October 2010

AEROSPACE AMERICA

X-51 scrams into the future

Conversations with Werner J.A. Dahm

Critical times for India's space program

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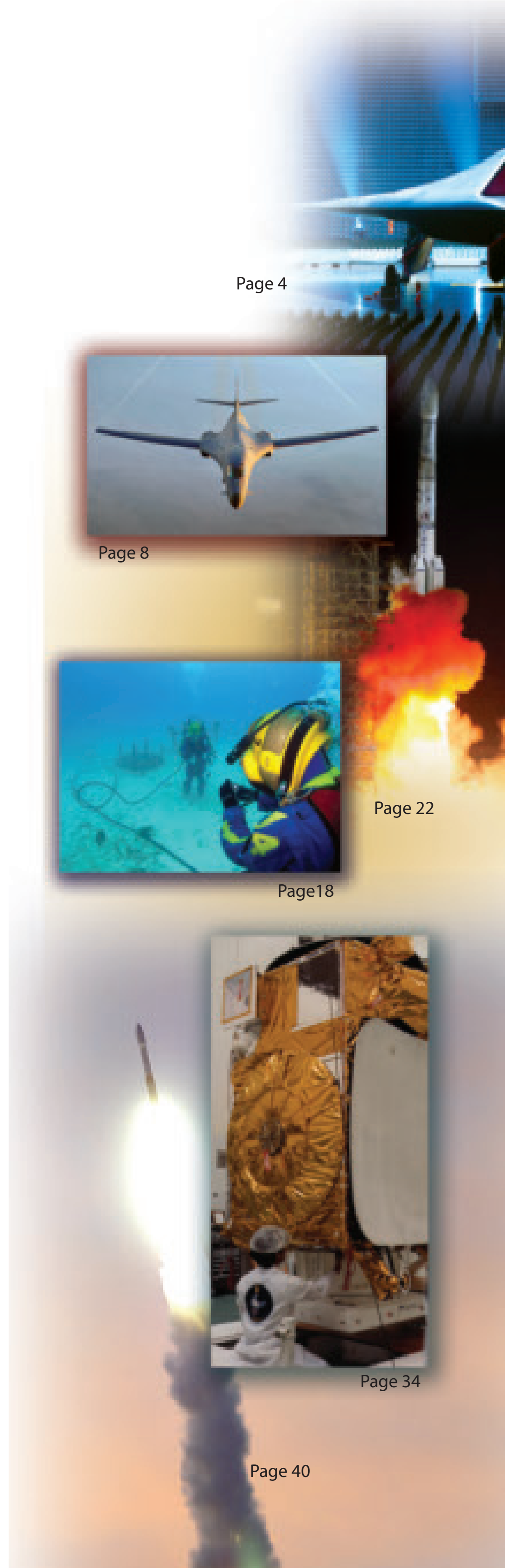

COVER

On May 26 an X-51A WaveRider, lofted by a converted B-52, took off on a historic flight, reaching speeds greater than Mach 5. To learn about this remarkable test flight, and the scramjet engine, turn to the story on page 26.

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Editorial

A good first step

On August 30, President Obama announced his plans for taking on the task of bringing some order to the unwieldy, irksome quagmire known as export controls. While the executive order he issued will begin the process of enabling some international trade to get back on track, much of the reform will require congressional action.

The president initiated the review of export control issues, and their impact on foreign trade, about a year ago. His August address outlining the administration's first steps toward reform should at least smooth out some of the bumps and curves U.S. corporations have encountered on the road to the global marketplace, and perhaps even shorten the travel time.

The first step—combining the U.S. Munitions List, under the purview of the State Department, and the Commerce Department's Commercial Control List, which covers many dual use items—should eliminate some delays, as decisions as to where items fell were haggled over, sometimes for years. Instead, there will be one tiered list, and "a single set of licensing policies that will apply to each tier of control" according to the announcement. The highest walls would be built around those most sensitive items in the top tier, which would receive the greatest scrutiny before the possible issuance of a license. A single set of licensing policies "will apply to each tier of control, bringing clarity and consistency across our system."

The president also announced an executive order establishing a single Export Enforcement Coordination Center "to coordinate and strengthen our enforcement efforts—and eliminate gaps and duplication—across all relevant departments and agencies."

Licenses will be managed by a single information technology system, rather than the maze of different systems and documents currently in place.

The address concludes with the promise of additional efforts, including "working to create a single licensing agency"—the brass ring in the export merry-go-round.

All of this represents progress in redressing some of the unintended economic harm that has resulted from efforts, beginning in the 1990s, to keep potentially damaging technology from falling into the hands of adversaries. What emerged, however, was a maze of rules and regulations, compounded by agency turf wars, that made the export of almost anything with a technology application a long, wearisome procedure. This prompted companies in other nations to develop themselves items they once would have imported. "ITAR-Free" became a marketing slogan in Europe and parts of Asia.

Some of those markets may be lost forever; some may be recompeted if this export control reform effort gains momentum. But a great deal of work remains to be done, and a good bit of it resides in the Congress. Decisions as to what items will remain on the munitions list, or the top tier, and which may be removed must be reviewed by House and Senate committees. If those committees continue to consider these changes by broad category, this new push may be for naught.

So, much work remains. But these initial efforts, eagerly awaited by industry, coupled with the recently created President's Export Council, led by Boeing CEO Jim McNerney and Xerox CEO Ursula Burns, are a pretty good first step.

Elaine Camhi
Editor-in-Chief

Europe charts path to sixth-generation fighter

At the Farnborough International Airshow in July, the European Defence Agency (EDA) signed a $512,000 contract with Sweden's Saab group for a study to map out Europe's current military aerospace and industrial landscape, identifying gaps where R&D projects will be needed to provide Europe's defense forces with European-sourced aerospace capabilities in the future.

That study, "The future of the European military aerospace Defence Technological Industrial Base (DTIB—Mil-Aerospace 2035+" (or "FAS4 Europe"), will involve a consortium of Europe's industry and is due to be completed by October 2011. Although the value of the contract is relatively small—and is overshadowed by the $47 billion worth of aircraft orders announced at the show—its strategic importance to Europe's aerospace industry is immense.

The EDA wants to develop a future air system (FAS) that will not just support EU, national security, and defense policies in the future but will also do so in a way that retains strategic aerospace and defense know-how within the continent.

"If we want to keep the capability to manufacture key defense equipment in Europe, thereby retaining the 'operational sovereignty' to act in future world events, we need to look beyond the immediate financial turmoil and focus now on what are the critical European defense industrial capabilities needed to meet future military capability requirements," said Alexander Weis, EDA chief executive, speaking at Farnborough.

It is important that, if the choices are at all economically possible, European Union member states retain the capability to source from the global market, Weis continued. He warned, however, that "military-unique industrial capabilities can be eliminated very quickly, and whilst theoretically industrial capabilities can be regenerated, this is normally unrealistic in both time scale and cost."

From national to continental

The study is part of EDA's European defense technological and industrial base (EDTIB) strategy, which seeks to develop a continental, rather than a national, defense manufacturing and research industry in the face of growing competition from the U.S. and Asia.

For decades Europe's defense departments have been struggling with the problem of how they can save money and access new technologies by working more closely with their neighbors on complex future military aerospace programs. While the Eurofighter Typhoon project has delivered a fifth-generation fighter through collaboration, it competes with other European combat aircraft—the Saab Gripen and the Dassault Rafale. Europe's military planners want just one European successor to these aircraft, and they want it without a pilot in the cockpit.

For the FAS project to be successful, it will need to be fused at some stage with the European Technology Acquisition Program (ETAP), a 2001 initiative by France, Germany, Italy, Spain, Sweden, and the U.K. to work together on

The U.K unveiled the Taranis UCAV in July.

FAS4 Europe consortium members

Saab AB is the lead company and main contractor of the program. Other consortium members are:

- Alenia Aeronautica SpA
- Association of the Aviation Manufacturers of the Czech Republic
- ASG Luftfahrttechnik und Sensorik GmbH
- BAE Systems
- Dassault Aviation
- EADS Construcciones Aeronauticas, SAU
- EADS Deutschland GmbH, Military
- ESD-Partners
- Hellenic Aerospace Industry SA
- Patria Aviation Oy
- SELEX Galileo Ltd.
- Thales Systemes Aeroportes SA
- Westland Helicopters Ltd.

Additional participating stakeholders:

- Avio Spa
- ITP
- MTU Aero Engines
- Safran SA
- Volvo Aero AB
- Aerospace and Defence Industries Association of Europe
- DA Design Oy
- Diehl Aerospace GmbH
- Equipment Industrial Management Group
- GMV-SKYSOFT (GMV)
- Intracom Defense Electronics SA

developing the technologies needed for a post-2020 future combat air system. ETAP comprises a series of technology demonstration projects (TDPs) covering areas such as stealth, avionics, airframes, and weapons guidance. The EDA has been commissioned to undertake TDP research into high-bandwidth datalink communications.

The future is unmanned

The obstacles to creating a common European sixth-generation air combat vehicle are substantial. Despite the EU's best efforts to create a single EU foreign and security policy, there are still substantial differences among European states in how they see their future role in the world. For example, larger European nations with a global naval capability, planning to deploy new aircraft carriers, will view FAS very differently from the way small, land-locked European countries view it. The ideological fault lines running through the continent have been underlined by Europe's failure to develop a single, common unmanned combat vehicle program, which would provide many of the key technologies for FAS.

In July, the U.K. Ministry of Defence unveiled its Taranis UCAV (unmanned combat air vehicle). The ministry's DE&S (Defence Equipment and Support) strategic unmanned aerial vehicle experiment, or SUAVE, group is responsible for developing the program. Although SUAVE is looking for partners in Europe and the U.S. to cooperate on the project, the current plans are for an autonomous U.K. UCAV to be deployed toward the end of the decade. In contrast, the nEUROn UCAV, masterminded by France's DGA defense procurement agency with support from Sweden, Italy, Switzerland, Spain, and Greece, is due to make its first flight in mid-2012.

European industry's most recent response to the problem is a report by the AeroSpace and Defence Industries Association of Europe's (ASD) Air Sectorial Group (ASG). The report outlines the key capabilities for what it defines as European future air power systems (EFAPS) and some of the key actions that will be needed to deliver the appropriate technologies. These include versatility, affordability, and the right mix of legacy system performance versus new development.

These are high-level requirements, but the ASG also highlights specific technologies that it identifies as areas where Europe will need to cooperate more closely—specifically, unmanned autonomous systems, novel weapons with key capabilities to cope with larger operational context, and new space or hypersonic capabilities.

First flight of the nEUROn is expected in mid-2010.

National governments, the EDA, aerospace industries (via the ASD), and, most recently, the European Commission have now been brought into debate on what sort of future fighter/strike aircraft Europe needs—and how industry can deliver in terms of time, cost, and technology. But the process is not likely to stop there. In February EDA and the European Space Agency (ESA) signed a series of contracts covering the integration of UAS vehicles within civil airspace—initially covering civil applications, but opening the door to more wide-ranging cooperative efforts.

Says Magali Vaissiere, ESA's director of telecommunications and integrated applications, "This contract signature marks the first milestone on the common EDA-ESA journey and paves the road for future joint activities—extending, possibly, also to other areas such as maritime security, and reaching at some point in time a global dimension."

(Continued on page 9)

Needed actions for developing EFAPS capabilities

The ASD's ASG has identified some of the necessary actions that governments and industry must undertake to ensure the continent's aerospace companies will be able to provide appropriate technologies for European future air power systems (EFAPS). The key capabilities, according to the ASG, will be:

•Network-enabled capability, or NEC, which will be essential to ensure information exploitation and situational awareness.

•Extensive use of multirole capabilities and commonality of subsystems.

•Longer reach and endurance to cope with broader operational scenarios.

•Increased Interoperability within national air systems, between national forces, and with civilian actors.

•Increased survivability where appropriate.

•Increased reliability, maintainability, and sustainability to support the customer along the extended life cycle.

To realize these capabilities, government and industry must work together to:

•Obtain the political support expressed in the EDTIB strategy and define near-term actions. The potential for civil and security exploitation of the capabilities developed and sustained by this strategy should also be taken into account.

•Agree on the mechanisms for funding the actions identified within an EFAPS roadmap to enable the start of required initiatives.

•Mature the requirements for the systems and reach commonality among the different nations.

•Provide necessary detail on the appropriate "national coordinated approach" for EFAPS, such as alignment of future investments, identification of common and unique national requirements, shareable/nonshareable capabilities, and the national sustainment and security of supply priorities.

•Define the system design process that considers both the maturation of the solution and the flexibility toward late changes in the requirements. The aspect of support and low life-cycle cost solutions must be considered a vital part of the process and involve the industrial base.

•Establish the required industrial capabilities, both for the military aerospace primes and for the supply chain, to meet future needs. Special attention should be given to enabling technologies where Europe is currently dependent on external sources, and to keeping the "cutting edge" in capabilities where Europe has primacy.

•Define and develop a future joint management of the implementation of EFAPS.

•Create the new business models and harmonized commercial processes that will be needed, from customers through prime contractors and into the supply chain.

Outlasting the opposition

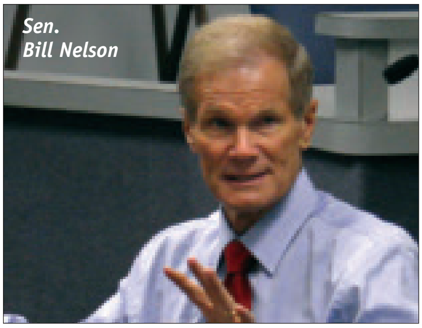
WITH CONGRESS IN RECESS, NASA AND defense programs faced continued delays and uncertainties. Legal obstacles to canceling Constellation, closing military bases, and eliminating some DOD offices did not bode well for an early end to the current holding pattern.

Unresolved plans for spaceflight

The future of spaceflight for U.S. astronauts was left undefined as members of Congress headed home in late summer, leaving behind conflicting proposals for a NASA funding bill in the Senate and House of Representatives.

Observers in Washington say that, on Capitol Hill, even the strongest critics of President Barack Obama's plan to privatize spaceflight are searching for a compromise, not a fight. But before Congress and the White House can achieve a meeting of minds on leaving behind the "old" Constellation program and ringing in the "new" commercial effort, legislation is needed: Currently NASA is prohibited by law from canceling any part of Constellation. And no one is expecting lawmakers to act until after the November 2 election at the earliest.

Until now, the government (through NASA) has overseen the design and development of virtually all U.S. spacecraft. Now, however, the Obama administration wants commercial firms to construct privately built space vehicles. Under the administration's plan, NASA would cancel Constellation, which was intended to build Ares I and Ares V rockets to carry astronauts back to the Moon aboard a spacecraft called Orion. The White House insists the Obama plan has the eventual goal of sending expeditions to the asteroids and Mars, bypassing the Moon, but has not spelled out how this will happen.


Sen. Bill Nelson


Sen. Sam Brownback

Until new legislation is enacted, elements of the old plan are alive, if not thriving. Although NASA Headquarters has banned the term Constellation in correspondence, scientists at Huntsville, Ala., and elsewhere are still working on Ares I and Orion. On August 23, Lockheed Martin announced the start of crucial tests of the Orion crew capsule, which, said the company's Larry Price, "is capable of supporting missions to LEO and beyond, to the Moon and deep space." A full-sized Orion intended to lift astronauts from the launch pad is a holdover from the old plan.

Midway between the old and the new is the Senate version of an FY11 NASA appropriations bill that provides for development of an Ares V-type heavy-lift rocket. This is a compromise that would keep enough of the old to protect a lot of jobs, says Sen. Bill Nelson (D-Fla.), who sponsored the bill with Sen. Kay Bailey Hutchison (R-Texas). NASA Deputy Administrator Lori Garver told reporters the space agency is ready to begin work on the heavy-lift rocket if Congress directs it to do so.

But the House version of the FY11 appropriations measure does not include the heavy-lift rocket and provides far less money for commercial space companies. In fact, the measure seeks to modify, rather than drop, Constellation's over-budget, technically troubled smaller Ares I rocket.

Under the administration's plan, NASA would proceed with Orion only on a much-reduced scale and only in a stripped-down version that astronauts would use as a lifeboat to escape the ISS in an emergency. NASA held an August 19 event for 35 companies interested in building commercial spacecraft and stressed that privately designed and developed vehicles are the "new" way for the nation.

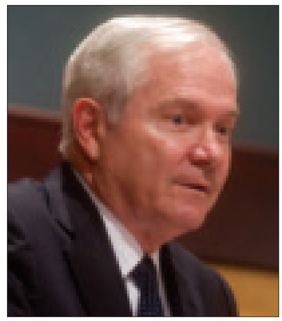
Nelson, the most visible space advocate on Capitol Hill, is clearly seeking compromise, and proposes legislation to offer tax breaks for investors and companies looking to develop commercial spacecraft. Nelson wants to create five business enterprise zones around the country in localities that already have NASA centers; qualified businesses in each Commercial Space Enterprise Zone would get a tax credit of 20-30%.

The idea of federal funding for commercial spaceflight is a natural on the campaign trail. Gubernatorial candidate Sen. Sam Brownback (R-Kansas) is promoting the deep-rooted aerospace industry of Wichita as a logical place for enterprise-zone spending. Elsewhere around the country, elected leaders are pushing their home localities.

While Washington awaits a postelection sort-out of future spaceflight plans, the shuttle will not be going to pasture on October 1 as once expected. NASA has delayed the two final shuttle missions by several months. The Senate's proposed spending bill would add a third flight that might take place as late as June of next year.

Air Force changes

On July 29, the Air Force—clearly anticipating belt-tightening measures by Defense Secretary Robert Gates—acted on



Secretary of Defense Robert Gates

An Air Force MC-12W arrives at Balad Airbase in Iraq.

its own to announce its largest shift of airplanes and people in decades. "This will get us right-sized," said a member of chief of staff Gen. Norton Schwartz's office. The changes affect 12,000 airmen and 680 aircraft, but not everyone sees much purpose to them.

Gates has already halted development of a next-generation bomber, mandated the retirement of 250 fighters that will not be replaced, and canceled a combat search and rescue helicopter. The only remaining large aircraft programs are the KC-X air-refueling tanker, which is unaffected by the changes, and the F-35 Lightning II Joint Strike Fighter.

Because the gain or loss of an Air Force or Air National Guard squadron affects jobs, the economy, and the prestige of a locality, many in Washington analyzed the changes in terms of winners and losers. In that context the big loser was Holloman AFB, adjacent to Alamogordo, N.M. Holloman became host to an F-22 Raptor wing only recently and to MQ-1B Predator and MQ-9 Reaper remotely piloted aircraft even more recently. In fact, when the Predators and Reapers came aboard, officials touted the "synergy" of high-tech RPAs operating alongside the high-tech F-22. The DOD spent $19.1 billion (according to the Air Force), or $40 billion (say local news reports), on building new infrastructure to accommodate the Raptors.

Now, the Holloman wing's two F-22 squadrons are being taken away. One will transfer to Tyndall AFB, Fla. The other, which had not yet reached full strength, will be deactivated. The service says its purpose is to consolidate F-22 operations at four bases—Elmendorf in Alaska, Langley in Virginia, Nellis in Nevada, and Tyndall. However, because of Sen. Daniel Inouye's (D-Hi.) enormous clout, one F-22 squadron will remain in Hawaii. The service says the change will enable most squadrons to have 21 aircraft instead of the current 18. The F-22 fleet is limited to 187 airframes, now that Gates has halted further production of the superfighter.

Holloman will pick up two F-16 training squadrons. Considering the fanfare with which the F-22s arrived at Holloman as recently as June 2008, the F-16s are very much a consolation prize. To make matters worse, Holloman was not chosen as a base for the JSF.

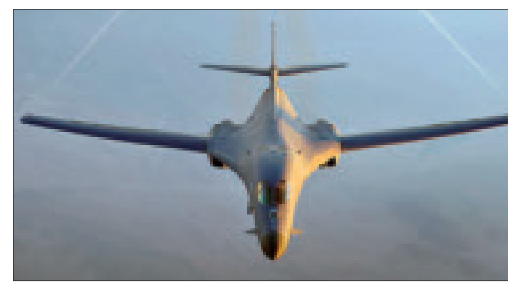
Also turned down as F-35 bases, after making strong bids, were Tucson Air Guard Station in Arizona; Boise Air Guard Station in Idaho; Mountain Home AFB near Boise; Shaw AFB near Sumter, South Carolina; and Jacksonville Air Guard Station, Florida.

The big winners, thanks to the F-35, are Luke AFB near Glendale, Arizona, Burlington Air Guard Station in Vermont, and Hill AFB, Utah. All will become operators of the Air Force's conventional takeoff and landing version, known as the F-35A.

Unchanged is the role of Eglin AFB, Fla., as the initial joint training base for JSF maintainers and pilots of the Air Force, Marine Corps, and Navy.

The Air Force picked Beale AFB in California as a new host for its MC-12W reconnaissance aircraft, based on the Beechcraft King Air 350-200. Two "finalists" to host the C-27J Joint Cargo Aircraft are Key Field, Mississippi, and the Ohio Air National Guard's Mansfield Lahm Regional Airport. These selections were a blow to the Maryland Air National Guard base at Glenn L. Martin Airport near Baltimore, which had hoped to operate the C-27J and will lose a flying squadron that, until now, operated the C-130J Hercules.

Several air stations vied for the opportunity to become home for the F-35.



A B-1B Lancer flies a combat patrol over Afghanistan. USAF photo/Staff Sgt. Aaron Allmon.

Gates defense changes

Gates has not imposed further changes on the Air Force, but draconian measures are being rumored for the near future. Speculation is focused on the Air Force fleet of 65 B-1B Lancer bombers, which have proven effective in Iraq and Afghanistan but are prohibitively expensive to operate. "We're expecting the axe to fall on the B-1B," said the member of Schwartz's staff.

Gates did, however, dangle two conflicting messages in front of Congress. The first was his announcement that he would like to retire from the top Pentagon post next year—in effect becoming a "lame duck" after a long run as one of the most influential defense secretaries ever. The second message was Gates'

Sen. Jim Webb

plan to close Joint Forces Command (JFCOM) in Norfolk, Va., hire fewer contractors in the Pentagon, and reduce the number of generals, admirals, and senior executives in the top ranks.

These proposals were widely reported as defense cuts, but Gates never claimed he was cutting defense costs. He said instead that he would be redirecting about $100 billion from administrative to operational needs to repair a force weakened by years of constant deployments and fighting.

Gates insists he has the authority to make these changes without action on Capitol Hill. Critics say he does not, and must rely on the cumbersome Base Realignment and Closure process, which can take years to produce a decision.

JFCOM was created in 1999 to transform the military and foster jointness. Gates' supporters say the command was needed then but is no longer essential now that the service branches operate jointly all the time. Because about $500 million of its $704-million annual budget pays for services by private contractors, many of them analysts, JFCOM is viewed as a tempting target for Gates' axe.

Outside the war zones, Gates wants to cut contractors by 10% a year for the next three years. But JFCOM also means jobs: The command employs 2,200 people in Hampton Roads and about 1,000 elsewhere. Gates has repeatedly acknowledged that his plan will cut thousands of jobs.

Predictably, and even while on recess, hometown lawmakers rose to challenge the Gates changes. Sen. Jim Webb (D-Va.), normally a supporter of Gates and of the administration, insisted that "further action by the president or Secretary Gates should be suspended until Congress has had ample opportunity to review the full scope of the secretary's actions."

In a move reflecting "political outrage," as *The Washington Post* termed it, Sen. Mark Warner (D-Va.) and four Virginia congressmen demanded that Gates reconsider. All said the future of JFCOM must be left to the BRAC process—which is tantamount to killing Gates' plan. When we went to press, the Senate Armed Services Committee was planning to hold a hearing when the upper house reconvened in September.

Gates also wants to get rid of the Business Transformation Agency, which oversees individual acquisition programs and, in his view, is redundant. He also wants to eliminate the office of the assistant secretary of defense for networks, integration, and information and the Joint Chiefs of Staff's command, control, communications, and computer systems unit.

Taking aim at "brass creep"—the phenomenon of higher ranking people performing jobs once carried out by those in lower grades—Gates plans to freeze the number of positions in his own office, defense agencies, and combatant commands for the next three years. No more full-time positions in the Office of the Secretary of Defense will be created after this year to replace contractors, except when "critical needs" are involved. Gates is also mandating a review of the Pentagon's numerous outside boards and commissions—which total 65 and cost $75 million each year in his own office alone. Rumors are also rife that Gates will reduce the number of military bands, which currently total about 60.

Gates is widely thought to hold the initiative when crafting defense policy, with relatively little guidance from Obama or the White House military office. He has proven to be a powerful force when trying to get his way. Few believed he would succeed in paring down the Raptor program, but he did. Observers of Gates' strong-willed actions say it would be foolish to count him out.

But the JFCOM issue could linger, and some in Washington who cannot beat Gates may seek to outlast him.

Robert F. Dorr
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Continued from page 5)

Larger strategic value

Given the large number of European bodies, commercial organizations, and national governments now involved in defining capabilities for a single European future air combat vehicle, it would be easy to conclude that all they are creating is a growing circle of debating forums, rather than a concrete decision-making process. But this is not necessarily the case.

Europe's defense ministries are engaged in a strategically important review of where they should be in the world and how their armed forces should be restructured to take account of the need to increase deployability, improve intelligence gathering, and enhance force projection capabilities, while decreasing personnel and equipment costs. These undercurrents all point toward fewer but more capable platforms, each interlinked with those of its neighbors.

According to Weis, "Europe's industrial capabilities will also need to be more integrated, less duplicative, and more interdependent. Increased specialization, at all levels of the supply chain, must take over from too many trying to do everything. And this is not about fortress Europe policies—we recognize that protected industries will not thrive in the global market—but rather about making ourselves better competitors and partners for our allies."

The debate has also highlighted the growing importance of the EDA as a program instigator. The agency has taken the lead role in the future tactical unmanned aerial system (FUAS) program, begun in November 2008 with the initial aim of developing a transnational maritime surveillance system—and which has since evolved to encompass tactical intelligence, surveillance, target acquisition, and reconnaissance operations for navy and army applications—for Germany, France, Spain, Finland, Poland, Portugal, and Sweden. The EDA Armaments Directorate plans to finish the preparatory phase of the unmanned VTOL program by the end of this year, with an in-service horizon in the 2016-2018 timeframe.

If FUAS hits all its milestones, it will enhance the authority of the EDA as a key player in enabling development of common European military aircraft programs. But a sixth-generation fighter or strike aircraft is something else—it goes to the very heart of how a government sees itself on the world stage, of what capabilities it wishes to deploy, and where.

Form follows function—and until Europe's disparate nation states can all agree on their future political role in the world, it will be hard for the continent's military aerospace planners to define the exact requirements of a common European sixth-generation aircraft.

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The Future Air Systems concept

In May 2008 European defense ministers agreed to work on identifying key industrial capabilities to support the development of future air combat systems. Following an EDA request asking which sectors should be prioritized, 23 European nations responded, voting on where they would like to see technology efforts concentrated. They highlighted combat aircraft, helicopters, and UAVs:

Combat aircraft	*14*
Trainers	*10*
Airborne early warning	*8*
Transports	*7*
Helicopters	*14*
Combat helicopters	*13*
UAVs	*17*
UCAVs	*10*

The EDA is targeting military aerospace as a test case in its strategy for more closely aligning European industry in support of common strategic targets, because aerospace, in terms of spending, jobs, and exports, accounts for 60% of the current defense technology industrial base.

The EDA is also working with the ASD's Air Sectorial Group in defining the critical elements of FAS research. This work includes identifying which European technological and industrial capabilities need to be maintained at a strategic level; where the critical gaps and/or dependencies on non-EU sources of supply are; how Europe's military aerospace global competitiveness can be enhanced; and which supply chain issues must be addressed. The support of the European Commission in this work is also being sought.

Werner J.A. Dahm

Let's begin with the Technology Horizons study that your office conducted for the Air Force. How would you describe it?

Technology Horizons is the product of a year-long assessment to identify the most essential science and technology [S&T] areas that the Air Force must focus on during the next decade and beyond, to prepare for the challenges it faces in 2020-2030. This was an immense effort. It not only determined the greatest technology opportunities for the Air Force, but it assessed them in the context of the strategic, technology, and budget environments during this time.

So how would you sum it up?

It is a guiding document for our S&T enterprise over the next decade. Twenty years from now, the Air Force will look very different from the way it looks today, and this will be partly the result of the technologies that the study identifies as being essential for the Air Force. It is vitally important.

Exactly why?

An organization that is as technology dependent as the Air Force cannot accomplish its mission without a clear understanding of what the high-payoff technologies will be. At some level, all technologies are valuable, but the point here is that we have sought to identify the most valuable—the disproportionately valuable—technologies that will define much of the Air Force in 2030.

The Air Force has conducted several such studies over the years. How does Technology Horizons fit in from a historical perspective?

The first study was Toward New Horizons, done right after WW II by Theodore von Kármán, and it really laid the technology foundation for much of the Air Force as we know it today. Since then the Air Force has developed an updated S&T vision at the headquarters level roughly once every decade. Technology Horizons is the latest in this series of major S&T visions for the Air Force.

Describe your role in all this.

The role of chief scientist in Headquarters Air Force is to give independent, objective technical advice to the highest levels of leadership and to help guide the Air Force's overall S&T enterprise. The biggest single thing that I have been asked to do by the secretary and the chief of staff of the Air Force is to lead the development of this vision. The office of the chief scientist has been involved in one way or another in developing several of the previous visions, but Technology Horizons is the first one that this office has been asked to lead.

Who else was involved?

We worked with inputs from the Air

Werner J.A. Dahm is chief scientist of the Air Force. He serves as chief science advisor to the chief of staff and to the secretary of the Air Force on a wide range of scientific and technical issues affecting the Air Force mission. Dahm interacts with Air Force operational commands, combatant commands, and acquisition and science and technology communities to address cross-organizational technical issues and solutions, also interacting with the other services and the secretary of defense.

Dahm serves on the Steering Committee and Senior Review Group of the Air Force Scientific Advisory Board (SAB). He is the Air Force's principal science and technology representative to the civilian scientific and engineering community and to the public at large.

Dahm has served on the SAB, where he chaired major studies on spectrum management and thermal management, having participated in two other SAB studies as well. He also chaired SAB science and technology reviews of propulsion and air vehicles in the Air Force Research Laboratory. He took part in the recent SAB review of the Air Force Office of Scientific Research and in two other SAB science and technology reviews. He has participated in four studies for the Defense Science Board and is a former member of the Defense Science Study Group at the Institute for Defense Analyses.

Dahm is on leave of absence as professor of aerospace engineering and as head of the Laboratory for Turbulence and Combustion at the University of Michigan. He is the author of more than 180 technical publications and holds several U.S. patents. He has given more than 220 technical presentations worldwide in the areas of fluid dynamics, turbulence, combustion, and propulsion.

He holds a bachelor of science degree in mechanical engineering from the University of Alabama in Huntsville, a master of science degree in mechanical engineering from the University of Tennessee Space Institute, and a Ph.D. in aeronautics from Caltech. Dahm has received numerous awards and honors, and is a member of the American Physical Society (Division of Fluid Dynamics), ASME, the European Mechanics Society, and the Interntional Combustion Institute, and is an AIAA Fellow.

Interview by James W. Canan

Force's major commands, its product centers, the Air Force Research Laboratory, industry, other federal agencies, and so on. My job was to ensure that we distilled all this down to develop the best possible guidance for S&T, given the strategic, technological, and budget environments that we face.

I am convinced that what we have delivered is immensely valuable for the Air Force, and it is already being used to help guide our S&T investments.

"An organization that is as technology dependent as the Air Force cannot accomplish its mission without a clear understanding of what the high-payoff technologies will be."

What part does your office play in developing Air Force programs and requirements?

The chief scientist's office serves in a technical advisory role. As the Air Staff builds operational requirements, there are technical elements involved, and we help contribute to the understanding of those elements. The senior leaders have many sources of technical input, but my office is supposed to be more than just another source. Our overarching requirement is to be independent and objective. The technical opportunities and risks in our programs have to be fully understood and must be communicated. The chief scientist's office is a resource that the leadership can count on to give them what we believe are the right answers, not necessarily what they might want to hear.

Is it more difficult to arrive at the right answers in science and technology than it used to be, back when weapons and other systems were more clearly defined and less technologically sophisticated?

Yes, it can be more difficult. For a very long time, Air Force S&T was mostly about how to make particular systems with particular purposes, such as a better air platform or a better propulsion system. Then we began entering a period in which the range of technologies got so broad, and the ways in which they could be mixed or matched to produce more kinds of capabilities became so numerous, that S&T guidance increasingly had to incorporate additional elements that are less narrowly technical.

Can you give an example?

Let's take autonomy. When is the right time to use more autonomy? In what kinds of systems, what kinds of processes? To what degree? There are technical elements to all these questions, but the answers require breadth as much as depth [of analysis]. The kinds of S&T insights that are most valuable to the Air Force leadership today are significantly different from what they were before.

The Technology Horizons report puts a great deal of emphasis on autonomy and autonomous systems. Please tell us about that.

We have been using autonomy for quite some time in the form of semi-autonomous platforms, such as remote-piloted aircraft [RPA]. But today's RPA have only relatively low levels of autonomy. For the most part, they are just automated systems. What we are talking about for the next decade and beyond is "autonomy writ large."

"What we are talking about for the next decade and beyond is 'autonomy writ large.'"

Explain that, please.

The difference between an autonomous system and an automated system is the autonomous system's ability to use information about its environment and, on its own—with some constraints—make genuine decisions about how it is going to execute the intent of the operator. The most important finding in our Technology Horizons document is that the Air Force today has the need and the opportunity to gain enormous capability increases, manpower efficiencies, and cost reductions through much, much greater use of autonomous systems.

Many of our operations are very manpower intensive. Some can be replaced or supported by autonomous reasoning and control systems that can operate much faster than humans can, especially in complex situations where humans are often not able to sift through large amounts of data and evaluate large numbers of alternative courses of action as well as autonomous systems can.

What do you mean by a fully autonomous RPA, for instance?

It would be capable of assessing its own battle damage, for example, and could autonomously decide how to adjust the way it executes its mission in order to maximize its remaining effectiveness. It might even be part of a much larger, fractionated system architecture in which individual RPA elements operate collaboratively to act as a coherent system. The entire system would be able to autonomously readjust its mission execution as individual elements are degraded, or as their operating environment changes. We are talking about a system that can take on very high levels of autonomy if the operator wants it to do so.

The software of autonomous systems must be incredibly complex.

Yes, and that makes its verification and validation [V&V] very difficult. That is a real challenge for us, because our ability to gain the enormous advantages of autonomous systems depends on this. Software used to be deterministic, in the sense that there were small numbers of possible inputs, and the logic paths that the software could follow were very limited. As a result, every one of them could be tested to ensure that there were no errors in coding or logic, so that the system did what it was supposed to do.

Over time, in part with the advent of massive processing capability, we were able to write software that could accept a large number of inputs and use those to go through potentially very complex logic processes. The result is that it became essentially impossible to test all of the combinations of states that such a system could operate in. In theory the inputs and outputs may still be deterministically related, but there is no way to test all these combinations.

Please explain all this with reference to an actual system.

Let's take the OFP—the operational flight program—in a modern fighter aircraft. That is an autonomous system. It is the software that runs the fighter. It runs all of the aircraft's systems—the engines, control surfaces, all of that. It takes in and processes not just information on the current flight speed, the wind, the altitude, and so forth, but a lot more, too, such as the RF [radio frequency] environment that the aircraft is working in, and the variety of signals it is being subjected to, and makes decisions about what the aircraft should do.

How do you devise and test operational flight program software?

It typically has many millions of lines of codes, and we no longer have humans writing those codes line by line. We use automated software generation for much of that, and that's a good thing. If those lines were still written by humans, the number of errors in them would be so large that we couldn't build those millions of lines of code. But when you put it all together, there are still logic errors in the OFP, typically about one for every 4,000 lines of code, and finding them is immensely difficult.

What does all that mean in terms of testing the code for accuracy?

The set of possible inputs is so large that not only can't we test them all, we can't test more than an insignificant fraction of them. Software glitches in an OFP are essentially unavoidable, because we cannot comprehensively test these programs anymore. So V&V is a major challenge for us today. It will be essential for enabling the high levels of autonomy that we need in future systems.

Back when software was highly deterministic, we could take a brute-force approach—examine all the inputs and see if the outputs made sense. We still largely do V&V that way, because we don't know how to do it any differently. Yet we know that we can test only a minuscule subset of all possible states of the system. Our ability to do V&V has not kept up with our ability to generate complexity in increasingly capable software.

That seems like a huge problem.

It is. For sure we need a fundamentally new insight into how to do V&V, not just better ways for how we do it today. The cost of developing and verifying the OFP, for example, is a major part of the overall cost of an aircraft system. And it is very hard to change the OFP. When we want to change it, we can't just tinker with it—we have to go back and completely revalidate the whole code at huge costs and with uncertain results. Quantum computing may eventually help, but that's far down the road. We need an approach we can implement in about a decade.

"The big issue is that potential adversaries have learned how immensely dependent on GPS our warfighting capabilities have become, and so they have focused on ways to deny us access to GPS."

Let's talk about the here-and-now S&T programs that your office is fostering for the Air Force. What are some of these?

There are many, but let's take GPS augmentation as an example. That is a very strong focus area for us right now. GPS is critical. It runs throughout everything the Air Force does, and everything our society and the world do, too. The big issue is that potential adversaries have learned how immensely dependent on GPS our warfighting capabilities have become, and so they have focused on ways to deny us access to GPS. We know that we will need methods to augment GPS in such situations.

What is the S&T community working on now?

One avenue is chip-scale inertial navigation and timing systems that give us a GPS-independent way of getting position and timing information. This uses chip fabrication technologies to make tiny IMUs [inertial measurement units] and clocks for miniaturized guidance systems.

In parallel with that, but in an earlier stage of maturity, is another technology, based on cold-atom approaches, that looks hugely promising. Despite the name, this has nothing to do with cryogenics. It traps a set of atoms and molecules in a narrow range of quantum states—matter at the quantum level is a wave. Matter waves have wavelengths that are very much shorter than light waves, and—without going into too much detail—that lets us use interferometry to build tiny and ultraprecise inertial navigation units based on those cold atoms.

Explain the practical effect of all this.

Sure. For example, this would enable a GPS-guided aircraft or missile to still have an accurate position system when it enters a hostile environment that is GPS-denied. Once it loses its GPS connection, its cold-atom system takes over, and it can fly then for hours, maybe days, and still have the level of precision in position that it would have had with GPS all the way through.

So this would be a good guidance system to have on an ocean-spanning, precision-strike hypersonic missile?

Absolutely. Precision strike is based on a delivery vehicle or munition being able to know where it is relative to its target coordinates. Currently, precision strike becomes very difficult in regions where GPS information is denied. In our Technology Horizons report, we noted that the third most important area for Air Force S&T to focus on—after autonomous systems and augmenting human capacities by autonomy and other means—is ensuring our freedom of operations in contested and denied environments. We can no longer count on having access to GPS the way we have over the past 20 years.

Many more countries have the technology to deny us access and threaten us in other ways too, I gather.

The whole global science and technology landscape has changed. The number of countries that have S&T programs that are peers or near-peers to ours is growing. Given the worldwide access to the Internet and to the growing number of technical publications—upwards of 10,000 every single day—someone on the other side of the world can come up to speed very quickly in just about any S&T area and be doing leading-edge work on militarily relevant technologies very quickly.

Speaking of hypersonic missiles, how is that area of S&T coming along?

Our hypersonic X-51 WaveRider had a successful first flight not long ago, and so did a hypersonic vehicle developed in HIFiRE, a basic science research program that the Air Force is conducting in partnership with Australia. Both programs look promising. HIFiRE is focused on advancing our understanding of the fundamental physics of hypersonics, including boundary-layer transition and scramjet inlet flow characteristics.

From X-51, we now know how to achieve sustained hypersonic flight, and we know about how large an investment it will take to advance to real systems. Now we have to weigh the advantages of hypersonic flight against the risk of competing technologies in the rest of the world denying us those advantages.

"Now we have to weigh the advantages of hypersonic flight against the risk of competing technologies in the rest of the world denying us those advantages."

How about your work on new ways of gaining access to space?

The TSTO [two-stage-to-orbit] program that we are doing with NASA is a very important one in terms of future air-breathing access to space. The Air Force has focused on rocket-based, combined-cycle designs; NASA has done turbine-based designs. From what we have seen so far, rocket-based systems are very attractive. We are now moving to a more detailed, level-2 design of the complete system, so that we can begin to really understand, for a fully integrated system, how those advantages and disadvantages will carry forward.

Is directed energy finally coming to the fore as a potentially useful weapon?

Definitely. Let's take laser-based directed energy for tactical strike as an example. We are on a roadmap now via our ELLA [electric laser on a large aircraft] program to integrate a solid-state electric laser into the forward weapons bay of a B-1 in 2017. The laser system will be a complete module that is inserted in the weapons bay in the same way as a bomb rack and is then hooked into the aircraft's thermal management system. We will conduct demonstration tests with the fully integrated system.

We have seen high-energy laser programs come and go for many years. What are this laser's prospects for becoming an actual weapon?

Airborne lasers, especially at tactical scale for strike and self-defense, will give us a very important low-collateral-damage weapon system. We've been working on them since the 1970s—first gas dynamic lasers, and then the chemical oxygen iodine laser that flew on the strategic-scale ABL [airborne laser] missile defense aircraft and on the ATL [airborne tactical laser] C-130 demonstration program. In each case, technology moved along and displaced each of these lasers with better ones.

"As with any S&T program, the central question is: How long do we continue to invest in a current technology before we find that there is a better way to do it?"

Is the technology progression endless?

As with any S&T program, the central question is: How long do we continue to invest in a current technology before we find that there is a better way to do it? So we have to decide what we can afford to put into a given technology—not just from a budget point of view but from an intelligent investment point of view—knowing that there are other technologies that might displace it rather quickly.

My job as the chief scientist is not to make budget decisions, but to help understand how big the technical challenges are and how long the lifetimes of technologies will be.

Jetliners: Bright spot in the world economy

In the great 2009 recession, exactly one major segment of the commercial economy held up with no pain: Large jetliner output increased, despite the worst economy the world had seen since WW II. This is not because jetliner production is a lagging economic indicator; deliveries will stay at a high level this year, and Airbus and Boeing are largely concerned about logistical challenges to any future production rate increases.

This somewhat unexpected market performance was certainly welcome in an industry more accustomed to painful cyclical downturns. It also raises questions about the scope of further growth and any risks that lie ahead.

Mystery achievement demystified

The year 2009 was the first since WW II to see a global economic contraction. In all, worldwide economic activity dropped by about 1%. Not surprisingly, this resulted in the worst year in jet aviation history. According to the International Air Transport Association, RPKs (revenue passenger kilometers) dropped by 3.5% in 2009. Cargo (freight ton kilometers) fell by an unheard of 10.1%.

Economic and air travel contractions like these have historically produced unpleasant jetliner market busts. The economic indicators clearly pointed to a jetliner production drop of more than 30%, which historically is typical for a bust cycle. Most other industries felt severe pain. Indeed, the World Bank's unit value of manufactured exports fell at a rate of 4.9%.

A320

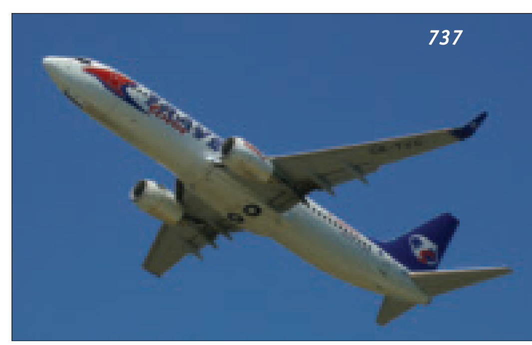
Yet the large jetliner industry's behavior was anomalous relative to both its history and the global economy. Regional jet deliveries fell by 5.7%. Business jets fell by 24.3%. Civil helicopters fell by 12.5%. Yet the large jetliner market grew by 10.1%. Much of that was Boeing output recovering from the 2008 machinists' strike, but some of this growth was organic. Airbus output grew by about 2% as well.

Several factors differentiate this downturn from previous ones. The first major difference that helped to keep jetliner output high involves fuel prices. Normally, a recession of this magnitude translates into slack oil demand, which means lower prices. Yet while the price of oil came down from its July 2008 record high of $147/barrel, by historical standards it has stayed stubbornly high.

While high fuel prices made new jets considerably more appealing than older types, past demand downturns usually have resulted in serious financial problems at the airlines. The credit crunch of 2008-2009 also had the potential to keep carriers from obtaining financing for the planes they wanted. This brings up the second major difference with this cycle: An increasingly high level of government financial support.

The most direct government help came in the form of ECA (Export Credit Agency) financing, which reached all-time record levels. ECAs such as the U.S. Export-Import Bank increased their presence in the market, helping with about 35% of transactions. In addition to ECAs, government-owned banks such as Bank of China and sovereign wealth funds have confidently gotten into jetliner funding. The percentage of deliveries going to airlines with government financial backing also increased. Chinese and Mideastern carriers, typically owned by governments, both took delivery of a record number of jets, as a percentage of the total world market.

Government support for the jetliner business also took indirect forms. Government actions taken to stabilize major financial institutions such as AIG, the Royal Bank of Scotland (RBS), CIT, and others forestalled massive fire sales of the aircraft. Imagine if AIG had had to force its ILFC unit into dumping its portfolio on the market to generate cash. Repeat that with a few other lessors and you would have seen a particularly severe jet glut, creating low prices for used jets that would have made many of them more competitive against new jets.

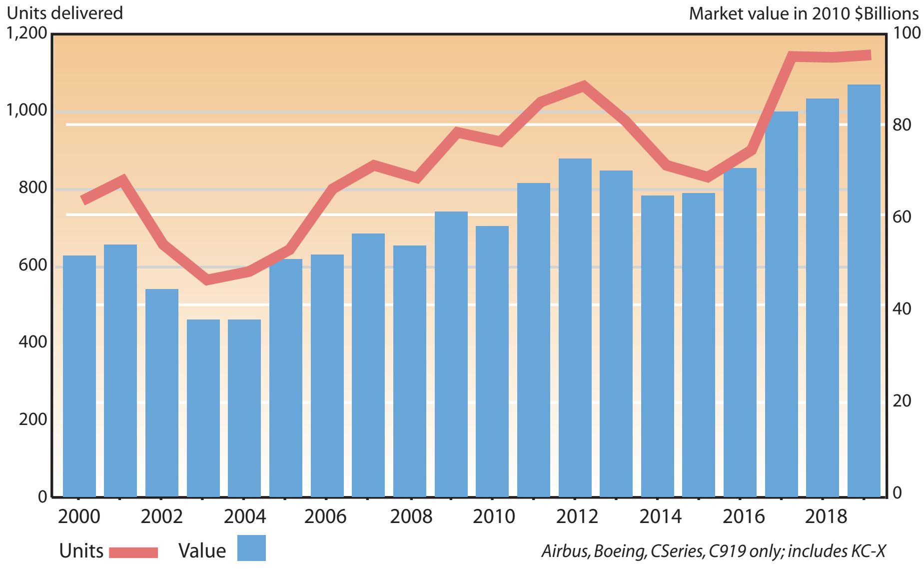


737

Government policy has also helped create the third factor that is different with this downturn. Thanks to low interest rates set by central banks that are eager to stimulate the economy, the world is now awash in cash that has nowhere else to go. With few investment opportunities in housing or new technology—or much of anything else—investing in jets seems smart, or at least harmless. Thus, orders at the July Farnborough Air Show were largely from lessors. Almost all of these were for the Airbus A320 and the Boeing 737, the two jet families with the best asset value track records and the broadest end-user market.

Meanwhile, air transport demand has come back strongly. RPKs indicated a 7.9% increase in the first half of this year relative to the first half of 2009. Cargo shipments have risen at a faster pace, corresponding with a remarkable comeback in world trade. Not surprisingly, both Airbus and Boeing have announced production rate increases. If these industry health indicators are sustainable, then all the actions taken to sustain jetliner production in 2009 and 2010 were worth it, from the standpoint of keeping output steady and avoiding unpleasant layoffs and revenue drops.

COMMERCIAL JETLINERS: HISTORY AND FORECAST



Airbus, Boeing, CSeries, C919 only; includes KC-X

Risks ahead

Yet there are big risks with this optimistic prognosis. While the air travel industry is doing very well, the economic recovery that should be its primary driver has been relatively muted, with the developed world experiencing fairly anemic growth. U.S. second-quarter 2010 GDP growth, for example, was just 2.4%. The International Monetary Fund is forecasting euro-zone growth of just 1% for this year. Japan saw only 0.4% growth in the second quarter. Even China is starting to slow, although its numbers are still enviable. The Chinese government now expects that the second quarter's 10.3% rate will fall to 8-8.5% by the fourth quarter.

Clearly, there is a degree of separation between today's air traffic numbers and the broader economy. Travel demand is currently disconnected from, and much better than, the economic indicators that typically drive them. Stock prices, GDP growth, inflation (or even deflation), bond rates, retail sales, housing inventories, employment, and consumer confidence numbers in the U.S. and Europe all show continuing uncertainty. We have seen this disconnect before. In 2008-2009, plummeting air traffic numbers were much worse than the prevailing economic indicators.

The jetliner primes would maintain that we should ignore U.S. and European numbers and focus instead on the strong economies of China and the Mideast. But the recent orders have all been for lessors, and those Chinese and Mideast airlines already have large order positions of their own. So do the established low-cost carriers. The lessors are not looking at China and the Mideast as their core markets. They are betting that the rest of the world economy will keep coming back despite economic uncertainties. Yet if there is a double-dip recession, traffic will drop again. That recession is unlikely, but any kind of serious slowing of economic growth represents the greatest risk to this market.

The second risk is basically political risk. This arises when politicians control a much broader swath of the economy. Most of the 2009 deliveries financed by private banks and lessors were arranged before the credit crunch. Although this crunch is easing, many key jetliner financiers remain under heavy pressure, particularly AIG's ILFC unit, CIT, and RBS. Any government decision to scale back ECA finance, or to cut government support for government-backed lessors or airlines, could hurt jetliner demand.

The third biggest risk is irrational exuberance at the airline level. Airlines have returned to profitability largely because they held the line on capacity growth. That 3.5% RPK demand drop in 2009 was accompanied by a 3% ASK (available seat kilometer) capacity cut, which allowed airlines to avoid ruinous losses. Halfway through this year, capacity was up just 2%, meaning the 7.9% RPK increase has translated into superb


787

profits. With multiple airlines now adding capacity, there is a danger that any kind of market slowdown could result in too many seats chasing too few passengers.

On a related note, the fourth risk concerns irrational exuberance at the manufacturer level. Both jet primes have announced plans for modest, incremental increases. But if they get too aggressive, any market slowdown would have an unpleasant impact, particularly on the supply chain that would need to add capacity to serve the jet primes.

There are also valid reasons to question the strength of some of the backlog. For example, at Farnborough, Airbus announced a large A320 order from Air Lease, with deliveries beginning in six months. The availability of these production slots is cause for concern.

The fifth risk concerns damage to existing jet portfolios. While demand and financing for newer jets have been strong, older jets have not recovered their predownturn values and lease rates. It is also relatively difficult to find financing for these older jets. Recent financial troubles at several midsized and small airlines, particularly Mexicana and Italy's Wind Jet, also indicate the dependence of older jets on less healthy and somewhat marginal players in the aviation business. All of this, of course, means financial pain for lessors and other finance providers who had planned on these assets better holding their values. Also, if the wide spread between new and old jet values and lease rates gets even wider, those old jets will get irresistibly cheap, undermining new jet values and demand.

Finally, there is significant risk to aftermarket business models. With a very high level of new jet production relative to capacity growth, the world's jet fleet is getting younger; thus older, more maintenance-intensive aircraft will be retired faster or consigned to marginal markets with lower utilization. Seventy 737 classics were parked in early 2005. That number is up to 260 today, and retirements of this type are ramping up. Many companies in the supply chain sold their original equipment at a discount in anticipation of strong revenue as aircraft got older. These manufacturers are likely to face lower aggregate margins, and will find that they need to adjust their pricing strategies.

Powered by technology

One unusual aspect of this market is that the "modern" planes now in high demand are not particularly modern. This is not a typical case of new technology serving as a market stimulant; rather, the market is simply buying newer copies of jet families that have been in production for 10-20 years, particularly Boeing's 737NG and Airbus' A320.

This raises an intriguing question: If all-new technology with even lower fuel and maintenance costs were available, would the market be propelled to even greater heights? Assuming the answer is yes, the market can look forward to a strong, technology-induced growth wave starting in the middle of the decade.

Boeing's 787 will be the first to arrive. While it will enter service late this year or in the first half of 2011, deliveries will likely ramp up gradually, eventually reaching 10 per month by around 2014. Around the same time, Airbus' A350XWB will arrive. These two long-range midmarket twinjets offer significant cost savings over their predecessors, the 767, A330, and 777-200ER.

Just after these new twin-aisle jetliners arrive, we will likely see a new version of the A320 series, using Pratt & Whitney's Geared TurboFan (GTF), and perhaps General Electric/Safran's Leap-X engine. There is a good chance that Boeing will be forced to follow Airbus with a product reengining. Bombardier's GTF-powered C Series will also arrive in this period. Our forecast assumes that Airbus will introduce its new product in the second half of 2015, with Boeing following one year later.

In all, our forecast calls for the current plateau to be sustainable, with a few small production increases. Our 2010 jetliner forecast calls for a 4% decline by value from 2009, but this is due solely to a temporary dip in 777 numbers and the transition between the 747-400 and -800. While we do call for a narrowbody market dip immediately before the new reengined versions arrive, Teal Group also forecasts a technology-driven upturn, starting around 2016.

All of this, of course, assumes that the world economy will cooperate. The current macroeconomic environment, which combines a respectable level of growth with relatively high oil prices and government-assisted liquidity, might not continue indefinitely.

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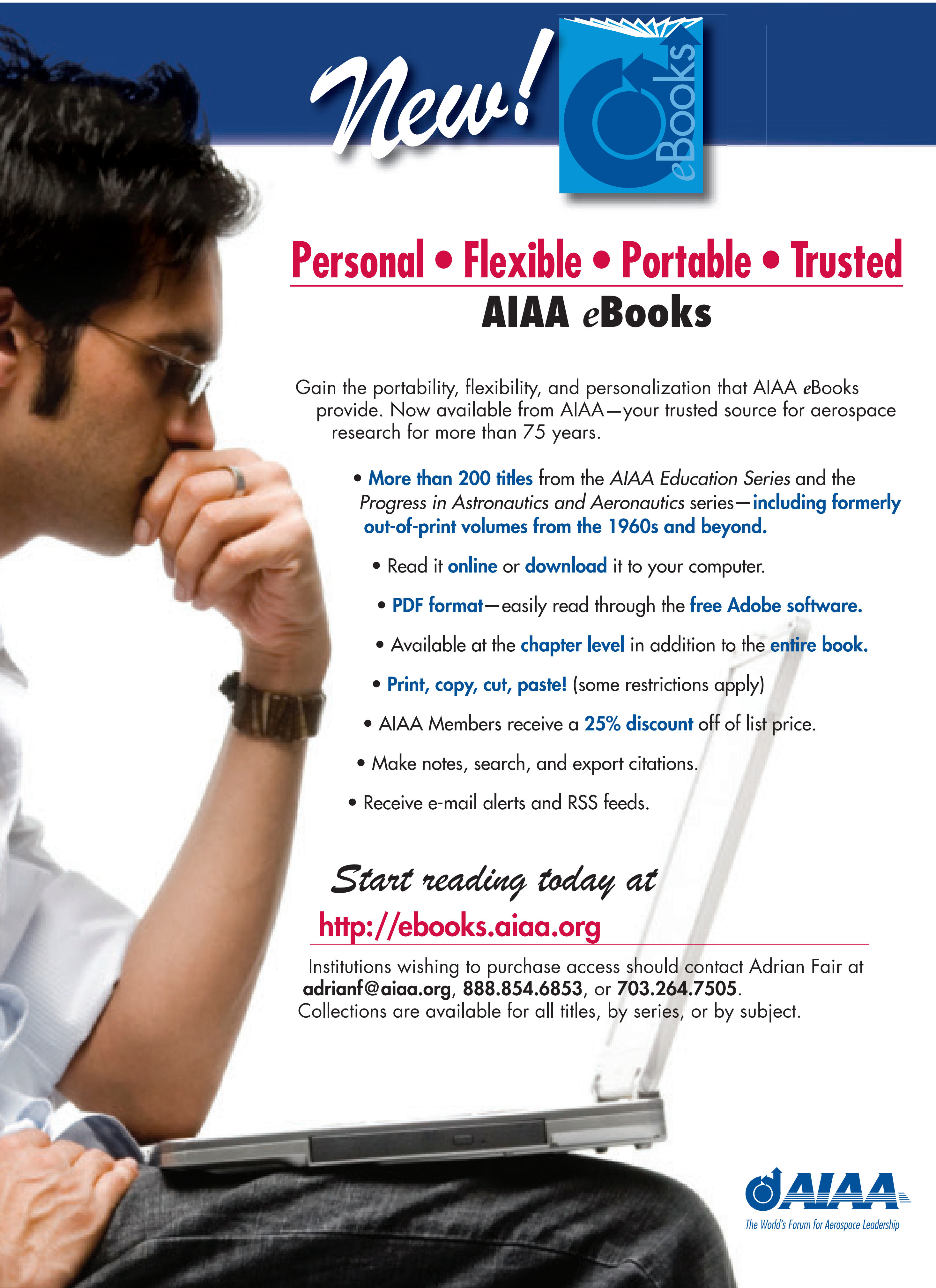
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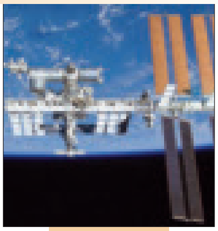


Ad astra: The future of NASA's astronaut corps

"THERE IS NO EASY WAY FROM THE EARTH to the stars" (Non est ad astra mollis e terris via) wrote the Roman philosopher Seneca the Younger in the first century A.D. Given the uncertain future of NASA's human spaceflight plans, the Stoic's words must resonate with present and prospective members of NASA's astronaut corps. They face the 2011 end of the space shuttle era, inaugurating a decade when perhaps only 40 U.S. astronauts may journey to Earth orbit. By contrast, when I first flew as a shuttle crewmember, NASA launched 84 astronauts in just two calendar years, 1994-1995. But those days are gone, and today's corps must grapple with shrinking flight opportunities, new training challenges, and serious questions about the future of human space exploration.

The Soyuz TMA-19 rocket launches from Baikonur Cosmodrome on June 16 carrying Expedition 24 NASA Flight Engineers Shannon Walker and Douglas Wheelock, and Soyuz Commander Fyodor Yurchikhin, to the ISS. Photo credit: NASA/Carla Cioffi.

From a high of about 140 astronauts when I left NASA in 2001, the Astronaut Office numbers today about 65 flight-qualified crewmembers. In addition, a dozen or more veteran astronauts continue to work for the agency in nonflying management roles, contributing hard-won operations experience. For the active astronauts, the mission is clear: To train for and fly expeditions aboard the ISS, and when not flying, to support their colleagues who do.

The six crewmembers of each ISS expedition generally serve six-month tours, and an average of a dozen astronauts and cosmonauts will live aboard the station annually. By partner agreement, Russian cosmonauts fill half those slots. This leaves two for other ISS partner astronauts and four for Americans, all of whom fly aboard the four Russian Soyuz spacecraft, launched annually to provide crew transport and emergency escape at the station. After 2012, the number of U.S. astronauts needed to crew ISS, fill the training pipeline, and cover office technical assignments is about 55, says Brent Jett, chief of flight crew operations at NASA Johnson.

Training for long-haul spaceflight

The ISS has been manned continuously for nearly a decade, starting with the November 2, 2000, arrival of Expedition 1. Supplying crewmembers to keep the station productive and operable for another 10 years is the challenge for the current astronaut corps. Jett, who flew four shuttle missions and commanded STS-115 in 2006, noted in an interview that he personally envies ISS crewmembers, who "really get a chance to 'live' in space," as opposed to just "enduring" the hectic, flat-out sprint of a shuttle mission.

But that long-duration experience has come at a high price. The normal ISS training flow has often exceeded three years, with half the time spent at Russia's Star City for systems classes, simulations, and, for the Americans, a steady diet of Russian language courses. The first few years of ISS expedition training followed the Mir-era "backup crew" model, with each crew of three shadowed by a replacement team that could step into the shoes of the prime crew right up through launch day.

But such last-minute substitutions seldom happened, and backup crewmembers were then fed back into the training grind for a year or more before their own turns came. Watching his prime crew rumble aloft from Baikonur on a trail of golden flame, one backup cosmonaut once turned to his U.S. colleague and wryly lamented the prospect of starting over: "We are now considered the dumbest cosmonauts on the planet."

ISS training managers have now instituted a concept called "single flow to launch," where the backup team trains with the prime crew through launch, then tackles only six more months of expedition-specific classes before flying. First-time flyers typically spend about 2.5 years training for an expedition, says Jett, with less than two years needed for repeat ISS flyers.

Although the travel and family separation burden is still hard on crewmembers, the single-flow streamlining reduces those stresses and makes it more likely that some astronauts will volunteer for a second long-duration flight. Repeat flyers include Peggy Whitson (now chief of the Astronaut Office) and Jeff Williams. Their colleagues Mike Fossum, Don Pettit, and Sunni Williams have all been assigned to their second ISS tours (29, 31, and 33, respectively).

Still hiring?

Shannon Walker, the last member of the 2004 class to fly, is now at the ISS with Expedition 24. Nearly all of the astronauts who will fly on the station in the next decade have already been hired. Will NASA shut down its astronaut selection process? Not at all, says Whitson—NASA will continue to hire them in small

Cosmonaut Fyodor Yurchikhin and NASA astronaut Shannon Walker, both Expedition 24 flight engineers, occupy their seats in the Soyuz TMA-19 spacecraft. On June 28 the crew relocated the Soyuz from the Zvezda service module's aft port to the Rassvet mini research module 1.

numbers, both to replace the few who will leave with the shuttle's final flight and to introduce younger crewmembers into the corps.

"We get literally thousands of applicants," says Whitson, who served on the 2004 selection board and chaired the 2009 panel. "We want a diverse group of candidates," she explains. "People with different backgrounds—pilots, scientists, engineers—can learn from each other." Test pilots share their operational and decision-making experience, while scientists teach their classmates about how research—on the ground or at ISS—gets done.

The 23 members of my 1990 "Hairball" group trained for the challenge of the space shuttle; in 1990, "Space Station Freedom" was just a stack of viewgraphs, and few of us imagined we would ever fly aboard an orbiting outpost called the ISS. The station is now the only flight opportunity available, and astronaut hiring and candidate training reflect that reality.

Formal astronaut qualifications are posted at http://nasajobs.nasa.gov/astronauts/. Jett says that in addition to meeting educational, professional experience, and medical standards, an astronaut candidate, or "ascan," must fit the part physically. Because Russia provides both the crew transport and emergency escape vehicles at ISS, "we won't select a candidate [who can't] fit in a Soyuz."

Who makes an ideal candidate? Whitson, who spent more than a year on orbit with Expedition 5 and as commander of 16, says she's looking for "people who are easy to work with and be around." Surveys of expedition crews, she says, have ranked traits such as "self-caring, team-oriented, good follower, and leadership" at the top of those desired in a future astronaut. A high-maintenance crewmember is poison on a long-duration flight, or even a shuttle mission.

My 1990 classmates were hired either as mission specialists or pilot astronauts. But when the nine new U.S. hires of the 2009 group complete their training, they will be termed astronauts. Only when named to an ISS expedition will they receive temporary designations such as "flight engineer," "U.S. segment lead," or "commander."

Always training

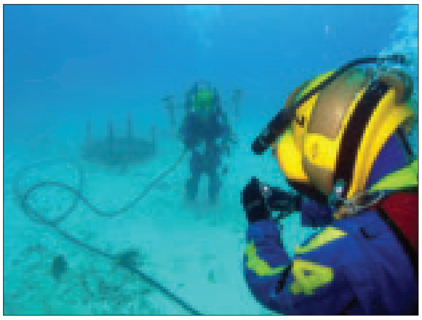
Although the hiring process is not perfect, Whitson thinks the training that candidates receive can confirm first impressions and produce astronauts with the right skills and temperament to succeed aboard ISS. Flight Crew Operations has already refocused astronaut candidate training for the coming decade of long-duration missions.

Jett says that "the astronaut corps is not immune to the fundamental changes that NASA is undergoing, the biggest in 30 years. But in many ways we were better prepared for change, because we already knew the shuttle era was ending." U.S. astronauts have also known since 2005 that Soyuz would be their ticket to LEO for years, pending the development of shuttle's successor. "Other than the current uncertainty [about NASA's long-range direction], not much has changed," says Jett.

The curriculum for the 2009 astronaut class reflects this reality. None of its members will fly on the orbiter, so except for a few ascent orientation sessions in the shuttle mission simulator, shuttle training has been supplanted by ISS and Soyuz systems training, long-duration skills in areas such as robotics and EVA, and Russian language classes.

The language classes are an integral part of Soyuz training. Jett says that he wants to see an experienced U.S. crewmember in the left, flight engineer's seat, working directly with the center-seat Russian commander on rendezvous, proximity operations, and emergency procedures. Shannon Walker took on this demanding engineer role during her June launch to ISS. The right-seater is less responsible for piloting tasks but still has duties in orbit operations and emergencies. Soyuz skills will carry over to

The class chosen in 2009 will train in the NEEMO subsea habitat.




Astronauts Stephen N. Frick (front) and Rex J. Walheim, STS-122 commander and mission specialist, respectively, prepare to fly a NASA T-38.

operations in new commercial or NASA-built vehicles when these appear.

For the past 10 years, ascans have also participated in expedition training. This exposes them to field experiences that showcase team-building and leadership, often under wilderness conditions. The 2009 class members will find themselves on physically demanding treks with the National Outdoor Leadership School, underwater at the NASA Extreme Environment Mission Operations (NEEMO) subsea habitat, or trekking through snow-laden forests with Canadian military survival experts. Instructors critique the candidates' performance in leadership roles, and expedition members see how their colleagues get along in a stressful work environment that demands effective teamwork.

My classmates and I began our 1990-1991 ascan training in the classroom, then practiced in part-task trainers, moving up finally to the mission simulator. Instructors gave few, if any, exams; we demonstrated our competence in practice, but this made it difficult for supervisors to assess individual performance.

Ascans today are evaluated systematically by experienced instructors and astronauts, and NASA is no longer shy about giving feedback. Those who cannot meet standards after supplemental training are dropped from the program before graduation. Throughout the ISS expedition training, right up through launch day, evaluations continue. Russian instructors sent the members of a recent Soyuz crew, a little rusty during their final simulator session, back for refresher training before clearing them for their station launch.

Value of the cockpit

One challenge for Whitson and Jett is exposing new ascans to the dynamic decision-making environment characteristic of spaceflight. Fast-paced emergency-filled sessions in the shuttle simulator in Houston were at the core of this process. But the ISS simulator is better suited to systems or facilities training, where problems unfold over hours or days, and maintenance or repairs might take weeks, as with the August coolant pump package failure.

But spaceflight emergencies do not always grant astronauts the luxury of time. Life-and-death situations can arise quickly, especially during launch and landing, or in the risk-laden hours of a spacewalk. The most effective generic training for those situations, says Jett, comes at the controls of an airplane.

"The value of aviation training is that decisions made in the cockpit have real-world consequences," he explains. No simulator offers that same dynamic environment, demanding a steady stream of critical thinking and decisions, small and large, that determine one's survival. Flying, or "spaceflight proficiency training," gives ascans from a wide range of backgrounds a common grounding in the art of good judgment.

During the shuttle era, astronauts flew T-38 Talon jet trainers, and shuttle pilots trained in the STA (shuttle training aircraft), a modified Gulfstream business jet capable of replicating the orbiter's approach performance and handling qualities. The STA will retire with the shuttle, and the T-38 complement at NASA's Ellington Field aircraft operation in Houston has already dropped from 30 to about 20 aircraft, reflecting the smaller size of the astronaut corps and the reduced need for high-performance jet proficiency in largely ballistic vehicles such as Soyuz, Orion, or many commercial designs.

As the T-38, originally an Air Force trainer, approaches 50 years in service with the astronaut corps, NASA is examining other aircraft to complement the Talon. Candidates include business jets for practicing crew coordination, or modern turboprop trainers like the T-6 Texan II, suitable for introducing the complex aviation environment to ascans without flying backgrounds.

21st-century astronauts

What mix of skills will a future astronaut corps need? Will there be opportunities beyond the current LEO/ISS/Soyuz operations? Jett says he had planned in 2012 to assign a cadre of about six experienced astronauts to flight testing of the Orion vehicle, but that plan is on hold until a firm schedule emerges for either a stripped-down, LEO-only Orion or commercial vehicles.

Veteran astronaut Linda Godwin, who works with Jett in Flight Crew Operations, says much depends on who will be doing the driving: Will commercial vehicles follow a "rental car" model, requiring NASA astronaut operators, or a "space taxi" concept, where commercial crews or ground-based operators deliver a NASA crew to the station?

The astronauts will be involved in the design and testing of any NASA-built spacecraft that emerges from current congressional and White House debate. They also stand ready to advise commercial designers on meeting human spaceflight standards and operations requirements. Beyond 2020, NASA explorers and their international partners may undertake exploration on NEOs, on the Moon, or at Lagrange points such as Sun-Earth L2. These tasks will require scientific exploration skills different from those needed on ISS.

Outside government, commercial access to space may lead to privately owned facilities in LEO. Employee astronauts would tend these, serving in positions ranging from adventure tour guides to researchers in orbiting industrial facilities.

Ken Bowersox, who led ISS Expedition 6 and is a veteran shuttle commander, is now SpaceX vice president

NASA astronaut Tracy Caldwell Dyson, Expedition 24 flight engineer, prepares to exit the Quest airlock of the International Space Station to begin the first of three planned spacewalks to remove and replace an ammonia pump module that failed July 31.

for astronaut safety and mission assurance. He says NASA will need ISS crewmembers who "have the right mindset for long duration [and are] able to deal with the ups and downs in the pace of an expedition."

In contrast to the short, high-intensity sprint of a shuttle mission, ISS crewmembers have the luxury of time. "You can't focus for six months on station with that same intensity," Bowersox says. "On ISS, you can afford to make a mistake, with the knowledge you have time to recover." He points out that the fundamental reason for flying an astronaut is to add value to that specific mission. "We'll need different types....perhaps with broader backgrounds, maybe more experience in the sciences or other activities than in operations."

Corps of Discovery

Today, NASA's projected human spaceflight manifest is relatively high on mandays in LEO, but low on individual opportunity. I waited just under four years for my first spaceflight; new astronaut hires may have to wait a decade, and future flight assignments depend on Washington decisions not yet taken.

If a new program crystallizes in the next few years—whether expeditions to near-Earth objects, a journey to Lagrange points, or pioneering the Moon—crews for testing new vehicles and flying operational missions will be drawn preferentially from the ranks of experienced ISS astronauts. In the tradition of Lewis and Clark, the nation will need a Corps of Discovery to challenge such new frontiers. While cruising the weightless modules of the space station, the astronaut corps is acquiring the judgment, leadership, scientific skills, and—perhaps most important—the stamina needed to navigate the uncertain corridors of NASA's future.

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Space launches spike upward

THIRTY-FIVE SPACE LAUNCH MISSIONS WERE attempted during the first six months of this year. Only two of the missions failed, India's GSLV 1 rocket on April 15 and South Korea's Naro 1 on June 11. The number of missions is slightly more than the 34 posted in the first half of 2009. There were also two launch failures during those six months, Orbital Sciences' Taurus XL booster on February 24 and North Korea's Taepo Dong 2.

The Long March and the Proton, opposite, are two of the most active launch programs.

Based on launch activity through the end of June, recent-year launch totals, known launch manifests worldwide, and the predictable trend of more launches in the second half of the year than in the first, we project that the total number of missions attempted for this year may surpass 80 for the first time since 2000. For most of the past decade, the annual launch numbers have hovered between the mid-50s and mid-60s.

More active launch programs

There is now clearly a trend upward, and it is being driven by a combination of three factors: Most of the major launch vehicle programs are as active as they have been in the past decade; some of the traditionally less active programs have begun to pick up the pace of their launches slightly; and a few new launch vehicles have been introduced.

There are five launcher programs that we classify as highly active—programs that consistently launch five or more times a year. They are Russia's Soyuz and Proton, Boeing's Delta II, Arianespace's Ariane 5, and China's Long March family. In 2009, all but one of them—Long March, which was coming off a record 11 launches in 2008—launched as many as or more than they had at any time in recent memory. Those four vehicles alone accounted for nearly half of all the launch missions attempted last year.

Soyuz had an exceptional year, with a total of 12 successful missions. For a launch vehicle program to average one mission per month is unheard of these days. Meanwhile, the Ariane 5's seven missions were at around maximum capacity for that program.

Whenever the most active launchers happen to have a good year together, the probability of a robust launch market increases significantly. That is what occurred last year, and (with the exception of the Delta II) this year it appears to be happening again.

This probability of a robust market rises even more when we factor in activity by a second group of launch vehicle programs that account for an average of one to five missions annually. These less active but established programs include NASA's shuttle, Sea Launch's Zenit 3, ULA's Atlas V and Delta IV, Japan's H-2A, Russia's Cosmos 3M and Dnepr 1, India's PSLV, Eurockot Launch Services' Rockot 1, Space Exploration Technologies' Falcon 1, and the Air Force's Minotaur I. Most of these programs posted average to good launch activity last year.

From a relative standpoint, the shuttle, Atlas V, and Rockot 1 had an excellent year in 2009. The space shuttle launched five successful missions, more than at any time since 2002—the year before the loss of Columbia. Atlas V's five missions were more than the vehicle had ever launched in its eight-year career. And the three missions for Rockot were a record for that 20-year program.

Had we only taken into account activity by the established launcher programs, 2009 would have been a fairly dynamic year. Not since 2000 has there been a year when more launches were attempted. The addition of three new launch vehicle programs made last year stand out just a little more as the most active period for the global launch services industry in recent years, with a total of 75 missions attempted.

Three new vehicles made their initial flights last year—South Korea's Naro 1, Iran's Safir 2, and North Korea's Taepo Dong 2. Although their impact on the launch market is slight, these programs do contribute to the upward trend in launch activity we are now seeing.

Both South Korea and Iran are currently developing satellites they would like to launch aboard their own vehicles for the sake of national pride, as well as the more pragmatic purpose of gaining independent access to space. Consequently, we believe that at least the Naro and Safir programs may eventually produce vehicles that could compete in the market.

South Korea seems especially determined to move forward with Naro. After the vehicle's failed maiden launch on August 25, 2009, the government moved quickly to launch a second Naro earlier this year. That mission failed as well, but it suggests that South Korea is determined to field an operational vehicle as soon as possible. It is easy to speculate that Naro could accelerate North Korea's efforts to develop its Taepo Dong 2.

The introduction of new launch vehicles continued this year with the successful maiden flight of SpaceX's Falcon 9 medium- to heavy-lift rocket on June 4. We anticipate the first launch of Orbital Sciences' new Taurus II during the first quarter of next year. Both of these vehicles have been contracted by NASA to provide commercial resupply services for the ISS as part of the Commercial Orbital Transportation Services program.

Civil and military payloads rule

So what is driving all this activity? Why do so many of the launch vehicle programs seem to be so busy at about the same time? It is understandable that some rockets would be more active than others in a given year. But lately it seems like a larger number of vehicles than usual are launching at relatively high rates in roughly the same period.

If you look at the types of payloads launched to Earth orbit during 2009 and the first six months of this year, the largest percentage is civil. Last year, 43% of all payloads launched were civil. During the first half of this year, 52% were civil payloads. By comparison, only 27% of the payloads launched last year were commercial, and 26% were military. During the first six months this year, 35% of the payloads were military and only 13% were commercial.

In short, there are clearly more civil and military payloads being launched, and far fewer commercial ones. In 2009, the number of civil payloads launched grew by 13%, military payloads by 33%. The number of commercial payloads launched last year was down 30%. This trend continued through the first half of this year. In fact, even fewer commercial satellites were launched during the first six months of 2010 than during the same period last year, while many more military payloads were placed in orbit. Civil payloads launched have remained on pace with last year's numbers.

The preponderance of civil payloads is due largely to a rise in the number of ISS missions launched by both the shuttle and Soyuz. Normally, there are three or four space shuttle missions launched annually to transport assembly hardware for the ISS, and six Soyuz missions to transport crews and supplies to the station. In 2009 there were four shuttle and eight Soyuz flights to the ISS. As of the

VEHICLES LAUNCHED (by program)

	2005	2006	2007	2008	2009	2010*
Soyuz	11	11	11	8	12	6
Proton	7	6	7	10	10	6
Delta II	3	6	8	5	8	0
Ariane 5	5	5	6	6	7	2
Atlas V	2	2	4	2	5	2
Space shuttle	1	3	3	4	5	3
Long March	5	6	10	11	4	4
Zenit 3	4	5	1	6	4	0
Delta IV	0	3	1	0	3	2
H-2A	1	4	2	1	3	0
Rockot 1	2	1	0	0	3	1
PSLV 1	1	0	2	3	2	0
Cosmos 3M	3	1	3	3	1	1
Dnepr 1	1	2	3	2	1	3
Falcon 1	0	1	1	2	1	0
Minotaur I	2	2	1	0	1	0
Naro 1	0	0	0	0	1	1
Safir 2	0	0	0	0	1	0
Taepo Dong 2	0	0	0	0	1	0
Taurus XL	0	0	0	0	1	0
Tsyklon	0	1	0	0	1	0
Atlas IIIB	1	0	0	0	0	0
Falcon 9	0	0	0	0	0	1
GSLV 1	0	1	1	0	0	1
M-5	1	2	0	0	0	1
Molniya M	1	1	1	1	0	0
Pegasus XL	1	1	1	2	0	0
Shavit 1	0	0	1	0	0	1
Shtil 1	0	1	0	0	0	0
Start 1	0	1	0	0	0	0
Titan 4B	2	0	0	0	0	0
Volna	1	0	0	0	0	0
Zenit 2	0	0	1	0	0	0
Total	**55**	**66**	**68**	**66**	**75**	**35**

*Through June.

PAYLOADS LAUNCHED (by type)

	2005	2006	2007	2008	2009	2010*
Commercial	19	24	35	40	28	7
Civil	29	44	48	39	45	27
Military	22	27	37	18	27	18
University	3	18	5	7	5	0
Total	**73**	**113**	**125**	**104**	**105**	**52**

*Through June.

NASA has contracted with both the Taurus II (left) and Falcon 9 for resupply missions to the ISS.

end of June this year, there had been three shuttle and five Soyuz flights to the station, surpassing last year's pace.

The shuttle will be launched for the last time in 2011, and will cease playing a role in carrying assembly hardware to the ISS. But this kind of payload was going to drop off anyway, given the scheduled completion of the station next year.

Launches of civil payloads to the ISS will continue for the foreseeable future, but these will consist of crewmembers and supplies. Soyuz rockets will continue to launch an average of six Progress resupply and Soyuz crew capsules annually, while new vehicles such as Falcon 9 and Taurus II will help with resupply missions using the Dragon and Cygnus capsules, respectively.

A secondary factor in the growth of civil payload numbers involves the recent push by the governments of Iran, North Korea, and South Korea and by SpaceX to field new rockets. When governments develop launch vehicles, it is usually for deploying civil and military payloads. The initial payloads assigned to these vehicles are often small scientific or technology development satellites that, at least officially, are designed for civil, not military, purposes. This has been the case with the Naro 1, Safir 2, Taepo Dong 2, and Falcon 9.

Both the failed Naro missions carried 100-kg STSAT scientific satellites for the Korean Aerospace Research Institute. The Safir reportedly launched Omid, the 37.2-kg experimental communications satellite for the Iranian Space Organization. The North Korean government stated that the Kwangmyongsong 2 civil communications microsatellite was aboard the failed Taepo Dong. And the Falcon carried a demonstration Dragon capsule in preparation for a series of Dragon missions to the ISS for NASA.

While civil payloads are clearly the most numerous in the launch market, it is military payloads that have shown the most dramatic growth during the past two years. There is no single factor that accounts for this. The U.S. and Russia are launching roughly the same number of military satellites they usually launch—8-10 each. The difference lately is that most of the countries that are capable of building and launching military satellites have been actively doing so.

From 2009 through June 2010, China, France, Germany, Israel, Italy, and Japan, as well as the U.S. and Russia, have built and launched military satellites. Germany and Japan have each launched more than one military satellite; France has launched three. This phenomenon is similar to what is happening with launch vehicle programs—nearly everyone happens to be active at about the same time.

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The X-51A flight test vehicle is uploaded to a B-52 at Edwards AFB, July 17 for fit testing. USAF photo/Chad Bellay.

X-51 scrams into the future

by Mark Lewis
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On the long road to achieving practical hypersonic flight, progress has been incremental, with each advance building on the work of earlier programs that were canceled or curtailed. But the recent first flight of the X-51A, with its airbreathing scramjet engine, is a milestone that skeptics in this field cannot ignore.

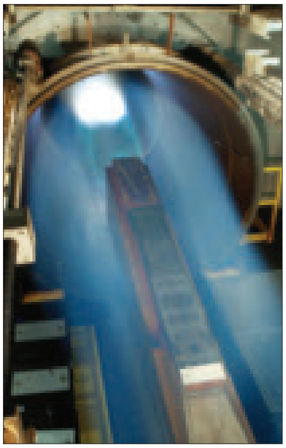
Edwards AFB, May 26: A converted B-52 bomber taxis down a runway in the high California desert, carrying beneath its wings the first of four experimental X-51A flight test vehicles, and with it the hopes of the airbreathing hypersonics research community.

Even mounted on its solid rocket booster, X-51A is dwarfed by the B-52 mothership. With a nose often described as shark-like, the test vehicle is about 14 ft long, sporting a chin-mounted rectangular inlet and four small control surfaces at the rear. The airframe is a type of "waverider," designed to ride on top of the shockwave that is generated at supersonic speeds for highly efficient aerodynamic performance. One of X-51A's greatest advances is its engine—a supersonic combustion ramjet, or scramjet—which is designed to power the craft through the atmosphere at hypersonic speeds, in the Mach-5 realm and beyond.

On that May morning X-51A saw its first flight test, the culmination of a nearly seven-year R&D effort whose continuing goal is the realization of practical hypersonic flight. Spawned from a DARPA activity called the Affordable Rapid Response Missile Demonstrator, which was canceled in 2000 (and also initiated the Navy's HyFly program), X-51 had begun as the Scramjet Engine Demonstrator (SED). That program was part of a joint USAF-NASA effort that shared an engine similar to NASA's canceled X-43C, a planned hydrocarbon-fueled follow-on to X-43A.

In a very real sense, the X-51 program incorporated lessons learned from many preceding efforts (including the ill-fated X-30 National Aero-Space Plane). This first vehicle was designated an X-plane by the USAF to denote its experimental intentions; the letter A indicates it is the first in a series of X-51 craft, with later versions incorporating new engine designs and improved systems.

The plan was for X-51A to be carried aloft on the B-52 and dropped at nearly 50,000 ft altitude over the Pacific Ocean, where a converted Army solid rocket booster would light off, carrying the stack to nearly Mach 5. At that point, X-51A's airbreathing scramjet engine would take over and provide up to 250 additional seconds of powered, accelerating hypersonic flight, with a goal of reaching Mach 6 before engine cutoff. Though



In 2008 the SJX61 successfully completed ground tests simulating Mach-5 flight conditions at NASA Langley.

AB-52H Stratofortress performed a captive carry flight of the X-51A in December 2009 over Edwards AFB. USAF photo/Mike Cassidy.

it did not quite reach those goals, X-51A would set a new milestone in high-speed flight that day.

Mounting suspense

Just getting to flight was quite a challenge; a previous day's attempt was scrubbed right before takeoff because a freighter had sailed into the projected splash zone. As the various engineers from the Air Force, NASA, and industry gathered after that abort, there was a palpable sense of gloom. The range at Edwards would be available only one more day; after that, a new launch window would have to be identified for some undefined future time.

With the threat of indefinite postponement looming, the test crew also noted that the weather report was discouraging—predicted cloud cover could force another flight cancellation. Even worse, the space shuttle was due to land in Florida that next day, but its possible alternate landing at Edwards could supersede X-51A's flight clearance.

As the May 25 evening gathering was winding down, Curtis Berger, Pratt & Whitney's lead for hypersonics—and the man who had overseen the development and test of X-51A's SJY61 scramjet engine—announced his unwavering confidence in a successful flight for the next day. "I know we're going to fly tomorrow; I just feel it," Berger insisted to all who would listen.

As it turned out, Berger was absolutely right. Morning dawned bringing news that the shuttle had landed safely in Florida. The sky at Edwards was absolutely cloudless, removing fears of a weather scrub. As the launch window approached, patrol planes operating out of the Navy's Point Mugu station confirmed that the test area was clear of all traffic. The flight was a go. By about 10 a.m. local time, the B-52 was aloft, piloted by Lt. Col. Dan Millman with copilot Maj. Swami Iyer of the 419th Flight Test Squadron.

Huddled over displays inside the observers' monitoring room were engineers from AFRL and NASA, representatives from prime airframe manufacturer Boeing and engine lead Pratt & Whitney, as well as other guests, collectively seeming to will the B-52 into the air. Among them was Parker Buckley, who had retired as the chief of AFRL's Aerospace Propulsion Office and had overseen X-51 when it began as the SED program.

Also present were Pratt & Whitney Rocketdyne's manager of defense marketing and strategy, Joaquin Castro, who reminisced about the origins of the program, and Boeing's Kevin Bowcutt, who recounted his original design work on X-51A's airframe. Randy Voland, who had retired from NASA, offered observations from his experiences as lead engineer on X-43 six years earlier.

In the main control room, the Edwards AFB flight test crew monitored every sensor on board, overseen by Lt. Col. Todd Venema, director of the Hypersonic Combined Test Force. Among the Edwards team was the legendary Johnny Armstrong, who began his storied career in Air Force flight test with the supersonic X-2 and had participated in every major high-speed flight out of the California base in the past five-and-a-half decades.

The test begins

As the B-52 began its climb out over Point Mugu on the coast of California, all eyes in the control room were on the computer graphic of the projected flight path, a racetrack pattern over the Pacific Ocean. The plan was for the pilots to fly one practice run, line up at the drop point, and then circle back round and do it a second time for real. Their launch was to occur in a very precise imaginary box in the atmosphere, and with a very specific requirement for the aircraft's speed at the time of launch. Both the required altitude and speed pushed the performance limits of the B-52 and taxed the skills of its talented flight crew. In fact, the usual Air Force chase planes would have been unable to follow the bomber, so NASA provided its Dryden-based F-18s to fill that role.

On its practice leg, the B-52 passed exactly through the desired point in space where the launch was to occur; but as it swung around for the second run, the aircraft appeared slightly off course. Amid puzzled cries of "What's he doing?" from the control room, the B-52 gradually corrected course, compensating for some unexpected winds. By the time the bomber was at the launch point, Lt. Col. Millman had it at a near-perfect bull's-eye within the desired launch box.

From that point, events happened very

quickly. The X-51A dropped from the B-52; 4 sec later the booster lit flawlessly and the vehicle was off, rocketing quickly out of sight of the chase planes. X-51A's separation from its booster was also flawless; the scramjet ignited exactly as expected using ethylene to begin the combustion process, then switched smoothly to hydrocarbon JP-7, the same jet fuel that powered the SR-71 Blackbird. Engineers in the control room noted immediately that the X-51A was accelerating uphill on its scramjet engine, forever proving that hypersonic airbreathing engines can produce thrust greater than drag.

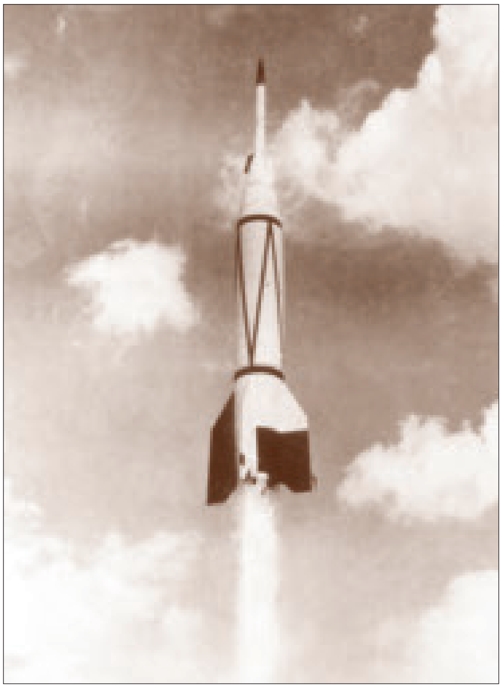
On the aircraft, pilots Millman and Iyer had decided at the last minute to flip down their helmet visors before the drop—good thinking as it turned out, since the booster was indeed very bright. They also reported feeling the X-51A drop away from their aircraft, then felt the concussion as its solid rocket motor lit off while they rolled the B-52 away from the drop point.

Total flight time of X-51A was approximately 200 sec, including about a minute on its first-stage rocket booster. This flight time exceeded each of the X-43's powered flight durations by a factor of about 13. During its airbreathing flight, engineers noted that the X-51A's flowpath temperatures were steady and behaved exactly as expected, and that engine pressures (and thus thrust) were actually higher than had been measured on the ground in the 8-Ft Tunnel at NASA Langley.

The engine ultimately cut off about a minute and a half short of its intended goal of 300 sec. As a result, acceleration, though positive, was somewhat shy of predictions, and the vehicle did not reach its ultimate desired Mach-6 speed. That premature termination did little to spoil the excitement and satisfaction of those who had just witnessed what, by any description, was overall a successful flight. Every critical point in the flight worked flawlessly, including, most significantly, the transition to sustained airbreathing propulsion. Engineers are still examining flight data to identify the cause of the early termination, but strong evidence suggests it was an engine-airframe integration problem, related to a nozzle seal that failed soon after engine start.

Major leap forward

Program Manager Charlie Brink, normally known to be unflappable, was understandably upbeat. "We are ecstatic to have accomplished most of our test points on the X-51A's very first hypersonic mission," he said. "We [view] this leap in engine technology as equivalent to the post-WW II jump from propeller-driven aircraft to jet engines."



In February 1949 Bumper became the first vehicle to enter the hypersonic realm.

Is the X-51A's first flight really that significant? Almost certainly the answer is yes. In many ways it represents the next logical step in the quest to fly at hypersonic speeds through the atmosphere. In a very real sense the X-51 program has built on the experience of previous hypersonic flight tests going back to the NASA-Air Force-Navy X-15 and including NASA's X-43A, which reached Mach 7, and later Mach 10, in 2004 under scramjet power. Indeed, a number of the NASA engineers who had designed and flown the X-43 worked in support of the X-51 program, and significant tests of the X-51 were conducted in NASA wind tunnels, drawing on that agency's hard-won expertise.

Where the X-43 craft operated a scramjet engine for only a few seconds on fast-burning hydrogen fuel, X-51 uses more conventional, and more easily handled and packaged, hydrocarbon jet fuel, for a duration representative of an actual missile flight. In addition, the X-43 engines were heat-soak designs—meaning the solid metal of the engine walls absorbed some of the intense heat of combustion, but would ultimately have melted if the engine had continued operating past a few seconds. In contrast, X-51 is a thermally balanced design, with active cooling of the engine walls provided by the fuel itself, meaning the engine could operate for as long as fuel is supplied.

The X-15 (above) and X-43 were precursors to the X-51 in the effort to master hypersonic flight.

Another significant difference is engine startup: Where X-43 primed its engines with highly volatile silane, X-51 uses a more manageable ethylene to begin the combustion process. Further, X-51 is much closer to a final missile configuration, directly pointing the way to practical near-term hypersonic designs.

There were also important similarities between the two vehicles. Both were rocket-boosted to scramjet speeds off the wing of a B-52. Both were developed from waverider aerodynamic shapes. In the case of X-43, the airframe was a scaled-down version of a cruise vehicle, which was itself loosely based on a waverider-derived concept for the X-30 National Aero-Space Plane. X-51 was designed directly with a waverider forebody, for very efficient aerodynamics and inlet performance, but both airframes benefit from using that advanced aerodynamic shape.

The engineers behind X-51 followed best practices for successful flight test. Extensive measurements were performed in NASA and DOD ground facilities to fully characterize in-flight performance. The vehicles have been thoroughly instrumented to maximize the data return. But in keeping with the most recent advances in the field, X-51 has also been thoroughly analyzed with powerful computational tools, using basic research codes developed to capture as much of the real physics as possible. At the same time, X-51 minimized risk where possible, especially for elements not directly related to the hypersonic components. For instance, its on-board digital controller is an off-the-shelf computer from a fighter aircraft, not quite state-of-the-art, but extremely reliable and relatively inexpensive.

A long history

To fully understand the importance of X-51's first flight test, it is useful to consider its place in the history of high-speed flight. Hypersonic flight has been a reality since the first spacecraft and ballistic missiles reentered from space. Bumper, a WAC Corporal sounding rocket mounted on top of a captured WW II German V-2, became the first vehicle to enter the hypersonic realm, in February 1949. Since that time, every astronaut returning from orbit or beyond, and every probe entering a planetary atmosphere, has done so at hypersonic speeds.

But while these applications have all been for short durations, or while decelerating, the current focus on hypersonic flight is aimed at sustained flight using engines that burn fuel with oxygen from the atmosphere. To this end, the X-51 vehicles, like the X-43s before them, are powered by scramjets, generally seen as the most promising engines for air-breathing hypersonic flight.

Two researchers at the National Advisory Committee on Aeronautics, or NACA. the precursor to NASA, wrote the first detailed theoretical description of a scramjet engine in 1958. Working at the Langley Center, R.J. Weber and J.S. McKay produced technical note number 4386, which described a means of flying a ramjet engine at higher speeds by keeping the flow moving through the engine at supersonic speeds.

Ten years later, one of the X-15 rocket planes was scheduled to fly the Hypersonic Research Engine on a ventrally mounted pylon. The X-15 program was canceled before a functioning engine could be flown, but not before a flight test with a dummy engine that almost ended in catastrophe.

Throughout the 1970s, theoretical and ground-based experimental work proceeded on scramjets at reduced levels at NASA and various laboratories around the globe. They were envisioned as the engines of choice for the ill-fated X-30 NASP in the 1980s, and in several follow-on concepts. However, it was not until a small team from the University of Queensland flew a scramjet on a sounding rocket in July 2002 at the Woomera Range in the Australian Outback that supersonic combustion was achieved in flight.

That first flight test produced thrust that was smaller than the engine's drag, by design, but still served as a definitive proof of the possibility of combustion in a supersonic flow. It was followed soon after by NASA's X-43 vehicles, each of which was a subscale version of a fully integrated airframe blended with a hydrogen-powered scramjet, and each of which showed that scramjet thrust could be greater than drag, albeit for only a short time, and with high-energy hydrogen fuel. The X-51 vehicles are full scale, and can be seen as leading directly to a high-speed weapon system.

Burgeoning efforts

Today, there are hypersonic flight programs in progress in the U.S. and throughout the world. DARPA's HTV-2 unpowered hypersonic reentry glider flew an aborted test on April 22 of this year; the USAF's unmanned reusable X-37 successfully began its flight the same day. In the Woomera range, researchers from the USAF, NASA, and the Australian Defence Science and Technology Organisation have already begun a series of sounding rocket flights under the joint HiFire program. And the U.S. Navy, with DARPA support, was pursuing the HyFly program, though after three flight faliures unrelated to its hypersonic engine, that program is now dormant.

The X-51 program itself has a long way to go, with three more flight vehicles ready to fly, and more concepts for evolved airframes and engines on the drawing board, including an X-51B with a modified, 3D inlet.

As these programs evolve, there can be little doubt that the hypersonic frontier will be systematically pushed back, and that the potential uses of hypersonic technology for both civilian and military applications will be refined and explored.

Among skeptics in this field there is a saying that "hypersonics is the future…and always will be." But the May 26 flight ensured that no one will ever be able to question whether a high-speed airbreathing engine can power a vehicle in sustained atmospheric flight. As Curtis Berger of Pratt & Whitney said in the control room that day, "Hypersonics is the future, and the future is *now*."

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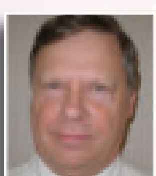

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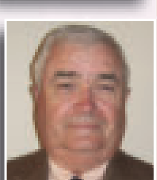

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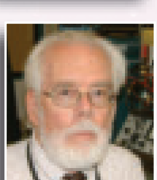

de Florez Award for Flight Simulation
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Electronics Engineer
Aerospace Simulation Research & Development Branch
NASA Ames Research Center
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Essam Khalil
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Cairo University
Cairo, Egypt

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Michael Gass
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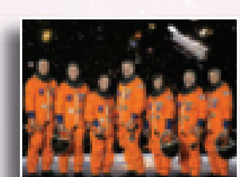
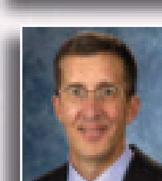


Haley Space Flight Award
STS-125 Team
Award Accepted by:
John Grunsfeld, *Deputy Director*
Space Telescope Science Institute



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Advanced Programs and Technology Division
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Monterey, California

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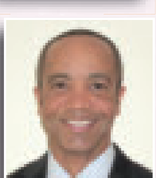

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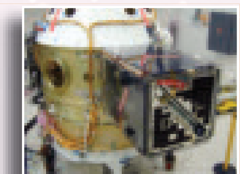

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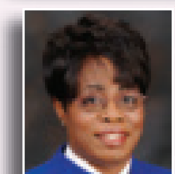
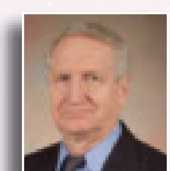


Von Braun Award for Excellence in Space Program Management
Wanda Austin
President and CEO
The Aerospace Corporation
El Segundo, California



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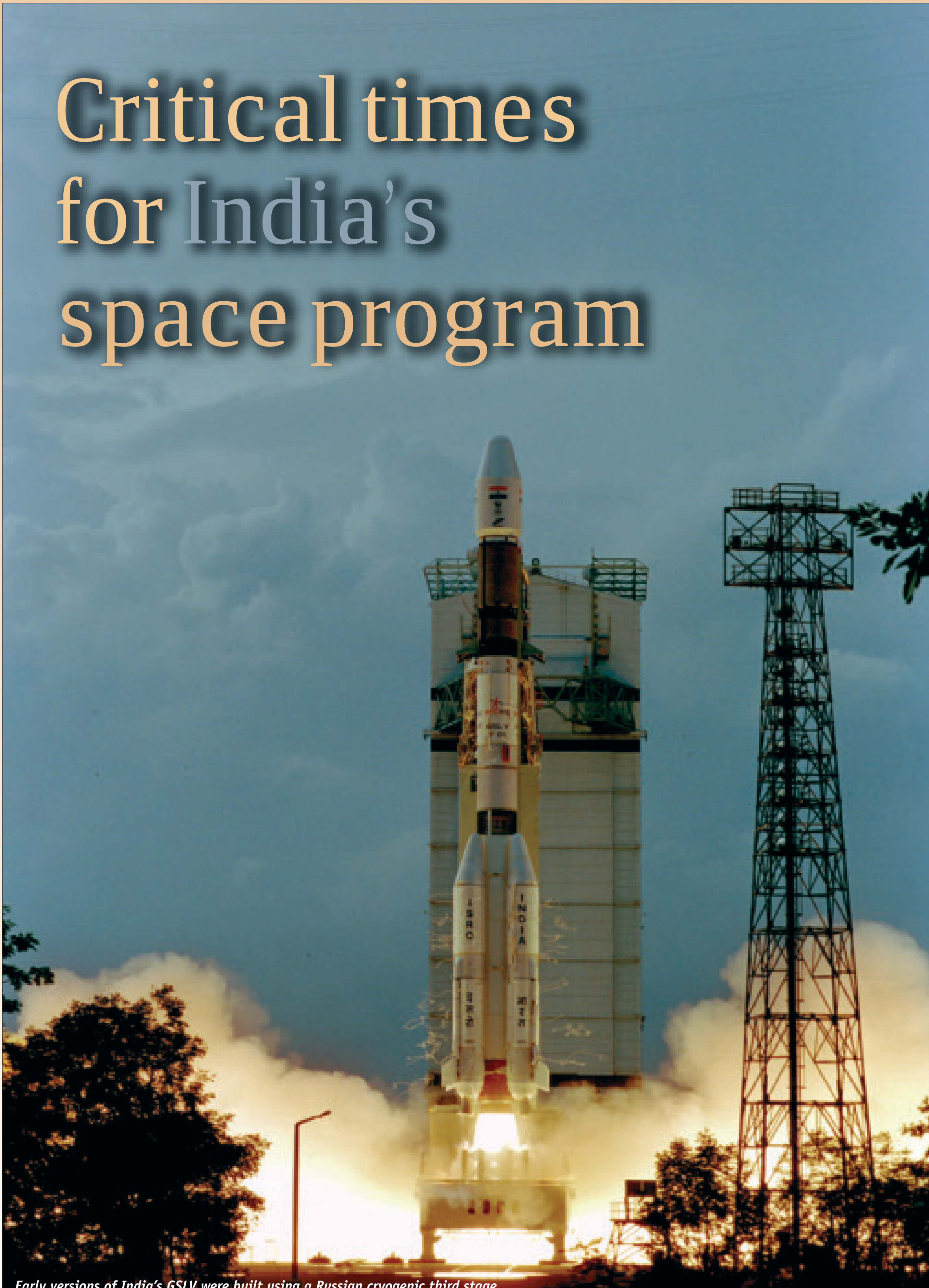
Critical times for India's space program



Early versions of India's GSLV were built using a Russian cryogenic third stage.

Although a recent launch failure has dealt India's space program a setback, the country is determined to move beyond its success in the small satellite launch arena and become a serious player in the global heavy-lift market as well. Its ambitious plans include perfecting its cryogenic technology and developing its own manned spaceflight capability.

On April 15, the Indian Space Research Organization's (ISRO) launch of a rocket with a cryogenic third stage designed and built in India ended in failure.

Although the cryogenic stage of the geosynchronous satellite launch vehicle GSLV-D3 appeared to have ignited, according to ISRO Chairman K. Radhakrishnan the rocket began to lose altitude seconds after the third-stage ignition, having reached a height of 87 mi. and a speed of around 11,000 mph.

This was a major blow to ISRO's plans to compete in the global satellite launch business and to develop a manned spaceflight capability. The Mark-3 version of the GSLV is intended to make ISRO self-reliant in launching heavy satellite payloads in the 4,500-5,000-kg weight class—the April 15 launch was carrying a 2,224-kg GSAT-4 experimental communications and navigation satellite, which was destroyed during the launch failure.

Earlier versions of the GSLV have been built using a Russian cryogenic third stage. India acquired seven of these stages during the 1990s; it launched five on board earlier GSLV flights, with varying degrees of success, and now has two in storage.

The ISRO has a very challenging set of programs, including the GAGAN (GPS-aided geoaugmented navigation) satellite constellation, two further Moon observation missions, and a manned spaceflight project. This makes it increasingly important for India to develop its own cryogenic propulsive technology. Following the GSLV-D3 failure, ISRO will be targeting a second flight of the indigenous cryogenic upper stage as soon as possible.

According to an ISRO release issued shortly after the failure, "Detailed analysis of the flight data is being carried out to find out the exact reasons for the failure and take corrective measures to realize the next flight test of the indigenous cryogenic engine and stage within the next one year."

Small beginnings

So far the ISRO has developed its programs on a relatively small budget, especially compared to its nearest competitor, China. But as the payload sizes increase and the scientific programs become more complex, the government will need to find increasing amounts of money to fund the country's space ambitions. India is competing in the small-satellite launch market, having won contracts with Germany, Israel, Italy, and Singapore, among others, for Polar Satellite Launch Vehicle (PSLV) flights, and this has provided some modest but useful revenue streams.

"For the launch of small satellites into LEO, India offers a low-cost and reliable solution with PSLV, on par with Russian converted missiles," says one space industry market expert. "However, to become a player in the much larger commercial GTO [geosyn-

by
Philip Butterworth-Hayes
Contributing writer

The INSAT constellation provides telecommunications, broadcasting, search and rescue, and meteorological services.

chronous transfer orbit] marketplace, India will need a more capable launch vehicle than GSLV-Mark 2."

India has been relatively late entering the space race. From the start, its space program has been driven overtly by supporting domestic infrastructure programs such as remote sensing, communications, distance learning, telemedicine—using satellites to set up video conference communications for medical staff in remote locations—and security.

"In India, the space program has not been a geopolitical tool; it supports the social and economic development requirements of the country," according to Rachel Villain, director of space and communications at Paris-based space consultancy Euroconsult. "Indigenous capability is sought in launch vehicle and applications satellites (communications, Earth observation and navigation). However, as experienced in other countries, a capability gap still exists between GSLV and Insat that makes Insat 4 satellites too large to be launched by the domestic launch vehicle."

The Indian National Satellite System (INSAT) constellation is a network of communications satellites providing telecommunications, broadcasting, search and rescue, and meteorological services throughout India. The first in the constellation, INSAT-1A, was flown in April 1982, and launches are continuing, with the INSAT-4F, a 2,330-kg multiband satellite carrying payloads in UHF, S-band, C-band and Ku-band, to be launched next year onboard the GSLV.

Growing ambitions

In recent years, India's ISRO has started to play a wider role in the global space market. The first ISRO Moon probe, Chandrayaan-1, launched on a modified version of the PSLV in October 2008, was the first truly scientific mission ISRO has undertaken. The unmanned lunar exploration mission comprises a lunar orbiter and an impact probe. The orbiter carries five ISRO payloads and other payloads from NASA, ESA, and the Bulgarian Aerospace Agency, underlining India's new commitment to international cooperation in its space programs. It is also equipped with a NASA mini-SAR (synthetic aperture radar), and Chandrayaan-1 has been transmitting images from the Moon for more than two years—the most recent and spectacular reveal ice deposits near the Moon's north pole.

A follow-on Chandrayaan-2—with a lander/rover mission ISRO is developing with assistance from Russia—is planned for 2012, with Chandrayaan-3 coming later, although these missions are now subject to delays following the failure of the April 15 launch.

India's manned space program offers a further definitive break from the past focus on domestic infrastructure programs, though one more in line with its growing importance as a regional and global economic power. Among its neighbors, China and Japan have sent missions to the Moon, and South Korea has embarked on its own space program.

Manned space program takes shape

In February 2009, the Indian government approved the $3-billion budget for ISRO's manned space mission. ISRO wants to launch

LAUNCH VEHICLES

Launcher	Description
Satellite launch vehicle	The four-stage, solid-propellant SLV launched India's first satellite, the 40-kg Rohini-1B, in 1980.
Advanced satellite launch vehicle	After four SLV-3 launches India developed the Advanced SLV, which launched four times between 1987 and 1994 but with two failures.
Polar satellite launch vehicle	ISRO's first fully operational launcher, the four-stage PSLV can take 1,600-kg satellites to 620-km Sun-synchronous polar orbit (SSPO) or 1,050-kg satellites to GTO. With Chandrayaan-1 a PSLV with strap-on motors enhanced the payload capability to 1,750 kg in 620-km SSPO. The PSLV has been India's entrée into the global satellite launch market, with 16 foreign and 14 Indian satellite payloads launched up to the end of 2009.
Geosynchronous satellite launch vehicle	The GSLV was designed to place a payload of up to 5,000 kg in LEO and 2,200 kg into GTO. Five flights have taken place using the Russian cryogenic stage. The first, developmental, flight took place in April 2001, launching a 1,540-kg GSAT-1. The flight was partially successful, but an upper-stage early shutdown left the satellite 4,000 km short of the planned GTO apogee. Flights two and three were fully successful but flight four—the launch of a 2,168-kg INSAT-4C satellite—failed. Flight five, carrying the replacement INSAT-4C, was fully successful.

ISRO SATELLITE PROGRAMS

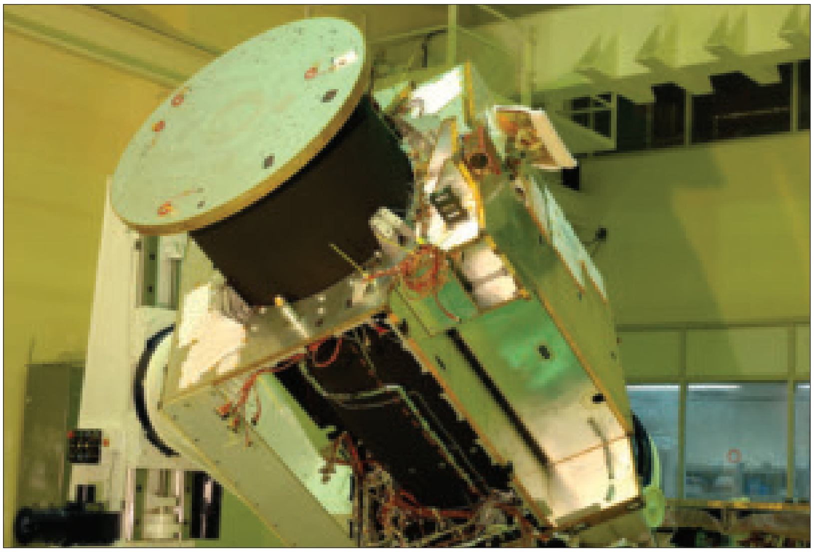
Satellite type	Program	Applications
Earth observation	Cartosat-2B	Enhanced cartographic and other civil applications.
	RISAT 1 and 2	A microwave remote sensing satellite carrying an Israeli-supplied SAR for border control and other security applications.
	Resourcesat-2	Agricultural crop distribution and production, forest mapping, water resources.
	SARAL	Oceanic and climate conditions.
Scientific	ASTROSAT	Multiwavelength observations of the celestial bodies and cosmic sources in X-ray and UV spectral bands simultaneously.
	Chandrayaan-2	Orbiter/lander/rover capabilities to improve our understanding of the origin and evolution of the Moon.
	Megha-Tropiques	An ISRO/French National Space Centre joint venture to improve understanding of the life cycle of convective systems and their role in the associated energy and moisture budget of the atmosphere in tropical regions.
	Corona	Study of the solar corona in visible and near IR bands.
	YOUTHSAT	A joint Russian-Indian microsatellite carrying scientific payloads with participation from universities at graduate, postgraduate, and research scholar levels.
Navigation	GAGAN	Indigenous satellite-based regional GPS augmentation system as part of India's program of Satellite-Based Communications, Navigation and Surveillance/Air Traffic Management plan for civil aviation. First GAGAN navigation payload is due to be launched this year.
Communications	INSAT	A constellation of 199 transponders to support wide-ranging communications applications throughout India. INSAT-3D is due to be launched 2010-2011 for meteorological applications in 2010-2011. INSAT-2 satellites provide telephone links to remote areas and communications for transport operators and television broadcast signals.
	GSAT	Supporting a wide range of broadcast satellites. GSAT-5/INSAT-4D will carry 12 normal C-band transponders and six extended C-band transponders with wider coverage in uplink and downlink over Asia, Africa, and Eastern Europe. GSAT-6/INSAT-4E is a multimedia broadcast satellite.

a two-person mission into space, with Indian astronauts staying aloft for seven days in an orbit of 275 km. The original date for this was set for 2015, though this looks likely to slip to 2017 at the earliest.

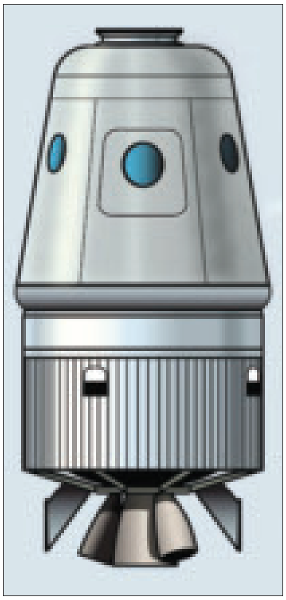
"It depends whether the 2017 deadline is a 'must be,'" says Euroconsult's Villain. "In China it took over 10 years to develop a manned capability, and there was no issue of having to undertake parliamentary approval for budget spending. It's a lengthy process to develop a manned rated capability, and outside help can accelerate it."

The failure of the GSLV-D3 launch may mean ISRO will have to compromise further its policy of autonomy, looking increasingly to support from Russia. India is working closely with that country on the astronaut program, following an agreement signed between the two countries in December 2008. Russia will help develop the astronaut selection program, and ISRO has reserved a Russian Energia Soyuz TMA spacecraft flight in 2013 for two Indian astronauts in a classified "space tourist" deal, to fly with a Russian cosmonaut. India's first astronaut was Sqn. Ldr. Rakesh Sharma, who traveled into space aboard the Russian Soyuz T-11 in April 1984.

Work has been under way on the manned space program in India for some years. In January 2007, ISRO launched its 600-kg Space Capsule Recovery Experiment aboard a PSLV rocket, to test the agency's ability to develop carbon phenolic ablative material and silica tiles, heat-resistant materials needed for reentry. The full manned spaceflight program encompasses the development of an orbital vehicle, a new mission control center, an astronaut training site, and a new launch pad at the ISRO's Satish Dhawan Space Centre in Sriharikota.



Chandrayaan-1 has been transmitting images from the Moon for more than two years.



Preliminary designs of the orbital vehicle have been completed, but much work still remains.

The preliminary designs of the 3-ton orbital vehicle (OV) have been completed. In early 2009 a full-scale mockup of the OV crew capsule was finished, but a great deal of work still needs to be finished before the final design is mature. There are conflicting reports on whether the ISRO OV crew capsule will be a new Indian design or a modification of the Soyuz capsule.

ISRO, meanwhile, is setting up an astronaut training facility in Bangalore, close to Bengaluru International Airport. ISRO is recruiting 200 Indian air force pilots as a first part of the selection process, with the aim of selecting four astronauts—two plus two reserves—at the end of the process.

The manned spaceflight program will require a third launch pad at the Satish Dhawan Space Centre. The preliminary design for the new pad, 1 km south of the spaceport's second pad, is now complete, including the provision of a crew entry and crew escape module system. It should also be capable of handling reusable launch vehicle flights; ISRO has started designing a landing strip for a reusable launch vehicle at the Sriharikota Range.

Cryogenics and cooperation needed

Beyond the first manned spaceflight, ISRO is planning a series of technology demonstrator

In July 2006, GSLV-F02, carrying the INSAT-4C communication satellite, failed seconds after a perfect takeoff as it deviated from its trajectory and plunged into the Bay of Bengal.

WORLD GOVERNMENT EXPENDITURES ON CIVIL SPACE PROGRAMS (2009)

Asia and Australia	**$Millions**
Australia	36
China	1,269
India	906
Indonesia	18
Japan	2,340
Malaysia	25
Pakistan	71
South Korea	208
Taiwan	42
Thailand	20
Vietnam	19
Europe	
Austria	81
Belgium	237
Czech Republic	16
Denmark	47
European Union	735
Finland	71
France	2,436
Germany	1,245
Greece	24
Ireland	21
Italy	940
Luxembourg	21
Netherlands	194
Poland	9
Portugal	26
Romania	30
Spain	324
Sweden	117
Switzerland	137
Turkey	71
U.K.	406
Middle East and Africa	
Algeria	5
Egypt	3
Iran	100
Israel	11
Nigeria	43
South Africa	5
UAE	60
Latin America	
Argentina	82
Brazil	85
Chile	15
Peru	1
Venezuela	8
North America	
U.S. (NASA, 18,135; NOAA, 1,158; others, 790)	20,083
Canada (including ESA 33)	298
Russia and the states of the former Soviet Union	
Azerbaijan	67
Kazakhstan	55
Russia	2,719
Ukraine	109
Total	**$35,970**

Source: Euroconsult's Profiles of Government Space Programs.

missions as part of its plan to develop a two-stage-to-orbit fully reusable launch vehicle. The first of these is the Winged Reusable Launch Vehicle Technology Demonstrator, a flying test bed to evaluate various technologies, including hypersonic flight and autonomous landing. The vehicle is reported to incorporate supersonic combustion ramjet technology, which is being tested this year. Meanwhile ISRO has also announced it plans to carry out an unmanned mission to Mars and a manned mission to the Moon by 2020.

But many of these programs ultimately will depend on the successful development of Indian cryogenic engine technology. India has been limited to accessing this via international agreements on the transfer of dual-use technology, which has meant Russia could only provide ready-made third stages for the GSLV series. It has taken nearly 20 years and a reported $76 million for India to develop its own cryogenic rocket stage, so the April failure was a significant setback. The cryogenic stage was built at ISRO's Liquid Propulsion Systems Centre in Tamil Nadu.

To meet its target dates for improved launcher and manned space mission capabilities, India might well have to increase its cooperative efforts with other countries. Its policy of autonomy has not stopped it entirely from such cooperation. The PSLV Vikas engine built by ISRO is based on the Viking 4A engine manufactured by Snecma of France for Ariane. More recently, India has developed closer ties with Israel, using the PSLV to launch the Israeli military surveillance Polaris satellite, for example. In June 2005 India and the European Union signed a bilateral agreement of cooperation in the fields of science and technology, including space science.

In July 2005, then-President George W. Bush and Indian Prime Minister Manmohan Singh reached an agreement on space exploration, satellite navigation, and launch technology. It would give India access to U.S. technology in the commercial market, with India agreeing to adhere to Missile Technology Control Regime guidelines.

Military space efforts

India's civil launch capabilities have developed in parallel with its military launch programs, most notably the Agni missile family, which has evolved from a short-range (500-700-km) ballistic missile, through to an intermediate range (the Agni III, with a range of potentially more than 3,500 km). Reports that India is developing an intercontinental missile capability (over 5,000 km)—via the Agni V or the Surya programs—have been denied by Indian officials, but a test flight of the latest in the Agni range is due before early 2011.

The Agni missile family has evolved from a short-range ballistic missile, through to an intermediate range.

In May 2008 the Indian Institute of Science announced that a team from the Dept. of Aerospace Engineering and Dept. of Inorganic and Physical Chemistry had developed new materials to reduce the drag on a rocket's blunt nose by adding a treated coating of chromium-based material and thereby increasing the range by at least 40%. According to some reports, this new technology would be applied to future versions of the Agni. Early versions of the missiles are understood to have incorporated SLV launcher technologies.

For many reasons the next few months will be critical for India's space program, as ISRO engineers research the reasons for the failure of the April 15 launch. If the failure is due to a relatively minor fault rather than a wider design flaw, then India will be able to accelerate work once again on its manned spaceflight program and other more ambitious missions such as the RLV. But these are increasingly risky areas where, for some projects, outside help is no longer available.

"In terms of the reusable launch vehicle, there will be fewer possibilities of support from other countries as most of the work on reusable space launchers began to slow down in the early 2000s as more effort was put into developing more capable expendable launchers," according to Euroconsult's Villain.

But if the fault can be traced quickly and a fix identified, then the door is open for India to play a much-enhanced role in the global space science and satellite launch markets.

Controlling launch vehicle

Over the course of 40 years, we have devolped safe, reliable—but expensive—space transportation systems. By considering life-cycle cost as a fundamental driver early in any future designs, we may be able to develop vehicles that are also both sustainable and affordable.

Space transportation systems historically have been designed for maximum performance based on the design history of the 1950s and 1960s, and to throw the maximum weight to orbit while minimizing the propellants required. Payload and vehicle unit cost and development costs were "managed" to meet the performance goals.

Except for the Air Force's evolved expendable launch vehicle program, a cost-sensitive design goal was not the overall driver. The Thor, Atlas, and Delta launch vehicles, the Saturn V Moon rocket, the mostly reus-able space shuttle, as well as some foreign systems were all performance-driven designs, without serious consideration of overall life-cycle cost (LCC) as a design driver. These vehicles lifted extremely expensive payloads and demonstrated safe and dependable delivery—but at high cost.

A sustainable low-LCC delivery system has been a goal for more than four decades. Fully expendable and partially reusable systems have been developed and operated, but neither approach has achieved this goal. Today, we have an even greater need for safe, dependable, affordable, and sustainable systems. New entries by commercial spaceflight providers promise to change the focus, but will they be life-cycle-cost driven or profit driven, which may not be the same thing.

At present, access to space is very expensive, and will remain so until there is a breakthrough in the way we do business.

The Space Propulsion Synergy Team

Recognizing the gap in previous development efforts, the Space Propulsion Synergy Team (SPST), chartered in 1991 by NASA, took on the task in 2004 of analyzing and defining an LCC control approach to launch vehicle design, focused on affordablity and sustainablity.

The SPST is a national volunteer organization of government, industry, and university experts in space propulsion and propulsion- and other system-related technologies. The members' diverse expertise was used to develop new engineering management decision-making tools—specifically, developing innovative engineering processes in the architectural design, development, and operation of space transportation systems. These tools permit quantification of the requirements of both the system operators and the payload customers.

The team maintains an active dialogue among the personnel involved in all phases of the technology, design, development, and operation of space transportation systems. Since its inception, the SPST has reviewed and assessed the lessons learned from all of the major U.S. programs, past and present, focusing on what has been learned from the assessment and control of LCC.

A new approach

From its analysis of previous programs, the SPST determined that a development process *must* focus first on developing system requirements. These include the usual flight performance and functional requirements as well as the total relevant infrastructure on Earth, in space, or on the Moon/Mars surface, as appropriate. These requirements determine the overall LCC.

Specific innovative engineering and management approaches and processes were then developed that included a focus on flight hardware maturity for reliability, ground operations approaches, and business processes between industry and government.

Achieving sustainable LCC will require a major change in program cost control. That cost control must be used as a program metric in addition to the existing practice of controlling performance and weight. Without a firm requirement for cost control and a methodically structured process to achieve it, it is unlikely that an affordable and sustainable LCC will ever be realized.

The basic approach was to adapt the management process for weight control that NASA used on the space shuttle program to control LCC. The process would be used for technology development; advanced development; system design, development, test, and engineering (DDT&E); manufacture; operation; and recycle/disposal. This requires a major cul-

life-cycle costs

tural adjustment in the way the government in general and NASA and the aerospace industry specifically do business. The approach is clearly feasible; commercial enterprises already use it. They are required to budget and control the LCC of their programs—otherwise they fail and go out of business.

All requirements that address a program's major objectives (performance, affordability, safety, and sustainability) must be in place from concept definition through flowdown to the unique element requirements level. The recommended approach is the use of structured engineering management processes to budget and control those functions that are the primary LCC drivers of the program.

Shuttle shortfall study and analysis

The SPST conducted several analyses to uncover the areas that caused the significant cost shortfalls of the space shuttle program from 2000 to 2004. The shuttle shortfall study first identified the major cost drivers that affected shuttle cost. The team found that design decisions that affected development and acquisition costs also drove the operations costs, which then dominated the LCC. The SPST proceeded to identify all the major operations cost drivers.

The study reformatted the major lessons learned from previous programs as technical performance metrics (TPMs). To the degree that these can be implemented, both the design and the operations elemental cost will then cause a decrease in the LCC. Performance and weight can be adversely impacted by the pursuit of these TPMs in some missions and architectures. Consequently, a balance must be struck between these cost TPMs and the performance and weight TPMs in order to meet any LCC goal.

The optimization process will form the framework of the architecture development. Of the 64 TPMs identified in the study, 18 were determined to be major cost drivers. The design and operations aspects of LCC can then be decreased by establishing minimum values of the TPMs consistent with mission objectives and then flowing down the values of the TPMs as actual requirements.

by **John W. Robinson**
Chairman, SPST

After defining an architecture using these TPMs, structured engineering management and a disciplined program development process would be implemented throughout the design and development phases of a program.

Functional breakdown structures

Complete requirement definitions are a necessity at the onset of a program. The SPST developed a unique approach to formulating requirements, one that provides full accountability of all the functions needed to define an architecture's capability to perform missions. That approach is to develop a top-level functional breakdown structure (FBS) with modular subsets that can be used as the basis for defining the functional requirements in any system.

The FBS is a structured, modular breakdown of every function that addresses the capability within an architecture to perform the mission's transportation function. It is also usable for any subset of the mission. It is not tied to any particular architectural implementation because it is a listing of the needed functions (not elements of the architecture). The FBS offers a universal hierarchy of required functions, including ground and space operations and infrastructure. It provides total visibility of all the elements needed to perform an entire mission. This is a new approach that will provide full accountability/traceability of all functions required to perform a mission. It serves as an integrated checklist so no functions are omitted, especially in the early architectural design phase. The approach allows upfront visibility to achieve the desired TPMs required to meet the objectives of affordability and sustainability.

Without a firm requirement for cost control and a methodically structured process for achieving it, it is unlikely that an affordable and sustainable LCC will ever be realized.

One significant characteristic of an FBS is that missing or redundant elements of options within architectures are identified. As a result, valid LCC comparisons can be made between architectures. For instance, one architecture option might not need a particular function (for example, vertical launch with vertical landing does not need the same controls a winged vehicle would need). Or one option may have specific elements perform multiple functions while another option uses one element to perform the multiple functions.

Once the architecture is selected, the FBS will serve as a guide in development of the work breakdown structure, highlight those technologies that need further development, and help identify the discipline resources required to develop and operate that architecture. It also will allow the systems engineering activities to totally integrate each discipline to the maximum extent possible and optimize at the total system level rather than at the element level (stovepiping). In addition, it furnishes a framework that will help prevent incorrect requirements or specifications because all functions are identified and all elements are aligned to functions.

The FBS should be used to ensure that the architecture options are compared fully and validly. After the selection of an architecture that can meet the performance and LCC requirements, these requirements must be allocated and flowed down to all lower tiers. All the requirements and elements of an architecture must be identified at the beginning of a program if the LCC is to be controlled.

Steps to achieving low life-cycle cost

•Establish cost credibility through the use of extensive system-level and component-cost databases. Develop anchor values and LCC models to assure the credibility of initial early estimates and explore the alternatives within the architecture.

•Assess annual funding constraints while exploring alternative system concepts.

•Use a design-to-LCC management process that is an integral part of a performance management system, thereby assuring an integrated cost management system that is coupled with the technical performance measurement system to enhance the early detection of unfavorable trends.

•Use a design-to-LCC manager who reports directly to the program manager, thereby providing a high-level single point of contact.

•Trade cost reduction design solutions through system engineering control of the technical performance and operations cost assessment.

•Establish realistic but rigorous cost objectives early on and emplace highly visible management processes that include the design-to-LCC approach and follow a disciplined process to achieve them.

Designing to life-cycle cost

Controlling life-cycle costs also requires the use of a structured mechanism to implement a design-to-LCC process. This should be a rigorous, disciplined process and must be implemented and demonstrated early in the definition of an architecture and the conceptualization of its elements, including its ground infrastructure, and then refined continuously. It is a process where tradeoffs among development, operation, performance, technical risk, schedule, DDT&E cost, and life-cycle

Recommendations

The improved life-cycle-control processes developed by the SPST will provide the necessary cost controls when properly applied in the future advanced systems. The SPST recommendations are:

- *Make both nonrecurring and recurring costs a required metric, coequal with weight and performance, and flow it down to the individual element developments, with rewards and penalties, in the same way this is done for weight and performance control. Do not allow life-cycle cost to become a goal.*
- *Fully and clearly define competing architectures and alternate implementations of architectural elements. Use an FBS to accomplish this full definition.*
- *Fully and clearly define the requirements at the program's beginning. Use an FBS to accomplish this full definition.*
- *Define architectures using the TPMs and implement a structured engineering management process to budget and control the TPMs throughout the design and development phases of the program.*
- *Develop and implement a very active process of reallocating requirements to lower levels to achieve overall system requirements throughout the DDT&E program. This should be done across multiple requirements.*
- *Balance the safety, reliability, and maintainability requirements to provide controls on recurring maintenance burden to provide operational effectiveness and LCC control.*
- *Develop a thorough understanding of the cost dependence on reliability and maintainability tradeoffs.*
- *Develop a thorough appreciation of the coupling of maintainability and reliability.*
- *Use a methodology or process for developing and balancing quantitative safety, reliability, and maintainability requirements.*
- *Develop and use a structured mechanism for design-to-life-cycle cost.*

costs must be addressed on an ongoing basis. LCC must be the primary TPM used to make decisions within these trade studies. An ability to control costs within stringent total program and fiscal constraints must be demonstrated early in the design development phase and carried throughout the last day of operation of the vehicles.

The design-to-LCC management process should allow definition and implementation of cost-effective design improvements early in the design phase. Implementation early on assures visibility into production and life-cycle cost trends. It also facilitates credible cost, schedule, and technical performance feedback. Moreover, coordination with responsible design engineers and functional managers gives them the capability to provide effective and timely cost-reduction decisions when they have the most impact on LCC.

The system engineering discipline would employ the design-to-LCC management process as a guide to allocating resources and performance requirements, identifying high-risk or high-cost components that are major LCC drivers, managing system-level cost/capability/risk tradeoffs, analyzing technology selection impacts on program costs, and monitoring design engineering technical performance against identified system goals. There should be a focus on both development and operational cost containment. If system LCC projections exceed target values, design trades should be initiated to redefine system design characteristics to meet the LCC TPM and still meet the minimum requirements.

As the design phase progresses, the emphasis should shift to producibility and maintainability improvements that will benefit production and life-cycle costs. An operations cost model should be used during the design process to provide operations cost impact data for design option selections. Operational life-cycle costs must be continuously and rigorously evaluated as an integral component of overall system design.

Outlook

Based on study and analysis of several programs, including the space shuttle, it is clear that past and current efforts to control LCC have been inadequate and ineffective.

The "lesson learned" from these studies is that vastly improved, innovative processes must be developed and rigorously applied to adequately control life-cycle costs. These processes must be enforced by program managers throughout the design, development, production, and operation of a system. The objective is to establish LCC as a true requirement that is flowed down to all tiers. Requirements not flowed down become "goals," and are rarely met.

Proper application of these processes can provide the necessary cost controls, resulting in sustainable low life-cycle cost space transportation systems.

An ability to control costs within stringent total program and fiscal constraints must be demonstrated early in the design development phase and carried throughout the last day of operation of the vehicles.

25 years Ago, October 1985

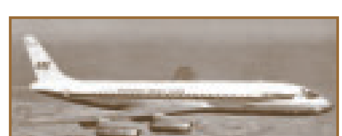
Oct. 3 The space shuttle Atlantis blasts off from Kennedy Space Center on its first voyage. STS 51-J carries a military payload for the DOD and makes Atlantis the fourth shuttle to go into orbit. Ten years later, Atlantis becomes the first shuttle to dock with Russia's Mir space station on STS 71. *Astronautics and Aeronautics 1985*, pp. 278-279, 309.

50 Years Ago, October 1960

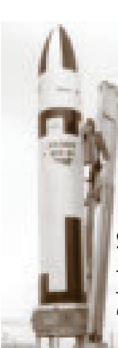
Oct. 1 The first Ballistic Missile Early Warning System (BMEWS) station, at Thule, Greenland, becomes operational. BMEWS can alert the U.S. and Canada to any large-scale Soviet ICBM attacks over the North Polar regions and gives both countries a 15-min warning. The BMEWS radar equipment has a 3,000-mi. range. *The Aeroplane*, Oct. 21, 1960, pp. 560-561.

Oct. 4 A Thor Able Star vehicle launches the 500-lb Courier I-B communications satellite into orbit from Cape Canaveral, Fla. After completing one orbit, the satellite receives and records a transcribed message to the U.N. sent from President Eisenhower at Ft. Monmouth, N.J., then transmits it to an Earth station in Puerto Rico. This launch is the 100th for the Thor, which has now lofted a record 60% of all U.S. satellites into orbit. E. Emme, ed., *Aeronautics and Astronautics 1915-60*, p. 129.

Oct. 11 A prototype of the Air Force's SAMOS 1 (Satellite and Missile Observation System 1) reconnaissance satellite is launched from the new Pacific Missile Range site at Point Arguello, Calif. The spacecraft fails to orbit, however, because the second stage of its Atlas-Agena launch vehicle falls short of orbital velocity. *The Aeroplane*, Oct. 21, 1960, p. 563.



Oct. 11 SAS initiates jet polar service between Europe and the Far East using DC-8s, cutting the flying time to less than 16 hr. On this Copenhagen-to-Tokyo route the airline flies the DC-8 Rurik Viking, which earlier inaugurated a new 10,000-ft runway at Bodø in northern Norway. *The Aeroplane*, Oct. 28, 1960, p. 579, and Oct. 21, 1960, p. 553.


Polaris-A3

Oct. 13 The first color photos of Earth from space are taken by a camera in the nose of an Atlas ICBM at an altitude of 600 mi. The camera also takes pictures of star formations from a 700-mi. altitude. E. Emme, ed., *Aeronautics and Astronautics 1915-60*, p. 129.

Oct. 15-18 Four operational-type Polaris solid-fuel ballistic missiles are test fired successfully from the submerged submarine Patrick Henry off the Florida coast. E. Emme, ed., *Aeronautics and Astronautics 1915-60*, p. 129.

Oct. 19 Peter Thorneycroft, Britain's minister of aviation, opens the

new supersonic wind tunnels at English Electric's aviation facility at Warton, England. Thorneycroft arrives in a Vickers-Armstrong Vanguard, the first passenger flight of this aircraft in the U.K. *The Aeroplane*, Oct. 28, 1960, p. 594.

Oct. 21 Britain's Hawker P.1127 VTOL fighter, powered by a Bristol Siddeley BS.53 turbojet, starts its initial trials. *The Aeroplane*, Nov. 25, 1960, p. 702.

Oct. 21 Grumman's W2F-1 Hawkeye, powered by two Allison T56-A8 turboprop engines, has its first flight. It is to replace the Navy's Grumman WF-2s for airborne early warning service. The Hawkeye can fly higher, faster, and for a longer duration than its predecessor and other carrier-based early warning aircraft. *The Aeroplane*, Nov. 18, 1960, p. 684.

Oct. 24 The Boeing Vertol 107 twin-turbine helicopter achieves its first successful flight. *The 1961 Aerospace Year Book*, p. 445.

Oct. 25 Harry Ferguson dies at age 75. He is well known for the tractors he manufactured and also for designing and building the first heavier-than-air machines flown in Ireland, where he first piloted his

Past

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

small monoplane on Dec. 31, 1909, with the late C.G. Gray. *The Aeroplane*, Nov. 18, 1960, p. 677.

Oct. 25 Three U-2 very high altitude reconnaissance aircraft fly nonstop from Fiji to East Sale, Victoria, Australia. From there they make high-altitude flights over the ocean to the south, conducting research on radiation and fallout. *The Aeroplane*, Nov. 4, 1960, p. 606.

Oct. 27 The Institute of the Aeronautical Sciences changes its name to Institute of the Aerospace Sciences. E. Emme, ed., *Aeronautics and Astronautics 1915-60*, p. 129.

75 Years Ago, October 1935

Oct. 1 Sylvanus Reed, inventor of the Reed metal airscrew, dies at 81. A secretary to the head of the American Section of the Paris Exposition of 1878, he later became a mining engineer. In 1915 Reed began experimenting with metal airscrews, or propellers, as they were later called. The prop, which was successfully demonstrated at Curtiss Field on Aug. 30, 1921, was sold to Curtiss; large-scale production followed. In 1925 Reed received the Collier Trophy. *The Aeroplane,* Oct. 16, 1925, pp. 461-462.

Oct. 3 The successful and popular Stinson Reliant model SR6-A makes its first British flight when

H.C. Constant lends his private machine for a public demonstration at London's Croydon Airport. The new model has a Smith controllable-pitch air-screw. The light, high-wing cabin aircraft has a 225-hp Lycoming radial engine and a range of 700 mi. *The Aeroplane*, Oct. 9, 1935, p. 446.

Oct. 9 Pan American Airways receives its first Martin M-130 flying boat during a ceremony attended by Col. Charles A. Lindbergh at Martin's Baltimore plant. Pan Am is shortly to use this and two other M-130s for its transpacific passenger service, which experimentally now uses the Sikorsky S-42. Capt. Edwin Musick, who is to inaugurate the transpacific service, flies the first M-130 from Baltimore to Washington, D.C., with 38 passengers and a crew of five. *The Aeroplane*, Oct. 16, 1935, p. 481.

Oct. 11 Aircraft play an important role in Italy's invasion of Ethiopia, begun this month. On this day, Italian planes bomb the fort of Daguerre on the left bank of the Webbe Shibeli. The son-in-law of Emperor Haile Selassie of Ethiopia surrenders to the Italians on October 12 with a large number of followers. Italy issues orders not to bomb Addis Ababa unless it becomes a military base. *The Aeroplane*, Oct. 23, 1935, p. 494.

Oct. 12 A report from Baghdad says that the Iraqi air force recently completed successful operations against rebels in the Jebel Sinjar region, 80 mi. west of Mosul. *The Aeroplane*, Oct. 30, 1935, p. 520.

100 Years Ago, October 1910

Oct. 15-Nov. 2 The Second International Exposition of Aerial Locomotion is held in Paris. Undoubtedly the most unusual aircraft displayed is Henri Coanda's Turbopropulseur, which some later claim is the world's first jet. Moreover, Coanda is alleged to have made the first and only flight in this aircraft after the exhibition, on December 10, 1910. However, exhaustive examinations of all the aviation journals and newspapers of the time, as well as later accounts, fail to reveal any actual flight or attempts. Rather, these sources and Coanda patents strongly indicate the Propulseur is no more than a sesquiplane fitted with an internal 50-hp Clerget engine. The engine drives a large ducted fan in front of it to suck in air, which then mixes with the exhaust of the Clerget and is expelled out of the rear. There is no evidence at all that fuel is injected to provide combustion for expulsion of these gases, as in a real jet. C. Gibbs-Smith, *Aviation*, p. 156; *Aeronautical Journal of the Royal Aeronautical Society*, December 1980, pp. 408-416.

And During October 1910

—Russian aviator Alexandre Kouzminski is the first to fly an aircraft in China, piloting a French Bleriot XI air-cooled monoplane over Peking. M. Rosholt, *Flight in the China Air Space 1910-1950*, pp. 7-9.

SENIOR SCIENTIST IN MICRO-ROBOTIC TECHNOLOGY

The Air Force Research Laboratory, Munitions Directorate, located at Eglin AFB, FL, seeks applicants for a Senior Scientist with experience in the interdisciplinary field of Micro-Robotic Technology for weapon airframes.

This position will serve as the principal scientific authority and researcher, and will focus micro-robotic research with the purpose of strengthening in-house activities and collaborations, both academic and inter-governmental. The position requires a nationally and internationally recognized authority in the field, with the ability to conceive, conduct, and lead advanced research and development. The position also requires demonstrated expertise in the broad area of micro-robotic technology, including micro-scaled technologies that would permit mobility, navigation, and payload delivery. Expertise in one or more of the following areas is required:

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- Micro/nano energetic materials
- Micro multispectral seekers
- Carbon nanotube composite materials

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To apply for this position, go to the USAJOBS website at www.usajobs.gov, and click on Senior Executives, and then input micro-robotic. Closing date for the application is 18 Oct 2010. For technical questions, you may contact Mr. Fred Davis at Frederick.davis@eglin.af.mil.

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CLARKSON UNIVERSITY

Wallace H. Coulter School of Engineering
Michael E. '78 and Janet Jesanis Endowed Chair in Sustainable Energy Systems

Clarkson University, New York State's highest ranked small research institution is located in the northern Adirondacks in the college town of Potsdam.

Wallace H. Coulter School of Engineering (CSoE) at Clarkson University invites applications for the Michael and Janet Jesanis Endowed Chair in sustainable Energy Systems in the Department of Mechanical and Aeronautical Engineering (MAE) (anticipated starting date: August 2011). Strong record of scholarly accomplishment and a Ph.D. in Mechanical Engineering, Aeronautical Engineering, or energy related area is required. Applications are encouraged from individuals whose research programs can contribute to areas of renewable and sustainable energy including energy efficiency, solar, wind, biofuel and nuclear energy conversions and resources.

Clarkson University has established interdisciplinary focus areas of research in advanced materials (including biomaterials), environment and energy (including sustainable energy systems), bio-rehabilitation engineering, and innovation and entrepreneurship. The Coulter School of Engineering offers B.S. degrees (mechanical, aeronautical, civil, environmental, chemical, electrical, computer and software) engineering, and M.E., M.S. and Ph.D. degrees in mechanical engineering, civil engineering, electrical and computer engineering, chemical engineering, environmental science and engineering, and engineering science. In addition, the school offers a minor in sustainable energy systems engineering for undergraduates.

The successful Michael E. Jesanis Chair will be expected to develop strong funded research programs in emerging areas of sustainable energy, lead and mentor junior faculty members, and develop and teach graduate and undergraduate courses and curricula in energy related areas in mechanical/aeronautical engineering. Applicants need to articulate a clear and substantiated vision of their plan for their sustained accomplishments.

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University of Kansas

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- ***Dynamics and control (aircraft and/or spacecraft)***
- ***Experimental aerodynamics***
- ***Avionics, especially intelligence and autonomy (aircraft and/or spacecraft)***

Experience in the aerospace industry, especially with ***uninhabited vehicles***, is a plus. Research productivity at KU is evaluated with respect to publications in respected academic journals and success in supporting and mentoring PhD and MS students. Faculty members are expected to teach both undergraduate and graduate courses in an effective manner, and to be active in service to the University and the engineering profession. An earned doctorate in Aerospace Engineering or a closely-related field is required. The successful candidate should be eligible to work in the U.S. prior to the start date of the appointment, 18 August 2011. Salary is commensurate with experience. Review of complete applications will begin on 15 January, 2011.

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Faculty (Position #00065055) and post-doc (Position #00208702) applicants should apply on-line at https://jobs.ku.edu, attaching the following documents to the applicant data form: a letter stating your teaching and research interests, a resume, contact information for three references, and up to three selected published papers. Attachments exceeding 5MB may be emailed to aerohawk@ku.edu or mailed to KU Aerospace Engineering Department, 2120 Learned Hall,1530 W 15th St, Lawrence, KS 66045.

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Department Chair

DEPARTMENT OF AEROSPACE ENGINEERING
UNIVERSITY OF MICHIGAN, ANN ARBOR

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The Chair will provide leadership for the department and make sustained contributions to instructional and research programs of the department. The Department currently has 26 tenured and tenure-track faculty members, with a broad portfolio of externally funded research programs covering the full spectrum of aerospace engineering. Annual graduation rates are about 120 undergraduate students, 60 masters students, and 20 doctoral students.

Inquiries and applications (including a complete resume, a vision statement for the department, and a list of at least three references) should be directed to:

Professor Iain D. Boyd
Chair Search Advisory Committee
Department of Aerospace Engineering
University of Michigan
1320 Beal Avenue, Ann Arbor, MI 48109-2140
iainboyd@umich.edu

Applicant screening will begin in the Fall of 2010 and continue until the position is filled.

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