a measure to reduce $CO_2$ emissions by 20% below 1990 levels by the year 2020. The ETS itself includes more stringent limits as time goes on, with industrial enterprises increasingly having to bid for credits. The aluminum sector will be included within the ETS from 2013.

"In one respect, the ETS may be seen as an opportunity for the aircraft manufacturers, as to reduce the costs of their emissions in the scheme will require the airlines to invest in new aircraft," says Morris. "However, those airlines need to make a profit before buying any new technology, and removing money from an industry when it is already in a precarious state will have negative impacts as well. The industry is collectively committed to a global sectoral emissions trading scheme as highlighted by ICCAIA, ACI and IATA in Copenhagen, as there is a good deal of concern that national or regional schemes will only serve to distort the market."

The EU could still decide to extend the ETS to imports into the continent from states that are not taking comparable action to reduce greenhouse gas emissions—though this would probably trigger a series of court cases at the World Trade Organization and other international courts.

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"There are many twists and turns to come" according to Aviation Advocacy's Charlton. "The newly appointed European Commissioners have made clear their commitment to environmental issues. They even acknowledge that it will come at a price. There is a dire need for leadership now. If it does not come from ICAO, it will come from somewhere else. The clock is ticking."

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## Events Calendar

**MARCH 6-13**
2010 IEEE Aerospace Conference, Big Sky, Montana.
***Contact: David Woerner, 818/726-8228***

**MARCH 16-17**
Congressional Visits Day, Washington, D.C.
***703/264-7500***

**MARCH 22-24**
Eighth U.S. Missile Defense Conference and Exhibit, Washington, D.C.
***Contact: 703/264-7500***

**MARCH 22-24**
Forty-fifth 3AF Symposium of Applied Aerodynamics, Marseilles, France
***Contact: Anne Venables, secr.exec@aaaf.asso.fr***

**APRIL 12-15**
Fifty-first AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics and Materials Conference; 18th AIAA/ASME/AHS Adaptive Structures Conference; 12th AIAA Nondeterministic Approaches Conference; 11th AIAA Gossamer Systems Forum; Sixth AIAA Multidisciplinary Design Optimization Specialist Conference. Orlando, Florida.
***Contact: 703/264-7500***

**APRIL 20-22**
AIAA Infotech@Aerospace 2010, Atlanta, Georgia.
***Contact: 703/264-7500***

**APRIL 25-30**
SpaceOps 2010 Conference: Delivering on the Dream (hosted by NASA Marshall and organized by AIAA), Huntsville, Alabama.
***Contact: 703/264-7500***

**MAY 4-6**
ASTRO 2010—15th CASI Astronautics Conference, Toronto, Ontario, Canada.
***Contact: G. Languedoc, 613/591-8787; www.casi.ca***

**MAY 11-12**
Inside Aerospace—An International Forum for Aviation and Space Leaders, Arlington, Virginia.
***Contact: 703/264-7500***

**MAY 13-15**
Fifth Argentine Congress on Space Technology, Mar del Plata, Argentina.
***Contact: Pablo de Leon, 701/777-2369; Deleon@aate.org***

**MAY 31-JUNE 2**
Seventeenth St. Petersburg International Conference on Integrated Navigation Systems, St. Petersburg, Russia.
***Contact: Prof. V. Peshekhonov, www.elektropribor.spb.ru***

# Big budget, big changes

In February, the nation's capital was humming with debate about NASA's human spaceflight program after release of the Obama administration's FY11 budget request .

The NASA request would add $6 billion over five years, far less than the amount recommended in the Augustine commission report on the future of human spaceflight. The administration has been focusing on deficit reduction, even though polls show Americans favor government spending as a source of employment in today's jobless economy.

The plan would kill the Constellation program, including the Ares I and Ares V launch vehicles and, while allotting R&D funds for future heavy-lift development, transport of astronauts to the ISS after retirement of the shuttle would fall to commercial ventures. The additional $6 billion will be used to "spur the development of American commercial human spaceflight vehicles."

*ESA Director General Jean-Jacques Dordain*

***The Ares I-X rocket was a test platform in the Constellation program that was canceled in the administration's budget request.***

In January, the *New York Times* has quoted NASA Aministrator Charles Bolden, speaking in Israel, as saying, "What NASA will focus on is facilitating the success of—I like to use the term 'entrepreneurial interests.'"

Robotic precursor missions would be sent to the Moon, Mars, and various asteroids and Lagrange points to scout targets for future manned activities .

Critics on Capitol Hill are uncomfortable with what they call the "outsourcing" of human spaceflight, and the cancellation of a program that has already cost billions of dillars.

Last year a blue-ribbon panel headed by former aerospace executive Norman Augustine concluded that NASA would need an increase of $3 billion to sustain the human spaceflight program (known as the "vision") that it has been pursuing. "That kind of money was never going to be there," says a NASA insider, citing growing concern over this year's $1.42-trillion federal deficit. Space enthusiasts fear the public is no longer inspired by journeys beyond the atmosphere. Social critics question whether a debt-burdened federal government should finance any space program at all.

In Washington and in the capitals of other participating nations, experts are preparing to meet in Japan later this year to debate the future of the ISS. U.S. funding for the space station had been due to expire at the end of FY15. In a worst-case scenario, that would require deorbiting the ISS and destroying the result of many years of work aimed at establishing a permanent presence in space. Obama's budget request, however, calls for station funding to continue through 2020.

ESA boss Jean-Jacques Dordain said in a January statement that participating nations will have to decide the future of the space station together—a rebuff to the idea that the U.S. can decide unilaterally—and that future planning requires the U.S. human spaceflight policy to be clearly defined.

"The decision must be made early enough to put the budget in place, to build the hardware necessary and to decide on which transportation policy we shall use between 2015 and 2020," said Dordain. "There are a lot of aspects to be discussed, and if decisions are not made by the end of this year [or the] beginning of next year, it will become more and more difficult to have the approach under which we will exploit the space station."

Dordain acknowledged that measures can be taken to make ISS operations more economical. He questioned whether participating nations need four control centers, and whether six astronauts must staff the station, arguing that during some periods a smaller crew might suffice.

*The budget commits additional funding to extend the lifetime of the ISS to at least 2020.*

As if to punctuate the decline in public enthusiasm for spaceflight, NASA has lowered its prices in what amounts to a yard sale of shuttle vehicles and support equipment. The agency is offering two shuttles to approved purchasers—almost certainly museums—for $28.8 million each, or about 40% less than it once sought. NASA already plans to transfer the shuttle Discovery to the Smithsonian Institution's National Air and Space Museum but is offering Atlantis and Endeavour to any buyer who can assure they will be "displayed in the broadest interest of the American public."

Under the proposed deal, NASA will retain ownership while the shuttles stay on permanent display. The agency also wants to dispose of surplus main engines from the shuttle and other memorabilia from the soon-to-end program, including spacesuits and wind tunnel models.

## Global positioning problem

The U.S. has become so reliant on satellite technology that it could be vulnerable to attacks on key nodes of the global positioning system, Air Force chief of staff Gen. Norton Schwartz warned at a January 20 conference in Washington. Military officers have long called for an alternative to GPS to give the U.S. a fallback method of navigation in time of crisis.

"Global positioning has transformed [our] war-fighting capability," Schwartz said. "Our dependence on precision navigation in time will continue to grow." But he said U.S. military service branches must find a way to reduce, rather than increase, their reliance on GPS.

Schwartz said he worries that an enemy might find a way to attack the GPS datalink or might hack into and program U.S. satellites to send inaccurate coordinates. He noted that the military now relies heavily not just on GPS but on other space-based capabilities, including satellite imagery and communications.

*Discovery will head off to the National Air and Space Museum after its final mission;, the other shuttles will be on the auction block.*

*Gen. Norton Schwartz*

The general wants the military to field a more diverse range of weapons. He is especially enamored of advanced targeting pods (ATPs) that increase the intelligence, surveillance and reconnaissance capabilities of existing platforms and can also assist with navigation.

Almost unnoticed, the Air Force has installed 448 Northrop Grumman Litening and Lockheed Martin Sniper ATPs on A-10, F-15, F-16, B-1 and other warplanes and has established a requirement for 1,230 ATPs altogether. A modest $160 million in the FY10 defense appropriations law will underwrite ongoing ATP development, including a new competition between Litening and Sniper for further purchase orders.

Schwartz offered a B-52 Stratofortress with a Sniper ATP to take pictures of the damage inflicted by the January 12 earthquake in Haiti. The offer was not taken up, but ATPs are in increasingly widespread use and offer an alternative to space-based technology. The general said Air Force scientists are developing other technologies to augment GPS. Some high-tech alternatives to space-based systems are thought to be included among the Pentagon's "black" programs—those not publicly disclosed in budgeting documents.

## Army aviation

When President Obama decided to increase U.S. troop strength by 30,000 in Afghanistan—a process to be completed by late autumn—U.S. Army aviation found itself facing unexpected challenges.

"We carry out air assault and medical evacuation missions," says Lt. Col. William C. George, an Army spokesman. "A large part of our duty consists of simply hauling people and equipment around the country." Vertical lift offers a way of circumventing the improvised explosive devices, or roadside bombs, that insurgents regularly plant on Afghanistan's few passable roads.

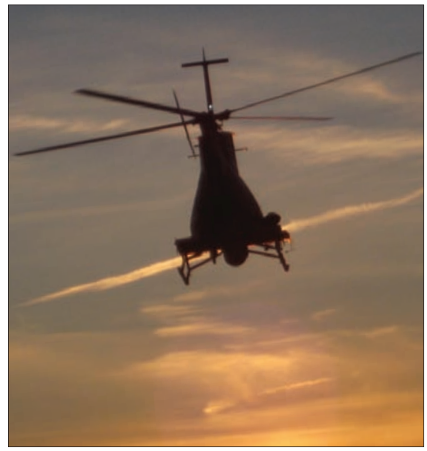
Altogether, the Army has 19 Combat Aviation Brigades (CABs), including eight in the National Guard. A "heavy" CAB consists of four battalions each with 48 AH-64D Apache, 38 UH-60M Black Hawk, 12 HH-60M Black Hawk and 12 CH-47F Chinook helicopters. The Army has maintained three to four CABs in Iraq, a country two-thirds the

*A U.S. CH-47 Chinook resupplies Charlie Company at its outpost in the Kandahar province of Afghanistan on Dec. 12, 2009. DOD photo by Master Sgt. Juan Valdes, USAF.*

size of Afghanistan, but kept only one in Afghanistan until recently.

Notorious for its lofty mountain elevations and scattered special operations outposts, Afghanistan has always needed—and tested—military helicopters. During the period June to September, the country experiences harsh atmospheric winds that create high clouds of dust amidst very hot temperatures. Only the twin-tandem Chinook has consistently coped with "high and hot" conditions in the Hindu Kush.

At the start of this year, the Army had two CABs in Afghanistan, one each from the 3rd Infantry and 82nd Airborne Divisions. At press time, the CAB of the 4th Infantry Division (Mechanized) was departing Fort Hood, Texas, to join them. The 159th CAB, associated with the 101st Airborne Division, completed a one-year stint last December but was expected almost immediately to turn around and deploy again. At least two other CABs are expected in Afghanistan by late autumn.



*The Army canceled the RQ-8B because of limits on funding for aviation.*

An upsurge in the need for military helicopters is a boon to industry. As analyst Richard Aboulafia noted (see "Aircraft industry rides out the recession…so far," January, page 21), the rotary-wing market grew by 30.1% in 2009. This year, growth could reach 40%. The FY10 defense appropriations law devoted $3.34 billion to the largest recent increase in U.S. military helicopters: The Obama administration got its request for $1.26 billion for 79 Black Hawks, $882 million for 27 Chinooks, and $326 million for 54 remarkably economical UH-72 Lakota light utility helicopters.

Still, Pentagon staff officers are talking about an Army "helicopter shortage" similar to the "fighter gap" being predicted in the Air Force and Navy. The service hopes to compensate, in part, with unmanned aerial systems.

That will not include the RQ-8B Fire Scout unmanned minihelicopter, which only six years ago was touted as a key component of the Future Combat System net-centric weapons program. In January, the Army canceled the RQ-8B, saying it did not improve on existing systems. The problem was not with the vehicle itself but with limits on overall funding for Army aviation programs. “This was a handy thing to have,” says one officer, “but we have other systems that perform as well or better.”

Although little noted in the press, the Army’s largest unmanned flyer is the General Atomics MQ-1C Sky Warrior, often described as a Predator on steroids. The MQ-1C has a wingspan of 56 ft (25 ft more than an F-16 and 9 ft more than a Predator) and can carry AGM-114 Hellfire air-to-ground missiles. This UAS has been quietly under development with support from Congress. The program has proceeded on schedule and on budget.

The 1st Air Cavalry Bri-gade became first to deploy with the Sky Warrior in January when it moved to Taji, Iraq. Although still in the test phase, the Sky Warrior will now support soldiers on the ground, including troops in combat with insurgents. If the deployment and field use of the Sky Warrior prove success-ful, it will move into full-rate production and emerge as one of the most prominent Army aerospace programs. The Iraq deployment will enable the Army to scrutinize the system’s strengths and limitations, and to develop a concept of operations for wider use of the MQ-1C. Army chief of staff Gen. George W. Casey Jr. says his service hopes to give every CAB a Sky Warrior capability starting in 2012.

*After completing a 24-hour mission, an MQ-1C Sky Warrior aircraft makes a landing on January 11.*

While the Army continues to sort out its aviation needs and tries to accommodate the Afghanistan buildup, it may catch some flak from a sister service over the nagging question of who should operate a UAS in flight. The Air Force has just unveiled a separate career field for UAS pilots, separating them from pilots of manned aircraft—and they are all officers. The Army allows enlisted soldiers to pilot the MQ-1C and other UASs.

**Robert F. Dorr**
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# Why asteroids beckon: NASA and near-Earth objects

NEAR-EARTH OBJECTS (NEOS), GENERALLY speaking, are asteroids and comets that approach or cross Earth's orbit. As the White House and Congress take up the details of NASA's future, NEOs are grabbing attention on several fronts. From a minor scientific curiosity two decades ago, these denizens of the inner solar system have been recognized as both a hazard and a major option for NASA's human exploration program.

Even before the release of NASA's FY11 exploration budget, NEOs had emerged as realistic destinations for U.S. astronauts. Six months ago, the Augustine commission put the exploration of NEOs at the center of its Flexible Path options for human spaceflight. The committee's attraction to piloted NEO missions was based on their accessibility, scientific value, operational challenge and potential for tapping space resources. Late last year, asteroid missions were front and center with NASA managers, at the Office of Science and Technology Policy and in White House discussions of the agency's future direction.

One superficial reason for heightened NEO visibility was that "they're not the Moon." More substantively, NEOs comprise an attractive suite of deep space destinations that will enhance NASA's human exploration effort and deliver cutting-edge scientific and technical benefits.

*Charles Bolden (l.) and Anatoly Perminov met last October at Mission Control Center Moscow in Korolev. (NASA photo; Bill Ingalls.)*

## Close encounters with NEOs

NEOs were garnering plenty of attention outside NASA as well. In early January, ROSKOSMOS head Anatoly Perminov told reporters that Russia would begin planning a robotic mission to deflect asteroid 99942 Apophis. "I don't remember exactly, but it seems to me it could hit the Earth by 2032," Perminov said. "People's lives are at stake. We should pay several hundred million dollars and build a system that would allow us to prevent a collision, rather than sit and wait for it to happen and kill hundreds of thousands of people."

Perminov's worries, like Apophis itself, are a little wide of the mark: The NASA NEO program's latest orbital analysis gives Apophis only a four-in-a-million chance of striking Earth in 2036. Still, it was noteworthy that the head of Russia's space agency views NEOs as a distinct hazard to our planet, and offered Russian leadership to demonstrate an asteroid deflection. If NASA moves toward extensive robotic and eventual human exploration of NEOs, Perminov plainly does not intend Russia to be left on the ground.

In a letter to the Russian administrator, Rep. Dana Rohrabacher (R-Calif.) applauded Perminov's proposal: "It would be foolish and irresponsible for America to cede our responsibility on this critical threat to all of humanity. You can count on me to try to make this a joint project with the United States." Rohrabacher's missive was plainly aimed at NASA, too. He has long cajoled the agency to take a more active role in planetary protection from NEOs.

Apophis is clearly not a threat, but a botched deflection could put it on an impact trajectory. Perminov was quickly advised by his scientists that Russia should choose a NEO with zero chance of striking Earth for a demonstration.

*The boulder-studded surface of Itokawa, about 500 m long, loomed toward Japan's Hayabusa spacecraft in 2005. (JAXA image.)*

As the growing catalog of known NEOs approaches 7,000 (see http://neo.jpl.nasa.gov/stats/), we are aware of more frequent close encounters with small asteroids. A recent attention-getter was 2010 AL30, some 10-15 m across, which streaked by on January 13 just 130,000 km from Earth. A NEO this size will pass within the Moon's orbit about once a week on average.

If smaller than 30 m, asteroids generally will be too small to penetrate the atmosphere; nonetheless, 2010 AL30's close approach reminds us that some 2 million NEOs roam the inner solar system. The random rock that caused the 1908 Tunguska explosion, estimated at about 5 Mt of TNT-equivalent energy, was just 30-40 m across; there are more than 100,000 future Tunguskas out there, and one of them will strike Earth every 300-500 years. On a bad day, hitting in the wrong place, such an explosion would destroy a city.

## You can get there from here

We are undoubtedly in some undiscovered NEO's gunsight. By exploring these objects, we gain an opportunity not only to reduce the future impact hazard, but to turn these potential blockbusters to our advantage, through benefits in science, operations, space resources and planetary protection.

These benefits all stem from one practical characteristic of a small but special group of NEOs: their accessibility. A small fraction of NEOs circle the Sun in Earth-like orbits. Of this "attractive" group, with orbital inclinations, eccentricities and semimajor axes close to Earth's, nearly 60 known NEOs would have been within the reach of the Orion crew exploration vehicle. More than half of those could be reached for a round-trip delta-V less than that of a lunar round trip (about 9 km/sec). Any system sized to reach lunar orbit or the Earth-Sun gravitational Lagrange points can also reach a set of the best-situated NEOs. NASA has already identified a few Orion can reach in a single heavy-lift launch. With cancellation of the Constellation program, however, they remain beyond our grasp.

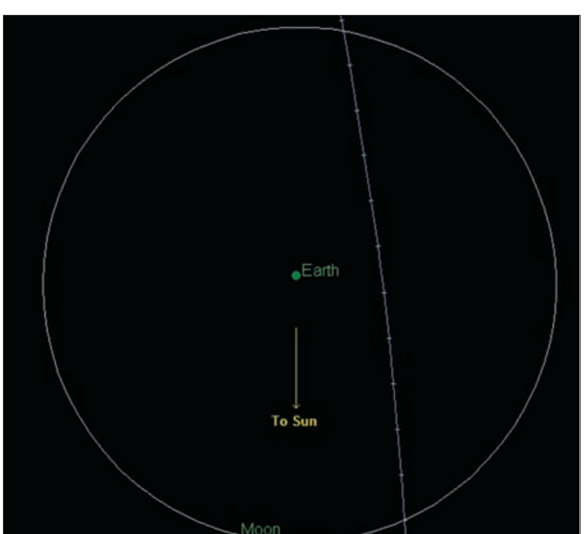
The list of these accessible objects will only grow as new search capabilities become operational (such as PanSTARRS and LSST; see http://pan-starrs.ifa.hawaii.edu/public/; http://www.lsst.org/lsst). Thousands of new asteroids will be found in the coming decade.

The key long-lead-time capability for expanding this NEO target set is early and sustained funding for the next-generation search systems. NASA should step forward to provide this, given its mission requirements, but DOD, NSF and international support should also help. The more NEOs we discover, the larger the number of opportunities for reaching them with robotic and human explorers.

NASA's Constellation program, in studying NEO missions in 2007, found that with minor modifications the Orion spacecraft can support crews on deep space missions lasting up to six months. NEOs a few hundred meters across have almost no surface gravity, so Orion missions would not require development of a separate, expensive lander. For a crew of just two or three, astronaut comfort and safety could be improved by adding a small (perhaps inflatable) habitation module, including an airlock. NASA has also considered adding more propellant capacity to Orion's service module, which would expand the target set of accessible NEOs.

## Are NEOs worth visiting?

Previous robotic touchdowns by the NEAR-Shoemaker and Hayabusa spacecraft demonstrate that NEOs represent a strange and varied zoo of solar system relics whose materials have been unaltered for more than 4.5 billion years. Some will be loosely bound piles of fragmented rubble; some, solid chunks of iron and nickel. Some will be of uniform composition; others, like Itokawa with its sprinkling of very dark boulders, display dramatic signs of surface heterogeneity. Each NEO, with its own story of formation, collision and orbital evolution, represents a surprise package of untapped knowledge.



*Asteroid 2010 AL30, discovered by MIT's Lincoln Laboratories LINEAR survey on Jan. 10, 2010, came within 125,000 km of Earth on Jan. 13. JPL says the NEO was about 10-15 m across. (JPL image.)*

After rendezvous, astronaut field geologists will survey the object while stationkeeping. Initial remote sensing will pinpoint a few prime "docking" sites on the low-gravity surface. Using EVA jetpacks, or piloting Orion to a physical touchdown, astronauts will collect tens of kilograms of the NEO regolith. They'll not only sample the surface but also probe crater floors and snoop under the bulk of nearly weightless boulders.


*Astronauts using EVA jetpacks could visit NEOs and collect samples of regolith.*

As in Apollo, crews will emplace instruments such as tracking transponders, active seismometers and heat transfer probes. An Orion-mounted radar might probe the asteroid's internal structure (Itokawa's interior turned out to be 40% empty space). Measuring such physical properties will be essential to devising engineering methods for deflecting future Earth impactors.

NEO explorers will also experiment with resource extraction technologies, demonstrating practical recovery of asteroidal water, volatiles and rare metals. These technologies are the key to moving space exploration from total logistical dependence on Earth to harnessing off-planet raw materials for propellant and industrial feedstock.

We are just beginning to learn about NEOs up close, and are bound to be surprised by the results of robotic and human expeditions. By exploring NEOs, we will immediately add an independent, third "planetary" surface to our ongoing lunar research and expanding investigation of Mars.

### Learning the ropes for deep space exploration

Deep space operations experience is one of the most valuable benefits of venturing well beyond the Moon. Multimonth NEO expeditions will stress all areas of mission operations. Designers will have to produce reliable, fault-tolerant systems for life support, computing and communications. Millions of kilometers from Earth, the communications lag will force a high degree of on-board autonomy and decision-making. Mission planning and vehicle control specialists must conduct intense exploration campaigns while maintaining situational awareness and safety.

By taking on these challenges at NEOs, we will be better able to explore the Moon, build a thriving space economy and confidently send astronauts to Mars.

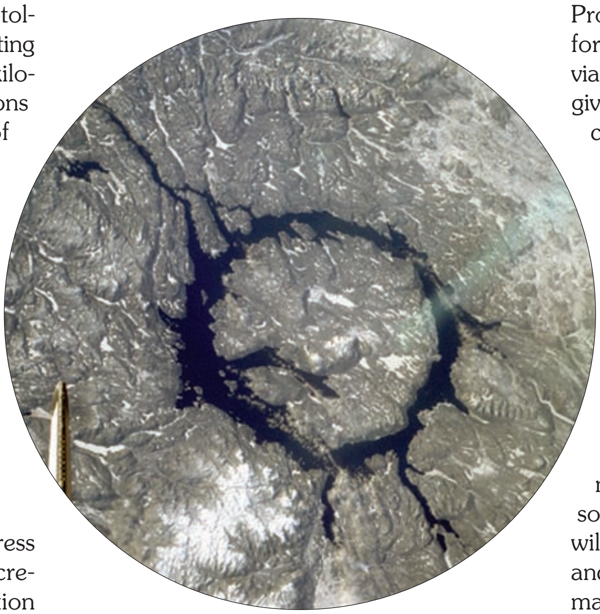
### Outward momentum

Since the close of Apollo, our progress in human exploration has been incremental. The shuttle and space station have been effective classrooms in space, teaching us how to live and work there with confidence. To what purpose do we apply our hard-won education?

The 2004 Vision for Space Exploration, stripped of funding, has yet to propel us outward. Sending astronauts to NEOs will be an unmistakable commitment to long-term, ambitious exploration. Reaching and returning from these ancient landscapes will demand the best talents of NASA's exploration, operations and scientific organizations.

Our choices are excellence or failure; "muddling through" will not be a successful strategy. NASA will have to scour the government and nation for the young engineers and scientists driven to break new ground in human and machine performance.

Political momentum will be as important as technical progress if out-of-LEO exploration is to succeed. NASA will have to deliver highly visible technical and programmatic results on a scale suited to our short political attention spans. A NEO exploration program will start with robotic precursors surveying the varied compositions and structure of several potential NEO destinations. While the new Orion spacecraft and heavy-lift launcher are tested, first in LEO and then in lunar orbit, engineers will prove life support and crew health systems on the ISS. These incremental efforts will give policymakers a cumulative record of milestones, building momentum toward a commitment to true deep space expeditions.



*Formed almost 212 million years ago by a NEO impact, the 100-km-wide Manicouagan Reservoir is located in a heavily timbered area of the Canadian Shield in Quebec. Astronauts aboard STS-9 took this photo in 1983.*

The timing of our beyond-LEO efforts will clearly be budget driven. If the Augustine commission recommendation for a space budget worthy of a great nation is realized, we could be ready for NEO missions even before 2020. Between now and then, NASA will have to accumulate the public, congressional and executive support needed to make its first trans-NEO injection burn.

One element of creating that support is international cooperation. Although it might add political and technical complexity, some of our ISS partners could provide a NEO campaign with propulsion modules, habitation systems, EVA mobility systems and scientific hardware. Buttressed by these international commitments, a NEO exploration program would be less vulnerable to political turbulence during the decade or more required for execution.

### NEOs: An offer we can't refuse

The public understands today that protecting Earth from a future NEO catastrophe is a worthy mission for NASA. Proving technologies and gathering information to head off an Earth impact, via robotic and human NEO exploration, gives the agency's efforts in deep space a commonsense foundation. When those efforts take the form of astronauts drifting across the rocky surface of a NEO under a gleaming, BB-sized Earth 5 million miles distant, our imaginations will be fully engaged.

With the White House's direction to NASA just released, we cannot yet gauge the prominence NEOs have taken in the agency's revised exploration charter. But I believe we should seize the opportunity to include these science- and resource-rich objects in our plans. NEOs will reinforce the scientific, economic and technical strengths of the U.S. human exploration program. We would reap the benefits of synergistic scientific return from a "new" planetary surface, substantially different in origin, age and composition from those of the Moon or Mars. Explorers would also assay NEO resources potentially vital to future U.S. economic activity in space.

In coming decades, the global community will certainly face a decision to deflect a hazardous NEO. Impact prevention is a fundamental, "know your enemy" mission, and a commonsense rationale for NEO exploration. Grappling with these objects at a distance, before we are faced with such a threat, will provide us the operations experience and civil engineering data needed for a successful future deflection.

Finally, in the event that policymakers defer a U.S. return to the Moon, NEOs provide NASA with a challenging exploration alternative. Less expensive to reach than the lunar surface, NEOs will nevertheless stretch our capabilities and set the U.S. on an ambitious and rewarding course of unapologetic human exploration.

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# World tanker market: More than just KC-X

OVER THE PAST DECADE, DISCUSSION OF the world air refueling tanker market has centered on the USAF KC-X program, the largest tanker requirement by far. Yet despite the program's importance, international requirements for these aircraft have grown, reflecting a new, if somewhat uneven, appreciation of what they bring to the table.

Meanwhile, the shifting dynamics of the KC-X competition look set to impact this world market. The USAF draft request for proposals has produced considerable speculation that Boeing's KC-767 now has the upper hand. This could restore Boeing's position in this market, following several high-profile losses to Airbus's KC-30.

### A broader requirement

Until 2001, the pool of customers willing to spend cash on Western new-build jet tankers was limited to one customer. While many countries maintained some kind of air-to-air refueling capability, Saudi Arabia was the only one that had actually purchased them new (in the form of eight 707s built as KE-3s). Even the RAF, the biggest tanker user outside the U.S., used Lockheed L-1011s originally operated by Pan Am and British Airways, and Vickers VC-10s formerly operated by British Airways, BOAC and East African Airways. All the other users either also operated converted used jetliners or KC-135s previously owned by the USAF. France, for example, uses the KC-135R (the reengined type predominant in the USAF); Turkey and Singapore have received them as well. Other countries used turboprop tankers, most notably Lockheed Martin's KC-130.

In 2001, the Italian air force signed on for the first new-generation, new-build tanker, Boeing's KC-767. This purchase of four aircraft was followed by a Japanese purchase of four planes later that year. Thus the pool of new-build jet tanker customers tripled in one year.

However, this promising start foundered. There were numerous technical problems and program delays; delivery did not begin until 2008, when Japan received the first aircraft, followed by Italy in 2009. No further orders have been received. Boeing continues to refine the KC-767 offering, but the company is focusing on the home market customer.

Even worse for the KC-767, Airbus/EADS began developing a Multi-Role Tanker Transport variant of its A330. Airbus had produced MRTT variants of its smaller A310 twin-aisle jet, but these were conversions of civil jetliners that had gone only to Canada and Germany. The KC-30 was a more ambitious effort: a larger, more capable jet with a robust cargo and tanker capability, offered as a new-build product. In particular, the company moved beyond hose-and-drogue air refueling technology, developing its own boom under the Advanced Refueling Boom System.

This more aggressive approach to the market has been rewarded, with four more countries joining the new-build jet tanker market. In 2005 the RAF chose it to replace its aging converted jetliners under a private finance initiative program. Australia has also ordered five KC-30s, followed by the UAE (three planes) in February 2007 and Saudi Arabia in early 2008 (three planes, followed by three more ordered in 2009).

Thus the scorecard for new-generation tankers is currently 28 orders for Airbus versus eight for Boeing. This competition will continue for some time. Both have new twin-aisle midsized jets, the A350XWB and the 787, and neither has any plans to develop a tanker version. Given the advanced airframe technology used by both these new aircraft, developing tanker versions would be particularly difficult, even if there were a deep-pocketed launch customer to sponsor them.

The only other new-build product in this class is Russia's Ilyushin Il-78. About 34 of these are in service throughout the world, with about half in Russia and the rest in India, in China and with other export customers. It is much heavier, less reliable, less capable and more expensive to operate than the two Western products, but it is cheap to buy. As such, it represents a competitive threat in markets such as India that are focused on low up-front prices.

The only other product on the drawing board is Embraer's KC-390, a tacti-


*The KC-X decision may be driven as much by political considerations as by technical and economic ones.*

cal transport considerably smaller than the KC-130. The current plan is to create a refueling derivative, but there is no certainty that this will proceed, and the baseline KC-390 transport will by itself be a major challenge.

The one certainty is that there is no hope of a dedicated new aerial refueling airframe. While the Air Force's creation of the KC-135 helped usher in decades of U.S. jetliner industry dominance, there is absolutely no way to identify new technologies—structures, propulsion and so on—that would guarantee an easy transition from a new military tanker to a new design concept for a series of commercial jetliners. Just as important, the USAF has made it quite clear that it cannot provide the development dollars to fund an all-new strategic aircraft optimized for just this role.

### Estimating the market

There is growing recognition of the importance of aerial refueling tankers, although some countries are quicker than others to realize how crucial they are. Israel, unsurprisingly, has always been at the forefront of developing this capability, and it has had an in-country tanker modification capability for years. Israel Aircraft Industries has modified eight KC-707s to serve in this role. Of course, these are old aircraft, and even with upgrades they cannot provide the fuel and range of new-generation equipment. However, in 2008 the Bush administration, usually friendly toward Israeli arms requests, denied their request for a KC-767 purchase, reportedly because it believed the new tanker would give Israel a considerably greater offensive strike capability, thereby increasing the likelihood of a strike against Iran's nuclear facilities.

At the other end of the spectrum is India. In January 2010 the Indian government decided to cancel the Indian air force's proposed acquisition of six KC-30s on the grounds that they would be too expensive. The country instead is funding the acquisition of well over 300 new combat aircraft in the next decade, including the largest single purchase of export fighters in world history. India's current fleet of 12 Il-78s will continue to soldier on as the country's only jet tanker force, perhaps with a follow-on buy.

Clearly, for some countries, buying additional "shooter" planes will always be more attractive than buying "enabler" planes, no matter how useful those enablers would be as force extenders. With all the uncertainty over how much priority nations will actually give to funding tankers, it is difficult to estimate a market size. After all, if a major air power like India balks at purchasing a modest fleet of 10 modern planes to supplement 12 old Russian models, are there any certain prospects? And while many countries claim to be in the market (Turkey, Finland and Poland, for example, have all recently expressed interest in an acquisition), some of them may be happy with used and converted jets.

Still, surveying the world of current and potential tanker customers, we can arrive at a rough approximation of demand over the next decade. At a minimum, the KC-30 should be able to get another 12 orders just from home market countries (particularly France) and follow-on buys from one or more of the four current users. Also, given the ages of tanker fleets worldwide, there should be an additional market for a minimum of 30 new-build tankers over the next decade.

Right now, the KC-30 appears extremely well placed to dominate that 30-aircraft market, which could easily grow to as many as 50 planes. It should also be noted that tanker contracts tend to involve a higher degree of aftermarket and service work than other military aircraft contracts, and they are certainly much more lucrative than commercial jetliner contracts. This makes the KC-30 project even more worthwhile as an Airbus/EADS strategic goal. But the USAF KC-X program might change this.

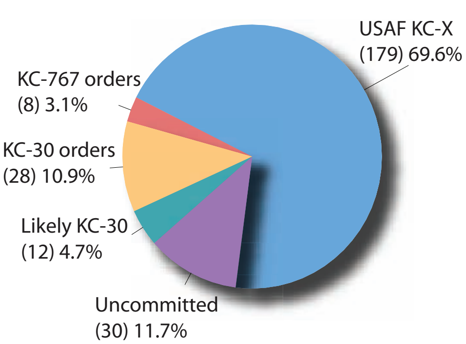
### Oh, THAT tanker competition...

The U.S. is the one country that has understood the importance of tankers, and its fleet of 500 KC-135s and KC-10s represents a powerful symbol of global reach. Unfortunately, for the past two decades that understanding has not translated into an actual funding commitment, leaving a force that averages over 40 years old. Even if the KC-X program succeeds in starting acquisition of 179 aircraft at a leisurely pace of about 14 planes a year, the oldest KC-135s will be close to 80 years old by the time a future KC acquisition program replaces them.

*(Continued on page 23)*

KC-45

**JET TANKER MARKETS**
Current generation, through 2020



# Reconnecting with a magnetic mystery

Magnetic reconnection makes things explode. It operates anywhere magnetic fields pervade space—which is to say almost everywhere. On the Sun, magnetic reconnection causes solar flares as powerful as a billion atomic bombs. In Earth's atmosphere, it fuels magnetic storms and auroras. In laboratories, it can cause big problems in fusion reactors.

However, scientists cannot explain it.

The basics are clear enough. Magnetic lines of force cross, cancel and reconnect, and an explosion results. Magnetic energy is unleashed in the form of heat and charged-particle kinetic energy.

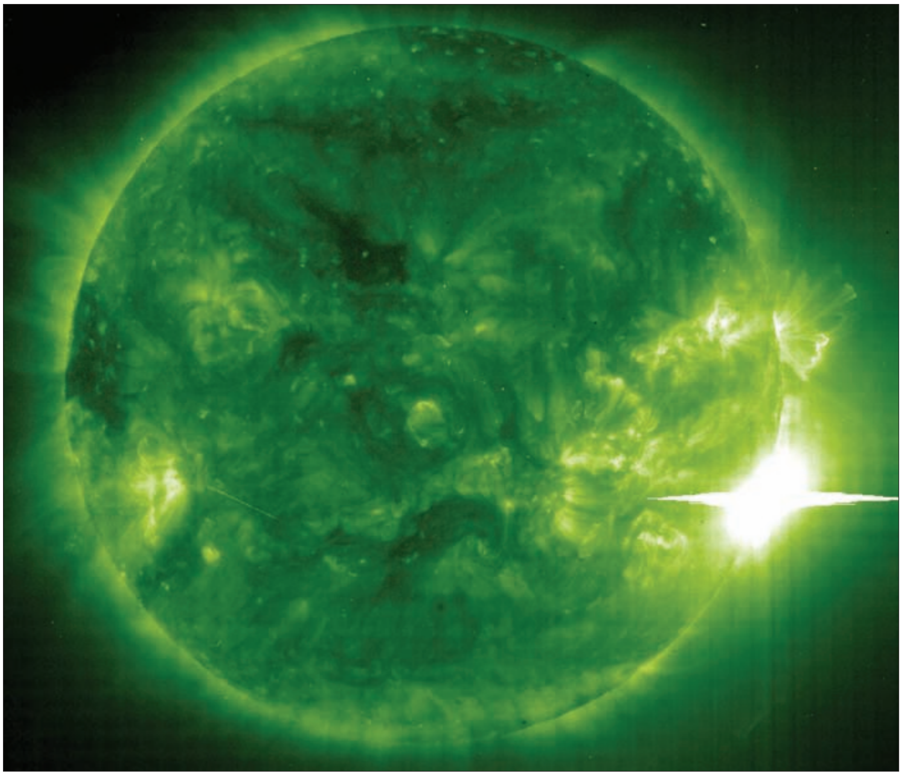
Researchers are trying to understand why the simple act of crisscrossing magnetic field lines triggers such a ferocious explosion. "Something very interesting and fundamental is going on that we do not really understand—not from lab experiments or from simulations," says Melvyn Goldstein, chief of the Geospace Physics Laboratory at NASA Goddard.

NASA is going to launch a mission to try to get to the bottom of the mystery, through the Magnetospheric MultiScale or MMS mission. MMS consists of four identical satellites that will fly in a tetrahedron formation through Earth's magnetosphere to discover how magnetic reconnection works.

When magnetic fields become tangled, as they often do in the magnetosphere, they can merge, which creates an explosive release of energy whereby magnetic energy is converted directly into heat and charged-particle kinetic energy. Magnetic reconnection sparks solar flares and powers auroras; it even pops up in nuclear fusion chambers (tokamaks) on Earth. It is the ultimate driver of space weather, impacting human technologies such as communications, navigation and power grids.

MMS will seek to solve the mystery of the small-scale physics of reconnection. It will also investigate how the energy conversion that occurs during the process accelerates particles to high energies, and what role plasma turbulence plays in reconnection events.

*The Sun unleashed a powerful flare on November 4, 2003, that could be the most powerful ever witnessed and probably as strong as anything detected since satellites were able to record these events in the mid-1970s. It was captured by instruments aboard the SOHO satellite.*



## A natural laboratory

These processes—magnetic reconnection, particle acceleration and turbulence—occur in all astrophysical plasma systems but can be studied in situ only in our solar system, and most efficiently only in Earth's magnetosphere, where they control the dynamics of the geospace environment and play an important role in phenomena known as space weather.

The MMS science investigation is called SMART—solving magnetospheric acceleration, reconnection and turbulence. Principal investigator James L. Burch of Southwest Research Institute (SwRI) in San Antonio will head the SMART team, comprising a group of researchers from several U.S. and foreign institutions.

The mission passed its preliminary design review in May 2009 and was approved for implementation the following month. Engineers can now start building the spacecraft.

"Earth's magnetosphere is a wonderful natural laboratory for studying reconnection," Burch points out. "It is big and roomy, and reconnection is taking place there almost nonstop."

In its outer layer, where Earth's magnetic field meets the solar wind, reconnection events create temporary magnetic "portals" connecting the Earth to the Sun. Inside the magnetosphere, in a long drawn-out structure called the magnetotail, reconnection propels high-energy plasma clouds toward Earth, triggering the Northern Lights when they hit. There are many other examples, and MMS will explore them all.

### The spacecraft and instruments

NASA Goddard will build all four spacecraft and integrate four sets of instruments into the four MMS observatories. "Each observatory is shaped like a giant hockey puck, about 12 ft in diameter and 4 ft in height," says Karen Halterman, MMS project manager at Goddard.

Goddard scientists will conduct environmental testing and support launch vehicle integration and operations. Goddard is also developing the Mission Operations Center that will monitor and control the satellites and provide all the flight dynamics support for the extensive maneuvering and orbit raising required for the mission. Scientists and engineers at Goddard are also building the Fast Plasma Investigation, which is part of the instrument suite.

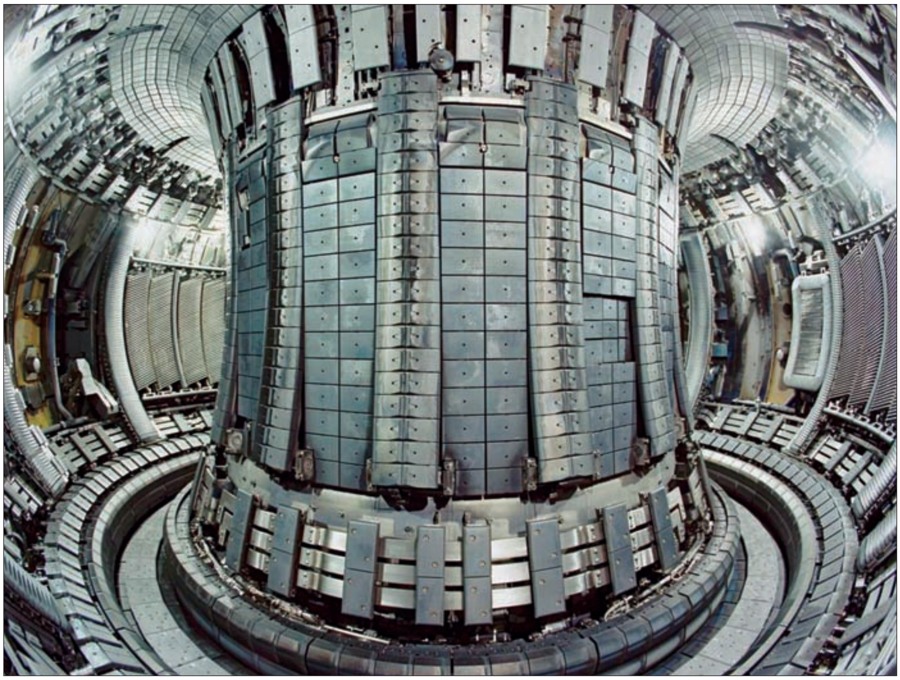
Engineers at SwRI will provide the MMS instruments as a suite. Under contract to Goddard, SwRI is responsible for the mission science, development of the instruments for the four observatories, science operations, data analysis, theory and modeling, education and public outreach.

The mission's sensors will monitor electromagnetic fields and charged particles. The sensors are being built at a number of universities and labs around the country, led by scientists at SwRI. When the instruments are completed, they will be integrated into the spacecraft frames at Goddard. Launch is scheduled for 2014 onboard an Atlas V rocket.

### Improving on tokamaks

Any new physics that MMS learns could ultimately help alleviate the energy crisis on Earth.

"For many years, researchers have looked to fusion as a clean and abundant source of energy for our planet," notes Burch. "One approach, magnetic confinement fusion, has yielded very promising results with devices such as tokamaks. But there have been problems keeping the plasma [hot ionized gas] contained in the chamber.



*Inside a tokamak, magnetic reconnection can cause a sawtooth crash.*

"One of the main problems is magnetic reconnection," he adds. "A spectacular and even dangerous result of reconnection is known as the sawtooth crash: As the heat in the tokamak builds up, the electron temperature reaches a peak and then 'crashes' to a lower value, and some of the hot plasma escapes. This is caused by reconnection of the containment field."

In light of this, one might suppose that tokamaks would be a good place to study reconnection. But no, says Burch—reconnection in a tokamak happens in such a tiny volume, only a few millimeters wide, that it is very difficult to study. It is practically impossible to build sensors small enough to probe the reconnection zone.

Earth's magnetosphere is much better. In the expansive magnetic bubble that surrounds our planet, the process plays out over volumes as large as tens of kilometers across. "We can fly spacecraft in and around it and get a good look at what's going on," he says.

The MMS spacecraft will fly directly into the reconnection zone. They are sturdy enough to withstand the energy released by the reconnection events known to occur in Earth's magnetosphere. There is nothing standing in the way of a full two-year discovery mission.

### Program structure

Science team members and instrument development for the MMS mission are provided by the Universities of California-Los Angeles, Colorado, Iowa, and New Hampshire; Johns Hopkins University Applied Physics Laboratory; Rice University; NASA Goddard; Lockheed Martin Advanced Technology Center; and the Aerospace Corporation. International contributions to the MMS instrument suite are provided by the Austrian Academy of Sciences, Sweden's Royal Institute of Technology and Institute of Space Physics; France's Plasma Physics Laboratory and Toulouse Space Center; and Japan's Institute of Space and Astronautical Science.

MMS is a NASA Science Mission Directorate Heliophysics mission in the Solar Terrestrial Probes Program. Goddard manages the effort, and Kennedy Space Center is providing launch services.

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# DARPA's Vulcan engine goes Navy

DARPA HAS A LONG HISTORY OF INNOVATION and technology breakthroughs involving speed. Many of the platforms and engines it has designed have pushed the limits on how quickly and efficiently an aircraft or missile can fly through the atmosphere or into space.

The agency has focused considerable attention on hypersonic research, which involves speeds above Mach 5. But in 2009, DARPA also began looking at prospects for creating an engine capable of accelerating a full-scale hypersonic vehicle from rest to Mach 4+. A key goal of the new program—called Vulcan—was to accomplish this without developing a new Mach 4+ turbine engine, instead using an existing full-scale production Mach 2+ turbine with only minimal modifications.

When the first of its four planned phases ended, however, the program was significantly modified. While still working toward a high-Mach aerospace engine, Vulcan will now also focus on using the same hybrid concept for a ship-based system to provide increased energy and efficiency for naval power generation applications.

As a result, the final two phases were merged, with a goal of transitioning an aerospace engine to the Air Force at the end of Phase II and a shipborne system to the Navy at the end of Phase III.

Vulcan Phase I looked at a combined-cycle propulsion system architecture, integrating separate constant volume combustion (CVC) engines and full-scale turbine engines for high-Mach military aircraft. Possible CVC architectures included pulsed-detonation engines, continuous-detonation engines and other unsteady CVC engine architectures, according to DARPA Vulcan program manager Thomas Bussing.

The idea was to extract more useful work from the engine by replicating the Humphrey cycle, characterized by CVC. Traditional jet and auto engines operate on a less efficient constant pressure cycle called the Brayton cycle. While only minor improvements are possible for Brayton cycle engines, "a Humphrey or pulse detonation CVC cycle offers a novel way to achieve game-changing performance improvements," Bussing says. This is why Vulcan is seen as offering significant improvements for a variety of power applications.

"Phase I was high Mach, successful; Phase II is still CVC technology, but now the application is a marine power turbine that also can be applicable to aviation and high-Mach engines. So we are starting off from a different corner of the box, but with a very compelling business case," Bussing tells *Aerospace America*. "We combined Phases III and IV into one because we were integrating the technologies earlier. The only difference is these are smaller, 3-5-MW turbines rather than the 25-MW machines we originally planned; the smaller turbine has greater applicability to the fleet.

"The initial application for hybrid engines is the same for both the Air Force and Navy, but the aviation engine is much more complicated. We picked the naval engine because they are much more common in the industrial world as well as the Navy. With a huge commercial tail, that gave us a better opportunity to get industry co-investment, getting it into the Navy's hands much sooner and more cheaply than had there been no commercial tail."

The overall program length remains roughly the same, with the final two phases to run about two years each, compared to an anticipated 18 months for each of the original phases.

**By mandating the use of existing production engines and reducing the top speed requirement, Vulcan development should be both less costly and faster.**

### Shooting for subhypersonic

For the aerospace engine, the Vulcan program focuses on the subhypersonic speed realm, both to avoid the inclusion of a scramjet and because of the numerous potential applications to strike and reconnaissance vehicles operating at speeds between Mach 2 and Mach 4.9.

"It also could serve as the accelerator for a hypersonic system, but we didn't want the contractors to design systems with scramjets, which would be more complicated," Bussing points out. "However, if we solve the first, we set the stage for the second. By itself, Vulcan is an intermediate step that would open the way for a whole new class of vehicles not available today, both manned and unmanned."

Vulcan builds on a variety of previous efforts, including multicombustor pulsed-detonation engine demonstrators and other work showing it is possible to burn liquid hydrocarbon and air directly at low total pressures. By mandating the use of existing production engines and reducing the top speed requirement, Vulcan development should be both less costly and faster.

"The CVC would operate below the upper Mach level of the turbine, which would be off-the-shelf, such as the [Pratt & Whitney] F100-229 and F119 or [General Electric] F110-129 and F414, which are currently used in F-18s and F-22s. The idea then is to use the CVC cycle to get from where the turbine leaves off to Mach 4+ and cocoon the turbine when not in use, so it is not exposed to the high-temperature airflow," Bussing says. "There are different architectures for doing that, but I can't give specific details, because the program is classified. But there has to be a mechanism to close off the airflow and to keep temperatures inside the cocoon low.

"The idea is to build a Mach 4 engine for less than it would cost to build a

Mach 6 turbine, as well as to demonstrate the CVC technology. We believe that this technology will outperform any high-Mach turbine you could potentially envision."

### Naval applications

This approach also significantly expands potential applications, which led to a restructuring of the program to address smaller power systems for ships, as well as a variety of commercial applications.

The main nonnuclear propulsion system in the Navy fleet today is the LM2500. Used on 129 ships, those engines burn an estimated $2 billion in fuel each year. According to DARPA, retrofitting only half the 434 LM2500 engines in the fleet with CVC technology could save the Navy $300 million-$400 million a year.

As added advantages, a Vulcan-style hybrid engine would have significantly increased endurance and a reduced infrared signature, an important defensive feature.

### Potential pluses

"You could replace combustors in conventional gas turbines and see a 20%-plus fuel burn efficiency in ground applications. Subsonic jet engines could apply it with a 10% fuel burn gain. It also could be used in powerplants and many other applications," Bussing says. "Many of the combustion processes we use today potentially could benefit from an unsteady combustion process, which is a paradigm shift from how you burn fuel and air.

"We have been focusing on improvements in performance, but there are other things the process enables. You could take advantage of the detonation wave and use it to remove ash from coal furnace heat exchangers or produce ceramic materials and drive them into substrates. There are applications in nonlethal effects devices, mine-clearing and other new and unique possibilities using this cycle."

If applied to existing military and commercial aircraft, the cost savings in fuel alone would be significant, according to DARPA program office estimates. A 10% fuel efficiency improvement using a CVC hybrid engine replacement on the Air Force's fleet of 543 KC-135 tankers could save as much as $270 million a year. And a CVC-powered missile could be built using low-cost automotive manufacturing tolerances, yet have a 50% performance increase over a ramjet missile.

In the commercial world, replacing current powerplants with a pulsed-detonation engine could mean $500,000 a year in operations savings on Boeing 757 jetliners and $1.4 million for the larger Boeing 777. With some 87,000 gas turbine engines currently powering commercial aircraft—including 35,000 large gas turbines—the impact of conversion on U.S. airlines alone is estimated at $2.8 billion.

***"Many of the combustion processes we use today potentially could benefit from an unsteady combustion process, which is a paradigm shift from how you burn fuel and air."*** —Thomas Bussing

### Spaceflight possibilities

The Vulcan engine concept also has possible applications to spaceflight, both manned and unmanned.

"It has been looked at as a first-stage accelerator, coupled with a ramjet that would get you to Mach 6+, then a second stage to orbit. In fact, this technology also applies directly to rocket propulsion, which involves different cycles from low thrust to high," Bussing says.

"From Earth to Moon, low thrust is required, but for anything getting into orbit, pulsed-detonation rockets would be good replacements for current chemical propulsion. It also could be used for spacecraft attitude control—if you can precisely pulse the microthrusters, it is a better mode for controlling attitude and uses less fuel, in addition to just operating more efficiently."

DARPA and the U.S. are not alone in pursuing this level of high-speed flight capability. Bussing cites known projects under way in France, Russia, Japan, China, Sweden, Germany, Poland and Singapore, for example.

### Hard—and DARPA-hard

The decision to build a high-Mach aviation application, Bussing notes, is in line with DARPA's traditional role of looking at new enabling technologies for the military and ensuring the U.S. is not caught by surprise, as it was by the Soviet Union's launch of the first satellite, Sputnik, in the 1950s, which led directly to the creation of DARPA.

"DARPA's role is to demonstrate the impossible; the services' responsibility is to then take Tier Level 6 technology, mature it and implement it into the fleet," says Bussing.

Technology Readiness Level 6 is near the end of a nine-level scale from TRL 1—basic principles observed and reported—to TRL 9—actual system "flight proven" through successful mission operations. At TRL 6, a model or prototype is successfully demonstrated in a relevant operating environment.

"At the end of Phase II, the proof of technology will be demonstrated to TRL 6 and transitioned to the Air Force for potential application to their improved efficiency turbine development program," Bussing continues. "At the end of Phase III, it transitions to the Navy. The Navy wants to increase both offensive and defensive systems that require more power, so they may want bigger engines; but either way, they will be CVC-based.

"The goal of Phase III is basically a TRL 6 demonstration of a fully integrated hybrid engine that is 20% more efficient than existing power turbines, operating for 500 hr in the same volume and dimensional footprint as existing engines. So you have a retrofit to existing 3-MW turbines or new 4-MW turbines that are backwards compatible to existing ship engines. The Navy will need to do a business case by the end of Phase II on whether to do a retrofit or an all-new engine."

For the aerospace side, a primary end-goal for Vulcan would be full-scale hypersonic cruise vehicles for strike, intelligence, surveillance, reconnaissance, or other critical national missions.

"A Mach 4 aircraft would be a lot lower technology effort than a Mach 6.

It is about half the thermal load, so temperatures in the vehicle are much lower and wouldn't require the exotic materials a Mach 6 would need. That makes the aircraft relatively straightforward," says Bussing.

"The only thing operating at Mach 4 today is a ramjet, and I would expect to see a 20% fuel burn improvement with Vulcan. Ramjets operate at M 2.5+ and don't perform as well as CVC or pulsed-detonation engines. CVC also can operate at much lower speeds, including subsonic. One critical factor is getting through the transonic pinch point; this technology would enable that."

All this is not to say there are no significant "DARPA-hard" hurdles to overcome. Those include designing an efficient air valve for the respective engine, fuel injection and detonation initiation systems, efficient nozzles to handle expansion of the gases—which have to be brought together at the back end in a unique way—and materials. Despite temperatures lower than those generated by a Mach 6 vehicle, it is still important to minimize the thermal load generated to simplify the thermal management system.

"Ideally, I would like to design it with minimal or no cooling," Bussing notes.

### Phased approach

Phase I, which ran from April through September 2009, involved a system concept definition by four contractors—Alliant TechSystems, General Electric, Rolls-Royce and United Technologies. It ended with a conceptual design review (CDR) by each contractor that, according to DARPA, generated several interesting turbine/CVC architectures that appear viable for building a full-scale high-Mach engine incorporating an off-the-shelf turbine and a CVC.

Following the CDRs, DARPA began work on a new broad area announcement (BAA) incorporating the changes Bussing detailed. That BAA was released in mid-January 2010, with industry responses due by the middle of this month.

Under the new structure, Phase II will involve component demonstration and risk reduction—retiring all the technology risks identified in Phase I (at both component and subcomponent levels) required to build the engine—full-scale CVC component integration and durability testing; and turbine and compressor rig testing with a full-scale CVC simulator. Phase III will focus on the development, design and testing of a complete Vulcan engine.

"The desire at the end of Phase III, at a minimum, is to demonstrate a complete Vulcan engine with the fully integrated CVC module and validate durability, operability, capability and performance at various turbine engine power settings," according to the January BAA.

"We have added a CVC turbine and CVC compressor test, so it is more integrated than Phase I, where the turbine and CVC could be separate. But in Phase II, we basically are effectively replacing the combustors in the phase turbine with CVC combustors," Bussing adds. "The program is designed to move step by step through the technologies required to make this work, retiring all risks and minimizing costs by doing just what is required."

Because of its higher complexity, getting the Air Force version of Vulcan to a production program and initial operating capability could take another decade.

"It could be done faster if there is a change in national priority, of course, as was the case in building the SR-71," Bussing says, referring to the long-range, high-altitude Mach 3 reconnaissance aircraft fast-tracked after an American U-2 spy plane was shot down over the Soviet Union in 1959.

"So if future leadership decides to move in that direction full-scale, this engine is the biggest enabler for Mach 6+, which is basically a flying engine. For Mach 4 applications, it's not quite that dynamic; the aircraft would look more traditional, like the SR-71 or high-Mach F-22."

With its wide range of potential applications, from powerplants to spacecraft, Vulcan is the quintessential DARPA program, combining existing capabilities with new technology to achieve previously unattainable goals across multiple missions, military and civilian.

"If we can solve this technology," Bussing concludes, "I truly believe we are on the precipice of enabling a whole new class of systems not available today."

**J.R. Wilson**
Contributing writer

*(Continued from page 17)*

Unfortunately for Airbus, dominance of the global tanker market has not translated into a lasting victory in the only truly noteworthy competition: the USAF's KC-X. While the KC-30 was selected as the winning contender for this 179-aircraft competition (as the KC-45), the victory was overturned following a successful Boeing protest.

The new KC-X draft RFP is intended to increase transparency, aiming to redress a concern expressed about the previous RFP's somewhat opaque scoring system. However, Northrop Grumman has claimed that the new RFP achieves this transparency through an excessive emphasis on costs, resulting in what it has termed a "price shootout." This means, according to the company, that the KC-767, which is a less capable but less expensive airplane, would have a strong advantage under the new scoring system. As a result, the company has threatened not to bid on KC-X.

Meanwhile, the political winds have

*Creation of the KC-135 helped usher in decades of U.S. jetliner industry dominance.*

shifted. The KC-45 production plans largely involve congressional districts that are Republican, while the KC-767's largely affect Democratic districts. With Democrats currently in control, any political leverage brought to bear in this contest will favor the Boeing airplane. Even if Northrop Grumman does bid, it will likely face an uphill battle. And if it does not bid, Congress will be less likely to oppose a contract awarded to a single bidder with a Democratic industrial and labor footprint. Of course, given these partisan political dynamics, it is possible that ongoing deadlock keeps either side from walking away with the contract unopposed. This would imply either a split buy, or an endless series of protests and program delays.

If the KC-767 were to win KC-X, it would change the battle for tanker exports. A USAF endorsement would be extremely valuable in pursuing the remaining undecided customers. It would allow Boeing to reassure customers that they had improved the original product, and would imply a steady stream of future upgrades. It would also create a broader global training and support base, which would certainly be appealing to export customers. The KC-767 would effectively be back in the export game.

If the KC-767 wins the competition, the KC-30 can be regarded as a successful European platform that had the good fortune to enter the world market before the U.S. military endorsed a locally built competitor. But it would almost certainly lose its tight grip on the export tanker market.

**Richard Aboulafia**
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*Boeing's latest plans call for vigorous development of unmanned aircraft systems–not just the vehicles, but also the ground segment, communications, and full range of systems needed in this fast-growing sector. Freedom from the constraints of manned aircraft requirements is also opening a wide range of possibilities for UAV designs.*

# Unmanned and airborne

## A NEW PLAN

*The Phantom Ray is under development as the follow-on vehicle for the J-UCAS program.*

Boeing and the companies it has acquired—McDonnell Douglas, North American Rockwell, and Hughes, for example—were responsible for many of the most advanced military and commercial aircraft of the 20th century.

Those included most of the military's advanced aircraft—the F-15 Eagle, E-3 AWACS, B-1B Lancer, F/A-18 Hornet, CH-47 Chinook, AH-64 Apache, V-22 Osprey, AV-8B Harrier, C-17 Globemaster III, KC-135 Stratotanker, KC-10 tanker—and more than two-thirds of the world's commercial airliners, from the 707 to the 787 and the DC-8 to the MD-11, as well as the space shuttle.

But by the mid-1990s, after the merger with McDonnell Douglas, Boeing's domination of military aircraft began to wane. The only two new fighter aircraft prime contracts—the F-22 Raptor and F-35 Lightning II Joint Strike Fighter—went to Lockheed Martin, new helicopter contracts to Bell and Sikorsky, and a still-disputed new tanker initially to a Northrop Grumman-EADS team. Plans for a new bomber, presidential helicopter, and a combat aircraft were canceled or indefinitely delayed.

In decades past, the ebbs and tides of military aviation were balanced by commercial contracts. But the trifecta of post-September 11 declines in air travel, a splintering of the global economy, and wildly fluctuating—though often record-high—oil prices led to airline bankruptcies, cutbacks, and new order delays or cancellations.

Space programs provided little help, as Boeing's role in a stalled U.S. human spaceflight program was dramatically reduced and the competition for satellite launches grew almost daily.

Although still one of the three largest aerospace companies in the world—along with Lockheed Martin and EADS, which, despite some contract wins, also face a greatly reduced market demand—Boeing began a hard reassessment of its markets and product lines, and of how and where it might regain its historically strong position.

One major element of Boeing's approach appears to be a new and full-blown commitment to one of the fastest growing markets in military aviation—and, potentially, major new civilian markets to come: unmanned aerial vehicles (UAVs) and the ground and satellite systems supporting them, typically combined under the title unmanned aerial systems (UAS).

**by J.R. Wilson**
Contributing writer

## UAV push

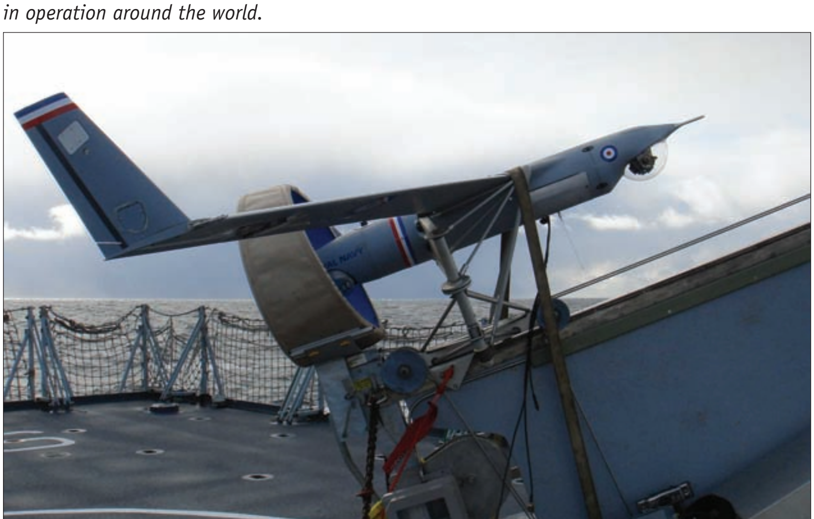
At the Paris Air Show in June 2009, Boeing announced the creation of a new Unmanned Airborne Systems Division within Boeing Military Aircraft. The business plan calls for the UAS Division to build and market a wide range of UAVs, with new projects and technologies fed to it by Boeing Phantom Works, the company's advanced research component.

"That was driven primarily by the marketplace and the increase in applications and utilization by all our military customers of unmanned systems. There was a lot of discovery in Iraq and Afghanistan about the utility of UAVs," UAS Director Vic Sweberg tells *Aerospace America*. "This is one defense market that is clearly growing and, we believe, will continue to grow—from a defense standpoint, certainly—and we believe the civil and commercial markets also will be robust at some point.

> "From our perspective, unmanned systems will be a greater and greater portion of the DOD budget as time goes forward."
>
> ***Darryl Davis, president***
> ***Boeing Phantom Works***

"And it will become a major component of Boeing, at some time, based on the progression of the military need. Even without activity in Southwest Asia, I think we will see a continued use of UAVs for training and development of doctrine and CONOPs [concepts of operations] for future requirements. The technology is evolving to the point where we can accomplish a lot more with smaller, less expensive systems than some of the manned equivalents, which also tends to drive demand. And when civil/commercial markets ultimately open up, that will increase the potential for larger unmanned systems to be a part of the growing Boeing business."

*ScanEagle recently passed 200,000 flight hours and is in operation around the world.*



It is a particularly interesting decision on Boeing's part, because unmanned systems were barely a blip on the corporate spreadsheet when UAVs went from interesting technology to vital asset in the opening decade of the 21st century.

Boeing's first big win in the arena was a DARPA program to develop an unmanned combat air vehicle (UCAV) for a DARPA/Air Force/Navy Joint-Unmanned Combat Air System (J-UCAS) program. Boeing received a $130-million contract in 1999 to evolve and demonstrate that technology.

"Today, looking at all the money that has been spent within Boeing on UAVs, we're probably pushing $1-$1.5 billion, with probably 80% of that government funded through the DARPA/Air Force UCAV program," says Phantom Works President Darryl Davis. "So there has been a significant investment in the past decade. And that does not include the money spent to acquire Insitu. If you do, we're probably pushing $2 billion in the past decade in UAV investments."

In September 2008 Boeing acquired the Insitu Group, a Bingen, Wash.-based company created in 1994 to pursue requirements for ISR (intelligence, surveillance and reconnaissance) UAVs. Its primary product is the ScanEagle. This long-endurance tactical UAV, developed with Boeing in 2004, recently passed 200,000 flight hours and is in operation around the world by the U.S., Canadian, and Australian militaries.

Insitu is a big part of Boeing's new strategy to become a major player in the UAV market, through acquisition, partnerships and significantly increased internal development.

"Our plan is to build our legacy and grow our position in unmanned systems. We're looking at everything except, today, the insect-sized platforms that universities and others are doing R&D on for nanotech-type capabilities, which would not normally be Boeing's forte. But we are looking across the board at how we can work with other companies or develop capabilities on our own to bring good solutions to our customers," says Sweberg.

"One thing we are working to implement is being quick and innovative, which also means open-minded to looking across industry, domestic and international, for other companies with complementary capabilities we can take advantage of and help both them and Boeing in being successful. The strategy is to continue to look for opportunities to partner, to invest organically in technologies at Phantom Works and on the division side, extending some of the systems we have today as well as talking to other companies about how we might lash up together."


*Boeing is also working on a high-altitude long-endurance concept.*

### Hot growth prospects

Industry reports on global UAV sales range from a predicted $4.4 billion in 2009 to as much as $8.7 billion within a decade, making it "one of the hottest areas of growth for defense and aerospace companies," according to Philip Finnegan, an author of the Teal Group's "World Unmanned Aerial Vehicle Systems 2009" market profile and forecast. Given their own internal forecasts and the reality of continued growth in UAV purchases by nearly every military in the world, Boeing believes its new commitment to the UAV market ultimately will bring a substantial return on investment.

"The Air Force just issued its UAS Roadmap through 2047, showing plans to migrate toward an unmanned fleet of systems to cover all mission areas, from ISR to strike to air dominance and, potentially, mobility," Davis tells *Aerospace America*. "That has been in the works for some time—greater and greater numbers, increasing in capability across the full spectrum of aviation missions. Last year, DOD bought more UAVs than fixed-wing aircraft. And that will grow as time goes on."

However, Boeing's current estimated investment of $2 billion in the past decade is not even a drop in the bucket for a corporation that, even in depressed economic times, reported total revenues of more than $33.6 billion for the first half of 2009—half of that from Boeing Defense, Space and Security military work, including $6.4 billion from Boeing Military Aircraft (BMA). Obviously, UAVs will not replace that level of business, so the goal is to pick up as much as possible to supplement future manned aircraft programs—including nonprime positions, as Boeing has on the F-22 and F-35.

"We have goals to grow, but we don't yet have what I consider firm targets or numbers," Sweberg says. "There are two moving parts to that—the unmanned part and the rest of the business part. The expectation on our division is to grow at a faster rate than others, because the market is growing and because Boeing has some unique capabilities and competencies to grow in this marketplace. So we hope to put up some good numbers in the next 5-10 years."

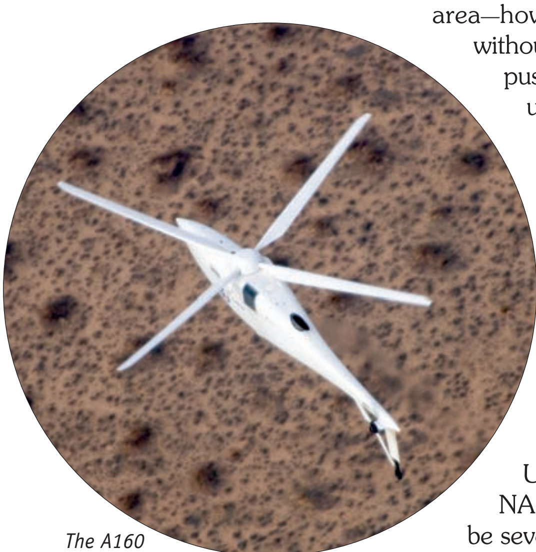
Davis agrees: "From today, which is a very small percentage of that BMA total portfolio, we see substantial growth and are making substantial investments to capture our fair share of the market—to be the number-one or number-two player in the realm of unmanned systems. Over the next 10 years, we project the unmanned portion could grow to 20-30% of BMA's total revenue, from all types and classes of UAVs, but particularly in the area of HALE (high altitude/long endurance), electronic attack, and ISR strike.

"Our plans tend to be about 10 years out; how we target our investments based on what we expect the environment to be like. Our mission in Phantom Works is to be the incubator for the next generation of technology and capability and, at the right time, transition those to the business side for execution. Using the USAF road map, they predict a significant part of the Air Force mission spectrum will be handled by unmanned in 2047. If that happens, then greater than 50% of defense aircraft business may become unmanned. So it's an exciting time to be in the UAS business, and we will have a lot more to talk about in the next year than we are willing to discuss today."

To achieve its goal, Boeing plans to address the full spectrum of UAS market needs, not only the aircraft, but ground stations, command and control, interoperability, coordinated operations, and so on.

### Sharing airspace

"The biggest challenge for us in the next half-decade will be merging manned and unmanned in the national airspace [NAS]—how to deconflict them as they become a greater



*The A160 Hummingbird offers many advantages over traditional, manned helicopters.*

part of air traffic," Davis points out. "There will be lots of shapes, sizes, and capabilities as we continue to push the boundaries on how they work with manned aircraft, flying in the same airspace. And that is a big attention area—how do you do sense and avoid without a man in the cockpit? We are pushing technologies that will give us that capability in the next 10 years."

Maneuvering a UAV—generally classified as a noncooperative aircraft because there is no pilot on board—to avoid conflict with other air traffic within boundaries set by the FAA is a major concern for all UAV manufacturers and operators. And without FAA approval for UAV operations within the NAS, commercial applications will be severely limited.

"We hope, in less than 24 months, to demonstrate how all that can come together," Davis vows, but adds it is far from the end of the problem. "Then you have to deal with instrument flight conditions, including atmospheric absorption of whatever spectrum you're using. Those technologies are a little farther out and integrated into the air traffic control NextGen effort, all communicating their positions back to ATC.

"You may have as many unmanned airplanes flying in a given space as manned, so how do they deconflict, do collision avoidance? We have to solve that problem, but we think it is very solvable in the next few years and are making investments in that direction."

Cooperation, interoperability, and collaborative operations are not just a problem for NAS operations, however. The skies over Iraq and Afghanistan have been so filled with dozens of types of UAVs flying thousands of missions that manned aircraft pilots have begun to refer to them as "airborne FOD" (foreign object debris).

"We have been looking at how manned and unmanned will become interoperable—extensions of manned aircraft in some areas, replacements for manned in others. With the Hummingbird [unmanned helicopter], Phantom Ray test bed, and HALE UAVs, plus smaller UAVs such as ScanEagle and Integrator, we will have a spectrum from low end to high end, from 6 hr minimum endurance to up to five years on station with DARPA's Vulture program," he says.

## Military efforts

Phantom Ray may be a blueprint for the way Boeing plans to move forward in the early stages of its new UAV effort. Internally funded, it will pick up where J-UCAS left off in 2006, starting with the X-45C, a larger UCAV Boeing designed to be a follow-on to its X-45A UCAS demonstrator. Applying Phantom Works rapid prototyping to meet a first flight target of December 2010, the Phantom Ray demonstrator is scheduled for a six-month series of 10 test flights that may involve ISR, suppression of enemy air defenses, electronic attack, hunter/killer missions and autonomous aerial refueling.

"We have mobilized our assets to continue the tremendous potential we developed under J-UCAS and now will fully demonstrate that capability," says Davis.

While the FAA's concerns about UAVs flying in the same airspace with other civil aircraft mirrors military concerns for combat airspace, Davis says the key for the military is not just interoperability, but collaboration as well. And to become a key player in the future UAV marketplace, Boeing believes it must address all of those issues rather than just building platforms.

"You have a flight of manned/unmanned or all unmanned vehicles, and how they operate as a single entity. DOD is looking at things like swarm technology, such as a beehive. How do UAVs work in a swarm—not flying a preprogrammed flight, but aggressively maneuvering like a swarm of bees? You will want to do what, in a fully manned configuration, would be done in a formation where everyone knows what everyone else will do," he says.

"Those are being thought about today, including how to employ those in an urban environment, where you may have terrorists or noncombatants you want to track, or even very small UAVs you may want to fly indoors. So you would have nano- or micro-UAVs up to very large, five-year UAVs. You have to take the limitations of the human being out of the equation, because you can rotate humans in the ground station while the UAV never comes home. All those things are in the realm of the possible, and we're working on all those."

## Out of the box

Sweberg believes Boeing is extremely well placed to bring all of the necessary technologies and requirements together—and, where necessary, push the envelope with out-of-the-box thinking on the future of UAVs.

"We are at an interesting point in history, where unmanned has clearly demonstrated new capabilities people did not envision just 10 years ago. And the technology continues to evolve to enable unmanned to meet some manned missions, but we still have not enough time and experience with unmanned to tell where they ultimately will go. So it is a time for positioning," he says. "Obviously, Boeing has a very strong legacy, and today still has a strong installed base of fighter and mobility aircraft and rotorcraft, which we still see as a growth area. And it may be premature to think manned aircraft are on the way out and unmanned will be the future.

"I do think unmanned aircraft systems have proven very capable, and clearly there are niches where it makes a lot of sense to go unmanned. And as the technology continues to advance, we will see a growth in unmanned applications. I also see unmanned/manned interoperability being a very powerful capability to meet the mission requirements our defense customers have."

### The push for commonality

Another requirement that is high on the U.S. military list is achieving the greatest possible degree of commonality in the ground stations that operate a diverse range of UAVs.

"The pressing requirement customers are expressing for common control harkens back to there being a lot of systems out there, each with its own hardware and software, logistics tail, ground control, etc. So if customers want to operate more than one system, they have to haul around multiple complete sets, which is cumbersome and logistically difficult to accommodate," Sweberg points out. "I am hearing more and more that customers want more commonality—not just from one company, but across providers—with one ground control system to accommodate many different UAV systems, which would be a significant savings.

"So we are all thinking about how to meet customer requirements there. However, the Army, Air Force, Navy, and Marines all have their own thoughts on common C2 [command and control] and using their own systems as a baseline, so it will be interesting to see how DOD will come out with standards and an approach to achieve as much commonality as possible."

### Changing paradigms

UAVs originally were seen as less expensive replacements for manned aircraft in a traditional robot operational paradigm—doing the dull, dirty, dangerous jobs on which commanders would prefer not to waste or risk human pilots. But the growing complexity of these platforms has, in some cases, changed that perspective as well.

*The X-45A was Boeing's demonstrator for the UCAS program.*

"We tend to inhibit ourselves based on what we've done previously with manned aircraft, but those who have spent their lives in unmanned are not hindered by those experiences," Davis says. "When you open up the design constraints of the vehicle beyond what was possible with human flight, you can maneuver more aggressively and design thinner platforms, depending on what you are designing the aircraft to do. It is more a blending of paradigms in some mission areas.

> "Boeing took stock and determined it had a lot of capabilities, but scattered around the enterprise, and decided it was time to bring all those under one roof and provide a focused face to the marketplace in the area of unmanned aerial systems."
>
> *Vic Sweberg, director*
> *Boeing Unmanned Airborne Systems Division*

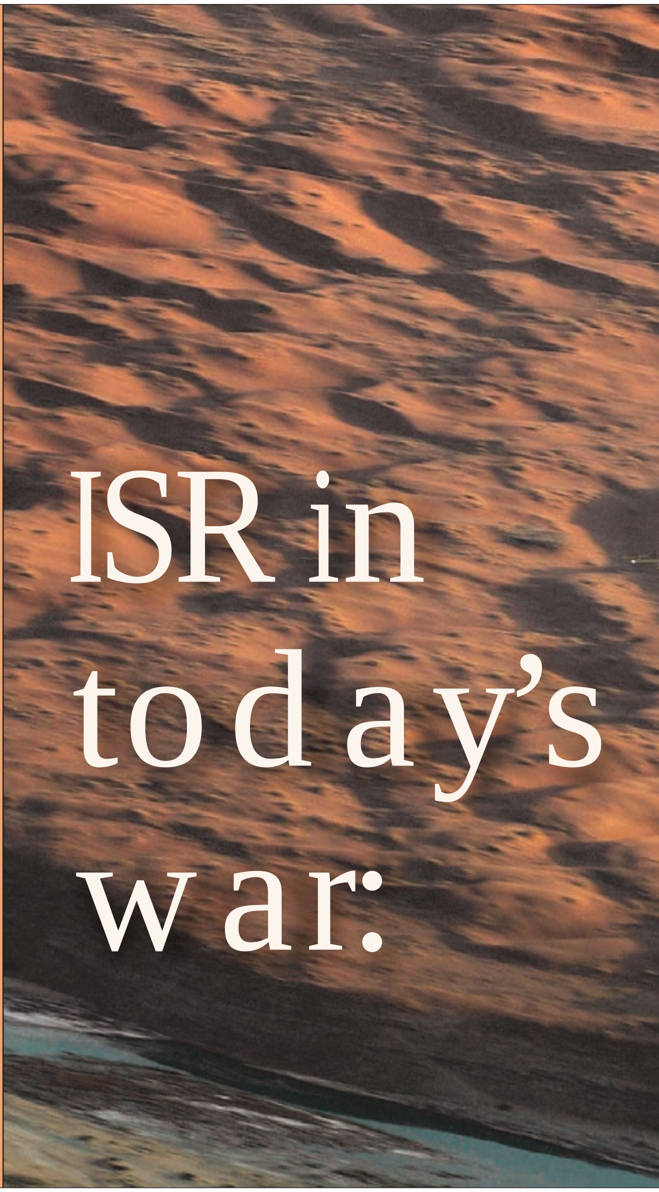
"And paradigms will change—already are changing. Some medium- to large-scale unmanned vehicles cannot have loss rates such as were acceptable in manned aircraft a few decades ago, especially when flying over populated areas. So in some cases things are going in a different direction, to get more reliability into them, but you also have more design freedom that allows you to do more with sensors, for example. Our challenge is to bring the best of both together and leverage both. Each comes with its own mindset, and we need to take advantage of that expertise on both sides."

The future of UAVs, then, is a blending of manned and unmanned experience and capabilities, of bringing experienced pilots from

*(Continued on page 42)*

# ISR in today's war:

*Intelligence, surveillance and reconnaissance technologies are growing more and more vital to U.S. campaigns in Afghanistan, Iraq and other potential trouble spots. Advanced instruments and new aircraft, including UAVs, are enabling warfighters to see farther, respond faster and strike with greater precision than ever before.*



**by James W. Canan**
Contributing writer

**U.S. and allied forces in Afghanistan are relying ever** more heavily on intelligence, surveillance and reconnaissance (ISR) to thwart and defeat Taliban and Al Qaeda insurgents. ISR operations are at the core of the U.S. counterinsurgency strategy for stabilizing the country and making it inhospitable to terrorists, and will strongly influence whether that strategy ultimately succeeds or fails.

This viewpoint is widely shared by Pentagon officers and other officials with connections to the military campaign in Afghanistan. As they see it, ISR is the essential means of locating, identifying, tracking and targeting adversaries around the clock and in all kinds of terrain. ISR also makes it possible to distinguish and isolate enemy combatants from civilian bystanders and attack them selectively.

Selective targeting has become all the more important in light of the restrictive rules of engagement that Gen. Stanley McChrystal, the top commander of U.S. and coalition forces, promulgated for his troops in 2009. Those rules are aimed at eliminating or greatly reducing civilian casualties from air strikes and ground fire, and thus at precluding postattack backlash reactions among the Afghan populace.

ISR is also seen as the first line of defense for U.S. and allied ground troops against

# A closer look

*An MQ-1 Predator, armed with AGM-114 Hellfire missiles, flies a combat mission over southern Afghanistan. (USAF photo/Lt. Col. Leslie Pratt.)*

deadly roadside bombs. The troops rely on timely information from ISR aircraft and other sources to detect insurgents in the act of emplacing those improvised explosive devices (IEDs). The IED threat is expected to worsen as the Obama administration's deployment of 30,000 additional troops to Afghanistan gains momentum in the coming months. This will make ISR an increasingly urgent priority, officials say.

Those who believe that the U.S. and its allies are unlikely to prevail in Afghanistan often cite the failure of Soviet forces there through the 1980s. But those forces suffered heavy losses of helicopters and other combat aircraft shot down by shoulder-fired infrared missiles that the U.S. supplied the Afghan fighters of that era. Perhaps more to the point, military analysts note, the Soviets lacked the sophisticated counterinsurgency strategy of today's U.S. forces and the air and space surveillance and reconnaissance assets that make that strategy viable.

## Renewed emphasis

Late last year, well in advance of President Obama's decision to send 30,000 more U.S. troops to Afghanistan, the Pentagon began concentrating on stepping up its deployment and use of ISR assets there. Defense Secre-

*IEDs like these collected in Baghdad are an ever-increasing threat to ground troops in Afghanistan.*

tary Robert Gates noted in mid-November 2009 that "we're pushing a lot into the theater…we're moving as fast as we can. The Air Force has significantly expanded its [ISR] capability, and we intend to keep expanding it."

Gates explained that the ISR expansion would involve not only airborne platforms such as manned MC-12 Liberty aircraft and unmanned MQ-1 Predators and MQ-9 Reapers, but also ground stations and their personnel, notably linguists and intelligence analysts. At the same time, Gates formed a multiservice ISR task force and set about reprogramming $1.2 billion from other DOD projects to help pay for the escalation of ISR.

The secretary had been pressing the Air Force to deploy more UAVs for ISR in the Afghanistan/Pakistan theater. Air Force officials insist that the service had been building up its ISR assets and overhead intelligence-gathering capability all along, and that it is moving more Predators and Reapers into the theater as fast as it can.

Gen. Norton Schwartz, Air Force chief of staff, and Michael Donley, secretary of the Air Force, made ISR a blue-ribbon priority for the USAF. Schwartz observes that a major key to making a smaller Air Force even more effective is "persistent and pervasive ISR," along with the precise air strikes that it fosters.

In accentuating ISR, the Air Force appointed Lt. Gen. David Deptula, a veteran fighter pilot, wing commander and planner, to the newly created post of deputy chief of staff for ISR. The service also unveiled its first-ever comprehensive ISR strategy, made sweeping changes in how it trains and uses operators of UAVs (which it prefers to call remotely piloted aircraft) and other ISR platforms, and set about improving its ISR capabilities across the board.

"The more ISR we provide, the more is demanded," Deptula declares. "We may never fulfill the demand, but we are getting better and better at defining the [ISR] requirements and then matching them with our present capabilities. We are also beginning to look out to the future and wed technology advancements with emerging needs."

### Advanced capabilities

Deptula observes that the advanced technologies of today's aircraft, bombs, missiles, sensors and communications enable the Air Force to strike any target rapidly and precisely, anywhere on Earth, around the clock and in all kinds of weather. Now, he says, the biggest challenge for the Air Force lies not in finishing off targets, but in finding and pinpointing them by means of ISR.

It took only a few minutes of flight time for two USAF F-16 strike fighters to deliver the bombs that killed Abu Musab al-Zarqawi, the head of Al-Qaeda in Iraq, but 6,000 prior hours of Predator UAV flight time to track him and finally fix his position for the kill, Deptula notes. Those Predator hours are a classic example of "persistent ISR," he says.

UAVs are uniquely capable of persistent ISR "in their ability to stay in position or maneuver over large areas for a long period of time—and that's where a person in an aircraft becomes a limitation," Deptula explains. UAVs "can operate in dangerous environments and can either watch or strike and…conduct undetected operations and penetrations," he says.

Pentagon officials cite many examples of persistent ISR in Iraq that, they claim, demonstrate its vital importance in so-called irregular warfare against roving insurgents. ISR was the essence of Task Force ODIN (observe, detect, identify and neutralize), an aviation unit created during the Iraq war expressly to counter and check the rising toll from roadside bombs.

Military sources claim that ODIN, taking advantage of more numerous and increasingly

*The Air Force's new manned intelligence, surveillance and reconnaissance platform, the MC-12, is designed to directly support ground forces with real-time ISR capability. (USAF photo/Senior Airman Tiffany Trojca.)*

*Schuyler Dunn replaces a part of the multispectral targeting system ball on an MQ-1B Predator at Ali Base, Iraq.(USAF photo/ Tech. Sgt. Sabrina Johnson.)*

capable ISR assets, resulted in the capture or killing of more than 3,000 insurgents and a dramatic decrease in the number of coalition forces killed or wounded by IEDs. ODIN forces flew Warrior Alpha UAVs equipped with electrooptical and infrared sensors or with synthetic aperture radar, along with laser target markers, laser rangefinders and missiles, to detect and destroy IED emplacers.

ISR may be more challenging in the irregular warfare of Afghanistan than it was in Iraq, officials say. It must detect and track not only the tactical formations of enemy fighters and the movements of individual IED emplacers, for example, but also the foot traffic of roving Al-Qaeda insurgents inside the country and across the mountainous 1,500-mi. Afghanistan-Pakistan border, which is not conducive to infantry reconnaissance patrols.

To accomplish ISR all across the Afghanistan/Pakistan theater, U.S. and allied forces rely most heavily on manned and unmanned aircraft equipped with cameras, radars and infrared sensors. Those ISR platforms have direct communications links with rapid-reaction special forces on the ground, and with helicopters, artillery, strike fighters and unmanned aircraft armed with air-to-ground missiles.

Schwartz notes that the surveillance and targeting provided by the UAVs make strike aircraft and other types much more effective. "A UAV may tip a gunship, or tell a rescue helicopter crew where their pickup needs to occur, [and] these are the kinds of things that are happening all the time," he says.

## Saving the day again and again

ISR is credited with saving the day in Afghanistan on innumerable occasions. In one, a Predator spotted a substantial force of Taliban fighters moving into position to attack the U.S. air base at Kandahar, and notified the combined air operations center. The center quickly transferred control of the drone from Creech AFB in Nevada back to its launch-and-recovery crew near Kandahar. That crew contacted the Joint Terminal Attack Controller (JTAC), who guided Apache attack helicopters to the scene. The Apaches destroyed much of the Taliban force and prevented its planned attack on the air base.

In another operation, a Predator discovered a small band of insurgents emplacing a roadside bomb and communicated their position to the JTAC, who relayed it to an airborne B-1 bomber. The bomber attacked the insurgents, three of whom ran from the blast. The Predator tracked them, saw one drop by the wayside, and attacked the other two with its Hellfire missile. One was killed; the other rolled into a ditch. The Predator coordinated again with the JTAC, who guided an A-10 close-support aircraft to the scene to finish the job. The Predator loitered overhead "for a long period of time," to make sure that no Taliban fighter escaped, says an Air Force source.


*Task Force ODIN forces flew Warrior Alpha UAVs equipped with electrooptical and infrared sensors or with synthetic aperture radar, along with laser target markers, laser rangefinders and missiles.*

Deptula cites yet another successful operation in Afghanistan as an example of the timely and seamless distribution of communications in ISR at its best: The automated signals intelligence (SIGINT) suite in a high-altitude U-2 intercepted Taliban communications traffic and automatically transmitted it to Beale AFB, Calif. Traffic analysts there deduced considerable Taliban activity around Kandahar and immediately called the U-2 pilot back and told him what was happening. The pilot then alerted the U.S. JTAC on the ground, who relayed it to an Army combat unit in the vicinity, enabling that unit to thwart a Taliban ambush in the making.

The distribution of communications in that operation "took less than two minutes," and exemplified the seamless nature of ISR, Deptula says. He notes that an Army unit may take its cue from data collected by a U-2 to request a follow-up video feed from a UAV, and then take action. The unit may also direct the UAV to point out the target to a manned bomber, "and all this may have been planned in a forward operating post with imagery collected from a Global Hawk the day before."

*Information gathered by high-flying U-2s is sent to analysis centers, processed and returned to the theater.*

The Air Force ISR boss points out that ISR enables air and ground forces to distinguish among potential targets in order to avoid killing and wounding civilians while firing on enemy combatants. "The issue is where and what we want to strike," Deptula explains. "We might want to achieve a nonkinetic outcome."

## Integration and analysis

ISR practitioners emphasize that networks of sensors are required to provide timely and comprehensive coverage, and that sensors operating singly are not usually adequate to the task. This, they say, is why U.S. and coalition forces in Afghanistan require a wholly integrated ISR architecture that embodies the full range of ISR assets (including space systems) and is capable of fulfilling diverse combat requirements.

Sensors on ISR aircraft include infrared imagers and cameras that provide air and ground commanders with still photos or full-motion videos. Rapid correlation and distribution of imagery is vital. Daniel Leaf, a Northrop Grumman vice president and former three-star general in charge of Air Force requirements, observes that information gathered by ISR platforms represents "wasted effort if we can't get it to the warfighters in usable form" via communications networks.

This is why the Air Force created its so-called "distributed common ground system" of ISR analysis centers in Korea, Germany, Ha-


*Among the UAVs operated by ground troops are the 40-lb ScanEagle (right), the BATMAV and the RQ-11 Raven (facing page, top and bottom).*

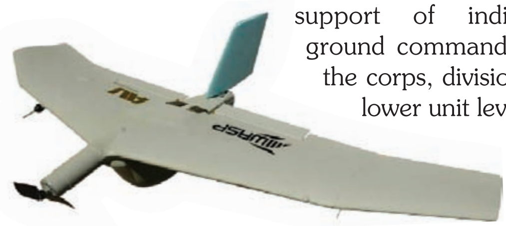
waii, California, and Virginia. The centers are manned by communications operators, linguists, analysts and maintenance personnel, among others, and serve as "the linchpins of our completely integrated [ISR] process," Deptula explains.

"The information coming from a variety of platforms, including our Predators, Reapers, Global Hawks and U-2s, is sent to these analysis centers, processed, evaluated and transmitted right back into the theater for immediate use," he says. "And the beauty of this system is that we don't have to add more [ISR] people in Afghanistan as part of the [U.S.] surge there. What we do is shift workload among the five analysis centers; and we have the personnel to do that."

### Proliferation of UAVs

According to the Air Force, Global Hawks operate at an altitude of 65,000 ft. They are equipped with electrooptical sensors, ground moving-target indicators, infrared sensors, synthetic aperture radar and a SIGINT suite. Reapers operate at 50,000 ft, twice as high as the lighter Predators. Both carry EO sensors for full-motion video, infrared sensors, SIGINT suites and laser target designators. Predators can be armed with Hellfire missiles, Reapers with Hellfires and various bombs.

In Afghanistan, as in Iraq, Air Force UAVs operate in support of the joint force commander at both the tactical and theater levels of operation. Army and Marine Corps UAVs operate in tactical support of individual ground commanders at the corps, division and lower unit levels.



*Soldiers in Kandahar depend on ISR input from myriad sources. (Photo by Tech. Sgt. Francisco V. Govea II.)*

More than 1,000 UAVs of assorted sizes and capabilities are said to be operating in the region. Michael Isherwood, a senior analyst at Northrop Grumman's analysis center and a former Air Force colonel and command pilot in Iraq and Afghanistan, notes that the UAVs include more than 10 types of small, man-portable handheld systems operated by Army and Marine Corps companies and platoons, plus seven additional types controlled by battalion and brigade commanders.

Among the UAVs operated by ground troops are the 1-lb Battlefield Air Targeting Micro Air Vehicle (BATMAV) with forward- and side-looking cameras; the slightly larger, 4-lb, all-weather, all-hours, GPS-guided RQ-11 Raven with TV and IR sensors; and the 40-lb ScanEagle, with a turreted camera for both EO and IR reconnaissance at distances up to 5 mi. BATMAVs, also called Wasps, fly relatively short distances at low altitudes to provide over-the-hill and around-the-bend reconnaissance, and are operated by the Air Force as well.

In a recent position paper, the Army emphasized its "continuing expansion of persistent surveillance capability through both manned and unmanned systems," including the Shadow UAV used by soldiers and Marines for reconnaissance, target acquisition and battlefield damage assessment. Shadows have seen heavy duty over Iraq and Afghanistan, providing surveillance and targeting support to brigade combat teams and battalions at distances out to 125 km.

Shadows complement the higher flying, longer loitering Sky Warrior, Hunter and Gnat UAVs that engage in surveillance and reconnaissance for corps and division commanders at ranges of hundreds of kilometers, the Army document explains. Warrior Alphas flown by the Army are almost identical to Air Force Predators, and are used, as in Task Force ODIN, for target acquisition, communications relay and counter-IED operations, as well as for surveillance and reconnaissance.


*Aircrews performed a preflight check on an MQ-9 Reaper before it took off for a mission in Afghanistan on September 31. Reapers will be outfitted with "Gorgon Stare" pods. (Photo by Rinze Klein.)*

*The Joint Surveillance Target Attack Radar System crew from the 7th Expeditionary Air Combat and Control Squadron preflights an E-8C Joint STARS for a mission. (USAF photo/ Staff Sgt. Aaron Allmon II.)*

Near the end of 2009, as the U.S. troop buildup began in Afghanistan, Air Force officials confirmed reports of a new, stealthy ISR remotely piloted aircraft: the RQ-170 Sentinel, built by the Lockheed Skunk Works. Flown by operators at two Air Force facilities in Nevada (Creech AFB and the Tonopah Test Range), the Sentinel was test flown over Afghanistan but was not yet operational there, according to reports.

### Sensor and communications advances

Deptula claims that advances in sensor technology have enabled the Air Force to enhance its ISR capability and capacity "throughout the [electromagnetic] spectrum," but that much more must be done. For example, he says, "we tend to focus on video because it is easy to see and understand, but we have to increase our capabilities to rapidly revisit locations, provide still imagery and collect signals intelligence and human intelligence."

Airborne radar and communications intercept platforms are considered vital elements of the overall ISR architecture. For example, the Air Force E-8C Joint Surveillance Target Attack Radar System (J STARS) aircraft, while conducting wide area radar surveillance, can alert a Predator or a Hunter (Army UAV) to take a closer look at something suspicious that it detects from afar. The Air Force RC-135 Rivet Joint aircraft, operating at 30,000 ft, can pick up communications traffic 240 mi. away. Global Hawks and U-2s, operating at 60,000 ft or higher, can detect signals out to 300 mi.

The Air Force will expand its capacity for wide-area surveillance by equipping Reaper UAVs with new "Gorgon Stare" pods. Their deployment is scheduled to begin in April.

"They will be able to see the same distance as the video sensors now onboard the Reapers, and they will be able to do it not just through a little soda-straw area but all across an area of 4x4 km," Deptula explains. "They will be able to provide video from 10 different images anywhere in that area to 10 different people on the ground."

The pods weigh 1,000 lb each, which makes them too heavy for the Predators, but not the larger Reapers, to carry. Deptula calls them "one of the biggest things" now coming into play in Afghanistan ISR. "The quickest way we can introduce additional ISR capacity is not to build additional platforms but to increase the capability of the platforms we already have," he declares.

Deptula calls ISR "extremely important" to the successful outcome of the U.S. strategy and operations in Afghanistan and environs. Could ISR make the difference between success and failure?

"Absolutely," he replies.

# Open rotor research revs up

*Researchers in the U.S. and Europe are reviving an old concept and reshaping it into advanced technology for a new generation of open rotor aircraft engines. When first proposed in the 1980s, the idea met with low acceptance from the public, who viewed propellers as noisy and outmoded. Today, however, the promise of greater fuel savings and lesser environmental effects will likely give the updated technology a better reception.*

It is increasingly possible that the next generation of Airbus and Boeing single-aisle aircraft, due to enter service around 2019/2020, will fly with open rotor engines.

Open rotor engines use a gas-turbine core to drive a large-diameter fan which propels large amounts of cool air around the outer part of the engine—creating very high "by-pass" ratios and thereby considerably increasing the efficiency of the engine over conventional turbofans.

Rolls-Royce and General Electric (GE) have made sufficient progress in their competing open rotor technology demonstration programs that both companies believe the engines will be able to deliver the necessary step-changes in economics while meeting stringent new performance and noise targets. The concept has been proven, both say—now the hard work starts on defining the details of the engine architecture that will provide the vital 1-2% competitive advantage.

**by Philip Butterworth-Hayes**
Contributing writer

## Reviving an old idea

For GE, the past two years of open rotor research has involved revisiting the unducted fan (UDF) technology of the past. GE and the Fundamental Aeronautics Program of NASA's Aeronautics Research Mission Directorate in Washington are jointly funding a research program into open rotor research, while GE's partner in the CFM International consortium Snecma is concentrating on fan blade designs. The three organizations are essentially recreating the GE36 research team of the mid-1980s.

LEAP-X is the CFM International technology program focusing on future advances for next-generation CFM-56 engines. Ted Ingling, the program's manager of engineering, leads the company's open rotor work.

"The early generation of engines were built at a time when fuel was at a very high price, and it was thought it would stay like that forever," according to Ingling. "We demonstrated in ground and flight tests the theory and practice of open rotors. Fundamentally it was a sound technology to put fuel performance first and then work on delivering Stage III noise performance in the production version."

*The acoustic challenge will have to be met by any open rotor design going forward.*

## Two basic challenges

Ingling believes that, apart from meeting stringent new reliability certification and operating standards, there are two fundamental design challenges to be met in the next generation of open rotor engines: acoustics, and the reliability of the pitch-change mechanism.

"Today requirements are different," he says. "Regulations are more stringent, and the challenge is to reduce the source of noise dramatically. This means looking at the source noise of the props and how they integrate with the airframe. We will have to make substantial changes to blade designs, and it's still not clear exactly what the optimal acoustic performance will look like.

"All propellers lose efficiency at high speed, as the tips of the propeller approach the speed of sound. This creates increasing 'wave drag,' which can be obviated by increasing the number of blades and developing 'swept' or 'scimitar' designs. In these designs the blade is progressively more swept toward the outside, to counter the increasing speed.

"The second enabling technology to bring the engine up to today's standard of reliability is the design of the pitch change mechanism, which will allow us to change the fan-blade orientation depending on the Mach number and throttle setting. That mechanism is a piece of equipment that will be embedded in machinery, so reliability and weight are key

*Increased wave drag can be obviated by increasing the number of blades and developing swept or scimitar designs.*

*Snecma is heading up SAGE work on the direct-drive open rotor concept engine.*

enablers of the technology," Ingling says.

For the past two years GE has been reviewing the data from the 1980s, talking to the technicians and engineers involved in earlier UDF studies and seeing what improvements could be made with current testing technology. "We have focused on how much more acoustic benefit we could get using modern tools—especially in areas such as predicting outcomes of new aerodynamic designs," says Ingling. "In the 1980s there was a lot of trial and error. We've taken some of the data from the old rigs, run new aerodynamic designs, and launched additional analysis in areas such as aerodynamic testing, aeroperformance, and acoustics. The new advanced codes tell us that for the same acoustic signature, we could recover overall engine performance."

With the first-generation UDF, according to Ingling, GE engineers had to sacrifice some of the engine's overall performance capabilities to meet the Stage III noise requirements.

### Wind tunnel testing

In the next stage of research, GE Aviation and NASA have been working together on a wind tunnel test program to evaluate counterrotating fan-blade systems. The research phase began in 2009 and is continuing into 2010. The team has built a one-fifth subscale model comprising two rows of counterrotating fan blades, with 12 blades in the front row and 10 in the back. They are being tested in simulated flight conditions in NASA Glenn's low-speed wind tunnel to simulate low-altitude aircraft speeds for acoustic evaluation, and in Glenn's high-speed wind tunnel to simulate high-altitude cruise conditions.

### Building on the past

*General Electric developed its GE36 unducted fan (UDF) featuring an aft-mounted, open rotor fan system with two rows of counterrotating composite fan blades during the mid-1980s. It was a joint development with NASA and Snecma, GE's French partner in the Snecma consortium that had a 35% stake in the program.*

*The core was based on a GE F404 military turbofan. Exhaust gases were discharged through a seven-stage low-pressure (LP) turbine; each stator ring was designed to move freely in the opposite direction to that of the rotors. One set of fan blades was connected to the LP turbine rotor system and the other set to the contra-rotating LP turbine stators—effectively creating a 14-stage LP turbine system.*

*The GE36 flew on the Boeing 727 and MD-80 aircraft and enabled speeds of around Mach 0.75. Although specific fuel consumption improvements of around 30% better than contemporary jet aircraft were measured, there were extensive noise and vibration issues—though the engine met Stage III noise limits, according to company officials.*

*An alternative UDF test program in the mid-1980s was pioneered by Allison and Pratt & Whitney. The 578-DX propfan featured a more conventional reduction gearbox between the LP turbine and the propfan blades and was also flight tested on an MD-80.*

The team is currently designing and testing a classic airfoil design to a certain level of performance and will then be "looking at an enhanced design to see how the goal of a Stage III tradeoff with performance can be made," says Ingling.

"The speed at which the aircraft cruises will have major implications for the design," he says. "As a company we are putting a great deal of investment into the program, but we have to be selective about where that investment goes.

"I am extremely encouraged on the acoustic side that we will get to where we need to be—but at some stage we will have to look at how we are going to trade overall engine efficiency against acoustics. Will the noise issue be more important than greenhouse gas emissions, for example? Should we customize performance or trade it against environmental improvements? Many of these issues will depend on what certification standards are employed. At the moment it's too early to determine how much we should look at trading noise improvements with fuel burn performance," Ingling says.

### Other efforts toward the goal

The goal is to have a certified engine in production, providing double-digit performance enhancements over contemporary turbofans, by the end of the next decade.

GE and Snecma will feed new technologies into the open rotor research from the Leap X research program as they become available. GE is redesigning the CFM-56 core to provide around 7% of the targeted 16% fuel consumption improvement for the new engine; Snecma's work on the CFM Leap X program is focused on developing new 1.8-m-diam blades manufactured through a 3D resin transfer molding process.

Snecma's understanding of open rotor fan-blade design will be enhanced through its work on the €40-million DREAM (validation of radical engine architecture systems) program, a three-year research project led by Rolls-Royce and funded half by European industry and half by the European Commission. During the past year one-fifth-scale and one-seventh-scale blade testing has taken place at Russia's Central Aerohydrodynamic Institute, on electrically powered rigs at speeds of up to Mach 0.85.

The DREAM work is also part of a wider European research initiative into next-generation engines called the Sustainable and Green Engine Integrated Technology Demonstrator

(SAGE ITD), a component of the €1.6-billion Clean Sky Joint Technology Initiative research program. SAGE researchers will develop two types of open rotor demonstrator engines.

Rolls-Royce is heading up work on a geared open rotor demonstrator, in a €111-million program involving Rolls-Royce ITP, Deutschland, Volvo Aero, Airbus, and Alenia. The research will focus on the propeller pitch mechanism, the donor core gas turbine, the transmission system that transfers energy from the free power turbine to the contrarotating assemblies, and the contrarotating propellers themselves.

Snecma is heading up SAGE work on the direct-drive open rotor concept engine. This €135-million program involves Hispano-Suiza, Techspace Aero, Aircelle, AVIO, Volvo Aero, Airbus, and Alenia Macchi, with work focused on the propeller pitch change mechanism, the contrarotating propellers, the contrarotating turbine directly linked to the propellers, and the gas generator.

Rolls-Royce, meanwhile, has already undertaken high- and low-speed tests of various configurations of its own propriety technology research program and has dedicated a new testing regime, which it calls "Rig 145," to detailed open rotor concept validation.

"We have now moved open rotor work from the theoretical physics to the engineering stage," says Robert Nuttall, vice president for strategic marketing at Rolls-Royce. Early wind tunnel tests have shown its design would comfortably meet current Stage IV noise regulations. Tests were finished earlier this year at the DNW wind tunnel in the Netherlands, using a one-sixth-scale electrically driven rotor to simulate low-speed operations, including takeoffs and landings. "We ran different configurations and different numbers of blades at different blade speeds—we finally discovered the optimal configuration for low-noise open rotor operations," says Nuttall.

The model is now undergoing high-speed tests at the Bedford (U.K.) Aircraft Research Association transonic wind tunnel. "We first ran these tests at the end of 2008 and spent the first quarter of 2009 understanding the results," says Nuttall. "We're still being very cautious with our claims but we think that, in terms of economic performance, our open rotor engine will perform 25% to 30% better than current turbofans."

Rolls-Royce has yet to firm up on a core design. "We have a number of options in this area," says Nuttall, "and we now have an internal competition between our two-shaft center of excellence in Dahlewitz [Germany] and our three-core center of excellence in Derby, U.K."

Nuttall believes there are five key technology risks that must be addressed—the gearbox, pitch change mechanism, blades,

### Competitive market and technology challenges

*Developers of open rotor technologies face a number of challenging hurdles, not all of them technical:*

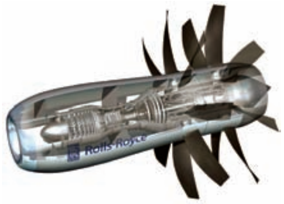
***•Competing technologies.*** *The efficiency of current technology engines is improving at an average of 1% a year—which means traditional turbofan engines available in 2020 are likely to be at least 11% more efficient than today's production models, without any major technology risk. Meanwhile, the Pratt & Whitney PW1000G geared turbofan could provide a 22-23% fuelefficiency gain by 2017, according to the company, while the CFM International non-open rotor LEAP-X design could provide 16% lower fuel consumption than the CFM56-7 by 2018. Some manufacturers are skeptical about open rotor technology, worried that installation effects, additional weight, complexity and interference drag could obviate any improvements in fuel savings.*

***•Slower aircraft operating speeds.*** *An open rotor powered aircraft is likely to have a cruising speed 5-10% slower than a turbofan powered aircraft. "The average route length for a single-aisle short/medium-range airliner is around 500 n.mi.," according to Rolls-Royce's Nuttall, "and at that range, speed is not crucially important."*

***•Regulatory issues.*** *Engine and airframe manufacturers have already approached regulators such as the European Aviation Safety Agency and the FAA to determine whether there might be any airworthiness certification concerns around issues such as engine layout and blade containment. Manufacturers would need to know as early as possible if regulators did have major concerns, to eliminate areas of potentially wasteful research.*

***•Airframe integration.*** *The integration of the engine within the airframe will be a critical issue, especially if the prop diameter is close to the 170 in. under review by Rolls-Royce. With this size blade a "pusher" arrangement would be more elegant, as the engines would be placed behind the rear pressure bulkhead in the fuselage, minimizing noise. It also would allow for an aerodynamically "clean" wing. A "puller" arrangement would dictate a high wing design, with the large rotating assembly next to the fuselage.*

***•Public perception.*** *In the 1980s manufacturers were concerned that passengers viewed propeller-driven aircraft as outmoded, noisy and slow. Open rotor engine manufacturers have started some early research into this area. But it is likely that the environmental concerns of the 20th-century traveling public would make the open rotor concept an easier "sell" than the UDF concepts of the 1980s.*



*Rolls-Royce is targeting 2014 for a flight demonstration of its open rotor engine but its design has not yet been locked in.*

noise/vibration, and airframe integration. In one of its preferred current configurations, Rolls-Royce is working on an engine with 170-in.-diam contrarotating blades—roughly the diameter of regional jet fuselage. This will demand a 16,000 shp gearbox to drive the contrarotating blades, a sophisticated pitch-change mechanism and highly aerodynamic blade design made of composite materials.

"In the work so far we have proved we can deliver what we thought we could at a macro level. Now the work is to zoom down to specific work areas such as blades and the gearbox. In this we are now looking for partners—a pitch-change mechanism is not something we are expert in, for example."

Airframe integration is a sensitive issue, as much of this work will have to be pioneered by airframe manufacturers themselves. Rolls-Royce, Boeing, Ruag Aerospace, and Deharde Maschinenbau began a research program in May 2009 to test a model concept airframe this year at Ruag's low-speed wind tunnel in Emmen, Switzerland. Airbus is working with engine manufacturers on new engine integration issues within the Clean Sky program, which should deliver the first results around 2014.

Both GE and Rolls-Royce are working to a similar timescale. Rolls-Royce has targeted its flight demonstration with an open rotor engine—based on the core of a current production engine—for 2014, and a final go/no-go decision shortly after that, with a service date of 2020.

## Market uncertainties

While both GE and Rolls-Royce have proven that the core concept of the open rotor is viable—that 25% fuel improvements over current engines are possible within current and planned noise regulations—there are still a great many market uncertainties to overcome.

For Airbus or Boeing to consider an open rotor for their A320 or B737 replacement families, they would have to embrace some radical new design concepts and be sure about the key operating cost and environmental drivers that will prevail over the next 40 years. "One of the fundamental remaining questions is whether you trade noise for carbon dioxide emissions," according to Nuttall. "It will depend on what the industry wants."

The problem for engine and airframe manufacturers is that no one can be quite sure what the industry will really want in 2030.

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## *Unmanned and airborne*

*(Continued from page 17)*

the cockpit to the design labs and ground control stations—and making the same kinds of transitions and merged conceptualizations among engineers and even corporations. It is a challenge many others are taking on, at various levels—with hundreds of companies in dozens of nations around the world producing hundreds, if not thousands, of different UAVs every year.

For Boeing, it is both a small gamble—in terms of actual money invested by a company accustomed to spending billions on developing a single new aircraft—and a big change in perspective.

Whether UAS someday represents 10% or 50% of Boeing Military Aircraft revenues depends on the company's ability not only to bring all the requisite components together to meet stated requirements, but also to anticipate future needs and push the thresholds of technology. It also depends on how a military customer that essentially dismissed UAVs for decades—until technology evolved to make them an indispensable combat asset—will look at them in the future.

For small militaries that cannot afford large fleets of expensive manned aircraft, it will be far easier to acquire and field UAVs to perform virtually any task now handled by manned platforms. And there will be growing pressure, both budgetary and political, on nations such as the U.S. to use UAVs and other robotic platforms instead of far less expendable human warfighters.

"I don't think unmanned necessarily will supplant lots of manned, but there will be plenty of both. I don't believe today we know for sure if a next-generation fighter, bomber, or tanker will be manned, unmanned, or partially both. Across the board, the services are still evaluating what those future systems will look like," says Sweberg.

"Augmenting the power of the larger manned aircraft today—the fighters and command and control—with unmanned real-time ISR and, in some cases, real-time strike capability and the CONOPs and mission scenarios employing that duality of systems—I think ultimately we will be able to do missions faster and more effectively."

## 25 Years Ago, March 1985

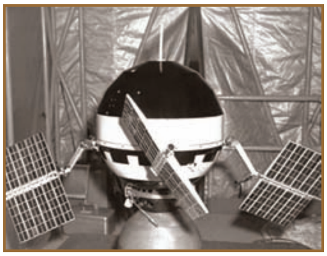
**March 25** The secretary of the Air Force announces changes in the combat exclusion policy to allow women to serve as forward air controllers, fly and crew several models of C-130 Hercules aircraft, and serve at munitions storage facilities. USAF History Web site.

## 50 Years Ago, March 1960

**March 1** As part of the space exploration program, NASA establishes its Office of Life Sciences to undertake research on basic medical and behavioral sciences. Studies will examine the effects of space and planetary environments on living organisms, and the possibilities for the existence of extraterrestrial life. D. Baker, *Spaceflight and Rocketry*, pp. 99-100.

**March 6** Aviation pioneer Roy Knabenshue, whose early accomplishments included making the first dirigible flight over New York in 1905, dies at 83. In 1904, he also made a record-breaking lighter-than-air flight when he piloted the California Arrow airship at the Pan American Exposition to 2,000 ft. In 1910-1911 he was an aviator for the Wright exposition team; in 1913 he flew the first passenger dirigible in the U.S., the White City. *Flight*, March 11, 1960, p. 327; Roy Knabenshue file, NASM.

**March 8** The 60th and last Thor IRBM missile supplied to Britain is flown to the U.K. from the Douglas plant in Santa Monica, Calif., in a USAF Military Air Transport C-124 Globemaster. *Flight*, March 18, 1960, pp. 359-360.



**March 11** The 90-lb Pioneer V space probe is launched into a solar orbit around the Sun by a Thor-Able 4. The spherical probe, featuring solar cells and four paddle-like vanes, measures radiation and magnetic fields between Earth and Venus. On its closest approach, the probe comes within 74.7 million mi. of the Sun. *Flight*, March 18, 1960, p. 358; *The Aeroplane*, March 18, 1960, p. 331.

**March 15** The Saturn launch vehicle project is officially transferred from the Army Ballistic Missile Agency, headquartered at Redstone Arsenal, Ala., to NASA. Consequently, the rocket's development team, led by Wernher von Braun, is also moved to NASA and assigned to the Marshall Space Flight Center, adjacent to Redstone Arsenal. E. Emme, ed., *Astronautics and Aeronautics 1915-60*, p. 120.

**March 15** Russian plans for sending spacecraft to Venus and Mars are approved by Mstislav V. Keldysh, vice president of the Soviet Academy of Sciences. D. Baker, *Spaceflight and Rocketry*, p. 100.

**March 15** The 43rd Bomb Wing at Carswell AFB, near Fort Worth, Texas, becomes the first USAF unit activated with the Convair B-58B Hustler delta wing bomber. F. Mason and M. Windrow, *Know Aviation*, p. 60.

**March 18** At the U.K.'s Jodrell Bank Experimental Station (later the Jodrell Bank Observatory), Princess Margaret presses a switch that activates a command radio signal for the transmission of data by the NASA Pioneer probe, which is now 1,040,000 mi. from Earth and heading toward the exploration of a 26-million-mi. gap between the orbits of Earth and Venus. *Flight*, March 25, 1960, p. 400.

**March 25** The Aerobee 150-A, the latest model in the famous Aerobee family of sounding rockets, is launched for the first time. Lofted from a new launch tower at NASA's facility at Wallops Island, Va., the rocket reaches an altitude of 150 mi., where it conducts micrometeorite counts. E. Emme, ed., *Astronautics and Aeronautics 1915-60*, p. 121.

**March 25** The hypersonic X-15 rocket research aircraft achieves powered flight, piloted by NASA's Joseph A. Walker to 48,630 ft and 1,320 mph. D. Jenkins, *X-15*, p. 611.

**March 28** Clustered engines of the Saturn launch vehicle are fired for the first time. In this first test, two H-1 engines in an eight-engine cluster are fired. In further tests on April 6, four of the engines are fired together, then all eight. A maximum thrust of 1.3 million lb is reached when the clustered engines are fired on May 17. D. Baker, *Spaceflight and Rocketry*, pp. 100-101.

## 75 Years Ago, March 1935

**March 7** John Tranum, the world's most famous parachutist, dies in a

# Past

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


Danish army plane over Copenhagen when his oxygen equipment malfunctions. He was attempting a parachute drop from 25,000 ft. Danish-born Tranum emigrated to California, where was a movie stunt man. In the late 1920s he went to England and demonstrated Russell parachutes and Irving Air Chutes. His longest drop took place in May 1933, when he jumped from a plane at 21,000 ft over Salisbury Plain. He dropped more than 17,000 ft, claimed as a world's record. Tranum scientifically checked his parachute results with a stopwatch and aneroid barometer and turned over the results to the U.S. Army Air Corps. *The Aeroplane*, March 13, 1935, p. 290.

**March 8** Robert H. Goddard launches one of his liquid-propellant rockets from Roswell, N.M. He tests an equalizer to prevent liquid oxygen tank pressure from exceeding gasoline pressure. The rocket is also equipped with a pendulum stabilizer and a 10-ft recovery parachute. It reaches an altitude of 1,000 ft and lands 11,000 ft from the tower. In a letter written a few days later Goddard remarks, "We had the best flight we have ever had during the entire research. The streamlined rocket traveled nearly 700 mph and…showed the first real indication of the rocket directing itself. It was very impressive. It looked like a meteor passing across the sky." E. Goddard and G. Pendray, eds., *The Papers of Robert H. Goddard*.

**March 8** Three Dornier Wal flying boats of the Royal Dutch Navy under the command of Cmdr. W.H. Tepenburg arrive in Manila from the Netherlands East Indies, the first Dutch aircraft to be seen in the Philippines. Although Tepenburg announces that this is a goodwill flight, it is actually a mission to explore the possibility of air service from Batavia to Manila. This service is not begun. E. Santos, *Trails in Philippine Skies*, pp. 183-184; *The Aeroplane*, March 27, 1935, p. 365.

**March 9** Hermann Goering announces the existence of the German air force to Ward Price, correspondent of the *London Daily Mail*. This implies the unilateral breaking of the Treaty of Versailles clauses that prohibit a German air force. E. Emme, ed., *Aeronautics and Astronautics, 1915-60*, p. 32.

**March 14** The Percival Gull aircraft is demonstrated for the first time at Gravesend, England. The low-wing cantilever monoplane cruises at 152 mph with three people, 75 lb of luggage and enough fuel for 600 mi. Top speed is 172 mph. It lands at 43 mph with flaps down. The designer, Edgar Percival, demonstrates the plane to a private party. *The Aeroplane*, March 20, 1935, p. 328.

**March 22** Deutsche Zeppelin Reederei, a new Zeppelin company, is formed with Hermann Goering as president. Since Goering is Germany's air minister, the firm will come under close government supervision. Zeppelin pioneer Hugo Eckner is president of the company's board of control. The firm is to develop transoceanic Zeppelin services over the North and South Atlantic. *The Aeroplane*, March 27, 1935, p. 366.

**March 28** Robert H. Goddard launches the first liquid-fueled rocket equipped with gyroscopic controls. The nearly 15-ft-tall rocket reaches 4,800 ft at an average speed of 550 mph at Roswell, N.M. German experimenter Alfred Maul was the first to use a gyroscope in a rocket for stabilization, although the rocket was propelled by solid-fuel gunpowder. His experiments, in about 1912, were for the purpose of developing military reconnaissance rockets that would carry cameras for photographing terrain from high altitudes. E. Goddard and G. Pendray, eds., *The Papers of Robert H. Goddard*; E. Emme, ed., *Aeronautics and Astronautics 1915-60*; W. Ley, *Rockets, Missiles, and Space Travel* (1958 ed.).

## 100 Years Ago, March 1910

**March 8** Baroness de Laroche of France is the first woman to receive a pilot's license. C. Gibbs-Smith, *Aviation*, p. 158; *Flight*, Oct. 30, 1909, p. 695.

**March 10** Night flights are made for the first time by Emil Aubrun of France, who makes two such trips of 20 km each on a Blériot to and from Villalugano, a suburb of Buenos Aires, Argentina. C. Gibbs-Smith, *Aviation*, p. 152.

**March 28** Henri Fabre achieves the first flight in a seaplane, a Gnome-powered floatplane, at Martigues, near Marseilles, France. C. Gibbs-Smith, *Aviation*, p. 153.

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