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Abstract

Drop impact on an airfoil surface takes place in drop-laden two-phase flow conditions such as rain and icing, which are encountered by wind turbines or airplanes. This phenomenon is characterized by complex nonlinear interactions that manifest rich flow physics and pose unique modeling challenges. In this article, the state of the art of the research about drop impact on airfoil surface in the natural drop-laden two-phase flow environment is presented. The potential flow physics, hazards, characteristic parameters, droplet trajectory calculation, drop impact dynamics and effects are discussed. The most key points in establishing the governing equations for a drop-laden flow lie in the modeling of raindrop splash and water film. The various factors affecting the drop impact dynamics and the effects of drop impact on airfoil aerodynamic performance are summarized. Finally, the principle challenges and future research directions in the field as well as some promising measures to deal with the adverse effects of drop-laden flows on airfoil performance are proposed.

Keywords: Drop impact; splash; water film; multiphase flow; airfoil;

1. Introduction

Drop impact plays a critical role in various natural phenomena and technical applications such as rainfall, snow, icing, liquid spray and atomization, ink-print, combustion, painting, spray and coating, etc. [1]. In a broad sense, the topic of drop impact can be classified into three main branches based on the impingement target: drop impact on solid surfaces, pre-existing liquid films, and deep liquid pools. The third case is not applicable on an airfoil surface, thus will not be discussed in this review. Previous studies indicate that, due to the influence of the surface texturing, a series of complex dynamic phenomena can happen after a drop hits a dry solid surface, such as deposition, splash, breakup, rebound, etc. [2]. Due to the extreme complexity of the research subject, there are still many problems deserving further investigations. For example, for normal drop impacts on a dry surface where the spreading stage is followed by a receding stage, there is a transition stage between the two stages. Although for analytical modeling, the radial velocity of the rim can be assumed to be zero and the contact angle changes with time during this transition [3], the axial velocity of the rim is not necessarily zero. In addition, for direct numerical simulations with solving the Navier-Stokes equations, the boundary condition at the moving contact line needs to be set. In this circumstance, it can not be simply assumed that the radial velocity of the whole rim is zero. Fukai et al. [4] applied the no-slip boundary conditions at the contact lines during this transition in their numerical simulations, where the rim motion is so slow very close to the wall that molecular wettability-driven slip becomes dominant near the contact line [1]. As a drop impacts a thin liquid film, various dynamic phenomena may occur with respect to different impact speeds [5], as shown in Figure 1. From the perspective of aviation meteorology, both of the above two issues are present, i.e., drops impacting the dry solid airfoil surface in the early stage and later the water films accumulated on the airfoil surface. The phenomenon of drop impact on an airfoil surface is characterized by the presence of an airfoil immersed in a drop-laden airflow in the nature which can also be called a drop-laden two-phase flow, such as cloud, drizzle, rainfall, icing and fog. Such drop-laden two-phase flows possess adverse effects in various industrial fields. For example, liquid drop icing and heavy rainfall are known to be hazardous to aviation safety [6-8] and wind turbine power efficiency [9-11].