Forecasting Bumpy Skies

Government weather agencies have high-tech tools for warning pilots about turbulence.

by Ed Brotak | December 19, 2022

In addition to its role as the number one cause of air carrier accidents, turbulence is the second leading cause of capacity problems in the U.S. National Airspace System (NAS).

The U.S. National Transportation Safety Board (NTSB) says that turbulence was a factor in more than a third of the 295 accidents[1] involving U.S. Federal Aviation Regulations Part 121 air carrier accidents from 2009 through 2018.[2] Most of those accidents resulted in serious injuries to at least one passenger or crewmember but no damage to the aircraft.

As for capacity issues, turbulence is second only to summertime convective storms as a cause of crowding in the NAS. Tammy Flowe, research meteorologist and acting manager of the Weather Research Branch of the U.S. Federal Aviation Administration

(FAA) Aviation Weather Division, describes the domino effect that follows a turbulence-prompted change of altitude by one aircraft.

"If one plane changes altitude to avoid turbulence, other planes following often do, too," Flowe said. "Such actions can unofficially close the altitude, possibly for hours, until another plane goes through that altitude safely. This can seriously affect traffic flow."

Turbulence is a result of eddies (circular movements) in the air and is categorized according to its source — for example, convective turbulence is caused by the uneven heating of the air along an aircraft's flight path; mechanical turbulence is caused by obstructions to the wind flow such as trees, buildings and mountains; and wind shear turbulence results from the convergence of two wind currents moving at different directions or speeds, or both.[3]

Flight crews receive information about forecasted turbulence on their routes from a variety of weather sources.

Real-time turbulence warnings are based on pilot reports (PIREPS). If pilots encounter moderate or greater turbulence, they are requested to officially file a PIREP, which should include location, altitude or range of altitudes, type of aircraft and whether the turbulence was in clouds or clear air. The pilot should also estimate the severity of the turbulence.[4]

For many years, forecasts for turbulence were only available in SIGMETs and AIRMETs. SIGMETs are used for predicted severe or extreme turbulence considered hazardous to all aircraft and not associated with convection. Convective SIGMETs cover "severe or extreme turbulence associated with thunderstorm activity." AIRMETs are issued for moderate turbulence. A problem with SIGMETs and AIRMETs is that they cover large areas (at least 3,000 sq mi [776 sq km]) and the hazard may be occurring only in a small portion of the warned area and only for a limited time.

In the United States, SIGMETs and AIRMETs are produced by aviation meteorologists of the National Weather Service at the Aviation Weather Center (AWC), based in Kansas City, Missouri, with separate offices in Alaska and Hawaii. The turbulence forecasts are basically qualitative. Meteorologists know the situations that produce turbulence: clear air turbulence (CAT) with the jet stream, downwind mountain waves with strong winds, and convective updrafts and downdrafts. If they see these situations developing, they send out an appropriate turbulence forecast product.

Nevertheless, the extent and severity of the turbulence remained problematic.

Then, in the 1990s, the FAA’s Aviation Weather Research Program began funding research at the National Centers for Atmospheric Research (NCAR) to develop a quantitative turbulence forecast system for the continental United States. The Graphical Turbulence Guidance System (GTG) was the end result, with the initial version released in March 2003. Currently, the system is in its third iteration, GTG3, with a global version of the GTG used in Europe.

The GTG starts with output from one of the most accurate numerical forecast models, the National Oceanic and Atmospheric Administration’s High-Resolution Rapid Refresh model. The GTG utilizes 10 turbulence algorithms and compares them to turbulence observations from PIREPS and AMDAR data — data collected by aircraft equipped with meteorological sensors as part of the Aircraft Meteorological Data Relay program. Forty airlines around the world participate and provide a vast amount of atmospheric data not available by other means.

The GTG uses information from the PIREPS and AMDAR data to produce a single turbulence forecast.

The numerical values generated by the GTG are the eddy dissipation rate (EDR), described as a “state of the atmosphere turbulence metric.” It is physically related to how fast eddies in the atmosphere dissipate. The more turbulent the atmosphere, the faster eddies dissipate. The EDR can then be used as a measure of atmospheric turbulence and, in fact, is the International Civil Aviation Organization standard for aviation turbulence. Actual EDR values range from 0 (calm) to 1 (extreme turbulence for all aircraft). For ease of interpretation, EDR values are multiplied by 100.The calculated EDR value is independent of aircraft size.

Initially, the GTG produces numerical turbulence data for the same grid points as the numerical weather prediction model being used. The turbulence data is then interpolated and given for vertical levels (1,000 ft above sea level to Flight Level 450 [about 45,000 ft] by 2,000-ft increments and by maximum turbulence found at any level). The information also is converted to map form, encompassing southern Canada, the lower 48 states, northern Mexico, and adjacent ocean waters.

The GTG system calculates separately the turbulence induced by mountain waves and CAT produced by self-induced circulations in the atmosphere. EDR values are adjusted for aircraft size (light, medium or heavy) and then color-coded by intensity level. The time frames covered are current to three hours by one-hour increments and out to 18 hours by three-hour increments. Also shown are PIREP turbulence reports. The GTG product is available on the AWC website.

Flowe says, “The GTG is a strategic product,” meaning it can be used for route planning to avoid areas of turbulence. But as Flowe notes, “Turbulence is a transitory phenomena, and we needed something more real-time for tactical use by flight crews in flight to determine where to go to deviate or change altitude to avoid turbulence. And for safety, they need to know when to turn the seat belt sign on and off.”

Pilots en route need current, accurate depictions of turbulence not possible with the GTG which doesn’t include real-time information.

“We (at NCAR) created the GTG Nowcast (GTGN). It takes the GTG one-hour forecast, and we update it with actual observations every 15 minutes, including PIREPS, aircraft-based observations, and information derived from NEXRAD [Next Generation Weather Radar] radar system,” says Flowe.

More than 1,000 aircraft in the United States are outfitted with a system that uses on-board sensors to determine *in situ* EDR “to calculate a measure of the atmospheric turbulence that an aircraft is transiting,” Flowe explains. As of Sept. 10, 2021, those aircraft were reporting an average of more than 68,000 measurements a day, according to FAA officials. The NEXRAD WSR-88D radar sets can detect air motion. The NEXRAD Turbulence Detection Algorithm can convert these readings to EDR readings within clouds.

According to Flowe, “This gives us a real-time turbulence forecast for pilots to use in the cockpit. If you look at GTGN output head of you, you can determine if you need to change altitude.” The GTGN has been approved by the FAA, and although not operational yet, prototype gridded GTGN output is available at NCAR to anyone through a license agreement.

Officials at Delta Airlines recognized the benefits of the GTG, provided that the information could be relayed quickly to pilots.

“In 2008, Delta Airlines approached us with a proposal to do a collaborative effort to see if this data could be used in the cockpit,” remembers Flowe.

According to Matt Eckstein, technical pilot – EFB Applications, Delta Airlines, “In 2015, GTG data became available to pilots using Delta’s Flight Weather Viewer app.” This gave pilots access to real-time graphics of turbulence observations and forecasts while in flight.

Flowe says, “The Weather Technology in the Cockpit (WTIC) program was the source for the initial prototyping of GTGN in the cockpit via tablets through a partnership with Delta Air Lines.”

Eckstein says that, with GTGN data only available in the raw, gridded format, they “took the numbers and converted them to colors: green, yellow, red for different turbulence levels. Since the GTGN data is independent of aircraft type, and, in reality, it is aircraft-dependent, this past year, we transitioned to fleet-dependent depiction by converting EDR values to color-coded turbulence values relevant to type of aircraft.” Basically, Delta converts GTGN data into the standard GTG format and display.

Delta pilots immediately saw the advantages of having turbulence information readily available to them en route, with some calling it a “game changer.” Eckstein says, “By looking at the displays, pilots can decide to secure cabin or avoid the turbulence.”

He also noted that “GTGN is good at identifying areas of smooth flying, channels of green on the display. Pilots can use recent flight observations to find or verify these and don’t have to “chase altitudes” to find smooth flying conditions.” He says that Delta has converted to “a single iPad application which displays current GTGN to be used in flight, future GTG products for destination forecasts, and the Global GTG for flights outside of the U.S.”

One complaint about GTGN data, Eckstein says, is that “Delta pilots have noted that the GTGN tends to over-forecast turbulence severity.”

In response, Flowe says that this may be due to how the EDR values are handled. “The way things are configured in GTGN now [is] arguably the worst case. We do have a safety-first attitude. If we under-forecasted, we might miss an event that could cause an accident. It’s a difficult balance.”

Looking ahead, the next version of the GTG, the GTG4, is already being developed and is projected to be available in 2023. A reduced horizontal grid spacing, down to 3 km (1.6 nm), will make the GTG4 even more accurate. Also, a convectively induced turbulence diagnostic (CIT) is being developed in addition to the mountain wave and CAT components currently available. Current plans are for the GTGN to be fully operational and available at the AWC website for fiscal year 2024–2025, and it will have the same elements as the GTG.

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Edward Brotak, Ph.D., retired in 2007 after 25 years as a professor and program director in the Department of Atmospheric Sciences at the University of North Carolina, Asheville.

Notes

1. *The NTSB defines an accident as "an occurrence associated with the operations of an aircraft in which any person suffers death or serious injury or in which the aircraft receives substantial damage."*
2. *NTSB. Safety Research Report NTSB/SS-21/01, "Preventing Turbulence-Related Injuries in Air Carrier Operations Conducted Under Title 14, Code of Federal Regulations Part 121." Aug. 10, 2021.*
3. *FAA. Advisory Circular 00-6B, "Aviation Weather." Aug. 23, 2016.*
4. *The degree of turbulence is broken down into the four standard categories: light, moderate, severe and extreme. Donald Eick, senior meteorologist in the NTSB Operational Factors Division's Office of Aviation Safety, adds, "An important note is that turbulence doesn't have to be severe to cause injuries. For many of the cases we are getting, the flight crew reported it as moderate." The 2021 NTSB study indicated that in turbulence accidents, 44.1 percent involved what was reported as severe turbulence, and 41.4 percent involved moderate turbulence.*