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Feasibility Study
Airborne LIDAR for Clear Air Turbulence Detection

RTCA FS-2
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Prepared by: SC-230

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FOREWORD

This feasibility study was prepared by Special Committee 230 (SC-230) and approved by the RTCA Program Management Committee (PMC) on June 11, 2020.

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- coalescing aviation system user and provider technical requirements in a manner that helps government and industry meet their mutual objectives and responsibilities;

- analyzing and recommending solutions to the system technical issues that aviation faces as it continues to pursue increased safety, system capacity and efficiency;

- developing consensus on the application of pertinent technology to fulfill user and provider requirements, including development of minimum operational performance standards for electronic systems and equipment that support aviation; and

- assisting in developing the appropriate technical material upon which positions for the International Civil Aviation Organization and the International Telecommunication Union and other appropriate international organizations can be based.

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EXECUTIVE SUMMARY

RTCA Special Committee 230 was tasked with assessing and documenting the maturity and the feasibility of using an airborne Light Detection and Ranging (LIDAR) system for detection of clear air turbulence (CAT).

This feasibility study document details the context of the study and a description of the intended function (situational display of regions ahead of the aircraft that present potential hazards to the aircraft due to clear air turbulence). Its goals are:

- To determine realistic goals for an airborne LIDAR system when used for clear air turbulence detection.
- To determine aircraft manufacturer needs for an airborne LIDAR clear air detection function.
- To determine the feasibility that LIDAR systems can meet aircraft manufacturer needs.

Aircraft manufacturers have expressed the following operational goals for a LIDAR-based CAT detection function:

- A minimum detection range of 12 NM, in order to provide at least 90 seconds to secure the majority of passengers and crew.
- An angular display extent of +/- 25 degrees from the aircraft's longitudinal axis or track.
- Consistency with WXR-based ATA or Turbulence functions for:
  - Display thresholds
  - Precision/refresh rates
  - Must and must-not detector requirements

CAT Detection

SNR analysis was performed on two types of LIDAR systems, with the following results:

- Coherent LIDAR: Existing coherent LIDAR systems are not able to meet the OEM's requirements for long range CAT detection at high altitude (around 32,000 ft), although it may be possible to meet these requirements at lower altitudes. Although many experimental demonstrations of CAT detection have been shown in the past, further research is needed in the area of LIDAR transmitters if coherent LIDAR systems are to be used for airborne CAT detection.
- Direct Detection LIDAR: Direct detection LIDAR systems with state-of-the-art laser power, telescope sizes, and detection equipment may be able to detect moderate to severe clear air turbulence for all altitudes up to 39,000 ft. Numerical simulations suggest that the direct detection LIDAR can meet OEM requirements. Further research and flight tests are needed to substantiate the simulations.

Gust Load Alleviation

Using the same SNR analysis, LIDAR manufacturers concluded that it may be feasible to meet OEM requirements for gust load alleviation. Analysis indicates that when enough aerosols are present in the atmosphere, coherent LIDAR systems with lower output power have comparable performance to much higher-powered direct detection LIDAR systems. However, areas that are low in aerosol content will be challenging for coherent LIDAR systems.

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GUIDELINES

This document uses a structure similar to a Minimal Operational Performance Standard (MOPS). It will assess and document the maturity and the feasibility of using airborne LIDAR for clear air turbulence (CAT) detection. The content has not been written as requirements (no "shall" statements). It considers existing functions and their criticality.

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1. INTRODUCTION/CONTEXT

1.1 Background

One of the most significant forms of threat to an aircraft comes in the form of turbulence. Clear air turbulence (CAT), which is usually encountered in cloud-free regions at high-altitudes (~20,000 ft – 50,000 ft) outside of convective regions, can be sudden and severe. CAT is a recognized problem which impacts all aircraft operations. This phenomenon is especially troublesome because it is often encountered unexpectedly, and frequently does not provide visual clues to warn the pilots of the hazard.

Per the FAA Advisory Circular on Clear Air Turbulence Avoidance, AC 00-30C [5]:

> CAT is defined as “sudden severe turbulence occurring in cloudless regions that causes violent buffeting of aircraft.” This term is commonly applied to higher altitude turbulence associated with wind shear. The most comprehensive definition is high-altitude turbulence encountered outside of convective clouds. This includes turbulence in cirrus clouds, within and in the vicinity of standing lenticular clouds and, in some cases, in clear air in the vicinity of thunderstorms. Generally, though, CAT definitions exclude turbulence caused by thunderstorms, low-altitude temperature inversions, thermals, strong surface winds, or local terrain features.

Historically, Light Detection and Ranging (LIDAR) sensors have been shown to detect various atmospheric phenomenon including but not limited to: mountain wave induced turbulence, low altitude rotors, volcanic ash, high altitude ice crystals, low level Windshear, etc.

The scope of this report includes the detection of moderate or greater turbulence. It also addresses detection of turbulence due to terrain features such as mountain waves, low altitude rotors, and convectively induced turbulence in cloud-free regions.

One of the principal areas where CAT is found is in the vicinity of jet streams. Jet streams are relatively narrow bands of strong wind in the upper levels of the atmosphere. In jet streams, winds blow from west to east, but the flow meanders southward and northward in waves. Jet streams follow the boundaries between hot and cold air. Because these hot and cold air boundaries are most pronounced in winter, jet streams are strongest in winter in both the northern and southern hemispheres. One noteworthy generator of CAT is the confluence of two jet streams. The wind shear effect between two jet streams in the region of confluence and immediately downstream is often highly turbulent.

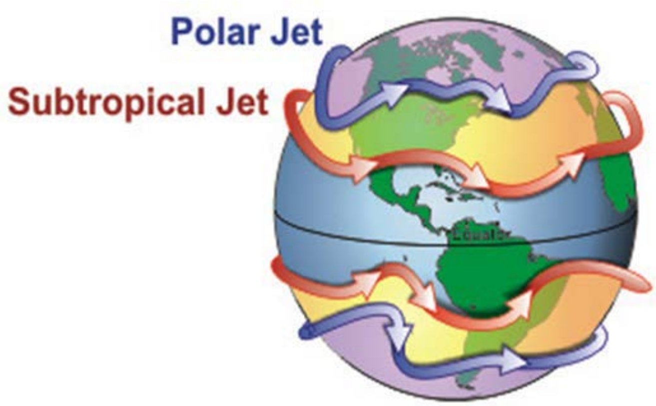

Figure 1-1: Illustration of Polar and Subtropical Jet Streams and Their Relative Location Around the Globe [5]

Another phenomenon that can cause CAT is Kelvin-Helmholtz instability. This instability can occur when there is a velocity shear in a single contiguous fluid, or when there is a vertical velocity difference across

