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Comparison Of Flight Safety Between Different Aircraft Modifications

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Abstract

This paper discusses the relationship between the next aircraft modifications on the number and consequences of accidents or incidents. The problem is discussed on the example of selected models of the Boeing brand. The first part of the paper discusses the impact of introducing new designs on flight safety. The differences between modifications of selected Boeing aircraft are briefly presented. Definitions of an accident and an aircraft incident are quoted and the sources of data used for the analysis are presented. In the next part of the study, the number of aircraft of a given type in service at a given time was estimated based on delivery reports. The numbers of aircraft in service were compared with aircraft accident and incident reports. The number of adverse occurrences per aircraft of a given type in the sequential years following the introduction of a new model was presented in tables and graphs. In the following part of the study, the probability of occurrence of different loss categories in the first two years of operation after the launch of the new aircraft models was calculated. Finally, the results obtained are summarised and discussed as well as interpreted.

Keywords: aviation, boeing, aircraft evolution, cause of accidents

1. Introduction

The civil aviation industry is characterised by a high level of safety (Ingraham, 2015; Dąbrowska and Soszyńska-Budny, 2018; Valis, et al. 2019). This is the result of stringent procedures for the design, maintenance and operation of aircraft and all surrounding infrastructure. It is not possible to achieve a 100 per cent level of reliability. However, it is possible to strive to improve it.

The purpose of this research is to examine differences in safety levels for newly introduced aircraft designs over successive years of operation. The analysis is based on the example of Boeing aircraft and accidents and incidents in the United States of America.

2. Risk aspects in the introduction of new aircraft designs

The aviation industry is constantly evolving and, with advances in technology and widespread computerisation, seeks to optimise operating costs and improve travel safety. Aviation is characterised by a high level of safety compared to other forms of transport (Ingraham, 2015; Kuben et al. 2019; Kołowrocki, et al. 2017). This is due to the numerous requirements that both aeronautical structures and crew training programmes and operating processes must meet. Certification procedures are developed, among other things, on the basis of accident and incident investigation experience (Organizacja Midzynarodowego Lotnictwa Cywilnego, 2010; Tłoczynski, 2017; Kołowrocki and Kuligowska, 2018).

The introduction of a design to the market involves the deployment of new technological solutions both in terms of operation and in maintaining continuous airworthiness. These new developments require training of the operators both during normal operation and in abnormal situations. Training is time-consuming and the programme is designed to minimise the risk of hazardous situations during operation.

2.1. Impact of the introduction of new designs on flight safety

The critical examination of the introduction of new designs on flight safety encompasses a thorough analysis of various technical factors. Research indicates that innovative approaches, such as the deployment of stratospheric aerosol injection tactics, play a significant role in mitigating anthropogenic radiative forcing, thereby addressing environmental challenges in aviation. This is complemented by the advancement in aircraft design, exemplified by models like the Flying-V, which aims to enhance efficiency while minimizing noise and environmental impact, highlighting the industry's dedication to sustainable practices (Overeem et al. 2022). The commitment to ensuring aircraft operational reliability through model-based approaches is pivotal for improving safety standards and design innovations (Tiassou et al. 2013). Furthermore, the application of reliability methods in the management of aircraft design projects offers invaluable insights into improving aircraft safety and maintainability (Vieira et al. 2016). This is augmented by the integration of process standards for system safety analysis, which facilitates the initial airworthiness certification process for military aircraft, underlining the significance of streamlined and effective certification procedures.

In contrast, the majority of literature on the safety of next-generation commercial jets focuses on individual cases, with significant attention directed towards the 737 MAX model. The two crashes associated with this model, caused by the introduction of new aircraft trim solutions, underscore the complexities involved in integrating new designs (Gelles, 2021; Valis et al. 2019a; Grzejda et al. 2021). Additionally, the discourse on successive generations of aircraft often revolves around the reduction of unit costs and environmental impact, reflecting a broader concern for economic and environmental sustainability (MWL, 2021; Grabowski et al. 2021; Hasilova and Valis, 2018). However, scholarly discussions on commercial flight safety over time do not correlate the number of aircraft accidents with the age of a particular design. Instead, they prioritize understanding the causes of accidents and exploring potential improvements in safety statistics from year to year (Karen and Marais, 2012; Oszczypala et al. 2022; Jaszak et al. 2022).

In conclusion, the intersection of technical advancements, from aircraft design and reliability to certification processes, with the nuanced examination of specific case studies and overarching trends in commercial flight safety, forms a comprehensive framework essential for ensuring the safety and efficiency of modern aircraft designs.

2.2. Aircraft used in the analyses conducted

The study considered Boeing 737, 747, 757, 767, 777 aircraft in variants manufactured between 1959 and 2007. This allowed information to be collected on aircraft of selected types in service between 1982 and 2007. The average service life was assumed equal to 25.7 years (25 years, 8 months and 21 days) based on data from year 2015 (Forsberg, 2015; Cicmanec and Petrasek, 2019).

3. Data sources

3.1. NTSB National Transportation Safety Board

Accident data was taken from the National Transportation Safety Board (NTSB) (NTBS - National Transportation Safety Board, 2022; Palasz and Przysowa, 2019; Grzejda et al, 2022). The organisation was founded in 1967 to improve transport safety. The agency covers areas such as road, rail, sea and air transport, among others. The agency's main objective is to improve safety by conducting independent investigations into the causes of accidents. Based on the obtained findings, the NTSB makes recommendations to prevent or reduce similar incidents in the future (NTBS - National Transportation Safety Board, 2023; Ivchenko and Zhuzhukin, 2020; Giel and Plewa, 2016).

The agency publishes detailed statistics on civil aviation accidents. The data collected is published on the NTSB website. The compilation includes data such as:

- type of incident (incident, accident);
- the daily date of the incident;
- approximate or exact location, including geographical coordinates;

- the code of the airport where the incident occurred (if applicable);
- degree of injury and number of casualties;
- total number of persons on board;
- degree of damage to the aircraft;
- registration number of the aircraft involved;
- manufacturer and model of aircraft;
- type and number of engines;
- carrier operating the service;
- weather conditions;
- phase of flight.

3.2. Boeing

Data on delivered aircraft was obtained from the manufacturer's website (Boeing, 2022; Giel et al. 2017; Wang and Pham, 2020). Boeing is one of the largest manufacturers in the aerospace industry. Its product range includes commercial aircraft, systems and military aircraft, and is involved in the space industry (Boeing, 2022a; Oravec et al. 2021; Giel and Plewa, 2016a). The corporation employs more than 140,000 people in more than 65 countries worldwide (Boeing, 2022b; Sun and Geng, 2021; Rządkowski et al. 2021). Aircraft delivery data published on the website includes parameters such as:

- name of recipient;
- country of delivery;
- model and series of aircraft delivered;
- engine type;
- month and year of delivery;
- number of aircraft delivered in a given delivery.

4. The methodology of calculation

The paper calculates the probability of accidents and incidents in the first years after the introduction of a particular aircraft type on a per-aircraft basis. The number of aircraft operating in the US was approximated by the percentage of passengers carried by US-registered aircraft relative to all commercial traffic worldwide (The World Bank IBRD – IDA, 2010; Bielawski et al. 2017; Hoskova-Mayerova et al. 2020). The resulting ratio is as follows:

$$p = \frac{number\ of\ US\ passengers}{number\ of\ passengers\ worldwide} = \frac{926\ 737\ 000}{4\ 369\ 655\ 800} = 21.08\% \quad (1)$$

$$eks = wyp \cdot p, \quad (2)$$

where:

- p – percentage of passengers carried by aircraft of airlines registered in the USA;
- wyp – the number of aircraft of a given type in service worldwide at any given time;
- eks – the number of aircraft of a given type in service in the US at a given time.

The number of aircraft of a given type in service at any given time was approximated on the basis of the average service life of the aircraft and the delivery dates of the aircraft.

The following relationships were used to calculate the number of incidents by aircraft type:

$$number\ of\ incidents\ per\ aircraft = \frac{\begin{array}{c} number\ of\ incidents\ involving\ the\ type \\ in\ the\ following\ 12\ months\ after\ release \end{array}}{\begin{array}{c} average\ number\ of\ aircraft\ of\ a\ type\ in\ service \\ over\ the\ following\ 12\ months\ after\ release \end{array}} \quad (3)$$

The following equation was used to average the number of incidents and accidents:

$$average\ number\ of\ incidents\ per\ aircraft = \frac{\begin{array}{c} total\ number\ of\ incidents \\ per\ aircraft\ of\ all\ types \end{array}}{number\ of\ types\ under\ consideration} \quad (4)$$

The following classification was used in calculating the probability of loss by category:

- u_0 – no damage to the aircraft;
- u_1 – light damage to the aircraft;
- u_2 – significant damage to the aircraft;
- u_3 – destruction of the aircraft;

- r_0 – no injuries to persons present on board;
- r_1 – slight injury to at least one person present on board;
- r_2 – serious injury to at least one person present on board;
- r_3 – fatal injuries to at least one person present on board.

The risk measure was calculated based on the following relationship (Szopa, 2016; Mogilski, et al. 2020; Ameri et al. 2019):

$$\Lambda(c,t) = Q(t) \cdot Z(c) \tag{5}$$

where:

- $\Lambda(c,t)$ – risk measure;
- $Q(t)$ – probability of the adverse event occurring in period t;
- $Z(c)$ – probability that the adverse event will cause.

It was assumed in the calculations that the variable t represents the first 2 years from the introduction of the new model into service.

5. Analysis

Based on Boeing aircraft delivered data from 1959 to 2007 (Boeing, 2022a; Bekesiene and Hoskova-Mayerova, 2018; Babiarz, 2015) and assuming an average service life of 25.7 years (Forsberg, 2015; Babiarz, 2018), the number of aircraft of a given type in service at a given time was calculated. Up to 2007, eight main variants of the 737 were produced. Table 1 shows the delivery dates of the first units.

Table 1. Delivery dates for the first 737s.

	Originals		Classic			Next Generation			
	737-100	737-200	737-300	737-400	737-500	737-600	737-700	737-800	737-900
Date of first delivery	12.1967	12.1967	11.1984	09.1988	02.1990	09.1998	12.1997	04.1998	05.2001

Figure 1(a) shows the number of examples of a particular series remaining in service at a given time.

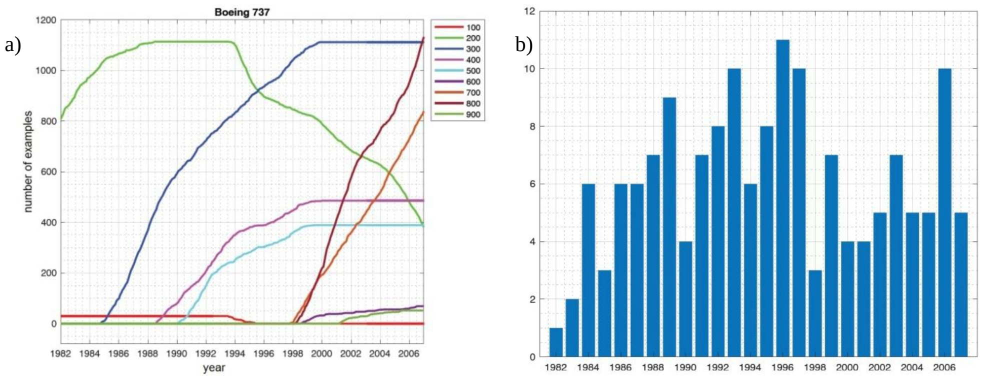

Fig. 1. (a) Number of model 737s in service; (b) Total incidents involving aircraft types 737, 747, 757, 767, 777.

5.1. Number of incidents

Using data downloaded from the NTSB website (NTBS - National Transportation Safety Board, 2023; Babiarz and Szymanski, 2020), information was collected on the number of incidents of each series of Boeing aircraft. The data is from 1982-2007.

Figure 1 (b) shows that the number of accidents involving Boeing aircraft of the series in discussion ranges from one to eleven per year.

Figure 2 (a) shows the number of incidents by year involving aircraft of the Boeing 737s of each series. There were no incidents involving 600-series aircraft between 1982 and 2007.

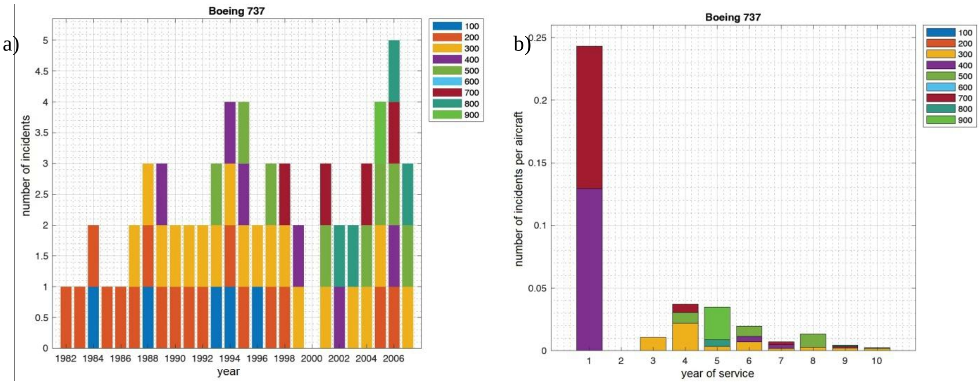

Fig. 2. (a) Number of incidents involving Boeing 737s; (b) Number of incidents per 737 aircraft in service.

5.2. Comparison of the number of incidents with the release date

The number of incidents involving aircraft of a particular series in the years following the launch of the variety was calculated. The data is presented per aircraft in service at the time.

The calculation for the 737 excludes the 100 and 200 series due to the launch date of these types prior to 1982, the first year for which US incident data is available.

The sum of the number of incidents by year is shown in the graph (Figure 2(b)).

The most incidents are certainly in the first year of service.

5.3. Average number of incidents

Totals of incidents were averaged across aircraft types which allowed data to be obtained without a breakdown by type. The results are presented below (Figure 3(a)).

The highest number of incidents per aircraft occurs in the first two years after the beginning of service for an aircraft of a given type. The probability of an incident in the first two years is on average almost five times (4.84) higher than in the following eight years. In the following years, the calculated values are significantly lower and fluctuate within a small range.

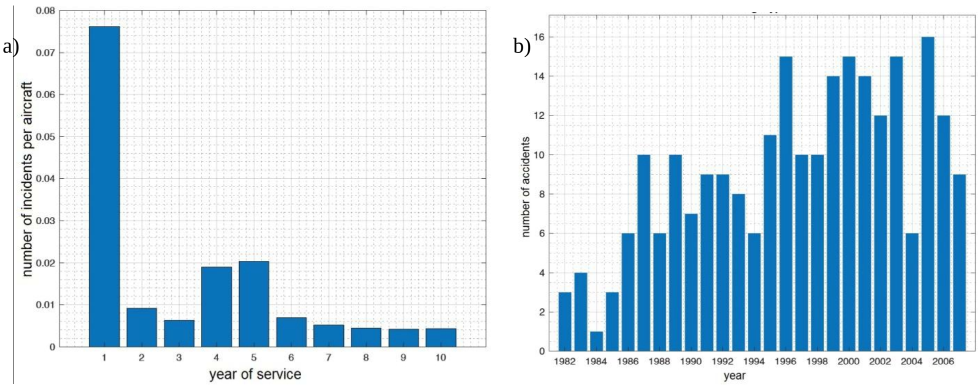

Fig. 3. (a) Average number of incidents per type of aircraft in subsequent years of service;
(b) Total accidents for aircraft types 737, 747, 757, 767, 777.

5.4. Average number of accidents

Total accidents were averaged across aircraft types, allowing data to be obtained without a division into a given type. The results are presented in Figure 4(a).

The highest number of accidents per aircraft occurs in the first two years after the beginning of service for an aircraft of a given type. The probability of an accident in the first two years is on average more than seven times (7.16) higher than in the following eight years. In the following years, the calculated values are significantly lower and fluctuate within a small range.

5.5. Probability of loss

The highest number of incidents occurs during the first two years of aircraft operation. To illustrate the risks involved, the probability of loss by category was calculated.

The calculated values are shown in Table 2.

Table 2. Probability of loss in the first two years of service.

Category of loss	Probability
u_0	0.042
u_1	0.085
u_2	0.051
u_3	0.026
r_0	0.127
r_1	0.009
r_2	0.042
r_3	0.026

The results from the Table 2 are shown in Figure 4(b).

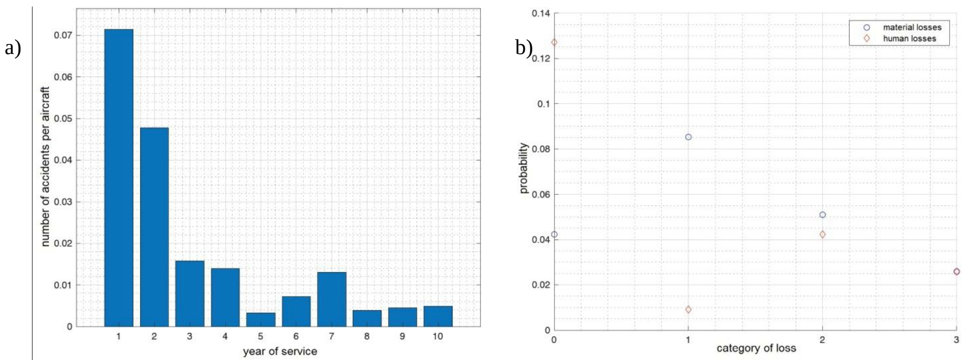

Fig. 4. (a) Average number of accidents per type of aircraft in consecutive years of operation;
(b) Probability of loss in the first two years of service.

Most accidents and incidents result in no injuries to persons on board. The lowest probability is for minor injuries during an incident and accident. The highest probability level in the damage category is for minor damage. The lowest probability level occurs for damage resulting in the destruction of the aircraft.

The calculated probability values are relatively high, this is influenced by the calculation method or methodology, in which only aircraft in service in the first two years after introduction to the commercial sector are considered. The real probability of loss during regular aircraft travel is much lower.

5.6 Discussion of results

The analysis of Boeing aircraft delivered from 1959 to 2007, considering an average service life of 25.7 years, provides critical insights into the operational reliability and safety of these aircraft over time. With eight main variants of the 737 produced up to 2007, the examination of the first delivery dates and subsequent service records sheds light on the evolution of aircraft design and its impact on safety.

The assessment of incidents involving Boeing aircraft from 1982 to 2007 reveals a pattern where the number of accidents varies annually but consistently shows a higher incidence rate in the initial years of an aircraft's service. Specifically, no incidents were reported for the 600-series between 1982 and 2007, suggesting improvements in design and safety measures over time. The correlation between the number of incidents and the years following the launch of each aircraft series indicates that the majority of incidents occur within the first year of service, highlighting the challenges associated with the introduction of new aircraft designs.

Furthermore, the analysis extends to average the number of incidents and accidents across all aircraft types, revealing a significantly higher probability of incidents and accidents within the first two years of service. This probability decreases markedly in subsequent years, demonstrating that while the initial phase of service poses greater risks, the likelihood of incidents stabilizes over time.

The calculation of the probability of loss in the first two years of service further emphasizes the heightened risk during this period. However, it's crucial to note that most accidents and incidents result in no injuries, and the probabilities calculated reflect a specific methodology focused on the early service years, which might not fully represent the overall safety during regular aircraft operation.

This comprehensive analysis underscores the inherent risks associated with the introduction of new aircraft designs, particularly in their initial service years. It also highlights the importance of continuous improvement in design, safety measures, and operational protocols to mitigate these risks. The data suggests that as aircraft undergo service and accumulate operational experience, their safety records improve, reflecting the aviation industry's commitment to enhancing the reliability and safety of air travel.

6. Summary

The calculations show that the highest probability of adverse events, i.e. incidents and accidents, occurs within the first two years after the launch of a given aircraft model. The distribution of adverse events is analogous to the typical course of malfunctions of a technical object. In the calculations, no increase in the failure rate, characteristic during Phase III, was observed. One reason for this may be that the calculations were carried out for the first ten years after the launch, which may be a non-exhaustive period for the occurrence of Phase III.

The safest period is Phase II, which is dominant over time. During this period, the number of adverse events is relatively low. From the results obtained, it can be concluded that it occurs from the third year of operation. This is the time when most of the defects resulting from the design and operating procedures have been eliminated and the undesirable phenomena characteristic of Phase III are prevented by not allowing excessive wear and tear and continuous aircraft modernizations. In Phase II, crew training programmes are revised and improved over Phase I. This allows for a significant reduction in human error causing accidents and incidents.

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