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Investigation of water impingement on a multi-element high-lift airfoil by Lagrangian and Eulerian approach

Chenxing Yu[a], Peng Ke[a],*, Guangfeng Yu[b], Chunxin Yang[b]

[a] *School of Transportation Science and Engineering, Beihang University, Beijing 100191, China*
[b] *School of Aeronautics Science and Engineering, Beihang University, Beijing 100191, China*

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Abstract McDonnell Douglas Aerospace (MDA) high-lift model is widely used in the study of multi-element airfoil, while there is still short knowledge of ice accretion and water impingement on it. In this paper, based on two-phase flow theory, two numerical models were presented by using both Eulerian approach and Lagrangian approach, respectively, in order to predict the water impingement efficiency on a two-dimensional (2D) multi-element high-lift airfoil. Both computational results were validated with the experiment data, which shown good agreements in the impingement limitations and tendency. The trend that how the attack angle and droplet diameter affect the feather of local water impingement characteristics on the different elements of MDA were further investigated. As shown in this research, the trends that the local impingement intensity and extent on flap of MDA varied differently as in general understanding due to the complex structures of flow field, which should be careful cognized in design of the ice protection system.

*Corresponding author. Tel.: +8610 82316627.
E-mail address: p.ke@buaa.edu.cn (Peng Ke).

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1. Introduction

Many efforts have been made around the McDonnell Douglas Aerospace (MDA) high-lift model to investigate and optimize its aerodynamic performance both experimentally and numerically since it was proposed. Anderson [1] utilized a two-dimensional (2D) unstructured Navier-Stokes code to compute the flow past the MDA multi-element airfoil configurations and compared them with the experimental data to validate the effectiveness of computational fluid dynamics (CFD) code with normal landing configuration. Steven [2] also shown that the CFD methods did well in predicting lift with good agreement between several codes and the experimental results.

The gap and overhang settings of MDA are highly optimized to provide special high lift, and have very little tolerance for contamination, such as ice accretion, which can significantly degrade aircraft performance and safety. Shin [3,4] conducted many tests by using the NASA Lewis Icing Research Tunnel (IRT) to obtain the ice shapes accreted on all three elements of the multi-element configuration, and revealed the huge effects of potential in-flight ice accretion on the aerodynamic performance. Dominik [5] confirmed the aerodynamic performance degradation of the multi-element high-lift airfoil numerically with ice accretion using the simulated ice shapes obtained by Shin [3,4].

Numerical simulation of ice accretion on multi-element high-lift airfoil is a useful and powerful tool to supplement the ice shapes obtained in experiments. Many researchers focused on similar structures with the aid of CFD tools, such as two or four elements airfoils. For example, Sang [6] investigated the icing effect of a four-element airfoil by solving the Navier-Stokes equations with a conventional algorithm and multi-block grids. Iuliano [7] build and validated a Eulerian method through the comparison with Lagrangian and experimental results on a multi-element airfoils, furthermore the authors investigated the effect of viscosity on the impingement curves by comparison between inviscid and viscous flow solvers and found that prediction of impingement level on multi-component airfoil must be performed by means of a viscous flow solver. Zhou [8] developed and validated a 2D ice accretion prediction code to simulate the ice accretion on multi-element airfoils using Lagrangian approach. Most of the research focused on the development and validation of icing simulation algorithms, while there is still short knowledge of water impingement analysis on MDA.

The droplet impingement analysis is the basic element for simulation of aircraft ice accretion and design of the ice protection system. Papadakis [9] gave the experimental water droplet impingement data for MDA, including large droplet impingement characteristics, obtained at the NASA and partially compared with analysis impingement data from NASA Glenn LEWI3DGR codes due to the limitations of numerical tool.

The main purpose of this paper focused on water impingement characteristics of the high lift device of MDA. Firstly, both 2D Eulerian and Lagrangian models were presented for water droplet impingement prediction on multi-block structured grids, where the widely used Lagrangian approach is based on the computation of a discrete set of water trajectories impinged on the body by freezing the flow field, but has some shortcomings for the application on more particular geometry, such as multi-element airfoils. Meanwhile, the Eulerian method can overcome such limitations by treating the carried phase as a continuous medium and provides the cloud characteristics in all the domain without tracking the paths of each droplet. Secondly, both models were validated with experimental data and cross-validation of the airfoil of MS317 and MDA. Finally, the emphasis were further placed on the trend that how the attack angle and droplet diameter affect the feather of local water impingement characteristics on the different elements of MDA.

2. MDA high-lift model

In this section, we outlined the overall introduction of MDA and the effects to compute and validate the flow filed around it that will be adopted later for both droplet impingement models.

2.1. Geometry

The MDA high-lift model investigated here is a 2D, single-flap, three-element airfoil, where the reference airfoil chord is 22 inches according to Ref. [2]. The airfoil is configured in a typical approach/landing configuration with slat and flap deflections of 30 deg. The slot size between the main element and the high lift components is defined in terms of the overhang (OH) and the gap overhang is the horizontal distance from the trailing edge of the upstream

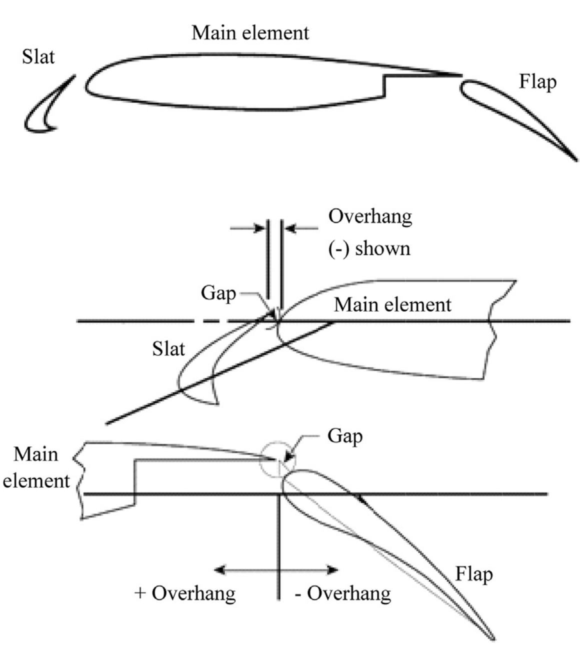

Figure 1 Configuration of MDA high-lift model.