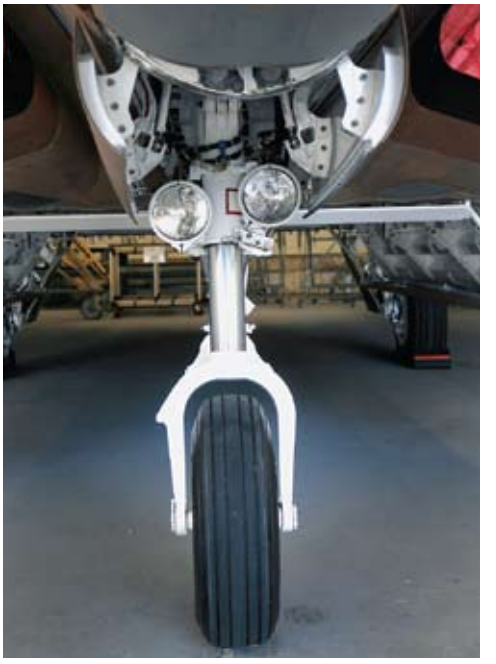
Manufacturing

Lockheed Martin leverages advanced metals on C-130J, F-22, and F-35



Originally designed with a composite nose-gear door, Lockheed Martin now builds the door in aluminum because it is less expensive and easier to manufacture.

Lockheed Martin is drawing upon its experience in the practical use of advanced metals to make a number of significant improvements to the manufacturability and supportability of its three most important aircraft: the C-130J, F-22, and F-35.

On the Super Hercules, Lockheed Martin is now qualified to use friction stir welding in the manufacture of the transport's aluminum structures, particularly its cargo ramp.

"This saves hundreds of fasteners and dozens of parts," said Andy Poole, Research Manager in the technology development and integration organization within Lockheed Martin's Advanced Development Programs (ADP) office. "While there is some weight reduction associated with part-count reduction, the significant cost savings is in maintainability, not necessarily in weight reduction."

The terminology of friction stir welding is interesting given that "weld" has always been a four-letter word in aircraft manufacturing because it is considered a process that is not well in control and also one that generates defects due to porosity and cracking.

"A technical challenge is tuning the friction stir joining process to the material and application," said David Chellman, Corporate Senior Fellow in structures and materials within the ADP office. "Fusion welding is more an art, not a science. Friction stir welding enabled us to weld things we couldn't weld before, like 7000 series aluminum."

On the Raptor, Lockheed Martin has reverted to using metallic nose-gear doors made of 7050 aluminum. It was difficult to control the processes used to manufacture the previous composite doors. The new doors provided a 30% cost savings.

"The original graphite-epoxy door had producibility issues," said Poole. The aluminum door is basically weight-neutral in that it does not save weight, but it does save money.

More than 100 Raptors have been delivered to date, and a total of 183 are on order to the **U.S. Air Force**. All F-22s are getting the aluminum nose-gear doors, including spares.

Those are two instances in which Lockheed Martin is using metals to make incremental improvements. There is nothing slight, however, about the use of large-scale aluminum-alloy die forgings on the Joint Strike Fighter (JSF).

Alcoa is under contract to design and manufacture all the large aluminum structural die forgings for the program.

The large-scale die forgings on the F-35 let Lockheed Martin significantly reduce manufacturing time.

Forgings with Alcoa's 7085 aluminum alloy include: 15 large bulkheads (the primary structural supports for the wing and engine that can have a mass of 1800 to 6000 lb each and range from 10 to 23 ft in length), and six wing-box parts that serve as important components of the skeletal structure to the wing.

Alcoa Forged and Cast Products' Cleveland operations is supplying the 7085 alloy to the F-35 program under a 10-year, $360 million contract signed last October. The first application of 7085 was for large die forgings on the **Airbus** A380 wing spars.

"JSF has the integrated capability of a forging design, and you can turn the design very quickly," said Poole. "Where you would have had to wait outside the forge shop for a year to a year and a half, the die forging can be done in half or one-third of that time. That helps meet performance and weight targets, helps with scheduling issues, and eventually it will show up in the cost, as well."

Barry Rosenberg

Manufacturing

Boeing getting a handle on 787 'traveled work' problems

"If there's anything that we have learned over this past three months, it's that we underestimated how long it would take to complete someone else's work."

That was the blunt assessment of **Boeing**'s Pat Shanahan, 787 Vice President and General Manager, during a January 16 conference call announcing another three-month delay—from the end of the first quarter in 2008 to the end of second quarter—for first flight. Boeing is pushing back first delivery from late 2008 to early 2009.

"We designed our factory to be a lean operation, and the tools and the processes, the flow of material, the skill of the personnel are all tailored to perform last-stage high-level integration checkout and test," he said. "We thought we could modify that production system and accommodate the 'traveled work' from our suppliers. We were wrong. If we had been set up more like an MRO, I really believe we would have made more progress."

Patrick Ponticel

Boeing has announced two delays in the 787 program since the July 7, 2007, rollout ceremony.

Boeing

This was the 787's state of production in early December. The first unit (dedicated to flight testing) was nearing completion while the two ground-test units were undergoing major assembly.

Declining to specify which partners are most responsible for so-called traveled work (work that the partners agreed to but for whatever reason have been unable to perform before shipping their sections of the aircraft to Boeing's Seattle-area final-assembly plant), Shanahan said the company is focusing on reducing the amount of undone partner work that is most disruptive to the final-assembly scheme.

Both Shanahan and Scott Carson, President and CEO of Boeing Commercial Airplanes, expressed confidence that the company can stick to its new target for first flight—despite having delayed it three times. The last delay was announced in October.

"We have a very clear assessment of the work that remains to be done and how we will do it, and from that assessment we have set this revised schedule for first flight," Carson said. "Building on our commitment to first flight, we are also working with our suppliers to assess our schedule on the airplanes following number one to make sure they meet the required condition of assembly and reduce the amount of traveled work coming into Everett. This assessment, which will also include discussions with our customers, will determine the details of our flight-test and delivery schedules. We expect to complete this assessment by the end of the first quarter."

Carson noted that Boeing has committed more resources to tackle the supply-chain problems. Those resources will be based at the Everett plant as well as at partner plants.

Shanahan, who took over as head of the 787 program in October, said: "Why am I more confident that this is a better plan? October's plan was based more on analysis. The case is, we have not done our partners' work in our facility before. There's no history there. There is no demonstrated performance, and we did not have a detailed statement of work. That plan was really kind of rooted in parametrics and very limited experience.

"I'm confident we will execute this plan because we have demonstrated performance over the last three months. We have more experience and knowledge of the work statement. We have more of the right skills and the resources, and we have a comprehensive and detailed plan in the process

to get that done.

"But let me go into more of the specifics. Specifically, I can see a path forward based on how much work we have completed. We have made significant progress in completing the primary structure. I can see a path forward based on the part shortages and the fastener shortages being reduced dramatically from where they were several months ago. When I look at the condition of the aircraft, the wings are in good shape in the critical fuselage areas. In a few weeks we will be routing wires through the airplane. The wire bundles are done. The extra time we've had here has given us more opportunity to test the functionality of those bundles. We incorporated the change in engineering into those bundles, and I'm confident that the functionality we require … will be there.

"And probably most importantly, the plan that we have laid out is parametrically consistent with demonstrated performance we have had on other programs in the past. Based on the combination of all those things, empirical data, analytics from past programs, and our day-to-day work progress, I'm confident that we've got the right plan, and it's really about focus and execution."

Shanahan dismissed rumors that part of the 787's delay owns to unanticipated problems with systems.

Patrick Ponticel

Manufacturing

GKN ramps up production of blended winglets

Delivering ahead of schedule, **GKN Aerospace** recently supplied **Aviation Partners Boeing** (APB) with the first blended winglets for the Boeing 737-300/500. Under a multi-year agreement finalized in April 2007, GKN is to deliver 200 737-300/500 blended winglet aircraft sets over several years.

The winglets are produced at GKN Aerospace's facility on Isle of Wight, U.K.

Winglets are transforming the performance of aircraft today, according to GKN. By significantly reducing drag, blended winglets cut the aircraft's fuel consumption by about 5%—improving performance and reducing environmental impact. The company notes that blended winglets can be retrofitted to the huge number of aircraft already flying, as well as fitted to new airframes.

"By 2010, just over two years from now, APB has predicted that blended winglets will have saved the world's airlines over 2 billion gal of fuel," said Jeff Armitage, Vice President and Director, Nacelles, GKN Aerospace. "For 737-300/500 operators, APB estimates savings of up to 100,000 gal of fuel per aircraft per year."

GKN's move into blended winglets is a key business development for the company.

"This is a key contract for GKN Aerospace here in Cowes, and it is our aim to play a significant part in this hugely promising market in the coming years," Armitage said.

GKN is delivering Boeing 737 blended winglets to Aviation Partners Boeing ahead of schedule.

GKN is a second-source supplier to APB for the winglets. "GKN Aerospace is one of the world's top producers of aerospace composite structures, and this agreement [allows] us to significantly increase blended winglet production on our 737-300/500 program," said APB CEO John Reimers. "We look forward to working with GKN Aerospace as the world airline industry continues its transition to blended winglet technology."

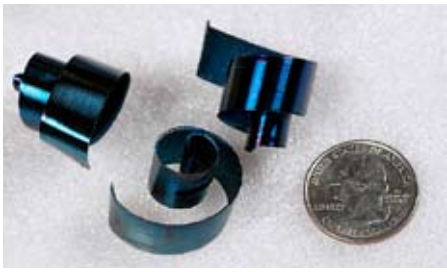
Each 737 winglet is 7 ft long. The composition is primarily carbon-fiber composite and the process is hand-laid.

The agreement between GKN and APB also calls for delivery of 300 sets of 11-ft-long winglets for the Boeing 767-300ER. Like 737 winglets, 767 winglets will be produced at the GKN facility on the Isle of Wight. The company is responsible for design, development, and manufacture of the 767 winglets, unlike the 737 winglets, which are built-to-print.

For winglet manufacture, GKN uses an automated tape-laying machine similar to the one shown, which is used to make the Airbus A400M composite wing spar.

APB is a joint venture between Aviation Partners and Boeing, and its headquarters are in Seattle.

Patrick Ponticel



Titanium chips from a MAG Cincinnati Ti profiler illustrate the type of chatter-free, high-performance machining that achieves superior surface finish and accuracy.

Manufacturing
MAG Cincinnati finds Russian takers for profilers

The world's largest titanium producer, **VSMPO-Avisma**, has ordered four three-spindle **MAG Cincinnati** Ti (titanium) profilers for its plant in Verkhnaya Salda, Russia. The three-spindle machines will be used to produce several parts, including large landing gear components, for **Airbus** and **Boeing** aircraft.

The new order follows a 2006 order from **Ural Boeing Manufacturing** (UBM) for six five-spindle titanium profilers. UBM is a joint venture between Boeing and VSMPO-Avisma, with a new 8900-m^2 plant in the same city. UBM uses the machines for roughing of large titanium components for Boeing. This reduces shipping costs and increases manufacturing efficiency by keeping initial metal-cutting steps near the metal production and forging operation, according to MAG Cincinnati.

"The local metal-cutting strategy facilitates recycling of chips to the source and allows the most efficient use of higher-level machining capabilities at Boeing's Portland plant and its subcontractors," said Chip Storie, MAG Cincinnati Vice President and General Manager, Advanced Systems. MAG Cincinnati will also provide installation and support services through April 2009.

According to Storie, the new MAG Russia office and its President, Sergey Gerasimov, were instrumental in obtaining the order. MAG Russia, established in 2007, provides local sales and service for the area's emerging aerospace market, driven by companies such as VSMPO-Avisma. MAG Maintenance Technologies, a sister organization to MAG Cincinnati within MAG Industrial Automation Systems, is providing process optimization services and proprietary tooling for the profilers.

The four latest machines will be configured as two profilers each on two individual rail sets, each 30 m long. The machines will be specially equipped to optimize titanium cutting with high-pressure 800-psi coolant, high-volume 90-gal/min external coolant, side conveyors, and cross conveyors. Shipping of the machines will begin in late 2008 and early 2009.

The six titanium profilers ordered in 2006 are configured as two five-spindle gantries, each on three rail sets, 144 ft long, with side and cross conveyors. Delivery of these machines will be completed this year.

Storie noted that there has been a dramatic increase in demand for titanium processing equipment across the globe.

Patrick Ponticel

Optimized titanium cutting on one of the six MAG Cincinnati five-axis, five-spindle Ti profilers for Ural Boeing Manufacturing, similar to the four three-spindle profilers recently ordered by the company for its manufacturing facility in Verkhnaya Salda, Russia.

Manufacturing
Gearing up for Westec

Machine tool makers, software developers, and companies involved in other facets of manufacturing are gearing up for the Westec show later this month in Los Angeles.

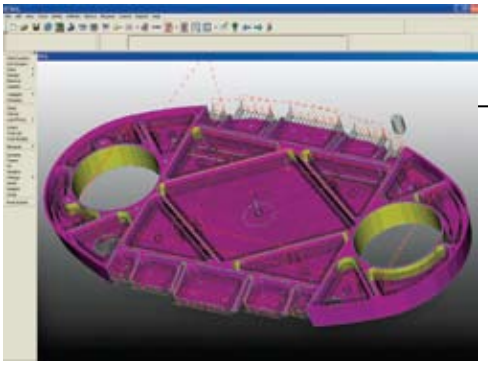
Among them will be **Tri-Tech Precision Products**, which plans to display its Model 5414 five-axis programmable head attachment. The M5414 attaches to virtually any three-axis CNC milling center to provide true simultaneous five-axis machining and drilling capability.

The product is suitable for use in aerospace and other industries.

The M5414 offers enhancements including an upgraded spindle with high-precision bearings designed to further increase rigidity and deliver a noticeably smoother surface finish. The recently upgraded worm gears offer a measurable improvement in accuracy over previous models. The M5414 now includes an Inpro spindle seal that virtually eliminates potential spindle contamination.

Designed to handle the most complex machining, including full five-axis profiling,

Tri-Tech Precision Products' M5414 attaches to virtually any three-axis CNC milling center to provide true simultaneous five-axis machining and drilling capability.



Users of Numerical Control Computer Sciences' NCL multi-axis machining software now have the ability to machine multiple surfaces in a single operation, such as on an aircraft bulkhead.

contouring, slots, and holes, the M5414's sturdy holding fixture enables a quick installation time—less than 30 min. Construction uses A2 tool steel in the drive block and main bevel gears and 17-4 stainless steel in the spindle and worm gear housing.

High-speed options are achieved through either a mechanical speeder or a pneumatic spindle that does not lose torque or rpm under load and uses clean, oil-free compressed air that eliminates oil drip from the spindle. High-speed spindle options offer 20,000 to 40,000 rpm capabilities.

The M5414 still provides access to all points within the hemisphere of the machine's work envelope. Rapid tool change is provided by the high-precision HSK tooling system.

To date, Tri-Tech has adapted the head to 40 and 50 taper vertical, horizontal, and bridge type machines from **Anilam**, **Dynapath**, **MAG**, **Fanuc**, **Fadal**, **Haas**, **Hurco**, **Johnford**, **Kuraki**, **Milltronics**, **Mighty USA**, **Mitsubishi**, **Okuma**, **Siemens**, and several PC-controlled machines.

On the software side, **Numerical Control Computer Sciences** will present the latest version of NCL multi-axis machining software, which, the company says, saves users time in the generation of complex tool paths. New strategies have been added to the flowline milling feature; users now have the ability to machine multiple surfaces in a single operation, the ability to mill around avoidance surfaces, and the ability to control the axis of the tool with a secondary part surface to assist in machining highly curved surfaces. These features are beneficial when machining rib-top and fillet surfaces.

In addition, a new visual calculator has been incorporated into NCL version 9.6, giving users more functionality in a single interface and the ability to compute geometric entities faster.

Patrick Ponticel

Testing

Purdue engineers perform quiet wind-tunnel testing

Purdue University engineers have been using an on-site wind tunnel to conduct experiments aimed at yielding critical data for the design of the X-51A test vehicle.

Purdue doctoral student Matthew P. Borg holds a model of the X-51A, which will be capable of flying at Mach 6. Purdue engineers have used a wind tunnel capable of running quietly at hypersonic speeds to yield data critical to the vehicle's design.

According to Steven Schneider, an aerospace engineer and professor in Purdue's School of Aeronautics and Astronautics, no other wind tunnel runs quietly while conducting experiments in airstreams traveling at Mach 6. Quiet operation, which more closely simulates actual flight, is critical for collecting data to show precisely how air flows over a vehicle's surface in flight. **NASA** previously operated a tunnel capable of similar results but it is not currently in use.

To properly design vehicles that fly at hypersonic speeds, engineers need detailed information about how airflow changes from laminar, or smooth, to turbulent as it speeds over an aircraft's surfaces.

The Purdue research is focusing on the forebody of the craft, using a 1-ft-long model for wind-tunnel testing. The findings are providing information in two areas: maintaining the turbulent flow of air into the engine's combustor and increasing the amount of smooth airflow over the vehicle's upper surfaces to reduce potentially damaging friction and heat.

The X-51A, powered by scramjet engines, is expected to evolve into missiles capable of flying at Mach 6, enabling them to hit mobile, time-critical targets. The project is being led by the **Air Force Research Laboratory** and **DARPA**, and the vehicle is being built by **Pratt & Whitney** and **Boeing**.

The aircraft is wedge-shaped with a scoop-like cowl on its underbelly, where air rushes into the inlet of the engine's combustor. The air entering the inlet must be turbulent at hyper speeds or the engine could fail, causing the engine to crash. To convert the air to turbulent flow before entering the inlet, a raised strip of metal is placed near the inlet to trip the air from smooth to turbulent. Research findings will enable engineers to determine precisely where to place the trips and how far they should be placed from the aircraft's skin.

Experiments under quiet conditions yielded more accurate findings than those conducted under noisy conditions. Data from the quiet experiments indicated that the trips should be raised twice as high. Researchers are able to switch the wind tunnel back and forth from quiet to high-noise airflow, allowing them to compare the quality of the data.

To obtain quiet flow, the throat of the Mach 6 nozzle must be polished to a near-perfect mirror finish, eliminating roughness that will trip the flow near the wall from laminar to turbulent. For the wind tunnel itself to remain quiet, it must be entirely free of particles. A single speck of sand inside the tunnel could cause turbulence, damaging the finish and ruining the quiet effect.

Friction and heat created from air flowing over the top of the vehicle increases drag and necessitates a heavier thermal protection system for the vehicle's thin metal skin. Wind-tunnel data is being used to assess the performance of that portion of the vehicle.

Researchers used a temperature-sensitive paint to measure how hot the skin of the model gets during testing. The paint was applied to a nylon strip inserted into the model, and by shining a blue light onto the strip during testing a temperature-dependent red light is generated from the paint. The intensity of the red light signals how hot the surface is.

"Laminar airflows can have eight times less heating than turbulent ones," Schneider said. "The results of our work can be used to help determine the heating and the skin friction of the vehicle, which is important to the design of the X-51A."

To measure the airflow velocity and turbulence, researchers use a heated wire about one-tenth the diameter of a human hair. The higher the speed of the airflow, the more the wire is cooled and the greater the electrical current needed to maintain the wire's hot temperature. Monitoring the changing current needed to maintain the wire's temperature reveals the changing air speed at fluctuations of up to 250,000 times per second.

A total of 18 years of research and about $1 million from Purdue, the **U.S. Air Force**, and private industry have been invested to perfect the facility.

"It's finally working and getting results that are affecting the design of these vehicles," Schneider said.

Matt Monaghan

Materials

Scorpius Space Launch propels all-composite tanks forward

Scorpius Space Launch Co. (SSLC) is capitalizing on—and contributing to—a growing trend in the aerospace industry: the increasing use of composite materials in place of more traditional metals. One has to look no further than the **Boeing** 787 Dreamliner, which according to market research company **Lucintel** uses about 50% composites by structural weight, as evidence.

The Pressurmaxx tanks, which in the Prospector 9 are being used for fuel and oxidizer, conform to **ASME** (American Society of Mechanical Engineers) standards, and their liner-less design reduces cost and weight compared to metal tanks, explained Markus Rufer, Scorpius' Executive Vice President and Chief Operating Officer. "Depending on application, size, and pressure requirements, both cost and weight savings are in the 30-50% range," he said.

Depending on application, size, and pressure requirements, Scorpius Space Launch's Pressurmaxx all-composite liner-less tanks can reduce cost and weight by 30-50% compared to metal tanks.

Last fall, SSLC, in partnership with **Microcosm**, delivered a pair of next-generation all-composite cryogenic propellant tanks for integration into a prototype reusable launch vehicle in development by **Garvey Spacecraft** under a Phase II SBIR project for the **Air Force Research Laboratory**'s Propulsion Directorate. When Garvey's Prospector 9 begins flight testing, which is planned for this month, it will be the first time that a launch vehicle has flown with two such all-composite propellant tanks, according to SSLC.

The tanks also offer performance enhancements compared to traditional aluminum structures, Rufer noted. "All-composite tanks eliminate the problems concerning delamination and corrosion issues that carbon fiber over-wrapped metal tanks have," he said, adding that they are also structurally stronger and have shorter manufacturing lead times.

"What's unique about our all-composite tanks is that they can hold up to several

thousand psi pressure under cryogenic conditions—an achievement that has never been attained before without resorting to the use of metal liners," said Rufer. "We are not aware of any other production all-composite liner-less tanks on the market that are made for high-pressure cryogenic applications."

The current composite-fuel-tank program builds upon previous cooperative efforts between the two companies. In 2000, Garvey Spacecraft accomplished the first-ever flight demonstration of a composite cryogenic tank carrying liquid oxygen, using a prototype test tank supplied by SSLC.

Many advancements have been made to the composite-tank technology since earlier development programs. "Major progress was achieved in weight optimization by reducing wall thickness," Rufer said. "Also, compatibility was expanded to include alcohol- and natural gas-based propellants and pressurants. [And] high-load, sealed Y-joints were developed for the mounting skirts."

According to Garvey Spacecraft's John Garvey, "When we first defined the P-9 vehicle configuration, we assumed it would feature aluminum tanks to minimize risk. However, Scorpius' recent progress in refining, testing, and producing their latest generation of composite tanks gave us enough confidence to make the switch now rather than waiting until a future vehicle.

"One of the goals of our work with AFRL is to evaluate and, if possible, increase the technology readiness levels of candidate advanced launch vehicle technologies, with all-composite tanks like the Pressurmaxx being right near the top of the list," Garvey added.

In 2007, Pressurmaxx tank products were ordered by a variety of companies, "from small aerospace component manufacturers to the nation's largest defense contractors," Rufer said. They have been selected for applications in launch vehicles, experimental spacecraft, sub-orbital vehicles, sounding rockets, lunar and Mars-lander vehicle concepts, as well as superconductor coil technology.

Microcosm's Scorpius family of launch vehicles uses Pressurmaxx technology to increase the payload-to-orbit by 30% with no increase in cost.

Ryan Gehm

Materials
3M eases sticky tasks

Meeting safety requirements in all aspects of aerospace production and engineering demands high levels of expertise. Now, specialist technology company **3M** has developed what it believes to be the world's first two-part structural epoxy adhesive to meet aerospace fire, smoke, and toxicity (FST) standards (when tested stand-alone) without the need for additional treatments or surface coatings.

The adhesive has been developed to meet the requirements of FAR 25.853 (a) flaming mode, JAR 25.853 (a) flaming mode, and ABD 0031 & AITM 2.0002A as defined by the U.S. flight authorities, European flight authorities, and **Airbus**, respectively.

Scotch-Weld adhesive 7246-2 B/A FST is aimed at simplifying many aircraft interior manufacturing tasks by allowing builders to complete assembly and FST compatibility operations in one step. The product will replace several types of conventional adhesive, simplifying stock requirements and improving productivity.

Scotch-Weld adhesive 7246-2 B/A FST is a room-temperature-curing structural two-part epoxy paste adhesive system. Its thixotropic, non-sag formulation makes it easy to apply without dripping or deformation, says 3M. The product has been created for many aerospace interior tasks, such as the corner splicing of honeycomb panels, insert bonding, and the bonding of tubular ducting. It allows completed assemblies to meet FST requirements without additional surface treatment. Light tan in color to match conventional honeycomb skin materials, the material can be over painted using the same surface coatings as the panels without leaving shadows.

"Our aerospace customers need to produce assemblies that meet extremely demanding FST standards," said John Lester, Key Account Manager at 3M. "Until now, those requirements have precluded them from taking advantage of modern easy-to-use structural epoxy adhesives where the adhesive will form part of the outer surface of the finished product."

The adhesive has a typical work life of 45 min and reaches handling strength in 3-4 h under the same conditions.

3M's Scotch-Weld adhesive 7246-2 B/A FST is aimed at simplifying many aircraft interior manufacturing tasks.

The product is available in an EPX duo-pack cartridge or in bulk containers for hand mixing or use with automated mixing equipment. Compatible with most common aerospace interior substrates, including aluminum honeycomb, polycarbonate, glass/phenolic panels, polyetherimide, and polyphenylsulfone, Scotch-Weld adhesive 7246-2 B/A FST is resistant to damage by water, salt spray, jet fuel, and mineral oils.

Stuart Birch

Materials

Quatro Composites keeps carbon-fiber panels coming

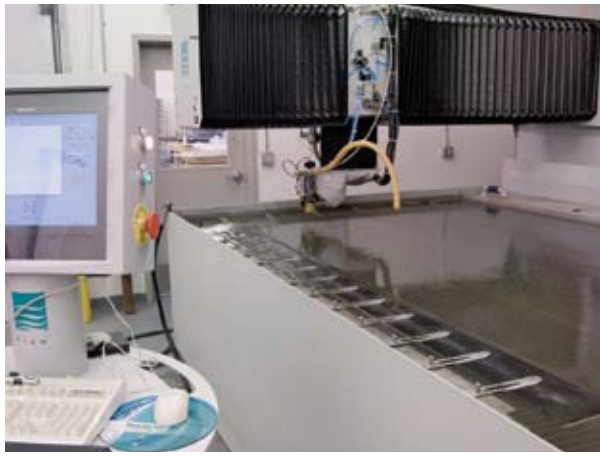
Quatro Composites, a designer and manufacturer of carbon-fiber molded products, has been awarded three contracts to supply carbon-fiber panels to airframers and Tier 1 suppliers for drill qualification and assembly training.

These contracts underscore the significance that outsourcing plays in the industry. "Most aircraft manufacturers have been producing these in-house at their facilities, and it became a priority to outsource the panels so they can focus on assembly," said Ken Gamble, Vice President of Composite Technology at Quatro Composites.

The carbon-fiber panels that the company produces are not for production use on aircraft. "At this time, they are for qualification/training purposes for on-the-floor technicians," Gamble noted. He declined to mention which companies Quatro is supplying these panels to, as well as volume figures.

"As the airplane manufacturers make the radical shift from aluminum to carbon composite materials for the primary structure, much support is required to address the new techniques of drilling, fastening, and bonding," Steve Roesner, Quatro's Chief Operating Officer, said in a statement.

The company supports the manufacturers of composite fuselage and wing skins by supplying carbon/epoxy panels



Quatro Composites supplies carbon-fiber panels to airframers and Tier 1 suppliers for drill qualification and assembly training. Shown is a panel being water-jet-cut down to size.

that are built to the aircraft manufacturer's process specifications.

"Carbon fiber is very abrasive and requires carbide or diamond tooling, [and] the dust is conductive so it either needs a very good vacuum or flood coolant," said Gamble, noting a couple of the challenges presented by drilling and assembling carbon-fiber panels.

Despite any challenges, Gamble predicts that carbon-fiber-panel usage on future aircraft "will only increase as fuel prices increase. Carbon parts, if designed well, provide a 30% weight savings over aluminum parts."

To meet increased demand, Quatro has recently added 30% more manufacturing space to its Orange City, IA, facility for the manufacture of carbon-fiber panels, as well as structural aerospace composite brackets.

Most of the panels it produces are made with Toray T800 carbon epoxy prepreg.

The panels are manufactured from engineered laminate schedules in a variety of shapes and configurations. The panels are then machined, water jet cut, packaged, and shipped as specified by the customer.

Quatro also offers product-development services to aerospace companies. "The customer brings an aluminum part with a design space, attachment points, and part loading, and the Quatro team optimizes the part for weight, stiffness, thickness, geometry, and manufacturability," Gamble explained. "On smaller fittings, we have seen up to 40% weight savings over the aluminum fitting."

The company specializes in producing parts of complex geometry using bladder molding, compression molding, autoclave, and a proprietary out-of-autoclave process called UltraClave.

Ryan Gehm

Materials

Ball Aerospace completes primary mirror for Kepler Mission

Ball Aerospace & Technologies has completed the precision coating process of the primary mirror for **NASA**'s Kepler Mission, a mission that is specifically designed to detect Earth-size and smaller planets near stars within our region of the Milky Way galaxy. The mission will search for planets in or near the habitable zone (HZ) of stars in our galaxy, where HZ is defined as the distance from a star where liquid water can exist on a planet's surface.

Completion of the primary mirror's coating culminates a four-year development program to design and build a large, lightweight mirror for use in space. The mirror was coated using an enhanced, silver coating technology provided by **Surface Optics** that is designed to provide the NASA mission with the sensitivity needed to detect planets as they pass in front of stars.

Ball Aerospace's completion of the Kepler primary mirror's coating culminates a four-year development program to design and build a large, lightweight mirror for use in space.

The enhanced, silver coating technology used for the primary mirror was provided by Surface Optics.

In addition to completing the primary mirror's coating, Ball Aerospace has also completed integration of the detector array assembly. These milestones meet a critical path requirement and allow the program to begin integration and test on the photometer telescope and focal plane array assembly.

The Kepler instrument, a custom-built, 0.95-m aperture Schmidt telescope, operates with a 1.4-m primary mirror and an array of 46 charge-coupled devices at the focus. It features a focal plane array of 95 megapixels that will measure the brightness of 100,000 stars every 30 min.

Ball Aerospace is also building the spacecraft for the Kepler Mission, which is scheduled to launch in February 2009.

Darlene Fritz

Propulsion

Engines get digital transformation

ASB Avionics used rack-mounted Ametek engine interface units (EIUs) in its Avionics Modernization Program for the L382G. The EIUs collect multiple analog signals from the engines and convert them to digital format.

ASB Avionics uses dual **Ametek** engine interface units (EIUs) to transform analog engine sensor data into a digital format for its engine instrument display (EID) system, approved by the **FAA** for the L382G (civilian version of the C-130H) cargo aircraft. The EID system provides digital engine display capability to a **Honeywell** CDS/R electronic flight instrument system and replaces 32 traditional 2-in round indicators with a single 8- x 10-in flat panel.

The rack-mounted EIU collects multiple analog signals from the aircraft engines and converts them to digital format. The EIU outputs the data over an industry-standard ARINC 429 data bus that interfaces directly with the cockpit's multifunctional display (MFD). Each of the EIUs has dual-channel redundancy and is transferable from the EID to either pilot's MFD in the event of a display default. Data also is output directly to the flight data recorder via analog and ARINC 429 signals. In addition, the EIU is able to store a host of engine parameter data to aid in trend monitoring and exceedence tracking.

In other Ametek news, **Clifford Development** has incorporated the company's Sentinel II instrument display system as part of its Supplemental Type Certification (STC) program for the **Cessna** Citation II and their recently announced Citation SII. The program re-engines the Citation aircraft with high-efficiency **Williams International** FJ44-3 turbofan engines. Clifford expects to achieve significant performance improvements from the retrofitted Citations, including increased range, cruising speed, and fuel efficiency.

"Clifford's goal is to achieve best-in-class performance by marrying the latest in aircraft engine and avionics technology aboard [the] business jets," said Wes Hardin, Senior Vice President and General Manager, Ametek Aerospace & Defense.

"The 3000-lb thrust Williams FJ44-3 engine utilizes full authority digital electronic control (FADEC) providing pilots with advanced engine diagnostics and monitoring, while our fully digital Sentinel II with its dual redundant AMLCDs (active-matrix LCDs) accepts all standard

Ametek's Sentinel II instrument display system that was used in the Supplemental Type Certification program for the Citation II is fully redundant and accepts all standard aircraft input and output signals without requiring a major aircraft systems retrofit.

aircraft input and output signals without requiring a major aircraft systems retrofit."

The Sentinel is fully redundant. "Should a failure occur in either its data processing or its AMLCD, the other system is instantly ready to display all input parameters," said Hardin.

"The SENTINEL II system is the perfect replacement for the original vertical tape engine instruments. Pilots will appreciate the range of easy-to-interpret engine data that the SENTINEL II draws from the Williams FJ44-3 FADEC system. This is just one of the more than 30 systems improvements made as part of this STC," said Jim Clifford, CEO, Clifford Development.

The Williams J44-3 engine that powers the Citation IIs is the first FAA-certified engine of less than 6400 lb thrust to incorporate dual channel FADEC and the smallest and lightest turbofan engine to have passed all of the rigorous FAA certification tests, according to Clifford. Ametek developed a combined total temperature/total pressure probe specifically for the engine.

Jean L. Broge

Electronics
It's all in the math for Athena's UAV control systems

A variety of manufacturers have successfully shown how small, tactical, relatively low-cost UAVs can provide soldiers and marines on the ground with timely data on enemy positions. One of the keys to such programs is not the electro-optic/IR sensors through which data is collected, but the autonomous control systems that make such systems operable.

Engineers working for companies that develop autonomous control systems for UAVs tell stories about potential customers who think that creating an autonomous command and control system for a small UAV is akin to flying a hobbyist's radio-controlled aircraft and can be accomplished in a weekend. That misconception does not last long, though.

"Unmanned vehicles are limited in size, power, and the amount of weight they can carry," said Dave Vos, founder, Chief Technology Officer, and CEO of Warrenton, VA-based **Athena Technologies**. "If you look at the way many of the manned aviation autopilots in general aviation were developed, you'll see a lot of trial and error. You can do that with unmanned systems, but it is risky and expensive.

"The challenge is to push the button for the first time and have it work. If you can do that, you can save a tremendous amount of time and money in getting a vehicle up and flying in the marketplace."

Athena's main program is the **U.S Army**'s Shadow 200 UAV built by **IAI**. Athena has supplied "hundreds" of systems to the Shadow program since 2001.

"Since then we've essentially shrunk 20 lb of stuff down to a 4-lb cube while improving the accuracy of the control system and navigation, which impacts every phase of flight from launch to mission," said Vos.

"The control theory is straight-up mathematics," he said. "Without knowing exactly how the airplane will behave, we use non-linear control design theory and modeling so all you essentially do is push the button on the math tool set. That is followed by engineering qualification.

"Then you're ready [to fly]. That cycle is extremely fast and robust. The military loves it because they get to test it more and it behaves the way they want it to very quickly,"

Both the German-built Luna UAV and the Shadow tactical unmanned air system (shown) have autonomous navigation and control systems from Athena Technologies.

said Vos.

The market to develop UAV command and control is extremely competitive, particularly on the smaller Class I end.

"Military customers have a mission they need to perform, and they want to do it extremely reliably and at low cost," said Vos. "That's why this market is so unbelievably competitive. In competition against the incumbents like **Honeywell** and **Rockwell Collins**, companies like Athena have been required to show up with performance and prices that they cannot match."

Athena was founded in 1998, and grew 1400% from 2000 to 2005, according to Vos. It employs 75 people. "We focused on winning major programs, not serving onesy-twosy activity," said Vos.

Though, admittedly, some of that one-off work could be potentially lucrative. Athena's research and development into controlling and autonomously landing a damaged UAV is one such program.

"How attritable is an unmanned airplane?" asked Vos. "There are a lot of issues. If it goes down into enemy territory, the current protocol is to send soldiers out to retrieve it. One of the key pieces with damage tolerance is to maintain flight control, but even if you have to put it down you have a better chance of getting it into friendly territory."

Last year, Athena and **DARPA** successfully demonstrated damage-tolerant flight control and autonomous landing capabilities on a subscale F/A-18 UAV. "The program lives on top of the control and navigation function," said Vos.

The objective of the test was to prove that adaptive flight controls could regain baseline aircraft performance after the aircraft had sustained simulated battle damage and then safely land the aircraft autonomously with only the onboard inertial navigation system (INS)/GPS functionality of an Athena system for navigation.

The subscale F/A-18 UAV was powered by a turbojet engine and sustained simulated wing damage and the in-flight ejection of an aileron. Athena's damage-tolerant controls detected the damage in flight and adapted to the new air vehicle configuration for the effects of the lost aileron, recovering the baseline vehicle performance. Using only Athena's INS/GPS autonomous landing system, the vehicle landed within a few feet of the target touch down point on the airfield runway.

Barry Rosenberg

Simulation

AERC employs Faro and Geomagic tools in aviation feasibility studies

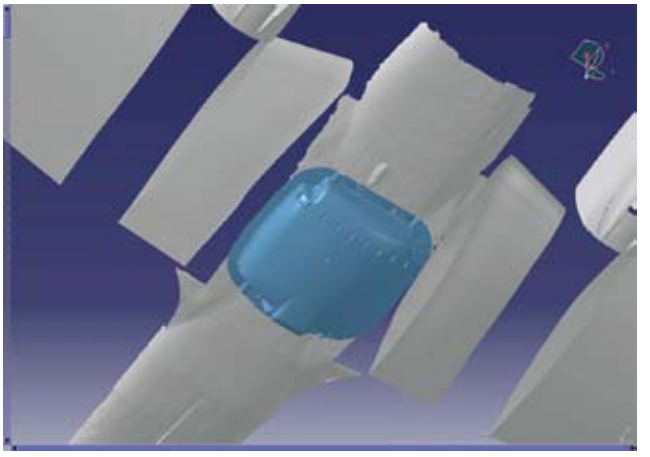
Ever wonder whether a diesel engine can be used to power a helicopter? Or if you can safely attach a 1-ton spray pod to a passenger turboprop plane with a cruising speed of 284 mph?

These are not the typical subjects of aviation feasibility studies, but they are practically meat-and-potatoes for **Embry-Riddle Aeronautical University**'s Applied Engineering Research Center (AERC) in Daytona Beach, FL.

The central tools in AERC's explorations are **Faro**'s Platinum ScanArm and **Geomagic** Studio digital reconstruction software. The combination of Faro hardware and Geomagic software enables digital shape sampling and processing (DSSP), which describes the ability to traverse physical and digital worlds. AERC takes advantage of DSSP to create accurate digital replicas of assemblies and parts for which there is no CAD data, and then test them in the virtual world.

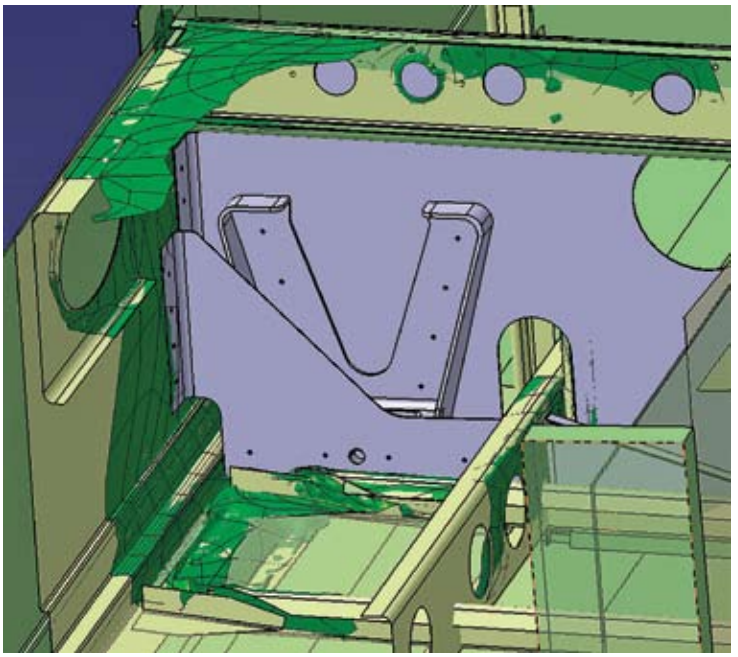
The spray pod project is AERC's latest, and an example of the kind of challenges the testing lab routinely takes on.

A county agency approached AERC to develop a removable spray pod tank that could be attached to a King Air C90, a twin-turboprop plane produced by **Beech Aircraft**. The King Air has been in continuous production since 1964, but it is most often used for hauling passengers, not carrying a spray tank that weighs about 2000 lb when fully loaded with insecticide.



The spray pod, designed in CATIA, is shown attached to the fuselage model created in Geomagic.

AERC purchased the Faro Platinum ScanArm in 2006 and teamed it with Geomagic Studio software to collect, process, store, and analyze 3-D data in digital form. The first project was the successful adaptation of a diesel engine for a small helicopter.



The surface model from Geomagic of the actual structure is overlaid with the newly designed CATIA structure to align the old and new.

Before that, AERC had used a Faro Gold Arm with a hard-probe. It increased accuracy and saved time over the old methods—measuring by hand and marking points with tape measures and T-squares—but there were still difficulties turning the point data from the Gold Arm into accurate surfaces within CATIA CAD/CAM software.

With the Faro Platinum ScanArm, AERC has the ability to collect 19,000 points per second with accuracy within hundredths of an inch. The ScanArm is fully integrated with Geomagic Studio, which provides patented processes for quickly converting point-cloud data into polygons and accurate surfaces.

According to Stephen Roth, Associate Director of AERC, no training was necessary with Geomagic.

For the spray pod project, AERC scanned the King Air inside and out, since the addition of the spray pod requires reinforcing the inner structure of the fuselage. The plane was also jacked up so the underside could be captured by the scanner. AERC had to plan for two opposing requirements: scanning large areas where very little detail is needed, and capturing areas where precise measurements within hundredths of an inch are needed for features such as rivet heads.

"This was our first large-scale project with the laser scanner," said Roth. "One of the biggest challenges was determining the most efficient ways to capture the varying level of detail we needed from different parts of the fuselage."

Multiple scans were used to capture the geometry of the King Air fuselage inside and out, in both relatively flat and highly curved areas, and in little and great detail. The scans were imported into Geomagic Studio, where they were automatically registered to closely fit one another. The scans were then merged and a polygon model of the fuselage was created. Geomagic Studio also enabled AERC to fine-tune the model, removing noisy data, filling holes, sharpening edges, and performing other edits.

Using a logical, step-by-step work flow in Geomagic, AERC engineers converted the polygon model into a NURBS surface model. First, regions were defined by unique colors separated by red boundary lines. Contour lines were extracted from the regions and used to create individual panels within the model. The panels were then used to create and refine a patch layout, to which grids were applied and the resolution of the NURBS surfaces determined.

Once the NURBS surface model was created, the transformation from physical to digital was complete, and the model was ready for importing into CATIA.

"The process was simple and automated," said Monica Londono, a design engineer who was part of the project. "Geomagic gave us a true surface representation of the fuselage that we could seamlessly import into CATIA to use for designing the spray tank."

The model created in Geomagic was used in CATIA to help create the optimal design for the spray tank, and to determine the best way to connect the spray tank to the fuselage. The completed tank model, connected to the fuselage, was loaded into CATIA FEA software to simulate loading and conduct structural analysis. When the spray tank design was completed to AERC's satisfaction, it was sent out for CNC milling. The resulting physical prototype of the spray tank was an excellent match for the fuselage, according to Roth.

At this point, the tank has been built, mated to the King Air, and is currently undergoing testing by the **FAA**. Further verification will be provided by Geomagic Qualify computer-aided inspection software, which AERC will use to compare the manufactured spray pod to the CAD model to ensure that design integrity is kept intact.

"It's hard to quantify exactly how much time we've saved and how much we've increased modeling accuracy with Faro and Geomagic," said Roth. "[However], there have been major improvements in both areas."

Bob Cramblitt, Cramblitt & Co., wrote this article for *Aerospace Engineering & Manufacturing*.

Regulations & standards

SAE S-15 Committee decides what's hot and what's not

For the average person, what constitutes a hot day is subjective. The same with a cold day.

For aerospace engineers, though, it's not subjective—and there's a new **SAE** standard to prove it. The S-15 Gas Turbine Performance Simulation Nomenclature and Interfaces Committee recently published ARP210, "Definition of Commonly Used Day Types (Atmospheric Ambient Temperature Characteristics Versus Pressure Altitude)."

The standard recognizes that an aircraft performs differently, depending on meteorological factors such as temperature and other atmospheric conditions. The gas-turbine industry has long used nonstandard atmospheric temperature profiles in the design and testing of aircraft and their engines. There really are "hot" and "cold" days. "And aircraft really do not perform the same on hot days as they do on cold days," said committee member Thomas Roadinger, Project Manager at **Pratt & Whitney**.

Going back to 1953, the military defined specifications for what was a hot day, a cold day, a tropical day, *etc*. The aircraft industry used these specifications as a good, convenient way to describe performance at varying conditions, according to Roadinger. The problem is that the military canceled the specifications. So the common definitions of hot day, cold day, *etc*., disappeared.

In ARP210 can be found all the nonstandard atmospheric temperature profiles that used to be in the military specifications. But the S-15 committee went a little further than the original specifications, Roadinger said. In addition to the complete temperature profiles, the committee has a recommended set of profiles that are smaller and have been scrutinized for consistency.

The atmospheric temperature profiles are presented in terms of ambient temperature as a function of pressure altitude. And just to make sure everybody is on the same page, Roadinger noted, ARP210 includes an appendix that gives the details of exactly what altitude means, including physical altitude, geometric altitude, geopotential altitude, GPS altitude, and pressure altitude.

"**Honeywell** and other gas-turbine engine manufacturers conduct ground and flight tests to assure they meet customer requirements," said S-15 Committee Chairman Mark Steele, Manager of Advanced Engines, APU, Commercial Propulsion Performance, Honeywell. "The customers and gas-turbine manufacturers depend on atmospheric standards to avoid confusion and disagreements. Honeywell has used the definitions that are now incorporated in ARP210 for many years, and they have saved untold hours of disagreements and retesting."

This Boeing 720 is a good, stable testbed for the size of turbofan engines that Honeywell produces, according to Mark Steele, Manager of Advanced Engines, APU, Commercial Propulsion Performance, Honeywell. The engine under test in this photo is the one attached to the front fuselage.

Between actual flights and this cell located in Phoenix, Honeywell can run all of the engine rating tests required by customers, said Steele. Temperature is not controlled in the cell, but Honeywell engineers can refer the engine data to temperatures defined in ARP210.

Honeywell uses a **Boeing** 720—one of the few remaining in operation—for its in-flight testing of turbofan engines. It has a cell in Phoenix for ground testing. Between the two, Honeywell is able to cover 99% of all engine rating tests, according to Steele.

Test engines are mounted on the front fuselage of the 720 and are small enough in comparison with the four engines powering the airplane that a turbofan under test can be run through its entire power range while the main engines maintain the aircraft's altitude and speed, said Steele.

"The test engine can even be shut down, and the aircraft can still maintain the desired flight condition," he said. "This allows the gathering of 'windmilling' data, and also engine starting data can be obtained for a multitude of flight conditions. With the 720 we can set just about any desired altitude and Mach number within the engine's flight envelope. The one thing we can't control is the ambient temperature, which is where ARP210 comes into play. We adjust the data from the tested temperature to the appropriate temperature from ARP210."

Most gas-turbine engine testing is done in ambient cells, according to Steele, and the data is corrected to the desired inlet temperature. "Again, this is where ARP210 can come into play."

Patrick Ponticel

Vehicles
First KC-767 night refueling

In late January, a **Boeing** KC-767 tanker, scheduled for delivery to Japan's **Air Self-Defense Force** (JASDF) early this year, departed McConnell Air Force Base, adjacent to the Boeing Integrated Defense Systems Wichita facility, and flew a 3-h, 9-min flight. The aircrew connected the KC-767s fifth-generation, fly-by-wire boom (a telescoping tube used to deliver fuel to military aircraft) to an F-15E 11 times during dusk and night conditions and successfully offloaded fuel before returning safely. The company uses the fighter under a cooperative research and development agreement with the **U.S. Air Force**.

The Japan KC-767 tanker, a military derivative of the proven 767-200 commercial airplane, was selected over its competitor, the **Airbus** A-310, in a direct competition in 2001.

Its advanced boom builds on the aerodynamic shape and size of previous systems and provides more precise and responsive controls to the operator. With 2600 fewer parts than previous booms, it also is easier to maintain, says Boeing.

A Boeing KC-767, one of two tankers scheduled for delivery to Japan this quarter, prepares to transfer fuel to an F-15E over the skies of Missouri in late January. It was the first nighttime refueling ever accomplished on a KC-767, which features a remote vision system for the boom operator.

The tanker uses a remote vision system that provides boom operators with a picture that accurately details the refueling receptacle, even at night.

"This milestone highlighted the KC-767's ability to perform refueling operations under all lighting conditions and demonstrated an upgrade to the lighting system we promised our Japan customer," said George Hildebrand, Boeing KC-767 Japan program manager. "Our next step is to complete the remaining **FAA** certifications and deliver two new tankers to Japan early this year."

Boeing has built nearly 2000 tankers in its history and is under contract to build four KC-767s for Japan. The JASDF has selected the convertible freighter configuration, which will provide flexibility in carrying cargo or passengers, while maintaining its primary role as an aerial tanker.

Boeing also is building four KC-767s for Italy with delivery of the first two tankers in the second quarter of 2008. To date, Boeing has logged more than 350 flights accumulating more than 1000 flight hours on the KC-767.

In addition to flight-testing the KC-767 for international customers, Boeing is competing for a contract to replace the USAF's KC-135 tanker fleet. It has offered the KC-767 Advanced Tanker, and a decision is expected in the first quarter of this year. Transferring fuel through a boom, via the remote vision system during nighttime conditions, will reduce risk for future tanker customers.

Jean L. Broge

Vehicles

All-aluminum Cessna to be assembled, and disassembled, in China

Cessna unveiled a proof-of-concept of a light sport aircraft (LSA) in July 2006 and announced one year later that it would proceed with development of the aircraft, which was named the SkyCatcher. The aluminum aircraft is being designed to meet American Society for Testing and Materials (**ASTM**) standard F2245 for the light sport category.

As the company prepares for first flight, its engineering team in Wichita is building three airframes: prototype, first production, and a test article for the ASTM compliance work. First flight of the prototype version is expected before June, with deliveries to begin in the second half of 2009.

After about a year of evaluations and design modifications, the proof-of-concept aircraft first flew with a 100-hp **Teledyne Continental** O-200D engine last August. In recent testing, Cessna engineers have been evaluating engine cooling and propeller pitch settings, as well as overall flight characteristics that it says "are targeted to be fun but forgiving, suiting the training and sport flying market."

Preliminary design parameters for the SkyCatcher include a maximum gross weight of 1320 lb, a service ceiling of 15,500 ft, a useful load of 490 lb, and 24 gal of usable fuel. It has a cabin width at shoulder height of 44.25 in, equal to that of the much-larger, six-place Cessna 206 Stationair. It features two top-hinged cabin entry doors and forward pivoting seats giving access to a 12.5-ft^3 baggage compartment. The aircraft will have tricycle landing gear with a castering nose wheel and standard dual toe-actuated disc brakes.

The two-place (pilot and one passenger) 162 will cruise at speeds up to 118 knot and have a maximum range and en-

The Cessna 162 SkyCatcher, whose prototype is due to make its first flight in a couple months, is an all-metal, single engine piston, high-wing monoplane that will be equipped per FAR 91.205 to meet both day and night VFR flight requirements.

The SkyCatcher will feature a single Garmin G300 display that will provide primary flight and engine information in a split-screen format. A Garmin SL40 Com radio, Garmin GTX327 Mode C transponder, and a 121.5 MHz ELT will be standard.

The aircraft's interior will consist of two forward-hinged seats that pivot forward to allow access to the aft baggage area.

durance of 470 nmi at 6000 ft. It will be equipped with what is described as "an exclusive" **Garmin** G300 glass cockpit avionics system. Pilots can view information in a single, split-screen primary flight display and multi-function display, or as two full-screen displays with an optional second screen. The aircraft will be capable of day and night, visual flight rules (VFR) operations.

To get the aircraft on the market, Cessna is partnering with **Shenyang Aircraft** Corp. (SAC), a subsidiary of **AVIC I** (China Aviation Industry Corp. I), a government-owned consortium of aircraft manufacturers. Cessna will ship the engine and avionics, along with raw materials, from the U.S. to Shenyang, China, for assembly by SAC. Cessna will be providing on-site personnel to oversee assembly, quality assurance, and technical support.

Following final production in China, SkyCatchers will be test flown, disassembled, and shipped to three Cessna authorized service stations in the U.S.: Eagle Aviation in West Columbia, SC; Yingling Aviation in Wichita; and Southwest Platinum Aviation in North Las Vegas. The facilities will reassemble the aircraft and conduct acceptance test flights prior to delivery.

Other SAC customers include **Boeing**, **Airbus**, **Bombardier**, **Spirit AeroSystems**, and **Singapore Aerospace**.

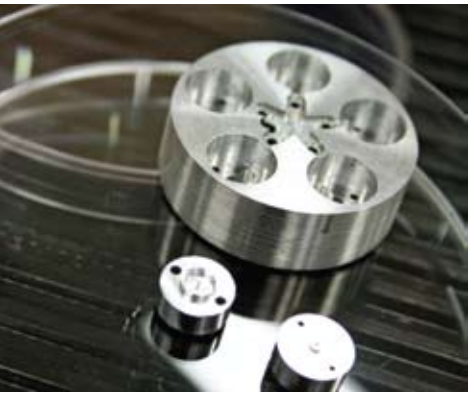
Cessna expects to produce up to 700 a year at full-rate production. It currently has almost 900 orders.

Jean L. Broge

Education

New laboratory will aid NASA research

The Hexagon Loxham Precision Laboratory, a new facility designed for leading-edge ultra precision research, has been opened at **Cranfield University** in the U.K. Cranfield has strong links with aerospace technology, and the laboratory will aid significant research into the manufacture of mirrors for the **NASA** James Webb Space Telescope and will also help scientists develop technologies for finding Earth-like planets and forms of life in space. The facility is also designed to support master's students studying on Cranfield's new Ultra Precision Technologies course.



The Hexagon Loxham Precision Laboratory at the U.K.'s Cranfield University is a new facility designed for leading-edge ultra precision research. This is a metal master for a 3-D disposable microfluidic device.

The 400-m^2 laboratory includes a state-of-the-art temperature and humidity controlled workspace and is the latest addition to the Cranfield University Precision Engineering Center. This center of excellence in advanced manufacturing technologies houses what are stated to be the most accurate diamond machining facilities in the world, together with high-specification equipment including the most accurate large-scale measuring machine in the U.K.

The Precision Engineering Center also manages the **Engineering Physical Sciences Research Council**'s (EPSRC's) Integrated Knowledge Center for Ultra Precision based at the **OpTIC Technium** in North Wales, and is currently contributing to the EPSRC's Grand Challenge 3-D mintigration, which focuses on micro device fabrication methods.

Paul Shore, McKeown Chair of Ultra Precision Technologies and Head of the Precision Engineering Center, said: "Cranfield has a history of delivering high-quality ultra precision technologies for a range of different applications and sectors. This new facility reinforces our commitment to precision engineering."

The new laboratory is sponsored by **Hexagon Metrology**, a global manufacturer of ultra-precision metrology systems. The company has supplied it with an ultra-high accuracy **Leitz** PMM-F coordinate measuring machine to facilitate mirror production for extra-large telescopes.

The laboratory is named after the late John Loxham, who was an eminent precision engineer and metrologist. In 1958, he was appointed Head of Cranfield's Department of Aircraft Economics and Production, where he diversified its activities to include Management Science, which eventually led to the formation of the Cranfield School of Management, and Precision Engineering, producing the Cranfield Unit for Precision Engineering.

Stuart Birch

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