INVESTIGATING EN-ROUTE TURBULENCE INJURY EVENTS

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The very serious turbulence injury event to a Boeing 777-300 whilst in the vicinity of significant convective weather on 21 May this year as it crossed over southern Myanmar en route to Singapore is of course subject to an ongoing Annex 13 Investigation which will provide the full context for what happened. At this stage, all that can be said is that the origin of the severe turbulence experienced appears to have been, as is not infrequently the case, windshear in clear air consequent on overflying convective activity rather than windshear within the definition of clear air turbulence CAT[1] and that, as usual, the injured crew and many of the passengers were not secured in their respective seats because the operating flight crew were not anticipating it. In this instance, because of the significant number of serious injuries amongst those initially hospitalised - reportedly nearly 50 - we can at least be confident that the efficacy of the flight crew turbulence risk assessment will be closely examined during the investigation and that these findings will be one of the most important aspects of its wider relevance given that many turbulence injury events occur in similar circumstances.

However, when turbulence events of similar origin resulting in far fewer serious injuries - and fewer headlines - occur, an objective assessment of this prelude to them is unfortunately not always made. Perhaps this is attributable to the fact that it is generally unsecured cabin crew who are more vulnerable to serious injury at times when passenger injuries, if any, are minor despite the apparently widespread extent of non-compliance with seat belt use instructions by a minority of passengers. It is worth noting for aircraft with a certified MTOW[2] over 5,700kg engaged in scheduled commercial operations, almost all the 35 serious injuries in the 24 serious injury turbulence events recorded by the ICAO last year were sustained by cabin crew. The picture for 2022, with allowance for the slightly lower number of flights and passengers as the recovery from the pandemic was completed, was very similar. Fortunately the longer-term history of turbulence injury events shows that those involving large numbers of serious injuries have proved to be comparatively rare.

All data sources show that the majority of turbulence injury events involve aircraft occupants who, for whatever reason, were unrestrained during a severe turbulence encounter. The important distinction is that for cabin crew this risk is firmly linked to the duties they perform and, in the case of short haul flights by narrow body aircraft, is almost guaranteed to reduce the number of cabin crew below the regulatory minimum requirement for emergency evacuation purposes. For passenger injuries, the evidence points towards the most common cause of injuries being either intentional or inadvertent non-compliance with instructions to keep them fastened or the lack of effective communication of the need to do so until insufficient time remains before the expected turbulence begins.

In the context of the Annex 13 definitions of a 'serious injury' and 'serious incident', the omission of the word 'serious' from the title of this paper perhaps invites a brief explanation:

- If any injury passes the defined 'threshold' for serious, an Accident Investigation becomes mandatory
- A Serious Incident Investigation is required in circumstances where "an accident nearly occurred", which in this case may be interpreted as only 'minor' injuries occurred.

The relevance of not overlooking minor injury events can be justified by the fact that the identified or implied causes of all turbulence injuries are invariably drawn from the same shortlist.

On a point of clarification, the "en-route" events to which this review is limited are defined as those occurring above the atmospheric surface boundary layer within which turbulence is endemic and strongly influenced by air movements and/or air temperature changes directly arising from proximity to the ground. This layer varies in thickness but does not reach anywhere near 10,000 feet agl which is increasingly becoming an industry default height above which cabin service takes place and seat belt signs are off unless the flight crew judge that there is a turbulence injury risk to unsecured passengers.

At the outset, it is important to fully appreciate the importance for both proactive risk management and effective investigation of the two origins of en-route turbulence. The nature of the first - CAT - may seem superficially obvious and but the second, turbulence of convective origin, is less so as it explicitly includes turbulence in the 'clear air' around and above convective (Cumulonimbus and Cumulus) cloud. This meteorological definition does not specify any vertical or horizontal distance from that cloud because these distances will vary according to the size and rate of development of the convective cell(s) involved. It is also evident from all recent data reviews that far more severe turbulence injury events - and probably also turbulence encounters with only minor injuries occur - are caused by convective turbulence (in clear air or not) than by CAT. Whilst aircraft operators usually have generalised guidance on the minimum distance for avoidance of clear air convective-source turbulence - typically 20 nm horizontally and 5,000 feet above - such guidance is only indicative.

Whilst there can be no visible or detectable boundary between these two forms of turbulence in clear air, the implication of the distinction for flight crew is important because when severe turbulence of either sort is anticipated, a SIGMET[3] is issued. Whilst a CAT SIGMET has obvious applicability, a Convective SIGMET, which is also explicitly relevant to the clear air turbulence risk surrounding visible convective activity, is more likely to be issued and, on the evidence of investigated turbulence injury events, for airspace where the numerical majority of such events occur. Whilst many turbulence injury events occur after entry into convective cloud was either not expected to have significant turbulent consequences or occurred unintentionally, these two explanations appear to be the overwhelming context for them.

In respect of the definition of CAT, it should also be remembered that whilst it most often occurs in relation to the windshear associated with strong jetstreams and is usually encountered above an altitude of 15,000 feet, it also now includes any en-route turbulence of orographic (mountain wave) origin. Such mountain waves are generated on the lee side of linear mountain ranges when strong and at least partially transverse upper winds cross over them. Should mountain waves occur concurrently with other CAT turbulence, very severe turbulence can be created and may justify absolute avoidance rather than merely all occupants being strapped in because of the potential for aircraft control difficulty and even airframe structural integrity risk. In this respect, it should also be appreciated that a CAT SIGMET does not specify the origin(s) of the severe turbulence risk which has been identified. And finally, for the avoidance of doubt, this subject review does not consider the en-route turbulence injury risk attributable to windshear created by flight through the wake vortex from another aircraft, which has fortunately has become a relatively rare event en-route now that both controllers and pilots have visual displays of proximate traffic.

One observation that is true of severe turbulence of any origin is that it nearly always begins without any useful prior indication with the worst invariably coming first. This means that unless the possibility has been anticipated in good time and precautionary action to ensure all occupants are secured in their seats, some injuries, possibly including serious ones, are almost inevitable. Another is that in any relatively long aircraft, it is now clear that the motion and consequent risk of injury to unsecured occupants during severe turbulence increases considerably towards the rear.

A selection of examples of investigated turbulence serious injury events which illustrate the range of circumstances in which they occur now follows.

- <u>Norway</u> May 2022 [Convective - clear of cloud]
  Cabin Service offered during a 50 minute Boeing 737 flight from Stavanger and Oslo during was conducted with the seat belt signs off and had been completed at speed because the cabin crew had been advised that the seat belt signs would be switched on a little earlier than usual because of the possibility of turbulence during the descent. Unfortunately, turbulence attributed to proximity to scattered but significant convective cells in VMC[4] occurred only four minutes into the descent at FL 170 whilst the cabin crew were clearing up and the three in the rear galley were all thrown upwards twice and all ended up lying on the floor next to two unsecured 60 kg galley carts, one overturned, which had also been sent into the air.
  <u>Observation</u>: It can be argued that cabin meal service is not really necessary on such short flights which will not infrequently be subject to significant en-route turbulence when the common short sector climb-descent flight profile is used.

- <u>French Guiana</u> December 2021 [Convective - clear of cloud]
  There was widespread convective activity during the descent of an Airbus A350-900 from FL 400 in an area and at a time of day where this was normal, the seat belts were on throughout and the cabin crew had twice been advised to temporarily suspend cabin service and secure themselves as the aircraft was navigated so as to "visually avoid the cloud cells by flying alongside the cloud masses and between cloud layers". However, at FL 100, the cabin crew had again been released in order to finalise the pre-landing post-service clear up and when turbulence re-occurred the Purser and two other cabin crew in the rear galley lost their footing and fell with the Purser sustaining a serious double

fracture injury. It was noted that the operator recommendation to avoid significant convective cells laterally by at least 20nm was ignored and that the aircraft Captain involved was very familiar with the destination.

Observation: A poor assessment by the Captain of the cabin crew turbulence injury risk to complete duties which whilst common practice were not essential and could in any case have been safely completed much earlier.

- Alaska USA December 2015 [CAT]

The flight crew of a Boeing 777-300 in the cruise at FL 330 responded to a CAT SIGMET by ensuring in good time that the seats belt signs were on and all cabin crew were secured but when the turbulence occurred, 21 unsecured passengers were injured, one of them seriously. Most had remained awake in their seats but two had been asleep and one had had left his seat to use the toilet and ignored a request not to do so.

Observation*: Checking of passenger compliance with seat belt use by cabin crew is unlikely to be wholly effective even if, as in this case, time permits.*

- France February 2015 [CAT]

Shortly after crossing the Pyrenees northbound in the cruise in night VMC at FL 380 with the cabin crew having been released to commence service, a Boeing 737 suddenly encountered severe turbulence not anticipated by the aircraft commander and two of the four cabin crew sustained serious injuries which resulted in a diversion to Bordeaux for hospitalisation. The event was attributed to inadequate lateral and vertical separation from a correctly forecast jetstream core - the aircraft was only 3nm from the boundary of the severe turbulence zone depicted on the SIGWX[5] chart and was covered by a corresponding CAT SIGMET. The Captain authorised cabin service after being told by ATC on request that there were no relevant PIREPs[6].

Observation*: Poor understanding by the Captain of how to make use of a SIGWX chart and in deriving safety assurance from the fact that there were no relevant PIREPs .*

- Montenegro February 2019 [CAT]

Whilst en-route at FL 370 in day VMC, a Boeing 737 flight crew was advised by ATC of the risk of severe CAT The cabin crew had just finished cabin service and were advised by Captain that “there was going to be turbulence in two to three minutes” without adding that it could be severe. Soon afterwards he switched on the seat belt signs and the cabin crew began to check passenger compliance. The turbulence began only about a minute after the signs had been switched on and the two cabin crew carrying out a seat belt compliance check and eight unsecured passengers sustained minor injuries. The severe turbulence had been correctly forecast and a CAT SIGMET issued but although the corresponding information had been downloaded to the First Officer’s EFB[7], it had not been accessed and in any case it was found that neither pilot was familiar with the turbulence severity colour coding system used on the app involved.

Observation: *The Training Captain in command did not ensure that available up to date weather information was used and then failed to put the seat belt signs on and ensure that the cabin crew were secured prior to the turbulence (which was a combination of mountain wave and jetstream CAT).*

- Bay of Bengal June 2014 [Convective]

Almost two hours after leaving Singapore at night on a westerly track, a Boeing 777-300 was over the Bay of Bengal level at FL 300 in an area of correctly forecast convective

weather with the seat belt signs on. When the Captain considered that there was a risk of increased turbulence, he suggested that the cabin crew should “sit down” as turbulence severity could increase “in a few minutes”. Less than two minutes later, two seconds of severe turbulence resulted in serious injuries to two cabin crew in the rear galley with three other cabin crew sustaining minor injuries. Medical advice led to a return to Singapore.
Observation: The Captain’s advice to the cabin crew was insufficiently directive and too late.

- Mozambique January 2020 [Convective]

An Airbus A380 in the cruise at FL 400 without the seat belt signs in the vicinity of quite widespread convective activity was unable to avoid entering convective cloud which had been correctly forecast to contain embedded active cells. The seat belt sign were not put on nor were the cabin crew alerted when 30 seconds of severe turbulence subsequently occurred, multiple passengers and cabin crew were lifted into the air and some impacted the ceiling or galley equipment. Only one serious injury resulted, to a passenger. The pilots were found not to have used the full capabilities of the weather radar or even noticed the eventual appearance of weather radar returns indicating that the flight would enter a severe turbulence risk area until it was too late to avoid it or ensure occupants were secured.
Observation: The Captain did not ensure appropriate use of the seat belt signs and did not ensure that proper use was made of a good weather radar.

- California USA July 2023 [Convective]

The crew of a Boeing 737 in the cruise at FL 330 with the seat belts off were attempting to visually avoid entering or overflying developing convective cells when a turn to avoid one resulted in entering another and severe turbulence occurred causing injuries to two of the four cabin crew, one serious and one minor.
Observation: A failure to recognise the risk of encountering severe turbulence and ensure the seat belts were on and the cabin crew were secured in their crew seats

- Eastern Mediterranean January 2021 [CAT]

A Boeing 777-300 descending into Haifa encountered unanticipated severe CAT 3½ minutes after beginning descent from FL 360 at which point the seat belt signs had been switched on. The flight crew made a “cabin crew take your seats” PA[8] announcement without sufficient time for them to be seated and one serious and two minor injuries to unsecured passengers and four minor injuries to cabin crew as the aircraft passed through significant windshear on the northern underside of a jetstream core. A CAT SIGMET had been issued but was unknown to the crew due to a company data processing issue not identified as representing an operational safety risk which resulted in it not being transmitted to them and the absence of any ATC alert.
Observation: The Captain had no reason to antipate severe CAT and the company SMS[9] had failed to identify format limitations in new software at their OCC[10].

Those examples will, I hope, have served to illustrate the key issues which alone or together represent the underlying origins of turbulence injury events which include:

Some points of concern, more than one of which underlies almost all serious turbulence injury events can be identified in more detail and are presented in no particular order as follows:

(1) The most up to date relevant pre-departure en-route forecast weather information did not foresee moderate and/or severe clear air turbulence or the likelihood of significant convective turbulence in the vicinity of the intended flight track.

(2) Once airborne, the flight crew were not provided with or to the extent possible did not avail themselves of the most up to date en-route forecast weather information in respect of both potential turbulence origins including relevant SIGMETs issued after the latest SIGWX forecast consulted.

(3) Once airborne, a collective and continuing review of all relevant turbulence risk information including that gained from visual observation, forecasts, ATC, other aircraft and appropriate use of the aircraft weather radar did not prompt the aircraft Captain to issue definitive precautionary instructions to the cabin crew to remain in or return to their full harness seats and/or to refrain from preparing for, commencing, continuing or clearing up after cabin service of any type and/or with sufficient time to act as instructed.

(4) An aircraft operator's actual or perceived requirement for cabin crew to check seat belt compliance other than prior to takeoff and prior to landing resulted in the onset of severe turbulence when cabin crew were still conducting such checks following advice of such a risk.

(5) Following a period in flight when severe turbulence risk has prompted an instruction to cabin crew to be secured in their seats, any decision to release them in order to continue or complete cabin service related duties was made without first conducting a further risk assessment.

(6) Frequent use of recommendations to passengers to "keep their seat belts on when seated" even when the seat belt sign is off rather than limiting announcements to audible and concise instructions to have them on when deemed necessary.

(7) The absence of a short and clearly worded announcement to passengers of the need to return to and secure themselves in their seats to a accompany selection on the seat belt signs to on (or if the signs were already on because of moderate turbulence then a strongly worded reminder).

(8) The absence of any initial and routine reminder after takeoff that if the seat belt signs are off passengers should take note when they are switched on and comply and if likely to sleep must ensure they do so with their seat belts on.

(9) The widespread policy of routinely permitting toilet use when the seat belt signs are on in moderate turbulence which has sometimes led to serious injury to both passengers and cabin crew seeking to assist them when a risk of severe turbulence is then notified without time for either to return to their seats.

(10) The failure of some flight crew to make the best possible use of increasingly effective airborne weather radar equipment to stay clear of convective turbulence in clear air if visual avoidance is insufficiently effective.

(11) The absence of a clear understanding between the flight and cabin crew - in advance or at the time it is communicated - as to who is going to make the cabin seat belt use announcement when a severe turbulence risk is identified.

(12) The absence of any standard procedure for use of seat belt sign cycling as a means for the flight crew to signal a need for all cabin crew to immediately take their seats when it is suspected that severe turbulence may be imminent and that they should immediately secure themselves before making any corresponding cabin announcement.

Whilst it is State Safety Regulators' and their approved aircraft operators who should be taking action to address the persistent issue of recurrent en-route turbulence injuries based on their origins, it is evident that many in the industry appear to agree with a Captain employed by a major airline who was quoted recently in an investigation report as observing that "unexpected turbulence is a normal operating hazard". That is of course easy to say when the operating flight crew are the only occupants guaranteed to be secured in their seats by at least the lower part of their 5 point harness.

Whilst some Regulators and airlines have recognised the need to adapt practices and procedures to try and reduced turbulence injuries, their overall effects and any safety improvement consequences of the action plan presented in the 2021 NTSB Safety Research Report 'Preventing Turbulence Related Injuries in Air Carrier Operations' have been all but invisible so far.

Annex 13 Investigation findings to date have overwhelming indicated that the origin of most turbulence injury events, especially those involving serious injury, has effectively - although often not explicitly - been that the underlying cause was either the flight crew underestimating the risk of severe turbulence either altogether or not sufficiently far in advance and/or not ensuring that appropriate and timely risk management instructions were effectively communicated to both cabin crew and passengers.

It is, I suggest, possible that the contribution which independent accident investigation can make to better management of this risk can be improved if workload allows more investigations to be done thoroughly. At present, the output of en-route turbulence injury investigations where the sum of 'serious' and 'minor' injuries is in single figures are often no more than a factual account based on crew written statements with perhaps a validation of these accounts by a quick look at the recorded flight data and the forecast and actual meteorological circumstances. However, even that is not guaranteed and even something as basic as the origin of the turbulence encountered (i.e. CAT or convective) is not always identified when this is fundamental to focussing effective attention on the source of the problem as well as on how to minimise the consequences.

So what does a really useful turbulence accident investigation look like? Here is a checklist of aspects worthy of attention and, if found, relevant space in the completed investigation report. Some are almost always already covered, but others less so:

(1) The actual meteorological circumstances which led to the turbulence which caused injury and the accuracy of the relevant meteorological forecasts and alerts issued.

(2) What relevant information on turbulence risk was available to, obtained and assessed for action or otherwise by the flight crew prior to and during the flight and how it influenced their tactical decision making.

(3) The aircraft Captain's decision making on use of the seat belt signs within or outwith the aircraft operator's applicable existing procedures for passenger alerting and compliance.

(4) The aircraft Captain's decision making and communication process in respect of relevant guidance or instructions related to turbulence risk given to the Cabin Crew.

(5) The relevant context for the event provided by an aircraft operator's SOPs[11] and their other arrangements for supporting crew turbulence risk awareness prior to and during a flight.

(6) The aircraft operator's process for reviewing whether a turbulence serious injury event warrants changes to existing procedures, training or guidance.

(7) The nature of any formal or informal proactive general passenger safety briefing given once airborne in relation to seat belt use beyond the standard reference to their use in the pre-takeoff emergency briefing.

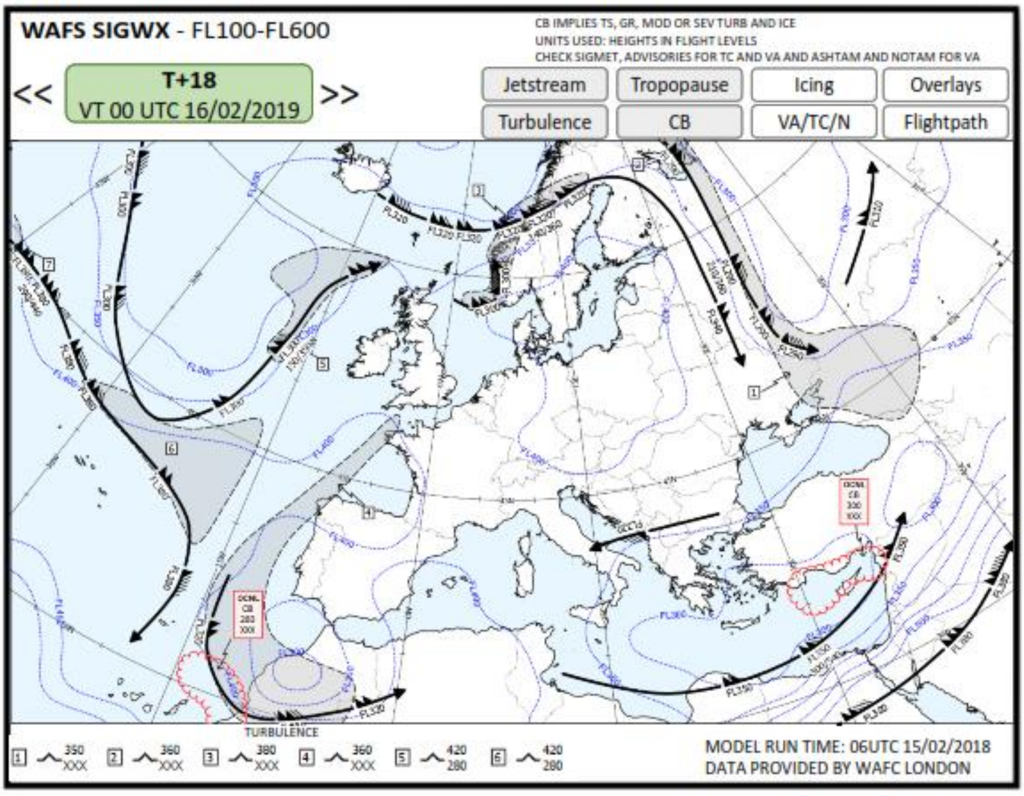
(8) Whether a physical check of passenger compliance when cabin crew are advised of a heightened turbulence risk is an aircraft operator requirement in all instances where severe turbulence has not yet occurred or is subject to discretion exercised by the senior member of cabin crew with or without guidance from the flight crew if it is considered by them that cabin crew safety may be compromised.

In respect of item (2), the rapid move already taking place from paper to digital data and the trend of operators to provide their flight crew with in-flight access to digitally presented up to date en-route weather information is a good development especially for long haul flights given the patchy performance of ATC significant weather alerting. In respect of items (3) and (4) it is extremely difficult to effectively evaluate flight crew decision making prior to an event unless the CVR[12] data are available which in practice is almost never with 2 hour CVRs. In most cases, a full and objective assessment of performance will not be an option until 25 hour CVRs appear. Only then will vital evidence of how a flight crew really handled turbulence risk management not be almost automatically overwritten.

It is of course existing good practice to support the impact of any investigation by recording any relevant safety improvement action taken by the aircraft operator and as always the opportunity exists to make generally applicable safety recommendations on the issues identified. However, in the case of turbulence injury investigations, this opportunity has been only occasionally taken up and more in-depth investigations might be able to generate recommendations which would help the wider industry to "learn from the experiences of others".

Given that severe turbulence encounters cannot be completely prevented and recognising that they are unlikely to cause airframe structural damage, the principal goal must be ensuring that the injury risk is anticipated and minimised. Whilst the costs to aircraft operators of both diversions and subsequent litigation are potentially significant, they remain relatively insignificant amidst the costs of running an airline and the industry-wide risk of serious injury events is not reducing. For any commercial air transport operator, the influences on both the procedural and tactical minimisation of serious turbulence injuries can perhaps be characterised (a) <u>the balance between safety and service</u> and (b) <u>the balance between avoidance and protection</u>. In both cases, the pendulum currently appears to be in mid position. I conclude that if investigation reports can clearly better communicate why turbulence injury events were not avoided then effective mitigation of the current level of risk becomes more likely.

Finally, to end on a positive note, next month will see the first appearance of thoroughly tested major improvements to WAFS[13] SIGWX forecasts which are to be introduced by the two WAFCs[14] (London and Washington). They have announced that they are both intending to file a difference against ICAO Annex 3 to enable earlier implementation of changes which are currently planned worldwide for November 2025. The current T+24 only fixed format analogue charts will be replaced with a new digitally-based system providing user-configurable charts spanning which will span FL100 to FL600 for T+6 to T+48 at 3 hourly intervals. An example of one of these charts configured to show Tropopause, Jetstream, Turbulence and CB[15] is shown below (note that indicated CB will continue to imply associated turbulence both within and in the vicinity).



An example of the new SIGWX Chart Format
[source: ICAO Meteorological Panel WAFS SIGWX Novembver 24 Upgrade Briefing]

[1] Clear Air Turbulence
[2] Maximum Take Off Weight
[3] Significant Meteorological Information
[4] Visual Meteorological Conditions
[5] Significant Weather
[6] Pilot Reports
[7] Electronic Flight Bag
[8] Public Address
[9] Safety Management System
[10] Operations Control Centre
[11] Standard Operating Procedures
[12] Cockpit Voice Recorder
[13] World Area Forecast System
[14] World Area Forecast Centre
[15] Cumulonimbus