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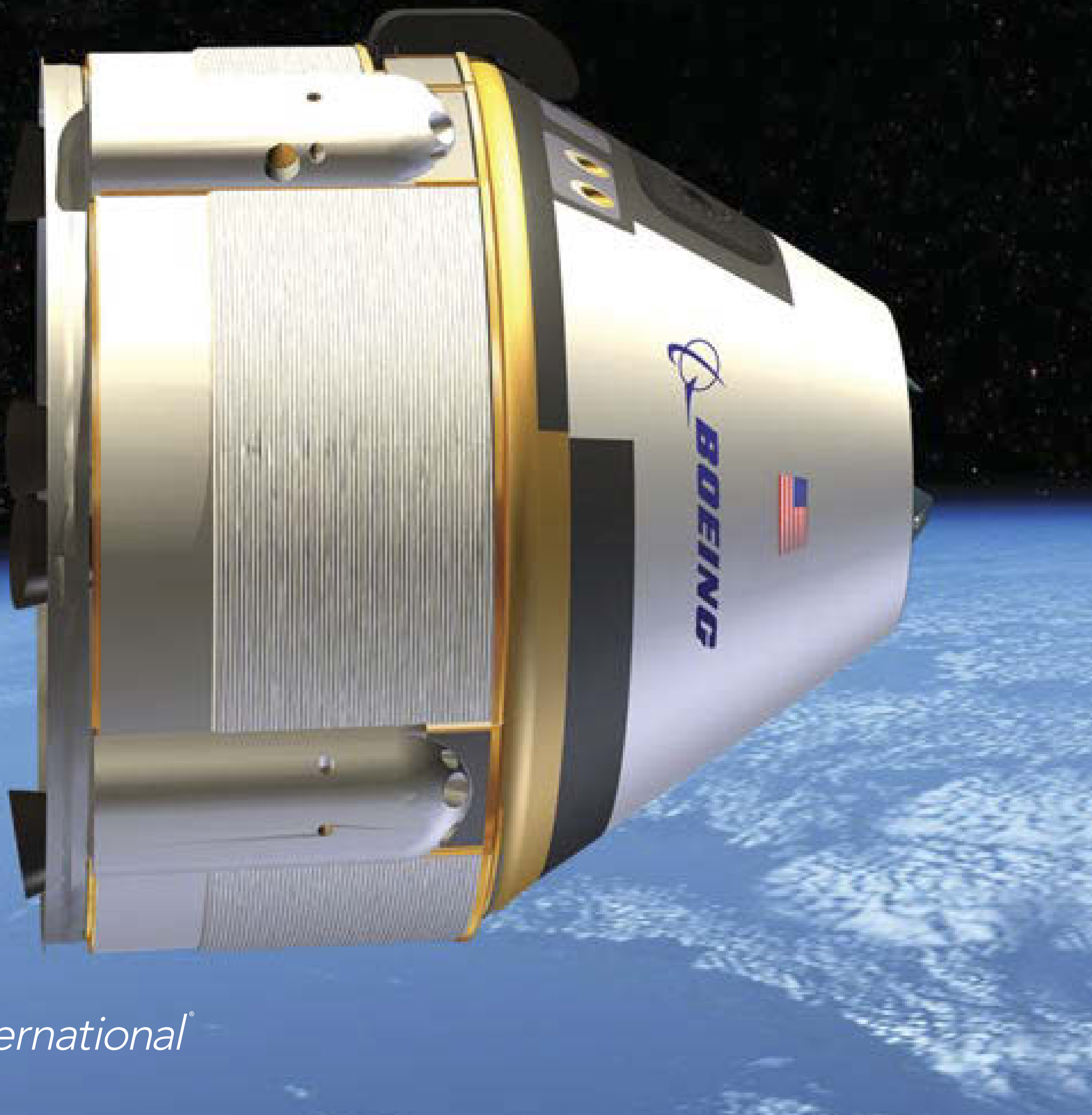
June 2013

AEROSPACE ENGINEERING™

Progress in Space

Turboelectric Propulsion

Boeing's Seven-Crew CST-100



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What's Online

Top Products

Nonferrous furnace capability

Wallwork Heat Treatment has commissioned a new 800-kg-capacity furnace for the processing of aluminum and magnesium products. The furnace provides variable heat treatment for cast, forged, wrought, or fabricated components from single items of up to 2 m^3 to batches of components as small as 0.5-mm diameter. The firm's core business remains the thermal processing and surface coating of high-value components, including those for the aerospace and motorsport industries. Read more at ***www.sae.org/mags/aem/11952***.

Horizontal machining center

The next-generation Horizontal Center Nexus (HCN) 4000-III horizontal machining center from Mazak Corp. includes performance enhancements that provide increased productivity and cost effectiveness, especially when it is used as a go-to workhorse machine for high-volume part-processing operations. The enhancements include those that shorten part cycle times and allow the center to handle a wider variety of part sizes and more parts per setup. Read more at ***www.sae.org/mags/aem/11951***.

I/O panel meter

The Ashcroft Model DM61 digital panel meter does more than just display the analog or Modbus RTU (remote terminal unit) digital signal from a sensing device with an output. Equipped with a variety of electronic features, this I/O device allows the user to configure the display to read out in the required engineering unit, recall minimum and maximum readings, and set high-low alarms. Read more at ***www.sae.org/mags/aem/11950***.

Arbitrary waveform generators

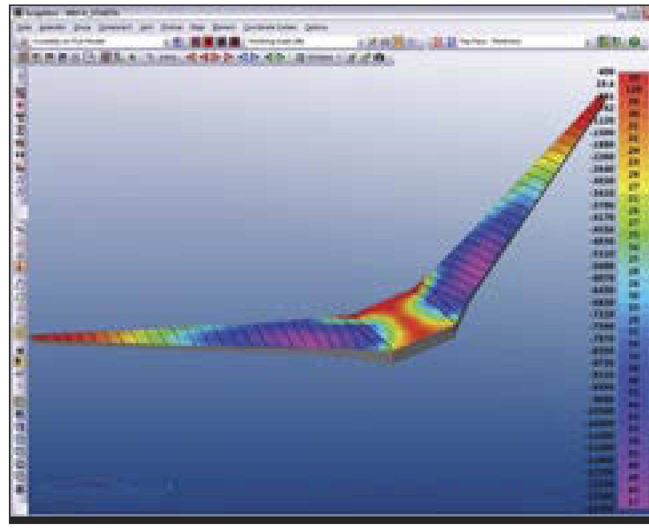
Tektronix's AWG 70000 Series arbitrary waveform generators provide up to 50 GS/s sample rate, 16 GS of waveform memory, and 10-bit vertical resolution, making them suited for high-speed testing and advanced research applications. The devices produce fast, clean signals that can be routed through a receiver or other device under test for long periods of time for comprehensive testing. Read more at ***www.sae.org/mags/aem/11949.***

Multitasking turn/mill center

Methods Machine Tools' Nakamura-Tome NTJ-100 Multitasking Turn/Mill Center offers fast tool changes compared to a full-tool-spindle ATC machine. A large tool capacity — up to 54 tool stations for turning and 24 tool stations for milling tools — reduces setup time. For faster cycle times, the new center has two high-rigidity turrets, each with a Y-axis, 3.5" on the upper and 2.6" on the lower, aiding pinch turn and pinch mill operations. Read more at ***www.sae.org/mags/aem/11948***.

Top Articles

Addressing limitations of composite/metallic airframe structure optimization



Given the growing adoption of complex composites in wing box and other airframe structures — as in the Boeing 787, Airbus 350, and Bombardier Learjet 85 and CSeries — analysis is now a highly complicated exercise involving layups in some areas that are nearly 100 plies thick. Read more at ***www.sae.org/mags/aem/11858***.

Tracking the health of aircraft electrical generators

Researchers have come up with basic modules of a proposed diagnostic and health-management system architecture based upon data-driven algorithms. Read more at ***www.sae.org/mags/aem/11662***.

NASA Langley explores nanomaterials for next-gen structures

Researchers at NASA's Langley Research Center in Hampton, VA are looking beyond the current state-of-the-art lightweight material — carbon-fiber composites — to promising nanostructured materials; namely, carbon nanotube composites. Read more at ***www.sae.org/mags/aem/11794***.

Non-orthogonal rotary axes featured in automated fiber placement machine

Electroimpact says that with this approach, the lay-down rate can remain high over high-contour surfaces because the linear axes never reverse direction during a change in compaction axis normality. Read more at ***www.sae.org/mags/aem/11865***.

New temperature-indicating paints for turbines

Researchers have developed a thermal-history paint — a ceramic-based coating — that is faster, more robust, and nontoxic. Past temperature exposures can be determined when the coated component has cooled to room temperature. Read more at ***www.sae.org/mags/aem/11936***.

Web Casts

The following webcasts are available for free on-demand viewing at *www.sae.org/webcasts*:

- "Taking Data to New Heights: How Airlines, Plane Manufacturers, and Suppliers Are Shaping the Future of Integrated Vehicle Health Management" explores Integrated Vehicle Health Management (IVHM) from three different perspectives. The IVHM Centre, Cranfield University, offers an academic view of the subject including educational offerings and research; UTC Aerospace Systems gives a supplier's perspective of utilizing IVHM to improve field service and supply chain management for components of major aircraft systems; and Gulfstream discusses the subject of an airplane manufacturer that has IVHM-enabled its latest business jet, the G650.

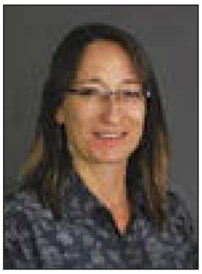
- "Enabling Vehicle Lightweighting with Advancements in Surface Treatment and Adhesive Technologies" explores how adhesives and surface treatments can enable automotive suppliers and manufacturers to overcome the unique challenges that certain materials such as aluminum can present while contributing to a smaller environmental footprint. Sponsor: Henkel

- "Bringing Advanced Control Systems to Market with On-Target Prototyping on Production-Intent ECUs" discusses the pros and cons of traditional vs. on-target prototyping on a real ECU, illustrated with practical examples from industry experts including: how to rapidly enable development on a production engine with non-typical crank patterns, how to produce working control system prototypes in a very short time, and how to enable research in alternative fuels and power systems. Sponsor: ETAS Inc.

- "How to Reduce Your Development Time Using a Virtual Test Environment" looks at how engineers working on complex vehicle systems, such as engine development and calibration, face tough, real-world challenges on a daily basis.

  What they need is the ability to operate a low-cost virtual test bench using closed loop interaction between the ECU, engine, and after-treatment model. This one-hour webcast examines the advantages of such systems and discusses how to maximize efficiency and minimize development time and resources. Sponsor: FEV Inc

Towering Decisions



For the first time since the initial 1998 release of the Report Card for America's Infrastructure by the American Society of Civil Engineers (ASCE), in the most recent Report Card released in March 2013, the overall grade for the nation's infrastructure improved from four years ago. That's the good news. The bad news is that it improved all the way to a D+. The worse news is that aviation didn't even do that good, contributing a D to the overall infrastructure GPA. (For the record, the highest-ranking score was a B- for solid waste.)

In an era when, from school kids to scientists, there is much energy and interest in the "next frontier" of aircraft and air travel that includes everything from UAVs to the commercialization of space travel and space tourism (for more on the latter, check out the feature "Filling the Space" on page 24), it could appear that our industry is looking to get its driver's license before it has mastered its tricycle.

While not meaning to downplay the difficulties of managing the National Aerospace System (NAS) — according to the FAA, there are around 7,000 aircraft in the air over the U.S. at any given time — we didn't go from 0 to 7,000 overnight.

To be sure, the human race has been dealing with solid waste much longer than it has been dealing with 7,000 aircraft in the air. But, wouldn't the changes that have allowed for extreme advances in aircraft technologies over the past couple of decades also have allowed for the advancement of control and coordination of said aircraft?

Without even bringing up the added complexity of managing the NAS with UAVs possibly gathering traffic data amidst spacecraft possibly blasting off for Disneyland-Mars, how about considering the added complexity of, oh, say, 10% of air traffic controllers being furloughed on any given day.

While there were certainly some who claimed that the sky was indeed falling the day that sequestration hit the FAA in late April, in all honesty, it really didn't look all that different from any other day in the East Coast skies. That is to say, there were plenty of delays, some "over an hour."

Let me say that to this traveler, just an hour delay trying to get into or out of Newark or Philadelphia or La Guardia or JFK is the equivalent of what Christmas must feel to a five-year old child. In fact, it honestly seems sometimes that I've spent more time trying to get into or out of those airports in the past year than I ever spent in kindergarten.

There are many more problems with the management of the NAS than a 10% staff reduction. Yet, some have been arguing there are better ways for the FAA to cut the $600 million it needs as required by the sequester than furloughs, such as cutting money out of the NextGen (Next Generation Air Transportation System) budget.

Now, if there's truly anything that will lead to an even lower grade on the next ASCE Report Card, it would be taking money away from the already painfully delayed NextGen program. If anything, the continued development and implementation of NextGen needs to be expedited, not stalled further.

According to the Reason Foundation, closing over 100 targeted air traffic facilities would generate approximately $1.7 billion in one-time savings, and, going forward, would contribute to productivity gains and reduced maintenance and facility costs by $1 billion annually.

Most important, according to Reason, "The days of air traffic controllers needing to be right below specific portions of the airspace are over. Today's technology allows air traffic controllers to guide planes from anywhere."

Logical, technologically sound solutions are available to solve airspace management issues. All we need now is someone licensed and knowledgeable in the driver's seat.

Jean L. Broge
Managing Editor

Hitachi Metals Reduces Rare-Earth Dysprosium in Electric-Motor Magnets

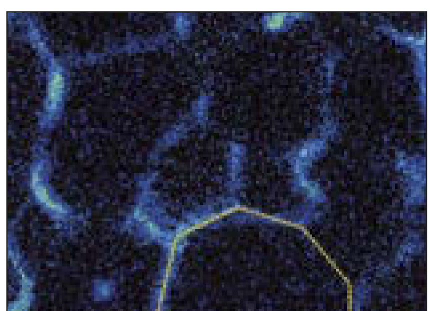
Hitachi Metals' reduced-dysprosium NEOMAX series Nd-Fe-B sintered magnets are suited for HEV/EV traction motors and other actuators and electric motors in various applications.

In response to high prices and supply risks for dysprosium and other rare-earth elements used in neodymium sintered magnets for hybrid and electric vehicle (HEV/EV) traction motors, electric power steering, and other actuators and electric motors, Hitachi Metals America (HMA) has developed an alternative solution that reduces dependence on such rare earths.

The Purchase, NY-based company's reduced-dysprosium NEOMAX series Nd-Fe-B sintered magnets are enabled by DDMagic, a dysprosium vapor deposition diffusion technology. HMA first applied DDMagic technology in 2009 for factory automation and extended it to the NEOMAX series for HEV applications starting in 2011.

Dysprosium (Dy), one of the most expensive heavy rare-earth elements, is used in neodymium sintered magnets to improve temperature resistance. Despite its performance-boosting characteristics, Dy has a significant downside: it's currently sourced from a single country — China — which leads to supply shortages and erratic pricing as demand increases.

"The main objectives of our decision to develop these new NEOMAX magnets are product differentiation based on reduced-Dy magnet technology to achieve high performance; reduction of Dy volume, which had a big impact in production cost; and lowering the risk of depending on one supply source," explained Koshi Okamoto, Executive Director, Corporate Business Development, Hitachi Metals America, Ltd. "Cost saving compared with traditional sintered magnets depends on the market price of dysprosium, which has fluctuated very much in the past and is hard to predict."



Hitachi Metals' DDMagic is a method for thermally diffusing Dy vapor over a magnet's surface. The technology not only reduces Dy usage, but also increases heat-resistant temperature and coercivity.

DDMagic is a method for thermally diffusing Dy vapor over a magnet's surface. The technology mitigates the fall in remanence (Br) caused by Dy, according to HMA. Dy deposition diffusion not only reduces Dy usage, but also increases heat-resistant temperature and coercivity (HcJ). Coercivity is improved by 320 kA/m (4 kOe) or more (effect differs by magnet shape), and Br can be raised more than 40 mT compared with conventional materials of the same coercivity, the company claims. These features can contribute to a lighter, more compact motor.

"There are other heavy rare-earth elements besides dysprosium, such as terbium (Tb), which is more rare and more expensive," said Okamoto. "Magnets that are so-called Dy-free sometimes may include other heavy rare elements such as Tb, which is adversely more expensive and is sourced solely by China. Our DDMagic technology-based reduced-Dy NEOMAX magnets really reduce heavy rare elements as a whole."

HMA has recently developed new technologies to even further reduce dysprosium use, which Okamoto referred to as "one of our top-priority projects." However, he could not disclose any more technical details about this next-generation magnet.

"We think that the trends are for reduced-Dy magnets and even for Dy-free magnets," he said.

The company is currently running a sample evaluation program with key customers, and expects full commercialization of the NEOMAX series with new Dy-reduction technologies in 2014.

HMA's main target segment for NEOMAX magnets is currently automotive, "mainly for EV/HEV including off-highway applications," Okamoto shared. But he noted that aerospace applications for actuators and electric motors are a possibility as well.

NMF series sintered ferrite magnets have long been manufactured at HMA's subsidiary in North Carolina for North American and European customers. In April 2013, Hitachi Metals will begin North American production of the NEOMAX series Nd-Fe-B sintered magnets at its NC subsidiary to meet increasing demands.

This article was written by Ryan Gehm, Associate Editor.

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Filling the Space

A look at the changing face of manned spaceflight and the commercialization of orbital access.

by Richard Gardner, European Editor

The SpaceX Dragon new-generation space transport vehicle.

Persuading politicians to fund big-scale space projects is more difficult today than ever, as witnessed by the scores of advanced spaceplane and expendable launcher projects that have fallen by the wayside over the last 30 years.

But access to space is still vital as satellites keep the global economy moving and enable seamless real-time financial trading and communication at a level of reliability and accuracy that was unthinkable three decades ago, and plenty of nations still want to do it. Apart from the established major space players in the U.S., Europe, and Russia, China, Japan, and India also have ambitious national space programs.

The biggest change in a national approach to space policy, however, came from the U.S. The trend started in 1984 when the Commercial Space Launch Act abandoned the NASA monopoly on space launchers and opened up the opportunity for private operators to develop expendable launch vehicles. Six years later, President George Bush followed up with further legislation to enable commercial companies to supply NASA with launch services.

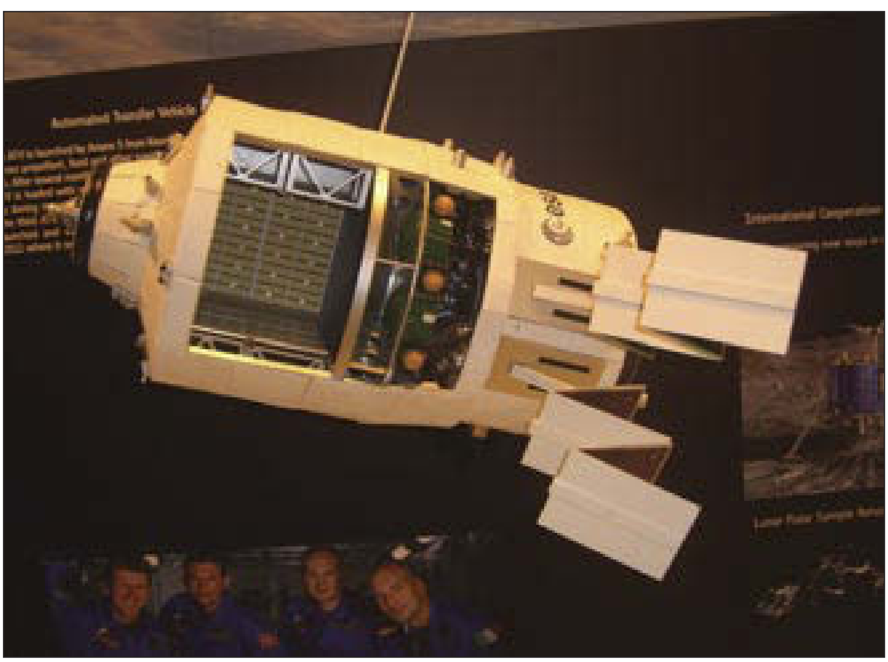
Detail of the unique Burt Rutan design of wing feathering on SpaceShip 2, which allows the spaceplane to return in a controlled, low-speed glide back to Earth. (Richard Gardner)

Transitions in Space

The last launch and recovery of a NASA space shuttle occurred in 2011. This 1980s-era space vehicle had originally been intended as the first of a new generation of space vehicles that would offer a more frequent, high-capacity space transportation capability.

It was supposed to be more affordable over a lifetime of operation than reliance on expendable heavy launch vehicles. It was certainly flexible in op-

The commercially developed Skylon project features disruptive technology in its hybrid engine and will offer single-vehicle takeoff-to-landing access to space. (Reaction Engines)



The European Automated Transfer Vehicle (ATV) is a space cargo carrier, and is to be combined with the Orion capsule for extended ISS support capability. (Richard Gardner)

eration, with its abilities to dock in space with other manned vehicles, place large satellites in orbit, and service and repair others. Its huge cargo bay, equipped with a Canadian-supplied remote operating arm, looked like the shape of the future.

But in reality, the space shuttle fleet became very costly to maintain with its large and complex vehicle, and substantial launch and support infrastructure. The European Space Agency, formed in 1975, looked at its own smaller shuttle, known as Hermes. This was to be launched from a new heavy-lift launcher, Ariane V.

As the weight and cost of the French-led Hermes project grew, the vehicle capacity for carrying astronauts or cargo got smaller and smaller until the concept was abandoned. However, the Ariane V launcher continued as a vehicle to lift large satellites into high orbit, and over the last 20 years, has proved to be a most reliable launcher, with 52 consecutive launch successes.

With the prospect of NASA being unable to fund a shuttle follow-on of its own, a less ambitious series of projects began to gain momentum. In many ways, they looked like a throwback to the early Apollo-mission Earth orbit and support capsules. Yet they incorporated the latest materials and control technology and were modest in scope, thus looking realistically affordable compared to earlier proposals. Most importantly, they focused on commercial innovation, breaking away from the traditional path of reliance on state-funded space programs. The revolution had arrived.

Partnering for Success

Many leading decision-makers in the space sector believe that the key to sustainable space transportation is reliable, safe, and affordable vehicles that can be used over and over again in much the same way that we accept and use global air transport today. This is, of course, easier said than done.

But, the constant evolution of space technology has enabled new launchers and transit vehicles to be designed to deliver genuinely reusable components that should help avoid the runaway cost escalation that killed so many previous major national space programs. Partnerships between space agencies and space companies, and between companies, are now starting to show how this can be done, though as safety is so essential with manned missions, the development, test, and evaluation process cannot be rushed.

NASA remains the national champion in the U.S. for space implementation, but as a part of its more outward policy

A SpaceX Falcon 9 rocket lifts off at Cape Canaveral this past March, carrying a Dragon capsule filled with cargo. The capsule was making its third trip to the ISS, following a demonstration flight in May 2012 and the first resupply mission in October 2012.

toward commercial partnerships, it has focused on a small number of specific company initiatives to develop new space vehicles that could provide continuing transport to the International Space Station.

There are clearly good prospects for some of these programs to provide manned access to more challenging tasks later in the next decade, such as a return to the Moon, or as a building block in a more comprehensive Mars mission later still. In addition to new space vehicles, the U.S. space vision playing out over the next decade includes the modernization of the launch infrastructure at the Kennedy Space Center.

In place of the shuttle will be more conventional-looking booster rockets that will carry a transport capsule that will return by parachute. The booster rocket stages are intended to be recoverable and reusable. The new Space Lift System will be suitable for extended human exploration missions. Initially it will have a lifting capability of 70 tons, but later versions will be almost double, lifting 130 tons. The first SLS launch and full test is due in 2014, with a long-duration flight planned for 2017.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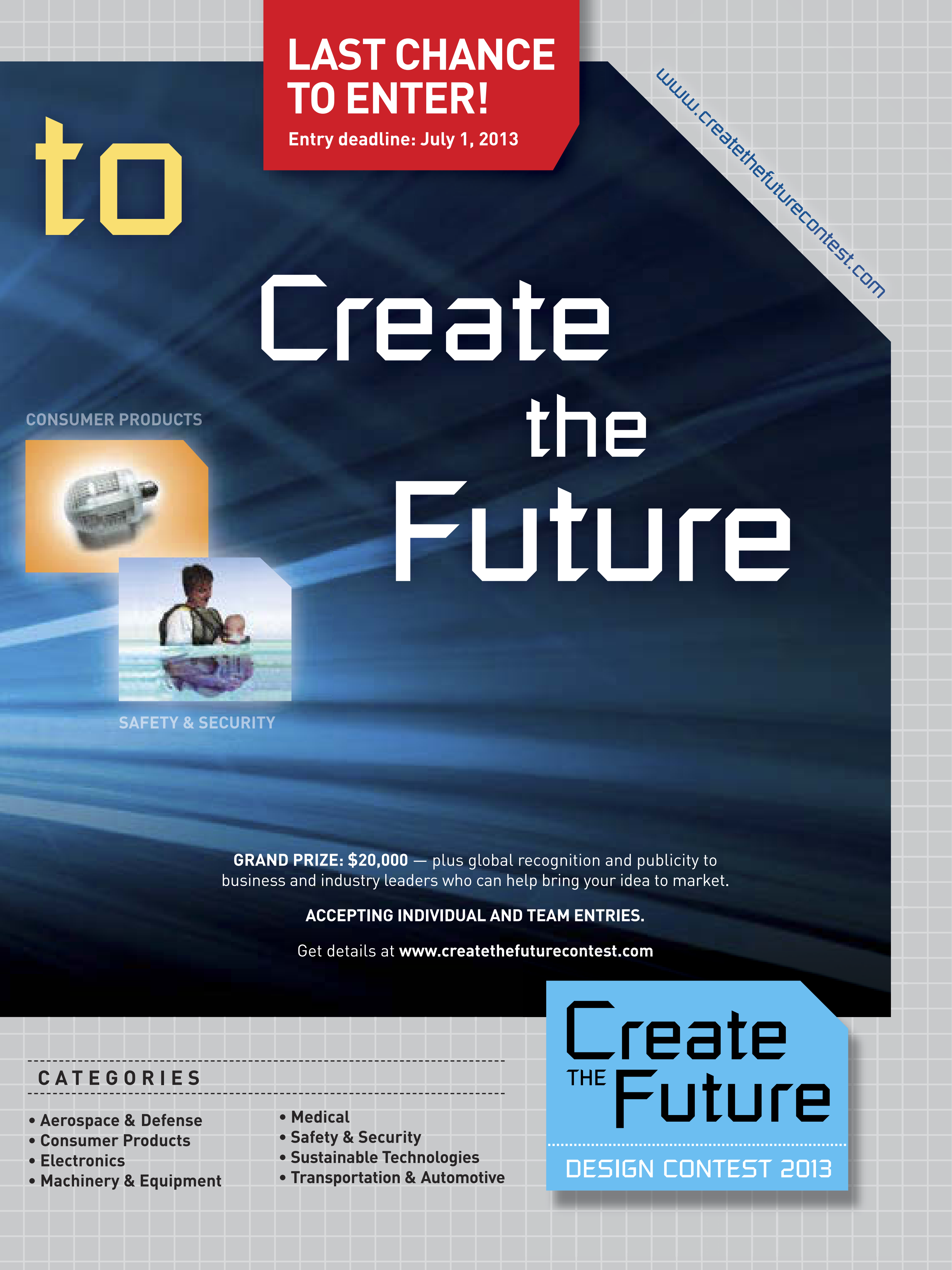

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DESIGN CONTEST 2013

NASA chose the Lockheed Martin Orion project capsule for a pre-2020 launch. Orion's design was optimized to carry crew into space for International Space Station (ISS) changeovers or to sustain longer space missions beyond low-Earth orbit. Now Europe is joining the U.S. by combining ESA's ATV support vehicle with Orion for greater cargo capacity and extended mission duration.

Options in Space

NASA has signed contracts for commercial companies to design, build, and test commercial spacecraft that will be safe and certifiable for carrying NASA astronauts into space. Through these contracts, there is constant feedback on how the competing designs are likely to meet the NASA requirements.

Apart from the Orion program, selected space transport projects include SpaceX's Dragon, Boeing's CST-100, and Sierra Nevada's Dream Chaser. The latter is the only spaceplane proposal within this NASA initiative — the others being space capsules. NASA has awarded contracts worth $3.5 billion for at least 20 replenishment missions to the ISS.

The Dragon made history in 2012 as the first private spacecraft to visit and dock with the ISS. This vehicle is designed for crew transportation and can carry up to seven crew/passengers. More testing is required before humans will fly on a Dragon mission, but work is progressing on the plan to undertake the first manned orbital mission in 2015.

The company's other big program is the Falcon re-usable launcher family powered by the Merlin 1-D rocket. The Falcon 9 uses nine rockets. SpaceX is currently undergoing vertical takeoff/vertical landing tests in the form of one modified Falcon Stage 1 rocket, known as the Grasshopper, to evaluate and refine its performance. It is an essential part of an ambitious scheme to make the whole Falcon launch vehicle recoverable. Beyond the standard Falcon 9 will be an even larger Falcon Heavy rocket that is claimed to offer twice the launch capacity (in weight) of any existing launcher.

Elon Musk, CEO and Chief Designer at SpaceX, said that the intention was to recover the entire rocket and be able to relaunch the whole vehicle quickly. This has long been a dream for space planners, but so far, the successful recovery and reuse of the whole space vehicle, and all its launchers, has been elusive. Maybe this aim is now getting closer. If so, the overall cost of commercial as well as exploratory science-based space missions could be seriously reduced.

Like the Dragon, Boeing's CST-100 crew space transportation capsule is reusable and can carry up to seven crew. It is intended to have a life of at least 10 missions, and use a combination of parachutes and air bags to return to Earth. The first test is due in 2015. Detailed capsule design is currently being evaluated, with attention to the displays and controls, carried out at the company's Houston Product Support Center.

Sierra Nevada's Dream Chaser is the only winged spaceplane in NASA's current evaluation program. At the end of last year, landing gear tests were carried out on the engineering flight-test vehicle. Launch will be on top of a booster rocket, but after the mission, recovery will be on a runway. Engine tests continue, including work on the reaction control propulsion system that will steer the vehicle in space and make small adjustments in directional thrust when docking with the ISS or other future stations.

Blue Origin offers another capsule space vehicle designed to carry up to four astronauts. A successful pad escape test was

achieved in October 2012 at the company's West Texas launch site, and the vehicle flew up to 2,307 feet under active thrust vector control before making a parachute descent to a soft landing. As a part of the re-usable booster configuration tests, a rocket chamber engine thrust firing also took place last October. The 100,000-pound thrust BE-3 engine is a liquid oxygen design.

Space Landings

Commercialization of space is moving beyond the established national space agencies. Bigelow Aerospace has been proposing a huge space station, the BA-330, featuring multiple linked inflatable manned units that could be used to house space laboratories or act as an orbital hotel, where paying space tourists could spend some time enjoying extended periods in the weightless conditions while enjoying spectacular views of Earth. The privatized Russian space sector is proposing a new space station called the Excalibur Almaz.

Back down on Earth in New Mexico, future space tourists will soon get their first taste of space travel when they check in at the impressive Spaceport America terminal for a flight aboard a Virgin Galactic SpaceShip Two spaceplane. This, more than any other to date, is a space access project on a sufficiently grand scale to generate widespread public interest when the commercial flights begin later this year.

The vision and enterprise of Sir Richard Branson, combined with the innovation and engineering genius of Burt Rutan, are set to transform how we think of space travel. No longer a prospect available only to the fittest of the fit, with a track record as a test pilot or space scientist, the Virgin Galactic vision aims to cut the cost of space access in a meaningful way over time, just as aviation has become a global enabler when once it was available only to the super-rich.

It is thought that by 2020 the cost of a sub-orbital tourist trip into space could be down to $50,000, and maybe $10,000 by 2030. More significantly perhaps is that companies such as Virgin Galactic and SpaceX are looking at reducing the cost of delivering one pound of cargo into space to around $1,000.

XCOR Aerospace's Lynx is a smaller spaceplane that takes off and lands from a normal runway at Curacao. It is intended to start flight tests in 2013. First bookings have been taken. The first generation of lucky space tourists will no doubt be the super-rich, but the cost of space access will most likely come tumbling down as more efficient vehicles arrive in service.

Sierra Nevada's Dream Chaser full-scale test vehicle is lifted by a helicopter to verify proper aerodynamic flight performance. Data from this test will provide an opportunity to evaluate and prove hardware, facilities, and ground operations in preparation for approach and landing tests scheduled for later this year

This image was taken during a series of wind tunnel tests for Blue Origin's Space Vehicle at Lockheed Martin's High Speed Wind Tunnel Facility in Dallas. The vehicle's biconic shape is designed to provide more cross-range and interior volume than a traditional capsule, and weigh less than a winged vehicle.

Distribution of Power

When designing the electrical distribution system for a turboelectric architecture, it is imperative to select technologies that will provide the highest efficiency and stability for the propulsion system.

Researchers from Georgia Institute of Technology considered the NASA concept vehicle, N3-X, for its study of turboelectric propulsion systems.

Turboelectric propulsion is a revolutionary system in which the propulsor (fan) is not connected to the turbine through a mechanical connection; thus, both components can be set at their individual optimum speeds. Also, turboelectric propulsion makes use of distributed fans, using several small fans in place of the traditional large propulsors on the wings or sides of the fuselage.

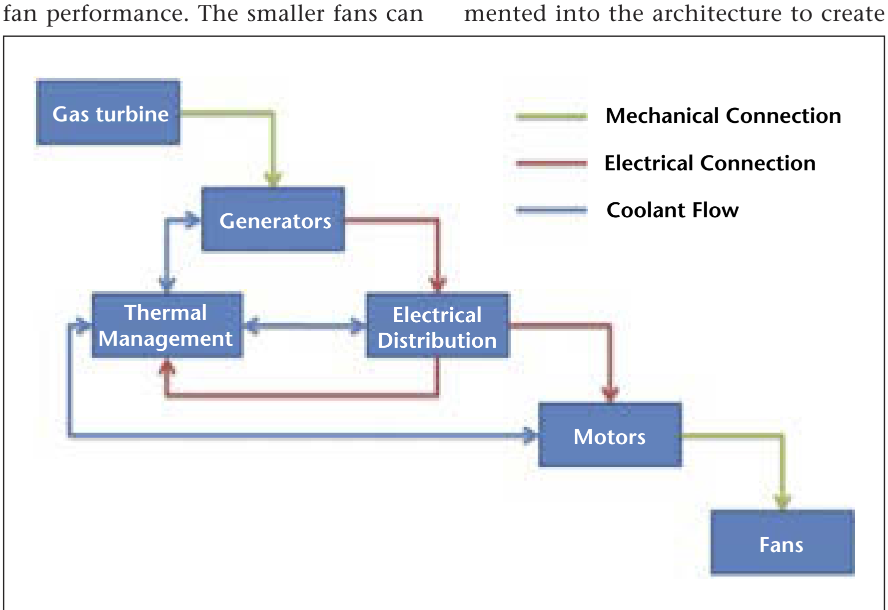
Distributed fans are usually placed on the top side of the fuselage of a blended wing body aircraft to take advantage of boundary layer ingestion that increases fan performance. The smaller fans can run at faster speeds than their larger counterpart in a turbofan engine.

By applying this new propulsion system concept, NASA has estimated that fuel burn could be reduced by 10%, also contributing to reduced harmful emissions. In addition, this architecture could be modified to allow for the use of alternative fuels such as hydrogen. The system can also aid in the reduction of noise by using the fuselage to shield the noise from the ground.

To implement this system, many challenges must be overcome. New technologies will have to be implemented into the architecture to create this system. Most of these technologies are still in the experimental stages; consequently, data is limited.

Since these technologies are not completely developed, there is uncertainty in their weights and performance. The increased number of components adds complexity to the system, and the interactions between components are not yet understood.

One of the primary components of the turboelectric architecture that needs to be designed is the electrical distribution system. A recent study by scientists at Georgia Institute of Technology focused on the design of the two primary components of the power distribution system: the power distribution cables and power converters.



Schematic of a turboelectric propulsion system architecture. The direction of the arrows shows which component is the source of energy and which component receives it (at the arrow head). The blue arrows are in both directions for each line because the coolant will circulate through the system.

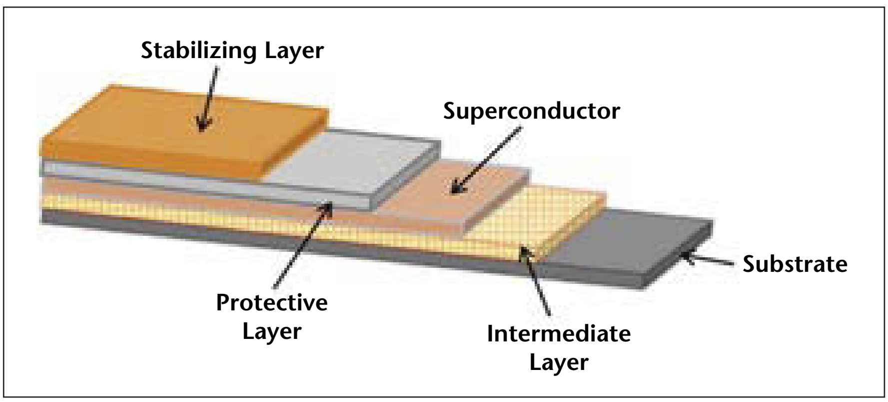
System Architecture

The size and performance of the electrical distribution is dependent on the entire turboelectric propulsion architecture since it will be responsible for power flow between components. The power output and power requirements of each element will be important factors in the design of the electrical distribution system. The placement of the components will also be important because it will determine the length of the cables in the system.

The aircraft selected for this study was NASA's N3-X concept vehicle. The N3-X was conceived as a blended wing body aircraft that can carry approximately 300 passengers at a range of 7500 nautical miles, cruise speed of Mach 0.84, and cruise altitude of 30,000 feet. This air-

Transmission	AC			DC		
Type	Conventional			Superconducting		
Material	Copper	Aluminum		YBCO	BSCCO	
Structure	Single-core	2-core	3-core	Single-core	2-core	3-core
Coolant	Water	Air	Oil	Hydrogen	Nitrogen	

Cable design choices.



For superconducting cable, cylindrical wires do not carry the current. Instead, they are made into "tapes." Shown is the YBCO tape structure.

craft has a distributed propulsion system consisting of 14 fans driven by electric motors that span the upper body of the aircraft. The gas turbines and generators are located at the wing tips so they receive undisturbed air and supply a bending moment for the wings.

This concept aircraft was selected because some preliminary design had been conducted for its turboelectric propulsion system. Components such as the generators and motors had been sized, and preliminary weight and performance values had been published. Sizing the electrical distribution system would further contribute to the preliminary sizing information for the overall N3-X propulsion system.

A turboelectric propulsion system consists of six primary components: gas turbine, superconducting generator, distribution system, thermal-management system, superconducting motors, and fans.

The primary task of the electric distribution system is to deliver power from the generator to the motors for the fans. Also, the electrical distribution system must be cooled. Therefore, coolant will be delivered from a thermal-management system.

In turn, the electrical distribution system must deliver power to the thermal-management system. In this study the focus was on delivering power from the generator to the loads. The cables and power converters were designed for the maximum power draw by the system. For the NASA N3-X, the expected value for the maximum power load is 40 MW.

Power Distribution Cables

The power distribution cables are responsible for delivering power between components. A number of design choices must be made to determine the size and performance of the cables.

One of the initial decisions that must be made is whether the power will be distributed in ac or dc. Although ac power is traditionally used, in high-power applications such as turboelectric propulsion, dc has the potential to outperform ac for several reasons.

First, the bus may require the use of superconducting cables, which have virtually no losses when operating with dc power; ac superconducting cables have losses and will force a fixed ratio between the generator and motor. That feature inhibits being able to operate the generator and motor independently to achieve the best efficiency.

Second, batteries and other storage devices can easily be added to the bus to provide additional back-up power.

Lastly, if any load is capable of producing regenerated power, the power can easily be returned to the bus.

Although many advantages for dc distribution exist, some issues have to be addressed, particularly system stability and power quality. The system must be able to remain stable under transient loads. One way to address these concerns is through converter design.

With the proper design, converters can help stabilize the bus by properly mitigating power while maintaining high power quality. The next decision to be made is whether to use conventional cables or superconducting cables.

Conventional Cable Design

The first decision that must be made in the design of the conventional cable is determining its structure. Most conventional cables have a cylindrical core that acts as a conductor. Conductor material is an important design choice as well. The material must have a sufficient current density to transmit and accommodate the power load while maintaining a reasonable weight and cost. The most popular choices for this type of cable are copper and aluminum. Copper is the most widely used because of its good current density, good conductivity, and relatively low cost.

In addition to the conductor, three protective layers must be added to the structure to complete the cable: a dielectric layer, a magnetic shield, and a cooling sleeve.

The purpose of the dielectric layer is to resist the potential between the wire and the magnetic shield. Its thickness is selected based on the system nominal voltage. Many standards for the selection of the dielectric thickness are available.

The AEIC (Association of Edison Illuminating Companies) standards are the most widely used in North America and were used to determine dielectric thickness in this study. XLPE (cross-linked polyethylene) was selected for the insulation for the cable due to its long-term reliability.

The purpose of the magnetic shield is to protect the wire from the magnetic field induced by the current flow, so the thickness of this layer is dependent on the maximum current flow through the wire. This layer is often made out of aluminum.

For this architecture, a cooling sleeve was necessary to maintain a safe temperature for the wire. The maximum allowable temperature is an important constraint to include in the design so that excess heat does not damage the cable or any surrounding electronics such as the power converters. Also, in situations where the cable may be in close proximity to fuel lines, the designer must ensure that the heat expelled by the cable will not ignite the fuel.

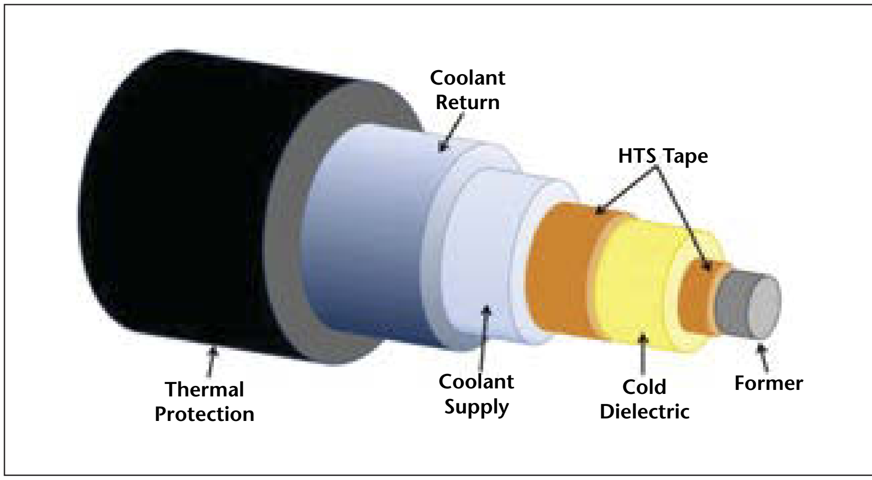
Superconducting Cable Design

For a material to be considered "superconducting," it must distribute two properties: zero electrical resistance and perfect diamagnetism when cooled below a critical temperature, usually cryogenic (below 123 K).

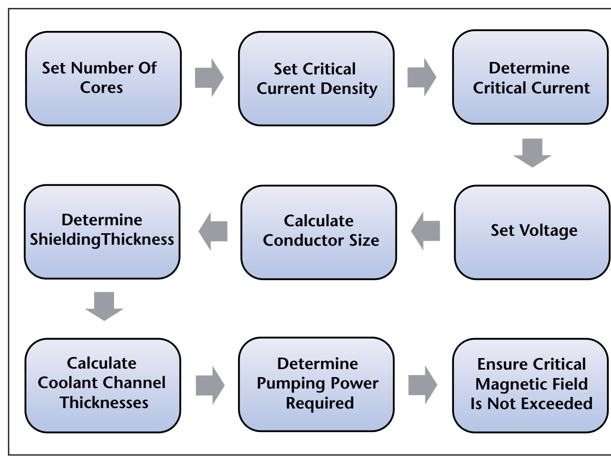
Zero resistance means that there are no losses when transmitting current. Perfect diamagnetism means that the material does not permit an externally applied magnetic field to penetrate into its interior.

In this application, dc transmission was chosen since there are some losses in superconducting cables when transmitting ac power. Also, high-temperature superconducting (HTS) dc cables only carry real power. There is no reactive power, so there will be no significant derating of the cables — meaning that the cables will not lose their ability to transmit their full power rating.

The structure of a superconducting cable is quite different from a conventional cable. There is no cylindrical wire that carries the current; instead, superconducting wires are made in "tapes." To make the cable in a cylindrical shape, these tape are wrapped around a former. The liquid coolant can flow through the center of the former, adjacent tubes, or in an outer layer surrounding the HTS tape. On the outer side of the superconducting tape, there is electrical and magnetic shielding as in the case of the convectional cable.



To make the cable into a cylindrical shape, the tapes are wrapped around a former, as shown in the simple HTS cable configuration.



Outline of the basic steps of the algorithm for HTS cable sizing. The first step is to determine the number of cores.

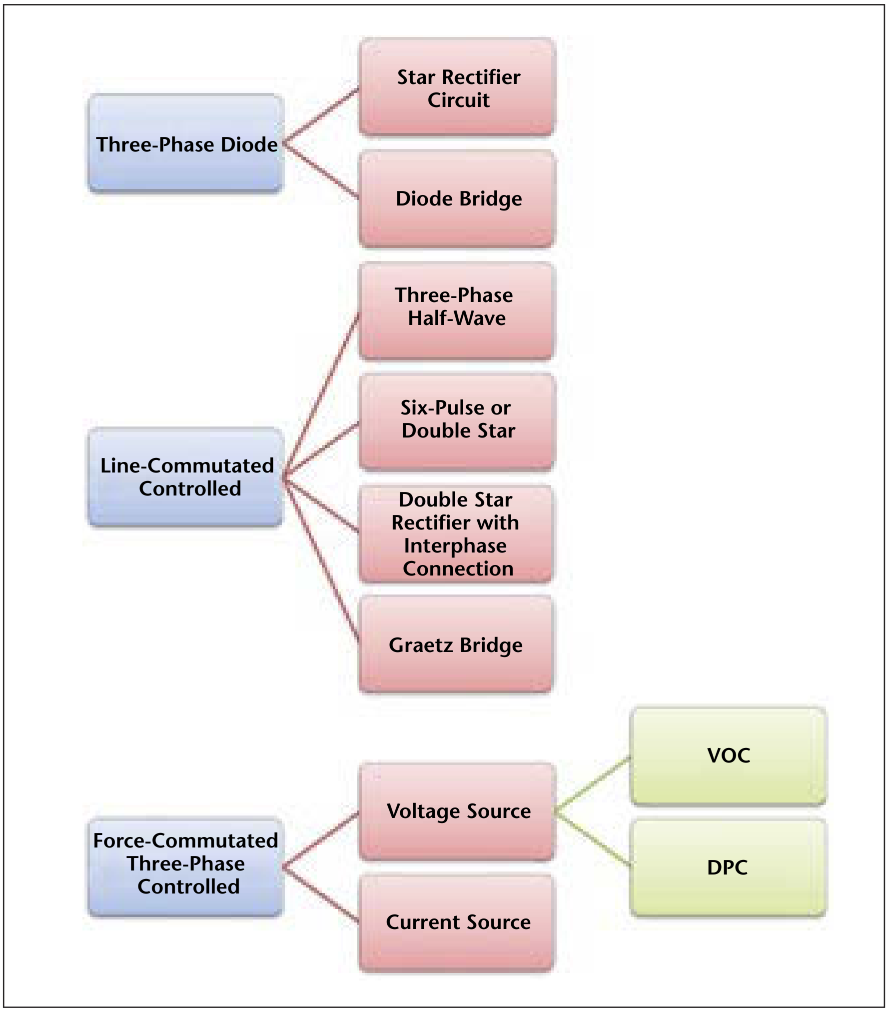
To determine the size of the wire, the following parameters must be determined: HTS tape material, HTS tape thickness, HTS tape winding pitch, dielectric thickness, coolant type, former diameter, and outer cable diameter.

Based on current research, the best superconducting material for this application is yttrium barium copper oxide (YBCO). It is the most cost-effective option for the current-carrying capacity required for this application. Studies have shown that YBCO tapes have been created that have a critical current density of 1.4-1.5 MA/cm^2. The current-carrying capacity of these wires is about 400 A/cm of wire width. When the wires are transmitting dc, the amount of power that the wire can carry is proportional to the volume of the wire.

As in the case of the conventional cable, electrical insulation will be needed. The amount of shielding needed depends on the cable dimension of the former and HTS tape, the system nominal voltage, and the design stress of the insulation. Along with the electrical tape and insulation, the cable will also include a thermal-management system to keep the superconducting tape under the critical temperature.

System Design

When designing the electrical distribution system for a turboelectric architecture, it is important to consider ways



Power converter type is a critical choice in turboelectric propulsion systems. Rectifiers convert ac into dc power; shown are the choices that must be in during rectifier design.

that the other components in the turboelectric system may affect the performance of the electrical distribution system. Therefore, the basic architecture of the system must be determined to identify interactions between the electrical distribution system and other system components. The electrical distribution itself will consist of many components.

The type of power transmission cables selected for electrical distribution will have a significant impact on the efficiency of the system. Within an aircraft, a limited amount of space is available to place power transmission cables, and their weights will have an impact on the performance of the aircraft; therefore, minimizing the size of the cables is crucial.

Due to the high power loads on the aircraft, superconducting cables are the logical choice for power transmission. Compared to conventional copper cables, superconducting cables can transmit power with a significant reduction in cable thickness and weight.

Also, by using dc distribution, the power losses during transmission can be minimized. Of course, using superconducting cables will present the unique challenge of maintaining cryogenic temperatures throughout the length of the cable. The cooling of this system can be tied into the thermal management needed for the superconducting generators and motors that the turboelectric architecture requires.

Another concern is that even with the use of superconducting cables, the bus voltage must be much higher than voltages present on aircraft today. Safety must be carefully considered when designing a system of this type to prevent problems such as electrical fires.

The type of power converters selected also affects the performance of the system, having a large impact on the performance of the entire turboelectric system since they will control the power flow between the dc electrical bus and each component.

Power converters are required to maintain stability on the dc bus with the best possible efficiency. The greatest amount of stability and efficiency can be achieved through the use of actively controlled converters. Although active power converters can maintain stability during transient events fairly well, the responses of the converter must be carefully examined to ensure that voltages and currents throughout the system stay within specified limits.

The efficiency of actively controlled converters is very high. However, there are some losses associated with conduction and switching. These losses can be minimized by operating the converters at cryogenic temperatures.

Conduction losses will be less since the resistance of the materials used in the converter will be smaller. Furthermore, the switching frequency can be set much higher in a cryogenic converter to further improve efficiency.

The results of this study can assist in the selection of technologies for the electrical distribution that will provide the highest efficiency and stability for the propulsion system. In addition, the cable sizing results and converter modeling approach can contribute to estimating the size and performance of the electrical distribution system, and they can provide insight on the performance of the entire turboelectric propulsion system.

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