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ASME SETTING THE STANDARD

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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 2022 Turbo Expo

June 13 - 17, 2022 | Rotterdam, Netherlands

WE ARE BACK!

Plan now to join us in person in **Rotterdam**. Over 2,000 turbomachinery colleagues from around the world will be at **ASME Turbo Expo**, ASME's premier turbomachinery technical conference and exposition, set for **June 13-17, 2022**.

This year's technical program will include hundreds of presenting authors in the paper sessions along with tutorials and panels by leading industry experts. There will be recorded video presentations available on-demand for all registered attendees to review before, during, and after the event.

The Conference offers unrivalled networking opportunities, including an open bar Welcome Reception on Monday to kick-off the Conference, open bar afternoon exhibit hall receptions Tuesday to Thursday, a student networking event, the women in turbomachinery event and a dedicated and diverse trade show floor. The three-day exhibition attracts the industry's leading professionals and key decision makers, whose innovation and expertise are helping to shape the future of the turbomachinery industry. In addition, the Student Poster Session, presented by the Student Advisory Committee, will provide students an opportunity to display their research outside of a technical paper while still contributing to the continuing advancements in the turbomachinery community.

Please be assured that we are continuing to closely monitor the latest public health and government advice with regard to COVID-19 (coronavirus) and are carefully adhering to their directions. Our absolute priority is to safeguard the health and welfare of all those involved in our event. Thank you for your ongoing support and understanding as we return to our face to face event in Rotterdam.

Elevate Your Brand at ASME Turbo Expo

We are back – and we understand that you need return on investment for your sponsorship, exhibiting, and advertising dollars after the last few years of the unknown. Partnering with **ASME Turbo Expo** gives you strategically focused access to an influential audience of commercial, governmental and academic engineers in the field of turbomachinery. This alliance offers many key opportunities, including high visibility, hospitality, and networking.

Kicking off the conference on a positive note, the Keynote and Luncheon on Monday allows for establishing connections with the attendees prior to the exhibit opening on Tuesday. Monday evening, in a casual atmosphere with attendees, the Welcome Reception is an opportunity for exhibitors to establish new connections and strengthen existing ones. During the exhibit, Tuesday through Thursday, industry leading exhibitors showcase their innovative and essential products. Afternoon hall receptions and afternoon coffee breaks allow for more networking with the attendees and casual engagement time to showcase their products and services to the over 2,000 attendees.

Maximize your return on investment! Optimizing your dollars through partnering with ASME Turbo Expo, you ensure that your exhibit will get the attention of the attendees at the conference and throughout the year. Your company will be front and center with our influential community.

This partnership provides you with an exclusive opportunity to cultivate mutually beneficial relationships with our attendees in ways that are best suited to meet the individual needs of your business.

Combine any of the Conference sponsorship opportunities with an exhibit booth to maximize your exposure at Turbo Expo and customize your experience.

Complement the professional technical sessions by enabling attendees to see, hear, examine, question, and evaluate the latest developments in equipment, supplies and services which are recommended for use in the field of turbomachinery.

Contact igtiexpo@asme.org today for exhibition, sponsorship and advertising opportunities for ASME Turbo Expo 2022. event.asme.org/Turbo-Expo/Sponsor-Exhibit/Exhibition-Information

Awards & Scholarships

Young Engineer Turbo Expo Participation Award

The ASME IGTI Young Engineer Turbo Expo Participation Award (YETEP) 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 ASME Turbo Expo, where they can present a paper which they have authored or co-authored.

FEBRUARY 1, 2022

Nomination Deadline for ASME Turbo Expo 2022 in Rotterdam

Student Advisory Committee Travel Award

The Student Advisory Committee (SAC) represents the interest of the students who attend ASME Turbo Expo and serves as a student-specific liaison to the Gas Turbine Technology Group. The Committee will engage students by creating student-oriented programs at ASME Turbo Expo, such as poster presentation, tutorial sessions and activities that facilitate student interaction and networking with turbomachinery professionals.

DECEMBER 16, 2021

Nomination Deadline for ASME Turbo Expo 2022 in Rotterdam

For more information on the ASME International Gas Turbine Honors and Awards Opportunities, visit community.asme.org/international_gas_turbine_institute_igti/w/wiki/4029.honors-and-awards.aspx

ASME Scholarships

ASME Scholarships
go.asme.org/scholarships
ASME FOUNDATION

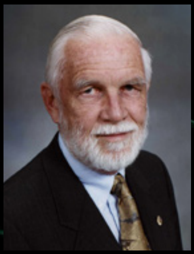
Is the financial burden of paying for education stressing you out? Are you working several jobs to pay for classes? Don't fret—ASME is here to help!

ASME has several scholarships available and we're looking for outstanding engineering students, like you, to take advantage of this opportunity and contribute to the turbomachinery community.
Here's what you need to know before applying:

- We have 60+ scholarships available—for both undergraduate, and graduate students. **IGTI is offering one for turbomachinery students for $2000**.
- Scholarship money is paid to the recipient's academic institution.
- Established college level GPA, minimum 2.5 out of 4.0.
- By completing a single electronic application, you will be applying for any ASME Scholarships for which you may be eligible, including the ASME IGTI Student Scholarship for students focusing on the turbomachinery field.
- ASME Student Members who demonstrate a high level of financial need—we want to help you graduate!

The application opens this year starting **November 24 to February 17** (for Undergraduate student applications), and **November 24 to March 3** (for Graduate student applications) for scholarships funding the following academic year: go.asme.org/scholarships.

The Ascent of Geared Turbofan Engines



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

This past year was a milestone for Pratt & Whitney, currently the largest producer of commercial aviation geared turbofan jet engines. It has been just over five years (January 2016) since P&W provided its first PW1100G, 30,000 pound thrust (lbt) engines for Lufthansa's new Airbus twin-engine A320neo aircraft. Pratt now has over 1000 aircraft powered by their geared turbofan (GTF) engines, for airframe companies Airbus, Irkut, Embraer and Mitsubishi, and ranging across some 51 airlines.

After a few years of “new engine” problems that have been sorted out, their GTF has achieved a competitive state of maturity and reliability, while yielding a record-breaking 16-20 percent reduction in fuel consumption and substantial noise reduction. This should guarantee the GTF family will have a growing market presence—and profitability—for decades to come.

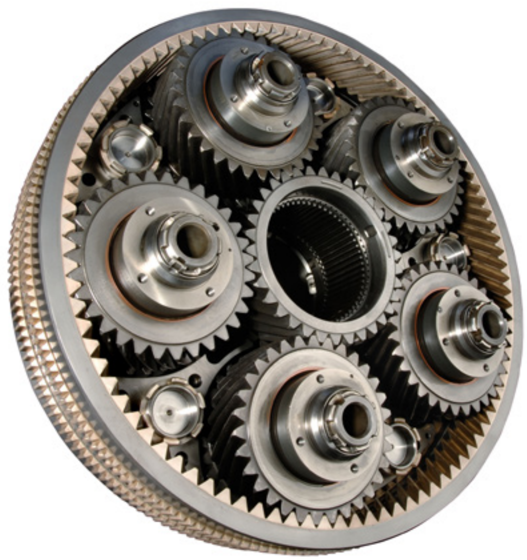


Figure 1. Pratt & Whitney epicyclic gearbox.

Why Gears?

In an earlier article [1], I traced a short history of the decades-long P&W geared fan development effort, which I will draw upon here.

The first commercial jetliners were powered by turbojets — jet engines in which all thrust is provided by gases that go through the engine from inlet to exhaust nozzle, exiting in a single high velocity jet. The resulting momentum increase provides the thrust force necessary for flight, but kinetic energy is “wasted” in the exiting jet.

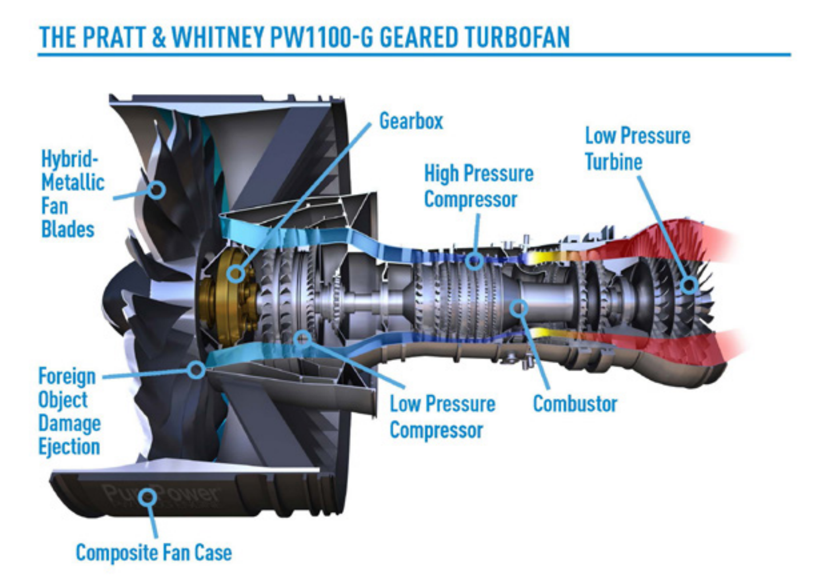
A more efficient design is the turbofan jet engine, so-named for a ducted fan mounted in the front. Air drawn into the fan is divided, with some flowing through the fan into the jet engine itself and the remainder bypassing the engine. The lower velocity bypassed air and the higher velocity engine air combine downstream to produce thrust with a larger mass flow at an average velocity lower than the high velocity jet exit flow.

With a large frontal area, the commercial aircraft turbofan is designed to produce peak thrust at takeoff with most of the thrust produced by air drawn in by the fan and bypassing the jet engine core itself. Bypass ratios—the mass of fan air bypassed for every unit mass of air through the engine—currently can be as high as 8.4:1, as in General Electric's 100,000 pound thrust GE90 engine that is used on Boeing 777s.

While driving the fan with the jet engine turbine spool is a necessity, the two components have divergent needs. On one hand, the turbine within the engine is most efficient at high rotational speeds. But the much larger diameter fan operates most efficiently and creates less noise at lower rpm. Also, by lowering fan tip speeds, engineers can satisfy stress and supersonic flow limitations.

The solution Pratt & Whitney engineers came up with involves separate gear-connected shafts for the fan and the compressor and turbine spool, so each component can run closer to its optimal operating speed. The geared turbofan uses a fan hub-mounted epicyclic gear train. (For reference, a hand-cranked pencil sharpener uses epicyclic gearing). A “sun” gear is mounted to the shaft running through the compressor and turbine. The sun gear meshes with five surrounding intermediate gears. A carrier, stationary with respect to the engine casing, supports the five intermediate gears which all mesh with an outer ring gear attached to and driving the fan.

Since the carrier is fixed, causing the five intermediate gears to be fixed in position, they are called “star” gears,



meshing with the sun gear. (If the ring gear was fixed and the carrier was coupled to the fan, the intermediate gears would be termed "planetary."). All five star gears have small-diameter, high-load carrying journal bearings, and have double helical teeth chosen for load sharing capacity and smoother meshing action.

Gearboxes add weight, to be sure, but that's compensated for by the elimination of components in the engine core. A conventional engine in the same thrust range would normally have 21 to 23 stages of blading; the GTF engine, with its core operating at non-compromised fan conditions, has only 17 stages. Also, the core engine parts that have been eliminated involve high-cost materials, such as superalloys that can withstand high temperatures, while the gearbox materials are less exotic, providing a potential cost benefit.

Even so, it is critical that the GTF gearbox be very efficient in transmitting power from the compressor/turbine spool to the fan. The transmitted power is as high as 18,000 hp for the Mitsubishi engine and 30,000 hp for the Airbus 320neo engine. Even small inefficiencies such as gear tooth mismatch and bearing misalignment would generate enough heat to "cook" gearbox lubricating oil. Testing has shown that GTF gearboxes must be at least 99.3 percent efficient to avoid that problem.

P&W engineers found that some 80 percent of the heat load in the gearbox actually comes from churning and foaming of the oil. Much of their design effort has gone into getting lubrication oil quickly into and out of the unit, to prevent heat load buildup.

Currently, P&W's first generation geared turbofan engines use a gear reduction of 3:1, with a resulting bypass ration of 12:1. The resultant fuel consumption is as much as 16-20 percent lower than with current conventional fan engines. Noise reduction is substantial, with the characteristic turbofan whine being replaced by a lower frequency "whoosh."

With the 3:1 gear ratio a success, Pratt plans to move on to higher thrust models—and to higher gear ratios. At a 4:1 ratio, for instance, the bypass ratio can be increased to 15:1. That would lead to potentially greater fuel savings, and possibly create a greater disruption in the jet engine market.

Other Gears and Fans: Embraced or Shunned

Honeywell, a leading OEM for small jet engines (less than 10,000 lbf) has had its TFE731 geared fan engine, beginning in the late 1960s. Since then, it has produced well over 15,000 geared fan engines, for business, and small airline and military jets [2].

Of the big three large jet engine OEMs—P&W, GE and Rolls-Royce—currently, only Pratt has geared fan engine production.

The view of the other two major OEMs on gears was best summarized during the keynote discussion period at the ASME Turbo Expo in Reno in 2005. Retired Rolls-Royce chairman Sir Ralph Robins and retired GE Aircraft Engines CEO Brian Rowe both remarked that as young apprentice jet engine engineers they had learned that gear systems were to be avoided. Louis Chenevert, then Pratt & Whitney's president, retorted that the company's successful engineering development of the GTF gear system showed that not to be the case.

Since then, R-R has been developing a epicyclic fan gearbox for its future Ultra Fan engine. GE is still geared fan free, but its affiliate CFM's RISE open rotor engine, does require a gearbox.

The Past and the Present

Gears have been around for a long time. Recently it has been discovered that the Greeks had used epicyclic gear systems two thousand years ago, in the Antikythera Mechanism, probably the world's first analog computer [3].

ASME participated in a ceremony to recognize it as an engineering landmark, at the National Archeological Museum in Athens, on June 26, 2019. More than 100 people attended the event, including representatives from Pratt & Whitney and Aegean Airlines. Aegean had just purchased P&W GTF engines, thus bridging some 2000 years of Greek gear history.

References

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3. Jones, Alexander, 2017, *A Portable Cosmos*, Oxford University Press.

A New Stall Warning Strategy for Gas Turbines

Dr. Fangyuan Lou, School of Mechanical Engineering, Purdue University

The Pall of Stall in Gas Turbines

Over the past 80 years, one challenge that has plagued the development of gas turbine engines, from early designs to the advanced engines of present days, is stall and surge. Stall is the partial breakdown of airflow through an engine which is typically caused by an increased air inlet angle to the compressor blade. It is a progressive condition that can lead to surge, which is the total breakdown of airflow through the engine. One excellent explanation of the differences between stall and surge is given by Day [1]. In one's words, stall is a flow disturbance in the tangential direction, whereas surge is a flow disturbance in the axial direction.

When the compressor surges, engine vibration increases, creates sudden banging sounds, and combustor-induced flames can shoot out. Thus, it can cause severe damage to gas turbine engines. Though modern design and fuel control systems usually keep gas turbine engines away from operations that bring stall or surge, the pall of stall in gas turbines is never gone. To clear this cloud, researchers have been actively looking for precursors signs that can be detected so the conditions can be avoided.

With extensive research on stall inception mechanisms, it is now clear that there are two routes to compressor rotating stall with different onset mechanisms. One is through the growth of small amplitude (compared to the mean velocity) disturbances with large-length scales (full annulus), which lead to the modal-type rotating stall. The other is through transient disturbances with much shorter length scales (several blade pitches), leading to the spike-type rotating stall.

Despite the progress in understanding the stall inception mechanism, it is hard to identify the small disturbances associated with compressor stall from those related to turbulent flow. When evident precursors occur, the gas turbine engine runs into stall within a few milliseconds. That is not enough warning time for action. For instance, one rotor revolution for an aircraft gas turbine typically takes about 5 milliseconds. It takes several revolutions for rotating stall to develop. The typical time period required for a variable stator or bleed to activate is around 200 milliseconds [2]. When considering the disparity of these time intervals, the challenge of having the engine health management (EHM) or full authority digital engine control (FADEC) sense a precursor and take the necessary action to avoid stall and surge becomes obvious.

The New Approach

Inspired by the successful implementation of nonlinear feature extraction algorithms in fault/failure diagnosis in engineering, researchers at Purdue University used a nonlinear feature extraction algorithm to extract the early and small stall precursors, providing enough warning time for action to correct the situation.

The nonlinear feature extraction algorithm includes phase reconstruction of time-series data and evaluation of approximate entropy. The parameter, approximate entropy (ApEn), was first introduced by Pincus [3]. The parameter has nothing to do with thermodynamic entropy. Instead, it is a statistical parameter that measures the amount of regularity and unpredictability of fluctuations in time-series data. A time series with more repetitive patterns of variations renders smaller approximate entropy values and vice versa.

The algorithm was applied to a multi-stage axial compressor that models the rear stages of a high-pressure core compressor. Compressor stall was approached by gradually closing the throttle while holding the corrected speed constant. The pressure signal from a single transducer instrumented upstream of Rotor 1 was used for stall warning,

Figure 1. Photo and Cross-section of the 3-stage Axial Compressor at Purdue University.

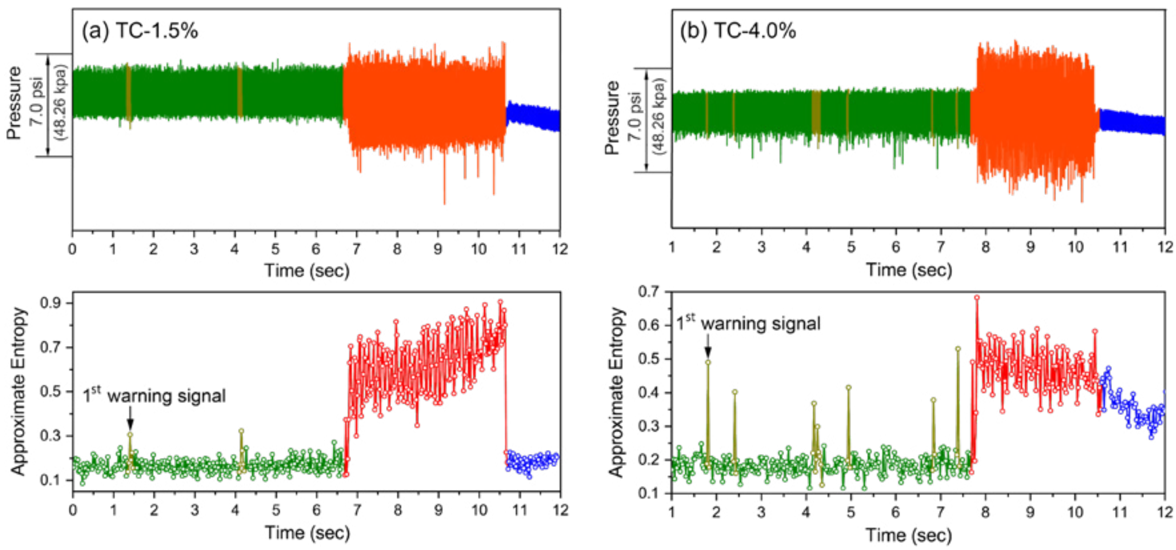

Figure 2. Instantaneous Pressure Traces over Roter 1 and the Corresponding Approximate Entropy at 1.5 percent Tip Clearance (a) and 4.0 percent Tip Clearance (b).

as indicated in Fig. 1. Previous research [4] shows that, for this compressor, stage 1 is always the limiting stage. Stall cells develop in stage 1, further extend to stages 2 and 3, and eventually cause the whole machine to stall. Additionally, the compressor showed a change in pre-stall signature with changes in rotor tip clearance. At design speed, the compressor has a strong pre-stall modal behavior at smaller rotor tip clearances (1.5 and 3 percent tip clearance with respect to the blade height) but is dominated by a spike-type stall at 4.0 percent tip clearance.

Figure 2 shows the instantaneous pressure traces over Rotor 1 during stall inception and the corresponding approximate entropy. For both tip clearance configurations, a significant increase in the magnitude of pressure traces and the calculated approximate entropy occurred at compressor stall.In addition, pre-stall disturbances were detected using the approximate entropy parameter. Each pre-stall disturbance results in a peak in approximate entropy, shown in dark yellow in the figure.

For instance, in the configuration of 1.5 percent tip clearance (TC-1.5 percent), the first disturbance during one stall inception campaign appears approximately 5-seconds prior to stall and results in a 75 percent increase in approximate entropy, as shown in Fig. 2a. Similarly, the first pre-stall disturbance observed in the 4.0 percent tip clearance (TC-4.0 percent) configuration with spike-type stall occurs approximately 6-seconds prior to stall and results in an almost 200 percent increase in approximate entropy, as indicated in Fig. 2b. These peaks in approximate entropy show the potential utility of using approximate entropy for compressor stall warning in gas turbine engines. Additionally, as with other stall warning techniques, the intelligent choice of several parameters must be exercised, including the number of data points, embedding dimension, time delay, and radius of similarity. Details of the considerations for selecting these parameters can be found in Ref. 5.

Implications

On the path of finding a reliable stall warning signal, this article introduces a new approach to detect small pre-stall or pre-surge disturbances using nonlinear feature extraction algorithms. Analysis of the unsteady pressure signals acquired in two compressor research facilities shows the potential of using approximate entropy for compressor stall warning.

Furthermore, with appropriate tuning of several parameters, including the number of data points, embedding dimension, time delay, and radius of similarity, the technique could be implemented within a real-time health monitoring system in a broad scope of turbomachines such as gas turbine engines and industrial compressors connected to large volumes.

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The ASME 2021 Advanced Manufacturing and Repair for Gas Turbines Symposium (AMRGT) held October 5-7, surpassed expectations bringing together engineers, designers, repair professionals and business leaders from around the globe.

Speakers discussed topics relevant to today's advanced manufacturing and repair industry tackling approaches to achieve zero emissions, addressing legal issues in manufacturing, and reviewing process compensated resonance testing. Session presenters provided in depth and informative presentations followed by interactive question and answer sessions. Topical networking sessions were alive with vibrant debates about the future of engineering and the role of repair in optimizing the hot section life cycle.

WE WOULD LIKE TO THANK

our platinum sponsors, **Ansys** and **Liburdi Turbine Services**, as well as our bronze sponsor **Pratt and Whitney**, for supporting this conference. We also recognize the **AMRGT Organizing Committee** for the wholehearted and selfless volunteer hours that they collectively dedicated toward the successful technical program of the conference.

ASME 2021 Gas Turbine India Conference

December 2 - 3, 2021

Virtual Event

The two-day virtual event attracts the industry's leading professionals and key decision makers, whose innovation and expertise are shaping the future of turbomachinery. Authors and presenters are invited to participate in this event to exchange ideas on research, development and best practices on Gas Turbines and allied areas. Participating in the conference and exhibition is an excellent opportunity to initiate and expand international co-operation.

Register today at event.asme.org/GT-India.