～ Case Studies and Accident Analysis ～

JTSB Digests

JTSB (Japan Transport Safety Board)

(Issued in January, 2015)

Digest of Aircraft Accident Analyses

For Prevention of Accidents due to the Shaking of the Aircraft

1. Preface

In July 2014, the Japan Transport Safety Board (JTSB) released the Aircraft Accident Investigation Report concerning serious and slight injuries of three passengers in August 2012 when an aircraft was shaken over Matsue City, Shimane Prefecture en route from Honolulu International Airport (The United States of America) to Incheon International Airport (The Republic of Korea).

When research was conducted on the injuries of passengers and cabin attendants due to the shaking of the aircraft while in flight excluding takeoff and landing (hereinafter referred to as "aircraft shaking accidents") similar to this accident in preparation for the release of the report, it was found that of the 245 aircraft accidents that have occurred since October 2001, when the Aircraft and Railway Accidents Investigation Commission was established, to June 2014, about 20 aircraft accidents involving large aircraft were aircraft shaking accidents.

While there have been no fatal accident, the injury occurrence rate is high for aircraft shaking accidents when compared to aircraft accidents overall, and there was a case of injuries being caused to almost 40 people in one accident.

Moreover, while aircraft shaking accidents are caused by encounters with sudden turbulence in-flight, it is believed that there are many lessons to be learned in terms of the responses and actions taken before and after the occurrence of these accidents in order to prevent the occurrence of similar accidents in the future.

In light of this situation, in this digest we have decided to introduce various statistical information and cases from accident investigations conducted by JTSB in an aim to prevent the recurrence of and mitigate the damage caused by aircraft shaking accidents.

We hope that this digest will facilitate measures to further ensure safety and will contribute to the prevention of the recurrence of similar accidents through it 's use as a teaching tool for people involved with safety seminars and similar purposes.

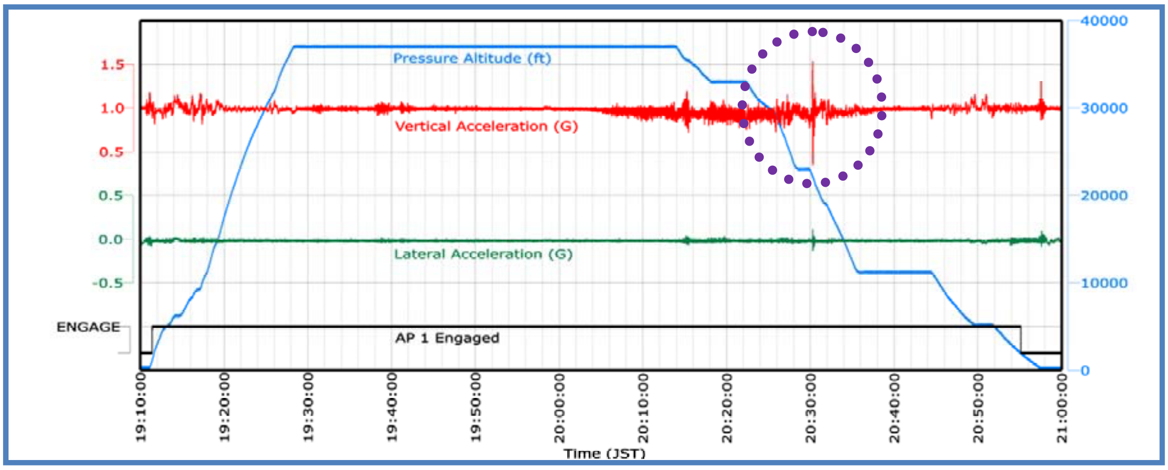


Figure 1 Example of Recording by DFDR (Digital Flight Data Recorder) (a large change in vertical acceleration (G) can be seen in aircraft shaking accidents)

Aircraft shaking accidents as defined in this digest

Refers to aircraft accidents investigated by JTSB (including the former Aircraft and Railway Accidents Investigation Commission) from October 2001 to June 2014 involving large aircraft (maximum takeoff weight of at least 5,700 kg) in which passengers and cabin attendants suffered injuries from the shaking of the aircraft. Note that the data stated include an accident that is still under investigation.

2. Statistics

There have been 19 aircraft shaking accidents, among which we have made accident investigation reports public for 18 cases and one accident is under investigation.

Shown below is the statistical information on the aircraft shaking accidents we have investigated.

* Figures 2 to 7, 12 to 14 show data for a total of 19 cases including accidents under investigation, and Figures 8 to 11, 15 show data for 18 cases whose investigation reports of accidents have been made public.

Statistics on the accidents

The changes in the number of accidents show that while there were some years without any accidents, the yearly average was 1.49 cases (one to three cases per year), with the most accidents occurring in 2012 (four cases). There were 40 aircraft accidents involving large aircraft, and 19 of these (nearly half) were aircraft shaking accidents. (See Figure 2)

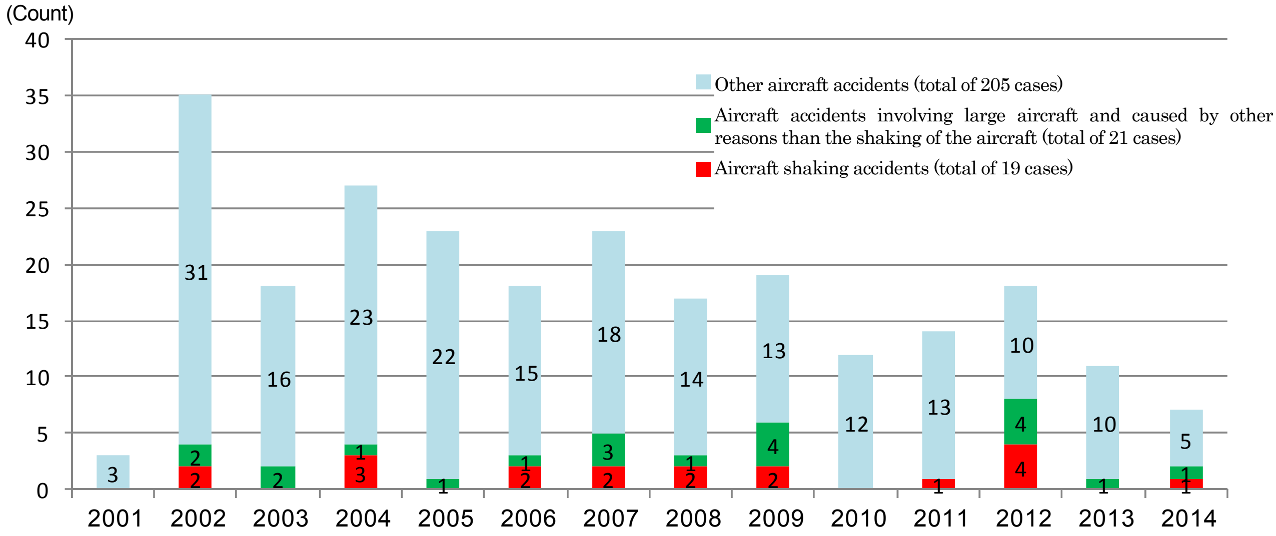


Figure 2　Changes in the number of accidents

Breakdown of accidents by site

The accident sites were widely distributed from the Tohoku to the Chugoku and Shikoku regions. Three cases occurred in the skies over Shimane Prefecture. (See Figure 3)

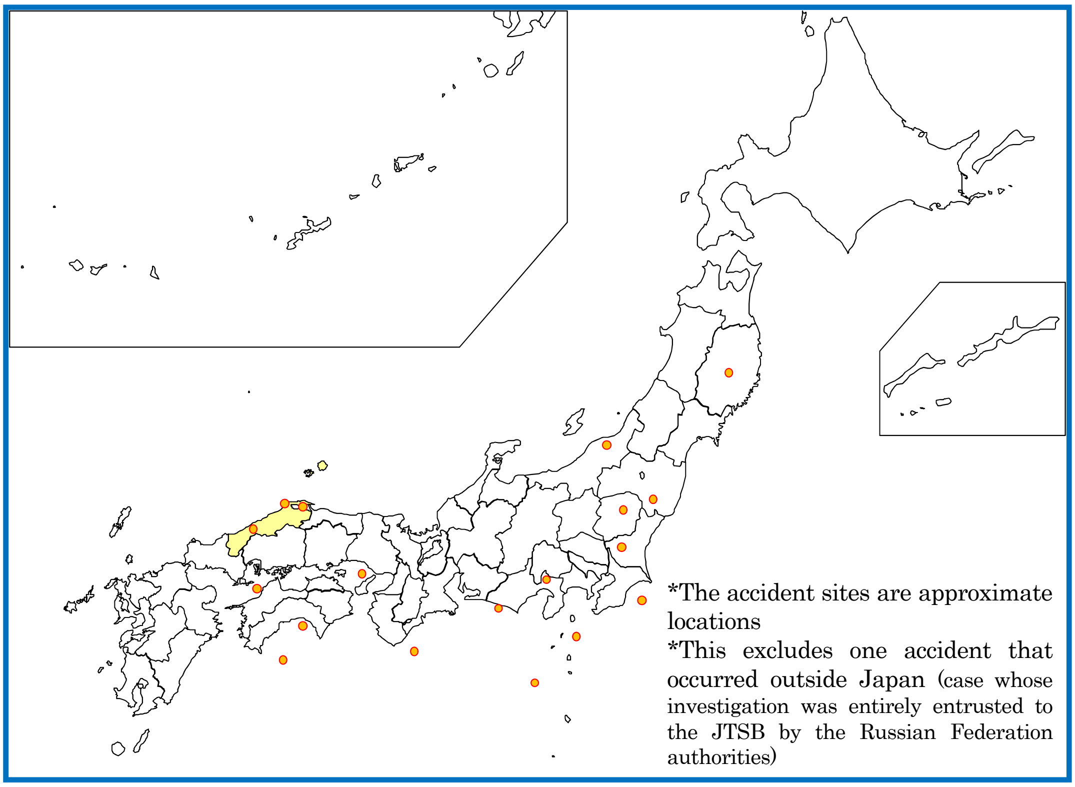


Figure 3　Breakdown of accident sites

Breakdown of the injuried

The breakdown of the number of injuries shows that there was a total of 111 people injured in the 19 aircraft shaking accidents, with 29 people suffering serious injuries and 82 people suffering slight injuries, and that there were about 5.8 people injured per accident. Meanwhile, there was a total of 32 people injured in the 21 aircraft accidents involving large aircraft and caused by other reasons than the shaking of the aircraft, with an average of 1.5 people injured per accident. This indicates that the injury occurrence rate is higher for aircraft shaking accidents than other accidents. During 2002 and 2009 there were cases in which one accident resulted in nearly 40 people injured. (See Figure 4)

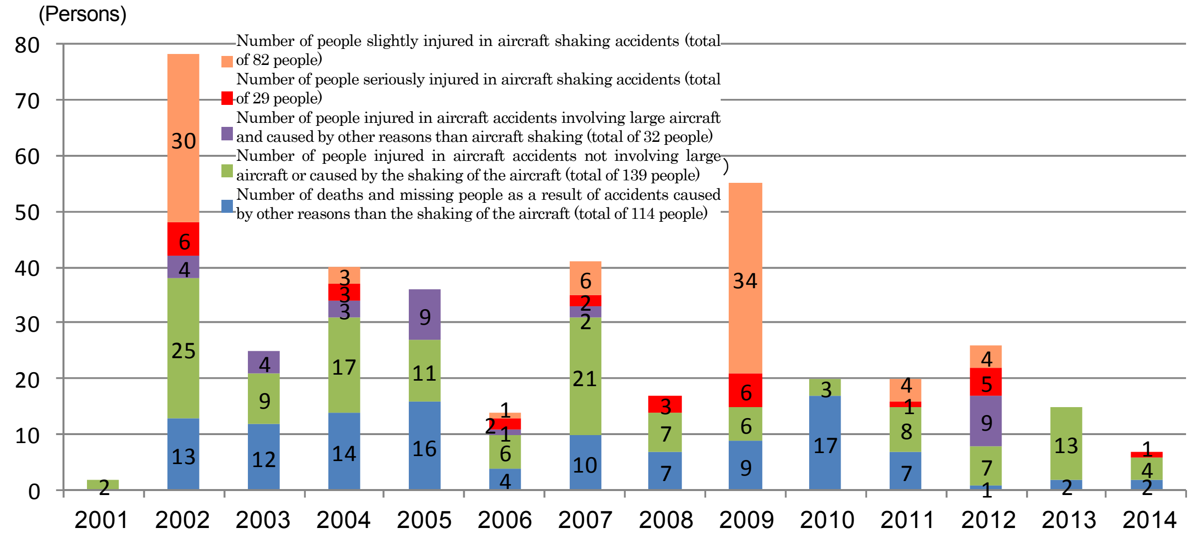


Figure 4 Changes in the number of injuries

Looking at attributes of people injured, we can see that 72 passengers were injured (18 seriously injured, 54 slightly injured) and 39 cabin attendants were injured (11 seriously injured, 28 slightly injured). It is believed that the number of injuries for cabin attendants is high because they often stand while working. (See Figure 5)

Looking at the positions in the aircraft where injuries occurred, we can see that out of the 100 cases for which the position was ascertained, the most occurred in the aft (72), followed by the center (19) and forward (9). There were cases that suggested the possibility that there were many injuries in the aft because negative vertical acceleration affected more on the aft than on the foreside when the pitch angle (*1) of the aircraft changed rapidly. (See Figure 6) (*1: This refers to the vertical inclination angle of the nose of the aircraft. The nose rises when positive and falls when negative.)

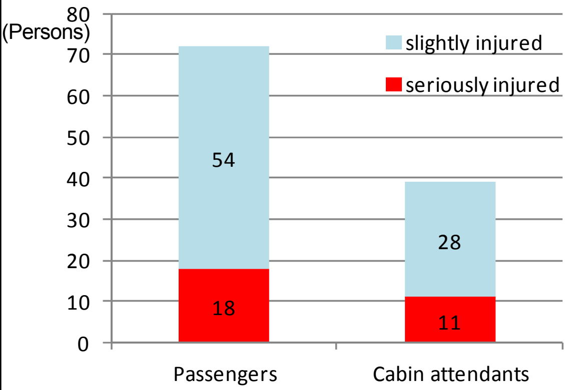


Figure 5 Attributes of people injured

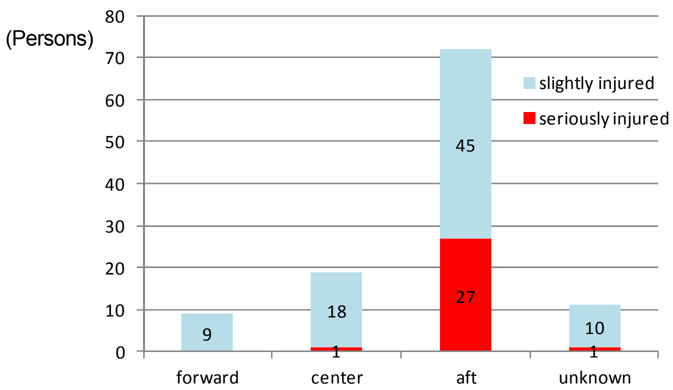


Figure 6 Positions of people injured in aircraft

Among the 28 seriously injured people for which the injury details have been revealed, 23 people suffered fractures (cervical, collarbone, ribs, thoracic vertebrae, sternum, lumbar spine, fibula, ankle, etc.), followed by concussions (brain and cervical vertebra), bruises (face, abdomen), and burns (right upper extremity, abdomen, etc. (suffered by an infant)). (See Figure 7)

In terms of situations leading to injuries, there were cases of the shaking of the aircraft causing people to fly up in the air and hit their heads on the ceiling, to fall on the floor after flying up in the air, to lose their balance while walking, and to get sprayed with hot coffee.

In terms of how people who suffered injuries were acting prior to the shaking of the aircraft, passengers were seated or using the lavatory (fastening or not fastening a seat belt), while cabin attendants were conducting activities such as preparations for in-flight service or cleaning. While injuries to the head or cervical vertebra were not observed among people fastening seat belts, there were cases of serious injuries even among people fastening seat belts due to severe horizontal shaking.

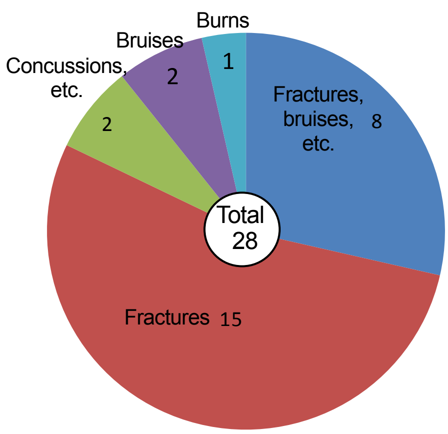


Figure 7 Injuries of people with serious injuries

Turbulence and vertical wind shear

○ Turbulence is classified as light, moderate, or severe as shown in Table 1 depending on the magnitude of the shaking as felt by the pilot.

There are three types of turbulence: INC TURB (in-cloud turbulence) that occurs in clouds such as cumulonimbus clouds, CAT (clear-air turbulence) that occurs in clear air without clouds (excluding high level clouds), and MTW (mountain wave) that occurs as a result of winds arising from the leeward side of mountains.

Table 1. Turbulence Intensity

Turbulence intensity	Feeling
Light	Occupants may feel some shaking, but it is not enough to fly up from the seat
Moderate	Conditions in which moderate changes in aircraft attitude and/or attitude may occur but the aircraft remains in positive control at all times. Usually, small variations in airspped. Difficulty in walking. Occupants feel strain against seat belts. Loose objects move about.
Severe	Conditions in which abrupt changes in aircraft attitude and/or attitude occur; aircraft may be out of control for short periods. Usually, large variations in airspeed. Occupants are forced violently against seat belts. Loose objects are tossed about.

By ICAO (International Civil Aviation Organization) Aeronautical Board

From *Haneda Airport Weather Topics* (Issue nine) (http://www.jma-net.go.jp/haneda-airport/)

○ Vertical wind shear is the difference in wind direction and velocity at locations obtained through wind analysis, between the top and bottom layers converted into the difference per 1,000 ft. It becomes larger as the change in wind direction or velocity, or both in accordance with altitude change (Extracted from notes to an Aircraft Accident Investigation Report).

Turbulence forecasts

In terms of whether it was possible to forecast the turbulence in the aircraft before occurrence, it was possible to forecast the turbulence in seven cases and impossible to do so in 11 cases. While there were cases of it being difficult to forecast the signs of turbulence, there were also cases of not being able to detect cumulonimbus clouds due to the weather radar being off. (See Figure 8)

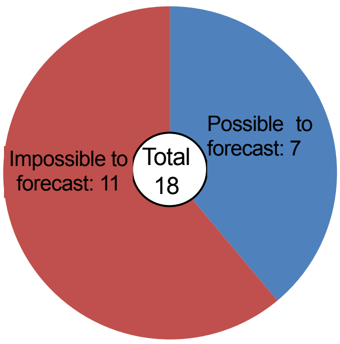


Figure 8 Turbulence forecasts

Breakdown of weather

In terms of the principal weather conditions at the time of accident occurrence, there were eight cases of INC TURB, six cases of wind shear (*2), and four cases of CAT. (See Figure 10)

(*2: Differences in wind level, in which there are differences in wind direction or velocity in horizontal or vertical directions.)

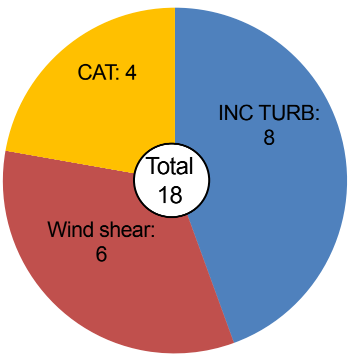


Figure 10 Breakdown of weather

Illumination of the seatbelt sign at the time of accident occurrence

In terms of the seatbelt sign at the time of accident occurrence, there were nine cases of it being lit and nine cases of it not being lit.

There were various cases of it being lit as the aircraft were in the approach phase, not being lit as the air current was stable, and being lit so immediately before the shaking of the aircraft that there was not sufficient time to fasten seat belts resulting in injuries. (See Figure 9)

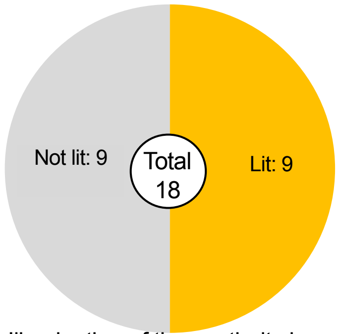
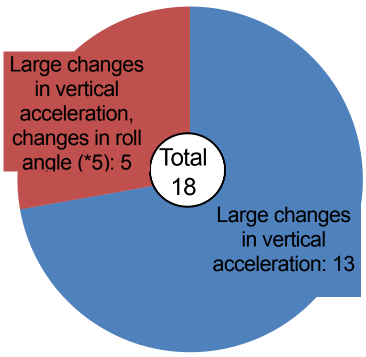


Figure 9 Illumination of the seatbelt sign at the time of accident occurrence

Changes to aircraft at the time of accident occurrence

In terms of changes to aircraft at the time of accident occurrence, there were large changes in vertical acceleration in 18 cases, with the majority consisting of vertical changes in the pitch angle, and five cases of rolling (*3) being combined with pitching (*4). (See Figure 11)



(*3: The tilting of the aircraft to the left or right, horizontal shaking.)

(*4. The moving of the aircraft's nose up or down, vertical shaking)

(*5: The left or right inclination angle of the aircraft)

Figure 11 Changes to aircraft at the time of accident occurrence

Breakdown of accidents by altitude

The breakdown of accidents by altitude shows that a large number occurred at 20,000ft or above, with the most accidents occurring at 30,000ft or above (nine cases), followed by 20,000ft to 29,999ft (six cases). (See Figure 12)

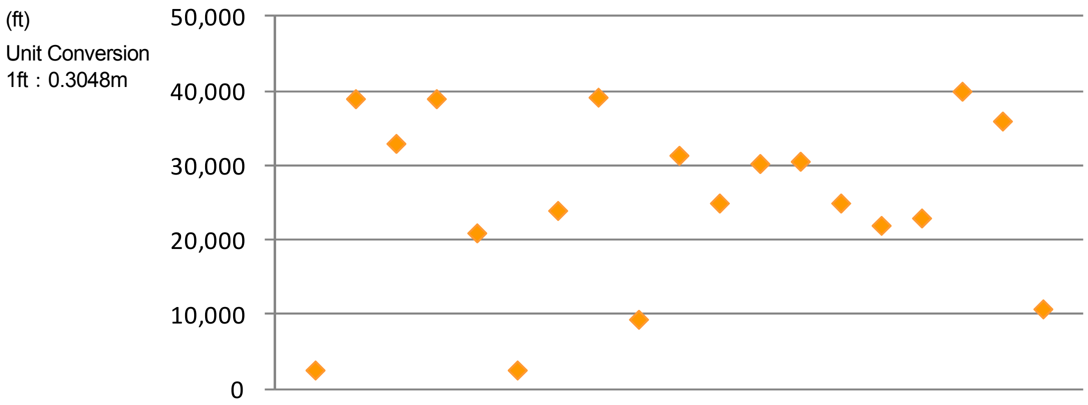


Figure 12 Breakdown of accidents by altitude

Breakdown of accidents by month

The breakdown of accidents by month indicates that accidents occurred throughout the year regardless of the season, with the most accidents occurring during July (four cases), and one to two accidents occurring in the other months. (See Figure 13)

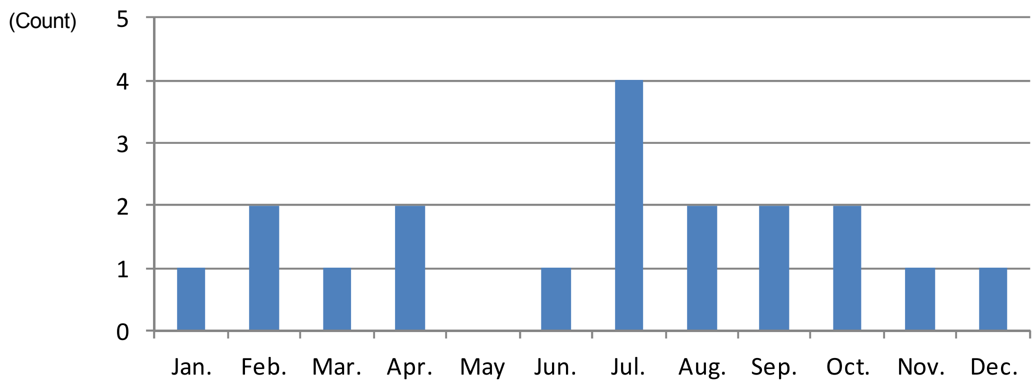


Figure 13 Number of accidents by month

Breakdown of accidents by the time of day

The breakdown of accidents by the time of day reveals that while accidents occurred at the highest frequency from 15:00 to 16:00 (three cases), one to two accidents occurred per hour from 8:00 to 22:00. (See Figure 14)

Looking at the relationship between the time of accident occurrence and the time of take-off and landing, we can see that nine accidents occurred within 30 minutes before or after take-off and landing, that six accidents occurred over 30 minutes before or after take-off and landing, and that there were four cases without information on this point.

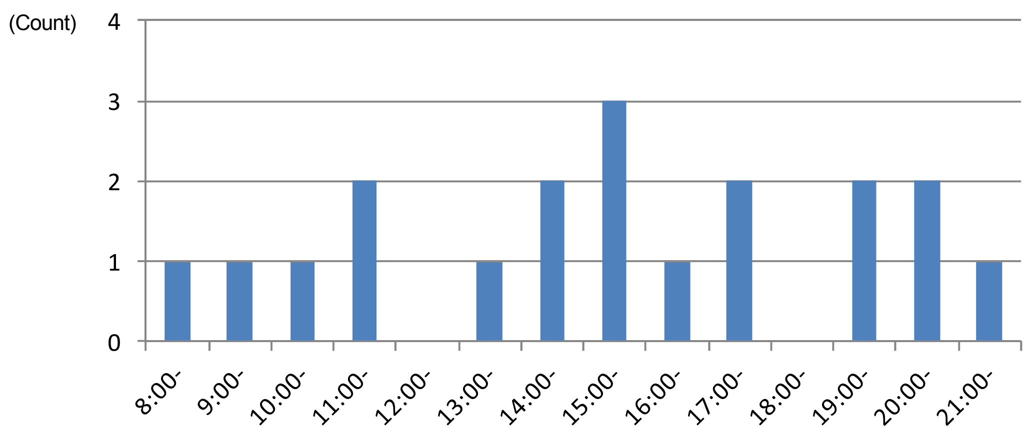


Figure 14 Number of accidents by the time of day

Categories of Causes

Not only environmental factors but also organizational and other factors contributed to accidents

When the causes of accidents described in Aircraft Accident Investigation Reports are classified into the categories of human factors, mechanical factors, environmental factors, and organizational factors, seven cases were caused by environmental factors, five cases by environmental and organizational factors, four cases by human and environmental factors, and two cases by human, environmental, and organizational factors. This indicates that not only environmental factors but also organizational and other factors contributed to accidents. (See Figure 15)

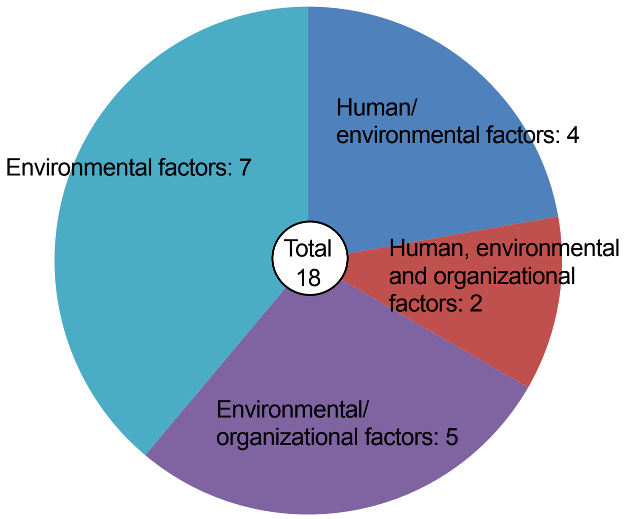


Figure 15　Breakdown of cause categories

A close analysis of these causes reveals that environmental factors consisted of aircraft shaking intensely as a result of weather conditions.

Organizational factors consisted of cases where the latest information were not provided to the flight in pre-flight briefings and when in-flight and where crew members information were not shared between flight crew members and cabin attendants when in-flight.

Human factors included cases where the aircraft weather radar was not used properly and which are related to aircraft piloting when the aircraft was affected by weather conditions.

Examples of human factors

- ○ Excessive input on column in response to a nose-up movement
- ○ Autopilot disengaged during the shaking of the aircraft
- ○ Lack of awareness that the aircraft weather radar was off

Examples of environmental factors

- ○ Active cumulonimbus cloud
- ○ Local turbulence occurring within stratus clouds
- ○ Turbulence not forecast due to fine weather
- ○ Frontal zone occurring on the north side of a typhoon
- ○ Large vertical wind shear

Examples of organizational factors

- ○ Cabin attendants were not warned of the large attitude changes of the aircraft such as turning while there was shaking.
- ○ Enough information was not provided by operation support staff.
- ○ The TB4 (*7) information input in J-PIREP (*6) was not communicated from the OCC (operation control center) to the airport flight division or the aircraft
- ○ The OCC did not provide the updated information to the aircraft in-flight

(*6: A system for entering and displaying turbulence information from pilot reports)

(*7: The intensity of turbulence is expressed on a scale of TB 0 to 7)

Fastening seat belts

The website of each airline informs passengers that they should always fasten their seatbelt in preparation for sudden turbulence even if the seatbelt sign is turn off.

Because your body may be tossed around or intensely shaken by the shaking of the aircraft if your seat belt is loose, it is important to fasten your seatbelt firmly and low.

Because you may fall or fly up into the air when encountering sudden turbulence, you should support your body immediately in these situations by sitting down in an empty seat and tightening your seat belt or lowering your body and holding onto a fixed seat. Moreover, you may hold on to handles near or within the lavatory if available.

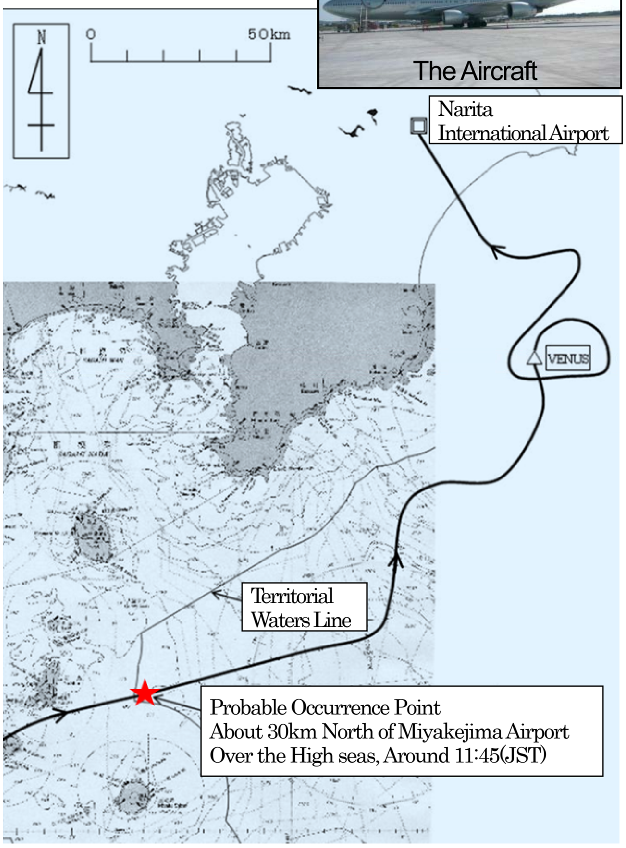
Case 1

Injuries suffered by passengers and cabin attendants from the shaking of the aircraft encountering turbulence during its descent in convective clouds

Summary : On Friday February 20, 2009, a Boeing 747-400, operated by Company A, took off from Manila (Ninoy Aquino) International Airport (Republic of the Philippines) bound for Narita International Airport (Japan) as the company's scheduled Flight. Around 11:45 Japan Standard Time (JST: UTC+9hr, unless otherwise stated, all times are indicated in JST on a 24-hour clock), the aircraft was hit by turbulence when it was flying at an altitude of about 30,300 ft about 174 km south-southwest of Narita International Airport (about 30 km north of Miyakejima Airport). Four passengers sustained serious injuries while 27 other passengers and seven flight attendants (FA) sustained minor injuries.
There were 422 people on board, consisting of the pilot in command (PIC), 13 other crewmembers and 408 passengers.
The aircraft interior was partially damaged.

Estimated Flight Route


The Aircraft



Events leading to the Accident

Around 08:47

The aircraft departed from Manila International Airport bound for Narita International Airport as the company's scheduled flight.

Around 11:30

The aircraft was instructed by the Tokyo Area Control Center (hereinafter "Tokyo Control") to descend from 37,000ft to 35,000ft, and the aircraft requested Tokyo Control to change its heading from 055° to 040° to avoid cumulonimbi.

Around 11:42

While descending from an altitude of approximately 34,000ft, the aircraft changed its heading to 080° based on instructions from Tokyo Control, and the aircraft began to jolt.

Around 11:44

The wind velocity began to change and dropped to approximately 100kt from approximately 150kt when the aircraft was descending by approximately 500ft from an altitude of approximately 30,700ft. At around that time, the bumpiness became intensified with altitude fluctuations.

When the Aircraft was descending at an altitude of about 30,300 ft, the vertical acceleration changed; from +1.36G to -0.52G, then to +1.70G. At that time, the pitch angle of the Aircraft decreased by about 0.5 degree in the nose-down direction and after the decrease, quickly increased by about two degrees in the nose-up direction.

Until landing, the vertical acceleration changed intermittently while decreasing, and the aircraft landed at Narita International Airport at around 12:19.

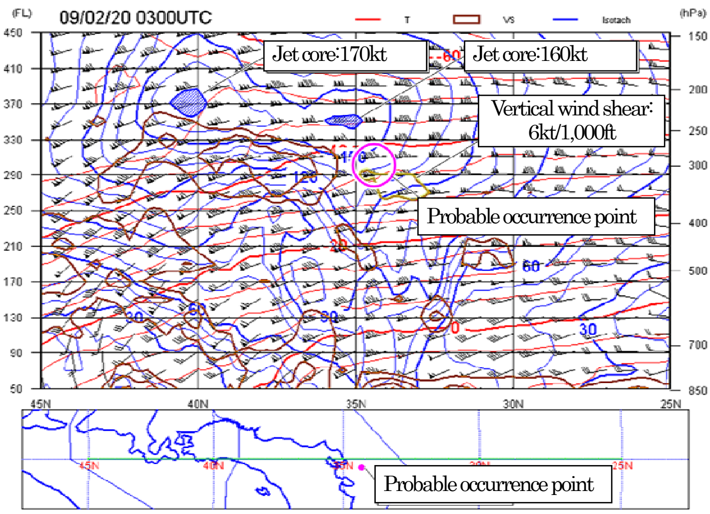
Meteorological Phenomena

Because warm and damp winds were blowing from the south into the low pressure near the Tokai region, generating unstable atmospheric condition. As a result, it is considered highly probable that clumpy convective clouds were developing there.

It is highly probable that clumpy convective clouds developed from the waters off the Tokai region to the Kanto region.

A vertical wind shear of 6kt/1,000 ft was observed amid jet stream near Latitude 35° N at an altitude of 26,000 to 30,000 ft. Therefore, it is considered highly probable that turbulent air was generated in the airspace near the place where the accident occurred.

Unit Conversion
1G : 9.807m/s²
1kt : 1.852km/h



Hourly Analysis Chart
1200JST 20 FEB 2009(Longitude 140°E) Some information was overlaid onto the JMA document.

Comparison of Situation in Forward and Aft Cabin Sections

In the briefing conducted at the Aircraft, the PIC briefed the all of FAs about the possible turbulence and requested them to observe the seat belt signs and have all duties finished prior to descent.

Situation in the forward and upper deck cabin sections

While the aircraft has 65 seats, there were 64 passengers 5 FAs responsible for these sections.

Situation in the middle and aft cabin sections

While the aircraft has 338 seats, there were 338 passengers and 6 FAs responsible for these sections.

The seats on the Aircraft were almost fully occupied. Passenger density was higher in the middle and aft cabin sections compared to the forward and upper deck sections. The number of passengers per one FA was about 13 persons in the forward and upper deck sections, while the number was far higher at about 56 seats in the middle and aft cabin sections. It is considered probable that it took longer to finalize post-service duties and confirm the safety of passengers in the middle and aft cabin sections.

The FAs of the forward cabin section took their seats earlier than usual after confirming the safety of the galleys and finishing their duties.

When the seat belt sign was illuminated, FAs in the upper deck confirmed whether the passengers fastened their seat belts and took their own seats with the seat belts fastened.

The aircraft became bumpy soon after the seat belt sign was illuminated. The FAs of the middle and aft cabin sections hurriedly tried to take the nearest jumpseats, they were not able to become seated.

In the middle and aft cabin sections where one FA had to take care of more passengers and more time was necessary for post-service clean-up and safety confirmation, it is considered probable that big bumpiness started before safety was fully confirmed after the lighting up of the seat belt sign.

There was intense shaking, and FAs who happened to be in the aisles were keeping themselves by holding on to the rack, and then crawling to the jumpseats. There were no injured persons in the forward cabin section, nor was there anybody screaming.

When the Aircraft dropped violently, nobody was standing in the upper deck, and all were safe.

In the mid cabin section, some unseated passengers fell on the floor after bumping their heads against the ceiling, and one of them was unable to move.

Some people, including FAs, were thrown upward to the ceiling, and many passengers were injured.

It is considered probable that when big bumpiness occurred, the passengers in the forward and upper deck sections had been seated with their seat belts fastened, while some passengers in the middle and aft cabin sections had left their seats or had not fastened their seat belts, or their seat belts had not been fastened properly.
The Aircraft encountered big bumpiness around 11:44:54, and a vertical acceleration of -0.52G was registered concurrently the pitch angle decreased followed by quick increase. It is considered probable that the aft section of the Aircraft sank suddenly corresponding to this pitch change and as a result it was subjected to a large negative vertical acceleration than in the forward.

Cabin ceiling

Armrest

Lavatory ceiling

It is considered somewhat likely that these factors led to more injuries in the middle and aft cabin sections.
Aircraft bumpiness might be greater in the aft cabin section than in the forward cabin section.
FAs in the aft cabin section are required to keep this in mind when they prepare in-flight service plans and confirm the safety of passengers.

With the PIC's pre-flight briefing all crewmembers had knowledge of anticipated turbulence during the descent. Therefore, like the FAs in the forward and upper deck sections did, it is considered probable that the FAs in other sections of cabin were able to confirm passengers' safety before the Aircraft encountered the turbulence.

Flight of the Aircraft

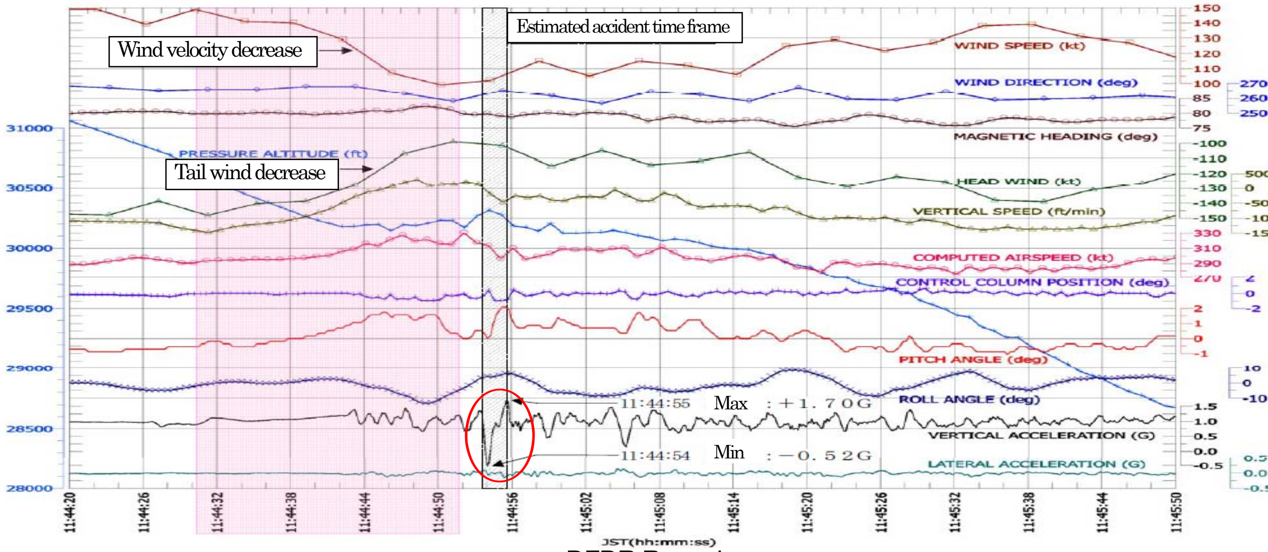
The aircraft requested permission to change its heading when it descended from the cruising altitude of 37,000ft to 35,000ft based on the instruction by Tokyo Control. It is highly probable that this was aimed to avoid cumulonimbi.

The Aircraft was instructed by Tokyo Control to descend to 18,000 and change its heading to 080° . Because clouds were observed in that direction, the Aircraft examined the clouds ahead with its radar, but there was no clear cumulonimbus on the radar screen. Therefore, it is considered highly probable that the Aircraft made a descent through the clouds keeping the direction as instructed.

According to the DFDR record concerning the vertical acceleration which indicates vertical bumpiness of flight, it is considered highly probable that the Aircraft encountered turbulence around 11:44:26 and the bumpiness began bigger from around 11:44:43 with the Aircraft's attitude change and then, reaching its culmination at 11:44:53 to 11:44:55 at an altitude of about 30,300 ft.

It is considered highly probable that this bumpiness resulted from the influence of the turbulence.

The wind velocity was 130 to 140kt in the vicinity of the airspace where the accident occurred. But the wind velocity that the Aircraft actually flew varied by about 50kt from about 150 kt to about 100kt. Therefore, it is considered highly probable that the Aircraft was influenced by the sudden large wind velocity change near the airspace where the accident occurred.



DFDR Records

Probable Causes: It is considered highly probable that this accident occurred when the Aircraft pitched greatly upon encountering a turbulence during its descent through a turbulent airspace of convective clouds near the front and below the jet stream, causing serious injuries to four passengers in the aft cabin section: who were not seated; who were not being buckled up; or if done so, who did it in an inappropriate manner.

It is considered somewhat likely that the following factors contributed to the serious injuries of aft cabin passengers: safety of passengers was not fully confirmed in the aft cabin section during the time frame between the seat belt sign illumination and the abrupt big aircraft pitching; and the aft cabin was exposed to a stronger negative vertical acceleration compared to the forward.

In order to Prevent Recurrence

- It is necessary for FAs to have common understanding about the indication of the seat belt sign and to take measures to call passengers' attention to the need of fastening seat belts properly and carefully listening to in-flight announcements.
- When an aircraft is anticipated to encounter turbulence, the cockpit crew should turn on the seat belt sign at the earliest possible time so that FAs may have enough time to finish their duties before the encounter, because a lot of time is necessary for them to provide services to passengers, clean up and confirm the safety of passengers.
- When informed by the PIC of the possible turbulence and the need to be seated during the descent, in the pre-flight briefing, FAs need to plan to finish in-flight services well before the anticipated encounter with turbulence. If the situation required, FAs need to consider discontinuing or canceling in-flight services. When the seat belt sign is illuminated, FAs are required to urge non-seated passengers to be seated and perform safety checks mainly by confirming their seat belt fastening manner. Accordingly, it is necessary to make plans while taking into account the time needed for these activities.

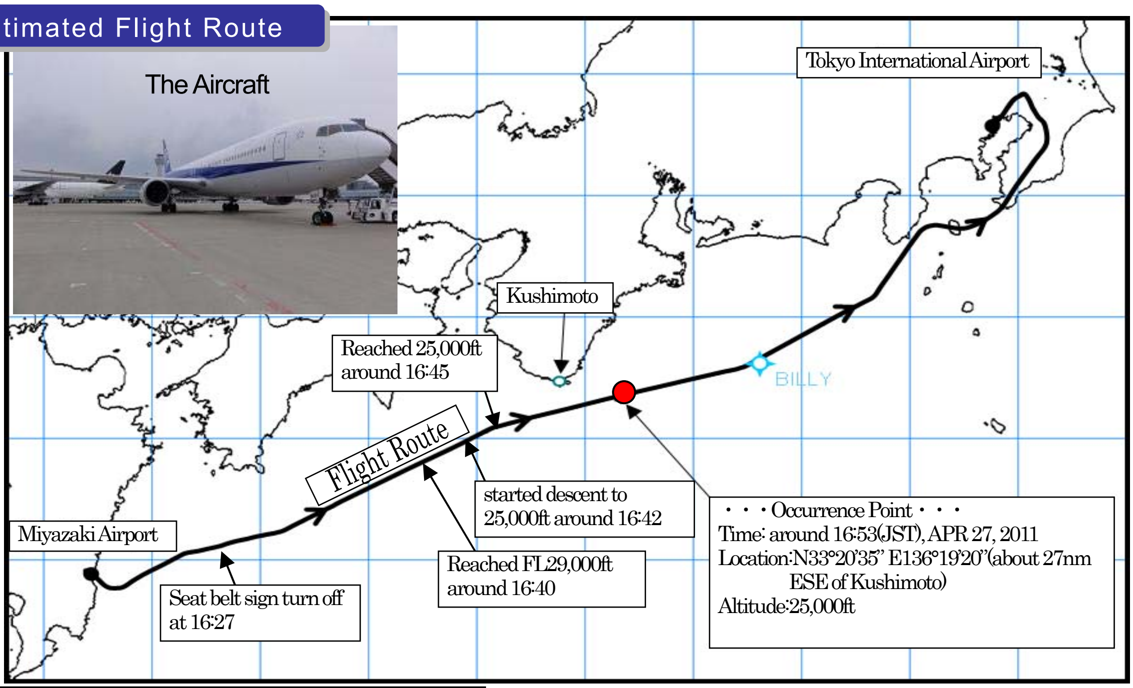
The investigation report of this case is published on the Board's website (issued on Dec. 16, 2011).
http://www.mlit.go.jp/jtsb/eng-air_report/N676NW.pdf
(This report is a translation of the Japanese original investigation report. The text in Japanese shall prevail in the interpretation of the report.)

Case 2

Serious injuries suffered by one FA and slight injuries suffered by four passengers from the shaking of the aircraft caused by locally-occurring clear-air turbulence

Summary: On Wednesday April 27, 2011, a Boeing 767-300, operated by Company A, at 16:16 Japan Standard Time (JST: UTC+9hr, unless otherwise stated, all times are indicated in JST on a 24-hour clock), took off from Miyazaki Airport for Tokyo International Airport as a scheduled flight. While flying at 25,000 ft, 27 nm east-southeast of Kushimoto, around 16:53, the aircraft encountered turbulence and one cabin attendant was seriously injured in front of the left aft lavatory. Four other people consisting of passengers and cabin attendants were slightly injured.
There were 119 people on board: a Pilot in Command (PIC), seven crew members and 111 passengers.
The aircraft was not damaged.

Estimated Flight Route



Events leading to the Accident

Around 16:16
The aircraft took off from Miyazaki Airport.

Around 16:26
The aircraft maintained the cruising altitude of 27,000ft.

Around 16:27
The seat belt sign had been turned off.

Around 16:40
The aircraft reached and levelled off at around 29,000ft.

Around 16:42
The aircraft received permission to descend to 25,000ft from ATC

Around 16:45
It descended and levelled off at around 25,000ft.

16:52:38
The aircraft was shaken when it encountered strong turbulence at 27nm east-southeast of Kushimoto.

16:52:41
The seat belt sign had been turned on.

16:52:58
The First Officer (FO) reported to the Tokyo Area Control Center that the aircraft had encountered turbulence.

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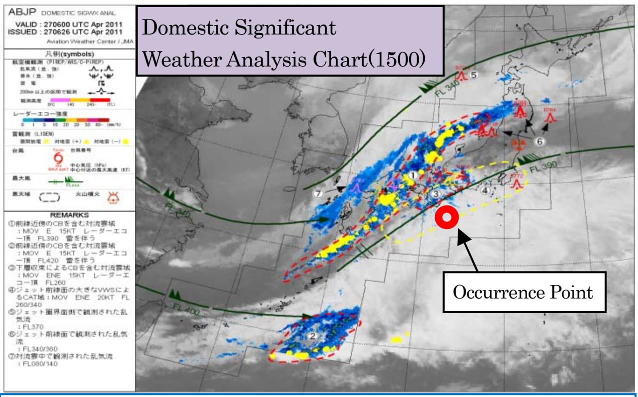


A radar echo area which developed along the forefront of the cold front extending from the low spread like a belt and was advancing to the east at 15kt. The area of strong radar echo intensity and high top radar echo altitudes were observed along the area off the coast of Shikoku, Chugoku Region and off the coast of Hokuriku. However, there were very few echoes present with 5mm/h or less in the airspace where the accident occurred, and their tops were as low as 2 to 4km high.

Statements of Flight Crew Members (PIC)

He felt a "floating" sensation as if he had been riding on a big wave. Although the shaking was a light one, the PIC retarded the thrust lever to reduce speed as a precaution. Immediately following that, the aircraft was thrust upward all of a sudden, and then was violently thrust downward. The shaking lasted only an instant, and the suddenness and the intensity of the shaking was far greater than any other shaking he had experienced before.

From previous page

Around 16:55

Cabin attendant (CA) reported to the PIC the situation observed in the cabin.

Around 16:56

The FO reported with company radio that the aircraft had encountered turbulence, and that several persons were injured.

Around 17:22

The PIC informed passengers over the Passenger Address (PA) system that the aircraft had encountered turbulence and it would not affect the scheduled flight.

Around 17:43

The aircraft landed at Tokyo International Airport.

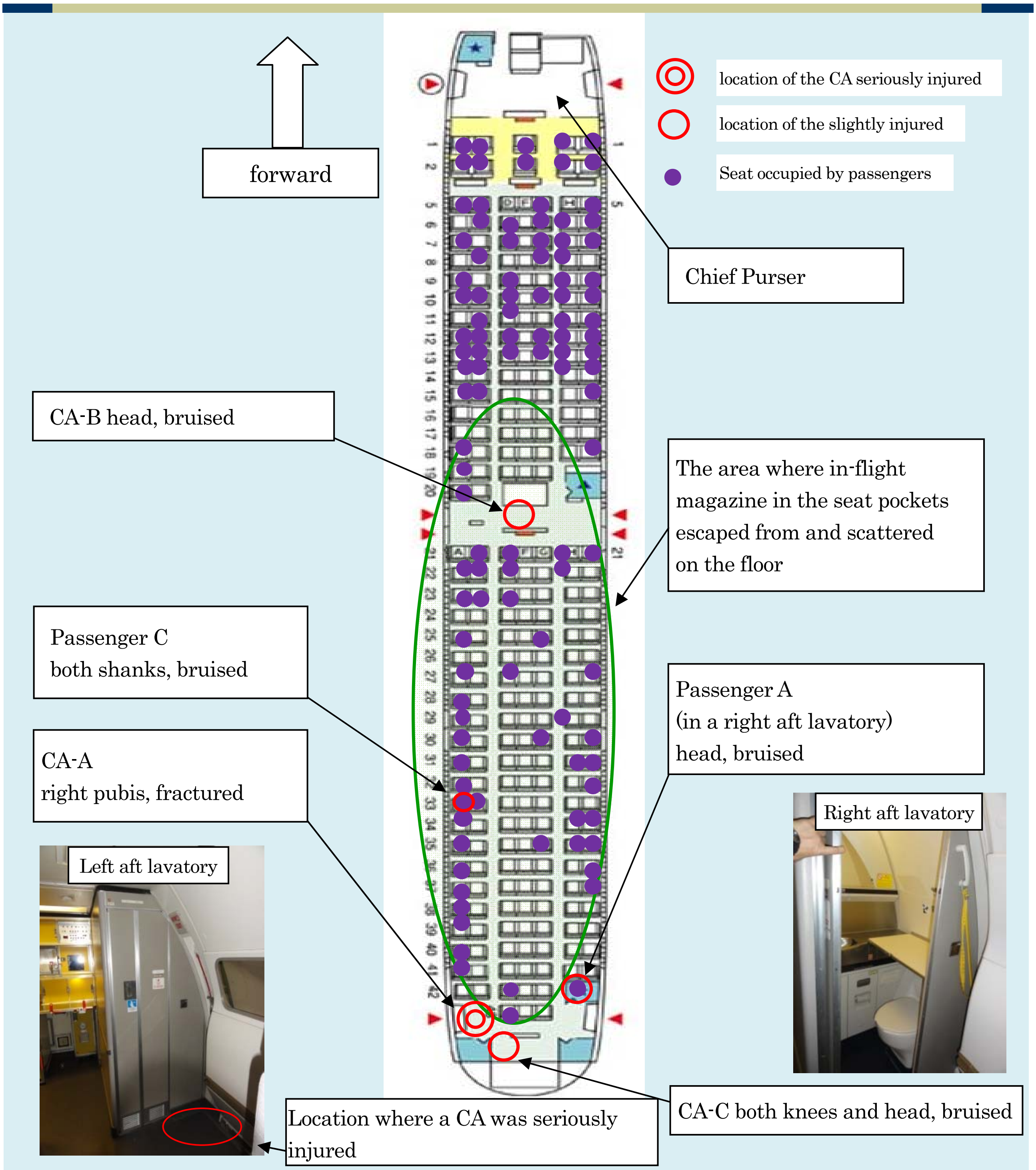
Statements of Cabin Attendants (Chief Purser)

She felt like she was lifted up very softly. Although the chief purser instantaneously grabbed a curtain in front of her, she was lifted up by 20 cm only to be dropped to the floor with the hem of the curtain over her arm. There was no report of damage observed in the cabin, though most of the in-flight magazines and headphone sets in the seat pockets were found scattered over the floor in the aft cabin.

Statements of Passengers (Passenger A)

Before the strong shaking she felt rolling and she anticipated another shaking in the aft lavatory, but her anticipation was betrayed by the pitching by which she was thrown upward to have her head hit against the ceiling, and was dropped on the floor.

Locations of injured persons



Causal Factors of the Accident

Convective Clouds

observing no clouds at their altitudes while flying between the thin cloud layers.

It is highly probable that the aircraft was not shaken by the influence of convective clouds judging.

Winds

The existence of layers in the accident airspace, whose temperature and atmospheric pressure values were different, accompanied by wind velocity difference (wind shear), generated the unsteady air conditions where turbulence was likely to occur near the layer boundary.

While the aircraft was flying in the vicinity of the boundary, it is possible that the unsteady airspace generated the turbulence and shook the aircraft with a downdraft, judging from the fact that at the moment of the turbulence.

The Turbulence

The aircraft gradually approached the frontal zone under the jet stream.

Nothing more than a weak vertical shear with 0 to 6kt was analyzed at the occurrence point.

The strong shaking lasted only for a very short period and ended without recurring.

The flight encountered it while flying through cloudless airspace.

It is highly probable that the aircraft encountered a local and temporary, strong CAT induced by wind shear judging from the findings.

The Shaking

The combination of the aircraft motion around the center of gravity caused by the increase in the pitch angle and the sharp descent of the aircraft by 80 ft gave the aft section of the aircraft a sudden lowering.

It is highly probable that the CA near the left aft lavatory flew up into the air and suffered a serious injury upon the fall to the floor.

Probable Causes : It is highly probable that the accident occurred as follows:
The aircraft encountered atmospheric disturbance all of a sudden during flight, and was shaken so severely that one of the cabin attendants in the aft section of the aircraft was seriously injured when she was thrown up in the air and fell on the floor.
It is possible that the atmospheric disturbance the aircraft encountered were CAT which was created locally and temporarily by a wind shear in the vicinity of frontal zone beneath a jet stream.

In order to Prevent Recurrence

➢ It would be recommended to continue to examine the effectiveness of measures such as the installation of handrails at locations where passengers pass by and consider taking further safety measures to prevent accidents.

➢It is desired that the Company's adoption of such a procedure should be considered as advising passengers in advance of preventive measures in case of a shaking.

➢ It would be recommended to promote studies on and development of an airborne Doppler light detection and ranging (LIDAR) to detect CAT.

➢It is expected that providing meteorological organizations with access to analyze more detailed information including accelerated velocity suffered by the aircraft involved in a turbulence of MODERATE intensity or more, will contribute to the improvement of more accurate CAT prediction.

The investigation report of this case is published on the Board's website (issued on Jun. 29, 2012).
http://www.mlit.go.jp/jtsb/eng-air_report/JA8569.pdf
(This report is a translation of the Japanese original investigation report. The text in Japanese shall prevail in the interpretation of the report.)

Case 3

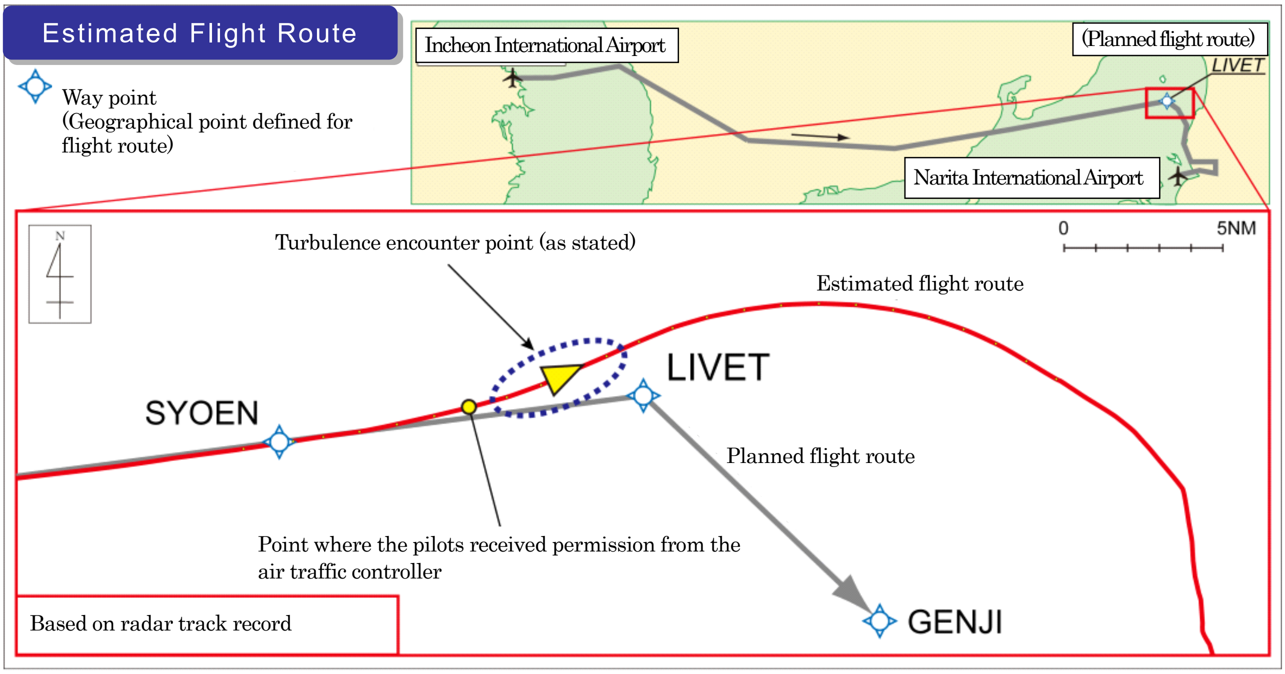
Injuries suffered by FAs from the shaking of the aircraft encountering turbulence after entering cumulonimbus clouds that suddenly developed

Summary: On Thursday July 5, 2012, a Boeing 777-200 operated by Company A took off from Incheon International Airport (Republic of Korea) for Narita International Airport as a scheduled flight. At 14:18 Japan Standard Time (JST: UTC+9hr, unless otherwise stated, all times are indicated in JST on a 24-hour clock), the aircraft was shaken at approximately 150km north of Narita International Airport at an altitude of approximately 23,000ft, and four flight attendants (FAs) working in the rear galley were thrown into the air and against the floor twice in succession due to the sudden shaking of the aircraft. Consequently, one of them was seriously injured, and the other three sustained minor injuries.

There were a total of 256 persons on the aircraft, consisting of the pilot in command (PIC), 11 other crew members, and 244 passengers.

The aircraft was not damaged.

Estimated Flight Route



Events leading to the Accident

Around 12:55

The aircraft took off from Incheon International Airport for Narita International Airport as a scheduled flight.

The PIC and the first officer (FO) found a small cumulonimbus to the right of the course very close to LIVET (waypoint) as the aircraft was descending before LIVET. The aircraft's weather radar displayed only green weak weather returns. It became apparent they needed to go further left to avoid it; therefore, they started to make a deviation flight to the left after receiving permission from the air traffic controller.

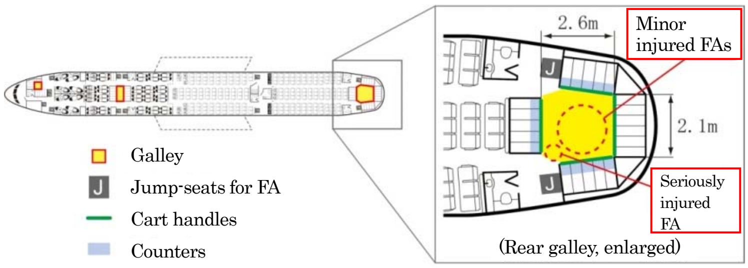
Because no information concerning turbulence or other bad weather conditions was reported, the PIC turned on the seat belt sign for the passengers as part of the approach and landing phase of flight shortly after the aircraft started to descend, but he did not instruct FAs to be seated or inform them of the turbulence.

Around 14:18

The aircraft encountered a moderate turbulence when it entered some clouds while going around. Serious and slight injuries were suffered by four FAs working in the rear galley of the aircraft as a result of the severe shaking of the aircraft.

The Aircraft

In the rear galley where the four injured FAs were working



- Handholds designed specifically for the shaking of the aircraft were not equipped.
- Fixed objects such as the counters and the cart handles stored in the lower part of the galley on four sides were available to hang on as substitute for handholds.
  (All of the carts had been stored when the accident occurred)
- Making the FAs and the fixed objects, which were substitute for handholds, slightly far apart.

Meteorological Information

1. General Weather Conditions

The atmosphere was in an unstable condition in eastern and northern Japan from the afternoon through the night due to the passage of a trough accompanied by a cold of minus nine degrees C or less in the vicinity of an altitude 5,500 m, and convective clouds such as cumulonimbus and cumulus developed in several places.

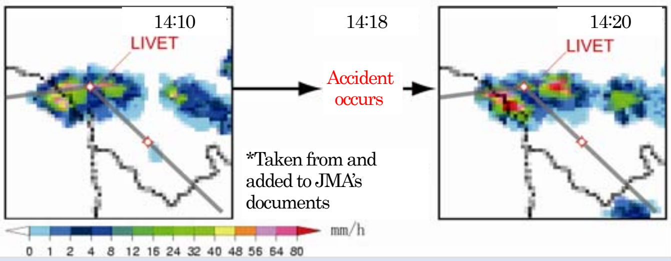
2. Weather Radar Imagery around occurrence point (Strength and Top Height)

According to the Weather Radar Imagery at 14:10: before the accident occurred, and 14:20: shortly after the accident occurred, the echo strength increased during this period as its top height reached 26,000 ft and over.

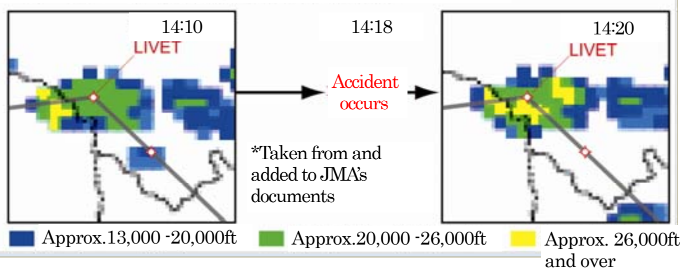
3. Prognostic Chart of Significant Weather (for domestic use)

No significant weather including turbulence was forecasted to affect the flight on their route.

Weather Radar Imagery (Strength: indicates precipitation intensity)



Weather Radar Imagery (Top height: indicates cloud height)



Flight Operations Manual of Company A contains the following description

※Flight Operations Manual of Company A contains the following description: (excerpt)

1. Aircraft's weather radar displays

WEATHER RADAR REFLECTIVITY DISPLAYS

Weak Echo(Green Display)

If an echo is green only (assuming no attenuation and/or severe thunderstorm shapes), it can be consider non-hazardous throughout. Expect light turbulence, with a slight chance of moderate turbulence, but no chance of severe.

2. How to respond to unexpected turbulence

Unexpected Turbulence

If moderate or greater turbulence is encountered unexpectedly:

Flight attendants must stop, drop, and hold on – sit on the floor,in the nearest customer seat or jumpseat. Securely fasten seat belts (and shoulder harnesses, if applicable).If no empty seat is available, sit on an armrest or sit on the floor and hold on to a stationary object.

Causal Factors of the Accident

●Flight Crew members' Judgment on the Weather

It is highly probable that judging from the weather information before and during the flight, the fact that the cumulonimbus discovered before LIVET did not appear to be developing, with its cloud top being low, and the fact that it was indicated as a weak return on the weather radar display, crew members expected no significant turbulence to affect the flight, but only light turbulence, during the deviation from cumulonimbus, and that they did not inform the FAs of any information about the turbulence.

●Development of Cumulonimbus

It is highly probable that the cumulonimbus the aircraft avoided had developed quickly immediately before the time of the accident. It is probable that the aircraft took detour the cumulonimbus to avoid it, but was forced into a part of the cloud which had developed rapidly, and then encountered its disturbance.

●Injured FAs' Response to the Shaking of the aircraft

It is probable that the four FAs working in the rear galley were thrown into the air because they had not been informed by the PIC of the turbulence in advance and were unable to hang onto fixed objects around them when the rear of the airframe sank suddenly.

It is considered somewhat likely that the FAs could have responded to the shaking of the aircraft if the PIC had informed them of some information about the turbulence.

Probable Causes : It is highly probable that the accident occurred when the FA in the rear section of the aircraft was seriously injured because it was shaken heavily.

It is probable that the aircraft was shaken heavily because it was unable to avoid the cumulonimbus which had developed so rapidly, and then entered a part of the cloud.

It is probable that the FA was seriously injured because she was unable to hang onto the fixed objects around her when the aircraft was shaken suddenly.

In order to Prevent Recurrence

Safety Actions taken by Company A after the accident occurred

➢After the occurrence of this accident, Company A strengthened the contents of Flight Attendant Operations Manual (UNEXPECTED TURBULENCE).

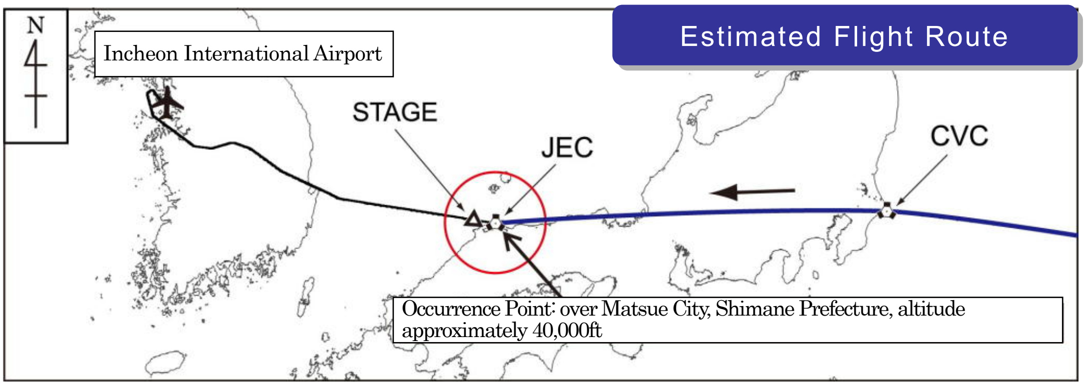
The investigation report of this case is published on the Board's website (issued on Mar. 29, 2013).
http://www.mlit.go.jp/jtsb/eng-air_report/N224UA.pdf
(This report is a translation of the Japanese original investigation report. The text in Japanese shall prevail in the interpretation of the report.)

Case 4

Serious injuries suffered by passengers from the shaking of the aircraft encountering severe atmospheric disturbance

Summary : On Tuesday August 21, 2012, an Airbus A330-300, operated by Company A, took off from Honolulu International Airport (the United States of America) for Incheon International Airport (the Republic of Korea), as a scheduled flight. While flying at approximately 40,000 ft over Matsue City, Shimane Prefecture, around 15:17 Japan Standard Time (JST: UTC+9hr, unless otherwise stated, all times are indicated in JST on a 24-hour clock), the aircraft was shaken. Two passengers were seriously injured and one passenger was slightly injured.

There were 221 people on board, consisting of the pilot in command (PIC), 14 other crew members and 206 passengers. The aircraft was not damaged.



Events leading to the Accident

15:14:17 Communications in Japanese were exchanged between the Tokyo Area Control Center (ACC) and another aircraft stating that JEC (Miho VORTAC(*8)) was out of service due to a lightning strike.

Aircraft	Cockpit	Passenger cabin	Weather conditions
15:16:14 A small change of the vertical acceleration started.	**15:16:24** Route Captain (*9) set the speed selector at M0.78.		
15:16:30 A relatively large change in vertical acceleration began.	The route captain turned on the seat belt selector.		**15:16:30** The wind had been blowing from the right rear direction of the Aircraft at an average speed of 16kt, it began to change in a counter-clockwise direction.
			15:16:33 The static air temperature began to change.
15:16:36 The Aircraft's angle of attack (*10) increased suddenly, but there was no change to the pitch angle.			**15:16:36** The wind direction changed to blow directly against the Aircraft.
15:16:38 The speed of the Aircraft became M0.872, temporarily exceeding the maximum operating speed limit:M0.86.	Causing the over speed warning to sound.		**15:16:38** The wind speed became 34kt.
The entire aircraft began to be lifted up due to a strong updraft.			
15:16:40 The vertical acceleration became 1.88G, the highest value for this flight.			**15:16:40** The static air temperature increased rapidly by 4°C, and this high value was maintained for approximately 15 seconds.
15:16:41 The rate of climb became approximately 3,300 ft/min.			The wind began to change in a counter-clockwise direction.
15:16:42 The vertical acceleration became 0.04G, which was the greatest change during this flight.			**15:16:42** The wind became a crosswind from the left, and the wind speed became 20kt.

(*8…VORTAC: combined VOR and TACAN navigational radio facility)

(*9…"Route Captain"as referred to by the Company A is a pilot in a three-member crew formation who assumes the PIC's duties in place of the regular Captain only during cruising flight.)

(*10…When a wing is located in a uniform air current, it is the angle formed by the direction of this current and the chord line.)

To next page

From previous page

15:16:46

The Aircraft continued to climb.

The altitude deviation alert sounded.

15:16:48

The PIC took operations over from the route captain and disengaged the A/P (*11).

The pitch angle of the aircraft changed rapidly to -6.3°, while the vertical acceleration became -0.09G, the lowest value during this accident.

15:16:54

The PIC pushed the side stick forward (the direction to lower the nose).

15:16:55

As the roll angle varied within the range from 30.2° on the right side to 17.9° on the left side, the pitch angle reached a maximum of +14.8°.

The input of roll and pitch by the sidestick on the PIC side changed greatly. (~15:17:30)

At the initial shaking, Passenger A was thrown into the air and fell forcefully to the floor.

15:16:44

Cabin attendants made a Passenger Address (PA) regarding shaking of the aircraft and fastening of seat belts.

When Passenger B took off her seat belt to assist Passenger A, Passenger B was thrown into the air and fell as the aircraft shook once again.

(*11…Auto Pilot)

15:16:45

The wind speed became 2kt.

15:16:46

The wind became a tailwind, and the wind speed began to increase.

15:16:55

While remaining as a tailwind, the wind speed increased to a maximum of 52kt.

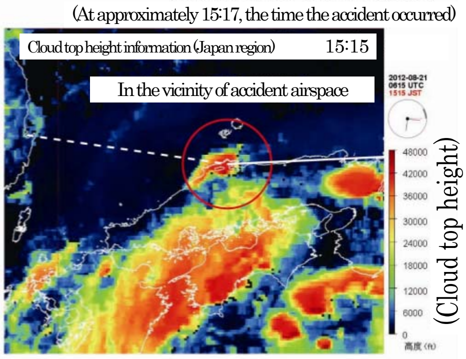
Relation to Meteorological Conditions

Effect of Cumulonimbus

Cumulonimbus were generated rapidly in the vicinity of the accident airspace from approximately one hour before the accident occurred, with a cloud top height exceeding the Aircraft's flight altitude of 40,000 ft. Moreover, it was recorded in the Cockpit Voice Recorder that immediately before the accident occurred, JEC was out of service due to a lightning strike and that other aircraft flying around the Aircraft had been communicating with the Tokyo ACC to avoid significant weather conditions.

It is highly probable that cumulonimbus to which the PIC and the Route Captain should pay attention existed in the vicinity of the accident airspace.

(At approximately 15:17, the time the accident occurred)



*Taken from and added to JMA's materials

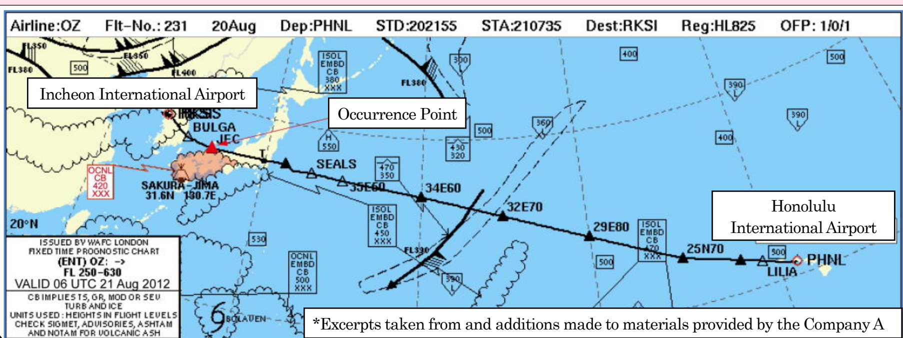
Rapid Scan Observation Imagery

Recognition of Cumulonimbus

It is probable that the PIC and the Route Captain did not recognize the existence of cumulonimbus as they did not sufficiently monitor the weather conditions and instruments or notice that the weather radar was off because they opened up manuals, etc. concentrating on confirming the operation guidelines while assuming various phases in the period of 30 minutes leading up to the accident.

According to the statements of the PIC, although it was forecast in the pre-flight weather briefing that there would be a cloud top height of 42,000ft around the flight route, no significant weather conditions such as clouds was forecast on the flight route including the accident point; however there was a possibility that the nearby clouds expanded to the site of the accident.

It was necessary for the PIC and the Route Captain to continually obtain the most current weather information from the Operation Control Center and other organizations during flight and also to pay close attention to the weather conditions on the flight route by watching outside and using the weather radar.



*Excerpts taken from and additions made to materials provided by the Company A

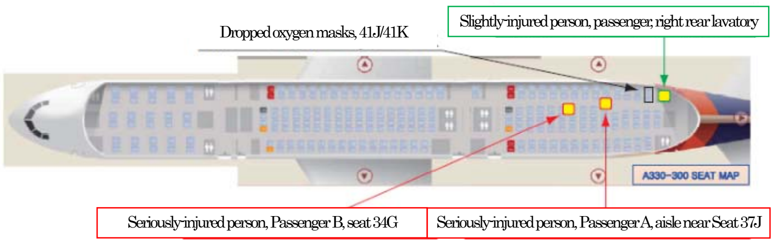
The Significant Weather Prognostic Chart for International Aviation issued by the London WAFC and confirmed by the PIC in the pre-flight briefing.

Disengagement of A/P

It is possible that the severe shaking of the aircraft was occurred resulting from the PIC's operation after disengaging the A/P.	It is probable that the PIC experienced difficulties in stabilizing the Aircraft by manual control while at a high altitude and in the midst of atmospheric disturbances.	The regulations of the Company A specify that the flight crew should keep the A/P on when encountering severe turbulence.

It is possible that if A/P had not been disengaged, there may not have been such large changes in the pitch angle.

The aircraft



Position of injured persons at the time of the accident

Probable Causes : It is highly probable that in this accident, serious injury was sustained by a passenger walking in the rear aisle due to the severe shaking of the Aircraft, and that serious injury was sustained by another passenger seated nearby when the passenger removed the seat belt in order to help the injured passenger, the Aircraft shook severely again at that moment.

It is probable that the initial severe shaking of the Aircraft was a result of the Aircraft passing through or nearby cumulonimbus, due to the PIC and the Route Captain failing to notice that the weather radar was off, and encountering atmospheric disturbances with severe changes in wind direction and speed coupled with strong updrafts.

It is possible that the next shaking of the Aircraft may have been influenced by the PIC's control operations after disengaging the A/P to stabilize the aircraft.

It is probable that the reason for the PIC and the Route Captain failing to notice that the weather radar was off was that their monitoring of the weather conditions and instruments was insufficient.

In order to Prevent Recurrence

Safety Actions taken by Company A after the accident occurred

➢The Company notified its flight crew members of this case along with the following items as points for enhancement of safety.

・We strongly recommend to brief turbulence information during a joint briefing and perform the safety procedures.
・Try to get real time weather through the information of ATC turbulence, weather radar and your eyes.
・Perform the severe turbulence procedures with cabin crew when severe turbulence is expected or encountered.
・Captain should make PA to relieve anxiety of passengers due to turbulence.
・Make and maintain GOOD CRM (Crew Resource Management).

➢The Company notified its cabin attendants of this case along with the following items as points for enhancement of safety.

・When the seat belt sign is on, continuously monitor that passengers are fastening their seatbelts no matter how serious the turbulence is.
・Cabin crew make an immediate cabin announcement to provide passengers with instructions for appropriate action in the case of turbulence even the other announcement is being already made.
・Ensure the policy and associated procedures regarding turbulence level. Please refer to CCM 2.10.
・When the seat belt sign is on, senior cabin crew contacts captain to check the time of configuration of the turbulence.
・Recently the number of unexpected turbulence has increased due to unstable air. Please always secure cabin.

Safety Actions taken by the company that designed and manufactured the aircraft

➢ A clear description of "Overspeed Recovery" was inserted into the FCOM (Flight Crew Operating Manual), stating that in the event of excessive speed, it is necessary to immediately set the speed brakes lever to full and monitor the status of thrust reduction while maintaining A/P.

The investigation report of this case is published on the Board's website (issued on Jul. 25, 2014).
http://www.mlit.go.jp/jtsb/eng-air_report/HL8258.pdf
(This report is a translation of the Japanese original investigation report. The text in Japanese shall prevail in the interpretation of the report.)

4. Conclusion

The occurrence conditions and lessons learned for recurrence prevention from the four accident investigations introduced in this digest and other accident investigations are summarized below.

Occurrence conditions for aircraft shaking accidents

◆Statistics on the accidents

There were 40 accidents involving large aircraft, and 19 of these (nearly half) were aircraft shaking accidents.

◆Breakdown of the injuried

The number of people injured per aircraft shaking accident was approximately four times larger than other aircraft accidents involving large aircraft.

The aft accounted for approximately 72% of the results for the position in aircraft where accidents occurred (excluding cases in which the position was unknown).

◆Categories of Causes

Not only environmental factors but also organizational and other factors contributed to accidents

In terms of categories of causes, seven cases were caused by environmental factors, five cases by environmental and organizational factors, four cases by human and environmental factors, and two cases by human, environmental, and organizational factors, indicating that not only environmental factors but also organizational and other factors contributed to accidents.

Lessons learned from the accident investigation

○ Flight crew members

- When aircraft is anticipated to encounter turbulence, the cockpit crew should turn on the seat belt sign at the earliest possible time so that FAs may have enough time to finish their duties before the encounter, because a lot of time is necessary for them to provide services to passengers, clean up and confirm the safety of passengers.

○ Flight attendants

- When informed by the PIC of the possible turbulence and the need to be seated during the descent in the pre-flight briefing, FAs should plan to finish in-flight services well before the anticipated encounter with turbulence.
- Pay attention to the seatbelt sign to ensure that passengers properly wear their seatbelts.
- Remind passengers to carefully listen to in-flight announcements.
- Consider discontinuing or canceling in-flight services depending on the circumstances.
- When the seat belt sign is illuminated, FAs are required to urge non-seated passengers to be seated.
- Perform safety checks mainly by confirming their seat belt fastening manner.

○ Other

- Some aircraft have taken safety measures such as installing handrails at locations where passengers pass by. Continue to examine the effectiveness of such measures and consider taking further safety measures to prevent accidents.
- Consider educating passengers on the response they should take in the event of the shaking of the aircraft.

A tip from Director for Analysis, Recommendation and Opinion

Aircraft shaking accidents occur when aircraft encounter sudden turbulence that is difficult for even aircraft operation and weather professionals to forecast.

While there are hopes that technologies for forecasting turbulence will be further developed, because there is always the possibility of such accidents occurring on aircraft that operate day and night, both operators and passengers should prepare as best they can in order to prevent these accidents from occurring and to mitigate damage in the event of their occurrence.

We hope that you act to protect yourself when boarding aircraft by properly fastening your seatbelt as much as possible, regardless of whether or not the seatbelt sign is on.

We welcome your comments on "JTSB Digests" , and requests of dispatching lecturers

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