**Predicting desert dust melting in aircraft turbines**

Volcanic ash melts at several hundred degrees lower temperatures than mineral dust. Unlike dust, ash was of serious concern for aviation over decades because of high risks to have its melted deposit in jet engines. With current aero-turbines which has significantly increased operating temperatures to 1300C or more, desert dust can also melt in engines and thus degrade aircraft performances. In order to examine the engine behavior to harmful influence of particles, the Arizona Test Dust (ADT) samples are usually used. Although this approach aims to mimic effects of volcanic ash and mineral dust to turbines, it cannot completely represent real-time flight conditions. We here describe a numerical modelling system developed to predict aerosol melting in engines when aircrafts pass through dust clouds. This system integrates a numerical weather prediction model and a transport model predicting concentration of dust and its minerals fractions. The melting temperature of the mineral mixture in our approach depends: on predicted dust concentration, on melting temperatures of considered minerals and on their fractions in dust and on exposure time of dust to turbine temperatures. The model has predicted a remarkable potential melting conditions for aviation during a recent Mid-East extreme dust storm when the flight traffic was badly disturbed. The proposed prognostic system, if applied in operational mode, could help in reducing the aviation risks due to dust melting.

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Atmospheric particulates are of large concern for aviation because of their potential adverse effects to aircraft turbines. According to USGS evidence, 129 accidents induced by volcanic particles has been recorded in the period 1953-2009, from what 53 has been due to turbines abrasion and ash melting under high turbine temperatures (Guffanti, 2010). Ash melting and depositing in engines often leads to engine degradation and/or failure. Volcanic particles has been until recently considered almost exclusively as the major threatening aerosol for the air traffic. However, the continuous increase of turbine working temperatures also raise the danger of mineral dust melting despite it has a few hundred degrees higher melting points than volcanic ash.

Mineral dust particles are mobilized from the surface by intense near-ground turbulence over dry erodible desert soils. Once emitted to the atmosphere, dust can travel hundreds or even thousands kilometers away from sources (Knippertz). Unlike volcanic ash, dust is not too dangerous for the aviation in the free atmosphere since it has lower concentrations and has higher melting points than ash. However, dust could reach extreme concentrations in the first kilometers above ground during major storms when it could adversely affect aircrafts, especially in the landing and take-off phase when turbine temperatures reach peak values. The amount of eventual melted dust deposited within engines mainly depends (a) on dust concentration, (b) on time of turbine exposure to dust, and (c) on physical and mineralogical features of dust.

Previous studies have investigated behavior of jet turbines in tests made with controlled engines exposure to synthesized mixture of dusts and/or sampled volcanic ash (VIPR3 VAE) (Clarkson). Other studies based on the evidence on past accidents and laboratory tests, explore turbine engine susceptibility to the aerosol estimating the level of engine damage. For that purpose, the Duration of Exposure versus Ash Concentration(DEvAC) chart has been introduced to quantify levels of engine vulnerability as a function of aerosol concentration and time an aircraft spends in the ash cloud (Clarkson et al., 2016 [3]). The chart has been applied to both, volcanic ash and dust.

Although the controlled engine tests and their susceptibility estimates provide useful general information to aviation operators, they yet cannot assess the expected aerosol effects along known flights trajectories in real time. In order to fill such gap, we have developed a prognostic modeling system ©DREAM-MELT designed to predict melting of mineral dust in turbines along aircraft routes. In this system, we used the NMME high-resolution numerical weather prediction model (see Methods-modelling) to drive the DREAMdust transport model. In order to parameterize the dust melting process, we have added in DREAM prognostic concentration fractions for eight typical dust minerals: illite, kaolinite, quartz, feldspar, calcite, gypsum smectite and hematite. The high-resolution global database on mineral fractions in potentially erodible soils GMINER3 is used to specify emissions of the selected minerals (see Methods-minerals).

For the considered minerals we have specified their typical melting points ( ** - the melting point for the i-th mineral) (see Fig xx) (ref). The solid-to-melted phase transition and the resulting melting point of mineral mixtures with more than three components is too complex to be analytically calculated. In the proposed forecasting system the melting point of the mixture  has been approximated instead as a mean weighted with respect to the predicted mass of mineral fractions:

 (1)

Here, dust particles are considered to be internally mixed so that each particle is a mixture of all eight minerals (Atkinson). In addition, we introduce the Melting Index (MI) to reflect the melting capacity of a particular mineral:

 (2)

Here,  is the predefined constant for a specific aircraft. We calculate its prognostic value for the mixture as a mean weighted with respect to the mass of mineral fractions:

 (3)

In DREAM-MELT,  and are the model prediction parameters introduced to quantify the sensitivity of aircrafts to potential dust melting in turbines. The model has been tested for the massive dust storm event occurred between 1 and 2 April 2015 over Doha when the civil aviation has experienced dust melting in turbines. The event has been classified as a 'long-term damage' case in a DEvAC chart, (Clarkson, 2015), with engines exposed to dust concentrations of several mg/m3 during ~10-15 min in the landing/take-off flight phase. The dust storm was generated in a desert area of Iraq a day before, which passed swiftly along the eastern Saudi Arabian Peninsula before arriving to Qatar. According the environmental and meteorological authorities in Qatar, this was the strongest ever recorded dust storm at the place.

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Klaus Brun, Particle Transport Analysis of Sand Ingestion in Gas Turbine Engines

specifically, jet engines that see significant inlet sand or ash ingestion of particles impacting significant amount of ingestion of fine particulate matter path. Significant interest exists in the military and commercial aerospace industry

In the combustor, the local flame temperature can be as high as 1650C. At these temperatures, sand will become a liquid silicone oxide

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accretion growth or increase by the gradual accumulation of additional layers or matter.

passing through ash and dust completely diff. dust - in uptake and landing critical

damage mechanisms

lack of good data, was a quantitative understanding of the damage mechanisms

ash vs dust; the other more accurate prediction

local vs regional treansport

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* Walsh: The combination of extreme temperature and residenceime can lead to sand even melting inside the turbine component. With increasing temperatures of gas turbine engines and the development of new cooling designs, it is critical to evaluate the effects of ingested sand particles.
* Zhao: Since the surfaces of components in future engines are likely to be cyclically exposed to temperatures of 1250 °C and above
* Singh: At temperatures above 1000 C, sand particles started melting and promoted blocking of cooling holes. Particle ingestion is excessive while takeoff and landing when engines are in ground proximity and running at full power[1]; According to studies by Edwards and Rouse[7], high sand ingestion can reduce engine stability by eroding blade profiles and lowering the compressor efficiency, as a result of which the line of operation is closer to the surge line.
* *Taltavull,* It is increasingly clear that gas turbines, particularly aeroengines, are susceptible to damage caused by ingested particulate, such as sand, fly ash and volcanic ash, often referred to generically as calcia-magnesia-alumina-silica (CMAS). Such particles may melt, or at least soften, in flight, making it more likely that, if they strike solid surfaces within the turbine, they will adhere to them on impact.

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**parameterization**

* Singh Figure 5.4 shows the probability of sticking for sandparticles based on viscosity*visc P* with temperature. Sticking probability rises exponentially as the particle approaches softening temperature.

surface area and have made two limiting calculations, one assuming that dust particles are internally mixed (that is, each particle contains all eight minerals) and the other assuming they are externally mixed (each particle is composed of an individual mineral).

**Melting points**

Guffanti, (USGS, 2010) **Encounters of Aircraft with Volcanic Ash Clouds: A Compilation of Known Incidents, 1953–2009**

Rory Clarkson Volcanic Ash and Gas Turbine Aero Engines

**WMO VAAC ‘Best Practice’ Workshop, London, 5th- 8th May 2015**

https://www.wmo.int/aemp/sites/default/files/RR\_Volcanic\_Ash\_and\_Gas\_Turbine\_Aero\_Engines\_Update.pdf