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Modelling of Non-Spherical Particle Evolution for Ice Crystals Simulation with an Eulerian Approach

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Abstract

In this study a comparison is made between results from three Eulerian-based computational methods that predict the ice crystal trajectories and impingement on a NACA-0012 airfoil. The computational methods are being developed within CIRA (Imp2D/3D), ONERA (CEDRE/Spiree) and University of Twente (MooseMBIce). Eulerian models describing ice crystal transport are complex because physical phenomena, like drag force, heat transfer and phase change, depend on the particle's sphericity. Few correlations exist for the drag of non-spherical particles and heat transfer of these particles. The effect or non-spherical particles on the collection efficiency will be shown on a 2D airfoil.

Introduction

Turbofan jet engines flying at high altitudes near convective clouds are vulnerable to icing caused by crystals. Mixed phase or glaciated icing conditions can cause power loss, flame-out or even damage to the compressor blades. The European Union funded project HAIC (High Altitude Ice Crystals) is a large-scale integrated project which aims at enhancing aircraft safety when flying in these icing conditions. The cooperation between CIRA, ONERA and University of Twente on the topic of Eulerian modelling was initiated in the framework of HAIC.

One of the objectives of HAIC is to understand and model the physical phenomena and develop numerical tools to simulate ice crystal conditions on aircraft components. CIRA, ONERA and University of Twente have extended their in-house Eulerian dispersed phase computational methods to achieve this. A short description of each method will be given at the end of this introduction.

The applicability of an Eulerian method to describe ice crystals transport is limited both by constitutive hypotheses and by the inherent complexity to model specific physical phenomena. The aim of this paper is to inter-compare results of the implementation of non-spherical ice crystal drag and heat transfer and their effect on the collection efficiency of a 2D airfoil. The classical Eulerian method will be presented and the main improvements for extension to ice crystals will be introduced. An overview will be given of drag and Nusselt number correlations from literature which account for the particle's sphericity.

Subsequently, simulations will be performed for a 2D NACA-0012 airfoil. The test cases involve various particle properties (size and sphericity) as well as various environmental conditions (particle release temperature). The results include influence of the non-spherical particle drag and heat transfer on the collection efficiency.

CIRA - Imp2D/3D

CIRA extended its in-house Eulerian methods, Imp2D (2D version) and Imp3D (3D version). Both are based on a finite-volume approach and can handle multi-block structured grids. The spatial discretization is carried out by means of the Jameson-Schmidt-Turkel (JST) numerical scheme, which is cell-centered with the addition of blended (2nd-4th order) artificial dissipation. Formally 2nd order spatial accuracy is achieved. The solution evolves in pseudo-time by means of a 4th order Runge-Kutta multi-stage scheme. Imp2D/Imp3D are interfaced with CIRA ZEN Euler/RANS flow solver.

ONERA - CEDRE/Spiree

ONERA has extended its in-house Eulerian dispersed phase method, CEDRE/Spiree. It is based on a finite-volume approach and generalized unstructured meshes. This Eulerian dispersed phase method is derived from energetic applications including: mass