

AEROSPACETM **ENGINEERING**

Aluminum Makes a Comeback

Flight Display Trends

Top Technologies of 2012

**Airbus Looks
to the Future**



The Future of 3D Technology

From This Day, Forward

3D technology is all around us. It's changing how we design and manufacture products, make movies, heal our bodies and interact with the world. Work that used to take place on a page or screen now reaches into space. And faster than ever before, 3D technology is transforming our world.

To see the impact of 3D, look to the realm of design. Designers led the way in embracing 3D CAD and then 3D printing, incorporating more and more physical models into their iterations and thinking with their heads and their hands. And they've reaped the benefits: design problems surface sooner and solutions are less costly. Inspiration happens faster. Ultimately, products are better and consumers are happier. Black & Decker makes a safer tree trimmer and Lamborghini makes a faster car because



A few examples of the Stratasys 3D Printer line.

reviews and trials are more frequently executed on models very much resembling a final product.

Now, 3D printing applications are expanding from design into production, and freeing manufacturers to build without traditional restrictions. DDM

stands for direct digital manufacturing, a way to produce a finished product, part or tool straight from a computer design. More importantly, DDM means the rewards of faster, leaner, smarter methods are coming to the production floor. When we at Stratasys (and publications like *The Economist*, *Forbes* and *The New York Times*) call 3D printing "the next industrial revolution," we're not exaggerating.

A hundred years ago, the assembly line changed the world with mass production. It brought luxuries to the middle class, good wages to workers and economies of scale to investors. Today, companies like BMW already know that DDM is mass production's heir apparent. One factory-floor fixture, a nameplate-application device, offers an elegant example. Liberated from tooling

WHATEVER YOUR GAME, 3D PRINTING IS GOING TO CHANGE IT.



3D printing means virtual inventories and low-volume production, which for manufacturers is the next big step.

constraints, BMW engineers reduced the device's weight by half and replaced its blocky stock-metal handles with ergonomic grips — a great relief to workers who might lift the fixture hundreds of times per shift.

Today, NASA can shape a complex, human-supporting vehicle suitable for Martian terrain, despite the fact that its



This rover includes about 70 FDM parts, including housings, vents and fixtures.

parts are too complex to machine, too rapidly iterated to outsource and too customized for traditional tooling.

In a 3D world, we leave behind injection molding, casting and machining, gaining economy without the scale. 3D printing leads us beyond mass production and into mass customization. It's how a researcher at a Delaware hospital creates a durable ABS-plastic exoskeleton customized to perfectly fit one child, Emma, allowing her to play, explore and hug for the first time. Then that researcher can make a 3D-printed exoskeleton to fit a different child. And another. And a dozen more. Now 15 children with rare disorders can raise their hands because of mass customization.

Ideas born today — your ideas — are freer to solve problems faster than ever



A pediatric engineering research lab has developed and 3D-printed custom devices for their smallest patients.

before. Now, two innovators who helped spark this revolution have fused to lead the charge together, and more great changes are at hand.

Welcome to the new Stratasys, leader of the next industrial revolution.

– By David Reis, Stratasys CEO

They look like shoes. They feel like shoes. But they're actually prototypes. Printed layer by layer on a 3D printer. / Every day, 3D printing rewrites another rule of how things are made. / 3D printers are at work in product design studios, engineering departments and manufacturing plants. In schools and hospitals and dental labs. Wherever speed, efficiency, and accuracy matter. / It is the next industrial revolution. And Stratasys is here to lead it. / Come explore the game-changing possibilities of a 3D World at Stratasys.com.

3D printing means prototypes like these, that help product designers put their best foot forward.



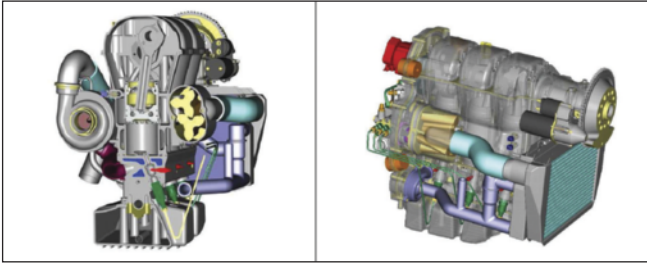
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Aerospace Engineering's Top Articles of 2012

Diesel aircraft coming soon to an airport near you?

Recent developments of diesel technology have made the two-stroke, compression ignition engine an interesting option for light aircraft manufacturers. Read more at www.sae.org/mags/aem/11241.



For modeling uniflow scavenged engines, researchers referenced a modern aircraft two-stroke turbocharged diesel power plant, named WAM 100/120, produced by Wilsch Airmotive, with a top brake power of 100-120 hp. A GT-Power model of the IDI engine was built and calibrated against experiments.

UAVs shrink as technology grows

AeroVironment says it achieved a technological milestone never achieved before by building and flying a wing-flapping air vehicle, carrying its own energy source and using only two

flapping wings for propulsion and control. Read more at www.sae.org/mags/aem/10587.

Handheld ultrasonic camera 'gun' finds composite cracks

Norwegian start-up's easy-to-use nondestructive testing technology for carbon fiber-reinforced plastics has been adopted by EADS. Read more at www.sae.org/mags/aem/10548.

Countering the counterfeiters

Counterfeit electronic parts affect safety and national security, pose long-term reliability risks, and drive up sustainment costs. Read more at www.sae.org/mags/aem/11304.

Europe's aerospace sector at a crossroads

According to a report by the European Defence Agency, the continent is facing a massive black hole in its future defense procurement portfolio. Read more at www.sae.org/mags/aem/11363.

Avoiding traffic congestion in the air

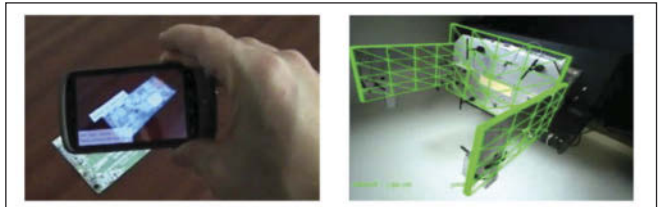
Once aircraft are linked to satellites or ground-based stations, the design challenge shifts to disseminating signals to passengers. Read more at www.sae.org/mags/aem/11359.

Advantages of additive manufacturing begin to add up

Metal-based, powder-bed additive manufacturing builds up parts layer by layer, forming cross sections of the part in 20- to 80-micron thicknesses. Read more at www.sae.org/mags/aem/11358.

Boeing engineers visualize technologies for manufacturing

Boeing recently looked at the use of augmented reality as a tool to help get design intent to the builder so the product can build right the first time and every time. Read more at www.sae.org/mags/aem/10715.



Examples of augmented reality work being done within Boeing.

CAD, fasteners, projections, and quality

Today, mechanics refer to drawings prepared by manufacturing engineers, using mark-ups on the part to provide reference features and measurements, but there are problems with this approach. Read more at www.sae.org/mags/aem/11053.

Composite structures pose EMI challenges

The all-composite commercial aircraft has become a reality, and the need for the aircraft designer to consider electromagnetic threats has also grown. Bombardier Core Electromagnetic Engineering has conducted a lightning indirect effect measurements campaign on different cylindrical barrels simulating all-metal and all-composite fuselages. Read more at www.sae.org/mags/aem/11335.

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Editorial

Change is in the Air

While it seems the last six months of 2012, and especially that last quarter, were full of dread and doom in terms of fiscal cliffs and potential hits to defense budgets, things have been looking relatively good for both commercial airlines and the companies that supply their fleet.



In fact, both the features in this issue of Aerospace Engineering, the inaugural issue as a supplement to Defense Tech Briefs, make reference to the ever-increasing need for commercial aircraft over the next couple of decades.

As referenced in the feature "Advanced Aluminum Solutions for Next-Gen Aerospace Structures" on page 34, "Over the next 30 years, both Boeing and Airbus project demand for approximately 19,000-23,000 single-aisle aircraft like the 737 and A320. In addition to being able to achieve performance improvements, any structural technology and material used to build these future aircraft must be capable of meeting the required build rates."

While programs such as the Airbus A350 and Boeing 787 have emphasized and championed the increased use of composites in new aircraft, there are those quite willing to say, "Not so fast." Especially those in the aluminum industry.

The feature, adapted from a technical paper written by Alcoa engineers, goes into some detail about the progress aluminum alloys have made over the past few years, and the advantages for their use over composites. "Advanced aluminum and aluminum-lithium alloys enable improvements in structural performance while utilizing the current manufacturing supply chain, reducing manufacturing risk, and supporting rate readiness."

Just as Airbus and Boeing agree there will be an aggressive buildup of new aircraft to meet future market demands, it's really not a stretch to imagine that there could potentially be some forecasters at both companies who also agree on a dread and doom outlook as to whether the supply chain will be able to keep up with that demand. Alcoa does not seem to share that concern, at least when it comes to aluminum.

In the feature on page 30 titled "2050 Vision," the author quotes Airbus' forecasts that "the world's passenger aircraft fleets will increase by 109% over the next 20 years. Some 28,200 new aircraft are expected to be delivered to meet growth and replacement needs." (For the record, Boeing believes the figure is more like 34,000 aircraft over the next 20 years, 41% of which will replace older, less efficient planes; 59% will be new deliveries.)

Whatever the actual figure of aircraft over the next 20 years, the "2050 Vision" feature offers up a good point or two. "With existing efficient airplane designs likely to continue in production for at least the next two decades, the next-generation follow-up civil programs will not only have to offer truly breakthrough performance, but be just one component in a transformed civil aviation infrastructure."

The feature details Airbus' future concepts studies, and looks not at just what we will fly, but how we will fly in 2050 and beyond, and the technologies and changes that will be needed to allow it to happen. In essence, while the number of aircraft over the next 20 year will continue to increase, so must the extent of the technologies that will allow them to remain, or become, sustainable and viable.

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WIMPs and the Future of Flight Displays

Today, interactive glass cockpit displays in aircraft look and behave very similarly to other computers, with windows and data that can be manipulated with point-and-click devices. As we see a growing adoption of natural, or post-WIMP (windows, icons, menus, pointer), HMIs in the general market — such as in smart phones, tablets, music, or video players — cockpit display system (CDS) suppliers are preparing now for the cockpits of the future, which will place the pilot at the center of the system. This objective will be achievable only if the proper engineering and design processes are deployed in conjunction with the proper development tools.

WIMP is often incorrectly used as an approximate synonym of graphical user interface (GUI). Any interface that utilizes graphics can be termed a GUI, and WIMP systems are a derivative of such systems. However, while all WIMP systems utilize graphics as a key element (namely, the icon and pointer element) and therefore all WIMPs are GUIs, the reverse is not true — some GUIs are not WIMPs.

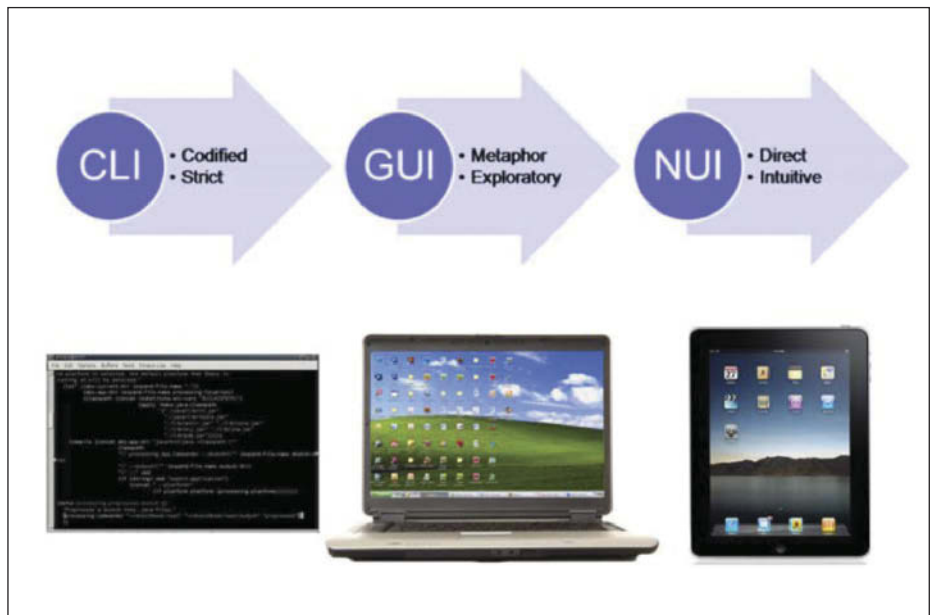
The primary benefit of WIMP systems is to improve the HMI by enabling better ease of use for non-technical people, both novice and power users. Know-how can be ported from one application to the next, given the high consistency between interfaces.

Due to the nature of the WIMP system, simple commands can be chained together to undertake a group of commands that would have taken several lines of command line instructions. For the average computer user, the introduction of the WIMP system has allowed for an expansion of users beyond the potential possible under the previous command line interface (CLI) systems.

User interfaces based on the WIMP style are very good at abstracting workspaces, documents, and their actions.



An example of a glass cockpit. In most modern commercial airplanes, including the A380, A350, and 787, the traditional “widget-based” (or WIMP) approach is mostly used for interactive cockpit displays.



The evolution of user interfaces. While all WIMP systems utilize graphics as a key element and therefore all WIMPs are GUIs, the reverse is not true: some GUIs are not WIMPs.

Their analogous paradigm to documents as paper sheets or folders makes WIMP interfaces easy to introduce to novice users.

Furthermore, their basic representations as rectangular regions on a 2D flat screen make them a good fit for system programmers. This explains

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why the paradigm has been prevalent for more than 20 years, both giving rise to and benefitting from commercial widget toolkits that support this style.

However, several researchers consider that there are applications for which WIMP is not well suited. This includes any application requiring devices that provide continuous input signals, showing 3D models, or simply portraying an interaction for which there is no defined standard widget. These interfaces are called post-WIMP GUIs.

Post-WIMP comprises work on user interfaces, mostly GUIs, that attempt to go beyond the paradigm of WIMP interfaces, which are not optimal for working with complex tasks such as computer-aided design (CAD), working on large amounts of data simultaneously, or complex interactive systems. Post-WIMP interfaces have today made their way to the general public, including portable music players, smart phones, tactile tablets, and ATM screens.

Today most operational and flying cockpit HMIs, as the majority of desktop computers, are still based on WIMP interfaces — some of them standardizing upon the ARINC 661 international standard for interactivity management — and have started undergoing major operational improvements to surpass the hurdles inherent to the classic WIMP inter-

face. These include the exploration of virtual 3D space, and natural interaction techniques for window/icon sorting, focus, and embellishment.

A natural user interface (NUI) is the common parlance used by designers and developers of HMIs to refer to a user interface that is (1) effectively invisible, or becomes invisible with successive learned interactions to its users, and (2) is based on nature or natural elements (i.e. physics).

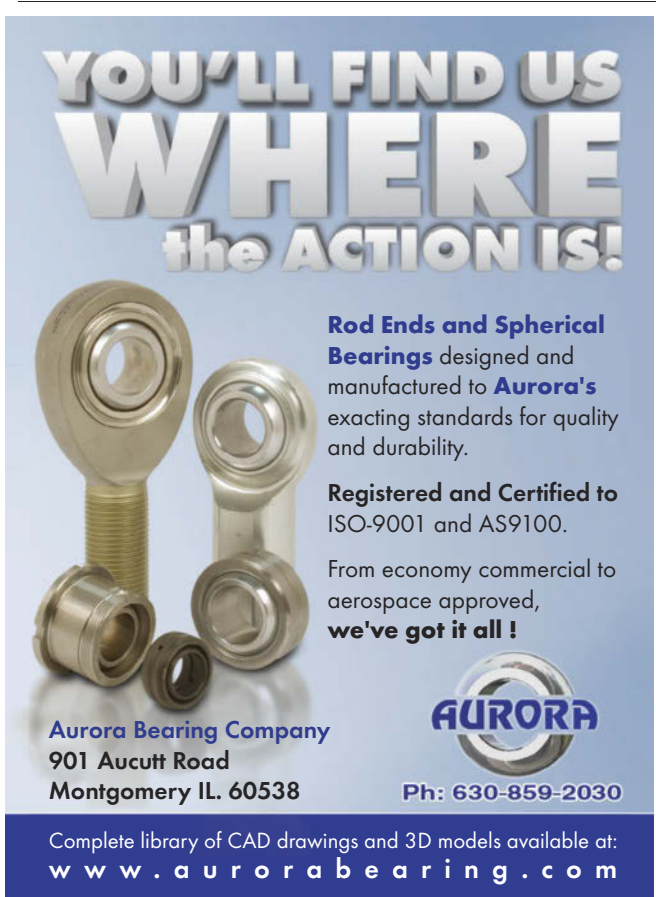
The word natural is used because in reverse, most computer or industrial interfaces use artificial control devices whose operation has to be learned. A NUI relies on a user being able to quickly transition from novice to expert. While the interface requires learning, that learning is eased through design that gives the user the feeling that they are instantly and continuously successful. Thus, natural refers to a goal in the user experience — that the interaction comes naturally while interacting with the technology, and that the interface itself is natural.

An example of a strategy for designing a NUI is the strict limiting of functionality and customization so that users have very little to learn in the operation of a device. Provided that the default capabilities match the user's goals, the interface is effortless to use.

In the early days of CLI, users had to learn an artificial means of input — the keyboard — and a series of codified inputs that had a limited range of responses, where the syntax of those commands was strict. Then, when the mouse enabled the GUI, users could more easily learn the mouse movements and actions and were able to explore the interface much more. The GUI relied on metaphors for interacting with onscreen content or objects. The "desktop" and "drag" are examples, being metaphors for a visual interface that ultimately was translated back into the strict codified language of the computer. NUIs intend to provide direct and intuitive interaction between the user(s) and the system(s).

As far as aerospace is concerned, in today's most modern commercial airplanes, including all recent Airbus and Boeing planes (such as the A380, A350, and 787), the traditional "widget-based" (or WIMP) approach is mostly used for interactive cockpit displays. The main reasons, among many others, are the system certification needs for the highest levels of safety for these CDSs, which often require the use of already mature and trusted technology, but also some kind of "resistance to change" from crews and pilots — thus airline companies — who are used to flying with traditional user interfaces in the cockpit.

This article is based on SAE technical paper 2012-01-2119 by Vincent Rossignol, Esterel Technologies, and Christophe Bey, Ecole Nationale Supérieure de Cognitique. Visit <http://papers.sae.org/2012-01-2119/> to view the full paper.



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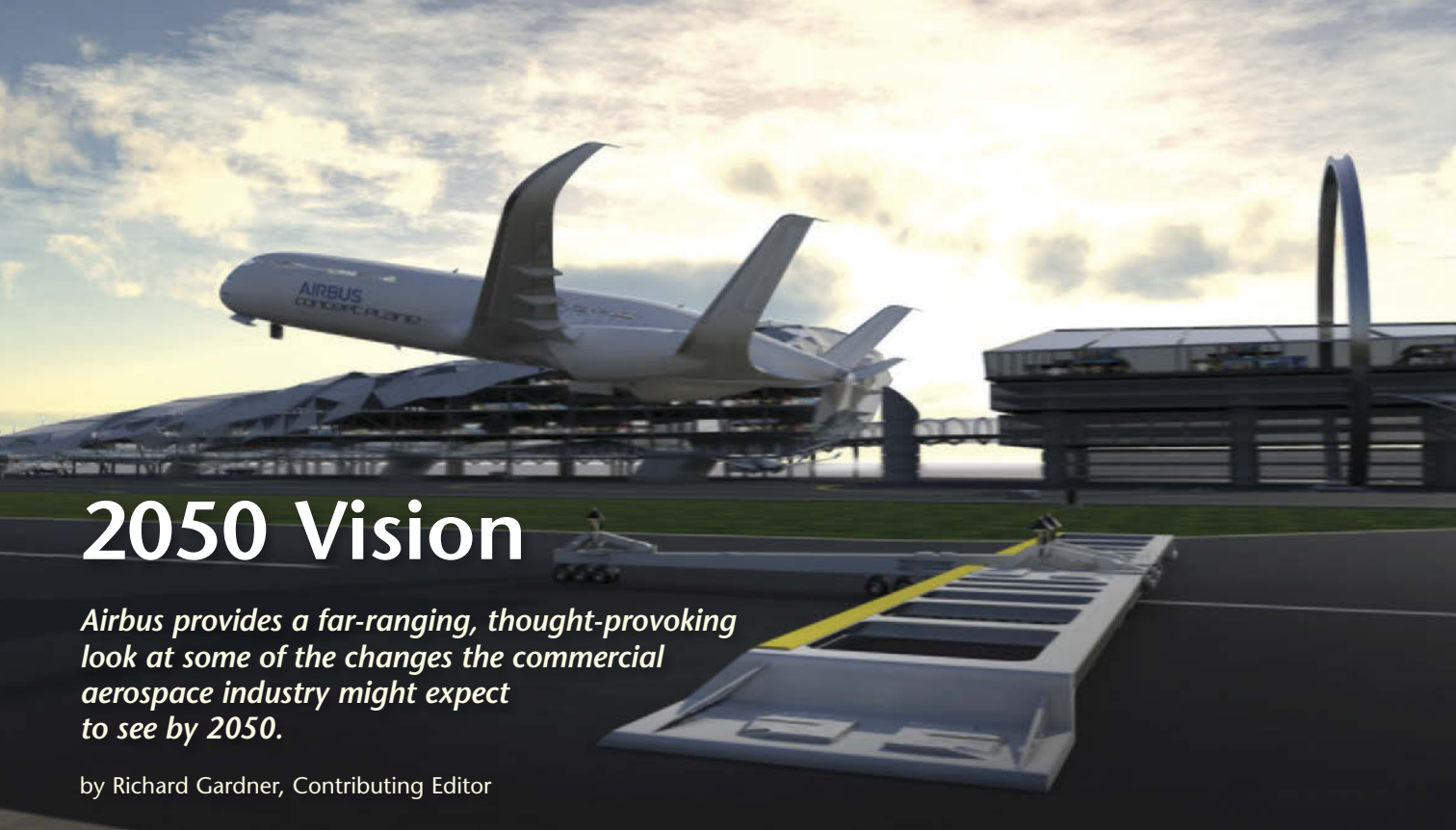
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2050 Vision

Airbus provides a far-ranging, thought-provoking look at some of the changes the commercial aerospace industry might expect to see by 2050.

by Richard Gardner, Contributing Editor

Impression of an Airbus concept plane lifting off from its launch cradle.

While aircraft cruising speeds have not changed significantly since jet air transport operations began in the late 1950s, overall journey times are actually getting longer in many cases as air traffic and airport delays are increasing at the world's busiest airport hubs.

Airbus global market forecasts indicate that the world's passenger aircraft fleets will increase by 109% over the next 20 years. Some 28,200 new aircraft are expected to be delivered to meet growth and replacement needs, but that is only up to the year 2031. Boeing predicts similar numbers up to that time.

How will the world be able to accommodate so much demand for air travel?

With existing efficient airplane designs likely to continue in production for at least the next two decades, the next-generation follow-up civil programs will not only have to offer truly breakthrough performance but, Airbus suggests, be just one component in a transformed civil aviation infrastructure, as different from today's aviation scene as were the early pioneering days when jets first appeared in passenger service.

Airbus said that its future concepts studies are focusing not just on what we will fly, but how we will fly in 2050 and beyond.

"Our engineers are continuously encouraged to think widely and come up with 'disruptive' ideas that will assist industry in meeting the 2050 targets we have signed up to," said Charles Champion, Executive Vice President of Engineering at Airbus. "Tough environmental targets will only be met by a combination of investment in smarter aircraft design and optimizing the environment in which aircraft operate."

Significant improvements could come from new aircraft design, alternative energy sources, and new ways of flying: Airbus' Smarter Skies vision for 2050 highlights five concepts, including eco-climb, optimized free-flight, free-glide approaches, low-emissions ground operations, and new energy usage.

Assisted Takeoff

Today, those countries with plenty of spare land, such as China and the desert nations of the Middle East, aspiring to become global hubs, appear happy to cover vast areas in new runways and terminals to meet future expansion needs.

But many developed countries — even large ones — find that it is not so easy politically, as well as physically, to find the space for new runways at airports that historically have been sited

relatively close to busy cities, with all the infrastructure close by, serving not only passengers and freight operators but also the thousands of people who actually work at and supply the day-to-day needs of those airports. At such hubs, and as mega-cities become a reality, land is at a premium. So, a new approach will be required, such as using shorter runways.

Airbus has examined a radical idea that involves aircraft launched through assisted takeoffs using renewably powered, propelled acceleration. It claims this could lead to steeper climbs from the runway, with less noise and faster times toward cruise altitudes.

When quizzed recently by *Aerospace Engineering* on the g-forces involved — as an aircraft-carrier-style launch might not be too sensible for senior citizens or those of a nervous disposition — Champion said that the acceleration would be gradual and within the acceptable limits established for civil aircraft and cabin seat requirements.

Although technical details remained vague, it was suggested through a series of computer-generated video sequences that such launches would involve the aircraft taxiing onto a special launch cradle that would project the aircraft into the air at the appropriate V1 position where it would climb at a high

angle using the thrust of its own engines. Presumably, the launch cradles would have to return to the start point rapidly after each takeoff, either by backtracking down the runway, or perhaps on a return loop, so there is always one waiting to be used at the start. How this would work was not explained, though the system would be highly automated and would have to be extremely reliable to avoid the airport coming to a standstill if a breakdown occurred.

The futuristic “Airbus Concept Plane” featured in the videos keeps the landing gear detail out of sight, but a conventional landing gear could not be deleted from the design, as there would be an operational need to move around at the airports and also to serve destinations that might not be fitted with handling cradles and associated automated launch aids.

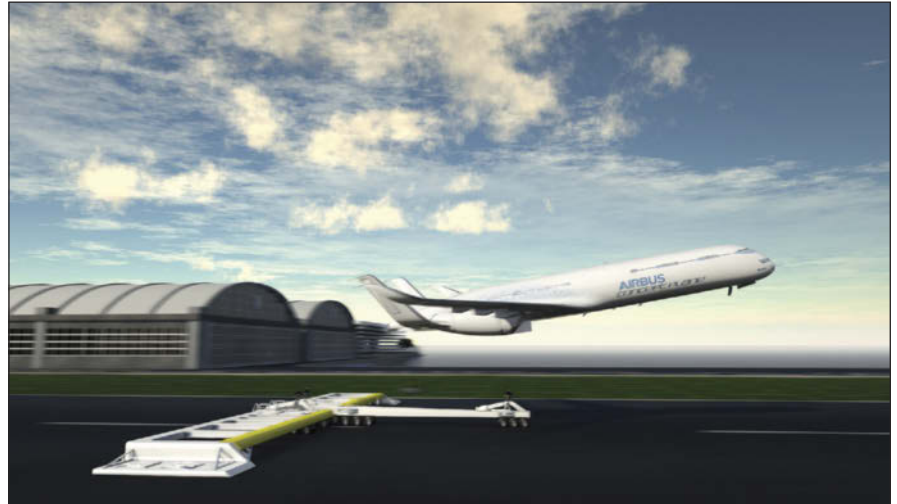
The advantages of having jet aircraft with no landing gear, in terms of saving weight and allowing automated handling movements, were extensively and quite successfully tested (using small military research jets) in the 1940s and 1950s in the U.K. and U.S., but they all proved to be too inflexible in use compared to aircraft with conventional wheeled landing gear, and the R&D programs were abandoned.

For the Airbus eco-climb concept to work, there would have to be global agreement on the use of standard take-off launch systems, but reliability and the cost of providing, operating, and maintaining the ground systems would have to be acceptable to airport and airline operators.

Despite the obvious technical, safety, and commercial challenges to be faced and overcome, this remains an exciting idea that might offer a way of breaking out of the traditional runway planning straightjacket.

Toward Free-Flight

No less radical, but perhaps more likely, Airbus envisions fully exploiting developments in air traffic management (ATM) systems and procedures to allow aircraft to “self-organize” and select the most efficient and environmentally friendly routes (so-called free-flight),



The future aircraft in its continuous eco-climb.



Impression of future aircraft in 2050 flying in free-flight and a formation flock along a long-haul express skyway.

making optimum use of prevailing weather and atmospheric conditions.

The aircraft would have highly intelligent, integrated onboard systems to select the most appropriate flight path and altitude, while using networked data for greatly enhanced situational awareness, incorporating navigation, communications, and collision avoidance information. This data would be used by the aircraft to fly the best path automatically, but the pilot would be fully in the loop at all times.

In technical terms, such comprehensive free-flight capability from pre-take-

off to arrival would not require human intervention. However, while a civil UAV could be introduced today, passenger acceptance would probably always demand a human in the cockpit, and that would probably mean two pilots on board, even if only one was needed.

On high-frequency routes between the biggest hubs, Champion said that advanced automated systems could allow aircraft to benefit from flying in formation like a flock of birds during the cruise phase of a long flight, bringing efficiency improvements due to drag reduction and lower energy use.



Aircraft in free-flight formation to maximize cruise efficiency.

This would only be practical on medium- to long-haul sectors, but automated collision avoidance and station-keeping capabilities could enable clusters of airliners to make greater use of any given block of sky, increasing the total volume of air traffic that could be handled in the future.

Onboard sensors and satellite-enabled navigation and formation-keeping systems would enable very precise 3D flight positioning to be maintained, with weather factors and other air traffic movements built into the programs.

A Free-Glide Approach

Another concept studied by Airbus involves low-noise, free-glide approaches and landings to reduce environmental impact and fuel consumption. This might make a more useful contribution at existing airports situated near large urban communities. It would seem that off-shore airports and those in deserts might not see much advantage other than perhaps allowing a faster turnaround of incoming flights.

Aircraft allowed to take free-glide approaches into airports would reduce emissions during the overall descent, and also reduce noise during a steeper approach as there would be no need for engine thrust or air braking. Such approaches would reduce landing speed earlier, which would make shorter land-

ing distances achievable with less runway length needed.

If the approach angle is steeper, but the landing speed lower (which does not sound logical), it must be assumed that new-generation aircraft intended for an in-service 2050 timeframe would incorporate advanced aerodynamic features to allow for both assisted takeoffs and free-glide landings without elaborate lift and air-braking devices, which would increase noise. Perhaps some kind of wing morphing, using new materials and structural properties, might

be perfected by then to make such movements a practical possibility.

Another Airbus concept entails low-emissions ground operations that would involve automated systems to deliver aircraft to and from the runway and terminals. On landing, aircraft engines would not be used for taxiing, runways could be cleared quicker, and ground handling emissions could be cut.

Advanced technology could optimize an aircraft's landing position with sufficient accuracy for an autonomous, renewably powered taxiing carriage to be ready so aircraft could be transported away from the runway quicker, also optimizing terminal space and removing runway and gate limitations.

Airlines are already looking very closely at emerging self-taxi systems to save time and fuel, either through a self-contained geared taxi drive on the landing gear itself, or via a "clip-on" taxi-tug that takes the aircraft between runway holding areas and the boarding dock.

What Airbus is suggesting is a built-in, automated, eco-friendly taxiing system, almost like a tramway, using computer-controlled mini-tugs that could run fully autonomously serving extensive terminals and satellite systems. This might require special dedicated tracks or roads for the tug devices to reposition themselves at the runway end of the cycle after each operational movement with



Future aircraft preparing for free-glide approach to reduce fuel, noise, and emissions.

the aircraft, but the task should be straightforward to design and establish, and could be used for any aircraft.

It might help if agreed operating standards and fittings for future aircraft could be adopted as early as possible, as this could eventually become a global “must-have” requirement even before 2050.

Seeing the Future

The fifth and final element in the Airbus 2050 vision is the use of sustainable biofuels and other potential alternative sources to secure supply and further reduce aviation’s environmental footprint in the long term. The company believes that this will allow the extensive introduction of regionally sourced renewable energy close to airports, feeding both aircraft and infrastructure requirements sustainably.

Airbus is playing a leading role today in working with the energy industry and other partners on alternative fuels, as

well as advanced aerodynamics and supporting new aero engine and ATM system developments. Airbus believes that if the ATM and technology aboard aircraft were optimized (assuming 30 million flights per year), flights in Europe and the U.S. could on average be 13 minutes shorter, with similar savings elsewhere in the world. This would save around 9 million t of excess fuel annually, which in turn equates to over 28 million t of avoidable CO2 emissions, and a saving of 5 million hours of excess flight time.

The U.S. NextGen and European SESAR programs are both aimed at enhancing the performance of the ATM system through the better use of aircraft capabilities and changes in infrastructure and organization on the ground. The ultimate aim of these initiatives is to reduce air traffic congestion and delays, and also to allow more direct flights, better flight profiles, and a reduction in the cost of air navigation

services using advanced technologies and communications.

“Our focus on meeting continuous growth in demand is to keep the passenger, our customers, and the environment at the center of our thinking,” said Champion. “The future of sustainable aviation is the sum of many parts, and success will require collaboration amongst all the parties who are passionate about ensuring a successful prospect for aviation.”

If aviation is currently pausing on a well-tested technology plateau, there will surely come a time in the not-too-distant future when a whole new series of innovative developments will arrive and change everything as we know it today.

The Airbus Smarter Skies vision gives us just a glimpse of how different the future of aviation might be, but this is based on some sound research and serious study. The reality might be even more far-fetched than we can imagine.

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Airline competitiveness and the demand for improved aircraft performance and affordability (acquisition and operational) are driving advancements in technologies that can enable these improvements.

Improvements in engine technology, aerodynamics, systems, and structural performance all have the effect of improving aircraft efficiency and reducing fuel costs. Extending inspection intervals and improving aircraft durability lead to reduced maintenance costs. These performance improvements also need to be delivered at a cost that solves the airline business case. From the airframer's perspective, these technologies need to be readily scalable to large-scale manufacturing and support the expected build rates.

While carbon fiber-reinforced polymer (CFRP) was chosen for the primary wing and fuselage structures of the most recent, all-new, twin-aisle aircraft — Boeing's 787 and Airbus's A350XWB — structural material choices are not so definitive for new and derivative single-aisle aircraft.

Bombardier chose an advanced aluminum fuselage combined with CFRP wings for the CSeries. The original Mitsubishi design for the MRJ included a CFRP wing. Mitsubishi has since redesigned the MRJ to utilize an aluminum wing box. Airbus and Boeing decided to keep an aluminum-intensive airframe when they made their decisions to develop the A320neo and 737 MAX.

Advanced aluminum and aluminum-lithium (Al-Li) alloys enable improvements in structural performance while utilizing the current manufacturing supply chain, reducing manufacturing risk, and supporting rate readiness. Researchers from Alcoa have focused on the applicability of these advanced aluminum alloy products for single-aisle aircraft such as the 737 and A320.

The Aluminum Mix

The first aluminum-intensive aircraft in the early 20th Century utilized a single alloy. As aircraft design and alloy development capabilities progressed, alu-

minum alloys, products, and tempers were optimized for specific applications.

Advanced aluminum alloys take advantage of alloy composition and processing parameters to achieve the combinations of strength, damage tolerance, and corrosion resistance necessary to enable improved structural performance. These advanced alloys represent conventional 2000 and 7000 alloys. Additionally, many of these advanced alloys utilize lithium as an alloying element.

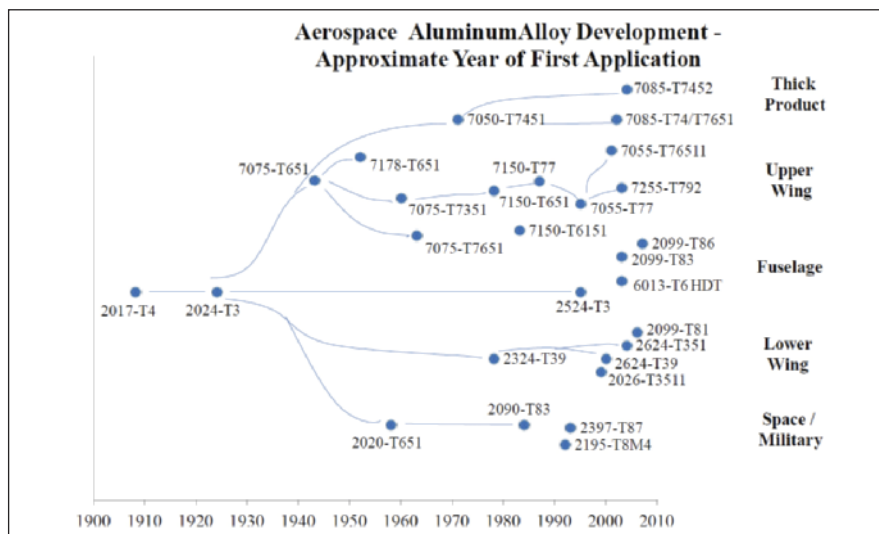
The use of Al-Li alloys is not new in aerospace. One of the earliest Al-Li alloys, 2020, was developed and found applications in the late 1950s. When alloyed with aluminum, lithium reduces the density, increases the modulus, improves fatigue crack growth performance, and acts as a strengthening agent.

Early Al-Li alloys had high levels of lithium as alloy designers sought to maximize density reductions. These high levels of lithium also resulted in poor manufacturing characteristics, corrosion, and damage tolerance performance for these alloys.

Development of third-generation Al-Li alloys has focused on lithium additions for strength and fatigue crack growth improvements with more balanced alloy performance. By reducing the lithium content and optimizing thermomechanical processing, many of the shortcomings with the previous Al-Li alloys can be overcome.

The Product Mix

Fuselage skins support the structural loads from the payload as well as maintain the cabin pressure. The key material requirements for fuselage skins are toughness, damage tolerance, and static strength. In addition to the structural requirements, corrosion can also be a concern in the fuselage, especially in



This chart shows the progression of aluminum alloy and temper implementation for aerospace applications. Over time, alloy and product development have become focused toward specific applications.

the belly sections where moisture can accumulate during service.

A more recently developed incumbent alloy, 2024-T3 sheet, is the baseline sheet alloy for single-aisle fuselage structures. It has a good combination of strength and toughness. To protect against corrosion, a thin layer of pure aluminum, alclad, is added to the surface.

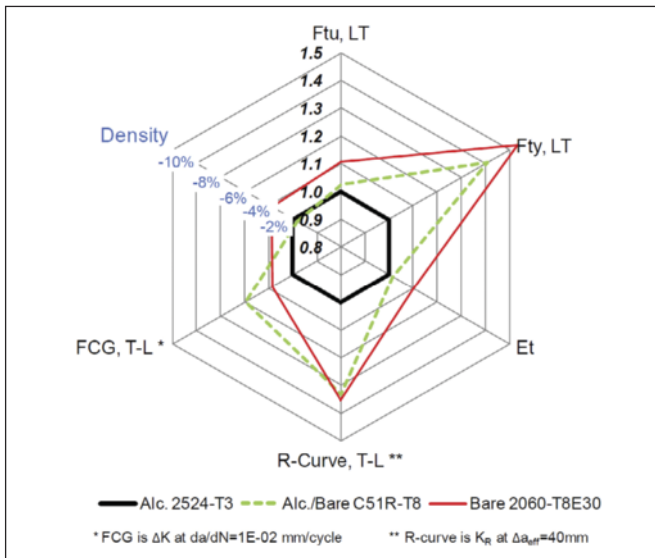
The wings provide the lift for the aircraft and support the full weight. The

upper and lower covers, joined by spars and ribs, form a beam that supports the aerodynamic loads, keeping the aircraft in flight. The wing covers of the 737 and A320 aircraft consist of a plate skin with fastened, extruded stringers.

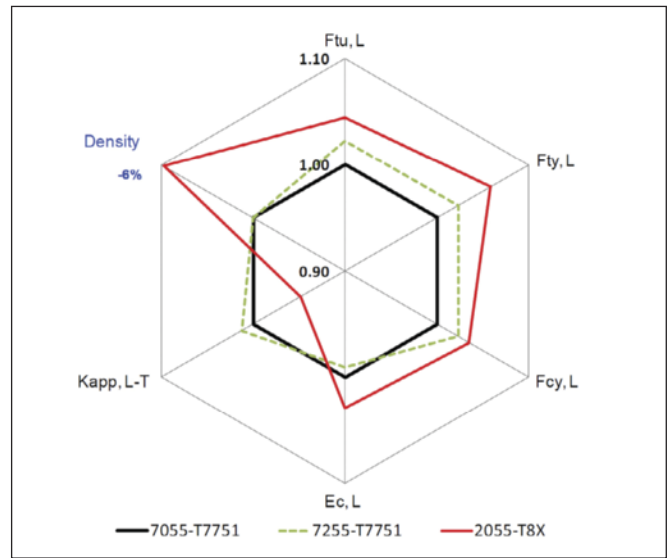
The bending loads on the wing cause the upper cover to be loaded in compression and the lower cover to be loaded in tension. The principal material requirements for upper wing plate

and extrusion products are compression strength and modulus. The principal material requirements for lower wing plates and extrusions are tensile strength and damage tolerance to withstand the fatigue loads.

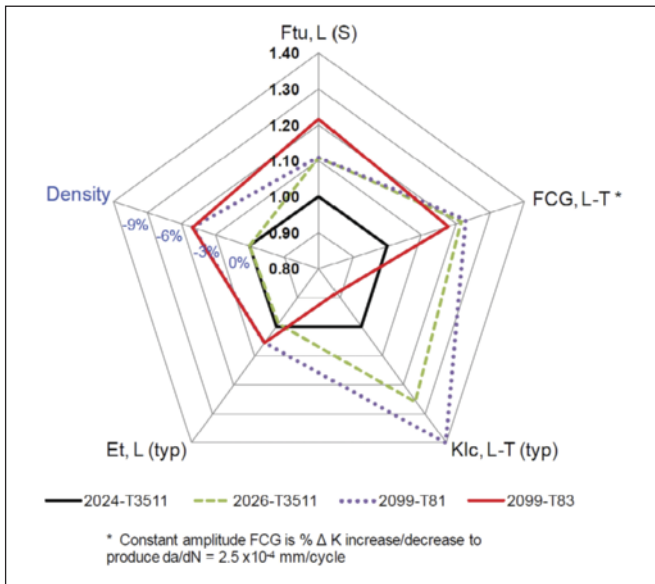
Advanced upper wing products include conventional alloys, such as 7255 plate, with increased strength and fatigue properties. Al-Li products, like 2055 plate and extrusions, enable com-



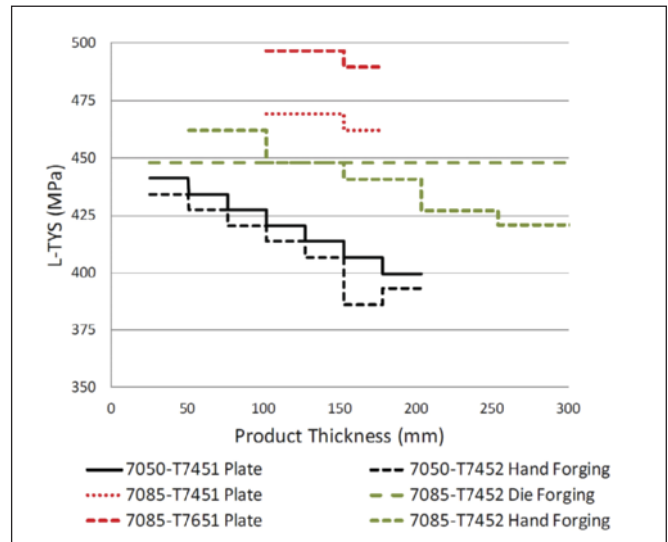
The material properties for advanced fuselage sheet alloys are shown as a ratio of alclad 2524-T3 material properties.



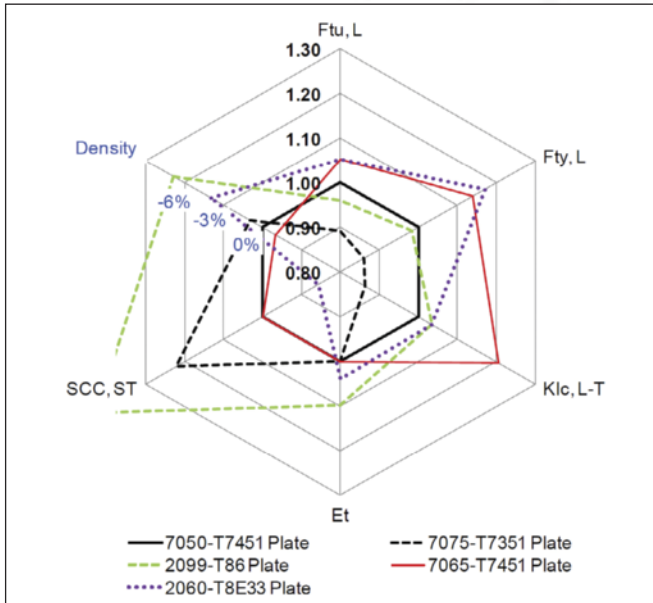
Key material properties for advanced upper wing plate products are shown as a ratio of 7055-T7751.



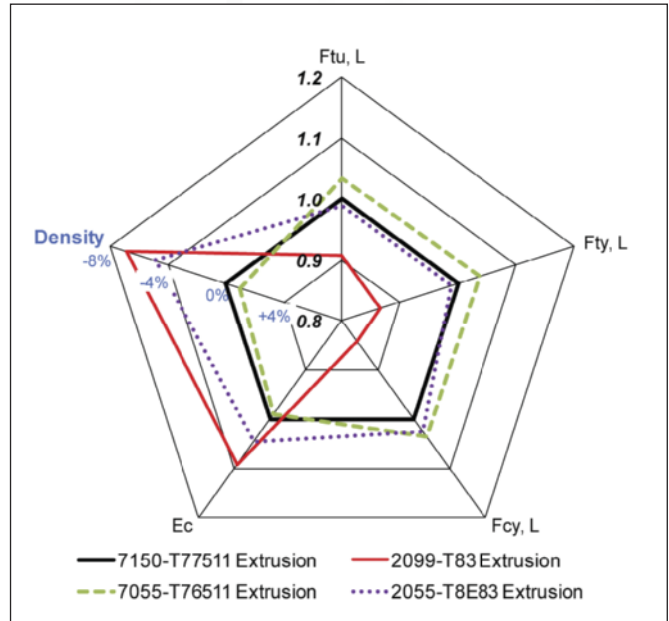
Comparison of key properties for advanced lower wing extrusion products compared to 2024-T3511.



This chart shows the comparative specification minimum longitudinal yield strength as a function of thickness for 7085 forging and plate products compared to 7050 forging and plate products. The 7085 alloy is able to achieve higher strengths in thicker sections.



Plot comparing characteristics of advanced plate products for machined parts. The variation in key properties across the alloys enables optimization for a variety of applications.



Plot comparing the relative performance of advanced high-strength extrusion alloys to 7150-T77511 for use in floor structures.

comparable strength with increased stiffness and reduced density.

Improvements for lower wing alloys focus on increased static strength and damage tolerance, including toughness and spectrum fatigue crack growth, to enable increased inspection and maintenance intervals. Both conventional and Al-Li alloys have been developed that offer performance improvements over the existing structures.

Modern aircraft designers are taking advantage of developments in high-speed machining to reduce structural weight and cost by implementing monolithic and integrally machined structures. Monolithic designs are being used to replace built-up structures. Example parts are fittings, bulkheads, wing ribs, and beams. The variety of parts corresponds to a variety of design drivers and material requirements. Typically, the material requirements are strength with an acceptable level of toughness and fatigue performance.

Seat tracks, floor beams, and stanchions are strength- and stiffness-driven components. High-strength aluminum alloys such as 7178-T6511 and 7150-T77511 have traditionally been employed in these applications. The floor structure is also exposed to moisture

and liquid, presenting the need for corrosion resistance. The combination of strength, density, modulus, and corrosion performance of third-generation Al-Li alloys makes them ideally suited for use in floor structures.

Manufacturing Mix

Over the next 30 years, both Boeing and Airbus project demand for approximately 19,000 to 23,000 single-aisle aircraft like the 737 and A320. In addition to being able to achieve performance improvements, any structural technology and material used to build these future aircraft must be capable of meeting the required build rates.

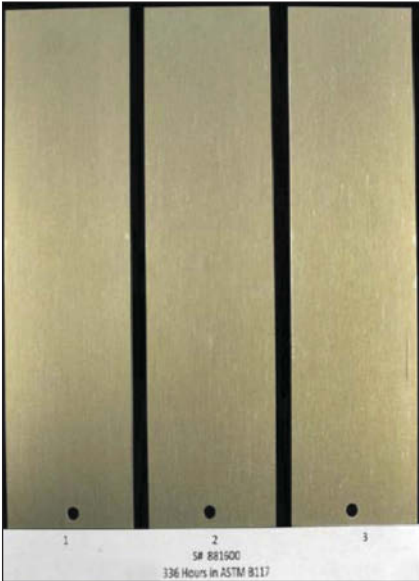
The notable difference in production of Al-Li products compared to conventional alloys is the ingot casting practice and facilities. Because of the chemical reaction of lithium with oxygen, it is necessary that Al-Li alloys are cast in an inert atmosphere, using specialized equipment and corresponding dedicated casting facilities. Conventional casting facilities cannot be used for Al-Li alloys.

Alcoa and other aluminum manufacturers have recently announced development and expansion of aluminum-lithium casting facilities. This expansion

will increase the availability of Al-Li ingot for aerospace applications. Once the raw ingot or billet is cast, the remainder of the Al-Li plate, forging, sheet, or extrusion production flow path is similar to the conventional alloys of the same product form.

The processing of the Al-Li ingots takes place in the same factories and on the same production equipment and tooling as conventional, non-lithium alloys. Although the Al-Li products run alongside the conventional products, the specific thermal-mechanical processes required to achieve the desired properties are optimized specifically for each alloy and product. It is not expected that investments specific to Al-Li alloys would be required at sheet, plate, forging, or extrusion mills to support future build rates.

While early generations of Al-Li had poor machining characteristics, the current, third-generation alloys are significantly improved. Machining trials at Alcoa and multiple end users have demonstrated machining success of Al-Li products using the same tools, machines, and techniques as are used for conventional aluminum alloys. For example, these Al-Li products can be machined using both carbide and high-speed steel



This figure shows chromic acid anodized 2060T8E30 sheet specimens after 336 h corrosion testing exposure in ASTM B117 in accordance with MILA-8625F. All specimens passed.

tooling. It has been shown to be capable of both conventional machining and high-speed machining. While specific parameters will need to be optimized for the alloy, product forms, and part geometry, similar speeds, feeds, and depths of cut can be used.

Tooling wear studies were done comparing 2099-T83 extrusion to other commonly machined alloys. Testing followed ASTM E618-81 and results showed that the amount of tool wear observed for the 2099-T83 extrusion was less than half that of 2024-T351 plate. The surface finish on the 2099-T83 parts was excellent throughout.

Cooling and lubrication using both oil- and water-soluble coolants have worked well, with both conventional and minimum quantity lubrication (MQL) techniques. Machinists also report that the Al-Li alloys have good chipping characteristics. However, dry machining is not recommended. MQL should be utilized if dry parts are required.

Another consideration for producibility of machined parts is machining distortion, which is caused by residual stresses and can be prevented by using stress-relieved material. The 7050-T7451 plate is an example of a stress-relieved product that has gained widespread ac-

ceptance because of good machining performance and low distortion.

The 7085 and 7065 plate and forging products presented are stress relieved. Advancements in forging analysis, tooling design, and press capability, including Alcoa's large 50,000-MT press, have enabled stress relief of large and complex forgings, enabling repeatable machining of monolithic parts with reduced distortion.

The Al-Li products presented here are used in a -T8 temper. The -T8 temper denotes that cold work is required to achieve target mechanical properties. Much like -TX51 tempers in 2xxx and 7xxx alloys, the cold work imparted as part of the T8 temper and associated stress relief will contribute to successful machining operations. This has been demonstrated in practice by many customers who have successfully machined Alcoa's 2099, 2055, and 2060 extrusion and plate alloys.

Many applications, such as fuselage and wing skins, require forming to meet dimensional requirements. Formability in the final -T8 temper may be limited. In most cases, the material will be aged to the final -T8 temper at the producing mill. However, for applications where the desired contour cannot be achieved in the -T8 temper, the product can be provided in an intermediate temper to facilitate customer forming operations.

For applications with small amounts of contour, such as wing skins and stringers or constant section fuselage skins, the Al-Li alloys have been successfully chip formed and brake formed. Age-creep forming parameters have been developed for the 7255 plate product. For sections requiring more complex curvature than what can be achieved in the finished temper, stretch forming in the -T3 temper and subsequent aging to the final -T8 temper is an option.

Stretch-forming trials of 2060-T3 sheet and 2099-T3 extrusions have demonstrated capability to achieve the desired contours. Forming limit diagrams for 2060-T3 sheet indicate that the material should have improved stretch-forming capability to 2524-T3 sheet. However, because a minimum amount of cold work is required to achieve target prop-

erties, stretch forming and post-forming aging parameters need to be developed to ensure performance requirements are met in the finished product.

Providing surface finishes to protect against corrosion is common practice in the aerospace industry. Experience shows that surface treatment and chemical operations can be successfully conducted on Al-Li alloys. Alcoa has demonstrated anodizing, conversion coating, priming, and finish top-coat painting operations on third-generation Al-Li alloys using conventional processes.

Trials on 2099 plate and extrusions investigated pretreatment, deoxidization, and etching, followed by anodizing, priming, and painting operations. Throughout the trials, 2099 plate and extrusion specimens passed the same relevant quality control tests as the baseline 7075 and 2024 alloys. Throughout this testing, the same process baths were used for 2099 as well as 7075 and 2024 alloys. There was no degradation of the chemical baths observed due to the Al-Li alloys. After processing, both the Al-Li and the non-lithium products met the pertinent specification and quality assurance requirements. Al-Li alloys can be processed in the same baths as conventional alloys. This has been demonstrated for chromic acid anodize, phosphoric acid anodize, and boric sulfuric acid anodize processes.

For 2060 sheet, it has been observed that when processing mill finish sheet (not machined, with the mill finish oxide layer still on the surface) the pre-treatment and chemical processes need to be optimized to remove the oxide layer. Once the optimized process is incorporated, the 2060 sheet successfully passes anodize and conversion coating specification requirements. This optimization is applicable to the surface preparation when the mill finish oxide is intact. Once this oxide layer is removed, conventional processes can be applied.

This article is based on SAE technical paper 2012-01-1874 by Brandon Bodily, Markus Heinemann, Gary Bray, Edward Colvin, and Jeffrey Witters of Alcoa. Visit <http://papers.sae.org/2012-01-1874/> to view the full paper.