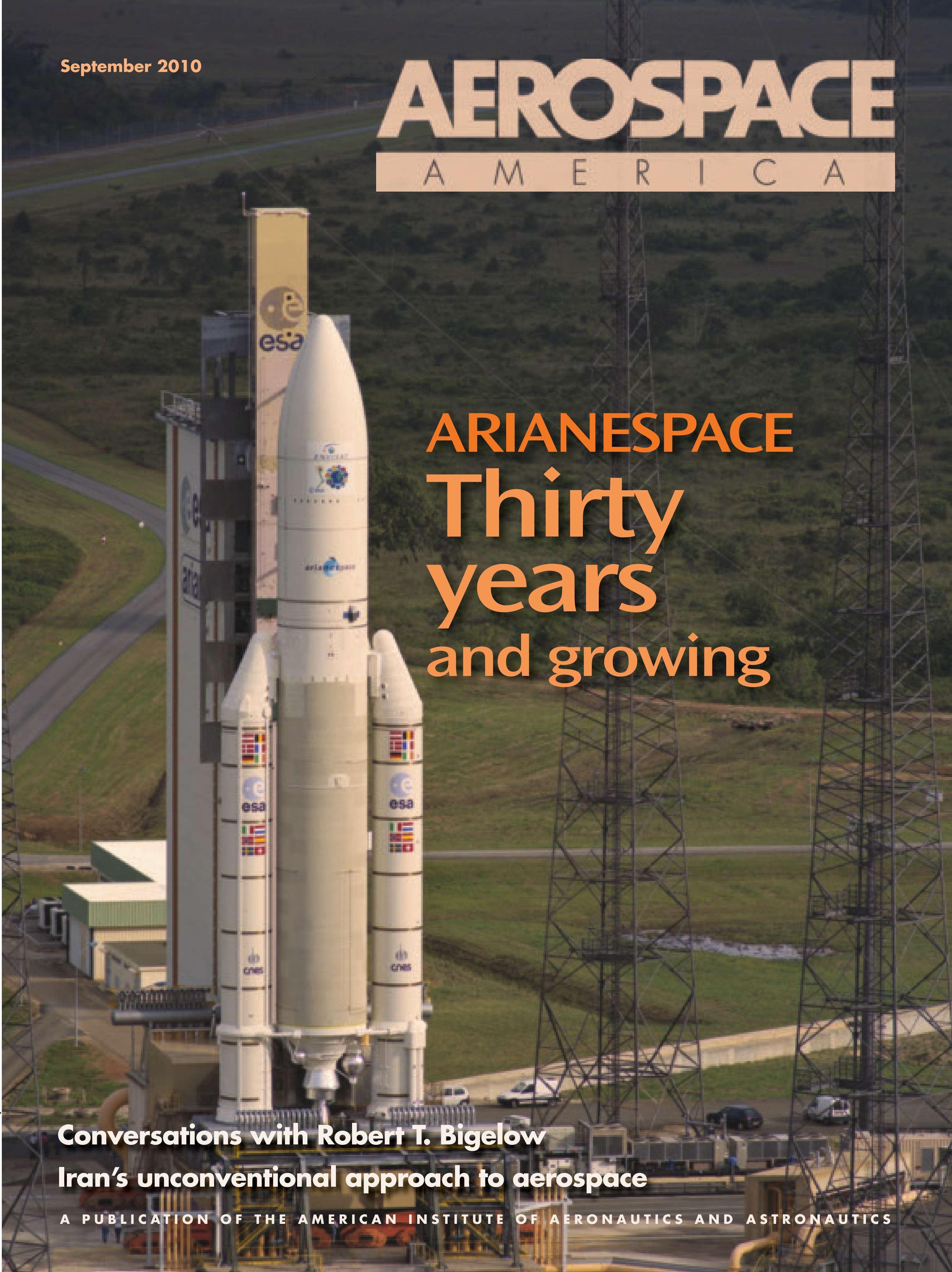
September 2010

AEROSPACE AMERICA



ARIANESPACE Thirty years and growing

Conversations with Robert T. Bigelow

Iran's unconventional approach to aerospace

A PUBLICATION OF THE AMERICAN INSTITUTE OF AERONAUTICS AND ASTRONAUTICS

8 AEROSPACE AMERICA SEPTEMBER 2010

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DEPARTMENTS

EDITORIAL 3
Dollars and sense.

INTERNATIONAL BEAT 4
Taxes and trains threaten aircraft market / Correspondence

WASHINGTON WATCH 8
The difficulties of letting go.

CONVERSATIONS 10
With Robert Bigelow.

INDUSTRY INSIGHTS 14
Defense companies brace for changes.

OUT OF THE PAST 44

CAREER OPPORTUNITIES 46

FEATURES

ARIANESPACE: THIRTY YEARS AND GROWING… 18
After three decades, Arianespace has a larger order book than ever and a family of launch vehicles whose lifting capacity continues to increase.
by Mark Williamson

ROBONAUT: THE NEXT GENERATION 26
R2, the NASA/GM robot soon to be launched to the ISS, can work alongside humans in space or on the shop floor.
by J.R. Wilson

A HIGHER CALLING FOR SUBORBITAL RESEARCH 32
New suborbital vehicles could bring a wealth of data from the edge of space, but tight budgets threaten NASA research in this vital region.
by Leonard David

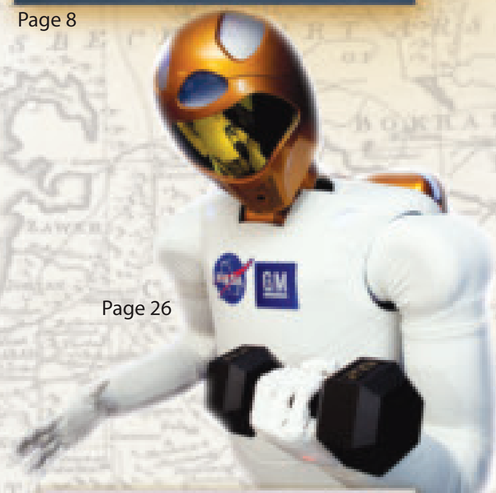
IRAN'S UNCONVENTIONAL APPROACH TO AEROSPACE 38
Surprising developments indicate that Iran's aerospace and defense efforts may be advancing more rapidly than expected.
by Philip Butterworth-Hayes

BULLETIN

AIAA Meeting Schedule B2
AIAA Courses and Training Program B4
AIAA News B5
Meeting Program B11
Calls for Papers B15


Page 4


Page 8


Page 26


Page 38


Page 32

COVER

March 2010 marked 30 years of successful space launch operations for Arianespace. For a look at how it all started, as well as a glance at the venture's future plans, turn to the story beginning on page 18.

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Elaine J. Camhi
Editor-in-Chief
Patricia Jefferson
Associate Editor
Greg Wilson
Production Editor
Jerry Grey, *Editor-at-Large*
Christine Williams, *Editor AIAA Bulletin*

Correspondents
Robert F. Dorr, *Washington*
Philip Butterworth-Hayes, *Europe*
Michael Westlake, *Hong Kong*

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

Fitzgerald Art & Design
Art Direction and Design

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

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

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American Institute of Aeronautics and Astronautics

Editorial

Dollars and sense

On July 15, shortly before the congressional summer recess began, the Senate Committee on Commerce, Science and Transportation unanimously approved a compromise NASA authorization bill challenging the Obama administration's budget proposal. Shortly thereafter, the House Committee on Science and Technology offered up its own proposal, which recommends the same amount of money, approximately $19 billion—a $1-billion increase over last year's budget—but distributed in quite a different fashion.

This month, when the Congress reconvenes, members from both chambers will work to reconcile the two widely divergent proposals in an effort to provide a path to the future of human spaceflight, both for NASA and for commercial enterprises that are actively involved in developing future space transportation systems.

One of the key differences between the proposals from the two chambers deals with the portion of NASA funding that should be allocated to those commercial human spaceflight efforts, a key element of the Obama budget request. How many of the companies now invested in developing human space transportation vehicles will be able, or willing, to stay in the business if that funding is severely cut back remains an issue.

Another key difference concerns the future of the Constellation program, and its cancellation, favored by the White House, or its continuation (albeit in altered form), which is the House position.

Unfortunately, the agreements reached may be driven more by regional or political concerns than technical ones. There is clearly more than jobs at stake in this debate; the future role of the United States in the human exploration of space may well be up for grabs. Questions concerning the viability or robustness of a particular decision may be trumped by concerns over the possible loss of local jobs, and technical hurdles are being met with economic responses.

In addition, neither the proposals from either chamber nor the administration's budget request incorporate the recommendations of the U.S. Human Space Flight Plans Committee. One of the key findings of the Augustine commission was that, regardless of which "path" to space the U.S. chose to follow, the NASA budget would need to be increased by at least $3 billion annually in order to develop a sustainable human spaceflight capability and maintain the U.S. position as a leader in human space activities.

In addition, although all proposals favor the continuation of the international space station, U.S. access to the orbiting laboratory will be, in and for the foreseeable future, out of our hands.

No doubt he was correct when Rep. Bart Gordon said, of the House proposal, "We are facing tough economic times that demand tough choices." But those choices must be based on clear, reasoned understanding of the difficult challenges of maintaining a human presence in space and expanding our exploration of the universe.

Human space transportation activities are now or soon will be taking place all around the globe. In that regard, the "local" in politics should be the U.S.

Elaine Camhi
Editor-in-Chief

Taxes and trains threaten aircraft market

This November, long-haul passengers flying from London Heathrow to Sydney face a tax hike on each ticket from £85 to £170. In June, the U.K. government announced a series of increases to the rate of air passenger duty (APD), which is charged on every airline ticket sale. According to the U.K.'s Office for Budget Responsibility, APD is expected to generate £3.8 billion in revenue by 2015/2016.

"We are in severe danger of pricing large numbers of people out of flying," said Willie Walsh, CEO of British Airways, in response to the announcement of the tax rise.

According to Sir Richard Branson, president of Virgin Atlantic Airways, "The U.K. government has been quietly increasing APD by huge amounts and claiming it is an environmental tax. Yet there's not a shred of evidence to suggest the £2 billion-plus currently raised is going towards environmental or sustainable projects."

"For many of the travellers contemplating long-haul pleasure trips, this is the final straw," says Ian Lowden, a partner in aviation consultants Airport Commercial Developments. "The tax rise has come on the back of a severe recession and will depress the long-haul leisure market."

The latest travel and tourism statistics would seem to underscore this thesis. APD was introduced in 1994 and has been rising ever since—the last major hike was in 2009. U.K. residents made 58.6 million visits overseas in 2009—15% fewer than in 2008, according to the U.K'.s Office for National Statistics. Travel abroad by U.K. residents for holidays fell 15%; trips for visits to friends or relatives fell 6.5%. This compares to a much more modest fall throughout Europe of just 3.4% in passenger kilometers performed in 2009 over 2008, according to the International Civil Aviation Organization (ICAO).

Taxes spark protests

For aerospace manufacturers, these are grim statistics. Increased tax revenues from cash-strapped governments and an economy that is struggling to lift itself from recession are depressing market demand for new long-haul aircraft, especially in Europe. There is more taxation pain to come for Europe's airlines, with the introduction in 2012 of the European Union's emission trading scheme (ETS). According to a recent forecast, the cost of spreading the ETS to aviation will mean a bill of between €1.3 billion and €2.0 billion for airlines flying in and out of Europe during 2012 and €6.5 billion to €13 billion in 2020.

Emirates Airline has placed orders for 90 A380s, at a time when many European airlines have seen their passenger numbers declining.

And the U.K. is not alone in introducing new revenue-generating aviation taxes. In June the German government announced it plans to impose a new departures tax, called an "ecological air travel levy," aimed at raising €1 billion annually.

"The tax is supposed to help the environment by discouraging people from flying," says Association of European Airlines (AEA) Secretary General Ulrich Schulte-Strathaus, "while at the same time pouring a billion euros into the treasury. But if a passenger flies and pays the tax, he is impacting the environment. If he doesn't fly, the treasury doesn't get his money. A classic example of doublethink."

"This is the worst kind of short-sighted policy irresponsibility," according to the CEO of the International Air Transport Association (IATA) Giovanni Bisignani. "It's a cash grab by a cash-strapped government. Painting it green adds insult to injury. There will be no environmental benefit from the economic damage caused."

IATA led the campaign against a similar tax imposed by the Dutch government in 2007. The government imposed a tax of between €11.25 and €45 for every passenger departing from Dutch airports in a bid to raise €300 million, but canceled the measure in 2009 when the costs to the economy of Dutch citizens driving to airports in nearby Germany and Belgium were estimated, according to IATA, to be more than €1.2 billion.

According to the AEA, the trade association of European scheduled airlines, "The Dutch estimated that the imposition of this €25 charge cost the country an estimated 900,000 tourists over the last year of this tax's operation. Belgium also introduced a tax of between €5 and

€50 per passenger, depending on their destination, but this too was scrapped."

Low-tax alternatives

The lessons seem clear: Imposing aviation taxes depresses demand for air travel and is therefore bad news for airlines, airports, and airliner manufacturers.

But the truth is not so simple. "There is no evidence that tax hikes impact air travel demand," says Andrew Charlton of Geneva-based aviation law firm Aviation Advocacy. "You don't see a change in overall demand, but you do see, as in the case of the Netherlands, passengers choosing less highly taxed alternatives."

The less highly taxed alternatives to legacy European long-haul carriers such as British Airways and Air France/KLM are the new fast-growing airlines of the Middle East gulf states. Over the past few years they have been very successful at opening new routes from secondary European cities to destinations in the Far East, via Dubai and Abu Dhabi. There are fewer environmental restrictions to aviation growth in the Middle East and much lower levels of taxes—a competitive advantage that will become larger in the next few years. From 2012, and the introduction of the ETS, a trip from Singapore to New York via London will incur charges on both legs of the flight; flying through Dubai will incur no environmental tax surcharges.

To underline the gulf's improving position as an intercontinental transfer point, Emirates Airline placed an $11.5-billion order for 32 489-seat Airbus A380 aircraft in June, bringing the total of A380s it has ordered to 90—70 more than any other airline.

If this theory is correct—that increased taxation in one area of the world merely shifts demand to another area, without impacting the overall requirement for new airliners—then manufacturers have less to worry about. The main change will be that European full-fare carriers will become less significant customers. This is already happening.

While long-haul services are being threatened by the new competitors of the Middle East, their short-haul services are shrinking under the pressure from low-fare airlines. Europe's scheduled airlines saw annual passenger numbers drop 5.8% in 2009 over 2008, from 346 million to just below 326 million. At the same time, their low-fare competitors saw annual passenger numbers increase 8.7% in 2009, to 162.5 million passengers.

While this trend had been identified by Airbus and Boeing in their long-term forecasts, the rise in European taxation levels will probably accelerate the trend in the short term—shifting demand for new long-haul aircraft more rapidly to less taxed airlines, away from the European legacy full-fare airlines. European airlines are becoming less and less significant purchasers of widebody, long-range aircraft. Although Europeans will want to fly long haul in ever greater numbers, in the future they will choose to fly increasingly with non-European airlines.

Passenger traffic is expected to return to growth this year, led by a strong demand in international traffic in the Asia-Pacific region. The good news for most of Europe's airlines is that the long-haul business market—less price sensitive than the tourist sector—is also rebounding. But the bad news is that even if the new aviation taxes result in a net loss to the national bank, many European politicians want to restrict flying still further—some of them see the environmental benefits from constraining aviation growth as a mandate to consider increasingly radical transport policies.

High-speed rail option

In a June interview with the *Financial Times*, the new U.K. transport minister Philip Hammond said, "Domestic flying in the U.K. will become in time a thing of the past," having already stopped plans to build a new runway at London Heathrow. For environmental reasons, the U.K. government would prefer to build new high-speed rail links.

In 2009 there were over 22 million domestic passengers in the U.K.

Europe has plenty of experience with the impact of fast-rail services on the airline market. In France, domestic air travel fell 7% between 2000 and 2007, mainly as a result of a rapid increase in TGV (high-speed) services. But the growth in these competitive networks in Europe has been broadly beneficial. The airlines have benefited because, although they have lost traffic, they have gained new slots at their congested airports. They have concluded that high-speed rail services take passengers mainly from cars rather than from aircraft. Both Germany and France combine excellent fast-train services with a healthy domestic air service.

The China factor

More worrying for aircraft manufacturers

FORECAST DEMAND FOR AIRCRAFT 2008-2028

Aircraft type	Asia-Pacific	Europe	Middle East
Small twin-aisle	1,618	810	475
Intermediate twin-aisle	785	396	193
Very large aircraft	711	281	189

Source: Airbus

FORECAST PERCENTAGE GROWTH IN PASSENGER-KILOMETERS

Region	2009	2010	2011	2012
Africa	-3.3%	9.8%	8.5%	7.7%
Asia-Pacific	-0.2	10.8	7.5	7.5
Europe	-3.9	3.5	2.5	2.7
Middle East	9.1	15.5	12.0	11.5
North America	-3.9	2.8	2.2	2.5
Latin America/Caribbean	0.9	9.8	5.5	5.6
World	-2.0	6.4	4.7	4.9

Source: ICAO.

is the development of high-speed rail systems in China—a key growth market for both short-haul and long-haul aircraft. If Chinese politicians emulate their European counterparts by seeing aviation as a rich source of revenue in the short term, while preferring high-speed rail alternatives in the longer term, then many aircraft manufacturers will have to rewrite their long-term business plans.

High-speed rail has been a government priority in China for some time. By 2020 the government plans to build 18,000 km of high-speed lines where

High-speed trains have impacted the airline market throughout Europe.

trains travel over 250 kph. "Over 80% of the domestic aviation market will be impacted, and about 518 flights are expected to see a 50% fall in traffic when the planned high-speed rail lines enter service," said Si Xianmin, chairman of China Southern Airlines, at the recent Aviation Outlook Asia forum in Beijing. Weekly traffic on the Beijing-Taiyuan route, he said, dropped 60% following the introduction of a high-speed rail link between the two cities.

Chinese airlines are cutting the costs of tickets and improving service levels on routes where they are in competition with high-speed rail services. But ultimately they may have to look for further growth, as have their European rivals, on international and intercontinental routes—yet more unwelcome competition for European long-haul airlines.

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

Events Calendar

SEPT. 13-15
Tenth AIAA Aviation Technology, Integration, and Operations Conference; 13th AIAA/ISSMO Multidisciplinary Analysis and Optimization Conference. Ft. Worth, Texas.
Contact: 703/264-7500

SEPT. 13-15
Fifth Advanced Satellite Multimedia Systems Conference/11th Signal Processing for Space Communications Workshop—Joint Event. Sardinia, Italy.
Contact: Sandro Scalise, chairs@asms2010.org

SEPT. 19-24
Twenty-seventh Congress of the International Council of the Aeronautical Sciences, Nice, France.
Contact: www.icas.org

SEPT. 20-22
International Symposium on Asteroid Mitigation, College Station, Texas.
Contact: David Hyland, dhiland@tamu.edu

SEPT. 27-OCT. 1
Sixty-first International Astronautical Congress: Space for Human Benefit and Exploration, Prague, Czech Republic.
Contact: www.iac2010.cz

OCT. 3-6
Nineteenth International Meshing Roundtable, Chattanooga, Tenn.
Contact: Jacqueline Hunter, jafinle@sandia.gov

OCT. 3-7
2010 29th Digital Avionics Systems Conference, Salt Lake City, Utah.
Contact: Robert P. Lyons, 571/220-9257, lyonsrpl@ieee.org

OCT. 4-6
Twenty-first International Conference on Adaptive Structures and Technologies, State College, Pa.
Contact: George Lesieutre, 814/863-0103, gal4+ICAST2010@psu.edu

OCT. 5-7
2010 International Powered Lift Conference, Philadelphia, Pa.
Contact: 703/264-7500

OCT. 7-8
Aeroacoustics of High-Speed Aircraft Propellers and Open Rotors, Warsaw, Poland.
Contact: Damiano Casalino, d.casalino@cira.it

OCT. 18-21
Twenty-sixth Space Simulation Conference, Annapolis, Md.
Contact: Harold Fox, 847/981-0100, info@spacesimcon.org

OCT. 26-27
CANEUS Transatlantic Aerospace Conference, Brussels, Belgium.
Contact: Dasha Bespyotova, dasha.bespyotova@iscintelligence.com

OCT. 27-29
International Conference on Space, Aeronautical and Navigational Electronics 2010, Jeju, Korea.
Contact: Morio Toyoshima, morio@nict.go.jp; www.ieice.org/cs/sane/ICSANE2010

Correspondence

Feeling the pinch and fighting back, (Washington Watch, May, page 8) and a letter in Correspondence (page 6) deserve comment.

First, in Washington Watch, Mr. Dorr says, "The Constellation project…grew out of the farsighted 2004 "vision" of a replacement for the space shuttle…."

This was anything but a farsighted vision. It was a premature and irresponsible mandate for NASA to terminate the space shuttle before we have a replacement. It was premature and irresponsible to mandate space travel before we have advanced-performance rocket engines to perform these missions. The public was not getting its money's worth, because Constellation was going to use a grossly inefficient rocket engine, the RS-68, which has a specific impulse (I_{sp}) of 415 sec at best—much less than the shuttle main engines, which have an I_{sp} of 454 sec.

The complaint has been that the space shuttle costs too much. Constellation would be even more expensive, costing millions of dollars more per flight because of the cost of liquid hydrogen, $75-80/gal. We should support the decision to cancel Constellation.

In his letter to the editor, Mr. Eiger seems to support development of advanced-performance rocket engines as the appropriate thing for NASA to do. He says, "If…there will now be money for advanced propulsion system development, success in this area could resurrect the human spaceflight program."

Regarding a 'new' direction in space, it is possible to build an advanced-performance rocket engine with an I_{sp} of 470 sec—a much more efficient rocket engine. Such an engine will put a greater payload in orbit at lesser cost. Furthermore, it can be developed within the NASA's current budget. That is a winning proposition for the expenditure of public funds. It will also maintain U.S. leadership in space.

NASA should be directed to develop advanced-performance rocket engines before we return to the Moon or venture to Mars. No research is necessary to do this. All of the technology exists and can be built to flight weight and space rated standards. And the shuttle is the perfect test vehicle to demonstrate the engine.

Dale L. Jensen

Reply by Robert Dorr I did, in fact, use the term "farsighted" and that was a mistake. I meant something like "far-seeing," in the sense of looking far into the future. The Washington Watch column is not an opinion column. It attempts to discuss all sides of every issue.

Reply by Richard Eiger It appears that Mr. Jensen and I are in agreement with our support of President Obama's decision to cancel the Constellation program. However, I believe that Mr. Jensen failed to understand the extent to which I was recommending new initiatives in propulsion advancement for manned interplanetary exploration.

I believe that we have essentially wrung out every last drop of blood from conventional rocket engine development, which can trace its lineage directly back to the 65-year-old German V-2 development, which was a tremendous breakthrough itself at the time. However, today, whether the I_{sp} achieved is 415 or 470 sec, neither is a game changer.

Perhaps the most well-known game changer in development is the variable specific impulse magnetoplasma rocket (VASIMR) being pioneered by Franklin Chang-Diaz. He has been working on this concept for nearly 3 decades and has achieved excellent success.

In comparison to the $I_{sp}$of 470 sec cited by Mr. Jensen for a top-rated liquid fueled rocket engine, testing of the VX-200 VASIMR has demonstrated an I_{sp} range of 700 to 3500 sec. Dr. Chang-Diaz has projected that an advanced nuclear electric powered VASIMR engine could power a Mars-bound spaceship with an I_{sp} of 3,000 to 30,000 sec, allowing the ship to reach Mars in 1-2 months, rather than the 6-8 months projected for a chemical rocket engine powered ship. The shortening of trip length means tremendous savings and added crew safety, limiting the exposure of the crew to hostile radiation. This is the sort of game change I was considering.

However, I believe we will still need some way to get us to and from planetary surface to orbit and, unfortunately, we still seem to have chemical rockets as our only means to get there. To assemble the Mars ship in orbit will require another space truck of equal or greater capacity than the shuttle, and getting all of this to orbit could be extremely expensive. Right now, there is nothing on the books to do this.

As with the VASIMR, I would recommend an X-Prize goal for developing game-changing ground-to-orbit propulsion technology. And to assure that the intent of this prize was completely clear to all, I would suggest that it be called the Cavorite-X Prize. Anyone at all familiar with science fiction will easily understand the meaning of this.

Nor, for that matter, should we place all our eggs in the VASIMR basket. We should encourage all forms of radical thinking toward achieving breakthrough developments in space propulsion.

Constellation wasn't that. To paraphrase *Jaws*, it was simply a bigger boat.

Errata

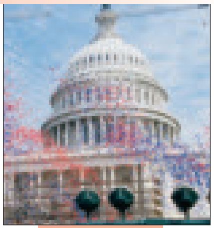
In the July-August Out of the Past, (page 48) the historical paragraph for July 28, 1960, refers to the McDonnell F4D-1 Skyray. That fighter was actually built by the Combat Aircraft Division of the Douglas Aircraft Company, in El Segundo, California.

Jerry L. Lundry
Bellevue, Washington

The August 12, 1935, citation concerning German aviator Elly Beinhorn refers to a flight from Gleiwitz to Costantinople. Costantinople changed its name officially to Istanbul in 1920s. Quotations should not be allowed to perpetuate obvious mistakes.

T. Sarpkaya
Monterey, California

All letters addressed to the editor are considered to be submitted for possible publication, unless it is expressly stated otherwise. All letters are subject to editing for length and to author response. Letters should be sent to: Correspondence, Aerospace America, 1801 Alexander Bell Drive, Suite 500, Reston, VA 20191-4344, or by e-mail to: elainec@aiaa.org.



The difficulties of letting go

WITH CAPITOL HILL DEBATE OVER FY11 budgets looming, lawmakers are trying to chisel out a compromise with the White House on human spaceflight. The Obama administration has said it wants to terminate the Constellation program, which includes eventually sending astronauts to the Moon and beyond.

Crux of the issue

At the crux of a potential Washington compromise is the extent to which the designing and developing of spacecraft—historically the purview of NASA alone—should be farmed out to, or at the least shared with, private entrepreneurship.

The House of Representatives and the Senate began the August recess before reconciling their slightly different approaches to a compromise, but some key points have emerged. A NASA edict cautions agency workers that the term Constellation is no longer to be used in documents referring to future human spaceflight efforts.

To salvage elements of Constellation—including two types of booster rockets and the Orion crew exploration vehicle—lawmakers argue that their differences with the White House are less about space exploration than about jobs. Typical is a July 2 letter from Rep. Pete Olson (R-Texas) sent to Vice President Joseph Biden. Olson wrote that scrapping Constellation "threatens as many as 30,000 jobs across the country, including Houston, home to NASA's Johnson Space Center." Olson also took issue with the $100 million President Obama would shift from the manned program to economic development for those affected by the termination of space shuttle flights.


Rep. Pete Olson


Rep. Bart Gordon

At press time, it appeared that a proposed, and hotly debated, $19-billion NASA authorization Senate bill would give the administration much of what it wants: the first government funding of spacecraft to be developed by private companies, an end to NASA's Moon program, and the long-expected end to the space shuttle program. However, the bill would also authorize one last shuttle flight to provide support to the ISS. That launch would occur after the currently scheduled final flight, whose previously mandated deadline of October 1 has already been extended to February.

The House was crafting its own NASA policy guideline, which would "restructure"—as used here, a euphemism for "retain"—the Constellation program. Reps. Bart Gordon (D-Tenn.) and Ralph Hall (R-Texas) told reporters they "want to continue Constellation or, at the very least, see NASA develop its own spacecraft." Under this proposed House bill, private sector companies would receive less federal funding to develop spaceflight technology.

Before talk of compromise began, the White House submitted to Congress a proposed FY11 NASA budget that narrowly increased the agency's total funding to $18.7 billion while redirecting that increase toward R&D and stronger support for commercial spaceflight. Those who want to address federal deficit spending—widely viewed as a hot topic for voters in the coming November congressional elections—say the president's proposal, if left unchanged, would bring economic ruin on communities in Texas, Alabama, Florida, and other areas that depend heavily on space. At one demonstration near Cape Canaveral, citizens had signs and bumper stickers with slogans like "Stop Obama. Save NASA.''

In Washington, with an election approaching and tempers short over other issues, the future of NASA evokes strong feelings but does not divide conveniently along partisan lines. The administration's plan to privatize manned spaceflight won plaudits from conservatives like Newt Gingrich, who called it "a brave reboot,'' but drew brickbats from others such as former Republican Majority Leader Tom DeLay, a longtime NASA champion who represented the district that includes the Johnson center. Democrats affected by the cuts have raised an outcry—among them, Florida Sen. Bill Nelson, who called the plan "dead wrong''—while others cheered the proposal to refocus the agency on other priorities such as climate change issues.

F136 and C-17

After executives testify, lawmakers are expected to enact the FY11 Pentagon appropriations bill late this fall. In what took legislators on both sides of the aisle by surprise, the nation's capital may be spared a bruising, too-familiar annual battle between Congress and the White House over two aerospace programs—the F136 alternate engine for the F-35 Lightning II Joint Strike Fighter and the C-17 Globemaster III airlifter.

Two successive administrations—both with Robert Gates as secretary of defense—have held that one engine, the F135 from Pratt & Whitney, is sufficient for the 4,000 F-35s planned for nine countries. Supporters of the F136, produced by General Electric/Rolls-Royce, insist that offering an alternate engine can lower costs.

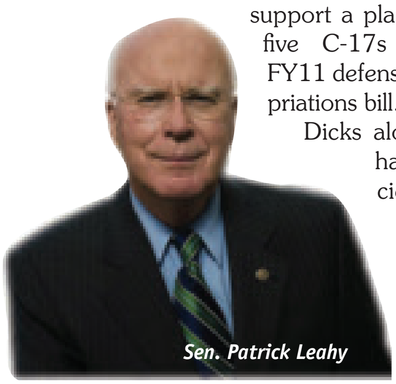
Those who favor an alternate engine are as disparate as Sen. Patrick Leahy (D-Vt.), Sen. Carl Levin (D-Mich.), and the British government, which is a JSF stakeholder. Since the mid-1970s, the ubiquitous F-16 Fighting Falcon has been built and operated with two engine types, an arrangement that provided a 21% savings benefit, according to the Government Accountability Office.

For airlift, the Bush and Obama administrations both argued that the current scheduled buy of 223 gives the U.S. more Globemasters than it needs. Sen. John McCain (R-Ariz.) agrees.

Gates insists that the JSF alternate engine and the C-17 are out. "I will …strongly recommend that the president veto any legislation that sustains the continuation of the C-17 or funding for the F136," Gates said in a meeting with reporters. "It would be a serious mistake to believe the president would accept these unneeded programs simply because… legislation includes other provisions important to him."

Leahy acknowledges that pro-F136 forces probably cannot muster enough support on Capitol Hill to overcome the administration this year. In July, Rep. Norm Dicks (D-Wash.), chairman of the House defense appropriations subcommittee and a stalwart C-17 supporter (Boeing builds the C-17 in California but also manufactures aircraft near Seattle in Dicks' district), surprised everyone in Washington by revealing that he will not support a plan to add five C-17s to the FY11 defense appropriations bill.

Dicks alone may have sufficient clout



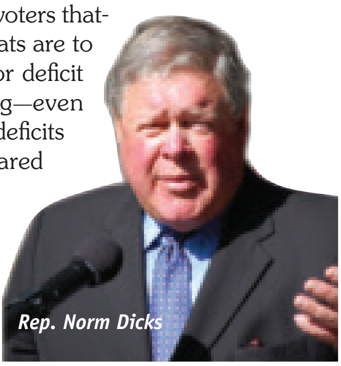
Sen. Patrick Leahy

Over the past several years, Congress has paid for 43 C-17s that two administrations said they did not want and the Air Force insisted it did not need.

to reverse the trend of the past several years, during which Congress paid for 43 C-17s that two administrations said they did not want and the Air Force insisted it did not need. Dicks' initial version of the FY11 spending bill contains no money for F136 engines or C-17 transports.

The federal deficit is fueling the national debt at a rate greater than ever before—a July White House projection for a $1.47-trillion deficit this year means that every dollar spent by the government now includes 41 cents in borrowed money. Thus, Democrats do not believe they can fare well in the off-year election by merely "nipping around the edges" of defense spending, as House Majority Leader Rep. Steny Hoyer (D-Md.) put it.

In a June 28 speech, Hoyer said defense spending can no longer be exempt from "hard choices" confronting the rest of the federal budget. Hoyer acknowledged that Republicans believe they can capitalize on a belief held by voters that Democrats are to blame for deficit spending—even though deficits have soared



Rep. Norm Dicks

under both parties. If F136 and C-17 legislative battles can be headed off, lawmakers on both sides of the aisle are likely to give broad support to other money-saving measures that will come from Gates but have not yet been defined. Among possibilities: retirement of all 65 of the Air Force's B-1B bombers, which are effecttive in Afghanistan but costly to operate.

Marine leaders at the fore

Only weeks after Gen. Stanley McChrystal, the U.S. commander in Afghanistan, was pressured to resign, Pentagon boss Gates sent mixed signals by nominating two Marines—one of them a well-known aviator—to four-star billets.

First, Gates picked Gen. James F. Amos to become the next commandant of the Marine Corps, replacing Gen. James T. Conway.

The choice was seen initially as a snub of Gen. James N. Mattis, commander of Norfolk, Va.-based U.S. Joint Forces Command. Mattis is a blunt-talking seasoned war veteran who led Marines into the bloody battle of Fallujah in Iraq in 2004. He won attention with a 2005 speech when he said of Taliban militants, "It's a hell of a lot of fun to shoot them." Mattis and outgoing commandant Conway are both crusty, their gruffness an asset within the Marine Corps' insular culture but sometimes an irritant in Washington politics.

(Continued on page 17)

Robert T. Bigelow

You have already launched two Genesis expandable space modules on Russian rockets, and inflated and tested them successfully in orbit. What's next for Bigelow Aerospace?

We are building a subscale technology demonstrator of our Sundancer module, and plan to build two spacecraft. Then we will build our very large BA 330 spacecraft, our full-sized standard space station module. We call it the 330 because it will have 330 m^3 of usable volume. This structure is three times the size of the average module of the space station.

How is everything going in general for Bigelow?

Just fine. We broke ground this summer on a 185,000-ft^2 expansion of our plant in north Las Vegas. We are expanding our staff, and are very active in developing hardware for our systems and in addressing some NASA programs.

Speaking of which, your company is partnered with Boeing in NASA's commercial crew development effort to design a capsule for carrying people and cargo to the ISS for NASA. What is the status of that project?

The program between ourselves and Boeing is going very well. We are very happy with the relationship and proud to be able to work with Boeing.

Go back to the beginning. When was Bigelow Aerospace formed, and for what purpose?

Our company was founded in 1999, and we are more confident than ever that we will accomplish our mission. Initially I became enamored with the idea of expandable space systems and their huge potential. We planned to build them and lease them to users. We would offer a turnkey service; we would provide the launches and all transportation of cargo and people and consumables that would be needed in space. And we would make it as easy and affordable as we possibly could, so that even middle-sized companies could afford to do business in orbit, not just the giant international corporations.

So your initial marketing focus was on the corporate world?

Yes, because we never assumed that NASA would be much of a customer, a major consumer, based on its historic posture. But then, in about 2006, I expanded our thinking as I began to realize that there were a lot of other countries, other governments, out there that might be customers, countries that have space departments and space agencies but have nowhere to go in space, no access. They were and are totally dependent on being given the nod by the Americans or the Russians to go to the ISS. So those nations became the centerpiece of our marketing plan, our number one goal, for our expandable space habitats.

How many nations figure into your thinking?

There are 50 or 60 countries with some kind of space department or agency, and probably another 75 or so that would like to have them. So we are hoping to serve the passion of such nations to move out with their own space programs in the new era that we hope is going to occur.

"The rest of the world has not stood still. Other countries are not content to depend on the U.S. for their space futures."

The U.S. and Russia have dominated space activities in the last half-century; 85% of the occupants of the ISS have been Americans and Russians. That does not leave a lot of room for the rest of the world. A lot of folks are not pleased with their lack of access to the ISS. And those that do have access are not pleased with the politics involved.

The rest of the world has not stood still. Other countries are not content to depend on the U.S. for their space futures. They have moved out into the satellite domain. In 1997, the U.S. had 100% of all commercial launches and 100% of all commercial satellite construction. Since then the U.S. has lost 97% of its commercial launches and more than 80% of its commercial satellite manufacturing. But except for China, other countries have not been able to move out in space in terms of human activity, with human beings in space. That is where we hope to make a difference.

Have you ruled out marketing to the corporate world?

Not at all. We intend to serve the corporate world. We see much future potential there. But we have not had time to address more than one of those communities—nations and corporations—all at once.

Which nations are you dealing with?

We have talked in depth to about a dozen countries, including Japan, England, Singapore, Sweden, Egypt, Dubai, and others in the Arab world.

What do you tell them?

At this point it is mostly a matter of introducing ourselves, our company, to other countries. We have been doing that pretty much continuously for the past two years. Some don't even know that we exist. Some do, but don't know much about what we have to offer.

A lot of it is explaining what our heritage is, that we picked up on a [NASA] program intended to take people and house them in space on their way to Mars, that our architecture is very safe, and in fact safer than the ISS architectures are, and that our expandable modules are stronger and offer more advan-

Interview by James Canan

tages than the conventional aluminum cans in numerous ways, such as resistance to meteorites and space debris.

Give us a sense of how you feel about all this—your personal stake in it at the emotional level.

I am excited. If you have a company that is trying to serve the needs of numerous countries, helping to promote and organize their space futures, that is very exciting, and that is what we are trying to do. Part of that is the feeling of satisfaction in providing the motivation for those countries, for what it is that they will be doing in space and what will be the benefits for them along the way.

I should not leave out my excitement over the potential for the corporate world, too, for providing companies with the space assets in which, for example, they can conduct microgravity research—all kinds of research under microgravity conditions. The potential for that kind of research is huge. Corporations and nations now lack the space assets to conduct it.

"Nations do not want to have to answer the question from their people, from their children and grandchildren: Why did you let us fall behind in space?"

Nations do not want to have to answer the question from their people, from their children and grandchildren: Why did you let us fall behind in space? That is a very sad question for a nation to have to answer.

Your space stations—Sundancers and BA 330s—will consist of individual modules connected to one another as a much larger whole. How and where will you assemble and operate them?

We see the potential for numerous space stations serving nations and corporations in LEO, but it doesn't have to be LEO only. The fact is that if we are successful in conducting those operations—in assembling the components of our space stations—for our clients in LEO, it is logical to expect that some of those same clients will be interested in becoming involved in lunar activities, in having lunar bases as well.

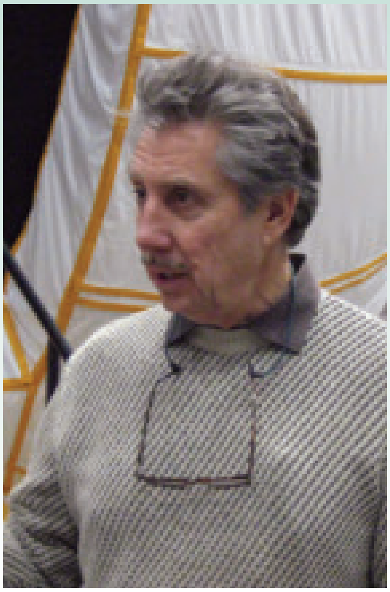
We are anticipating assembling many platforms in LEO for our clients, and at least several others to be operated as lunar bases. Many of our clientele in LEO would be interested in setting up operations and having permanent presence on a lunar base.

Please elaborate on that. It may be difficult for readers to visualize.

The same kinds of structures that we assemble in LEO can be assembled in

Robert T. Bigelow founded Bigelow Aerospace in 1999 as a general contracting, investment, and R&D company engaged in the design, development, and construction of habitable space stations and of space transportation and launch facilities. The company concentrates on making its products and services affordable for commercial application in the private sector.

Bigelow has led the company in developing relationships with large and small aerospace companies in the U.S. and abroad. In 2002 his company acquired exclusive licenses for the commercialization of NASA expandable space habitat technologies. It also has several other licensing agreements with NASA.



Bigelow has been granted 10 aerospace-related technology patents. He also runs BMI (Bigelow Management) and Bigelow Development, which has developed and constructed approximately 14,000 apartment, office, residential, hotel, motel, and industrial units since 1971, including the extended-stay hotel chain, Budget Suites of America, in five southwestern states. His business endeavors have included ownership of banks and a mortgage company.

A native of Las Vegas, Bigelow earned a bachelor of science degree in business administration from Arizona State University and has completed numerous postgraduate business courses through the years. In 1995 he received the Distinguished Nevadan of the Year award from the Board of Regents for the University and Community College System of Nevada. Among his many other awards, Bigelow received the AIAA Durand Lecture for Public Service Award in 2004, the Innovator's Award from the Arthur C. Clarke Foundation in 2006, and the Space Foundation Award for Space Achievement in 2007. He is a member of the UNLV (University of Nevada, Las Vegas) Foundation, an associate member of the Society for Scientific Exploration, and a founder of the Nevada Cancer Institute.

lunar orbit, and can be deployed from there to the lunar surface. They would have no problem landing on and resting on the hard surface of the Moon—none whatsoever. Our methodology of constructing a lunar base—and this is extremely important—has nothing to do with using machinery on the lunar surface, such as caterpillars, loaders, all those kinds of Earth-like construction equipment with which I am extremely familiar, having been a general contractor for four decades. Our lunar bases will be assembled in either L1 [Lagrange point 1] or lunar orbit. They will be deployed to the lunar surface as completed bases.

What is your chronology? What do you plan to do and when?

We will launch and begin assembling our first space station in 2014. Seven launches will be required—four launches to position the components of the station (a propulsion bus, two Sundancers, and a 330) in orbit, where they will be boxed to each other, and three launches to bring up crew and cargo.

Will your crew-and-cargo capsule project with Boeing have a bearing on that?

It could. We have to make sure that we can avail ourselves of perhaps more than one supplier of transportation, and more than one supplier of cargo, in taking the spacecraft to low Earth orbit. In terms of mass, we will be in the 21,000-22,000-lb range for some of our spacecraft, and that will be within the range of the SpaceX Falcon 9 rocket and the [Lockheed Martin] Atlas 401/402. Our 330 requires a heavy lifter, probably the Atlas 5 [552], about 43,500 lb. We will probably be flying between a 28-deg and a 40-deg inclination at about 230 n.mi. in space.

SpaceX seems to be coming right along, with successful launches of its Falcon 1 and Falcon 9 rockets, and is already under contract with NASA to ferry cargo to the ISS. Do you plan to launch your first station in 2014 on Falcon 9?

Potentially our payloads could be accommodated on two or three different rockets, and Falcon 9 is most definitely a candidate. SpaceX is an excellent company and, of course, so is Boeing. I am currently seeing Boeing take an aggressive position regarding space transportation. I don't doubt that both companies will be successful.

So what happens after your first space station is assembled?

That station hopefully will be in operation with national clients in 2015. We are taking a very conservative posture with regard to that first station in terms of its number of flights. It will have five flights per year in 2015, 2016, and 2017.

What do you mean by flights? The station will already be up there.

Those are CTV [crew transfer vehicle] flights to the station. Each will carry a combination of cargo and people, and not all the flights will carry the same number of people. In our prescription for serving our clients, we provide options for numbers of seats per quarter or per year. They can take very few seats, or they can have as many as a dozen a year. We will accommodate very ambitious pocketbooks, or budgets that are much more conservative.

"Realistically, we are hostage to the development of a space transportation system that is reliable and affordable.…"

Are you thinking of operating hotels in space?

No. If Marriott, for example, wanted to lease one of our space stations and make it into a hotel, they could do it. But that would not make Bigelow a space hotel company. We don't do space hotels and space tourism. The market for space tourism is far too small.

Back to your projections for space stations. What comes after the first one?

We are talking about operating a second station in the 2016-2017 time frame. That would require 20-25 rocket launches per year. Our country currently doesn't have enough available launch facilities to handle that, and it is also encumbered by the fact that the Dept. of Defense and NASA can interrupt any schedule, any flight, that the commercial space sector would plan to launch. So we will see what develops.

Quite an undertaking. What are the possible pitfalls?

We intend to have multiple stations, so our concern is whether there will be enough launch facilities and launch pads, enough vertical [launch vehicle] integration facilities, and enough suppliers of the space capsules themselves. We are also concerned that, because we will generate a significant amount of traffic, we could overwhelm our suppliers. The long pole in our tent is crew and cargo transportation.

Too bad you don't build your own rockets.

It would be a mistake for us to fight a two-front war.

The Obama administration's space policy, stemming from the Augustine Commission study, strongly supports commercial space endeavors in the private sector. It also puts great emphasis on affordability, on developing a wide variety of advanced technologies, and on devising new means of space transportation, including crew and cargo vehicles and a super-heavy launch vehicle. You must find it favorable to your pursuits.

Yes. Realistically, we are hostage to the development of a space transportation system that is reliable and affordable, so we approve of the Augustine Commission recommendations that the White House is supporting. They would benefit our company and the nation as a whole. Meanwhile, we will proceed with our activities.

You have said that you are also interested in positioning expandable modules in space that would facilitate journeys to the Moon and even Mars. Tell us more about that.

In 2020 I would like to see us form partnerships with our clients to assemble the first lunar depot in L1, which is 85% of the distance from Earth to the Moon, and to deploy LTVs—lunar transfer vehicles, similar to the LEO CTVs that would go from the depot to the lunar surface.

What are your launch vehicle requirements for all that?

If the proposed superheavy launch vehicle materializes, it will be excellent to use for the launch of space modules from Earth straight to L1. It would be capable of launching our 330s, for example, to that location. If the superheavy does not materialize, we could use the Atlas 552 to take propulsion buses to LEO to serve as tugs to propel other spacecraft to the L1 location.

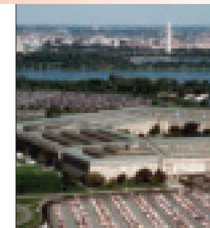
"We will accommodate very ambitious pocketbooks, or budgets that are much more conservative."

So you strongly support the development of a superheavy launch vehicle?

We can provide the superheavy with some very good missions. We can make it a valuable resource because it would have missions that really make sense. In 2020, if the superheavy exists, we would use our supersized expandable modules—each having either 2,100 m^3 or 3,200 m^3, depending on whether an 8-m fairing or a 9-m fairing is used—and supersized propulsion buses to create a trial depot in LEO. This structure would be used as one of the depots required for a mission to Mars. The prospect of a supersized expandable is very, very exciting to us, and it can be brought about only if a superheavy lifter exists.

What do you mean by a supersized expandable?

One would fit within an 8-m fairing, the other within a 10-m fairing. The first would be two times the size of the ISS; the other, three times the size of the ISS. That is very impressive volume.



Defense companies brace for changes

U.S. DEFENSE COMPANIES FACE A SERIES OF budgetary and procurement policy challenges in coming years that threaten to erode the strength built up over a decade of strong growth and healthy profits.

The world economic crisis is already having an impact on Europe's defense budgets. All the leading European countries—France, Germany, Italy, Spain, and the U.K.—are planning reductions that in some cases will be quite draconian. France's defense ministry may have to shave as much as €5 billion from its €32-billion budget over the next several years. The Italian government plans reductions of 8-10% for its defense and industry budgets, which together fund military procurement and research. And Germany plans to cut €8.3 billion from its annual €31.1-billion defense budget through 2014.

Ripple effect

As planned purchases of major systems are canceled or postponed, these cuts will hit U.S. defense companies as well as European firms. This raises new threats to U.K. purchases of Lockheed Martin F-35 Joint Strike Fighters and General Dynamics armored vehicles. German and Italian development funding for the Lockheed Martin MEADS (Medium Extended Air Defense System) could be imperiled. In addition, NATO purchases of Northrop Grumman Global Hawk UAVs could come under pressure.

This promises to have a secondary competitive effect as well as causing European companies to become more aggressive internationally to make up for poor domestic defense prospects. These firms will be bolder in their efforts to build up their U.S. presence and to win market share in Asia and other areas where markets remain strong.

Even outside Europe the outlook for defense spending is more uncertain amid growing concerns about sovereign debt. For example, there are signs of pressure on defense spending in the United Arab Emirates, which reportedly is postponing its plans to purchase Alenia Aermacchi's M-346 trainer.

Warning signs

While the U.S. defense budget is not yet in decline, the signs of pressure are already there. As the economy recovers, pressure to tackle the budget deficit promises to increase. That will leave defense as a likely target for fiscal hawks.

Procurement and R&D budgets—the bread and butter of defense companies—are likely to come under greater pressure even if the defense budget remains flat. With Congress frequently enacting pay raises above inflation, personnel costs have been rising. Military health-care costs, now a tenth of the defense budget, have been increasing at 6.9% annually. In a tough budgetary environment, cutting procurement and R&D is likely to be a more palatable option for politicians.

The sums available for contractors remain sizeable. The FY11 defense budget, released earlier this year, provides for $112.9 billion in procurement and $76.1 billion in R&D funding.

Over the period from 2011 to 2015, the Pentagon's Future Year Defense Plan anticipates a compound annual increase to 3.3%, while it declines by 3.9% compounded in R&D. As a result, throughout the period the overall modernization budget remains flat.

Procurement and profitability

As the defense modernization budget grows more uncertain, defense companies will also face a growing number of procurement policy changes that will put pressure on their growth and profitability in coming years.

As these changes threaten their future procurement and research programs, another form of budgetary pressure has also arisen: Defense Secretary Robert Gates has announced plans to cut $101.9 billion from defense spending over five years. As a result, some weapons could be cut. Moreover, some of the initiatives likely to be involved promise to hurt defense companies' profitability.

One of the procurement shifts is already under way: The military is working to insource a growing number of functions, based on the conviction that certain activities are inherently governmental and should not have been outsourced in recent years to private contractors. In addition, there is the conviction that the government can save money by making workers public sector employees.

While that conviction is questionable over the long run, insourcing is under way. In 2009 the DOD added funding for 33,400 new civilian employees, 10,000 of them to be in defense acquisition. Some support work for systems previously done by private companies is being shifted to government depots.

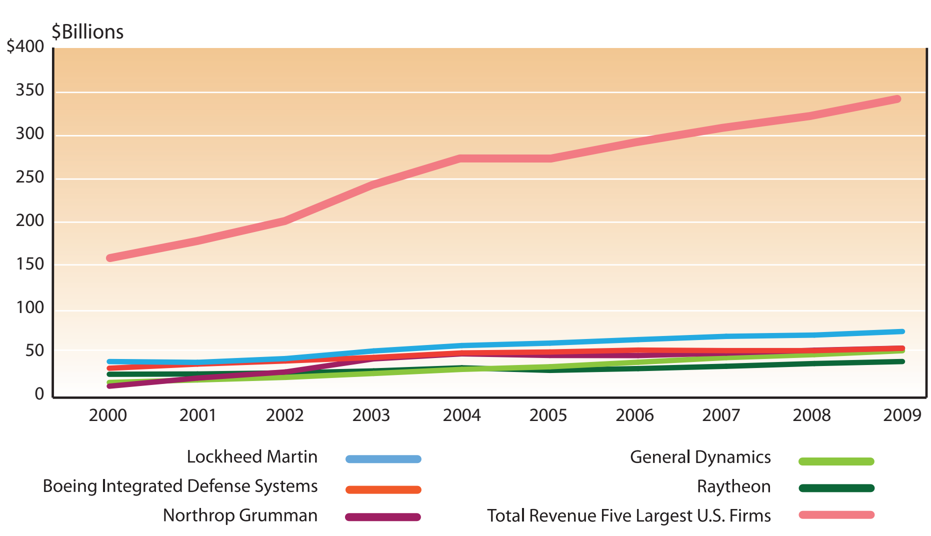
The implication of this for defense companies is clear: Instead of the growth that results from increased outsourcing by the federal government, now companies' work may shrink as the DOD and the intelligence agencies take back an increasing number of tasks. This flies in the face of company plans to bolster their service work to offset any future declines in the procurement of new systems.

The Obama administration also is in the process of changing rules on defense procurement in ways that promise to hurt corporate profits in coming years. These changes are intended to cut costs as well as improve ethical standards in contracting.

Organizational conflict-of-interest changes will be among the most sweeping. The new regulations, although still being hammered out by the DOD, seek to go beyond eliminating actual conflicts of interest; they are moving toward eliminating even the appearance of a conflict. That means going beyond ensuring that requirements cannot be tilted in favor of a company's own products, or that it has knowledge about a system under competition that its competitors do not have. Exactly how that will be interpreted going forward will be determined only after the final rules are issued and contracting officers interpret them.

At a minimum, the new rules promise to make it difficult for major defense contractors involved in system development to do systems evaluation and technical analysis work. There would be concerns about contractors' favoring their own systems as they determine future requirements.

DEFENSE COMPANIES' GROWTH DECADE



Contracting approaches

There also has been government interest in increasing the number of fixed-price development contracts as a way to avoid the cost overruns that have become chronic in new weapon systems. The Air Force's $35-billion KC-X tanker will be a fixed-price contract. Under pressure to show that it can deliver the F-35 for significantly less than recent government estimates, Lockheed Martin is negotiating a fixed-price contract rather than a more traditional cost-plus agreement on the fourth batch of F-35 fighters in the low-rate initial production contract.

The shift to fixed-price contracts could be difficult for industry if the result is to start doing such contracts on technologically immature systems with requirements in flux. These systems have been a prescription for cost overruns in the past. So far, there has been no movement in this regard, but it is a key area to watch for future corporate profitability.

Even areas such as fixed-price maintenance contracts can be risky for defense companies if they involve high-technology systems, or systems for which there is little maintenance experience, or bundling of diverse systems.

There is a thrust to increase competition in the defense industry by reducing the use of sole-source contracts and dividing the work among multiple contractors. Indefinite delivery/indefinite quantity (IDIQ) contracts are being used to help foster a more competitive environment. IDIQ contracts provide for the purchase of an indefinite quantity of services during a fixed time. Whenever the DOD seeks to buy additional services, it can give a task order to one of the companies holding IDIQ contracts for a program.

Obviously, increasing the number of bids done competitively has the prospect of increasing a company's bid and proposal costs. It also threatens to cut prospective profits on what had been lucrative contracts in the past.

Strength remains

As the defense companies enter a potentially more difficult period, they nonetheless seem considerably stronger than they were a decade ago, before the 2001 terror attacks on the World Trade Center and the Pentagon began the explosive growth in military spending.

The five largest defense companies have generally made significant improvements in their profitability. Lockheed Martin went from a $519-million loss in 2000 to a $3-billion profit in 2009, a level of profitability that beat its four major competitors. Raytheon saw its net income rise from $141 million in 2000 to $1.9 billion in 2009, a thirteenfold increase. Northrop Grumman's net profits grew from $625 million in 2000 to $1.6 billion in 2009. General Dynamics' net income rose from $901 million in 2000 to $2.4 billion in 2009. Only Boeing's revenues fell, and that decline was due to its commercial airliner business.

Many defense companies have used these profits to reduce their debt levels, helping to prepare for any future downturn. Lockheed Martin reduced its long-term debt level from $9.1 billion in 2000 to $5.1 billion in 2009. Raytheon slashed its debt from $9.1 billion in 2000 to $2.3 billion in 2009, giving it one of the best balance sheets in the defense industry.

Other major defense companies used their higher profits combined with additional debt to prepare for a downturn by growing, to ensure that they have the critical mass to remain major players in the future. Northrop Grumman, which made a string of acquisitions that increased the size of the company more than fourfold in a decade, raised its debt from $1.6 billion to as high as $9.6 billion in 2002 before cutting it back to $5.1 billion in 2009. General Dynamics, which had no long-term debt in 2000, took on $3.2 billion by 2009 to fuel a threefold expansion of the company over the period.

Other areas of concern

Despite these indicators of financial health, there are also warning signs looming. In particular, reliance on government sales has gone up during the past decade for major defense companies. As their defense sales have grown, leading firms have also divested commercial businesses; Raytheon's divestiture of its business aircraft unit is just one example. This heavy dependence on defense leaves companies more vulnerable to a defense downturn.

Reliance on U.S. government sales rose for all five of the largest defense manufacturers, increasing on average from 63% in 2000 to 76% in 2009. Raytheon saw the sharpest rise, up 20 percentage points to 88%. At General Dynamics the figure increased by 11 percentage points to 71%.

In another area of concern, defense R&D also has fallen, cutting prospects for new products and leaving less room for making cuts to preserve profitability.

Company-funded R&D as a percentage of sales has slid throughout the period, leaving companies little room for future cuts. Three of the five largest defense companies cut their R&D funding (Lockheed Martin, Northrop Grumman, and Raytheon), with Lockheed Martin and Northrop Grumman slashing it by more than half. Lockheed Martin spent 1.7% of sales in 2009 compared with 3.5% in 2000. Northrop Grumman spent 1.8% of sales versus 4.2% in 2000. Although Boeing increased its percentage sharply to 9.5%, this was connected with development of the 787 and other commercial airliners.

Despite the warning signs in the defense procurement environment, there appears to be little danger that companies will go back to the bleak days of the early 1990s. No precipitous decline in defense spending is likely. Moreover, the industry is in a considerably stronger financial and strategic position today.

Philip Finnegan
Teal Group
pfinnegan@tealgroup.com

Continued from page 9)

Amos, in contrast, is "courtly" and "polished," says a Marine colonel who worked for him in assignments at home and overseas. "He has finesse; he's a real politician." Military pilots typically have nicknames, known as call signs, bestowed by their contemporaries. Amos' call sign is Tamer—"as in 'lion tamer,'" the colonel said. "That's partly for warfighting skill and partly because he's the kind of leader who can herd cats."

In that culture, which dictates that every member is a rifleman, the nomination of a pilot as the nation's top Marine was a dramatic break with tradition.

Amos, an F-4 Phantom II and F/A-18 Hornet pilot, will become the first aviator to hold the top Marine job, which includes a seat on the Joint Chiefs of Staff. He has experience with tactical aviation on Navy carrier decks and on land bases from which Marines traditionally operate. In 2003, as a major general, Amos led the 3rd Marine Aircraft Wing on operations in Kuwait and in the U.S.-led invasion of Iraq.

Amos inherits Marine aviation programs that are going reasonably well. The F-35B short takeoff/vertical landing version is more advanced in its flight test program than the Air Force F-35A or Navy F-35C. The once-controversial MV-22B Osprey tiltrotor aircraft is operational in Iraq and Afghanistan. And after delays, technical glitches, and cost issues, the corps is fielding the UH-1Y Viper (Super Huey) and AH-1Z Venom

Gen. James F. Amos

Gen. James N. Mattis

combat helicopters and has both in full-rate production.

Like commandants before him in times of tight budgets, Amos will be challenged on Capitol Hill to defend not only aviation programs (especially the high cost of focusing on STOVL capability) but the very existence of the Marine Corps itself. For decades, Marines have argued that they are needed as a separate service branch because of their expertise in amphibious warfare and because of their ability to respond rapidly to a breaking crisis.

Lt. Gen. Joseph F. Dunford Jr., an infantry officer, is expected to replace Amos as assistant commandant.

Just when some in Washington thought it was safe to be a Marine and not be brusque, Gates followed up the Amos appointment with the nomination of Mattis to be head of the U.S. Central Command (Centcom, headquartered at MacDill AFB, Fla.) and responsible for operations in the Middle East and Asia. Mattis will replace, and nominally will be the boss of, Army Gen. David H. Petraeus, who has followed McChrystal in Afghanistan. To offset his tough talk, Mattis often cites lessons from classic literature and quotes poetry.

Given Petraeus' greater clout in Washington, Mattis is expected to focus on Iraq, Somalia, Yemen, and other trouble spots and give Petraeus a free hand managing efforts in Afghanistan.

The three were not expected to face any hurdles in receiving a formal nomination from the president or winning the advice and consent of the Senate.

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

ARIANESPACE

Thirty years and growing...

Since its founding in 1980, Arianespace has developed its launch vehicles in tandem with the satellite industry, enabling them to lift heavier and heavier payloads into orbit. Over half the commercial satellites now in service were launched by Ariane rockets, says the company, whose order book is now larger than ever.

by Mark Williamson
Contributing writer

March 2010 marked the 30th anniversary of the creation of Arianespace, the space launch provider that bills itself as "the world's first commercial space transportation company." Although 30 years is a relatively short time in the context of terrestrial freight transportation systems, it represents a significant portion of the Space Age and a considerable heritage for Europe's leading rocket company.

Numbers announced to commemorate the anniversary tell a story of success. As of April 2010, Arianespace had launched a total of 277 satellites (plus 51 auxiliary payloads) for 73 customers. According to company spokesman Mario de Lepine, this accounts for "more than half of the commercial satellites" now in service worldwide.

Arianespace's current order book stands at an "all-time record" of €4.3 billion, and includes 34 geostationary satellites, six Ariane 5 launches of ESA's automated transfer vehicle to the international space station, and 17 launches of the Russian-built Soyuz, soon to be flown from the Guiana Space Center. It is clear that the development of Arianespace is

Arianespace's December 18 daytime mission with Helios 2B was the company's seventh flight in 2009 and the 35th success in a row.

far from complete. On the contrary, the clock reads "30 years and counting."

Great minds, great location

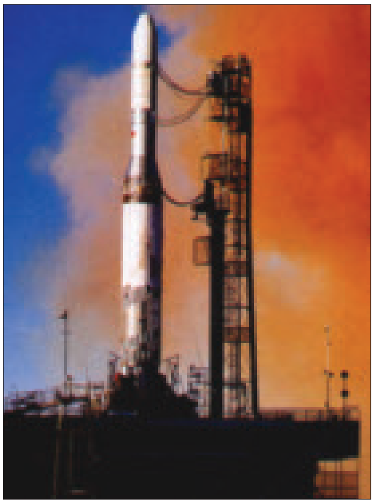
So how did it all begin? Why does Arianespace exist at all?

Like the U.S., Europe began its development of satellite launch vehicles as a spinoff of its ballistic missile programs of the 1950s. For example, when the U.K. abandoned the concept of an independent nuclear deterrent in April 1960, its delivery system, the Blue Streak missile, was proposed as the first stage of a European three-stage satellite launcher. Originally called ELDO-A after the newly created European Launcher Development Organisation, it was later renamed Europa.

Unfortunately, a number of demoralizing failures of the various stages, and the ever-present pressures to cut costs, eventually led to the abandonment of Europa, and ELDO itself was disbanded in 1973. ELDO's activities were amalgamated with those of the European Space Research Organization to form the European Space Agency in May 1975.

This placed Europe in the position of being totally reliant on its Cold War ally, the U.S., to deliver its satellites to orbit. However, the French space agency CNES came to the rescue with its proposal for a new three-stage launch vehicle, known as L3S. Thus in 1973, when ESA initiated the Ariane launch vehicle program (based on the L3S), it delegated its management to CNES, giving France a leading role in the project.

The first flight of an Ariane 1, from a French-run launch site near Kourou, French Guiana, occurred in December 1979, and the operation of the vehicle was handed over to an international partnership company, Arianespace, the following



The failure of Europa pushed France to suggest a "substitution launcher" that would become Ariane. (Courtesy ESA, CNES.)

At 14:14 local Guiana time on December 24, 1979, the first Ariane blasted off. (Courtesy ESA, CNES.)

year. In fact, the Ariane was the first rocket designed from the outset as a commercial satellite launch vehicle, in contrast with its competitors—such as Atlas and Delta—which had been developed from existing ICBMs.

According to Arianespace Chairman and CEO Jean-Yves Le Gall, writing about the company's 25th anniversary in *International Space Review* magazine in 2005, "The creation of Arianespace in March 1980 brought an entirely new perspective to commercial launch services. Our founders believed that satellite operators could best be served by a truly business-oriented access to space, run by a company that was totally dedicated to its customers from the moment of contract signature to the postlaunch supply of orbital injection parameters."

In fact, a key advantage of Ariane in terms of injection parameters arose from the location of its launch site, which, at a latitude of 5.2° N, on the northeast coast of South America, is one of the closest fixed launch sites to the equator. Equatorial launches are the most efficient for delivery of satellites into geostationary orbit, as they avoid the need to carry extra propellant to change the orbit's inclination. This means, quite simply, that for the same launch vehicle, about 12% more payload can be launched from Kourou than from Cape Canaveral in Florida, at 28.5° N, and nearly 30% more than from Baikonur, the main Russian launch site, at 46° N.

Ariane 4, which could lift satellites weighing up to about 4.5 tons to GTO, was introduced in 1988.

Interviewed for *Aerospace America* on the occasion of the 30th anniversary, Le Gall was asked to recall some of the individuals who helped form the company we know today. He paid tribute to his three predecessors: Frédéric d'Allest, "who had the imagination to create the company at a time when nobody believed in it"; Charles Bigot, who served through "the golden age of Ariane 4 and led the company to its success in the marketplace due to this launcher"; and Jean-Marie Luton, who "bet on Ariane 5 when he was director-general of the European Space Agency" and then "won this bet as the chairman and CEO of Arianespace" when Ariane 5 became "the world's most reliable and available launcher."

As Le Gall suggests, the evolution of the Ariane family has been a key factor in its success. In response to the development of larger and heavier satellites, the launcher evolved through several variants, leading by 1988 to the Ariane 4, which could lift satellites weighing up to about 4.5 tons to geostationary transfer orbit (GTO), the most common delivery orbit for commercial satellites.

Ariane 5, the current vehicle, was introduced to launch still larger and heavier payloads. It was initially capable of launching 6.8 tons to GTO; enhancements have since increased this to 10 tons. Unfortunately, its first demonstration launch, in June 1996, was a complete failure, destroying a payload of four science satellites named Cluster and delaying its commercial inauguration to 1999.

Requiem for Ariane 4

As the main causes of launch failures have historically involved either propulsion systems or stage separation events, the engineering fraternity has striven to design simpler vehicles, which are inherently more reliable. This was the design philosophy for the Ariane 5, for example, which has far fewer engines and stage separations than the now-defunct Ariane 4. Theory aside, it remains to be seen when, or whether, Ariane 5 will reach the 74 consecutive successful launches and 2.59% overall failure rate of the much-vaunted Ariane 4.

Interestingly, not everyone in the industry was convinced of the need to graduate from Ariane 4 to Ariane 5, including a former Arianespace marketing executive, Ralph Jaeger, who led the call to "save Ariane 4." Citing the vehicle as "the most flexible launch system ever built [because of its] kit-like system, which allows different configurations to be built from one set of elements—stages, boosters, fairings, and adapters," he asked why the two vehicles could not be operated together as part of "a chain of European-produced vehicles."

With equal amounts of prescience and insider knowledge, Jaeger suggested that retaining Ariane 4 could "at least protect Arianespace against competition from Soyuz." Another reason to keep the Ariane 4 lines running, in Jaeger's view, would be to allow the Ariane 5 to demonstrate its reliability, which he said "could take more than three years." The V157 failure less than two years later made his point better than any op-ed ever could.

Of course, there are many factors in a company's decision to progress from one variant to another, presumably more advanced, more efficient, and more marketable product. For Ariane, other factors included the apparently inexorable rise in satellite mass and the need to support Arianespace's dual-launch philosophy, as well as pressures from ESA and European industry to develop new technology and preserve an active workforce.

Although the Ariane 5 has dominated Le Gall's term at the helm of Arianespace, he is clear about the importance of Ariane 4 in the company's history. Asked for his views on the highlights of the past 30 years, he says that Arianespace has seen three main periods of development: the first 20 years (1980-2000), which included what he terms "the golden age of Ariane 4"; a second period from 2000 to the present, including "the ramp-up of Ariane 5 operations"; and a third period that he says begins this year. It will see the introduction of a "complete family of launchers," he notes, "as Soyuz and Vega join Ariane 5."

New challenges, new solutions

For the first two decades of Arianespace's existence, the trend in commercial satellites and launchers was fairly predictable: Satellites were getting bigger, and placing them in orbit required more powerful launch vehicles. However, the market has become diversified, with a resurgence of medium-sized satellites and the introduction of smaller geostationary platforms. It is difficult to predict how this diversified market for satellites will evolve, but launch providers are obliged to find cheaper, more efficient ways of deploying them.

The solution, which became clear several years ago, was to diversify the fleet, maintaining the Ariane 5 for the larger payloads while adding the Russian-built Soyuz for medium-sized satellites and the ESA-developed Vega for smaller payloads. In a sense, the company was forced into this solution by the inability of the Ariane 5 to carry two of the larger communications satellites, thus limiting the company's long-held dual-launch philosophy.

Adding Soyuz to the manifest has not been a quick fix, however: The agreement between Arianespace and Roskosmos, the Russian space agency, was signed in April 2005, but its introduction to the Guiana Space Center—with a launch of Avanti's HYLAS-1 satellite—is not expected to occur much before the end of the year. Vega, meanwhile, is not expected to debut until 2011, more than two years later than originally planned.

Reliability is key

The aerospace consulting and information firm Ascend provides independent analyses of the international launch industry. Asked how Arianespace had performed over its 30-year history, senior space analyst David Todd confirms that "Arianespace is one of the two major launch providers of the commercial market, the other being International Launch Services [ILS]," which operates the Proton.

In terms of historical performance, figures from the Ascend SpaceTrak online database show that care should always be taken when comparing launch vehicle statistics. While early versions of Ariane experienced the usual problems, reliability improved substantially with the Ariane 4 variant, with just three failures among 116 launches, for an overall failure rate of just 2.59%. Ariane 5, by contrast, has experienced three or four failures in 49 flights, depending how one reads the data.

Ariane 5 and Soyuz models were on display at the Paris Air Show in 2009. (Photo by Mark Williamson.)

Ascend, which tailors its advice to the space insurance industry, quotes four failures, giving a failure percentage of 8.16%, while Arianespace recognizes three failures (giving 6.1%). The discrepancy involves the V101 mission of October 1997, which carried two "mass dummy" payloads as part of a test launch. Unfortunately, the vehicle's main engine was shut down by the onboard computer several seconds prematurely, resulting in an apogee 9,000 km less than the planned 36,000-km GTO. According to Ascend, had the payload been a commercial geostationary satellite, it would have had to use its own propellant to boost its orbit, thus losing "about 10-15%" of its in-orbit design life.

While Arianespace agrees that the consequence of the vehicle's underperformance would have been "13 instead of 15 years of lifetime in orbit," according to de Lepine, "If we'd had commercial satellites on that launch, they could have reached the final orbit" using their own propulsion systems. Given that this procedure has since been demonstrated, it seems harsh to class the launch as an outright failure that degrades the overall statistics.

Indeed, Todd readily admits that "the overall failure rate does not tell the whole story." For the insurance community in particular, it is the recent record that counts, he says, citing the 35 consecutive Ariane 5 successes since the V157 mission of December 2002, which carried the Hotbird 7 and Stentor satellites into oblivion. "The rocket has now settled into that 'nirvana' state of having a long uninterrupted run of successful flights," says Todd.

Todd describes the insurance community's current view of Arianespace as "very good," adding, "The space insurance market rewards this recent good record with a very low premium rate." Indeed, comparing Ariane with other launch vehicles, Ascend contrasts an overall reliability figure of 6.22% for 193 Ariane flights with 11.30% for 354 Proton flights and 8.8% over 34 launches of the Zenit 3 (currently used by Sea Launch).

Asked to compare Arianespace with other commercial launch vehicles in terms of reliability, Mario de Lepine says flatly, "we do not like to compare," but continues to point out that Arianespace has experienced "no failures since 2003, [whereas] Proton failed in 2006, 2007, and 2008, Sea Launch in 2008, Long March in 2009, and GSLV in 2006 and 2010."

The Vega, to be provided by ESA, is a brand-new, unproven rocket.

Says Le Gall, "Soyuz and Vega are in the process of changing the scope of our company, since we will be going from six or seven launches a year with Ariane 5, to a total of 10 or 12," including three or four Soyuz launches a year and one or two Vega launches.

He also expects the diversification of payload capabilities to expand the company's client base. "This is extremely important, since with Soyuz and Vega we will be able to launch all types of satellites for all customers, especially those European governmental satellites that are too small to use Ariane 5," Le Gall explains. "This comprehensive launch capability will be our calling card," he adds.

How is the insurance market likely to view these developments? Ascend consulting analyst David Todd expects Soyuz to provide competition "for the Land Launch version of the Zenit 2 and 3 rocket systems, for smaller GEO satellites and LEO constellations." Moreover, he does not expect the Soyuz to reduce Ariane 5's market share, because "its payloads tend to be much larger satellites."

Vega, on the other hand, is a "brand new rocket," says Todd, "and our records show that maiden flights have failure rates in excess of 60%." So customers flying payloads on Vega should not expect the low insurance rates associated with Ariane 5, warns Todd, "at least not until Vega proves itself."

Le Gall admits that maintaining the company's leadership position is "a real challenge," but sees more uncertainty outside the company than within: "Will Sea Launch resume service or not? Will SpaceX be a success? Will China make a market breakthrough? How about India?"

Ascend recognizes these and other potential competitors. "While unimportant individually," advises Todd, "if all the minor players in the commercial launch market take one or two satellite payloads apiece from the total available, this may have major implications for the viability of the major launch providers such as Arianespace and ILS.

"Nevertheless," he adds, "with its reputation for a good quality of service and good recent reliability, for the time being at least, Arianespace remains the launch provider that the others have to beat."

Mission success

For Europe, the road to space has been somewhat long, especially in providing its own access to orbit. But within a little more than 30 years, its commercial launch industry—embodied in Arianespace—will have gone from the first launch of an Ariane 1 to the operation of a family of vehicles designed to access all types of orbits, providing Europe with the autonomy it has long desired.

Understandably, the commercial success of Arianespace instills feelings of pride among its workforce and across a wider European space community. "From the political standpoint," states Le Gall, "it's because we are so successful commercially that we can guarantee independent access to space for Europe, which is Arianespace's 'raison d'être' in the final analysis. In short, we are successful in both of our assigned missions."

However, Le Gall is keen to stress the international aspects of his company. "Arianespace may be a European company," he says, "but we're also American. We have a subsidiary in the United States [and] we launch a lot of satellites either for American operators or built by American manufacturers." And while it is clear that the U.S. is "a key to Arianespace's success," he believes that Arianespace is "a key to the success of the commercial space market in the United States."

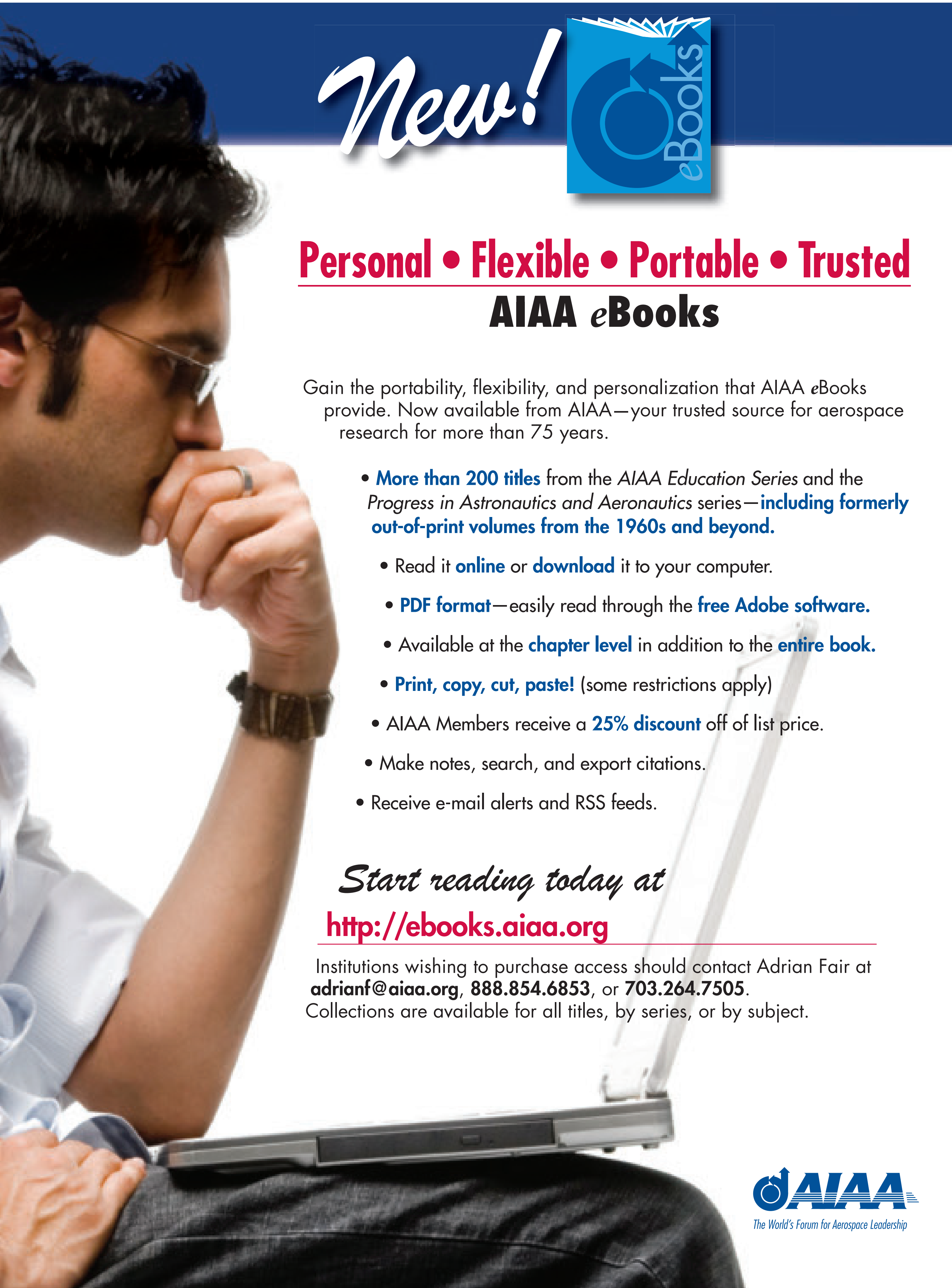
So, three decades after the first Ariane thundered into the French Guiana skies, the CEO of Arianespace has reasons to celebrate. Thirty years ago, says Le Gall, "Arianespace was a pioneer in space transportation. Today, we are very proud of the fact that Arianespace has launched over half of all commercial satellites now in orbit. With the success of Ariane 5, including a perfect record for the last 35 launches, and the advent of a complete family of launchers, that's an excellent way to celebrate our 30th anniversary."

Ariane 6

Europe plans to replace the workhorse Ariane 5 with a new heavy-lift vehicle sometime around 2025. As with other variants, the vehicle will be studied and developed under the auspices of ESA and funded by its member states. Currently part of ESA's Future Launcher Preparatory Program and dubbed Next Generation Launcher or NGL, it is more commonly referred to as Ariane 6. According to Jean-Jacques Dordain, ESA's director general, the intention is to arrive at the next ministerial summit in 2011 with a firm definition proposal for the new booster.

Once again, the French government is providing the political impetus for Ariane 6, which it expects to cost between €3.5 billion and €8 billion to develop, and has issued a special bond to provide €250 million to begin the definition phase.

Although many of the design choices remain to be confirmed, including the type, or types, of propellant to be used, the vehicle is expected to be capable of launching a single 6-7-ton satellite, thus shifting the focus from dual launches. Arianespace CEO Jean-Yves Le Gall has been quoted as saying that a price reduction from the €150 million-€160 million for an Ariane 5 "would be very helpful to develop space applications." Of course, the cost to roll an Ariane 6 off the production line depends on many things, and it remains to be seen whether European industry can produce the new vehicle for less than the Ariane 5.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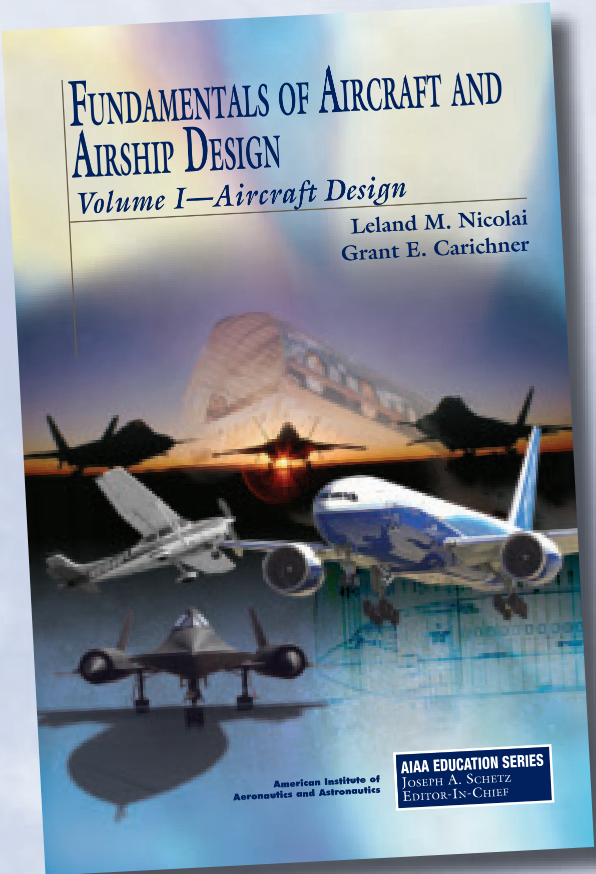

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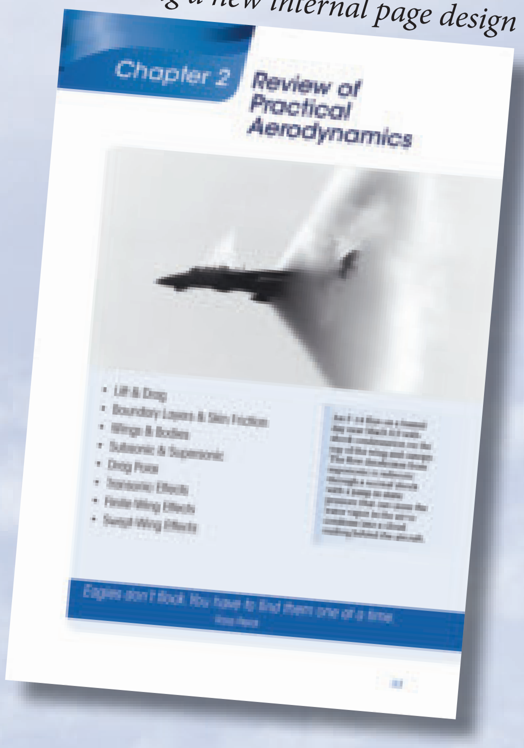

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Robona

When NASA's new R2 (for Robonaut 2nd Generation) arrives on the space station, it will do something no other humanoid robot has ever done—perform useful work, side-by-side with human astronauts in space.

The similarity in name to Star Wars' famous R2D2 is purely coincidental—indeed, R2 is closer in appearance and capability to the movie robot's sidekick, C3PO. Except this R2 does not speak. Yet.

"This version does not have the same voice synthesis capability we had on the original [R1], but we can do that," notes Nicolaus Radford, Robonaut deputy project manager at NASA Johnson.

"We do a lot of nonverbal communication with the way the robot can gesticulate, based on research from DARPA showing you can point and the robot can develop a response as to what you mean. However, this program was primarily looking at how NASA and General Motors [Robonaut prime contractor] come together to further the state-of-the-art of humanoid robots that will work around people. So our main focus was really developing the manipulator and dexterity portions of that first."

by J.R. Wilson
Contributing writer

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The next generation

R2, soon to be launched to the ISS, will become the first humanoid robot to do useful work alongside astronauts in space. Developed by a NASA/General Motors team, R2's advanced features will enable it to perform increasingly difficult tasks both in space and on GM's shop floor. Team members say the two organizations' differing needs and perspectives have sparked innovation and even helped to speed progress.

"Both speech recognition and response would increase the robot's capability, absolutely—and that already is part of the game plan," says John Olson, director of the Exploration Systems Integration Office at NASA Headquarters. The obvious benefit, he says, is that the human could deliver simple instructions or requests. "So the goal for future development is hearing first, then speaking."

Mobility: It's complicated

At present, R2 has only an upper body—torso, head, and two arms, with the most advanced mechanical hands and fingers yet developed. In null gravity inside the ISS, legs are unnecessary. But mobility, beyond simple floating, is part of the Robonaut's future, both in space and on Earth, where GM sees it as a major addition to its manufacturing plant workforce. "We see a dominance of applications that do not require mobility....But there are applications where we can take advantage of it," says Alan Taub, GM vice president for global R&D.

Mobility also raises major complications for the robot's programmers: It is one thing to enable R2 to pick up a wrench and tighten a nut—it is far more complicated if the robot is

"You just keep plowing ahead until incremental successes aggregate into a technological leap."

Nicolaus Radford,
deputy project manager-Robonaut, NASA Johnson

walking or rolling toward the nut while reaching out with its arm and manipulating the wrench in its hand.

"Once I have allowed the torso to move, I get extra complications in getting coordinates aligned between what is seen and touched. There are a lot of algorithm and math challenges to overcome to allow fine motor skill operations if the torso has major large-scale movement," Taub says.

The first "leg" fitted to R2 will likely be a grappling element that would enable it to move along the outside of the space station and lock itself down while leaving its arms free. By using power plug-in points already in place for Dextre, the station's existing external, albeit nonhumanoid, robot, R2 could keep itself fully powered.

In an EVA mode, R2 also could get into tight spaces where a human astronaut in a bulky spacesuit could not fit. But R2's first duties will be inside the ISS.

NASA and GM, although working toward some common goals, have decidedly different futures in mind for the humanoid robot. Both see R2 primarily as a partner to humans, doing jobs that are too dull, dirty, or dangerous for far more expensive—and fragile—human beings. But government and industry officials are quick to say that although robots may take over some tasks, they will not replace their biological masters.

Robonauts built for space and those built for automobile assembly plants have much in common—and a great many differences.

Spacefaring humanoids

R2 and its successors will face significant tasks working inside and later outside the ISS. But NASA also has long-term plans for Robonauts to prepare initial sites for human missions to the Moon, Mars, and other destinations.

"As we look out 5, 10, 20 years, I think we will see some amazing capabilities," notes Olson. "But that is couched in the sense of better developing synergy between humans and robots, not one replacing the other."

Robots will first be assigned simple but essential tasks that do not really need the human touch. "The nice part about Robonaut is it can use the tools we have designed for humans and leverage existing hand restraints. ISS is sized to human dimensions, so having the robot fit into those is added utility," Olson says. "As its capabilities and our comfort with it evolve, so will its tasks and utility."

Safety is a primary focus of the Robonaut program, and is also among the most difficult elements to achieve. It is essential in space, where medical attention for astronauts is limited, but is of no less importance on a terrestrial manufacturing floor.

"This program was designed from the get-go to have humans and robots working in close interaction. For example, if you bump into R2, it is compliant, unlike other robots," Olson says, referring to its ability to give way to a human. "It also is designed to sense proximity and location, so it has been optimized for a close working environment, revolutionizing the way humans and robots interact.

"In every element of our missions, training has safety as a critical element. Inside the ISS, part of the profile is to expand our comfort zone and human/robot interaction. R2... can detect the presence of a human, which impacts its algorithms appropriately."

There are obvious advantages in interplanetary missions to sending robots ahead to prepare a landing site, locate water and other local essentials (such as useful metal ore), build initial habitats, even start gardens to provide food and oxygen and remove carbon dioxide. But that advance guard need not—probably will not—be humanoid.

"Do we need a humanoid robot to go to those places or would another type serve, either with better, lighter, or different mass or volume? The question is, what are the needs of those missions?" Olson explains. "The humanoid shape of R2 allows it to use a lot of the same tools if we plan to send humans or if they already are there. But if we are sending the robot there first, it doesn't have to have a humanoid shape."

Advanced features

Radford says R2 already demonstrates a number of significant advances over R1. Many have been combined, shrinking it to nearer human size and enabling it to function far more quickly. Employing force-torque rather than position-controlled manipulators allows greater variance in the forces used when R2 interacts with people. It has the world's most advanced sensors and sensing capabilities, especially in its fingertips.

"We have a lot of actuator and motion controller development. It doesn't do you any good to have the world's greatest sensing robot if you can't resolve those forces into action," says Radford. Using its sensory data and turning it into joint motions "takes a significant amount of processing power. So we have a hierarchy of embedded processors distributed all around the robot that are able to process the sensors at a very local level to enact a control methodology.

"In the original Robonaut, we had bus cables and sensor wires on hundreds of conductor levels back through the arms to a central processor. On this robot, we have a single bus network, a high-speed communications bus, with a very small number of wires, because we do all our joint processing locally in each actuator. That was a main design requirement, to reduce the number of wires, because wires tend to propagate failures. So this robot was designed from a maintenance and serviceability point of view, on which GM had a considerable amount of influence."

What distinguishes Robonaut from all other robots, he adds, is the use of a series of elastic actuators for manipulation.

"We have a rotational, torsional spring on the outside of all our gear trains, our joints, and sense the positional differences of that spring and resolve that into torques, which we can measure very finely and turn into control methodology for the robot.That is what gives it its unique control so it can interact with people in a way a positional robot cannot," Radford notes.

"We have a bunch of FPGAs [field-programmable gate arrays] for our distributed processing—about 25 with dual Power PC processors each—which form the backbone of the robot's motor control." This is "similar to a human spinal column, where a lot of low-level reflexes are handled locally rather than going back up to the brain. That allows us to run very high speed control loops—torque control loops at 10,000 Hz at each joint level, which is the highest we know about.

"We have a lot of sensing in the hands, including the world's smallest six-axis load cell in the fingertips, a customized load cell we invented here at JSC that exists in all the fingers, so it has a very good idea of how it touches things. Tactile feedback was paramount on this system; we wanted it to have a very fine touch….So the palm has its own processor, taking all the data from the fingers, computing necessary actions and sending the relevant information back upstream to the bigger processors."

All of this is also important to GM as it looks to the Robonaut concept for terrestrial manufacturing. And any success R2 and its successors have in building cars can transfer to similar tasks in aerospace manufacturing.

Gravity and other issues

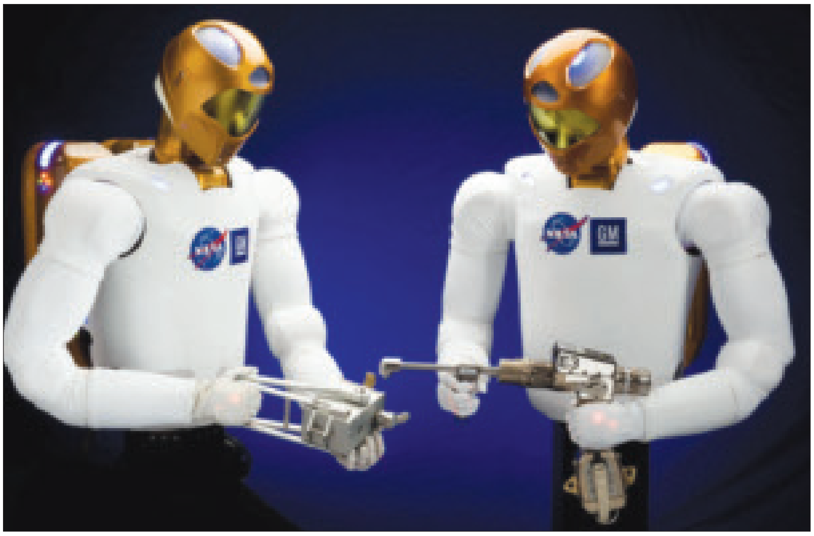
There is one aspect of development that, although of little or no interest to GM, is critical to NASA, and that is gravity.

"We have an array of tasks we have developed in a 1-*g* environment. First and foremost, we want to re-prove those in space, because robot control will be a lot different in 0 *g*," Radford says. "There is a lot of control involved with this robot that takes into account the effects of gravity. To see what happens in that environment, we are flying a task board along with the robot with a lot of common-use tools and connectors. Those represent things the crew has to perform on orbit; it will demonstrate how the robot can interact with a lot of ready, available things on the ISS."

Earlier robots in general have been "really bad at working with floppy materials," notes Radford. "This robot handles those very well," a major design goal. "We have a lot of soft goods on the space station, so we see a future use of this robot in handling a lot of those soft materials that have to be removed in order to access what is behind them."

UAW robot guild?

In the 1970s and 1980s, one of the first advantages Japanese industry employed to over-



R2 was designed to use the same tools as humans, which allows them to work safely side-by-side with humans.

take America's Big Three automakers was the industrial robot. By replacing humans with robotic welders and painters around the clock, Toyota and others were able to speed up production, enhance quality, and cut costs.

Detroit responded by bringing in robots of its own—a difficult task, because the assembly line essentially had to be built around them. However, humanoid robots such as R2 can move into an existing facility, use its tools and procedures—and do so much more safely than a multiton welding robot could.

"When a big robot is doing its routine, it will head to where it needs to go whether a human is in the way or not," says Radford. "Most factories spend more money protecting the workers from robots than on the robots themselves." This led to developing "the impedance-controlled manipulator, which allows R2 to interact with humans in a very safe way."

Susan Smyth, director of manufacturing systems research at GM's Manufacturing Assembly & Automation Center, says success is a combination of equally important factors such as safety, reliability, human comfort in working alongside a humanoid robot, and ease of maintenance.

"It's one thing to have a mechanism that performs a number of tasks in a controlled environment. But when you try doing that task 100,000 times, with people around it, a much greater level of physical robustness is required," she adds. "So having a really robust electrical system going forward is a big thrust."

Seeing and feeling

"In robotics today, you find a lot of talk about vision and sensors. But the challenge is sensor fusion," says Roland Menassa, GM's manager for advanced robotics. "Humans use many different sensors—when vision is occluded, you can rely on touch. We've done the same with the Robonaut.

"It is the interplay between sensors that makes possible the handling of flexible parts. And fundamentally, what makes that possible is the miniaturization of a lot of the componentry and high-speed computing. You can embed that technology just about anywhere you want."

Taub cites one of the challenges GM gave Robonaut: Installing a floppy sheet of rubber into a precise location on the inside of a car door to protect it from water.

"In the past, robots in our plants could barely deal with solid pieces of metal. That was solved only about five years ago. So now we have two arms, operating semiindependently, pulling on fragile pieces without ripping them," he says. "Second, you have to find precise locating points—one of which can only be identified by feeling a bump on the part—then insert that locating point into a part on the vehicle it has to find by vision. So R2 had to find a part by feel, using robotic fingers, then deal with what it was holding using mechanical vision.

"In the end, the robot was able to do all those things. The only limit is it is slower than a human, but the fact it could do all three in a demonstration project says this robot can basically handle ergonomically difficult, highly repetitive operations in the plant."

Testing period

Testing R2 inside the ISS will provide an important intermediate environment between Earth and extravehicular space. There the robot will be subjected to microgravity and to the radiation and electromagnetic interference environment of the station.

"Our goal is for R2 to perform routine maintenance tasks, freeing up the station crew for more important work," explains Ron Diftler, Robonaut project manager at NASA Johnson. "Here is a robot that can see the objects it is going after, feel the environment, and adjust to it as needed. That is pretty human. It opens up endless possibilities."

The ground team and the ISS crew will control the robot with identical systems, each comprising a graphical user interface on a computer screen and pushbutton navigation.

"R2 operates under 'supervised autonomy,'" says Diftler. "It can think for itself, within the limits we give it. We will send it scripts—sequences of commands."

The interior operations will provide performance data about how a robot may work side by side with astronauts. Then it will slowly progress from simple tasks, such as monitoring its own health, to more complicated assignments. As development activities progress on the ground, station crews may be provided hardware and software to update R2 and enable it to perform new tasks.

The Robonaut project also seeks to develop and demonstrate a robotic system that can function as an EVA astronaut equivalent. Robonaut jumps generations ahead by eliminating the robotic scars (special robotic grapples and targets) and specialized robotic tools of traditional on-orbit robotics. However, it still keeps the human operator in the control loop through its telepresence control system. Robonaut is designed to be used for EVA tasks that were not specifically intended for robots.

R2 is undergoing extensive testing in preparation for its flight. Vibration, vacuum, and radiation testing along with other procedures being conducted on R2 also benefit the team at GM, who plan to use technologies from R2 in future advanced vehicle safety systems and manufacturing plant applications.

Edward Flinn

Taub also says GM sees the coming generations of factory robots as augmenting their human partners, not replacing them. Indeed, manufacturing improvements and cost savings brought about by robots such as R2 may lead to more sales, more plants, more jobs.

Benefits of partnership

Factories also could take the lead in developing mobility for R2, as they are likely to need that capability sooner than NASA will.

"Our plan is to enhance our current robots," says Taub, noting that they are "still experimental, expensive, and not robust; so it will be awhile before we see a full Robonaut on the plant floor. "We can get 80% of the benefit of a humanoid robot just with a world-class torso….But in parallel to developing a hardened version of Robonaut, we will be working on a not-yet-announced initiative to make it mobile."

Eventually, the GM/NASA partnership will expand further.

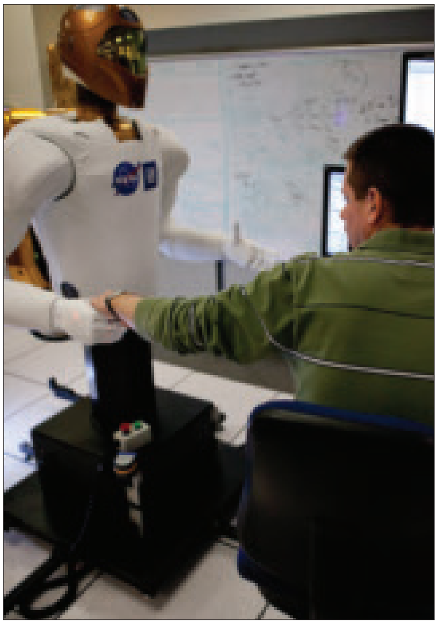
"Breakthroughs in technology and applications used to come from multidisciplinary teams in a given organization. But R2 has demonstrated the value of crossing industries and application space," Taub explains. "For example, GM and Boeing have a 50-50 ownership for a lab in California where we do research at the intersection of aerospace and automotive. One of the Robonaut team members came from that lab.

"It might seem difficult to meet the needs of two different industries….But the surprising thing is, even though you end up putting higher requirements on a joint project, a team bringing different viewpoints and backgrounds to resolve challenges unique to both actually moves faster. The innovations come from the team looking at the problem from two different perspectives.

Those perspectives are colored by the roles they see humanoid robots performing in their particular environment. But basically they all come down to turning one of the oldest science fiction dreams into reality.

From the perspective of scientists and engineers, Robonaut represents a coming together of multiple enabling technologies in ways that would not have been possible any earlier.

"As I look at the technology breakthroughs, it was fundamentally a biomimetic force system, using a tendon-like actuation mechanism, a terrific job of miniaturization of components to get size and moment of inertia down; then some very critical intellectual property around how to make forcing systems compliant, and the sensors around that," concludes Taub. That combination produced "a robot capable of lifting heavy weights and doing real work, but with the compliance of a human. Now superimpose extra sensors so we can get predictive capability."



The 300-lb R2 consists of a head and a torso with two arms and two hands.

Forward steps

Menassa sees R2 as the first of many generational leaps to come. "R2 is really a giant step forward, designed from the onset to mimic human motion, size, and speed…." The compactness of R2 is truly a testimonial to the technology that went into making it. But we also had to do advances in controls actuation and human/machine interface, so you can interact with the robot the same way you would with a human."

For many of those involved in the development of Robonaut, the future of humans and robots is inextricably linked.

"This project exemplifies the promise that a future generation of robots can have, both in space and on Earth," Olson notes. "The combined potential of humans and robots is a perfect example of the sum equaling more than the parts. It will allow us to go farther and achieve more than we can probably even imagine today."

"This is the opposite of technology replacing humans; rather, [it is] fundamentally enhancing the ability of an individual human or a system of humans and machines working together."

Susan Smyth, director, manufacturing systems research, GM Manufacturing Assembly & Automation Center

A higher calling

The edge of space, at the uppermost reaches of Earth's atmosphere, is an area long studied by sounding rockets, balloons, and research aircraft. Today, with an array of new commercial suborbital vehicles nearing completion, this region also promises to yield a wealth of data critically important to NASA missions, particularly in the sciences. Tight budgets, however, threaten programs in this realm, which has been called the "heart and soul" of the agency's activities.

In the rarefied upper atmosphere of Earth there are visitors—an array of suborbital platforms that for decades have carried out key research tasks. Sounding rockets, high-altitude balloons, and aircraft have probed that environment to perform all manner of studies, from gauging solar and space physics phenomena to conducting astronomy, astrophysics, and Earth science exploration. Aircraft and sounding rockets can also be used to study short-duration microgravity effects.

Suborbital vehicles of varying payload mass and flight duration capabilities can gain right of entry to different altitudes and latitudes, addressing a broad array of scientific questions. No single class of suborbital vehicle can satisfy these wide-ranging requirements.

It is against this backdrop that a new fledgling technology may offer a fresh approach to accessing the suborbital heights. A number of privately backed enterprises are developing reusable piloted and unpiloted suborbital launch vehicles. The intent is to deliver passengers and payloads to near space, where Earth's atmosphere ends and space be-

for suborbital research

Sir Richard Branson, British billionaire and adventurer, is bankrolling Virgin Galactic to carry people and payloads on suborbital treks to the edge of space. Credit: Virgin Galactic.

gins, roughly 100 km above terra firma.

But before that regime becomes available to researchers, reusable suborbital platforms face rigorous shakeout schedules. Several flight safety hurdles must be overcome and extensive evaluations of vehicle performance must take place as these vessels plow up into suborbital space.

Meanwhile, a study assessing NASA's rich history of suborbital program elements—airborne, balloon, and sounding rocket systems—has found this capability in disarray, fiscally challenged, poorly managed, and without a clear champion inside the agency. At peril is a vital foundation for cutting-edge, high-altitude studies, as well as a training avenue for students, principal investigators, and project managers.

"Ineluctable conclusion"

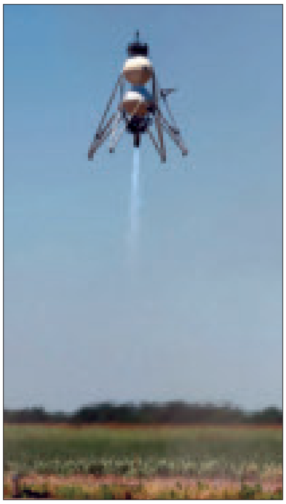
A National Research Council (NRC) report released early this year, *Revitalizing NASA's Suborbital Program—Advancing Science, Driving Innovation, and Developing a Workforce*, pulls no punches in describing the dismal state of NASA's suborbital enterprise:

"Whether because of budget cuts, changing priorities, full-cost accounting, outsourcing, development of government-owned, contractor-operated facilities, or other com\plexities and challenges facing NASA and its suborbital program, the committee could not escape the ineluctable conclusion that NASA has lost its bearings with respect to the suborbital program's essential importance to the future of the agency," says the report.

Furthermore, the NRC appraisal finds that these capabilities are slipping away, and that with that loss, so too is the engine of NASA's success. "The lack of sufficient funding for the suborbital program appears to be driven more by NASA priorities than by the overall NASA budget," the report stresses. Budget pressures apparently have caused NASA "to ignore the warning that the declining health of the suborbital program might presage the fate of the rest of NASA's capabilities as well."

In short, the NRC reviewers found

by Leonard David
Contributing writer



Armadillo Aerospace of Rockwall, Texas, is a developer of reusable rocket-powered craft, having completed over 200 flight tests spread over a dozen different vehicles since it was founded in 2000. Credit: NASA.

NASA's suborbital elements and facilities "insufficiently funded and hence not fully or effectively used."

Heart and soul

NASA, of course, cannot be compelled to heed the report's findings, notes Frank Martin, an aerospace project consultant who served on the NRC study group. "I've always considered the suborbital programs as the heart and soul of NASA. It's the one capability NASA has that [allows it to] do end-to-end, cradle-to-grave project management, systems engineering, technology development, on a quick turnaround basis. It gives people real hands-on experience…it develops your people," he tells *Aerospace America*.

Sharing that view is Daniel Baker, director of the Laboratory for Atmospheric and Space Physics at the University of Colorado, Boulder. "There is ample evidence from many studies that the suborbital programs—broadly interpreted—are crucial to the health of the U.S. space program," he says. "It has been well documented that rockets, balloons, and aircraft missions are highly beneficial for new technology demonstration, for advanced instrument development, for education of experimental scientists, and for providing young engineers and managers the 'systems' experience that they will need to design, build, test, and fly future major spacecraft missions."

Baker, a reviewer of the NRC report, adds that in light of the suborbital program's indispensable contributions, he was heartened to see the report's strong advocacy for more missions to provide the hands-on experience so sorely needed.

Blue Origin's vertical takeoff/landing vessel, the Goddard, has flown as a precursor to the firm's suborbital Shepard vehicle now in development. Credit: Blue Origin.

Asked how important the emerging private suborbital vehicles are to space access, Baker says, "I think that any new ways to access space can be quite important. In a sense, the more traditional suborbital programs are a 'bird in the hand.' Thus I would like to see those missions well supported. Newer approaches can then be aggressively pursued."

Rising hopes for future markets

There is rising anticipation that a new crop of commercial suborbital platforms can serve scientific and educational markets. Such vehicles are in varying stages of development at a number of private firms, including Armadillo Aerospace, Blue Origin, Masten Space Systems, Virgin Galactic, and XCOR Aerospace.

Although these craft are still in early developmental stages, the builders see reusable rocket-propelled vehicles as offering high flight rates and quick, routine, affordable access to the edge of space. That was one message stemming from a Next-Generation Suborbital Researchers Conference held in February in Boulder, Colo., and convened by the Southwest Research Institute (SwRI), the Lunar and Planetary Institute, the Universities Space Research Association, and the Commercial Spaceflight Federation.

"Thanks to the new generation of reusable suborbital vehicles coming on line, we are on the verge of a revolution in space access, with breakthrough prices and flight frequencies that will open up many new applications," says a leading advocate, Alan Stern, associate vice president of SwRI's Space Science and Engineering Division in Boulder. A former NASA associate administrator for science, he also chairs the Commercial Spaceflight Federation's Suborbital Applications Researchers Group.

Stern is a consultant to several of the suborbital vehicle vendors and emphasizes that suborbital research applications are blossoming. "I also believe in the transformative power of suborbital to reignite public interest in human spaceflight," he says.

As he considers the unique features of suborbital research brought about by reusable craft, Stern sees fewer constraints on payloads and gentler rides for them as well. Off-the-shelf laboratory equipment can be flown along with researchers. Also, larger payloads can take to the air, in contrast to equipment carried inside the space shuttle or installed on the ISS, says Stern. He envisions simple, fast safety/integration processes, much like those used for 0-*g* aircraft.

SwRI researcher Daniel Durda also expects to fly with and operate suborbital experiments while in flight. He senses that the day has finally arrived when space scientists can conduct their research "in the field"—just as botanists, geologists, and oceanographers have done all along.

Niche science

Ardent about keeping infectious enthusiasm in line with reality is Laurence Young, Apollo program professor of astronautics and professor of health sciences and technology at MIT. "In terms of life sciences, you have to ask, is there a niche that can be filled effectively and at relatively modest cost by suborbital flight?"

Young says there is, such as probing for effects that occur within several minutes into microgravity; these cannot be studied effectively on the ISS. The expense of doing studies on the shuttle or station is excessive, he continues.

"Cardiovascular effects are things that take place within the first few minutes of going into microgravity…and those are what we're really interested in studying," Young explains. Also of interest is "the transition from zero gravity up to something above 1 *g*, taking us through the critical subgravity levels. We just know so little about that area. It's never been practical to go and do much science on the way up or down."

Young's optimism about these possibilities is guarded, however, given the lessons learned from the space shuttle/Spacelab era of quick turnaround time, repeat experiments, and low cost.

His colleague Erika Wagner, executive director of the X-Prize Lab at MIT, sees multiple opportunities for life sciences research in areas such as vestibular and sensorimotor responses, lung deposition of particulates, and acute cellular responses. Watching for early responses to microgravity exposure can lead to better understanding of fluid shift, motion sickness, pharmacokinetics, and heightened gene expression within the body, she notes.

Using the unique features of suborbital research, Wagner adds, a large, diverse passenger base could tease apart differences involving age, sex, experience, and health status. "There's also an important opportunity here to engage students," she points out, noting that rapid approval and frequency of flight are factors that fit well with academic timelines, providing low-risk proof of concept for larger research programs. Thus, payloads of opportunity that hitch rides whenever margins allow could also include "pocket payloads" that fit in tourists' flightsuits. There is also the prospect for eventually flying students, she says.

Masten Space Systems, based in Mojave, Calif., is developing fully reusable vertical takeoff, vertical landing suborbital platforms. Credit: Masten Space Systems.

Supportive boost

February's Next-Generation Suborbital Researchers Conference drew some 250 scientists, educators, and suborbital rocket vehicle makers. Scientific papers focused on high-altitude science studies and how best to utilize 3-4 min of microgravity for experimentation, discovery, and testing.

Restorative steps

A blue-ribbon panel of experts took part in the recently issued National Research Council study, Revitalizing NASA's Suborbital Program—Advancing Science, Driving Innovation, and Developing a Workforce.

Among the study group's key recommendations:

•NASA should undertake restoration of the suborbital program as a foundation for meeting its mission responsibilities, workforce requirements, instrumentation development needs, and anticipated capability requirements. To do this, the agency should reorder its priorities to increase funding for suborbital programs.

•To increase the number of space scientists, engineers, and system engineers with hands-on training, NASA should use the suborbital program elements as an integral part of on-the-job training and career development for these employees and for project managers.

•NASA should make essential investments in stabilizing and advancing the capabilities in each of the suborbital program elements, including development of ultra-long-duration superpressure balloons capable of carrying 2-3 tons of payload to 130,000 ft; execution of a thorough conceptual study of a short-duration orbital capability for sounding rockets; and modernization of the core suborbital airborne fleet.

•NASA should continue to monitor commercial suborbital space developments. Given that the commercial developers stated to the committee that they do not need NASA funding to meet their business objectives, this entrepreneurial approach holds potential for a range of opportunities for low-cost, quick access to space that may benefit NASA as well as other federal agencies.

Over a blanket of snow covering California's southern Sierra Nevada mountains, NASA's SOFIA (Stratospheric Observatory for Infrared Astronomy) conducts a test mission with the sliding door over its telescope cavity fully open. NASA operates several research aircraft capable of carrying a suite of instruments to various altitudes from locations around the world. Some of these aircraft can reach altitudes approximately twice as high as those achieved by commercial airliners. Credit: NASA/Jim Ross.

Both prospective users and suborbital vehicle builders received a supportive boost at the gathering from NASA's deputy administrator, Lori Garver. She announced that the agency is seeking congressional approval in its FY11 budget for $75 million in planned funding over five years for NASA's Commercial Reusable Suborbital Research (CRuSR) program "to show how serious we are about developing and opening this market."

Indeed, several NASA speakers emphasized that the CRuSR initiative mimics the government/industry/academia partnership of the National Advisory Committee for Aeronautics—the federal agency that morphed into NASA in 1958.

NASA conducts flights of high-altitude balloons such as this BESS (Balloon-borne Experiment with a Superconducting Spectrometer). Such craft, which often carry large astronomical observatories, allow for long-term observations (lasting up to several weeks) and for safe recovery of the payload.

Vehicles in both piloted and unpiloted mode could support suborbital flights up to 100 km above Earth, conducting research in disciplines such as astronomy, the life sciences, and microgravity physics. They could even probe a little-known atmospheric region too high for balloons and too low for satellites, one that has been labeled "the ignorosphere." This ultrahigh upper atmospheric research was specifically flagged by NASA Ames Director Pete Worden, who believes it offers opportunities for world-class research. Suborbital vehicles rocketing to this region could take samples for studies.

"There's beginning to be evidence that there are some very complicated coupling mechanisms, particularly in changes of solar ultraviolet flux on the upper atmosphere, and climate changes on the ground. We don't know how that works," notes Worden. Moreover, he says, life may well exist in that region. If so, "that begins to tell us where we can look in other places," such as in the upper atmosphere of Venus or perhaps Mars.

The National Oceanic and Atmospheric Administration is already planning to fly scientific gear on a reusable suborbital vessel. In 2008, NOAA and Virgin Galactic agreed to explore use of the WhiteKnightTwo carrier ship and the six-passenger, two-pilot SpaceShipTwo for climate science and other research relevant to NOAA's mission.

One NOAA instrument that could fly on the Virgin Galactic launch system would pro-

Pulling back the curtain on a next-generation suborbital vehicle

For all the roar churned out by a rocket liftoff, this continues to be a quiet time for Blue Origin, a private firm bankrolled by Jeff Bezos of Amazon.com fame. The rocket company is developing the New Shepard, a suborbital vertical takeoff, vertical landing vehicle designed to haul a crew of three or more. The craft would depart from Blue Origin's already operational private spaceport in west Texas.

New Shepard is drawing on three years of effort, explains Gary Lai, Blue Origin's engineer/manager responsible for crew cabin development, an initiative that already includes repeat launches of its Goddard rocket—a first development vehicle in the New Shepard program. The Goddard 's first flight was in November 2006 under tight-lipped conditions, a mode of business that continues today. "If we're famous for anything…it's for being quiet," Lai says. "One of the reasons…it certainly keeps our marketing and public relations staff small," he quips.

Lai offers a small glimpse into the New Shepard craft, which will consist of a pressurized crew capsule mounted atop a propulsion module that will hurl experiments and astronauts upward more than 400,000 ft (120 km). It will take all of 2.5 min to accelerate, with the vehicle trajectory putting it at the edge of space after its engines are shut off. In this region, "high-quality" microgravity is promised in durations of 3 min or more.

New Shepard will fly nearly vertically, straight up and straight down, restarting its engines for a powered landing on its propulsion module. In the event of an anomaly, the crew capsule could separate from the propulsion module and the two segments would land individually for reuse. The crew capsule is outfitted with a parachute to land softly at the launch site.

Along with giving the public pay-per-view flight opportunities, New Shepard will also be geared to fly researchers and their investigations on suborbital hops. Blue Origin has already begun soliciting investigator experiments to be flown on a no-exchange-of-funds basis. A trio of scientific experiments picked last September represents part of a New Shepard flight demonstration program. The selected investigations are:

- *Three-Dimensional Critical Wetting Experiment in Microgravity, by principal investigator Steven Collicott of Purdue University.*
- *Microgravity Experiment on Dust Environments in Astrophysics, spearheaded by Joshua Colwell of the University of Central Florida.*
- *Effective Interfacial Tension Induced Convection, by principal investigator John Pojman of Louisiana State University.*

Lai admits that the research and education market needs to evolve. Still, Blue Origin has organized scientific workshops around the nation to pulse the life science, astronomy, atmospheric sciences, and education communities regarding suborbital investigations.

"There are some things that these vehicles will be very good for. There are some things they will not be good for," says Lai. Sounding rockets, parabolic aircraft, high-altitude balloons, as well as the ISS, he notes, will all have their place, in addition to next-generation suborbital vehicles.

vide data on atmospheric composition, particularly CO_2 and other greenhouse gases, contributing significantly to global climate science. This kind of data would also provide important in-situ measurements that would help scientists calibrate satellite-based atmospheric measurements.

New realm in R&D

The private suborbital rocket work now under way—primarily to cater to a space tourism market—was noted in the NRC study. But the panel also suggested that the main question is what role, if any, commercial suborbital vehicles can play in enabling NASA's future missions, advancing its technology, conducting cutting-edge science, and training the next-generation workforce.

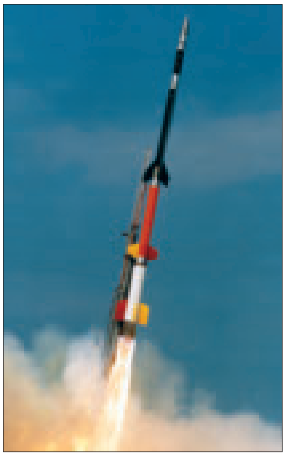
The various commercial vehicles, said the study, are expected to yield 3-5 min of microgravity, powering up to altitudes of 60-160 km. That is comparable to the smaller sounding rockets and significantly greater than parabolic-flying, 0-*g*-producing aircraft.

Commercial suborbital platforms also promise lower cost per flight. For example, one pricetag is $200,000 per seat on the Virgin Galactic system, now being tested. In addition, higher projected flight rates would allow for greater design innovation and experimental manipulation. Another plus is flexibility in terms of launch sites. Suborbital craft also would enable human-tended experiments, as in the case of the traditional 0-*g* aircraft, providing rapid access to these payloads before, during, and after launch. And a primary selling point, says NRC, would be potential for less bureaucracy than is typically experienced with government space access.

Because these vehicles are being developed primarily for piloted flight, environments will likely be much more benign than those for sounding rockets, notes the NRC report. Peak ascent loads are projected to be roughly 4-5 *g*s, and reentry loads in the 5-6-*g* range. Those low accelerations should simplify the design and flight qualification of the experimental hardware. Equipment racks could be mounted at the hard points intended for seats, while the windows may allow for optical viewing experiments.

The life sciences, materials science, physics, and Earth sciences are research areas that could make use of commercial suborbital platforms. Another plus, the report indicates, is that access by NASA to commercial suborbital spaceflight could open up a new realm in R&D—a way for the agency to advance technology readiness.

According to Martin, the budding commercial suborbital vehicle business is clearly a new capability. "It's all true, good, and new… and a very different capability. What we didn't hear [is]…what's the new breakthrough science that's going to come out of this? But at the same time, we didn't want to make any assumptions that it wouldn't happen. We did not want to prejudge the science."



NASA currently conducts about two dozen research-related sounding rocket launches each year, using a variety of rockets capable of carrying payloads ranging from 100 to several hundred kilograms, from altitudes of 100-1,000 km or higher. These rockets are launched from several locations around the globe, depending on the mission requirements. Their payloads can sometimes be recovered. Credit: Goddard/Wallops Flight Facility.


When Did You Know?
"I launched an Estes Astron Scout – I saw the smoke trail go up in the air and thought it was cool. Suddenly for the first time I could see how fins were angles, nose cones were parabolas. Geometry had value now and I loved it."
David Newill
AIAA Associate Fellow

Iran's aerospace and defense sectors have been impacted by sanctions that deny access to Western expertise and spare parts. Dwindling funds for its technology efforts have further clouded the possibilities for rapid progress. Yet some surprising developments in unexpected areas indicate it may be progressing at a faster rate than experts had predicted.

Iran's unconventional approach to aerospace

International interest in Iran's aerospace and defense industries has, for obvious reasons, focused mainly on the speed with which the country is developing a ballistic missile capability. Yet Iran's recent progress in other aerospace areas—such as unmanned air systems (UAS), combat helicopters, and satellite launch capabilities—is perhaps more remarkable, given its lack of access to Western technology and expertise. A lack of spare parts and of upgraded systems for its manned aircraft fleet has encouraged Iran to develop asymmetric capabilities, giving it a key edge over its neighbors in many areas of defense technology.

"Looking at the programs which have been developed over the last decade, it is clear Iran has established a robust and managed engineering system along Western lines, taking progressive steps, incrementally and logically," according to Michael Elleman, senior fellow for missile defense at the Institute for International Strategic Studies in Washington, D.C. "They have

Safir 2

by Philip Butterworth-Hayes
Contributing writer

RECENT CIVIL SAFETY INCIDENTS IN IRAN

Date	Type	Operator	Fatalities	Location
01/24/10	Tupolev 154M	Kolavia, opf. Taban Air	0	Mashhad Airport
11/18/09	Fokker 100	Iran Air	0	Isfahan
09/22/09	Ilyushin 76MD	Iran AF	7	near Varamin
08/03/09	Boeing 707-3J9C	Saha Air	0	Ahwaz Airport
07/24/09	Ilyushin 62M	Aria Air	16	Mashhad-Shah
07/15/09	Tupolev 154M	Caspian Airlines	168	Near Qazvin
05/08/09	Tupolev 154M	Iran Air Tours	0	Near Mashad Airport
02/15/09	HESA IrAn-140-100	HESA	5	near Isfahan
01/19/09	Fokker 100	Chabahar Airlines, opf. Iran Air	0	Tehran Airport
07/02/08	Ilyushin Il-76TD	Click Airways International	0	near Zahedan

Source: Flight Safety Foundation.

tested new systems, and when they haven't worked they have fixed them. This suggests that they will be able to absorb new technologies in the future."

ACCELERATION...AT A PRICE

Although most of the developing capability of Iran's aerospace and defense sector has more or less followed a predictable path of technological maturity, the country has also shown it can suddenly accelerate its technical capabilities. The Mohajer-1 UAS, outfitted with six rocket-propelled grenades, was probably the first combat application of a weaponized UAS when it was introduced during the late 1980s in the Iran-Iraq war.

Mohajer-1 UAS

A more recent surprise was the emergence of the two-stage solid-fuel Sajjil missile in 2008, according to a report by an independent think tank, the U.S. Council on Foreign Relations. And the launch of the 27-kg Omid (Hope) satellite on board a Safir 2 rocket in February 2009 suggested Iran was further down the track to developing a reliable space launcher industry than most experts had estimated.

This specialization in asymmetric systems has come at the expense of fielding a modern, capable military and civil aircraft fleet. In the 1970s, during the reign of Shah Muhammad Reza Pahlavi, Iran acquired a fleet of advanced military front-line fighters and airliners. But the ensuing years of isolation from the West have left the Iranian air force with a quixotic mix of MiG-29s and Su-24 bombers from the former Soviet Union, F-7M and FT-7 fighters from China, alongside U.S.-built F-4 Phantoms, F-5 Tigers, and F-14 Tomcats. During the 1991 Persian Gulf War, a number of Iraqi air force pilots flew their aircraft—including Mirage F-1s, MiG-25s, and Su-25s—to Iran, where they remain.

Without access to spare parts, Iran has seen its numbers of fully operational military aircraft slowly dwindle over the years. This has encouraged the government to build up its capabilities in antiaircraft defenses and surface-to-surface rocket systems as an alternative to conventional fighters and strike aircraft.

Iran's civil aircraft fleet also consists of mainly obsolete models, such as early-generation Boeing and Airbus widebodies, and the average age of Iran's civil aircraft is more than 20 years. Since a U.S. embargo imposed on the import of U.S. aviation parts in 1995, Iran's aerospace industry has focused on reverse engineering and building up its maintenance capabilities to keep both military and civil aircraft flying.

The lack of access to spare parts has had a significant impact on the country's aviation safety record. Infrastructure is suffering. During a recent storm the civil secondary surveillance radar antenna in Jiroft (near Bam, in

Building a missile base

According to the London-based Institute for International Strategic Studies, which produced its Strategic Dossier on Iran's Ballistic Missile Capabilities *in May: "Iran is making robust strides in developing ballistic missiles, with the apparent aim of being able to deliver nuclear warheads well beyond its borders. Iran's modifications of the North Korean No-dong missile, resulting in the longer range Ghadr-1, and its recent success in testing locally produced space launch vehicles and two-stage solid-propellant missiles have heightened concerns." However, a notional Iranian ICBM, based on No-dong and Scud technologies, is more than a decade away from development, said the institute.*

The purchase of Russian-built Scud missiles from North Korea in the 1980s gave Iran the technology platform on which to base its missile program, and by the late 1990s it had developed the medium-range Shahab-3. This liquid-fuel-propelled missile, modeled after the North Korean No-dong, had a range of 1,500-2,500 km. In November 2008 Iran's Fars news agency reported it had successfully launched the Sajjil two-stage solid-fuel missile, with a range between 2,000 km and 2,510 km (1,200-1,560 mi.). This is a substantially more capable missile than the Shahab-3, as it can in theory be easily transported and, with a solid propellant, quickly readied for firing. It also has a payload capability of more than 1,000 kg, large enough for a nuclear warhead.

The emergence of the Safir space launcher has raised concerns that Iran may be developing an ICBM with a range of more than 5,500 km. However, opinion is divided as to whether a liquid-propellant-based Safir could provide an effective technology platform for an ICBM, or work on such a program would be based on developing the expertise Iran acquired on the solid-fuel Sajjil missile.

southern Iran) blew over, and radar coverage in the southeastern part of the Tehran flight information region was lost. Because of the sanctions, Iran has been unable to replace the Thales antenna. This means there is now no radar coverage of one of the country's busiest en-route sectors, above high, mountainous terrain (the minimum safe altitude is 17,000 ft in some areas) next to the Afghan and Pakistani borders.

INDIGENOUS ACTIVITY

Iran responded to the U.S. embargo by first turning to Russia for new military and civil aircraft and then developing its own versions of aircraft in service. Over the past few years this process of "indigenous" development has accelerated. In May the government announced it was taking delivery of 10 new Iranian Helicopter Support and Renewal Company (Panha) "Toufan" attack helicopters, upgraded versions of the Bell AH-1J Sea Cobra bought before the 1979 revolution. That same month Iran's defense minister, Ahmad Vahidi, announced that the government was proceeding with development of a 150-seat airliner, following on from the work HESA (Iran Aircraft Manufacturing Industries) has been undertaking on the IrAN-140.

HESA completed licensed assembly of its first 50-passenger Ukrainian Antonov An-140 in 2001 at a new plant in Isfahan and has rebranded the aircraft the IrAN-140. Under a 1995 agreement with Ukraine, 70% of the aircraft's components are being supplied by Iranian companies. Airline customers Safiran Airlines, Mahan Airlines, and Iran Air Tour Airlines have been identified as early recipients of the aircraft, but it is unclear how many of these are currently in service; the national border guard is likely to be the main customer, and production is likely to plateau at 12 aircraft a year.

The HESA project has been overshadowed by three accidents—46 passengers and crew died in a December 2002 crash of an Antonov An-140 carrying Ukrainian aerospace engineers on their way to Isfahan to assess progress on the IrAN-140. A further accident, reportedly due to engine flameout, occurred in August 2005 when an IrAN-140 of Safiran Airlines diverted to Arak airport, where it made an emergency landing, running off the runway and sustaining serious damage but not causing any fatalities. Then in February 2009 an IrAN-140 on a training flight crashed near Isfahan, killing all five occupants.

This photo was released by the Iranian Defense Ministry, which says Nasr 1 (Victory) missiles are seen in a factory in Tehran, on March 7, 2010.

AREAS OF FOCUS

The problems the country has faced in developing a home-grown aircraft manufacturing sector will probably encourage the government to put even more resources into asymmetric aerospace and defense programs, such as longer range missiles and unmanned air systems. Access to Western technology to support aircraft production has been made even more difficult with the round of new trading sanctions on Iran agreed by the U.N. Security Council in June.

These latest sanctions were supported by Iran's closest trading partners, Russia and

In May the Iranian government took delivery of 10 new Toufan attack helicopters.

MILITARY EXPENDITURE IN IRAN

	2002	2003	2004	2005	2006	2007	2008
Iranian rial, billions	21,665	34,955	49,628	69,664	81,283	74,616	90,464
Constant 2008 dollars, millions	6,148	7,195	9,109	11,296	12,233	10,158	9,174

Information from the Stockholm International Peace Research Institute – www.sipri.org.

China; as a result of the Security Council move, Russia stopped the contract to deliver S-300 air defense missiles to Iran, a critical setback for the country.

Fielding new-generation air defense systems is of particular importance to Iran—not only for their tactical significance in defending nuclear industrial sites but also for their strategic importance as the nation tries to develop a modern C4I (command, control, communications, computers, and intelligence) infrastructure, linking more capable air defense missiles with new surveillance systems and communications equipment.

The Russian-built long-range S-300s were due to be integrated with 29 short-range TOR-M1 short-surface-to-air missiles that Russia is reported to have delivered to Iran in early 2007. The government announced in April it was putting into operation a new short-range Iranian-developed air defense system called Mersad (Ambush) using domestically developed Shahin missiles and had begun developing a chain of domestic radars to protect borders along the Persian Gulf. In July 2010 the Iranian Fars news agency reported that the indigenously developed radar system has been deployed, including long and medium-range radars and missile shield systems.

GAUGING PROGRESS

It is difficult to be sure just how far Iran has progressed in being able to implement these individual systems within a net-enabled capability. One of the significant implications of the successful launch of a satillite on a Safir Omid rocket in February is that it could pave the way to the future deployment of an Iranian military satellite communications network, although there are several technology mountains to climb before this can be achieved—especially in terms of ground stations and guidance systems.

In April, Iran's telecommunications minister, Reza Taghipour, said the country would be launching its first generation of communications satellites by March 2011 and had already built three prototype satellites—Toloo (Dawn), Navid (Good News), and Mesbah-2 (Lantern). To move from essentially a proof-of-concept launch capability to deploying a network of working telecommunications satellites within three years would be a remarkable feat.

In general, the goals being set for Iran's communications, space, and aircraft manufacturing industries—to develop new indigenous aircraft and systems to a technology level enjoyed by North America and Europe in the early 1980s—look particularly daunting, especially given recent sanctions and the ensuing loss of technical support from China and Russia.

SHRINKING FINANCES

Another impact of the sanctions has been to reduce the amount of money available for investment in new programs. Defense spending in Iran has been growing, but not at a huge rate. Measured as a percentage of gross domestic product, it has actually fallen in recent years—though the figures do not include the activities of the Iranian Revolutionary Guard, who have played an increasingly important role in the country's military industrial activities in recent years.

The pre-June sanctions have reduced Iran's oil production capacity by approximately 300,000 barrels a day, depriving the country of billions of dollars of income. China is one of its biggest customers, but so too is Pakistan, which signed a major deal with Iran for gas supplies after the June U.N. sanctions were agreed.

HESA assembles 50-passenger Ukrainian Antonov An-140s rebranded as the IrAN-140.

MILITARY EXPENDITURE AS A PERCENTAGE OF GDP

Year	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Percentage	2.4	3	3.8	4	2.5	2.9	3.3	3.8	3.8	2.9	2.7

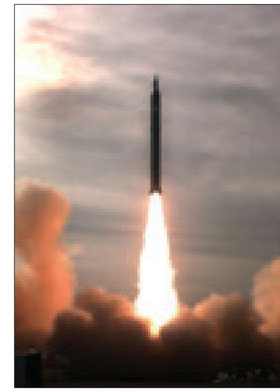
Information from the Stockholm International Peace Research Institute – www.sipri.org.

Another challenge for the country's industry is the sheer number of new systems it has been asked to develop. April saw the unveiling of new types of Iranian-built shore-to-sea and sea-to-sea missiles, called Nasr (Victory), Saeqeh (Lightning), and Noor (Light). A few weeks earlier, the government announced it would be deploying a new generation of UAVs—a long-range precision attack Ra'd (Thunder) and surveillance Nazir (Harbinger).

The country's aerospace and defense companies have, over the last five years, changed the main thrust of their activities from maintaining aging aircraft to reverse-engineering U.S. engine and airframe systems and developing new Iranian programs. Most of the country's aerospace companies, including HESA and Panha, have for many years operated under the umbrella of the Iran Aviation Industries Organization. In March 2009 the government announced it would be building a new UAS manufacturing center in Mazandaran, in the north of the country, to support the rapid dissemination of new Iran UAS at military air bases throughout the country.

But Iran also has a history of announcing grandiose military aerospace programs that either fail to appear or, when they do appear, do not live up to their advance publicity.

The next few months will be critical to Iran's aerospace and defense industries. The government will have fewer financial resources, and access to technical help from outside the country is drying up. At the same time, there are growing pressures to develop new and more capable platforms. Given these pressures it is difficult to see how the country can continue to accelerate its developing technological capabilities at the same pace it has achieved over the past two or three years. But further successful satellite launches or the appearance of new aircraft in flight—civil or military—during the next year or so would indicate that Iran is continuing to develop indigenous aerospace skills at a surprisingly fast rate.



The Safir Omid rocket is capable of carrying a satellite to orbit.

Out of the

25 Years Ago, September 1985

Sept. 13 A McDonnell Douglas F-15 destroys the Solwind, a non-functioning research satellite in orbit around the Earth, by launching an experimental missile while flying at 40,000 ft. This is the first successful test of an aircraft-carried antisatellite weapon. R. Puffer, *The Death of a Satellite*, AFFTC History Office Web site.

50 Years Ago, September 1960

Sept. 5 A McDonnell F-4H Phantom II sets a new world record for speed, flying 1,215 mph over a 500-km closed course. *The 1961 Aerospace Year Book*, p. 445.

Sept. 7 Sikorsky Aircraft delivers the first turbine-powered helicopter, the S-62, to Los Angeles Airways for use in the airline's regularly scheduled passenger service. *The 1961 Aerospace Year Book*, p. 445.

Sept. 8 The Office of Naval Research announces that radio signals from Saturn and from a star 3,000 light-years away have been received by the University of Michigan's 85-ft radio telescope. E. Emme, ed., *Aeronautics and Astronautics 1915-60*, p. 127.

Sept. 10 Pilot Robert M. White flies the North American X-15 rocket research aircraft to Mach 3.2 and reaches an altitude of 80,000 ft. D. Jenkins, *X-15: Extending the Frontiers of Flight*, p. 614.

Sept. 14 Two Nike-Hercules missiles intercept each other successfully at a height of 19 mi. at Mach 7 (about 4,600 mph) above White Sands Proving Ground in New Mexico. This is believed to be the highest speed yet achieved for such an interception. *Flight*, Sept. 23, 1960, p. 497.

Sept. 19 An Atlas ICBM flies 9,000 mi. from Cape Canaveral, Fla., to the Indian Ocean. It is the second record flight for this vehicle. E. Emme, ed., *Aeronautics and Astronautics 1915-60*, p. 127.

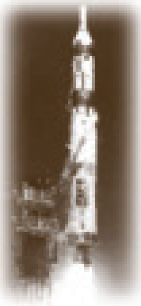
Sept. 19 A record speed of 1,130 mph over a 1,000-km closed circuit is claimed by a French Dassault Mirage IV flown by Rene Bigan, Dassault's chief test pilot. *Flight*, Sept. 30, 1960, p. 525.

Sept. 20 Jerrie Cobb sets a new world altitude record of 36,932 ft for light aircraft, flying an Aero Commander 680F. E. Emme, ed., *Aeronautics and Astronautics 1915-60*, p. 127.

Sept. 21 The military version of the Scout, the USAF Blue Scout all-solid-fuel launch vehicle, orbits an instrumented payload at 16,000 mi. in the first of 11 such tests. The radio malfunctions, however, and no data are received. E. Emme, ed., *Aeronautics and Astronautics 1915-60*, p. 127.

Sept. 25 Shortly after its launch, a NASA Atlas Able 3 275-lb Pioneer lunar orbital probe fails to achieve trajectory because of a malfunction in one of its upper stages. Debris from this attempt, a 3-ft blackened circular object with a camera lens, is picked up on a farm in Northern Transvaal, Africa. E. Emme, ed., *Aeronautics and Astronautics 1915-60*, p. 127; *The Aeroplane*, Oct. 28, 1960, p. 578; *Flight*, Sept. 30, 1960, p. 528.

Sept. 28-30 The International Union of Aviation Insurers holds its annual conference in Sicily with delegates from 19 countries including, for the first time, Brazil, India, and Japan. *The Aeroplane*, Sept. 30, 1960, p. 468.



Sept. 29 An attempt to fly a Titan ICBM more than 10,000 mi. from Cape Canaveral to the Indian Ocean fails when the second-stage engine cuts off prematurely. However, the nose cone does reach 6,000 mi. before falling into the Atlantic. *The Aeroplane*, Oct. 7, 1960, p. 492.

Sept. 30 Over the course of a year Silver City Airways has flown 90,332 cars across the English Channel via its fleet of Bristol Freighters. This is a new channel record and an increase of nearly 30% over the last fiscal year. *The Aeroplane*, Oct. 28, 1960, p. 579.

Past

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

75 Years Ago, September 1935

Sept. 7 Britain's prestigious Jubilee King's Cup Race, sponsored by the Royal Aero Club, is won by Flight Lt. Tom Rose in a Miles Falcon entered by Lady Wakefield of Hythe. The annual race begins at Hatfield, north of London, and makes its way up to Edinburgh, then Renfrew, Scotland, over to Newtownards, Ireland, across to Dalfeattie, then Blackpool, and finally to Cardiff, Wales, and back to Hatfield. The total distance is about 900 mi. *The Aeroplane*, Sept. 11, 1935, p. 311-312.

Sept. 8 At Artukais in Åbo, Finland, the Finnish president opens the world's most northerly commercial airport, the first of three that will be used to link Stockholm and Helsinki. The Artukais facility is well drained in order to handle the country's heavy winter snowfalls and the ensuing thaws. The airport is circular and has eight runways. *Flight*, Sept. 19, 1935, p. 313.

Sept. 9 D.W. "Tommy" Tomlinson makes the longest blind flight ever conducted in a commercial plane, on a 7-hr flight from Newark, N.J., to Kansas City. The windows of the cabin are covered throughout the flight, and the plane is guided by instruments only. *Aero Digest*, Oct. 1935, p. 94.

September 9, 1935

Sept. 13 Two Dutch mail rocket experimenters, Karl Roberti and Gerard A.G. Thoplen, attempt to launch their mail rocket from Calais, on the French coast, across the English Channel to Dover, England. Crowds of onlookers watch as Roberti prepares to fire the rocket, which carries 1,000 letters, but a police official intervenes and announces that the experiment is canceled by order of the secretary of the interior. Permission can be granted only if the British authorities agree. *The Aeroplane*, Sept. 18, 1935, p. 368.

Sept. 13 Film producer, aircraft designer, and industrialist Howard Hughes claims a new world speed record of 352.322 mph for land airplanes, flying his specially designed and built Hughes H-1 racer over a specially instrumented course at Santa Ana, Calif. Although designed for record-setting, the H-1 has a great impact on the design of high-performance aircraft. It has a remarkably smooth finish highlighted by extensive use of flush rivets in its fuselage. The aircraft is now in the National Air and Space Museum. *The Aeroplane*, Sept. 18, 1935, p. 348.

And During September 1935

—Maj. Gen. Benjamin D. Foulois announces he will retire on December 31. In 1908 he became the first to fly a U.S. government dirigible balloon and in 1909 was one of the first pilots of an Army airplane purchased from the Wright brothers. Foulois also accompanied Orville Wright on the Army acceptance flight from Fort Myer to Alexandria, Va. Foulois was the only pilot, navigator, observer, and commander in the Army's heavier-than-air division from 1909 to 1911, and commanded the First Aero Squadron, which in 1916 was sent on the Mexican Punitive Expedition. He was later chief of air service. *Aero Digest*, October 1935.

100 Years Ago, September 1910

Sept. 23 French-born Peruvian aviator Jorge Chavez makes the first successful flight over the Italian Alps, from Donodossia, Italy, piloting a Blériot more than 11,660 ft. But after passing over the mountains with 30 ft to spare, his plane falls for reasons unknown and he dies a few days later. In 1920 a monument to Chavez is erected at Brig am Simplon, Switzerland, where he landed. Prince Roland Bonaparte unveils the monument with other dignitaries in attendance from France, Switzerland, and Italy. *Flight*, July 8, 1920, p. 741 and Sept. 23, 1920, p. 1029.