ASME SETTING THE STANDARD
ASME INTERNATIONAL GAS TURBINE INSTITUTE

AUG '24 / SEPT '24

VOL. 64 NO. 1

GLOBAL GAS TURBINE NEWS

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AMERICAN SOCIETY OF MECHANICAL ENGINEERS (ASME)

ASME Gas Turbine Technology Group / 11757 Katy Frwy, Suite 1500 Houston, Texas 77079 / go.asme.org/igti

ETOPS—Turbojet Extended Range Operations

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ETOPS is a hugely successful global program under which, since 1985, the airline industry has long operated two-engine jetliners on extended routes (e.g., transatlantic) that at some point take the twinjet more than 60 minutes flight time (at single-engine cruise speed, in the event of a failure of one engine) from an alternate airport [1]. An ETOPS certification rating for a twinjet airliner essentially gives the distance away from the nearest diversion airport and is based on how many minutes (75, 120, 180, etc.) it can fly on one engine before it needs to land. The acronym "ETOPS" stands for "Extended-range Twin-engine Operation Performance Standards". (Engine company engineers sometimes colloquialize ETOPS to "Engines Turn Or Passengers Swim.")

THE CURRENT TWO-ENGINE JETLINER DOMINANCE

Airline jet aircraft operating expenses decrease directly by reducing the number of flight engines. Twinjets thus have made intercontinental trijets (such as the L1011 and MD-11) obsolete and have cut into the market for four jet aircraft like the Airbus 340 and the iconic Boeing 747 (first flown in 1968, with the last 747 completed in 2023). The reliability of passenger jet engines has been greatly increased through engineering at OEMs such as Pratt & Whitney, GE Aerospace and Rolls-Royce (more on this later), that largely account for the two-engine dominance.

SOME HISTORY

The age of engine-powered flight began at Kitty Hawk on the Outer Banks of North Carolina on a wintery day, December 17, 1903 [2]. The Wright brothers'… Orville and Wilbur… Wright Flyer had its first successful flight on Kill Devil Hills, with Orville piloting and Wilbur running beside its wing tips. The Flyer was driven by two separate propellors, both powered by a single gasoline-fueled, 12 hp four-cylinder spark ignition engine, built by their Dayton, Ohio mechanic, Charlie Taylor.

This opened the eventual possibility of worldwide engine-powered passenger air travel. The challenge to that was to have reliable aircraft engines for safe travel for extended flights over the Earth's oceans, where engine failures could put passengers at the mercy of the wind and ocean waves.

An encouraging event for the promise of safe engine-powered passenger transoceanic air travel occurred on May 20, 1927. Twenty-five-year-old pilot Charles Lindbergh took off on the first nonstop solo monoplane flight across the North Atlantic Ocean, in his "Spirit of St. Louis", single-engine Ryan aircraft [3]. Starting from New York's Long Island Roosevelt Field, he landed at Le Bourget, near Paris, some 33.5 hours later on May 21, after a sleep-deprived total flying distance of some 3610 miles (average flying speed of 108 mph, with some favorable tail winds).

Lindbergh's Ryan M2 aircraft could seat five people but was modified to fit in 450 gallons of gasoline fuel tanks for the historic long flight, leaving just enough space for the pilot. It had a single propellor, powered by a 220 hp, "Super inspected" nine-cylinder Wright Whirlwind J-5C radial engine.

Lindbergh's "Spirit of St. Louis" passenger-less flight was a result of careful planning and piloting of the single engine plane, and it triggered a worldwide public recognition of the potential for long-distance passenger flight. Aircraft industry stocks rose and interest in commercial aviation skyrocketed.

FROM PISTON ENGINES TO THE JET ENGINE

From Lindbergh's 1927 historic flight until the 1960s, the answer to safe transoceanic air travel was multiengine propeller driven airliners. However, given the many coordinated moving parts of a reciprocated piston engine, failures on long flights were not infrequent.

For instance, on Oct. 16, 1956, Pan American Flight 6, a Boeing 377 Stratocruiser was on an around-the-world leg between Honolulu and San Francisco. After passing the point of equal flight time, two of the four piston engines failed, and the crew was forced

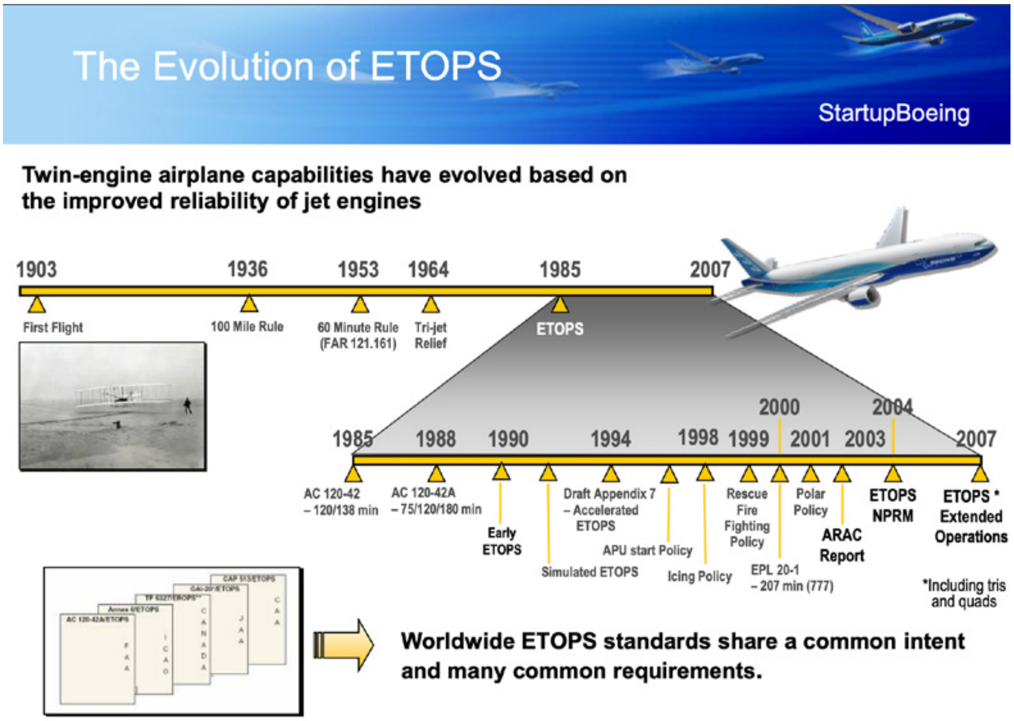

Figure 1. Some ETOPS history, from The Boeing Company

to ditch in the Pacific Ocean. The potential calamity was averted thanks to the U.S. Coast Guard cutter Pontchartrain, which was on monitoring duty, one of a small fleet of ships stationed in the north Atlantic and Pacific oceans for weather reporting and rescue. All 31 crew and passengers on the plane were rescued by the Pontchartrain, but 44 cases of live canaries in the 377's cargo hold were lost when the plane sank.

That Pan Am Clipper was powered by four Pratt & Whitney Aircraft piston engines. Although emblematic of the pioneering age of air travel, those commercial aviation piston engines were still prone to failure. Federal Aviation Administration published a statistic in which aircraft piston engines have an average failure rate of one every 3,200 flight hours, while jet engines have a failure rate of one per 375,000 flight hours [4]. The best jet engines will have an even lower failure rate. Most importantly, the current inflight shutdown rate of a commercial jet engine is less than 1 per 100,000 flight hours—on average an engine fails in flight once every 30 years.

During the 1990s to achieve these low jet engine flight failure rates, engine companies such as Pratt & Whitney, Rolls-Royce, and General Electric carried out extensive engine component testing to meet ETOPS certifications. Operational data showed that inflight engine shutdowns were most frequently caused not by the failure of gas path components (disks, blades, and stators), but by problems with engine ancillaries such as fuel control components and exterior engine case tubing. Thus, some ETOPS test programs involved mounting engines on shaker tables, to reveal weak points in engine ancillaries, under sustained vibrational loading.

ETOPS IN ACTION

ETOPS, based on the reliability of commercial jet engines, has changed the way airlines and aircraft manufacturers operate. In 2015 for instance, my wife, Liz, and I flew 4,108 miles (6,612 km) in an Air France twin-engine jetliner over the Pacific Ocean, on a nonstop eight-hour flight from Los Angeles to Papeete, Tahiti. Today, Air France does the same flight using the newer Airbus twinjet A350-900, which is currently is the title holder for the aircraft with the longest ETOPS rating. It is certified to fly for up to 370 minutes on one engine, giving it a maximum diversion distance up to 2,500 nautical miles (4,630 km).

To conclude, we note that ETOPS, based on the reliability of jet engines, and the availability of unmanned weather buoys (and later, satellites) also eliminated the need for ocean weather ships. The last U.S. Coast Guard weather ship left service in 1977, although one Norwegian ship continued duty until 2010.

Thus, in the end, ETOPS becomes "Engines Turn… Our Passengers Safe". [5]. ◆

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Auxiliary Power Units – Workhorses with Unique Challenges in Aviation

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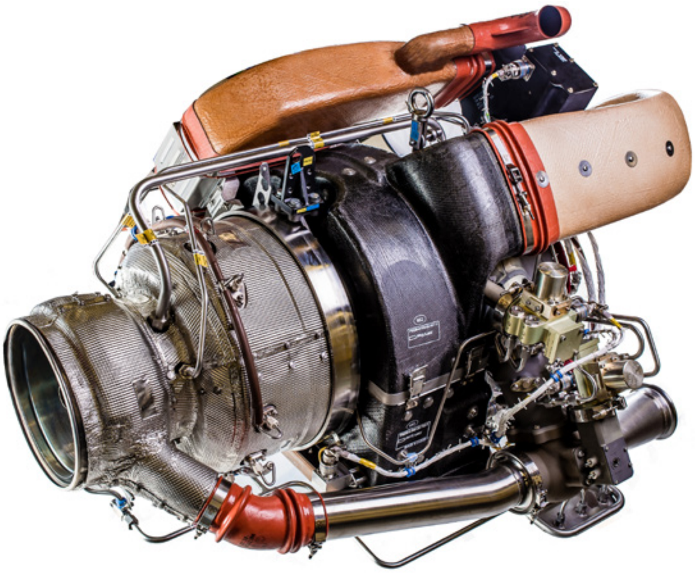

Pratt & Whitney Canada APS3200 auxiliary power unit.

When people think of the uses of gas turbine engines in aviation, they typically quickly converge on the jets, turbofans, turboprops, and turboshafts that propel or power fixed wing aircraft and helicopters. Few will know of Auxiliary Power Units (APUs). They are the workhorses that provide power when the aircraft are at the gate, or on the tarmac.

APUs are used primarily while the aircraft is on the ground to provide electrical power as well as compressed air – also known as bleed air – that is required for the air conditioning or heating systems as well as for starting the main engines, depending on the aircraft configuration. They allow the aircraft systems to function while the main engines are not running. They supply light, cabin comfort, power computers and entertainment systems as well as power the pumps and hydraulics used to load up an aircraft with its cargo and supplies. APUs can also be used for back up electrical power while the aircraft is in flight, if required.

APUs are gas turbine engines with unique technology specific to their application. They are available in a wide range of power outputs, some as high as 1800 SHP. The components of APUs are like those of a propulsion engine; largely defined by a cold section with a compressor and a hot section including the combustor and turbine. An APU will have a gearbox to drive one or two generators, connect to a battery-powered starter, and a means to create and deliver the bleed air flow, in some cases requiring a dedicated compressor. Their operating speed, temperatures, materials are typical to those found in smaller turbine engines.

APUs are 'auxiliary' but to what extent? There are APUs designed and certified for use on the ground only; they are known as Category 2 or 'non-essential'. There are those that are designed to also include use in flight; they are known as Category 1 or 'essential'. The latter are installed on aircraft that rely on the APU as a proper backup system included in the redundancies required to meet the certification at of the aircraft itself. The most obvious is the link between the APUs and the Extended-range Twin-engine Operational Performance Standards (ETOPS) of the large modern twin passenger jets like the B777, B787 and A350. The aircraft ETOPS rating necessitates the ability of the APU to start reliably in flight in case of a main engine malfunction or if a main generator goes off-line. As such, the essential APUs are tightly designed into the aircraft powerplant system.

Compared to main engines, APUs face unique challenges and realities they must surmount to fulfill their role in the aircraft they power. And this is where the technology and engineering step in. This article touches on two specific particularities.

The first unique challenge is reserved to essential APUs; the requirements for high-speed, cold-soaked, in-flight start capability and reliability. Imagine this scenario: the airplane is well into a four-hour cruise at 39,000 feet, zipping along at Mach number = 0.8, and there is a malfunction with a main engine or its generator. The pilots immediately power up the APU that has been sitting at -35°C (sometimes colder) for hours. The oil consistency is somewhere between molasses and margarine. As the inlet door opens, it scoops high-speed frigid air into the APU's gas path. The starter engages. The APU design includes features to de-activate the oil system during the start sequence. That allows the starter to spool up the turbomachine's main rotor without the drag associated with circulating the cold, highly viscous oil. This is taken into consideration into the design of the bearings for example, as they will need to function properly for some time before the oil flow needed for lubrication and cooling is delivered.

For the combustor, the situation is akin to lighting a BBQ on the top of Mount Everest in the middle of a blizzard. The combustor liner and primary fuel nozzle designs, as well the fuel metering controls, are key to get a successful and reliable light-offs. The stable flame accelerates the turbines and compressor until the cycle becomes self-sustaining and ready to provide power. And this all happens in less than a minute. The architecture of the APU design allows the rotor to accelerate without impediment, handling the extreme thermal gradients that develop, managing the internal clearances between rotating and static parts, be it airfoils or seals, to avoid rubs or worse, rotor seizures.

The second unique challenge is common to all APUs as they operate mostly on the ground. As such, they breathe in the same air that we do, with pollution, salts, dust, sand, etc. That differs from main engines that will start on the ground, idle along, and do a take-off run before quickly climbing to higher altitudes where the air is much cleaner. Operations in maritime areas or in highly polluted environments drive the need for specific coatings to delay onset of hot corrosion or sulfidation. Operations in or near deserts drives the need for robust compressor designs to offset erosion as well as other means to ensure the internal air passages that deliver the critical cooling air for the hot-end components and the sealing of the bearing compartments will flow air without clogging up within a maintenance interval.

Herein lies a good example of competing requirements where new technology can help. Legacy combustor liner designs will lead to larger holes in the primary and dilution zones, as well as louvers that will maintain the liner within the desired temperature range while robustly directing the flow of gas. Modern design will favor smaller holes and complex swirlers in the primary zone and will ensure the liner is maintained within operating temperatures through effusion cooling, also known as full-coverage film cooling, that involves small uniformly spaced holes distributed throughout the liner's curved surface area. The modern design allows operating at higher turbine inlet temperatures, making the APU more efficient, smaller, more powerful, and better control of emissions, smoke, and even noise. They are, however, much more prone to suffer from particulate buildup clogging the smaller holes, resulting in durability and cost challenges.

Looking ahead, the increased use of Sustainable Aviation Fuels (SAF) and the possibility of 'hydrogenation' will follow suit with the rest of the turbine engine industry. The 'hybridization' of aircraft powerplants may mean that APUs evolve into Supplementary Power Units (SPUs) within a different safe redundant aircraft-level power architecture. The trend towards more electric aircraft systems has started with Boeing's 787 pushing the envelope and requiring an APU that only outputs electrical power, no bleed flow.

It seems trivial on the surface, however, the simple fact is that bleed flow demand and delivery is progressive over a few seconds and ensures the compressor flow stability. Electrical loading is more instantaneous. This has a ripple effect in design requirements, including the use of advanced electronics to manage the step change in power output without surging the turbomachine. The advent of variable frequency aircraft electrical systems opens new doors to APU operating cycles as they have traditionally been 'fixed RPM' engines. The development of more powerful and higher speed generators will simplify gearbox architectures, reducing APU weight and cost.

An APU is required to deliver durability through simplicity while reducing manufacturing and maintenance costs. It does this in consideration of its market and operational needs providing capability at a size and cost. The technology required for this market will continue to bring innovation in years to come. ◆

Benefits of Additive Manufacturing For Refurbished Gas Turbine Components Redesign

A. Fardelli & F. Ceccanti, *Baker Hughes*

LEGACY GAS TURBINES CHALLENGES

Gas Turbines (GT) have been extensively present in the market since the 1950s to serve the growing needs of energy of the world. GTs can be classified in three categories: heavy duty, industrial and aeroderivative. The former were the first to be introduced in the market and are characterized by high reliability, ease of maintenance, fuel flexibility and availability in a wide range of power output. These engines are still vital after decades of operation and, thus, require an adequate service program. For this reason, Gas Turbine OEMs must guarantee an efficient supply chain able to meet customer's needs, especially for replacements.

HOW GT MAINTENANCE WORKS

Gas turbine components have a defined life, depending on design, running hours and number of cycles the engine experienced. At programmed inspection, the residual life of each component is checked. If the parts are in good condition to be able to operate for a further life cycle, they remain in place, while, if any damage is recorded, it must be decided if they can be repaired or need to be swapped with new ones.

SUPPLY CHAIN ISSUES

For legacy GTs, it can be hard to maintain a high-quality supply chain. This is particularly valid for components produced by Investment Casting (IC) like blades and nozzles since mold obsolescence can occur if components are not produced for some years. This requirement is even truer for parts that were designed for a specific customer need, resulting in small production lots. Therefore, from a strategic and financial perspective, the use of a supply chain based on IC is quite critical.

ADDITIVE MANUFACTURING AS AN ALTERNATIVE FOR MASS PRODUCTION

A promising alternative to IC is Additive Manufacturing (AM). AM is a disruptive manufacturing technology that is transforming the way engineers approach design. Its working principle consists in making parts by adding material in form of welded layers. This mechanism also allows the creation of extremely complex geometries that wouldn't be feasible with conventional manufacturing processes. The adoption of this technology has allowed OEMs to modify their strategy to produce spare parts by switching to full internal supply chain. This facilitates component management, allowing the reduction of lead time and dependence on external suppliers. In addition, it permits the business to manage raw material in a much more efficient way. In fact, once the feedstock materials are procured, they can be used to produce different parts, significantly reducing raw material inventory. Indeed, IC tools like molds and dies can cost over several hundred thousand dollars, require multiple years to be developed and certified, and are applicable to one single part number. On the other hand, for AM, the main investment are the printing machine and the feedstock material. Both can be used, after printing process qualification, to produce several components with different geometry. In addition, AM is a flexible process, every modification to the piece doesn't require tools, molds or dies change, resulting in a maximization of the machine's utilization.

ADDITIVE MANUFACTURING AS A REPAIRING TECHNOLOGY

As already explained, once the serviceability limit is reached, a damaged component can be either replaced or repaired. Turbo machinery equipment, especially those adopted in the Oil & Gas Industry, have a life of decades and, since engines shut down represents huge production losses, customers require to minimize maintenance stops. In this concern, not only can AM be adopted as a production process but also to repair damaged GT parts [1], allowing an increase of the overall components' lifespan with no disadvantages. Repaired components expected life can be shorter than a new part, but it allows a reduced frequency of new component production [2]. This circumstance is beneficial from a technical perspective since engine performance is not affected by maintenance. Also, from a sustainability standpoint, less resources are consumed in repair versus new part production. Typical repaired GT items are blades and shrouds [1], where the most common repaired areas are the tip or the root of the blade. For such repairs, alongside the Direct Laser Metal Melting, also Laser Cladding and Cold Metal Transfer are viable technologies. In all cases, the part to be repaired must be properly prepared (cleaned, machined, etc.) before the material deposition. For all the technologies the new material is added layer by layer only on the damaged area, minimizing the overstock.

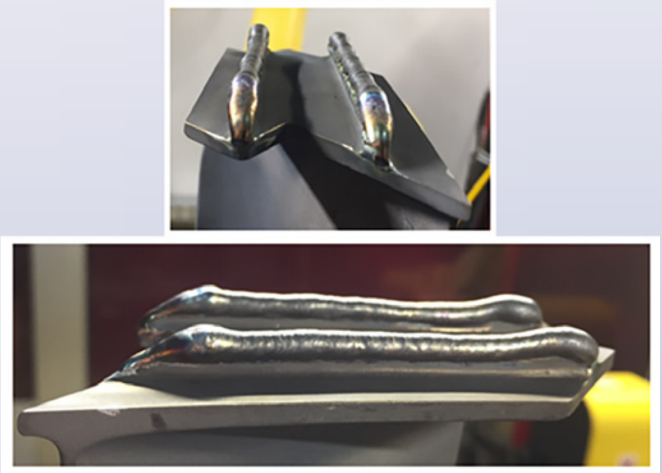

Figure 1. Layer deposition on blade rail tip through CMT technology (front and lateral views)

BENEFITS OF ADDITIVE MANUFACTURING

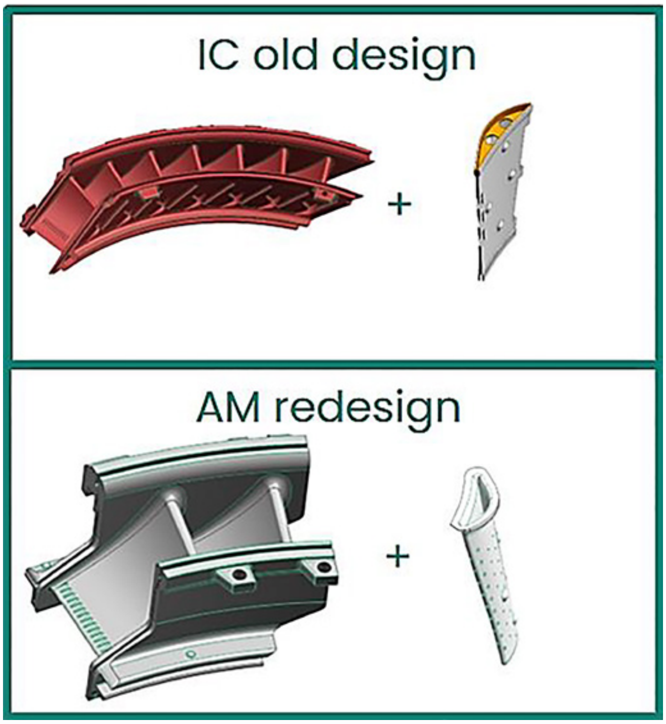

Figure 2. Differences in design for gas turbine nozzle and cooling insert, note that in the AM case the number of airfoils for the sector has changed.

Introducing additive manufacturing (AM) in spare parts supply chains has the potential to yield significant benefits. It allows to produce more performant components, increasing the overall life of critical GT parts such as nozzles and blades. This can be achieved thanks to better physical and mechanical properties of the AM alloys with respect to the base materials [3]. Abhimanyu [3] shows that the life of two service nozzles made by AM has been improved thanks to the properties of the AM material. Life extension can also be achieved by redesigning the nozzle's cooling system. Thanks to its working principle, AM allows the generation of complex geometries like swirled holes that it wouldn't be possible to manufacture with traditional production processes. Those features can be adopted by engineers to rethink the component's design for efficiency improvement. For example, by redesigning the cooling systems of a nozzle or blade it is possible to increase the engine's performance, reducing the amount of cooling air, and/or increase component's life.

All these modifications can be performed maintaining the original interfaces with the other components, allowing an easy replacement without the need to modify other engine parts. This capability represents a significant asset for gas turbine producers since they can upgrade old engines by increasing their efficiency without revolutionizing the entire project.

SUSTAINABILITY OPPORTUINITIES OF ADDITIVE MANUFACTURING

AM as a production process has several benefits from the environmental point of view. As shown in [4], by replacing IC with AM to produce a nozzle it is possible to save 26% of energy consumption and 42% of raw material. Moreover, thanks to the ability of AM to create complex geometries, certain features like cooling holes can be obtained directly without a machining phase of drilling, reducing both costs and environmental impact. Furthermore, the adoption of AM gives the opportunity to replace critical raw materials defined by EU as those needed for energy transition and "with a high risk of supply disruption due to their concentration of sources and lack of good, affordable substitutes" (see table 1). In [4] a Cobalt based superalloy was replaced in favor of a Nickel based one that offered comparable mechanical properties reducing not only the environmental impact of production but also the exposition to future increasing metal costs. ◆

Table 1. 2020 critical raw materials issued by the EU commission (new as compared to 2017 in bold)

Antimony	Hafnium	Phosphorus
Baryte	Heavy Rare Earth Elements	Scandium
Beryllium	Light Rare Earth Elements	Silicon metal
Bismuth	Indium	Tantalum
Borate	Magnesium	Tungsten
Cobalt	Natural graphite	Vanadium
Coking coal	Natural rubber	**Bauxite**
Fluorspar	Niobium	**Lithium**
Gallium	Platinum Group Metals	**Titanium**
Germanium	Phosphate rock	**Strontium**

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ASME IGTI Division Executive Committee

The IGTI's vision is to be the world's leader and champion of innovative gas turbines and related energy systems to power a sustainable way of life.

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The IGTI Division Executive Committee is structured into three departments dedicated to serving the gas turbine community. These departments encompass in total twelve sub-committees that cover all aspects of the division's activities.

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The Operations Department delivers networking opportunities and disseminates knowledge through Turbo Expo and associated events. It drives technical excellence through support of the technical committees and maintaining high standards in all publications through the peer review processes while ensuring financial goals are achieved in all IGTI departments.

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The Professional Engagement Department strives to create and serve a thriving global community of gas turbine professionals and enthusiasts. It is committed to attracting and maintaining a diverse membership, to engaging and developing members through all stages of their careers, and to recognising technical excellence and outstanding contributions to the community.

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The Outreach Department identifies and develops strategic topics that are not yet in an operational format within IGTI. This team works to curate and prototype next generation concepts based on what is needed or anticipated in our Technical Community. Ideation is done through connecting and working with critical networks within IGTI, other ASME Groups, government agencies and international think tanks.

Awards & Scholarship Information

Congratulations to all award recipients and thank you to all ASME IGTI committee award representatives whose work assists the awards and honors chair and the awards committee in the recognition of important gas turbine technological achievements. Thank you to Douglas Nagy for serving as the IGTI Honors and Awards Committee Chair, John Gülen as Industrial Gas Turbine Technology Award Committee Chair, and Konstantinos Kyprianidis as the Aircraft Engine Technology Award Committee Chair.

2024 ASME R. Tom Sawyer Award

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Dr. Jay Kapat
UCF Pegasus Professor and Trustee Chair Professor
University of Central Florida

Congratulations to the Student Winners we recognized in London during Turbo Expo 2024!

ASME Turbo Expo Early Career Engineer Travel Award (TEECE)

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Antoine Durocher
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Edwin Joseph
Munoz Lopez
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Ruonan Wang
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Upcoming Award Opportunities

2025 ASME IGTI AIRCRAFT ENGINE TECHNOLOGY AWARD

Nominations Due **OCTOBER 15, 2024**

2025 INDUSTRIAL GAS TURBINE TECHNOLOGY AWARD

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ASME International Gas Turbine Institute Scholarship

Application Opens **DECEMBER 1, 2024**

asme.org/asme-programs/students-and-faculty/scholarships

Wrap Up

ASME Turbo Expo 2024, in London, The United Kingdom maintained its reputation as the world's premier turbomachinery conference with over 2000 professionals. Throughout the week, delegates shared practical experiences, knowledge, and ideas on the latest turbine technology trends. Over 1000 peer-reviewed technical presentations provided insight into the minds of industry professionals and students.

Turbo Expo 2024 buzzed with the excitement of the turbomachinery industry creating new ideas and generating productive connections between professionals. On Monday evening 2,400 turbomachinery experts attended the welcome reception and enjoyed the opportunity to socialize with professionals from industry and academia. The Celebrating Women in Engineering networking event was a great success with a speaker from GE Aerospace sharing their journey and how to build a successful career in turbomachinery. With a new Networking format over 700 early career engineers and students attended a series of mini lectures discussing industry hot topics and connected with industry leaders serving as mentors for the evening. This year's three-day exhibition featured over 100 exhibitors from 25 countries. The exhibit floor was filled with activity as exhibitors and attendees networked and discussed future collaborations. The 2025 Memphis exhibition floor is now open for selection. Contact exhibits@asme.org for sponsorship and exhibiting opportunities to meet your marketing budget.

A special thanks to the sponsors that support the event. At the Platinum and most prestigious level, Ansys, Siemens Energy & Rolls Royce. Gold sponsor was Honeywell. Silver sponsors were NASA, Coolbrook & GE Aerospace. The Bronze level was supported by Baker Hughes, Solar Turbines, Cadence Design Systems, Safran & SoftinWay Incorporated.

Please plan to attend Turbo Expo 2025 in Memphis, Tennessee, USA from June 16-20 to participate in the turbomachinery industry's most highly recognized conference and exhibition.

TELL US WHAT YOU THINK – TURBO EXPO'S HOT TOPICS

The IGTI Executive Committee's Communications Committee wants to hear from you!

Let us know what your areas of interest from London's Turbo Expo were, to help us pursue articles that will best resonate for our upcoming Global Gas Turbine News segment.

Please email ahmedh@asme.org with your input. We look forward to hearing from you.

Thank you!

Your IGTI Executive Committee Leadership