GLOBAL GAS TURBINE NEWS

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In this Issue...

AMERICAN SOCIETY OF MECHANICAL ENGINEERS (ASME)
ASME Gas Turbine Technology Group / 11757 Katy Frwy, Suite 1500 Houston, Texas 77079 / go.asme.org/igti

ASME Gas Turbine Technology Group and the IGTI Executive Committee Appoint New Members

In November of 2020, the ASME Technical Events & Content Sector (TEC) structure was reorganized to form technology groups instead of segments.

Starting in ASME's 2022 fiscal year, July 1, 2021, the Gas Turbine Segment will now be called the **Gas Turbine Technology Group (GTTG)**. All divisions, research committees and technology groups are reporting directly to the TEC Council. This does not change the IGTI Division.

ASME Gas Turbine Technology Group is pleased to announce the appointment of Zoltan Spakovszky, MIT, as the Gas Turbine Technology Group Chair for 2021-2022.

In addition, the Gas Turbine Technology Group welcomes three new Technology Group members: **Caroline March-mont**, Ansaldo Energia; **Sean Bradshaw**, Pratt & Whitney; and **Richard Sandberg**, University of Melbourne.

New Members

Caroline Marchmont

Director, Turbine and Technology
Ansaldo Energia

Sean Bradshaw

Fellow, Sustainable Propulsion
Pratt & Whitney

Richard Sandberg

Chair of Computational
Mechanics, Department of
Mechanical Engineering
University of Melbourne

ASME IGTI Executive Committee

ASME Gas Turbine Technology Group is also pleased to announce the members of the 2021-2022 IGTI Executive Committee led by the Executive Committee Chair, **Kenneth L. Suder**, PhD, NASA Glenn Research Center.

Kenneth L. Suder, PhD

Senior Technologist,
Airbreathing Propulsion
Propulsion Division, Research
and Engineering Directorate
NASA Glenn Research Center

Douglas Hofer, PhD

Engineering Fellow
Heliogen

Akin Keskin, PhD

Chief of Integrated
Design Systems
Rolls-Royce

Ricardo Martinez-Botas, FREng

Professor of Turbomachinery
Mechanical Engineering
Imperial College London

Karen Thole, PhD

Distinguished Professor
Pennsylvania State University

ASME Gas Turbine Technology Group would like to thank the outgoing Segment Leadership Team Members for their participation and contribution to the organization. Thank you to Segment Leader, Mark Zelesky, Pratt & Whitney; Segment Members Nicole Key, Purdue University; and Damian Vogt, University of Stuttgart. Your dedication to the industry is greatly appreciated.

ASME Turbo Expo 2021 Virtual Statistics

1,541 attendees from 39 different countries convened at the second virtual Turbo Expo conference where they participated in 157 technical sessions. In these sessions, authors presented over 700 final papers. **The virtual event site will be available for registered attendees to visit until September 11, 2021.**

Thank you to our Volunteers!

- Turbo Expo 2021 Organizing Committee
- Point Contacts, Vanguard Chairs, Session Chairs, Session Co-Chairs, Authors, Speakers, and Reviewers

Student Poster Competition Winners

First Place $500

Tim Hertwig, TU Braunschweig - Institute of Jet Propulsion and Turbomachinery

GT2021-1310: Simulation of the Condensation Phenomena in the Turbine of a Fuel Cell Turbocharger

Second Place $250

Catherine Julia Sophie Rau, Institute of Jet Propulsion and Turbomachinery

GT2021-1302: Simulation of the Particle Transport in the Fan Stage of a Jet Engine

People's Choice Award $250

Norzaima Nordin, UPNM

GT2021-1316: Experimental Investigation of Savonius Wind Turbine Blade for Low Wind Speed Region

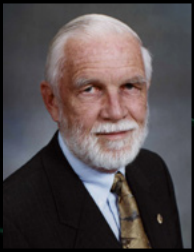
Turbo Expo 2022

June 13 - 17
Rotterdam, The Netherlands
Rotterdam Ahoy

Abstract Submission Deadline

October 29, 2021
www.turboexpo.org

The World's Most Efficient Heat Engine



By Lee S. Langston, Professor Emeritus, University of Connecticut, lee.langston@uconn.edu

An engineering thermodynamic landmark based on the gas turbine, has been achieved in roughly the short space of the last 20-30 years. New heat engine electric power plants, formed by pairing two existing heat engines, the gas turbine and the steam turbine, are achieving record breaking thermal efficiencies, at high levels of flexible operation and low costs.

The New Power Plant

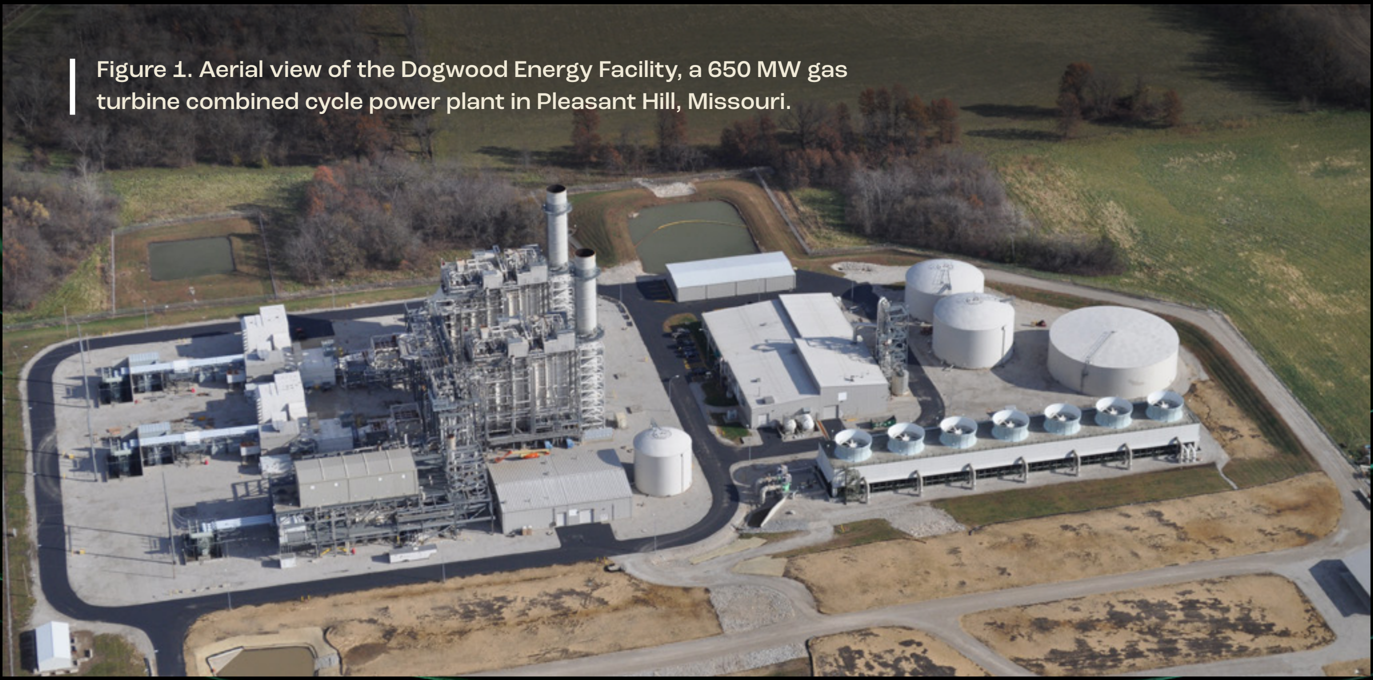
Fueling a gas turbine with natural gas and using its exhaust gases to make steam to drive a steam turbine provides two prime movers to generate electricity using only one unit of fuel. The resulting heat engine, now called a *gas turbine combined cycle power plant* (GTCC), has by far the highest thermal efficiency yet perfected by humankind.

The authoritative 2020 Gas Turbine World Handbook list [1] of commercially available GTCCs, shows that four OEMs (GE, Siemens, Mitsubishi Hitachi and Ansaldo) now have GTCC units with thermal efficiencies (η) between 62 - 64 percent in the 600 MW - 1700 MW electrical output range. Clearly these record setting values of η are double that of power plants that existed when I was an undergraduate engineering student in the 1950s. OEMs are now aiming their GTCC development to values of η at 65 percent or higher.

In a GTCC, the Brayton cycle gas turbine exhaust gases, in the range of 1000° F (538° C), pass through a heat recovery steam generator (HRSG) to supply steam to a Rankine cycle steam turbine, with both turbines powering electric generators. As an example, Fig. 1 [2] shows an aerial view of the Dogwood Energy Facility in Pleasant Hill, Missouri. It is a natural gas fired, 650 MW GTCC with two gas turbines and one steam turbine. One can readily see the white inlets to each of the gas turbines, the two HRSGs each exiting to a chimney, and the steam turbine enclosure in the foreground. To the right in the figure, are evaporative cooling towers to reject steam condenser waste heat.

The secret of success of the GTCC can be shown by a simple equation. Using conservation of energy and the definition of thermodynamic thermal efficiency, the combined cycle thermal efficiency can be derived fairly simply as the sum of the two cycles' efficiencies minus their prod-

Figure 1. Aerial view of the Dogwood Energy Facility, a 650 MW gas turbine combined cycle power plant in Pleasant Hill, Missouri.



uct. Thus, operating alone, the thermal efficiencies of the Brayton and Rankine cycles can be taken, say, to be about 40 percent and 30 percent respectively. Together in a gas turbine combined cycle plant, they achieve an estimated average 58 percent thermal efficiency, a remarkable increase, and a value greater than either of the component efficiencies.

Some GTCC History

The beginning history of the gas turbine combined cycle power plant really harkens back to 1824 and the publication of Reflections on the Motive Power of Fire by the brilliant French military engineer Nicolas Leonard Sadi Carnot (1796-1832). (I remind our readers that Robert Thurston, ASME's first president (1880-82), translated from French and edited the English edition of Carnot's work [3].)

Carnot was the first to develop a fundamental theory of heat engines (which became one form of the 2nd law of thermodynamics). Carnot was well aware of some of the early short comings of the then only operating heat engine, the steam engine. He had these prescient words [3,4] that foretold the advent of the GTCC:

> *"The phenomenon of the production of motion by heat has not been considered from a sufficiently general point of view. .....It is necessary to establish principles applicable not only to steam-engines but to all imaginable heat-engines, whatever the working substance and whatever the method by which it is operated. .....One of the gravest inconveniences of steam is that it cannot be used at high temperatures without necessitating the use of vessels of extraordinary strength. It is not so with air for which there exists no necessary relation between the elastic force and the temperature. Air, then, would seem more suitable than steam to realize the motive power of falls of caloric from high temperatures; perhaps at low temperatures steam may be more convenient. We might conceive even the possibility of making the same heat act successively upon air and vapor of water. It would be only necessary that the air should have, after its use, an elevated temperature and instead of throwing it out immediately into the atmosphere, to make it envelop a steam boiler, as if it issued directly from a furnace."*

For the GTCC, Carnot's "imaginable best-engine" is the gas turbine. As a heat engine it had a dual development in 1939 as the jet engine and in its land use to generate electricity, some 115 years after the publication of Carnot's seminal work. The gas turbine exhaust air, at "an elevated temperature envelopes a steam boiler ", in the form of the HRSG.

As Dietrich Eckardt relates in his ASME award-winning *Gas Turbine Powerhouse* [4], GTCC power plants started to be deployed in large numbers at about 1990. At that time, gas turbine combustion and hot turbine technology had advanced, so that exhaust gas exit temperatures reached the range of 1000° F (538° C) in electric power gas turbines, which allowed high temperature steam to be generated in HRSGs to efficiently power steam turbines.

A comprehensive history of GTCC development is given by both Eckardt [4] and Gülen [5]. Both give an account of one of the earliest GTCC power plants at Korneuburg, Austria on the Danube river, 15 km upstream of Vienna. Unit A, a Brown Boveri 75 MW GTCC went into operation in 1961, followed in 1980 by 125 MW Unit B which had a thermal efficiency of 47 percent. Subsequently, in 2011, in Irsching, Germany 200 km to the west of Korneuburg and also on the Danube, a new Siemens GTCC 578 MW plant broke the milestone 60 percent mark, with a full load thermal efficiency of 60.75 percent.

Other GTCC Attributes

Currently, gas turbine combined cycle power plants have low capital costs, ranging between $700 and $1,000 per kilowatt, compared to $3,000 and $6,000 (or more) per kilowatt for coal and nuclear, respectively. And because combined cycle gas turbine plants can rapidly start up and shut down as needed, they can provide reliable backup power for emergencies and intermittent renewable power facilities.

Replacing coal-powered Rankine cycle power plants with gas turbine combined cycle power plants, fueled with natural gas, results in a substantial 75 percent reduction in CO_2 production per unit of electricity, and it nearly doubles existing power plant thermal efficiencies.

Currently, hydrogen gas, which could be produced by electrolysis from water and surplus renewable electricity, can be combusted in GTCCs to emit only water vapor. Companies and countries are currently researching hydrogen injection into gas pipelines and networks already in use by GTCC power plants, and a number of pilot programs are in process.

In summary, as the world's most efficient heat engine, GTCCs are playing an increasingly important role in electrical power production. Quoting Carnot again [3], *"The study of these [heat] engines is enormous, their use is continually increasing, and they seem destined to produce a great revolution in the civilized world."*

References

1. Gas Turbine World 2020 GTW Handbook, 2020, Volume 35, Gas Turbine World, Pequot Publishing, pp. 53-61.
2. Combined Cycle Journal, 2013, "Best Practices – Dogwood", https://www.ccj-online.com/2013-best-practices/best-practices-Dogwood/.
3. Carnot, Sadi, 1960, *Reflections on the Motive Power of Fire*, Dover Publications, pp.3, 6, 55.
4. Eckardt, Dietrich, 2014, Gas Turbine Powerhouse, Oldenbourg Verlag.
5. Gülen, S. Can, 2020, *Gas Turbine Combined Cycle Power Plants*, CRC Press, pp. 203-23

The Road to a Digital Twin

Rob Fox, Chief of Structural Systems Design, Rolls-Royce plc
Akin Keskin, Chief of Integrated Design Systems, Rolls-Royce plc

A Digital Twin can be expressed as a virtual representation of a connected physical asset and encompasses its entire product lifecycle [1].

Digital Twin is no longer just a 'buzz word' or technology on a hype curve [2, 3], it is a concept that technology companies started adopting to change the way they do business. The Digital Twin concept creates new business models and value streams in product design, test, maintenance and aftermarket support. The main essence of this concept is to better connect different business areas to drive decision making during all stages of a product, process or service offering.

As part of this journey, Rolls-Royce has started many initiatives to utilise the Digital Twin concept. One recent example is a digital twin of an aero engine for safety assessments of Fan Blade-Off (FBO) events. This digital twin can be used to confirm the behaviour of a particular engine under many versions of failure events and provides assurance for design decisions but can also be used to predict how the behaviour of the engine might change with changing parameters such as material, environmental conditions or operation. The underlying model needs to have sufficient detail and accuracy such that it can update to replicate specific assets; either pre-empting planned tests or replicating in-service failures to support incident investigations. Although FBO events are rare, they represent one of the most extreme failure events. Historically the safety of products was demonstrated via expensive one-off tests which demonstrated safe blade containment under maximum operating conditions. These tests could then be used to calibrate the models used to assess installed behaviour.

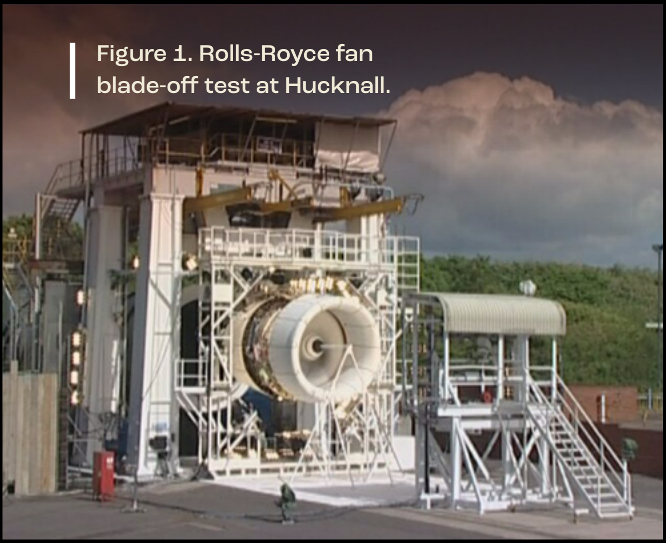


Figure 1. Rolls-Royce fan blade-off test at Hucknall.

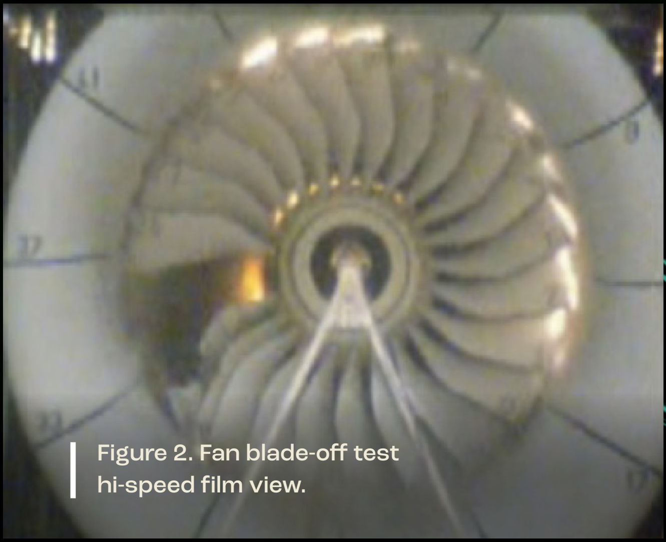


Figure 2. Fan blade-off test hi-speed film view.

The analysis models used were targeted at two aspects of the event and were built in very different ways:

- The Containment model focussed on the very early parts of the event and covered a very small timeframe. The model was used to determine that the initially released elements would not penetrate the containment casing and escape the engine.
- The loads model was used to assess the remainder of the event until the engine had come to a complete stop. This model was used to determine that the engine structure would remain whole and attached to the aircraft.

The calibration exercise mentioned previously was performed by taking generic models and updating these to represent the exact condition of the FBO test engine; for example adding in test specific component definitions and accounting for the particular performance parameters of the test engine. This could be considered in essence an early version of a digital twin since it represented a particular engine under specific conditions. In the early 2000's, the models themselves were quite simple, which resulted in certain parameters needing to be extracted from the test itself; such as the exact timing of blade failures or of internal structures used to reduce loads.

It is a well-established principle to develop improved analytical models for such events and the quality of the generic models have improved thanks to a combination of increases in computing power and understanding of the overall behaviour of the engines themselves, gathered by companies from their historical experience of performing tests over multiple programs and also from investigation of in-service events. The models have been used for a number of years to demonstrate that installed performance of the powerplant and aircraft is acceptable under a range of conditions beyond the single point demonstrated by the test.

The improvements in computing have allowed Rolls-Royce to bridge the gap between the two classical models, producing an extremely detailed representation of the whole engine, which includes all of the physics necessary to model both containment elements as well as whole engine effects. A number of activities are required when attempting such an exercise as simply building the largest model conceivable would either exceed ones computing capability or take so long to build and run as to be useless as a tool.

The approach taken within Rolls-Royce was to focus on understanding the fundamental elements of an FBO event using the existing simplistic models and then develop that functionality within a much more detailed model. These efforts began by adding simple representations of the engine into the detailed model to account for whole engine features.

In the 1990s, it was usual for the containment model to simply have a disc with a small number of blades represented and this was sufficient to predict the behaviour of the released blade and its interaction with the blade immediately behind it [trailing blade] to demonstrate that the released blade could be captured by the casing. In the early stages of this journey, these models were expanded to include the stiffness of structures adjacent to the containment casing, improving the modelling of the containment event. This was then further improved by including the shaft systems such that the fan assembly could move off-centre as would happen in a real event. This led to a requirement to include the rest of the fan blades as these would limit the movement of the fan assembly by rubbing into the casing, an example of the knock-on effects of increased physical modelling as this increased the size of the models significantly by moving from 2-3 blades to ~26 in a single step.

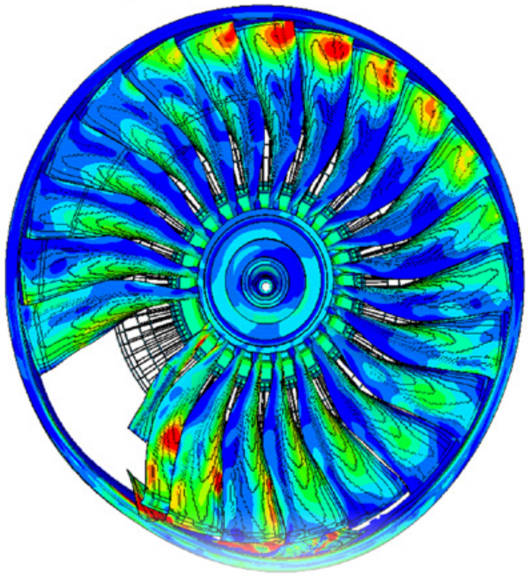


Figure 3. Digital twin analysis results.

A close collaboration of a multidisciplinary team with experts in structural, thermal and whole engine integration modelling has gradually identified a series of elements which needed to be included to move toward a Virtual Engine which could then function as a digital twin of assets under failure conditions.

These models represent "digital twins" of the test vehicles which eventually only needed updating to account for day-to-day variations in engine performance and normal scatter in material performance. This has allowed Rolls-Royce to use these models in place of physical testing, exercising these over a much wider range of conditions than was possible with single tests, greatly increasing safety of the final product. The results are very promising at such an early stage of the Digital Twin journey and show how this concept can help tackling very complex engineering challenges in the future.

References

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2. Gartner. Prepare for the Impact of Digital Twins. https://www.gartner.com/smarterwithgartner/prepare-for-the-impact-of-digital-twins/
3. Gartner. 5-trends-drive-the-gartner-hype-cycle-for-emerging-technologies-2020. https://www.gartner.com/smarterwithgartner/5-trends-drive-the-gartner-hype-cycle-for-emerging-technologies-2020/
4. EASA Certification Specifications for Engines - CS-E 810
5. Federal Regulation –Aeronautics and Space, Chapter 1—Federal Aviation Administration, Department of Transportation, Subchapter C – Aircraft, Part 33—Airworthiness Standards: Aircraft Engines, Subpart F—Block Tests; Turbine Aircraft Engines, 33.94 - Blade containment and rotor unbalance tests.

Awards Information

Congratulations to all award winners...

...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 William T. Cousins for serving as the IGTI Honors and Awards Committee Chair, John Gülen as Industrial Gas Turbine Technology Award Committee Chair, and Wilfried Visser as the Aircraft Engine Technology Award Committee Chair.

2021 ASME R. Tom Sawyer Award

Dr. Robert Kielb
Duke University

2019 ASME Gas Turbine Award

For their paper "The Impact of Combustor Turbulence on Turbine Loss Mechanisms"

Dr. Masha Folk
Rolls-Royce Corp.

Dr. John D. Coull
University of Oxford

Robert J. Miller
University of Cambridge

2021 ASME Dedicated Service Award

Dr. Damian Vogt
University of Stuttgart

Richard Dennis
US. Department of
Energy's National Energy
Technology Laboratory

2019 John P. Davis Award

Dr. David John Rajendran
Cranfield University

Dr. Vassilios Pachidis
Cranfield University

2021 Aircraft Engine Technology Award

Dr. Guillermo Paniagua
Purdue University

2021 Dilip R. Ballal Early Career Award

Lt. Col. Brian T. Bohan, PhD.
Air Force Institute of Technology

2021 Scholar Award

Dr. Zoltan S. Spakovszky
Massachusetts Institute
of Technology

2021 Industrial Gas Turbine Technology Award

Richard Dennis
US. Department of
Energy's National Energy
Technology Laboratory

2021 Young Engineer Turbo Expo Participant Award Winners (YETEP)

Amrita Basak
Pennsylvania State University

Eva van Beurden
Cooll Sustainable Energy
Solutions B.V

Xiao He
Imperial College

Richard Hollenbach
Duke University

Nikola Kafedzhiyski
Siemens Energy AB

Amit Kumar
Indian Institute of
Technology Bombay

Marcel Otto
University of Central Florida

Ajey Singh
Indian Institute of
Technology Kharagpur

Alberto Vannoni
University of Genoa

Peter Warren
University of Central Floria

Tingcheng Wu
Texas A&M University

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linkedin.com/company/asme-international-gas-turbine-institute

2021 Student Advisory Committee Travel Award Winners (SACTA)

Hessein Ali
University of Central Florida

Lakshya Bhatnagar
Purdue University

Simone Braccio
Université Savoie Mont Blanc

Tania Sofia
Cacao Ferreira von
Karman Institute/Universite
Catholique de Louvain

Jaime Aaron Cano
University of Texas at El Paso

Daniel Castillo
Imperial College London

Louis Edward Christensen
The Ohio State University

Eric T DeShong
Pennsylvania State University

Dimitra Eirini Diamantidou
Mälardalen University (MDH)

Hossein Ebrahimi
University of Central Florida

Ryan Douglas Edelson
Pennsylvania State University

Alfredo Fantetti
Imperial College London

Benjamin Francolini
McGill University

Emmanuel Gabriel-Ohanu
University of Central Florida

Vipul Goyal
University of Central Florida

Shreyas Hegde
Duke University

Richard Lee Hollenbach III
Duke University

Kristyn Blake Johnson
West Virginia University

Mohammed Ibrahim Kittur
University of Malaya

Brian Frederick Knisely
Pennsylvania State University

Amit Kumar
Indian Institute of Technology
Bombay, Mumbai

Austin Carl Matthews
Georgia Institute of Technology

Andrea Notaristefano
Politecnico di Milano

Papa Aye Nyansafo Aye-Addo
Purdue University

Antonio Escamilla Perejón
University of Seville

Hien Minh Phan
Univeristy of Oxford

CP Premchand
Indian Institute of
Technology Bombay

Avinash Ambadas Renuke
University of Genova, Italy

Alessandro Romei
Politecnico di Milano

Alexander J Rusted
The Pennsylvania State University

Izzet Sahin
Texas A&M University

Jainam Shah
Ahmedabad University

Ajey Singh
IIT Kharagpur

Spencer Jordan Sperling
The Ohio State University

Mohammed Aqeel Talikoti
Vesvesvaraya Technological
University

Vamsi Krishna Undavalli
Moscow Aviation Institute
(National Research Univeristy)

**Aravind Chandh
Velayuthapattnam Shanmugam**
Georgia Institute of Technology

Peter Ove Warren
University of Central Florida

Peter Hansen Wilkins
Pennsylvania State University

Upcoming Award Opportunities

Visit go.asme.org/IGTI and click on **Honors and Awards** for more information.

2022 ASME IGTI Aircraft Engine Technology and Industrial Gas Turbine Technology Awards

Nominations due to igtiawards@asme.org by **October 15, 2021**.

2022 Student Scholarships

https://www.asme.org/asme-programs/students-and-faculty/scholarships

Correction to GGTN December 2020/January 2021 Technical Article

In Vol 60 No. 4 (December 2020/January 2021), the article "Adding Another Gas Turbine Decarbonization Path: Adding Energy Storage to the Combined Cycle" presented the Fuel Heat Rate in Table 1 as Btu/kWh instead of kJ/kWh for Liquid Salt Combined Cycle. Table 1 is corrected below.

Table 1

	GE 7FA.04 Gas Turbine		
Net Ratings	**Simple Cycle**	**Combined Cycle**	**Liquid Salt Combined Cycle**
Power (KW)	198,000	305,000	398,874
Fuel Heat Rate (KJ/KWH)	9,324	6,030	4,605
Stored Energy Rate (KJ/KWH)	0	0	2,396
Thermal Efficiency	38.6%	59.7%	51.4%

ASME 2021 AMRGT Symposium (Advanced Manufacturing & Repair for Gas Turbines)

October 5 - 8, 2021

Virtual Event

ASME's Advanced Manufacturing and Repair for Gas Turbines (AMRGT) Symposium is designed to bring together gas turbine manufacturing community with operators, support engineers and manufacturing process developers. The symposium will feature technical presentations that will explore the challenges and solutions at the forefront of advanced manufacturing and repair of gas turbine components. The peer-reviewed presentations without publication format including video-on-demand during and after the event are specifically intended to allow convenient participation for industrial stakeholders and maximum value to participants.

Registration is available online at event.asme.org/AMRGT.

ASME 2021 Gas Turbine India Conference

December 2 - 3, 2021

Virtual Event

The ASME Gas Turbine India Virtual Conference is the must-attend event for turbomachinery professionals. Gas Turbine experts will gather to present their peer-reviewed research and the latest technology advancements in the industry.

Registration is available online at event.asme.org/GT-India.