LIQUID WATER FADE MARGIN REQUIREMENTS FOR
INFRARED AND MILLIMETER WAVE RUNWAY
IMAGING SENSORS IN FOG

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Abstract - Liquid water content and particle size distribution at
each ten meters in the vertical for a deep advection fog and a
shallow radiation fog are analyzed to determine the liquid water
loss at millimeter and infrared wavelengths. The liquid water fade
margin is calculated along a three degree glideslope in each fog
from the current height above the runway to the touchdown
point. Millimeter wave fade margin requirements are calculated
from the vertical distribution of bulk liquid water content and
infrared fade margin requirements are predicted from the vertical
distribution of dropsize. Fog dropsize distributions for both fog
layers are well fitted to a gamma distribution with a median drop
diameter of approximately 9 microns. Millimeter wave imaging
sensors operating in a shallow radiation fog are shown to require
less than 1 dB of one-way liquid water fade margin. In the deep
advection fog, one-way liquid water fade margin requirements at
8.6 mm, 6.8 mm, and 3.2 mm are predicted to be 1, 2, and 6.7 dB
respectively. In comparison, the one-way liquid water fade
margin requirements at near, middle, and far infrared
wavelengths are two orders of magnitude greater than at
millimeter wavelengths and indicate the fog layers are opaque to
infrared imaging sensors even near the touchdown point. The
specific attenuations predicted in the two fogs are consistent
with previously reported values.
1. INTRODUCTION

Recent interest in assessing imaging technologies to allow aircraft to land and taxi in low visibility weather conditions has renewed interest in the liquid water fade margin requirements for infrared and millimeter wave imaging sensors in fog [1]. Although runway incursions, emergency vehicle movement, controller visibility, and airport surface navigation are potential applications of imaging through fog, approaches, landings and take off are of primary concern [2]. Fade margin is a millimeter wave through infrared system design consideration whenever the atmosphere between the imaging sensor and the scene contains liquid or frozen water molecules in the form of haze, fog, rain, and snow. Fade margin may be defined as the excess clear air system signal to noise ratio required to insure adequate image quality when the path between the imaging sensor and the scene is populated with liquid or frozen water. This paper concentrates on the non-precipitating ensemble of spherical water drops called fog. The ensemble of drops in fog form a size distribution with typical radii between approximately 1 μm and 50 μm with an average drop radius near 5 μm [3].

The fog data sets employed in the following calculations are a deep, dense coastal advection fog documented at Vandenberg Air Force Base (VAFB), California in August, 1992 and a shallow, moderate to thick radiation fog recorded at Huntington West Virginia (HUN) on September 28, 1992 [4]. A Gulfstream II aircraft with a forward scattering spectrometer probe, optical array probe, liquid water content probe, and temperature sensor made six landings at VAFB and two landings at HUN along a three degree glideslope at approximately ten minute intervals. This resulted in particle size distribution, liquid water content, and temperature data available at each ten meters in the vertical. The aircraft also carried optical, 3-5 μm, and 8.6 mm imaging sensors in an attempt to provide runway images for the flight crew. The 260 meter deep fog layer at VAFB is characterized by a strong temperature inversion of approximately 28 °C km⁻¹. Median volume drop radius varied in height and from