# In This Issue



Global Gas Turbine News

Volume 57, No. 3 • September 2017

ASME International Gas Turbine Institute

# ASME 2017 Turbo Expo Co-locates With Power & Energy and ICOPE

ASME Turbo Expo 2017, in Charlotte, North Carolina, USA, maintained its reputation as the world's premier gathering of over 3,000 turbomachinery professionals. Throughout the week, delegates shared practical experiences, knowledge and ideas on the latest turbine technology trends and challenges. Many expressed their appreciation for the conference, noting that it was an amazing experience, particularly for receiving valuable feedback on research from experts in the field. The moderated keynote panel session was, again, well received as the attendees submitted their questions to the moderators via their smartphones or personal electronic devices.

The audience actively submitted questions, while the moderators collected and asked the panelists for their insight. Bringing their expertise and experience, they made this format a worthwhile part of the conference. Led by Paul Garbett of Siemens Power & Gas Division, and Mark Turner of University of Cincinnati, the opening session featured an exceptional keynote focused on "Disruptive Technologies & Accelerating the Pace of Innovation in Gas Turbines", with panelists Dag Calafell, Karen Florschuetz, and Kevin Murray, followed by the annual awards program of prestigious ASME and IGTI awards.

The plenary panel sessions were well attended with great audience participation. Led by Mark Turner and Dirk Nuernberger, from Siemens, the Tuesday morning plenary session, Multidisciplinary Computations and Optimization in Gas Turbine Design, answered questions about why Computer-Aided Multi-Discipline Optimization (MDO) is important. Panelists Andrew Aggarwala, Ingrid Lepot, Robert Nichols, and Eisaku Ito did a great job presenting and responding. Additive Manufacturing Day, new at Turbo Expo, featured the Wednesday Plenary Session "Disruptive Technologies and Accelerating Innovation in Gas Turbines: The Role of Additive Manufacturing". The session, led by Karen Thole and Rich Dennis, showcased the current activities and future potential on how this rapidly developing technology will impact the gas turbine industry. Panelists Kurt Goodwin, Thomas W. Prete, Markus Seibold, Mike Aller and Rob Gorham answered the questions from the audience via the ASME app. The day was followed by panels sessions featuring the following topics: Processes & Materials for Additive Manufacturing; Design & Performance for Additive Manufacturing; Challenges and Opportunities in Using AM for Turbine Cooling; and Combustor/Fuel Injector applications for Additive Manufacturing. The day ended with AM Posters in the exhibit hall.

The Technical Conference offered five days of almost 2,000 technical paper presentations, including the Scholar Lecture by Dr. Ronald Bunker. After the technical sessions finished for the day, it was nice to wind down with the evening events throughout the week. On Monday evening over 2,000 came out for the welcome reception at the NASCAR Hall of Fame where they enjoyed the car simulator. On Tuesday, Women in Engineering held a networking event featuring a talk from Diane Beagle of GE, sponsor of the event. On Wednesday many students and early career engineers got acquainted with one another at the mixer sponsored by Dresser Rand. During the three-day exposition, delegates met with representatives from premier companies supplying quality turbomachinery products and services. Special recognition during the Closing Ceremony went to MMP Technologies and Vectoflow, as exhibition visitors voted their displays the best. Student Posters were presented on Tuesday and Wednesday afternoon in the exhibition hall, with first place going to Ariane Emmanuelli, second place to Andrew Boulanger, and the People's Choice awarded to Eric Bach.

If turbomachinery is part of your professional life, you cannot afford to miss the annual ASME Turbo Expo! To plan for 2018, see page 60 of this issue and keep informed throughout the year by visiting ASME Turbo Expo online at https://www.asme.org/events/turbo-expo.

***See the award winners on page 56***

## ASME Turbo Expo 2017 Statistics

This year at Turbo Expo, attendees represented 56 countries worldwide participating in 333 conference sessions. In these sessions, authors presented 1,098 final papers with 45 tutorial sessions and 24 panel sessions.

## Thank you to our volunteers!

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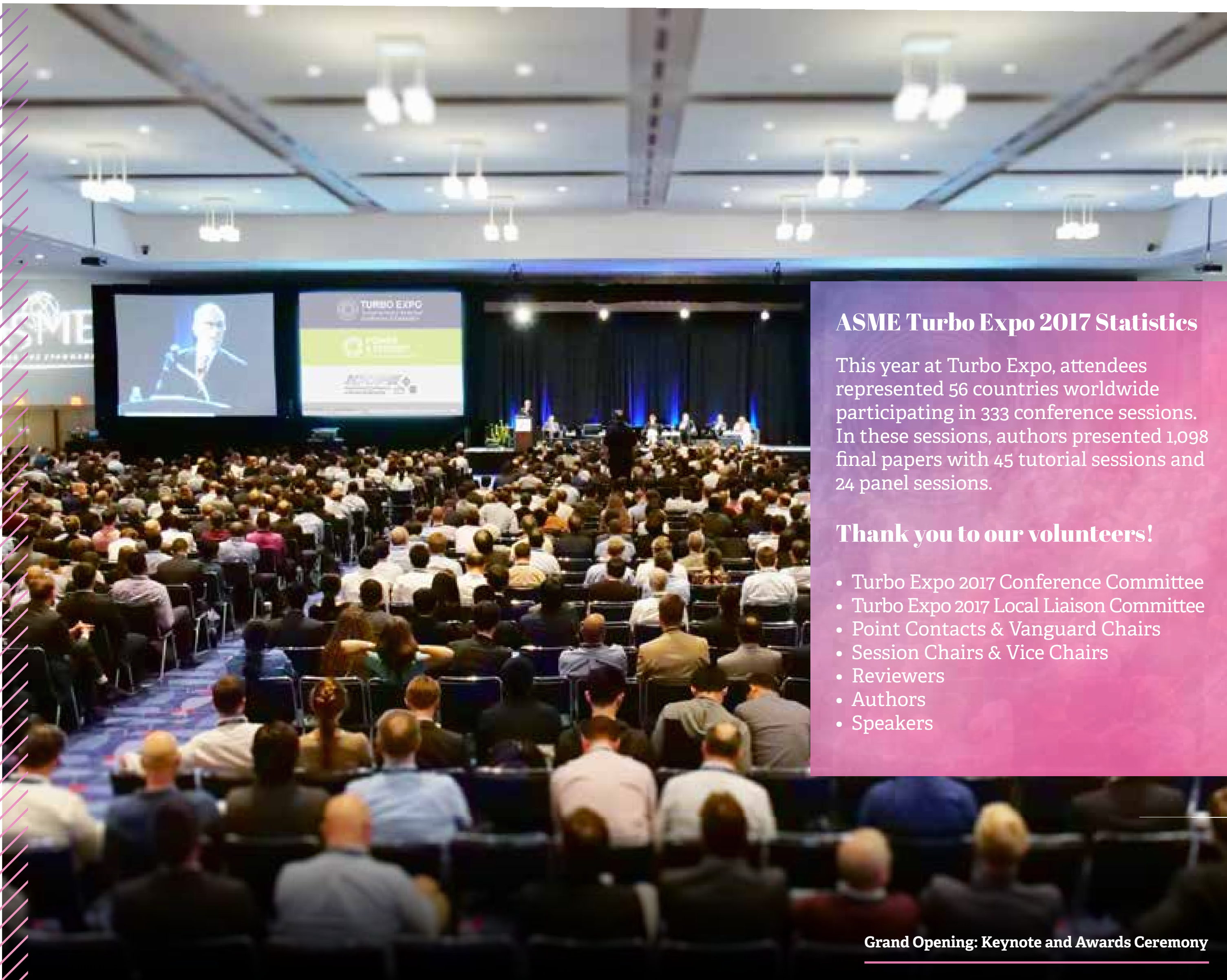


**Grand Opening: Keynote and Awards Ceremony**


**Panel Discussion: Moderated, with Audience Q&A**

**Dr. Alan Epstein, R. Tom Sawyer Award Winner**

*ASME 2017 PETE Highlights continued on the next page...*


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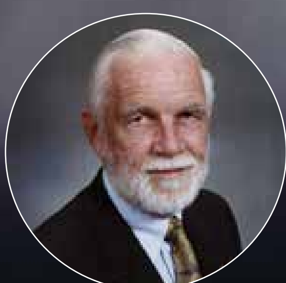
# ASME 2017 Turbo Expo Conference Highlights

1. Additive Manufacturing Plenary
2. Scholar Lecture with Ron Bunker
3. Congratulations to the 2017 Turbo Expo Student Advisory Committee Travel Award Winners.
4. Congratulations to the 2017 Young Engineer Turbo Expo Participation Award Winners.
5. Dr. Robert J. Miller and Dr. Ho-On To, University of Cambridge 2015 ASME Gas Turbine Award Winers, pictured with Piero Colonna, ASME Gas Turbine Segment Leader
6. Subith Vasu - Dilip R. Ballal Early Career Award Winner, with Piero Colonna, ASME Gas Turbine Segment Leader
7. Michael Dunn, Ohio State University - Aircraft Engine Technology Award Winner, pictured with Keith Boyer and Piero Colonna, ASME Gas Turbine Segment Leader
8. Dr. Eisaku Ito, MHI - Industrial Gas Turbine Technology Award Winner, pictured with Piero Colonna, ASME Gas Turbine Segment Leader
9. The Exhibit Hall was a consistent attraction and forum for companies to meet, network, and present themselves to the industry.
10. Congratulations to MMP Technologies for being selected as the People's Choice for Best Large Booth.
11. Congratulations to Vectoflow for being selected as the People's Choice for Best Small Booth.
12. The Welcome Reception this year was held in the NASCAR Hall of Fame.
13. Student Mixer sponsored by Dresser Rand
14. Women in Engineering Networking Event sponsored by GE


# As the Turbine Turns...

#31 September 2017



**Lee S. Langston, Professor Emeritus**
University of Connecticut
Mechanical Engineering Dept.

## Gears Steer New Engine Designs

The coterie of geared turbofan jet engine companies is growing. Rolls-Royce is now developing a geared turbofan (GTF) for its future engines in the 25,000-110,000 pound-thrust (lbt) range, slated for production in the next decade [1]. This major OEM will join Pratt & Whitney and Honeywell, who both have been designing, developing and producing GTF engines for some years.

***Figure 1***
**Rolls-Royce Epicyclic Planetary Gearbox (4;1 gear ratio 31 inches diameter)**

GTF engines have a hub-mounted epicyclic gearbox that drives the front-mounted fan at lower rotational speeds than the engine turbine section that powers the fan. The turbine driving the fan is most efficient at high rotational speeds. The fan operates most efficiently and creates less noise at lower rpm. By lowering fan blade tip speeds by means of gearing, engineers can more easily satisfy fan blade and disk stress limits and avoid the onset of power-robbing supersonic fan blade flows.

The operating gear reduction ratio also permits increasing the engine's bypass ratio with larger fans. Bypass ratios - the mass of fan air bypassed around the engine for every unit mass of air through the engine - can be increased, which improves the propulsion efficiency of the turbofan engine.

The net result is a great reduction in fan generated noise and as much as a double digit reduction in engine fuel consumption. Both of these attributes are causing airlines to demand from airframe companies, new commercial aircraft that mount the GTF engines.

## Gear Lore

Gear trains are one of the oldest known machines and none is more closely identified by the general public, with the profession of mechanical engineering. Gears use the principle of the lever to alter the speed and torque carried by shafts, and can be traced back as far as 3000 BC in use in China.

One of the most famous of ancient gear assemblies is the Antikythera Mechanism [2], recovered in 1900 from a shipwreck off the coast of Greece. Possibly constructed in Rhodes in 150-100 BC, the mechanism is an astronomical analog calculator (or orrery) that was probably used as one of the first analog computers to show celestial positions of the sun and moon, the time of solar eclipses and the dates of Olympic and Pan-Hellenic games. The Antikythera Mechanism has some 30 intermeshing gears, which include an epicyclic gear train.

So here we are, two thousand years later using the same type of gear train to improve the performance of modern gas turbines. The name epicycle goes back to Greek astronomy, where planets were believed to move in circular orbits, with the earth as center - a geocentric system. Such orbits could not explain why at times, planets moved backward, relative to the earth-bound observer. Ptolemy (150 AD) explained such retrograde motion by superposing small circles - epicycles - on the original assumed circular orbit.

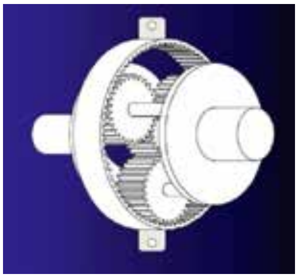


**Figure 2a. Planetary Gearbox Sketch.**

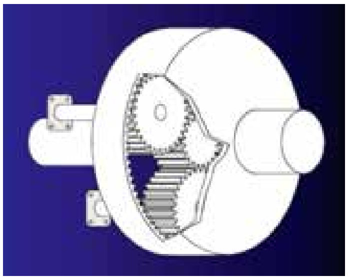


**Figure 2b. Star Gearbox Sketch**

Currently, a geared fan epicyclic gearbox consists of a center sun gear, mounted on the driving turbine shaft. The sun gear meshes with normatively, five equally-sized surrounding pinion gears, which also mesh with an encompassing annular ring gear. A circular carrier houses the five pinion gear shafts to support and position them.

If the carrier is fixed to the engine casing, the ring gear drives the fan. The pinion gears, now fixed as they transmit motion from sun to ring gear, are now called star gears. If the ring gear is fixed the carrier rotates to drive the fan. The pinion gears now rotate about the sun gear, and are called planet gears. A planetary gearbox can have higher gear ratios than a star gearbox.

# Current Production GTFs

Honeywell first started developing geared fans almost 50 years ago [3]. In 1968, then as the Garrett Air Research Phoenix Division, they developed their 3500 lbt TFE731 business jet engine from an existing auxiliary power unit (APU). Given the high rotational speed of the APU low pressure turbine (about 20,000 rpm), to avoid excessive fan tip speeds, Garrett engineers developed a epicyclic gearbox (about 8.5 inches in diameter and with a 1.8:1 gear ratio), which allowed the TFE731 to have a 2.5:1 bypass ratio (high for 1972, when it was certified). Still in production, it has been one of the most successful small gas turbine aircraft engines, with over 13,000 units produced.

Pratt & Whitney is in production of their first generation of GTF engines in the 18,000 - 30,000 lbt range, which power twin engine single-aisle, narrow body 70 - 200 passenger aircraft [4]. As an example, their PW1100-JM is currently powering the Airbus A320neo, with airlines reporting up to 20% in fuel savings. The epicyclic gearbox (about 20 inches in diameter) has journal bearings for its star gears rather than roller element bearings, with transmitted power as high as 30,000 hp. The gear ratio is 3:1, yielding a bypass ratio of 12:1. Even small inefficiencies in its double helical gear teeth and bearings could generate enough heat to "cook" gearbox lubricating oil. Testing has shown that the P&W GTF gearboxes must be at least 99.3% efficient to avoid that problem.

# Future Directions

One of my colleagues, Kazem Kazerounian (currently our Dean of Engineering at UConn) who is a gear systems researcher and an early consultant for P&W on gears, has some observations on possible future work on GTF gearboxes:

1. The challenges of light-weight, high-powered epicyclic gear systems include large deflections and vibration induced in the relatively thin ring gears (as the planets/stars pass), and the possibilities of large displacement of the center of the sun gear.

2. New developments include using Herringbone bevel gears (bevel gears of opposite directions to cancel axial thrust) and using spiral bevel gears instead of straight bevels. Additional advantages in smoothness and load carrying capacity might be obtained by phasing the two bevel gears that constitute the Herringbones, so that teeth on both sides do not enter the mesh simultaneously.

3. There is significant room for optimization if designers consider nonstandard, or even non-involute gearing. This is uncharted territory in gear design, that might decide the future leaders in GTF design and manufacturing.

* * *

New technologies evolve based on the chaotic and constant recombining of existing technologies [4]. The GTF combines existing jet engine technology with the well-established mechanical engineering technology of gears.

# References


1. Norris, Guy, 2017, "Power Plan" and "Shifting Gears", Aviation Week & Space Technology, April 17-30, pp. 58-61.

2. Jones, Alexander, 2017, A Portable Cosmos, Oxford University Press.

3. Langston, Lee S., 2013, "Gears Galore!", Global Gas Turbine News, April, pp. 51,54.

4. Langston, Lee S., 2013, "Not So Simple Machines", Mechanical Engineering Magazine, January, pp. 46-51.

# Recognizing Award Winners

## *at ASME 2017 Turbo Expo*

## 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 reading committee in the recognition of important gas turbine technological achievements.

IGTI Committees honored more than 100 authors with Best Paper Awards for papers presented. Thank you to Thomas Sattelmayer for serving as the IGTI Honors and Awards Committee Chair, John Gülen as Industrial Gas Turbine Technology Award Committee Chair, and Keith Boyer as the Industrial Gas Turbine Technology Award Committee Chair.

**2017 ASME R. Tom Sawyer Award**
Dr. Alan H. Epstein, Pratt & Whitney

**2015 ASME Gas Turbine Award**
Dr. Robert J. Miller, University of Cambridge
Dr. Ho-On To, University of Cambridge

**2015 John P. Davis Award**
Rakesh Bhargava, Innovative Turbomachinery Technologies Corp. Lisa Branchini, Michele Bianchi, Andrea Depascale, Valentina Orlandini, University of Bologna

**2017 Dilip R. Ballal Early Career Award**
Subith Vasu, University of Central Florida

**2017 Scholar Award**
Dr. Ronald Bunker, Retired from GE Aviation

**2017 Aircraft Engine Technology Award**
Michael Dunn, Ohio State University

**2017 Industrial Gas Turbine Technology Award**
Dr. Eisaku Ito, MHI

**ASME Dedicated Service Award**
Dr.-Ing. Christoph Hirsch, Technical University of Munich

**Outgoing ASME IGTI Technical Committee Chairs**

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| WIND ENERGY | KEN VAN TREUREN |

## 2017 Student Best Poster Winners

**First Place:** *Indirect combustion noise in a stator row: 2D modelling and CAA study* - Ariane Emmanuelli
**Second Place:** *Experimental Investigation of Sand Deposits on Hastelloy-X from 1000 ˚C to 1100 ˚C Using Particle Tracking* - Andrew Boulanger
**People's Choice:** *Study of the Thermoacoustic Properties of an Autoignition Stabilized Liquid Fuel Flame Using a Newly Designed Atmospheric Reheat Combustion Test Rig* – Eric Bach

**Young Engineer ASME Turbo Expo Participation Award Winners**

Alessio Abrassi
Valeria Andreoli
Myeonggeun Choi
Arifur Chowdhury
Ward De Paepe
Adam Feneley
Seyed M. Ghoreyshi
David Holst
Seongpil Joo
Julia Ling
Anandkumar Makwana
Georg Atta Mensah
Alom Mohammed Nur
Aravin Daas Naidu
Stefano Puggelli
Janith Samarasinghe
Prashant Singh
Natalie R. Smith
Adam Gabor Vermes
Sheng Wei

**Student Advisory Committee Travel Award Winners**

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James Braun
Bogdan Cezar Cernat
Theofilos Efstathiadis
Masha Folk
Chiara Gastaldi
Simone Giorgetti
David Gonzalez Cuadrado
Niclas Hanraths
Shane Haydt
Alexander Heinrich
Thomas Jackowski
Salman Javed
Nguyen LaTray
Maria Rinaldi
Deepanshu Singh
Cori Watson
Suo Yang
Lv Ye
Lisa Zander

# Call for Papers

## *ASME 2018 Turbo Expo in Lillestrøm, Norway (close to Oslo)*

### You are invited to offer a paper for publication at the ASME 2018 Turbo Expo Turbomachinery Technical Conference, June 11-15, 2018 in Lillestrøm, Norway

Prepare your abstract and submit it to the list of track topics for which ASME IGTI Technical Committees are seeking papers. Abstracts are due by August 28, 2017 and must be submitted online (plain text, 400 word limit) via the ASME Turbo Expo Conference Website at asme.org/events/turbo-expo.

**ASME IGTI Journals**
If warranted by review, papers may also be recommended for publication in the Journal of Engineering for Gas Turbines and Power or the Journal of Turbomachinery.

**Indexing**
All ASME Conference Proceedings are submitted for indexing to Scopus, Compendex, ISI Conference Proceedings Citation Index, and other major indexers. In addition, all ASME Conference papers are discoverable through Google Scholar search and all other major search engines. Indexing publishers are independent organizations and determine which and when conference proceedings are indexed.

**Publication Schedule:**

**Submission of Abstract**
August 28, 2017

**Author Notification of Abstract Acceptance**
September 18, 2017

**Submission of Full-Length Draft Paper for Review**
October 30, 2017

**Notification of Paper Acceptance**
January 3, 2018

**Copyright Form Submission Process Opens**
January 3, 2018

**Submission of Revised Paper for Review**
January 29, 2018

**Notification of Acceptance of Revised Paper**
February 12, 2018

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# Using Splitters to Control Secondary Flow

*C.Clark and G.Pullan, Whittle Laboratory, University of Cambridge*

## Aerodynamic Opportunity

Turbine design involves many engineering disciplines. The final product is a compromise between aerodynamic performance and constraints arising from mechanical, structural or material requirements. As turbine efficiency increases, engineers must revisit the performance penalties associated with these compromises and develop new ideas to improve the design. In this article, we describe one such concept: splitter vanes.

An example of an aerodynamic challenge created by a mechanical requirement is the use of turbine stators to encase components that pass through the main gas path. These components could be part of the engine structure or pipes carrying oil or air. Engineers have used two approaches to tackle this problem. In the first approach, an additional row of non-turning faired struts is added to house the components. This increases machine length, weight and wetted surface area, all reducing performance. In the second, an existing stator row is adapted to accommodate the components. In this case the machine length remains almost constant. However, the modified stators are thick, have a low aspect ratio, and secondary flows dominate.

## Secondary Flow

Secondary flow is defined as fluid with a velocity component in a direction normal to the average flow. Secondary flow is typically characterised by vortices such as those that dig away at the riverbed upstream of a bridge buttress.

“Secondary flow vortices are formed by the rotation of vorticity filaments, located in the endwall boundary layers, as the filaments move through the passage. Around each stator leading edge the inlet boundary layer rolls up into a vortex tube. A vortex “leg” enters the passage on each side of the stator. The leg next to the pressure surface at the leading edge (PS leg) sweeps across the passage, entraining more vorticity as it does so, to produce the dominant flow structure known as the “passage vortex”. The leg formed at the suction side (SS leg) remains close to the suction surface forming the counter vortex, a much smaller flow feature.

A simple equation for the production of secondary flow was proposed by Squire and Winter [1],

$$w_{sec} = -2\varepsilon \frac{\partial U}{\partial z}$$

This model predicts that the secondary vorticity ($w_{sec}$) at row exit is a function of inlet velocity gradient ($\frac{\partial U}{\partial z}$) and row turning only and thus, for a fixed inlet boundary layer profile and stator turning, the secondary vorticity will be constant.

## Secondary Losses

Although the secondary vorticity is of interest, the designer is principally concerned with the associated aerodynamic loss. The primary loss contribution is the dissipation of the secondary kinetic energy (SKE) as the vortices mix out. The SKE of a vortex is proportional to the square of its circulation. In turn, the circulation is proportional to the width of the passage (the reciprocal of the stator count). Thus, summing the secondary kinetic energy across every stator, we find an inverse dependence with stator count. Therefore, when low stator counts are used, as is common in current designs, SKE is a large contributor to aerodynamic loss.

The effect of increasing the number of stators is to produce a higher number of smaller passage vortices and a net reduction in secondary kinetic energy.

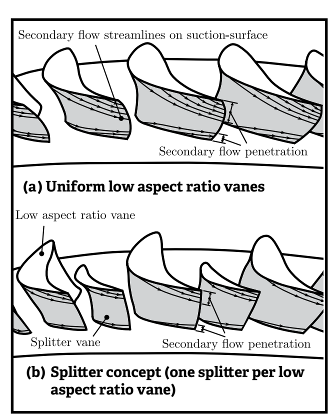



**Fig1. Schematic showing both conventional (top) and splitter (bottom) designs, both featuring streamlines due to secondary flows.**

## Splitter Vanes

The connection between the number of stators and the secondary kinetic energy suggests that the only way to significantly reduce the mixing loss is to increase the number of blades in the row. However, the large thickness needed to pass the structural or pipe components means that the stator count is limited.

The solution requires challenging one of the most common features of a turbomachine – that all blades in a row are the same. Once the possibility of a "non-uniform" stator row with thick blades shielding components and thinner "splitter vanes" to reduce the secondary flow is considered, the design space is greatly expanded.

It was found that both the stators and splitter vanes must be designed simultaneously to achieve peak performance. This increases not only the design possibilities but also the complexity of any numerical simulations performed. The designs evaluated in the current work were produced with fast turn-around computational fluid dynamics (10 minutes per solution) and automated optimization techniques.

## The Horseshoe Vortex Jump

During the design process a critical flow feature, only found in non-uniform blade rows, was identified. If the leg of the horseshoe vortex of the thick stator passes upstream of the splitter vane leading edge the vorticity that the designer intended for the first passage is now diverted to the second. This results in a single large passage vortex rather than two smaller ones. In this situation the primary benefit from including splitter vanes is not achieved. Through careful profile design, it was possible to avoid the horseshoe vortex jump and hence successfully reduce the secondary flow strength, improving stage performance.

Experimental tests showed that the underlying theory was correct and that by increasing vane count the secondary kinetic energy was reduced by up to 80%. This in turn lead to increases in stage efficiency of almost 1%, representing a significant fuel saving [2].

## References


1. Squire, HB and Winter, KG, 1951 "The Secondary Flow in a Cascade of Airfoils in a Nonuniform Stream". Journal of the Aeronautical Sciences, April 1951

2. "Secondary Flow Control in Low Aspect Ratio Vanes Using Splitters, J. Turbomach 139 (Apr 11, 2017) (11 pages) Paper No: TURBO-16-1304; doi: 10.1115/1.4036190"

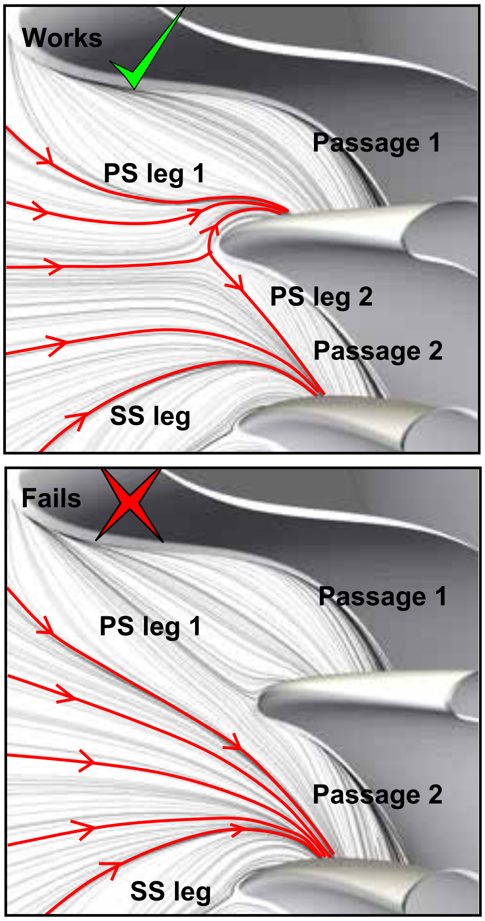
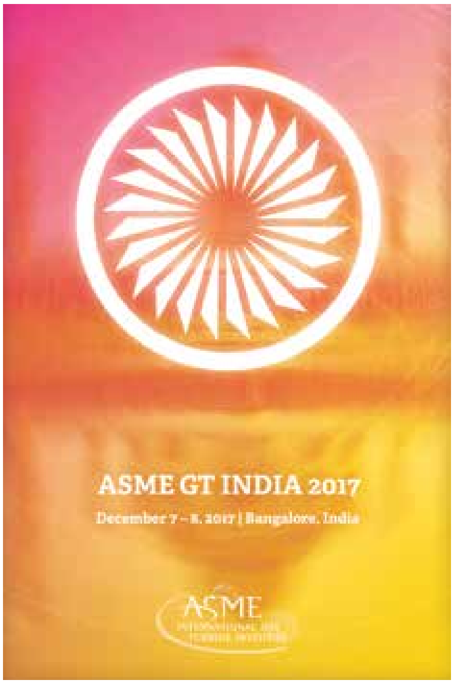




**Fig2. Computational endwall streamlines demonstrating a horseshoe vortex jump caused by slight design differences.**

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