Development of an Onboard Safety Avionics System using a Doppler Lidar

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Abstract: We are developing an airborne Doppler lidar for onboard turbulence detection. Flight experiments have shown that it is difficult for the present lidar to be used for guiding turbulence evasion maneuvers during cruise, but at low altitudes or airspeeds a lidar will enable vertical avoidance maneuvers to be provided during landing approach. It is also considered that measured wind data will be communicated directly to the aircraft's automatic flight control system during cruise. An outline of prior flight experiments and a development program of the safety avionics system are explained.

Keywords: Flight Safety, Air Turbulence, Doppler Lidar

1. Introduction

Figure 1 shows a breakdown of the causes of large airplane accidents during the 10 years between 2005 and 2014, based on an analysis of aircraft accident reports published by the Japan Transport Safety Board [1]. There were a total of 30 airliner accidents during this period, of which 16 were caused by air turbulence and 3 are judged to be due to human factors related to air turbulence. It therefore appears that more than half of the accidents were related to air turbulence. Although pilot error is sometimes identified as a factor in turbulence-related accidents, it is considered that advance warning of turbulent conditions would allow crews time to prepare and so eliminate human error as a cause. Moreover, turbulence-related accidents have been increasing in recent years according to the Federal Aviation Administration's Advisory Circular (AC) 120-88A [2]. Therefore, turbulence is the most important flight safety issue that needs to be urgently addressed by preventive measures.

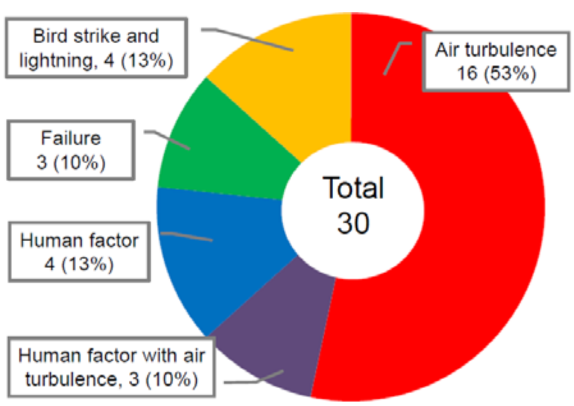

Figure 1. Aircraft Accidents to Large Civil Airplanes in Japan (2005-2014).

Conventional weather radar can detect turbulence associated with thick cloud. However, since it cannot detect turbulence in clear air, there is currently no effective means to predict Clear Air Turbulence (CAT) encounters. To reduce the number of in-flight accidents caused by CAT, we need an onboard system to detect turbulence, immediately determine its intensity, and warn the pilots if necessary. This would make flights operations safer. Based on this consideration, we are developing a lidar system to detect turbulence ahead of an aircraft even in clear air conditions and give advance warning of CAT encounters. We have developed a high-power Doppler lidar as an aircraft onboard device, and a flight demonstration successfully detected CAT ahead of an aircraft.

2. Development of the Doppler Lidar

We have been developing coherent Doppler lidars that use 1.5 μm eye-safe wavelength lasers [3]. Because aerosol densities are low at jet airliner cruising altitudes, somewhat high output power is necessary. We have therefore developed a high power optical planar waveguide amplifier (WGA) which achieved an available laser pulse energy of 1.9 mJ at a pulse repetition rate of 4 kHz [4], and applied it into our previous experimental lidar to produce a 'high altitude lidar' model shown in Figure 2. The optical transceiver includes a master laser oscillator and a heterodyne detector, and the optical antenna contains an optical telescope and optical amplifiers. A personal computer performs signal processing. A chiller provides liquid cooling of the WGA, and two amplifier drivers control the pump light for the optical amplifiers. Because this is a proof-of-concept model, no special attention was paid to miniaturizing of integrating the system components. The high altitude lidar model was installed in a Gulfstream II jet aircraft and demonstrated wind measurement capability at high speed and high altitude [5]. The system components were installed in a rack of the aircraft's cabin as shown in Figure 3, while the optical antenna was mounted in a fairing on the bottom of the fuselage. Laser light was emitted forward from the aircraft.

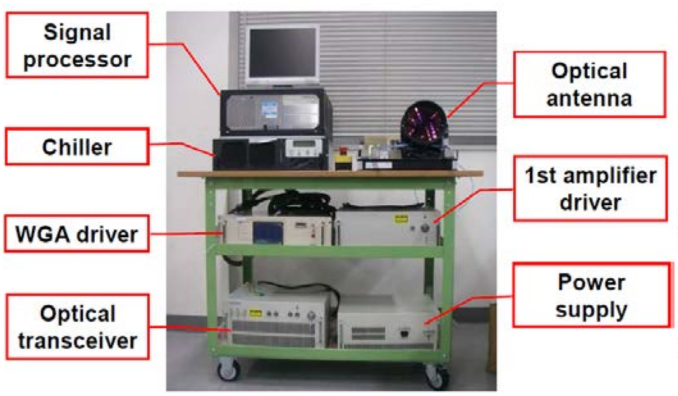

Figure 2. High Altitude Lidar Model.

Figure 3. Experimental System Installation.

Figure 4 shows an example of CAT detected ahead of the aircraft while flying at altitude of 3,200 m [6]. The upper plot shows the wind intensities detected by the lidar, with distance ahead of the aircraft along the ordinate, so the aircraft flies along the upward direction of the graph. Time is shown along the abscissa, and vertical lines are plotted at one-second intervals. Each vertical column of blocks shows color-coded wind speed variances (Wlos) in each range bin observed each second. Wlos is used as an index of turbulence intensity. As shown in the key in the upper right corner of the figure, the color changes toward red as the Wlos value increases to indicate stronger turbulence. Since the received signal level weakens with distance, black is used to represent the absence of Wlos measurement due to insufficient received laser light. A region of turbulence detected ahead of the aircraft gets closer with time as the aircraft flies towards it. Therefore, if turbulence is detected, a downward-sloping line will appear in the graph. The upper and middle plots in Figure 4 show that a periodic change in vertical acceleration (Az) was measured and Wlos increased corresponding to the increases in Az. A periodic change of outside air temperature (OAT), shown in the bottom plot of Figure 4, was also observed that corresponded to the change of Az. Although the flight altitude fluctuated over a range of 25 m during the period of the observations shown, this is too small to account for the change in OAT. Since it is known that temperature variations are associated with CAT [7], this observation example indicates that the aircraft had encountered CAT.

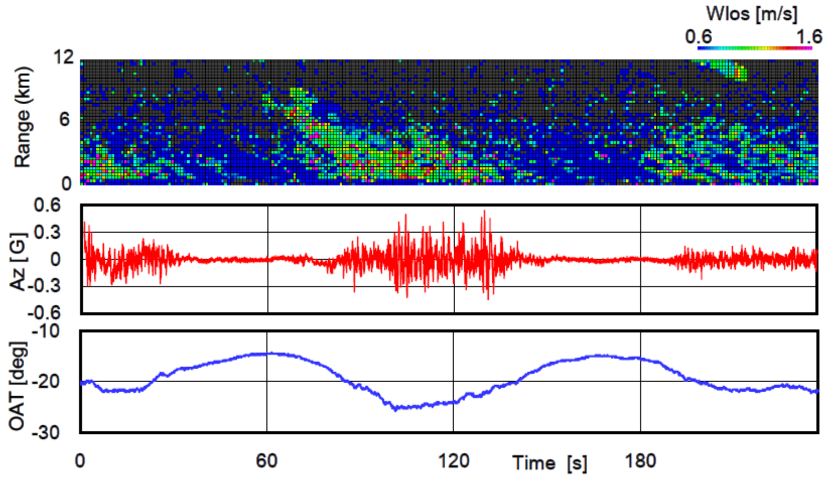

Figure 4. CAT Detection Sample.

3. R&D of Onboard Safety Avionics Technology

Although these flight experiments successfully demonstrated CAT detection in flight, at cruising speeds the present detection range means only a short warning time is available so it is difficult for the present 'high altitude lidar' model to be used to guide turbulence avoidance maneuvers during cruise. This is because high altitude CAT usually extends along horizontal layers and rapid vertical maneuvers during cruise to avoid it may have higher risk than the turbulence itself. The main aim of the lidar turbulence detection function in cruise is to therefore provide sufficient advance warning of turbulence to allow passengers and heavy cabin service items to be secured, although at lower altitudes or airspeeds a lidar will permit vertical avoidance maneuvers. Further improving the detection range of the lidar will require increases in size, weight and power consumption, with attendant higher installation cost. Consequently, now that the main components have been proven, we will now focus on reducing the size of the device and improving its reliability rather than on achieving greater detection range.

Our research and development project is moving toward achieving a system to prevent in-flight accidents caused by turbulence. The system will determine the turbulence intensity, warn the pilots if there is a risk, and automatically alleviate lurching through flight control inputs, making air travel safer for passengers and crew. An overview of operations by the system is shown in Figure 5. The system to prevent turbulence-induced in-flight accidents will have two main technical advances: reducing lurching while cruising or changing altitude, and warning pilots of turbulence encounter during landing approach.

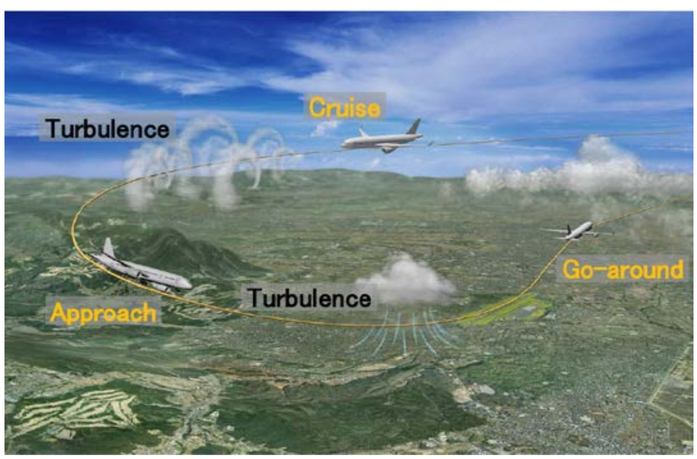

Figure 5. An Overview of Operations by Onboard Safety Avionics.

If the Doppler lidar detects distant turbulence during cruise, the seatbelt signs are turned on and the cabin is secured. Meanwhile, the lidar measures the vertical components of airflows ahead of the aircraft by two-axis observations. Based on these measurements of the airflow ahead of the aircraft, the flight control system generates control commands to suppress lurching when the aircraft enters the turbulence. Conventional automatic flight control systems use only information on the aircraft's current state, but our system utilizes data on the airflow one second ahead of the aircraft to generate control commands to counteract turbulence using the aircraft's control surfaces. If the Doppler lidar detect distant turbulence during climb or descent, the pilots can decide to level off and delay further altitude change to avoid the turbulent region.

During landing approach, the data obtained by the Doppler lidar system is used to immediately determine the risk associated with detected turbulence, and if necessary, advise the pilots to perform a go-around maneuver to avoid the hazard. The aircraft can then make another safer landing approach. Since it is unnecessary to obtain permission of air traffic control to execute a go-around, immediate action is possible. In addition, airspeed is low during landing approach and all passengers must fasten their seatbelts, so the go-around maneuver does not pose a risk of injuries. We plan to demonstrate this advisory function by flight experiments in 2016 to 2017.

4. Development of a next Doppler Lidar

In order to demonstrate an aircraft onboard safety avionics system that can improve the safety of flight operations, we are developing a prototype high-power compact Doppler lidar that integrates the components into a more suitable package for general aircraft installation. Table 1 shows the specifications of this lidar and Figure 6 shows a schematic diagram. The lidar consists of four units: an optical antenna unit, an optical transmitter and receiver (TRX) unit, a signal processor and a chiller. The optical antenna unit includes two telescopes and two optical amplifiers. A larger telescope is used by the warning function and a smaller telescope is used for measurement of the airflow vector. The optical antenna unit can switch between the telescopes by an optical polarization switch and polarized beam splitter (PBS). The lines of sight of each telescope are not parallel, and this allows the vertical component of wind speed to be obtained by measuring the wind speeds along each line-of-sight axis,. Compared with the proof-of-concept high altitude lidar model, the 1st amplifier drive, the WGA driver and the optical antenna have been downsized and integrated into the optical antenna unit. Furthermore, power supplies are integrated into each unit, and the optical antenna and the optical TRX can be operated with only a 28 VDC supply. Figure 7 shows the optical antenna of the next Doppler lidar.

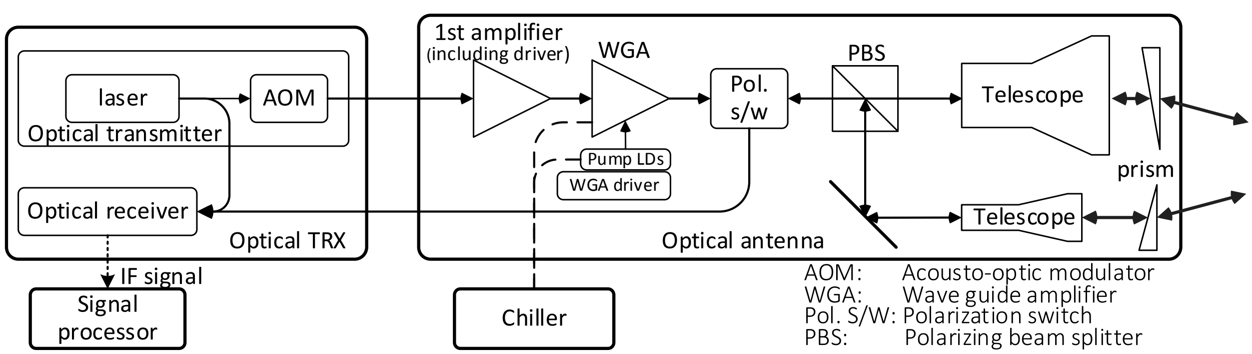

Figure 6. Schematic Diagram of the Next Doppler Lidar.

Table 1. Spec. of the Next Doppler Lidar

Wavelength	1550 nm
Pulse energy	≥3.3 mJ
Pulse repetition frequency	1 kHz
Pulse width	600 nsec
LOS switching frequency	5 Hz
Telescope diameter	150 mm 50 mm

Figure 7. Optical Antenna of the Next Doppler Lidar.

5. Concluding Remarks

We have developed a Doppler lidar for airborne turbulence detection and demonstrated CAT detection in flight. However, high aircraft cruising speeds mean that it is difficult for the present lidar to be used for guiding turbulence avoidance maneuvers during cruise. Consequently, we will focus on an advisory system, and expand its application to the landing approach phase of flight. It is also considered that measured wind data will be communicated directly to the aircraft's automatic flight control system for gust alleviation. Therefore, we have started a development program of an onboard safety avionics system using our Doppler lidar.

The Doppler lidar developed for the safety avionics system is now being tested on the ground. Compared to the proof-of-concept system, the number of components and total volume of the system have been reduced, and an airflow vector measurement function has been added.

When this system is has been proven effective and installed on passenger aircraft, we can expect a reduction in turbulence-related in-flight accidents. Flying will then be more comfortable and relaxing and passengers will be able to sleep better.

6. References

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