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Development of an Onboard Doppler LIDAR for Flight Safety

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Abstract: Air turbulence has become a major cause of significant injuries and aircraft damages. Timely advance warning of turbulence ahead of an aircraft may allow pilots to take appropriate action to minimize potential damage, such as reducing speed and securing passengers and unsecured objects, or to avoid the turbulence altogether. The aim of our research is to develop a practical onboard LIDAR-based proactive sensor that will detect air turbulence in clear air at a range of 5 nautical miles (9.3 km) at cruising altitudes. In February 2007 we successfully measured wind speeds approximately 3 nautical miles (5.6 km) ahead of an aircraft in low altitude flight experiments, and in a subsequent experiment in July of the same year, we succeeded in detecting air turbulence before encountering it. An upgraded 5 nautical mile LIDAR for low altitudes was developed in fiscal year 2007, and has successfully measured wind speeds at ranges up to 5 nautical miles in ground tests. This paper describes the results of basic flight and ground experiments.

Keywords: Doppler LIDAR, Flight testing, Aircraft accident, Air turbulence, Onboard laser sensor

1. INTRODUCTION

While the number of aircraft crashes is decreasing, accidents in which crew and passengers have been injured due to turbulence have occurred frequently in Japan in recent years. In most such accidents, unsecured articles such as service carts or crew and passengers are caused to jump up by negative vertical acceleration due to turbulence, then they are often slammed violently into the ceiling and drop to the cabin floor or onto seats causing damage or injury.

The most direct and effective means of preventing such accidents is detecting turbulence ahead of an aircraft in flight and giving advance warning to the pilots. If the pilots have adequate warning of an area of turbulence and its intensity, they can turn on seat belt signs and order that the cabin be secured. Also, if sufficient time is available, pilots may reduce the shaking of the aircraft by reducing speed, add positive vertical acceleration by turning, or change course to avoid the turbulent area.

With the aim of reducing such accidents, the JAXA (Japan Aerospace Exploration Agency) launched the research and development of an onboard proactive wind measurement sensor in 1999 [1]. The aim is to develop a practical onboard Doppler LIDAR (Light Detection and Ranging) which can detect wind shear, downbursts, wake-vortex, clear air turbulence and mountain wave in clear air conditions at a range of 5 nautical miles ahead of an aircraft at cruising altitude. A typical jet airliner cruises at an airspeed of about 250 m/s, and takes about 37 seconds to fly this distance. While this was never considered to be sufficient time for turbulence evasion, it should enable some precautions to be taken.

2. ONBOARD DOPPLER LIDAR

2.1 Concept

The overall concept of the onboard wind measurement LIDAR is shown in Fig. 1. The Doppler LIDAR is installed in an aircraft to measure air turbulence ahead of it in flight. Pulsed laser light emitted forward from the aircraft is scattered by aerosol particles in the atmosphere, such as fine water droplets and dust, and some of the backscattered radiation is received back at the aircraft. Light aerosol particles travel with the wind so that the wavelength of the scattered laser light is shifted in proportion to the velocity of the particles due to the Doppler effect, enabling measurement of the wind speed. Range information can be obtained by measuring the delay between the transmission of a pulse of laser light and the reception of the backscattered radiation.

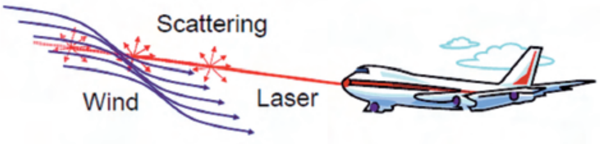

Fig. 1 Concept of an Onboard Doppler LIDAR

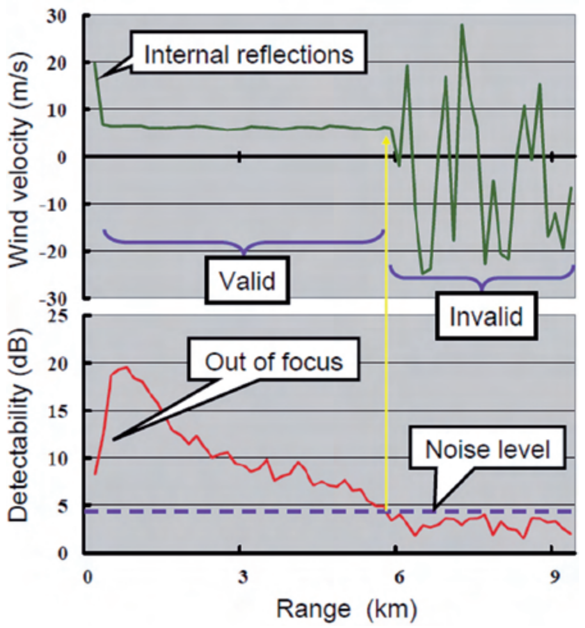

Fig. 2 In-Flight Measured Data by the 3NM Class LIDAR

2.2 3NM class LIDAR

A 3NM (5.6 km) class prototype Doppler LIDAR was developed in FY 2006 to demonstrate a practically useful detection range [2]. The first flight experiment was conducted in 2007 in calm, clear air conditions. A sample of the in-flight measured data at an altitude of 600 meters is shown in Fig. 2. The measurable distance (range) is defined as that at which the detectability is greater than 4.5 dB, which is the noise level. The flight experiment demonstrated that the 3NM class LIDAR was able to measure wind speed at a maximum distance of approximately 6 km in flight in clear weather.

2.3 5NM class LIDAR

A 5NM (9.3 km) class prototype Doppler LIDAR was developed in FY 2007 to demonstrate greater long range performance obtained by increasing the laser output to about three times that of the 3NM class LIDAR. A high output amplifier using a large core diameter (25 μm) optical fiber was developed, and was inserted as a second amplifier behind the 3NM class LIDAR amplifier [3].

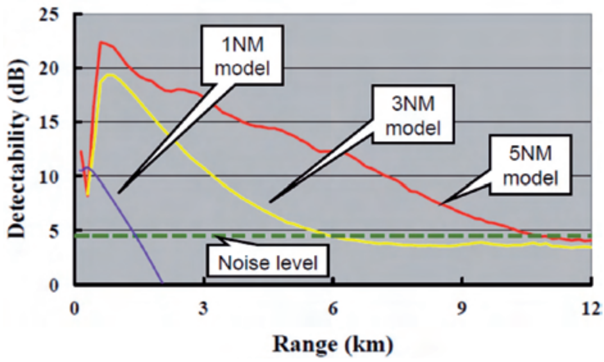

Fig. 3 Ground Measured Data by Each LIDAR

The results of a ground experiment in ordinary aerosol conditions are shown in Fig. 3. The 5NM class LIDAR demonstrated a maximum measurable distance of approximately 10 km.

3. CONCLUDING REMARKS

The summary is as follows:

- Flight demonstrations to measure wind speeds at a range of 3 nautical miles (5.6 km) at low altitude were carried out in 2007.

- Ground-based demonstrations to measure wind speeds at a range of 5 nautical miles (9.3 km) were carried out in FY 2007.

The present research will only result in development of a wind measurement remote sensor, and maintainability and reliability aspects will have to be addressed for practical use. The methods of indicating detected wind turbulence, warning pilots and action to minimize any damage will have to be researched in order to develop a useful device that can contribute to flight safety. It is also considered that measured wind data will be communicated directly to the aircraft's automatic flight control system rather than to the human pilots. We have recently begun such research.

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