# Boeing 737 Commercial Jet Aircraft Accident Analysis

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## ABTRACT

The Boeing 737 is the most produced commercial jet aircraft in aviation history. Accidents involving the Boeing 737 family of aircraft were statistically evaluated. Aircraft flight phases were found to have a significant effect on the risk of having an accident. Risk indicators based on the flight phase of the aircraft were developed. The multiplex risk indicator $I_m$ that had been created from a motion study approach in industrial engineering was found to fit well with the percentage of aircraft accidents, with an $R^2$ value greater than 0.84. The phase of flight had a significant effect on accident occurrence for Boeing 737 aircraft. The multiple risk indicator $I_m$, however, was found to have no effect on the number of fatalities, which was probably due to the very complicated nature of fatalities in aircraft accidents.

**Keywords:** commercial aircraft, accident, Boeing 737 family, aircraft flight phase, risk indicator

## INTRODUCTION

Aircraft accidents are costly and have a disastrous effect on air transportation industries, such as airlines, aircraft manufacturers, and even the people involved and their families. Aviation regulation authorities issue rules, standards and regulations, mainly for safety. Aircraft manufacturing companies have spent an enormous amount of money on research and development associated with aircraft safety. Most airlines have good pilot recruitment and training programs. However, aircraft accidents still happen and research papers about aircraft accidents appear limited. This paper is a result of a statistical analysis of global aircraft accidents based mainly on aircraft accident investigation reports and databases (Aviation Safety Network, 2009). It seems appropriate to bring some findings to promote further study and attempt to find better ways of operating an aircraft fleet to achieve an even better safety records.

The accident process and the importance of human factors have been explained by Reason (1990). The Human Factors Analysis and Classification System (HFACS) was proposed by Wiegmann and Shappell (2003). It seems, however, that further study and continual development are still needed. While the accident investigation process and HFACS are useful, a "back to fundamentals" approach is still necessary.

In this study, as a starting point, it was not accepted that human factors are the dominating effect in aircraft accidents, but rather, a fundamental statistical approach was applied. It was anticipated that the careful analysis of trends using appropriate statistical techniques would produce some interesting information.

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## MATERIALS AND METHODS

### Equation for annual deliveries of Boeing 737 aircraft

The Boeing 737 family of aircraft is the most used commercially, with the annual delivery volume still increasing (Figure 1). At the end of 2007, the estimated number of aircraft produced was 5,438 and the estimated number of aircraft ordered was 7,800, with 84% of them still in operation (Boeing, 2006). This made them the most popular aircraft series ever produced. From the observed increasing trend and the possible cyclical relationship with time (*t*), Equation 1 representing the number of annual deliveries was derived from curve fitting:

$$Nd = (5.7332t - 369.63) + \{1 - \frac{1}{2}\cos(\frac{2\pi t - 3}{6})\}$$

$$(1)$$

where Nd = number of aircraft delivered, t = (year - 1900). This equation fitted the data with a mean absolute deviation (MAD) of 44.7 units, which appeared reasonable.

Due to the popularity and the availability of an extended period of recorded data, the Boeing 737 family of aircraft appeared to be suitable for study in more detail. This paper considered the commercial jet aircraft in the Boeing 737 family.

### Time-series analysis of accidents involving aircraft in the Boeing 737 family

The frequency of accidents may vary with time. There can be many variables involved that can cause an accident, including aircraft age, outdated technology, pilot error, adverse weather and low visibility, deficiencies in communication and maintenance system failure. If the number of aircraft used and aircraft age are the dominating factors causing accidents, it would be expected that the annual frequency of aircraft accidents would increase with the number of aircraft used and hence time. However, if the improvements in technology, pilot and supporting personnel training and other factors are the dominating factors, the frequency rate of aircraft accidents should decrease with time, which seems to be the case for Boeing 737 aircraft.

It may be appropriate to consider the ratio of accident cases per thousand of the cumulative total number of this family of aircraft delivered f/(N/1000). The trend of f/(N/1000) against time is illustrated in Figure 3. The relationship can be represented by Equation (2):

$$f/(N/1000) = 2.00*10^{20} \, t^{-10.266} \qquad (2)$$

The $R^2$ value of Equation 2 was 0.801, which indicated a good fit with the data. Figure 3 shows that the accident ratio f/(N/1000) decreases appreciably as time increases, which seems to suggest that newer technology and better personnel training may lead to lower rate of accidents. The function f/(N/1000) approaches zero, which indicates continuing improvement of safety in air transportation for Boeing 737 aircraft.
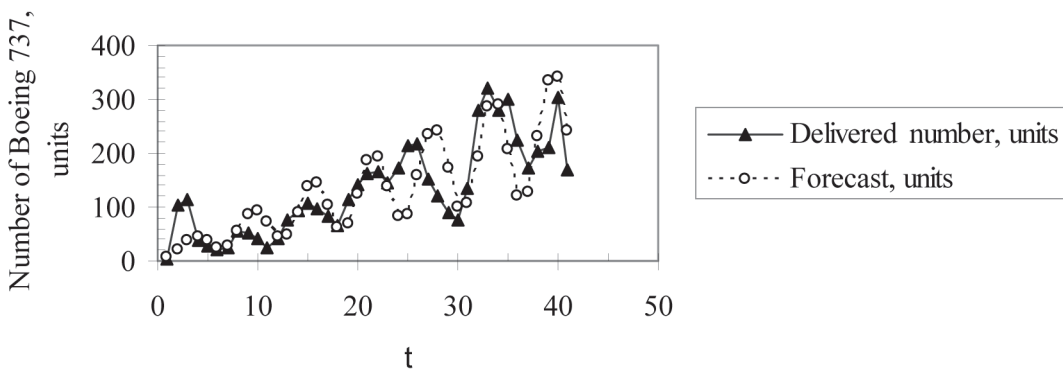


**Figure 1** Number of aircraft in the Boeing 737 family delivered annually.
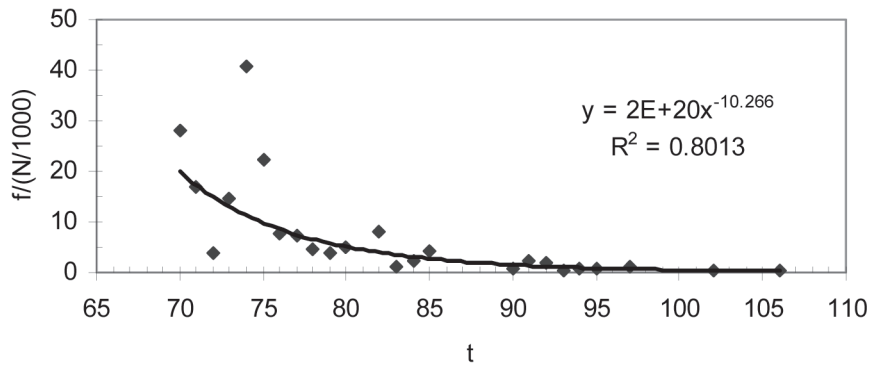
**Figure 3**  Ratio of number of annual accident case per 1000 units of Boeing 737 family aircraft delivered.

**Analysis of the flight phase in Boeing 737 accidents**

It seems that many factors relating to aircraft movement, such as media and environment, altitude change, axial speed and axial acceleration may be involved and cause accidents, as well as human error, weather and mechanical and instrument failure. The relationship between these causal factors is complicated. Fundamental statistical analysis was used to gain a better understanding of the relationship between the number of accidents and various factors. This was then used to propose an empirical equation relating some important relationships.

Initially, only the aircraft motion related factors were investigated. The flight phase of an aircraft has been classified by the International Civil Aviation Organization, Canada (2006) as including standing, pushing back, taxiing, taking off, climbing, en route, maneuvering, approaching and landing. However, in most accident investigation reports, the maneuvering phase is usually combined with the approaching phase.

For Boeing 737 aircraft, the relationship between the frequency of accidents and the flight phase of the aircraft can be represented by a diagram (Figure 4). Based on analysis from the first flight of a Boeing 737 aircraft in 1967, until the end of 2006, there have been 125 Boeing 737 accidents involving hull loss. Further analysis of accident cases where the flight phase at the time
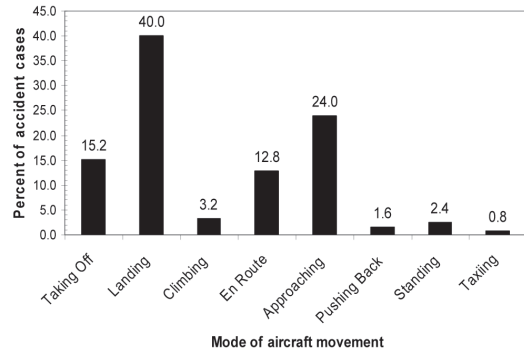


**Figure 4**  Percentage of accident cases associated with modes of aircraft movement.

of the accident were considered showed that most accidents occurred while landing (40.0%), followed by approaching (24.0%), taking off (15.2%), and en route (12.8%).

**Mathematical model of risk indicator for flight phases**

To develop a mathematical model, the aircraft flight phases were regrouped according to aircraft movement and the associated risk factors, i.e., the media, altitude change, axial speed and acceleration. The associated risk indicator for each risk factor was assigned as I1, I2, I3 and I4 respectively.

A Likert scale ranging from 1 to 5 was assigned to each movement characteristic (Table 1), with a higher assigned number relating to higher accident risk. A traditional motion study

approach from industrial engineering was
employed in the development of each risk indicator
and its value (Gilbreth and Lillian, 1921) as shown
in Table 1.

### RESULTS

**Linear summation of risk indicator**

The use of risk indicators was proposed
based on determining the risk indicator associated
with each aircraft flight phase according to the
factors of media and environment, altitude change,
axial speed and axial acceleration. Two major
indicators were considered, namely the linear
summation of risk indicator ($I_s$) and the multiplex
risk indicator ($I_m$).

**Table 1**  Interpretation of aircraft accident flight phases.

| Factors related to risk | Risk indicator and its value | Remark | Movement mode |
|---|---|---|---|
| Media and environment | I1 = 1 | Ground | Pushing back, Standing, Taxiing |
|  | I1 = 2 | Air | En Route |
|  | I1 = 3 | Terrain/Air interphase | Climbing, Approaching |
|  | I1 = 4 | Ground/ Terrain/Air interphase | Taking off, Landing |
| Altitude Change | I2 = 1 | No change | Standing, Taxiing, Pushing back, En route |
|  | I2 = 2 | Up (in air/Terrain) | Climbing |
|  | I2 = 3 | Up in Ground/Terrain/Air interphase | Taking off |
|  | I2 = 4 | Down in air/Terrain interphase | Approaching |
|  | I2 = 5 | Down in ground/ Terrain/ Air interphase | Landing |
| Axial speed | I3 = 1 | Near zero speed (On ground) | Pushing back, Standing, Taxiing |
|  | I3 = 2 | Interphase low speed In ground/Terrain/ Air interphase | Taking off, Landing |
|  | I3= 3 | Low speed flight | Climbing, |
|  | I3 = 4 | Medium speed flight | Approaching |
|  | I3 = 5 | High speed flight | En route |
| Axial acceleration | I4 = 1 | Steady speed | Standing, Taxiing, Pushing Back, En route |
|  | I4 = 2 | Acceleration | Taking off, Climbing |
|  | I4 = 3 | Deceleration | Approaching |
|  | I4 = 4 | Severe deceleration | Landing |

$I_s$ was defined as the linear summation of the risk indicators in each accident flight phase for each risk factor. For example, $I_{s\_ld}$ for the "landing" mode was calculated with reference to Table 1 (Equation 3):

$$I_{s\_ld} = I1_{\_ld} + I2_{\_ld} + I3_{\_ld} + I4_{\_ld} \qquad (3)$$
$$= 4 + 5 + 2 + 4 = 15$$

**The multiplex risk indicator**

$I_m$ was defined as the multiplex risk indicator in each flight phase for each risk factor. Equation 4 shows the calculation of the multiplex risk indicator for the "landing" mode:

$$I_{m\_ld} = (I1_{\_ld})(I2_{\_ld})(I3_{\_ld})(I4_{\_ld}) \qquad (4)$$
$$= 4 \times 5 \times 2 \times 4 = 160$$

Table 2 shows, the linear risk indicators ($I_s$) and multiplex risk indicators ($I_m$) for each aircraft flight phase.

**Percentage of aircraft accident cases**

The percentage of accident cases ($P_a$), which represented accident risk, was plotted against $I_s$ and $I_m$ (Figures 4 and 5). Empirical Equations 5 and 6 were derived by fitting curves to these relations:
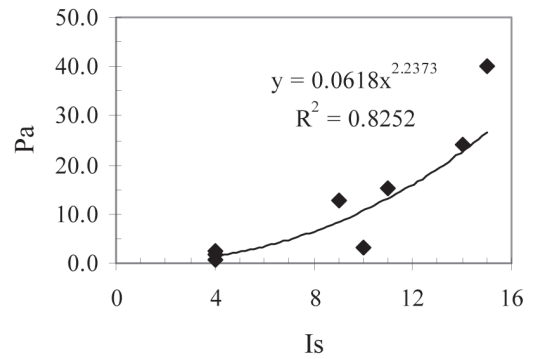
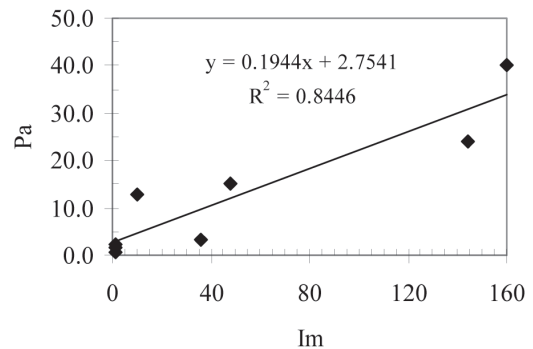$$P_a = 0.0618\, I_s^{2.2372} \qquad (5)$$

and

$$P_a = 2.7541 + 0.1944\, I_m \qquad (6)$$

**Relationship between percentage of aircraft accident cases and risk indicator**

The $R^2$ value for Equations 5 and 6 was 0.8252 and 0.8446, respectively. Both equations yielded very good fits to data. It appears that using



**Figure 5** Relationship between $P_a$ and $I_s$.



**Figure 6** Relationship between $P_a$ and $I_m$.

**Table 2** Risk indicators for aircraft flight phase.

| Aircraft flight phase | Media and environment (I1) | Altitude change (I2) | Axial speed (I3) | Axial acceleration (I4) | linear summation of risk indicator (Is) | Multiplex risk indicator (Im) |
|---|---|---|---|---|---|---|
| Pushing back | 1 | 1 | 1 | 1 | 4 | 1 |
| Standing | 1 | 1 | 1 | 1 | 4 | 1 |
| Taxiing | 1 | 1 | 1 | 1 | 4 | 1 |
| Taking off | 4 | 3 | 2 | 2 | 11 | 48 |
| Climbing | 3 | 2 | 3 | 2 | 10 | 36 |
| En route | 2 | 1 | 5 | 1 | 9 | 10 |
| Approaching | 3 | 4 | 4 | 3 | 14 | 144 |
| Landing | 4 | 5 | 2 | 4 | 15 | 160 |

the proposed approach of analysis and rating of aircraft movement using Equations 3-6 prodcued a simple and yet reasonable aircraft accident risk estimation.

At this stage, it was not possible to estimate the risk of an accident occurring using Equations 5 or 6. However, the next step of investigation, considered the severity of accidents concerning the Boeing 737 family of aircraft..

## Effect of Boeing 737 risk models on accident rate

It would be expected that newer technology reflected in newer models of Boeing 737 aircraft should be related to a lower accident rate. The values for f/(N/1000) associated with different models were plotted against each model, and the models were arranged according to the time of model introduction. The number of deliveries was assumed approximately equal to the production numbers for each model provided (Boeing, 2006). From the 125 cases available for analysis (Aviation Safety Network, 2009) as illustrated in Figure 7, it can be seen clearly that f/(N/1000) decreases as newer models of aircraft

are introduced. It is quite clear that newer technology has decreased the number of accidents per number of aircraft delivered.

## DISCUSSION

### Severity of Boeing737 aircraft accidents

It is rather difficult to estimate the severity of accidents, as the loss of property and financial damage is not easy to evaluate. An obvious and clear indicator of damage seems to be the numbers of deaths and total losses of aircraft, usually called hull loss. Almost all fatal accidents are related to hull loss.

The only accident severity indicator considered in this paper was the number of human lives lost in an accident. Fatalities included both people on the aircraft and on the ground.

The relationship between fatalities and the aircraft movement indicator ($I_s$) in hull loss accidents, concerning Boeing 737 aircraft using data from all 125 cases, is illustrated in Figure 8. It is interesting to note that there was no relationship between fatalities and $I_s$ judging by the $R^2$ value of 0.0039, which was extremely small.
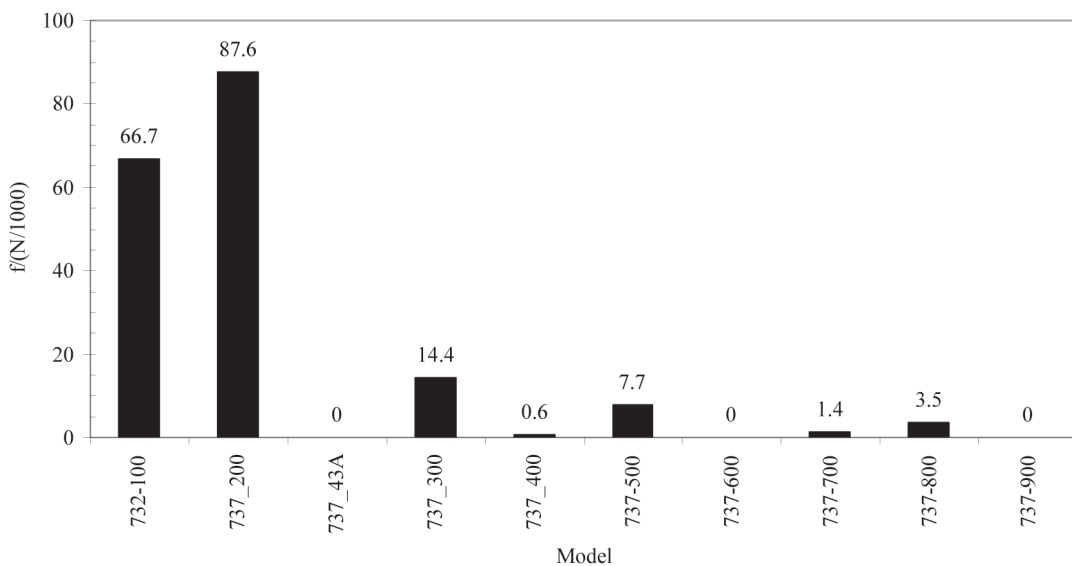


**Figure 7** Accidents per thousand deliveries for different models of Boeing 737 aircraft.

The number of fatalities was also plotted against the aircraft movement indicator ($I_m$), as illustrated in Figure 8. Again, no relationship between $I_m$ and fatalities was detected. It appears that predicting the fatality rate based on the available data is very complicated and cannot be explained simply by the aircraft flight phase.

Fatality was also plotted against the aircraft movement indicator ($I_m$) as illustrated in Figure 9. Again, no relationship between $I_m$ and the fatality rate was detected at $R^2 = 0.01$. Again, the complexity of the relationship suggests that the fatality rate cannot be explained simply by modes of aircraft movement.

This finding appears to support the concept of randomness of damage and injury by

Wood (2003), who argued that when a hazardous situation occurs, there is no way of predicting the result of that situation. There is very little correlation between any particular event and any resulting damage or injury.

**CONCLUSION**

It appears that with newer technology reflected in the newer models of the Boeing 737 family of aircraft, fewer accidents can be expected. With the introduction of modern computers and instruments, in-flight decisions are less dependent on pilots and more dependent on computers and instrument systems, As a whole, however, the accident rate per aircraft delivered decreased
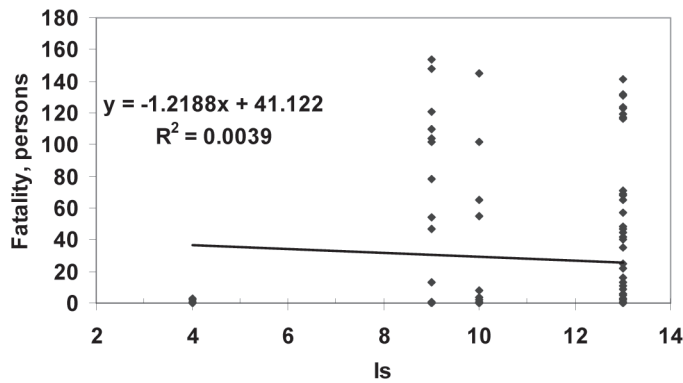


**Figure 8**  There is no apparent relationship between fatalities and aircraft movement indicator $I_s$.
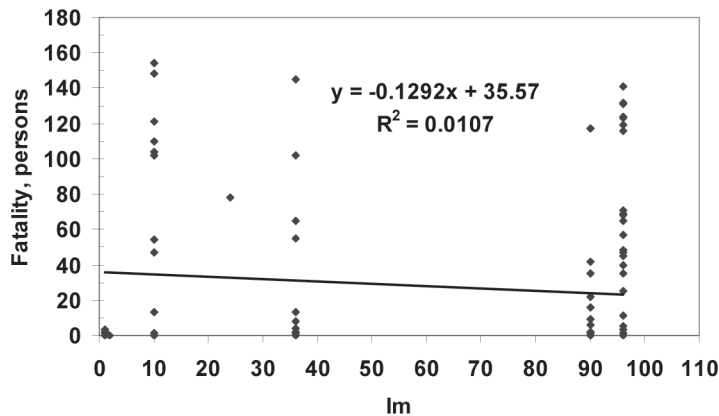


**Figure 9**  There is no apparent relationship between fatalities and aircraft movement indicator $I_m$.

clearly with time. Further studies on other families of aircraft should be carried out. Many factors that contribute to aircraft accidents including pilot error, adverse weather and flight duration should be further investigated, so that the results and conclusions may be compared to those for the Boeing 737 family of aircraft to gain deeper insight into the nature of aircraft accidents.

## ACKNOWLEDGEMENTS

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