global
Gas Turbine News
Volume 52, No. 4 • December 2012
ATLANTA, GEORGIA USA /// ASME INTERNATIONAL GAS TURBINE INSTITUTE

ASME SETTING THE STANDARD · IGTI · mechanical engineering magazine

Guiding Global Turbomachinery & Energy Innovations at ASME Turbo Expo in San Antonio

In this issue

Join us at the San Antonio Convention Center, June 3-7, 2013, in San Antonio, Texas USA, for ASME Turbo Expo!

The 2013 keynote theme is ***Trends in the Global Energy Supply and Implications for the Turbomachinery Industry.*** Turbomachinery plays a critical role in the global energy industry, especially in transportation, power generation, and oil & gas sectors. In recent years, the global energy supply has been undergoing momentous changes. First, increased environmental concerns have led to a significant push for renewable energy sources. Second, the renaissance of the nuclear age has been called into question due to the 2011 tsunami in Japan. Third, substantial additional oil sources have been identified worldwide; but the technical challenges to developing these reserves are significant. Furthermore, the political events in the Middle East and rising demand have added to the uncertainty regarding the global supply of oil. Fourth, the global gas supply is undergoing a "revolution" with the coming online of shale gas, especially in North America. So what does all this imply for those of us in the fields of gas turbines, steam turbines, and other turbomachinery? In the keynote session, leaders of the aviation, oil & gas, and power generation industries will examine the changes that are occurring in the global energy supply and discuss what technologies may be needed in light of such changes.

TURBO EXPO
Turbine Technical Conference & Exposition
Presented by ASME International Gas Turbine Institute

The 2013 grand opening and keynote session will take place on Monday, June 3 at the Convention Center. Additional details will be announced in the February issue of the GGTN.

Conference

Now in its 58th year, ASME TURBO EXPO is recognized as the must attend event for turbomachinery professionals. ASME Turbo Expo includes technical sessions, tutorials, panel discussions, trade show exhibits, committee meetings, career development and

...continued on page 53

Welcome to San Antonio!

San Antonio has always been a crossroads for travelers, explorers, and those on a quest for liberty. Its sights, sounds, tastes and past captivate, while friendly people, the relaxing river and a superb climate entice visitors to come back for more.

From its important role in Texas independence to its fusion of cultures, San Antonio is a truly unique and authentic destination. Explore the routes of the conquistadors, the settlements of the first missions, and the Shrine of Texas Liberty—the Alamo. San Antonio's heart is in its past—but its future is in its celebration of cultures.

Plan your trip now. Register for the Conference and Exposition and secure your hotel room at one of the Conference Hotels online at www.turboexpo.org.

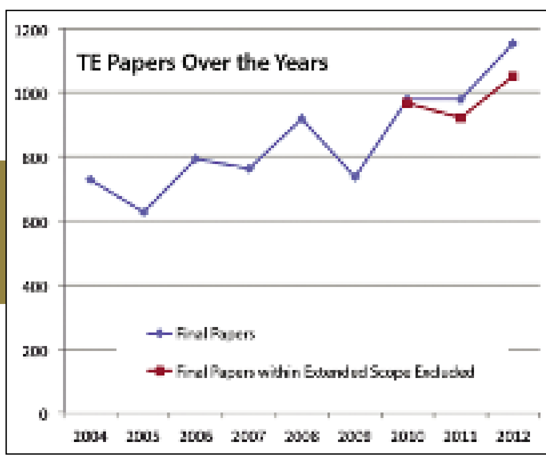
View From The Chair

By Dr.-Ing. Thomas Sattelmayer, Chair, IGTI Board

Dr.-Ing. Thomas Sattelmayer, is the Chair of Thermodynamics at the Technical University Munich, Garching, Germany.

It is again my honor and pleasure to provide you with some background information on the development of IGTI in this issue of the *Global Gas Turbine News*.

Although the holidays are just around the corner, this is the first issue of GGTN which offers me an opportunity for a retrospective of the Turbo Expo in Copenhagen. I am very happy to be able to report that it was again a big success. The number of final papers rose to 1154: a record and a large jump of 18% on the numbers of the past two years. The organization of the sessions and the assessment of the papers were tough jobs for which, on behalf of the Board, I would particularly like to thank the Review Chair and Co-Chair, the Point Contacts, the Vanguard Chairs, the Session Organizers and above all, the Reviewers. Also, many thanks to the IGTI staff who turned the conference in Copenhagen into such an unforgettable experience.



It would seem that the attraction of Turbo Expo has continually risen over the last ten years, with even the crisis in the industry causing only a slight slump in 2009. IGTI can be justifiably proud of this development. It is interesting to note that this is only partially a result of the extended focus within the framework of IGTI+. Even if the papers which fall into the area of extended scope are disregarded, the long-term growth trend still remains. Where the conference takes place, whether in Europe or on the North American continent, has a large influence on paper numbers as the saw-toothed form of the curve indicates.

As soon as one Turbo Expo has ended, preparations are underway for the next Turbo Expo. We will all meet again in San Antonio, Texas in June 2013 for the next edition of this premier event. It is expected that the conference numbers will continue to follow a growth trend.

Should the standards for the acceptance of papers be raised in order to curb this growth? Does the quality suffer from the increasing quantity? From what I have heard, the opinions in the various committees are very different. Each committee is wholly autonomous and has the necessary control mechanisms for adjusting standards individually via their reviewers. But it essentially all comes down to the principles of peer review and majority vote. In my opinion, I feel that we should not question these rather strict scientific fundamentals and that they should not be supplemented by quantity regulations from above.

The IGTI Board pursues the target of offering a more varied portfolio at IGTI conferences in the future and to also take regional issues into consideration. Of course the BRIC (Brazil, Russia, India & China) countries are especially attractive as conference venues. This year, the Gas Turbine India Conference took place for the first time with approximately 100 papers presented. That was a special success which also strengthened the foundation of IGTI in India. The review process was carried out by a local team under the guidance of our current Review Chair, Prof. Howard Hodson. Many thanks to the key volunteers Joseph Machnaim (GE Aviation), Prof. Bhamidi VSS Prasad (Indian Institute of Technology Madras), Prof. Bhaskar Roy and Prof. Amboor Madathil Pradeep (Indian Institute of Technology Bombay) without whom the conference could not have taken place.

In conclusion, permit me to reference a different subject that has often been raised. The recording of the IGTI heritage in a series of DVDs with all publications going back to the beginnings of IGTI is a continued goal for the Institute. This means plunging into the pre-electronic era paper production of IGTI from 1956 to 1999. We are looking at roughly 11,000 documents, which are only available in hard copy. The complexity of the digitalization and transformation into an optically high-quality format will require more time than was originally planned but all concerned are on track. It is merely a pleasure deferred!

I would like to wish you all a wonderful holiday season and all the very best for 2013. ✻

ASME IGTI Professional & Member Development

By Shirley Barton, IGTI Professional & Member Development Manager

IGTI Awards & Scholarships

Young Engineer Travel Award

IGTI offers several travel awards to students and young engineers employed in industry or government to attend ASME Turbo Expo **to present papers of which they are authors.** ***Applications are due by March 1, 2013.***
For more detailed information please visit:
http://igti.asme.org/Honors/Young_Engineer_Travel_Award.cfm

Congratulations to our 2012 IGTI Student Scholarship Winners!

- Vishal Srinivas Acharya - Georgia Tech
- Amin Akbarimonfared - U of California, Irvine
- David Beerer - U of California, Irvine
- Joshua Robert Brinkerhoff - Carleton (Canada)
- Md. Nafiz Chowdhury - U of North Dakota
- Stephen Clark – Duke
- Christopher Foley - Georgia Tech
- Hunter Guilliams - Virginia Tech
- Karthik Kashinath - Trinity College (Cambridge)
- Bhupendra Khandelwal – Cranfield
- Mitch Kibey - Carleton (Canada)
- Julia Ling – Stanford
- Andrew Marshall – Georgia Tech
- Amy Mensch – Penn State
- Patrick Migliorini - U of Virginia
- Abdulkarim Nasir – Cranfield
- Tareq Salameh - Lunds University (Sweden)
- Aditya Saurabh - TU Berlin
- Shazib Vijlee - U of Washington Seattle
- William Witt - U of Virginia

The deadline to submit an application is May 15, 2013.
For more detailed information on applying, please visit:
http://igti.asme.org/Honors/IGTI_Student_Scholarship.cfm

The ASME International Gas Turbine Institute Scholarship Award

The ASME International Gas Turbine Institute awards one $5,000 scholarship every year based on superior academic performance and demonstrated interest in the gas turbine, propulsion, or turbomachinery industries to an undergraduate or graduate student. ***Applications for each academic year are accepted online each year only from January 15 through March 1, after which the online application is closed.*** For more detailed information, please visit: http://igti.asme.org/News/International_Gas_Turbine_2.cfm

Professional Development

2013 IGTI Gas Turbine Training Week
March 18 – 22, 2013 | Atlanta, GA

For more detailed information please visit the IGTI web site at: http://igti.asme.org/

2013 Turbo Expo Workshops Announced!

1-Day, Saturday, June 1, 2013

- *New - "Life Prediction of Gas Turbine Components & Coatings"*
- *"Gas Turbine Operations & Maintenance"*

2-Days, Saturday-Sunday, June 1-2, 2013

- *"Advances in Turbines Aero-thermo-mechanical Design and Analysis"*
- *"Introduction to Optimization Methods and Tools for Multi-disciplinary Design"*
- *"Gas Turbine Aerothermodynamics & Performance Calculations"*

1-Day, Sunday, June 2, 2013

- *"A Primer on CHP Technologies"*
- *New! - "Nonisentropic Compressible Flows in Gas Turbine Design"*

For more detailed information please visit the IGTI web site at: http://igti.asme.org/

If you have a topic you think will be of value to the turbine industry and would like to present it in a webinar format or a "face-to-face" format, please contact Shirley at bartons@asme.org.

ASME Turbine Blade Tip Symposium & Course Week

Monday - Thursday, Sep. 30 – Oct. 3, 2013 | Hamburg Marriott | Hamburg, Germany

The present multidisciplinary Technical Symposium and Course Week addresses the current state of the art in the design, analysis, and improvement of turbine blade tips. Despite decades of applied research, the issue of blade tip burnout has remained as one of the most intractable in gas turbines. Yet the degradation of blade tips continues to represent a large fraction of the turbine losses, both in terms of the operational aero-thermal efficiency and the engine life cycle maintainability. A two-day course of lectures will precede the technical symposium to provide background, state-of-the-art design, and operability issues surrounding the topic. A two-day symposium will build upon the lecture series with current proposed or enacted solutions, studies to gain insight to the physics, and an industry panel session for open discussion.

To view the Call for Papers for this event or for more information, please visit: http://asmeconferences.org/TBTS2013/

Solar Hybrid Combined Cycle Performance Prediction: Influence of GT Model and Spool Arrangement

By G. Barigozzi, G. Franchini, A. Perdichizzi and S. Ravelli | Università degli Studi di Bergamo Dipartimento di Ingegneria Industriale Viale Marconi 24044 Dalmine (BG) Italy Tel +39 0352052306 fax +39 0352052077 | giovanna.barigozzi@unibg.it, giulio.bonetti@unibg.it, giuseppe.franchini@unibg.it, antonio.perdichizzi@unibg.it, silvia.ravelli@unibg.it

Power generation by Concentrated Solar Power systems is a way to reduce dependency on fossil fuels and at the same time to accomplish the international commitment of CO2 reduction. First attempts to integrate large scale power plants with concentrated solar systems were carried out in the Solar Electric Generating Systems like those operating since 1985 in California, USA. Solar energy is used to produce superheated steam on a 300-500°C temperature level depending on the used thermo fluid (oil, air, molten salt or direct steam). This steam is eventually combined in an hybrid power plant with the one produced in a conventional steam generator, prior to expansion. This solution was also proposed for Combined Cycle (CC) applications under the name of Integrated Solar Combined Cycle systems. In integrated solar cycles, thermal energy is usually introduced into the steam cycle at 500-600°C. A reasonable value for peak thermal to electric efficiency in medium temperature steam cycles is about 37%. In the last decade a large effort was made to develop high temperature and high pressure central receivers in order to increase the temperature level at receiver outlet up to 800°C - 1000°C. This higher temperature level is expected to allow the integration of solar systems with gas turbine (GT) power plants. Significant improvements in solar-to-electricity efficiency can be gained by supplying thermal energy directly to the topping Brayton cycle. A higher efficiency in solar power generation is the most valuable advantage of hybrid solar gas turbine technology, compared to other solar-fossil hybrid solutions.

A hybrid solar gas turbine uses concentrated solar power to preheat pressurized air exiting the compressor before entering the combustion chamber. The solar tower technology allows for very high concentration ratios to achieve the highest tolerable receiver temperature. A two axis tracking heliostat field collects and concentrates the solar radiation onto an absorbing device. The key component in the solar system is the receiver, where the concentrated solar power energy is absorbed and transferred to pressurized air. Hybrid solar gas turbine systems have reached a demonstration level: a 230 kWe unit has been solarized and tested in the EU-funded Solgate project. The technical feasibility of solar energy generation was successfully established also with 65 kW Capstone Microturbine. A crucial point is certainly the development of high temperature solar receivers. Even though prototypes at 30 bar with aperture radiation flux of up to 10 MW/m^2 have been shown to reach 1300°C exit temperatures, more work needs to be done to get a reliable operation state.

To investigate the hybridized solar CC power plant, and particularly the way the GT interacts with the solar system, two commercial codes were used. The simulation environment TRNSYS® with the model library STEC (developed by DLR) was used to model the heliostat solar field and the solar tower receiver. The gas turbine model as well as the heat recovery steam cycle were modeled by means of Thermoflex®. A "user defined" GT model was first developed on the base of design conditions performance, then carefully calibrated against manufacturer data to accurately predict its off design

...continued on page 54

CALENDAR OF EVENTS

DECEMBER 1, 2012
ASME Gas Turbine India Conference
Mumbai, India
http://www.asmeconferences.org/GTIndia2012/index.cfm
This conference will give you the unique opportunity to interact with experts in the gas turbine industry, as well as find out the latest methods and cutting-edge technology that can improve how gas turbines operate in the future.

JANUARY 14-18, 2013
Ultra Low NOx Gas Turbine Combustion Course
University of Leeds, Weetwood Hall Conference Centre & Hotel
Contact: CPD, Conference and Events Unit T: +44 (0)113 343 2494
Email: cpd@engineering.leeds.ac.uk
Web: www.engineering.leeds.ac.uk/short-courses/

MARCH 17-21, 2013
Middle East Turbomachinery Symposium
The program consists of Short Courses, which last all day, while the rest of the days feature alternating Lectures, Tutorials, Discussion Groups, and Case Studies. The daily schedule is set to maximize learning and networking opportunities. For more details, visit: http://middleeastturbo.tamu.edu/

MARCH 18-22, 2013
2013 IGTI Gas Turbine Training Week
Atlanta, Georgia, USA

JUNE 1-2, 2013
ASME International Gas Turbine Institute Turbo Expo Pre-Conference Workshops
San Antonio Convention Center, San Antonio, Texas USA | http://igti.asme.org/

June 1:
- *New! "Life Prediction of Gas Turbine Components & Coatings"*
- *"Gas Turbine Operations & Maintenance"*

June 1 & 2:
- *"Advances in Turbines Aero-thermo-mechanical Design and Analysis"*
- *"Introduction to Optimization Methods and Tools for Multi-disciplinary Design"*
- *"Gas Turbine Aerothermodynamics & Performance Calculations"*

June 2:
- *"A Primer on CHP Technologies"*
- *New! "Nonisentropic Compressible Flows in Gas Turbine Design"*

JUNE 3-7, 2013
ASME Turbo Expo 2013
San Antonio Convention Center | San Antonio, Texas
IGTI's flagship event comprises a major turbine conference and exhibition.

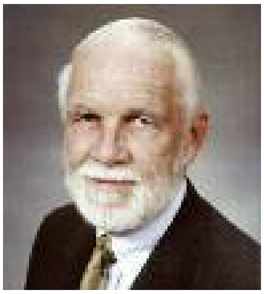
SEPTEMBER 30 - OCTOBER 3, 2013
ASME Turbine Blade Tip Symposium & Course Week
Hamburg, Germany
This technical symposium and course week will address the current state-of-the-art in the design, analysis, and improvement of turbine blade tips. A two-day course of lectures will precede the technical symposium to provide background, state-of-the-art design, and operability issues surrounding the topic. A two-day symposium will build upon the lecture series with current proposed or enacted solutions, studies to gain insight to the physics, and an industry panel session for open discussion. The course and symposium is aimed at turbomachinery designers, as well as experimental and CFD aero-thermal scientists.

JUNE 16-20, 2014
ASME Turbo Expo 2014
CCD Congress Center Düsseldorf | Save the Date!

Featured Column: ***As the Turbine Turns...***

Birds and Jet Engines

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



Langston is a former editor of the ASME Journal of Engineering for Gas Turbines and Power and has served on the IGTI Board of Directors as both Chair and Treasurer.

Since the earliest days of powered flight, airplanes and birds have on occasion run into one another.

After their historic December 17, 1903 first-powered flight at Kitty Hawk, the Wright brothers, Orville and Wilbur, continued test and training flights over Huffman Prairie in Dayton, Ohio. On September 7, 1905 Wilbur was piloting and recorded that he tangled with a flock of birds (probably red-winged blackbirds), killing one, but with no ill effects to pilot or plane.

The earliest fatal airplane crash attributed to a bird strike, took place seven years later on April 4, 1912. Calbraith (Cal) Perry Rodgers, flying in a Wright Flyer over Long Beach, California, ran into a flock of sea gulls, crashed the biplane into the surf and was killed.

The conflict between birds and airplanes has grown greatly since these earlier times, with engineers striving to ensure the safety of crew and passengers in the event of a bird strike. Jet propulsion itself seriously increased the gravity of bird strike damage, giving birds less time in which to avoid an approaching aircraft, with the resulting higher speed impact causing much greater aircraft (and bird) damage.

As many of us know, jet engines themselves are probably aircraft components most vulnerable to damage by ingested birds, composed as they are of intricate high-speed rotating parts.

All commercial jet engines must comply with bird ingestion regulations established by worldwide regulatory authorities. As pointed out in an earlier GGTN article[1], these regulations are all similar and call for demonstrations of an engine's ability to ingest birds in small, medium and large categories. Not being able to meet these regulations can have serious consequences for an engine company. For instance, while in the final stages of developing their early RB211 turbofan engine, Rolls-Royce failed certification-required bird ingestion tests, causing the bankruptcy of the company in 1971.

Most jet engine bird encounters occur during takeoff. Stuart Frost, a retired Pratt & Whitney engineer gave me a first hand account of an engine bird strike he experienced while traveling on business on a flight from Dublin to London on December 7, 1985. He was sitting in seat 2A on an Aer Lingus Boeing 737, with a good view of the front of the Pratt & Whitney JT8D-9A left engine #1. After lift-off from Dublin Airport the aircraft, with 117 passengers, encountered a flock of 20-30 Black-headed gulls (about a pound (0.5 kg) each) near the end of the runway. Several bangs were heard and the 737 yawed and buffeted. Stuart heard a loud explosive noise from engine #1, as gulls were ingested. Subsequent fan blade breakage caused an almost immediate stoppage of the engine, forcing two of the three engine mounts to fail. The now thrustless engine hung from the wing by the one remaining engine mount and two thrust reverser hydraulic lines. In the short time it took for this to happen Stuart remembers thinking, "This is going to hurt!" However, with remaining thrust from engine #2 (which had also ingested gulls) the pilot and co-pilot managed to make an emergency landing on an adjacent runway, with engine #1 barely hanging from the wing.

Frost (center) and others inspect damaged engine #1.

Photos by Stuart Frost.

Dublin Airport Black-headed gull (in winter plumage).

More recently, there was an airline bird strike incident that has come to be called "Miracle on the Hudson." On January 15, 2009 US Airways flight 1549, an Airbus 320 with 150 passengers was taking off from La Guardia Airport bound for Charlotte. About 3 minutes from take off and at about 2800 feet altitude, it struck a flock of Canada geese (which can weigh 14 pounds (6.5 kg) each), just northeast of the George Washington Bridge, losing all power in both CFM56 engines. The crew then successfully ditched the aircraft in the Hudson River with no loss of life.

According to a recent US Department of Transportation report,[2] bird strikes have steadily and dramatically increased from1,770 reported in 1990 to 9,840 in 2011, representing a five-fold increase in 20 years. The rise in strikes, as in other parts of the world is due in part to sizable increases in large bird populations. According to the DOT report, since 1988, bird strikes have resulted in 229 deaths worldwide. Annually, these incidents have caused nearly 600,000 hours of aircraft downtime, and $625M in damages.

A recent book[3] deals with some of the background and history of bird strikes and advocates a radar based warning system. The US Airforce has developed various programs for their flights to avoid bird populations. To learn more, I invite you to attend a panel that Dr. Aspi Wadia and I will co-chair, "Jet Engine Bird Ingestion–Current Issues and Ways Forward." Panel members will include bird strike experts, representatives from engine and airframe OEMs and government agencies. It will be held on June 4, 2013 at our TURBO EXPO '13 in San Antonio. ✼

References

1. Martindale, Ian, 1994, "Bird Ingestion into Aero-Engines," *Global Gas Turbine News*, Fall, pp. 4-6.
2. Gazzetti, Jeffrey B., 2012, "FAA has not effectively implemented its wildlife hazard mitigation program," Federal Aviation Administration Office of Inspector General Audit Report, AV-212-170, August 22.
3. LeMieux, Jerry, 2009, *One Bird Strike & You're Out!*, Trafford.

Experimental Investigation of Turbulent Boundary Layer Flashback Limits for Premixed Hydrogen-Air Flames Confined in Ducts

By Christian Eichler, Georg Baumgartner and Thomas Sattelmayer | christian.eichler@mtu.de

The concept of premixing fuel and oxidizer well ahead of the flame zone is omnipresent in today's combustion technology. Its application spans from laminar premixed flames in domestic gas stoves and hot water tanks over the well-known laboratory Bunsen burner up to turbulent combustion in stationary gas turbines and even aircraft engines. All these premixed combustion devices share a common type of failure mode, which is associated with the detachment of the flame from its designated stabilization region and a rapid upstream propagation into the fuel supply. The term 'flame flashback' has been coined for this scenario, which usually has to be avoided by all means to guarantee safe and stable burner operation.

While the combustion literature distinguishes between several types of flashback, the underlying principle is always the same: The vector sum of flame consumption speed and flow velocity points upstream. A particularly interesting form of flame flashback occurs inside the velocity boundary layer close to solid walls. On the one hand, flow velocity drops due to the no-slip condition at the wall. On the other hand, reactions are slowed down by heat losses to non-adiabatic walls, resulting in a finite gap between wall and flame, the quenching distance, where the global reaction is extinguished.

Intuitively, a velocity balance between the local flow velocity and the local flame speed appears to be a proper basis for the correlation of wall flashback. This concept was elaborated by Lewis and von Elbe (1943) in their well-known research article on burner flame stability. They established the critical gradient model, which expresses the flashback limit as a balance between the flow velocity, simplified as the axial velocity gradient at the wall times a wall distance, and the flame speed just at the same wall distance. Very important to say here, an interaction between flow and flame was not accounted for in the critical gradient model, i.e. the velocity profile was assumed to be undisturbed or only weakly influenced by the exothermicity of the flame.

After its introduction by Lewis and von Elbe, the critical gradient model was used for almost 70 years to explain and to correlate flashback limits in a considerable number of numerical and experimental efforts for both laminar and turbulent flows, and has been included in many textbooks on combustion technology.

Ambitious goals and initial doubts

The work presented in our paper did not intend to challenge the critical gradient concept. The design of a flashback channel with rectangular cross-section was rather based on critical gradients from the literature to provide for a well-defined experiment. The rig was set up to deliver turbulent wall flashback limits for premixed H2-air combustion at high inlet Reynolds numbers by inclining the lower wall of the duct to form an asymmetric diffuser, reducing wall shear and thus the velocity gradient along the axial coordinate. However, first results from the rig were discouraging in the fact that its stability was much lower than expected and flashback could only be observed for extremely lean mixtures combined with the highest air massflow the supply was capable of.

The ambitious goal to merge a premixed combustion experiment with a boundary layer tunnel required some unconventional designs for flow straightening, avoidance of flashback in the edges of the channel as well as for full optical access through large quartz windows. The obvious suspicion was that some peculiarity of this complex setup distorted the experimental results. To have a direct comparison against flashback limits from the literature, which were almost exclusively recorded for zero pressure-gradient boundary layers of tube burners, the lower wall of the rectangular duct was adjusted horizontal, such that a straight channel could be investigated. However, in contrast to the literature setups where flames were burning on top of the tube burner in free atmosphere prior to flashback, the flame was stabilized yet inside the channel in the current setup shown in Fig. 1, which is more representative for the safety-critical failure case and has experimental advantages.

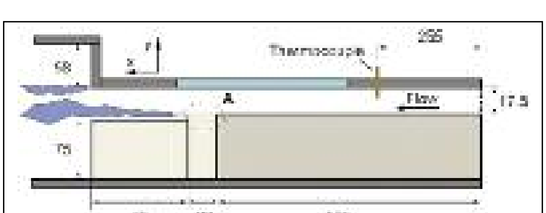


Figure 1: Straight channel measurement section.

Straight channel and a tube burner experiment

Figure 2 shows an intensified OH* chemiluminescence image of a lean H2-air flame during turbulent wall flashback in the straight channel. The measurements resulted in critical gradients that lay up to an order of magnitude above literature values from comparable tube burner experiments. At the same time, it was known from extensive cold flow characterization inside the channel, using LDA and micro-PIV, that turbulent boundary layers were in a self-similar state and mean and fluctuating velocity distributions were quasi-2D in the center of the channel as intended. With these results on the table, the picture began to clear up. The fact that the flame anchor was not positioned outside of the channel, but confined by the channel walls, must have been responsible for the drastic decrease of flame stability against wall flashback.

Figure 2: Lean H2-air flame during wall flashback in the straight channel.

At this point, one could think of two different explanations for the observation that a premixed flame which is confined inside a duct has many times the wall flashback propensity of a flame burning in free atmosphere: (1) The presence of the flame inside the duct may change the macroscopic axial velocity field, up to regions considerably upstream of the flame, which would distort the formerly quasi two-dimensional, canonical turbulent boundary layer of the isothermal flow in such a way that the near-wall region becomes retarded and velocity gradients decrease. However, since velocity gradients are computed for undisturbed flow, such changes would not be captured in the data processing. The Lewis and von Elbe model of a velocity balance in the near-wall region could then explain the large critical gradients observed in the channel. (2) The

...continued on page 53

Experimental Investigation . . .

CONTINUED FROM PAGE 52

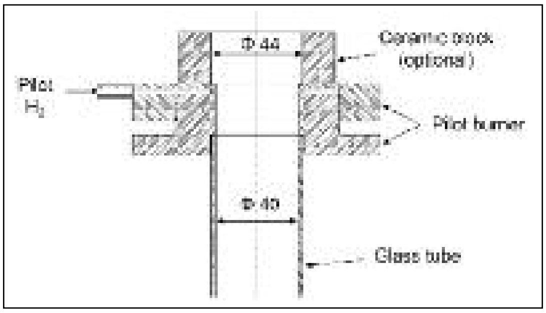


Figure 3: Tube burner setup.

presence of the flame inside the duct could only change the microscopic flow field in a small region upstream of the flame tip relative to unconfined flame holding. Since the Lewis and von Elbe model does not include a coupling between flame and flow, it fails to predict the flashback limit in this case, even if the wall velocity gradients on the duct walls are precisely known.

The channel experiment had an asymmetric flame configuration, as shown in Fig. 1. Thus, a macroscopic distortion of the channel flow profile seems much more feasible than for the axisymmetric flame holding of a circular geometry. For that reason, a tube burner experiment was set up to double-check the findings of the channel rig. The burner configuration is shown in Fig. 3. Unconfined flashback experiments were carried out by stabilizing the flame on top of the pilot burner in free atmosphere. A confined flame configuration was achieved by simply fixing a ceramic ring with a diameter higher by four millimeters on top of the pilot burner. Flashback measurements with unconfined flame holding neatly reproduced literature values for fully premixed, atmospheric H2-air mixtures and turbulent flow. Putting the ceramic ring on top was the decisive step in order to find out whether the critical gradient model of Lewis and von Elbe would still hold or not. The results of unconfined and confined tube burner experiments are plotted in Fig. 4 together with the channel results. The drastic decrease of wall flashback stability for confined flames was the very same for both, tube and channel.

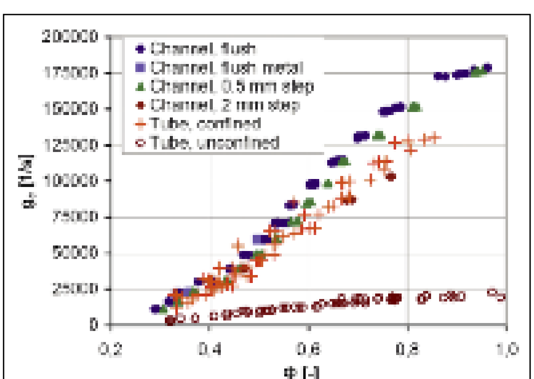


Figure 4: Turbulent wall flashback Limits of confined and unconfined premixed atmospheric H2-air flames.

Conclusion

The excellent match of confined wall flashback limits in tube and channel geometries rules out the explanation for increased limits by macroscopic flow distortion since such a strong upstream influence can be excluded for an axisymmetric tube burner arrangement (it was confirmed later on by high-speed micro-PIV in the wall region before and during flashback that this also holds for the channel setup). A microscopic interaction between the boundary layer flow field and the local pressure rise upstream of the flame obviously is a key process for the onset of wall flashback and should consequently be represented in any physically sound method for the correlation of flashback limits. The Lewis and von Elbe model, as intuitive and appealing as it appeared during almost 70 years, becomes obsolete at this point. ✻

TURBO EXPO

Turbine Technical Conference & Exposition

Presented by ASME International Gas Turbine Institute

CONTINUED FROM PAGE 47

unrivaled networking opportunities. There are benefits for all turbine industry segments: design, manufacturing, R & D, education, operations, repair/maintenance. Take the lead and plan to attend ASME Turbo Expo. Meet 3000+ turbomachinery professionals from more than 50 countries.

Young Engineer Travel Award

Applications for the Young Engineer Travel Award are now being accepted through March 1, 2013. The Young Engineer Travel Award is intended for young engineers at companies, in government service, or engineering undergraduate or graduate students in the gas turbine or related fields, to obtain travel funding to attend Turbo Expo to present a paper of which they have authored or co-authored. To apply, please visit http://igti.asme.org/Honors/.

Visa Letters of Invitation

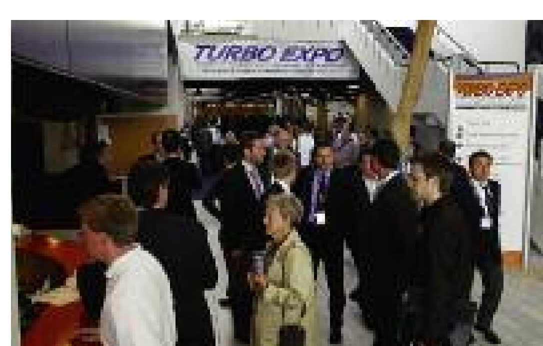
Every international visitor should check with his or her local consulate regarding visa and entry regulations for the United States. Please do this well in advance of the conference. If you require a letter of invitation to Turbo Expo as a part of a visa application, please plan on requesting the letter of invitation early.

Exposition and Sponsorship

When you exhibit at Turbo Expo, you will be among other key industry players. Exhibiting at Turbo Expo will maximize your ROI by placing your company in front of a focused target market, enabling you to generate high-quality leads to achieve your marketing objectives. Space is still available to join the leaders in the turbomachinery industry on the show floor.

Brand-enhancing sponsorship packages are available! Packages are designed around your particular corporate goals and are an extremely effective way for your company to really stand out from the crowd – before, during and after the show.

Contact IGTI at +1-404-847-0072 x1646 or via email at igtiexpo@asme.org now to be make the most with your marketing dollars. ✻



Registration at Turbo Expo 2012 in Copenhagen, Denmark

Solar Hybrid Combined Cycle Performance Prediction . . .

CONTINUED FROM PAGE 50

behavior depending on load and ambient temperature conditions. Once calibrated, the GT model was integrated in the CC power plant and coupled with the solar system. Pressure and heat losses between compressor and combustion chamber were explicitly taken into account. The hourly performance of the hybrid solar plant was calculated by making TRNSYS® and Thermoflex® to interact each other in an iterative way. This method can be easily adapted to different gas turbines since Thermoflex® permits to set "user defined gas turbine" components.

This modeling tool was applied to study three solarized hybrid GT models operating in a two pressure levels combined cycle (Figure 1). To assess the influence of GT model and spool arrangement on the solarized CC performance the following GTs were selected: the single shaft Siemens SGT800 and two two-shaft engines: the heavy-duty GT Siemens SGT750 and the aero derivative GE LM6000. Four ambient temperature profiles have been selected, one representative for each season in a high solar potential site. For each GT model, the solar field was designed so to obtain a receiver air outlet temperature of 950°C in the hottest hour of the year.

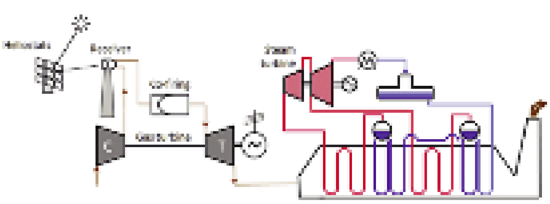


Figure 1: Layout of the combined cycle with hybrid solar gas turbine.

The simulation tool was able to predict on an hourly basis the variation of parameters like the compressor pressure ratio β, the GT inlet flow and the normalized GT free spool rotational speed influencing the hybrid GT behavior (Figure 2 – continuous lines refer to the pure fossil reference GT model). Single spool SGT-800 engine responds to solarization by slightly increasing the compressor pressure ratio, since the inlet air mass flow is governed only by the ambient conditions. When considering SGT-750 two-spool engine with a power turbine, the expansion ratio of the core engine turbine reduces. So the free shaft speed n decreases to guarantee the shaft power balance. This in turns produces a reduction in the inlet air mass flow. Finally, GE LM6000 PF engine combines both control strategies. Because of solar heating, HP shaft speed decreases slightly, leading to a small reduction in the compressor pressure ratio. This combines with the reduction in compressor inlet air flow. Note also that shaft speed variations for this engine are smaller than for SGT-750 model, resulting in a more stable behavior against variable solar input.

The solarized CC performance was then evaluated in terms of power production penalty, fossil fuel saving and solar fraction due to solarization (Figure 3 – typical Summer day). During the night, the pressure drop across pipings and receiver counteracts the beneficial effect of a decreasing ambient temperature on power production. This results in a power penalty in the range between 2% and 4% depending on the GT model. During the day, for hours between 9 and 19, the increase in the ambient temperature is overlaid with the solar heating, thus leading to a more significant power penalty up to 12%. The single spool SGT-800 was found to assure the lowest power penalty while the SGT-750 appeared to provide the highest fuel saving in the middle of the day, both in Winter and Summer, and the highest solar fraction as well. Overall Hybrid CC performances were finally evaluated and compared with the standard CC, in terms of electric power and efficiency reduction, fossil fuel saving, and solar energy to electricity conversion efficiency. The modeling results here reported provide a glimpse into the solar hybrid technologies and their impact on the efficiency standards in power generation. SGT-800 GT was found to assure an annual solar fraction of 34.2 %, the smallest penalty in GT power production because of solarization (-18.4 GWh/year) and the highest solar energy to electricity conversion efficiency of about 52%. ✲

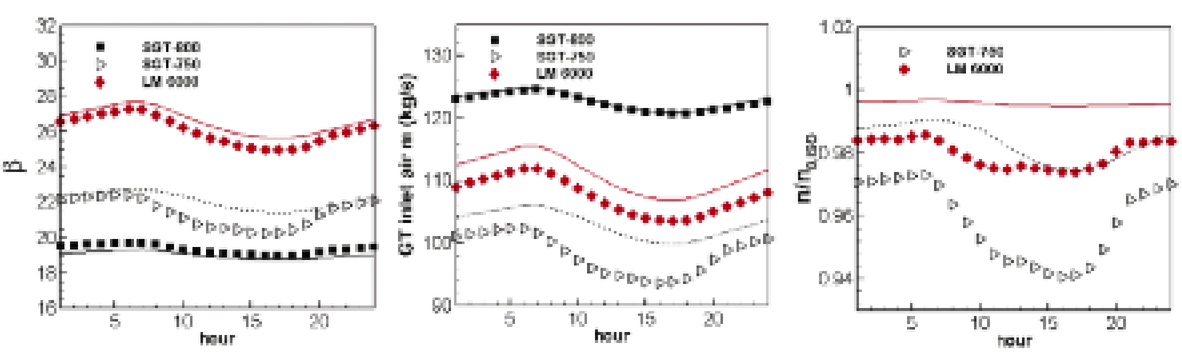


Figure 2. Hourly compressor pressure ratio β, GT inlet air mass flow, and free spool normalized speed $n/n_{0,ISO}$ in a typical Summer day.

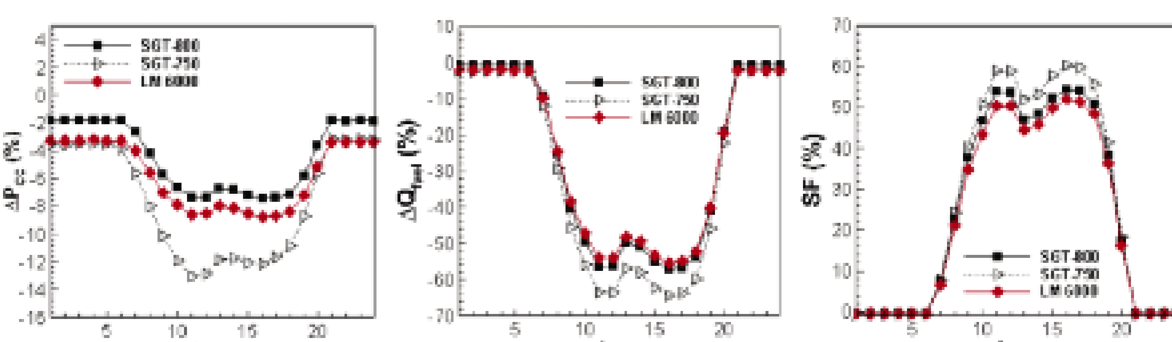


Figure 3. Hourly Net Power penalty, fossil fuel saving and Solar Fraction *SF* in a typical Summer day.