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Analysis of Aviation Safety Reporting System Incident Data Associated With the Technical Challenges of the Atmospheric Environment Safety Technology Project

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Summary

This study analyzed aircraft incidents in the NASA Aviation Safety Reporting System (ASRS) that apply to two of the three technical challenges (TCs) in NASA's Aviation Safety Program's Atmospheric Environment Safety Technology Project. The aircraft incidents are related to airframe icing and atmospheric hazards TCs. The study reviewed incidents that listed their primary problem as weather or environment-nonweather between 1994 and 2011 for aircraft defined by Federal Aviation Regulations (FAR) Parts 121, 135, and 91. The study investigated the phases of flight, a variety of anomalies, flight conditions, and incidents by FAR part, along with other categories.

The first part of the analysis focused on airframe-icing-related incidents and found 275 incidents out of 3526 weather-related incidents over the 18-yr period. The second portion of the study focused on atmospheric hazards and found 4647 incidents over the same time period. Atmospheric hazards-related incidents included a range of conditions from clear air turbulence and wake vortex, to controlled flight toward terrain, ground encounters, and incursions.

1.0 Introduction

This analysis was conducted to support the Aviation Safety Program's (AvSP's) Atmospheric Environment Safety Technology (AEST) Project milestone AEST.3.2.SA.01 (Ref. 1), Identification of AEST-Related Trends. In particular, this is a review of incident data from the NASA Aviation Safety Reporting System (ASRS) (Ref. 2). The following three AEST-related technical challenges (TCs) were the focus of the incidents searched in the ASRS database:

TC1: Engine icing characterization and simulation capability
TC2: Airframe icing simulation and engineering tool capability
TC3: Atmospheric hazard sensing and mitigation technology capability

The database was searched for incidents that listed either weather- or environment-nonweather-related primary problems. It was difficult to find any TC1-related incidents that resulted from engine icing due to clouds with high ice water content (HIWC). Twenty-four engine-related icing incidents were found, but none appeared to be related to clouds with HIWC. There is no further discussion on TC1 in this report because most incidents were related to engine ice, snow ingestion, or carburetor icing. The primary problem of weather was analyzed for TC2 and TC3, and the environment-nonweather-related primary problem was also analyzed for TC3. Acronyms used in this report are defined in Appendix A.

The AvSP is primarily interested in Federal Aviation Regulations (FAR) Parts 121, 135, and 91 aircraft operations. Part 121 applies to major airlines and cargo carriers that fly large transport category aircraft. Part 135 applies to commercial aircraft air carriers, also referred to as "commuter airlines." Prior to March 1997, Part 121 operations included aircraft with 30 or more seats. In March 1997, the definition of Part 121 operations changed to include aircraft with 10 or more seats. Part 91 applies to general aviation and noncommercial operations.

2.0 Aviation Safety Reporting System Database

Information requested from the ASRS database included weather- and environment-nonweather-related incidents only. At the time of the search, 163 558 full-form reports were in the database. The search, which was restricted to January 1994 to November 2011 for FAR Parts 121, 135, and 91, resulted in 3526 incidents with weather listed as the primary problem and 1122 incidents with environment-nonweather-related listed as the primary problem. Weather-related incidents are excluded in this ASRS category.

The ASRS database includes incidents only, not accidents. The following definitions are used for incidents and accidents in aviation and are listed in the International Civil Aviation Organization (ICAO) Annex 13 (Ref. 3).

- An incident is an occurrence, other than an accident, associated with the operation of an aircraft which affects or could affect the safety of operation.
- An accident is an occurrence associated with the operation of an aircraft which takes place between the time any person boards the aircraft with the intention of flight until such time as all such persons have disembarked, in which (a) a person is fatally or seriously injured or (b) the aircraft sustains damage or structural failure which: adversely affects the structural strength, performance or flight characteristics of the aircraft and would normally require major repair or replacement of the affected component (*except* for engine failure or damage, when the damage is limited to the engine, its cowlings or accessories; or for damage limited to propellers, wingtips, antennas, tires, brakes, fairings, small dents or puncture holes in the aircraft skin); or (c) the aircraft is missing or is completely inaccessible.

There are caveats to be aware of when using ASRS data: incidents are reported voluntarily, are subject to self-reporting biases, and are not corroborated by the Federal Aviation Administration (FAA) or the National Transportation Safety Board. Voluntary incident reports cannot be considered to be a representative sample of the underlying population of events they describe (Ref. 4). Also, only a fraction of the incidents reported are found in the public database because of the lack of resources for reviewing and categorizing incidents as they are received. Even though the data cannot be used for statistical or trend analysis, they can be used to identify vulnerabilities and to gain a better understanding of the root causes of human error. Also, they should be considered to complement data generated by mandatory, statistical, and monitoring systems.

The data received from ASRS contained a variety of information for each incident including FAR part, phase of flight, flight conditions, and narrative. The following AEST search criteria categories were used in this analysis:

1. FAR part
2. Phase of flight
3. Flight crew results
4. General results
5. Anomalies
    a. In-flight event or encounter
    b. Ground event or encounter
    c. Ground incursion
    d. Conflict
    e. Procedural deviation
    f. Altitude deviation
    g. Aircraft equipment problem
    h. Track/heading deviation
    i. Flight planning

6. Flight conditions
7. Visibility weather element
8. Air traffic control (ATC) results
9. Route in use
10. U.S. region

ASRS category definitions used in this report are listed in Appendix B. Most category options are not mutually exclusive, which can cause an incident to have multiple values under a single category. For example, an icing-related incident by phase of flight could be counted twice if the incident occurred during both cruise and descent phases of flight.

3.0 Technical Challenge 2: Airframe Icing Simulation and Engineering Tool Capability

TC2 consists of airframe ice accretion and aerodynamic performance degradation, including freezing rain and freezing drizzle conditions. Several data sets were used for the TC2 analyses. The weather-related data sets included factors such as icing conditions, thunderstorms, turbulence, windshear, runway, taxiway, or ramp icing, and deicing. The weather-related incident narratives and synopses were searched (free-string text) for "ic% OR rime OR rhime OR de-ice OR sleet OR frost" and reviewed to create the icing-related dataset as shown in Table 1.

TABLE 1.—UPDATE OF ICING- AND WEATHER-RELATED INCIDENTS IN THE ASRS[A]

Year	Icing and weather incidents									
	2008 NASA icing paper (Ref. 5)			Update to NASA icing paper			1994 to 2011 data for FAR[b] Parts 121, 135, and 91 combined			
	Total in ASRS	Weather-related	Icing-related	Total in ASRS	Weather-related	Icing-related	Weather-related	Airframe-icing-related	Airframe icing, percent	
									Weather-related	Total in ASRS
1994				6 764	300	44	282	30	10.6	0.44
1995				9 125	352	55	343	38	11.1	0.42
1996				8 044	378	45	346	28	8.1	0.35
1997	8 018	332	52	8 017	332	45	307	27	8.8	0.34
1998	8 428	276	34	8 428	276	22	250	18	7.2	0.21
1999	9 866	245	29	9 868	245	22	233	17	7.3	0.17
2000	7 998	232	38	7 999	232	26	229	17	7.4	0.21
2001	8 612	197	21	8 618	197	17	140	11	7.9	0.13
2002	7 198	201	26	7 200	201	22	200	10	5.0	0.14
2003	8 143	266	32	8 143	226	24	226	11	4.9	0.14
2004	6 200	161	27	6 205	161	22	161	12	7.5	0.19
2005	3 524	109	25	3 534	109	19	108	12	11.1	0.34
2006	5 196	188	11	6 574	140	13	138	8	5.8	0.12
2007				5 131	80	8	79	4	5.1	0.08
2008				6 476	138	24	133	9	6.8	0.14
2009				5 303	137	102	129	8	6.2	0.15
2010				5 485	121	94	118	7	5.9	0.13
2011				2 877	112	82	104	8	7.7	0.28
Total	73 183	2207	295	123 791	3737	686	3526	275		

[a]Aviation Safety Reporting System.
[b]Federal Aviation Regulations.

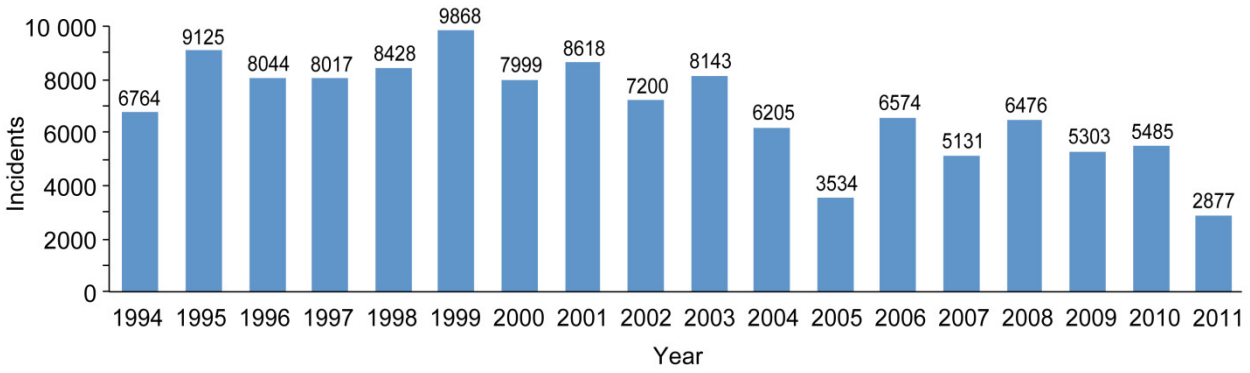

Figure 1.—Total number of incidents in the Aviation Safety Reporting System.

TABLE 2.—SUMMARY OF 2008 NASA ICING PAPER INCIDENTS AND UPDATE THROUGH 2011 BY FAR PART

FAR Part	Incidents			
	1997 to 2006	1994 to 2011		
	2008 NASA icing paper	Weather-related	Update to NASA icing paper	Airframe-icing-related
121	131	2190	332	51
135	25	245	67	42
91	129	1091	287	182
Total	285	3526	686	275

The Aviation Safety Systems Analysis team published a report entitled "Subsonic Aircraft Safety Icing Study" (Ref. 5) and is referred to in this report as the "2008 NASA icing paper." At the time of the study, there were 73 183 incidents in the ASRS database from 1997 through 2006. The study found 2207 weather-related incidents and 295 icing-related incidents for the same timeframe.

A new search of the ASRS database from 1994 to 2011 was performed following the same methods as the 2008 NASA icing paper. Section 3.1 through 3.4 presents an update to Section 2 of the 2008 NASA icing paper and is hereafter referred to as the "update to the NASA icing paper." At the time of the updated analysis, the ASRS online database contained 123 791 incidents, and the search resulted in 3737 weather-related incidents and 686 icing-related incidents. Figure 1 shows the results of the weather-related incidents by year.

The updated weather-related data set was further reduced to 3526 incidents because the AEST project is only interested in FAR Parts 121, 135, and 91. To analyze airframe-icing-related incidents more precisely, the weather-related incident narratives were searched for "ice" or "icing." The resulting data set that contained 275 incidents will be referred to as the "airframe-icing-related" incidents.

3.1 Federal Aviation Regulations Parts

Table 2 shows the 2008 NASA icing paper results and the updated results for each FAR part. Of the total 3526 weather-related incidents for 1994 to 2011, most were categorized as Part 121, followed by Part 91. Only 245 weather-related incidents were reported for Part 135. The updated analysis resulted in 686 icing-related incidents compared to 285 in the 2008 NASA icing paper. There were 332 Part 121 incidents in the updated analysis compared to 131 in 2008. Finally, the updated results showed 275 total airframe-icing-related incidents; most were in Part 91 with 182 incidents, followed by Part 121 with 51, and Part 135 with 42.

Figure 2 and Figure 3 show respective annual weather-related and airframe-icing-related incidents for each of the three FAR parts. Even though there has been a downward trend in reported weather and airframe-icing incidents over the last 18 yr, it is uncertain whether the trend is due to fewer actual incidents or to fewer

reported incidents. Because the ASRS is a voluntary reporting system and not all reports submitted actually make it into the searchable database, trend analysis is not recommended for ASRS data.

Figure 4 compares the percentage of airframe-icing-related incidents to weather-related incidents for each year. Part 121 incidents stayed between 0 and 9 percent for the 18-yr period, and averaged 2.3 percent. Part 91 incidents fluctuated between 11.4 and 24.4 percent, and averaged 16.4 percent. Part 135 incidents varied significantly, with 100 percent of the weather-related incidents being airframe-icing-related in 2008, but they were not listed as weather-related incidents in 2000, 2003, 2006, and 2007. More airframe-icing-related incidents were reported for Part 91 each year than for Parts 121 and 135.

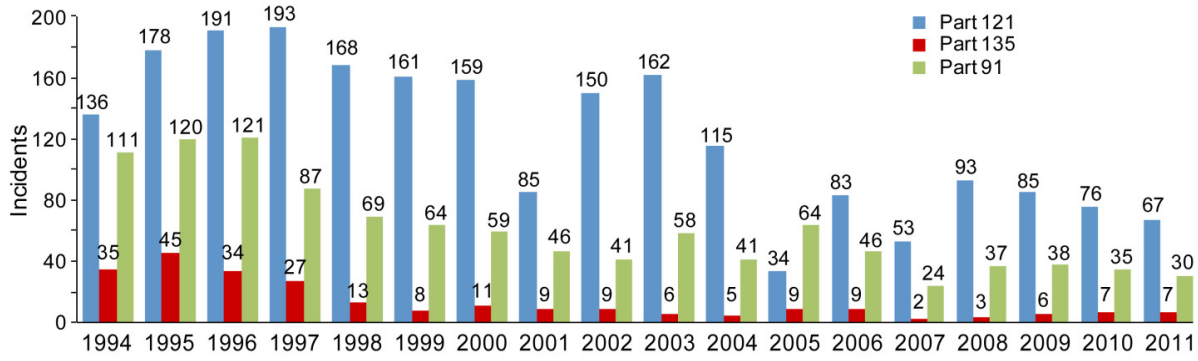

Figure 2.—Annual weather-related incidents.

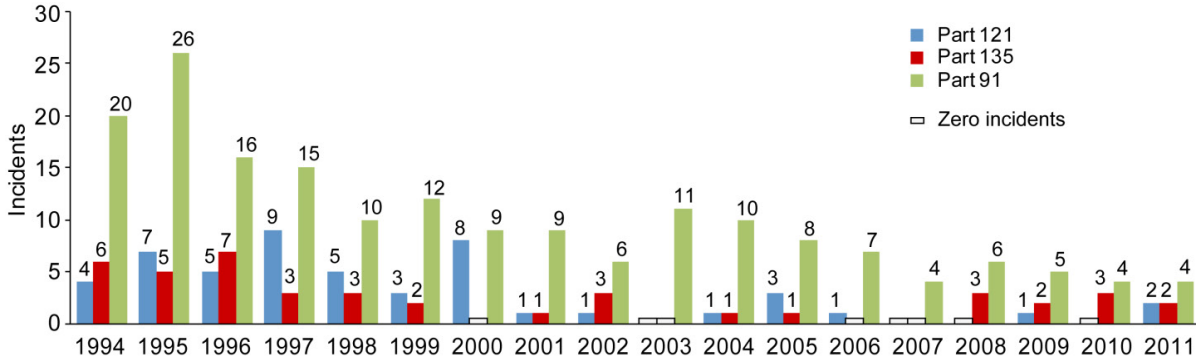

Figure 3.—Annual airframe-icing-related incidents.

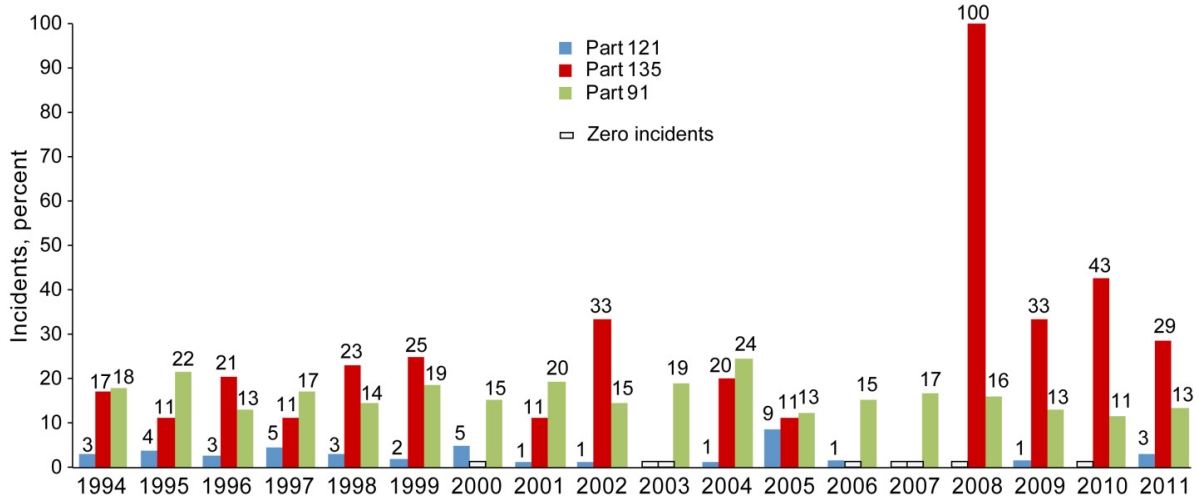

Figure 4.—Airframe-icing-related incidents compared to weather-related incidents per year, percent.

TABLE 3.—UPDATE OF ICING-RELATED INCIDENTS BY PHASE OF FLIGHT FOR FAR PARTS 121, 135, AND 91 COMBINED

Phase of flight	Incidents		
	Weather-related	Update to NASA icing paper	Airframe-icing-related
Taxi	167	62	0
Takeoff	167	33	5
Initial climb	121	20	10
Climb	285	54	25
Cruise	1495	292	168
Descent	447	101	58
Initial approach	767	95	49
Final approach	32	24	4
Landing	644	75	23
Parked	168	62	3
Phase listed	3412	667	269
Phase not listed	114	19	6

3.2 Phase of Flight

Table 3 shows an update to the icing-related incidents by phase of flight. Of the total 3526 weather-related incidents, 3412 listed a phase of flight and 269 airframe-icing-related incidents listed a phase of flight. The largest number of incidents occurred during cruise, followed by initial approach, landing, and descent, respectively.

3.3 Flight Crew and General Results

The flight crew and general results categories were labeled “Incidents by Resolutory Actions” in the 2008 NASA icing paper (Ref. 5). The current ASRS database keeps this type of data in the *flight crew results* and *general results* categories. The *flight crew results* show the types of actions taken by the flight crew or others to resolve the airframe-icing-related anomalies. There were 116 incidents that listed 1 or more *flight crew results* and 159 that did not. Under *flight crew results*, the largest result was regained aircraft control (39), followed by aircraft diverted (32), and took evasive action (22) as shown in Figure 5. The flight crew overcame equipment problems in 17 incidents and returned to clearance in 16 incidents.

Figure 6 shows that the *general results* category included incidents in five of the nine possible results. There were 119 incidents that listed 1 or more *general results*. Declare an emergency was the largest result with 69 incidents. This is fewer than the 141 incidents in the 2008 NASA icing paper and is most likely because the category was narrowed down to airframe-icing-related incidents only. Many of the *declare emergency* incidents were due to icing on the aircraft, meaning that declaring an emergency was the only way the pilot could get clearance from ATC to maneuver out of the icing conditions to a different altitude.

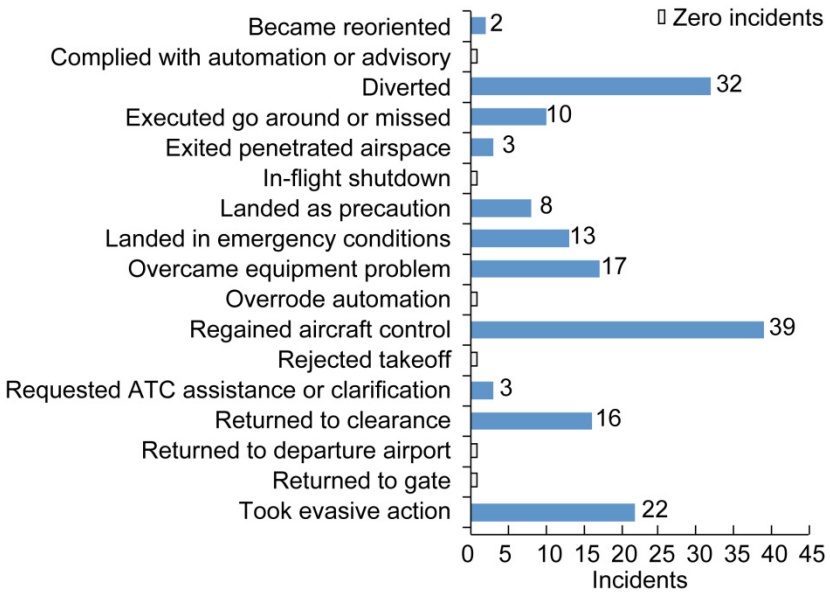

Figure 5.—Flight crew results for airframe-icing-related incidents.

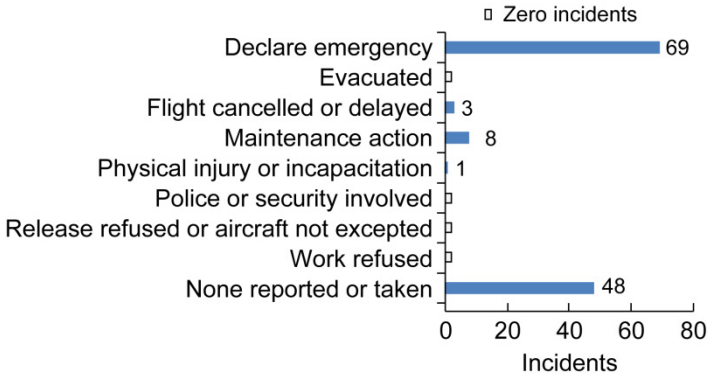

Figure 6.—General results for airframe-icing-related incidents.

TABLE 4.—CARBURETOR ICING INCIDENTS IN THE ASRS

Year	1994	1995	1996	1998	2000	2001	2003	2010	2011
Incidents/year	1	1	1	2	1	1	1	1	1

3.4 Carburetor Icing

Table 4 shows the 10 carburetor icing incidents found between 1994 and 2011. The weather primary problems data set was searched for “ice” OR “icing” AND “carb” and the narratives were read to ensure that the incidents were related to carburetor icing.

3.5 Anomaly Categories

An anomaly is an abnormality that occurs during an incident. Table 5 shows the anomaly categories for the 2008 NASA icing paper, the updated results, and weather and airframe icing results for Parts 121, 135, and 91. The 2008 NASA icing paper grouped ATC issues, procedural deviation, track/heading deviation, and speed deviation into a nonadherence category.

The greatest number of incidents listed was in the anomaly category of *in-flight event or encounter*, *procedural deviation*, *altitude deviation*, and *aircraft equipment*. Table 6 to Table 9 look more closely at each of the anomaly categories by FAR part for airframe-icing-related incidents.

3.5.1 In-Flight Event or Encounter

The *in-flight event or encounter anomaly* category covers problems such as loss of control (LOC), weather or turbulence, flying under visual flight rules in instrument meteorological conditions (VFR in IMC), and controlled flight toward terrain or controlled flight into terrain (CFTT or CFIT). Table 6 shows the in-flight event or encounter anomalies for airframe-icing-related incidents. The airframe-icing-related data listed an *in-flight event or encounter anomaly* for 268 incidents, with over two-thirds for Part 91. Weather or turbulence was the most frequently cited problem, followed by other or unknown, and LOC for all three FAR parts combined and individually.

TABLE 5.—ANOMALY INCIDENTS BY SEARCH CRITERIA

Anomaly	Incident search criteria			
	2008 NASA icing paper	Update to NASA icing paper	FAR Parts 121, 135, and 91 combined	
			Weather-related	Airframe-icing-related
Aircraft equipment problem	172	142	407	73
Airspace violation	5	7	75	0
Altitude deviation	165	139	665	74
Conflict	28	28	249	5
Flight deck or cabin aircraft event	8	16	0	0
Ground event encounter	12	62	168	3
Ground excursion	156	19	65	2
Ground incursion	7	4	31	0
In-flight event or encounter	532	574	3103	268
Other	415	183	1402	96
Nonadherence	267			
ATC issues		42	87	4
Procedural deviation		251	1532	111
Speed deviation		44	160	7
Track or heading deviation		66	475	23
Total	663	686	3526	275

TABLE 6.—AIRFRAME-ICING-RELATED INCIDENTS BY IN-FLIGHT EVENT OR ENCOUNTER ANOMALY AND FAR PART

In-flight event or encounter	Incidents			
	FAR Part			Total
	121	135	91	
Bird or animal	0	0	0	0
CFTT or CFIT[a]	0	2	6	8
Fuel issue	1	1	0	2
LOC	9	11	33	53
Object	0	0	0	0
Unstabilized approach	3	0	1	4
VFR in IMC[b]	0	0	10	10
Wake vortex encounter	0	0	0	0
Weather or turbulence	44	38	170	252
Other or unknown	16	11	55	82
Total	51	42	182	268

[a]Controlled flight toward terrain or controlled flight into terrain.
[b]Visual flight rules in instrument meteorological conditions.

3.5.2 Procedural Deviation

Table 7 shows the *procedural deviation anomalies* for airframe-icing-related incidents by procedural deviation type and FAR part. Of the 111 total *procedural deviation anomalies* for all 3 FAR parts, clearance was listed in 55 percent and Federal Aviation Regulations was listed in 46 percent. Clearance problems usually involved aircraft changing flight direction because of weather in the area or by aircraft that could not maintain altitude because of icing. Many pilots requested different headings or altitudes but were told to wait by ATC, which caused the pilots to make changes without proper clearance. In some cases the pilots were unable to communicate with the ATC because of ice buildup on the aircraft antennas. Of the 61 clearance anomalies, 43 incidents were for Part 91 and 14 were in Part 121. The Federal Aviation Regulations category involves noncompliance with, or violation of, any regulation except during an emergency. Of the 51 total Federal Aviation Regulations incidents, 35 were for Part 91 and 8 each were for Parts 121 and 135. The third largest category was published material or policy, with 14 for Part 91, 11 for Part 121, and 4 for Part 135. Some of these incidents were related to the regulations covering takeoff or landing in known icing conditions.

3.5.3 Altitude Deviation

Table 8 shows the *altitude deviation anomalies* for airframe-icing-related incidents by altitude deviation type and FAR part. Of the total 74 incidents, 69 were excursions from assigned altitude, 5 were overshoots, 1 was an undershoot, and 1 crossing restriction was not met. Most of the excursions from assigned altitude were for Part 91 with 50 incidents, followed by Part 121 with 11, and Part 135 with 8. Many of these excursions took place when the aircraft could not maintain the assigned altitude because of icing in the area or ice buildup. General aviation aircraft (Part 91) are less likely to have the same deicing

TABLE 7.—AIRFRAME-ICING-RELATED INCIDENTS BY PROCEDURAL DEVIATION ANOMALY AND FAR PART

Procedural deviation	Incidents			
	FAR Part			Total
	121	135	91	
Clearance	14	4	43	61
Federal Aviation Regulations	8	8	35	51
Hazardous material violation	0	0	0	0
Landing without clearance	1	0	0	1
Maintenance	0	0	0	0
MEL[a]	0	0	0	0
Published material or policy	11	4	14	29
Security	0	0	0	0
Weight and balance	0	0	0	0
Other or unknown	3	0	1	4
Total	27	13	71	111

[a]Minimum equipment list.

TABLE 8.—AIRFRAME-ICING-RELATED INCIDENTS BY ALTITUDE DEVIATION ANOMALY AND FAR PART

Altitude deviation	Incidents			
	FAR Part			Total
	121	135	91	
Crossing restriction not met	1	0	0	1
Excursion from assigned altitude	11	8	50	69
Overshoot	1	1	3	5
Undershoot	1	0	0	1
Total	13	9	52	74

abilities that commercial aircraft have, and thus are more likely to have problems with maintaining or changing altitude because of icing conditions. Ten of the Part 91 incidents listed VFR in IMC and had either not filed a flight plan or were flying under VFR.

3.5.4 Aircraft Equipment Problem

The two types of *aircraft equipment problem anomalies* are critical and less severe. Table 9 shows the breakdown by type and FAR part. Of the 73 airframe-icing-related incidents that listed an aircraft equipment problem anomaly, 49 were critical and 24 were less severe. The largest number of critical equipment problems was for Part 91 with 31, followed by Part 121 with 11. Some of these incidents included deicing equipment not keeping up with ice accretion, loss of airspeed indicator, iced radio antennae, and propeller icing.

3.5.5 Track/Heading Deviation and Speed Deviation

There were 23 *track/heading deviation anomalies*: 19 for Part 91 and two each for Parts 135 and 121. Most of these anomalies were caused by changes in aircraft direction to get out of icing conditions. There were seven speed deviation anomalies with four for Part 121, two for Part 91, and one for Part 135.

3.6 Flight Plan and Flight Conditions

Table 10 shows the flight conditions and the flight plan filed by the pilot by FAR part. The pilots flew under instrument flight rules (IFR) for all of Part 121 incidents, all but two Part 135 incidents, and the majority of Part 91 incidents.

TABLE 9.—AIRFRAME-ICING-RELATED INCIDENTS BY AIRCRAFT EQUIPMENT PROBLEM ANOMALY AND FAR PART

Aircraft equipment problem	Incidents			
	FAR Part			Total
	121	135	91	
Critical	11	7	31	49
Less severe	9	3	12	24
Total	20	10	43	73

TABLE 10.—AIRFRAME-ICING-RELATED INCIDENTS BY FLIGHT CONDITIONS, FLIGHT PLAN, AND FAR PART

Flight conditions or plan	Incidents			
	FAR Part			Total
	121	135	91	
Flight conditions				
IMC[a]	46	34	138	218
Marginal	0	2	4	6
Mixed	4	2	27	33
VMC[b]	1	4	8	13
Flight conditions listed	51	42	177	270
Flight plan				
DVFR[c]	0	0	1	1
IFR[d]	51	38	164	253
VFR[e]	0	0	9	9
No flight plan filed	0	2	8	10
Flight plan listed	51	40	181	272

[a]Instrument meteorological conditions.
[b]Visual meteorological conditions.
[c]Defense visual flight rules.
[d]Instrument flight rules.
[e]Visual flight rules.

3.7 Weather Element—Visibility

Table 11 shows the *visibility weather element* conditions for the airframe-icing-related incidents by FAR part. Of the 21 incidents for Part 121 that listed 1 or more weather element, all 21 incidents listed icing, 8 also listed snow, 5 rain, 6 turbulence, and 4 thunderstorms. Of the 18 airframe-icing-related incidents for Part 135, 16 incidents also listed icing, 6 listed rain, 3 thunderstorms, and 3 turbulence. Of the 95 incidents for Part 91, all 95 listed weather, 94 also listed icing, 24 rain, 20 turbulence, 9 snow, and 8 thunderstorms.

3.8 Air Traffic Control Results

Table 12 shows the *ATC results* for the airframe-icing-related incidents by FAR part. Controllers issued new clearances in 71 incidents and provided assistance in 53. Most of the new clearances (55) and assistance (46) incidents were for FAR Part 91. These results included issuing new clearances to avoid icing conditions or providing assistance to get around storms.

TABLE 11.—AIRFRAME-ICING-RELATED INCIDENTS BY VISIBILITY WEATHER ELEMENT AND FAR PART

Visibility weather element	Incidents			
	FAR Part			Total
	121	135	91	
Cloudy	0	0	0	0
Fog	1	1	5	7
Hail	0	0	0	0
Haze or smoke	0	0	0	0
Icing	21	16	94	131
Rain	5	6	24	35
Snow	8	1	9	18
Thunderstorm	4	3	8	15
Turbulence	6	3	20	29
Windshear	2	1	5	8
Weather conditions listed	21	18	95	134
Weather conditions not listed	30	24	87	141

TABLE 12.—AIRFRAME-ICING-RELATED INCIDENTS BY AIR TRAFFIC CONTROL RESULTS AND FAR PART

ATC results	Incidents			
	FAR Part			Total
	121	135	91	
Issued advisory or alert	1	1	8	10
Issued new clearance	10	6	55	71
Provided assistance	3	4	46	53
Separated traffic	1	0	1	2
Total	11	9	89	109

3.9 Route in Use

Table 13 shows the route used by the aircraft during airframe-icing-related incidents. The majority of the airframe-icing-related incidents (275 incidents of the 364 total) did not list the route in use. For Part 121 aircraft that did list a route in use, 9 of the 10 total incidents listed using a vector route and 1 an oceanic route. For Part 135, five aircraft used a vector route and one a direct route. For Part 91, 73 incidents listed a route: 54 aircraft used a vector route, 19 a direct route, and 2 a VFR route. The single oceanic route listed for Part 91 was a turbofan corporate jet that flew into icing conditions and made an excursion from the assigned altitude because it could not maintain altitude.

3.10 U.S. Region

Table 14 shows the occurrence of airframe-icing-related incidents in each major region of the United States. There were 236 airframe-icing-related incidents that listed the state where the incident took place. States were grouped into West, Midwest, South, and Northeast regions.

The West had the most icing incidents (86), with 58 for Part 91, 18 for Part 121, and 10 for Part 135. Figure 7(a) shows the western U.S. breakdown by state. California had the greatest number of incidents in Parts 121 and 91 incidents (6 and 13, respectively), followed by Colorado (4 and 11, respectively), and Washington (2 and 10, respectively). Both New Mexico and Arizona each had two incidents for Part 135.

TABLE 13.—AIRFRAME-ICING-RELATED INCIDENTS
BY ROUTE IN USE AND FAR PART

Route in use	Incidents			
	FAR Part			Total
	121	135	91	
Direct	0	1	19	20
Oceanic	1	0	1	2
Vector	9	5	54	68
VFR[a] route	0	0	2	2
Visual approach	0	0	1	1
None	0	0	0	0
Route listed	10	6	73	89
Route not listed	51	42	182	275

[a]Visual flight rules.

TABLE 14.—AIRFRAME-ICING-RELATED INCIDENTS
BY U.S. REGION AND FAR PART

Region	Incidents			
	FAR Part			Total
	121	135	91	
West	18	10	58	86
Midwest	11	11	44	66
South	11	7	28	46
Northeast	5	3	30	38
Total	45	31	160	236

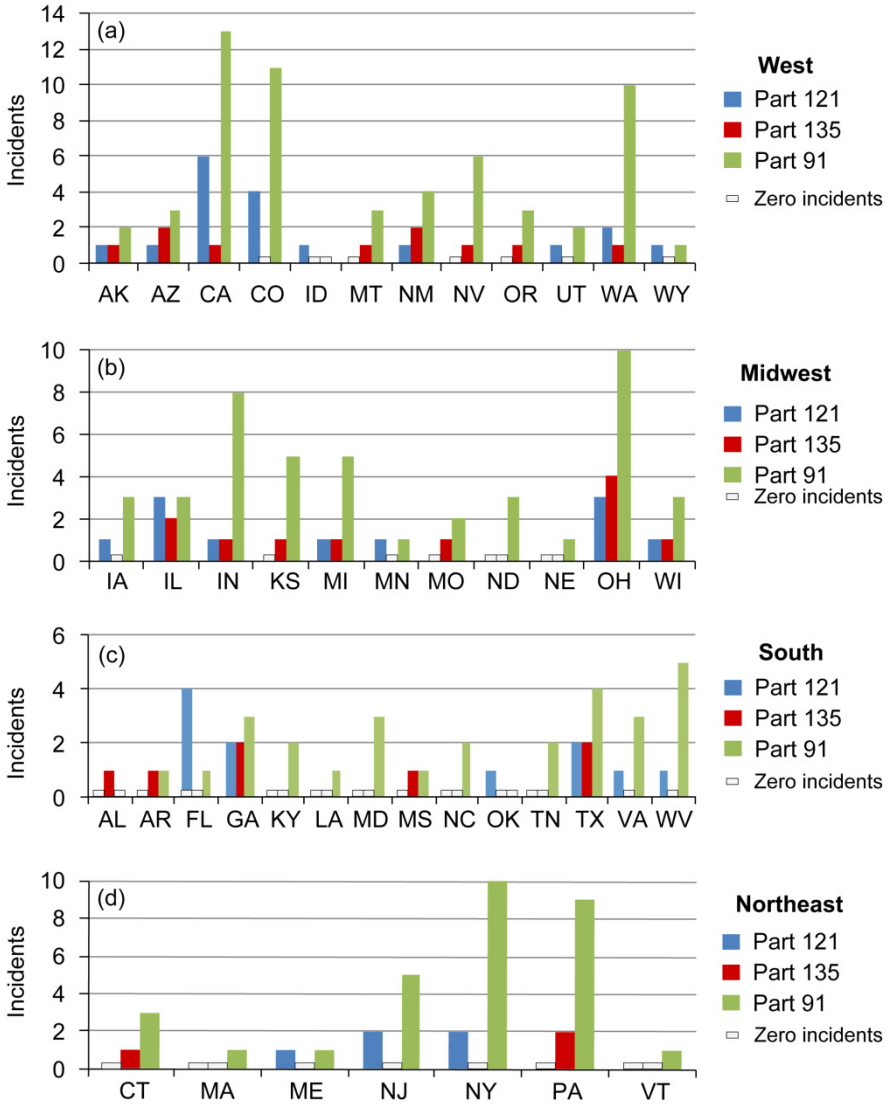

Figure 7.—Airframe-icing incidents by U.S. region and FAR part. (a) West. (b) Midwest. (c) South. (d) Northeast.

Figure 7(b) shows the Midwest's 38 airframe-icing-related incidents. Ohio had 10 incidents for Part 91, 3 for Part 121, and 4 for Part 135, followed by Indiana with 8 for Part 91, and 1 each for Parts 121 and 135.

Figure 7(c) shows the South, which had 28 incidents for Part 91 across 12 states; 11 incidents for Part 121 across 6 states, and 7 incidents for Part 135 across 5 states. For Part 121 the most incidents occurred in Florida with four, followed by Georgia and Texas with two each. For Part 135, two incidents each occurred in Georgia and Texas. West Virginia had the most: Part 91 incidents with five, followed by Texas with four, and Georgia, Maryland, and Virginia with three each.

Figure 7(d) shows the Northeast, which had the fewest number of incidents. For Part 91 there were 30 incidents across 7 states, with the most in New York (10) and Pennsylvania (9). For Part 121 there were only five incidents in three states, with New Jersey and New York each with two incidents. For Part 135 only three incidents were reported in the Northeast: Pennsylvania with two and Connecticut with one.

3.11 Technical Challenge 2—Conclusion

The ASRS analysis for TC2, airframe icing simulation and engineering tool capability, resulted in 275 incidents from January 1994 to November 2011 for FAR Parts 121, 135, and 91. The updated AEST analysis studied the 2008 NASA icing paper (Ref. 5) incidents in more detail to confirm that they were in-flight airframe-icing-related incidents and not runway or deicing incidents. The current analysis determined that the number of incidents decreased over what was previously shown. Since 1994, fewer incidents were submitted or entered into the ASRS database from a high of 9868 in 1999 to a low of 3534 in 2005.

When the data were broken down by FAR part, there were 51 icing incidents for Part 121, 42 for Part 135, and 182 for Part 91. For some years, no airframe-icing-related incidents were entered into the database for Parts 121 or 135. The cruise, descent, and initial approach phases of flight had the greatest number of incidents. The *visibility weather element anomaly* was listed in 131 of the 134 icing incidents, with rain listed in 35, and turbulence listed in 29, although weather or turbulence was an in-flight event in 252 of the 275 incidents.

A majority of the flights filed an IFR flight plan (93 percent) and flew in IMC (80 percent). Of the 109 incidents for *ATC results*, 71 were issued a new clearance, 53 were provided assistance, 10 were issued an advisory or alert, and 2 were separated traffic. Only 11 *ATC results* were for Part 121, but Part 91 had 89. The *general results* had 69 incidents where the flight crew declared an emergency and the *flight crew results* had 32 aircraft that diverted to other airports, many of these due to the need to exit icing conditions. Sixty-nine incidents from the *altitude deviation anomaly* involved an excursion from the assigned altitude. Fifty-three incidents under *in-flight event or encounter* reported an in-flight LOC. Thirty-nine *flight crew result* incidents reported that the flight crew regained control.

Most airframe-icing-related incidents, 86 of the 236, occurred in the West. California had 20 incidents, more than any other state; of these, 6 were for Part 121 and 13 were for Part 91. In the Midwest, Ohio, with 17 incidents, was second. Of these, 3 incidents were for Part 121, 10 were for Part 91, and 4 were for Part 135. Surprisingly, Alaska had only four reported airframe-icing-related incidents.

4.0 Technical Challenge 3: Atmospheric Hazard Sensing and Mitigation Technology Capability

The objective of TC3 is to improve and expand the remote sensing and mitigation of hazardous atmospheric environments and phenomena (Ref. 1) by

- Maturing technologies for real-time sensing and measurement of icing, turbulence, and wake vortex
- Dealing with low-visibility conditions for safer runway operations
- Developing technologies for lightning-immune composite aircraft

More advanced, affordable, and improved methods must be developed to provide pilots with needed atmospheric information, as well as detecting, collecting, mitigating, and disseminating information.

To address TC3, the current analysis reviewed ASRS data in the following areas:

1. Clear air turbulence (CAT)
2. Wake vortex
3. Windshear
4. St. Elmo’s fire
5. Volcanic ash
6. CFTT or CFIT
7. Ground event or encounter
8. Ground incursion
9. Midair collision hazard

Turbulence and wake vortex from the first TC3 goal are addressed with the ASRS analysis on CAT, wake vortex, and windshear.

Although not specifically mentioned in the TC3 goals, volcanic ash and midair collision hazards were also analyzed for relevance to maturing technologies for real-time sensing and measurement. To address low-visibility conditions for safer runway operation, ASRS data relating to CFTT or CFIT, ground event or encounter, and ground incursion were analyzed. The St. Elmo's fire data analysis can be indirectly applied to lightning-immune aircraft technology development because St. Elmo's fire is thought to be a precursor to lightning strikes. Lightning was not included in this analysis because that work is planned for the future.

Current remote-sensing capabilities to detect CAT, wake vortex, icing, and low-visibility aircraft environments are insufficient. The AEST project is working on technologies to provide real-time information to pilots and controllers in the national airspace with a broader range of atmospheric hazards information.

4.1 Clear Air Turbulence

The AEST project is working on atmospheric hazard sensing of CAT that is not associated with clouds and thus cannot be detected visually or by conventional weather radar. CAT can be caused by terrain, thunderstorm complexes, and jet streams, especially at the edges of the jet stream. CAT can damage aircraft structures, injure crew or passengers, and impair flight crew performance by making it difficult to read instruments.

There were 4647 incidents in the ASRS database that listed the primary problem as either weather- or environment-nonweather-related. Of the total number, 916 listed turbulence as a *visibility weather element* and 986 mentioned CAT in the *narrative*. Only 177 incidents mentioned CAT in the *narrative* and turbulence as a *visibility weather element*, meaning that 809 incidents mentioned CAT in the *narrative* but did not list turbulence, and that 739 incidents listed turbulence as a *visibility weather element* but did not mention CAT.

Because the database does not have a specific option for CAT, it is hard to be certain that CAT has been reported properly. The only way to determine if CAT occurred is by reading the narrative and not all incidents contain enough detail. It should not be assumed that all turbulence *visibility weather elements* are associated with CAT. It is also possible that weather caused some flights to experience CAT and turbulence at different times. For the remainder of this section, only the 986 incidents that specifically mentioned "CAT" or "clear air turbulence" in the narrative are discussed. Although the narratives mention CAT, it does not necessarily mean that CAT was the primary cause of each incident. A more detailed study would be required to make that determination.

Sorting the CAT-related incidents by FAR part resulted in 621 incidents for Part 121, 68 for Part 135, and 297 for Part 91. Figure 8 shows the number of incidents that mentioned CAT in the narrative by year and FAR part. Comparing these data to the number of incidents in the database by year did not show any pattern, except a large decrease in the number of reported incidents from 2009 to 2011. This decrease could have been because fewer incidents mentioned CAT, fewer incidents were reported, or not all reported CAT incidents were entered into the database. Until 2009, an average of 0.91 percent of all incidents mentioned CAT.

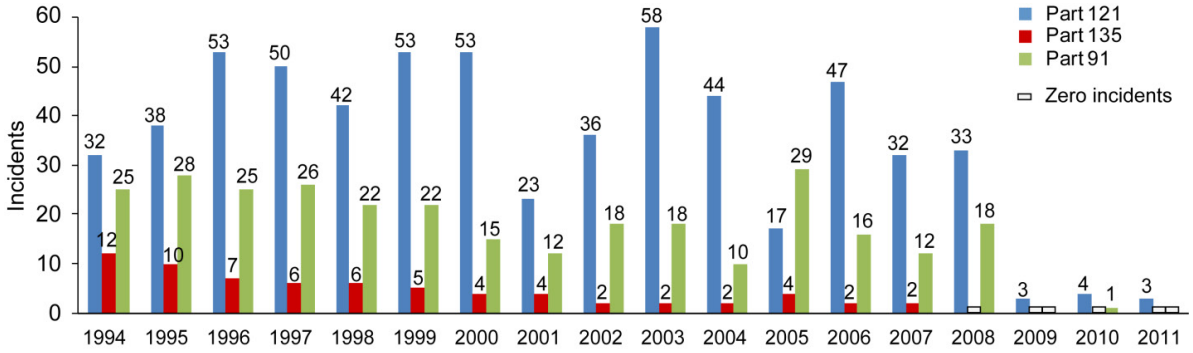

Figure 8.—Annual clear air turbulence-related incidents by FAR part.

Figure 9 shows the 349 *visibility weather element* incidents that mention CAT in the narrative. Many more Part 121 incidents (132) mentioned CAT than Part 135 (91). Of the Part 121 incidents that mentioned CAT, the following weather elements were also listed: thunderstorms (47), rain (21), and windshear (14).

Figure 10 shows CAT-related incidents by phase of flight. The greatest number of incidents occurred during cruise, followed by initial approach. A phase of flight was reported for 949 incidents and sometimes more than 1 phase of flight was reported for an incident.

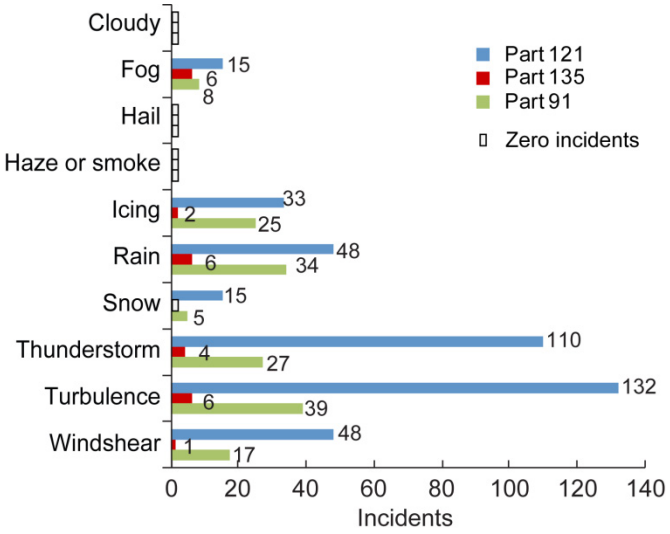

Figure 9.—Visibility weather elements for clear air turbulence-related incidents by FAR part.

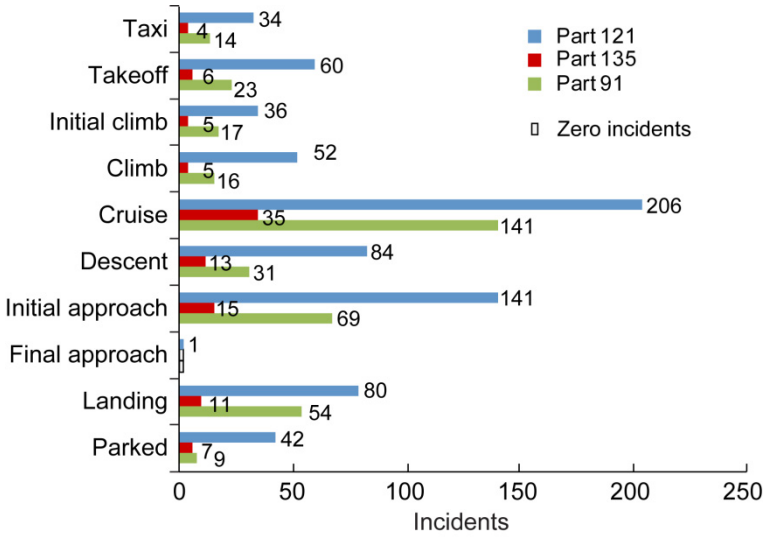

Figure 10.—Phase of flight for clear air turbulence-related incidents by FAR part.

As shown in Table 15, 578 CAT-related incidents reported 1 or more *general result*. The largest category was declare emergency with 173 incidents (117 in Part 121), followed by maintenance action with 119 incidents (95 in Part 121), and physical injury or incapacitation with 95 incidents (89 in Part 121). Many of the physical injuries were to the flight attendants when the planes hit turbulence.

Table 16 shows the *flight crew results* for CAT incidents. There were 437 total CAT-related incidents that reported a flight crew result. The largest category was regained control of the aircraft, with 117 incidents (77 for Part 121), followed by 96 incidents where the aircraft returned to clearance (71 for Part 121), 90 incidents where the aircraft diverted to another airport (53 for Part 121), and 88 incidents where the flight crew took evasive action (62 for Part 121).

TABLE 15.—CLEAR AIR TURBULENCE-RELATED INCIDENTS
BY GENERAL RESULTS AND FAR PART

General results	Incidents			
	FAR Part			Total
	121	135	91	
Declare emergency	117	16	40	173
Evacuated	0	0	0	0
Flight canceled or delayed	11	0	3	14
Maintenance action	95	2	22	119
Physical injury or incapacitation	89	2	4	95
Police or security involved	0	0	0	0
Release refused or aircraft not accepted	0	0	0	0
Work refused	0	0	0	0
None reported or taken	223	29	91	343
Total	393	43	142	578

TABLE 16.—CLEAR AIR TURBULENCE-RELATED INCIDENTS
FOR FLIGHT CREW RESULTS AND FAR PART

Flight crew results	Incidents			
	FAR Part			Total
	121	135	91	
Became reoriented	11	1	8	20
Diverted	53	3	34	90
Executed go around or missed approach	49	1	12	62
Exited penetrated airspace	5	0	10	15
Complied with automation or advisory	0	0	0	0
Overrode automation	13	0	1	14
In-flight shutdown	0	0	0	0
Landed as precaution	14	2	21	37
Landed in emergency conditions	31	1	10	42
Overcame equipment problem	9	0	11	20
Regained aircraft control	77	3	37	117
Rejected takeoff	11	0	4	15
Requested ATC assistance or clarification	0	0	0	0
Returned to clearance	71	3	22	96
Returned to departure airport	0	0	0	0
Returned to gate	0	0	0	0
Took evasive action	62	6	20	88
Total	292	17	128	437

The *in-flight event or encounter* results for CAT-related incidents are shown in Table 17. There were 677 CAT incidents that reported weather or turbulence affected the flight, with 409 incidents for Part 121 alone. There were 142 incidents that reported an LOC, with 80 incidents for Part 121.

Table 18 shows the *flight conditions* and *the flight plan* filed for the CAT-related incidents. For the 3 FAR parts combined, 342 incidents were under VMC compared with 309 incidents under IMC; 52 aircraft flew in marginal flight conditions and 130 in mixed conditions. For Part 121 there were 211 CAT incidents with VMC flight conditions and 186 in IMC. As would be expected for Part 121 incidents, 617 were under an IFR flight plan and only 1 did not have a flight plan filed. Part 91 had 129 IFR incidents, 53 VFR incidents, 112 without a flight plan filed, 116 incidents in VMC, and 93 in IMC.

TABLE 17.—CLEAR AIR TURBULENCE-RELATED INCIDENTS FOR IN-FLIGHT EVENT OR ENCOUNTER ANOMALY AND FAR PART

In-flight event or encounter	Incidents			
	FAR Part			Total
	121	135	91	
Bird or animal	53	0	4	57
CFTT or CFIT[a]	2	3	13	18
Fuel issue	1	0	0	1
LOC[b]	80	7	55	142
Object	0	0	0	0
Unstabilized approach	13	1	6	20
VFR in IMC[c]	4	11	72	87
Wake vortex encounter	17	0	4	21
Weather or turbulence	409	52	216	677
Other or unknown	109	11	49	169
Total	529	59	263	851

[a]Controlled flight toward terrain or controlled flight into terrain.
[b]Loss of control.
[c]Visual flight rules in instrument meteorological conditions.

TABLE 18.—CLEAR AIR TURBULENCE-RELATED INCIDENTS BY FLIGHT CONDITIONS OR FLIGHT PLAN, AND FAR PART

Flight conditions or flight plan	Incidents			
	FAR Part			Total
	121	135	91	
Flight conditions				
IMC[a]	186	30	93	309
Marginal	14	6	32	52
Mixed	67	14	49	130
VMC[b]	211	15	116	342
Flight condition total	478	65	290	833
Flight plan				
DVFR[c]	0	0	2	2
IFR[d]	617	45	129	791
SVFR[e]	0	0	4	4
VFR[f]	0	10	53	63
No flight plan filed	1	10	112	123
Flight plan total	618	65	292	975

[a]Instrument meteorological conditions.
[b]Visual meteorological conditions.
[c]Defense visual flight rules.
[d]Instrument flight rules.
[e]Special visual flight rules.
[f]Visual flight rules.

There are a few other categories for CAT incidents that might be interesting to consider. Almost 69 percent of the incidents (604) in the *environmental lighting category* occurred during daylight and 25 percent (223) occurred at night. The *aircraft results category* listed 126 aircraft as receiving damage out of the 130 that reported an aircraft result, with 80 of those in Part 121. An *altitude deviation* was reported in 167 CAT incidents. An *altitude excursion* was reported in 139 incidents with 88 of them in Part 121; 217 CAT incidents reported their *route*, with 106 vector routes, 45 oceanic, 44 visual approach, 31 direct, and 6 VFR.

4.2 Wake Vortex

Wake vortex—turbulence that is created by an aircraft in flight—is caused primarily by wingtip vortices. A wake vortex encounter occurs when an aircraft enters the wake vortex turbulence created by another aircraft. The decay of wingtip vortices can take several minutes and can cause a considerable rotational influence on the aircraft that passes through it. The strength of the vortex increases proportionately to the weight of the aircraft and is also influenced by the speed and wing shape of the aircraft generating it. Wake vortices are encountered most often during initial climb and final approach. The ASRS only started listing the option for wake vortex encounter in 1999.

Table 19 shows the *in-flight event or encounter anomalies*. In the data set used for this analysis, 234 incidents reported a wake vortex encounter: 176 for Part 121, 3 for Part 135, and 55 for Part 91. An LOC event occurred during 72 of the incidents: 47 for Part 121, 1 for Part 135, and 24 for Part 91. For Part 121, 7 unstabilized approaches and 8 weather or turbulence encounters were reported for the 176 wake vortex encounters.

Figure 11 shows the number of reported wake vortex encounter incidents by phase of flight. For all three FAR parts the greatest number of incidents occurred during initial approach. Part 121 had the most incidents with 54 occurring during initial approach, 37 during descent, and surprisingly 29 during cruise.

TABLE 19.—WAKE VORTEX-RELATED INCIDENTS BY IN-FLIGHT EVENT OR ENCOUNTER ANOMALY AND FAR PART

In-flight event or encounter	Incidents			
	FAR Part			Total
	121	135	91	
Bird or animal	0	0	0	0
CFTT or CFIT[a]	0	0	0	0
Fuel issue	0	0	0	0
LOC[b]	47	1	24	72
Object	0	0	0	0
Unstabilized approach	7	0	0	7
VFR in IMC[b]	0	0	0	0
Wake vortex encounter	176	3	55	234
Weather or turbulence	8	0	1	9
Other or unknown	3	0	0	3
Total	176	3	55	234

[a]Controlled flight toward terrain/controlled flight into terrain.
[b]Loss of control.
[c]Visual flight rules in instrument meteorological conditions.

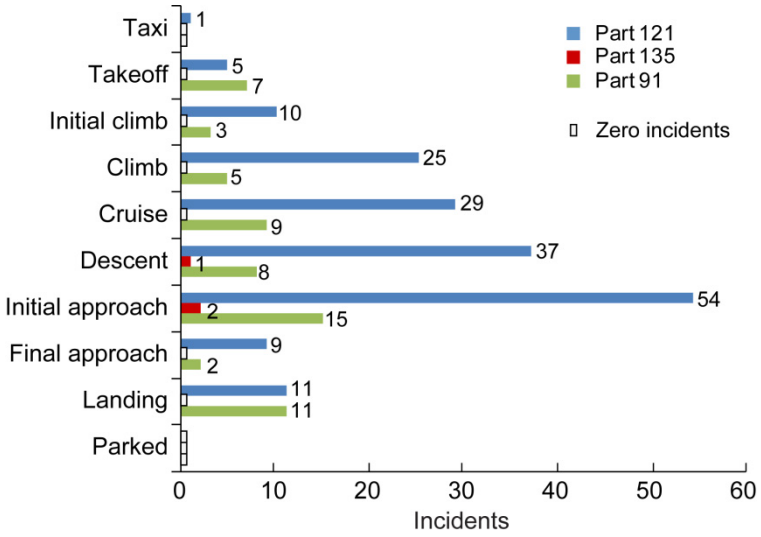

Figure 11.—Phase of flight for wake vortex encounters by FAR part.

TABLE 20.—WAKE VORTEX-RELATED INCIDENTS BY GENERAL RESULTS AND FAR PART

General results	Incidents			
	FAR Part			Total
	121	135	91	
Declare emergency	1	0	0	1
Evacuated	0	0	1	1
Flight canceled or delayed	0	0	0	0
Maintenance action	8	0	3	11
Physical injury or incapacitation	25	0	4	29
Police or security involved	0	0	0	0
Release refused or aircraft not accepted	0	0	0	0
Work refused	0	0	0	0
None reported or taken	44	0	11	55
Total	65	0	17	82

In the *general results* category for wake vortex encounters, there were 29 physical injuries or incapacitations, with 25 for Part 121. Eleven maintenance actions were required, as shown in Table 20.

Figure 12 shows the *flight crew results* for wake vortex encounters. There were a total of 142 incidents for *flight crew results*: 101 for Part 121, 3 for Part 135, and 38 for Part 91. In the 79 incidents where the flight crew regained control of the aircraft, 49 were for Part 121, 1 was for Part 135, and 29 were for Part 91. In the 32 incidents where the flight crew took evasive action, 25 were for Part 121, 1 for Part 135, and 6 for Part 91. The flight crew executed a go around or missed approach in 24 incidents, with 21 for Part 121 and 3 for Part 91. Returned to clearance was the only other category with more than 20 incidents, with 15 for Part 121, 1 for Part 135, and 5 for Part 91.

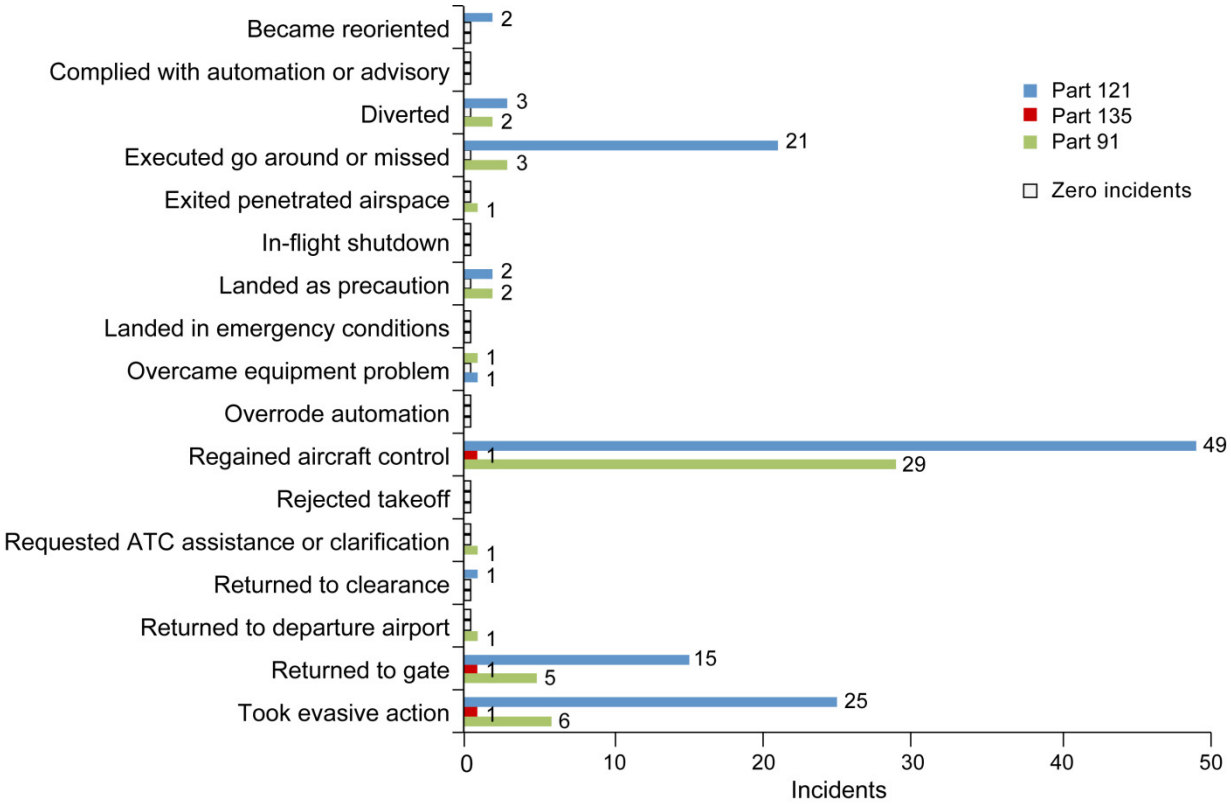

Figure 12.—Flight crew results for wake vortex encounters by FAR part.

4.3 Windshear

Windshear is a rapid change in wind current, both wind speed and direction, over a short distance in the atmosphere. According to an FAA advisory, a severe windshear is a rapid change in wind direction or velocity causing airspeed changes greater than 15 knot or vertical speed changes greater than 500 ft per minute (Ref. 6). Windshear is most dangerous to aircraft at low altitudes and in particular, at takeoff and landing because of the short amount of time and distance for recovery. Windshear conditions can occur in thunderstorms, rain, strong surface winds, frontal systems, sea breezes, temperature inversions, and because of topographical conditions. Windshear is not always associated with rain.

The ASRS database added a windshear option under the weather search option in 1999. From 1999 through 2011, 355 incidents that listed the primary problem as either weather- or environment-nonweather-related had a *windshear element*: 244 incidents were for Part 121, 9 for Part 135, and 102 for Part 91. Windshear incidents by year and FAR part can be seen in Figure 13 and Table 21. Windshear accounts for 8 to 16 percent of the weather or environmental primary problems. There is no pattern of windshear incidents decreasing.

Figure 14 shows the *phases of flight* for windshear incidents by FAR part. The greatest number of incidents occurred during initial approach (126) and landing (108). The majority of the incidents reported were for Part 121, with 97 during initial approach and 80 during landing. During cruise there were almost as many Part 91 incidents (25) as Part 121 incidents (27).

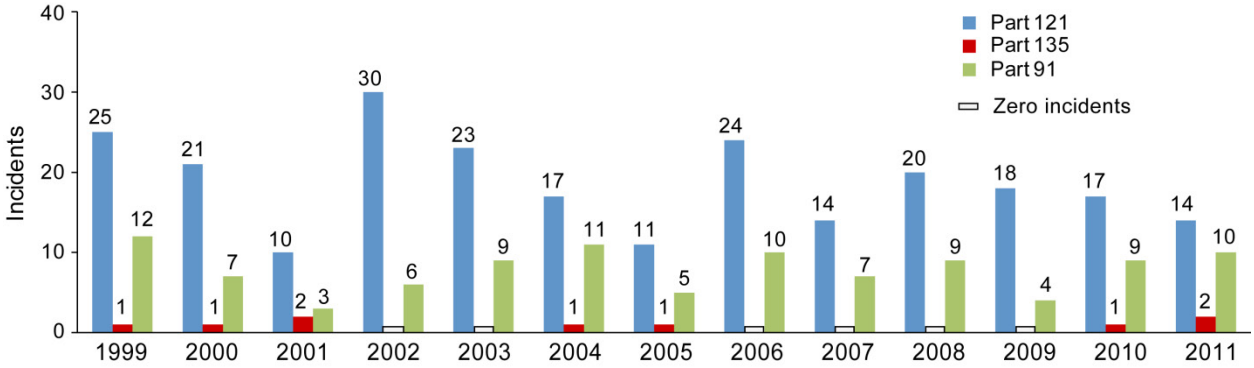

Figure 13.—Windshear-related incidents by year and FAR part.

TABLE 21.—NUMBER AND PERCENTAGE OF WINDSHEAR-RELATED INCIDENTS BY FAR PART

Category	Incidents per year													Total
	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	
Weather or environmental	339	292	184	277	339	243	150	247	186	253	232	218	158	3118
Windshear-related	38	29	15	36	32	29	17	34	21	29	22	27	26	355
Windshear-related, percent	11	10	8	13	9	12	11	14	11	11	9	12	16	11
FAR Part														
121	25	21	10	30	23	17	11	24	14	20	18	17	14	244
135	1	1	2	0	0	1	1	0	0	0	0	1	2	9
91	12	7	3	6	9	11	5	10	7	9	4	9	10	102

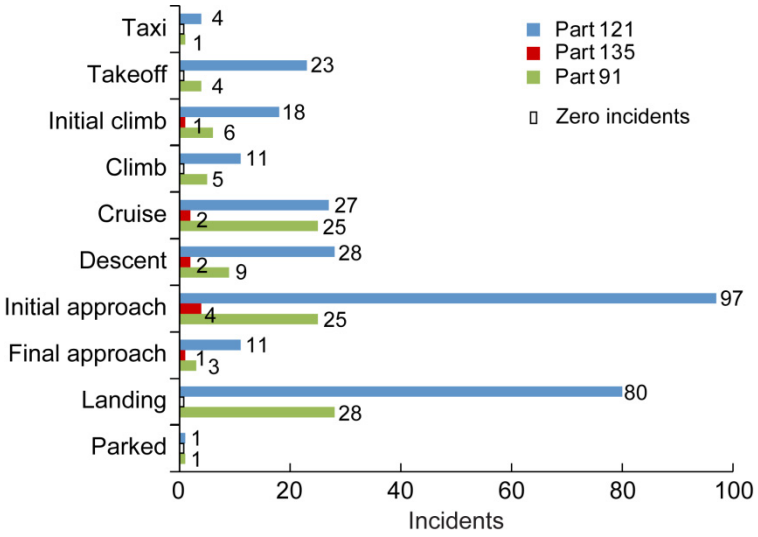

Figure 14.—Phase of flight for windshear-related incidents by FAR part.

Figure 15 shows the *visibility weather element* for windshear-related incidents. Some of the incidents involved other weather elements: turbulence was reported in 60 percent of the incidents, thunderstorms in 32 percent, and rain in 27 percent.

Table 22 shows the *general results* for windshear-related incidents. The most frequent general result was maintenance action with 73 total incidents: 58 for Part 121, 14 for Part 91, and 1 for Part 135. An emergency was declared in 31 incidents: 26 for Part 121, 4 for Part 91, and 1 for Part 135. Physical injury or incapacitation occurred in eight incidents: six for Part 121 and two for Part 91.

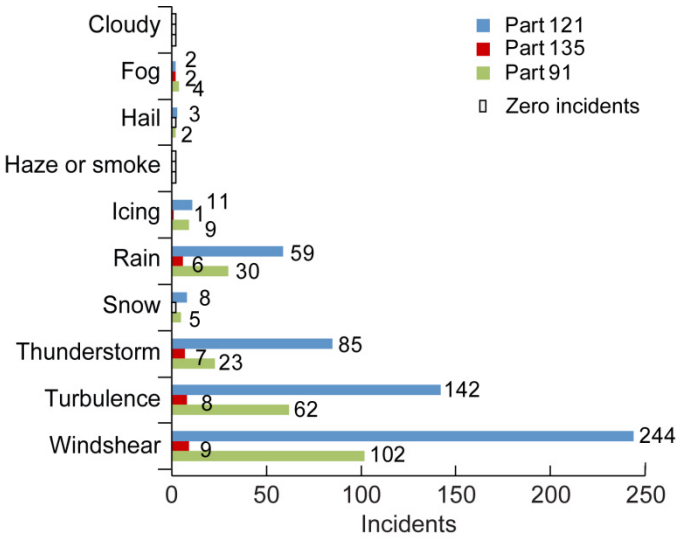

Figure 15.—Visibility weather elements for windshear-related incidents by FAR part.

TABLE 22.—WINDSHEAR-RELATED INCIDENTS
BY GENERAL RESULTS AND FAR PART

General results	Incidents			
	FAR part			Total
	121	135	91	
Declare emergency	26	1	4	31
Evacuated	0	0	1	1
Flight canceled or delayed	8	0	3	11
Maintenance action	58	1	14	73
Physical injury or incapacitation	6	0	2	8
Police or security involved	0	0	0	0
Release refused or aircraft not accepted	0	0	0	0
Work refused	0	0	0	0
None reported or taken	44	1	23	68
Total	109	3	37	149

As shown in Figure 16, 264 incidents reported a *flight crew result* with 184 for Part 121, 8 for Part 135, and 72 for Part 91. The greatest number of incidents (114) executed a go around or missed approach, with 99 for Part 121, 13 for Part 91, and 2 for Part 135. This was followed by 108 incidents that regained aircraft control (65 incidents for Part 121, 39 for Part 91, and 4 for Part 135). Diverted was third with 76 incidents (57 for Part 121, 17 for Part 91, and 2 for Part 135) followed by took evasive action with 54 incidents (37 for Part 121, 13 for Part 91, and 4 for Part 135). Eleven incidents rejected takeoff.

Table 23 shows the *in-flight event or encounter anomalies* for windshear-related incidents. LOC was reported in 116 total incidents with 65 for Part 121 and 47 for Part 91. Unstabilized approaches were reported for 51 incidents, and weather or turbulence for 302 incidents. The majority of the encounters were for Part 121 categories.

Table 24 shows the last areas analyzed for windshear-related incidents—*flight conditions* and *flight plan*. *Flight conditions* were reported for 267 incidents. Of these, 137 were in VMC: 80 for Part 121 and 54 for Part 91. IMC was reported for 87 incidents: 57 for Part 121, 27 for Part 91, and 3 for Part 135. Of the 345 incidents that provided *flight plan* information, 305 had an instrument flight plan, 24 had not filed a flight plan (22 for Part 91), and 16 had a visual flight plan (15 for Part 91).

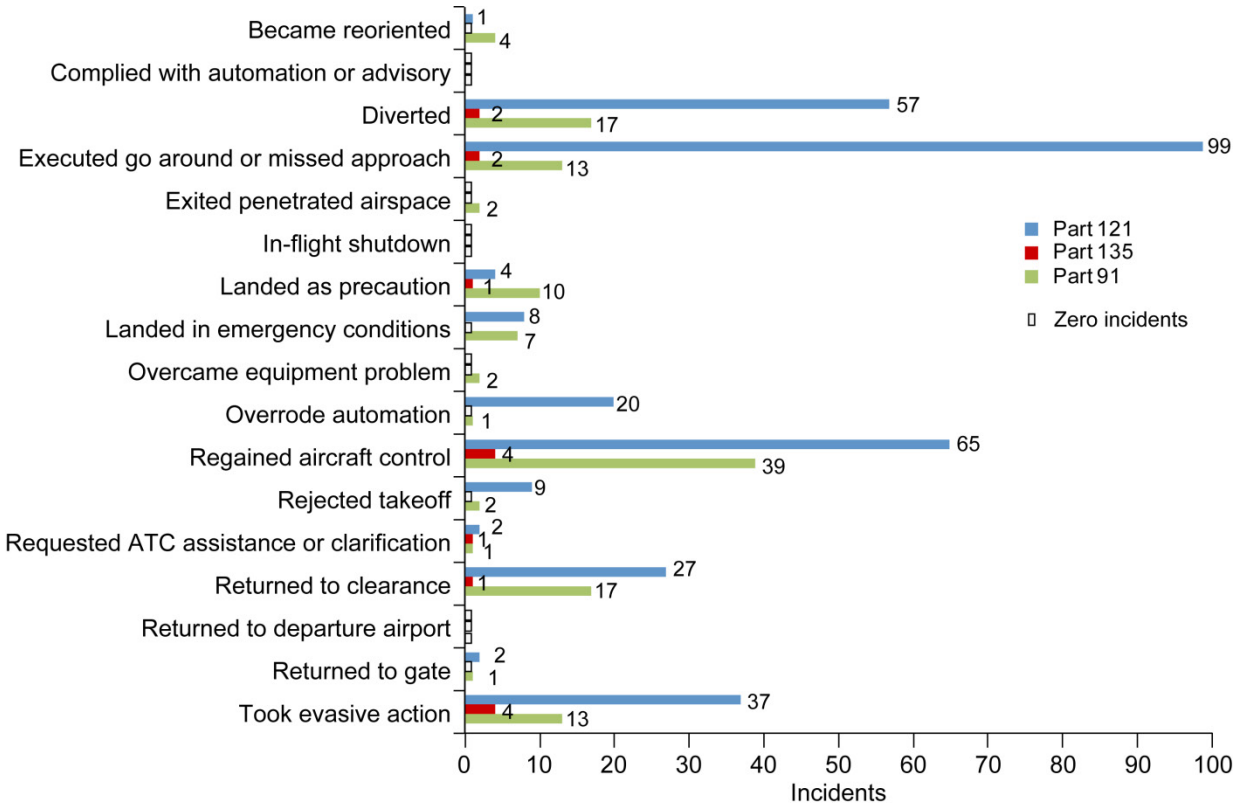

Figure 16.—Flight crew results for windshear-related incidents by FAR part.

TABLE 23.—WINDSHEAR-RELATED INCIDENTS BY IN-FLIGHT EVENT OR ENCOUNTER ANOMALY AND FAR PART

In-flight event or encounter	Incidents			
	FAR Part			Total
	121	135	91	
Bird or animal	0	0	2	2
CFTT or CFIT[a]	1	0	5	6
Fuel issue	7	0	0	7
LOC[b]	65	4	47	116
Object	0	0	0	0
Unstabilized approach	38	0	13	51
VFR in IMC[c]	0	2	3	5
Wake vortex encounter	4	0	0	4
Weather or turbulence	209	9	84	302
Other or unknown	70	1	25	96
Total	226	9	97	332

[a]Controlled flight toward terrain or controlled flight into terrain.
[b]Loss of control.
[c]Visual flight rules in instrument meteorological conditions.

TABLE 24.—WINDSHEAR-RELATED INCIDENTS BY FLIGHT CONDITIONS OR FLIGHT PLAN AND FAR PART

Flight conditions or flight plan	Incidents			
	FAR Part			Total
	121	135	91	
Flight conditions				
IMC[a]	57	3	27	87
Marginal	5	2	5	12
Mixed	22	1	8	31
VMC[b]	80	3	54	137
Flight condition total	164	9	94	267
Flight plan				
DVFR or SVFR[c]	0	1	2	3
IFR[d]	236	7	62	305
VFR[e]	0	1	15	16
No flight plan filed	1	1	22	24
Flight plan total	237	9	99	345

[a]Instrument meteorological conditions.
[b]Visual meteorological conditions.
[c]Defense visual flight rules or special visual flight rules.
[d]Instrument flight rules.
[e]Visual flight rules.

4.4 St. Elmo's Fire

St. Elmo's fire is a weather phenomenon in which a coronal discharge lights up the aircraft surface where maximum electrical static discharge occurs (Ref. 7). It is an indication that thunderstorm activity is in the area and could be a precursor to a lightning strike.

A search of weather and nonweather primary problems for "st. elmo" *or* "saint elmo" found 13 St. Elmo's fire incidents in the narratives, with 12 for Part 121 and 1 for Part 135. Nine incidents occurred during cruise, two each during descent and initial approach, and one each during climb and landing.

In the *general results* category for St. Elmo's fire shown in Figure 17, four incidents reported physical injury or incapacitation, four declared an emergency, and two required a maintenance action. The flight crew results in Figure 18 show that the flight crew regained control in five incidents and the aircraft returned to clearance in four incidents.

Figure 19 shows the *in-flight event or encounter anomalies* for St. Elmo's fire incidents. Eleven incidents reported weather or turbulence and four each reported an LOC and other or unknown. The *visibility weather elements* that occurred at the time of the St. Elmo's fire incidents for FAR Part 121 is shown in Figure 20. Five incidents were involved with turbulence, four with thunderstorms, and three each icing and rain. Eleven of the St. Elmo's fire incidents reported the time as night and one reported daylight. The only Part 135 St. Elmo's fire incident did not report a *visibility weather element.*

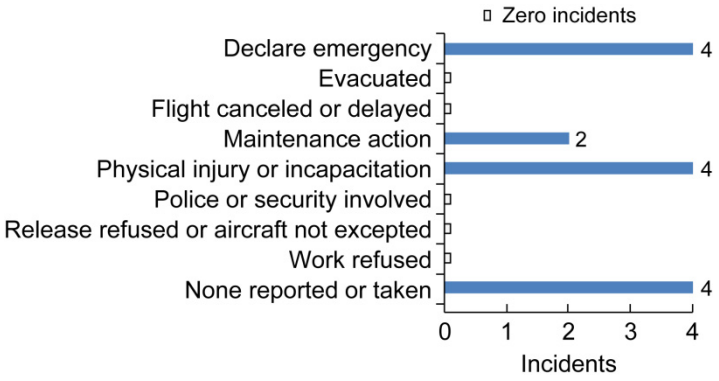

Figure 17.—General results for St. Elmo's fire incidents.

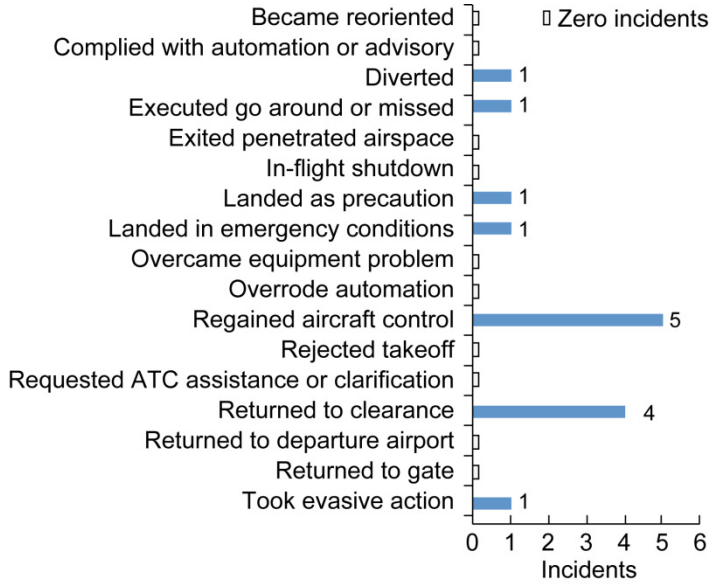

Figure 18.—Flight crew results for St. Elmo's fire incidents.

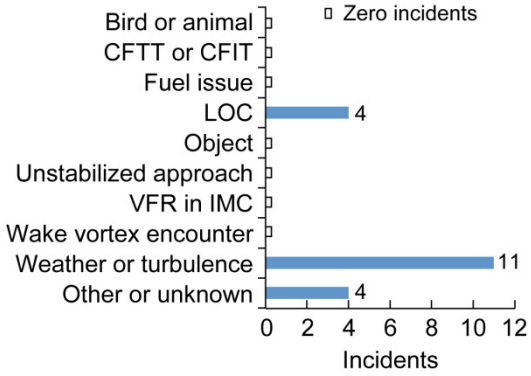

Figure 19.—In-flight events or encounters for St. Elmo's fire incidents.

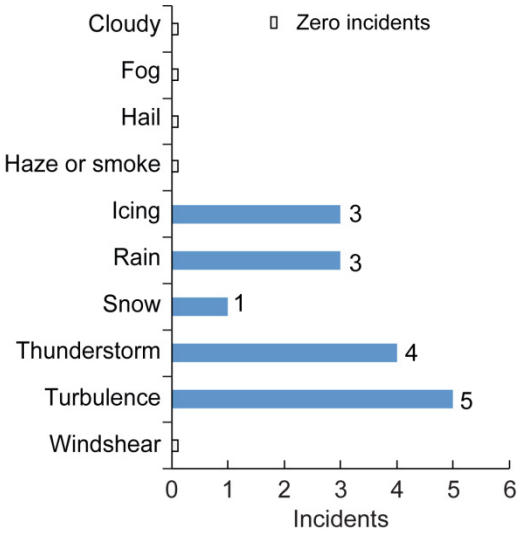

Figure 20.—Visibility weather element for St. Elmo's fire.

4.5 Volcanic Ash

Eight incidents mentioned volcano, volcanic, or ash with a primary problem of environment-nonweather-related, and all were for FAR Part 121. Three incidents required a maintenance action and one flight was canceled. Narratives mentioned that ash clouds were encountered but had not been reported; ash clouds had expanded from where they were predicted; pilots had tried to get rerouting information around ash clouds, but dispatch said there was no issue, even though the pilots could see the brown ash cloud in the distance; or that foreign weather services were not reporting on volcanic activity properly. There was no mention of actual damage to aircraft or engines, but a few incidents did report brown specks on the windscreen.

4.6 Controlled Flight Toward Terrain or Controlled Flight Into Terrain

Most of the CFTT or CFIT incidents involved CFTT and spot checks of the narratives provided a variety of reasons. Some aircraft were too low on the glide slope, while others made visual approaches, or were too close to low hills, which caused the terrain warning to sound. Other incidents were caused by towers on the ground or on top of buildings. Some pilots reported flying into the warning area to try to figure out what caused the warning. In other incidents, the flight crews complained about approach plates and the lack of navigation information only to discover that they were not the only ones having these issues.

There were 101 CFTT or CFIT incidents in the database for primary problems of weather or environment: 35 for Part 121, 8 for Part 135, and 58 for Part 91. Figure 21 shows the *phases of flight* in which the incidents occurred. Initial approach had the greatest number of incidents, followed by landing and cruise. Figure 22 shows the *flight crew* results for CFTT or CFIT incidents. The flight crew took evasive action in 19 incidents and executed a go around or missed approach in 13 incidents.

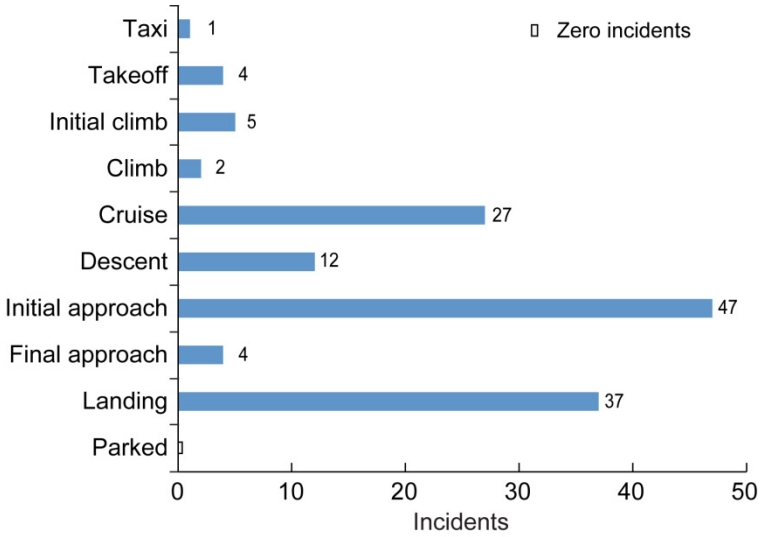

Figure 21.—Phase of flight for controlled flight toward terrain or controlled flight into terrain incidents.

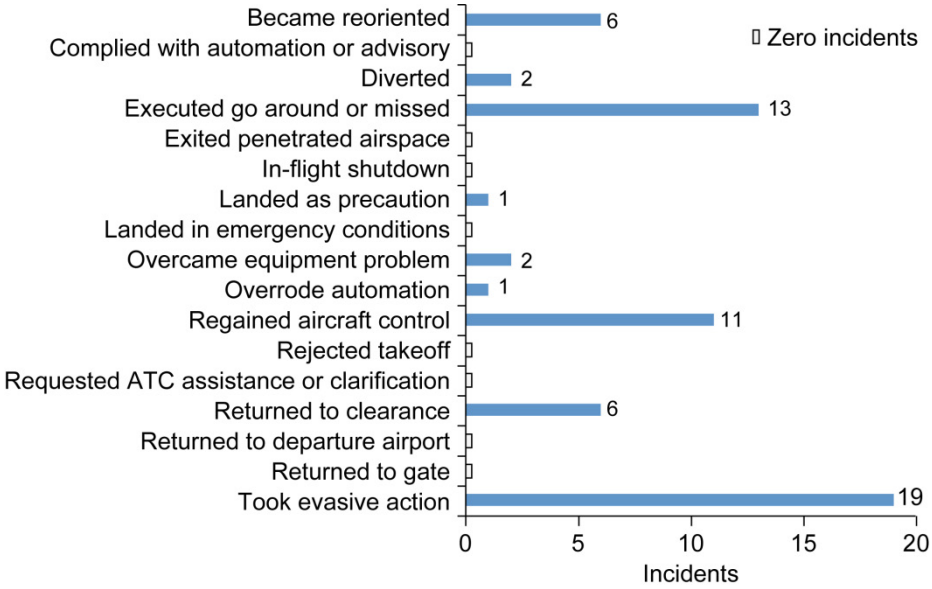

Figure 22.—Flight crew results for controlled flight toward terrain or controlled flight into terrain incidents.

Table 25 shows the 101 total *in-flight event or encounter anomalies* that occurred during CFTT or CFIT incidents; 4 of the 35 incidents for Part 121 also had an LOC and 14 involved weather or turbulence. Twelve of the 58 incidents for Part 91 also had an LOC and 36 involved weather or turbulence.

Table 26 shows the *environmental light conditions* reported during CFTT or CFIT incidents. Of the 95 total incidents reporting light conditions, 65 occurred during daylight with 14 for Part 121, 7 for Part 135, and 44 for Part 91. Only one Part 121 and one Part 91 occurred at dawn, and one Part 121 and five Part 91 incidents occurred at dusk. Thirteen incidents for Part 121, one for Part 135, and eight for Part 91 occurred at night.

Table 27 shows the *visibility weather elements* that were listed for CFTT or CFIT incidents. Only 22 of the 101 incidents listed a weather element, with rain and turbulence both at 7. Windshear and icing followed with six incidents each.

TABLE 25.—CFTT/CFIT[a]-RELATED INCIDENTS BY IN-FLIGHT EVENT OR ENCOUNTER ANOMALY AND FAR PART

In-flight event or encounter	Incidents			
	FAR Part			Total
	121	135	91	
Bird or animal	0	0	0	0
CFTT or CFIT[a]	35	8	58	101
Fuel issue	0	0	0	0
LOC[b]	4	0	12	16
Object	0	0	0	0
Unstabilized approach	2	0	2	4
VFR in IMC[c]	0	1	8	9
Wake vortex encounter	0	0	0	0
Weather or turbulence	14	7	36	57
Other or unknown	1	0	11	12
Total	35	8	58	101

[a]Controlled flight toward terrain or controlled flight into terrain.
[b]Loss of control.
[c]Visual flight rules in instrument meteorological conditions.

TABLE 26.—CFTT/CFIT[a]–RELATED INCIDENTS BY ENVIRONMENTAL LIGHT CONDITIONS AND FAR PART

Light conditions	Incidents			
	FAR Part			Total
	121	135	91	
Dawn	1	0	1	2
Daylight	14	7	44	65
Dusk	1	0	5	6
Night	13	1	8	22
Total	29	8	58	95

[a]Controlled flight toward terrain or controlled flight into terrain.

Table 27.—CFTT/CFIT[a]-RELATED INCIDENTS BY VISIBILITY WEATHER ELEMENT AND FAR PART

Visibility weather element	Incidents			
	FAR Part			Total
	121	135	91	
Cloudy	0	0	0	0
Fog	1	0	3	4
Hail	0	0	0	0
Haze or smoke	0	0	0	0
Icing	0	0	6	6
Rain	3	0	4	7
Snow	0	0	2	2
Thunderstorm	1	0	1	2
Turbulence	2	1	4	7
Windshear	1	0	5	6
Total	6	1	15	22

[a]Controlled flight toward terrain or controlled flight into terrain.

During the CFTT or CFIT incidents 11 emergencies were declared; there were 5 maintenance actions and 2 physical injuries or incapacitations, and 20 aircraft were damaged. Obtaining a better understanding of the CFTT or CFIT incidents would require reading through all 101 narratives and trying to add more categorizations.

4.7 Ground Event or Encounter

The ground event or encounter and runway incursion data sets with the primary problem of weather or environment-nonweather are used to address TC3's low-visibility conditions for safer runway operations. Both of these could occur during low visibility conditions on the runway. The ground event or encounter category includes

- Near misses or physical contact of such items as aircraft, vehicles, animals, people, and birds within the aerodrome
- Foreign object damage (FOD)
- Gear-up landings
- Aircraft ground strikes

There were 315 ground events or encounters, with 174 for Part 121, 22 for Part 135, and 118 for Part 91. By definition, a ground event or encounter only include incidents that occurred during taxi, takeoff, landing, and while parked when any part of the aircraft is in contact with the surface. The *aircraft* category, which is the aircraft striking another aircraft on the ground, had 176 incidents with 90 Part 121, 13 Part 135, and 73 Part 91. LOC on the ground had 167 incidents, with 87 Part 121, 13 Part 135, and 67 Part 91.

Figure 23 shows ground event or encounter incidents by phase of flight and FAR part. The most frequent phase of flight cited was landing with 124 incidents, followed by taxi with 102, takeoff with 54,

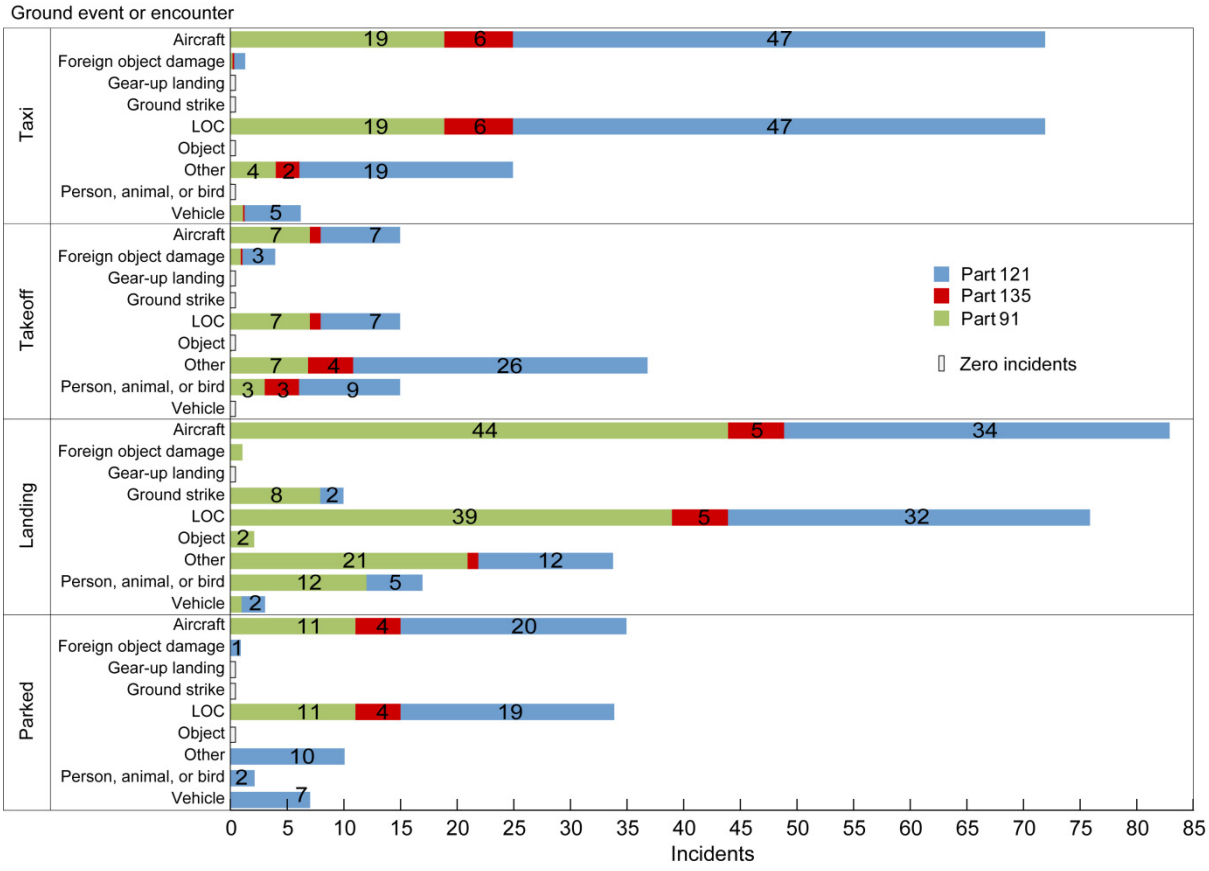

Figure 23.—Ground event or encounter incidents during four phases of flight by FAR part.

and parked with 50 incidents. Aircraft (strikes another aircraft) and LOC were the most frequent incidents in the landing phase of flight for all FAR Parts, with 34 and 32 incidents for Part 121, respectively, 5 each for Part 135, and Part 91 had 44 and 39, respectively. The taxi phase of flight was the second largest group with 102 incidents and the majority in aircraft (strikes another aircraft) and LOC, with Part 121 having 47 each, Part 135 having 6 each, and Part 91 having 19 each. The takeoff phase of flight had three top categories: aircraft (strikes another aircraft), LOC, and person/animal/bird.

Table 28 shows the *environmental lighting conditions* during the ground event or encounter incidents: 181 incidents occurred during daylight and 78 at night.

Table 29 shows the *visibility weather elements* for ground event or encounter incidents. Snow was a factor in 44 of the incidents with 34 for Part 121. Icing—primarily on the runway or taxiway surface—was a factor in 39 incidents. Fog had an impact on 11 incidents and rain, thunderstorms, and turbulence were also factors for incidents. Obtaining a full understanding of the impact that the weather had on ground event or encounters would require reading through each of the narratives. There was not sufficient time to do so for this study.

TABLE 28.—GROUND EVENT OR ENCOUNTER-RELATED INCIDENTS BY ENVIRONMENTAL LIGHT CONDITIONS AND FAR PART

Light conditions	Incidents			
	FAR Part			Total
	121	135	91	
Dawn	5	3	2	10
Daylight	79	11	91	181
Dusk	20	0	4	6
Night	55	7	16	78
Total	141	21	113	275

TABLE 29.—GROUND EVENT- OR ENCOUNTER-RELATED INCIDENTS BY VISIBILITY WEATHER ELEMENT AND FAR PART

Visibility weather element	Incidents			
	FAR Part			Total
	121	135	91	
Cloudy	0	0	0	0
Fog	6	4	1	11
Hail	2	0	0	2
Haze/smoke	0	0	2	2
Icing	31	3	5	39
Rain	22	3	11	36
Snow	34	0	10	44
Thunderstorm	13	1	6	20
Turbulence	14	0	14	28
Windshear	18	0	13	31
Total	82	8	39	129

Other noteworthy ground event or encounter-related incident data that is not shown in tables or figures is summarized below:

- Of the 66 *ground excursions*, 51 occurred on the runway, 14 on the taxiway, and 2 at ramps.
- Of the 10 *ground incursions*, 9 occurred on the runway and 2 on the taxiway.
- Of the 225 *general results*, 108 required maintenance actions, 24 flights were canceled or delayed, and 8 encounters resulted in physical injuries or incapacitations.
- Of the 127 *aircraft results*, 126 aircraft received damage, with 49 Part 121, 11 Part 135, and 66 Part 91.

4.8 Ground Incursions

The ASRS considered a ground incursion to be the undesirable or unwanted entry of an aircraft, vehicle, person, or animal into a confined, marked, or identified standard movement area within the runway or taxiway. Ground incursions include collision with, risk of collision, or evasive action being taken. There were 53 ground incursions with a primary problem of weather or environment: 47 on a runway and 8 on a taxiway; 25 incidents were for Part 121, 8 were for Part 135, and 20 were for Part 91.

Figure 24 shows the *phase of flight* results for ground incursion incidents: 35 incidents occurred during taxi and 12 during landing. As shown in Table 30, 47 total incidents reported *environmental light conditions* during the incursion with 23 incidents occurring at night, 22 in daylight, and 1 each at dusk and dawn.

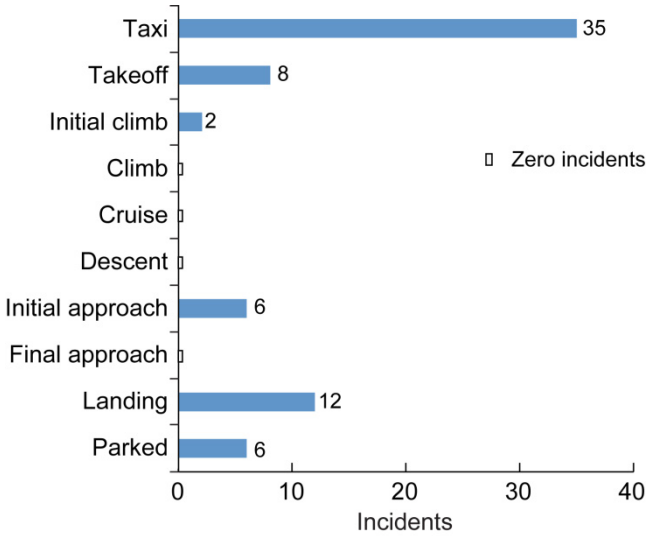

Figure 24.—Phase of flight for ground incursion incidents.

TABLE 30.—GROUND INCURSION-RELATED INCIDENTS BY ENVIRONMENTAL LIGHT CONDITIONS AND FAR PART

Light conditions	Incidents			
	FAR Part			Total
	121	135	91	
Dawn	1	0	0	1
Daylight	6	3	13	22
Dusk	0	0	1	1
Night	12	5	6	23
Total	19	8	20	47

Table 31 shows the *visibility weather elements* that affected the ground incursions and could have affected the pilots' visibility. Ten incidents involved snow, seven rain, and five thunderstorms.

4.9 Near-Midair Collision Hazard

The ASRS incident database had 46 near-midair collisions (NMACs) that listed weather or environment as the primary problem. An NMAC is defined in the ASRS as an event that has less than 500 ft of vertical and horizontal separation between two airborne aircraft. A total of 12 of the NMACs were for Part 121, 1 for Part 135, and 33 for Part 91. Only four NMAC incidents listed one or more *visibility weather elements*: one listed haze or smoke, two listed rain, three listed thunderstorms, three listed turbulence, and two listed windshear. Figure 25 shows the *phases of flight* for the NMAC incidents by FAR part—17 incidents occurred during cruise including 4 for Part 121, 1 for Part 135, and 12 for Part 91. During initial approach there were nine incidents for Part 91 and two for Part 121. The single Part 121 incident that occurred during the parked phase of flight also listed the taxi and landing phases of flight. It was actually on the ground, but was described in the ASRS as an NMAC on the ground in dense fog.

TABLE 31.—GROUND INCURSION-RELATED INCIDENTS BY VISIBILITY WEATHER ELEMENT AND FAR PART

Visibility weather element	Incidents			
	FAR Part			Total
	121	135	91	
Cloudy	0	0	0	0
Fog	2	1	0	3
Hail	0	0	0	0
Haze or smoke	0	0	1	1
Icing	1	1	1	3
Rain	3	1	3	7
Snow	5	1	4	10
Thunderstorm	3	1	1	5
Turbulence	0	0	1	1
Windshear	1	0	1	2
Total	10	3	8	21

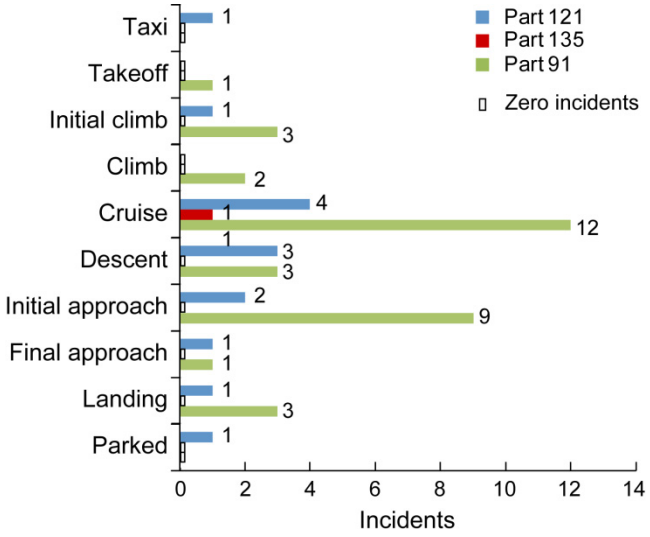

Figure 25.—Phase of flight for near-midair collision-related incidents.

Figure 26 shows the *flight crew results* for NMAC-related incidents; 32 reported a *flight crew result* with 28 incidents taking evasive action. The aircraft returned to clearance in seven incidents and the flight crew executed a go around or missed approach in three. Only 15 of the NMAC incidents reported an in-flight event or encounter as shown in Table 32. Weather or turbulence was involved in the most in-flight event or encounters with nine.

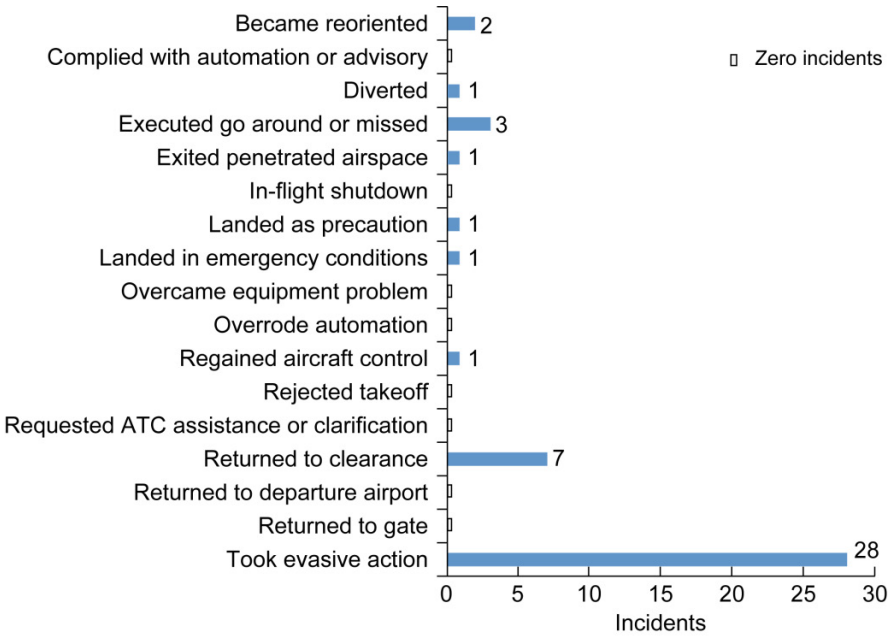

Figure 26.—Flight crew results for near-midair-collision-related incidents.

TABLE 32.—NEAR-MIDAIR-COLLISION-RELATED INCIDENTS BY IN-FLIGHT EVENT OR ENCOUNTER ANOMALY AND FAR PART

In-flight event or encounter	Incidents			
	FAR Part			Total
	121	135	91	
Bird or animal	0	0	0	0
CFTT or CFIT[a]	0	0	1	1
Fuel issue	0	0	0	0
LOC[b]	1	0	0	1
Object	0	0	1	1
Unstabilized approach	1	0	0	1
VFR in IMC[c]	0	0	1	1
Wake vortex encounter	0	0	0	0
Weather or turbulence	3	0	6	9
Other or unknown	2	0	2	4
Total	5	0	10	15

[a]Controlled flight toward terrain or controlled flight into terrain.
[b]Loss of control.
[c]Visual flight rules in instrument meteorological conditions.

TABLE 33.—NEAR-MIDAIR-COLLISION-RELATED INCIDENTS BY FLIGHT CONDITIONS AND FAR[A] PART

Flight conditions	Incidents			
	FAR Part			Total
	121	135	91	
IMC[b]	4	0	1	5
Marginal	0	0	1	1
Mixed	2	0	2	4
VMC[c]	4	1	29	34
Total	10	1	33	44

[a]Federal Aviation Regulations.
[b]Instrument meteorological conditions.
[c]Visual meteorological conditions.

Table 33 shows the *flight conditions* in which the NMAC-related incidents occurred. Of the 44 total incidents 34 occurred while the aircraft was flying in VMC. Only five incidents occurred in IMC, four in mixed conditions, and one in marginal meteorological conditions. Thirty-nine incidents occurred in daylight, four were at night, and two were at dusk.

4.10 Technical Challenge 3—Conclusion

The ASRS analysis for TC3, atmospheric hazard sensing and mitigation technology capability, reviewed the 4647 incidents in the database that involved the primary problems of weather- and environment- nonweather-related incidents. A variety of atmospheric hazards were analyzed, both in the air and on the ground. All categories could undergo a more detailed analysis in the future if the project is interested. That analysis would include reading all narratives to gain a better understanding of how the events affected each other.

CAT was specifically mentioned in 986 incident narratives, with two-thirds of the incidents for FAR Part 121. Most of the incidents occurred during cruise and initial approach. The CAT-related incidents resulted in 95 physical injuries or incapacitations, 173 declared emergencies, and 119 maintenance actions. Of the 142 CAT incidents that reported an in-flight LOC, the flight crew regained control in 117 incidents and the aircraft returned to clearance in 96. The number of CAT reports decreased from 1994 to 2011, especially in 2001, 2009, and 2011. This could have been caused by fewer incidents or insufficient ASRS analysis resources.

Of the 3118 weather or environmental incidents from 1999 through 2011, 355 were windshear-related incidents. Although the percentage varied between 8 and 16 percent over the last 14 yr, windshear-related incidents in the weather or environment categories have not declined. Windshear incidents occurred most frequently during initial approach and landing, especially for Part 121. Flight crews had to execute a go around in 114 of these incidents. As a result, 73 incidents reported a maintenance action and 31 declared an emergency.

Wake vortex was reported in 234 incidents for all 3 FAR parts, with the greatest number in Part 121 aircraft during initial approach and descent. Twenty-nine of these incidents caused physical injury or incapacitation. Following the wake vortex encounters, flight crew regained aircraft control (79 incidents), took evasive action (32), executed a go around or missed approach (24), or returned to clearance (21).

The ASRS database had 101 CFTT or CFIT incidents that listed weather or environment as the primary problem: 58 for Part 91 and 35 for Part 121. These incidents occurred most frequently during initial approach, landing, and cruise. Weather or turbulence was reported as a factor in 57 incidents and 65 occurred during daylight and 22 at night. The flight crews took evasive action in 19 incidents and executed a go around in 13.

NMAC incidents were reported in 46 incidents with a primary problem of weather or environment: 33 for Part 91, 1 for Part 135, and 12 for Part 121. NMACs occurred most frequently during cruise and

initial approach; 34 of these incidents occurred in VMC, 5 in IMC, 4 in mixed conditions, and 1 in marginal conditions.

The analysis on St. Elmo's fire resulted in 13 St. Elmo's fire incidents along with 8 incidents that involved volcanic ash with 3 that required maintenance action.

Two areas were analyzed for low-visibility runway environments: ground event or encounters and ground incursions. There were 314 ground event or encounter incidents: 174 for Part 121 and 118 for Part 91. Another aircraft was involved in 176 incidents, an LOC in 167, and a bird, animal, or person in 33. The greatest number of encounters occurred during landing and taxi, with 181 incidents during daylight and 78 at night. A visibility weather element was reported for 129 of the incidents and aircraft damage was reported for 126. Maintenance actions were required for 108 incidents and 8 incidents resulted in physical injury or incapacitation.

A total of 53 ground incursion incidents were found in the data set with 35 incursions during the taxi phase of flight; 23 incidents occurred at night and 22 during the day. A visibility weather element was a factor in 21 of the incidents.

5.0 Conclusions

The Aviation Safety Reporting System (ASRS) database was searched for any incidents related to the three Aviation Safety Atmospheric Environment Safety Technology (AEST) technical challenges (TCs) in support of milestone AEST3.2.SA.01: Identification of AEST-Related Trends. Of the 163 558 incident reports in the ASRS database, 3526 incidents were related to weather and 1122 incidents were related to the environment.

Airframe icing is the focus of TC2, airframe icing simulation and engineering tool capability. The current study performed an update to the 2008 NASA icing paper as well as a search of incident data through 2011. The search resulted in 275 incidents related to airframe icing from 1994 through 2011, with the majority (182 incidents) for Part 91 aircraft. Incidents are presented by FAR Parts 121, 135, and 91 and by phase of flight. Airframe incidents occurred most often during cruise, descent, and initial approach. Flight crews declared emergencies in 69 incidents, 252 involved an encounter with weather or turbulence, 53 involved a loss of control (LOC), and 218 flew in instrument meteorological conditions (IMC) under an instrument flight rules (IFR) flight plan. In addition, 61 incidents resulted in a clearance deviation, 69 resulted in an altitude deviation, and 49 involved critical equipment problems.

The focus of TC3, atmospheric hazard sensing and mitigation technology capability, includes real-time sensing and measurement of icing, turbulence, wake vortex hazards, runway safety under low-visibility conditions, and lightning-immune composite aircraft. The airframe-icing-related analysis completed for TC2 also applies to TC3. The ASRS database was searched for incidents that involved

1. Clear air turbulence (CAT)
2. Wake vortex
3. Windshear
4. St. Elmo's fire (related to lightning risk)
5. Volcanic ash
6. Runway safety (ground event or encounters and ground incursions)
7. Low visibility (controlled flight toward terrain or controlled flight into terrain and near-midair collisions)

CAT was involved in a total of 986 incidents with 621 incidents for Part 121. Of the 986 incidents, 677 resulted in an encounter with weather or turbulence (409 for Part 121), and 142 resulted in a LOC (80 for Part 121). CAT incidents, which occurred primarily during cruise, resulted in 173 declared emergencies, 119 required maintenance actions, and 95 physical injuries/incapacitations. Aircraft control was regained in 177 incidents, aircraft were diverted during 90 incidents, and evasive action was taken for 88 incidents. An IFR plan was filed for 791 of the flights and 309 aircraft flew in IMC.

Wake vortex was involved in 234 incidents (176 for Part 121). Of these, 72 incidents involved an LOC, 29 involved physical injury or incapacitation, and 11 required maintenance action. A majority of wake vortex incidents occurred during the initial approach and descent phases of flight.

Windshear was reported in 355 incidents (244 for Part 121). The majority of these incidents occurred during the initial approach and landing phases of flight, and they most frequently resulted in an executed go around/missed approach, regained aircraft control, and diverted. Maintenance action was required for 73 incidents and emergencies were declared in 31 incidents. An IFR flight plan was used in 305 of the incidents, and 137 incidents involved aircraft flying in VMC.

St. Elmo's fire was involved in 13 incidents and volcanic ash in 8 incidents.

CFTT or CFIT was reported in 101 incidents (35 for Part 121). Of these, 47 incidents occurred during initial approach, 57 involved weather or turbulence, and 65 occurred during daylight. Most often CFTT or CFIT resulted in the flight crew taking evasive action and executing a go around.

Ground events/encounters occurred in 314 incidents (174 for Part 121); 176 incidents involved encounters with other aircraft and 167 incidents involved LOC. The majority of these incidents occurred during the landing phase of flight during daylight hours.

To verify which of the incidents lightning, CAT, windshear, and other conditions were causal factors would require an analyst to read each narrative. This could be done in a future AEST project study.

Appendix A.—Acronyms

AEST	Atmospheric Environment Safety Technology
ASRS	Aviation Safety Reporting System
ATC	air traffic control
AvSP	Aviation Safety Program
CAST	Commercial Aviation Safety Team
CAT	clear air turbulence
CDL	Configuration Deviation List
CFTT or CFIT	controlled flight toward terrain or controlled flight into terrain
DVFR	defense visual flight rules
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
FOD	foreign object damage
HAT	height above terrain
HIWC	high ice water content
ICAO	International Civil Aviation Organization
IFR	instrument flight rules
IMC	instrument meteorological conditions
LOC	loss of control or loss of aircraft control
MEL	minimum equipment list
NEF	nonessential function (list)
NMAC	near-midair collision
SID	standard instrument departure
STAR	standard terminal arrival route
TC	technical challenge
VFR	visual flight rules
VMC	visual meteorological conditions

Appendix B.—Aviation Safety Reporting System Category Descriptions

Only some ASRS categories apply to Atmospheric Environment Safety Technology and if the category is discussed, all options are presented. Most of the descriptions and notes came from the ASRS Standard Operating Procedures (an internal document). Many of the terms and definitions are from the Commercial Aviation Safety Team (CAST)/ICAO web site for aviation common taxonomies (Ref. 5).

Phase of flight (10 options)

- Taxi
- Takeoff
- Initial climb
- Climb
- Cruise
- Descent
- Initial approach
- Final approach
- Landing
- Parked

Flight crew results (17 options or subcategories)

- Became reoriented: Overcame disorientation
- Diverted: Diverted to a filed alternate or any airport that is not a filed alternate. Does not include returning to departure airport
- Executed go around or missed approach: A pilot or controller-initiated action, typically to avoid a potentially hazardous situation/condition on a movement surface, that does not require adherence to a published missed approach procedure. A missed approach is a procedure that is formulated for each published instrument approach and it is initiated by either the pilot or the controller due to weather, unstable approach, "fouled" runway, etc. It allows the pilot to enter a new approach while remaining clear of obstacles.
- Exited penetrated airspace: Airborne maneuver to exit erroneously penetrated airspace
- Flight crew complied with automation or advisory: Flight crew followed what was recommended by what computer
- Flight crew overrode automation: Pilot or flight crew took action and overrode any aircraft programmed system
- In-flight shutdown: Pilot or flight crew shut down one or more engines
- Landed as precaution: May or may not be caused by an emergency event
- Landed in emergency conditions
- Overcame equipment problem: Pilot or flight crew restored function of malfunctioning equipment, or developed a successful "work-around" to deal with loss of equipment
- Regained aircraft control: Pilot or flight crew became aware of and took successful action to resolve an LOC
- Rejected takeoff: Pilot- or ATC-initiated takeoff abort
- Requested ATC assistance or clarification: Pilot or flight crew asked ATC for vectors or other assistance including filing an en route IFR clearance
- Returned to clearance
- Returned to departure airport: Diverted or returned to departure airport
- Returned to gate: While on ground, aircraft returned to gate
- Took evasive action: Evasive, typically an abrupt action taken, whether on the ground or airborne, to avoid another aircraft, object, terrain, weather, or environmental conditions (such as wake turbulence). Also includes precautionary avoidance action.

General results (9 options)

- Declare emergency
- Evacuated: Personnel and/or passengers leave the aircraft
- Flight canceled or delayed: The flight did not proceed on a previously planned or scheduled flight or was delayed
- Maintenance action: The reporter has provided information that maintenance activity was or is to be conducted
- Physical injury or incapacitation: Injury or incapacitation has occurred as *a result* of the event or incident, airborne or on the ground. If it "was" the event, it should be coded under anomaly.
- Police or security involved—As a result of the event or incident
- Release refused or aircraft not accepted—Usually pertaining to flight crew not accepting the aircraft release
- Work refused: As a result of the incident, the person refused to do their work. Can include flight assignment or any assignment refused by reporter
- Nonreported or taken: This can only be coded if nothing else can be coded under "result." No result is reported and no action is taken can be for insufficient time, detection after the fact, reporter was unaware of the problem, or the reporter was aware but accepted the condition.

Of the 15 different event anomaly categories that can be searched in ASRS, only 8 were of value to this analysis and are listed below. Anomalies are coded to reflect what happened when those involved became aware of the problem. Some of the anomalies list deviations or violations. An anomaly deviation does not necessarily mean that a violation of rules, regulations, or procedures has occurred.

In-flight event or encounter (10 options)

- CFTT or CFIT: Pilot or crew has control of an airworthy, mechanically normal aircraft, but is unaware of in-flight proximity to dangerous or unsafe terrain or obstacles. An example is an aircraft in IMC vectored unacceptably close to terrain.
- Fuel issue: Event related to a fuel concern that occurred during flight
- LOC: Pilot is unable to effectively maintain control of the aircraft in flight, due to pilot error, environment, aircraft, or other reasons
- Object: Physical contact with any object during aircraft flight other than what is covered in the other categories
- Person/animal/bird: Actual physical contact or near miss to a bird, animal, or skydiver when aircraft is in flight
- Unstabilized approach: Failure to establish and maintain a constant attitude, airspeed, or descent rate on approach; or making aircraft configuration changes at or below 500-ft height above terrain (HAT) (above ground level) on approach when conducting a precision approach in VMC; or at or below 1000-ft HAT on approach when conducting a precision approach in IMC. A nonprecision approach may also be considered unstabilized if there is a significant variance from appropriate speed, rate of descent, attitude, or configuration profiles.
- Visual flight rules in IMC: Flight in IMC without an ATC clearance is usually reported by a general aviation pilot without IFR qualifications or not on an IFR clearance. Note: if a pilot is not instrument-qualified but enters IMC with ATC clearance, the event is a violation of Federal Aviation Regulations, and not considered VFR in IMC.
- Wake vortex encounter: Any encounter with another aircraft's wake vortices in the terminal environment or en route (does not include jet or propeller blast events)
- Weather or turbulence: An encounter with weather or turbulence, including CAT, that is commented on by the reporter in the narrative
- Other/unknown: No other fields in this section are appropriate

Ground event or encounter (9 options)

Note: an aircraft is considered to be on the ground when any of the aircraft's main gear, nosewheel, tailwheel, or all skids are on the ground at both takeoff and landing.

- Aircraft: Actual physical contact with another aircraft when aircraft is on the ground
- FOD: Hazard to an aircraft caused by unavoidable or unseen plant, animal, or object
- Gear-up landing: Aircraft is landed without landing gear extended (does not include gear collapse)
- Ground strike—aircraft: Physical contact by a portion of the aircraft such as a wingtip, prop, or tail strike to the ground
- Loss of aircraft control: the pilot is unable to effectively maintain control of the aircraft due to pilot error, environment, aircraft, or other reasons
- Object: Physical contact with any object (not alive) other than what is covered in the other categories when the aircraft is on the ground (runway lights, airport signs, fencing, etc.)
- Person/animal/bird: Actual physical contact or near miss with a person, animal, bird, or any "live object" when aircraft is on the ground. Includes encounters with birds or live objects during the takeoff roll.
- Vehicle: Actual physical contact with a vehicle (not aircraft) when aircraft is on the ground. A jetway, bridge, or baggage cart is considered an object, not a vehicle. A vehicle is defined as being equipped with an engine, is self-propelled, and can be driven, legally or illegally, to the store.
- Other/unknown: Everything not covered elsewhere in this section

Ground incursion (2 options)

Ground incursion is an undesirable or unwanted entry into a confined, marked, or identified standard movement area

- Runway: Uncoordinated, unauthorized, or improper entry to any active runway by an aircraft, vehicle, or person, but *does* include landing on a closed runway. Actual collision hazard or conflict does not need to not occur.
- Taxiway: Uncoordinated, unauthorized, or improper entry to a taxiway by an aircraft, vehicle, or person

Conflict anomaly (4 options)

- Near-midair collision: Conflict between two airborne aircraft with LESS than 500 ft vertical *and* horizontal separation
- Airborne conflict: two or more airborne aircraft in conflict, which may be equal to, or less than legal standard separation, or incidents where the reporter claims a potential conflict. This also includes a conflict that requires an evasive maneuver initiated by a controller, a pilot, or by cockpit equipment.
- Ground conflict, critical: Two or more aircraft (one may be airborne) in conflict, or an aircraft in conflict with a vehicle/aircraft/person/object in which the reporter or other involved took some evasive action to avoid a collision, or a collision that almost occurred in cases where evasive action was not taken or was not possible
- Ground conflict, less severe: Two or more aircraft (one may be airborne) in conflict, or an aircraft in conflict with a vehicle/aircraft/person/object in which the reporter or other involved may, or may not, have taken some precautionary avoidance action, and in which a collision hazard was *not* imminent

Procedural deviation (10 options)

- Clearance—Noncompliance with an ATC clearance. Note: noncompliance with a clearance does not imply a pilot deviation has occurred. Certain conditions, such as an emergency, evasive action, ground proximity warning system escape maneuver, weather factors, etc., mitigate pilot violation of Federal Aviation Regulations.
- FAR—Noncompliance with, or violation of, any Federal Aviation Regulation, other than in an emergency
- Hazardous material violation—All illegally loaded or boarded hazardous materials. Also includes incorrect or improper paperwork associated with legal carriage of hazardous materials.
- Landing without clearance—Landing without an ATC clearance, any wrong-runway landing, or an unauthorized landing on a taxiway
- Maintenance—Failure to comply with a normal, standard, or required maintenance procedures. Caution: This anomaly must be the event type—do not code contributory factors or results in this field.
- Minimum equipment list (MEL)—Any violation of an MEL and associated configuration deviation list (CDL) and/or nonessential function (NEF) requirement, including documentation issues
- Published material/policy—Noncompliance with a published operational procedure, policy, or practice, for example, published approach or departure procedure, published company operational requirement, or ATC Handbook. This also includes improper documentation issues, including but not limited to, maintenance logs, journey logs, and other associated documentation.
- Security—Any noncompliance with Federal, local, or company security requirements. Note: this anomaly must be the event type—not security as an anomaly if security was an event contributor or result
- Weight and balance—Flight crew, maintenance, dispatch, or ground crew noncompliance with weight and balance requirements or standards including improper loading of passengers, luggage, or freight that compromises standard or calculated center of gravity balance calculations. This also includes circumstances where weight and balance were improperly calculated or omitted.
- Other/unknown—this field can be used where it is determined that a procedural deviation has occurred, but no other fields in this section are appropriate

Altitude deviation (4 options)

This includes events where a specified altitude requirement is not met due to an emergency or other defensible operational reason, such as a traffic collision avoidance system resolution advisory or collision avoidance.

- Crossing restriction not met—charted or ATC-assigned altitude crossing restriction not met
- Excursion from assigned altitude—Aircraft departs from a level ATC-assigned altitude
- Overshoot—Aircraft climbs or descends through an ATC-assigned or published altitude
- Undershoot—Aircraft in climb or descent fails to reach an ATC-assigned altitude

Aircraft equipment problem (2 options)

- Critical—Equipment problem that is vital to the specific flight and circumstances, whose failure or malfunction could significantly impact the safety of flight
- Less severe—Equipment problem that is not vital to the specific flight and circumstances

Track/heading deviation (1 option)

Aircraft deviates from ATC-assigned heading, track, airway or published heading, track, routing or airway requirement, such as a standard instrument departure (SID) or standard terminal arrival route (STAR). Note: this includes track, route, or heading deviations due to weather avoidance or other defensible reasons.

Flight planning (Ref. 8) (4 options)

- Instrument flight rules(IFR)—A type of flight plan that follows a set of FAA rules governing the conduct of flight under instrument meteorological conditions
- Visual flight rules(VFR)—Type of flight plan that follows FAA rules that govern the procedures for conducting flight under visual conditions
- No flight plan filed—Pilot did not file a flight plan
- Defense visual flight rules (DVFR)—All VFR aircraft are required to file a DVFR prior to entering into the air defense identification zone

Flight conditions (4 options)

- IMC—Meteorological conditions expressed in terms of visibility, distance from cloud, and ceiling less than the minima specified for visual meteorological conditions (Ref. 9)
- Marginal—Weather flight conditions that are on edge between VMC and IMC
- Mixed—Weather flight conditions that are a combination of VMC and IMC
- VMC—Meteorological conditions expressed in terms of visibility, distance from cloud, and ceiling equal to or better than specified minima (Ref. 9). The pilot is able fly by outside visual references under VFR.

Weather element—visibility (10 options)

- Cloudy
- Fog
- Hail
- Haze or smoke
- Icing
- Rain
- Snow
- Thunderstorm
- Turbulence
- Windshear

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14. ABSTRACT
This study analyzed aircraft incidents in the NASA Aviation Safety Reporting System (ASRS) that apply to two of the three technical challenges in NASA's Aviation Safety Program's Atmospheric Environment Safety Technology Project. The aircraft incidents are related to airframe icing and atmospheric hazards technical challenges. The study reviewed incidents that listed their primary problem as weather or environment-nonweather between 1994 and 2011 for aircraft defined by Federal Aviation Regulations (FAR) Parts 121, 135, and 91. The study investigated the phases of flight, a variety of anomalies, flight conditions, and incidents by FAR part, along with other categories. The first part of the analysis focused on airframe icing-related incidents and found 275 incidents out of 3526 weather-related incidents over the 18-year period. The second portion of the study focused on atmospheric hazards and found 4647 incidents over the same time period. Atmospheric hazards-related incidents included a range of conditions from clear air turbulence and wake vortex, to controlled flight toward terrain, ground encounters, and incursions.

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