THE POTENTIAL INFLUENCE OF RAIN ON AIRFOIL PERFORMANCE

by

R. Earl Dunham, Jr.
NASA Langley Research Center
Hampton, Virginia 23665

Lecture Presented at the
von Karman Institute for Fluid Dynamics
Lecture Series Entitled
"Influence of Environmental Factors on Aircraft Wing Performance"
February 1987

Introduction

Around 1970, attention began to focus on the effect of low altitude wind shears and the hazard they present to airplanes. Wind shears have since become a recognized hazard and concerted efforts are underway to provide warning, guidance, and operating procedures for avoiding and escaping serious wind shear threats. Recently, attention has been given to the possible effects of rain on airfoil performance and the effect of rain-induced performance degradation during a simultaneous wind shear encounter.

The effects of finite roughness elements, frost accumulation, and icing on single- and multi-element airfoil performance has long been recognized, but until recently little attention has been directed at the influence of rain. The influence of rain on airfoil performance has long been thought to be insignificant, although the potential for rain to act as a contaminant on an airfoil surface is generally recognized. The primary hazards associated with airplane operations in rain were generally considered to result from a loss of visual reference. In considering rain effects, the basic fluid mechanics problem to be addressed is the generation of lift in a two-component, two-phase (water-air), low-quality flow. Low quality in the fluid dynamic sense refers to one component representing a very small percent of the total mass flow. The details of the deposition of water on the airfoil, the formation of a water layer, the movement of the water over the airfoil, and the interaction of the water with the general airflow around the airfoil and in the boundary layer all determine the aerodynamic characteristics of the airfoil.

This paper is an overview of the most recent work conducted by NASA and others to study the potential influences of heavy rain on airfoil performance. The overview includes a discussion of some of the previous analytical investigations of rain effects on airfoils, reviews some promising experimental methods for evaluating rain effects, and presents some important scaling considerations for extrapolating model data. The latest experimental results are also presented and discussed. At this time a complete understanding of the influence of rain on airfoil aerodynamics is very elusive, and considerable additional effort, both analytically and experimentally, is required to understand the degree of hazard associated with flight operations in a rain environment. It is hoped that this paper will serve to stimulate additional research in this important area.

Properties of Rain

In order to develop analytical models of the effect of rain on airfoil performance and to conduct experimental studies, the phenomenon of naturally occuring precipitation needs to be understood. Two "lump parameter" quantities generally used to describe rain are rainfall rate (R) and liquid water content (LWC). Rainfall rate is a linear accumulation depth at ground level per unit time, and the liquid water content is the mass of liquid water per unit volume, usually expressed as gm/m^3. In the absence of a vertical wind velocity, the LWC is directly related to the rainfall rate. An additional important parameter for quantifying rain is the rain drop size distribution. An understanding of this distribution is required for experimentally and analytically modeling rain. An understanding of frequency of occurrence and range of rain rate is also required in order to assess hazard potential for aircraft operation .

In 1947 Marshal and Palmer (reference 1) collected data which showed that the size distribution of rain in a cloud could be estimated using an exponential expression of the form:

$$N(D) = N_0 \, e^{-ID} \qquad (1)$$

where N(D) is the drop size distribution (density function) in terms of the number of drops per cubic meter of air per unit interval, D is the drop diameter, and $I = nR^m$ where n, m, and N_0 are empirically determined constants and R is rainfall rate. Data from Marshall and Palmer indicated that $N_0 = 8000$, $n = 4.1$, and $m = -.21$ for light continuous rain. More recent studies (references 2 and 3) have shown that the values of N_0, n, and m are dependent upon storm type and intensity. Reference 2, for example, suggests that the distribution in heavy thunderstorm-type rain is best characterized by $N_0 = 1400$, $n = 3.0$, and $m = -.21$.