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by David E. Rapoport* and Matthew S. Sims**

> *A thunderstorm is a deadly cocktail with all the nasty ingredients required for a fatality, and any one of those ingredients can take you out of the sky.*[1]
>
> –Joe Casey, CFI[2]

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1 Joe Casey, *Pilot Confessions: Caught in a Nighttime Thunderstorm*, Twin & Turbine, Oct. 2022, at 4, https://www.twinandturbine.com/pilot-confessions-caught-in-a-nighttime-thunderstorm/.

2 Joe Casey's qualifications go far beyond being a mere CFI. He is an FAA-DPE and an ATP, CFI, CFII (A/H), MEI, CFIG, CFIH, as well as a retired U.S. Army UH-60 standardization instructor/examiner. An active

Introduction

Approximately one-third of air carrier accidents in the United States are weather-related.[3] Thunderstorm penetrations and flights close to thunderstorms cause many of them.[4] According to the U.S. Federal Aviation Administration (FAA), "avoiding thunderstorms is the best policy."[5]

Respecting the distance to keep away from thunderstorms in flight, the FAA advises pilots to:

> Avoid by at least 20 mi any thunderstorm identified as severe or giving an intense, heavy, or extreme radar echo. This is especially true under the anvil of a large cumulonimbus. Such echoes should be separated by at least 40 mi before flying between echoes. Separation distances may be reduced for avoiding weaker echoes.[6]

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instructor in the PA-46 and King Air markets, he has accumulated 14,300-plus hours of flight time, with more than 5,200 dual – given as a flight instructor. *Id.*

3 FAA/ASIAS, Weather-related Aviation Accident Study 2003–2007, at 37, § 4.3.1 (2010) (determining from observational data collected over a five-year period that 33.9 percent of air carrier accidents were weather-related).

4 *E.g.*, FAA, Aeronautical Information Manual §§ 7-1-26 & 7-1-27 (Sept. 5, 2024), https://www.faa.gov/air_traffic/publications/atpubs/aim_html/chap4_section_4.html [hereinafter AIM]. *See also* Appendix A for a table containing an illustrative listing of these accidents.

5 *Id.* § 7-1-27(a). Of course, in rare instances intentionally penetrating thunderstorms can be a part of the mission. For example, it is part of the job of a NOAA Hurricane Hunter "to fly specially equipped aircraft directly into the eye of the storm to collect crucial data that helps protects [sic] lives and property." Nat'l Weather Serv., *Flying through the Eye of the Storm: NOAA Hurricane Hunters*, https://www.weather.gov/wrn/hurricane_hunter (last visited Sept. 20, 2024). In contrast, there is no analogous "mission" in air carrier operations that could justify thunderstorm penetration or flight close to a thunderstorm.

6 FAA, Aviation Weather Handbook*,* FAA-H-8083-28, § 22.8.2(14) (Thunderstorm Avoidance Guidance) (2022) [hereinafter Aviation Weather Handbook]. A thunderstorm is "identified as severe" by the National Weather Service if it "create[s] at least one of the following: Hail that is one (1) inch in diameter or larger [or] Winds of 58 miles per hour (mph) or greater." Nat'l Weather Serv., *What Constitutes a Severe Thunderstorm?*, https://www.weather.gov/bmx/outreach_svr (last visited Sept. 20, 2024). Air traffic control classifies radar echoes as "heavy" if they show 40 to 50 dBZ of reflectivity, and "extreme" if over 50 dBZ of reflectivity. FAA, Pilot/Controller Glossary P-3 (Precipitation Radar Weather Descriptions) (Mar. 21, 2024), https://www.faa.gov/air_traffic/publications/

For "less severe storms," presumably those with weaker echoes than "intense, heavy or extreme," the FAA recommends "about 10 miles" of separation.[7]

The well-known hazards of flying into or near a thunderstorm are "low ceiling and visibility, lightning, adverse winds, downbursts, turbulence, icing, hail, rapid altimeter changes, static electricity, tornadoes, and engine water ingestion."[8]

Summing up, the FAA cogently concludes:

> Thunderstorms are barriers to air traffic because they are usually too tall to fly over, too dangerous to fly through or under, and can be difficult to circumnavigate. Weather recognizable as a thunderstorm should be considered hazardous, as *penetration of any thunderstorm can lead to an aircraft accident* and fatalities to those on board.[9]

With thunderstorm avoidance "guidance" coming from our nation's aviation regulator, close encounters with thunderstorms by any aircraft *should* be rare, especially in air carrier line operations.[10] Sadly though, they are not. Both aviation data and aviation accident

media/PCG_Chg_2_dtd_3-21-24.pdf [hereinafter Pilot/Controller Glossary]. The 40-50 dBZ "heavy" reflectivity level generally correlates with painting yellow on a color radar screen, while over 50 dBZ "extreme" painting red and bends toward purple as it goes into the 60s. Nat'l Oceanic & Atmospheric Admin., *Radar Images: Reflectivity* (Aug. 11, 2023), https://www.noaa.gov/jetstream/reflectivity. It is unclear what level of radar reflectivity the FAA has in mind in currently using the term "intense" in this context. At one time the National Weather Service may have used "intense" to refer to VIP level 5 storms with radar reflectivity of 50 to 57 dBZ. *Compare* Nolan Atkins, *dB Scale for the Reflectivity Field* (2015), https://apollo.nvu.vsc.edu/classes/remote/lecture_notes/radar/conventional/dbscale.html (stating that VIP level 5 "precipitation intensity" is "intense"), *with National Weather Service Glossary*, https://forecast.weather.gov/glossary.php?letter=v (last visited Oct. 2, 2024) (stating VIP level 5 involves "very heavy rain; hail possible").

7 AIM, *supra* note 4, § 7-1-26(b). The term "less severe storms" is not defined, but in context it may refer to storms ATC categorizes as "moderate reflectivity" ranging from 26 to 40 dBZ. Pilot/Controller Glossary, *supra* note 6, at P-3. However, reflectivity in the 26 to 40 dBZ range generally paints green. Nat'l Oceanic & Atmospheric Admin., *supra* note 6.

8 Aviation Weather Handbook, *supra* note 6, § 22.7.

9 *Id.* § 22.1 (emphasis added).

10 The FAA is not the sole source of guidance. For example, thunderstorm avoidance criteria are typically found in an air carrier's FAA-approved manuals and pilot training materials. *See, e.g.*, 14 C.F.R. §§ 121.133 & 121.141.

histories reviewed here reveal thunderstorm penetrations and flights too close to thunderstorms are regularly occurring in air carrier line operations. This has been a recurring problem for years, sometimes with tragic consequences, and other times without injury or property damage. Regarding the former, data is readily available. At the present time, not much data illuminates how often air carriers penetrate or nearly penetrate thunderstorms without injury or property damage. At least two studies, however, touch upon this issue and the findings are not reassuring.

In a published study by scientists from MIT's Lincoln Laboratory[11] who audited flight track data on storm days near the Dallas Fort Worth International Airport, this alarming conclusion was reached:

> The vast majority of encounters near the airport in this study resulted in penetrations. Pilots penetrated storms with precipitation intensities of NWS level 3, 4, and 5. Finally, arriving aircraft in this data set were more likely to penetrate storms when they were following another aircraft, more than 15 minutes behind where they ought to be based on the nominal flying time scheduled for the trip, or when they were flying after dark.[12]

In a follow-up study by the same MIT authors using different storm days near Memphis, the data again showed that most thunderstorm encounters near the airport resulted in penetrations

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11 D.A. Rhoda & M.L. Pawlak, An Assessment of Thunderstorm Penetrations and Deviations by Commercial Aircraft in the Terminal Area, NASA/A-2 (1999) (unclassified), https://archive.ll.mit.edu/mission/aviation/publications/publication-files/nasa-reports/Rhoda_1999_NASA-A2_WW-10087.pdf. This audit study used data from the Dallas-Fort Worth airspace on storm days that was sponsored by NASA's Ames Research Center and performed by MIT's Lincoln Laboratory under contract with the U.S. Air Force.

12 *Id.* at iii (abstract). The reference to NWS levels 3, 4, and 5 and correlation of these levels with radar reflectivity levels is shown in Figure 3 on page 7 of the paper. NWS level 3 at the time the paper was written correlated with 41 to 46 dBZ of radar reflectivity, which would appear as yellow on airborne radar. NWS level 4 correlated with 46 to 50 dBZ of radar reflectivity, which would appear yellow/red on airborne radar. NWS level 5 correlated with 50 to 57 dBZ of radar reflectivity, which would paint red on airborne radar. NWS level 6 correlated with greater than 57 dBZ of radar reflectivity, which would paint magenta on airborne radar.

despite the danger of this practice.[13] Though proportionately fewer, this study also revealed there were enroute thunderstorm penetrations and flights close to thunderstorms by air carriers, though enroute such encounters are easiest to avoid.[14]

This legal and empirical assessment begins by presenting two categories of additional data: 1) the grim history of commercial aviation accidents caused by flying into or close to thunderstorms; and 2) the legal principles governing the questions assessed. With this additional data and the results of the MIT aircraft tracking audits on storm days on the table, these critical questions are assessed: 1) Why are thunderstorm penetrations and near-penetrations still regularly happening in air carrier operations?; and 2) What can be done to prevent thunderstorm penetrations and near-penetrations in the future?

A. *Commercial Aviation Accidents Due to Flying Into, Under or in Proximity to Thunderstorms*

The history of aviation accidents[15] caused or contributed to by flying into or near thunderstorms begins with the dawn of aviation and continues through the present time. Appendix A lists illustrative air carrier accidents caused by flying into or too close to thunderstorms over the years.[16] In this section, we highlight three categories of information to help explain later why the risks have been with us for such a long time, what progress has been made,

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13 Dale A. Rhoda, et. al, *Commercial Aircraft Encounters with Thunderstorms in the Memphis Terminal Airspace*, 9 Am. Meteorological Soc'y Conf. on Aviation, Range & Aerospace Meteorology § 2.4 (2000), https://archive.ll.mit.edu/mission/aviation/publications/publication-files/ms-papers/Rhoda_2000_ARAM_MS-14106_WW-10188.pdf.

14 Dale A. Rhoda, et. al, *Aircraft Encounters with Thunderstorms in Enroute vs. Terminal Airspace Above Memphis, Tennessee*, 10 Am. Meteorological Soc'y Conf. on Aviation, Range & Aerospace Meteorology § 5.13 (2002), https://archive.ll.mit.edu/mission/aviation/publications/publication-files/ms-papers/Rhoda_2002_ARAM_MS-15308_WW-16138.pdf.

15 For clarity, the focus is on "accidents" which, by definition, caused death, injuries, or property damage. Nevertheless, that a flight through a thunderstorm is completed without death, injuries, or property damage does not mean it doesn't matter; because the decisions involved could very well have caused a catastrophe.

16 The listed accidents alone have caused 1,390 deaths and a minimum of 309 injuries. The worldwide death and injury toll for all thunderstorm-related aviation accidents is much higher. No recent total has, to the best of our knowledge, been published.

and what work lies ahead: 1) early crash investigations focusing in part on air carrier thunderstorm avoidance criteria; 2) select microburst windshear crashes; and 3) avoidable convective turbulence accident statistics and example cases.

1. ***Early Cases Focusing on Thunderstorm Avoidance Criteria***

a. The Crash of American Airlines Flight 63

On July 28, 1943, American Airlines Flight 63, a DC-3 in scheduled passenger service, crashed near Trammel, Kentucky.[17] The Civil Aeronautics Board (CAB) ruled the probable cause of the crash was "[l]oss of control of the aircraft due to unusually severe turbulence and violent downdraft caused by a thunderstorm of unknown and unpredictable intensity."[18] The four-member crew and 16 of the 18 passengers perished in the crash, while two surviving passengers, both pilots themselves, "escaped with serious injuries."[19] Tragically, "most of the occupants of the cabin were victims of suffocation or fire, or both, because of their inability to effect an exit from the aircraft."[20]

At the CAB public hearing on the crash, American Airlines' Chief Pilot testified about the airline's thunderstorm avoidance criteria. The CAB summarized this testimony:

> When asked if there had been any fixed company policy so far as pilots were concerned with regard to thunderstorm areas, he stated that the policy was to "avoid them . . . . as a safety factor and for passenger comfort." When queried as to whether or not they were prevented from going through thunderstorm areas provided they could find a spot that seemed reasonably safe, he answered, "No, they are not prevented. We give instructions to them in this

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17 Civil Aeronautics Bd., Aircraft Accident Report: American Airlines, Inc., Douglas DC-3, Near Trammel, Kentucky, July 28, 1943, File No. 3525-43, Dkt. No. SA-82 (Apr. 22, 1944), https://asn.flightsafety.org/reports/1943/19430728_DC3_NC16014.pdf.

18 *Id.* at 15. Four of the five corrective actions related to cabin survivability issues in air crashes, while the fifth called for more research on thunderstorm dynamics. *Id.* at 15–16.

19 *Id.* at 1.

20 *Id.* finding #12.

> manner, in the form of bulletins, in the form of personal contacts with the pilots. We discuss thunder activity in pilot meetings and general discussions regarding thunderstorm activity and thunderstorm flying." He stated in effect that the company does not forbid pilots to go through thunderstorms and that they did so at their own discretion.[21]

With a somewhat different point of view, one of the surviving passengers, a U.S. Army Air Force pilot with 16 years and over 5,000 hours of piloting experience, testified that he personally "always avoided flying through thunderstorms and, in fact, had never done so."[22] Perhaps because of this pilot's testimony, the CAB concluded in part that "flight through a thunderstorm *should* be avoided."[23]

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21 *Id.* at 8. One of the documents American Airlines' Chief Pilot introduced into evidence was a memorandum distributed to all pilots from American's Assistant Operations Manager in Charge of Flying months before the crash, which stated:

> Again, we want to caution Flight Officers, whenever possible, not to conduct flights through thunderstorm activity which appears to be severe in intensity. There can be no set rules to determine when such conditions do exist. However, good judgment and forethought on the part of Flight Officers will generally prevent flying through severe turbulence.

Id. at 8.

22 *Id.* at 4–5.

23 *Id.* at 15 (emphasis added). In the same passage, the CAB mentioned flights "in a thunderstorm area may not be hazardous." However, the CAB did not explain how large a "thunderstorm area" is or how anyone could determine which "thunderstorm areas" are safe to fly in and which are hazardous. Instead, four out of five corrective actions had nothing whatsoever to do with avoiding thunderstorms. The fifth only indirectly bore on avoidance, stating:

> The Board believes that there is a need for more information on the dynamics of thunderstorms and more accurate methods of forecasting severe developments. The Board has discussed the possibility of such research with the United States Weather Bureau and the National Advisory Committee for Aeronautics, and ways and means of its accomplishment are now being planned by those organizations.

Id. at 16, Rec. #5. A central question was thus perceived from the start: Should thunderstorm penetration be forbidden by the airlines (or the government)? The testifying Air Force pilot who never penetrates thunderstorms would surely have answered this question "yes," whereas *sub silencio* the CAB seems to have called for study.

b. The Crash of Delta Air Lines Flight 318

On May 17, 1953, 19 people lost their lives in the crash of Delta Airlines Flight 318, scheduled DC-3 service from Dallas, Texas to Shreveport, Louisiana.[24] After penetrating a thunderstorm, Flight 318 crashed near Marshall, Texas.[25] The CAB found that a "very intense localized thunderstorm, accompanied by frequent cloud-to-ground lightning, hail, heavy rain, turbulence, and high winds, was entered by the flight."[26] The CAB decided that:

> [T]he probable cause of this accident was (l) the encountering of conditions in a severe thunderstorm that resulted in loss of effective control of the aircraft, and (2) the failure of the captain to adhere to company directives requiring the avoidance of thunderstorms when conditions would allow such action.[27]

Unlike American Airlines' deferential thunderstorm policy in effect at the time of the Flight 63 crash, Delta's policy ten years later was clearer and more restrictive: "It is the policy of Delta Air Lines to circumnavigate thunderstorms insofar as practicable."[28] Using this standard and the facts known to the pilot in command, in the Flight 318 case the CAB concluded "there appears to be no logical reason why Captain Volk did not alter his course to avoid the storm, inasmuch as company instructions required him to bypass thunderstorms when practicable."[29]

2. *Select Microburst Wind Shear Cases*

a. Background

In the 1970s, University of Chicago Theoretical Meteorology Professor Ted Fujita and his team first posited that "microburst

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24 Civil Aeronautics Bd., Accident Investigation Report: Delta Air Lines, Inc. – Near Marshall, Texas, May 17, 1953, File No. 1-0030, Dkt. No. SA-278 (Dec. 31, 1953).

25 *Id.*

26 *Id.* at 6, finding #7.

27 *Id.* at 6–7.

28 *Id.* at 4.

29 *Id.* at 5. This is an early example of an airline nearly prohibiting thunderstorm penetrations and flights close to thunderstorms in its operations manual.

wind shear has caused or contributed to a significant number of aviation accidents."[30] John McCarthy, a retired meteorological scientist who was affiliated with the National Center for Atmospheric Research,[31] and who played a central part in validating and researching microbursts after Professor Fujita[32] first discovered them, recently reminisced:

> The microburst story begins with the unexplained crashes of commercial airliners in the 1960s and subsequent investigations . . . . The NTSB findings regarding the causes of several crashes were inconclusive, but suggested that hazardous weather played a role. Professor Tetsuya (Ted) Fujita, a scientist at the University of Chicago was closely following these studies. He hypothesized that the crashes could be caused by thunderstorm wind shears of a scale and intensity not yet observed by the scientific community (Fujita 1976; Wilson and Wakimoto 2001). Prior to his discovery, there had been a long history of aircraft encounters with sudden downdraft events during approach and departure that resulted in aircraft handling problems and, in some cases, crashes. After detailed analysis of the 1975 Eastern Air Lines (EAL) 66 accident (Fujita 1976), Fujita hypothesized that a low-altitude wind shear, not yet observed or understood, might have been the cause of the crash. He termed the phenomenon a "downburst." Later, he named small-scale

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30 John McCarthy, et al, *Addressing the Microburst Threat to Aviation: Research-to-Operation Success Story*, 103 Bull. Am. Meteorology Soc'y E2845, E2845 (abstract) (2022), https://journals.ametsoc.org/view/journals/bams/103/12/BAMS-D-22-0038.1.xml. *See also* Mike Smith, Warnings: The True Story of How Science Tamed the Weather 151 (ch. 13) (2010).

31 John McCarthy, LinkedIn, https://www.linkedin.com/in/john-mccarthy-685527135/ (last visited Sept. 20, 2024).

32 The late Professor Fujita was also well known for originally developing the "F-Scale," which was used to estimate tornado wind speeds based on damage left behind by a tornado, until it was replaced by the "Enhanced Fujita (EF) Scale," "developed by a forum of nationally renowned meteorologists and wind engineers, [which] makes improvements to the original F scale." *See* Nat'l Weather Serv., *Enhanced Fujita Scale*, https://www.weather.gov/tae/ef_scale#:~:text=The%20Fujita%20(F)%20Scale%20was,to%20the%20original%20F%20scale (last visited Sept. 20, 2024).

> downbursts with a diameter ≤ 4 km "microbursts." This was the scale most dangerous to commercial aircraft.[33]

In a seminal study published by Professor Fujita and his colleagues in 1985, "the lethal accidents of four microburst-entrapped aircraft" were each shown to involve microburst encounters.[34]

What follows is a brief chronological discussion of some of the air carrier microburst windshear crashes. Modern history reveals the disastrous microburst windshear accident pattern continues notwithstanding historic changes that have improved, but not eliminated, this tragic accident category.

b. The Crash of Eastern Air Lines Flight 66

On June 24, 1975, Eastern Air Lines Flight 66, a Boeing 727-22 aircraft, "crashed into the approach lights to runway 22L" at New York's JFK airport, while "on an ILS approach to the runway through a very strong thunderstorm that was located astride the ILS localizer course. Of the 124 persons aboard, 113 died of injuries received in the crash. The aircraft was destroyed by impact and fire."[35]

The National Transportation Safety Board (NTSB) determined that:

> [T]he probable cause of this accident was the aircraft's encounter with adverse winds associated with a very strong thunderstorm located astride the ILS localizer course, which resulted in a high descent rate into the nonfrangible approach light towers. The flightcrew's delayed recognition and correction of the high descent rate were probably associated with their reliance upon visual cues rather

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33 McCarthy, *supra* note 30, at E2846.

34 *Id.* at E2848. These four accidents were Pan American World Airways Flight 806 on January 30, 1974 (at Pago Pago, American Samoa); Eastern Air Lines Flight 66 on June 24, 1975 (at John F. Kennedy Airport in New York City); Pan American World Airways Flight 759 on July 9, 1982 (at Kenner, Louisiana, near the New Orleans Airport); and Delta Air Lines Flight 191 on August 2, 1985 (at the Dallas Ft. Worth Airport in Texas).

35 NTSB, Aircraft Accident Report: Eastern Airlines, Inc. Boeing 727-225, N8845E, John F. Kennedy International Airport, Jamaica, New York, June 24, 1975, NTSB/AAR-76/8, at 1 (synopsis) (Mar. 12, 1976) [hereinafter NTSB/AAR-76/8].

> than on flight instrument references. However, the adverse winds might have been too severe for a successful approach and landing even had they relied upon and responded rapidly to the indications of the flight instruments.
>
> Contributing to the accident was the continued use of runway 22L when it should have become evident to both air traffic control personnel and the flightcrew that a severe weather hazard existed along the approach path.[36]

In the "Analysis" section of the NTSB Report, the Board explained "two causal aspects of this accident require discussion and analysis: (1) The weather hazards that existed along the approach path to runway 22L and how they affected Eastern 66, and (2) the reason or reasons why approach operations to runway 22L were continued even though the thunderstorms along the final approach course were evident and hazardous wind conditions had been reported."[37]

Analyzing the first issue, the Board concluded:

> [A]n approach which places an airplane in or near a thunderstorm at low altitude is hazardous. The wind conditions which might exist can place the airplane in a position from which recovery is impossible--even if both the pilot and the airplane perform perfectly. The number of recent approach and landing accidents which have been caused by the airplane's passage through or near localized thunderstorm cells indicates that *many pilots and air traffic controllers do not have the proper appreciation for the hazards involved*.[38]

Analyzing the second issue, the Safety Board concluded:

> [T]he accident involving Eastern 66 and the near accident involving Flying Tiger 161 and Eastern 902 were the results of an underestimation of the significance of relatively severe and dynamic weather conditions in a high-density terminal area by all parties involved in the movement of air traffic in the

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36 *Id.* at 1–2.
37 *Id.* at 26.
38 *Id.* at 32 (emphasis added).

> airspace system. . . . *All parts of the system must recognize the serious hazards that are associated with thunderstorms in terminal areas.* A better means of providing pilots with more timely weather information must be designed.[39]

Importantly, Professor Fujita and his collaborators concluded Eastern Flight 66 "first encountered microburst head winds at an altitude of approximately ~500 ft AGL while on descent for landing, followed by the downdraft at 400 ft AGL. The aircraft crashed 2,400 ft short of the runway, killing 113 people and injuring 11."[40]

The Safety Board presciently commented the "accident involving Eastern 66 *and the near accidents involving Flying Tiger 161 and Eastern 902* [virtually the same time as Eastern 66, in the same storm and near the same microburst] were the results of an underestimation of the significance of relatively severe and dynamic weather conditions *in a high-density terminal area by all parties involved in the movement of air traffic in the airspace system.*"[41]

c. *The Crash of Pan Am Flight 759*

On July 9, 1982, Pan Am Flight 759, a Boeing 727-235 aircraft, crashed at the New Orleans International Airport in Kenner, Louisiana shortly after take-off from runway 10. The NTSB determined "that the probable cause of the accident was the airplane's encounter during the liftoff and the initial climb phase of flight with a microburst-induced wind shear which imposed a downdraft and a decreasing headwind, the effects of which the pilot would have had difficulty recognizing and reacting to in time for the aircraft's descent to be arrested before its impact with the trees."[42] The NTSB also found that contributing to the accident "was the limited capability of current ground based low level wind shear detection technology to provide definitive guidance for controllers and pilots for use in avoiding low level wind shear encounters."[43]

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39 *Id.* at 35 (emphasis added).
40 McCarthy, *supra* note 30, at E2848.
41 NTSB/AAR-76/8, *supra* note 35, at 35 (emphasis added).
42 NTSB, Aircraft Accident Report: Pan American World Airways, Inc. Clipper 759 Boeing 727-235, N4737, New Orleans International Airport, Kenner, Louisiana, July 9, 1982, NTSB/AAR-83/02, at. ii (abstract) (1983) [hereinafter NTSB/AAR-83/02].
43 *Id.*

Professor Fujita, who also investigated the crash, found that Flight 759 "encountered the microburst while on take-off, first experiencing the head winds while on rollout, followed by the downdraft once airborne. The aircraft stalled at 163 ft AGL, began descending, and hit trees before crashing and killing 152 people and injuring 9. Eight of the fatalities were killed on the ground."[44]

With respect to other aircraft near runway 10 in the minutes before and after Flight 759 began its takeoff roll:

- Approximately one minute before the takeoff roll began, Eastern Flight 956 was cleared to land on runway 10, and it accepted that clearance;[45]
- Approximately 51 seconds before the takeoff roll began the local controller responded to Eastern Flight 956's request for winds, stating: "And ah Eastern the wind zero seven zero one seven heavy DC eight er ah heavy Boeing just landed said a ten-knot windshear at about 100 feet on the final."[46]
- Approximately 15 seconds before the takeoff roll began USAir Flight 404, behind Flight 759, announced it was "ready to go whenever Pan Am is ready to go."[47]

Had the crash not occurred, it seems likely the pilots of the aircraft landing and taking off on runway 10 around that time would have carried on, and ATC would have cleared them to do so, despite the thunderstorm on the airport that was also impacting their intended routes of flight.

d. President Reagan's Near-Miss

On August 1, 2013, the *Washington Post*'s Jason Samenow reported:

> Thirty years ago today, a violent blast of cold air crashed down from a thunderstorm's clouds above Andrews Air Force Base. As the so-called

44 McCarthy, *supra* note 30, at E2848.
45 NTSB/AAR-83/02, *supra* note 42, app. D (Cockpit Voice Recorder Transcript, at 2107:02).
46 *Id.* at 2107:08.
47 *Id.* at 2107:44.

> microburst slammed into the ground and fanned out in all directions, the wind speed was clocked at 149 mph (at the time, the highest-ever measured wind speed by an anemometer).
>
> Just six minutes before this wind gust was measured, Air Force One had landed at Andrews, with President Ronald Reagan aboard. His timing was extraordinarily fortunate.
>
> "The pilot was aware of storms in the area, but apparently no warning had been issued of possible wind shear – sudden reversals of wind direction," describes a 1984 account from the New York Times. "The plane landed on a dry runway and was parked before the microburst struck."[48]

e. The Crash of Delta Flight 191

On August 2, 1985, Delta Flight 191, a Lockheed L-1011-385-1 aircraft crashed while approaching to land on runway 17L at the Dallas Fort Worth International Airport, Texas:

> While passing through the rain shaft beneath a thunderstorm, flight 191 entered a microburst which the pilot was unable to traverse successfully. The airplane struck the ground about 6,300 feet north of the approach end of runway 17L, hit a car on a highway north of the runway killing the driver, struck two water tanks on the airport, and broke apart. Except for a section of the airplane containing the aft fuselage and empennage, the remainder of the airplane disintegrated during the impact sequence, and a severe fire erupted during the impact sequence. Of the 163 persons aboard, 134 passengers and crewmembers were killed; 26 passengers and 3 cabin attendants survived.

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48 Jason Samenow, *Ronald Reagan's Near Brush with Weather-Induced Death: The August 1, 1983 Microburst*, WashingtonPost.com (Aug. 1, 2013, 4:39 PM), https://www.washingtonpost.com/news/capital-weather-gang/wp/2013/08/01/ronald-reagans-near-brush-with-weather-induced-death-the-august-1-1983-microburst/.

> The National Transportation Safety Board determines that the probable causes of the accident were the flightcrew's decision to initiate and continue the approach into a cumulonimbus cloud which they observed to contain visible lightning; the lack of specific guidelines, procedures, and training for avoiding and escaping from low-altitude wind shear; and the lack of definitive, real-time wind shear hazard information. This resulted in the aircraft's encounter at low altitude with a microburst-induced, severe wind shear from a rapidly developing thunderstorm located on the final approach course.[49]

The Safety Board, clearly aware of the pattern revealed in the Eastern 66 and Pan Am 759 cases, included a section in the factual portion of their final report titled "Flightcrews Landing at or Departing DFW Airport."[50] The Safety Board dedicated 4.5 pages of the report to this topic, to which the reader is referred. The section concludes with this:

> The flightcrew of one Boeing 737 did use its weather radar to examine the storm shortly before the accident. The airplane had its Bendix model RDR-4A color weather radar on and was facing north on the outer taxiway at the intersection with cross taxiway 21B. After seeing the storm, the first officer selected the 20-nmi range setting, and used full antenna tilt–from 0° to +15°–to examine the storm. The captain said that the storm cell, based on an earlier visual observation, was the easternmost cell in a "short line" of two to four medium-sized cells oriented along an east-west line. When viewed on the airplane's radar the storm cell was about 4 miles from their position. He said the cell was "3 to 5 miles thick and about 4 miles long." The first officer said that the southern edge of the cell was about 5 miles from their position. "The size of the cell was about that of a silver dollar on the radar screen, the

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49 NTSB, Aircraft Accident Report: Delta Air Lines, Inc., Lockheed L-1011-385-1, N726DA, Dallas/Fort Worth International Airport, Texas, August 2, 1985, NTSB/AAR-86/05, at 1 (synopsis) (1986).

50 *Id.* at 18.

> intensity was depicted by complete red, [and] there were no transitional colors at the edge of the cell, just solid red."[51]

With the controversy over the existence of microburst windshear in the rear-view mirror by the time the probable cause finding in the Pan Am Kenner crash was issued, incredible coordinated work by the United States government and private industry led to many innovations.[52] One of them was the development and dissemination of the Windshear Training Aid,[53] with its dual yet sometimes conflicting emphasis on thunderstorm avoidance and windshear escape maneuvers.

f. The Crash of USAir Flight 1016

On July 2, 1994, USAir Flight 1016, a DC-9-31 aircraft, crashed while attempting to break off their final approach to Charlotte Douglas International Airport. The aircraft "collided with trees and a private residence . . . after the flightcrew executed a missed approach from the instrument landing system approach to runway 18R. The captain, first officer, one flight attendant, and one passenger received minor injuries. Two flight attendants and 14 passengers sustained serious injuries. The remaining 37 passengers received fatal injuries. The airplane was destroyed by impact forces and a postcrash fire."[54]

The NTSB determined "that the probable causes of the accident were: 1) the flightcrew's decision to continue an approach into severe convective activity that was conducive to a microburst; 2) the flightcrew's failure to recognize a windshear situation in a timely manner; 3) the flightcrew's failure to establish and maintain the proper airplane attitude and thrust setting necessary to escape the

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51 *Id.* at 22.

52 Much has been written about this topic, which goes beyond the scope of this article. *See generally* NTSB, Flight into Terrain During Missed Approach, USAir Flight 1016, DC-9-31, N954VJ, Charlotte Douglas International Airport, Charlotte, North Carolina, July 2, 1994, NTSB/AAR-95/03, at 80–87, § 1.18.6 (1995) [hereinafter NTSB/AAR-95/03].

53 D. Alexander Stratton & Robert F. Stengel, *Probabilistic Reasoning for Intelligent Wind Shear Avoidance*, 15 J. Guidance, Control & Dynamics 247, 248–49 (1992), https://stengel.mycpanel.princeton.edu/StrattonJGCDProb1992.pdf.

54 NTSB/AAR-95/03, *supra* note 52, at vi (exec. summary).

windshear; and 4) the lack of real-time adverse weather and windshear hazard information dissemination from air traffic control, all of which led to an encounter with and failure to escape from a microburst-induced windshear that was produced by a rapidly developing thunderstorm located at the approach end of runway 18R."[55]

The NTSB determined the contributing factors "to the accident were: 1) the lack of air traffic control procedures that would have required the controller to display and issue airport surveillance radar (ASR-9) weather information to the pilots of flight 1016; 2) the Charlotte tower supervisor's failure to properly advise and ensure that all controllers were aware of and reporting the reduction in visibility and the runway visual range value information, and the low level windshear alerts that had occurred in multiple quadrants; 3) the inadequate remedial actions by USAir to ensure adherence to standard operating procedures; and 4) the inadequate software logic in the airplane's windshear warning system that did not provide an alert upon entry into the windshear."[56]

At the civil trial, the pilot in command of Flight 1016 testified he thought the thunderstorm was not over the airport or on their flight path at all; that it was, instead, located south of the airport. The pilots and USAir vehemently argued at the trial that the local air traffic controller speaking with Flight 1016 should have warned the pilots about the presence of the thunderstorm on the airport and over their final approach path. After a six-week jury trial, however, the jury voted unanimously to reject USAir's claim that negligence by the air traffic controller was the *sole* proximate cause of the disaster (after the United States admitted the air traffic controller was negligent and his negligence was "a" cause of the crash), finding negligence by USAir's pilots was also a proximate cause of the crash.

After the verdict, the foreman of the jury gave a newspaper reporter an interview explaining in part some of the conclusions of the jury:

> "We feel for the families, but we hope in some ways what we've done will help the airline industry set some kind of standards to change the way pilots are trained to fly in and out of thunderstorms," said

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55 *Id.*
56 *Id.*

> jury foreman Bill Wilkins. "We hope nothing like this will ever happen again." Wilkens said he paid special attention to testimony from witnesses at the airport who saw the storm. "We felt like, if the witnesses on the ground could see that, the pilots could see it."[57]

The "Microburst Windshear Probability Guidelines"[58] that USAir used to train its pilots were introduced into evidence at the trial and are accessible online.[59] Related to these guidelines is Appendix B, an analysis called "USAir-Crew Decisions" that was prepared by the plaintiffs' pilot expert and admitted into evidence at the Flight 1016 trial.[60] The "USAir-Crew Decisions" analysis evaluates the decisions of fourteen USAir pilots on seven different aircraft that were under the same thunderstorm within a few minutes before and after the time Flight 1016 crashed. The analysis documents that all seven flights had a "high" probability of windshear using USAir's tool for determining this.[61]

Two of the seven sets of pilots confronted with a high probability of wind shear did the right thing, choosing to delay by holding on the ground instead of accepting a take-off clearance in a thunderstorm. The other five sets of pilots all violated the company guidance: one landed in a thunderstorm two minutes before the crash; one took off with a microburst on the field one minute before the crash; Flight 1016 attempted to land in a thunderstorm, initiated a go-around after getting caught in microburst windshear and crashed; one took off with a microburst on the field one minute after the crash; and the last one would have landed three minutes

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57 Lisa Greene, *Jurors Hope Airlines Got the Message*, The State, Mar. 18, 1997, at B5.

58 NTSB/AAR-95/03, *supra* note 52, at 56–57.

59 Flight 1016 Plaintiffs' Trial Exhibit 43a (repeating verbatim Fed. Aviation Admin., Advisory Circular 00-54, Pilot Windshear Guide app. 1, at 36–37 (1988), https://www.faa.gov/documentLibrary/media/Advisory_Circular/AC00-54.pdf [hereinafter AC00-54]).

60 A reproduction of Plaintiff's Trial Exhibit 148 admitted into evidence at the civil trial in the Flight 1016 case, in a black and white format, is attached as Appendix B. Color highlighting of this exhibit was used at trial, with blue for listed cues which, if they were the only cue, showed a "low" probability of windshear, yellow for "medium" probability unaccompanied cues, and red for a cue that alone established a "high" probability of windshear. Red was also used to reflect a "high" probability of windshear overall.

61 AC00-54, *supra* note 59, at 37 (When there is a "high" probability using the guidelines, "[c]ritical attention need be given to this observation. A decision to avoid (e.g. divert or delay) is appropriate.").

after the crash, but ATC cancelled that flight's clearance to land because of the crash.

There is no evidence any of the ten pilots that did not follow the Microburst Windshear Probability Guidelines and company procedure on July 2, 1994, were either disciplined by USAir or subjected to certificate action by the FAA.

g. *The Crash of Georgian Airways Flight 834*

On April 4, 2011, Georgian Airways Flight 834, a Bombardier CRJ-100ER aircraft flying a charter flight for the United Nations, crashed while trying to land in a thunderstorm at Kinshasa International Airport in the Democratic Republic of the Congo.[62] Thirty-two of the 33 people on board lost their lives, making this crash the United Nations' all-time deadliest aviation disaster.[63]

According to the investigation by the DRC's Permanent Office of Investigations of Aviation Accidents/Incidents:

> The most probable cause of the accident was the aircraft's encounter with a severe Microburst like weather phenomenon at a very low altitude during the process of Go Around. The severe vertical gust/downdraft caused a significant and sudden pitch change to the aircraft which resulted in a considerable loss of height. Being at very low altitude, recovery from such a disturbance was not possible.[64]

The Permanent Office of Investigations of Aviation Accidents/Incidents listed six "probable contributing factors":

> 1. The inappropriate decision of the crew to continue the approach, in face of extremely inclement weather being displayed on their weather radar, was probably the principle contributing factor responsible for the accident.

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62 [Final] Investigation Report of Accident Involving Georgian Airways Aircraft CRJ-100ER (4L-GAE) at Kinshasa's N'DJILI Airport, Democratic Republic Of Congo (DRC) on 04 April 2011, at 5, https://skybrary.aero/sites/default/files/bookshelf/2946.pdf [hereinafter DRC Final Report].

63 *Id. See also Georgian Airways Flight 834*, Wikipedia, https://en.wikipedia.org/wiki/Georgian_Airways_Flight_834 (last visited Sept. 20, 2024).

64 DRC Final Report, *supra* note 62, at 38.

> 2. Lack of adequate supervision by the Operator to ensure that its crew complied with established procedures including weather avoidance procedures and Stabilized Approach criteria, was a probable contributing factor.
>
> 3. Inadequacy of Georgian Airways Training program for upgrade to Captain was a probable contributing Factor.
>
> 4. Lack of effective oversight of Georgian Airways by Georgian CAA was a probable contributing factor.
>
> 5. Lack of appropriate equipment at Kinshasa airport for identification and tracking of adverse weather phenomenon, resulting in failure by ATC to provide appropriate early warning to the aircraft, was probably a contributing factor.
>
> 6. ATC not declaring the airfield closed when visibility dropped below Minima was a probable contributory factor.[65]

h. The Crash of Bhoja Flight 213

On April 20, 2012, at approximately 14:40 UTC, Bhoja Air Flight 213, a Boeing 737-236A aircraft, crashed approximately four nautical miles from the approach end of runway 30 at Islamabad.[66] "The reported weather at Islamabad was thunderstorm with gusty winds. . . . [A]ll 127 souls onboard (121 passengers + 6 flight crew) had sustained fatal injuries along with complete destruction of [the] aircraft."[67] The Pakistani investigation team, supported by the NTSB and Boeing, determined that between 14:00 and 15:00 UTC on the day of the crash, "the severe updrafts and downdrafts (microburst) were the main feature of [the] weather" around the airport.[68]

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65 *Id.*

66 Civil Aviation Auth. Pakistan, Final Report: Aircraft Accident Investigation Into M/s Bhoja Air Flight BHO-213, Boeing 737-236A, Reg # AP-BKC Crashed on 20th April, 2012 Near Bbiap, Islamabad 1, 23, https://caapakistan.com.pk/Upload/SIBReports/SIB-350.pdf.

67 *Id.* at 1.

68 *Id.* at 53, § 2.4.13.

The investigation team concluded, *inter alia*, that these factors caused the crash:

> 4.1.1 The aircraft accident took place as a result of combination of various factors which directly and indirectly contributed towards the causation of accident. The primary causes of accident include, ineffective management of the basic flight parameters such as airspeed, altitude, descent rate attitude, as well as thrust management. The contributory factors include the crew's decision to continue the flight through significant changing winds associated with the prevailing weather conditions and the lack of experience of the crew to the airplane's automated flight deck.
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> . . . .
>
> 4.1.3 The incorrect decision to continue for the destination and not diverting to the alternate aerodrome despite the presence of squall line and very small gaps observed by the Captain between the active weather cells is also considered a contributory factor in causation of the accident.
>
> 4.1.4 The operator's Ops Manual (CAA Pakistan approved) clearly states to avoid active weather cells by 5 to 10 nm which was violated by the cockpit crew is also considered a contributory factor in causation of the accident.
>
> . . . .
>
> 4.1.8 None of the cockpit crew member[s] challenged the decision of each other to continue for the destination despite violation of Ops Manual instructions which is against the essence of CRM training.
>
> 4.1.9 After experiencing the extremely adverse weather conditions, the cockpit crew neither knew nor carried out the Boeing recommended QRH and FCOM / Ops Manual procedures to handle the abnormal set of conditions / situations due to non availability of customized Boeing documents for Boeing 737-236A (advanced version of Boeing 737-200 series).[69]

[69] *Id.* at 74–76, § 4.

i. The Crash of Aeroméxico Connect Flight 2431

Aeroméxico Connect Flight 2431 was a "flight bound for Mexico City that crashed on takeoff from Durango International Airport on July 31, 2018. Shortly after becoming airborne, the plane encountered sudden wind shear caused by a microburst. The plane rapidly lost speed and altitude and impacted the runway, detaching the engines and skidding to a halt about 1,000 feet (300 m) beyond the runway. The plane caught fire and was destroyed. All 103 people on board survived, but 39 passengers and crew members were injured."[70]

In the final report on the crash, Mexico's investigation board found:

> [T]he primary cause of the accident was adverse weather conditions encountered by the flight, and contributing factors included crew error, air traffic controller error, and the lack of equipment that could detect wind shear conditions at airports. Investigators determined that an unauthorized student pilot in the cockpit who was flying the plane during the take-off caused the crew to be distracted, leading to a loss of situational awareness. The crew failed to react to dangerous weather conditions that were developing, and did not notice irregularities in the airspeed indicators that could have alerted them to potential hazards. The sole air traffic controller on duty at the airport at the time also failed to notify the aircraft of rapidly deteriorating weather conditions.[71]

3. *Avoidable Convective Turbulence Statistics and Examples*

"From 2009 through 2018, the National Transportation Safety Board (NTSB) found that turbulence-related accidents accounted for more than a third of all Part 121 accidents; most of these

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70 *Aeroméxico Connect Flight 2431*, WIKIPEDIA, https://en.wikipedia.org/wiki/Aerom%C3%A9xico_Connect_Flight_2431 (last visited Sept. 20, 2024) (citing and relying on the final investigation report dated February 23, 2019, by Mexico's Dirección General de Aeronáutica Civil Dirección de Análisis de Accidentes e Incidentes de Aviación Comisión Investigadora y Dictaminadora de Accidentes e Incidentes de Aviación, accessible in Spanish at https://reports.aviation-safety.net/2018/20180731-0_E190_XA-GAL.pdf.).

71 *Id.*

accidents resulted in one or more serious injuries but no aircraft damage."[72] From 2009 to 2023, the NTSB reported there were 184 injuries from serious turbulence encounters suffered in Part 121 operations.[73]

The form of turbulence associated with thunderstorms is "convective" turbulence,[74] which the NTSB found "was present in 57.7% (64 of 111) of all turbulence-related Part 121 accidents from 2009 through 2018 . . . ."[75]

Convective turbulence encounters are events "in the immediate proximity of strong radar reflectivities and/or visible indication[s] of cumulonimbus or cumulus congestus type clouds in the immediate vicinity of the aircraft, even if it was being overflown,"[76] according to the NTSB.

In a study of data showing whether pilots were aware of the risk of a turbulence encounter before it happened in a series of documented turbulence accidents, the NTSB found pilots were *most often aware of the risk*:

> The NTSB analyzed investigation materials for evidence that flight crews were aware of the risk of encountering turbulence on accident flights, such as holding a preflight briefing, mentioning a weather report, hearing reports from ATC, seeing convective weather on radar, or experiencing light turbulence/chop. As shown . . . , in 53.2% of turbulence-related Part 121 accidents from 2009 through 2018 (59 of 111), the flight crew was aware of the risk of encountering turbulence before the accident occurred. In 29.7% of the accidents (33 of 111), the flight crew was not aware, and in the remaining accidents, flight crew awareness was unknown or not reported.[77]

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72 NTSB, Safety Research Report: Preventing Turbulence-Related Injuries in Air Carrier Operations Conducted Under Title 14 Code of Federal Regulations Part 121, NTSB/SS-21/01, PB2021-100927, at xii & 1 (exec. summary) (2021).

73 FAA, *Turbulence: Staying Safe* (Aug. 27, 2024), https://www.faa.gov/travelers/fly_safe/turbulence.

74 NTSB, *supra* note 72, at 17.

75 *Id.* at 16.

76 *Id.* at 16, n.26.

77 *Id.* at 20.

As an update, a current search of the NTSB Aviation Investigation database covering the last year, using the search term "thunderstorm" and limited to Part 121 operations, reveals three events. Two of them involved "serious" injuries and were categorized as "accidents."[78] Both involved thunderstorm penetration and flight too close to thunderstorms. The third case, which did not involve personal injuries, was categorized as an "incident" and, in any event, did not involve penetration or near-penetration of a thunderstorm.[79]

While the investigations in the two thunderstorm penetration cases remain open, the NTSB has made the essential facts for each available in preliminary reports and these facts are summarized here:

a. United Airlines Flight 1890 on February 10, 2024

On February 10, 2024, United Airlines Flight 1890, a Boeing 777, "experienced moderate turbulence when descending to flight level (FL) 190 inbound to the Newark Liberty International Airport (EWR) . . . ."[80] With 280 passengers and crew aboard, "two flight attendants received serious injuries and one received a minor injury."[81]

> The pilots reported that while descending through about FL210 in instrument meteorological conditions (IMC), the flight encountered moderate turbulence lasting a few seconds that caused unsecured items on the flightdeck to be thrown about. After the event, the captain immediately called the cabin crew and was informed of multiple injuries with one flight attendant sustaining a head laceration. Upon being notified of the injuries, the flight crew declared a medical emergency and requested paramedics

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78 These involved United Airlines Flight 1890 on February 10, 2024 and Southwest Airlines Flight 4273 on April 3, 2024. Both cases are discussed in detail *infra*.

79 NTSB, Aviation Investigation Preliminary Report, Incident No. DCA24LA206, https://data.ntsb.gov/carol-repgen/api/Aviation/ReportMain/GenerateNewestReport/194423/pdf (last visited Sept. 20, 2024).

80 NTSB, Aviation Investigation Preliminary Report, Accident No. DCA24LA097, at 1, https://data.ntsb.gov/carol-repgen/api/Aviation/ReportMain/GenerateNewestReport/193784/pdf (last visited Sept. 20, 2024).

81 *Id.*

> meet the aircraft at the gate in EWR. Post-flight, two FA's were diagnosed with fracture injuries and a third was diagnosed with a sub-cranial bleed.
>
> Postaccident examination of the weather in the area revealed a frontal boundary moving eastward across New York state. In addition, an upper-level jet stream maximum was located above the accident site. Satellite and weather radar imagery, along with lightning and surface data depicted strong cells in the vicinity of the flight. The U.S National Weather Service (NWS) had issued current Significant Meteorological (SIGMET) warning for embedded thunderstorms with tops reaching FL280 over the region.[82]

The NTSB noted in its preliminary report that "[d]ata from the digital flight data recorder (DFDR) and the cockpit voice recorder (CVR) were sent to the NTSB's Vehicle Recorder Laboratory in Washington, DC, for analysis."[83]

b. Southwest Airlines Flight 4273 on April 3, 2024

On April 3, 2024, Southwest Airlines Flight 4273, a Boeing 737-7CT, "experienced turbulence while enroute between Louis Armstrong New Orleans International Airport (MSY), New Orleans, Louisiana and Orlando International Airport (MCO), Orlando, Florida. Of the five crew and 140 passengers onboard, one flight attendant and one passenger sustained serious injuries, and one flight attendant sustained minor injuries."[84]

"The day of the accident, a major cold front was traversing the southeastern United States. The squall line of rapidly developing thunderstorms associated with the front extended south several hundred miles into the Gulf of Mexico. A convective Significant

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82 *Id.* at 2.

83 *Id.*

84 NTSB, AVIATION INVESTIGATION PRELIMINARY REPORT, Accident No. DCA24FA143, at 1, https://data.ntsb.gov/carol-repgen/api/Aviation/ReportMain/GenerateNewestReport/194028/pdf (last visited Sept. 20, 2024). However, interviews with passengers aboard this flight reveal that the injury toll is greater than what the NTSB has reported.

Meteorological Information (SIGMET) was issued at 1155 UTC for the area, warning pilots of cloud tops above 45,000 ft."[85]

The NTSB included in the preliminary report, as "Figure 1," two weather radar images with the aircraft track and location overlayed at the time of the turbulence encounter.[86] These images show that the squall line ended only a few miles west of where the pilots chose to penetrate it instead, at 37,000 feet. In other words, the squall line could easily have been completely avoided to the west. Why this was not planned before departure is not explained and hard to fathom. The report states:

> As the aircraft climbed to altitude, the aircraft encountered occasional chop. They leveled the aircraft at flight level (FL) 370, above the weather system with the tops of the clouds at FL340 – FL350. . . . About 40 minutes into the flight and approaching the REMIS waypoint, the flight began to encounter light turbulence and the crew began deviations around cells before waypoint ROZZI. The visibility was intermittent instrument meteorological conditions (IMC) and marginal visual meteorological conditions (VMC) with occasional light chop. As they returned to their route to REMIS, the visibility improved and they visually acquired a rapidly developing cloud top that was on their flight path, but not painting on the onboard radar. The captain made a passenger announcement to ensure those in the cabin were seated and then contacted air traffic control (ATC) to request the deviation. The first officer (FO) began a right turn to avoid the cell, however, was not able to complete the turn in time and entered the cloud buildup. They encountered severe turbulence that lasted about 10 seconds that resulted in fluctuations up to 30° of bank, 20 knots airspeed, and 200 ft of altitude. Moderate turbulence followed for about 1 minute. According to flight data, vertical acceleration ranged from -0.45 gravitational force equivalent (g) to +1.8g during the turbulence encounter.[87]

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85 *Id.*
86 *Id.* at 2.
87 *Id.* at 2–3.

c. American Eagle (Envoy) Flight 3960 on December 16, 2019

On December 16, 2019, American Eagle (Envoy) Flight 3960, an Embraer EMB140, "encountered severe turbulence during cruise flight" while enroute to Gainesville, Florida. One passenger was severely injured.[88]

> According to the flight crew, as the flight was cruising at flight level (FL) 370 in visual meteorological conditions, they could see convective activity ahead. . . . As the flight approached the weather, the first officer (FO), who was the pilot flying, began to maneuver around several cells visually. The airplane radar did not show any returns. Upon entering visible moisture, moderate rain and turbulence began immediately but increased rapidly in intensity. Airspeed and altitude began fluctuating rapidly and upon receiving an over speed warning, the FO retarded the thrust levers to idle and deployed the speed brakes. Large fluctuations in vertical speed continued to occur and the autopilot automatically disengaged simultaneously with stick shaker activation. EICAS displayed AUTOPILOT FAIL and YAW DAMPER FAIL. Shortly after, the FO returned the airplane to a normal flight condition and returned to FL 370.
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> . . . .
>
> Post accident examination of the weather data determined that the flight encountered convectively induced turbulence after penetrating cumulonimbus clouds, with tops near FL400, while attempting to overfly a large area of known convection. In the area of the encounter, Weather Surveillance Radar depicted extreme echoes at lower altitudes with lighter echoes at the airplane's altitude, with lightning in the vicinity. The National Weather Service (NWS) Convective Outlook had warned of a moderate risk of severe thunderstorms over the area. In

88 NTSB, Aviation Accident Investigation Final Report, Accident No. DCA20CA038, at 1 (2021).

> addition, there was a NWS tornado watch and a Convective SIGMET current for severe embedded thunderstorms in the area.
>
> The National Transportation Safety Board determines the probable cause of this accident to be: an encounter with convectively induced turbulence while overflying an area of known convective activity.[89]

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[89] *Id.* at 1–2. Attachment 6 to the NTSB Operational Factors Group Chair Report from the American Eagle (Envoy Airlines) investigation was placed in the public docket and consists of selected excerpts from Envoy Airlines' Flight Manual, Weather Section, in effect on December 16, 2019. This can be downloaded at https://data.ntsb.gov/Docket/Document/docBLOB?ID=10067828&FileExtension=pdf&FileName=Attachment%206%20-%20Flight%20Operations%20Manual%20%5BExcerpt%5D-Rel.pdf [hereinafter Attachment 6]. Sections 2.6 (Airborne Radar Usage), 2.7 (Radar Procedure), and 7.1 (Thunderstorms General) are found at pages 29–30, 30–31, and 35. Of particular significance to this paper are these provisions of Envoy Airlines' Flight Manual:

- "When thunderstorm activity is anticipated the Captain shall, after a thorough review of the weather reports and forecasts, plan his flight so as to avoid the storm areas or permit their circumnavigation with airborne and ground radar."
- "No approach will be continued, or departure initiated, when thunderstorms are located on the approach course or takeoff path of the aircraft, or over the airport of intended landing or takeoff."
- "The primary purpose of our airborne radar equipment is fixing the position of thunderstorm cells so that these areas of turbulence, and possible hail, may be avoided. In avoiding thunderstorm cells the following cell clearance rules shall be observed."
- "When operating below 20,000 feet aircraft may be flown through an area where radar echoes indicate a weak rainfall gradient, if such action dictates that this is the best course to follow."
- "Above 20,000 feet weak rainfall gradient areas should be avoided by 20 miles."
- "Areas where echoes indicate a steep rainfall gradient should be avoided by 20 miles at all altitudes."
- "Echoes that are rapidly changing in size, shape or intensity, and those having prominent scallops, hooks, fingers or other protrusions should be treated with concern and the above distance should be increased accordingly."
- "Hail damage and turbulence can be expected anytime an aircraft is flown too close to thunderstorms. Observe the clearance criteria set forth in the previous paragraphs. The most characteristic hail "patterns" are hooks or scallops protruding from the main thunderstorm echo."
- "When flying above echoes that are rapidly changing or those having prominent protrusions, maintain a minimum of 5,000 feet vertical separation."

B. *The Relevant Legal Principles*

The key players involved in efforts to avoid thunderstorms in air carrier operations are pilots, dispatchers, air traffic controllers, and weather specialists.[90] In the United States, the FAA is the agency responsible for regulating all of them.[91]

Overarchingly, under federal law, "the duty of an air carrier [is] to provide service with the highest possible degree of safety in the public interest;"[92] and the duties and responsibilities of air traffic controllers and government weather professionals are set forth in the manuals of the FAA.[93]

While federal law clearly provides the regulatory and enforcement regime for air carrier operations and ATC in the United States, it is most often state law that governs civil claims for relief brought by those suffering legal harm due to the negligence of pilots, dispatchers, air traffic controllers, weather specialists, and those involved in training and supervising any of them.[94]

The legal duties of airlines under the law of most U.S. states bears some similarity to the federal duty. Under the law of most states, if not all of them, airlines are subject to a "common carrier"

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90 *See, e.g.*, *In re* Air Crash at Dallas/Ft. Worth Airport, 720 F. Supp. 1258, 1268–91 (N.D. Tex. 1989), *aff'd*, 919 F.2d 1079 (5th Cir. 1991).

91 According to the *Federal Register*, the Federal Aviation Administration "was established by the Federal Aviation Act of 1958 (72 Stat. 731). . . . The mission of the FAA is to regulate civil aviation and U.S. commercial space transportation, maintain and operate air traffic control and navigation systems for both civil and military aircrafts, and develop and administer programs relating to aviation safety and the National Airspace System." Fed. Reg., *Federal Aviation Administration*, https://www.federalregister.gov/agencies/federal-aviation-administration#:~:text=The%20mission%20of%20the%20FAA,and%20the%20National%20Airspace%20System (last visited Sept. 20, 2024).

92 49 U.S.C. §§ 44701(d)(1)(A), 44702(b)(1)(A).

93 *See, e.g.*, *In re Air Crash at Dallas/Ft. Worth Airport*, 720 F. Supp. at 1288–89.

94 *E.g.*, *In re* Mexico City Aircrash, 708 F.2d 400, 404–08 (9th Cir. 1983); Wells v. UPS Airlines, 688 F. Supp. 3d 567, 572–74 (W.D. Ky. 2023). When an airline is sued, the actions are typically brought under state law. *Id.* When the United States is sued over the conduct of air traffic controllers or weather specialists, the claims are brought under a federal statute, the Federal Tort Claims Act. *See* Michael D. Contino & Andreas Kuersten, Cong. Res. Serv., R45732, The Federal Tort Claims Act (FTCA): A Legal Overview (2023), https://crsreports.congress.gov/product/pdf/R/R45732. However, this statute relies on state law, not federal law, to set the standard of care. *Id.* Of course, whether the defendant is an airline, the government, or both, state law may well borrow a standard of conduct supplied by federal law to trigger a state law remedy. *Id.*

standard of care. For example, in a civil case against an air carrier that was brought under Massachusetts law, the court described a prototypical common carrier standard of care under state law:

> Under Massachusetts law "[a] common carrier 'is required to exercise the utmost care consistent with the nature and extent of its business to carry its passengers to their destination in security and enable them to alight there with safety'" (citation omitted). Once a special relationship is imposed by law, the scope of the duty owed is a function of the foreseeability of the given harm (citations omitted). "[T]he carrier is not an insurer of the safety of its passengers, nor is it obliged by law to foresee and to guard against unlikely dangers and improbable harms" (citations omitted).
>
> "In deciding the [duty] question, [the court will] take into account social conditions and contemporary public policy concerns" (citation omitted). "A pre-condition to this duty is, of course, that the risk of harm to another be recognizable or foreseeable to the actor" (citations omitted).[95]

While the FAA's Federal Aviation Regulations (FARs) are extensive,[96] they only indirectly deal with thunderstorm avoidance in air carrier operations.[97] Importantly, for pilots, dispatchers, air

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95 Bower v. El-Nady, 847 F. Supp. 2d 266, 276–77 (D. Mass. 2012). *See also* Restatement (Second) of Torts § 314A(1)(a) ("A common carrier is under a duty to its passengers to take reasonable action . . . to protect them against unreasonable risk of physical harm . . . ."), and comment d to this section, stating in part:

> The duty to protect the other against unreasonable risk of harm extends to risks arising out of the actor's own conduct, or the condition of his land or chattels. It extends also to risks arising from forces of nature or animals, or from the acts of third persons, whether they be innocent, negligent, intentional, or even criminal (citation omitted). It extends also to risks arising from pure accident, or from the negligence of the plaintiff himself, as where a passenger is about to fall off a train, or has fallen.

96 14 C.F.R. §§ 1.1–198.17.

97 *See* 14 C.F.R. §§ 121.101; 121.135(b)(15); 121.357; 121.419(a)(1)(iii); 121.419(a)(2)(VI)(C); 121.601(b); 121.601(c). The FARs governing air carrier operations only mention thunderstorms when addressing air carriers' obligations to provide their crews with weather reporting services and training in meteorology; to provide manuals covering weather and other

traffic controllers, and weather specialists, the FARs have neither a thunderstorm avoidance rule, nor a rule setting the minimum safe separation distances from thunderstorms under varying circumstances.

What the FAA offers instead is guidance,[98] along with review and approval of the operational and aircraft-specific manuals each airline is required to maintain. Air carriers routinely claim these manuals are confidential.[99] Nevertheless, the thunderstorm avoidance criteria used by some airlines at some points in time *are* in the public domain, most commonly through NTSB investigations and/or civil litigation. These manuals do not uniformly address thunderstorm avoidance.[100]

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topics; to provide aircraft "equipped with working up to date airborne radar equipment"; and for dispatchers to provide pilots before beginning a flight and during a flight with "all available weather reports [or additional information enroute] and forecasts of weather phenomena that may affect the safety of flight, including adverse weather phenomena, such as clear air turbulence, thunderstorms, and low altitude wind shear . . . ."

98 *See, e.g.*, *supra* notes 4–9.

99 *See* Attachment 6, *supra* note 89, at 1 (where, using typical language seen in such documents, Envoy Air, Inc. states with respect to its Flight Manual: "All rights reserved. This publication and its contents may not be reproduced, stored in a retrieval system, disseminated or transmitted in any form or by any means (electronically, by photocopy, by recording, mechanically or otherwise) without the prior written permission of Envoy Air Inc." Of course, this document became public when the NTSB, presumably without objection by Envoy, placed it into the public docket of an investigation.

100 Compare Attachment 6, *supra* note 89, and the manual in effect when the Pan Am Kenner microburst windshear crash occurred, both of which largely prohibit thunderstorm penetrations and flights too close to thunderstorms; with the manuals in effect when Delta Flight 191 and USAir Flight 1016 crashed, which do not prohibit thunderstorm penetrations and flights too close to thunderstorms.

The manual in effect when the Pan Am Kenner microburst windshear crash occurred was described in the NTSB final report:

> The Pan Am FOM [Flight Operations Manual] states that in the event of "significant thunderstorm activity, . . . within 15 miles of the airport, the captain should consider conducting the departure or arrival from a different direction or delaying the takeoff or landing. Use all available information for this judgment including pireps, ground radar, aircraft radar, tower reported winds, and visual observations."

NTSB/AAR-83/02, *supra* note 42, at 63. Discussing this portion of the FOM in greater detail, the NTSB explained:

> The intent of the company manuals is straightforward. They describe the thunderstorm and wind shear phenomena, the possible consequences, and the necessity for avoiding them. They establish a distance standard–15nm–at which the captain must exercise options

Air traffic controller duties relative to thunderstorm avoidance were specifically summarized by the court in the Delta Flight 191 microburst windshear case[101]:

> 1. The duties and responsibilities of air traffic controllers are set forth in the manuals of the Federal Aviation Administration (citation omitted).

> to avoid the consequences of an encounter with the hazards associated with "significant thunderstorm activity." Thereafter, it is the captain's responsibility to evaluate and decide the severity of the weather with which he must contend, and based on this decision, to choose an appropriate course of action. The company manuals describe the available sources of the information on which this decision is to be based.

Id.

The manual in effect at Delta when Flight 191 crashed was materially different than Pan Am's 15nm guideline. Judge Belew described Delta's thunderstorm avoidance criteria in effect at the time of the crash of Flight 191:

> Delta's Flight Operations Procedures Manual contains a notation regarding the use of radar in thunderstorm conditions. This notation states that thunderstorm conditions should be avoided whenever possible. If early evasive action is not practicable, the manual indicates that certain practices should be followed: Avoid areas where sharp changes in rainfall intensity occur, any echoes which are rapidly changing in shape, size, or intensity, or any echoes which have prominent scallops, hooks or fingers by at least: - 5 miles at 10,000 feet or below. . . .
>
> The manual further states that weak echoes or areas of weak rainfall gradient may be flown through or adjacent to "if judgment dictates this to be the most desirable procedure."

In re Air Crash at Dallas/Ft. Worth Airport, 720 F. Supp. at 1280.

In the USAir Flight 1016 investigation (the most recent U.S. microburst windshear crash case), the public docket includes the following excerpts from USAir's DC-9 Pilot's Handbook (Operations Group Exhibits 2C and 2E):

- Page 3-41-3: "Flight crews should carefully evaluate all available weather information for the purpose of avoiding unusually severe storms with extreme precipitation. . . ."
- Page 3-39-1: "Provide reasonable clearance around rain areas by selecting a heading which will clear storm cells by:
  - 5 miles when OAT is above freezing.
  - 10 miles when OAT is below freezing.
  - 20 miles when at or above 25,000 feet."

Taken together, these provisions are ambiguous because the objective standard on Page 3-39-1 might apply to all "storm cells," or only those deemed to be "unusually severe storms with extreme precipitation" as stated on Page 3-41-3.

101 *In re Air Crash at Dallas/Ft. Worth Airport*, 720 F. Supp. at 1288–89.

> 2. Under the FAA Air Traffic Control Manual, the first priority of an air traffic controller is separation of aircraft. FAA Order 7110.65D.[102] The provision of weather information is secondary to the primary duty of separation. The air traffic controller must decide, in his judgment, whether other duties permit the performance of these services. (case citation omitted[103]).
>
> 3. Air traffic controllers are required to give all information and warnings specified in the manuals, and in certain situations they must give warnings beyond the manuals. Warnings not contained in the manuals must be made only when the danger is immediate, extreme, or known only to the federal personnel; or when the controller is in a better position to evaluate a given situation or to make more accurate observations than the pilot. (case citations omitted[104]).

As pilots and air traffic controllers know, an air traffic control "clearance" relates only to separation from other aircraft, structures, and the ground.[105] Air traffic control clearances do not provide any protection at all from the risk of flying into or too close to a thunderstorm.

In air carrier operations, airline dispatchers share a degree of operational control with the pilot in command.[106] From a flight

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102 This is now covered in FAA Order JO7110.65AA (2023), § 2-1-2(a).

103 This is now covered in FAA Order JO7110.65AA (2023), § 2-1-2(c).

104 *Id.* In a note following this, the FAA adds: "Controllers are responsible to become familiar with and stay aware of current weather information needed to perform ATC duties." The ATC manual only has two references to thunderstorms outside of the Pilot-Controllers Glossary. These are in §§ 2-6-2 and 2-6-4. The former governs collection and dissemination of "PIREPS" and the latter with required weather and chaff area warnings.

105 "A clearance issued by ATC is predicated on known traffic and known physical airport conditions. An ATC clearance means an authorization by ATC, for the purpose of preventing collision between known aircraft, for an aircraft to proceed under specified conditions within controlled airspace. IT IS NOT AUTHORIZATION FOR A PILOT TO DEVIATE FROM ANY RULE, REGULATION, OR MINIMUM ALTITUDE NOR TO CONDUCT UNSAFE OPERATION OF THE AIRCRAFT." AIM, *supra* note 4, § 4-4-1.

106 14 C.F.R. § 121.533 Responsibility for operational control: Domestic operations.

(a) Each certificate holder conducting domestic operations is responsible for operational control.

(b) The pilot in command and the aircraft dispatcher are jointly responsible for the preflight planning, delay, and dispatch release of a flight in compliance with this chapter and operations specifications.

planning perspective, dispatchers and pilots are equal partners in the operational control. But once in the air, the pilot in command has the ultimate authority and responsibility.[107]

C. *Assessment*

Having now reviewed the grim history of commercial aviation accidents caused by flying into or close to thunderstorms, and armed with a summary of the main legal principles involved, we are ready to tackle two fundamental questions: 1) Why are thunderstorm penetrations and near-penetrations still regularly happening in air carrier operations?; and 2) What can be done to prevent thunderstorm penetrations and near-penetrations in the future?

1. *Why are Thunderstorm Penetrations and Near-Penetrations Still Regularly Happening in Air Carrier Operations?*

Many have assumed a failure to appreciate the danger by pilots, air traffic controllers, and dispatchers is at the heart of the problem. This appears in quite a few NTSB final reports, particularly older reports. While there was at one time strong evidence supporting this view, now there is strong evidence to the contrary.[108] A good example of how and why pilots who know better can end up in a thunderstorm comes from a candid true story Joe Casey, a certified flight instructor, recently published in an aptly titled article, *Pilot Confessions: Caught in a Nighttime Thunderstorm*.[109]

(c) The aircraft dispatcher is responsible for—
  (1) Monitoring the progress of each flight;
  (2) Issuing necessary information for the safety of the flight; and
  (3) Cancelling or redispatching a flight if, in his opinion or the opinion of the pilot in command, the flight cannot operate or continue to operate safely as planned or released.

(d) Each pilot in command of an aircraft is, during flight time, in command of the aircraft and crew and is responsible for the safety of the passengers, crewmembers, cargo, and airplane.

(e) Each pilot in command has full control and authority in the operation of the aircraft, without limitation, over other crewmembers and their duties during flight time, whether or not he holds valid certificates authorizing him to perform the duties of those crewmembers.

107 *Id.*

108 *E.g.*, *compare* note 38, *supra*, *with* note 77, *supra*, and accompanying text.

109 Casey, *supra* note 1.

As a skilled flight instructor, Casey initially framed his story using aviation weather basics:

> There are 30,000-plus thunderstorms on the face of the earth every day. That is a shockingly large but factual number. Thunderstorms are easy to find on most of our planet. So, if you are a pilot, you'll get to make some decisions about circumnavigating and avoiding them. If it hasn't happened already, you will have to decide how close to get to a thunderstorm in the future.
>
> Alarmingly, accident records show that pilots choose to fly into thunderstorms with far too much frequency, and many of those airplanes don't come out the other side in one piece. A thunderstorm is a deadly cocktail with all the nasty ingredients required for a fatality, and any one of those ingredients can take you out of the sky.
>
> Lightning, hail, wind shear, icing and convection exist in every thunderstorm.[110]

Casey tells how he, knowing better, ended up penetrating a thunderstorm one evening that was not inadvertent. Joe's story is well worth reading in its entirety. Space here does not allow that, so instead here is a shortened version:

> So, how did I find myself in the throes of a large thunderstorm complex at night? How did a (then) 12,000-plus hour aviator, CFI, and examiner make such a decision? Well, I didn't wake up that morning with suicidal thoughts, but I did wake up with a strong desire to get home. Usually, that is all that is needed to start the accident chain in aviation.
>
> . . . .
>
> The problem was a huge weather system that stretched from the Great Lakes deep into the Gulf of Mexico. This was a cold front with a line of thunderstorms at the frontal boundary and a bunch of disorganized cells further ahead on the warm (east) side of the front.
>
> . . . .

110 *Id.*

I had no onboard radar, but I did have ADS-B radar images on my iPad with a Garmin 345R transponder providing the Bluetooth signal. I continued southwest bound but began to be pushed further south by another line of thunderstorms. Here's where my judgment failed me. The main line of storms associated with the cold front was well to my west, but several lines of cells formed all around. At this point, I should have landed at the next viable airport.

But I didn't. I thought, "If I can just round that next cell, I'll have a clear shot for another 200 nm." . . . . I felt safe, but that feeling was an illusion created by my best hopes. We all need hope, but hope is a poor plan.

I was talking with ATC . . . .

Then, I lost the ability to talk with ATC. I was simply too low in too remote of an area. So, I made the only choice that I could after looking at ADS-B weather images on my iPad. I guessed as to where the thunderstorms were the weakest. All I could do was guess.

. . . .

Rain pelted the airplane and lightning struck all around me. It was remarkably smooth, but I had no doubts that incredible turbulence awaited me if I were to bumble into a column of convection that surely lurked in the darkness. I felt like the only fool in the zoo, with all the cages left open and all the animals present. I slowed to about 10 knots below Va and said the "prayer of resignation."

I've heard it said, "There are no atheists in a foxhole," and I was certainly no atheist at this point. I had made a complete mess of things and gotten to the point of resignation. The prayer of resignation is the nondescript prayer made by the fool who finds himself in a situation that could be deadly but for which they have no control. Fate, luck or divine intervention is the decider of the outcome, not skill or experience. . . .

> If I flew into convection, I'd probably perish. If I flew into a microburst or downdraft, I'd probably not be able to outclimb the downdraft. . . .
>
> After about 10 minutes of flying through the driving rain, I saw the rain-dimmed, blurry and glorious lights of the city of Many and hoped the runway lights would soon come into view. The runway lights did come into view, and I made one of the happiest landings I've ever made. I was on the ground with no bent metal.[111]

Naturally, Joe Casey concludes his story, as any good teacher would, with the take-away:

> The FAA has produced really good wisdom concerning flying near thunderstorms. The FAA's advice is "avoid a thunderstorm by 20 miles." That's about as succinct advice as could be given. You can avoid a thunderstorm by 20 miles if you simply decide you'll never get closer. . . .
>
> Decide today that you will not get to a place where you have no outs nor where you are not the master of your airplane. I hope my confession helps you decide NOT to choose the path I chose. I dodged a bullet. Not because I was a good pilot, but because I was a lucky and blessed one.[112]

The MIT team, whose work is discussed and cited in the Introduction, took a deep dive into some of the possible explanations

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111 *Id.*

112 *Id.* In this article, Joe Casey may be quoting from an old version of the *Aeronautical Information Manual*, or he may be using quotations without a citation relying on his memory. In the current AIM, the *Thunderstorm Flying* section states, "avoiding thunderstorms is the best policy," and in the "dos and don'ts of thunderstorm avoidance" it adds: "Do avoid by at least 20 miles any thunderstorm identified as severe or giving an intense radar echo. This is especially true under the anvil of a large cumulonimbus." § 7-1-27, at 7-1-62-3, item (a)(14). The context of the FAA's published 20-mile thunderstorm avoidance guidance is general aviation. For air carriers, thunderstorm avoidance guidance and criteria are found instead in the specific air carrier's FAA-approved Airplane Flight Manuals required by 14 C.F.R. § 121.141, and/or the air carrier's Operations Manual required by 14 C.F.R. § 121.133. Some of these documents at points in time have entered into the public domain and are discussed *supra* in notes 89, 99 and accompanying text.

for why penetrations and flights close to thunderstorms keep happening, yet this occurs less frequently enroute than near the airport:

> These data do not lead to firm conclusions but it seems likely that pilots in terminal airspace have several disadvantages when compared to their enroute counterparts: Pilots in the terminal area are flying at low altitudes and may be unable to tilt their airborne radars up high enough to assess the intensity of the storm cores. Airborne radars in the terminal airspace are more likely to be subject to ground clutter. Terminal area pilots are busier than pilots at cruise altitudes. Terminal area pilots often turn in order to join the pattern of aircraft lining up to land on the runway. It is difficult to assess the intensity of precipitation when the plane is not pointed in the direction of the storm. Enroute pilots are able to manipulate the tilt of their airborne radars to assess precipitation intensity as a function of height. They often have some lateral room in which to deviate. Enroute pilots on jetways in many parts of the country are less likely than terminal pilots to have other streams of traffic nearby at the same altitude. Enroute pilots may also have more room to maneuver vertically than terminal area pilots.
>
> Furthermore, the 'cost' of deviating around a storm in enroute airspace may often be lower than that of deviating when a plane is near the airport. Planes that deviate in the final minutes of flight usually forfeit their position in the landing queue and have to 'go to the end of the line' which may very well mean encountering more storms on the next approach. The deviation may cost them a significant amount of time and put them back in the middle of storms that they recently threaded their way through. In extreme cases, pilots may feel that they only have enough fuel to make one approach at the nominal landing airport before diverting to their alternate destination. In those cases, a deviation might mean a diversion, which carries a high cost indeed. Deviating in enroute airspace may also mean a long delay if the flight path is completely blocked but it

> can often be accomplished by a slight turn followed by another slight turn to get back on course after passing the storm. These deviations may be so slight that they do not add appreciable time or distance to the trip.[113]

Outstanding work and amazing technological advances have materially reduced weather-related aviation accidents over the years. Even so, the evidence shows there are still avoidable thunderstorm penetrations and near-penetrations occurring in air carrier operations. The proposed explanations for why this is happening, as summarized above, include weak awareness of the hazards of thunderstorms, difficulties perceiving their presence, concerns about staying on time, desire to get home, concerns about increasing cost, and many others. There is no one-size-fits-all answer.

What is clear, though, and discussed in greater detail *infra*, is that few airlines forbid avoidable thunderstorm penetrations in their manuals and the FAA *still* has no regulation on the books at all that specifically forbids thunderstorm penetration and flying too close to thunderstorms. This despite irrefutable data showing thunderstorm penetrations and flights too close to thunderstorms are still regularly happening in air carrier operations. A ripple effect of this is a lack of enforcement or other actions involving pilots, air traffic controllers and dispatchers that, if present instead, could probably rein in thunderstorm penetrations and near-penetrations, all superimposed on a regulatory structure for air traffic controllers that prioritizes aircraft separation from one another and terrain over narrowly circumscribed ATC duties with respect to even the most obvious weather hazards.[114]

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113 Rhoda, et. al, *supra* note 14, sec. 5.

114 Recent research reaffirms the value of federal aviation regulation enforcement actions to deter conduct that violates the regulations. *E.g.*, Curtis G. Calabrese et. al, *Effects of the Federal Aviation Administration's Compliance Program on Aircraft Incidents and Accidents*, 163 Transp. Res. Pt. A: Pol'y & Prac. 304 (2022). In 2015, the FAA shifted from focusing on enforcement actions for FAR violations to its new "Compliance Program," which deemphasizes punishment for many violations of the federal aviation regulations. The Calabrese study statistically evaluated the safety impact of the FAA's move away from enforcement actions and concluded: "These results are all statistically significant, indicating strong evidence that the level of aviation safety in the United States has significantly decreased since 2015 in direct response to the Compliance Program's implementation." *Id.* at 315.

2. *What Can Be Done to Prevent Thunderstorm Penetrations and Near-Penetrations in the Future?*

Avoidable thunderstorms *must*, simply put, be avoided. Yet the data shows that many avoidable thunderstorm penetrations and near-penetrations are still regularly happening in air carrier operations.[115] Among the plausible reasons for this are poor awareness of the hazards of thunderstorms,[116] difficulties perceiving their presence,[117] concerns about staying on time,[118] a desire to get home more quickly,[119] and a group think mentality.[120] A key factor is that few airlines appear[121] to forbid avoidable thunderstorm penetrations

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115 *See, e.g.*, Section A, *supra*, and Appendix A, *infra*.

116 NTSB/AAR-76/8, *supra* note 35, at 32 ("The number of recent approach and landing accidents which have been caused by the airplane's passage through or near localized thunderstorm cells indicates that *many pilots and air traffic controllers do not have the proper appreciation for the hazards involved*." (emphasis added)). This situation has likely improved greatly since the NTSB wrote this in 1976.

117 Aviation Weather Handbook, *supra* note 6, §§ 15.2.5.1, 15.2.5.2, 15.2.6.1 & 22.8.2. These sections describe thunderstorm perception issues such as precipitation and range attenuation or airborne radar, beam resolution on airborne radar, the impact of tilt angle, and reliability issues associated with the view out the cockpit window. Technological developments have ameliorated many of these issues. *See, e.g.*, Honeywell Aerospace Technologies, *Weather Radar*, https://aerospace.honeywell.com/us/en/products-and-services/product/hardware-and-systems/weather-radar (last visited Oct. 7, 2024); Collins Aerospace, *Weather Radar*, https://www.collinsaerospace.com/what-we-do/industries/commercial-aviation/flight-deck/surveillance/weather-radar (last visited Oct. 7, 2024) (discussing airborne weather radar offerings for air carriers). *See also Honeywell, Rockwell Collins Roll Out Advanced Cockpit Radar*, Dallas Morning News (Aug. 18, 2014, 9:10 PM), https://www.dallasnews.com/business/airlines/2014/08/19/honeywell-rockwell-collins-roll-out-advanced-cockpit-radar/ (telling the story of the rollout of 3D weather radar simplifying the pilot's job of interrogating thunderstorms and providing improved information, with huge initial commitments by both American and Southwest Airlines).

118 According to the FAA, the "largest cause of air traffic delay in the National Airspace System is weather. . . . [W]eather caused 74.26 percent of system impacting delays of greater than 15 minutes over the six years from June 2017 to May 2023, as recorded in the OPSNET standard 'delay by cause' reports." Fed. Aviation Admin., *FAQ: Weather Delay*, https://www.faa.gov/nextgen/programs/weather/faq (last updated Sept. 5, 2024).

119 *See supra* notes 109–12 and accompanying text.

120 *See supra* notes 11–14, 41, 46–47, 50, 58–61 and accompanying text.

121 While the thunderstorm avoidance criteria of all air carriers regulated by the FAA are not currently in the public domain, some of these criteria have been included in public docket releases by the NTSB reflecting the criteria in effect on the days accidents the NTSB investigated took place. *See, e.g.*, *supra* notes 17–29, 88–89 and accompanying text.

or avoidable flights too close to thunderstorms in their manuals, even though the FAA has recently approved at least one air carrier's request to include such prohibitions.[122] Another key factor is the FAA has no regulation explicitly outlawing avoidable thunderstorm penetrations and avoidable flights too close to thunderstorms.[123] One foreseeable consequence of a dearth of such airline manual provisions is that there are few, if any, enforcement, compliance, or disciplinary actions being taken that could rein in air carrier encounters and close encounters with avoidable thunderstorms.

After evaluating the possible reasons for the troubling situation documented in this paper and elsewhere, we conclude that the FAA's principal operations inspectors should require all air carriers to include in their FAA approved manuals, as at least one U.S. carrier has already recently done,[124] prohibitions against avoidable thunderstorm penetrations and avoidable flights close to thunderstorms. With such manual provisions widely in place, air carriers and the FAA would be in a better position, through enforcement or compliance actions, and with the help of air traffic control's natural responses to more consistent pilot decision making, to stop future avoidable thunderstorm penetrations and avoidable flights close to thunderstorms. These actions would not require any new rulemaking and, therefore, could be done expeditiously.

In words that are often quoted, the late Frank Borman, Commander of Apollo 8, once said: "a superior pilot uses his superior judgment to avoid situations which require the use of his superior skill." Avoiding thunderstorms is a classic example of Borman's concept. "Superior" pilots can probably already be counted on to usually keep a wide berth from thunderstorms; however, as Casey candidly reminds us, even superior pilots sometimes penetrate or

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122 Envoy Airlines had a manual provision in effect on December 16, 2019, and probably thereafter, forbidding avoidable thunderstorm penetrations and avoidable flights too close to thunderstorms. *See supra* notes 88–89 and accompanying text. Before these manuals could be used, the law required they first be approved by the FAA.

123 *See supra* notes 97–99 and accompanying text. While there is no "explicit" regulation forbidding avoidable thunderstorm penetrations and avoidable flights too close to thunderstorms, regulatory action could theoretically be taken under 14 C.F.R. § 91.13(a) against pilots who penetrated or flew too close to an avoidable thunderstorm. This regulation generally prohibits operating "an aircraft in a careless or reckless manner so as to endanger the life or property of another."

124 *See supra* notes 88–89, 122 and accompanying text.

fly too close to avoidable thunderstorms.[125] When this fact is added to the more frequent penetrations by pilots whose skills are not superior, what is left is an argument that more than mere guidance could probably be valuable and help protect against poor future thunderstorm avoidance judgments.

Presumably over concerns about disrupting movement of planes through the system and inordinate delays as an unintended result, few air carrier manuals seem to contain mandatory thunderstorm avoidance rules. These concerns might be studied further by the FAA, but there are already mitigating factors suggesting the concern may not loom large. For example: 1) there is no evidence that air carriers that already have prohibitions in their FAA approved manuals against avoidable thunderstorm penetrations and avoidable flights too close to thunderstorms have less favorable on-time performance statistics than air carriers without these prohibitions;[126] 2) there are cautious pilots at every airline who for years have never penetrated or flown close to an avoidable thunderstorm and there is no evidence the on-time performance statistics for these pilots are any less favorable than the statistics for pilots who take more risk than the FAA recommends;[127] and 3) careful flight planning by pilots and dispatchers with proper air traffic control coordination and communication already reasonably minimizes delays attributable to the weather.[128] Simply put, there is no evidence there would be any material impact on delays by reining in avoidable thunderstorm penetrations and close encounters.[129] It is speculative to suggest that keeping proper separation from thunderstorms, whatever that separation is determined to be, would materially result in inordinate delays; and to the extent there is

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125 *See supra* notes 1, 2, 109–112 and accompanying text.

126 In 2019, Envoy Airlines, flying as American Eagle, had manuals that prohibited avoidable thunderstorm penetrations and close encounters in effect. *See supra* note 89. That same year, Envoy's average departure delay was 9.31 minutes, its average arrival delay was 6.91 minutes, .28 percent of its flights were diverted and 3.48 percent of its flights were cancelled. These statistics are well within the U.S. regional airline industry's averages. *See* Statista, *Most Punctual Regional Airlines in the United States in 2023, Ranked by On-Time Arrival Performance* (Feb. 2024), https://www.statista.com/statistics/382363/punctuality-of-regional-airlines-in-north-america/ (showing Envoy was in the upper half of all airline on time performance).

127 This is another way of saying careful conduct and whatever delay it might bring should already be baked into the system.

128 *Id.*

129 *Id.* This is not to say it is impossible for a careful study to reveal some effect, just to point out no current study does so.

a small additional delay introduced into the system due to these manual revisions, this would be a small price to pay for saving lives and preventing losses of aircraft.

While the issue in air carrier operations can be effectively handled with revisions to FAA-approved air carrier manuals, to reach beyond air carrier operations, it may be proper for the FAA to study the possibility of adopting a scientifically based new federal aviation regulation defining and explicitly forbidding avoidable thunderstorm penetrations and flights too close to thunderstorms in all types of flying. With a reasonable thunderstorm avoidance regulation in effect and a zero-tolerance approach, word would likely spread quickly and a future without avoidable thunderstorm penetrations and avoidable flights too close to thunderstorms for all of aviation may be more than just a dream.

Avoidable thunderstorm penetrations and near-penetrations are provable in all types of operations through eyewitness testimony by pilots, air traffic controllers, and others, along with physical evidence like weather data, flight track data, ATC/aircraft communications data, and in air carrier cases, cockpit voice recorder data and flight data recorder data.[130] This evidence can and should be used in enforcement actions, compliance actions, and general instruction. Moreover, enforcement or compliance actions would be valuable when pilots penetrate or nearly penetrate thunderstorms and then get away with it in the sense there were no personal injuries or property damage that time. This could also go a long way toward debunking the thought some small fraction of professionals may still have that the risk of something bad happening in a thunderstorm encounter is low.[131]

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130 Perhaps in the future a means will be developed to preserve images that appeared on the airborne radar screen in the cockpit for later use. In the meantime, recreation of what airborne radar would have shown at different times, in different aircraft positions and using varying airborne radar tilt angles is technologically feasible. There is nothing new about this. A recreation of airborne radar images was first admitted into evidence, over strenuous objection, at the USAir Flight 1016 civil trial in Columbia, South Carolina in 1997. The technology has improved since then.

131 No one has high-quality data from which to calculate what the chance of injury or property damage is when penetrating or flying close to a thunderstorm. While we have a good idea of how many bad results from thunderstorm encounters there are in the United States in a year, and this could arguably serve as a proper numerator, we have no reliable denominator at this time. It cannot be the total air carrier flights per year in the U.S., because most of those flights do not involve thunderstorm penetrations or near-penetrations. But anyone who used that figure anyway might come

As it must, pilot discretion has well-defined limits. While a pilot in command has wide discretion to do that which is deemed safest,[132] the rules, regulations, guidelines, and procedures do not authorize pilots in the name of discretion to choose dangerous options over reasonably safe ones. On the contrary, the regulations state unequivocally: "No person may operate an aircraft in a careless or reckless manner so as to endanger the life or property of another."[133] While pilots have emergency authority to break any rule or disregard any guidance or recommendations when that is the safer course of action in an unusual situation,[134] emergency authority cannot be properly invoked to justify a more dangerous course of action than following the rules and guidance would be.

Avoidable thunderstorm penetrations and near-penetrations are too dangerous to tolerate. The main reason these storms *are* so dangerous is because current weather detection technology cannot distinguish between thunderstorms that are safe to fly in and those that will wreak havoc on a plane and threaten the safety of everyone on board. Perhaps technology will get there one day, but until then it has to be the case that thunderstorms must be avoided. There is no evidence a zero-tolerance approach would overly burden our system, though some undoubtedly fear this. Use of a scientifically based rule should allow safe separation distances to be calculated that are tight enough to keep things moving, but far enough to maintain safety. Given the massive size of most thunderstorms, like moving mountains in the sky, it is not asking too much of the professionals in our system to make sure all aircraft avoid them by a safe distance. This is a good time to put an end to avoidable thunderstorm penetrations and avoidable flights too close to thunderstorms.

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away believing the risk of a bad result by flying in a thunderstorm is exceedingly remote. Most pilots, of course, would probably not contemplate this sort of unreliable statistical roughshod ciphering. But a few might.

132 *See, e.g.*, 14 C.F.R. § 91.3(b).

133 14 C.F.R. § 91.13(a).

134 14 C.F.R. § 91.13(b). For example, if running out of fuel is the alternative to penetrating a thunderstorm, use of emergency authority to penetrate the storm could be appropriate.

Conclusion

Targeted regulatory, investigative, management, compliance, and enforcement efforts focused on eliminating "avoidable" thunderstorm encounters are workable. As explained, this can probably be done without materially disrupting flight operations; striking an appropriate balance between safety considerations and efficiency. The proposed changes can easily dovetail with the FAA's controversial Compliance Program,[135] and alter a culture that tolerates thunderstorm penetrations and near-penetrations, without, in all probability, ruining any pilot's, dispatcher's, or air traffic controller's career.

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135 Fed. Aviation Admin. Compliance Program, Order No. 8000.373C (FAA, June 8, 2022). The "controversy" is discussed in Calabrese et al, *Effects of the Federal Aviation Administration's Compliance Program on Aircraft Incidents and Accidents*, 163 TRANSP. RES. PT. A 304–19 (2022).

Appendix A

Air Carrier Accidents Caused by Flying Into or Too Close to Thunderstorms – 1943-2024

Date	Carrier	Flight #	Aircraft Type	Fatalities	Injuries	Narrative
7/28/1943	American	63	DC-3	20	2	"Loss of control of the aircraft due to unusually severe turbulence and violent downdraft caused by a thunderstorm of unknown and unpredictable intensity." "The aircraft was completely destroyed by impact and fire." "There was evidence that most of the occupants of the cabin were victims of suffocation, or fire, or both, because of their inability to effect an exit from the aircraft."
5/17/1953	Delta	318	DC-3	19	1	"The Board determines that the probable cause of this accident was (l) the encountering of conditions in a severe thunderstorm that resulted in loss of effective control of the aircraft, and (2) the failure of the captain to adhere to company directives requiring the avoidance of thunderstorms when conditions would allow such action."

Date	Carrier	Flight #	Aircraft Type	Fatalities	Injuries	Narrative
6/24/1956	BOAC Argonaut		Canadair C4 Argonaut	32	13	"The accident was the result of a loss of height and airspeed caused by the aircraft encountering, at approximately 250ft after take-off, an unpredictable thunderstorm cell which gave rise to a sudden reversal of wind direction, heavy rain, and possible downdraft conditions. The formation of the cell could not have been predicted by the meteorological forecaster at Kano airport, nor was it visible to the pilot in command before taking off. In the circumstances, no blame can be attached to the pilot in command for taking off."
6/26/1959	TWA	891	Lockheed L-1649A Starliner	68	-	Lightning strike.
12/8/1963	Pan Am	214	Boeing 707 121	81	-	Lightning strike.
7/23/1973	Ozark	809	Fairchild-Hiller FH-227	38	3	"The National Transportation Safety Board determines that the probable cause of the accident was the aircraft's encounter with a downdraft following the captain's decision to initiate and continue an instrument approach into a thunderstorm."

Date	Carrier	Flight #	Aircraft Type	Fatalities	Injuries	Narrative
1/30/1974	Pan Am	806	Boeing 707 321B	97	4	"The National Transportation Safety Board determines that the probable cause of the accident was the flightcrew's late recognition and failure to correct ln a timely manner an excessive descent rate which developed as a result of the aircraft's penetration through destabilizing wind changes . . . produced by a heavy rainstorm and influenced by uneven terrain close to the aircraft's approach path."
6/25/1975	Eastern	66	Boeing 707 225	113	11	Microburst windshear spawned by a thunderstorm.
4/4/1977	Southern	242	DC-9	63	22	After penetration of severe thunderstorm, loss of both engines from massive hail and water ingestion.
3/14/1979	Alia Royal Jordanian	600	Boeing 727	45	19	Encounter with a downburst related to a thunderstorm. The downburst exceeded the performance capability of the aircraft.
7/9/1982	Pan Am	759	Boeing 727-200	153	-	Microburst windshear spawned by a thunderstorm at the airport was encountered during lift off and initial climb.
8/2/1985	Delta	191	L-1011	137	27	Approach flown into a thunderstorm, where microburst windshear was encountered.

Date	Carrier	Flight #	Aircraft Type	Fatalities	Injuries	Narrative
7/24/1992	Mandala	660	Vickers Viscount 816	70	-	"Mandala Airlines flight 660, a Vickers Viscount, impacted Liliboi Mountain at a height of 2300 feet while on an instrument approach to runway 04 at Ambon-Pattimura Airport, Indonesia in a heavy rainstorm."
7/2/1994	USAir	1016	DC-9	37	20	Microburst windshear spawned by a thunderstorm at the airport and over the approach path was encountered during final approach.
6/1/1999	American	1420	MD-82	11	105	The NTSB probable cause finding included "the flight crew's failure to discontinue the approach when severe thunderstorms and their associated hazards to flight operations had moved into the airport ...."
6/22/2000	Wuhan	343	Xian Y-7	42	-	"The aircraft entered an area of poor weather; rain and thunderstorms with associated windshear.........During the approach the first officer proposed to land at an alternate airport, but the captain decided to continue to Wuhan. . . . The plane was caught by windshear and crashed."

Date	Carrier	Flight #	Aircraft Type	Fatalities	Injuries	Narrative
12/10/2005	Sosoliso	1145	DC-9-32	108	2	Reducing visibility in thunderstorm and rain at the time the aircraft came in to land were contributory factors to the accident.
10/29/2006	ADC	53	Boeing 737 2B7	96	9	"The pilot's decision to take-off in known adverse weather conditions and failure to execute the proper windshear recovery procedure resulted in operating the aircraft outside the safe flight regime, causing the aircraft to stall very close to the ground from which recovery was not possible."
4/10/2011	Georgian Airways	834	Bombardier CRJ100ER	32	1	"The most probable cause of the accident was the aircraft's encounter with a severe Microburst like weather phenomenon at a very low altitude during the process of Go Around. The severe vertical gust/ downdraft caused a significant and sudden pitch change to the aircraft which resulted in a considerable loss of height. Being at very low altitude, recovery from such a disturbance was not possible The inappropriate decision of the crew to continue the approach, in face of extremely inclement weather being displayed on their weather radar, was probably the principle contributing factor responsible for the accident."

Date	Carrier	Flight #	Aircraft Type	Fatalities	Injuries	Narrative
4/20/2012	Bhoja	213	Boeing 737 236A	127	-	After penetrating a squall line on approach for landing, the aircraft encountered two downdrafts, then, with an airspeed of 215 knots and a pitch angle of 0 degrees, the aircraft initially crashed onto the ground with its main landing gear 4.24 nautical miles from the runway threshold in a heavy rain. The aircraft exploded and struck a 16 ft terrace, causing further breakup. The wreckage was spread over a 1.2-mile radius. All 127 people on board were killed.
9/5/2014	Express Jet	4538	Embraer 145LR	-	-	Flight through “a large thunderstorm.” Severe turbulence, pilots’ loss of control through a 4,000-foot descent.
7/31/2018	Aeroméxico Connect	2431	Embraer 190AR	-	39	“Shortly after becoming airborne, the plane encountered sudden wind shear caused by a microburst. The plane rapidly lost speed and altitude and impacted the runway, detaching the engines and skidding to a halt about 1,000 feet (300 m) beyond the runway. The plane caught fire and was destroyed.”

Date	Carrier	Flight #	Aircraft Type	Fatalities	Injuries	Narrative
9/1/2018	Utair	579	Boeing 737 8AS	1	18	"The cause of the accident was the flight crew ignoring repetitive windshear warnings when the aircraft experienced low-level horizontal windshear and the crew's decision to land on the runway when its conditions at the time of the accident prohibited doing so. Contributing factors included violation of standard operation procedures, improper use of the autopilot, poor crew resource management training, and late deployment of the spoilers."
12/16/2019	Envoy (Am Eagle)	3960	Embraer EMB140	-	1	"The National Transportation Safety Board determines the probable cause of this accident to be: an encounter with convectively induced turbulence while overflying an area of known convective activity."
2/16/2023	Spirit	641	A319-100	-	3	"Based on weather satellite information and upper air sounding data, the flight encountered convective activity while traversing building cumulus clouds during the descent."
3/21/2023	United	194	Boeing 777	-	-	"An encounter with forecast convective turbulence during climb."

Date	Carrier	Flight #	Aircraft Type	Fatalities	Injuries	Narrative
4/22/2023	American	748	Boeing 777	-	-	Encounter with forecast convective turbulence during cruise flight.
6/1/2023	United	1734	Boeing 737	-	-	"An encounter with convectively induced turbulence (CIT)."
2/10/2024	United	1890	Boeing 777	-	3	"Satellite and weather radar imagery, along with lightning and surface data depicted strong cells in the vicinity of the flight" when it experienced moderate turbulence while descending through 19,000 feet resulting in serious injuries.
4/3/2024	Southwest	4273	Boeing 737	-	6	Even though the Boeing 737-700 had a weather radar that was on and working, nevertheless it was flown into a red storm cell, where it encountered severe turbulence. As a result, passengers and at least one crew member were injured, at least two of them severely.
				TOTAL	TOTAL	
				1390	309	

Appendix B: USAir - Crew Decisions[136]

	Windshear Probability Assessment	Actual Weather at Airport	USAir 806 *Take Off 18 R*	USAir 983 *Landing 18 R*	USAir 797 *Take Off 18 R*	USAir 52 *Take Off 18 L*	USAir 1016 *Landing 18 R*	USAir 8926 *Take Off 18 L*	USAir 332 *Landing 18 R*
Weather Condition:		@ 6:41:18 PM Local	6:39	6:40	6:41	6:41	6:42	6:43	6:45
Forecast of: Convective Weather Rain Shower Lightning[137]	 Low Medium Medium	 YES YES YES	 YES YES YES	 YES YES ?	 YES YES ?	 YES YES YES	 YES YES ?	 YES YES YES	 YES YES ?
LLWAS Alert: Less than 20 kts Greater than 20 kts	 Medium High	 YES YES	 NO NO	 NO NO	 NO NO	 NO NO	 YES NO	 YES YES	 YES NO
Strong Winds	High	YES	NO	NO	NO	YES	YES	YES	YES
Heavy Rain Observed Radar	 High High	 YES YES	 YES NO	 YES YES	 YES YES	 YES NO	 YES YES	 YES NO	 YES NO
Probability Assessment:		*HIGH*	*HIGH*	*HIGH*	*HIGH*	*HIGH*	*HIGH*	*HIGH*	*HIGH*
Remarks:			*Held - Refused to Take Off*	*Circled to Land 18 R*	*Held- Refused to Take Off*	*Took off with Microburst on Field*	*Crashed*	*Took off with Microburst on Runway*	*Made Approach but Landing Clearance Denied*

136 This is a reproduction of Plaintiffs' Trial Exhibit 148 admitted into evidence in the USAir Flight 1016 jury trial in the United States District Court for the District of South Carolina.

137 The question marks in this row indicate the lightning condition existed – but crew awareness was neither ruled out nor established. "YES" in this row means the crew knew the lightning condition existed.