3

Risk Analysis for Aviation Weather Hazards

This section extends the analysis of NTSB accident data to examine trends in the frequency with which different kinds of weather hazards have been contributing to aviation accidents since 1995. The accident records in the NTSB database derive from entries in a form completed by an NTSB investigator for each accident. If weather was a possible cause or contributing factor, the form provides a fixed list of choices to describe what conditions were involved. This set of *weather factors* available for selection by an investigator appears to have remained relatively stable since 1995, the first year for which OFCM staff obtained data on the frequency with which weather factors were cited in the NTSB accident records.

Several caveats about the weather factor citation data must be borne in mind. First, an investigator may select more than one factor from the list. The count of citations for a given year will thus exceed the count of corresponding accidents (either all weather-related or weather-related fatal) in that year. Second, a number of the factors overlap, and there is no guarantee that different investigators (or even the same investigator over time) use the same criteria in deciding which factor(s) best describe similar weather situations. Third, as the data on weather-related accidents in a given year are divided into smaller categories, the numbers of accidents per year—and particularly the number of fatal accidents—often becomes small. The reliability of any statistical measure of central tendency, which is essential for an objective analysis of trends, decreases correspondingly. Despite these limitations, the analysis provides useful insights into the weather factors that have been involved in the accidents characterized at a broad level in Section 2.

Service Areas and Weather Hazard Categories

Beginning with the *National Aviation Weather Initiatives* report in 1999, the OFCM and the coordinating structure for aviation weather programs and initiatives have used service areas to characterize initiatives and projects. A *service area* focuses on "meteorological conditions which have either proven to be frequent causes of aviation accidents, injuries, and delays or, in the case of volcanic ash and other airborne hazardous materials, are considered to be serious potential causes" (OFCM 1999). The service areas, numbered as in other OFCM reports, are:

1. Ceiling and visibility
2. Convective hazards
3. En route winds and temperatures
4. Ground de-icing
5. In-flight icing
6. Terminal winds and temperatures
7. Turbulence
8. Volcanic ash and other airborne hazardous materials

The columns in Table 2 show how the weather factors cited in the NTSB data for 1995–2001 are distributed among these service areas, plus a ninth category of "Other" for factors that could not be assigned to an existing service area. (There were no NTSB weather factors identified for either ground de-icing or volcanic ash and other airborne hazardous materials; thus, these two service areas are not included in the table.) The groupings of weather factors within a column and across columns suggest the problems encountered if the service areas are used as the basis for identifying weather hazard trends.

Table 2. Weather factors by service area and hazard category

Hazard category	Service area: 1. Ceiling & visibility	2. Convective hazards	3. En route winds & temps	5. In-flight icing	6. Terminal winds & temps	7. Turbulence	9. Other
A. Restricted visibility and ceiling hazards	Obscuration Clouds Fog Haze/smoke Low ceiling Whiteout Below approach/landing minimums						
B. Precipitation (non-icing) hazards	Rain Drizzle/mist Snow						
C. Icing conditions				Icing conditions Ice fog Freezing rain			Carburetor icing conditions
D. Turbulence and convection hazards		Thunderstorm Thunderstorm (outflow) Turbulence (thunderstorms) Turbulence, convection induced Microburst/dry Microburst/wet Updraft Downdraft			Gusts Wind shear Dust devil/whirlwind Sudden wind shift Variable wind	Mountain wave Turbulence Turbulence, clear air Turbulence in clouds Turbulence (terrain induced)	
E. Temperature and lift hazards			Temperature inversion		High density altitude Temperature, high Temperature, low		Thermal lift No thermal lift
F. En route and terminal winds			Unfavorable wind		Crosswind High wind Tail wind		
G. Electrical hazards		Lightning					Static discharge
H. Airborne solids hazards	Sand/dust storm	Hail					

In particular, weather factors related to turbulence are spread among three service areas: convective hazards, terminal winds and temperatures, and turbulence.[1] The terminal winds and temperatures service area includes temperature-related factors and factors related to steady horizontal wind conditions, as well as air movements that, from a weather safety perspective, can be characterized as turbulence phenomena. When working with data series consisting of small numbers of observations, grouping like factors together in the same analysis category increases the clarity and strength with which trends emerge.

Rather than changing the definitions of the service areas, which continue to be useful for broader program analysis and planning, this hazard assessment groups related weather factors together as a *weather hazard category*. These hazard categories are shown by the row groupings in Table 2. Table 3 shows the number of times each weather factor is cited in the NTSB database for the period 1995–2001. Yearly citations by weather factor and hazard category are tabulated in Appendix A. The hazard analyses in the remainder of this section use the weather hazard categories. In Section 4, the relationship between hazard categories and the aviation weather service areas, shown in Table 2, is used to link conclusions from the hazard analysis back to service area initiatives and projects.

General Aviation Weather Hazard Trends

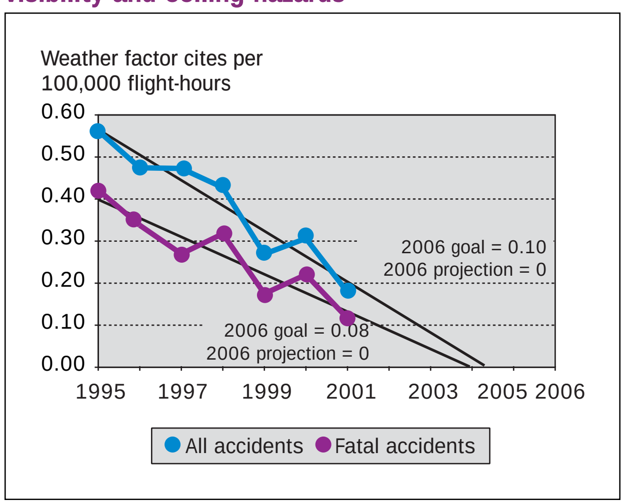
This presentation of weather hazard trends starts with the Part 91 weather-related accidents because the data set is larger. It thus provides a clearer picture of the trends. After the trends for Part 91 aviation are identified, it will be easier to draw comparisons with the sparser data sets for Part 121 and Part 135 weather-related accidents. (Compare the total citations, by aircraft regulatory category, for all weather hazard categories, given at the bottom of Table 3.)

Figures 7 through 12 plot the data series of annual citation frequency for weather factors, using weather hazard categories A through F (as labeled in Tables 2 and 3). Each figure shows two data series: the citation frequency per 100,000 flight-hours for *all* weather-related accidents and the citation frequency for *fatal* weather-related accidents. Linear regressions are plotted for each data series to project the trend to 2006 (or to the x axis, indicating that the trend approaches zero citations per 100,000 flight-hours before 2006). As explained in Section 1, a 2006 goal is calculated for each data series as 20 percent of the average citation frequency for 1995 and 1996. Weather hazard categories G through I are not plotted because the citations per year are too few to provide useful trend analysis. Tables A-1 and A-2 in Appendix A contain the citation frequency values from which Figures 7 through 12 were plotted.

Figure 7, for Category A, shows that the citation rates for both data series trend strongly toward zero before 2006. Furthermore, the data fall close to the trend lines. The Category A totals in Table 3 show that these hazards have in the past been a major contributor to Part 91 weather-related accidents (as well as Part 135 accidents). This steep decline in citation rates is an important contributor to the overall trends for Part 91 described in Section 2. The data for Category C, icing conditions, in Figure 9 also show strong downward trends for both data series.

The trends for Category B, non-icing precipitation hazards (Figure 8) and Category D, turbulence and convection hazards (Figure 10) also show downward trends for which the 80 percent reduction goals for fatal weather-related accidents are met before 2006. However, the

FIGURE 7. Part 91, trend for Category A, restricted visibility and ceiling hazards



[1]The term “turbulence” as used in this report corresponds to *aircraft turbulence*, defined by the American Meteorological Society Glossary of Meteorology as “irregular motion of an aircraft in flight, especially when characterized by a rapid up-and-down motion, caused by a rapid variation of atmospheric wind velocities.”

trends for all weather-related accidents come close to the desired 2006 benchmark, even exceeding it slightly in the case of non-icing precipitation hazards. These two categories will bear watching for Parts 121 and 135.

Table 3. Weather factor contributions to hazard category citation frequency, 1995–2001

		Citations, all weather accidents			Citations, fatal weather accidents		
Hazard category	Weather factor	Pt. 91	Pt. 135	Pt. 121	Pt. 91	Pt. 135	Pt. 121
A. Restricted visibility and ceiling hazards	Obscuration	56	6		43	3	
	Clouds	103	12		65	10	
	Fog	203	28	1	143	12	0
	Haze/smoke	26			11		
	Low ceiling	286	47	1	213	26	0
	Whiteout	8	17	1	1	4	0
	Below approach/ landing minimums	24	1		11	0	
	Category total	706	111	3	487	55	0
B. Precipitation (non-icing) hazards	Rain	60	8	2	35	3	0
	Drizzle/mist	18	2	1	13	1	0
	Snow	75	16	1	47	6	0
	Category total	153	26	4	95	10	0
C. Icing conditions	Icing conditions	88	23	1	44	11	0
	Ice fog	1			1		
	Freezing rain	7	3		4	0	
	Carburetor icing conditions	148	3		10	0	
	Category total	244	29	1	59	11	0
D. Turbulence and convection hazards	Thunderstorm	46	1		33	0	
	Thunderstorm (outflow)	7			1		
	Turbulence (thunderstorms)	12	1	7	10	1	0
	Turbulence, convection induced			2			0
	Microburst/dry	4			0		
	Microburst/wet	1			1		
	Updraft	4			0		
	Downdraft	135	13		12	2	
	Gusts	528	16	1	38	1	0
	Wind shear	46		2	7		0
	Dust devil/whirlwind	30			1		
	Sudden wind shift	61			2		
	Variable wind	62	3		1	0	
	Mountain wave	10		1	6		0
	Turbulence	59	3	24	21	0	0
	Turbulence, clear air	7		24	2		1
	Turbulence in clouds	7	1	10	5	1	0
	Turbulence (terrain induced)	29	5		14	2	
	Category total	1,048	43	71	154	7	1
E. Temperature and lift hazards	Temperature inversion	1			0		
	High density altitude	223	10		47	2	
	Temperature, high	15		2	1		1
	Temperature, low	4	1		1	1	
	Thermal lift	5			0		
	No thermal lift	23			2		
	Category total	271	11	2	51	3	1
F. En route and terminal winds	Unfavorable wind	72	6	2	5	0	0
	Crosswind	646	21	4	14	0	0
	High wind	136	8		22	4	
	Tail wind	307	18		33	1	
	Category total	1,161	53	6	74	5	0
G. Electrical hazards	Lightning	3	1		3	0	
	Static discharge	1			1		
	Category total	4	1	0	4	0	0
H. Airborne solids	Sand/dust storm	1			1		
	Hail	3		1	2		0
	Category total	4	0	1	3	0	0
I. Not specified			1	2			0
Total, all weather hazard categories		3,591	275	90	927	91	2

Figure 8. Part 91, trend for Category B, precipitation (non-icing) hazards

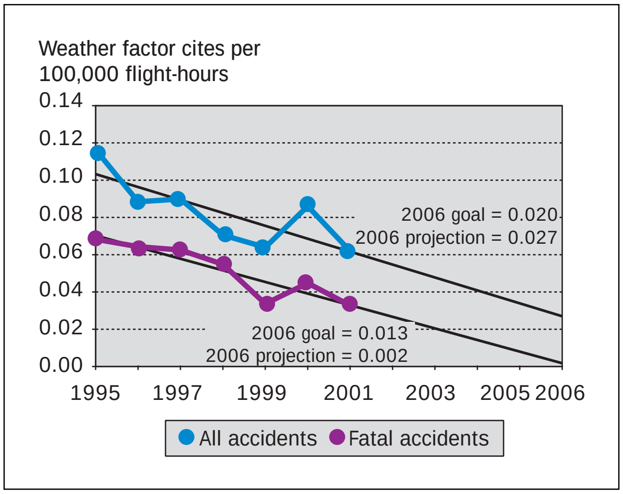


Figure 9. Part 91, trend for Category C, icing conditions

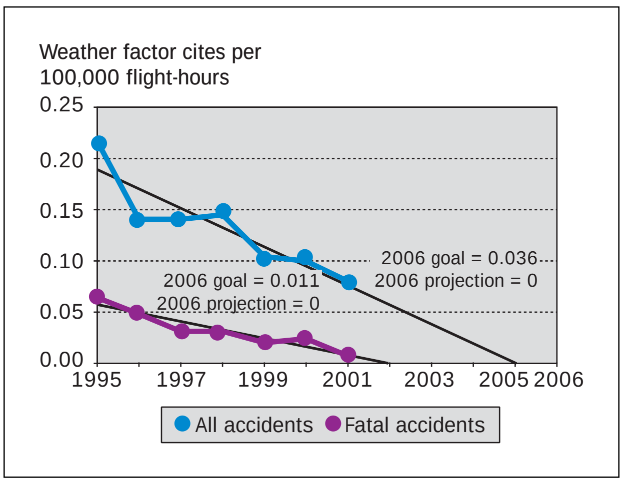


Figure 10. Part 91, trend for Category D, turbulence and convection hazards

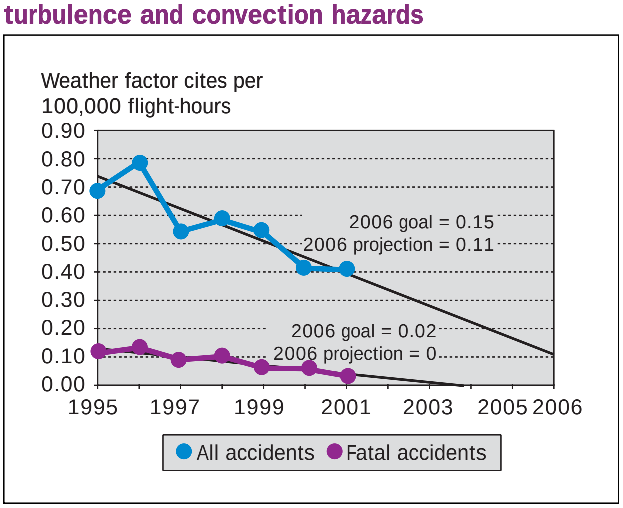
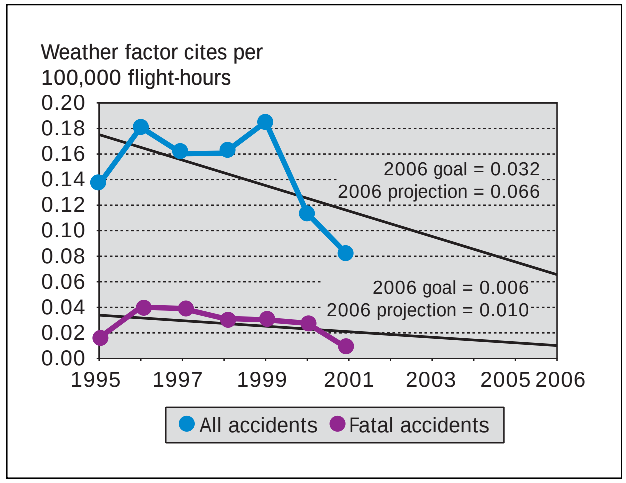


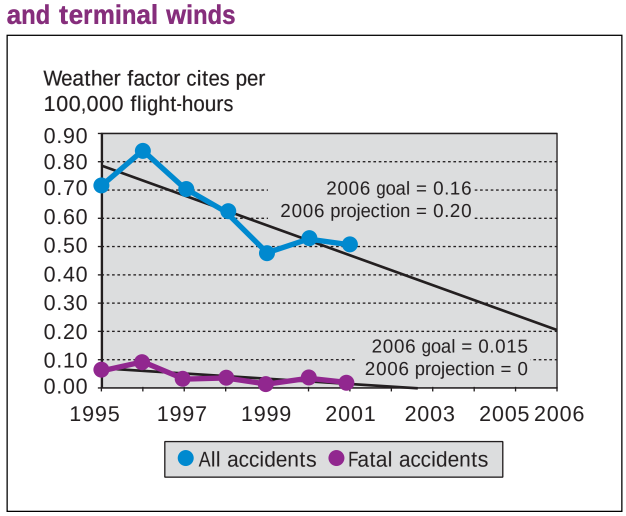
Figure 11 contains the data series for Category E, temperature and lift hazards. A noteworthy feature of the citation data for Category E is that 80 percent of the citations for all weather-related accidents and 90 percent of citations for weather-related fatal accidents are for high density altitude (see Table 3). The citations for this factor are distributed across the time period (see Appendix A) and dominate the shape of the data series graphs. Attention to this specific weather factor could make a significant difference in reducing accident rates in this weather hazard category. The trend lines in Figure 11 indicate that 80 percent reductions in this area are unlikely to be achieved without addressing the high density altitude problem.

Figure 11. Part 91, trend for Category E, temperature and lift hazards



Category F (Figure 12) is another interesting case. This category had the most citations for all accidents of any

Figure 12. Part 91, trend for Category F, en route and terminal winds



category, but fewer citations for fatal accidents than several others. The fatal accident trend in Figure 12 indicates that an 80 percent reduction is feasible by 2006, but the slope of the downward trend depends on a high value in 1996 and a low value in 2001. The data series for all weather-related accidents trends to just above the 80 percent reduction goal. This weather hazard category is another to keep in mind when examining the Part 121 and 135 data.

Part 121 Weather Hazard Trends

Weather-related fatal accidents in Part 121 aviation are too infrequent to provide adequate data for trend analysis. As Table 3 shows, there were just two weather factor citations for fatal accidents in the 1995–2001 period, one for turbulence, the other for high temperature. Table 4 shows the weather factor citations, aggregated by weather hazard categories, during this period for all weather-related accidents. These data series will serve as surrogate indicators of trends for the Part 121 aircraft category. (Complete Part 121 data are in Appendix A.)

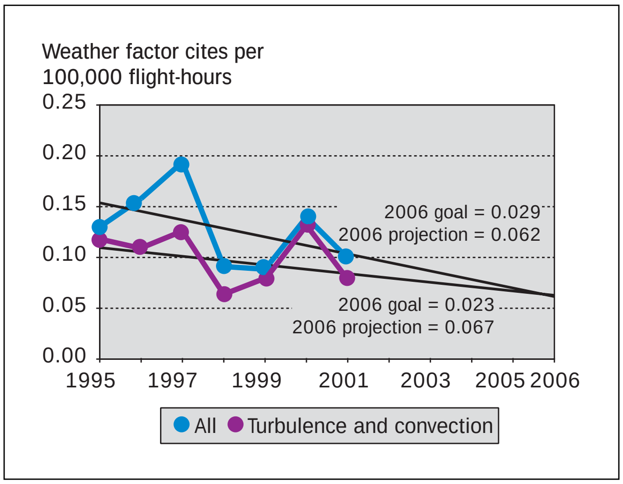
The most notable feature in the data is the prominence of Category D, turbulence and convection hazards, in the citations each year. Category D is just one among several weather hazard categories that contribute substantially to the citation totals for general aviation. But these turbulence and convection hazards dominate the weather conditions that continue to contribute to accidents—albeit not usually fatal ones—for the major air carriers.

Table 4. Part 121 weather factor citations, all accidents

Hazard category and weather factor	1995	1996	1997	1998	1999	2000	2001
All factors	11	13	20	10	10	16	10
Frequency per 100,000 departures	0.130	0.158	0.194	0.091	0.088	0.140	0.099
A. Restricted visibility and ceiling hazards							
Fog		1					
Low ceiling							1
Whiteout			1				
Total category citations	0	1	1	0	0	0	1
B. Precipitation (non-icing) hazards							
Rain		1	1				
Snow			1				
Drizzle/mist				1			
Total category citations	0	1	2	1	0	0	0
C. Icing conditions							
Icing conditions			1				
Total category citations	0	0	1	0	0	0	0
D. Turbulence and convection hazards							
Turbulence (thunderstorms)		1	1	3			2
Turbulence, convection induced						1	1
Gusts						1	
Wind shear	1					1	
Mountain wave						1	
Turbulence	5	1	3	1	5	6	3
Turbulence, clear air	3	7	7	2	3	2	
Turbulence in clouds	1		2	1	1	3	2
Total category citations	10	9	13	7	9	15	8
Frequency per 100,000 departures	0.118	0.109	0.126	0.064	0.080	0.131	0.079
E. Temperature and lift hazards							
Temperature, high		1					1
Total category citations	0	1	0	0	0	0	1
F. En route and terminal winds							
Unfavorable wind	1			1			
Crosswind		1	2			1	
Total category citations	1	1	2	1	0	1	0
H. Airborne solids hazards							
Hail				1			
Total category citations	0	0	0	1	0	0	0
I. Other			1		1		
Total category citations	0	0	1	0	1	0	0

Figure 13 graphs the data series for the Part 121 citation rates (per 100,000 departures) for all weather factors and for Category D. If these trends were to hold, by 2006 Category D would be responsible for virtually all the Part 121 weather-related accidents. In addition—and more significant for this mid-course assessment—the trend for all weather-related accident citations does not project to the desired 2006 goal. Category D is clearly the chief obstacle to greater progress.

Figure 13. Part 121, trends for all weather hazards and for turbulence and convection hazards



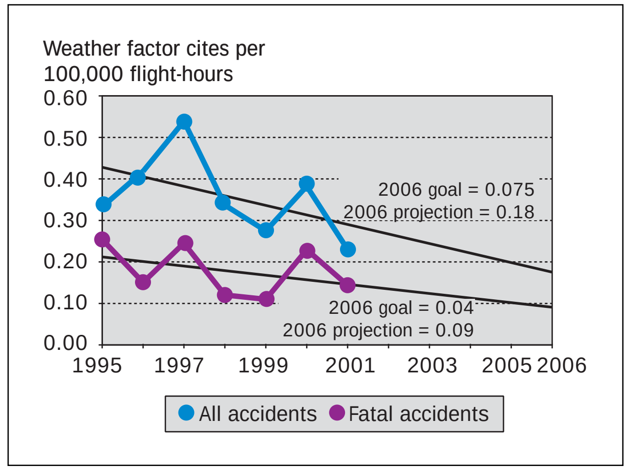
Part 135 Weather Hazard Trends

Figures 14 through 19 plot the data series for Part 135 aviation accidents corresponding to those in Figures 7 through 12 for Part 91. The yearly weather factor citation data from which the citation rate graphs derive are in Appendix A, Tables A-5 and A-6.

Comparisons of Part 135 and Part 91 by weather hazard category are valuable for two reasons. First, the aircraft types, flight durations and conditions, and airport facilities of Part 91 and Part 135 aviation are arguably more similar to each other than either is to Part 121 aviation. As noted in Section 1, the FAA often compiles data on nonscheduled Part 135 aviation with Part 91 data to create a “general aviation” category. The small propeller-driven or turboprop craft that still fall within the scheduled Part 135 category after the 1997 change to the FAR fly from and to airports, and at in-flight altitudes, more typical of general aviation than of the larger Part 121 aircraft. Second, given these basic similarities, differences between Part 135 and Part 91 in trends for the same weather hazard category suggest that factors specific to Part 135 may need to be identified and addressed if accident reduction goals are to be achieved.

Figure 14, compared with Figure 7, shows that Part 135 aviation is not experiencing the same improvement in risk of restricted visibility and ceiling hazards that holds

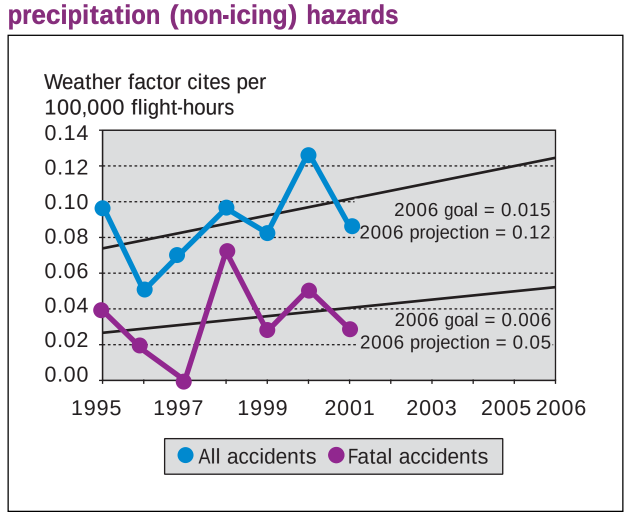
Figure 14. Part 135, trend for Category A, restricted visibility and ceiling hazards



for general aviation (Part 91). Whereas Part 91 is on a course to reach and exceed an 80 percent reduction in the Category A citation rate for all accidents and for fatal accidents well before 2006, neither data series for Part 135 is on a trend to achieve this goal by 2006.

The comparison between Figure 15 and Figure 8 for Category B is even more startling. Of course, the variability in the Part 135 data, which reflects the small numbers of non-icing precipitation citations per year, increases the

Figure 15. Part 135, trend for Category B, precipitation (non-icing) hazards



uncertainty about the trends. But the fact that both trends are on upward paths cannot be ignored, particularly when they are compared with the distinct downward trends for the Part 91 data series in Figure 8. The same pattern appears for Category C, icing conditions (Figure 16 for Part 135; Figure 9 for Part 91).

The first good news for Part 135 comes in Category D, turbulence and convection hazards (Figure 17 for Part 135, Figure 10 for Part 91). If the trend in citations for fatal accidents holds, this category of weather hazards will approach a zero rate for Part 135 even earlier than it will for Part 91. However, the citation trend for all weather-related accidents does not confirm the favorable trend. Turbulence should be viewed as a continuing issue for Part 135, just as it is for Parts 91 and 121.

For the two remaining weather hazard categories, temperature and lift hazards and en route and terminal winds,

Figure 16. Part 135, trend for Category C, icing conditions

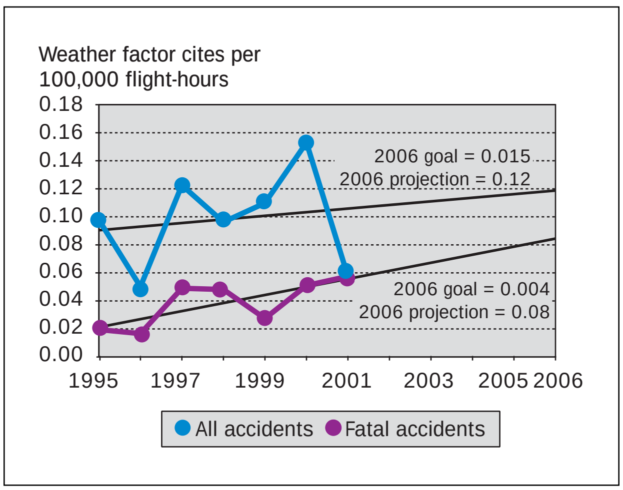
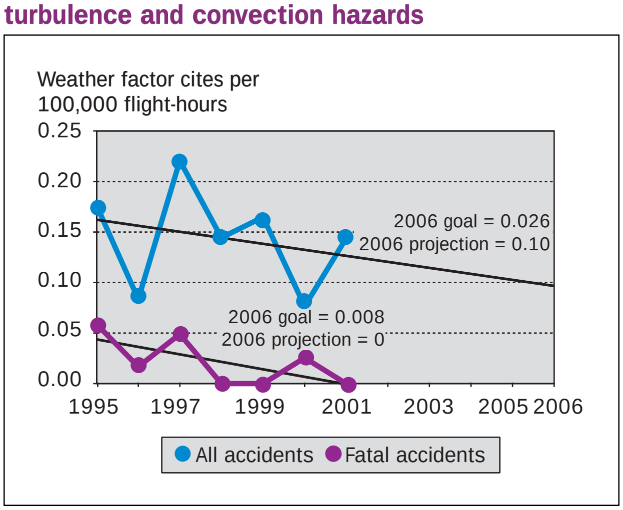


Figure 17. Part 135, trend for Category D, turbulence and convection hazards



there is considerable inter-year variability in the data series (Figures 18 and 19, respectively). The data series for citations in fatal accidents have downward trends. But unlike the counterpart data series for Part 91 (Figures 11 and 12), the data for all weather-related accidents do not corroborate these indications of improvement.

Figure 18. Part 135, trend for Category E, temperature and lift hazards

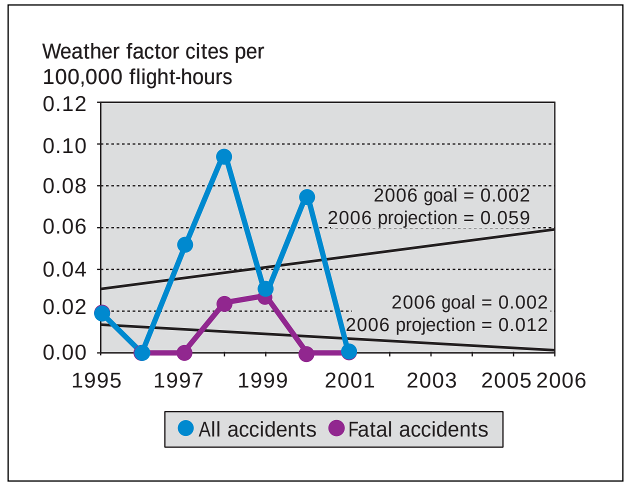
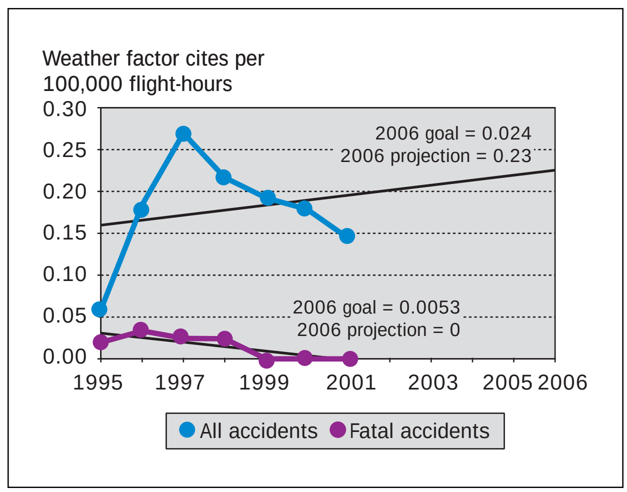


Figure 19. Part 135, trend for Category F, en route and terminal winds



Conclusions from the Weather Hazard Risk Analysis

The following conclusions, drawn from the data analyses described in Sections 2 and 3, provide the basis for the first part of the program portfolio analysis in Section 4.

1. Weather-related accidents involving Part 91 aircraft, particularly fatal accidents, have been decreasing over the period analyzed. Something has, or *some things* have, been going right for general aviation with re-

spect to decreasing weather-related accidents since 1996. If programs that have been implemented or extended within the past 7 to 10 years can be identified as contributing to these improvements, ways to further extend their reach into the aviation community should be promoted.

2. The aircraft category regulated under FAR Part 135 displays weather-related accident rate trends distinct from both the Part 91 and Part 121 categories. Aviation weather initiatives and programs should consider special factors relevant to this category, rather than assuming it is partly like the large commercial air carriers and partly like general aviation.

3. Weather-related fatal accidents in the Part 121 aircraft category are becoming rare events. This risk analysis has had to turn to trends in all weather-related accidents as a surrogate statistical indicator for major air carriers. Using this indicator, turbulence and convection hazards constitute the weather hazard category that contributes most often to Part 121 accidents. These weather phenomena continue to be problematic for Part 91 and Part 135 aircraft as well. The aviation weather program portfolio should have a balanced range of projects in the pipeline that can be expected to help reduce the impact of these hazards.

4. High density altitude is the factor within the temperature and lift hazards category that is most frequently cited in accidents for both Part 91 and Part 135 aviation. Although single factors in other categories are cited more often, this particular factor deserves attention in the aviation weather program portfolio.

5. The annual statistics on weather factor citations in Appendix A show that a number of other factors in different weather hazard categories continue to be cited in multiple accidents each year, particularly for Part 91 aircraft. Although the frequency of citations is generally declining over the analysis period, sustaining the downward trends until reduction goals are met will require continued support for programs and initiatives that address these factors. Examples of such factors are fog and low ceiling in Category A, restricted visibility and ceiling hazards; gusts in Category D, turbulence and convection hazards; and crosswinds and tail winds in Category F, en route and terminal winds.