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GLOBAL GAS TURBINE NEWS

In this Issue...

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

Turbo Expo Conference Theme

SUSTAINABLE ENERGY—ACCELERATING THE TRANSITION BY ADVANCING TURBINE TECHNOLOGY

Nations of the world are seeking a transition to a sustainable carbon neutral existence by 2050; a society-driven speed unparalleled in modern times. The ability to quickly apply and adapt turbine technology to carbon neutral fuels, hybrid power systems and alternate heat sources will help to accelerate the transition to sustainable energy systems. The transition will require a close collaboration between not only power generation and propulsion industries, the research communities and regulators but also other industries outside the traditional turbomachinery area in order to create a feasible roadmap for technology development.

To make this vital transition, the community will need further development of new digital design tools, advanced manufacturing, integrated sensor technology, machining learning with artificial intelligence, pre- and post-combustion carbon capture and advanced thermodynamic systems. Additional focus should be put onto the infrastructure requirements for alternative fuels and the end-to-end ecosystem of power and propulsion generation.

Organizers of Turbo Expo 2021 invite you to explore and share topics relevant to advance turbine technology as the industry works to provide solutions for sustainable energy. A series of plenary panel discussions will be organized with selected experts to discuss technologies needed to achieve sustainable energy solutions.

Plenary Panel Sessions include:

1. Opening up the design space to afford efficient gas turbines using H_2 and biofuels
2. Opening up the design space through computations and machine learning
3. Engineering in 2030 – how must our educational programs change to better equip the needed workforce

Leveraging ASME Focus on Manufacturing and Maintenance Engineering

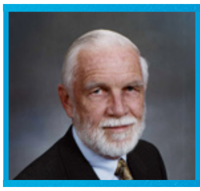
Manufacturing, which is one out of five ASME Key Technologies, and Maintenance are areas of industrial engineering for conveying business needs to customized technologies. The new **ASME Production and Maintenance Engineering (PME) Executive Committee** has been recently created to engage industry stakeholders, engineering service companies and academia to develop content focused on advanced manufacturing, repair technologies, and predictive maintenance of mechanical systems used in clean transportation, power and propulsion. They are also helping to support the planning committee of the AMRGT (Advance Manufacturing and Repair of Gas Turbines) Symposium, which will be held October 5-8, 2021 The members of the PME Executive Committee (see members listed below) look forward to engaging with you through ASME.org or LinkedIn.

Fig.: ASME "Production and Maintenance Engineering" Executive Committee; from left to right (1) Martin J. Conlon, CTO of Equispheres Inc., Canada, (2) Sam O'Leary, CEO of SLM Solutions AG, Germany, (3) Timothy W. Simpson, Prof at Penn State Unv, USA, (4) Charles Soothill, Head of Tech at Sulzer Rotating Equipment Services, Switzerland, (5) Richard Dennis, Program Manager at Department of Energy NETL, USA, and (6) Jaroslaw Szwedowicz, Principal Senior Key Expert at Siemens Energy AG, Switzerland

As the Turbine Turns...

SOME FLUID FLOW VEXATIONS

#46 - April/May 2021



By Lee S. Langston,
Professor Emeritus,
University of Connecticut

"Of all the fluid-dynamic devices invented by the human race, axial-flow turbomachines are probably the most complicated."

This aphorism by fluids experimentalist and author Peter Bradshaw [1] strikes home for many of us in the research, development and design of gas turbines. Vexations abound in our attempt to understand and to design hardware for the gas path fluid flow through gas turbine engines. (Vexation is used here as being vexed, or a cause of trouble.)

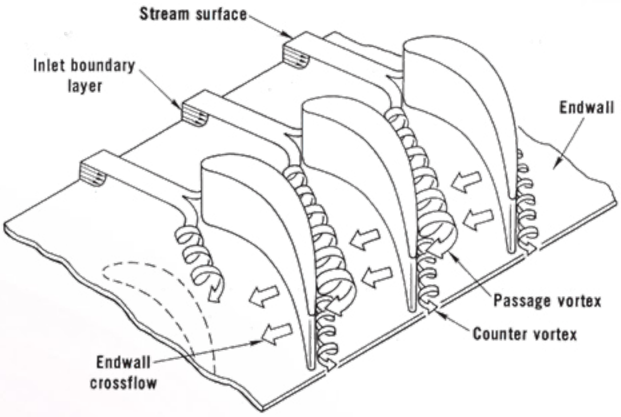
The Endwall Flow Vexation

One such important vexation in the axial flow turbine of a gas turbine, is the gas path fluid flow brought about by the existence of endwalls. These inner and outer surfaces constrain the working fluid as it passes through the turbine, bounding each airfoil and forming the gas path surfaces of the engine annular casing. Due to viscous effects, endwalls divert the primary flow produced by turbine blades and vanes, to give rise to what has come to be called secondary, or endwall flow.

The secondary or endwall flow in a cascade of turbine blades or vanes (such as depicted in Fig. 1) constitutes one of the most commonplace and widespread three dimensional flows that arise in the generation of electrical and motive power. Such fluid flows occur in all axial flow turbines (gas, steam and water) used to generate most of the world's electricity. They occur in all of the jet and turboprop engines (30,000 in the inventory (1993) of the U.S. Air Force, alone) which power most of the aircraft of the world.

The hardware sketched in Fig. 1 represents a plane (or linear) cascade, depicting the airfoils and endwalls in a turbomachine with a very large (infinite) radius. For many years now, experimenters studying these intriguing, but complex three-dimensional flows in axial turbines, have made use of planar cascades to sort out and measure fluid flow and heat transfer features. Numerical calculators modeling these flows, using computer fluid dynamics (CFD), have also relied on simple plane cascade geometries to attempt to "postdict" existing cascade data, or to separate out the effect of various analytical techniques (such as turbulence models).

Figure 1. Ribbon Sketch of Turbine Cascade Endwall Secondary Flow.



A typical three-dimensional endwall flow is shown schematically in Fig. 1. This figure, taken from Langston [2], shows that at the endwall of the cascade, the inlet boundary layer (or some other non-uniform inlet flow) separates at a saddle point and forms a horseshoe vortex. One leg of this vortex (sometimes called the "pressure" leg), drawn into a cascade passage, is "fed" by the passage pressure-to-suction endwall flow and becomes the passage vortex. The other leg (called the "suction" leg) is drawn into an adjacent passage and has an opposite sense of rotation to the larger passage vortex. This smaller vortex is labeled as a counter vortex in Fig. 1 and can be thought of as a "planet" possibly rotating about the axis of the passage vortex (the "sun"). Thus, the position of the counter vortex relative to the passage vortex may be different than that shown in Fig. 1. The ribbon arrows in the figure have been drawn to exaggerate vortex motion. The actual rotation of the vortices is much less than that shown (about two rotations for the passage vortex).

Following Denton [4], aerodynamic loss is a measure of entropy generation. In the case of the cascade experiment of Fig. 1, aerodynamic loss is obtained from measuring the fluid flow total pressure decrease through the cascade.

By turbine designer conventions, the effects of the highly interactive flow picture in Fig. 1 is artificially broken down to those caused by the blade or vane "profile" surface

Figure 2. Film-cooled turbine inlet guide vane. (Flow is right to left on the suction surface.)

and those caused by the endwall. (A third category of stator or blade tip clearance effects is summarized in [3]). The aerodynamic losses so attributed to the endwall—usually termed secondary flow losses or secondary losses—can be as high as 30-50% of the total aerodynamic losses in a blade or stator row. Turbine inlet guide vanes, with lower total turning and higher convergence (velocity) ratios, will have smaller secondary losses, amounting to as much as 20% of total loss for an inlet stator row.

A film-cooled turbine inlet guide vane taken from an operating jet engine is shown in Fig. 2. The ceramic thermal barrier coated (TBC) vane suction side is displayed, where entrained cooling hole flow temperature-induced discoloration clearly shows evidence of the endwall induced secondary flow. These limiting streamlines produced by the engine gas path flow show the same characteristics as the cascade flow in Fig. 1.

Endwall Loss Abatement Vexations

Because endwall losses can be so high, there have been and continue to be many studies and hardware attempts to reduce them. Here are a few of them:

- Various "bowed" and "leaned" airfoils.
- A wide variety of fences and grooves, either on the endwall or airfoil. (One researcher I met with in Germany in the 1970s had tested upwards of 400 different configurations!)
- Leading edge bulb protrusions at the endwall-airfoil junction
- Endwall contouring.

Each of these (or others) may lead to endwall loss reductions under certain conditions, but a general hardware endwall fix for a variety of operating conditions had yet to be developed.

Endwall Loss Prediction Vexations

There are no closed form analytical solutions to the secondary flow shown in Fig. 1. Since the early 1970's there has been a great deal of effort to model this complex flow using a variety of CFD codes and associated turbulence models.

Much progress has been made and it would be safe to say that most turbine manufacturers use 3D CFD codes routinely in the mid to later stages of the design process for a new machine. Generally loading curves (i.e. airfoil pressure distributions) can be predicted accurately even when secondary effects are quite large. However, the ability to routinely predict aerodynamic losses with strong secondary flows has been more limited. Just judging from the number of CFD papers in this area we see at recent Turbo Expo conferences, show that it is still a work in progress.

In summary, the turbine endwall flow vexation described here, is perhaps symbolized by that suggested in the 1817 Shelley poetic line, ".....like some calm wave Vexed into whirlpools by the chasms beneath." The result is turbine aerodynamic entropy generation, which in thermodynamic terms, is lost work. Clearly, endwall losses represent the lost ability to aerodynamically extract turbine work from gas path flow, thereby decreasing gas turbine thermal efficiencies.

1. Bradshaw, P.,1996. "Turbulence Modeling with Application to Turbomachinery", *Prog. Aerospace Sci.* 32: pp.575-624.
2. Langston, L.S. 1980. "Crossflows in a Turbine Cascade Passage", *ASME Jour. of Engineering for Power*, 102, pp.866-874.
3. Langston, L.S., 2013. "Blade Tips - Clearance and its Controls", *Global Gas Turbine News, Mechanical Engineering Magazine*, August, pp.64,69.
4. Denton, J.D., 1993, "Loss Mechanisms in Turbomachines", *ASME Jour. of Turbomachinery*, 115(4), pp.621-656.

RETROFITTING GAS TURBINES FOR INCREASED HYDROGEN LEVELS

Dr. Jeffrey Goldmeer
Emergency Technologies Director
GE Gas Power

John Catillaz
Decarbonization Marketing Director
GE Gas Power

Typically, when hydrogen (H_2) is available in large volumes it is used in hydrotreating crude oil or in the production of other commercial products, such as fertilizers. However, as hydrogen becomes increasingly popular in other industries for its carbon-free properties, there are likely to be more instances where larger volumes of hydrogen become available for use in the power generation sector. Almost all GE heavy-duty gas turbines and aeroderivative turbines, including units in operation today, can handle fuel blends of up to 5 percent hydrogen by volume with little to no modifications to the plant.

Due to differences in the physical and chemical properties of hydrogen, adding over 5 percent hydrogen to a gas turbine may require changes to the gas turbine, gas turbine accessories and/or the balance of plant as illustrated in Figure 1. The magnitude of the required changes is a function of the amount of hydrogen in the fuel. This section will highlight the potential impacts to power plant systems when using hydrogen.[1]

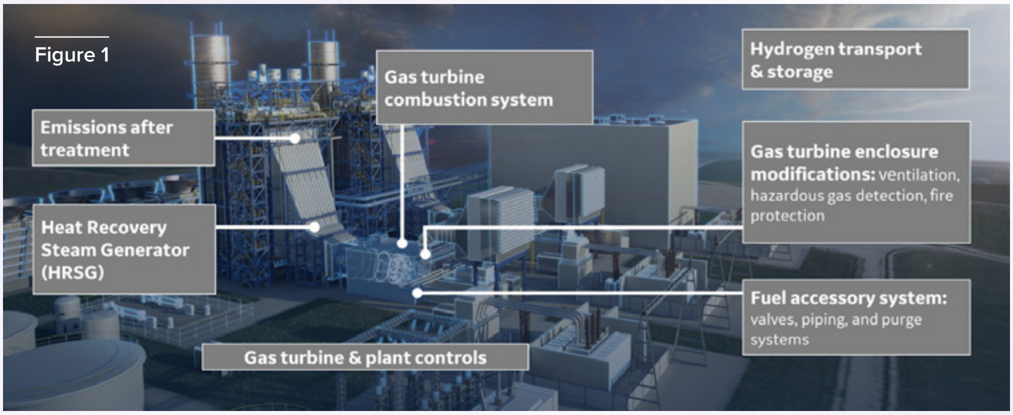
Fuel Accessory Systems

There are two fundamental operational scenarios with hydrogen: operating on a blend of hydrogen and natural gas, and operation on 100% hydrogen. If hydrogen is to be blended into an existing natural gas power plant, and the hydrogen is transported to the plant separately from natural gas, a fuel blending system will be required. This will ensure proper mixing of the hydrogen into the existing fuel system. This also allows proper control of the mix to ensure safe operation of the power plant. Regardless of how the hydrogen is transported to the plant, there will be changes required to the fuel blending system.

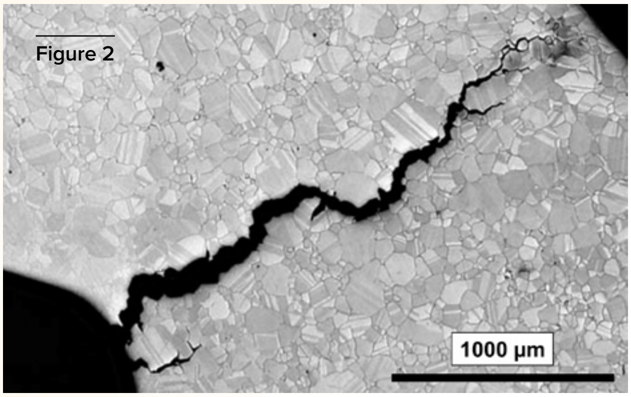
As hydrogen's volumetric heating value is 1/3 that of methane, it takes 3x more volume flow of hydrogen to provide the same heat (energy) input as methane. Therefore, if a fuel blend is to be used, the existing piping system might be acceptable, if using a small concentration of hydrogen. If planning to operate on high levels of hydrogen, a fuel accessory system configured for the required flow rates is required.

In addition to the increases in flow, hydrogen can impact materials and systems differently that other gases. For example, hydrogen is a smaller molecule than methane and may diffuse through seals that might be considered airtight or impermeable to other gases. Therefore, traditional sealing systems used with natural gas may need to be replaced with welded connections or with upgraded seals.

Another challenge when using hydrogen is its ability to diffuse into solid some materials, including some steel alloys. This process, known as hydrogen embrittlement, may lead to degradation of material strength properties. In this process, hydrogen diffuses to the grain boundaries in the alloys and interacts with the carbon forming microscopic methane bubbles. The result is a disruption in the microscopic structures that provide the strength of the alloy. Figure 2 shows



1. For more information, gepower.com/hydrogen



an example of embrittlement-based fatigue from an actual field failure.

Combustion System

The ability of a combustion system to operate safety and reliably on a fuel depends on many factors, some of which are defined by the fuel's fundamental properties. Hydrogen has a flame speed that is an order of magnitude faster than methane. Using fuels with higher flame speeds increases the risk that the flame could propagate upstream into the premixer, causing flashback. If the flame then anchors and stabilizes inside the premixer a flame holding event occurs. Both situations can lead to combustion hardware distress and even fuel nozzle damage.

Typically, combustion systems are configured to operate on a set of fuels that have a defined range of flame speeds. Due to the significant difference in the flame speeds of methane and hydrogen, combustion systems configured for operating on methane may not be suitable for operating on a high hydrogen fuel. Therefore, there are defined ranges for hydrogen on DLN and DLE combustion systems to avoid this issue. Mitigating this risk may require upgrading to a combustor specifically configured for operation on hydrogen and similar more reactive fuels.

Operating on a fuel with increased levels of hydrogen could also impact combustion system operability, including combustion dynamics (also known as combustion acoustics). Therefore, there could be changes in gas turbine controls, start-up and shutdown sequences.

There are also likely to be increased NOx emissions due to the increased flame temperature of hydrogen. The magnitude of the increase in NOx emissions will depend on the percentage of hydrogen in the fuel, and the specific combustion system and gas turbine operating conditions. At lower percentages of hydrogen the increase in NOx emissions are minimal, but at 50% hydrogen (by volume), NOx emissions could increase by as much as 35%, and could potentially double if operating at or near 100% hydrogen.

For power plants currently in development, one potential mitigation for increased NOx emissions is a larger or more efficient SCR (selective catalytic reduction) system. For existing power plants, there may be some ability to accept some increases in NOx emissions based on existing NOx emissions, existing SCR capabilities (if installed), and the plant's air permit limits. Other mitigations could include derating the power plant to maintain operation within the existing air permit's NOx emission limits.

Safety

There are additional operational challenges with hydrogen that relate to overall plant safety. Hydrogen is more flammable than methane. The lower explosion limit for methane (in air) is ~5%, while for hydrogen it is ~4%. In addition, hydrogen's upper explosion limit is 75% compared to methane at 15%. Therefore, hydrogen leaks could create increased safety risks requiring changes to plant procedures, safety / exclusions zones, etc. In addition, there may be other plant level safety issues that merit review.

Typical hazardous gas detection systems in power plants are targeted at hydrocarbon fuels. Increased levels of hydrogen can reduce the sensitivity of these instruments requiring new systems capable of detecting the presence of hydrogen. In addition, hydrogen flames have lower luminosity than hydrocarbon flames and are therefore hard to detect visually. This requires flame detection systems specifically configured for hydrogen flames. Therefore, the use of hydrogen may require the installation of sensors and instrumentation specifically configured for fuels containing hydrogen.

Before formalizing any plan to blend hydrogen into natural gas for an existing plant, a full audit of plant systems should be performed with a goal of developing a plan for safe operation.

1. NACE International, "Hydrogen Embrittlement," [Online]. Available: https://www.nace.org/resources/general-resources/corrosion-basics/group-3/hydrogen-embrittlement.
2. Matheson Gas, "Lower and Upper Explosive Limits for Flamable Gases and Vapors," [Online]. Available: https://www.mathesongas.com/pdfs/products/Lower-(LEL)-&-Upper-(UEL)-Explosive-Limits-.pdf.
3. S. J. Hawksworth, "Safe Operation of Combined Cycle Gas Turbine and Gas Engine Systems using Hydrogen Rich Fuels," in *EVI-GTI and PIWG Joint Conference on Gas Turbine Instrumentation*, 2016.

AWARDS INFORMATION

ASME IGTI Aircraft Engine Technology Award

Nominating and supporting letters for the Aircraft Engine Technology Award should be sent **by October 15** to: *igtiawards@asme.org*. Nominating letters should contain all information on the nominee's relevant qualifications. The Award Committee will not solicit or consider materials other than those described below. The selection committee will hold nominations active for a period of three years. A minimum of two supporting letters from individuals, other than the nominator, must accompany the nominating letter. Supporting letters should reflect peer recognition of the nominee's breadth of experience with various aspects of industrial gas turbine technology.

ASME IGTI Industrial Gas Turbine Technology Award

Nominating and supporting letters for the Industrial Gas Turbine Technology Award should be sent **by October 15** to: *igtiawards@asme.org*. Nomination requirements are identical to the ASME IGTI Aircraft Engine Technology Award.

ASME IGTI Dilip R. Ballal Early Career Award

Nomination packets are due to ASME **on or before August 1**. Send complete nomination to: *igtiawards@asme.org*. The nomination package should include the following:

A. A paragraph (less than 50 words) from the nominator highlighting nominee's contributions

B. Nomination letter

C. Two supporting letters

D. Current resume of the nominee

ASME R. Tom Sawyer Award

Your nomination package should be received at the ASME Office **no later than August 15** to be considered. The nomination must be complete and accompanied by three to five Letters of Recommendation from individuals who are well acquainted with the nominees' qualifications. Candidate nominations remain in effect for three years and are automatically carried over. The completed reference form from a minimum of three people will need to be sent in with the nomination package. It is up to the "Nominator" to submit all required information. Email completed nomination package to: *igtiawards@asme.org*.