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IN THIS ISSUE...

AMERICAN SOCIETY OF MECHANICAL ENGINEERS (ASME)

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Letter from the Editorial Committee #1

DEAR READERS,

Welcome to this edition of the ASME Global Gas Turbine News (GGTN). We are excited to introduce a new feature to our publication: a brief editorial note with each issue, offering highlights and context for the content we present, and reinforcing our connection to the global turbomachinery community.

But first, we would like to take a special moment to honor Professor Lee S. Langston, who over the past 15 years authored 58 insightful columns under the title "As the Turbine Turns". His blend of technical knowledge and storytelling has enriched this publication and shaped the way we connect across generations of turbomachinery enthusiasts. We deeply thank him for his exceptional dedication and impact.

This current issue features two outstanding technical articles that exemplify the innovation and diversity in our field. Researchers from the German Aerospace Center (DLR) share insights on Variable Cycle Engine technologies, a promising approach to achieving efficiency and flexibility across flight regimes. We also highlight work from NASA Glenn Research Center on Environmental Barrier Coatings for ceramic matrix composites, which are crucial for enabling high-performance, durable turbine components in extreme environments. These articles reflect the balance we strive for between topics relevant to aerospace propulsion and land-based power generation, while showcasing contributions from both industry and research institutions.

Going forward, we are committed to ensuring that GGTN remains a platform that reflects the breadth and diversity of our international community—featuring authors from academia, government, and industry, and including perspectives from across the globe. Your participation is vital to this effort. Whether you're submitting an article, suggesting a topic, or sharing your experience, we welcome your involvement. Together, we can continue to shape a publication that reflects the full spectrum of innovation and expertise in our field.

Thank you for being a part of the ASME Global Gas Turbine News community. We look forward to exploring the future of turbomachinery with you.

Warm regards,

DR. TAMY GUIMARÃES
On behalf of the Editorial Committee
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Variable Cycle Engine Concepts and Technologies: Bridging Efficiency and Performance

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INTRODUCTION

Modern aviation requires propulsion systems that can balance efficiency and performance across a range of flight conditions. This is particularly important for supersonic and military aircraft, where engines must operate efficiently at subsonic speeds while providing the necessary thrust for supersonic flight. Variable Cycle Engines (VCEs) address this requirement by using adaptive components to enable real-time optimisation of engine parameters. By adjusting bypass ratios, turbine operations and compressor settings, VCEs offer unparalleled flexibility. This reduces performance compromises and allows for more fuel-efficient and environmentally friendly operations, establishing VCEs as a cornerstone of next-generation propulsion technology.

But what exactly is a variable cycle engine? VCEs, also known as adaptive cycle engines (ACEs), aim to optimise the thermodynamic cycle, i.e. engine operating behaviour, in response to changing conditions and requirements. Unlike specific engine concepts such as the turbojet or the turbofan, the term 'variable cycle engine' refers to the broader idea of adapting and optimising the cycle to operational requirements throughout the flight envelope. These engines enable the adjustment and optimisation of various target variables according to the task at hand. This is accomplished with variable geometry components.

KEY COMPONENTS AND DESIGN FEATURES

VCEs achieve their adaptability through variable components, including compressors, turbines, and/or mixing systems. The ability to modulate these elements allows for significant adjustments to engine performance.

Variable Compression System: The fan pressure ratio (FPR) is an important parameter for turbofan engines. In traditional engines, the FPR at the design point determines the specific thrust and specific fuel consumption for the entire flight range. In engines with multiple bypass ducts, the fan is divided into front and rear sections (see Figure 1). Variable area mixers and nozzles can be used to control the FPR and increase engine flexibility, enabling efficient subsonic flight with low FPRs and high-thrust supersonic flight with high FPRs. However, this presents challenges for the compressor system, particularly for the rear fan block located between the bypass ducts, since it must operate efficiently with varying mass flows. The choice of shaft driving the rear fan has a significant impact on the aerodynamic design of the compressor system.

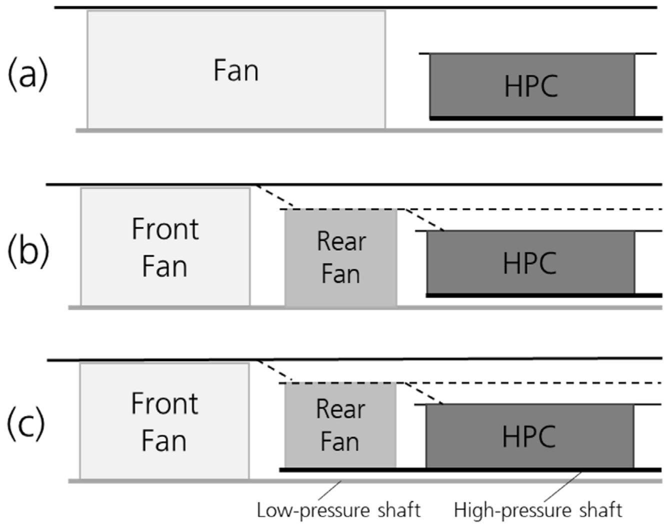

Figure 1. Schematic comparison of conventional compression system (a) versus split-fan (b) and core-driven fan (c). Dashed lines show possible variable geometries and a potential subdivision of the bypass flow.

Variable Turbines: Although variable turbines can significantly impact engine cycles and offer numerous benefits in terms of work and shaft-speed regulation between spools, they are not prioritised in aviation. This is because they are more complex than variable compressors and their practical implementation poses challenges. A variable geometry requires an actuating mechanism that is capable of withstanding the high temperatures and thermal stresses typical of the turbine section. In addition it must remain compact and lightweight for an aero-engine. Turbines face challenges in operating in thermally and mechanically demanding environments, where they are subjected to high temperatures and thermal expansion. In order to integrate a variable vane actuation mechanism alongside the complex secondary air system, it must be compact and able to withstand such conditions. The main reason variable turbines are not the focus of current VCE concepts is the difficulty of finding a lightweight, compact mechanism that can operate at high temperatures. Nevertheless, there is significant potential and interest in utilising variable turbines in aviation, as demonstrated by recent studies on combined cycles and recuperated engines.

Mixing systems or variable area bypass injectors (VABIs): To save weight and installation space, individual bypass ducts can be avoided by mixing the bypass flows. However, for certain mixing conditions, undesirable reverse flows can occur from the second bypass port to the first. This must be mitigated, as it can compromise stable engine operation. Mixing also imposes an additional design constraint that affects engine matching. Including a mechanism that allows the mixing areas and static pressures to be adjusted helps to avoid reverse flow. Area adjustment can also affect the mixing mass flow ratio, which can significantly impact a VCE's ability to adapt the cycle.

ADVANTAGES AND CHALLENGES

Variable cycle engines can offer several significant advantages over conventional turbofan engines.

Fuel efficiency: A VCE offers significant potential for improving propulsive efficiency at subsonic speeds by optimising the thermodynamic cycle and redistributing the mass flows within the engine.

Thrust flexibility: VCEs can adapt their bypass ratios and pressure ratios to deliver high thrust for supersonic flight while maintaining efficiency at lower speeds. This flexibility is particularly advantageous for military aircraft operating across a wide range of flight conditions.

Reduced installation drag: Through “flow holding” capabilities, VCEs maintain maximum inlet flow even under part-load conditions, thereby minimising drag forces at the engine inlet and nozzle. This improves aerodynamic performance and saves fuel.

Thermal management: The additional bypass streams in VCEs enhance cooling capabilities, allowing heat generated by advanced avionics and power-intensive systems to be dissipated. This feature is essential for next-generation combat aircraft.

However, it is difficult to quantify the benefits, as these depend on various criteria, such as aircraft requirements, the design of the flight mission, and financial and strategic considerations. A final assessment requires an overview of all factors. Focusing on values such as fuel efficiency or thrust alone is insufficient. VCEs face several challenges, including increased weight and complexity due to the additional variable components. Integrating these systems also requires sophisticated control mechanisms to ensure smooth

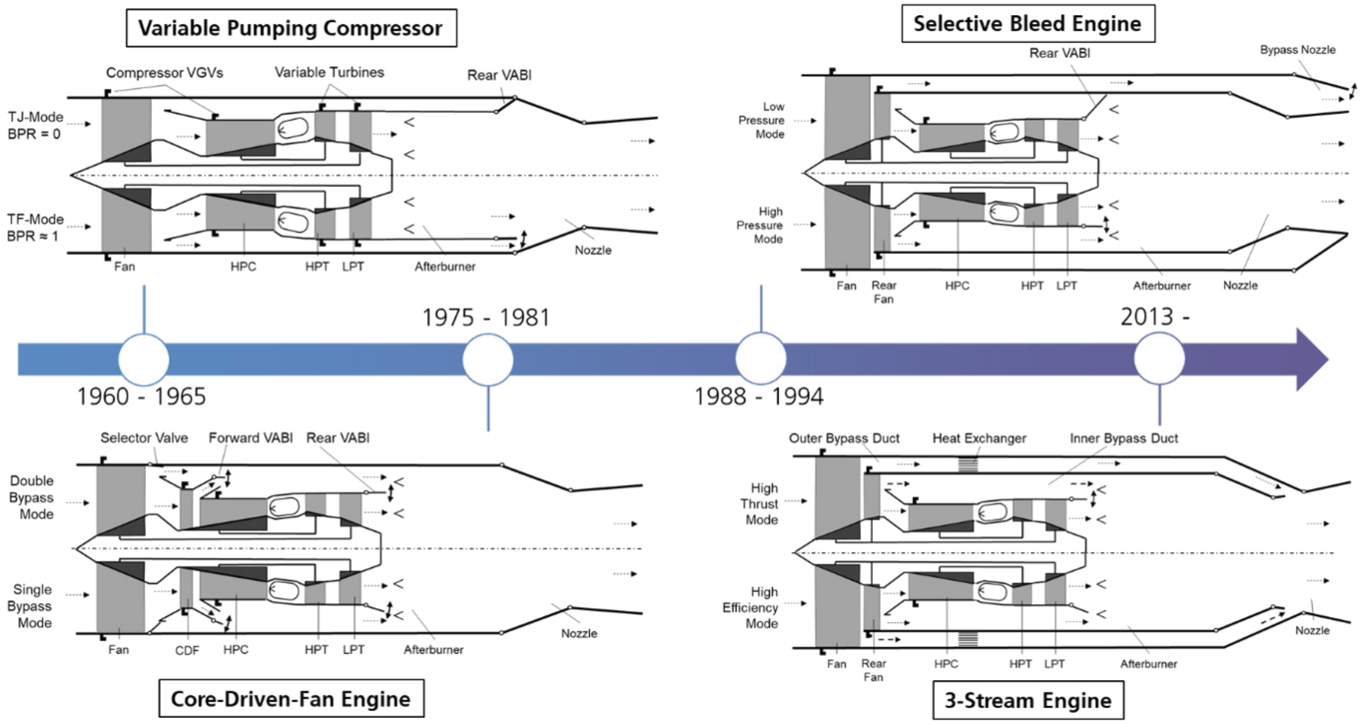

Figure 2. Timeline of selected VCE concepts.

transitions between operating modes. Research continues to address these limitations, with a focus on reducing system weight and enhancing reliability.

HISTORICAL EVOLUTION AND CONTEMPORARY RESEARCH

Research into VCE technology began in the 1960s in response to the need for engines capable of supporting supersonic transport aircraft. While early designs, such as General Electric's "Variable Pumping Compressor" and "Turbo Augmented Cycle Engine", demonstrated the potential of VCEs, they also had significant drawbacks. The performance benefits of these designs were marginal, while their weight and complexity presented considerable challenges. These limitations emphasised the need for new configurations that could overcome these shortcomings. Consequently, new engine architectures such as the "Core-Driven Fan Engine" emerged, utilising a split-fan concept to redistribute mass flow via the compression system. This approach represented a significant advancement, providing enhanced operational flexibility and paving the way for the ongoing development of modern VCE technology.

Current research focuses on three-stream engines, which introduce an additional bypass flow to improve thermal management, fuel efficiency and reduce infrared signature. Programmes such as the US Adaptive Engine Transition Programme (AETP) and Europe's Next Generation Fighter Engine (NGFE) demonstrate ongoing efforts to advance VCE technologies for next-generation military platforms. Figure 2 shows a timeline with selected VCE concepts. The authors' publication[1] in the Journal of Engineering for Gas Turbines and Power provides a more detailed overview of the state of the art in VCE published research.

FUTURE DIRECTIONS AND CONCLUSION

Reducing weight and complexity is a key technical challenge and a development focus of VCE technology. This is evident from the progress made by VCE technology in recent decades. Given the substantial advantages of VCEs and the ongoing reduction in weight and complexity, we can expect to see VCEs operating in the near future.

VCEs represent a transformative technology for advanced supersonic aircraft propulsion, offering unmatched adaptability and efficiency under various operating conditions. New engine system requirements, such as the integration and operation of a thermal management system, are also advancing the realisation of VCEs. Continued research and development will ensure that VCEs play a critical role in the future of military and civil supersonic aviation by meeting changing demands for performance, fuel efficiency and operational flexibility. ◆

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Environmental Barrier Coatings for Gas Turbine Ceramic Matrix Composites

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In 2001, scientists at the Institute for Defense Analyses published a report titled “Will Pigs Fly Before Ceramics Do?” [1] where it was concluded that technical barriers and lack of investments may result in a better chance of pigs soaring in the sky than ceramics. Implementing ceramics in gas turbine engines has long been viewed as an attractive path toward increasing engine efficiency and reducing emissions due to lower weight and higher temperature capabilities. While some ceramic components, such as silicon nitride seals and nozzles, were flying at the time the report was written, they were confined to less critical, static areas in smaller propulsion engines and in auxiliary power units (APUs) [1]. Ultimately, the goal of the report was to assess the technological maturity and barriers toward using structural ceramics, such as ceramic matrix composites (CMCs), for static and rotating components in the combustor and turbine sections. Incredibly, within 15 years of the report’s publication, the first CMC component, a high-pressure turbine shroud, was certified in May 2016 by the Federal Aviation Administration (FAA) and the European Union Aviation Safety Agency (EASA) for the LEAP engine developed by CFM International [2]. By April 2019, CMC shrouds surpassed four million hours of flight time [2], and in September 2020, the GE9X engine developed by GE Aerospace obtained FAA certification with five CMC components: an inner and outer combustor liner, high pressure turbine (HPT) Stage 1 shrouds and nozzles, and HPT Stage 2 nozzles [3].

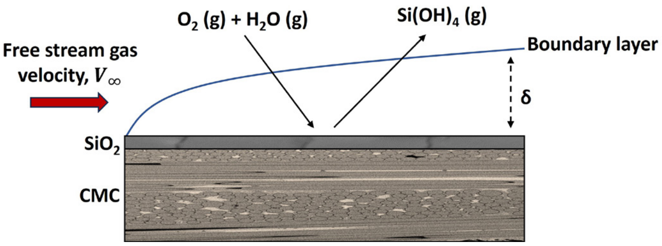

Figure 1. Schematic showing the oxidation of a SiC_f/SiC_m CMC and the volatilization of SiO_2.

THE DRIVING FORCE FOR ENVIRONMENTAL BARRIER COATING DEVELOPMENT

The most relevant CMCs for structural components within gas turbine engines are produced with silicon carbide fibers (SiC_f) that are embedded in a silicon carbide matrix (SiC_m), and referred to as SiC_f/SiC_m CMCs. Current state-of-the-art SiC_f/SiC_m CMCs offer great potential for gas turbine engines since they are approximately one-third the density of nickel (Ni)-based superalloys and can withstand 100 to 200°C higher temperature. By using a material with a higher temperature capability, the turbine inlet temperature (TIT) can be increased, which results in increased power and efficiency. In addition, higher-temperature materials require less cooling. The air that would normally be directed to cooling components can instead be pre-mixed with the fuel for more optimal air/fuel mixing leading to lower NO_x and CO emissions [4].

While SiC_f/SiC_m CMCs can provide significant increases in performance, they have a critical shortcoming. Oxygen and water vapor react with SiC at high temperature to form a silica (SiO_2) thermally grown oxide layer [4]. While the SiO_2 oxide scale is traditionally regarded as protective, this scale further reacts with water vapor to form a volatile silicon hydroxide species, $Si(OH)_4$ as shown schematically in Figure 1. The volatilized scale is exhausted out of the engine and additional SiC is consumed as the process repeats. This results in rapid material loss. To maintain the structural integrity and durability of SiC_f/SiC_m CMCs in gas turbine engines, environmental barrier coatings (EBCs) were developed. Ultimately, durable EBCs capable of tens of thousands of hours of operation are necessary to realize the full performance benefits of CMCs.

ENVIRONMENTAL BARRIER COATING REQUIREMENTS

Modern generation EBC systems are not a single layer, but multiple coating layers with various functions. The most basic EBC architectures contain a bond coat and a topcoat. The bond coat is typically a dense layer of silicon (Si) that exhibits good bonding and chemical compatibility with the CMC surface and protects the CMC against oxidation and volatilization. The topcoat serves as the main barrier against volatilization and must be relatively dense with no direct pathways to the underlying CMC. EBCs systems have been deposited via air plasma spray (APS), plasma spray – physical vapor deposition (PS-PVD), suspension plasma spray (SPS), and slurry methods [4]. Figure 2 shows EBC deposition via the PS-PVD process and a schematic showing the typical lamellar microstructure of an EBC/CMC system. Key requirements that must be balanced during processing are coefficient of thermal expansion (CTE) match between the substrate and coating layers, chemical compatibility between the coating layers and substrate, phase stability to avoid

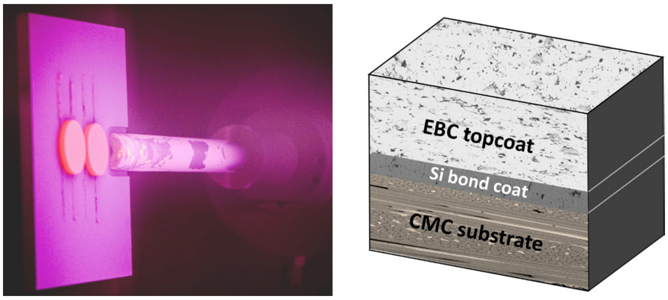

Figure 2. PS-PVD processing of EBCs (left) and the typical microstructure of an EBC/CMC system (right).

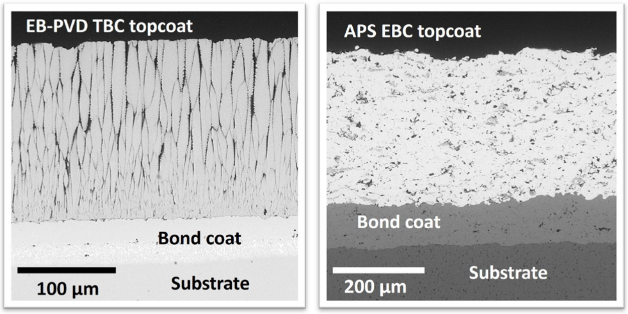

Figure 3. EB-PVD TBC compared to an APS EBC. Note the columnar microstructure of the EB-PVD TBC versus the lamellar microstructure of the EBC.

phase transformations within the coating, and adhesion of the layers. These requirements are important to prevent undesirable stress states that will reduce the structural integrity of the coating.

State-of-the-art EBC topcoats are based on rare-earth (RE) silicates: RE monosilicate (RE_2SiO_5) and RE disilicate ($RE_2Si_2O_7$). Supply and cost of RE elements certainly play a role in material selection with yttrium (Y) and ytterbium (Yb) being the most common RE elements used. Both RE monosilicates and disilicates offer good resistance against water vapor attack at high temperature and exhibit low thermal conductivity, but RE monosilicates exhibit CTE anisotropy and CTE mismatch with the SiC_f/SiC_m CMC. As such, two-layer architectures with an Si bond coat and a RE disilicate EBC topcoat are the most promising and commonly used [4].

On top of the requirements for processing and protection against oxidation and volatilization, EBCs must also exhibit sufficient durability to survive the harsh operating environment of gas turbines. Degradation mechanisms that reduce EBC durability are particulate corrosion, thermomechanical degradation, and impact damage. There are many on-going research efforts to develop a fundamental understanding of each issue and their combined effects along with promising mitigation strategies. One recent, major achievement was the development of EBCs with alumina-containing modifiers that reduce the oxidation rate of the bond coat which improves EBC lifetime by a factor of 20 [5].

FUTURE CHALLENGES

A key challenge moving forward is the feasibility of EBC/CMCs for rotating components. From a coatings perspective, EBCs present unique challenges compared to thermal barrier coatings (TBCs) for Ni-based superalloys. The development of TBCs has largely been a thermomechanics problem whereas EBC development is primarily focused on thermochemistry. For applications such as turbine blades, TBCs are usually deposited via electron beam - physical vapor deposition (EB-PVD) which generates a compliant, strain-tolerant, columnar microstructure which is critical for high stress components. A comparison of the columnar microstructure of an EB-PVD TBC compared to the lamellar microstructure of an EBC deposited via APS is shown in Figure 3. The intercolumnar gaps in the EB-PVD microstructure act as highways for oxygen and water vapor diffusion and do not provide an environmental barrier. This is not a problem for superalloys as their oxides are generally more stable in water vapor and the alumina layer that forms at the bond coat protects against corrosion. It's worth noting that TBCs are also deposited using techniques such as APS which form lamellar microstructures, but they are not typically preferred for high stress, critical components. As such, future EBC development will need to include a mechanics-based approach while balancing the chemistry requirements. There is also a desire to improve the upper temperature capability of EBCs and CMCs. Current EBC systems are limited in temperature due to the use of the Si bond coat which has a melting temperature of ~1410°C. As such, different oxide-based bond coats are being investigated with the hope of increasing the temperature capability of EBC/CMC systems between 1482°C and 1650°C [6]. Despite the inherent challenges and technical barriers for developing and implementing ceramics in gas turbine engines, ceramics are soaring high in the sky with a bright future ahead. As of this writing, pigs have not yet taken flight. ◆

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2025 TURBO EXPO

Wrap Up

ASME Turbo Expo 2025, in Memphis, Tennessee, USA maintained its reputation as the world's premier turbomachinery conference attended by over 2000 professionals. Throughout the week, delegates shared practical experiences, knowledge, and ideas on the latest turbine technology trends through networking opportunities and over 700 peer-reviewed technical presentations.

This year's three-day exhibition brought together more than 120 exhibitors representing 18 countries. The exhibit hall buzzed with energy as participants connected and explored potential partnerships. Floor selection is now open for the 2026 Milan, Italy exhibition.

To explore sponsorship and exhibiting options, contact exhibits@asme.org.

A special thanks to the sponsors that supported the event. At the Platinum and most prestigious level were Siemens Energy & Ansys. Our Gold sponsor was Honeywell. Silver sponsors were NASA, Cadence Design Systems, Pratt & Whitney, & GE Aerospace. The Bronze level was supported by Baker Hughes, Boom Supersonic, Flownex Simulation Environment, CBMM Technology Suisse SA, Solar Turbines, & SoftinWay Incorporated.

Please plan to attend Turbo Expo 2026 in Milan, Italy, from June 15 - 19 to participate in the turbomachinery industry's most highly recognized conference and exhibition.

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Submit by ***October 10, 2025*** for a chance to present your work. *Click to learn more*!

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