Introduction

In response to tasking by the FAA as defined in a letter dated July 3, 2013, titled, "Request Formation of Advisory Group to Address Specific Engine and Installation Icing Issues", the EIWG has studied the issue of ground operations of turbine engines during heavy snow conditions. This report provides the short term findings and recommendations. This will be provided to the FAA in response to their tasking request. It will also be provided to the SAE G12 for consideration when developing guidance for ground operations in heavy snow. This report addresses short term recommendations since a more detailed analysis has not yet been accomplished and may take a much longer time frame to address.

The FAA has participated on this AIA committee; however conclusions stated within this report do not necessarily represent the views of the FAA. Once this report is submitted to the FAA, the FAA has stated that they will review the final conclusions, respond to the recommendations and make a decision as to how to proceed forward.

AEROSPACE INDUSTRIES ASSOCIATION

Aerospace Industries Association
AIA/EIWG Subcommittee on Engine Ground Operations During Heavy Snow

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SECTIONS

1 Conclusions / Recommendations

The task group determined that a list of recommendations could be developed and provided to Operators (i.e. airlines) for consideration during ground operations in heavy snow. The recommended operating procedures for ground operations in heavy snow are discussed in Section 3.3.

2 Abbreviations

HOT – Hold Over Time
LWC – Liquid Water Content
LWE – Liquid Water Equivalent
POI – Principal Operations Inspector
TC – Type Certificate
TWC – Total Water Content

3 Discussion

The FAA's Flight Standards Division regulates aircraft operators' ground based operations in icing conditions under 14 CFR 121.629. On an annual basis the FAA reissues Notice 8900 to provide guidance to part 121 operators for the following winter ground icing operations. The guidance is used by an airline in the annual update of its ground deicing plan which it is required to submit to its Flight Standards principal operations inspector (POI). The POI must evaluate and approve the plan. For the winter of 2014-2015, the FAA is considering incorporating guidance in the notice on allowing the use of LWE systems to provide holdover times in heavy snow operations. The FAA raised the issue of whether aircraft turbine engines can be safely operated in these conditions, and if so, what additional procedures should be considered.

3 Discussion: Historic Basis for Engine Snow Requirements

In 2004 and 2005 the FAA sponsored Aviation Rulemaking Advisory Committee (ARAC) tasked the Engine Harmonization Working Group (EHWG) to review propulsion system icing service experience in order to recommend any potential changes to the airworthiness regulations. As a result, the EHWG reviewed and discussed the basis for snow concentration level for ground taxi operation certification. Consequently, they recommended changes which were proposed to turbine engine icing airworthiness standards in 14CFR 33.68 (reference FAA Notice of Proposed Rulemaking 10-10) [1]. 14 CFR 33.68 at Amendment 33-10 specifies 0.3 g/m3 LWC for ground taxi operation in freezing fog, but do not specifically address snow. Additionally, turbine engine installation icing airworthiness standards were also reviewed and revised. The propulsion installation requirements are contained within 14 CFR 25.1093. Amendment 25-72 of 14 CFR 25.1093 requires operation without adverse effect on engine operation or serious loss of power or thrust in “falling and blowing snow within the limitations established for the airplane for such operation,” but is not specific about snow concentration level. This requirement was originally introduced in amendment 25-36 of part 25.

FAA guidance in advisory circular 20-147 shows that snow concentration requirements have been based on visibility correlations [2]. These correlations specify 1/4 statute mile as the boundary between moderate and heavy snowfall. At the time, the ¼ mile visibility was assumed to be the worst case condition for ground operations. The correlation specifically is:

C = 2100 * V-1.29
where: C = concentration in g/m3
V = visibility in meters

Substituting V = 1/4 mile into the equation yields a concentration C = 0.91 g/m3.

Figure A, below, is a reproduction of Figure 12 from [3]. It includes two curves indicating cumulative probability of snow concentrations calculated from two data sets of observed visibility observations. Curve A is based on the same data set used to derive the correlation, and indicates that the probability is about 94% that snow concentration will not exceed 0.91 g/m3. Curve B is based on a larger multiyear data set, and indicates that the probability is greater than 99% that snow concentration will not exceed 0.91 g/m3.

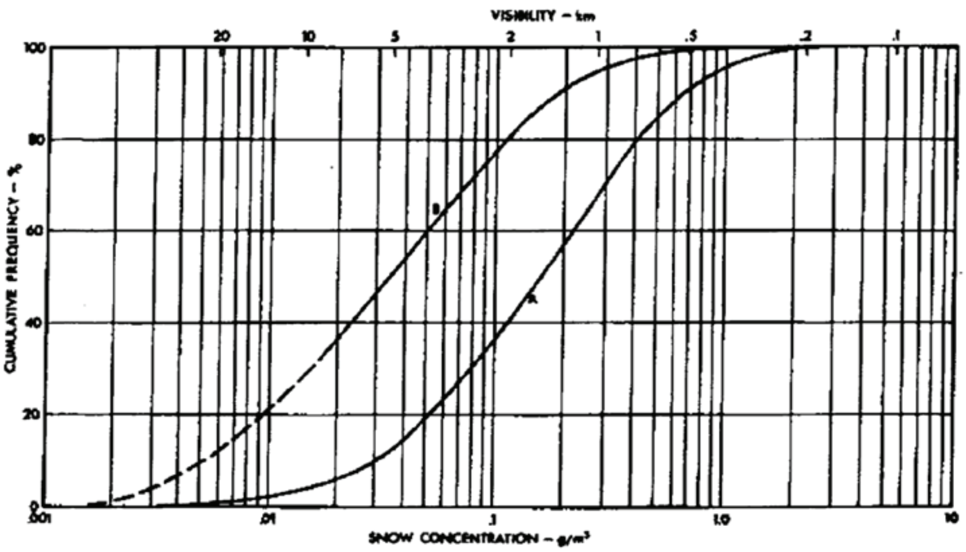

FIG. 12 CUMULATIVE FREQUENCY OF SNOW CONCENTRATION FOR OTTAWA

CURVE A: From N.R.C. Snow Concentration Measurements

CURVE B: As derived from Diurnal Frequencies of Reported Visibility in Combination with Snow for the 20-Year Period 1955-74 at Ottawa International Airport, using the Relation $C = 2100\ V^{-1.29}$

Figure A. Reference 1 Data on Snow Concentration

During the EHWG deliberations, Environment Canada membership offered concern that visibility has been shown by Rasmussen, et al. [2] to be a poor indicator of precipitation rate[1]. To check the above numbers, the following calculation was performed. The maximum precipitation rate for moderate snow is 2.5 mm/hr liquid water equivalent. From a Transport Canada data set of 338,000 minutes of snowfall data, the 95% and 99% values were 2 and 4 mm/hr, respectively, showing that a 2.5 mm/hr threshold provides a severe and unlikely threshold. It was also noted that holdover time tables for anti-icing fluids are only sanctioned by the FAA for use in light or moderate snow conditions. The upper threshold for endurance time testing for moderate snow is 2.5 mm/hr. Using a liquid water equivalent rate of 2.5 mm/hr and a conservative snow flake fall speed (terminal velocity) of 0.8 m/s, a snow concentration with an equivalent liquid water content of 0.9 g/m3 is obtained. The snow fall speed has a direct effect on the liquid water equivalent rate for a given snow concentration. The following table shows the effect for various fall rates at a constant accumulation rate:

Table 1
Dependence of LWC for Snow on assumed Fall Speed of Snow

Rate mm/hr	Fall speed m/s	LWC g/m^3
2.50	0.80	0.87
2.50	1.00	0.70
2.50	1.50	0.46
5.00	0.80	1.74
5.00	1.00	1.39
5.00	1.50	0.93

The EHWG deliberated on fall rates and decided to use a conservative fall rate of 0.8 m/s.

The EHWG further concluded that the two estimates described above (using visibility calculations of reference [3] or using a 2.5 mm/hr accumulation rate along with a 0.8 m/s fall rate) are similar, and consequently, 0.9 g/m3 became the recommended level for testing at ground idle in snow[1]. These considerations underlie the recommended value of 0.9 g/m3 for Condition 3 in the proposed amendments to 14CFR 33.68 and 14 CFR 25.1093 defined in NPRM 10-10. As described above, the value of 0.9 g/m3 atmospheric snow concentration was assumed to correspond to the limit for moderate snow conditions. Recent developments are challenging that assumption and ground operations in heavy snow conditions are recognized as more likely to occur.

The SAE G12 committee has been working over the past few years to clarify aircraft anti-icing hold-over-times (HOT) for operations in snow [4]. A recent development has occurred where airline operators may be able to use holdover times (HOTs) at airports in snow conditions that exceed moderate snow limits, when they use a newly developed liquid-water-equivalent (LWE) system. The LWE system measures LWE rate and other parameters to determine HOT using regression curves from endurance time testing of airframe deicing fluids. The proposed upper rate for HOT determination by these systems for snow is 5.0 mm/hr fall rate (equivalent to 50 g/dm2/hr catch rate), which is already permitted by Transport Canada under an exemption to their regulations. However, during the winter of 2013-2014, the FAA has temporarily established an upper limit for operations in heavy snowfall as 2.5 mm/hr (equivalent to 25 g/dm2/hr). This temporary limit will be lifted starting in the winter of 2014-2015. At that time there will be no upper limit for operation in heavy snow using the LWES.

Note that the FAA already allows users to operate in conditions that exceed moderate snow limits if a visual pre-takeoff aircraft wing contamination check is performed by the pilot within 5-minutes of takeoff. This allows operations in heavy snow conditions, with no upper limit other than conditions that would cause an interruption of airport operations.

From table 1 above, it can be seen for the proposed snow fall accumulation rate of 5.0 mm/hr, the atmospheric concentration is 1.74 g/m3 at a snow fall speed of 0.8 m/s. For aircraft turbine engine operations in heavy snow conditions, an atmospheric TWC concentration could potentially be 1.74 g/m3 or higher.

It should be noted that aircraft have been operated in snow conditions for as long as there have been aircraft engines. Since there has historically been no generally available, accurate way of determining snow fall rates and atmospheric concentrations during operations, it is likely that aircraft have periodically operated in heavy snow conditions in the past, with relatively few safety problems, although safety-significant events have occurred. Figure 1shows the range of snowfall rates possible using 1/4 statute mile visibility as the boundary between moderate and heavy snowfall. The historical data is from Rasmussen et al. and the range is defined by the Fujiyoshi data outline [5]. Figure 1 shows that snowfall rates of 8 mm/hr may have been encountered during operations where the snowfall was considered moderate based on visibility. This corresponds to an atmospheric concentration of 2.78 g/m3 based on the assumptions made in the previous subsection.

The FAA has stated its concern that by utilizing the relatively new LWE systems, operations in heavy snow could abruptly increase, resulting in turbine engines being exposed to levels of snow above the currently proposed regulations, and possibly resulting in an increase in safety-significant engine icing events. This may be additionally compounded by the fact that airports or aerodromes are increasingly staying open during heavier snow conditions, due to improved snow removal equipment and procedures. Associated power run-up procedures to clear engine internal ice accretions are based on the current freezing ground fog certification test point of 0.3 g/m3 therefore, these procedures may not be sufficient to clear engine ice accretions due to the high concentrations of snow. Further to this, power run-up procedures may not clear inlet barrel ice described in the subsection below.

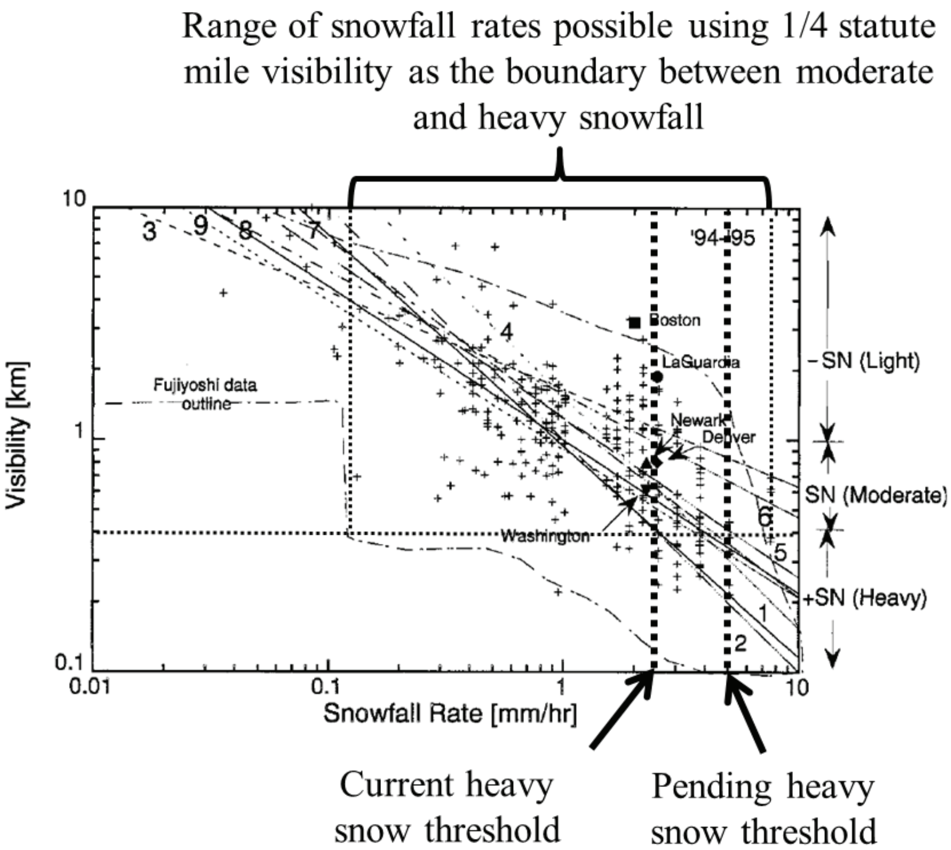

Figure 1: Range of snowfall rates possible using 1/4 statute mile visibility as the boundary between moderate and heavy snowfall

3.1 Service Event Data

Appendix 1 contains the list of events collected by the EHWG which are believed to have occurred as a result of ground operations in heavy snow conditions [1]. In general, the events can be classified into two categories. The first type of event affects the low-speed spool and symptoms include fan damage and high vibrations. The second type of events cause core operability issues and can result in stalls, high vibrations, and in rare instances, compressor damage. It should be noted that operators are not required to report events to airframe manufacturers, engine manufacturers, or the aviation authorities unless they surpass thresholds defined by airworthiness requirements. Thus the database in Appendix 1 may be incomplete.

3.1 Service Event Data (Continued)

The low-speed spool events resulting in fan blade damage are believed to be caused by ice accreting in the inlet barrel of the nacelle, downstream of the ice protection system extent, and upstream of the fan.29 engines have incurred damage of this nature since 2007 while dispatching in snow. Fan tip damage events have occurred when visibility was less than 3/4 statute mile, and strong winds generated blowing snow. Under these conditions, the taxiways can be laden with snow and melt water that can readily be lifted into the inlet of the engine by the ground vortex, as shown in Figure 2.After review of pilot statements and photographic evidence, this subcommittee concluded that taxiway contamination was the root cause of the fan damage. The snow, water and slush was lifted off the taxiway and deposited on the inlet barrel of the engine where it solidified downstream of the ice protection system at low engine speeds; this ice was then released when power was increased. Overall time from push back was determined to be the driving factor for the phenomenon, and roughly 30 min was required for the threat to materialize for a particular engine and airframe combination.

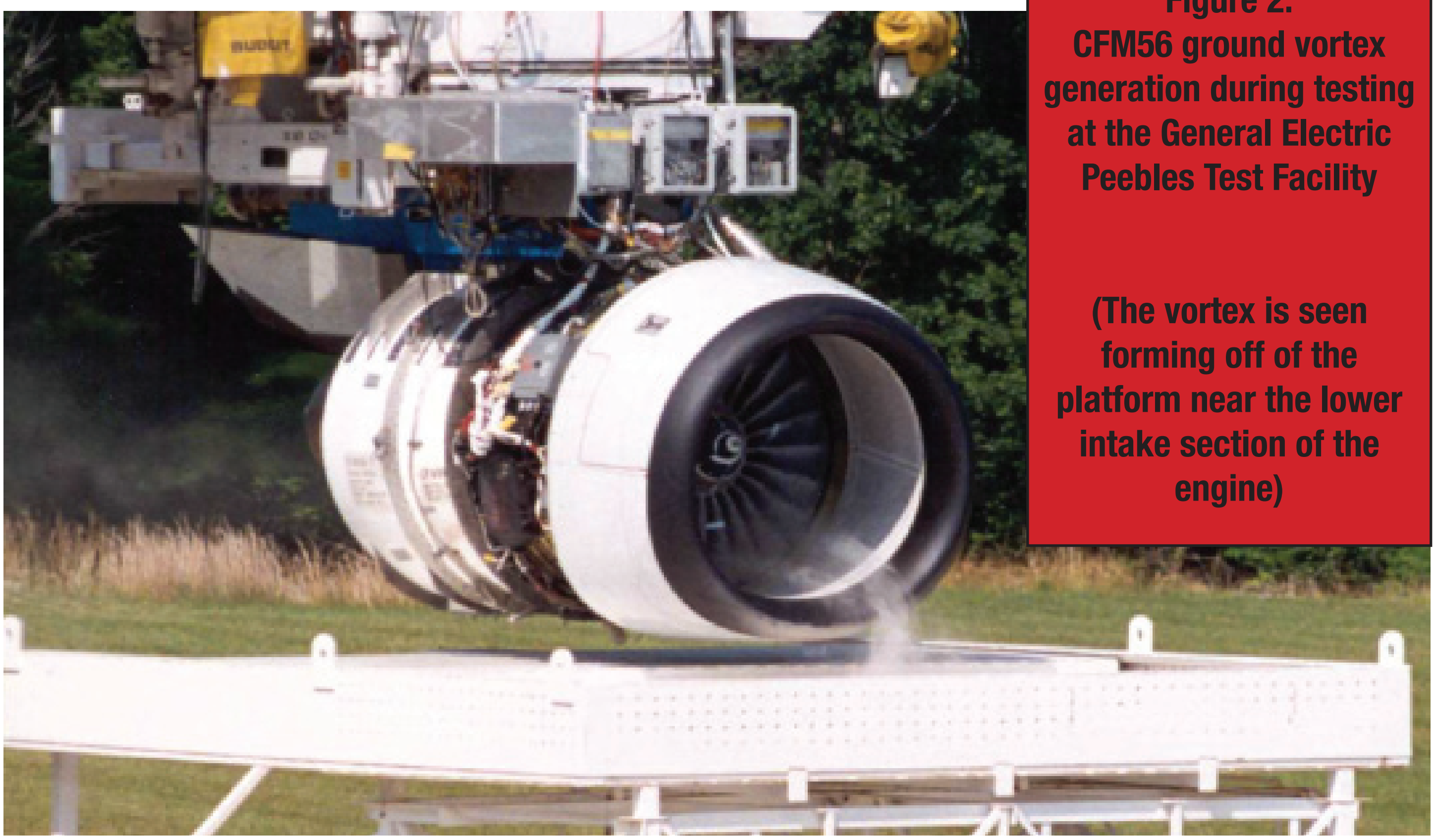

**Figure 2:
CFM56 ground vortex generation during testing at the General Electric Peebles Test Facility**

(The vortex is seen forming off of the platform near the lower intake section of the engine)

Dispatching during heavy snowfall has also caused core operability issues such as stalls, high vibrations, and in rare instances, compressor damage. These core damage and operability issues are believed to be caused by snow impacting and adhering to warm surfaces inside the booster, at the splitter or IGV to the low pressure compressor. This snow either freezes on these surfaces, or causes melt water to be generated that can re-freeze downstream. The accretion that is generated is liberated when the engine power is increased. If the time between run-ups is too long, the accretion can grow to a size that can lead to core operability events and compressor damage.

3.2 Rationale for Recommendations

In the database available to this subcommittee, dispatching in heavy snow has led to the following engine specific events since 1991: 47fan damage, 7 events were generally classified as engine damage with one instance specifically related to the core, 4 cases of high vibrations, and 6 stalls. These events have resulted in rejected take-offs, and air turnarounds. In some cases the damage was discovered upon inspection at the destination airport. Again, it should be noted this database may be incomplete as operators are not required to report events unless they surpass thresholds defined by airworthiness requirements.

Many of the engine events in heavy snow were model specific, or particular to an engine-airframe combination. However, due to the implementation of the new LWES, and the uncertainty of turbine engines being exposed to levels of snowfall beyond existing field experience,the recommendations in the following subsection are made for all turbofan powered transport-category airplane ground operations.

3.3 Recommendations

In addition to the typical best practices listed below, this group recommends inspecting the inlet of the engines at the central deicing station. Particular emphasis should be placed on the inlet barrel. If visible from a safe distance, the fan blades, spinner, splitter lip, and inlet guide vanes to the core should also be inspected. Operating engines should be visually inspection by a qualified Aircraft Maintenance Engineer from a spotter vehicle. Engines should be operating during the inspection so that thermal deicing systems remain active, and to maintain facility throughput. The airframe manufacturer (TC holder) should be consulted for inlet contamination removal procedures.

- Inspect and remove ice from engine inlet and fan area:
  - Prior to leaving gate
  - Prior to leaving central deicing station
- Cover engine inlet during heavy snow conditions when engines are not operating
- Ensure proper functioning of engine inlet ice protection systems per applicable AFM procedures
- Minimize time period from gate push-back to arrival at deicing station, and from departure from deicing station to arrival at runway in preparation for take-off roll
  - Adjust push-back rates to minimize taxi time during threat conditions
- Taxiways should be kept clear of snow and water
- Deicing stations should be kept clear of snow and water
  - Consider having a grating beneath engines to eliminate the ground vortex responsible for lifting snow, water and diluted deicing fluid into the engine
- Prior to engine start and push-back, verify that engines are free of contamination
  - This includes areas of fan blades (typically leading edge and back of blades), engine nacelle barrel, splitter lip, and core inlet guide vanes

3.3 Recommendations (Continued)

  - Consult airframe manufacturer (TC holder) for inlet contamination removal procedures
- Taxi with all engines running in heavy snow conditions
- Perform the AFM recommended procedures for engine power run-ups in icing conditions. Check with airframe manufacturer (TC holder) to determine if more frequent engine power run-ups would be prudent in heavy snow ground operations
  - It is critical that run up frequency and power sets are adhered to during heavy snow
- Avoid engine power increases near puddles, on the wet tarmac or taxi way, or near snow banks
- Prior to leaving the central deicing station, verify that engine nacelle barrels are free of contamination
  - Operating engines should be visually inspected by a qualified Aircraft Maintenance Engineer from a spotter vehicle to maintain facility throughput
    - Fan blade and core ice are removed if proper OEM recommended run-up procedures are adhered to
  - Consult airframe manufacturer (TC holder) for inlet contamination removal procedures
- Avoid close following of other aircraft during taxi since heavier snow concentrations can enter the engines
- Just prior to take-off roll, follow AFM procedures for pre-takeoff engine power setting

4 Acknowledgments

The AIA/EIWG Subcommittee on Engine Ground Operations during Heavy Snow would like to acknowledge the contributions of the Jason Brown, John Horrigan (Winter Operations, Air Canada) and Roy Rasmussen (National Center for Atmospheric Research).

5 Works Cited

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Appendix 1 Event Data

It should be noted that operators are not required to report events to airframe manufacturers, engine manufacturers, or the aviation authorities unless they surpass thresholds defined by airworthiness requirements. Thus the database may be incomplete.

DATE	LOCATION	EVENT SYMPTOMS / CONSEQUENCE	FD	CD	VIB	ST	RB	FO	VSD	MSD	ED	Error EPR	FLIGHT PHASE	ENGINE POWER LEVEL	WHEN DAMAGE DETECTED	SUSTAINED THRUST LOSS ?	PILOT REPORT	METEOROLOGICAL CONDITIONS
12/6/1992	XUS	FD	1										UNK	U	insp	N	S, I	SNOW/ICING
12/6/1992	XUS	FD	1										UNK	U	insp	N	S, I	SNOW/ICING
12/10/1993	FRA	FD	1										UNK	U	insp	N	S, I	SNOW/ICING
12/10/1993	FRA	FD	1										UNK	U	insp	N	S, I	SNOW/ICING
12/11/1993	FRA	ED									1		UNK	H	insp	N	S, I	SNOW/ICING
12/11/1993	FRA	FD, ED	1								1		UNK	H	insp	N	S, I	SNOW/ICING
2/11/1994	XUS	FD	1										UNK	U	insp	N	S, I	SNOW/ICING
2/22/1994	SLC	ST				1							UNK		flt		diversion	
2/22/1994	SLC	ST				1							UNK		flt		diversion	
2/22/1994	SLC	ST				1							UNK		flt		RTO	
2/22/1994	SLC	ST				1							UNK		flt		RTO	
2/22/1994	SLC	ST				1							UNK		flt		Air turn back	
3/4/1994	XUS	FD	1										UNK	U	insp	N	S, I	SNOW/ICING
12/20/1995	JFK	ED									1		TO	GI	flt	N	heavy s	HEAVY SNOW
12/20/1995	JFK	ED									1		TO	GI	flt	N	heavy s	HEAVY SNOW
12/20/1995	JFK	ED									1		TO	GI	flt	N	heavy s	HEAVY SNOW
12/20/1995	JFK	ED									1		TO	GI	flt	N	heavy s	HEAVY SNOW
2/2/1997	XUS	vb			1								TO	GI	flt	N	S, I	SNOW/ICING
10/25/1997	GEG	FD, ED, vb	1		1						1		TO	GI	flt	N	heavy s	HEAVY SNOW
2/17/2003	EWR	FD, Vb	1		1								TO	H	flt			ice, snow
2/18/2003	EWR	fd	1										UNK		insp			snow
2/18/2003	IAD	ST											UNK		flt		refused takeoff	blowing snow
10/31/2003	DEN					1							UNK		insp		None	freezing rain/snow
10/31/2003	DEN												UNK		insp		None	freezing rain/snow
10/31/2003	DEN												UNK		insp		None	freezing rain/snow
1/27/2004	EWR	ST			1								TO		flt		refused takeoff	snow
1/22/2005	EWR	FD	1										UNK		flt		Air turn back	snow
1/22/2005	EWR	FD	1										UNK		insp			snow
1/22/2005	EWR	FD	1										UNK		insp			snow
1/22/2005	EWR	FD	1										UNK		insp			snow
1/22/2005	EWR	FD	1										UNK		insp			snow
1/22/2005	EWR	FD	1										UNK		insp			snow
2/24/2005	EWR	CD		1									UNK		flt	Y		snow
2007 - 2014	Various	FD	29										TO		P or PN	N		snow
		Total:	47	1	4	6	0	0	0	0	7	0						