Utilization of onboard equipment	Onboard weather radar	Methods of utilization	Utilization during route changes to avoid adverse weather Understanding and utilizing data for hard-detect weather conditions (Japanese only) Proactive use of onboard weather radar (Japanese only) Characteristics, limitations, and effective use of onboard weather radar Avoidance of convective clouds echoes Understanding and avoiding conditions around cumulonimbus clouds
	Autopilot system	Methods of operation	Operations in compliance with aircraft operation regulations Operation of autopilot during turbulence encounters
		Training	Recovery procedures and training for wake turbulence encounters Providing information and training on maximum operation speed
	Utilize new technologies	Turbulence prediction	Enhancing prediction accuracy with Doppler Lidar Research and development of meteorological analysis techniques and forecast accuracy improvements

Many of the aforementioned recommendations have been addressed by operators through revisions to manuals and other preventive measures following accidents. However, in reality, similar accidents continue to be occurred due to factors such as sudden turbulence that was too abrupt for the prescribed manual response to be effective, unanticipated sudden local wind changes that were not predicted in pre-flight weather information, and insufficient avoidance of developing convective clouds.

Based on these analysis results, the next chapter will introduce potential accident prevention measures, including those that can be implemented by operators.

Chapter4 Measures to prevent aircraft turbulence-related accidents

For preventing turbulence-related accidents, drawing from the statistical analysis in Chapter 2, the findings from accident investigation reports in Chapter 3, and interviews with operators conducted during the creation of this digest, the main points for consideration can be broadly categorized into the following three areas.

1. Lack of unawareness in information sharing

Information sharing among crew members

- By sharing turbulence forecast information not only before the flight but also promptly and thoroughly during operations, cabin crew can prepare for turbulence by adopting protective postures and taking appropriate measures such as requesting passengers to fasten their seatbelts.
- It is important for crew members to share information regarding the timing and method of in-flight service based on turbulence conditions. If the likelihood of turbulence increases, consideration should be given to turning on the seatbelt sign regardless of the progress of service.
- Since turbulence conditions can vary significantly between the cockpit and the rear cabin, it is essential for crew members to share real-time turbulence information. Additionally, cabin crew should request the activation of the seatbelt sign when necessary.
- When the aircraft experiences turbulence, it is crucial to quickly assess the extent of passenger injuries and cabin conditions, accurately report the situation to the captain, and coordinate with ground personnel to ensure an effective

emergency response.

Information sharing between flight crew and flight dispatchers

- Flight dispatchers need to accurately analyze real-time weather information during pre-flight briefings and provide information that is not solely dependent on forecast data, such as identifying signs of turbulence based on changing conditions.
- During the flight, it is essential to use ACARS and other systems to quickly transmit the latest PIREP and weather information to flight crew members.
- Flight crew members should proactively report turbulence conditions and share this information among relevant personnel.
- C-PIREP (Common PIREP), which is shared among airlines, can serve as valuable supplementary information to standard PIREP reports, and its further utilization should be promoted.

Information sharing between flight crew and air traffic control authorities

- PIREP is an essential source of information for preventing turbulence-related accidents. It must be promptly reported so that air traffic control authorities can provide updates to following aircraft and meteorological agencies can utilize the data for analysis and forecasting.

2. Measures to mitigate damage during aircraft turbulence

Proper use of seatbelt

- Providing turbulence forecast information through in-flight announcements by flight crew can increase passenger attention and effectively raise awareness.
- Cabin crew should carefully observe passengers' body types and ensure the proper fastening of seat belts during in-flight services.
- Many injuries involve spinal or lower limb fractures, often caused by passengers being lifted off their seats and then falling due to turbulence. Therefore, it is important to educate passengers on the benefits of sitting deeply in their seats and securing their seat belts tightly at a low position on their waists.

  This measure is effective not only against vertical turbulence but also lateral turbulence.
- It is essential to fully understand the functions and proper usage of cabin seats (including those for cabin crew), service carts, and other onboard equipment to prevent their use from directly contributing to accidents. Efforts should be made to educate crew and passengers on proper usage.

Response to turbulence

- Passengers are not sufficiently informed about how to respond when turbulence occurs. It is important to provide them

with the same information as cabin crew, such as the location of handrails or handles to hold onto in case of sudden turbulence, lowering their posture and holding onto armrests when in the aisle, or sitting in an empty seat and fastening their seatbelt. These measures are crucial for preventing accidents.

- Additionally, when informing passengers, it is necessary to consider more effective methods that can reach as many passengers as possible.
- While procedures for responding to sudden turbulence are generally included in cabin crew manuals and communicated, practical training should be conducted to enhance cabin crew awareness and ensure they can apply these procedures effectively.
- Although cabin crew inherently face a much higher risk of injury than passengers due to the nature of their work, they must always remain aware of their role as safety personnel in the cabin. They should avoid prioritizing service to the extent that they become unable to fulfill their duties due to injury. Therefore, they should make every effort to remain seated whenever possible, especially in situations where turbulence is expected—but also in cases where it is not anticipated.
- Additionally, it is necessary to inform passengers that cabin crew seating is a safety measure and to seek their understanding and cooperation.
- Passengers should be continuously educated through in-flight announcements and other means to help them understand the importance of taking actions to ensure their own safety and to encourage their cooperation.

Column

“Efforts to reduce injury risks in the cabin”

Airlines are implementing various measures to prevent turbulence-related accidents. All Nippon Airways (ANA), for example, has introduced initiatives such as broadcasting educational videos to raise passenger awareness and conducting cabin crew training using a cabin simulator. The ANA Safety Promotion Center has contributed insights into their proactive measures for preventing turbulence-related accident.

"ANA's approach to turbulence countermeasures"

To reduce the risk of injuries caused by turbulence and maintain an acceptable level of safety, ANA is implementing and continuously improving the following measures.

1. Minimizing Turbulence

ANA is actively working on providing highly accurate turbulence forecast and real-time meteorological information to flight crew and flight dispatchers.

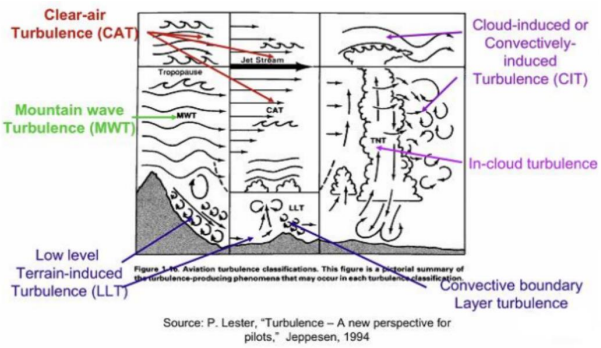
Regarding forecast data, conventional information was limited to VWS (Vertical Wind Shear), however, ANA now provides additional indicators such as CAT (Clear Air Turbulence), temperature changes, horizontal wind variations, stability, convective cloud effects, mountain waves, and real-time turbulence conditions. These factors are used to calculate and provide "Graphical Turbulence Guidance (GTG)" information.

For real-time turbulence data, in addition to the traditional PIREP (Pilot Report) transmitted via radio, ANA has joined IATA's (International Air Transport Association) Turbulence Aware platform, which enables the sharing of turbulence-related data among participating airlines worldwide. As part of this initiative, ANA has begun providing Eddy Dissipation Rate (EDR)*1 data.

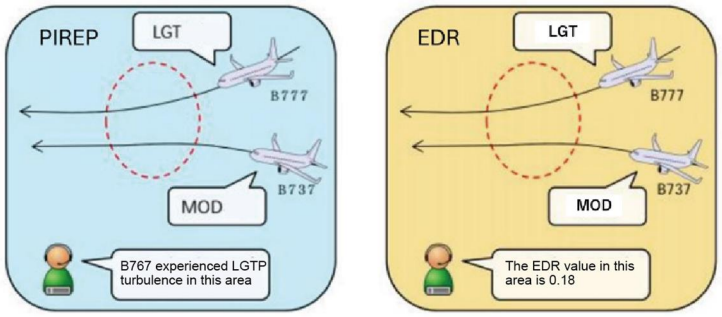
A major advantage of EDR is that turbulence data observed automatically by aircraft can be instantly collected, stored, and shared. Moreover, the data can be used across different aircraft types without distinction. The implementation of EDR is already progressing among international airlines, and ANA is expanding the number of aircraft equipped with this system.

At ANA, GTG and EDR data are accessible via tablet devices used by flight crew and ground-based dispatchers. Additionally, some international flights are equipped with in-flight Wi-Fi, allowing real-time access to the latest turbulence information. Moving forward, ANA plans to extend this capability to domestic flights as well. These initiatives enable improved turbulence forecasting and the selection of optimal flight routes.

*1: Eddy Dissipation Rate (EDR) – an index representing atmospheric turbulence intensity



GTG consideration factors



Source: Japan Meteorological Agency, "EDR (Eddy Dissipation Rate) and Automatic EDR Observation by Aircraft"

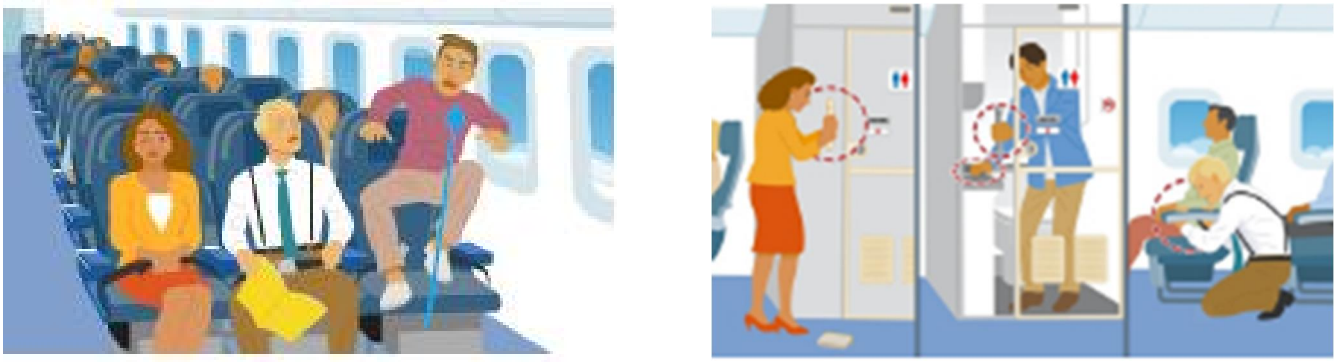
PIREP: Reports of turbulence from preceding aircraft allow the flight crew of following aircraft to anticipate turbulence severity based on their own aircraft's characteristics
EDR: The system calculates and provides turbulence intensity predictions to flight crew based on EDR values measured by preceding aircraft

Characteristics of PIREP and EDR

2. Preventing injuries & preparing for turbulence

Preventing injuries

Cabin crew issue announcements and provide verbal warnings to alert passengers when turbulence is expected or encountered. To further reduce injury risks, ANA introduced an in-flight educational video in September 2020. This video informs passengers about appropriate actions to take during turbulence, raising awareness and encouraging them to take proactive safety measures.



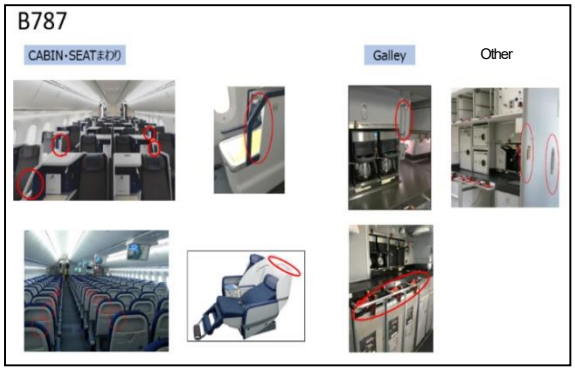
Passenger educational video

Preparing for Turbulence

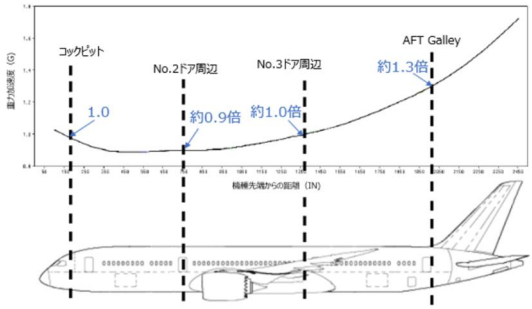
Effective crew communication is a crucial factor in reducing turbulence-related injury risks. Since flight crew are the primary source of information for both passengers and cabin crew, timely and accurate information sharing directly contributes to safety.

While different departments have individually implemented various measures, “turbulence-related injury prevention” should be addressed through cross-departmental collaboration. To facilitate this, ANA Group has published a Turbulence Prevention Pamphlet, outlining key factors and considerations for injury risk reduction. This initiative aims to enhance mutual understanding between flight and cabin crew, helping them identify and implement the appropriate actions necessary for safe operations.

Unexpected turbulence may be encountered, or actual turbulence conditions may differ from pre-flight information in terms of timing (earlier or later) and intensity (stronger or weaker). If safety measures are not in place beforehand, the risk of injury cannot be effectively reduced. To minimize the risk of being lifted off the ground during turbulence and to protect themselves, cabin crew are trained to familiarize themselves with available handholds on each aircraft type, identify secure handholds onboard before each flight, and experience turbulence response training using the Motion Mockup simulator, which replicates turbulence conditions, as part of new hire training. This ensures that crew members instinctively take protective actions in sudden turbulence situations.



B787 Secure handholds in the cabin



B787-9 Differences in turbulence intensity by aircraft position

According to Boeing data, turbulence experienced in the rear of the aircraft can be up to 1.5 times stronger than what is felt in the cockpit, though this varies by aircraft type. Based on this data, as well as ANA’s internal analysis of seatbelt sign activation during strong turbulence events, flight crews are encouraged to remain highly alert to the risk of severe turbulence and proactively activate the seatbelt sign without hesitation if turbulence is suspected.

3. Utilization of aircraft-mounted equipment (new technologies)

Utilization of onboard weather radar and meteorological information

- The most common cause of aircraft turbulence-related accidents is in-cloud turbulence. Since the development and dissipation of turbulence within clouds can be somewhat predicted by carefully monitoring the movement and intensity of observed radar echoes, it is crucial to make effective use of this information. To achieve this, flight crews must thoroughly understand the characteristics and limitations of weather radar and continuously practice proper operational techniques.
- Accurately assessing the development and dissipation of cumulonimbus clouds and thunderstorms allows for better turbulence avoidance strategies, such as horizontal course deviations or, depending on the situation, vertical avoidance by maintaining a sufficient altitude difference. When avoiding turbulence, it is important to recognize that certain types of airflow disturbances may not be easily detected by onboard weather radar. Therefore, pilots should ensure adequate time

and distance for avoidance maneuvers. Additionally, if turbulence is anticipated, proactively activating the seatbelt sign is essential to enhance passenger and crew safety.

- Regarding clear air turbulence (CAT), which remains difficult to predict with current technology, further advancements in meteorological analysis systems and improvements in forecasting capabilities are expected to enable more precise turbulence predictions before flight operations commence.

Practical implementation of aircraft-mounted Doppler Lidar

- Utilization of aircraft-mounted Doppler Lidar for flight control

By utilizing laser light and the Doppler effect of scattered light from aerosols in the atmosphere, it is possible to measure wind speed and other atmospheric conditions ahead of the aircraft even in the absence of precipitation particles, unlike conventional onboard weather radar. Based on this data, a technology development initiative led by JAXA (Japan Aerospace Exploration Agency) is underway to automatically control the aircraft and reduce turbulence. Through flight experiments, the capability to observe wind conditions at high altitudes has already been demonstrated. However, research is ongoing to extend the detection range further. Enhancing detection range requires higher output power and improved performance of observation equipment, which contradicts the need for miniaturization and weight reduction for aircraft installation. To overcome this challenge, efforts are being made to integrate new technologies to achieve both goals, and its practical implementation is eagerly anticipated.

Utilization of EDR and other turbulence information

- Sharing of turbulence information using EDR and other data

Currently, real-time turbulence information relies almost entirely on PIREP submitted by flight crews during flights. However, the reported turbulence intensity is largely influenced by the size of the aircraft and the subjective perception of the flight crew, making it less objective. By utilizing the automated reporting system developed with EDR turbulence information can be obtained in real-time, providing a more objective and quantitative assessment of turbulence intensity while also considering the aircraft's size. This enables aircraft to take appropriate actions based on the severity of the turbulence indicated by EDR values. Efforts to forecast and share turbulence information using EDR and other data are being officially recognized and integrated as standard indicators within various frameworks, including ICAO and IATA, where data is collected, stored, and shared systematically.

Column "Efforts to share real-time turbulence information utilizing new technologies"

Understanding where and what kind of turbulence is occurring is crucial for preventing turbulence-related accidents. However, the current system for sharing turbulence information faces challenges in terms of objectivity and timeliness. Japan Airlines (JAL) is working on utilizing real-time information-sharing systems that leverage EDR and services provided by private meteorological companies. The airline's Flight Operations Standards & Technology Department has contributed an article on this initiative.

"JAL's initiatives for preventing accidents caused by sudden aircraft turbulence"

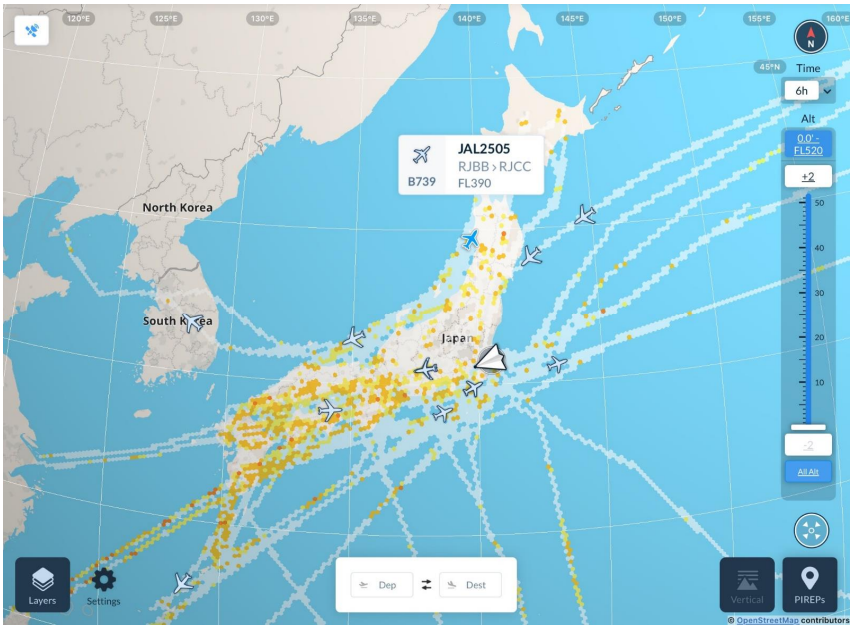
For airlines, it is essential to anticipate areas of sudden turbulence during flight and take measures to avoid its impact, ensuring a smooth in-flight experience and preventing injuries to passengers and crew.

To achieve this, airlines develop safe flight plans and corresponding service plans by making full use of the latest meteorological charts and weather data. However, supplementing weather information with reports from pilots who have actually encountered turbulence is extremely effective. When reporting turbulence encounters, key factors include the accuracy of location (latitude, longitude, altitude), turbulence intensity, and the exact time of occurrence. Additionally, the real-time nature of the reports is critical. However, the current C-PIREP (Collaborative Pilot Report) system, which enables airlines to share information, relies on pilots manually or verbally reporting turbulence intensity based on their subjective experience—often only after they have finished responding to the turbulence. This method presents challenges regarding the objectivity and timeliness of turbulence information.

EDR (Eddy Dissipation Rate) has gained attention as a technology to address the challenges of C-PIREP. EDR is an indicator of airflow turbulence recommended by ICAO as a turbulence standard. It is automatically calculated by a computation program installed in an aircraft's computer using sensor data from the aircraft and is reported to the ground in real-time. Theoretically, this eliminates ambiguity and time lag.

In January 2021, the JAL Group became the first in Japan to implement EDR, launching a system that automatically reports turbulence information to the ground in real-time. At the same time, the airline also introduced a system, jointly developed with a private meteorological company, which utilizes AI to rapidly process the automatically reported turbulence data and immediately notify aircraft in flight. As a result, there is now almost no time lag between turbulence occurrence and information sharing.

Currently, the EDR program is installed on some Boeing 737 and 767 aircraft, covering approximately 35% of the JAL Group's fleet. However, technical challenges remain in expanding its installation to more aircraft models, and increasing the volume of turbulence data will take time.



Turbulence information observed over Japan and surrounding areas

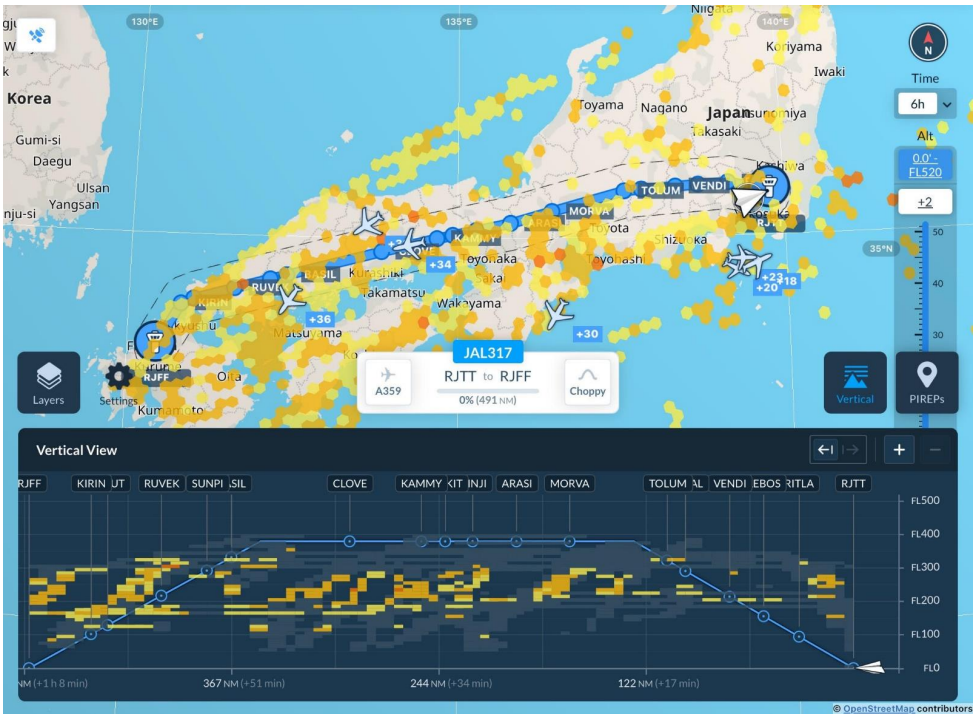
As one approach to overcoming the challenges of the existing EDR system, the JAL Group has been exploring the adoption

of the latest technology that allows for easier access to turbulence information from a greater number of aircraft. A trial operation of this technology began in fiscal year 2023.

This technology utilizes an application installed on tablet devices used by pilots during flight. The application automatically measures turbulence intensity at five levels using the tablet's GPS data and accelerometer sensors. The measured data is then transmitted in real-time to a ground server via in-flight Wi-Fi. The turbulence data collected from JAL flights and other airlines is sent to the ground server and can be accessed via the application on the tablet through in-flight Wi-Fi.

By registering the aircraft type in the application, the turbulence intensity is automatically adjusted based on the size of each aircraft. This ensures that turbulence information reflects an objective measure that closely matches the pilot's actual experience, regardless of the aircraft size. Additionally, the viewer function allows pilots to check turbulence data along their flight route in both horizontal and vertical cross-sections, as well as to visually grasp the distribution of turbulence information reported by other aircraft.

For aircraft where GPS reception and Wi-Fi communication are available in the cockpit, simply bringing a tablet device with the installed application into the cockpit enables both the transmission and reception of turbulence information. When used in combination with EDR, therefore, this system has the potential to enhance flight safety by adding another layer of protection. However, since real-time data transmission and reception require a stable in-flight Wi-Fi connection, airlines must carefully assess their own operational circumstances and determine the appropriate balance between EDR and this new technology.



Turbulence information along flight routes (vertical turbulence distribution)