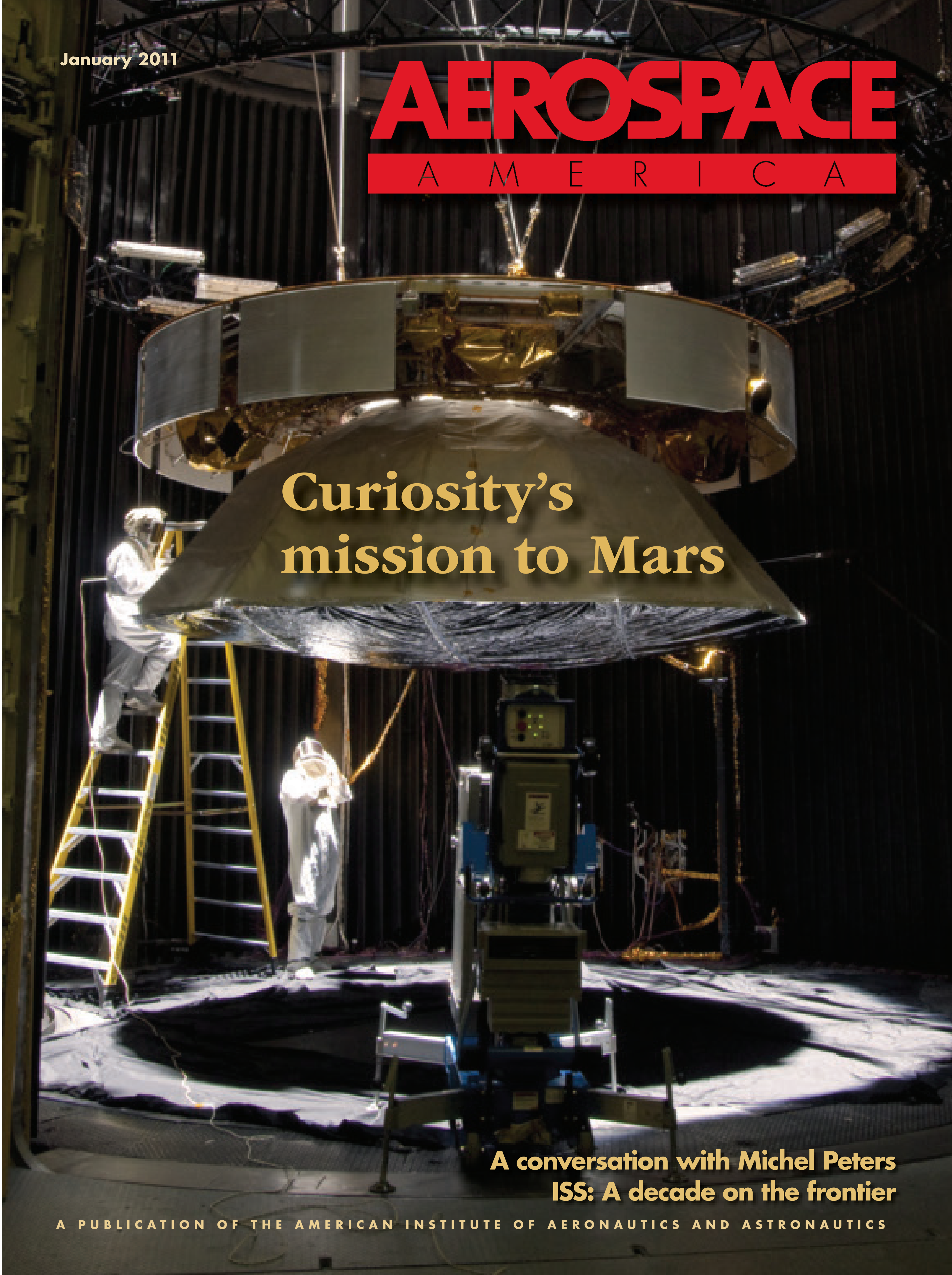
January 2011

AEROSPACE AMERICA



Curiosity's mission to Mars

A conversation with Michel Peters

ISS: A decade on the frontier

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1 AEROSPACE AMERICA JANUARY 2011

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January 2011

DEPARTMENTS

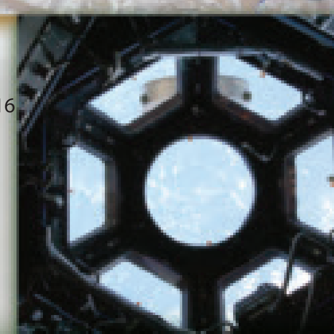
FEATURES

BULLETIN

Page 4

Page 20

Page 24



Page 16

Page 36

COVER
JPL technicians prepare a space-simulation test of the cruise stage of the Mars Science Laboratory. To learn about the MSL and the Curiosity rover, turn to the story beginning on page 28.

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Contributing Writers
Richard Aboulafia, James W. Canan, Marco Cáceres, Craig Covault, Leonard David, Philip Finnegan, Tom Jones, David Rockwell, Frank Sietzen, J.R. Wilson

Fitzgerald Art & Design
Art Direction and Design

Craig Byl, *Manufacturing and Distribution*
Mark Lewis, *President*
Robert S. Dickman, *Publisher*

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

Send Letters to the Editor to Elaine Camhi at the same address or elainec@aiaa.org.

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AIAA
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Commentary

The first A in NASA—Lost in the space debate

In the recent debate over NASA's future, its aeronautics program was totally ignored. The research program that enabled U.S. global aviation supremacy for over nine decades has been reduced to near oblivion.

From the 1960s through the 1990s, annual aeronautics funding averaged about $1.4 billion (all amounts inflation adjusted). This period of unprecedented technology progress sustained the nation's global leadership in both civil and military aviation. NASA research led this growth and helped establish our aviation products as the largest positive contributor to our trade balance. Then the axe fell and funding plummeted from $1.8 billion in 1998 to $500 million in 2010. Because of the time lag from research to application, we are only now seeing the results of NASA research during the '90s in the F-22 and F-35 and Boeing's 787 airliner. How did such a dramatic decline happen?

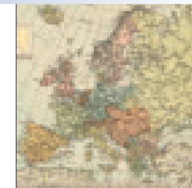
Traditionally, NASA's aero program consisted of basic research coupled with systems technology programs that brought promising technologies to flight demonstration and readiness for low-risk applications. In 1998 NASA began canceling systems technology programs that had produced many enabling technologies for the 787 and NextGen, eliminating $700 million from the aero budget. In 2001 NASA canceled the classified advanced aircraft military technology program, phasing out NASA-funded military aviation research. The NASA-DOD partnership that began in 1915 with establishment of NACA had a profound impact on almost all military aircraft and is now largely eliminated. Four additional systems technology programs were canceled between 2004 and 2007 with another $360-million funding reduction.

The good news is that a $70-million aeronautics increase is budgeted for 2011. Even so, the total aero budget is only 76% of what was allocated for basic research alone in 1995 and only 3.0% of today's total NASA budget. This is insufficient to sustain a world-class U.S. research effort and maintain long-term aviation leadership. Research test facilities are no longer well maintained, and many top researchers have moved on to other programs. Without a major change in priority, there is little hope of sustaining U.S. world leadership in aeronautics.

All this comes as our nation faces huge new technical challenges to the future of civil and military aviation. NASA should be leading efforts to address these issues with systems technology programs focused on "green" aviation and developing technologies to follow NextGen. Further, it makes no sense for NASA's expertise and facilities not to help solve military aviation problems. Aviation's importance to U.S. competitiveness and defense demands that NASA revitalize its aeronautics program. To meet the challenges, it needs a roughly $1-billion annual budget and a revitalized management structure.

Uncertainty over the direction of the human spaceflight program has overwhelmed all other NASA issues. Federal budget realities and the program's low priority do not bode well for aeronautics. Continuing to marginalize this critical national effort will have serious negative consequences for our nation's global competitiveness, yet there is no serious discussion of this issue in the debate over NASA's future. Shame on us.

Roy V. Harris Jr.
NASA Langley (ret.)



Anglo-French defense treaty: The changing dynamic

The MRTT might offer the British Ministry of Defence huge benefits if it can lease spare tanker capacity to a NATO ally.

THE U.K.'S "STRATEGIC DEFENCE and Security Review" in October and the November Anglo-French defense accord last year appear to have set the U.K.'s defense/aerospace industrial strategy on a new path. In the future, the country will have a much smaller army, air force, and navy, and much of its equipment will be codeveloped with France, rather than sourced directly from the U.S.

Ian Godden, chairman of the U.K. aerospace, defense, and security trade association ADS, says the defense treaty with France "may well prove crucial to both retaining and developing future capabilities within Europe by ensuring sustained investment in research and technology to deliver the next generation of programs for our armed forces. The alternative, buying off-the-shelf from the U.S., is often not the appropriate solution for our troops, and this development ensures that future governments will retain a choice of suppliers—both U.K.-based and from overseas—that meet the needs of our armed forces."

More, or less?

So do these agreements mark a major shift in defense/aerospace teaming arrangements for U.K. industry away from North America? Over the past few years, all of the U.K.'s major aerospace systems companies—BAE Systems, Rolls-Royce, QinetiQ, Cobham—have invested hugely in their U.S. operations rather than those in continental Europe, and have generated important new revenue streams as a result. But will this now change? Is the U.K.'s treaty with France more, or less, than it seems?

This is an especially major issue for BAE Systems, the U.K.'s largest aerospace and defense manufacturer, which now derives around half of its income from the U.S. In September 2010 the company announced it would be putting the U.S.-based platform solutions division, based in Johnson City, N.Y., up for sale. This is part of a much broader consolidation program the company has initiated in response to tightening defense budgets in most of its key markets.

For BAE Systems and other U.K. majors, the U.S. defense market remains the most lucrative in the world—accounting for around 50% of the global defense market—and their access to U.S. defense contracts is envied by their continental European competitors.

In contrast, the European continental defense market is a much more complex arena in which to operate—smaller, fragmented, and riddled by national politics. According to figures from the European Defense Agency, Europe spends around €200 billion a year on defense while the U.S. spends €466 billion. Defense (until now) accounts for just 1.63% of European nations' annual gross domestic product, while in the U.S. the figure is 4.7%.

But the new Anglo-French agreement could make BAE Systems think again about Europe. The treaty, after all, offers the prospect of a major share in two programs that are likely to be huge money-spinners at some point in the future: a single European unmanned combat air vehicle (UCAV) and the—probably related—single European replacement for the Eurofighter Typhoon, Dassault Rafale, and Saab Gripen fighters.

Under the agreement, a joint work-

The question remains whether BAE Systems will join the nEUROn initiative.

ing party will look at the next generation of unmanned surveillance aircraft that will be needed between 2015 and 2020. Longer term studies will look at prospects for development of a common UCAV system by around 2030. While continental European manufacturers have pooled their UCAV efforts—under Dassault's leadership—in the nEUROn program, BAE has developed its own UCAV prototype, Taranis. So will BAE Systems be joining the nEUROn initiative?


The MANTIS is a contender for the ISTAR UAS.

MALE and UAS opportunities

BAE Systems is treating this issue with some discretion and would only say, "We…note Prime Minister David Cameron and President Nicolas Sarkozy's joint statement regarding their intention to collaborate on a future medium altitude long endurance (MALE) unmanned aircraft system (UAS) program and a potential unmanned combat aircraft system. Not only is this an important milestone in terms of the development of our ongoing unmanned aircraft capability, but it represents a significant investment in the future of our U.K. and French military aerospace capability. We actively support this collaborative approach with the U.K. and French governments. Given the strong research and development investment that has already been made in this area by both BAE Systems and Dassault Aviation, we have entered into discussions with Dassault to explore how we could best deliver this opportunity."

The MALE market is dominated by Israel and the U.S.; the new accord gives France and the U.K. an opportunity to enter this growing sector with a combined product. The U.K.'s Ministry of Defence (MOD) Scavenger program entails the identification of a next-generation ISTAR (intelligence, surveillance, target acquisition, and reconnaissance) UAS by 2012, to follow on from the armed General Atomics MQ-9 Reaper in service with the MOD. Potential candidates include the General Atomics Predator C Avenger and a development of BAE Systems' own Mantis technology demonstrator, though the Anglo-French accord now opens the doors for a new European contender.

The treaty addresses two different levels of cooperation—the sourcing of material by the U.K. and French military (which together account for around 70% of the total European defense market) and the development of strategic partnerships between French and U.K. suppliers to reach domestic and global markets.

In terms of the first area of cooperation—acquisition of new equipment by and combined operations between U.K. and French defense forces—the agreement will take the U.K. and France much further than they have been before.

Benefits of pooling resources

With the U.K. military now rapidly downsizing, the need to pool resources with equally cash-strapped neighbors makes economic sense—and not just in terms of saving money. For example, the U.K.'s RAF has ordered 14 Airbus military MRTT (multirole tanker transports), nine of which will be delivered for RAF service, with five leased out to civil or military operators. There will be huge benefits if the MOD can lease spare tanker capacity to a NATO ally, a potential business area currently being discussed between the French and U.K. governments. France is looking to acquire new air tankers by 2015; any shortfall or delay in capability could be met by the RAF as the nine core aircraft are due to be delivered by 2014, with the five others, available for leasing, thereafter.

The U.K. will fit catapults and ar-

Two new treaties will redefine the U.K.'s defense capabilities

Key components of the November 2010 Anglo-French agreement:

- *Coordination of the aircraft carriers to ensure that there is always a British or French vessel available for joint operations.*
- *Creation of a Combined Joint Expeditionary Force training British and French troops to deploy on operations together.*
- *Development of a new nuclear testing facility at the Atomic Weapons Establishment at Aldermaston and its French counterpart at Valduc.*
- *Pooling training, maintenance, and logistics resources for the A400M transport aircraft.*
- *Increased cooperation on satellite communications, cyber security, and the development of new missile systems, submarine technologies, and unmanned air systems.*

Key air elements of the U.K.'s October 2010 Strategic Defence and Security Review:

- *Defense budget to be cut by 8% over the next four years.*
- *Retirement of current Harrier close-support aircraft this year—to be replaced by an unknown number of U.S. F-35s in 10 years' time.*
- *Cancellation of the BAE Systems Nimrod MRA4 surveillance aircraft program.*
- *Reduction of the Panavia Tornado GR4 strike aircraft fleet from eight to five squadrons.*
- *Replacement of the Trident submarine-based nuclear missile, but with £750 million savings to be made by specifying fewer warheads.*
- *Two aircraft carriers saved, but one will not enter service.*

It is likely that the British JSF buy will be the F-35C carrier version.

rester gear to its future aircraft carriers so that both countries' naval fighters can fly from each other's naval vessels. U.K. aircraft (Lockheed Martin F-35 Joint Strike Fighters) will be able to access the French nuclear carrier Charles de Gaulle.

The construction of two U.K. aircraft carriers will proceed; that should allow the creation of a "U.K.-French integrated carrier strike group" by the early 2020s. When the two new carriers, the Queen Elizabeth and Prince of Wales, are finally ready to enter service in 2020, the former is likely to be sold or stored and the latter adapted to take the conventional version of the JSF, which will use catapults to take off.

According to the International Institute for Strategic Studies (IISS), "The number of JSFs purchased will be reduced in line with the aircraft decision, and they will be the conventional F-35C carrier version rather than the advanced short takeoff and vertical landing variant, a change which may please the air force but will require that the deployable new carrier is equipped with catapult systems and arresting gear."

There will be further joint service ventures, most notably the Combined Joint Expeditionary Force available "at notice for bilateral, NATO, European Union, United Nations, or other" operations. Combined land and air exercises will begin this year.

But for the second part of the treaty—the closer alignment of U.K. and French aerospace concerns, and what this might mean for aerospace industries of other European countries and the U.S.—the implications are less clear, though the first indications are that this could lead to a new wave of further defense and aerospace consolidation in northern Europe.

The high-level agreement calls for the development of a common defense industry and research policy that aims to cut 30% of the cost of complex weapons systems through a 10-year strategic plan, including the emergence of a single European prime contractor. A combined €100-million minimum annual research and technology budget has been agreed on, to look at critical future areas such as electronic warfare.

A single prime contractor?

The reference to a "single European prime contractor" for complex weapons systems most probably refers to the further consolidation of Europe's missile business around MBDA, which was created in December 2001 after the merger of the main missile producers in France, Italy, and the U.K. The company has three major aeronautical and defense shareholders—BAE Systems (37.5%), EADS (37.5%), and Finmeccanica (25%).

Many in the industry now expect the missile interests of Thales to merge with MBDA. The two are already partners in ventures such as an up-rated version of the Storm Shadow air-to-surface missile fitted to the RAF's GR4 strike aircraft. This would complete the consolidation, for the first time, of virtually an entire aerospace sector into a single European company. MBDA acquired the German subsidiary EADS/LFK in March 2006 and in November 2010 announced an agreement with CIRA (the Italian Center for Aerospace Research) to work on a series of "flying test beds" for next-generation missile technologies.

Further synergies will be sought lower down the supply chain. "There has been for a while an attempt to bring the U.K. and France's aerospace and defense trade associations closer together," according to Derek Marshall, director of policy and public affairs at ADS. "We are now looking to build on this, making the process more systematic. It will also mean looking at how companies further down the supply chain can come closer together.

There have been attempts at this in the past, and we shouldn't underestimate the difficulties—but we need to be more persistent."

Prospects for U.S. business

Marshall does not, however, believe this rapprochement with France will mean the U.K. is seeking to realign its military and industrial links with the U.S. "This is a question of opening up new bilateral activity. What you are seeing is the identification of specific opportunities for cooperation with France. We've been attempting to work together for some time, through a high-level working group, and now this is a step up from that. The U.S. market remains the premier global market and I can't see the attitude of BAE Systems or any U.K. defense company changing directly as a result of this agreement."

The Anglo-French agreement was signed as the final touches were being made to a new Defense Trade Cooperation Treaty between the U.K. and the U.S.—which should reduce the bureaucracy associated with the movement of equipment and information between the two nations.

According to U.K. Defence Secretary Liam Fox in October 2010, "By simplifying export licensing arrangements, the treaty will allow for the better sharing of information and technology." Over the next year new administrative arrangements underpinning the treaty will be trialled on both sides of the Atlantic, opening the door to increasing the number of joint defense and aerospace projects, currently numbering around 140, between both countries.

Given the cutbacks announced in the U.K.'s October strategic defense review, it is likely that, despite the French treaty, there will be more, not less, U.K. defense business for U.S. contractors.

According to the ISS, "The U.K.'s key ally, the U.S., has indicated that it understands the Cameron government's predicament, and seems content that the U.K. will maintain its military commitment to Afghanistan, keep its defense spending above 2%

of GDP (thus setting an example to other European NATO partners), maintain 'full-spectrum' armed forces (including special forces), continue its wide-ranging intelligence collaboration with Washington, and press ahead with modernizing its nuclear deterrent (which is important to Washington because of the U.K.'s financial contribution to its Trident missile program). For its part, the U.K. will become rather less able to conduct independent military operations and more dependent on cooperation with allies. In the first place, this means the U.S."

It is likely that the countries most at risk from the Anglo-French accord will be Germany, Sweden, Italy, and Spain. If the U.K. and France do cooperate on military aerospace programs to the extent envisaged by the recent treaty, U.K. firms will probably replace the leading aerospace contenders from these countries, working with French companies on common European UCAV, weapons systems, and satellite programs.

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

Correspondence

I appreciated your roundtable discussion, **Human rating for future spaceflight** (July-August, page 26), but I was concerned that the moderator, Robert Dickman, seemed to want to focus on a set number for the Probability Risk Assessment (PRA). It should be recognized that even a PRA requirement with a specific number should not be taken as a line in the sand. Failure rates and percentages are easy to manipulate and highly inaccurate.

Panel members Bryan O'Connor and Michael Bloomfield touch upon the real benefit of PRA; that is, to produce the sorted list of failures upon which you can decide where to allocate resources.

Too often both contractors and procuring agencies draw that line in the sand at the requirement number and work on fixing failures above it and accepting failures below it. But often there are failures below the line that raise concerns due to the inaccuracies in the numbers and failures above the line that people are willing to accept.

A PRA is very valuable and should always be performed so that each failure mode and effect can be reviewed to determine which ones should be fixed. Deciding which ones to fix should be the function of an experienced board of reviewers and not based on an arbitrary requirement number. Instead of a PRA requirement, a fail-safe/fail-op requirement or a baseline set of safety design guidelines should be used.

In addition to hardware failures, a good PRA should include software errors (such as initialization), manufacturing errors (such as incorrect torque), operational errors (human error), maintenance errors (incorrect calibration), and errors in training material.

William P. Branch
Fort Worth, Texas

Reply by Bob Dickman I agree with the comment. My intent, as moderator, was to promote discussion—in part by suggesting that setting a PRA "too high" could drive solutions that are either unachievable or unaffordable.

In the feature **Air Force technology: Changes on the horizon** (November, page 28) it is stated on page 30 that "precise navigation and timing in GPS-denied environments" was deemed particularly important.

In 2009 I posted two documents at www.setterholm.com that solve the problem of coupling a stereo-pair image to WGS-84 (GPS) X,Y,Z coordinates using a fixed 4x4 homogeneous matrix. I conjecture that the mathematics is simple enough to teach to bright 9th graders taking linear algebra 1 after having had algebra 1 in 8th grade.

I call the concept "quantitative Visual Presence" (qVP); Google that phrase and my introductory pdf document is the No. 1 hit. The mathematical derivation is provided in the other pdf document in that subdirectory. Under that subdirectory you'll find sample qVPs of different areas. Once a qVP has been formed, GPS is no longer needed in order to have "coordinated Stereovision."

The whole world has access to qVP spatial mathematics. I predict that, by 50 years from now, qVPs will be in ubiquitous use in many disciplines because of the simplicity, robustness, and connectivity the algorithm provides to both human stereo perception and autocorrelation algorithms. Consider bringing the qVP/coordinated stereovision concept to the attention of your readers.

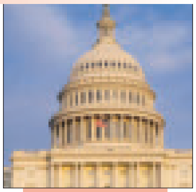
Jeff Setterholm
Lakeville, Minnesota

Arianespace: Thirty years and growing (September, page 18) provided very important information about the Ariane launch vehicle. But it failed to mention that the reason the Ariane was created was because European satellite builders were competing directly with U.S. satellite builders, who were the main customers of the existing launch vehicle suppliers such as the U.S. Atlas and Titan.

Since European satellite builders were competing directly with U.S. satellite suppliers, U.S. satellite builders/owners leverage their importance to the companies that launched the Atlas and Titan and have priority in receiving launch dates over European satellite launches.

Len Losik
Failure Analysis

Correction Authorship of "Futuristic aircraft: Old-fashioned look is only skin deep" (November, page 14) was incorrectly attributed. It was written by Jim Banke, NASA Aeronautics Research Mission Directorate.



A time of transition

WASHINGTON IS IN TRANSITION—ringing in a new Congress with Republicans controlling the House of Representatives and enjoying a larger presence in the Senate. Rep. John Boehner (R-Ohio), speaker-elect of the House, says Washington will be "doing things differently." President Barack Obama says he can work with the changing faces on the Hill.

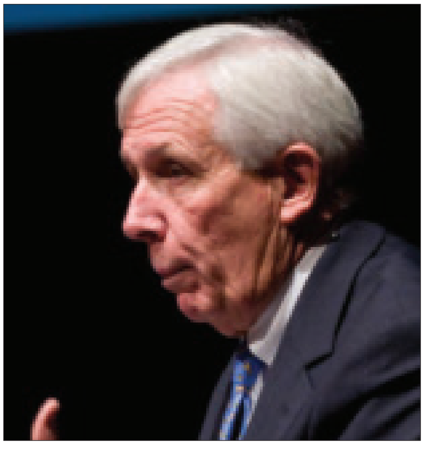
At the turn of the year, many in the nation's capital want cooperation on both sides of the aisle but are concerned over the possibility of legislative gridlock.

NASA's 'interesting times'

The changed mood in Washington could affect NASA's human spaceflight program, which is also in transition. Obama signed the NASA authorization bill in October, fixing policies that will require $19 billion for the agency in the current fiscal year. But Congress must still pass an appropriations measure.

The authorization directs NASA to work with private companies to develop commercial rockets for ferrying people to the ISS. It also directs the agency to develop a heavy-lift rocket to launch astronauts to the asteroids and ultimately to Mars.

Rep. Frank Wolf



NASA Administrator Charles Bolden

Rep. Frank Wolf (R-Va.) will become chairman of the House subcommittee that funds NASA. Wolf, a critic of Chinese human rights policy, criticized NASA Administrator Charles Bolden for attempts to improve ties with China on human spaceflight issues. A long-time incumbent with a constituency in the Washington area, Wolf may come under pressure from a new wave of freshman Republicans who were elected in part on a promise to trim government spending.

One potential target for cost-cutting is the extra STS-135 shuttle flight included in the authorizing legislation and scheduled for next summer. NASA argues that before it can finally retire the shuttle fleet, the flight is needed to support the ISS.

Bolden made a very public appearance at the Orbital Sciences "Mission Control Center–Dulles" event in Virginia on November 12. Bolden said he will push for $300 million in augmented funding for NASA's Commercial Orbital Transportation Center. That funding would in part support Orbital's Taurus II launch vehicle. Bolden told reporters he can see a day when human spaceflight is controlled from the Dulles facility.

In contrast, when Bolden appeared for an all-hands meeting at NASA Marshall, the gathering was off limits to reporters. Workers in Huntsville are uncertain whether their new task of managing the design of a new rocket, rather than simply building one, will keep their jobs secure. NASA and contract employees at the other space centers around the country are evincing similar anxieties.

Observers in Washington say the administration's human spaceflight program lacks focus and could benefit from being branded. "Until now we had what was called the Vision, and it had a name, Constellation," says one NASA insider, referring to the now-defunct plan for a shuttle replacement. Although engineers are still working on components of the abandoned program, the word Constellation is no longer used at NASA. "Just when we need real vision, we no longer have a term to describe the program we're trying to see in our future," says the insider.

Cracked support beams on the external tanks and a hydrogen leak halted the scheduled November STS-133 launch by the shuttle Discovery. As NASA engineers replaced a misaligned seal to plug the leak and contractors sprayed insulating foam over a section of the tank where the cracks were spotted, managers decided the analysis and tests required to launch safely were not complete. Launch has now been postponed to no earlier than February 3.

Six astronauts, led by Air Force Col. Steven W. Lindsey, are preparing for a belated journey to the ISS. Discovery will deliver a storage room for the station as well as a humanoid robot designed to help astronauts with work in space. The NASA authorization bill provides for two further missions—with the final flight next summer—before the shuttle program ends.

Cracks on Discovery have delayed its final launch to the ISS.

Plans for Discovery to become a display artifact at the Smithsonian Institution's Air and Space Museum may be killed by the $28.8-million cost. Neither the Smithsonian nor NASA can afford to move the shuttle to the museum. No announcement has been made as to which museums will acquire the other two shuttles, Atlantis and Endeavour.

[A correction: In the November issue this column reported that the FY11 NASA authorization bill eliminates the Moon as a destination in the postshuttle human spaceflight program. As a reader pointed out, although the administration's program does not include returning astronauts to the Moon, the NASA authorization bill does not preclude it.]

Deficit discussion

Cochairing an 18-member, bipartisan presidential commission on the debt and the deficit are Erskine Bowles, former chief of staff to President Bill Clinton, and Alan Simpson, former Republican senator from Wyoming. Bowles and Simpson want to address the nation's fiscal ills by trimming $100 billion from the Defense Dept., freezing federal salaries, extending the Social Security retirement age, and taking dozens of smaller steps—all the way down to having the Smithsonian charge a $7.50 admission fee. The cochairmen's scheme, available in draft form in early December, would wipe away the popular mortgage interest deduction for taxpayers.

Alice Rivlin, former budget director, and Pete Domenici, former Republican senator from New Mexico, are offering a different deficit-reduction plan that would include a 6.5% value added tax on consumer purchases. Both plans would reduce federal agricultural subsidies.

The proposals generated a lot of discussion in Washington and a little support from Congress, the press, and the public. But both plans appear unlikely to receive serious consideration in Congress or from the administration. Because of their austerity, Rep. Nancy Pelosi (D-Calif.) found the proposals to be "simply unacceptable."

Erskine Bowles and Alan Simpson

The News Herald of Panama City, Florida, editorialized that in the view of some, the draft report from the Bowles-Simpson commission arrived with a "toe tag" attached to it. A CBS News poll shows that 56% of Americans want Congress to concentrate on jobs and the economy. A mere 4% cite the budget deficit and the national debt as important.

The Marine Corps and Italy are the only remaining purchasers of the F-35B.

Greater costs and delays for JSF

The F-35 Lightning II Joint Strike Fighter program is undergoing its third restructuring in two years. Already behind schedule and above cost projections, the F-35 will now be delayed many months more than previously expected. The program is also reeling from drastic cost-cutting measures by Great Britain, including cancellation of the short takeoff vertical landing version. This leaves only the Marine Corps and Italy as purchasers of the STOVL fighter, known as the F-35B. Many in Washington wonder whether the STOVL variant is still viable.

More than any other program, JSF

stands as a symbol of U.S. military prowess and technology. A "fifth-generation" stealth fighter with completely new instruments, avionics, and helmet-mounted cueing, the JSF is a boon to industry. Some 2,443 of the high-performance fighters are slated for the Air Force, Navy, and Marine Corps, with many more going to eight international partners.

In test flights, the JSF "has a lot of power, handles well, is crisp in all axes, and is well behaved," said Lockheed Martin test pilot Bill "Gigs" Gigliotti in an October telephone interview. Compared to the present-day F-16 Fighting Falcon, which pilots find difficult to land, the JSF is "a dream during operations in and around an airfield," Gigliotti said.

But program delays and cost increases are being viewed with increasing seriousness in Washington.

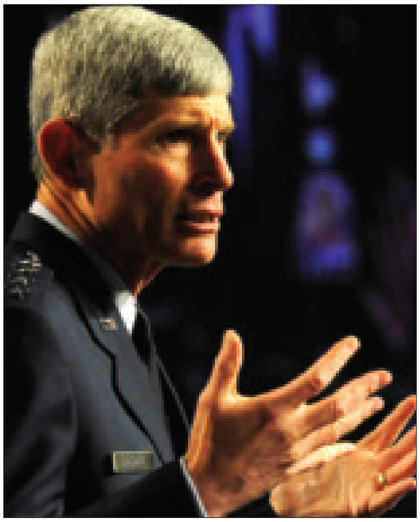
Secretary of Defense Robert Gates received a November 2 briefing telling him that operations and support costs for the F-35 will be rebudgeted at 1.5 times those of the aircraft it replaces, more than twice the original goal, and 50% more than projections that were being made as recently as one month earlier.

The delay is a serious blow to the Marine Corps, which has no alternative to the F-35B. Marines provide the aircraft aboard the Navy's amphibious assault ships. They sacrificed a chance to buy the F/A-18E/F Super Hornet because they wanted to invest aggressively in STOVL.

The latest delay resulted from a need for more time to carry out flight testing and to mature software. Two Air Force JSFs that had been intended for delivery to the 33rd Fighter Wing "Nomads" at Eglin AFB, Florida, in December 2010 will now stay at the factory until April to be instrumented for tests. After that, the two planes will go to Edwards AFB, California, for further evaluation. The wing at Eglin, slated to train JSF pilots and maintainers, is now growing toward full personnel strength but has an empty ramp.

Tanker snafu

An aircraft selection in the Air Force's KC-X air refueling tanker competition, once expected before the end of 2010, is now scheduled for this month.



Air Force Chief of Staff Gen. Norton A. Schwartz

Air Force Chief of Staff Gen. Norton A. Schwartz said on November 23 that he is reassigning two officials who mistakenly sent confidential data to Boeing and EADS about the other's proposal for the 179-plane, $35-billion tanker contract. Schwartz says "just one page" of information was sent. "Instead of receiving information about how the Air Force evaluated the fuel-carrying capabilities of its plane," each competitor "was given similar data on its rival," he adds. The Air Force chief says the mistake will not tarnish the bid process—but others believe the loser in the KC-X competition will now have firm ground for a protest.

Schwartz declined to name the two individuals fired from the tanker program, but he indicated more action would be taken "to hold accountable those responsible for the mistake."

Secretary of State Hillary Clinton

TSA, the public, and the Hill

A backlash by airline passengers was scoring hits on new airline security measures put into effect on the eve of the holiday travel season—but not as many hits as critics had once hoped. On November 14, Secretary of Homeland Security Janet Napolitano appeared at a news conference and defended full-body scanners and a new kind of body pat-down. Napolitano reminded the public, and indirectly lawmakers on Capitol Hill, that just one year has passed since a man attempted to blow up an airliner using a bomb embedded in his underwear. The Transportation Security Administration is part of Napolitano's department.

While many Americans support enhanced security measures, which they see as a necessary shared sacrifice, the measures may come under scrutiny by a new crop of legislators who favor smaller government.

John Pistole, head of the TSA, endured a grilling from the Senate Committee on Commerce, Science and Transportation on November 17. Secretary of State Hillary Clinton, appearing on NBC's *Meet the Press*, said she thought "everyone, including our security experts, are looking for ways to diminish the impact on the traveling public" and that "striking the right balance is what this is about." But Clinton also said that she would not like to submit to a security pat-down. The press attention to the issue brought forth the revelation that members of Congress, cabinet officials, and other Washington bigwigs never undergo security screening.

Outgoing Rep. Pete Hoekstra (R-Mich.) and Rep. Jason Chaffetz (R-Utah) called for profiling as a means for better addressing the threat to air travel. But the issue has not resonated with the public: A planned holiday boycott of scanning machines failed to materialize.

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

Michel Peters

I guess the pressure is increasing, in the Netherlands as elsewhere, to move increasingly quickly from theoretical research to real applications, to ensure the work you do in the laboratories reaches industry much faster than in the past.

Of course. It is especially important for us in the Netherlands, where we are about fifteenth place in the world on the economic scale. The government ordered a study about four years ago to see how the results of theoretical research could be brought faster to industry. They were quite concerned that fundamental research could be better interfaced with industry, and the vital role for undertaking this work was given to research establishments like NLR.

We are one of the four primary, or major, technology institutes [GTIs in Dutch] in the Netherlands. ECN deals with energy; the second, DELTARES, concerns water management; MARIN undertakes marine and naval research; and then you have NLR, focusing on aerospace research.

One of the specific tasks of these institutes is that we enable fundamental research to move to applied research; we build prototypes to get technology risk out of the research concept and bring it to the Dutch industry. If you look at the turnover of NLR, around 25% is received from the government for high-tech research and the remaining 75% is contracted from industry and government, both national and international.

Because you are tied to industry, how have the economic ups and downs in the market affected your work? Has it changed the products you are interested in or how much money you have available?

About 15 years ago we had the bankruptcy of Fokker, which had a big impact on NLR. But in the end the impact has not been too big. It's a pity that an independent airframe manufacturer was lost, but there are still large parts of Fokker which have remained and they are doing quite well. I think this has something to do with the fact that there is still a very large knowledge cluster in the Netherlands. We have an excellent technical university at Delft, with an important aerospace faculty, and NLR retains its close relationship with industry and small and medium-sized enterprises. A benefit is that the intricate knowledge level of aircraft design is still present.

Among the many aircraft programs you are working on, the Joint Strike Fighter and the Fokker 100 NG [Next Generation] seem to be particularly important to Dutch industry. Would you say they are the two biggest programs for you?

No, but they are important. If you look at the JSF, it's mainly a political decision whether the JSF will be selected—it's a parliamentary decision. In general I can say that when the time comes for the government and air force to choose a fighter aircraft, whatever it may be, Dutch industry should be positioned well to get the revenues out of it, and consequently NLR will support Dutch industry.

What is your biggest program, in terms of financial volume?

There is a variety. The Fokker 100 NG is not yet the biggest program, but we're working very hard on this. The program entails a complete avionics refit, new winglets, new engines, and the integration of the engine with the fuselage. We will also be involved in wind tunnel tests and flight tests during the preparation phase.

The biggest industrial program, indirectly through Dutch industry, would be the work we do for Airbus. This covers a variety of component testing, research into new aircraft materials, and other related work.

The Pplane personal transport is one of the very different programs you are engaged in—a platform you would not normally think of as a logical next step for the industry to take. Why are you doing this?

Despite the economic crisis here, globalization will continue. If that's the case, then mobility and transport demands will grow. When that happens there will be greater demand to improve the quality of travel, and that means multimodal transport options, so when you leave your house there should be a kind of seamless travel experience.

"Despite the economic crisis here, globalization will continue. If that's the case, then mobility and transport demands will grow."

Do we know when the JSF decision might be made?

In the Netherlands, we have just formed a new government. There is a high-level strategic draft governmental agreement, but a final decision on whether to buy the JSF will not be taken in the period of this government. However, there is an agreement for a second JSF test aircraft to be purchased.

One of the possible means of transport for this may be personal air travel, small personal aircraft, which will allow you to fly directly from your back yard to the airport. These programs will need technical solutions, but the big challenges will be human training and understanding what level of automation you will need in the personal aircraft. It will mean finding the balance between

Interview by Phillip Butterworth-Hayes

the capability of the crewmember and the level of automation available. And that's a problem—especially when you want to fly that aircraft in less than benign weather conditions.

The challenge of automation, it appears, is the key to the future for aviation—and not just for Pplane. It seems the real challenge is to map out where we are now to where we need to be, so pilots and controllers are systems managers rather than tactical, hands-on operators. In developing these systems, should we create a grand vision of what it should be like in 50 years and work toward that or introduce automation in a more pragmatic way, as it becomes available?

More automated tools will become available to pilots and controllers on the ground, that's true. But the human will remain in the loop, though more for a monitoring type of task. It's subtle, but important.

A long-term vision, the dot on the horizon as I like to call it, is important, but no one knows what it's going to be, because it's hard to forecast the future. So you look at it and then you make your evolutionary steps. It cannot be any other way. Developing new concepts is one thing, but they need to be integrated into the current system. The concept as such is important, but thinking about the transition is equally if not more important.

So what are the key evolutionary steps toward automation?

The most important, and unexplored, area is a better understanding of human factors. With the personal transport, a relatively unskilled person will have to fly it, which means the balance between the skill level and the level of automation provided by that aircraft needs to be found. This must also be undertaken in combination with the new generation air traffic management systems that will have to cope with all these new small aircraft.

Some of the main challenges are self-separation between two aircraft, how to deal with adverse meteorological conditions, and integrating these vehicles at large airports. Currently, we're looking at airports handling about 36 aircraft per runway per hour, but that won't be nearly enough.

For the challenge of self-separation that's quite close. Given the need to integrate unmanned air systems within civil airspace, we're only a few years away. Do you think we will have the technology available by 2015 or 2016?

The technology is not so much the issue any more. Regulation of the airspace and the role of controllers is more of an issue. I'm not saying the technology is not a problem, but a lot of the technology issues are known. For example, we have conducted a research program called OUTCAST where we equipped one of our research aircraft, a Cessna Citation, as a UAV, with very high resolution electrooptical and infrared sensors. We used them with a high level of automation for target tracking—in this case with air vehicles in the vicinity—to see if it was possible to mimic see-and-avoid operations. The an-

Michel A.G. Peters is currently CEO of the Netherlands National Aerospace Laboratory (NLR). In this role, he leads the primary organization in the Netherlands for aerospace research, technology development, test, and evaluation.

He has held a variety of increasingly responsible positions, both at NLR and at Martinair (now part of KLM). During his career with Martinair, managing the aircraft maintenance department, he was responsible for aircraft maintenance of both Martinair and KLM Cityhopper. At NLR he managed an avionics technical department, then managed NLR's Aerospace Systems and Applications division and NLR's Air Transport division before becoming CEO on January 1, 2010.

Peters is chairman of the Association of European Research Establishments, a member of the Advisory Council for Aeronautical Research in Europe and the DLR-NLR Joint Executive Board, chairman of the German-Dutch Wind Tunnels, and a member of the Netherlands Aerospace Council. He holds various other national positions in government and industry advisory bodies in aerospace, defense, and security.

Born in Rotterdam, Peters is a graduate (BS) of the College of Electrical Engineering, with a specialization in computer science. In addition he earned an MS. in 1987 from the Delft Technical University in electrical engineering with a specialization in avionics engineering.

NLR is an independent, not-for-profit organization that carries out contracts for aerospace customers from government and industry. It owns advanced research, development, testing, and evaluation facilities, including mission simulation and verification facilities, wind tunnels, and a secure networked computing infrastructure. NLR also carries out demand-driven long-term research programs under the auspices of the Netherlands government.

swer was "yes." It's not simple, but real flight testing over four to five years has shown it's possible.

Has that work formulated any new thinking among regulators?

Yes. Our civil and military aviation authorities were part of that experiment, which increased their knowledge of flying aircraft in segregated airspace. When it comes to certifying these UAVs, a lot of the work has focused on the aircraft—but that's not good enough. At NLR we have been very active in the ATM field, with respect to airspace simulation models, where we simulate in real time new airspace concepts, including arrivals like continuous descent approaches (CDAs) and departures.

The demand of the ATM system is not just safety, but overall capacity, coordination with military, flight efficiency, improved environmental performance. We have these huge research programs in place such as U.S. NextGen and SESAR [Single European Sky ATM Research], but I wonder whether we are really going to see the benefits in the next five years from all the billions of euros we are investing in the research.

I think so. SESAR and NextGen are huge programs. If you look at the current European airspace, there are around 600 sectors, so when you fly from southern France to Amsterdam you have to pass through more than 10 of these. Even though the U.S. has a larger volume of traffic than Europe, the costs per flight in the U.S. are around half of that of Europe.

In addition to SESAR are functional airspace blocks [airspace managed by multinational consortia of air navigation service providers]. This will lead to more direct routes and better coordination between military and civil users, and this will certainly benefit safety and capacity and lessen the environmental impact.

But that's changing what's already there. What about the next generation of ATM technology, to allow for large increases in numbers? We will need to increase the number of aircraft a controller can handle at any one time—currently around 20—so what technologies are you working to increase this volume?

With more direct routings, you have another class of airspace. NLR is looking at automation systems assisting the controller to handle more traffic while increasing safety levels. It will take some time, certainly more than five years, before we see a change in the controller's role from controlling to monitoring. Some of that automation has shifted to the aircraft itself, to systems such as airborne separation assurance systems (ASAS), which NLR has flight tested.

A second area for us is improved airport operations. At Schiphol airport, a very large airport lying in a highly populated area, we are working on CDAs where we have done a variety of national programs with our own and KLM aircraft. We've also undertaken work on automating highly accurate departure routes.

What improvements have you seen?

Less noise and higher fuel efficiency. We are looking at a new departure procedure where the aircraft accelerates earlier and at a lower altitude, with earlier retraction of flaps and slats, with the aim of reducing fuel burn and noise.

We are also in discussion about merging civil and military airspace, which is especially important when you're flying through the southeastern part of the Netherlands to Germany, when you have to extend your route by 10-15% to avoid flying into military airspace.

Many of these are changes in procedures rather than core technologies, for example, systems that automate flight plan processing and correlating this with radar data to increase the number of aircraft a controller can handle at one time.

One of the programs we have undertaken has been to provide real-time meteorological information to the flight deck. The aircraft has weather radar, but this has only a limited range. What the pilot would like to see is the actual weather all the way along the route. Around two years ago we undertook a trial with one of our aircraft on a flight from Paris to Amsterdam, using ground stations to provide exact meteorological information on weather along the route, uplinked directly to the flight deck, giving the pilot an excellent overview of what he or she could expect.

This will happen—it will be normal technology in a few years' time. The technology is now available, but it will be up to the operator to purchase it or not. It greatly improves safety, capacity, and, of course, the comfort of passengers..

"The idea is, in general, that we have one complete real-time system providing all relevant information of all aircraft to all actors in the European ATM network."

Hypersonic air travel—is it now off the agenda?

No, but it is long term. I think that progress on this will be evolutionary, perhaps through "recreational aviation" such as space tourism. I think space tourism will be the starter for that type of activity because, from a technological standpoint, there are still things to conquer—propulsion and reusability of the aircraft. I notice there are a lot of private initiatives for spaceports. Some will fail, but some of them will succeed. It will take place in the long term.

But how far away are we from hypersonic travel?

I think it will take a long time. The U.S. is working on ramjets, but with respect to safety levels, there are major challenges. If you look at the current rate of catastrophic equipment failure it is about 10^{-9}, or one failure per billion flight hours. When the public wants hypersonic flights, they will insist on the same levels of safety.

For many, the focus for aerospace has changed from speed to integrating aviation into a sustainable transport system. With personal transport and hypersonic vehicles you are going against the political demands of society for aviation to be primarily sustainable. How do you merge faster, more personal transport systems and the wider demands of society?

Within air transport there are three core elements—capacity, safety, and environmental impact. Those are the parameters you can play with. Of course you can increase safety levels by grounding all aircraft, but that doesn't help with respect to capacity.

I think with true innovation you can increase both capacity and safety while reducing environmental impact. If you look at the environmental impact—emissions and noise—then in the reduction of perceived noise levels from engines and airframes, there are still large improvements to be made. We're working on this.

But we are also looking at what kind of fuels we will need in the future. If I am correctly informed, in about 50 years fossil fuels will be depleted. One of the biggest challenges now is the development of so-called "drop-in fuels," which we can use on current technology engines, with the same specifications as current fuels but, for instance, based on biomass to extend the period until the fuels will be depleted.

We're looking at new ATM procedures and technologies, faster ascents, engine technology—as part of wider European programs like Clean Sky—and the safety culture of operators.

With respect to safety, we are undertaking more fundamental research into human factors, not merely relating to the man-machine-interface but more to "shared mental models," to understand how teams work together. Shared mental models are the shared knowledge structures, for instance, of pilots that they use during work. This is more than cockpit resource management. In addition, it is also looking in detail at the interaction between air traffic controllers and flight crew. That's really something new. If you really can understand how people's minds work, then you can start to improve training and thereby safety levels.

What have you been able to achieve in Europe through collaborative research rather than working at just a national level?

We face huge challenges. We don't know which are the most promising new propulsion types or new fuels and new materials. It's such a vast terrain, we have to collaborate. No one nation in Europe has the money or resources to do it by itself.

But what areas has NLR decided to specialize in?

Knowledge management is a big issue for us. We have made a taxonomy of 12 knowledge areas that we are pursuing, ranging from ATM research through aircraft safety, aerodynamics and so on. There are, furthermore, three areas we think are extra important—new materials, environmental issues, and aircraft safety.

"If you really can understand how people's minds work, then you can start to improve training and thereby safety levels."

What has been the result of your work in new material research?

This stems from the work we did when Fokker was still building aircraft. The company was one of the pioneers in bonded materials, invented by Fokker in close cooperation with NLR and the technical university of Delft. As a result of this work a new type of material was invented, glass-reinforced fiber metal laminate, or GLARE, which has been quite a success, with a large part of the A380 built from it.

But I haven't seen a GLARE application since the A380.

Boeing decided on a fully composite fuselage [for the 787]; the A350 is still not decided. We are doing additional research into GLARE, a higher strength version, and are planning research programs to develop affordability initiatives for it. But in parallel, we are also looking at composites with respect to the material itself—manufacturing, durability, and reparability—which is really new. The reparability of composites is a particular issue because the material is made of several layers, and if you have damage on the outer layer normally you don't see it on the inside. That's a real problem.

Last but not least, we are also researching life fatigue monitoring. We're currently embedding sensors into the material that continuously measure stress on a specific part of the airframe.

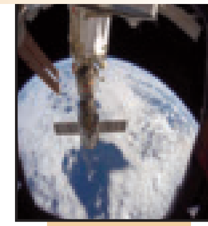
What results have you had?

We have done this mainly for our military customers. All military aircraft are now equipped with small sensors that measure stress on the airframe. Based on that raw data, we provide information to the air force that they use for fleet planning.

With respect to maintenance, this has decreased the cost of maintenance and increased the availability of aircraft. Reduction of maintenance costs is important, but knowing exactly if the aircraft is available is of the utmost importance for a military aircraft.

Do you think in the future we will be able to move the successful results of theoretical research more quickly into the market?

The speed of introduction has something to do with the maturity of the technology, but that's not the only parameter. It's sometimes quite easy to develop in an experimental environment a new concept and to test it relatively quickly in a research aircraft. But when it will be implemented it can only be enforced by ICAO [International Civil Aviation Organization] or by means of government mandates. TCAS [traffic collision avoidance system] was first invented in the mid-1960s but only finally mandated in 2004. Technology is not the only limiting factor.



ISS: A decade on the frontier

THE INTERNATIONAL SPACE STATION is our lone toehold on the frontier of deep space. Sometime after 2020, NASA astronauts may venture again beyond the confines of LEO, perhaps to an asteroid, perhaps to chase other nations to the surface of the Moon. But for the next 10 years and beyond, as it has been since November 2000, the U.S. destination in orbit will be the ISS, humanity's classroom for human spaceflight.

The ISS was born on December 7, 1998, when the first two modules were joined by the STS-88 shuttle crew. The Expedition 1 crew took up residence on Nov. 2, 2000. On October 25, 2010, the ISS surpassed Mir's 3,644 days as history's longest continually inhabited space station. As of last November, more than 196 individuals have visited the ISS, including seven private space travelers.

When I floated aboard in February 2001, the three-person crew already had far more elbow room than the shuttle; today, the station's work and living spaces are the equivalent of a five-bedroom house. Amenities include two bathrooms, a gym, and a seven-pane "bay window" (the cupola) with a breathtaking view of Earth 220 miles below.

Who's in LEO?

The ISS crew complement expanded from three to six in May 2009. Its current residents (as planned at press time) are the astronauts of Expedition 26: Scott Kelly (commander), Alexander Kaleri, Oleg Skripochka, Catherine Coleman, Dmitry Kondratyev, and Paolo Nespoli. The latter trio was due to arrive on December 15, 2010, and will stay aboard through May 2011. With delivery of the permanent multipurpose module Leonardo on Discovery's final flight, the ISS will expand to 12,000 ft^3 of pressurized living space. The last planned pressurized addition is the Russian Nauka multipurpose laboratory module, scheduled for arrival late this year.

NASA marked the 10-year crew presence milestone with November ceremonies. Peggy Whitson, NASA's chief astronaut and, on Expedition 16, the station's first female commander, noted:

"To have constructed something on orbit greater than a football field in length, with more internal pressurized volume than a 747, with parts and pieces and participation from 15 countries around the world, full-time 24-hour/7-day-a-week operations, and human presence for 10 years, fills me with an incredible sense of pride in what our organization can accomplish."

In the Tranquility node, NASA astronaut Doug Wheelock, Expedition 25 commander, works to install the new Sabatier system that will extract more water out of the ISS atmosphere.

Shift to science

That achievement is visible regularly in the evening or morning sky as a brilliant star traversing the heavens [see http://spaceflight.nasa.gov/realdata/sightings/]. The station's truss—its structural backbone—spans 108.5 m (about 0.75 acre), supporting the four immense but delicate solar arrays that generate most of the outpost's power. Much of that electricity will help the ISS achieve its original purpose, scientific research.

Col. Timothy J. "TJ" Creamer, who worked aboard the station on Expeditions 22 and 23, said in an interview that "It was a privilege and a blessing to have served on the ISS on the cusp of its career. During my tenure there, construction was nearly completed, and ISS was shifting from its assembly phase to utilization."

In its first decade, the orbiting laboratory has supported more than 600 experiments in the unique, nearly zero-gravity environment. ISS communication resources give researchers and engineers continuous access for fine-tuning their investigations. Between now and 2020, the research facilities will support not only fundamental science investigations, but also trials of promising exploration technologies.

NASA and its partners are currently using the research facility for long-planned experiments in the three laboratories: the U.S. Destiny, European Columbus, and Japanese Kibo. In the past decade, 59 countries have been involved in research in disciplines as varied as the physical sciences, life sciences, planetary and Earth science, heliophysics, and astrophysics [see www.Nasa.gov/iss-science/]; for example:

•The smoke aerosol measurement experiment found that burning spacecraft materials in free-fall produced soot particles 50% larger than those in terrestrial cabin fires. Studies of smoke propagation identified inadequacies in current spacecraft smoke detector technology, with a goal of improved astronaut safety.

•The Kibo-mounted MAXI (monitor of all-sky X-ray image) experiment uses highly sensitive X-ray slit cameras to survey for energetic sources like neutron stars and black holes. On September 25, the instrument discovered a new stellar nova whose center likely harbors a black hole. Astrophysics research will take a major step up when the massive alpha magnetic spectrometer arrives in early March, searching for energetic atomic particles linked to the cosmos' dark matter and energy.

Astronaut Susan J. Helms works at the Human Research Facility's ultrasound flat screen display and keyboard module in the Destiny/U.S. Laboratory.

•Astronauts were trained in orbit to use the advanced diagnostic ultrasound in microgravity (ADUM) experiment, testing new guiding methods to obtain rapid, accurate diagnostic ultrasound images. The space proven techniques have found application on Earth in remote diagnoses everywhere from Mt. Everest to Inuit maternity clinics.

•The nutritional status assessment study has demonstrated that ISS astronauts, living indoors under artificial lighting for months at a time, are deficient in vitamin D. Resulting vulnerabilities may include depression, chronic fatigue, weight loss, diabetes, heart disease, stroke and osteoporosis. The study also showed that adding omega-3 fatty acids to space food counteracted bone loss, a finding since confirmed by ground-based cellular studies and bed-rest results.

If on-orbit diet supplements can protect against bone loss, they may eliminate one of the major challenges of extended deep space voyages, as well as aiding osteoporosis patients back on Earth.

•ISS investigations since 2008 into microbial gene expression and virulence have revealed that pathogens like the common salmonella bacterium become more virulent in free fall. The resulting insight into the genetic trigger of this effect has led Astrogenetix to investigate a candidate antimicrobial drug.

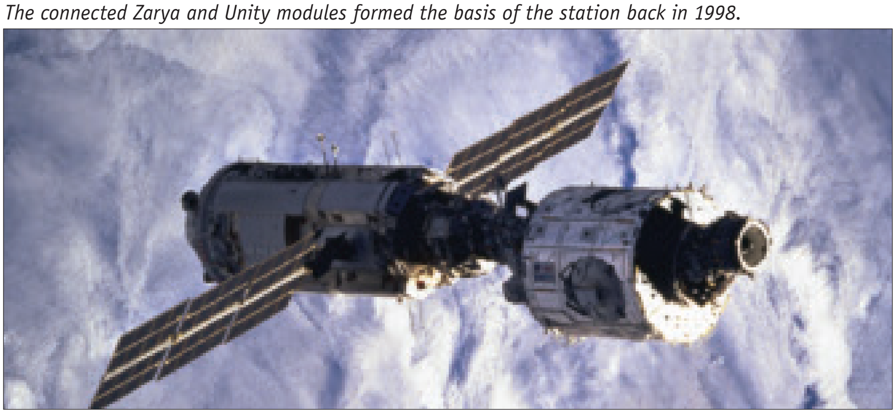
•AiroCide TiO_2, an air purification technique developed for the station's onboard mini-greenhouse, has demonstrated the ability to remove anthrax spores and similar pathogens from indoor spaces like mail handling facilities.

The space station is now engaging the imaginations of future explorers. Already, over 31 million students have viewed educational demonstrations conducted by ISS crewmembers, with 900,000 participating directly in research projects aboard. The careers of some of these aspiring scientists, engineers, and astronauts might one day take flight thanks to the ISS. In the Apollo era, students like me were captivated but passive observers of events unfolding on the Moon. Today, young experimenters can interact with crewmembers and researchers on Earth and aboard the station, participating in the process of scientific discovery.

During Expeditions 25 through 30, astronauts working in the three labs of the U.S. orbital segment will conduct 333 scientific investigations; Russian cosmonauts will operate experiments in the Poisk and Rassvet research modules farther aft. About a thousand scientists have been involved to date in ISS research.

An international panel of research

The connected Zarya and Unity modules formed the basis of the station back in 1998.



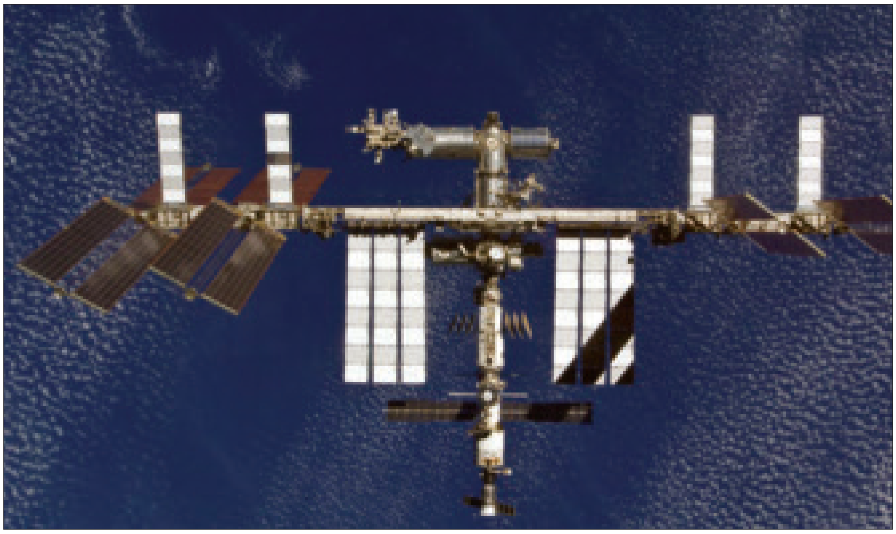
advisors recently cited the ISS characteristics attracting potential users: continuous access to microgravity, with gravity as a controlled experimental variable; high vacuum and conditions to create ultra-high vacuum; continuous presence in space for long experimental runs and cumulative results; and significant power and instrument support for geophysical and environmental observations from LEO, with an orbit covering over 90% of Earth's populated surface.

Exploration testbed

"We're now looking ahead to using the ISS as a platform for teaching us how to get to Mars," says Creamer. "We must extend this platform's original purpose from pure research to help us take on the challenges of deep space exploration. We can use the ISS as a testbed, incorporating challenges like communications delays, onboard autonomy, and new technologies like life support."

Other technology areas include crew health systems for exercise and radiation protection, advanced solar power systems, propulsion innovations, new spacesuits and mobility gear, inflatable habitats, and handling of planetary "ores" for space resource utilization.

One example of such exploration-driven experiments was the October activation of a water-generation system that recycles two ISS waste products. Hamilton-Sundstrand's Sabatier reactor, installed in the Tranquility node, combines hydrogen released by the station's waste-water-to-oxygen system with carbon dioxide exhaled by the crew to produce water and methane gas (CH_4). The water is purified for crew use while the methane vents overboard. The 530 gallons of water generated annually will further close the life support loop, and reduce water demand even as the era of shuttle-supplied water ends.

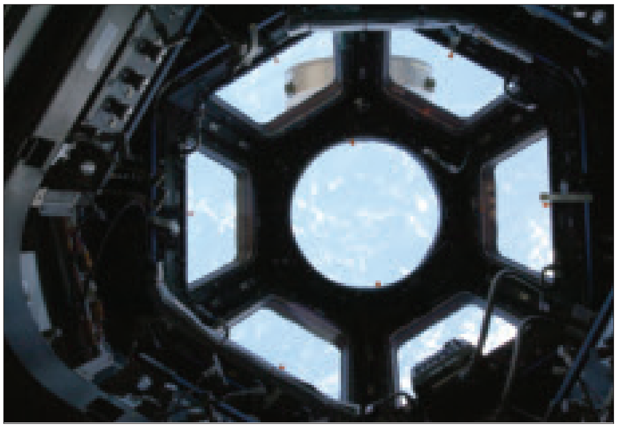


An STS-132 crewmember aboard Atlantis captured this view after the station and shuttle began their post-undocking separation.

The crew and flight controllers will work together on simulations to mimic operations during a deep-space voyage. "ISS is a great analog for the Mars transit phase" of an interplanetary mission, says Creamer. Controllers will introduce communications delays caused by extended light-travel times, and the crew will do without real-time interaction with the ground. These exercises should point to command, control, and planning software needed on extended deep-space missions.

A steady stream of exploration testing should follow these first steps aboard the station. The astronauts should check out a new generation of more flexible, comfortable spacesuits. Meteoritic and lunar materials should be fed into resource extraction processors operating in free fall. And lunar rover designs derived from Constellation may evolve into free-flying spacecraft like NASA's space exploration vehicle, to be tested at ISS before ferrying astronauts to the surface of a near-Earth asteroid.

Developed and built by Thales Alenia Space in Italy, the cupola is a spectacular technological, robotized control room that allows the astronauts to see and work through seven windows, looking out 360° around the ISS.



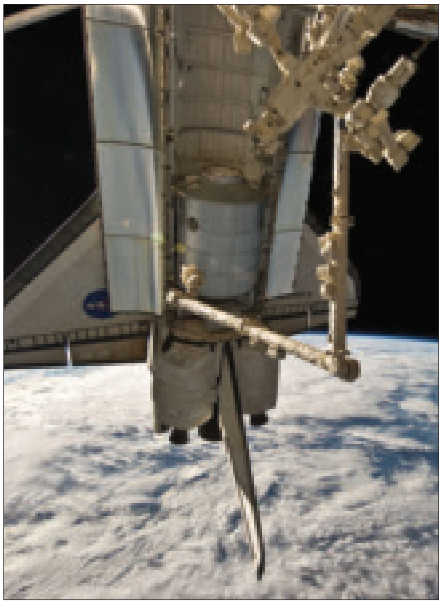
Astronaut guinea pigs are still in demand, too. Creamer notes that "Our return to Earth from the station gives us a chance to explore ways of getting a crew back on their feet in a *g*-field and working efficiently after arriving on the surface of a new planet. We have to deal with readapting the inner ear, muscle tone and mass, and strength and coordination to working well in gravity again." He recalls that after landing "it took me about five days to be able to walk a straight line again, and two to three weeks before I considered myself fully competent at driving."

Space station 2020

President Obama's FY11 budget proposes funds to support NASA ISS operations through 2020, in keeping with a goal endorsed last year by the ISS partners. They also agreed to examine the technical and programmatic feasibility of extending the ISS's life through at least 2025.

The station may not be alone in LEO by then: two Russian companies have proposed a commercial space

Parts of Europe and Africa are easily recognizable in this nighttime image shot by one of the Expedition 25 crewmembers flying 220 mi. above Earth.



Canadarm2 grapples the Leonardo MPLM from Discovery's payload bay for relocation to a port on the Harmony node of the ISS.

station, to be launched in 2016, and Bigelow Aerospace plans to use its inflatable Sundancer and BA330 modules in constructing a platform to host tourism and industrial activity sometime after 2015.

NASA hopes the ISS has at least 15 years of useful life ahead. When structural or systems degradation leads to its abandonment, safe disposal will be neither simple nor cheap. The station's small maneuvering engines, even with added thrust from a docked Progress cargo/tug, do not have enough fuel to guide the 900,000-lb hulk into the Pacific. A purpose-built deorbit module will cost hundreds of millions of dollars to launch and dock; an additional cost will be the embarrassing visual of dumping the $100-billion station into the ocean (with many systems still functioning). Such a denouement will be a distinctly unpleasant option for NASA and space policy makers.

A far more attractive plan is to repurpose those still-valuable components and fold them into NASA's exploration infrastructure. Laboratories or life support modules could serve as crew living space on a deep space vehicle; the 358-ft truss might support a future propellant depot or transportation node at the Earth-Moon L1 Lagrange point. Alternatively, salvaged structures might form the nucleus of an assembly garage where deep space vehicles might be constructed and checked out.

In all such proposals, the salvage value of the orbiting hardware must exceed the cost of propellant needed to shift it to a new orbit, or to launch additional support components.

Taking stock of the station

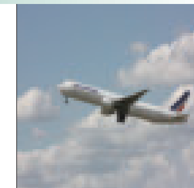
Whatever its ultimate function, the space station's current challenge is to deliver a high-profile return on the tens of billions of dollars invested in its development and construction. Already the ISS has delivered valuable lessons on international cooperation and operations, and forged partnerships that have withstood disaster aloft and shifting geopolitical winds on Earth. But to truly realize its promise, early hints of promising discoveries from the three ISS laboratories must swell into a steady stream of productive research results.

For at least the next five years, ISS will be the sole focus of the agency's human activity in space. NASA has a window of opportunity to shape the public perception of the station's value through a solid record of scientific achievement. If NASA can deliver on its research strategy of providing new scientific knowledge, new exploration technologies, and new products and processes that pay off on Earth, we may judge ISS to be a success long before 2020. But if another decade of research proves irrelevant to improving life here, or is incapable of vaulting humans into deep space, then the space station will likely be NASA's last large venture into human spaceflight.

The NASA of the 1960s had Apollo. Today's agency has the international space station, and can make the ISS an indispensable waypoint in the economic development and scientific exploration of space. It can provide engineers, scientists, and managers the experience needed to project a human presence beyond LEO, to the nearby asteroids, to the lunar surface, and eventually to Mars.

But before it can reach beyond LEO, NASA must deliver on the station's promise. From its ambitious inception through its tumultuous development, the ISS has demanded much treasure, and more than two decades of dedication and personal sacrifice from the designers, operators, and crews who built it and made it their home. The station today is a monument to successful engineering, and a triumph of international collaboration. Matching that achievement with scientific excellence and practical results will demand the same intensity of purpose.

Tom Jones
Skywalking1@gmail.com
www.AstronautTomJones.com



A global safe haven, for now

AIRCRAFT SURVIVED THE WORLD ECONOMIC crisis in better shape than any other industry. In 2009, the industry actually grew by 7%. In 2010, deliveries fell by 4.4%, but all told this is arguably the only industry in the world to finish 2010 delivering more product than when the crisis began in 2008.

With the world economy recovering but still experiencing relatively slow growth, the aircraft industry offers a unique combination of safety and long-term growth. However, it still suffers from patches of weakness, and there are risks moving forward in several key market segments.

The jetliner miracle

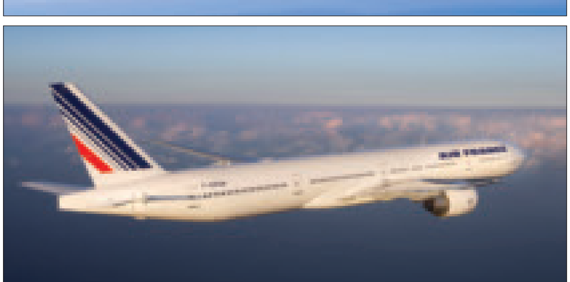
Today, two years through the great recession, jetliners remain the single brightest spot of the commercial economy. Production continues to rise at both prime manufacturers. Orders in 2010 look set to match deliveries, and the backlog remains above 6,500 aircraft for Airbus and Boeing alone. Boeing jets represent nearly 2% of all U.S. exports.

The primary reasons for this phenomenal performance in the face of broader economic pain are strong emerging market demand and persistently high fuel prices, which make newer equipment more desirable. Government support has played a key role as well. This has taken the form of export credit finance, as well as increased demand from government-owned airlines. Government-owned institutions such as sovereign wealth funds play an increasing role in jet finance as well.

Another important factor behind the strong jetliner sales and production is a growing appreciation for them as financial assets. The most common aircraft, Airbus's A320 and A330 and Boeing's 737-800 and 777-300ER, for example, are quite appealing to investors.

Of course, two defining characteristics of today's slack economy are a lack of good investment opportunities coupled with a strong dislike of risk. The result has been very strong, almost excessive demand for safe assets such as U.S. government debt. Jetliners fall under this category, too. Lessors have successfully attracted funds from investors looking for safe places to put their cash, such as popular current-generation jets. Through November, 145 of Airbus's 369 orders for 2010 came from lessors. Of Boeing's 480 orders, 152 are from lessors.

The popular A330 and Boeing 777 are appealing choices for investors.



In short, we could be seeing a very high level of jetliner output because people with money have no better places to invest it. If investment opportunities elsewhere return with renewed global growth, and if the cost of capital increases with better times, the current fashion for jetliner investment might diminish.

Still, on the strength of the backlog and market fundamentals, we see very little risk of jetliner market softness in the next few years. While we do see a 3.8% drop in deliveries in 2010, this is due to three highly program-specific matters. For one, because of delays with the 747-8, this will be the first year since 1969 to not see any 747 deliveries. Second, Boeing had announced a 777 rate cut, but this will rise again in 2011. And finally, Airbus's A340-500/600 looks set to end production after a relatively brief and unpopular career. Every other jetliner program will enjoy equal or greater numbers compared with 2009 output.

Bizjet bifurcation continues

The second half of 2010 provided confirmation of a key structural change in the business jet market. The mas-

The Global 8000 is a growth version the solid Bombardier Global Express line of business jets.

sive bifurcation between the two halves of the business jet industry continues to transform the market's structure, and has inflicted considerable pain on several key players.

Historically, the business jet market could be split in half by value. The top half consists of jets costing $25 million and more (in 2010 dollars). The bottom half consists of jets costing less than $25 million. In 2009, the bottom half fell by 42.8%, while the top half fell by just 4.1%. In 2010, the top half fell an additional 7%, but the bottom half fell an additional 17.8%, bringing it down to about 60% off its 2008 deliveries peak. This represents the worst decline of any aerospace market in the present downturn. It was worse than the decline suffered by the majority of world economic markets.

Two years into this downturn, it is clear that the market continues to favor top-end aircraft. Pricing in this segment has generally held up better than in the lower and middle segments. Anecdotal information points consistently to a generally healthier sales outlook for the top-half jets. High-end jet utilization (defined by the FAA as long-range jets) held up better in 2009 than for smaller jets, falling by just 15%, compared with 19% and 20% for the short- and medium-range jets respectively. Used aircraft availability numbers reflect this as well. As of October, just 10.1% of heavy jets were up for sale, compared with 14.5% for medium jets and 16.6% for light ones.

The Tornado fleet may be retired much faster than expected.

The Gulfstream order book is looking better now than it has since the downturn on 2008.

COMPOUND ANNUAL GROWTH RATE

Market	2008-2009	2009-2010	2010-2015 (Forecast)
Large jetliners	13.5%	-3.5%	2.4%
Business aircraft	-24.3	-14.2	7.2
Regionals	-5.7	-21.7	4.6
Civil rotorcraft	-12.5	-18.4	7.9
Military rotorcraft	32.0	10.5	3.8
Fighters	20.5	6.6	3.2
Military transports	15.5	-2.0	3.8
Total	**7.0%**	**-4.4%**	**3.6%**

The two key players in the bottom half, Cessna and Hawker Beechcraft, have suffered grievous losses. They have seen their businesses drop precipitously. In the interim, a powerful new competitor, Embraer, has entered their segment, aiming at taking market share at the very moment that the legacy players can least afford to fight back.

Both Cessna and Hawker continue to cut products and employees. Although macroeconomic indicators such as corporate profits look strong enough to imply an upturn in 2012, there is every likelihood that 2011 will represent a third year of pain.

Meanwhile, the companies at the top of the market continue to enjoy a reasonable level of prosperity, and are aggressively pushing ahead with new product development. According to Gulfstream, the company booked more orders in the third quarter of 2010 than in any quarter since the downturn started in mid-2008. In November, the company said it would spend $500 million on plant expansion and add 1,000 jobs in its Savannah, Georgia, facility to meet a growing market for large-cabin aircraft. Similarly, its rival Bombardier announced in October that it was launching its Global 7000 and 8000 growth versions of its high end Global Express product line.

Clearly, the bifurcation of the business jet market looks set to induce a notable structural change. What was once the top half of the market by value will from now on be the top 60-65%.

Defense: Collapse or plateau?

The U.S. and Europe are currently preoccupied with defense cuts. The massive increase in government debt and budget deficits has emboldened fiscal hawks on both sides of the Atlantic. Yet as with many other aspects of the government spending debate, Europe is actually acting on budget cuts, and the U.S. is not.

Despite the fear and hype, the FY11 U.S. defense budget is at a record level, and the cash provided by this will be trickling through the defense industrial base through 2012 and 2013. There have been no major program cuts, aside from the long-awaited termination of the Lockheed Martin F-22 and the VH-71 presidential helicopter. While a downturn in combat operations in Iraq will reduce the weapons support budget, there is little likelihood of a serious cut in weapons procurement for the next few years, at least.

However, it is notable that voices in favor of some limited defense cuts can now be heard on both sides of the political aisle. Even Republicans like Sen. John McCain are talking about the need to reduce defense spending. However, any discussion of specific cuts is hard to find.

One exception, however, is the Simpson-Bowles Fiscal Commission. This bipartisan deficit reduction study group has recommended a number of cuts throughout the federal budget, but two aircraft in particular have been singled out for attention. If the commission's proposals are accepted, V-22 Osprey procurement will end in a few years at 288 aircraft. F-35A procurement will be slashed, while the F-35B short takeoff and vertical landing version of the JSF will be canceled outright.

Yet even if these programs' many champions lose the fight, the commission is still recommending procurement of legacy systems as an alternative. Even if the V-22 and F-35 were cut, the Sikorsky MH-60s, Boeing F/A-18E/Fs and Lockheed Martin F-16s would gain.

In the interim, European governments have been far more aggressive in cutting their already truncated weapons programs. This is largely due to the more pressing nature of the eurozone crisis. The U.S. faces long-term challenges, but many eurozone countries are feeling pressured to cut their deficits immediately.

One problem with the European defense spending trends is that they fund systems today, but they jeopardize the future with very severe cuts. The best example of this is the U.K. RAF's fighter plans. The Ministry of Defence is now short £20 billion to pay for equipment over the decade. The RAF will still take delivery of Eurofighter Tranche 2s and 3As because those aircraft are under contract. But the legacy fleet of Tornados will likely be retired much faster than originally expected, and Eurofighter Tranche 3B will be cancelled. With this plan, the Eurofighter program will wind down in 2015/2016.

In all, in a few years we will see a day of reckoning for European military aircraft contractors. Unless something changes in its home markets, or unless it wins the key India medium multirole combat aircraft (MMRCA) competition, the last Eurofighter will be delivered in about five years. Rafale might make it to 2019. The last Gripen might be delivered in the next year or two. The last European military plane of any note might be the A400M military transport, assuming it survives the budget cuts.

In the U.S. defense segment, procurement of the V-22 Osprey may end early; however, this could be good news for the MH-60.

This budget-cutting strategy also jeopardizes Europe's standing in the export market. If the home market retires airplanes, it does not develop upgrade and support packages for them. This basically puts export customers on notice: They might be buying a plane that turns into an orphan faster than expected. And killing the line means the time available to search for export customers is running away fast.

With the U.S. market flat or declining and European companies hobbled by weak home markets, U.S. defense primes are starting to focus on international customers. With a combination of faster economic growth rates, high resource prices that help grow government budgets, and ongoing geopolitical tension, key markets in the Mideast and Asia look set to place record orders for U.S. and European equipment.

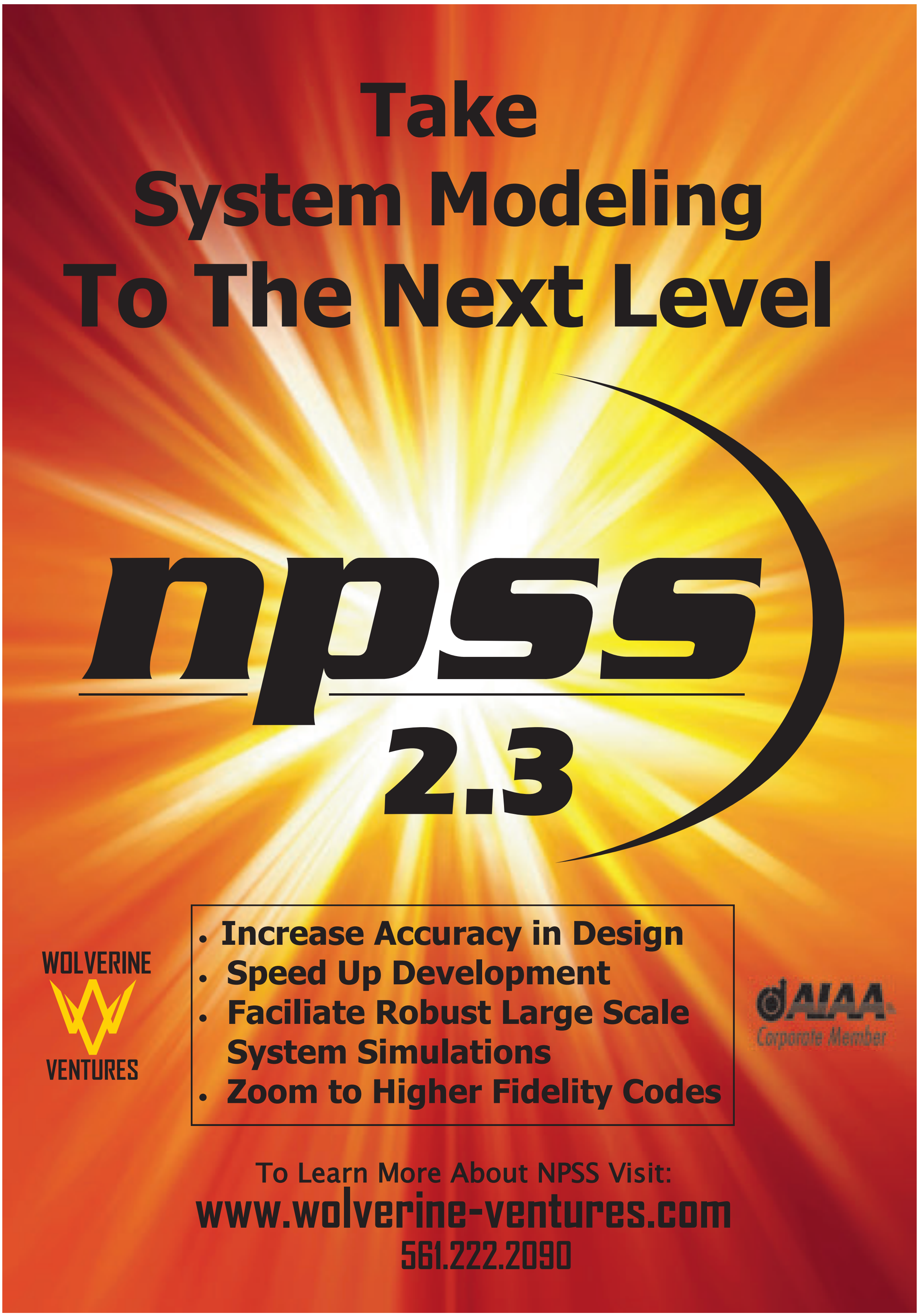
A good example of this is the recent Saudi arms package, worth about $60 billion. It includes the largest single export fighter buy of the past 30 years, covering 84 Boeing F-15s. The India market is also ramping up. In addition to the MMRCA competition covering another record fighter buy (126 planes), in November India signed for 10 Boeing C-17 airlifters. This means the C-17 has joined the F-15 and F-16 as military aircraft programs that are being kept alive entirely through export contracts, a testament to the strength of international markets and the global market standing of U.S. contractors.

The best part of the defense market has been the rotorcraft segment. While the civil side of the business fell by 12.5% in 2009 and another 18.4% in 2010, the military side has grown by over 40% since 2008. This is primarily due to worn out fleets that need replacement and the combined impact of several key programs ramping up to full production.

Also, helicopters are one of the only tools of war with broad utility in all three major military applications: traditional warfighting, counterinsurgency, and nationbuilding/peacekeeping. And despite the civil dropoff, in the mid and long term, civil helicopter sales will be boosted by emerging market demand. Sales to China and India have been extremely strong in recent years, helping to double the civil market's value between 2004 and 2008.

In all, the outlook for both the civil and military aircraft industry is quite strong, despite some areas of weakness and risk. Our forecast for the next five years is for a total market expansion at a 3.6% compound annual growth rate (CAGR). This is somewhat weaker than the 7.5% CAGR expansion enjoyed by the industry in 2003-2009. Then again, the industry avoided any kind of serious cyclical downturn during the worst economic recession since WW II.

Richard Aboulafia
Teal Group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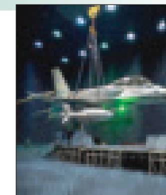


RF electronic warfare: From cold war to network invasion

Surprisingly, the highest growth rates in defense electronics over the next decade will be in electronic warfare (EW). In a major turnaround from the past two decades, EW will offer many of the best opportunities for both market growth and value.

This is perhaps not so strange when the U.S. again faces real threats and real casualties; as in the Vietnam War, funding has turned to EW. Intelligence, protection, and connectedness will grow faster than direct shooter electronics over the next 10 years. Some post-cold-war needs are only now being addressed, with several new programs aimed at the upgrade or replacement of legacy analog systems. One specific area of growth is radio frequency (RF) EW. (The discussion below does not focus on Joint Strike Fighter systems, which were covered in an earlier column.)

EA-6B Prowler

Radar systems add PLAID

Radar warning receivers (RWRs) have been a vital component of the combat aircraft EW suite since WW II, especially for fighters and fighter-bombers, which must detect and counter multiple ground and air radar as well as radar-guided missile threats. RWRs have been mounted on nearly every modern fighter in recent decades. Because of this long legacy, today's fighters often still serve with systems procured during the cold war. Some of these older systems are approaching the end of their useful service lives, and the RWR market over the next decade should see replacement of many of these analog systems with new or upgraded digital RWRs. The Navy has been buying the Raytheon AN/ALR-67(V)3 for Super Hornets for a decade, but thousands of RWRs still in service in the Air Force and Army are 20 or more years old and will need replacing.

Northrop Grumman's (formerly Litton's) ALR-69(V) is a standard analog Air Force RWR that first entered production in 1978. It detects threat radars, processes the detected signals, and provides the operator with range and azimuth information. Almost 2,000 ALR-69s were procured for F-16 fighters.

In August 2001, Raytheon won an Air Force contract to integrate precision location and identification (PLAID) system capabilities into the ALR-69, now known as the ALR-69A(V). PLAID improves aircrew situational awareness by providing more accurate ground emitter location and unambiguous identification. Threat radar systems can disrupt operational missions even without firing, by requiring aircrew reactions that affect mission objectives.

PLAID's improved threat information allows aircrews to determine threat range/directions and to provide option responses short of mission abort or violent aircraft maneuvering, such as rerouting around hostile areas. Thus, PLAID adds a SIGINT (signals intelligence) capabil-

ELECTRONIC ATTACK (AN/ALQ-)

RDT&E+ Procurement (FY10 $ Millions)	Legacy Ftr EA	EA-6B and EA-18G	NGJ	ALQ-211 173	FMS EA	Other New EA	$Total
FY10	$548	$609	$118	$216	$4	$67	$1,562
FY11	475	634	120	266	12	94	1,601
FY12	440	584	120	321	112	122	1,699
FY13	428	342	122	328	210	163	1,593
FY14	437	96	116	353	216	231	1,449
FY15	440	180	118	220	226	270	1,454
FY16	354	190	102	216	180	271	1,313
FY17	336	194	114	216	156	278	1,294
FY18	359	114	128	220	142	284	1,247
FY19	360	90	132	196	138	292	1,208

ity to earlier RWRs. Low-rate initial production (LRIP) was awarded in October 2007, and the Air Force planned a major production run for the four-engine C-130 Hercules transport. However, the May 2009 FY10 budget put production on hold, funding only 26 LRIP systems.

The Air Force's other legacy analog RWR is BAE Systems' ALR-56(V), originally designed for the F-15 Eagle fighter. Development of the current F-15 ALR-56C began in 1981. A modernized and miniaturized version, the ALR-56M, began development in 1988 (still cold war, still analog, still a primary in-service system today) to serve on later F-16C/D fighters and some C-130 transports. Nearly 3,000 ALR-56 systems have been produced for all platforms.

Funding fate of upgrades

In mid-2009, the Air Force finally had tentative plans (or, at least, hopes) to replace or upgrade the old ALR-69s and -56s on its F-15s, F-16s, A-10s, and C-130s, with the possibility of beginning procurement to put digital PLAID ALR-69As on F-16s in FY12. They also expected to upgrade the ALR-56Cs on F-15Es and older F-15Cs with digital components. BAE Systems reportedly had a study contract for an "LRU-3+" upgrade to the ALR-56C that would insert a digital receiver derived from the JSF EW suite.

But by early this year there was no significant funding in the FY11 budget. In mid-2010, the service still hoped to replace the ALR-69, but Col. Joseph Skaja of the Air Combat Command said, "that one is probably going to fall by the wayside because of [lack of] funding."

Still, with thousands of legacy fighters to remain in service for decades, it is only a matter of time before substantial digital upgrades are funded. Teal Group has added speculative USAF digital RWR replacement/upgrade funding forecast lines for thousands of ALR-56s and -69s. It is not certain when this market will break, or who will lead it, but it will happen this decade.

For the Army and other customers, about 10,000 Northrop Grumman (formerly Litton) AN/APR-39 RWRs have been produced over the past 30 years. New APR-39 contracts continue, especially for international helicopter buys, and about 3,000 systems were still in Army service in early 2009. But Apache pilots had "lost confidence" in the APR-39 even in 1999 in Kosovo. As an interim upgrade, the Army awarded Phase 1 development funding to Northrop Grumman in FY05, focusing on processor upgrades, with a full-rate production decision awarded in the third quarter of FY08. But Phase I procurement funding dropped off substantially after FY09.

Phase 2 of the APR-39 upgrade/replacement is to develop an improved Army digital RWR for modernized platforms. In mid-2008, Army officials spoke of funding for the program starting "in a couple of years," and the FY10 budget release in May 2009 showed system design and development beginning in FY13, preceded by low levels of "prototyping" funds. In February, the FY11 budget showed development funding beginning in FY11 and ramping up to $22 million annually by FY13. This should become a major program worth hundreds of millions of dollars, but as with USAF digital RWR funding, the schedule could move either right or left.

The AN/ALQ-99 is at the core of the Prowler.

Prowlers and Growlers

Electronic attack systems, once called electronic countermeasures or radar jammers, are another near-universal fit on U.S. and international combat aircraft. EA has had much higher funding recently, and there are many new programs. Capabilities have been added beyond traditional air defense missions—Prowlers and Growlers today can target improvised explosive devices with energy beams to prematurely detonate or disable bombs, or they can generate "cones of silence" to prevent enemy electronics communications within tactical areas.

The Air Force gave up its own dedicated EA aircraft, the EF-111A Raven, in the mid-1990s. Since then the ongoing EA behemoth has been the Navy's EA-6B Prowler, providing dedicated combat EA for the USAF, Navy, and Marine Corps. At the core of the Prowler is Northrop Grumman's AN/ALQ-99(V) airborne noise jammer system, carried in three to five externally mounted pods. The current version of the system in service throughout most of the Prowler fleet is the Improved Capability-II (ICAP-II). The Navy and the Marine Corps currently operate about 111 EA-6Bs, with 90 available or deployed at any one time. However, all the Navy's Prowlers are due to be retired by FY14, and all the Marine Corps' by 2019.

A recent upgrade for a limited number of Prowlers is ICAP-III, a complete receiver and sensor update of the ICAP-II. It includes Northrop's AN/ALQ-218(V) digital wideband receiver system, reliability improvements, and upgraded computers, displays, and communications. ICAP-III allows selective-reactive "surgical" jamming, focusing energy on multiple, specific radar or communications frequencies. ICAP-II jams across larger bandwidths, dispersing jamming power. According to the com-

EA-18G Growler (USN photo by Jamie Hunter/Aviacom)

pany, "The ALQ-218 utilizes a unique combination of short, medium, and long baseline interferometer techniques with a patented passive ranging algorithm to provide geolocation of emitters for cueing jammers and other onboard sensors."

The Marines received the first of their ICAP-III upgraded Prowlers last May and will also get the 16 earlier Navy ICAP-IIIs, for a total of 32.

In June 2008 the Navy received the first EW jammer/SEAD (suppression of enemy air defense) version of the F/A-18F Super Hornet, the EA-18G Growler. It mounts the same ALQ-99 system (three pods) as the ICAP-III EA-6B, but also uses the Super Hornet's active electronically scanned array AN/APG-79(V) radar for broadband noise and reactive jamming. It has a "Wild Weasel" ability to attack nonemitting targets. Early this year the Pentagon added funding to Growler procurement ($203 million in 2011 and $2.3 billion in 2012 for 26 more aircraft), and the Navy will now likely buy at least 98 Growlers, with limited international sales also likely.

Funding began in FY09 for development of the next generation jammer (NGJ), intended to replace (or possibly upgrade) the ALQ-99 on the Growler in the 2015-2020 time frame. In addition, a new NGJ could be procured by the Marines for mounting on the JSF or a UAV, which would then replace USMC Prowlers when they are retired from 2018 to 2020.

New capabilities such as computer invasion and network attack (using an electronic beam with "malicious algorithms") are planned, to penetrate integrated command and control networks. "Every antenna is a target," says Northrop Grumman.

In September 2009, the Navy issued the final NGJ broad agency announcement for up to four competitive technology maturation contracts it planned to award, to develop detailed engineering and programmatic plans for key technology demonstrations. These contracts will be worth $15 million-$30 million each, with a 10-14-month duration.

The Navy leads the program and is taking a creative approach to capabilities, leaving them up to potential contractors, with no set specifications. Of course, this philosophy is likely to end up with yet another long and expensive RDT&E process and no production systems. Leading the current teams are ITT/Boeing, Northrop Grumman, BAE Systems, and Raytheon.

The Air Force has also been working on EA ideas, but much funding and effort has been concentrated on the JSF. In 2009, Col. Bob Schwarze, the departing USAF chief of EW and cyber warfare requirements on the Air Staff, said the Air Force, which had thousands of cold-war-era jammers, planned to buy 400 digital RF memory-upgraded AN/ALQ-131(V) pods from Northrop Grumman with $190 million in FY10-FY15 funds. However, in the FY11 budget, no procurement funding was scheduled.

The Air Force also has ideas for developing a "cognitive jammer," having solicited proposals at midyear for a new generation of EA systems capable of adapting to agile threats that rely on new dynamic RF spectra. Initial efforts will focus on algorithm development and a prototype system, but this will likely remain a development program.

RADAR WARNING RECEIVERS (AN/ALR-)

RDT&E+ Procurement (FY10 $Millions)	Legacy RWR	ALR-67 (V)3	USAF Digital RWR	Army Digital RWR	Other New RWR	Total
FY10	$363	$154	$4	$0	$30	$551
FY11	376	132	20	5	35	568
FY12	313	126	120	10	37	606
FY13	245	108	196	22	36	607
FY14	233	116	222	26	39	636
FY15	225	108	222	35	40	630
FY16	207	92	226	52	46	623
FY17	160	62	186	56	47	511
FY18	131	40	120	66	49	406
FY19	118	36	172	64	52	442

International trends

Outside the U.S., on the other hand, nations that are not waiting for JSF need to pay more serious attention to upgrading or replacing legacy EA. Teal Group thus expects a large and varied foreign military sales (FMS) EA/jammer market. The FMS F-16 market, especially, could be good for several hundred new systems over our forecast period.

ITT's lightweight, inexpensive Army AN/ALQ-211(V)-derived AN/ALQ-173(V) AIDEWS (advanced integrated defense electronics warfare system) has earned several FMS contracts, with Chile, Poland, and Oman choosing AIDEWS for new F-16s in 2002 and 2003. Pakistan added an order in 2007, and Turkey followed in February 2009. Since Turkey's cancellation of the development of BAE Systems' AN/ALQ-178(V)5+ there are now two primary competitors for FAMS F-16 jammers: AIDEWS and Raytheon's AN/ALQ-187(V).

Though AIDEWS has earned more recent contracts, Raytheon's advanced countermeasures electronic system (ACES)—including the new AN/ALQ-187(V)2—was sold to Morocco in November 2008, and Lockheed Martin chose ACES for its Indian F-16IN bid in early 2009.

With a fairly equal competition, we have chosen to break out a competitive undetermined forecast for future FMS jammers, including new-build and upgraded F-16s, as well as possibilities for other aircraft (and other EA systems). For example, in October 2008 Boeing chose BAE Systems to develop a Digital Electronic Warfare Suite for international F-15 users, in particular Saudi Arabia and Japan, leveraging technologies and common modules developed for BAE's F-22 and JSF EW suites.

David L. Rockwell
Teal Group
drockwell@tealgroup.com

Curiosity's MISSION to MARS

by Craig Covault
Contributing writer

Curiosity, NASA's $2.3-billion Mars Science Laboratory (MSL) rover, is ready to push the bounds of science and technology in a search for clues to life on Mars. Although Curiosity cannot detect biological activity, it is designed to find specific geologic and carbon-based evidence relevant to past life. The 2,000-lb vehicle features a maze of sample flow paths, mini-laboratories, and instruments developed by the U.S., Europe, Russia, and Canada.

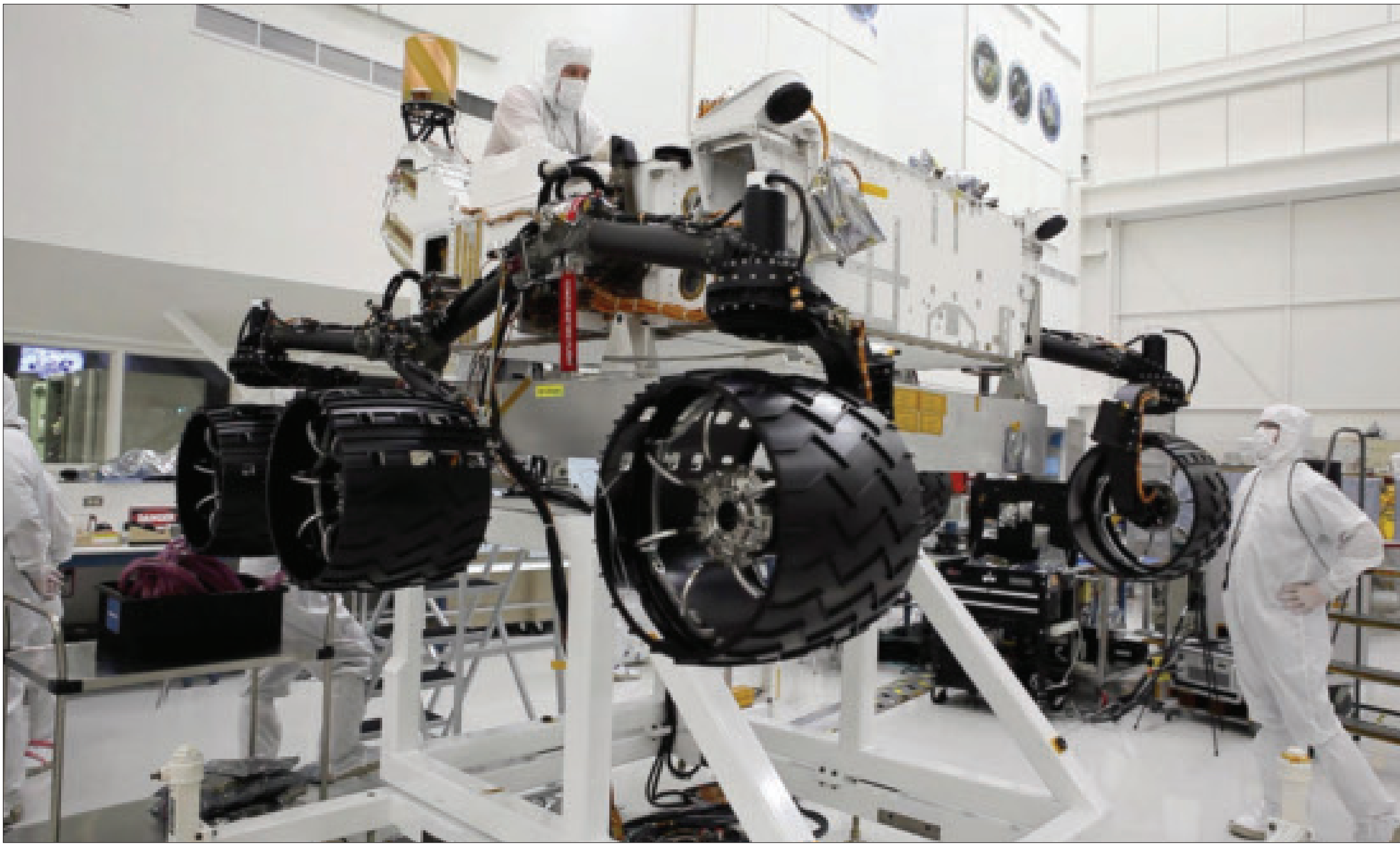
By June, the MSL spacecraft is to be shipped from Pasadena, California, to Cape Canaveral, Florida, on board an Air Force C-17. Scheduled for launch on an Atlas V rocket this November, Curiosity will lead NASA toward the future after the final shuttle mission recalls U.S. space glories of the past. MSL is targeted to land on Mars in August 2012.

The most complex spacecraft ever developed by JPL, MSL is so vital to the search for Martian life—and to NASA's faltering exploration strategy—that Congress voted to continue the program even with a 60% cost increase and a two-year launch delay to 2011. Part of the delay resulted from disappointing motor and actuator tests conducted at temperatures from -70 F to -90 F, similar to the levels Curiosity will experience on the coldest winter nights.

Pete Theisinger, MSL project manager, says that some of MSL's difficulties have also revealed strategically important problems with U.S. aerospace components. Although declining to be specific, he notes, "There are weaknesses in the U.S. space technology parts and supply community that have surprised us at JPL."

Curiosity is over five times heavier than either Spirit or Opportunity, the Mars exploration rovers (MERs) that made airbag landings in 2004. MSL's sky crane sys-

In searching for clues to life in Martian rocks and clay, NASA's Curiosity rover will also give the space program new life.



Engineers installed six new wheels on the Curiosity rover and rotated all six at once on July 9, 2010. This milestone marked the first in a series of "tuneups" to get the rover ready for a drive in the clean room at JPL, where it is being assembled.

tem will enable Curiosity to carry at least 165 lb of science instruments, compared with less than 20 lb of science hardware on Spirit and Opportunity.

Shortly after Curiosity begins to rove, a Russian robotic spacecraft will attempt to land on the Martian moon Phobos. Part of the lander is to return to Earth in 2014 with a sample of Phobos material that could be rich in Mars dust. This would be a huge achievement that might accelerate plans for manned Phobos missions.

During this first-ever round trip between Earth and Mars, the Russian spacecraft will also deploy a 250-lb Chinese Mars orbiter. China says that in about 2013 it will conduct its own launch of a heavier Mars orbiter that it is now developing.

Technology

Two major technological firsts will enable MSL to do more than previous rovers and aid the design of future Mars landers too heavy for airbags. One is sky crane, a landing system that will function like an Army helicopter lowering a vehicle to the surface of, in this case, another planet.

The other first is called active guidance with aerodynamic lift, a combination that will allow MSL to fly—rather than just fall—through the Martian atmosphere. No previous Mars mission has used a maneuvering, fully guided lifting aeroshell for precise landing capability.

"It is difficult to overstate what a major step forward this is beyond the earlier MERs," says Theisinger, who also led JPL development of Spirit and Opportunity. "MSL is not your father's Mars rover," he says. "We clearly underestimated the size and scope of MSL."

But a potential problem lies within the plutonium-fueled radioisotope thermoelectric generator (RTG) that will power Curi-

MSL mockup sits with the Mars exploration rover and Sojourner rover at the Jet Propulsion Laboratory.

osity. There is concern that the critical thermocouple device in the RTG that converts heat to electricity may be degrading ahead of its specification life, says John Grotzinger, MSL program scientist.

The newly designed Boeing/Dept. of Energy multimission RTG has proven design and hardening features to prevent dispersal of any plutonium dust in the event of an Atlas V launch accident. Just in case, however, the DOE will position more than a dozen mobile emergency field teams around Cape Canaveral for the launch. If an accident occurs, the teams will immediately check for any release of plutonium 238 or radiation.

What's new and different

There are several key differences between Curiosity and its MER predecessors:

•**Ballast to leverage angle of attack.** The MSL aeroshell will eject eight blocks of ballast, together weighing 660 lb, to maintain a proper angle of attack during different phases of the landing. The ballast alone weighs 250 lb, more than the Spirit and Opportunity rovers.

•**Wheels and speed.** Curiosity will use six 50-cm-diam. wheels, compared with the 20-cm-diam. wheels on the MERs. The larger wheels will provide a 20% increase in maximum speed to 6 cm/sec.

•**Mission duration.** The formal MSL mission specification is for two Earth years of lifetime while driving 10 mi. or more. The MER specification called for 90 days and about 900 ft of driving, which both rovers blew away following their January 2004 landings. Spirit remains silent after having become stuck in mid-2009 following 5 mi. of mountain exploration, while Opportunity is ready to begin its eighth year and has passed 15 mi. on its odometer.

•**Size.** Curiosity is 9 ft long, 8.8 ft wide, and 7.2 ft tall; the MERs are 5.2 ft long, 7.5 ft wide, and 4.9 ft tall.

•**Computer power.** Curiosity's computer is substantially more powerful, says Mark W. Maimone, a lead computer and robotics engineer for the MSL and MER. He says MSL's computer is a BAE Systems Rad 750 whose overall integration was done at JPL. Its central processing unit is five times faster than either of the MER CPUs.

Curiosity can perform runs at 100 MHz/sec, compared with 20 MHz/sec for the MERs. By contrast, a low-end home computer will have 2 GHz of power but is not radiation hardened, an upgrade that can take years of testing and certification.

More computer power will enable robotic roving to proceed faster with fewer mistakes. MSL will have the same basic capabilities as the MERs, such as hazard avoidance, the ability to circle a rock, terrain assessment, visual odometry, and autonomous arm functioning.

•**Arm operations.** The extra computer power will enable far more robotic arm operations, which will be substantially more demanding on MSL. Another difference is that for MSL, unlike for the MERs, the team will not have to write a sequence of hundreds and hundreds of lines of software for these daily operations.

"With MSL we will have those kinds of sequences, developed here at JPL, already on board the rover," says Chris Leger, robotic arm flight software developer and the surface software development lead for the MSL flight.

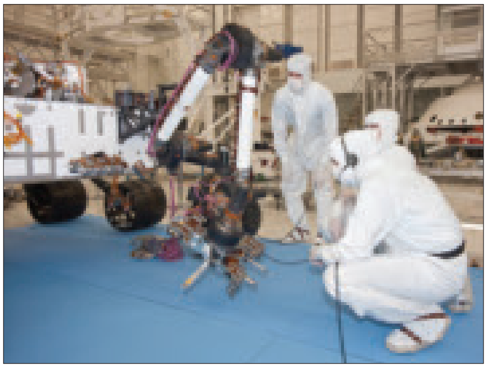
"In terms of mass and strength, the 7.5-ft MSL arm is much beefier and much stronger than the 3-ft MER arm," says Matt Robinson, lead engineer for robotic arm systems. "Just the turret on the MSL arm weighs more than the whole arm electronics and science on the smaller MER rovers," he notes.

"We have a whole different style of motions with the MSL arm, because we use a lot more 'gravity-relevant' motions to move samples where we want them to fall inside the mechanisms," adds Leger. "When we do sample processing you will see the turret spin around to do different sample orientations, while other actuators are creating vibrations to move the sample along."

Searching and sampling

The arm uses a percussion device to break rock into powder that can be moved to the rovers' mini-labs. "There are at least 50-100 different arm motions to get the samples out of the drill and over to the instruments," says Leger.

The rover will explore a once water-rich region in search of the carbon-based building-blocks of life. It will also sample Martian geology up to 10-20 mi. from the landing site and generate broader data to determine if habitable conditions ever existed during the Martian eons.



Curiosity's 7.5-ft robotic arm, which will use a percussion device to break rock into powder, is much stronger than the 3-ft MER arms.

The rover's labs should be able to assess rock and soil to obtain key data, such as how much life-giving oxygen has come and gone in the Martian atmosphere over the past 4 billon years.

More than any other planetary mission in history, MSL will benefit from extremely detailed collaboration with other NASA and ESA missions orbiting Mars.

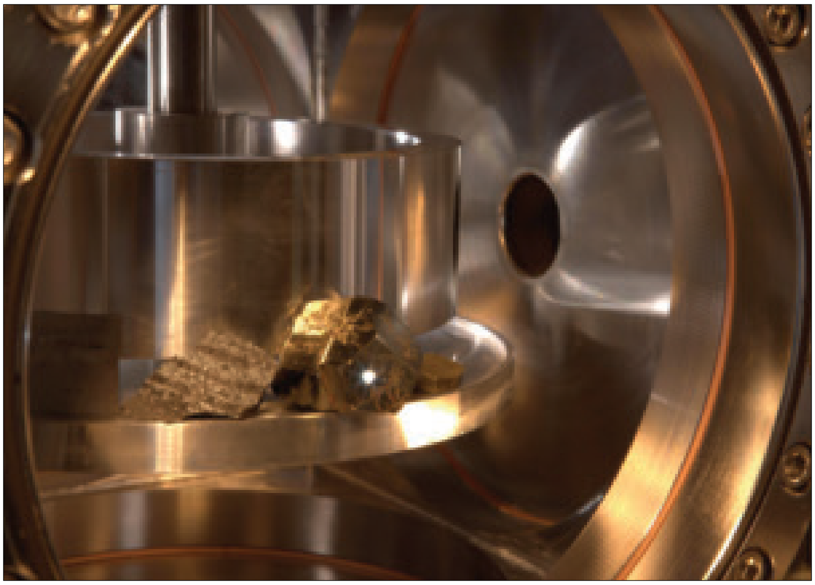
MSL's operations on the Martian surface will be more like a military campaign on Earth where reconnaissance satellites provide all manner of data before ground forces—in this case Curiosity—move in.

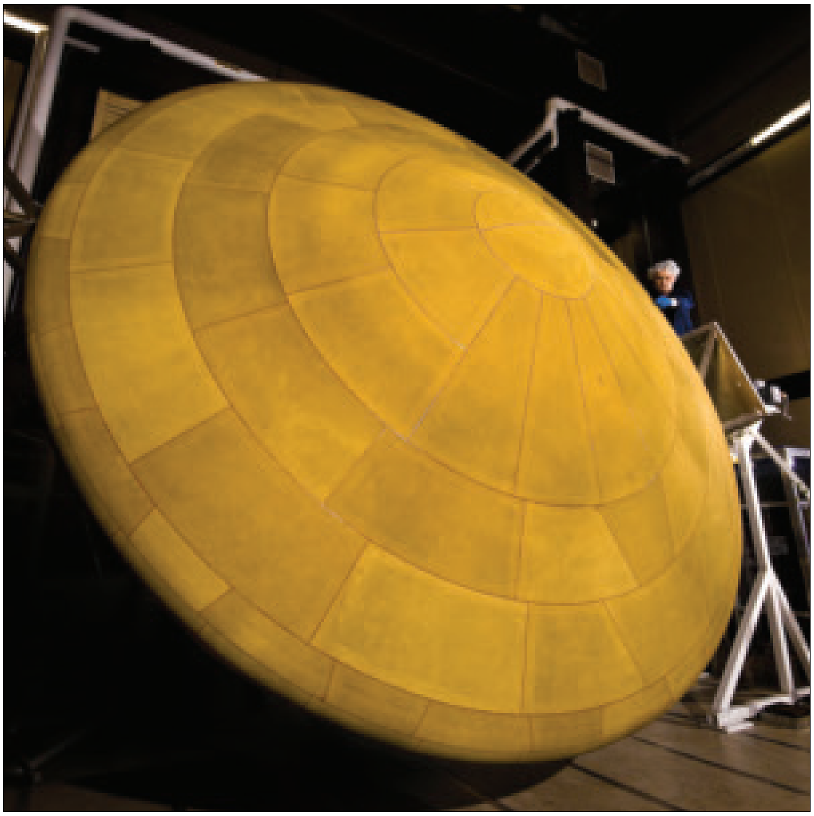
ESA's Mars Express and NASA's Mars Reconnaissance Orbiter have taken very high-resolution imagery, while the Mars Odyssey has helped trace the presence of water. They will also relay data to Earth from Curiosity, just as they continue to do for Opportunity and will do for Spirit, if it awakens from a power-starved winter.

The Wright approach

MSL's descent to the Martian surface will come 109 years after the Wright brothers made fundamental discoveries about aerodynamic lift, angle of attack, and active control. Those principles will now be demonstrated for the first time in the Martian atmosphere. MSL will use Apollo command module reentry algorithms and also roll re-

The ChemCam instrument uses a pulsed laser beam to vaporize a pinhead-size target, producing a flash of light from the ionized material (plasma) that can be analyzed to identify chemical elements in the target. Here a ball of luminous plasma erupts from the surface of an iron pyrite crystal in the sample chamber approximately 3 m from the instrument. The laser beam itself is invisible. Credit: NASA/JPL-Caltech/LANL.





The finished heat shield for the MSL, with a diameter of 4.5 m, is the largest ever built for descending through the atmosphere of any planet. Lockheed Martin Space Systems Denver built and tested the heat shield. Credit: Patrick H. Corkery. Courtesy Lockheed Martin.

versals, just like the space shuttle, to alter its lift vector during reentry.

Active guidance of a lift-generating vehicle and the sky crane will deliver the MSL rover to within a circular target area just 7.7 mi. in diameter. This compares with Pathfinder and MER unguided entries that targeted a 50 x 6-mi. ellipse. The 1976 Viking landers used a "full lift up" but unguided aeroshell that required a much larger landing footprint measuring 175 x 62 mi.

The MSL's entry into the Martian atmosphere at nearly 13,000 mph will use the largest aeroshell and heat shield ever flown in space. Curiosity and the Mars sky crane will be encased in an aeroshell shaped like an enlarged Apollo command module. It measures nearly 15 ft across its heat shield—2 ft larger than an Apollo command module and 6 ft larger in diameter than the MER and Pathfinder rover aeroshells.

Because the unique entry trajectory profile will create external temperatures of up to 3,800 F, the heat shield uses phenolic impregnated carbon ablator (PICA) thermal protection tiles. This is in place of the older Mars heritage SLA (super lightweight ablator) 561V used in past Mars landings.

On its nine-month flight, the aeroshell with the sky crane rover inside will fly attached to a large solar-array-equipped circular cruise stage. During cruise the aeroshell will have a symmetrical mass and will rotate at 2 rpm. But all that will change starting 10 min before reentry when the two 165-lb cruise balance mass weights are ejected. "During entry into the Martian atmosphere, we will fly a symmetrical aeroshell body but with asymmetric mass," says JPL's Adam D. Steltzner, manager of MSL entry, descent, and landing.

"That will make us fly at a canted angle that will enable the heat shield to develop lift," Steltzner says. To enable steering and lift control, the rover computer will calculate when to fire eight 57-lb-thrust attitude control jets to roll or bank the vehicle with the optimal angle of attack for a lift-over-drag ratio of 0.24 at Mach 24. For the first time in any Mars landing, the altitude, attitude, and velocity of the vehicle will be updated continuously in a closed-loop data stream for real-time maneuvering commands.

Innovative radar

Another key to accuracy and a safe landing will be a new radar configuration never before flown to Mars. "It has taken substantially more time to develop, but it is a superb radar," says Theisinger.

"We needed good velocity and altimetry data relative to the surface of Mars. When slowing from nearly 13,000 mph it is tough to get the velocity data correct down to under feet per sec—and that is what we need for landing this thing," says Steltzner.

"It would be difficult to near-impossible to land a vehicle like this using just an inertial measurement unit, so we chose to develop our own Ka-band six-beam radar. Recent helicopter tests of this system turned in excellent results and aided the MSL team in determining how best to cycle the antenna selection during the descent.

"We feel great about the radar," Steltzner continues. "One reason we decided to build our own is that we struggled in the past with Phoenix, MER, and Pathfinder radars when we tried to modify existing weapons system radars."

Enter sky crane

With a PICA heat shield, a flying aeroshell using Apollo-proven math, a tested parachute design, and spiffy new radar, the untested Mars sky crane must work perfectly. Here is how that will happen:

•**Additional ballast ejection.** The first 67 mi. of the entry will be with the vehicle's mass offset to enable it to generate lift, to fly, and to maneuver to a point almost directly above the landing site. Now six more pieces of ballast, each weighing 55 lb, are ejected at 2-sec intervals to reestablish a neutral center of gravity. The ballast separation phase is designated the "surfer" maneuver (for "straighten up and fly right"), followed immediately by MSL's "victory roll" to establish proper attitude. MSL is ready for its next big event.

•**Parachute deployment.** The aeroshell hypersonic entry phase will take out 99% of the kinetic energy imparted by launch and now by Mars gravity. At 6-mi. altitude and 1,000 mph, Curiosity will deploy its Pioneer Aerospace 52.5-ft-diam parachute. On MSL the chute will be lowering a mass of 3,400 lb, including the aeroshell, sky crane, and 1-ton rover. The MSL chute will remove 99% of the remaining 1% of kinetic energy.

•**Heat shield separation.** The chute will slow Curiosity's descent velocity after 2.5 min to 358 mph at 4-mi. altitude. At this point the PICA heat shield, just 1 in. thick, will be severed, opening the bottom of the aeroshell to reveal the six-wheeled rover grasped by the sky crane with an extended platform holding all six radar antennas. All computations and commands are being done by the rover's computer.

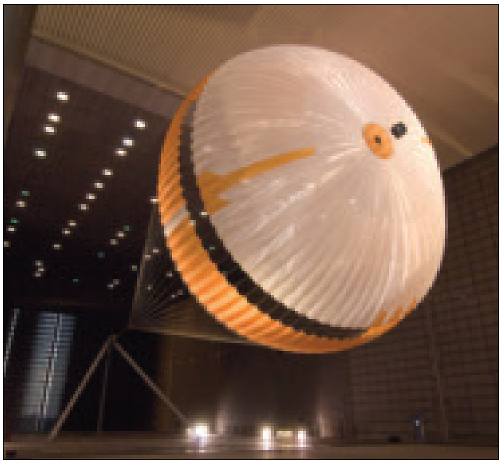
•**Radar activation.** With the heat shield gone, the sky crane's radar will be activated to measure altitude and velocity.

•**Real-time imaging.** The down-facing Mars descent imager, developed by Malin Space Science Systems, will begin taking a continuous stream of high-resolution images (up to four per second) to show the landing from the rover's perspective.

•**Backshell and parachute separation.** Descending through 6,000 ft, the vehicle will separate its backshell and parachute, revealing the sky crane and sports-car-sized rover.

Powered descent

Things begin to happen fast at backshell and parachute separation, but the first thing the sky crane and Curiosity do is nothing. The contraption is programmed to free-fall for 1 sec to be well clear of the 100-ft-long parachute canopy, risers, and backshell.



An MSL parachute test is conducted at the Ames/NFAC 80x120 wind tunnel. Credit: T. Wynne.

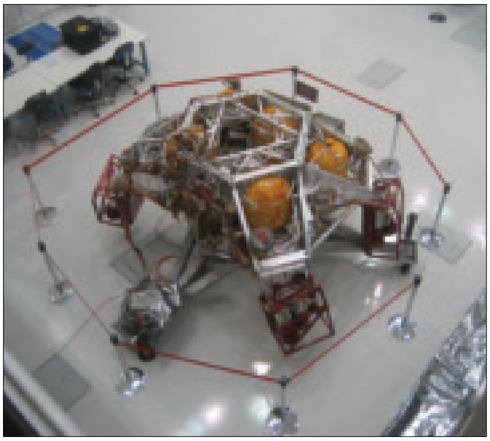
The sky crane has eight Aerojet 675-lb-thrust hydrazine-fueled Mars landing engines (MLEs). Paired on each corner, all eight MLEs are ignited as the whole shebang streaks below 5,000 ft. Engine ignition will dramatically slow the descent and gain attitude control for the fast-approaching Martian touchdown.

Next the vehicle maneuvers laterally to prevent having the backshell and parachute collide in midair or land on top of each other—the worst of luck 150 million mi. from Earth. After the lateral maneuver, the sky crane's engines will null out motions in all axes.

The rover computer will then command the sky crane to fly the vehicle to a point 656 ft above the spacecraft's estimate of where the Martian surface is.

Maximum velocity cancellation occurs at a point that the spacecraft's computer is programmed to perceive as a horizontal plane in the air—200 ft above the surface. But the computer is being tricked. The rover team calls the area "the terrain accordion," which in fact is at least 100 ft farther above the surface. This is ample space for

The aeroshell is a blunt-nosed cone that will encapsulate and protect Curiosity during its deep space cruise to Mars, and from the intense heat and friction that will be generated as the system descends through the Martian atmosphere. Credit: Adam Mattivi, courtesy Lockheed Martin.



The rocket platform (MSL descent stage) will act as a sky crane and lower the MSL rover onto Mar's surface from a hover, then fly away to crash at a safe distance.

the sky crane to exercise its descent capabilities, but with a plentiful safety margin.

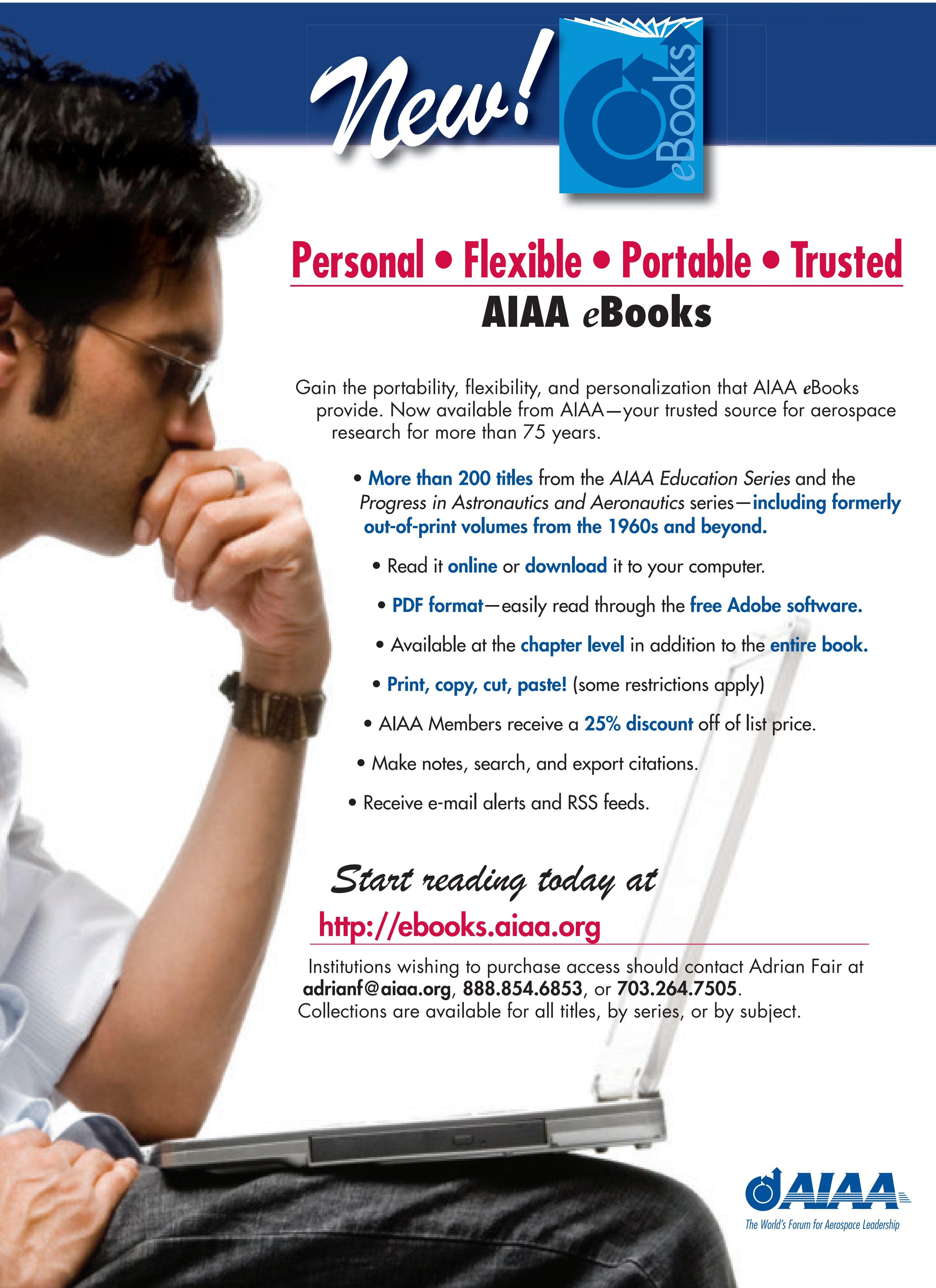
Rockets blazing, the sky crane descends, but slowly—like a Marine Corps Harrier landing, though with less noise because of the super thin Mars atmosphere. Still holding Curiosity tightly, sky crane will begin to descend at a sedate 7 mph, now on the thrust of just four engines at about 50% throttle. This setting gives maximum control.

The scene all around will be of endless red terrain. When the two vehicles descend to about 70 ft, the sky crane will release the rover on a 25-ft set of lines called the bridal umbilical device (BUD). It has three load-bearing lines of woven nylon wrapped with slackened electrical umbilical.

Both the rover and sky crane will continue to drop at 2.5 ft/sec. Halfway down, Curiosity unfolds its wheels, which had been tucked in to fit inside the aeroshell.

The rover will drop more rapidly on the bridal than the sky crane is descending. Suddenly the rover computer will sense the sky crane has no load—Curiosity has been safely deposited on Mars. This will cue Curiosity to fire a cable cutter to sever the BUD. It will also cue the sky crane to begin its flyaway maneuver. Notes Steltzner, "We love to smartly say that we do not look for the touchdown event, but rather perceive the postlanding state of the vehicle."

As MSL's Curiosity rover searches for evidence of life on Mars, it will do more than seek answers to an endlessly intriguing question. It will also serve to rejuvenate NASA's space program as other nations inevitably begin to challenge U.S. leadership in planetary exploration.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Son of Apollo

A new space capsule takes shape

CCDev, NASA's effort to stimulate development of a space transportation capability in industry, has emphasized safety, reliability, and economy. The result is a space capsule reminiscent of the Apollo command module of the 1960s and 1970s, geared for short trips to and from the ISS. And like the Apollo module, its crew accommodations will be more spartan than those of the space shuttle.

by Frank Sietzen Jr.
Contributing writer

NASA's Commercial Crew Development (CCDev) program is the agency's effort to seed the development of a commercial capability for launching cargo to the ISS. Its aim, says the program's announcement, is to "stimulate efforts within the private sector to develop and demonstrate safe, reliable, and cost-effective space transportation capabilities." The project manages two COTS (Commercial Orbital Transportation Services) partnership agreements totaling $500 million for commercial cargo transportation demonstration flights. After a competition, two U.S. firms, Orbital Sciences and SpaceX, were selected for the activity.

First contracts

In February, through an open competition, NASA also awarded Space Act Agreements totaling $50 million to five more firms, toward commercial crew launch development. All the crew funds came from stimulus money provided in the American Recovery and Reinvestment Act of 2009, not from the NASA budget. The companies are Blue Origin in Kent, Washington; Boeing in Houston, Texas; Paragon Space Development in Tucson, Arizona; Sierra in Louisville, Colorado; and United Launch Alliance in Centennial, Colorado.

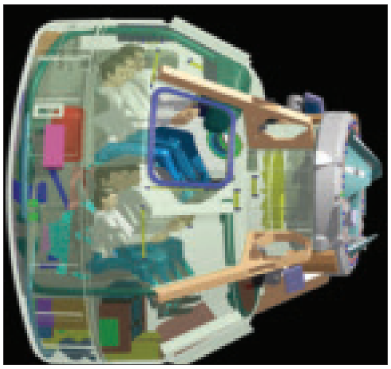
The agreements are for the design of crew-carrying spacecraft and related technology demonstrations, and investigations for future commercial support of human spaceflight. In its announcement NASA said, "Space Act Agreements will stimulate efforts within the private sector to develop and demonstrate human spaceflight capabilities." Out of the $50 million, Blue Origin will receive $3.7 million, Boeing $18 million, Paragon Space Development $1.4 million, Sierra Nevada $20 million, and United Launch Alliance $6.7 million. The project is being managed from NASA Johnson.

Using the stimulus funds, plus money received during the earlier CCDev competition, Boeing chose to accelerate design and development of a crew capsule it calls CST-100, for Commercial Space Transport 100 (100 refers to the 100 km from the ground to LEO). As a partner, Boeing selected Bigelow Aerospace, whose engineers are developing a possible space tourism destination for the Boeing capsule: a multipassenger space station comprised of inflatable modules. The company is currently testing scale models of the units in space. Bigelow could provide its space station to sovereign governments that cannot afford their own space program; this leased space could be used for scientific research.

Vehicle features

What emerged from Boeing designers is a capsule shape reminiscent of the Apollo Command Module flown to the Moon and to the Skylab space station in the 1960s and 1970s. The last such capsule was launched to rendezvous and dock with a Soyuz space vehicle in July 1975. The command module's manufacturer was a company later acquired by Boeing, Rockwell International (formerly North American Rockwell). "We have a great deal of capsule design heritage from Apollo, from the OSP [orbital spaceplane] program, and from our work on the Orion program," says Keith Reiley, Boeing's Commercial Crew Development Program Manager at the company's facility in Houston.

The spacecraft as proposed consists of two parts: a cabin called the crew module (CM), and an unpressurized unit beneath it called the service module (SM). The capsule, according to Reiley, is "bigger than Apollo and smaller than [today's] Orion." The Apollo command module was a cone 3.9 m wide at its base. The Orion's base is currently 5.02 m wide. The CST-100's base is 4.5 m wide, placing it be-



The CST-100 can accommodate a crew of up to seven.

tween Apollo and Orion. But there are major differences with Orion that make the new spacecraft closer in capability to its Apollo predecessor.

Limited accommodations, lower cost

Crew accommodations on Apollo were limited. It had no waste management facilities (the astronauts used bags) and no galley for food preparation. Hot water guns were used to reconstitute food contained in plastic pouches. An oven was carried on only two flights—Apollo 8, to provide astronauts Frank Borman, Jim Lovell, and Bill Anders a hot Christmas turkey dinner, and Apollo-Soyuz, to furnish the crew with hot meals. Orion promises better waste management facilities than those of the shuttle, and better galley equipment. The CST-100 has neither accommodation. "This is pretty primitive as far as the crew is concerned, more like Apollo," says Reiley. One reason is that the spacecraft is designed for very brief return flights from the ISS or Bigelow missions, trips lasting only a day. Another is to keep development and production costs as low as possible.

The capsule can carry up to seven astronauts arrayed in two tiers of seats. Missions with smaller crews can fly customer cargo in place of the empty seats. Windows are arranged so that the commander and pilot have rendezvous visibility, and the rest of the crew can see out via forward and side windows. Over a forward hatch on top of the capsule is a rounded ascent cover. In the center of the capsule is a main egress and entry hatch, and arrayed around the base is a series of thrusters. Boeing is using a proprietary ablative heatshield to cover the base. A parachute system is stored in mortars located around the apex, and an airbag landing system is stored above the heat shield, which is jettisoned during descent. The capsule is designed for a hard-surface landing but can be recovered in water if necessary.

The small SM consists of a short rectangle whose surface is covered in four places by radiators, four quads of thrusters, and a thermal shield that covers the bottom. An umbilical connection is also attached to the capsule. The most prominent features of the SM are two nozzles, one extending from each side.

Feeding the engines is a hypergolic bipropellant system that also fuels the thrusters. The engines provide a unique launch escape system that pressurizes the engines with 1,000 psia for a high-thrust firing that "pushes" both the CM and SM off a malfunctioning booster. The SM is then jettisoned, and the CM lands by parachute. This same engine system is used in space to maneuver the vehicle to the rendezvous target. Reiley notes the abort system can fire during any phase of the ascent: "There are no black zones," he says.

Testing activities

Boeing and Bigelow have conducted a test and validation risk-reduction program for the spacecraft to verify vehicle designs and to identify key technologies that must be matured before being integrated into the vehicle.

For simplicity and low cost, the abort apparatus uses a single pressurization system for both abort and on-orbit operations. Utilizing previous work done on the Atlas II sustainer engine, Boeing is using an ablative nozzle technology similar to that of the Rocketdyne Lance engine. The demonstration program will test engine ignition, performance, and combustion stability using a series of bipropellant fuel and oxidizer mixtures.

Previously, Boeing had tested a material called BLA (Boeing lightweight ablator) on a 5-ft-wide carrier test article. The test team formed and bonded reinforcing honeycomb to the heat shield structure, spreading batches of the BLA onto the honeycomb test structure in a single application. The CCDev testing effort uses a BLA simulated heat shield cured in an autoclave. The shield, which measures 4.2 m, demonstrates a production-ready capability. The tests will give Boeing engineers experience in assembly, production, transportation, and pressure testing for heat shields attached to the base of prospective CM capsules.

At its Avionics System Integration Facility in Houston, Boeing is testing prospective avionics software and hardware in simulated flight conditions. The company has also conducted tests involving the aluminum alloy pressure vessel of the CM to assess how the vehicle handles full pressure of the cabin in different flight environments. A full-scale boilerplate mass simulator has been used to test various elements of the recovery system, including airbag deployment, multiple descents using different parachute configurations, and water recovery stabilization of the capsule. Bigelow constructed the boilerplate model and tested it at the company's Aquatic Test Facility in Las Vegas, Nevada.

Also under way are life support air revitalization system demonstrations using Bigelow assembled components. Demonstrations of integrated guidance and navigation systems for autonomous rendezvous and docking have drawn on previous Boeing systems developed with DARPA.

The CST-100 is designed to transport astronauts to 250-n.mi. destinations at 51.6-deg inclinations for ISS missions, and 225 n.mi. at 35-deg inclinations for Bigelow station missions. The spacecraft can operate for up to 48 hr of autonomous free flight but is primarily aimed at a day-one rendezvous with a day-two backup. It can remain docked to a station for up to 210 days while drawing less than 1 kW of trickle power. It will be compliant with NASA's human rating requirements.

Boeing is working with potential human-rated launch vehicle providers to ensure compatibility with the CST-100 capsule. This compatibility should enable the flexibility required to reach the desired commercial launch price targets.

The markets

Bob Bigelow, founder of Bigelow Aerospace, told reporters at the Farnborough Air Show last July that he was proceeding with expansion of his Nevada facilities to accommodate more rapid development of his space station's inflatable modules. He displayed his customary confidence, telling the assembled reporters that his firm is building a new plant, also in Nevada, that has no other purpose than "mass production" of inflatable habitat modules. He added that no less than 75% of all the money he expects to take from customers leasing space stations and buying seats on rockets will be passed on to launch providers like Boeing. "We expect a significant Christmas card" from them, he said. Bigelow has constructed a full-sized mock-up of the CST crew module to test the interior layout and external arrangement of grappling attachments and crew hand-holds for use during Bigelow and ISS docking.

According to Reiley, Boeing is not planning for Bigelow to be its primary launch customer. "Our primary focus is NASA as our customer," he explains, "but we are working with Bigelow Aerospace to support their orbiting space complexes as an expansion of our market." Depending on funding, first test launches could take place in three years, with first commercial crew missions by 2015.

Pressure testing of the crew compartment structure anchors was conducted in September at the Bigelow Aerospace facility in Las Vegas.

NASA releases RFI

NASA released an RFI this summer to further test industry's interest in supporting commercial crews. The purpose was to gather information that would help the agency plan an overall strategy for the development and demonstration of a commercial crew transport capability and to receive comments on NASA human-rating technical requirements currently in the draft stage.

The agency held a meeting at Headquarters in August to review CCDev progress. Officials said 35 companies had responded to a May 21 NASA solicitation seeking input on the commercial crew initiative. NASA predicts that it could fund up to four providers if Congress approves the full $5.8 billion included in President Obama's initial budget request.

Funding uncertainties

The NASA authorization mandates a government-developed capsule as well as funding for commercial crew transport. Thus it is not readily apparent how the

Boeing is working closely with Bigelow Aerospace to support their space structures.

The Orion capsule was a larger, more complex structure.

commercial space transportation system will fare if it competes directly with a Lockheed Martin Orion derivative. Nor has NASA announced if it will recompete the Orion contract as the new "multipurpose crew transportation vehicle" called for in the legislation. The original Orion CEV for ISS or Moon missions was designed for launch aboard the Ares I, and Orion's weight growth eventually made it necessary for the spacecraft itself to complete the orbit insertion burn.

Congressional instructions call for a deep-space vehicle based on the CEV's capsule shape but not necessarily of the same size or complexity as Orion. Boeing is avoiding the launch vehicle selection initially by making its vehicle compatible for launch aboard one of the Atlas, Delta, or Falcon rockets—a first since the Apollo command/service module was designed for launch aboard Saturn I and V boosters. A smaller, simpler, cheaper Lockheed capsule would seem to be a head-to-head competitor for Boeing's new entry.

On October 25 NASA issued an announcement seeking proposals from U.S. industry to further advance commercial crew space transportation concepts and mature the design and development of system elements. Awards will result in funded Space Act Agreements.

Multiple awards are expected to be announced by March 2011 for terms of up to 14 months. A total of approximately $200 million is expected to be available for awards, but funding is dependent on the FY11 appropriations from Congress.

If Boeing and Lockheed—and possibly SpaceX, with a crewed Dragon—succeed in bringing their vehicles to market, it would mark the first time that multiple production and manufacturing capabilities for manned spacecraft were in operation. Keeping the two sets of space capsules—one commercial and one federal—from eliminating each other in the new U.S. human space program may prove as difficult as building the machines themselves.

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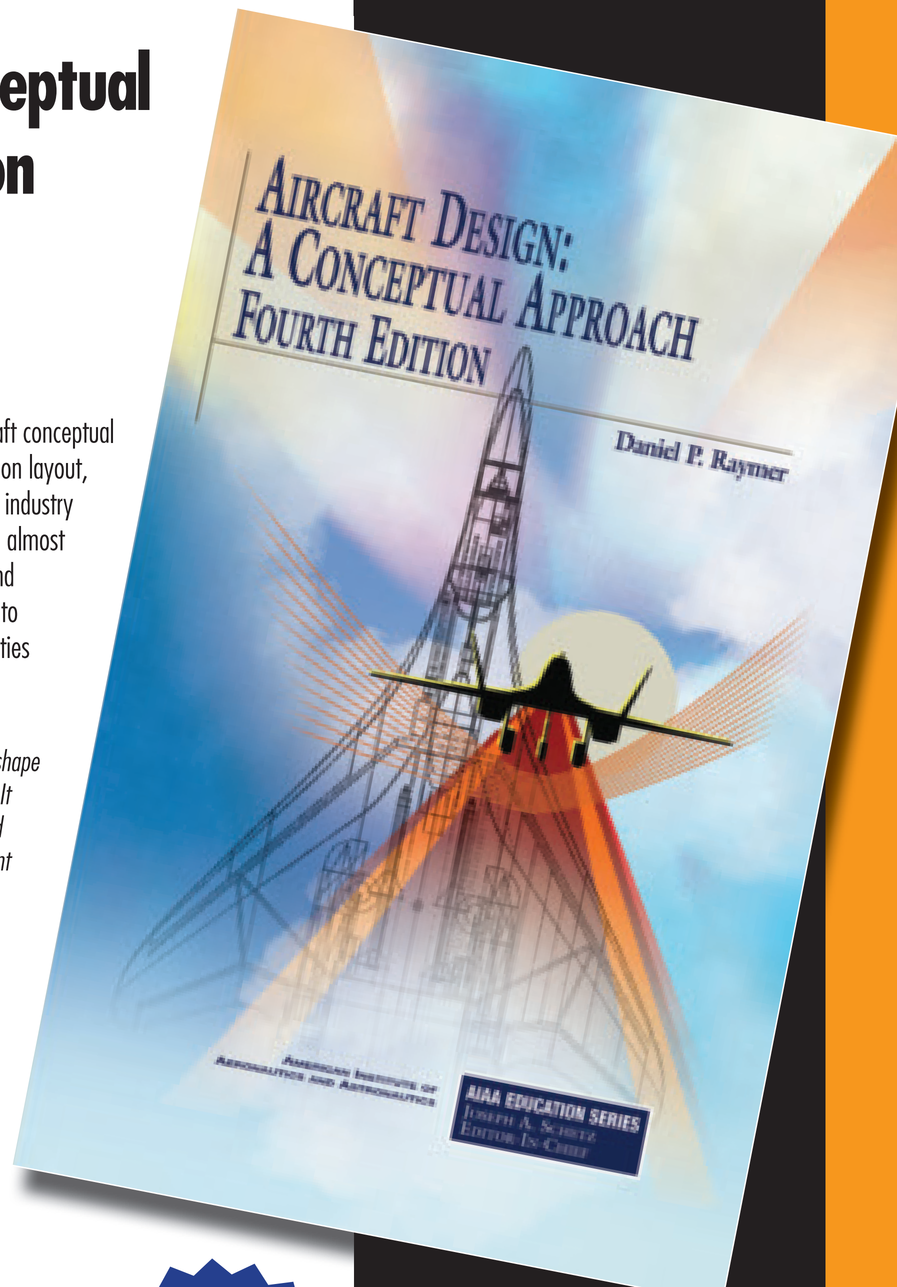

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Out of the

25 Years Ago, January 1986

Jan. 8 Voyager 2 discovers a new moon of Jupiter; throughout the following week it discovers five more, for a total of 14. NASA, *Astronautics and Aeronautics, 1986-90*, p. 8.

Jan. 28 The space shuttle Challenger explodes 74 sec after liftoff and 10 mi. above the Earth, killing all seven crewmembers—(front row) Michael J. Smith, Dick Scobee, Ronald McNair; (back row) Ellison Onizuka, Christa McAuliffe (who was to be the first teacher in space), Gregory Jarvis, and Judith Resnik. This is the worst U.S. space disaster and the 25th space shuttle launch. After an extensive investigation a panel of experts concludes that the accident was caused by a faulty seal on the right solid fuel booster, and that the craft should not have been launched at so low a temperature. NASA, *Aeronautics and Astronautics, 1986-1990*, pp. 9, 14-15.

50 Years Ago, January 1961

Jan. 6 The Bell HUL-1M helicopter, powered by an Allison T63 turboshaft engine, makes its first flight. *The Aeroplane*, Feb. 17, 1961, p. 164.

Jan. 6-7 The first U.K. symposium devoted strictly to rocket propulsion takes place at the College of Aeronautics in Cranfield, England. Organized by the Royal Aeronautical Society, the British Interplanetary Society, and the College of Aeronautics, the symposium attracts more than 100 delegates and features presentations of 17 papers surveying British work in this field. *The Aeroplane*, Jan. 13, 1961, p. 31.

Jan. 12 The first Italian space research begins with the successful launch of a U.S. Nike-Cajun sounding rocket from the Italian air force base at Perdasdefogu in Sardinia. The rocket, which carries an Italian scientific payload from the University of Rome, reaches 105 mi. and, on command, releases a stream of sodium vapor to obtain density, temperature, and other data on the outer atmosphere. *The Aeroplane*, Jan. 27, 1961, p. 80; *Flight*, Jan. 20, 1961, p. 77.

Jan. 14 A Convair B-58 Hustler averages 1,284.7 mph over a 1,000-km course near Edwards AFB, Calif., breaking three world speed records. The crew will be awarded the 1961 Thompson Trophy. *Flight*, Jan. 20, 1961, p. 73.

Jan. 19 President John F. Kennedy names Dallas-born attorney Najeeb E. Halaby, son of a Lebanese-Syrian immigrant, to be the second administrator of the FAA, the agency that regulates commercial air traffic in the U.S. He succeeds Elwood R. Quesada. A private pilot since 1933 and a Lockheed test pilot from 1941 to 1943, Halaby also served as a Navy test pilot until 1946 and made the first transcontinental jet flight. From 1948 to 1954 he was the deputy assistant secretary of defense for international security and from 1955 to 1957 was vice chairman of the White House Aviation Facilities Study Group, which helped form the FAA. In 1978, his daughter Lisa Halaby marries King Hussein of Jordan and becomes Queen Noor. *The Aeroplane*, Feb. 3, 1961, p. 113.

Jan. 19 American Telephone and Telegraph is authorized by the FCC to undertake experiments for radio repeater satellites that may include voice and TV signals transmitted between Holmdel, N.J., and receiving ground stations in the U.K., West Germany, and France. This is an important step toward communication satellites. *The Aeroplane*, Feb. 3, 1961, p. 123.

Jan. 19 NASA selects Hughes Aircraft to develop the Project Surveyor unmanned soft lunar landing spacecraft that is to touch down on the Moon and sample its surface. *The Aeroplane*, Feb. 10, 1961, p. 151.

Jan. 24 For the first time, a Hawk surface-to-air missile intercepts a high-speed Corporal surface-to-surface ballistic missile in flight at White Sands Proving Ground, N.M. Earlier, the Hawk had destroyed short-range Little John and Honest John unguided missiles. *The Aeroplane*, Feb. 10, 1961, p. 136.

Jan. 26 Italy's new Fiat 7002 medium-range helicopter with two-bladed rotor makes its first flight at Caselle airfield near Turin, Italy. The craft is powered by a Fiat 4700 turbogenerator with the rotor driven by "cold jets." It carries a useful load of 1,598 lb, has a seating capacity for a pilot and six passengers, a 186-mi.

by Frank H. Winter, Ret.
and Robert van der Linden

range, and a top speed of 106 mph. *The Aeroplane*, Feb. 10, 1961, p. 136, and Feb. 17, 1961, p. 163.

Jan. 30 At a conference in Strasbourg, France, delegates from the governments of several European countries approve Anglo-French proposals to develop a joint European vehicle for launching satellites. *Flight*, Feb. 10, 1961, p. 172.

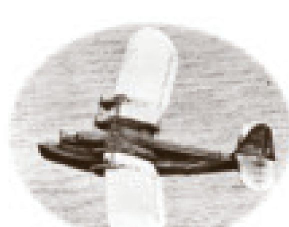
Jan. 31 The Mercury MR-2 space capsule with the chimpanzee Ham aboard is boosted to a suborbital 15-min flight by a modified Redstone rocket, successfully launched, and recovered from Cape Canaveral, Fla., although splashdown is made 130 mi. farther away and faster than planned. Thus the capsule remains in the Atlantic Ocean for 3 hr before being retrieved by a Marine helicopter. *The Aeroplane*, Feb. 10, 1961, p. 52; *United States Naval Aviation 1910-1980*, p. 241.

Jan. 31 A pair of De Havilland Gyron Junior DGJ 10 turbojet engines, the first British turbojets designed for supersonic speeds, are installed and flown in a Gloster Javelin aircraft. Each engine provides 10,000 lb of sea-level thrust. The Javelin is serving as a test-bed for the engines that are to power the Bristol 188 all-steel supersonic research aircraft. *The Aeroplane*, Feb. 10, 1961, p. 135.

75 Years Ago, January 1936

Jan. 2 French writer and aviator Antoine de Saint-Exupery, already acclaimed for his poetic novels *Southern Mail* and *Night Flight,* is found, along with his mechanic, in the Egyptian desert 95 mi. east of Cairo. The two had been lost for three days following an attempt to establish a new Paris-Saigon record. Their Caudron Simoun aircraft hit the ground at full speed and skidded over the sand until it stopped. Unhurt, the men walked for two days until they exhausted their food rations, and were found soon after. Saint-Exupery later writes *Wind, Sand and Stars, Flight to Arras,* and *The Little Prince. Flight*, Jan. 9, 1936, p. 36.

Jan. 9 Three De Havilland Dragon Rapides light airliners adapted for military use arrive in Spain from England and are turned over to the Spanish air force for service in Morocco. *The Aeroplane*, Jan. 22, 1936, p. 111.



Jan. 14 Roscoe Turner's transcontinental speed record of 10 hr 2 min 51 sec is broken when Howard Hughes flies from Burbank, Calif., to Newark, N.J., in 9 hr 27 min 10 sec. His plane is a 950-hp Wright Cyclone G Series powered Northrop Gamma. Flying nonstop, Hughes averages 263.5 mph for the 2,450-mi. flight. *Aero Digest*, February 1936, p. 74.

Jan. 20 The Navy Bureau of Engineering approves development of radio meteorgraphs, later called radiosondes, which are weather-recording instruments sent aloft by free balloons. Data are gathered and transmitted to ground stations for use in weather forecasting and flight planning. The Navy's Bureau of Aeronautics recommended the development. E. Emme, ed., *Aeronautics and Astronautics 1915-60*, p. 33.

100 Years Ago, January 1911

Jan. 26 From San Diego Bay, Calif., Glenn Curtiss takes off in his first seaplane and makes a successful water landing. The machine, called a hydro-aeroplane, is a standard biplane with pontoons. A few days later he flies the plane 5 mi. over the sea. Alphonse Pénaud of France may have been the first to patent the idea of a seaplane in 1874, and Fabre flew his float plane in March 1910, but it is Curtiss who develops the first practical float plane. In addition, he is credited with inventing the step that helps break the hydrodynamic forces that often prevent the float from leaving the water's surface. He also adds wheels, creating an amphibian that can operate on both land and water. On Nov. 12, 1912, at the Washington Navy Yard, a Curtiss Hydro will become one of the first aircraft to be catapulted. C. Gibbs-Smith, *Aviation*, pp. 44, 153, 161, 164.

And During January 1911

—French Capt. Albert Étevé tests the first practical airspeed indicator. C. Gibbs-Smith, *Aviation*, p. 158.

WPI

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Mechanical Engineering Department
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