-Overview and analysis of accident investigation cases-

Japan Transport Safety Board DIGESTS

JTSB (Japan Transport Safety Board) DIGESTS

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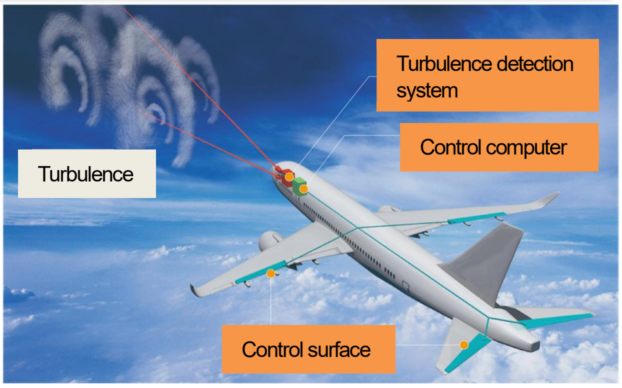
Aviation Accident Analysis Report

-Preparing for sudden turbulence during flight-

Preventing accidents caused by aircraft turbulence

Chapter 1 Introduction

The eradication of accidents caused by aircraft turbulence (hereinafter referred to as "turbulence accidents") has been a long-standing challenge for all airlines, with ongoing efforts to prevent them. However, in 2022, six turbulence accidents occurred, the highest number in the past 20 years. In recent years, this type of accident has accounted for more than half of all accidents involving large aircraft, and among accidents resulting in serious injuries, the majority were turbulence-related. On the other hand, some cases have demonstrated that proper responses can mitigate damage; therefore, learning from past accidents and taking preventive measures is an effective approach to reducing future occurrences.



Source: Japan aerospace exploration agency

Figure 1: Conceptual diagram of aircraft turbulence reduction technology

In this JTSB Digest, we will build upon the content of Digest No. 15 (August 2014) – Preventing Accidents Caused by Aircraft Turbulence by incorporating recent accident trends, injury statistics, and an analysis of turbulence-related factors, which account for the majority of causes. Additionally, we will introduce accident investigation cases conducted by the JTSB and explain current measures to prevent accidents and mitigate damage, including technological advancements in turbulence avoidance (see Figure 1).

In this digest, "turbulence accidents" refer to aviation accidents investigated by the Japan Transport Safety Board (including the former Aircraft and Railway Accident Investigation Commission) between 2004 and 2023, in which turbulence-induced aircraft movement caused serious injuries to passengers or cabin crew on large airliners (maximum takeoff weight exceeding 5,700 kg). Please note that some of the data presented may include ongoing investigations.

Chapter 2 Occurrence of aircraft turbulence-related accidents

1. Trend in the number of accidents

Examining the annual number of aviation accidents investigated by the JTSB over the past 20 years (2004–2023), the total number of accidents has remained relatively stable, as has the number of accidents involving large aircraft. Among these, turbulence-related accidents account for 37 out of 67 large aircraft accidents (approximately 55%), making up more than half of all cases.

Notably, in the past 10 years, 21 out of 35 large aircraft accidents (60%) were turbulence-related, with 2022 recording the highest number in 20 years, with six cases (see Figure 2).

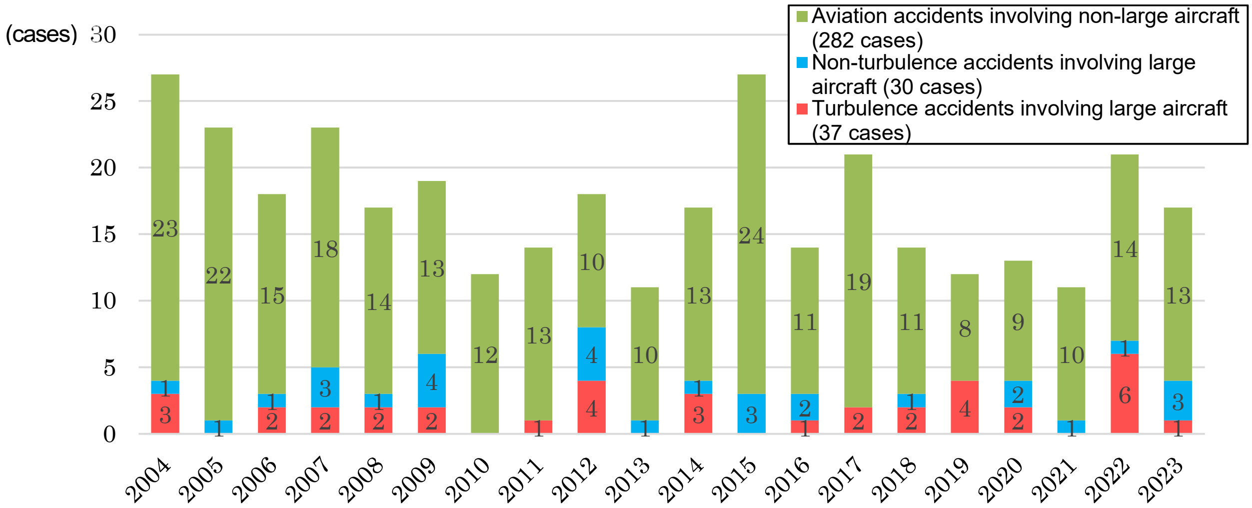


Figure 2: Number of aviation accidents

2. Locations of accidents

From here, we will examine 36 of the 37 turbulence-related accidents that occurred over the past 20 years (2004–2023) and were published in accident investigation reports as of December 2023.

First, looking at the locations of these accidents, they are widely distributed from the Tohoku region to the Nansei Islands. While the number of accidents is higher on the Pacific side, where air traffic is relatively dense, no clear distribution patterns are observed based on location (land, sea, etc.) or turbulence type. This means turbulence-related accidents can be occurred anywhere. (See Figure 3)

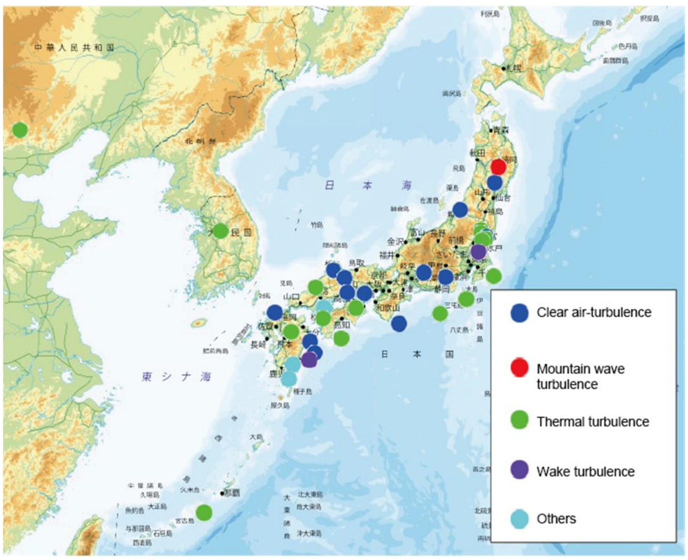


Figure 3: Locations of turbulence-related accidents (excluding one case over the Russian Federation)

3. Altitude and flight phase of turbulence-related accidents

Looking at the flight altitude at the time of turbulence-related accidents, 12 cases (about 30%) occurred below 20,000 feet, while 24 cases (about 70%) occurred above 20,000 feet. The most common altitude range was 25,000–29,999 feet, with 8 cases.

Regarding the flight phase, accidents were rare during ascent (4 cases) and final approach (1 case), when both passengers and cabin crew are likely to be wearing seat belts. Most accidents occurred during cruise (18 cases) or descent (13 cases, including descents for cruise altitude adjustments). This is likely influenced by the fact that passengers may leave their seats for lavatory use and in-flight services are provided during cruise, and that cabin crew are often out of their seats during descent for stowing in-flight service equipment and safety checks, such as ensuring seat belt compliance. (See Figure 4)

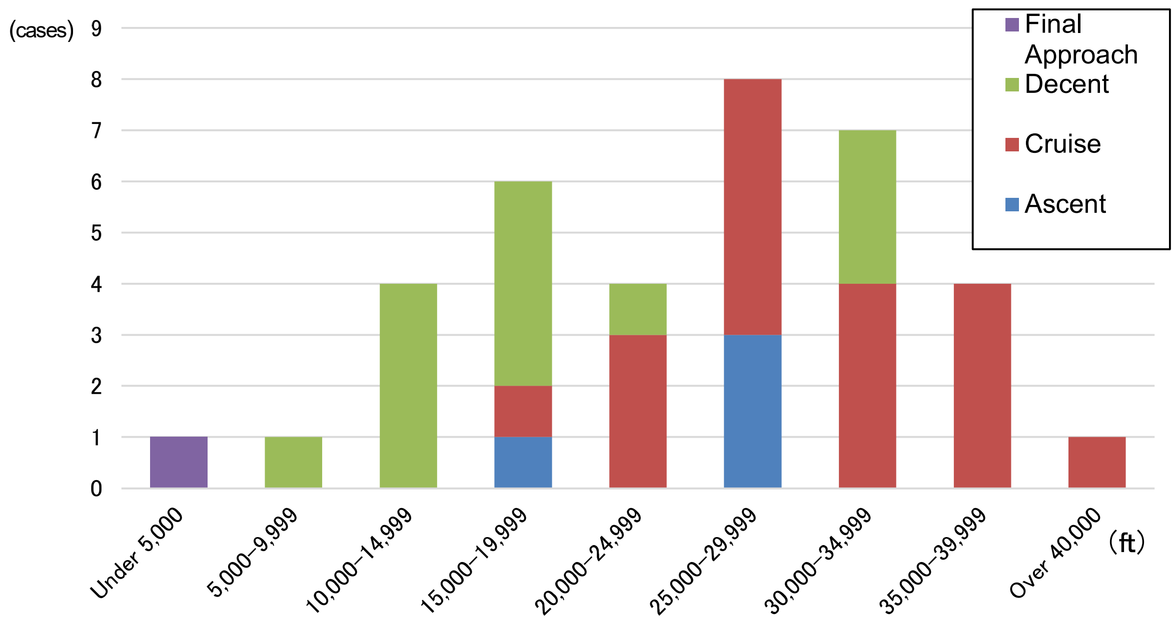


Figure 4: Altitude and flight phase of the accidents

4. Injury status

Looking at the injury statistics, there were 44 serious injuries, including 18 passengers and 26 cabin crew members. The total number of injured individuals, including minor injuries, was 118, consisting of 62 passengers and 56 cabin crew members. When comparing the injury rate to the total number of people on board the aircraft involved in turbulence-related accidents, the injury rate for cabin crew (approximately 16.2%) was 18 times higher than that for passengers (approximately 0.9%).

Similar to the previous section, this is likely because passengers are usually seated with seat belts fastened, whereas cabin crew are often standing and performing duties unless the seat belt sign is on. As a result, they are more vulnerable to sudden turbulence and may not be able to assume a protective posture in time. (See Figure 5)

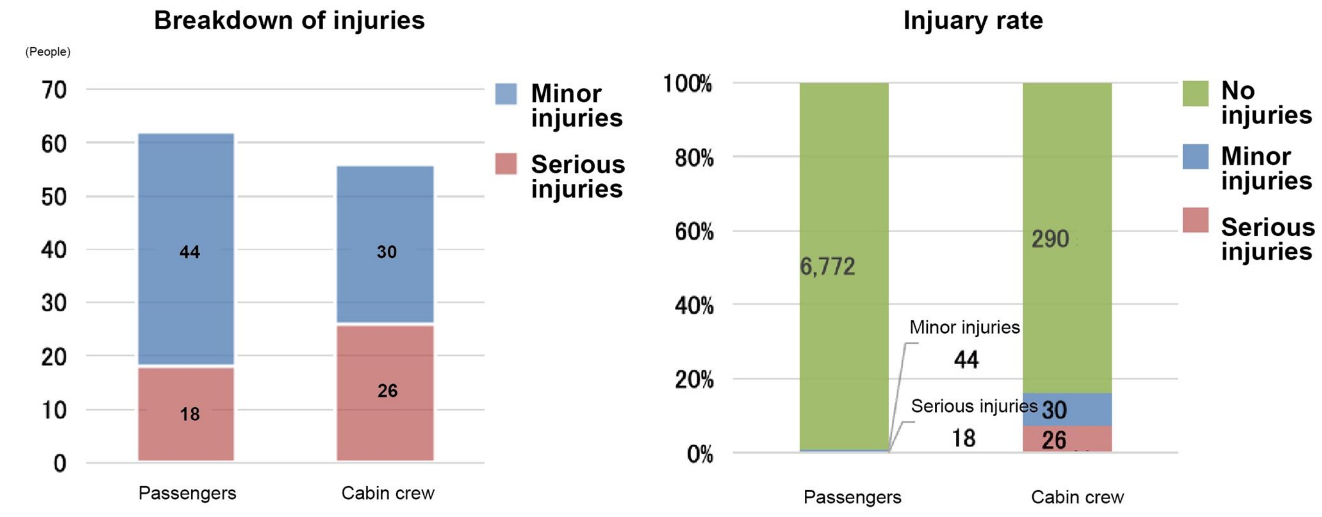


Figure5: Injury statistics

Looking at the trend of serious injuries, passenger injuries have been decreasing over the past 20 years, whereas injuries among cabin crew have been increasing. (See Figure 6)

One of the reasons for this is that for cabin crew, their job often requires them to remain standing and unable to take a seat immediately, making them more vulnerable to sudden turbulence; while the preventive measures, such as in-flight announcements encouraging passengers to keep their seatbelts fastened low and tight at all times while seated, have proven effective. To further reduce accidents in the future, it is essential to focus on implementing additional measures specifically for cabin crew.

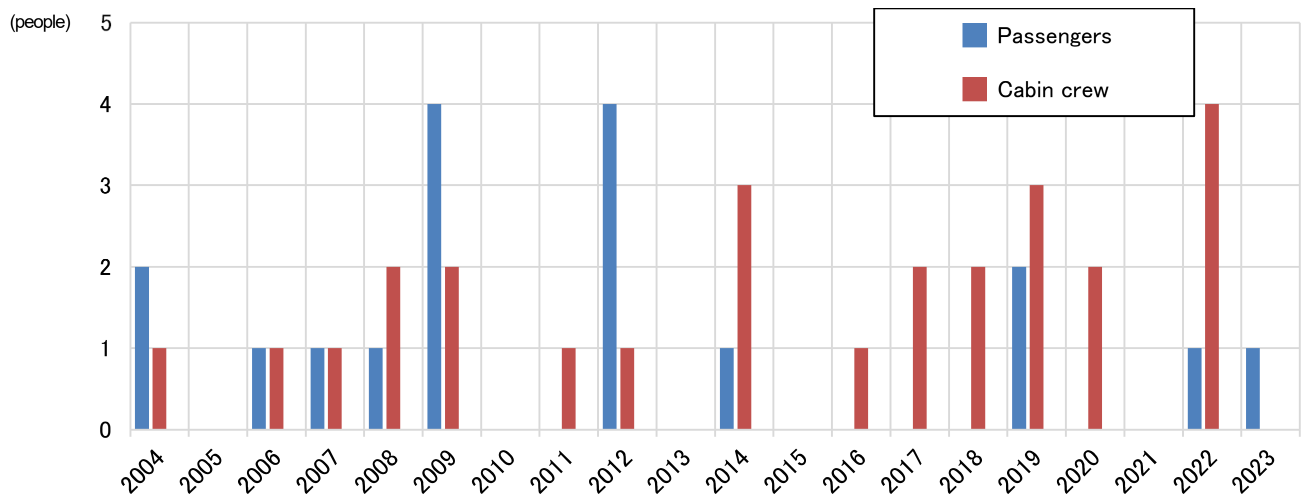


Figure 6: Trend of serious injuries

Next, looking at the injured body parts, 14 cases involved spinal fractures, followed by 13 cases of lower limb fractures, such as fractures in the legs. (See Figure 7)

Spinal fractures were commonly associated with accidents where the aircraft experienced vertical turbulence (up-and-down motion), causing passengers or crew to be lifted off their seats and land hard, similar to a tailbone impact. Lower limb fractures occurred in cases where individuals attempted to brace themselves against sudden turbulence but fell and struck their ankles, or when the force exceeded their ability to withstand the load, resulting in fractures.

Additionally, there were unique cases, such as a passenger who was seated with their seatbelt fastened but suffered a rib fracture after being thrown sideways into the armrest due to strong lateral turbulence.

There was only one case of burns, which suggests that airlines' preventive measures—such as serving beverages at lower temperatures or suspending the service of hot drinks when turbulence is expected—have been effective.

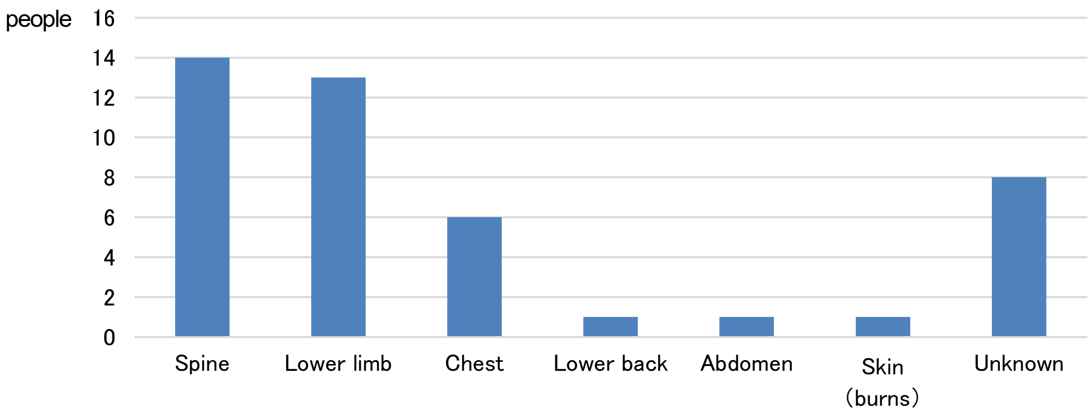


Figure 7: Injury locations from aircraft turbulence accidents (all cases except burns involved fractures)

5. Injury conditions and seatbelt usage

Next, we examined the circumstances of injured passengers and cabin crew at the time of the accident and whether they were wearing seatbelts.

Among the 18 seriously injured passengers, 8 (approximately 44%) were seated at the time of the accident, 6 (approximately 33%) were in the aisle, and 4 (approximately 22%) were in the lavatory. More than half of the injuries—10 out of 18 cases (approximately 56%)—occurred in locations where seatbelt use was not possible, such as while using the lavatory or walking in the aisle.

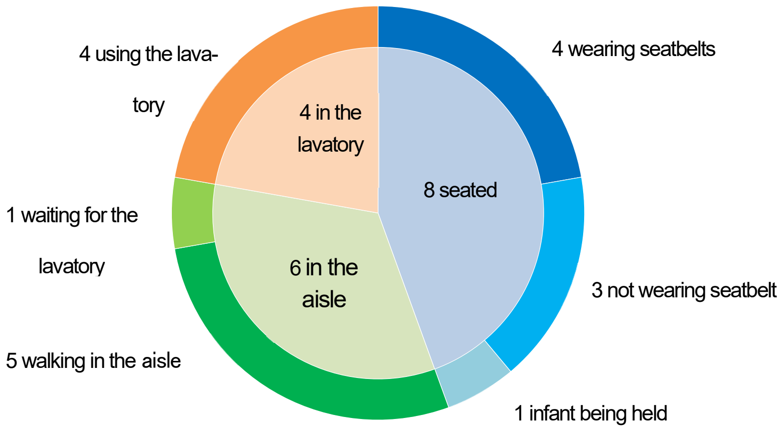


Figure 8-1: Injury conditions and seatbelt usage (passengers)

Among the eight seated passengers, four were wearing seatbelts, three were not, and one was an infant held by a mother wearing a seatbelt (who suffered burns from spilled coffee). (See Figure 8-1.)

However, two of the four passengers who were wearing seatbelts had them improperly fastened, such as being too loose. This indicates that properly fastening seatbelts is highly effective in preventing injuries.

Among the 26 seriously injured cabin crew members, two (approximately 8%) were seated at the time of the accident, eight (approximately 31%) were in the aisle, and sixteen (approximately 62%) were in the galley. In total, 24 out of 26 crew members (approximately 92%) were injured while in locations where seatbelt use was not possible, such as in the galley or the aisle. (See Figure 8-2.)

Among the two seated cabin crew members, one was wearing a seatbelt but was in a forward-leaning posture, which may have contributed to the injury. The other was injured due to sudden turbulence while momentarily unbuckling their seatbelt for cabin monitoring.

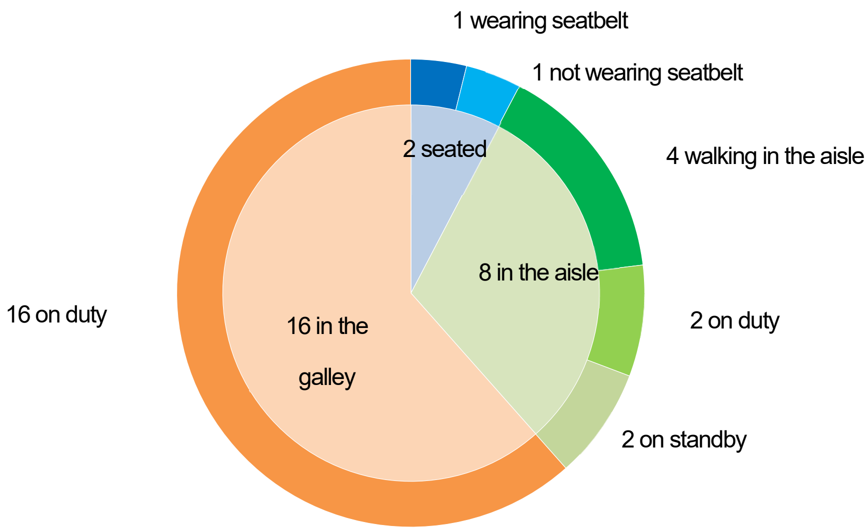


Figure 8-2: Injury conditions and seatbelt usage (cabin crew)

Looking at the injury locations, seatbelt usage, and seatbelt sign status, five passengers and six cabin crew members were injured outside their seats while the seatbelt sign was illuminated. When the seatbelt sign is on, both passengers and crew members must promptly return to their seats and fasten their seatbelts. Notably, 18 cabin crew members were injured outside their seats even when the seatbelt sign was off. Therefore, unless necessary, crew members should make efforts to remain seated whenever possible.

Additionally, when flight crew members anticipate turbulence, they must share this information with cabin crew and prioritize passenger and crew safety. Regardless of the status of in-flight services, they should immediately activate the seatbelt sign without hesitation. (See Table 1)

Table1: Seatbelt usage and seatbelt sign status at the time of injury

	Injury locations	Seatbelt usage		Seatbelt sign status		Notes
				On	Off	
Passengers	Seats	Used	Proper	2	0	Both struck the armrest hard
			Loosen	2	1	1 held in a lap, 1 had an unknown degree of seatbelt slack
		Not used		3	0	
	Outside their seats	—		5	5	
Cabin crew	Seats	Used	Proper	1	0	Posture was a contributing factor
			Loosen	0	0	
		Not used		1	0	Momentarily unbuckled for cabin monitoring
	Outside their seats	—		6	18	

6. Classification of turbulence causing aircraft upset

Although categorized as turbulence-related accidents, the causes vary significantly. We classified the 36 accidents based on turbulence categories outlined by the International Civil Aviation Organization (ICAO) and the U.S. National Transportation Safety Board (NTSB) statistics. Cloud turbulence (primarily caused by convective clouds such as cumulonimbus) and clear-air turbulence (occurring at high altitudes in cloud-free areas, except for cirrus clouds) together account for about 70% of the cases. These two types of turbulence are the primary contributing factors. (See Figure 9)

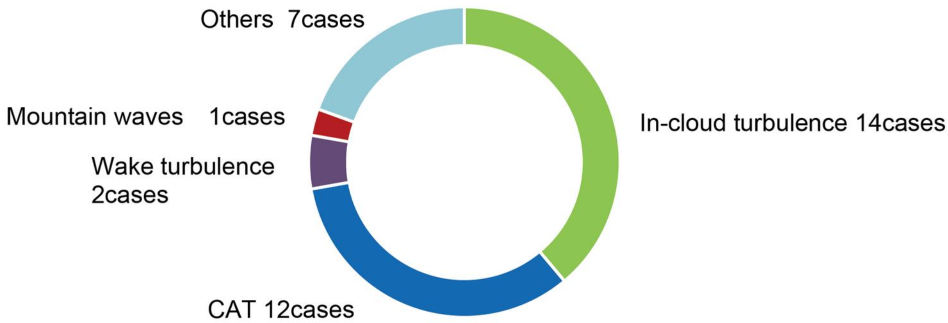


Figure 9 Classification of turbulence

The most frequent type was in-cloud turbulence, accounting for 14 cases (approximately 39%), making up more than one-third of the total accidents. Many of these accidents occurred during descent, often when convective clouds were either not identified or could not be avoided, leading to encounters with turbulence. The factors contributing to the development of these convective clouds included typhoons, low-pressure systems, seasonal rain fronts, and unstable atmospheric conditions caused by cold air aloft.

Clear-air turbulence (CAT) was also common, with 12 cases (approximately 33%), nearly as frequent as in-cloud turbulence. Most of these accidents occurred during cruise, with seven occurring in cloud-free conditions and five within or beneath stratiform clouds. The majority of these cases were associated with jet streams, as the accident airspaces were in proximity to jet streams or jet fronts (jet stream frontal zones).

Furthermore, a smaller number of accidents were caused by mountain waves due to terrain, wake turbulence from preceding aircraft, and low-level turbulence.

7. Seasonal trends in the causes of turbulence

Next, we examine the seasonal trends in the causes of turbulence-related accidents. In-cloud turbulence is more prevalent from July to September, accounting for 9 out of 12 accidents (75%) during this period. Meanwhile, from December to March, clear-air turbulence is more common, making up 8 out of 11 accidents (approximately 73%). This indicates a distinct seasonal trend. (See Figure 10.)

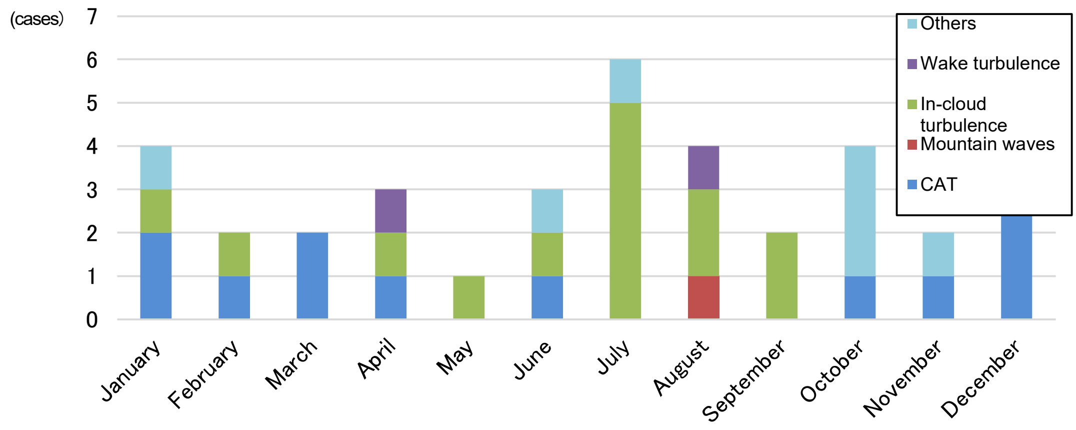


Figure 10 Monthly occurrence of turbulence-related accidents

8. Comparison of turbulence by aircraft position and size

The intensity of turbulence varies depending on the distance from specific points within an aircraft. Generally, turbulence is stronger toward the rear of an aircraft. The distribution of severe injury cases supports this: 35 cases (about 80%) occurred in the rear section, followed by 7 cases (about 16%) in the middle section, and only 2 cases (about 5%) in the front. This aligns with the widely accepted understanding that turbulence effects are more pronounced in the rear of the aircraft. (See Figure 11)

A comparison between the turbulence experienced by flight crew in the cockpit and that felt by cabin crew in the passenger cabin during accidents reveal a significant difference. Among the 36 accidents analyzed, in 14 cases (approximately 39%), flight crew in the cockpit perceived the turbulence as mild or moderate. In contrast, cabin crew reported experiencing strong turbulence in almost all cases. Given this discrepancy, there is a possibility that flight crew may not fully grasp the severity of turbulence in the cabin, potentially leading to delays in activating the seatbelt sign. Therefore, it is crucial that information flows not only from the cockpit to the cabin but also actively from the cabin to the cockpit to ensure better situational awareness and timely responses. (See Figure 12)

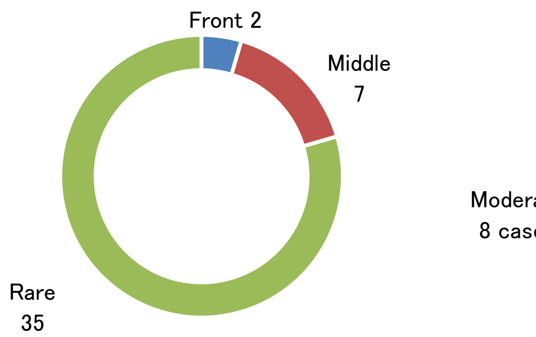


Figure 11 Seating locations of severely injured passengers

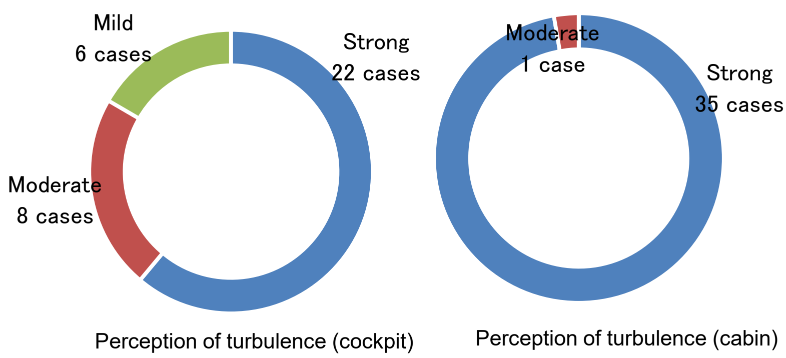


Figure 12 Comparison of perceived turbulence intensity

Next, we conducted a more detailed analysis of large aircraft by further subdividing them and comparing the occurrence of accidents based on aircraft size. When comparing the proportion of flight operations and the proportion of accidents by aircraft size from 2016 to 2022, the data showed the following: large aircraft (e.g., Boeing 777, Airbus A350) accounted for approximately 20% of flight operations and 19% of accidents; medium aircraft (e.g., Boeing 767, Airbus A330) accounted for approximately 12% of both flight operations and accidents; and small aircraft (e.g., Boeing 737, Airbus A320) accounted for approximately 68% of flight operations and 69% of accidents. These figures indicate no significant difference in the occurrence of accidents based on aircraft size. (See Figure 13)

Additionally, an analysis of vertical acceleration changes recorded in flight data recorders during accidents revealed that in 29 cases (approximately 81%), the variation exceeded 1.0G, accounting for more than 80% of the total. However, accidents also occurred in cases where the fluctuation was below 1.0G. Furthermore, there were cases where lateral acceleration also played a role. Additionally, while this change in acceleration correlates with the perception of turbulence in the cockpit, as shown in Figure 12, whether it leads to an accident depends not only on the magnitude and variation of vertical and horizontal acceleration but also on factors such as the posture and position of the injured individuals, the availability of handholds, the surrounding environment, and the awareness of how to respond to turbulence. (See Figure 14)

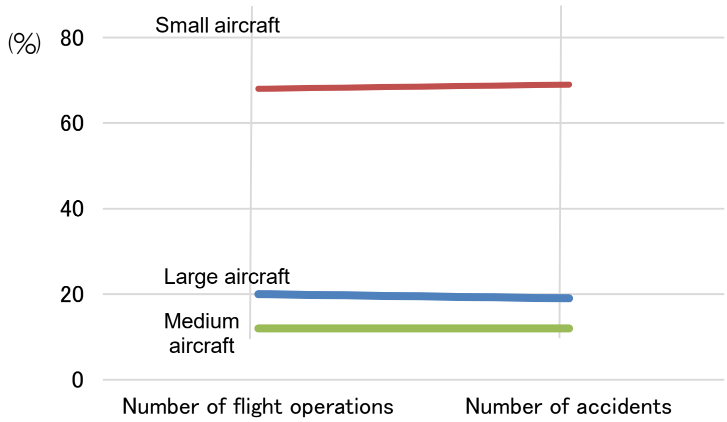


Figure 13 Comparison of the proportion of flight operations and the proportion of accidents

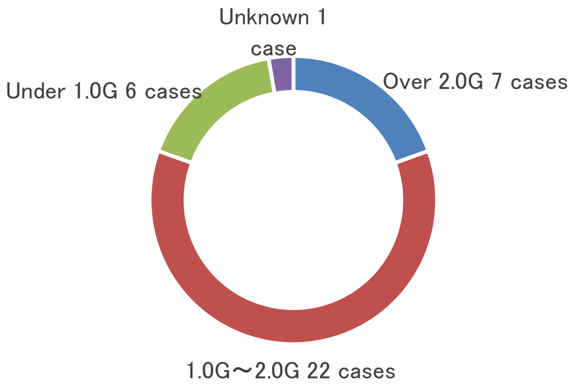


Figure 14 Changes in vertical acceleration

9. Crew awareness

An investigation into whether the flight crew of the accident aircraft recognized the possibility of turbulence, including before the start of the flight, revealed that in 17 out of 36 cases (approximately 47%), they were aware of the potential for significant turbulence. This indicates that about half of the flights began without anticipating major turbulence. (See Figure 15) This finding is also consistent with the results of an NTSB study on turbulence, which reported that approximately 53% of cases involved prior awareness.

Additionally, including newly obtained information available after the start of operations, it was found that in one-third of the cases, weather-related information related to turbulence was not sufficiently shared between flight crew members, flight dispatchers, and cabin crew. (See Figure 16)

This highlights the importance of identifying potential turbulence through meteorological analysis before flight operations begin and ensuring prompt and reliable information sharing regarding turbulence forecasts and real-time conditions among crew members and ground dispatchers after the flight has commenced.

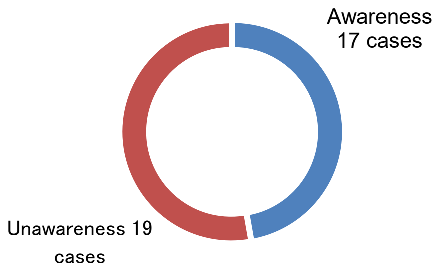


Figure 15 Flight crew awareness

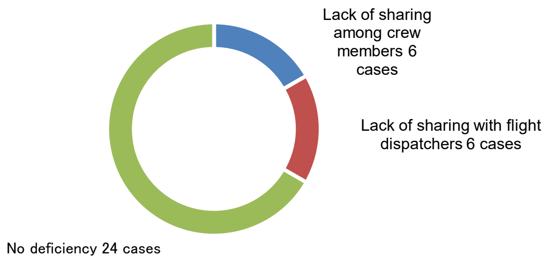


Figure 16 Status of information sharing

Chapter 3 Case studies and analysis of aircraft turbulence-related accidents

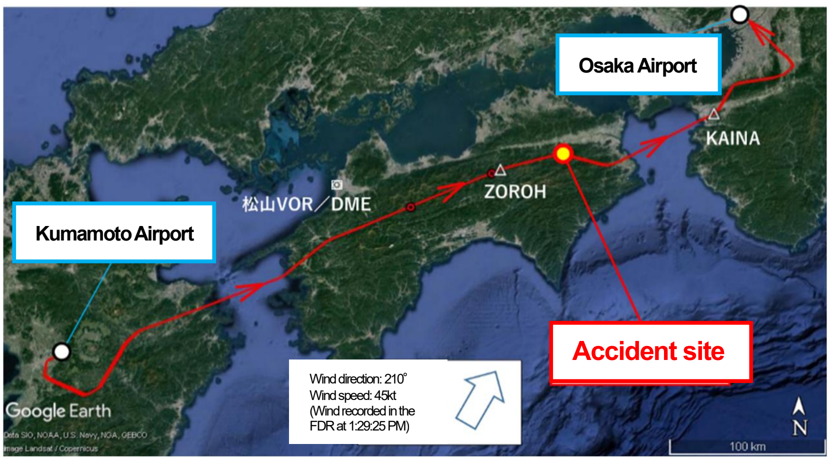
From this point onward, we will introduce case studies from accident investigation reports analyzed in Chapter 2 and explain the factors that led to the accidents, as well as key points highlighted in these reports for accident prevention.

1. Introduction of accident cases

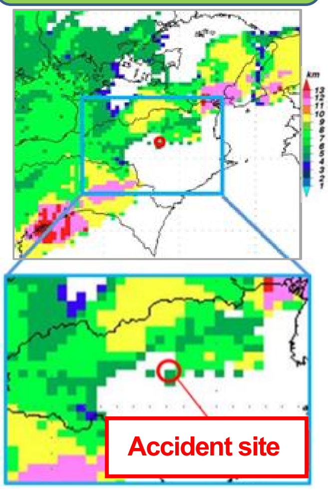
Case 1

Summary: A Bombardier DHC-8-402 aircraft operated by Company A encountered turbulence caused by convective clouds at 5:35 PM on Saturday, June 25, 2022, while en route from Kumamoto Airport to Osaka International Airport on a scheduled flight. As a result of the severe aircraft movement, one cabin crew member sustained serious injuries.

Estimated flight path diagram



Rader composite images (echo top altitude)



Weather conditions

Based on radar composite images (echo top altitude), it is highly probable that convective clouds had developed near the accident site, reaching altitudes between 5 km (16,403 ft) and 6 km (19,685 ft).

Aircraft turbulence

The FDR records show that between 1: 29:08 PM and approximately 12 seconds later, the vertical acceleration fluctuated between +0.2 G and +2.1 G. During this time, the aircraft was likely flying near developed convective clouds, encountering turbulence caused by these clouds, which resulted in significant aircraft movement.

Flight crew's weather assessment and seatbelt sign management

The flight crew probably kept the seatbelt sign off until the aircraft encountered significant vertical turbulence, as they believed they could avoid the echo by altering course and considered passenger needs. Regarding seatbelt sign operation, it is advisable for flight crews to take a more safety-conscious approach when there is a possibility of aircraft turbulence.

Probable Cause: This accident most likely has been occurred when the aircraft encountered turbulence caused by convective clouds while the seatbelt sign was off, resulting in severe aircraft movement, then a cabin crew member, who was crouching and working in the galley at the rear of the aircraft, was lifted off the floor, lost balance, and fell, sustaining injuries. The aircraft's encounter with turbulence from convective clouds was likely due to insufficient evasive maneuvers based on onboard weather radar displays of convective clouds. Additionally, the presence of developing convective clouds, which were difficult to detect on the onboard weather radar, likely have contributed to the inability to maintain an appropriate distance from the turbulence.

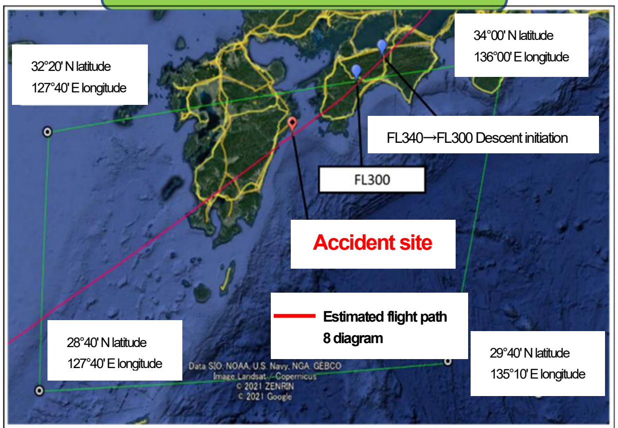
The accident investigation report for this case has been published on the committee's website (published on October 26, 2023).
https://jtsb.mlit.go.jp/eng-air_report/JA854A.pdf

Case 2

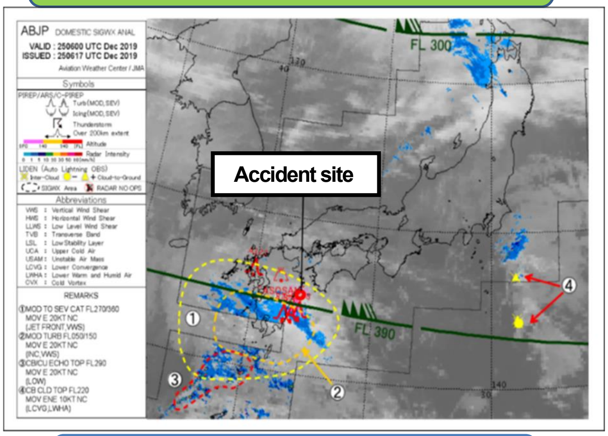
Summary: An Airbus A320-232 aircraft operated by Company B encountered wind shear near a jet stream at approximately 4:12 PM on Wednesday, December 25, 2019, while en route from Hakodate Airport to Taiwan Taoyuan International Airport on a scheduled flight. This resulted in significant aircraft movement, causing serious injuries to one cabin crew member and minor injuries to one passenger and two other cabin crew members.

Note: "Wind shear" refers to a phenomenon where wind direction and speed change rapidly over a localized area.

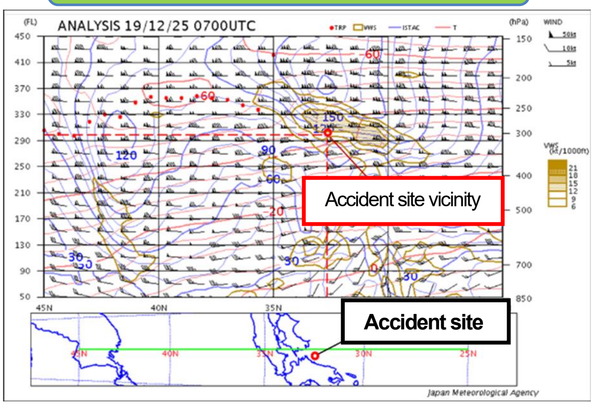
Estimated flight path diagram



Domestic severe weather analysis chart



Hourly atmospheric analysis chart



Weather conditions and aircraft turbulence

It is most likely that a strong wind shear existed along the jet stream near the accident site, as a transverse line of upper clouds and a vertical shear zone were observed. The aircraft most likely have experienced significant turbulence due to this wind shear. As a result of this turbulence, the senior cabin crew member, who was moving through the aisle to return from the rear of the cabin to the front jump seat, highly probably fell and fractured their right ankle.

Flight Crew's Decision-Making

The flight crew, based on the weather data reviewed before the flight, the onboard weather radar display, and pilot reports, more likely expected some turbulence but did not anticipate encountering turbulence of such severity. However, if they had obtained the SIGMET information issued by the Japan Meteorological Agency at 2:00 PM, it probably has been useful for the flight crew to proactively assess the need for altitude and route changes, seatbelt enforcement, and the timing of safety information dissemination to the cabin.

The Company's Operational Support System

The Operation Control Center (OCC) more likely have not obtained the SIGMET information issued by the Japan Meteorological Agency at 2:00 PM. Since SIGMET information provides critical updates on significant weather changes affecting flight safety, it probably be beneficial for OCC to acquire such information in a timely manner and appropriately relay it to the flight crew to help prevent similar accidents.

*"SIGMET information" refers to warnings issued for hazardous weather that may significantly impact aircraft operations and is expected to persist.

Autopilot Disengagement

When the aircraft experienced significant turbulence, the first officer probably had unintentionally pushed the sidestick forward. It is probable that the amount of input exceeded the autopilot disengagement threshold set for the aircraft (5° forward), causing the autopilot to disengage. The autopilot disengagement more likely had influenced the subsequent behavior of the aircraft.

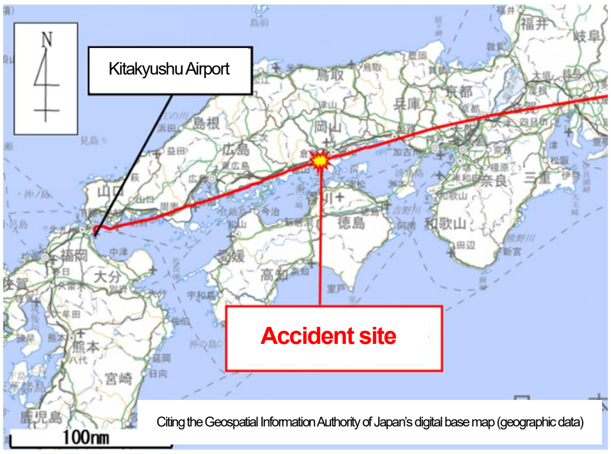
Probable Cause: This accident most likely has been occurred when the aircraft encountered wind shear near the jet stream, causing significant turbulence, which led to a cabin crew member falling while moving through the aisle and sustaining a serious injury.

The accident investigation report for this case has been published on the committee's website (published on March 24, 2022).
https://jtsb.mlit.go.jp/eng-air_report/B50001.pdf

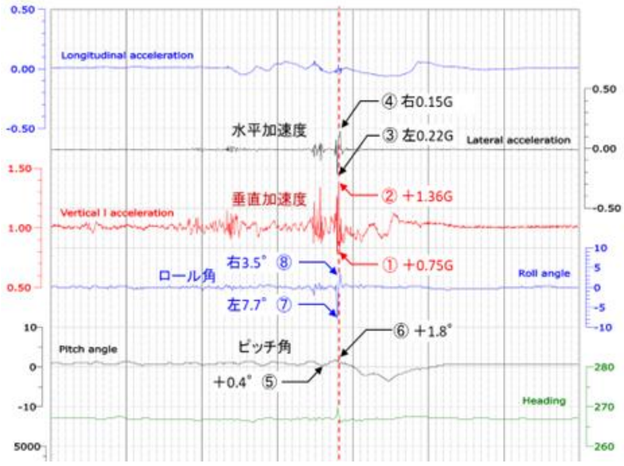
Case 3

Summary: An Airbus A320-214 operated by Company C was flying as a scheduled flight from Tokyo International Airport to Kitakyushu Airport on Sunday January 16, 2022. At approximately 7:48 PM, while flying over Okayama City at FL280, the aircraft experienced turbulence, injuring one passenger. The passenger, who was wearing a seatbelt, struck their right side against the right armrest of the seat after encountering clear-air turbulence.

Estimated flight path diagram



QAR records



Injured passenger's seat

seat 23A

Weather conditions and aircraft turbulence

Although no cloud echoes were observed near the accident site, it is probable that clear-air turbulence caused by the jet stream was present. At the time of the accident, PIREP reports indicated that clear-air turbulence had occurred around 7:48 PM at FL300, approximately 14 nm northwest of the accident site.

* "PIREP" stands for "Pilot Report," which refers to in-flight weather observations reported by pilots that may impact flight safety.

The vertical acceleration fluctuated between +0.75G and +1.36G, while the horizontal acceleration ranged from 0.22G to the left to 0.15G to the right. Given the presence of a vertical shear zone on the hourly atmospheric analysis chart and the absence of clouds, it is probable that the turbulence was caused by clear-air turbulence resulting from the influence of the jet stream.

Passenger injury

The armrest of the seat in question is 20 cm above the seat cushion, which aligns with the rib area for a relatively small person. The passenger remained seated with their seatbelt fastened at all times during the flight, even after the seatbelt sign was turned off. However, considering the aircraft's horizontal acceleration (ranging from 0.22G to the left to 0.15G to the right), roll angle (from 7.7° left to 3.5° right), and roll rate (4.5°/sec), it is probable that when the aircraft experienced turbulence, the passenger's body was thrown from left to right, causing them to strike their right ribcage against the right armrest of the seat, resulting in a fracture of the ninth rib.

Probable Cause: This accident more likely have occurred when the aircraft encountered clear-air turbulence caused by the influence of the jet stream. The turbulence caused the aircraft to jolt to the left, leading to the passenger striking their right ribcage against the right armrest of the seat and sustaining a serious injury.

Preventive measures

➢ To enhance passenger safety, cabin crew should continuously remind passengers to keep their seatbelts fastened securely and low on their waist at all times while seated. Additionally, cabin crew should be attentive to passengers' body types and ensure that seatbelts are properly fastened.

The accident investigation report for this case has been published on the committee's website (published on June 29, 2023)
https://jtsb.mlit.go.jp/eng-air_report/JA24MC.pdf

2. Causes of accidents and key points for prevention

Based on the factual information identified in accident investigations, we have extracted key points from the 36 accident investigation reports published over the past 20 years (2004–2023), including the cases introduced above. These key points can be broadly categorized into three groups: "Information sharing," "Cabin safety measures," and "Onboard equipment operations."

i) Information sharing

This includes insufficient information sharing between flight crew and cabin crew, as well as between flight crew and flight dispatchers. Overall, there is a noticeable tendency for turbulence-related information obtained after departure to be inadequately shared. Additionally, several reports have pointed out the need for improvements in procedural aspects, such as turbulence reporting systems.

Currently, PIREP provided from aircraft serves as the primary means for obtaining turbulence information among the means of obtaining real-time information on shaking during flight. However, enhanced sharing of onboard observational data using ACARS[1] is also needed.

Information sharing	Flight crew ↔ Cabin crew	Provision of turbulence information Provision of safety-related information Accurate information on flight routes (Japanese only) Information on expected aircraft turbulence Reporting of cabin crew injuries to the captain Recognition and reporting of injured passengers
	Flight crew ↔ Flight dispatchers	Provision of turbulence information as per regulations (Japanese only) Provision of information to flight crew from the ground (Japanese only) Provision of analytical information based on real-time weather monitoring (Japanese only) Provision of the latest meteorological and external monitoring information Acquisition and distribution of SIGMET information Utilization of SIGMET information related to turbulence
	Flight crew ↔Air traffic control authorities	Reporting turbulence intensity based on unified standards (Japanese only) Captain's reports on adverse weather Reporting of turbulence-related information

*Click on the blue text links to view the relevant pages of each accident investigation report.

ii) Cabin safety measures

This category includes issues related to in-flight service and seatbelt use. In recent trends, there has been an increasing focus on how seatbelts are fastened.

Additionally, some reports have highlighted concerns regarding physical aspects of the cabin, such as handrails and seating.

[1] "ACARS" (Aircraft Communications Addressing and Reporting System) refers to a system that digitally transmits essential operational information between aircraft and ground stations.

Cabin Safety Measures	Seatbelt	Proper seatbelt fastening	Proper seatbelts use 1 Proper seatbelts use 2
		Seatbelt sign operation	Operation of seatbelt sign during flying in clouds (Japanese only) Considerations for turning on the seatbelt sign Safe-side operation of the seatbelt sign
	Seat	Seating posture	Seating arrangements for infants during seatbelt sign activation Seat design and seating posture adopted to different body types Seating posture for cabin crew
	In-flight services	Services	Familiarization with service manuals for treating injuries (Japanese only) Active verbal engagement during cabin walkthroughs Improvements of coffee pots and implementation of burn prevention measures (Japanese only) Formulation and implementation of in-flight service plans
		Training	Awareness of aircraft turbulence handling through regular training Reinforcement of key learnings from similar accidents
		Announcements	Proactive announcements for cautionary measures Captain's announcements on weather conditions (Japanese only)
	Response to turbulence	Response procedures	Handling differences in turbulence conditions across various locations in the cabin Response to unexpected aircraft turbulence Measures to mitigate injury risks (Japanese only)
		Cabin equipment	Installation of handles in aisles Storage of luggage in overhead compartments and under seats

iii) Operation of Onboard Equipment

This category primarily involves the effective use of onboard weather radar, along with recommendations regarding the operation of the autopilot system.

While turbulence-related accidents are often caused by natural phenomena and can sometimes be unavoidable, accidents can be significantly reduced by utilizing onboard weather radar to avoid turbulence laterally or vertically and by obtaining real-time turbulence reports from other aircraft to activate the seatbelt sign earlier.

Furthermore, the provision of more detailed turbulence forecasts, as well as the potential future implementation of aircraft-mounted Doppler Lidar[2] systems for detecting clear-air turbulence and utilizing new technologies for aircraft control, are highly anticipated.

[2] "Aircraft-mounted Doppler Lidar" is a device that emits laser beams from an aircraft, receiving scattered light from aerosols (such as fine water droplets and dust) in the atmosphere. By analyzing wavelength changes due to the Doppler effect, it can detect clear-air turbulence, which cannot be detected by onboard weather radar.

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.

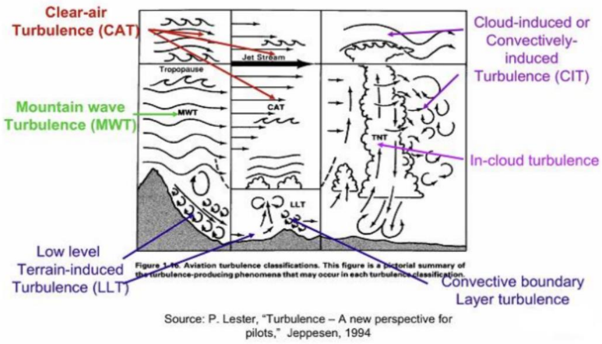
Regarding forecast data, conventional information was limited to VWS (Vertical Wind Shear), however, ANA now provides additional indicators such as CAT (Clear Air Turbulence), temperature changes, horizontal wind variations, stability, convective cloud effects, mountain waves, and real-time turbulence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

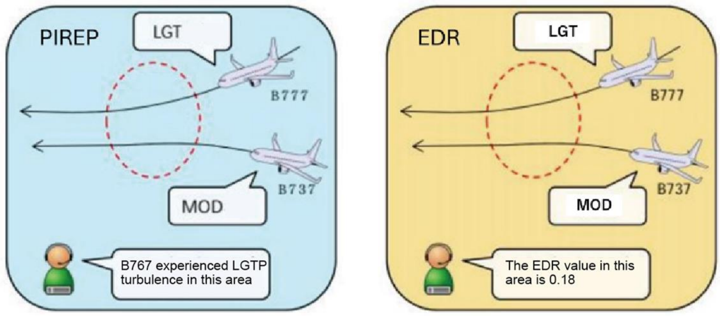
A major advantage of EDR is that turbulence data observed automatically by aircraft can be instantly collected, stored, and shared. Moreover, the data can be used across different aircraft types without distinction. The implementation of EDR is already progressing among international airlines, and ANA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

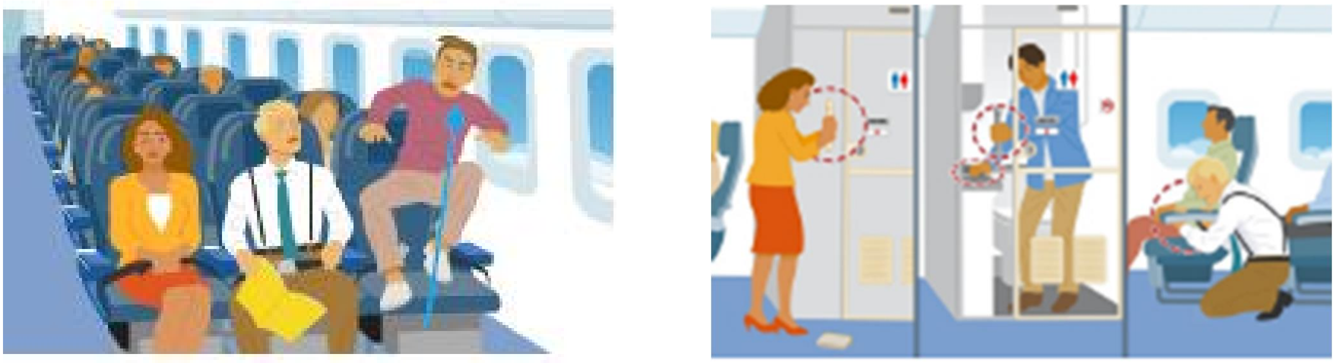
PIREP: Reports of turbulence from preceding aircraft allow the flight crew of following aircraft to anticipate turbulence severity based on their own aircraft's characteristics
EDR: The system calculates and provides turbulence intensity predictions to flight crew based on EDR values measured by preceding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



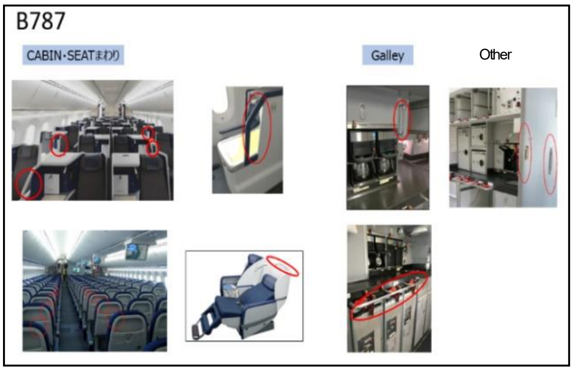
Passenger educational video

Preparing for Turbulence

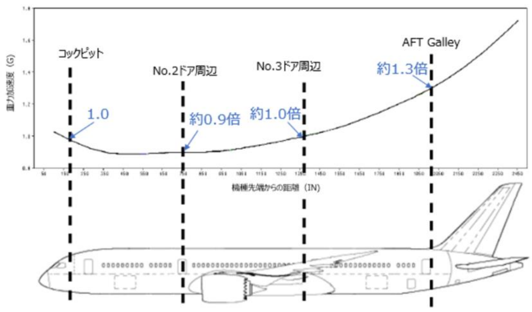
Effective crew communication is a crucial factor in reducing turbulence-related injury risks. Since flight crew are the primary source of information for both passengers and cabin crew, timely and accurate information sharing directly contributes to safety.

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"

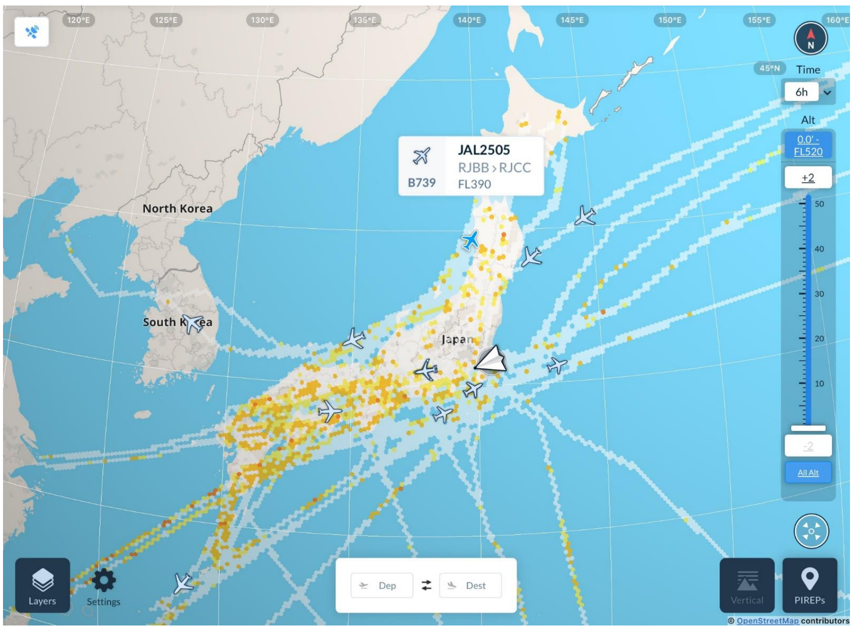
For airlines, it is essential to anticipate areas of sudden turbulence during flight and take measures to avoid its impact, ensuring a smooth in-flight experience and preventing injuries to passengers and crew.

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.



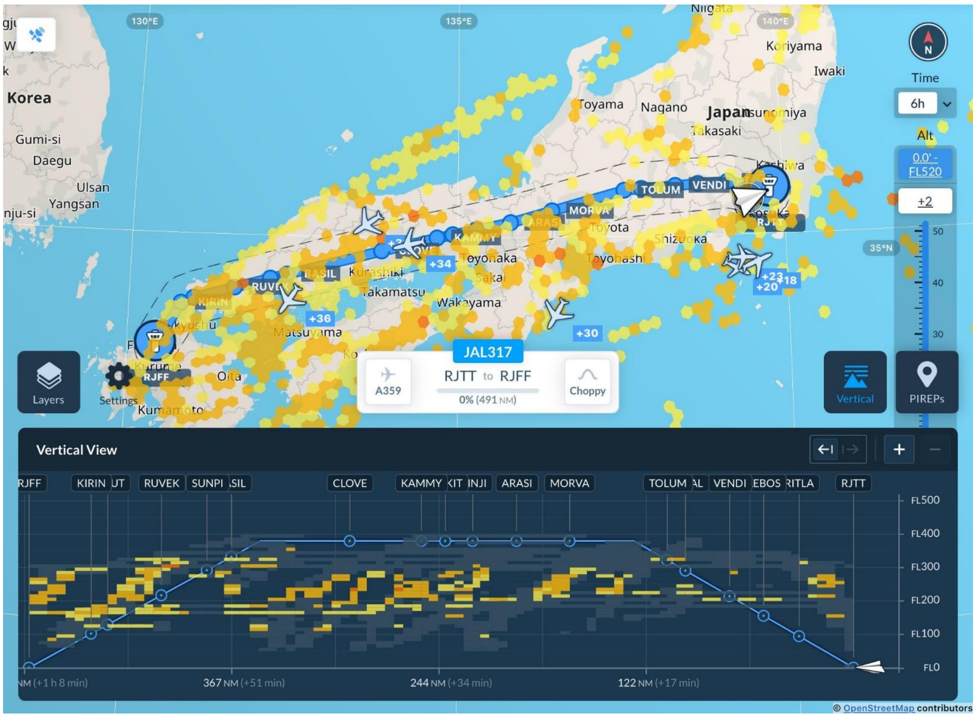
Turbulence information observed over Japan and surrounding areas

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)

Chapter 5 Summary

Occurrence of aircraft turbulence-related accidents

- From 2004 to 2023, there were 67 accidents involving large aircraft, with more than half (37 cases) classified as turbulence-related accidents.
- The leading cause of turbulence-related accidents was in-cloud turbulence (over one-third of cases), followed by clear-air turbulence (also one-third).
- The number of seriously injured passengers has been decreasing, whereas the number of injured cabin crew has been increasing.
- Most passenger injuries occurred while the seatbelt sign was ON, whereas approximately 70% of cabin crew injuries occurred while the seatbelt sign was OFF.
- About 80% of in-cabin injuries occurred in the rear section of the aircraft, with no significant differences observed based on aircraft size.
- Perception of turbulence differs between the cockpit and the cabin: in the cockpit, approximately 40% of cases were reported as "mild or less," whereas in the cabin, turbulence was almost always perceived as "strong."
- Changes in vertical acceleration during accidents exceeded 1.0G in over 80% of cases, though some cases were below 1.0G.
- About half of the flight crew were unaware of the possibility of severe turbulence, including before takeoff.
- One-third of cases showed insufficient information sharing among crew members or between crew and flight dispatchers.

Towards recurrence prevention (proactive measures)

The key points for accident prevention, derived from past accident data and case studies, are as follows: "Turbulence prediction" and "Response to turbulence" must be carried out in a timely and appropriate manner.

Information sharing among relevant personnel

- Among crew members
- Flight dispatchers ⇔ Crew members
- Air traffic control authorities ⇔ Crew members

- Live weather reports and forecast
- In-flight service plans
- Real-time turbulence
- Status of injuries and other damages
- Forecast information (including severe weather alerts)
- Real-time information (including PIREP)
- Turbulence information

Measures to mitigate damage during turbulence

- Seats and seatbelts
- Protection during turbulence events

- Awareness and verification of proper usage of methods
- Recommendation to remain seated
- Awareness of response methods during turbulence
- Implementation of practical training

Utilization of aircraft-mounted equipment

- Onboard weather radar
- Doppler Lidar
- EDR and other turbulence information

- Familiarization with usage
- Utilization for thunderstorm
- Promotion of research, development, and practical application
- Accident prevention through turbulence information sharing

Message from the head of accident prevention analysis office

Preventing turbulence-related accidents caused by natural phenomena such as turbulence is inherently difficult, and until new technologies are fully implemented, the only option is to continue with the current accident prevention (damage mitigation) measures appropriately.

Furthermore, aside from the development of new technologies, the recurrence prevention measures outlined in Chapter 4 are largely consistent with the measures that the Civil Aviation Bureau of the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) has repeatedly requested airlines to implement in the past. This underscores the challenge of preventing turbulence-related accidents in advance.

That being said, we cannot afford to remain passive. Even though predicting and detecting turbulence remains challenging, continued research and development must aim to improve the accuracy of turbulence forecasts and enable the real-time sharing of turbulence conditions.

Furthermore, since aircraft are designed with turbulence in mind, it is naturally expected that passengers always fasten their seatbelts low and tight around their waist, even while seated. Additionally, using the restroom as much as possible while on the ground and ensuring that all passengers are aware of turbulence safety measures can significantly reduce injuries and prevent accidents. Preventing turbulence-related accidents requires not only the efforts of airline operators but also the cooperation of passengers. We hope for your understanding in this matter.

Moreover, airlines should take a step back and reconsider the fundamental purpose of air transportation—which is to safely transport people and goods. Given the increasing number of injuries among cabin crew, it is crucial to ensure that prioritizing passenger service does not inadvertently lead to accidents. It may also be necessary to establish clear company policies, such as ensuring that cabin crew remain seated as a basic rule and suspending in-flight services when significant turbulence is expected. This would help create a psychologically safe environment for crew members when making decisions that may require prioritizing safety over service, rather than leaving such decisions solely to on-the-spot judgment.

We hope this digest serves as an opportunity for all airline operators to reflect on their commitment to safety.

Finally, in preparing this digest, we received valuable contributions through interviews and column submissions from ANA, JAL, and JAXA. Their insights allowed us to include important information about their respective initiatives. We sincerely appreciate their cooperation.

MLIT, Japan Transport Safety Board Secretariat

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