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Bleed Air Contamination Financial Related Costs on Board Commercial Flights

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ABSTRACT

This paper reviews reportable aviation incidents and associated cost losses. Aviation incidents include visible smoke incidents inside aircraft passenger cabins, occurrences of fumes and oily smells, and illness cases reported by flight crew members in 2012, for US based carriers for domestic flights and all international flights that either originated or terminated in the US. Cost losses include direct and indirect costs endured by different airlines due to diversions from the scheduled flight route, returns to departure airport, expedited arrival procedures, and cancellation of flights on ground. Two case study scenarios are presented to illustrate minimum and maximum costs limits. Sources used to collect data for this article include the Bureau of Labor Statistics, Federal Aviation Administration online database, Research and Innovative Technology Administration database (RITA), and official airline websites.

Average financial loss is estimated to be approximately $32,000 to $47,000 per aviation incident totaling approximately $4.5M to $7M US dollars in 2012. This figure could be doubled when under-reporting of such incidents is taken into consideration.

KEYWORDS: aviation incidents, aircraft cabin, fume odor-illness losses, risk assessment

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INTRODUCTION

This report discusses estimated expenses and financial losses endured by airlines due to unplanned flight diversions or cancellations incurred by oil, fume or illness incidents reported on flights operating inside the United States in 2012. The reports were extracted from the service difficulty reports (SDR) on the US Federal Aviation Administration online database [1].

Bleed air contamination events onboard flights are estimated between 0.09 to 3.9 incidents per 1,000 flight cycles [2]. According to data collected between 2007 and 2012, the Bureau of Transportation Statistics reports a total of approximately 64 million domestic flights in the United States serving approximately two million passengers per day (30,000 flights per day) [3,18]. Thus, considering the lowest limit of bleed air related incidents about 0.09 events per 1000 flight cycles [2], there might be an average of 2.7 incidents per day which can affect an average of two million passengers. A review of data from the FAA service difficulty reporting system (SDR) for the period between Jan. 1999 - Nov. 2008 indicated that there had been 252 events of air contaminants of which 33% were due to fuel leaks, 23% were due to engine oil leaks, 18% were due to APU oil leaks, 13% were due to hydraulic fluid leaks and the remaining 13% (33 events) were due to air cycle machine oil leaks [4]. Murawski and Supplee [5] conducted a survey on the incidents reported by the SDR system within the FAA database and by the Association of Flight Attendants over the period January 2006 to June 2007. The survey reported 470 incidents over an 18 months period yielding an average of 0.87 incidents per day.

Flight crew members around the world have reported neurological illness after reports of exposure to oil fume, but there were no exposure data to investigate [6]. According to Murawski and Supplee [5], in 2007 the International Transport Workers' Federation Civil Aviation Section in London indicated that flight crew around the world are reporting chronic health effects consistent with exposure to tricresyl phosphates (TCPs), oil aerosols, and carbon monoxide.

Concentrations of volatile and semi-volatile organic compounds (VOCs and SVOCs), airborne particulates, and carbon monoxide (CO) in aircraft cabin air have been suggested as potential indicators of bleed air contamination. The use of these indicators is limited by the background levels from other sources. There have been several additional studies not addressed specifically at bleed air contamination events but that do provide useful baseline information. Malmfors [7] measured CO on 48 Scandinavian Airline System (SAS) routine revenue flights including DC-9 and MD-80 aircraft models. O'Donnell et al. [8] conducted a study on 45 routine revenue flights from seven identical aircraft. The study showed a maximum of 4 ppm for CO; 200 $\mu g/m^3$ for total particulates; and no VOCs were detected. Waters et al. [9] conducted a study on 36 commercial transport routine revenue flight segments including 11 different aircraft. Average levels of carbon monoxide over the full-flight duration were generally less than 1 ppm and during 5-minutes sampling the average was as high as 9.4 ppm. The predominant volatile organic compound was ethanol. Toluene and limonene were also detected. Toluene levels ranged from less than 0.3 to 130 ppb, limonene from 3 to 12 ppb, and ethanol from 0.8 to 2.4 ppm. Inhalable particulates had an average 120 $\mu g/m^3$ over the full flight time whereas total particulates had 86 $\mu g/m^3$.

Guan et al. [10] conducted in-flight measurements on 107 commercial revenue flights operating between August 2010 and August 2012. Most samples were collected prior to take-off, during cruise, and upon landing phases of the flights. The selected aircraft included Boeing models B737, B747, B777, B757, B767, and Airbus models A319, A320, A321, A330, A340, and A380. On average, 59 volatile organic compounds were identified in each flight and were 41% alkanes and alkenes, 15% esters and alcohols, 11% ketones and aldehydes, 20% aromatics (mostly benzene), 6% halides, and 6% of other volatile organic compounds. It was concluded that among the three investigated flight phases, landing showed the lowest exposures compared to prior to take-off and cruise phases. The Institute of Environment and Health (IEH) at Cranfield University reported that the most abundant chemicals measured on 100 revenue flights in 2007, based on mean values, were toluene and limonene. The highest concentrations of tributyl phosphates, limonene, m+p-xylene, and undecane were detected during first engine start, while that for tetrachloroethylene (TCE) occurred at the instant when the sampling kits were opened. On the other hand, the highest levels of triorthocresyl phosphates (TOCP), tricresyl phosphates (TCP), and toluene occurred during climb, pre-landing, and take-off phases, respectively. More than 500,000 particles per cubic centimeter (particle/cm^3) of ultrafine particles were measured on five flights and more than 10 ppm of volatile organic compounds were measured on 19 flights with the majority being detected during taxi-out phase of the flights [11].

METHODS FOR IDENTIFYING AVIATION INCIDENTS

This report focuses on the costs associated with reported incidents that were related to oil smoke and fumes on board a wide range of commercial aircraft that originated or terminated in the US. The reported incidents were extracted from the US Federal Aviation Administration service difficulty service system [1]. The extracted reports were individually reviewed, case by case, to determine whether or not it qualified as a bleed air event (smoke/fume, illness, or others). Obviously, some degree of judgment had to be applied in many cases. In very general terms, approximately 75% of the incidents included were clearly attributable to bleed air contamination. The remaining 25% were less clear and may have been classified differently by different reviewers. Some incidents were represented more than once within a given database and duplicates were removed from the numbers reported. The bulk of the actual work for the research reported in this paper consisted of identifying and individually reviewing all these incidents reports.

The rates and the costs used were extracted from the Bureau of Labor Statistics [14], airline's websites, and aircraft manufacturers' published technical reports.

In the case of smoke or fume detection, the assumption was made that the flight would divert to the nearest available airport, the airplane would be evacuated, and passengers would be transferred to another airplane for continued travel. In the case of an illness incident, the assumption was made that the flight would divert to the nearest airport to seek medical care for the patient/s and then continue its flight with no changes in the plane. Therefore, many expenses were not included for illness-reported incidents, as indicated in the following sections.

DIRECT AND INDIRECT COSTS

Direct and indirect costs are analyzed in this report to provide an estimate for the cost of reported aviation incidents and events in 2012. Direct costs include costs that may arise due to diversion or cancellation of the flight, such as:

Landing fees: Many airports charge landing fees in order for an aircraft to land on their ground, regardless of whether or not the landing is a result of an emergency. Landing fees vary over a wide range that differ from one airport to another. Scheduled flights contracted between the airline and airport include special rates in a yearly contract for landing, parking, fuel handling, and facilities' equipment usage. However, in the case when there is an aviation incident, the flight would undergo an emergency landing including return to the departing airport or diversion to an alternate; therefore, agreed rates were assumed non-applicable and higher rates were considered.

Parking: Costs associated with parking the airplane in an alternate airport until relocation to maintenance facilities, if available, may be incurred. (Does not apply to illness cases.)

Leasing: While it is unlikely that an airline would make a one-time lease to replace an aircraft sidelined by an air quality incident, the net effect of multiple incidents could reduce the available fleet for an airline. Therefore, leasing a replacement airplane to transfer passengers from the “new-alternate” airport to their final destination may be reasonable. (Does not apply to illness cases.)

Maintenance fees: Maintenance fees incurred to inspect the airplane after a reported smoke smell or smoke detection (Do not apply to illness cases.)

Expenses for flight crew salaries: Flight crew maximum working hours and rest also contribute to the decision when diverting. If a flight crew exceeds maximum working hours as set by the US Federal Aviation Administration (FAA) [17], while the flight is on the ground, the flight cannot take off with that person on duty. (Does not apply to illness cases.)

Expenses and financial losses for extra fuel: Extra fuel used due to diversions, has two scenarios. In the first case scenario, if the incident was an emergency, the airplane would have landed directly without delay so the incurred expenses included the cost of fuel consumed from the point at which the plane began diversion to the temporary airport and then from the airport to the original route toward the intended destination. In the second scenario, depending on airplane location in the journey, the airplane may be severely overweight for landing. Large amounts of fuel in the fuel tanks may cause heavy loads on the aircraft brakes with the potential to create excessive heat and wear. Brake inspection and, possibly, replacement may be required. Heavy loads and high speeds can cause more heat generation in aircraft tires than normal landing situations [12]. The excess weight in the aircraft also causes over load on the tires [12]. Therefore, unless the situation is an emergency, most airlines opt to either circle in the air to consume fuel or dispose of the fuel into the atmosphere prior to landing, a measure that adds costs and is detrimental to the environment. A report released by BOEING entitled “Overweight Landing? Fuel Jettison? What to Consider?” recommended that when maximum in-flight weight with landing flaps and maximum landing weight are exceeded, an overweight landing inspection should be conducted [13].

Luggage transfer expenses: Since the diverted flight is under emergency landing and no prior scheduling would have been planned, luggage transfer expenses from the plane with an incident to another alternate plane might be incurred. (Does not apply to illness cases.)

Meal replacement expenses: Meals from flights with reported incidents have to be dumped for health and safety reasons. (Does not apply for illness cases.)

Other direct expenses: Direct costs may include expenses for reserving hotel accommodations for passengers when there are no alternate airplanes to continue their flights or when there are no flight crew available. Diversion costs can be significant when the flight crew runs out of duty time. If flight crew members will exceed either their allowed flight time or duty time as allowed by Title 14 Code of Federal Regulations Part 117 (14 CFR 117) [17] due to diversion, they will not be able to serve as planned on following flights possibly creating a crew shortage. Airlines must establish hotel accommodations and other means of transportation for passengers [2].

Examples of indirect costs, which are not included in this report due to the complexity of estimation or because of their wide variance, are:

1. Customers who prefer to use other airlines in the future due to resulting delay. If an aircraft arrives three hours late, a majority of connecting passengers will miss their connections and must be booked on alternate flights at the expense of the airline. These impacts may affect passengers' future decisions to use the offending airline, known as losing the “good will”, and resulting in passengers possibly choosing other airlines for future travel.
2. Medical expenses possibly incurred due to passenger illness. As indicated previously, an average of 2.7 incidents per day was reported over approximately 30,000 flights per day serving approximately two million passengers per day.
3. Possible lack of maintenance team and facilities in the alternate-temporary airport after aircraft diversion and landing and the resulting additional costs to supply a maintenance team. Additional charges may also be required to use other airlines' maintenance facilities.
4. Requirement of an overweight landing inspection when maximum in-flight weight with landing flaps is exceeded. In addition, the tires may be subjected to overheating which can increase tire deterioration. Therefore, this inspection and the cost of tire replacement adds more financial losses to airline operational expenses.

RATES

The rates used in this study were extracted from Bureau of Labor Statistics [14], regional and international airports, FAA online databases [1], and other sources, such as, airlines' websites, and manufacturers' catalogues and references.

1. *Landing Fees*: These fees are the product of maximum certified landing gross weight and a constant rate per plane weight ($/pound or $/kg) that differ between airports. Maximum Landing Gross Weight (MLGW) is obtained from registration certificates for each aircraft model and is available through the Federal Aviation Administration (FAA) online database on their website [1]. Rates listed in Table 1 were used to estimate the parking fees in this study.
2. *Parking Fees*: These fees do not apply for passenger illness cases because of the assumption that the aircraft diverted to allow patient transfer to a hospital and then continued the designated flight. For applicable incidents, 16 hours were estimated in this study as parking time until the plane was moved to a maintenance facility. No accurate information was available regarding parking duration, for that an average of 16 hours were considered which would be equivalent to two working days. Table 2 shows rates used to calculate parking expenses as averaged from multiple airport resources. Considered airports included local, regional, and international airports. Rates differ from regional to international airports, but this case study used fixed rates to compare different aviation incidents on equal basis.

Table 1. Landing fee rates

Rate per 1,000 lb	MLGW (lb)
$7.5	< 12,500
$10	12,500 - 65,000
$0.00509 (per lb)	> 65,000

Table 2. Parking fee rates

MLGW (lb)	Rate ($/ 8 hours)
< 200,000	$100
200,000 - 300,000	$150
300,000 - 750,000	$200
> 750,000	$500

3. *Leasing an Alternate Airplane*: This cost can be estimated based on aircraft lease rates. The average lease cost of an aircraft is approximately $422,000 per month, or $14,000 per day, as reported by International Lease Finance Corporation [15]. However, this average combines narrow body and wide body aircraft into one category. Various airline sources and online databases revealed rates that allowed more options for aircraft models, as shown in Table 3. These rates were used in the case study. Rates were reported as monthly leasing rates, so they could vary widely when only one day is considered. To accommodate for the difference between monthly and daily

rates, the monthly rate was divided by 30 days and multiplied by a factor of two. Leasing cost was not included when estimating financial losses for passenger illness cases.

Table 3. Daily leasing expenses for various aircraft models

Aircraft	Rate	Aircraft	Rate
A300	$48,000	B737	$40,000
A310	$48,000	B757	$46,000
A319	$22,000	B767-200	$46,000
A320	$34,000	B767-300	$66,000
A321	$42,000	B767-400	$66,000
A330	$66,000	B777-200	$70,000
MD-11	$70,000	CRJ-200/700	$20,000
MD-80	$36,000	Other Aircraft	
MD-82		20-50 passengers aircraft	$20,000
MD-83		10-20 passengers aircraft	$10,000
MD-88		< 10 passengers aircraft	$4,000

4. *Maintenance Expenses*: These expenses were estimated based on supervisors and technicians salaries for inspecting, checking, and maintaining the aircraft. Salaries included basic salaries plus overhead costs. In the best case (minimum financial losses), one supervisor and two technicians were considered working for four hours, whereas in the worst case (maximum estimated financial losses), one supervisor and four technicians were considered working for four hours. Rates were extracted from the Bureau of Labor Statistics [14] and overhead costs were estimated at 50% of the basic salaries. Overall rates are shown in Table 4.
5. *Flight Crew Hourly Rate*: Total costs for flight crew including pilots and cabin crew is composed of basic and overhead cost that is estimated to be approximately 50% of the basic salary. These rates are reported in [14] as annual salaries and do not show hourly rates. For this study, annual salaries were divided over 12 months and the assumption was made that 40 hours were worked per week. The rates are shown in Table 5.

Table 4. Maintenance labor hourly rates in US dollars [14]

Labor Category	Hourly rate
Aircraft Mechanics	$ 40.37
Aircraft Inspector	$ 61.28

Table 5. Pilot and cabin crew hourly rates in US dollars [14]

Flight Crew	Annual rate	Hourly rate
Pilots	$ 235,455	$ 122.63
Cabin Crew	$ 55,860	$ 29.09

6. *Fuel Consumption Rates*: As mentioned, airlines may opt to dispose of fuel or burn it prior to landing in order to reduce aircraft landing weight which could cause overload on the brakes and contribute to increased deterioration. Additional fuel weight can increase load on the gear system and tires, as well. Therefore, two cases were considered in which only 20% of fuel tank refilling cost was considered in the best case, thereby accommodating the diversion distance. In the worst case, all the fuel was disposed into the environment and the entire tank required refilling. Rates for fuel were estimated to be $2.9/gallon.
7. *Luggage Unloading and Loading*: Associated expenses for unloading luggage from the diverted aircraft and loading back into an alternate aircraft were estimated assuming one cargo handling supervisor and four porters for an estimated time of three hours per reported aviation incident. Basic hourly rates were obtained from the Bureau of Labor Statistics [14] and overhead costs and insurance were estimated to be 50% of the basic hourly rate (does not apply for illness cases.) Rates are shown in Table 6. Other expenses such as fuel and equipment leasing, used by the cargo workers to complete loading/unloading, were not included.

Table 6. Cargo handling personnel hourly rates in US dollars [14]

	Hourly rate
Aircraft Cargo Handling Supervisors	$36.81
Material Moving Workers	$25.37

8. *Meals Costs*: One meal per passenger was assumed to be served during the alternate flight from the temporary airport to the final destination. Associated rates for domestic and international flights were collected from different airline database, as shown in Table 7. A rate of $12 was used to estimate the loss in meal replacement.

Table 7. Meal average rates in US dollars

Meal Cost	
Rate ($/meal)	Flight Description
$7.50	Domestic
$10	International
$3.50	Other sources / different quality
$12	Used in the study

INCIDENTS REPORTED IN 2012

SDR reporting system from FAA online database was used to check smoke, fume, odor, and illness related incidents that were reported on board flights in 2012 that totaled 115 smoke-related reports and 28 illness incidents. The reported incidents were extracted from reports documented by SDR system [1]. The number of aircraft models in-service during 2012 were extracted from the Bureau of Transportation Statistics [3]. Aircraft models that were included in this study are listed in Table 8. As mentioned earlier, the reports generated from the SDR system on the FAA online database include explicit comments that describe the purpose for the reported incident. These reports were examined case by case to check whether they were related to smoke, oil, hydraulic odor, etc. The variations in describing the smell inside aircraft are due to many reasons such as the variations in temperature, the chemical composition of the oil and the different concentrations contained in the oil. Different contaminants might be released and may have no smell at all such as the case of carbon monoxide. Figure 1 shows the incidents reported for different aircraft models in 2012. It is seen that the incidents are widely spread over the entire list of aircraft models as given in Table 8 and there is no one model that has a reported value way above the others.

Figure 2 shows actions taken on board flights as a result of incident occurrences in 2012. Approximately 66% of flights that experienced an incident returned to the departing airport or diverted to other airports. When an airplane returned to the departing airport, the aircraft was replaced if the event was related to smoke and not illness. If the incident was due to an ill passenger, the entire fuel tank was emptied before landing or retained, but the alternate aircraft required fuel refilling for the trip. The same financial estimates were applied for cases when a flight was cancelled before taking-off, but the landing fee did not apply, because the airplane did not leave the airport.

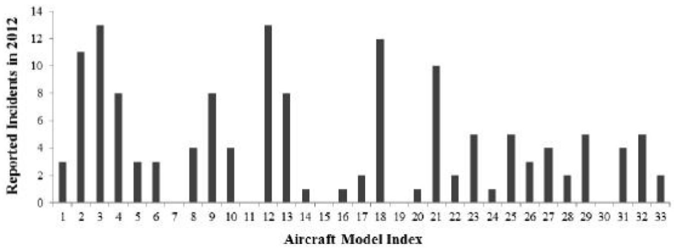

Figure 1. Reported incidents for different aircraft models (Aircraft model indices are tabulated in Table 8)

Table 8. Aircraft models included in the study

Index	Aircraft Model	Index	Aircraft Model	Index	Aircraft Model
1	A300	12	B737-700	23	B777-200/200ER
2	A319-100	13	B737-800	24	DC-10
3	A320-100/200	14	B737-900	25	DC-9
4	A321-200	15	B747-100	26	MD-11
5	A330-300	16	B747-200	27	MD-83/88
6	B717-200	17	B747-400	28	EMB 135
7	B727-200	18	B757-200	29	EMB 170-100
8	B737-100/200	19	B757-300	30	EMB 190-100
9	B737-300	20	B767-200/200ER	31	CRJ 900
10	B737-400	21	B767-300/300ER	32	CRJ 200
11	B737-500	22	B767-400/400ER	33	CRJ 700

A: Airbus – B: Boeing – DC: Douglas Commercial – MD: McDonnell Douglas – EMB: Embraer – CRJ: Canadair Regional Jet

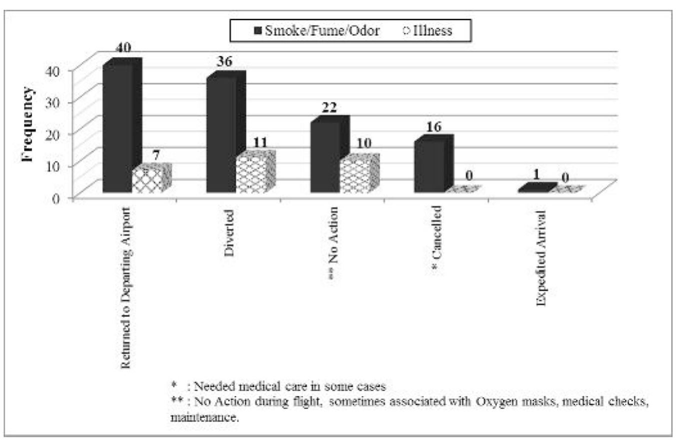

Figure 2. Actions taken due to event occurrence on flights in 2012

ESTIMATED COST LOSS SCENARIOS

To estimate associated cost loss for reported incidents that caused a return to the departing airport, diversion to an alternate airport, cancellation of the current flight including transfer to an alternate airplane, and expedited arrival procedures, two cases were considered to check the upper (maximum) and the lower (minimum) loss limits.

a. *Case 1 - Minimum Loss*

All prescribed cost estimates were used except

- for maintenance, one supervisor and two technicians were considered
- for fueling, only 20% of fuel tank capacity was considered

b. *Case 2 - Maximum Loss*

All prescribed cost estimates were used except

- for maintenance, one supervisor and four technicians were considered
- for fueling, all fuel tank capacity was considered

For an incident in which a flight was cancelled before taking-off, landing expenses and flight crew costs were not included because the airplane did not leave the airport and the flight crew remained on the ground. For "No Action" and "Expedited Arrival Procedures," only maintenance costs and additional parking duration were applied because landing and luggage unloading and loading were as scheduled and the rest of the mentioned direct expenses did not apply.

RESULTS AND DISCUSSION

Table 9 and Figure 3 provide estimates for cost losses due to diversion, return, cancellation, and expedited arrival procedures for flights that experienced smoke and illness incidents reported in the United States in 2012. Incidents were distributed by number of passengers or number of seats per airplane to estimate financial losses of each incident per airplane size.

Total financial loss in flight operations due to reported incidents in 2012 was estimated between $4.5M to $7M US dollars, and the average financial loss per event was approximately $32,000 to $47,000 US dollars. Figure 3 showed that the majority of the bleed air associated losses were identified for middle size airplanes with the highest losses being concluded for aircraft passenger capacities between "150-200" followed by "100-150" passengers. The losses were between one and two million US dollars. The next highest losses were for the "200-250" and "250-300" passengers aircraft. The reason for having the losses associated with the "300-350" passengers aircraft less than those associated with "250-300" passengers, despite having the same number of reported incidents over the same period of time, was that the "300-350" passengers aircraft is represented by A330 aircraft, whereas the "250-300" included A300, A310, A321, MD-11, B767-200/300/400, and B777-200 aircraft, with the second set of aircraft having higher rental/leasing rates per day.

Average incidents per day were estimated approximately 2.7 incidents according to the national research council [2] and 0.87 incidents by Murawski and Supplee [5]. With the highest estimates for both, the reported incidents (2.7 incidents) and the cost loss ($47,000), there was approximately $127,000 paid on daily basis as a result of such incidents. This figure could even be doubled when knowing that the reported incidents are being under reported as reported by [5]. Muraswki and Supplee [5] found that incidents are significantly under reported but the extent to which they are under reported is not clear. It is entirely possible that under reporting could vary considerably from airline to airline due to reporting policies and other factors.

In conclusion, there is substantial uncertainty in the reported results that comes from a variety of sources including, under-reporting of incidents, interpretation of reports of incidents which is solely dependent on the authors review and might change when reviewed by other individuals, the estimated rates from renting, parking, hourly rates, maintenance etc. Despite that, the results of this study showed that airlines could be paying approximately $127,000 on daily basis based on literature data for reported incidents (2.7 incidents/day × $47,000/incident). This can total up to $47M US dollars annually, if not more, with the under-reporting issue, a number that deserves a call to review airlines maintenance procedures, bleed air design, and other associated regulations.

Table 9. Lower and upper limit loss due to smoke and illness incidents reported on flights in 2012

Number of Passengers	Number of events	Case 1 - Low Limit Loss		Case 2 - Upper Limit Loss	
		Total Loss (USD)	Loss per event (USD)	Total Loss (USD)	Loss per event (USD)
< 50	24	$271,454	$11,311	$326,703	$13,613
50-100	15	$369,138	$24,609	$445,306	$29,687
100-150	38	$1,008,564	$26,541	$1,447,470	$38,091
150-200	37	$1,501,221	$40,574	$2,105,472	$56,905
200-250	17	$713,533	$41,973	$967,449	$56,909
250-300	6	$600,975	$100,163	$1,044,550	$174,092
300-350	6	$222,722	$37,120	$400,203	$66,701
Total # Events	**143**	$4,687,607	$32,780	$6,737,153	$47,113

This study was done as part of the planning process for a potential large-scale, on-board sampling study of bleed air contamination incidents. The intent was to draw the attention to the possible financial losses incurred due to such incidents.

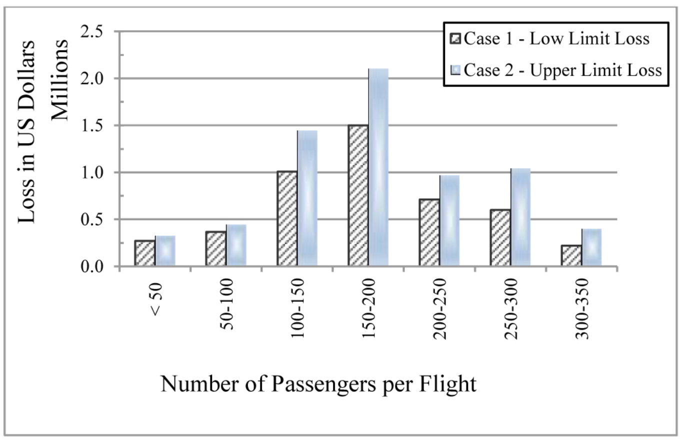

Figure 3. Estimated loss in flight operations in 2012 due to aviation incidents categorized per the airplanes' number of passengers

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