NATIONAL TRANSPORTATION SAFETY BOARD

Office of Aviation Safety
Washington, D.C. 20594

June 12, 2020

Attachment 14 – Airbus Managing Severe Turbulence

[Article Published September 2005]

OPERATIONAL FACTORS

DCA20CA058

Managing Severe Turbulence

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1 Introduction

Severe turbulence is identified as turbulence that causes large, abrupt changes in altitude and/or attitude. It usually causes also large variations in airspeed.

Inadvertent flight into such hazardous weather environment is the leading cause of injuries to passengers and cabin crew in non-fatal airline accidents, and is so a key safety issue for any aircraft.

This kind of events leads rarely to fatal accident but the shake-up triggered by the turbulence can cause serious injuries among non-buckled people but also generate trauma among passengers.
For example a few months ago, an A330 experienced very strong turbulence in early descent leading to more than forty people injured among passengers and cabin crew including one passenger seriously injured.

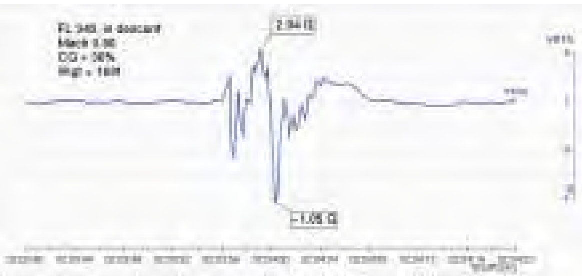
Inadvertent flight into atmospheric turbulence is also an economical issue. Indeed serious turbulence may cause substantial aircraft damage. An AOG situation with associated repair costs may make turbulence very costly.

2 Some figures

Usually only the most severe cases of turbulence are reported to the manufacturer.
Over 3 years, about 20 turbulence events have been annually reported to Airbus. These events have caused injuries for about one third of them.
Generally, during such event, the main vertical longitudinal and lateral acceleration changes are concentrated within a few seconds and injuries concern generally non-buckled passengers and cabin crew when the local vertical load factor decreases under 0g before increasing again (Load factor variations generated by the turbulence are not necessarily the same at any points of the cabin).

To give an order of magnitude of a severe turbulence here are 3 examples:

- The first concerns an A340 in cruise. The maximum and minimum vertical load factor excursions were 2.3g and –0.9g both recorded near the centre of gravity within a few seconds.
- The second concerns an A320. Within 10 seconds the successive up and down vertical load factor excursions were:
  1g/1.4g/ 0.2g/3g/ 0.3g/ +1.6g/-0.8g/+2.6g.
  During the same period of time the lateral load factor varied as follow:
  +0.2g/ -0.08g /+0.06g/ -0.2g/ +0.2g/ -0.22g/ +0.13g
- Eventually here below is the profile of the vertical load factor resulting from a turbulence encountered on an A330.



3 Maintenance actions

Turbulence can be considered as excessive when passengers and crew are moved violently against their seat belts and objects move around the aircraft. In this case, the pilot must make a logbook entry for maintenance action initiation.

Inspection that is recommended after flight in excessive turbulence (or in excess of VMO/MMO) is described in Aircraft Maintenance Manual (AMM) section 05-51-17.
In case of severe turbulence it is also recommended to inform Airbus.Note that in some remote cases we have determined that limit loads have been locally exceeded. In these cases some additional inspections (On top of what is recommended in AMM section 05-51-17) may be required.

4 Managing severe turbulence

Whenever possible, the best solution is to use all the existing means at the pilots' disposal to localise the turbulence as well and as early as possible in order to have enough time to properly avoid it or at least to secure the cabin when it is unavoidable. But the analysis of several turbulence events has led to the conclusion that, as further developed here below, pilot awareness on the appropriate use of available means could be improved.

4.1 Turbulence detection

Optimum use of weather forecast

Firstly weather forecast information available before taking-off as well as the weather briefing have to be as complete as possible and, depending on the weather context, this information has to be updated in flight as often as necessary. In some severe turbulence events, analysis has shown that an appropriate update of weather information in flight would have very likely allowed the detection and consequently the avoidance of the area of turbulence.

Optimum use of the weather radar

Modern aircraft are equipped with airborne weather radars. The principle of these radars is to detect precipitation such as wet turbulence and wet hail but these radars will not detect wind, ice, fog and Clear Air Turbulence (CAT).
Despite weather radar efficiency to detect convective clouds, in-service events analysis has shown that a large part of turbulence events comes from aircraft incursions into cumulonimbus (CB) that were either not localised by the crew or not avoided with sufficient margin.
Indeed weather radar is only helpful if:

- It is properly tuned (tilt, weather mode and range control on the Navigation Display) to present an optimum weather radar picture
- AND the flight crew performs regularly vertical scan
- AND the flight crew correctly interpretes the screen display.

For this a good knowledge of the radar system itself is essential and allows to optimise the use of the radar that will be tuned using all available information (pre-flight briefing, reported turbulence, updated weather forecast…).
The official investigation launched further to a turbulence event where six cabin crew and three passengers were seriously injured concluded the following:
"It is highly probable that the flight crew were not presented with the optimum weather radar picture that would have enable a full appreciation of the intensity and extend of the weather in the vicinity of the aircraft. As the result the deviation ...was not initiated early enough nor large enough to avoid the weather"

This event is not an isolated case. The analysis of a large percentage of turbulence events in convective environment shows a sudden heading change demand just before encountering the turbulence that has made the radar tuning and picture interpretation questionable.
For example it is important to notice that a tilt setting in cruise too close from horizon (as presented in red in the figure here below) will only scan in a high range of altitude where humidity is in ice shape and so not reflective.

As illustrated with the in service event example here above there is certainly a need to increase pilot knowledge on weather radar.
This is why Airbus Flight Operations Department has issued a Briefing Note dedicated to the Optimum Use of the Weather Radar.

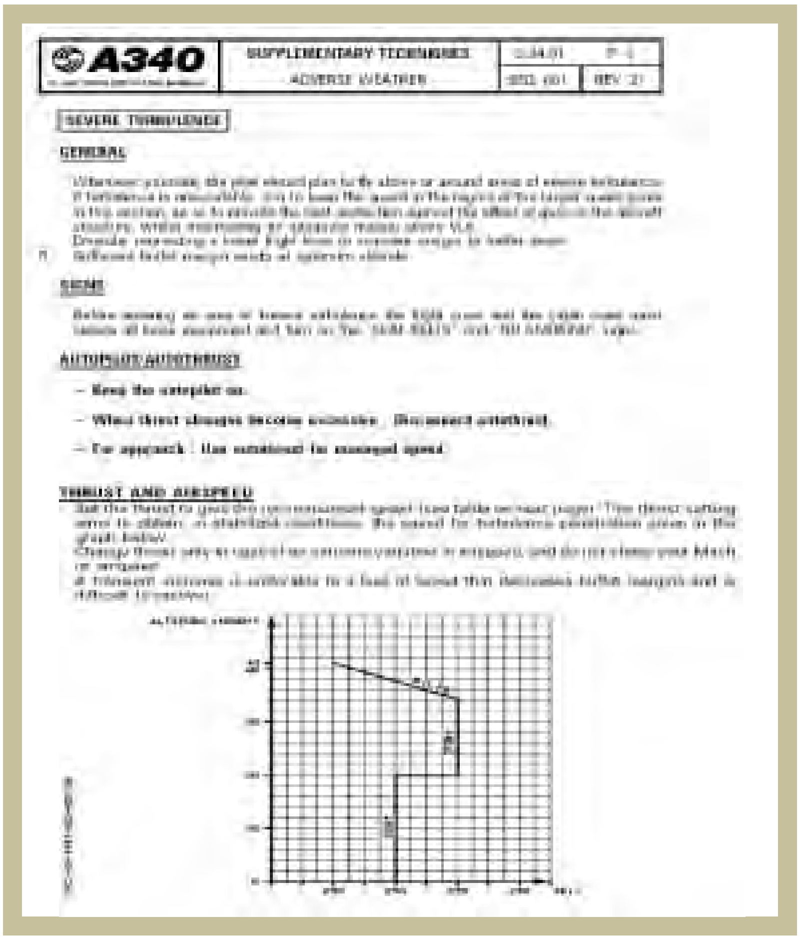
The aim of this brochure is to provide additional information about the capabilities and the limitations of the weather radar. It also presents practical information regarding the weather radar tuning and Navigation Display interpretation that can be used to improve the flight crew's overall understanding of the system.
Alike all other Flight Operations Briefing Note, the "optimum use of weather radar" Briefing Note can be downloaded from the Airbus Safety Library Website:
http:/www.airbus.com/en/corporate/ethics/safety_lib

4.2 Careful turbulence avoidance when detected

Furthermore as explained in the "optimum use of weather radar" Briefing Note and in the FCOM section 3.04.34 of Fly-by-wire aircraft (Weather radar section of the Supplementary techniques dedicated to navigation), turbulence associated with a cumulonimbus is not limited to inside the cloud.

Thus, as current weather radars cannot detect dry turbulence it is essential to take adequate precautionary measures:

- In particular, to minimise the risk of encountering severe turbulence, a cumulonimbus should be cleared by a minimum of 5000 feet vertically and 20NM laterally.
- Furthermore, if the top of cell is at or above 25000 feet, over-flying should be also avoided due to the possibility of encountering turbulence stronger than expected.
- In the same way flight under a thunderstorm should be avoided due to possible wind shears, microburst, severe turbulence or hail.



4.3 Secure passengers and cabin crew

Fasten equipment

A part of injuries comes from objects thrown out and coming down on buckled people.
Consequently a prime task of the cabin crew is to secure trolleys and any object that can be harmful.

Passengers

Most of injuries result from non-buckled passengers or crewmembers thrown out during the turbulence. This could be prevented with seat belts fastened. Although the ideal situation would be to consider "seat belts fastened" as a full-time countermeasure, the minimum recommendation, which is normally applied, consists in requiring seat belts fastened when moderate or stronger turbulence is anticipated.
In this case fasten seat belt sign should be illuminated and cabin crew should closely check passenger seatbelts compliance. But to be efficient this measure must be used with distinction since a too long or too frequent use will make it counterproductive because not strictly followed.
In the same spirit, advise announcement requiring passengers to keep their seatbelts fastened at all times when seated is also an efficient measure to prevent non-predictive turbulence as CAT.

Flight attendants

Except if this is specifically requested by the flight crew, when the seatbelt sign is illuminated, flight attendants usually continue the cabin service.
In case of specific announcement of turbulence anticipation by the flight crew, flight attendants will secure the trolleys and ensure that all passengers are fastened before sitting down and buckling up themselves. Consequently they secure themselves quite late, which explains that injuries often concern flight attendants.
Graduation in the urgency of the flight crew warning properly perceived by the cabin crew could allow them to better adapt their actions to the situation.

4.4 Turbulence crossing

Because some turbulence are not detectable by current onboard weather radar or other cannot be detected early enough to be avoided, aircraft behaviour when crossing a severe turbulence has also to be considered and optimised.
Recommendations depend on the aircraft type.

For A300/A310/A300-600: Disconnect ATHR/ Descent at or below optimum altitude /

Consider Autopilot disconnection if Autopilot does not perform as desired

- Disconnect the ATHR
- Set the target thrust to follow the speed target (that depends on altitude) given in QRH 13.04.
- Descent at or below the optimum altitude given in QRH 17.01. Indeed at the turbulence penetration target speed, this optimum altitude must provide sufficient margin to buffet to face severe turbulence.
- Consider Autopilot disconnection if Autopilot does not perform as desired.

For Fly-by-wire aircraft: Keep Autopilot engaged - Keep ATHR engaged except if thrust changes become excessive

Recent severe turbulence events have clearly illustrated that potential consequences have been minimised thanks to the appropriate use of automation by the crew, mainly in keeping Autopilot engaged instead of possible instinctive reaction, which is to take over manually.

As per FCOM recommendation (section 3.04.91) when encountering a severe turbulence the following procedure has to be applied:

- Follow the speed target (that depends on altitude) given in Section 3.04.91.
- Maintain ATHR engaged (target speed) except if thrust changes become excessive. In this case ATHR will be disconnected and thrust will be set to give the recommended speed (See thrust table versus speed target in the same FCOM section).
- Keep Autopilot engaged. Indeed, detailed studies regarding aircraft behaviour when crossing such external perturbations has shown that the less the aircraft reacts at short term to the turbulence, the better it is. Indeed, the dynamic of such severe turbulence is so, that any additional pitch down reaction to counter the initial up draught will accentuate in most cases the pitch down effect of the down draught usually subsequent to the up draught. This will accentuate the excursion in negative load factor and so increase the risk and number of injuries. To minimise the additional effect of such pitch down order coincident to the down draught, it is recommended to the crew not to react to the turbulence by short term side stick inputs corrections and to keep Autopilot engaged.

Software Flight Control modifications on Fly-by-wire aircraft

A severe turbulence may lead to excessive high speed excursion (beyond VMO/MMO) or to excessive low speed excursion (below 'alpha prot', angle of attack threshold of alpha protection law activation). This will induce Autopilot disconnection and activation of the appropriate manual flight control law (The VMO/MMO protection or the angle of attack protection that will command respectively pitch-up and pitch down movement to reduce these excursions).

In order to keep the Autopilot engaged as long as possible, flight controls software modifications have been developed on fly-by-wire aircraft. They make the Autopilot more robust to disconnection resulting from a transient VMO/MMO or 'alpha prot' exceeding subsequent to a severe turbulence.

Autopilot robustness improvement in case of transient 'alpha prot' angle of attack exceedance has been already implemented on all in-service fly-by-wire aircraft.

Autopilot robustness improvement in case of transient VMO/MMO exceedance has been introduced as shown in various flight control software.

These improvements will be also available at the entry into service of the A380.

Software including Autopilot robustness improvement in case of transient VMO/MMO exceedance

For the LR aircraft:

Standard FCPC L16/M14/P6 respectively for basic A340/A330-300/A330-200

Standard FCPC L17/M16/P7 respectively for Enhanced A340/A330-300/A330-200

Standard FCPC W10 for A340-500/-600 (under development).

For the SA aircraft:

Standard ELAC L91 and L83 for A318 and A 321

Not yet developed on A320 and A319

Managing altitude burst consequent to severe turbulence

Severe turbulence can induce significant altitude excursions because of the severe turbulence itself or as a consequence of the triggering of the VMO/MMO protection or the Angle of Attack protection. Without the pilot in the loop these protections will target respectively speed and incidence decrease rather than maintaining the trajectory.

Indeed, when VMO/MMO protection or Angle of Attack protection has been activated, the Autopilot is automatically disconnected. In these conditions, it is now to the pilot to apply smooth corrections to manage the aircraft trajectory (and to avoid to apply sudden corrections fighting the turbulence). Speed will not be closely targeted. Indeed a number of altitude bursts is the consequence of pilots targeting a large speed margin after recovery from VMO/MMO. Keeping aware of the surrounding traffic, a compromise has to be found since such too large speed margins will be obtained at the detrimental of the trajectory.

5 Areas of improvement

Benefiting of the progress of technology, several areas of improvement are being studied at Airbus in liaison with various partners such as:

Weather forecasting improvement that will make turbulence location more reliable and precise and consequently will allow optimising the route and reducing turbulence hazards.

Enhanced weather radar that will earlier detect turbulence (depending on the aircraft speed, 2 or 3 minutes is foreseen).

Turbulence now-casting that will broadcast pilot's reports of encountered turbulence to surrounding aircraft. Information regarding turbulence (intensity, location) will be sent by an automated turbulence-reporting system and displayed in other airplanes. This system will be particularly helpful to localise CAT.

Cabin safety improvement that will allow to quicker and better secure people and fasten equipment.

Clear Air Turbulence detector that will use optical technology.

6 Conclusion

Flights into severe turbulence are the leading cause of injuries among passengers and cabin crew and may induce also substantial aircraft damage.

Airbus has received a certain number of reports regarding severe turbulence events. All these events have been thoroughly analysed.

In response to these analyses the following can be said:

- Use of existing detection means to avoid encountering turbulence or to allow cabin preparation could be greatly improved.
- In this context Airbus Flight Operations Department has issued a briefing note dedicated to the Optimum Use of the Weather Radar.
- When the turbulence is unavoidable, the consequences of turbulence could be minimised in making appropriate use of operational procedures to better handle the turbulence.
- Airbus has also developed and implemented software flight control modifications on Fly-by-wire aircraft in order to improve Autopilot robustness to severe turbulence.
- Additional ways to mitigate the turbulence are under development. We will let you know when you get mature solutions.

The briefing note dedicated to the optimum use of the weather radar can be downloaded from the Airbus Safety Library website:

http:/www.airbus.com/en/corporate/ethics/safety_lib

SAFETY FIRST

The Airbus Safety Magazine
For the enhancement of safe flight through
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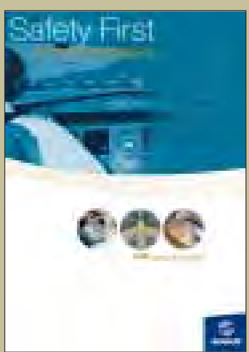

Safety First
 # 02 September 2005

Safety First is published by Airbus S.A.S
1, rond point Maurice Bellonte
31707 Blagnac Cedex / France

Editors:
Yannick Malinge,
Vice President Flight Safety
Christopher Courtenay,
Director of Flight Safety

Concept Design by
HCSGM 20050744
Production by Quat'coul

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Printed in France