March 2010

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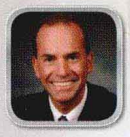

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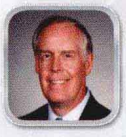

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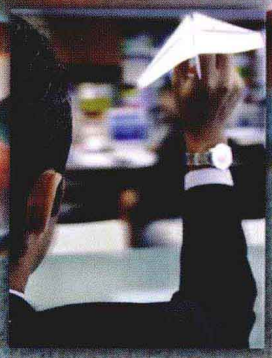

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Speakers' Briefing

Authors who are presenting papers, session chairs, and co-chairs will meet for a short briefing at 0700 hrs on the mornings of the conference. Continental breakfast will be provided. Please plan to attend only on the day of your session(s). Location will be in final program.

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A speaker practice room will be available for speakers wishing to practice their presentations. A sign-up sheet will be posted on the door for half-hour increments.

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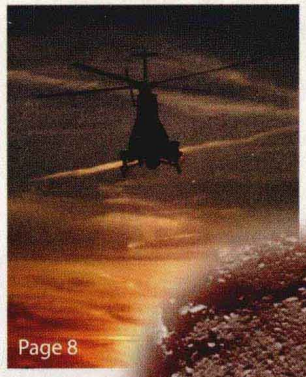


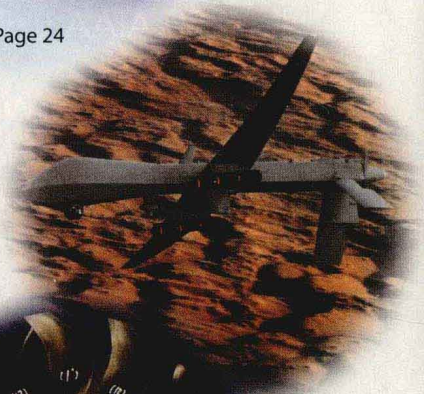
Page 8

Page 12

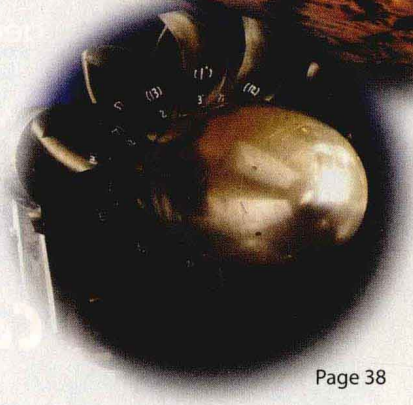
Page 16

Page 18

Page 24



Page 32



Page 38

DEPARTMENTS

EDITORIAL 3
Space, safety—and risk.

INTERNATIONAL BEAT 4
Environmental regulations fly high and wide.

WASHINGTON WATCH 8
Feeling the pinch and scaling back.

THE VIEW FROM HERE 12
Why asteroids beckon / NASA and near-Earth objects.

AIRCRAFT UPDATE 16
World tanker market: More than just KC-X.

ENGINEERING NOTEBOOK 18
Reconnecting with a magnetic mystery.
DARPA's Vulcan engine goes Navy.

OUT OF THE PAST 44

CAREER OPPORTUNITIES 46

FEATURES

UNMANNED AND AIRBORNE: A NEW PLAN 24
Boeing is pursuing vigorous development of UAVs and other systems needed in this fast-growing sector.
by J.R. Wilson

ISR IN TODAY'S WAR: A CLOSER LOOK 32
Advances in intelligence, surveillance and reconnaissance are allowing closer views of targets and faster, more precise strikes than ever before.
by James W. Canan

OPEN ROTOR RESEARCH REVS UP 38
Researchers are reshaping an old concept into advanced technology for a new generation of open rotor aircraft engines.
by Philip Butterworth-Hayes

BULLETIN

AIAA Meeting Schedule B2
AIAA Courses and Training Program B4
AIAA News B5
Meeting Program B17
Calls for Papers B24

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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March 2010, Vol. 48, No. 3

AIAA
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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.

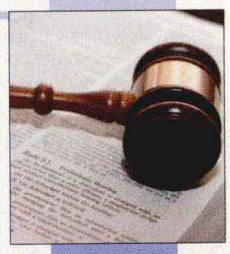
But determining exactly what the criteria are for human-rating a launch vehicle is no easy task. Some argue that the directives laid down by the Columbia Accident Investigation Board are so rigorous that building a new vehicle under those strictures would be next to impossible.

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 re-evaluation of the way the industry will be regulated on this issue in the future.

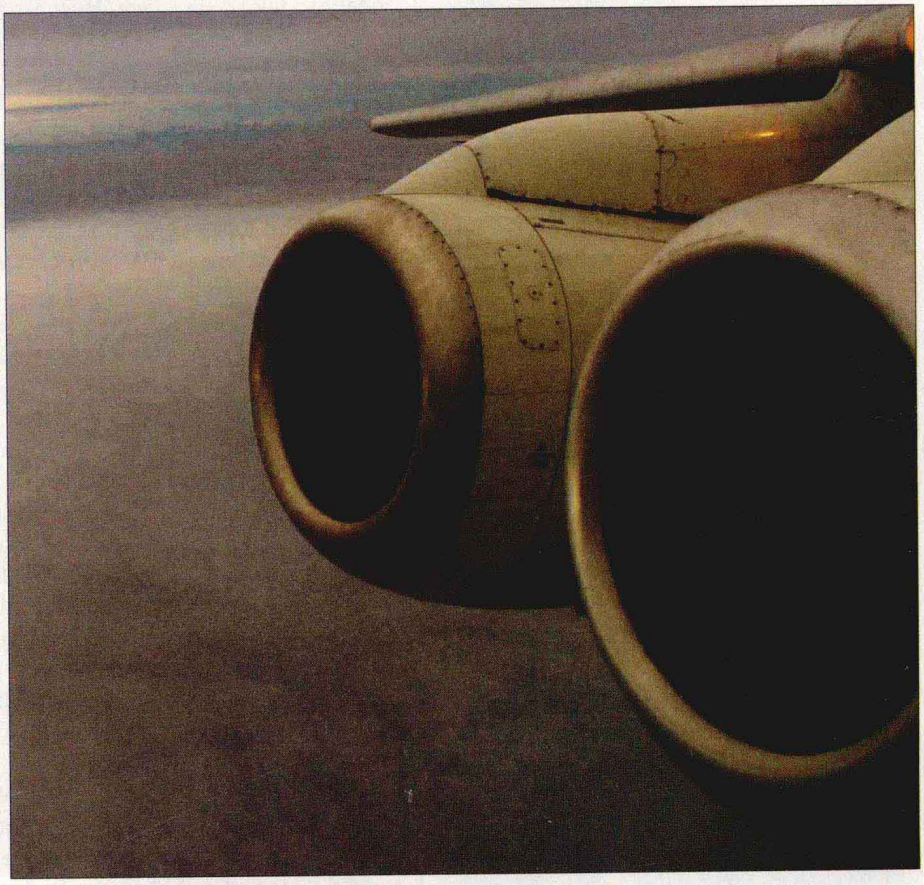
Environmental pressure groups had been campaigning for conference delegates to set a cap on aviation emissions and introduce charges to airlines, based on their emission performance, to fund climate change management schemes in developing countries. The final agreement—which was not agreed to unanimously—committed 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."

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

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.
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MARCH 22-24
Eighth U.S. Missile Defense Conference and Exhibit, Washington, D.C.
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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.
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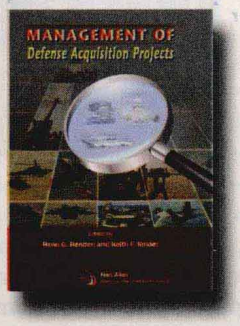

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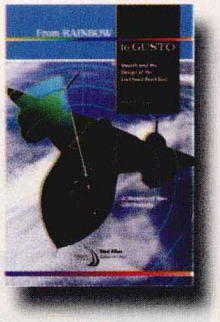

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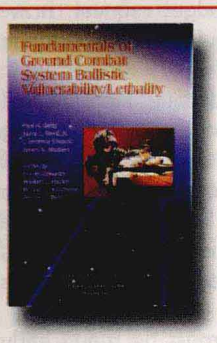

While the focus of this book is on ground combat system vulnerability, many of the principles, methodologies, and tools discussed are also applicable to the air and sea system communities.

Fundamentals of Ground Combat System Ballistic Vulnerability/Lethality

Paul H. Deitz, Harry L. Reed Jr., J. Terrence Klopcic, and James N. Walbert
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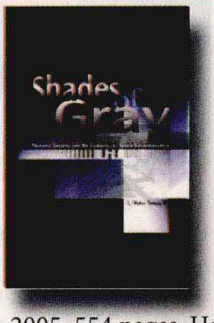

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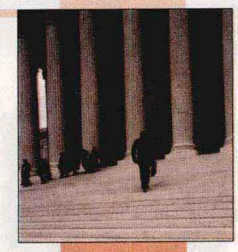


Big budget, big changes

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

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.

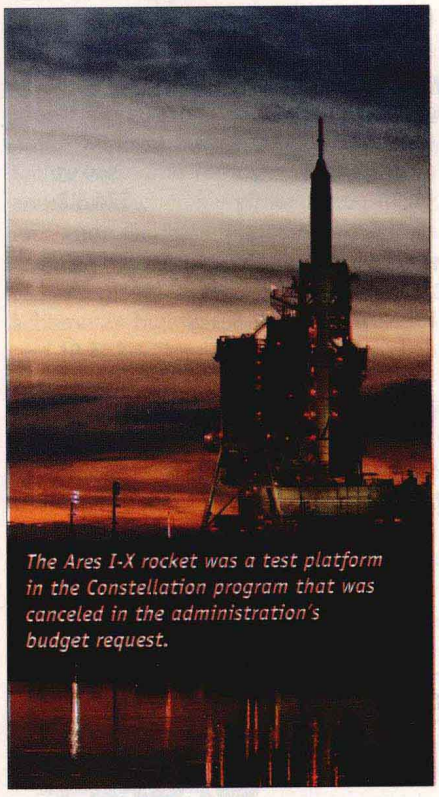
Last year a blue-ribbon panel headed by former aerospace executive Norman Augustine concluded that NASA would need an increase of $3 billion to sustain the human spaceflight program (known as the "vision") that it has been pursuing. "That kind of money was never going to be there," says a NASA insider, 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.

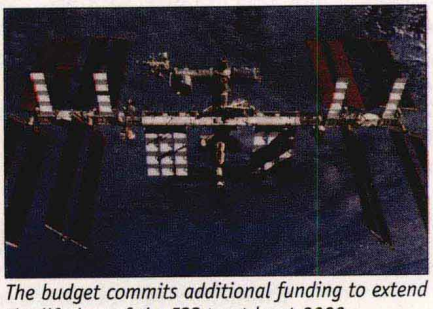
ESA boss Jean-Jacques Dordain said in a January statement that participating nations will have to decide the future of the space station together—a rebuff to the idea that the U.S. can decide unilaterally—and that future planning requires the U.S. human spaceflight policy to be clearly defined.

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



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

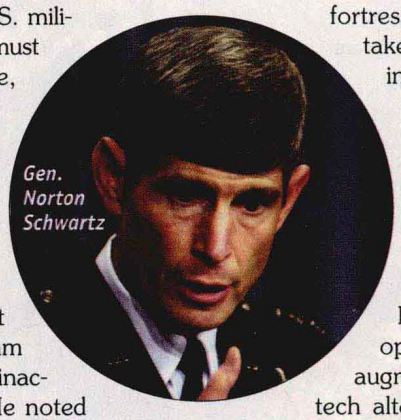
As if to punctuate the decline in public enthusiasm for spaceflight, NASA has lowered its prices in what amounts to a yard sale of shuttle vehicles and support equipment. The agency is offering two shuttles to approved purchasers—almost certainly museums—for $28.8 million each, or about 40% less than 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.


Gen. Norton Schwartz

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.

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.

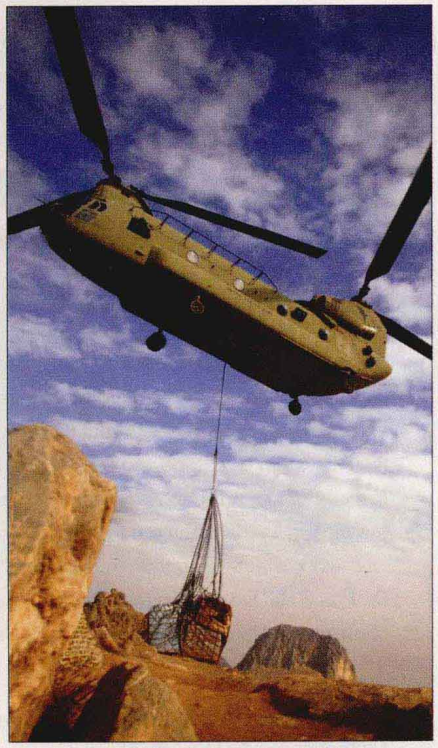
Schwartz offered a B-52 Stratofortress with a Sniper ATP to take pictures of the damage inflicted by the January 12 earthquake in Haiti. The offer was not taken up, but ATPs are in increasingly widespread use and offer an alternative to space-based technology. The general said Air Force scientists are 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.

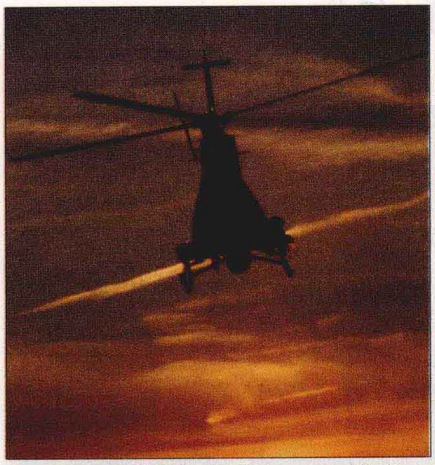
Altogether, the Army has 19 Combat Aviation Brigades (CABs), including eight in the National Guard. A "heavy" CAB consists of four battalions each with 48 AH-64D Apache, 38 UH-60M Black Hawk, 12 HH-60M Black Hawk and 12 CH-47F Chinook helicopters. The Army has maintained three to four CABs in Iraq, a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

tem 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.)

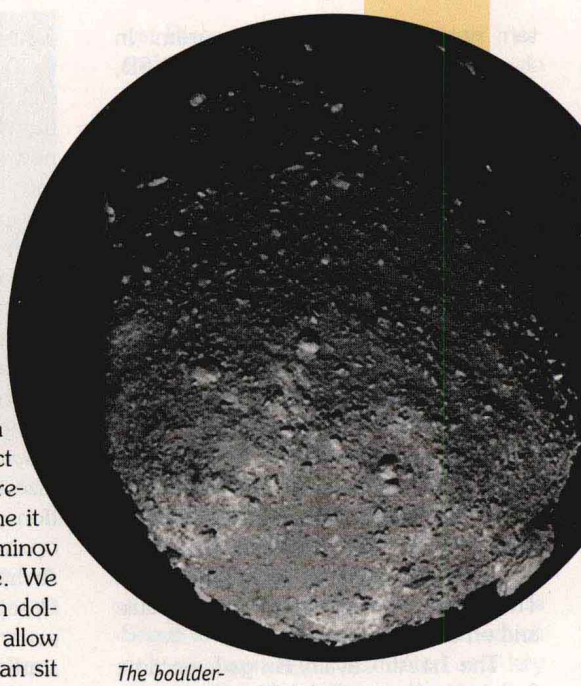
Close encounters with NEOs

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,

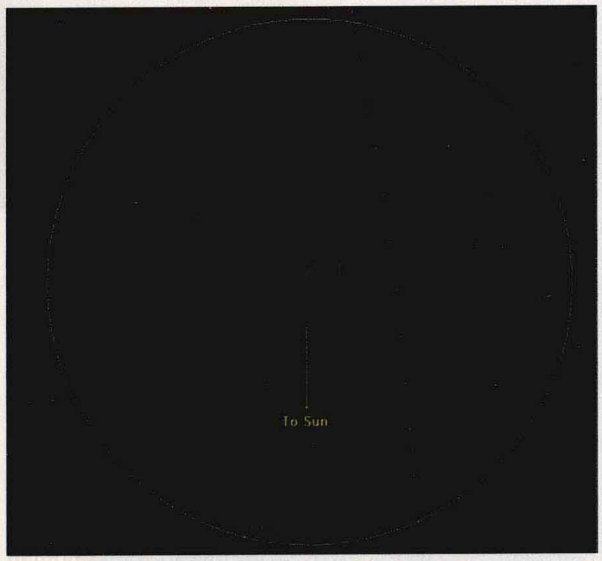
operations, space resources and planetary protection.

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.

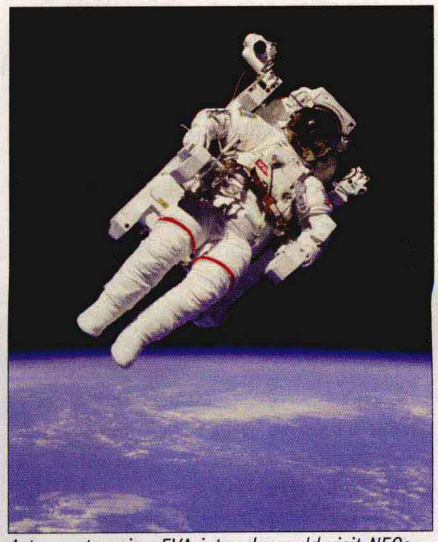


Asteroid 2010 AL30, discovered by MIT's Lincoln Laboratories LINEAR survey on Jan. 10, 2010, came within 125,000 km of Earth on Jan. 13. JPL says the NEO was about 10-15 m across. (JPL image.)

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.

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.