Analysis of Causes and Statistics of Commercial Jet Plane Accidents between 1983 and 2003

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Abstract

This paper presents an analysis of commercial jet plane accidents involving aircraft operated by U.S. Air Carriers between 1983 and 2003. These aircraft are classified under the Federal Aviation Regulations (FAR) 14- Parts 121 and 135 of the Code of Federal Regulations (CFR), listed on the National Transportation Safety Board (NTSB) website. The probable causes reported by the NTSB are analyzed and classified into four main categories: i) human action, ii) environmental factors, iii) structural failure and iv) system failure. In addition, the statistics of damaged aircraft parts, fatalities and accident rates are also listed in the paper. Besides, probabilities of failure of fuselage, wing and tail are estimated and compared with the data provided in literature.

I. Introduction

An *accident* is defined in 49 CFR Part 830.2 as "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 and all such persons have disembarked, and in which any person suffers death or serious injury, or in which the aircraft receives substantial damage." For civil aviation accidents, the National Transportation Safety Board (NTSB) maintains the Accident/Incident Database – the government's official repository of aviation accident data and causal factors. The record for each aviation accident contains data about the aircraft, environment, injuries, sequence of accident events, and other relevant topics.

In this paper, we used the database query tool available at the NTSB website[1] to search for aircraft accidents. We obtained aircraft accident listings given in the reports on the NTSB website, analyzed each accident including the causes of accidents, and classified them. The classification of causes of accidents aims to identify the relative importance of the causes over one another. Moreover, it aids in obtaining the failure probability of aircrafts due only to a particular cause, for instance structural failures. In addition, the damaged aircraft parts are also classified and listed in this paper. This classification helps to assess the failure probabilities of the different parts of the aircraft relative to each other.

The paper is organized as follows. Section II introduces the methodology that we used while searching the NTSB database and the accident classification definitions. Section III gives the statistics of the causes of accidents with a detailed analysis of each cause. The statistics of damaged aircraft parts are presented in Section IV. Accident rate statistics for each year from 1983 to 2003 are given in Section V. Statistics of fatalities are listed in Section VI. Finally, the paper culminates with Section VII, which covers discussions and concluding remarks.

II. Methodology and Classification Definitions

This section gives the research methodology used in the NTSB database search and defines the classification of the accident causes.

As noted earlier, the record of aircraft accidents was obtained from the database query tool available on the NTSB website[1]. This database has various search fields available for finding accidents. The selected search fields and corresponding criteria used in them for this report are given in Table 1. Search fields not listed in Table 1 were left as the default setting as given on the website.

Table 1. Search fields and criteria used for selected data types in the NTSB database.

Data Type	Search Field	Criteria Used
Accident/Incident Information	Date Range	1/1/1983 to 12/31/2003
	Investigation Type	Accident
Aircraft	Category	Airplane
	Amateur Built	No
Operation	Operation	Part 121: Air Carrier

After obtaining the listings of the accidents, the probable causes given in the NTSB reports are analyzed for each accident and the causes of accidents are classified into four main categories as: (1) human action, (2) environmental factors, (3) structural failure and (4) system failure. The definitions of these four categories are given below.

A. Human Action

Accidents classified as resulting from "human action" were caused by the actions of persons either directly or indirectly responsible for the operation of the aircraft, including passenger and criminal action. The types of human action are further broken down as follows:

1. Airport Ground Crew
2. Airline Procedures
3. Manufacturer Procedures
4. Pilot (Captain/First Officer)
5. Flight Crew
6. Maintenance Person
7. Passenger
8. Flight Attendant
9. Terrorist/Criminal
10. Airport Operator
11. FAA
12. Air Traffic Control
13. Pedestrian
14. Mechanic

B. Environmental Factors

Accidents classified under "environmental factors" category were caused by circumstances related to the environment in which an airplane operates. The types of environmental factors are classified into twelve categories as follows:

1. Wind Gusts
2. Turbulence
3. Ground Vehicle Failure
4. Deer Strike
5. Dark Night
6. Snow
7. Rain
8. Rough Landing Surface
9. Icing
10. Fire
11. Microburst
12. Lightning /Thunderstorm

C. Structural Failure

Accidents classified as resulting from "structural failure" were caused primarily by problems related with some part of the structure of the aircraft (as defined above in Section I), and for which the aircraft is typically designed to tolerate. The types of structural failure causes are distinguished as follows:

1. Bird Strike
2. Aging/Corrosion
3. Fatigue
4. Overstress
5. Maintenance/Inspection
6. Design/Manufacturing
7. Foreign Object Damage (excludes bird strike)
8. Unknown
9. Other (Door Latch, Failure of Passenger Stairs, Air-stairs)

D. System Failure

Accidents classified under "system failure" category were caused by problems with systems necessary for operation of the aircraft. The types of system failures are divided into four sub categories as follows:

1. Steering System
2. Electrical Unit
3. Hydraulic Unit
4. Fuel Tank

E. Unreleased cause

For some accidents the cause of the accident has not been determined by NTSB investigators, hence only the probable cause is supplied in the NTSB website. These types of accidents are listed under this heading. The accidents without released cause are not included in our statistical analyses in the next sections.

III. Statistics of the Accident Causes

This section presents statistics on the accident causes as classified in Section II. The statistics on the four general classifications are presented first, followed by a detailed analysis of each of these categories.

The prevalence of each of the four general accident causes as given in Section I are shown in Figure 1. This data set only includes accidents for which a cause was released. The total number of accidents from 1983 to 2003 listed in the NTSB website is 717, whereas the causes of 662 accidents were released.

Figure 1 shows that 448 accidents (68% of the total accidents for which a cause was released) involved human action as a contributing source. Environmental factors were present in 192 (or 29%) of these accidents. Structural failure accounted for 127 accidents (or 19%), and system failure was involved in 40 accidents (or 6%) of the total. It should be noted that the sum of the accident causes given above (807) is greater than the number of accidents with released cause (662) due to the fact that some accidents were attributed to more than one cause. Each of these general categories is further classified into sub-categories and analyzed in the following sub-sections.

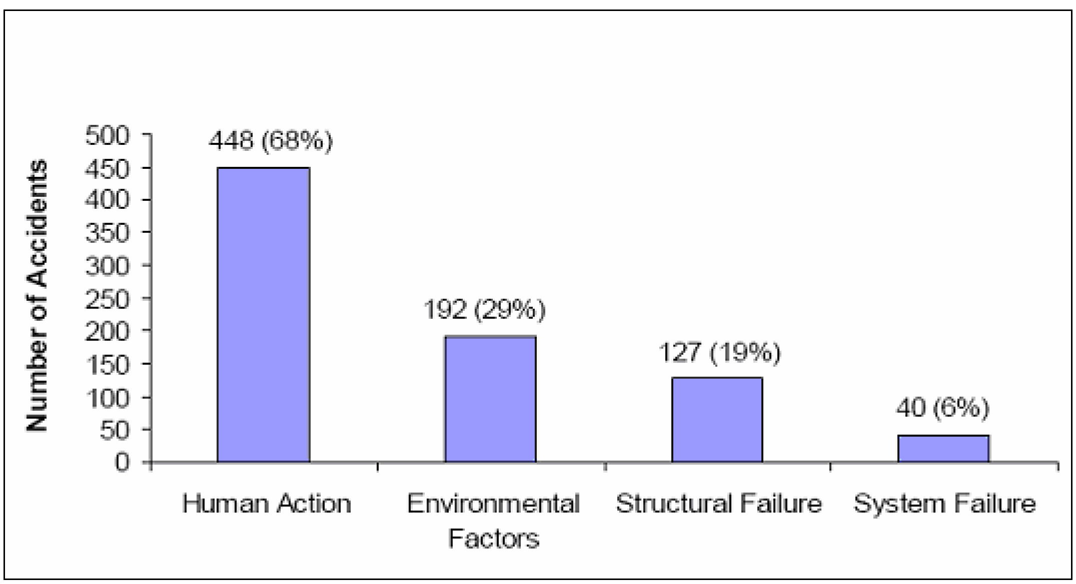

Figure 1. Accident causes as a percentage of total accidents reviewed for which a cause was released. *Note that the sum of the percentages is greater than 100% since some accidents were attributed to more than one cause.*

A. Human Action

The makeup of this category is shown below in Figure 2, which shows that the largest contributor to human action accidents was the pilot (Captain/First Officer), which accounted for 32.4% of all human action accidents. Since human action was involved in 68% of all accidents (with a released cause), this means pilot influence was related to roughly 22% of all accidents. Inadequate taxiing of aircraft, bad landing/takeoff and abrupt maneuvering of aircraft were examples of pilot actions that led to an accident. A list of common pilot actions that caused accidents is given in Appendix A.

The second largest contributor to human action accidents was the inadequate action of airport ground crew. Accidents resulting from the airport ground crew category accounted for 23.7% of all human action accidents, or about 16% of all accidents surveyed with a released cause. These accidents typically involved causes such as inadequate handling of ground vehicles, inadequate ground traffic control and inadequate securing of aircraft (see Appendix A for a more detailed list).

The next five largest contributors for human action accidents, in descending order, were flight crew, maintenance person, passenger, airline procedure, and flight attendant. These had similar proportions of the accident causes, ranging from 9.6% to 4.7% of all human action accidents, or about 6.5% to 3% of all accidents. Examples of accidents related to the flight crew include failure to inform of turbulent weather and inadequate pre-flight planning (e.g., weight calculations). The reader is referred to Appendix A to see more examples of actions of flight crew, maintenance person, passenger, airline procedure, and flight attendant that resulted in an accident.

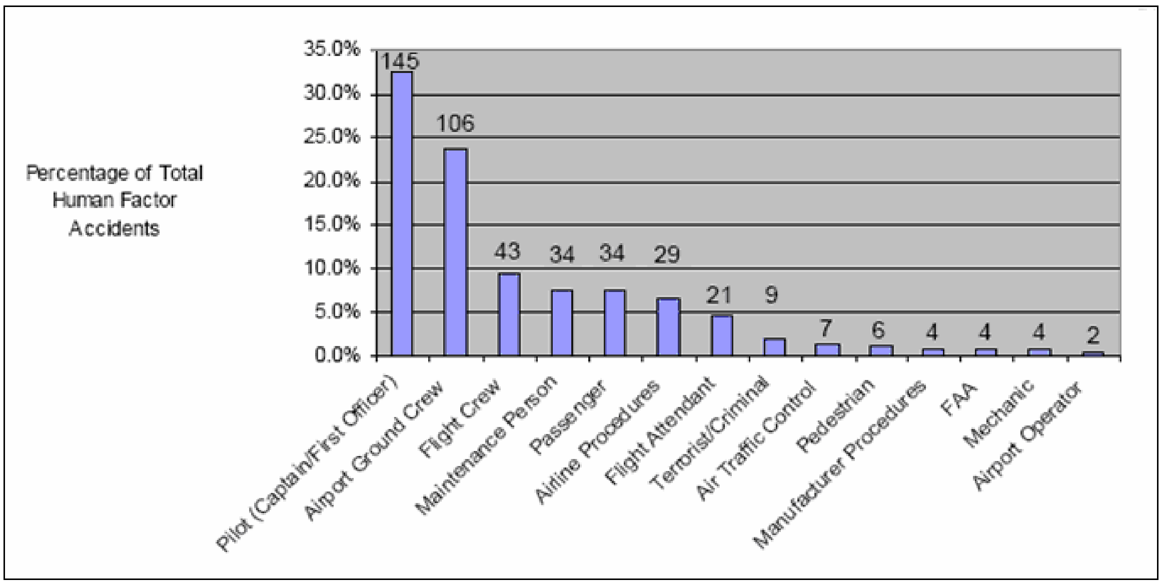

Figure 2. Breakdown of accidents caused by human factors as a percentage of total human factor accidents. *Number of accidents indicated above each bar. Note that the total number of accidents in this category is 448.*

B. Environmental Factors

The accident causes for the accidents due to "environmental factors" as a percentage of the total are shown in Figure 3, which shows that the overwhelming majority of environmental causes were due to turbulence. This category made up 79% of all accidents involving environmental causes, which amounts to 23% of all accidents surveyed with a released cause. Wind gusts were a factor in 5.2% of surveyed accidents with a released cause, and snow was involved in 3.6% of these accidents. The remaining categories were each equal to or less than 2.1% of environmental accidents.

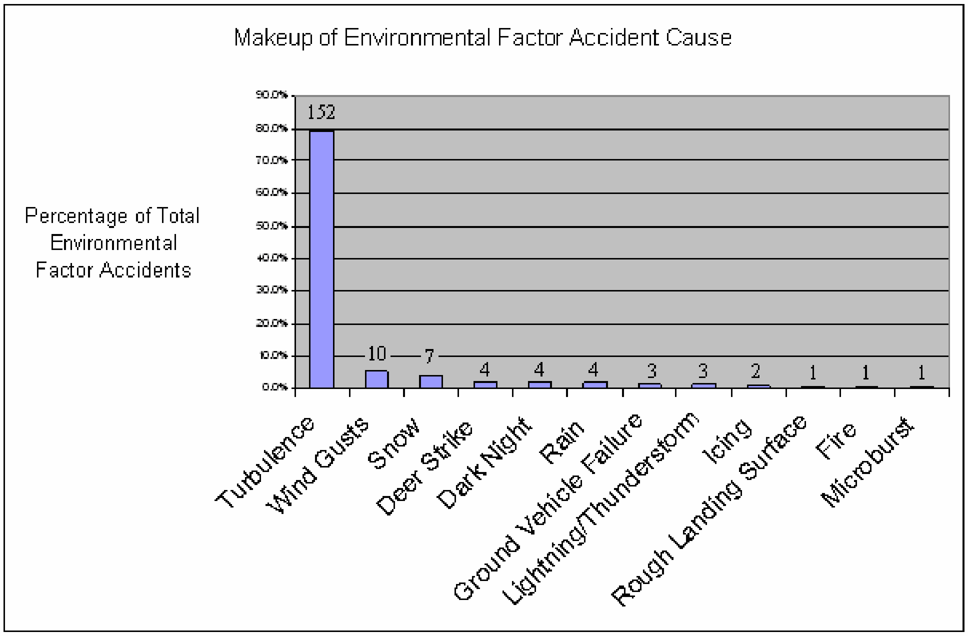

Figure 3. Makeup of the environmental factor accident cause as a percentage of total accidents involving environmental factors as a cause. *Number of accidents indicated above each bar. Note that the total number of accidents in this category is 192.*

C. Structural Failure

This section analyzes more closely the makeup of the structural failure cause. There are five major structural factors contributing the total number as depicted in Figure 4. Recall that human action had two categories with percentages in double digits and environmental had only one such category, structural failure has five such categories. The highest of these (just over 25%) was due to design/manufacturing causes. This was followed by fatigue (19%), overstress (19%), bird strike (14%), and maintenance/inspection (13%). Examples of causes due structural failure are listed in Appendix B.

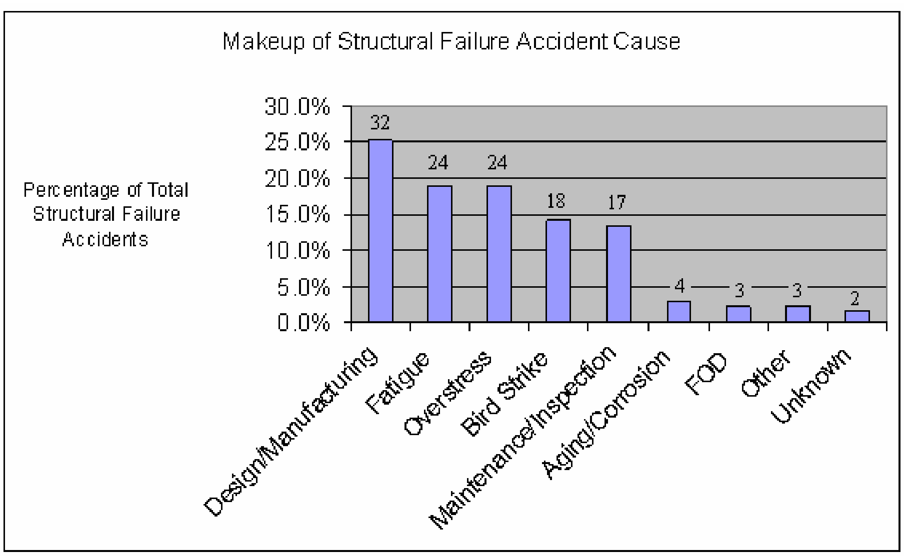

Figure 4. Makeup of the structural failure accident cause as a percentage of total accidents involving structural failure as a cause. *Number of accidents indicated above each bar. Note that the total number of accidents in this category is 127.*

D. System Failure

The sub-categories of system failure as a percentage of all accidents involving system failure are shown in Figure 5. The majority of system failures involved an electrical unit, which was related to 60% of all accidents with system failure as a cause. This amounts to 3.6% of all accidents surveyed with a released cause. The hydraulic unit was a factor in 35% of all accident with system failure as a cause, and the steering system and fuel tank were each involved in 2.5% of all accidents surveyed with a released cause. Examples of causes due to system failure are listed in Appendix C.

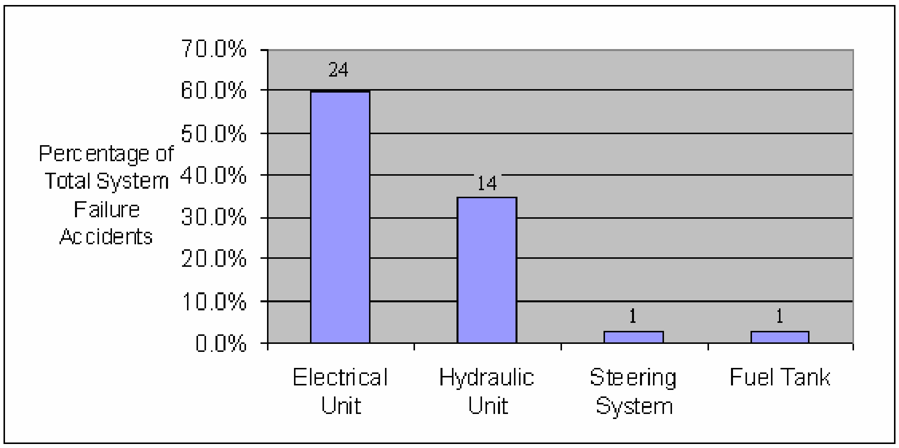

Figure 5. Makeup of the system failure accident cause as a percentage of total accidents involving system failure as a cause. *Number of accidents indicated above each bar. Note that the total number of accidents in this category is 40.*

IV. Damaged Part Statistics

This section analyzes the damaged parts of the aircraft structure in those accidents which involved structural damage. Figure 6 shows the number of times a part was damaged based on this classification. Out of the 662 accidents with released causes, 363 involved damage to the aircraft, or about 55%. The prevalence of damage to various parts of the aircraft's structure was analyzed as a percentage of the total number of accidents involving structural damage. Since some accidents involved damage to more than one part, the sum of accidents above is greater than the total number of accidents involving damage.

Figure 6 depicts that amongst the components considered here the fuselage sustained damage most frequently at 24% of accidents involving damage, or 87 times. The wing and engine/nacelle categories accounted for roughly the same amount of part damage at just over 18% each. The next most prevalent damaged part was the landing gear at roughly 15%. This was also the percentage of accidents for which there was no info as to the damaged part. About 13% of the accidents sustaining damage resulted in a completely destroyed aircraft. The unknown category was present in just over 6% of accidents, followed by the nose at 4%, and the windshield and other categories at about 1.5% each.

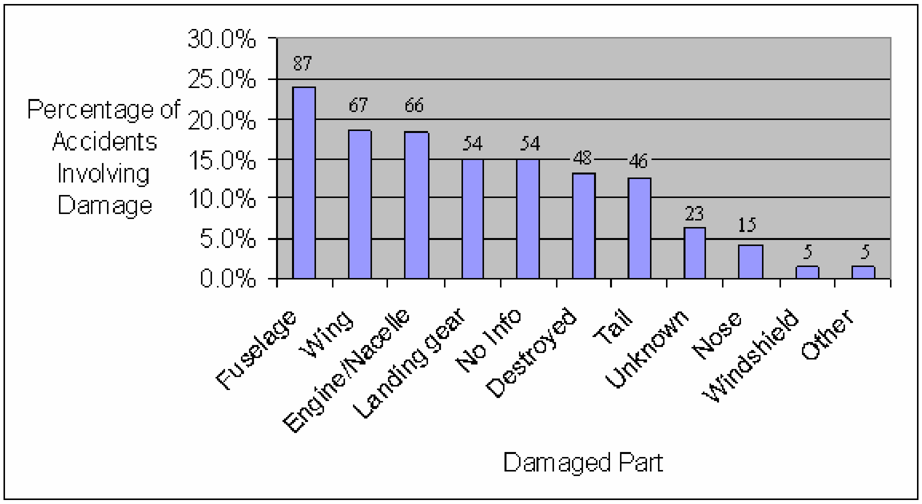

Figure 6. Prevalence of damage to the aircraft's structural parts. *Data is shown as a percentage of the total number of accidents involving structural damage. The number of accidents is indicated above each bar.*

Figure 6 shows the statistics of the damaged parts due to all causes listed, i.e., human action, environment, structural cause and system failure. For an aircraft structural designer, on the other hand, it may make more sense to have an estimate of the statistics of the damaged parts resulting from structural causes only. Figure 7 depicts the comparison of the numbers of failures of wing, fuselage and tails (vertical tail and horizontal tail) due to their own structural failure. We see that the numbers of fuselage, wing and tail failures are 18, 18 and 9, respectively. For a typical transport aircraft the structural weight is about 28% of the total aircraft weight, and out of this 28% the fuselage counts for 9%, the wing counts for 11% and the tails count for 2% (page 287, Ref. 2). We notice that the probabilities of failure of the aircraft structural components are related to their weights in that heavier components have larger probabilities of failure.

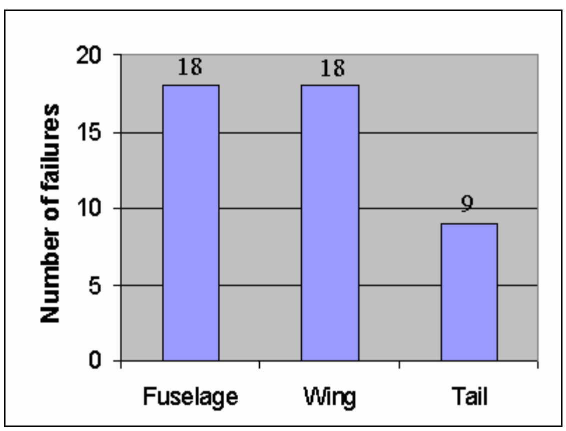

Figure 7. Damaged part statistics due only to structural causes. *Note that the number accidents due to structural causes is 127, and the number of accidents that resulted in damage to aircraft is 363.*

The number of damaged fuselage, wing and tails along with their structural causes are listed in Table 2. Amongst the structural causes bird strike and damage due to impact of failed engine parts are the leading reasons.

Table 2. Number of damaged fuselage, wing and tail due to structural causes

	Number of damaged parts

Structural cause	Fuselage	Wing	Tail
Bird strike	4	10	2
Damage due to impact of failed engine parts	7	4	3
Hard landing	5	1	0
Stress corrosion cracking	0	1	0
Buckling	0	0	1
Fatigue	1	0	1
Aging	1	0	0
Wing overload	0	1	1
Ailerom hinge moment reversal	0	0	1
Crack and delamination due to an unknown reason	0	0	1
TOTAL	18	18	9

V. Accident Rate Statistics and Probabilities of Failure of Structural Components

This section first lists the total number of accidents for a given cause for each year from 1983 to 2003. Then, estimates of average probabilities of failure of some structural components (fuselage, wing and tails) are presented. Finally, comparison of our probability of failure estimates are compared with the estimates provided in literature.

The accident rate for each year is calculated using two different criteria: flight hours and departures. We used the number of flight hours and number of departures given in the NTSB database[3]. Table 3 lists a general overview of all accidents. Table 3 shows that on average every year 30 accidents occur.

Table 3. Total accidents and accident rates by year for all accidents.

Year	Accidents	Flight Hours	Departures	Accidents per 1,000,000 Flight Hours	Accidents per 1,000,000 Departures
1983	23	6,914,969	5,235,262	3.326	4.393
1984	16	7,736,037	5,666,076	2.068	2.824
1985	21	8,265,332	6,068,893	2.541	3.460
1986	23	9,495,158	6,928,103	2.422	3.320
1987	37	10,115,407	7,293,025	3.658	5.073
1988	30	10,521,052	7,347,575	2.851	4.083
1989	28	10,597,922	7,267,341	2.642	3.853
1990	25	11,524,726	7,795,761	2.169	3.207
1991	27	11,139,166	7,503,873	2.424	3.598
1992	17	11,732,026	7,515,373	1.449	2.262
1993	23	11,981,347	7,721,870	1.920	2.979
1994	23	12,292,356	7,824,802	1.871	2.939
1995	37	12,776,679	8,105,570	2.896	4.565
1996	39	12,971,676	7,851,298	3.007	4.967
1997	49	15,061,662	9,925,058	3.253	4.937
1998	48	15,921,447	10,535,196	3.015	4.556
1999	52	16,693,365	10,860,692	3.115	4.788
2000	57	17,478,519	11,043,409	3.261	5.161
2001	48	17,157,858	10,634,051	2.798	4.514
2002	41	16,397,413	9,884,540	2.500	4.148
2003	53	16,600,000	9,800,000	3.193	5.408
Avg.	**29.67**	**12,541,625**	**8,228,941**	**2.685**	**4.049**

Total	**717**	**263,374,117**	**172,807,768**	**--**	**--**

Figure 8 depicts the variation of accidents per million departures with years. One might expect to see reduced number of frequency of accidents with increase in years, because the aircraft companies are constantly improving the manufacturing techniques, developing more accurate analysis techniques, increasing the accuracy of failure prediction, etc. On the other hand, Figure 8 does not follow this trend. The reason may be that the aircraft companies constantly translate the mentioned advances and improvements to weight savings from the structures, so that the safety does not drop to very low levels.

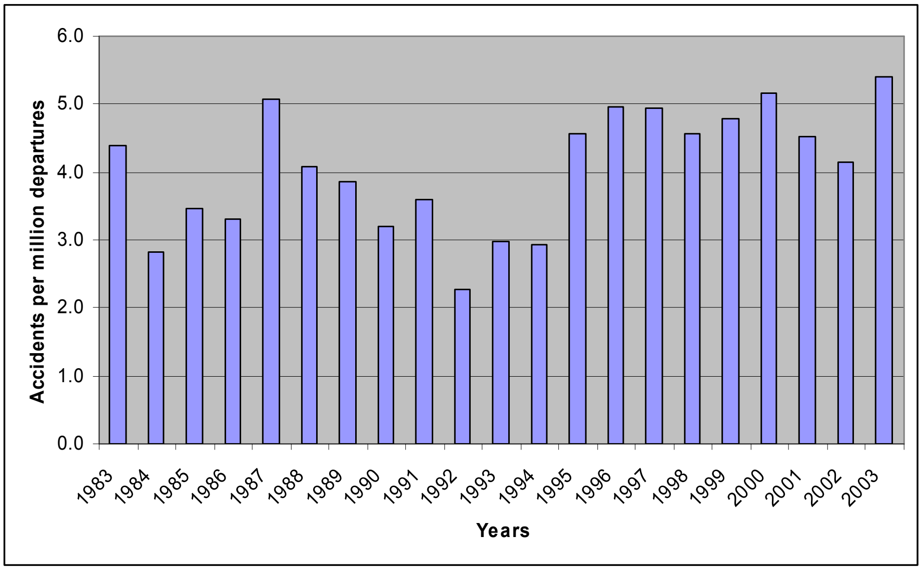

Figure 8. Variation of accidents per million departures with years

Average probabilities of failure of fuselage, wing and tail can be estimated by dividing the total number of failures of these components given in Table 2 to the total number of flight hours (or the total number of departures) given in Table 3. The probability of failure results are listed in Table 4. Comparison of our results with the earlier published work in literature is given next.

Table 4. Average probability of failure estimates of fuselage, wing and tail (average over 1983-2003)

Component	Total number of failures	Total flight hours	Total number of departures	Probability of failure based on flight hours	Probability of failure based on number of departures
Fuselage	18	263,374,117	172,807,768	6.8×10^{-8}	1.0×10^{-7}
Wing	18	263,374,117	172,807,768	6.8×10^{-8}	1.0×10^{-7}
Tail	9	263,374,117	172,807,768	3.4×10^{-8}	5.2×10^{-8}

Comparing our probability of failure estimates with other sources

Here we compare the probabilities of failures calculated in this section with other sources. Tong[4] performed a thorough literature review on aircraft structural risk and reliability analysis. Tong[4] refers to the paper by Lincoln[5] that reports the overall failure rate for all systems due to structural faults is one aircraft lost in more than ten million flight hours, i.e. $P_f = 10^{-7}$ per flight hours. Since an aircraft comprises several components, the component failure probabilities are expected to be smaller than the overall aircraft probability of failure. Our estimates of component probabilities of failure are meaningful in that they are all smaller than 10^{-7} per flight hours.

The Boeing Company publishes the Statistical Summary of Commercial Jet Aviation Accidents[6] each year, and provides data back to 1959 to indicate trends. Table 5 lists the number of accidents that occurred between 1959 and 2001 due to structural failure, the total number of accidents and the accident rate corresponding to different aircraft generations. We see from Table 5 that failure probability per departure of second generation airplanes is 4.31×10^{-8}, whereas the failure probability of early widebody airplanes and current generation airplanes are 2.0×10^{-7} and 1.86×10^{-8}, respectively. When we compare the results given in the Boeing report, we see that their failure probabilities are small. The reason for this discrepancy could be due to mismatch of definition of structural failure. For instance, we defined the bird strike as a structural cause, and they might not.

Table 5. Aircraft accidents and probability of failure of aircraft structures. *Examples of first generation airplanes are Comet 4, 707, 720, DC-8. Boeing 727, Trident, VC-10, 737-100/-200 are examples of second generation airplanes. Early widebody airplanes are 747-100/-200/-300/SP, DC-10, L-1011 and A300. Examples of current generation airplanes are MD-80/-90, 767, 757, A310, A300-600, 737-300/-400/-500, F-70, F-100, A320/319/321.*

Aircraft Generation*	Accident Rate per million departures* (A)	Total Number of accidents* (B)	Accidents due to structural failure* (C)	Structural failure rate per departure (A×C / B)
First	27.2	49	0	0
Second	2.8	130	2	4.31×10^{-8}
Early widebody	5.3	53	2	2.00×10^{-7}
Current	1.5	161	2	1.86×10^{-8}
Total	---	393	6	---

* These columns are taken from the Boeing accident report[6]

VI. Statistics of Fatalities

This section analyzes the fatalities in the aircraft accidents. The total number of fatalities from the 717 analyzed accident records (with and without a released cause) was 2,821. The distribution of fatalities by year is given below in Figure 7. Insight into the correlation between accident cause and the number of associated fatalities is given in Figure 8.

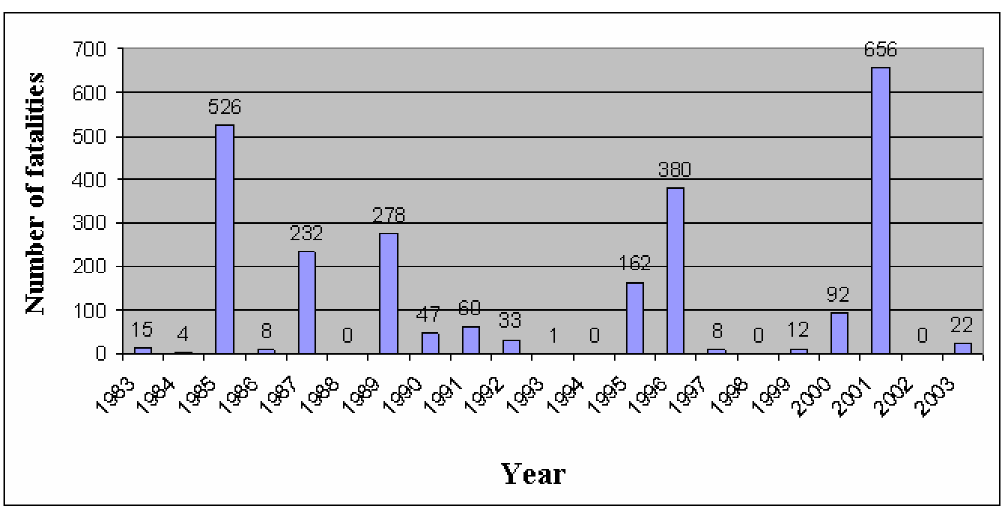

Figure 9. Fatalities by year

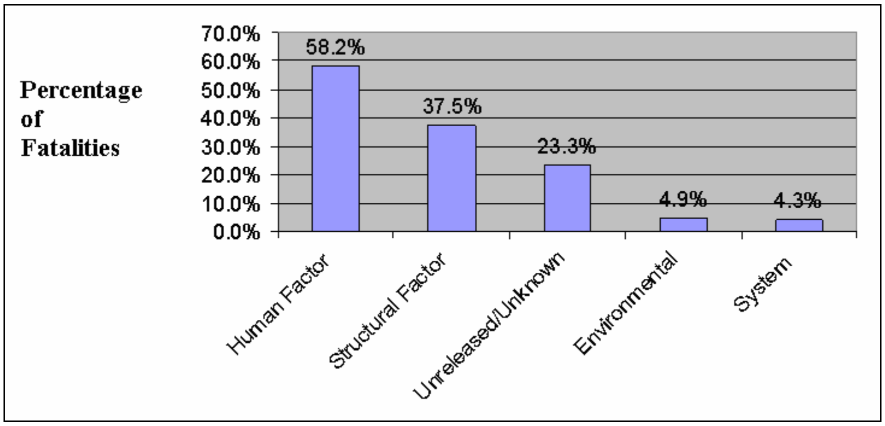

Figure 10. Contribution of each general accident category to fatalities.

VII. Concluding Remarks

From the results of this work, we drew the following observations on accident causes.

1. Human error accounted for most of the accidents (448 or 68%), which reveals that the airplanes themselves were generally performing relatively well. A majority of accident causes involve a human interaction. Moreover, pilot error was a significant contributor to the general human error classification. It turns out that 22% of all accidents were due to pilot error. Further research may be warranted to investigate the details of these pilot error accidents so that the number of accidents could be drastically decreased.
2. Turbulence dominated the environmental category, accounting for nearly 80% of this classification. This amounts to 23% or nearly one quarter of all accidents surveyed. This points to a need for better prevention of turbulence-induced accidents, possibly better training of pilots to deal with such situations or improved weather and environment prediction capabilities.
3. System failure accounted for a relatively small proportion of the accidents (only 6%). This is surprising given the potential for failure in complex systems, especially electronic systems such as avionics or fly-by-wire control systems.
4. Structural failure accidents may be more catastrophic than other types of accidents. Structural failure accounted for 19% of all accidents, but it was involved in 37.5% of all fatalities.

In addition, accident rate statistics are analyzed and estimates of the probabilities of failure of fuselage, wing and tail are presented. The probabilities of failure of heavy components are found to be larger than the lighter components. In particular, the probability of failure of wing and fuselage found to be twice of that the tail. We compared our estimates of probabilities of failure with two other estimates given in literature. We found that our estimates were close to the estimates given in one of the works (Ref, 5), while they were apart from estimates given in the other (Ref. 6). We argued that the reason for the discrepancy with the estimates in Ref. 6 might be due to the difference in definition of "structural cause".

The results presented herein this paper are covered with uncertainties. First, there was difficulty in identifying the root cause of some accidents, due to a coupled relation among some scenarios (e.g. poor visibility leading to pilot error, and as a result potential system failure, such as too much control surface input). Second, as in the case of a hard landing for instance, it was difficult to say if the touchdown was indeed within the range of acceptable forces for failed landing gear, which would point to a manufacturing error, or if the pilot did indeed exceed the limit, which is human error.

Acknowledgements

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Appendix A. Examples of human actions that were an accident cause

This section lists examples of human actions that led to an accident. We listed examples of pilot actions, airport ground crew, etc. in this section.

Examples of **pilot** actions that led to an accident were given below.

- Inadequate taxiing of aircraft
- Bad landing/takeoff
- Abrupt maneuvering of aircraft
- Inadequate pre-flight checklist
- Inadequate evaluation of weather reports
- Inexperience with flying
- Improper glide path along with fatigue
- Inadequate flare; remedial action not performed by the company check airman
- Parking brakes not set
- Excessive control surface input
- Pilot induced oscillations and delay in aborting the takeoff
- Failure to maintain proper wind-adjusted V_{ref} airspeed
- Failure to maintain directional control
- Spatial disorientation
- Failure to de-ice before takeoff

Examples of **ground-crew** actions that led to an accident were given below.

- Inadequate handling of ground vehicles
- Inadequate ground traffic control
- Inadequate securing of aircraft
- Medical condition of crew
- Jet blast from engines
- Failure to follow procedure
- Inadequate communication with pilots
- Tow bar structure failed on ground vehicle
- Inadequate chocks for securing airplane
- Inadequate snow removal from runway
- Engine overfilled with oil leading to fire
- Large portable maintenance stand left on runway

Examples of **flight crew** actions that led to an accident were given below

- Failure to inform of turbulent weather
- Inadequate pre-flight planning (weight calculations)
- Disregard for pre-landing checklist
- Failure to follow weather avoidance procedures and delay in activating seat belt sign

- Continued use of an un-stabilized GPS approach

Examples of accidents related to the **maintenance persons** include the following:

- Inadequate maintenance inspection (APU doors, engine cowls)
- Service bulletin ignored (engine)
- Systemic failure to identify and correct a long-standing history of intermittent faults, nuisance warnings, and erratic behavior with Ground Proximity Warning System
- Inadequate servicing of emergency landing gear extension system
- Missing parts in the nose landing gear shock strut inner cylinder assembly

Examples of accidents related to the **passengers** include the following:

- Fell while boarding/exiting the airplane
- False alarm of an emergency
- Failure to comply with seat belt sign
- Fell off emergency slide

Examples of accidents related to the **airline procedure** include the following:

- Lack of assistance for boarding passengers
- Inadequate chocking procedures
- Improper loading of airplane and subsequent wrong trim setting
- Engines were started with inlet plugs installed

Examples of accidents related to the **flight attendants** include the following:

- Inadequate food cart handling
- Inadequate preparation for severe weather
- Spilled coffee on passenger

Examples of accidents related to **terrorists/criminals** include the following:

- Terrorist hijacking and crashing of aircraft (9/11)
- Tampering/altering of a galley lift interlock microswitch

Examples of accidents related to **air traffic controllers** include the following:

- FAA approach/departure controller's improper service and failure to coordinate and resolve a conflict between aircraft

Examples of accidents related to **manufacturer procedures** include the following:

- Manufacturer's inadequate inspection procedures for the slat drive system

Examples of accidents related to **FAA** include the following:

- Poor procedural oversight for loading of airplane

Appendix B. Examples of accidents due to structural failures

Examples of causes under the heading of **design/manufacturing** are the following.

- Inadequate weight and balance analysis with oversight of incorrectly rigged elevator control system
- Windshield certification process did not take into account the effects of multiple bird strikes on the same windshield
- Rudder system design
- Moisture contamination of the elevator trim actuators
- Failure of clamp led to separation of engine cowling
- Inadequate nozzle lock design led to stress rupture
- Propeller blade impacted an unknown object that severed the blade from the hub
- Insufficient lubrication of horizontal stabilizer trim system jackscrew assembly's acme nut threads
- Wrinkled elevator skins after aggressive pitch change
- Manufacturing defect in a bolt hole that was not detected by the engine manufacturer
- Use of bolts susceptible to stress corrosion cracking to secure the inboard trailing edge flap
- Turbine blade fracture
- Inadequate installation of a thrust reverser, driver linkage arm pivot bolt and nut
- Fuselage stringers not aligned, unused holes plugged, led to cabin decompression

Fatigue was made up of such causes as follows:

- Fatigue failure of the main drag stay tube, right main landing gear collapsed during an emergency landing
- Fatigue failure of the main landing gear strut due to inclusions in the material, residual stresses, and dissolved hydrogen content
- Fatigue failure of right main landing gear
- Fatigue failure of left main landing gear on landing
- Forging fold in manufacturing resulted in fatigue crack in the right main landing gear cylinder, failure during landing
- Low cycle fatigue fracturing of the approach lighting cover bolts
- Fatigue failure of the nose landing gear due in part to change from forged to machined plate stock
- Failure of elevator drive shafts
- Fatigue failure of the master connecting rod due to corrosion pitting which compromised the engine crankcase
- Inadequate procedure for manufacturing the number two turbine disk
- Failure of engine fifth stage turbine hub due to a cyclic stress rupture
- Fatigue failure of 7th stage high compressor disc
- Fatigue failure of stator vain

Some of the major contributors to the **overstress** category include the following:

- Rudder separation from excessive loading
- Overstress of nose landing gear spray deflector
- Overstressed center landing gear on landing led to rearward failure
- Stall buffet or a high speed buffet buckled the elevator
- Tire rim failure due to over inflation
- Failed bearing in left engine

The makeup of the **bird strike** category involved the following examples:

- In-flight collision with geese, other birds
- Multiple bird strikes eventually led to failure of windshield
- Bird struck and damaged right wing on takeoff
- Two wild turkeys damaged inlet, windshield, and fuselage skin

- Collision on final approach
- Ingestion of birds into both engines, resulting in foreign object damage and subsequent partial power loss to both engines
- Bird ingestion caused an engine fire
- Struck a flock of geese, one penetrating the pressure bulkhead through the radome, one splattered debris on windshield, others damaged fairings, wing roots, and Krueger flaps

Some of the **maintenance/inspection** issues contributing to structural failure included:

- Engine cowls not latched led to separation in-flight
- Failure to properly secure and inspect the attachment bolt for right elevator control tab
- Inadequate and ineffective inspection techniques by the engine manufacturer
- Mechanical separation of the left engine beta control linkage during landing rollout
- Inadequate inspection of primary elevator shaft
- Fatigue failure of 7th stage high compressor disc

Aging

- Failure of accessory drive shaft due to deterioration

Deer Strikes

- Collision with deer during landing roll

Other (Passenger stairs, air stairs, door latches)

Passenger stair handrail collapsed

Appendix C.

Some of the examples of causes classified as "electrical unit" are the following:

- Failure of electrical unit prompted an emergency evacuation, during which a passenger's ankle was injured
- A failure of the left power control distribution unit (PCDU)
- Erratic ignition exciter
- An explosion of the center wing fuel tank (CWT) due to a short circuit and electrical wiring associated with the fuel quantity indication system
- Malfunctioning AOA sensor
- Diode inside a transformer was shorted

Hydraulic unit was made up in part by the following examples:

- Failure of a titanium hydraulic line resulted in fluid fire in a wing
- Worn out hydraulic line resulted in loss of steering and braking

The causes classified under the **steering unit** or **fuel tank** include the following:

- Steering system failed while taxiing, causing hard left turn and prompting abrupt input and braking to compensate and stay on runway
- An explosion of the center wing fuel tank (CWT) due to a short circuit and electrical wiring associated with the fuel quantity indication system