Chapter 9

SERVICE AREA: Turbulence

1. Problem Description Non-convective turbulence is a major aviation hazard; all aircraft are vulnerable to turbulent motions. Non-convective turbulence can be present at any altitude and in a wide range of weather conditions, often occurring in relatively clear skies as clear-air turbulence. Any aircraft entering turbulent conditions is vulnerable to damage and accident; smaller aircraft (both fixed- and rotary-wing) are susceptible at lower levels of turbulent intensity than are large aircraft.

The effects of turbulence range from a jostling of the aircraft that is mildly discomforting for passengers and crews to sudden accelerations that can result in serious injury and temporary loss of aircraft control.

Clear-air turbulence is not only dangerous, but also has a major impact on the efficiency of flight operations. Rerouting and delays of commercial carriers to avoid turbulent conditions lead to late arrivals and the resulting ripple effect throughout the National Airspace System. Diversions en route cause additional fuel and other costs for all classes of aircraft.

> Some of the conditions which can lead to the production of non-convective turbulence include:
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> - wind shear at frontal boundaries,
> - jet stream wind shear, and
> - orographic (terrain-induced) and other atmospheric density waves.
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> In the first two cases, turbulence arises in the area where air masses with significantly different wind speeds or directions make contact. In the third case, a heavy air mass has moved into a region of lighter air and the process of re-establishing equilibrium in the atmosphere generates wave motions which can propagate over long distances, creating turbulence as they move.

2. Objectives The goal is to improve the effectiveness of the turbulence service area for the aviation community. To meet this goal, the *National Aviation Weather Initiatives* must meet the following objectives:

- reduction in the rate of accidents and injuries related to non-convective turbulence, and
- reduction in the number of encounters with non-convective turbulence conditions.

3. Operational Decision Makers As is described in Chapter 2, aircraft operations and service providers and pilots need to be able to make safe decisions based on accurate information concerning turbulent conditions. Flight attendants also need to be made aware of impending turbulent conditions so that they can make timely decisions relating to passenger safety. Ultimately, even passengers need enough education and information to make decisions regarding individual safety.

4. *Current Operations Concept*

4.1 Pre-Flight Operations. During the pre-flight phase, a pilot obtains weather information using the facilities and procedures described in Chapter 2.

4.2 En Route Operations. Visual observations from the cockpit (when possible) can play a key role in en route decision making. Some types of non-convective turbulent activity, such as density waves and wind shear, may have specific cloud types associated with them. These formations— lenticular clouds, rotor clouds, cap clouds, and undulations in contrails, for example — can be used as markers of potentially turbulent air. Since the appropriate actions for turbulence avoidance involve changes in altitude and/or course, the pilot may need to coordinate evasion decisions with ATC.

A DC-8 with its #1 engine and a part of its wing missing after encountering turbulence over the Rocky Mountains.

The question of encounters with turbulence in the immediate terminal area is discussed in the section of this document describing the Terminal Wind and Temperature Hazards Service Area.

5. *Needed Service Improvements*

Non-convective turbulent conditions can be very difficult to identify directly and pilots may not always be able to avoid turbulent areas. Therefore, significant improvements must be made to various aspects of the non-convective turbulence service area.

5.1 Production of Weather Information. Analyses and forecasts of regions of high turbulence can only meet specific standards for accuracy of geographic location and time duration if they are based on high-resolution observations. Not only will possible satellite-based turbulence sensors and forward-looking sensors on aircraft themselves be invaluable to air crews, but, if they can be integrated into the normal data streams used for analyses and forecast models, they will greatly improve analysis and forecast accuracy. Increasingly accurate forecasts will provide pilots, controllers, and dispatchers with more information to plan avoidance routes. This level of accuracy will require observations that employ greatly expanded systems of fixed and mobile sensors that can provide data for finer-resolution forecast models.

5.2 Weather Product Generation and Delivery. Turbulence observation, analysis, and forecast products should be provided to decision makers in clear and understandable formats, both textual and graphical. Such products should relate turbulence location and intensity to geographical position, terrain features, and altitudes. The products must be easy to understand at a quick glance from the pilot, consistent in content across a range of providers, and available to the entire spectrum of decision makers.

5.3 Pilot Training. Pilots would benefit from more comprehensive training in identifying the visible indicators (when they exist) of potentially turbulent areas, applying improved turbulence-related forecast products, and, most importantly, in-flight techniques. Some of these skills can be refined with classroom training, but some are best learned through hands-on experience in a simulation environment. Turbulence-encounter simulators for small rotary- and fixed-wing aircraft are generally inaccessible or non-existent. As an adjunct training material, specially-designed interactive training aids provide a valuable resource.

The interior of a United Airlines 747 which encountered clear air turbulence over the Pacific Ocean in December 1997. One passenger was killed in this accident.

5.4 Information-Provider Training. Aircraft operations and service providers throughout the system need training to help them better understand non-convective turbulence conditions and hazards, the impact these hazards have on individual aircraft, and their ramifications in the sectors under their control.

5.5 Incident Reporting and In-flight Safety Procedures. Non-convective turbulence is rarely the cause of passenger fatalities in commercial passenger aircraft. The true extent of turbulence-related injuries is not clear, since air carriers are not routinely required to report such incidents unless they result in flight attendant injury or in severe passenger injuries or death.

Recent clear-air turbulence encounters highlight the need for increasing passenger awareness and responsibility for personal safety related to turbulence. The potential for injury increases greatly when a passenger is not belted in his or her seat. The Department of Transportation and air carriers should place special emphasis on in-cabin procedures and passenger education concerning this hazard. As the photograph in this section vividly demonstrates, unrestrained objects — passengers, service equipment, and contents of overhead bins — can become airborne projectiles in the cabin during severe turbulence. We strongly recommend that the aviation industry (organization names here) assume leadership for increasing passenger and cabin safety by, for example, rethinking overhead storage bin usage and design to increase safety and establishing more stringent requirements for passenger and crew lap belt usage.

6. Turbulence Initiatives On pages 9-4 and 9-5 are the initiatives which have been identified for this service area.

Number	Turbulence Initiatives	Relative Ranking*	Cooperating Organizations
1	Expand the number and types of aircraft capable of automatic reporting of aircraft independent turbulence observations.	★★★★	NASA, Industry**, NOAA/NWS, FAA
2	Develop and implement turbulence products which are applicable for use by pilots, ATC service providers, and airline operations centers for flight planning and decision making.	★★★★	NOAA/NWS, Industry, FAA
3	Develop and implement ground-to-air Flight Information Service capabilities to readily disseminate turbulence observations, within 5 minutes of availability, and forecast products, within 15 minutes of product generation, to aircraft for turbulence avoidance.	★★★★	NASA, DoD, FAA, Industry
4	Develop and implement a multi-functional, color cockpit display which includes turbulence along with terrain and traffic hazards.	★★★★	NASA, Industry
5	Establish and institutionalize an objective, quantitative standard for characterizing turbulence without regard to aircraft type.	★★★★	NOAA/NWS, NASA FAA
6	Improve current ground-based communications systems, including VHF, to readily disseminate turbulence warning products and reports for use by all aircraft.	★★★	FAA, NASA
7	Investigate the utility of different procedures for improving passenger and aircrew safety in turbulent encounters.	★★	FAA, Industry, NTSB
8	Develop and implement forecasting (for less than 1 hour) and modeling techniques that will improve turbulence guidance products for tactical avoidance.	★★	NOAA/NWS, DoD, FAA
9	Develop and implement aircraft-mounted, forward-looking technologies for detecting turbulence.	★★	NASA, Industry, FAA

10	Develop and implement forecasting (for 1 hour or greater) and modeling techniques that will improve turbulence guidance products for strategic avoidance.	★★	NOAA/NWS, DoD, FAA
11	Require pilot training in acquiring knowledge about turbulence hazards, their impact on aircraft, and suitable avoidance and recovery techniques.	★★	FAA, DoD, Industry
12	Develop and implement remote (e.g., satellite-based) capabilities for detecting turbulence.	★	NOAA/NWS,FAA, NASA

Turbulence Initiatives

* The relative rankings assigned to the initiatives are based on a qualitatively calculated benefit/cost ratio. It's possible that a high-benefit initiative which is costly to implement may rank lower than a medium- or low-benefit initiative which is medium or low in cost to implement. All these initiatives are considered to have a positive benefit to aviation; however, when benefits and costs are considered, some rank relatively higher than others. Details can be provided upon request. Four stars (★★★★) is the highest ranking.

** The term "Industry" in this context refers to private organizations (e.g., airlines, manufacturers, associations) which may represent both users and providers of weather information.