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Volcanic ash ingestion by a large gas turbine aeroengine: fan-particle interaction

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Airborne particles from explosive volcanic eruptions are a major safety threat for aviation operations. The fine fraction of the emitted particles (<63 microns diameter) may remain in the atmosphere for days, or even weeks, and can affect commercial air traffic routes. Over the past century, there have been a considerable number of aircraft encounters with drifting volcanic ash clouds. Particles ingested into the engine cause erosion of upstream surfaces of compressor fan blades and rotor-path components, and can also cause contamination or blockage of electrical systems and the fuel system such as fuel nozzles and air bleed filters. Ash particles that enter the hot-section of the engine (combustor and turbine stages; temperature between 1400-1800°C) are rapidly heated above the glass transition temperature (about 650-1000°C) and become soft (or form a melt) and can stick as re-solidified deposits on nozzle guide vanes. The glass deposits change the internal aerodynamic airflow in the engine and can affect the cooling capability of the different components by clogging the cooling inlets/outlets, which can lead to a loss of power or flame-out.

The nature of volcanic ash ingestion is primarily influenced by the fan at the front of the engine which produces the thrust that drives the aircraft. The ingested air is split between the core (compressor/combustor/turbine) and bypass (thrust) at a ratio of typically between, 1:5-10 on modern engines. Consequently, the ash particles are fractionated between the core and bypass by the geometry and dynamics of the fan blades. This study uses computational fluid dynamics (CFD) simulations of particle-laden airflows into a turbofan engine under different atmospheric and engine operation conditions. The main aim was to investigate the possible centrifugal effect of the fan blades as a function of particle size, and to relate this to the core intake concentration. We generated a generic 3D axial high-bypass turbofan engine using realistic dimensions of the turbofan, engine intake and other aerodynamically relevant parts. The CFD experiments include three scenarios of aircraft performance (climb, cruise and descent) and for two different typical altitude ranges (10000 and 39000 ft). The fluid dynamics simulations were carried out using a commercial code (CD Adapco STAR-CCM+ with an implicit coupled flow and energy algorithm) for compressible high-speed flows including a Lagrangian particle-tracking model for the simulation of the particle behaviour for typical atmospheric particle size ranges between 1 and 100 μm. The simulations indicate that the predominant proportion of larger particles (> 20 microns) tend to be transported into the bypass duct of the engine (by the centrifugal effect of the fan), whereas the smaller particles follow the fluid flow streamlines and are distributed homogenously in the engine (bypass ducts and core region). This result is significant as it indicates that the absolute ash mass that causes issues for aeroengine operation is a fraction of the ambient (observed or forecast) ash quantity.