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).

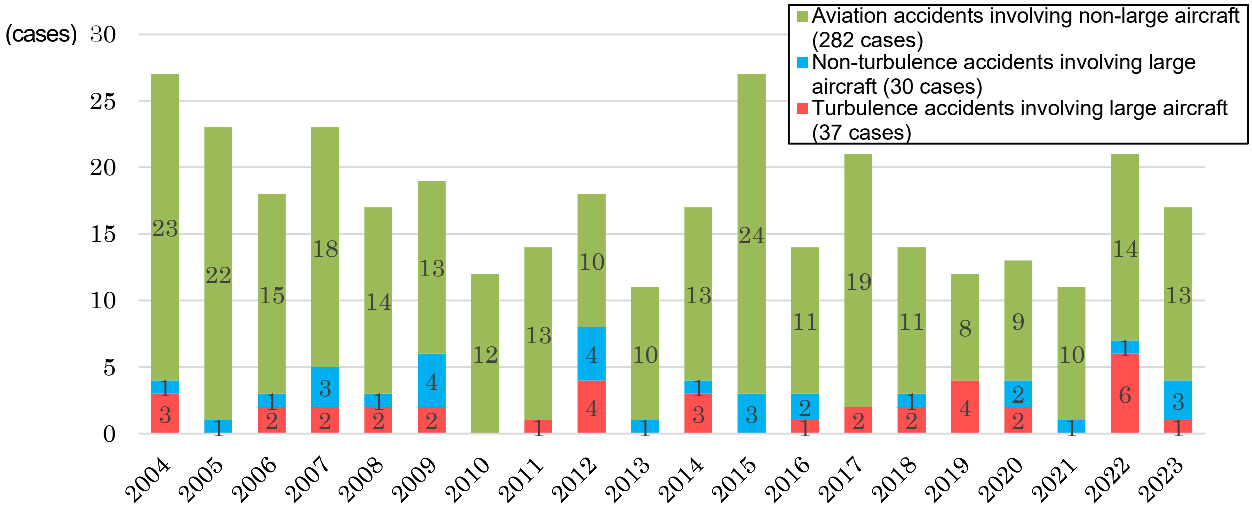

Figure 2: Number of aviation accidents

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)

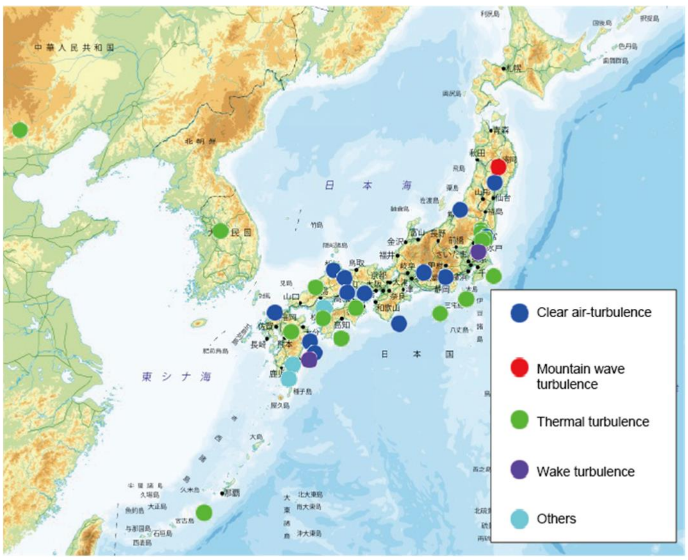

Figure 3: Locations of turbulence-related accidents (excluding one case over the Russian Federation)

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)

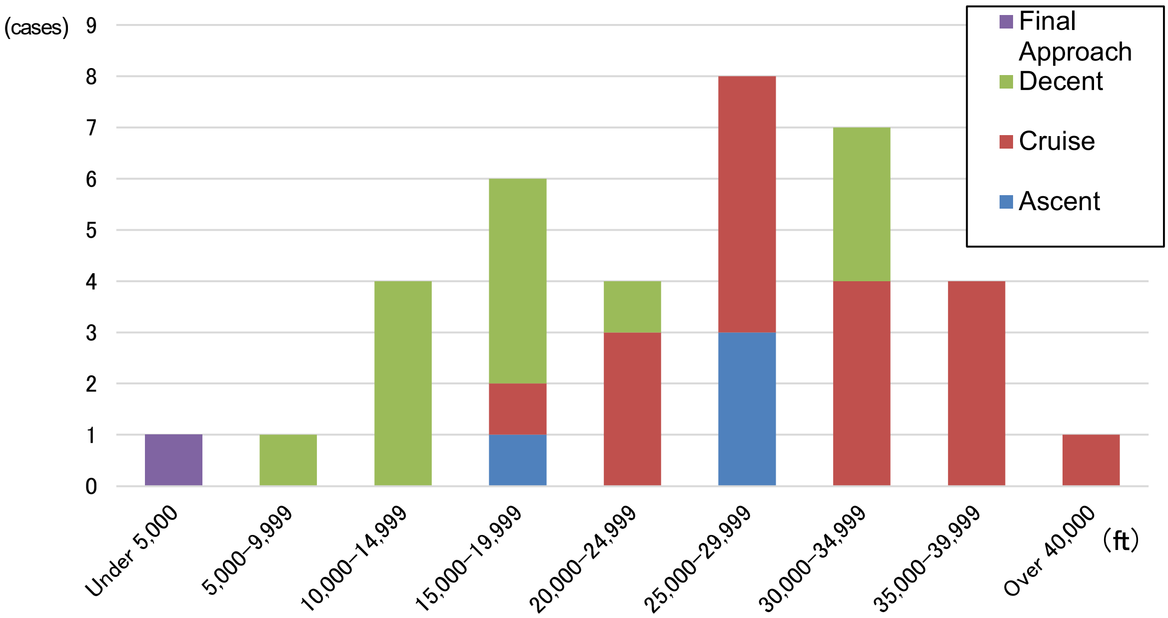

Figure 4: Altitude and flight phase of the accidents

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)

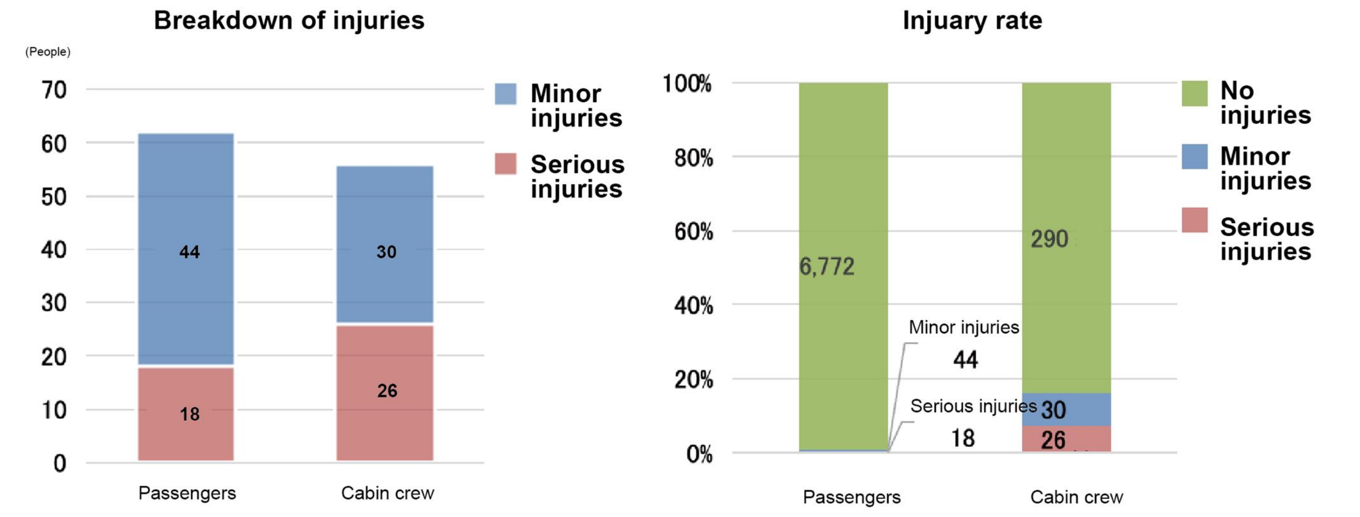

Figure5: Injury statistics

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.

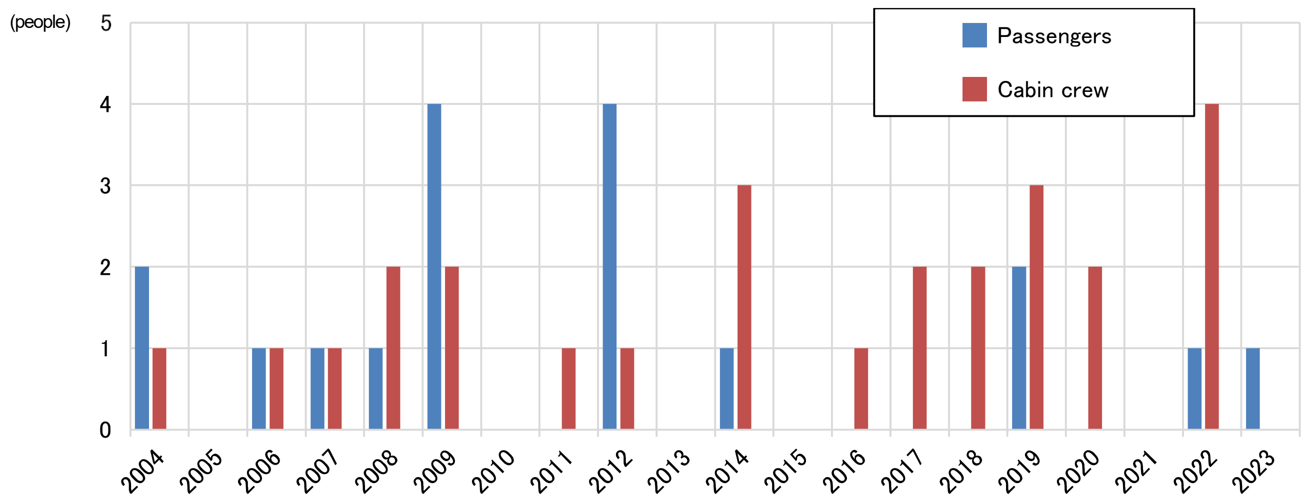

Figure 6: Trend of serious injuries

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.

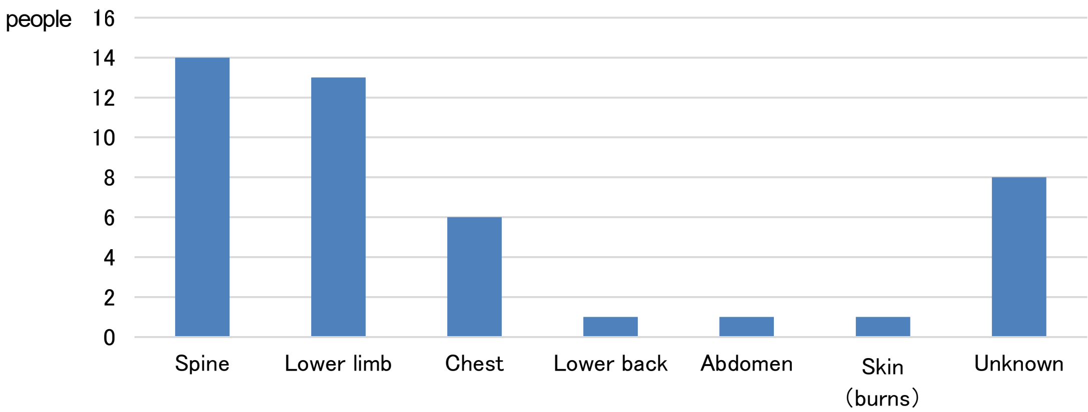

Figure 7: Injury locations from aircraft turbulence accidents (all cases except burns involved fractures)

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.

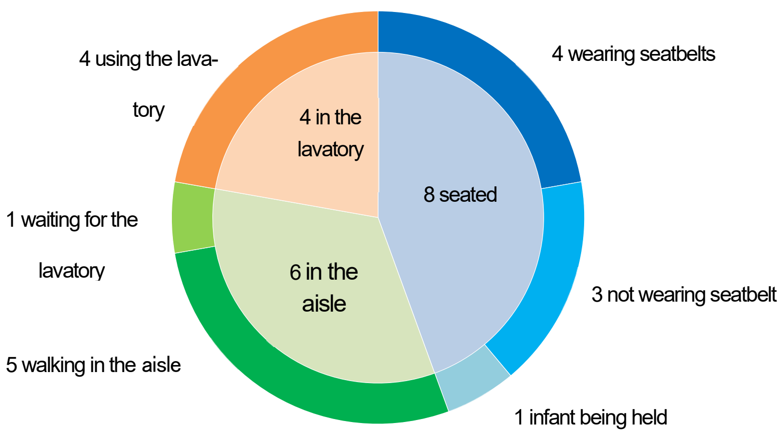

Figure 8-1: Injury conditions and seatbelt usage (passengers)

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.

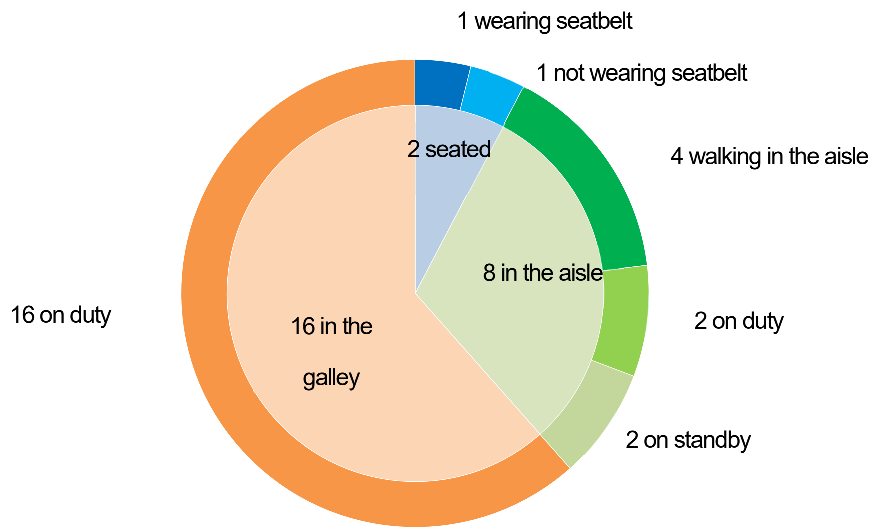

Figure 8-2: Injury conditions and seatbelt usage (cabin crew)

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)

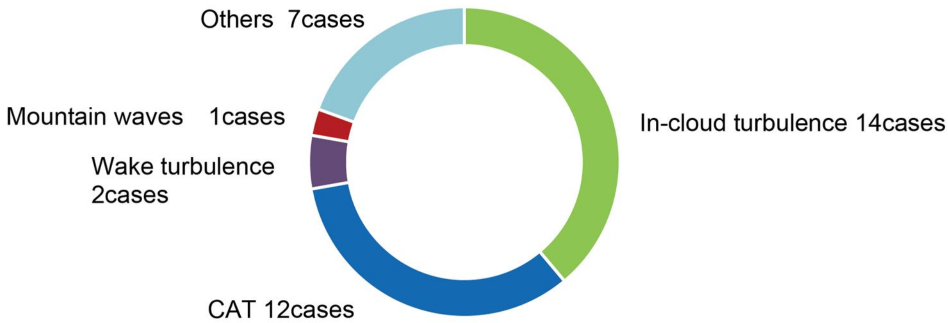

Figure 9 Classification of turbulence

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.)

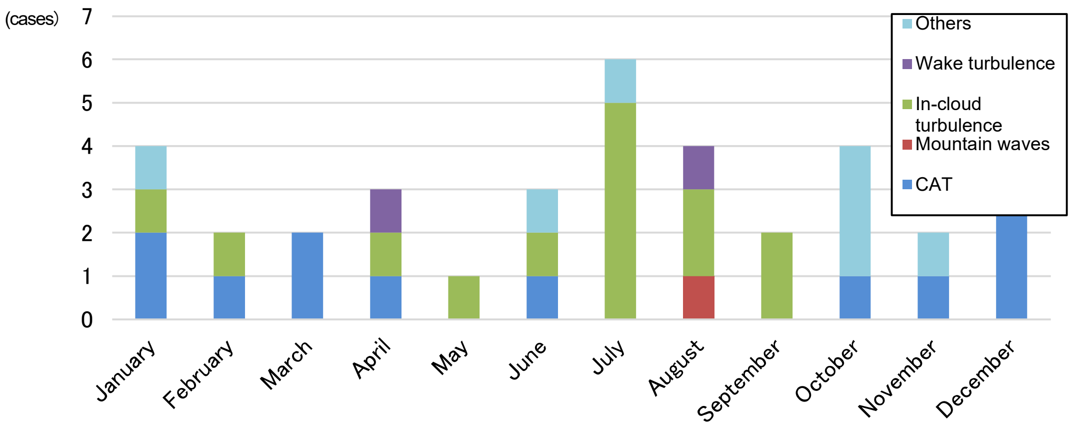

Figure 10 Monthly occurrence of turbulence-related accidents

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)

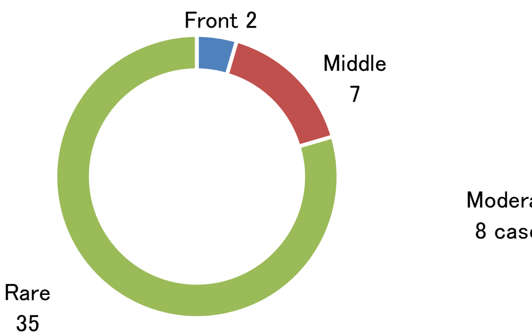

Figure 11 Seating locations of severely injured passengers

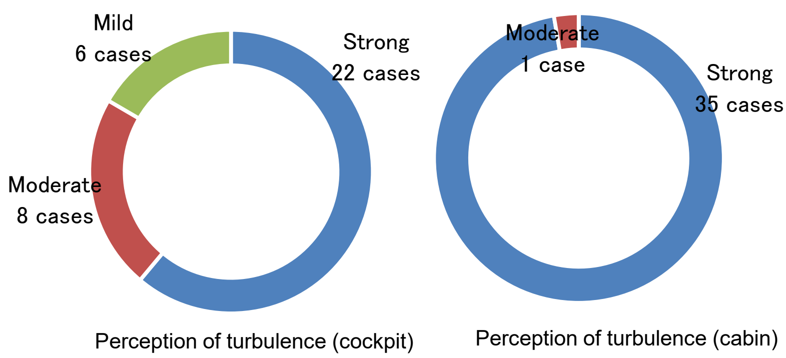

Figure 12 Comparison of perceived turbulence intensity

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)

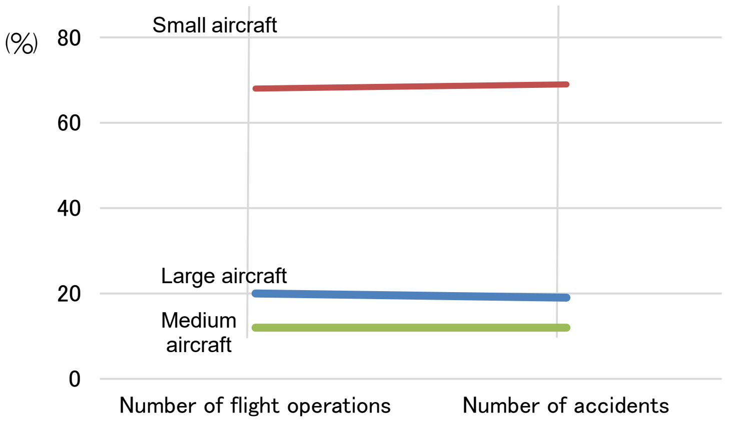

Figure 13 Comparison of the proportion of flight operations and the proportion of accidents

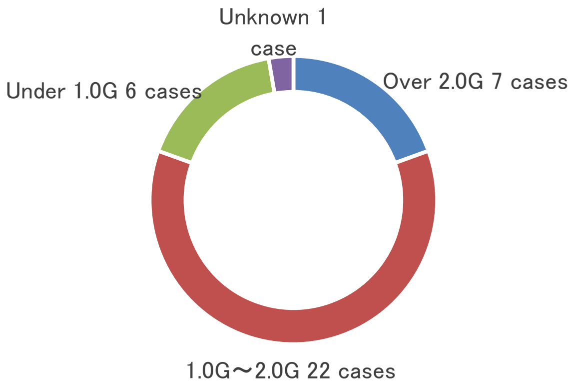

Figure 14 Changes in vertical acceleration

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.

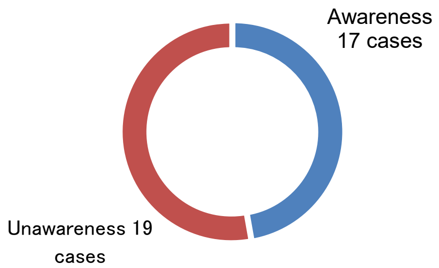

Figure 15 Flight crew awareness

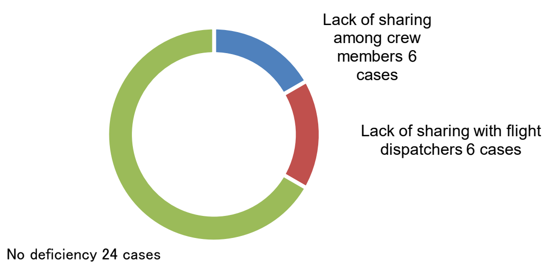

Figure 16 Status of information sharing