Introduction

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Particulate entrainment into gas turbine engines (GTEs) for fixed wing and vertical lift aircraft is a significant challenge for both military and civilian activities. In the past, this has primarily resulted in erosive damage from hard particulates, i.e. foreign object damage (FOD). Contemporary and next-generation GTEs typically have erosion-resistant coatings (in both the cold and hot sections) to improve durability and reduce the operational impact of FOD. However, advanced gas turbine engines operate at significantly higher temperatures (1500 °C and more) for improved efficiency and increased power density. This increase in operating temperatures has given rise to a new problem for turbine engines in aircraft, ships, and ground vehicles: hot tribo-corrosion from sand, dust, salt, and ash. Small/fine particulates (such as sand, dust, and/or ash) can pass through the cold-section, enter the combustor where the particulates undergo a phase transformation and melt, impinge on the high-pressure turbine components, adhere to the protective thermal/environmental barrier coatings (T/EBCs), infiltrate into these porous coatings, and solidify into a glassy coating that continues to react with and degrade the T/EBC material(s). The infiltration of these glassy calcia-magnesia-alumino-silicate (CMAS) materials into the T/EBCs can lead to spallation of the coating and a considerable knock-down on engine life. In addition, the adherence of CMAS can lead to substantial build-up on the blade/vane coating that may block air-flow passages, including blade film cooling holes, leading to engine surge and/or blade overheating causing catastrophic failure of the engine.

Operating in particulate-laden environments has increased the maintenance burden and costs on the operational availability of military aviation assets. Civilian aircraft operating in densely populated and desert regions encounter dust clouds that can significantly degrade their gas turbine engines. In addition, aircraft flying through even diffuse volcanic ash clouds can undergo similar engine degradations. The need

for aircraft to avoid severe volcanic ash clouds generated by volcanic eruptions in 2010 is estimated to have cost the global economy between \$3.3 – 5 billion USD.

In 2012, *MRS Bulletin* published a theme issue on the degradation of thermal barrier coatings by silicate deposits. The articles published in this issue have garnered over 980 citations (from Google Scholar) to date. Since that issue, there have been pivotal advances in the field of coating deposition and the understanding of the CMAS – T/EBC reaction kinetics. In this Focus Issue, we captured a small portion of the worldwide research portfolio developing sand-phobic and/or CMAS-resistant T/EBCs for use in aviation gas turbine engines. For example, significant research efforts have investigated the reaction kinetics of CMAS-T/EBCs, with regards to phase, composition, temperature, and time. These studies provided the details necessary for computational efforts to study the behavior of molten particulates in turbulent, hot-gas flows along with the subsequent interactions (i.e., deposition and infiltration) with ceramic T/EBCs. Additional work focused on developing sand-phobic and/or CMAS-resistant coatings through the use of rare-earth oxides, self-healing materials, and/or multi-phase compositions. As editors, we hope the readers will find these manuscripts scientifically engaging, insightful, and useful contributions to the research and development of this complex system.

Finally, we are very grateful to both the authors and reviewers of the many high-quality manuscripts submitted to this *JMR* Focus Issue on *Sand-phobic Thermal/Environmental Barrier Coatings for Gas Turbine Engines*.

ON THE COVER:

The cover of this Focus Issue shows several images related to the research and development of sand-phobic thermal/environmental barrier coatings (T/EBCs). Specifically, the image in the

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upper left and the main image on the right show developmental T/EBCs undergoing high-temperature, high thermal-gradient testing within the particulate-laden flame of the Hot Particulate Ingestion Rig at US Army Combat Capabilities Development Command - Army Research Laboratory. The second image on the left-hand side is a representative CMAS-damaged nozzle guide vane (NGV) of a typical turboshaft

engine, which was exposed to a sand-laden engine ground test. While the ingested material (AFRL-02 synthetic sand) was relatively rough, with a wide variation in particle sizes (lower left micrograph), the deposits morphed into relatively uniform needle-like structures, similar to the apatite formed by the reaction of CMAS with gadolinium zirconate (see second from bottom micrograph on left-hand side).