The Aviation Risk to Groundlings with Spatial Variability

R. Frank Rabouw, [2] Kimberly M. Thompson,[1] and Roger M. Cooke[2]

1. Harvard University, School of Public Health, Center for Risk Analysis, 718 Huntington Ave., Boston, MA 02115. 2. Delft University of Technology, Dept. of Mathematics, Mekelweg 4, 2628 CD Delft, The Netherlands. To whom all correspondence should be addressed.

Abstract

1. Introduction

Using data provided by the US National Transportation Safety Board, and the 1980 U.S. residence population Goldstein et al.[1] estimated the fatality risk of being hit by a crashing airplane while on the ground as 0.06 per million per year or a 70-year lifetime risk of 4.2 per million. They noted that the risk was above the one in a million threshold enshrined in many regulatory approaches and suggested that the risk of being killed by a crashing airplane could be a useful risk communication tool especially for comparisons with chemical and physical hazards in the environment. Subsequently, their estimate has been used for risk communication purposes[2]. Since then, accident and fatality rates have decreased significantly due to the introduction of new technologies. However, increases in air traffic and greater congestion of airspace, especially around airports, could lead to offsetting effects.

We update the estimate of Goldstein et al. and estimate the geographical variability of the risk for the US. This analysis also distinguishes the three different aviation categories: air carriers, air taxis and general aviation.[1] In this study a groundling accident or groundling crash is defined as an aviation accident that kills at least one groundling. We generally reserve the use of the term "groundling fatality" to denote fatality on the ground of someone involuntarily exposed to the risk from a crashing non-military airplane (Goldstein et al. 1992)[2]. Section 2 updates the data and presents the average risk using recent groundling fatality data. Section 3 focuses on the spatial variability of the groundling fatality risks and describes the method we applied to quantify the variability in the dimension distance to an airport.

2. Update of the average risk of groundling fatalities

A review of the accident database of the National Transportation Safety Board (NTSB) provided a list of civil aviation accidents in which fatalities to people on the ground occurred. These were first screened to remove occupational fatalities and fatalities due to voluntary exposure (e.g. taking photographs on the runway). Although we consulted several sources to confirm the "voluntary" nature of the ground fatalities, the nature of some of the groundling fatalities

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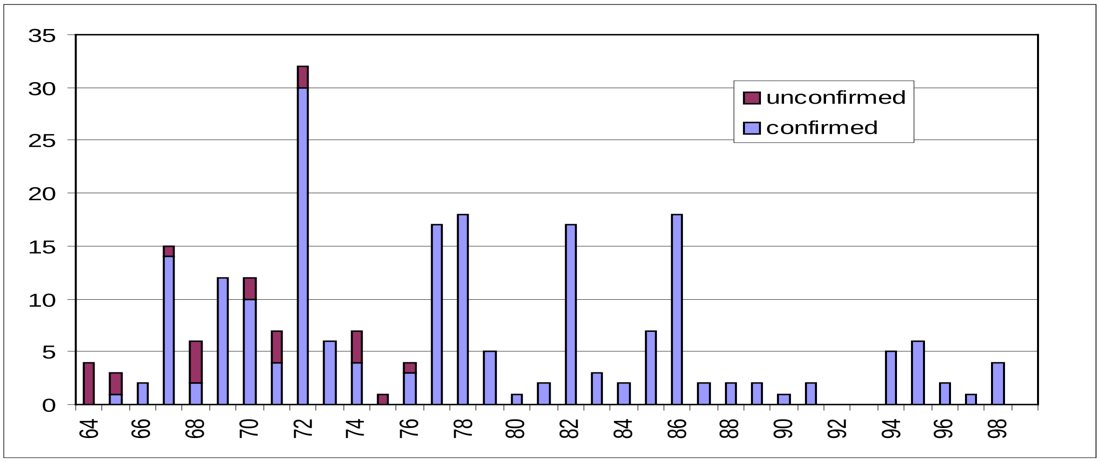
[1] Air carriers are aircraft with a payload capacity higher than 18,000 pounds or a seating capacity of more than 60 seats, air taxis are commercial aircraft that have a maximum of 18,000 pounds payload and a maximum of 60 seats, and general aviation aircraft are all other civil (non-military) aircraft.

[2] We include among the people exposed involuntarily those who live on private property near airports, because no policies exist to prevent them from doing so or to warn them about the risk, even though some might reasonably suspect that living near an airport leads to heightened exposure.

remained unknown (and we refer to them as uncomfirmed involuntary groundling fatalities). Figure 1 shows the annual number of groundling fatalities due to aviation accidents since 1964.

Figure 1 The annual number of groundling fatalities (an unconfirmed groundling fatality is one for which we could not verify the involuntary nature of the exposure).



The following formula is used to estimate the current US average groundling risk:

$$\text{average groundling risk} = \frac{\text{expected number of groundling fatalities in.U.S. in 2000}}{\text{U.S. resident population in 2000}} \qquad (1)$$

The U.S. Census Bureau estimated the U.S. resident population in the year 2000 as approximately 275 million people. Applying equation (1) requires an estimate of the expected number groundling fatalities in 2000. The easiest approach to estimate this expectation is by dividing the number of groundling fatalities in 1964-1999 (205) by the duration of the period (26 years). This simple model results in an estimate of 7.9 groundling fatalities per year in 2000. However, Figure 1 shows that the annual number of groundling fatalities followed a decreasing trend since 1964 and thus using groundling fatality data from 1964-1999 to estimate the expected number of groundling fatalities in 2000 is likely to overestimate the true number. Therefore, we adopted the following approach.

Let $N_{\text{ground fatalities}}(t)$ denote the number of groundling fatalities in year t. We are interested in $E[N_{\text{ground fatalities}}(2000)]$, the expected number of ground fatalities in the year 2000. This depends on the number of groundling accidents in year t, $N_{\text{ground accidents}}(t)$, and the (random) number of groundling fatalities occurring in one groundling accident, F/A, where a groundling accident means that at least one person on the ground is killed. Assuming independence, $E[N_{\text{ground fatalities}}(t)]$ can be estimated as:

$$E[N_{\text{ground fatalities}}(t)] = E[F/A]\ E[N_{\text{ground accidents}}(t)] \qquad (2)$$

Accidents and mortality rates can be measured by different units of exposure depending on the activity and the availability of data. For example, for the groundling accident rate, we could use three potential units of exposure: per year, per million airport operations (takeoff or landing), or per million hours flown. In this analysis, we measured accident rates per airport operation. The groundling accident rate per operation has not fluctuated significantly since the late eighties and therefore the current rate per operation can be reasonably estimated by using data from the last decade (see discussion below).

Equation (2) is expanded to include the expected number of operations in year t, E[O(t)]:

$$E[N_{\text{ground fatalities}}(t)] = E[F/A]\, E[N_{\text{ground accidents}}(t)/O]\, E[O(t)] \qquad (3)$$

where $E[N_{\text{ground accidents}}(t)/O]$ is the number of ground accidents per operation in year t.

We estimated the quantities E[F/A] and $E[N_{\text{ground accidents}}(t)/O]$ from the data discussed above and used the data on the number of airport operations at U.S. airports for 1978-1999 and forecasts for 2000-2015 provided by the Terminal Area Forecast system of the FAA.

Figure 2 shows that the groundling accident rate per operation decreased significantly between 1964 and the late 1980s, but that the rate remained relatively constant since the late 1980s. Based on these data, we believe that the current groundling accident rate per operation can be estimated reasonably by using groundling accident data since 1987. Large differences exist in groundling accident rates and crash consequences among aviation categories, so this analysis distinguishes them. Table 1 shows the groundling accident rates per operation.

Figure 2 The US groundling accident rate for the period 1970-1999.

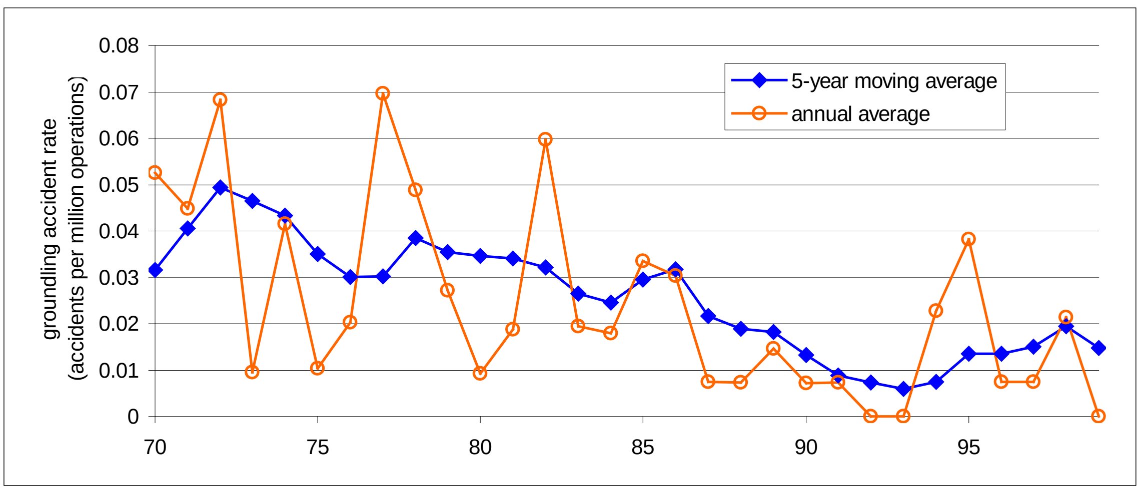


Table 1 Estimates of the current US groundling accident rates per operation for air carriers, air taxis and general aviation.

	Air carrier	Air taxi	General aviation
Number of groundling accidents in 1987-1999*	2	4	14
Number of airport operations in millions 1987-1999**	174.5	174.3	1,413.4
Groundling accident rate per million operations***	0.011	0.023	0.0099

* Collisions between aircraft of different categories are each counted as a half.

** Numbers are provided by the Terminal Area Forecasting system of the FAA.

*** Groundling accident is an accident that kills at least one groundling.

The data provided no indication that the number of groundling fatalities per groundling accident changed for any of the aviation categories since 1964. Consequently, we estimated the expected number of groundling fatalities per groundling accident using data from 1964-1999. Table 2 presents the calculations and results, and Figure 3 shows a graph that presents the number of fatalities per groundling accident for the whole set of accidents.

Figure 3 The number of groundling fatalities per groundling accident.

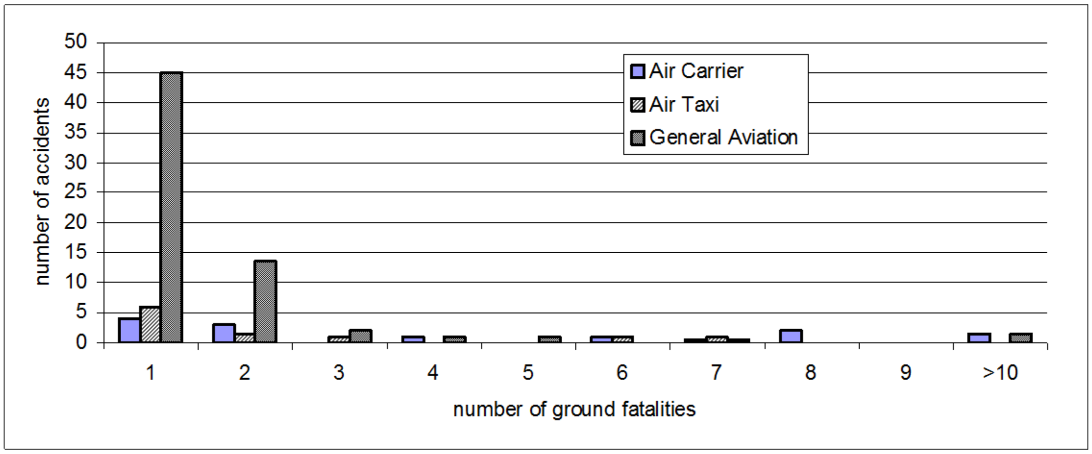


Table 2 Estimates of the expected number of groundling fatalities per groundling accident for air carriers, air taxis and general aviation.

Category	Air Carrier	Air Taxi	General Aviation
Number of groundling accidents* in 1964-1999	14	11	66
Number of groundling fatalities** in 1964-1999	60	25	120
Expected number of groundling fatalities per groundling accident	4.3	2.3	1.8

* Collisions between aircraft of different categories are each counted as a half.

** Groundling fatalities that resulted from a collision between aircraft of different categories were evenly divided.

The FAA Terminal Area Forecasting projects 15.5 million air carrier operations, 14.6 million air taxi operations and 113.1 million general aviation operations in 2000. The expected number of groundling fatalities in 2000 are:

Air carrier	:	$0.011\times4.3\times15.5 =$	0.7 groundling fatalities
Air taxi	:	$0.023\times2.3\times14.6 =$	0.8 groundling fatalities
General aviation	:	$0.0099\times1.8\times113.1 =$	2.0 groundling fatalities
Total	:		3.5 groundling fatalities

Using a U.S. resident population in 2000 of 275 million, the annual risk of dying due to a crashing aircraft can then be estimated by applying equation (1) as 3.5/275 million = $1.3\ 10^{-8}$. The corresponding 70-year lifetime risk is equal to $9\ 10^{-7}$ (or the 75-year lifetime risk is $1\ 10^{-6}$), which is just under the 1 in a million *de minimis* risk management threshold.

3 Variability of the groundling fatality risk

To consider variability we must begin by mathematically defining what we mean by the variability of the risk. Consider a random U.S. resident, X, and define the following event:

$B_{[t,t+\Delta t)}(X)$: {X becomes a groundling fatality in [t, t+Δt)}

The probability $P(B_{[t,t+\Delta t)}(X))$ represents the involuntary risk of death for individual X due to a crashing aircraft in the time interval [t, t+Δt). As mentioned above, airplanes are more likely to crash in the vicinity of an airport, and consequently, individuals who spend most of their time close to an airport are at higher risk. This analysis quantifies the variability of the risk associated with the dimension of distance to an airport. The following stochastic quantity defines the behavior of individual X with respect to this dimension:

D(X,t) : Distance between individual X and the nearest airport at time t.

D(X,t) is a stochastic process parameterized by time. Consider a time interval Δt and distance interval Δd and define the following event:

$$A_{[t,t+\Delta t)}^{[d,d+\Delta d)}(X) \quad = \quad \{D(X,\tilde{t}) \in [d, d+\Delta d) : \tilde{t} \in [t, t+\Delta t)\}$$

$P(B_{[t,t+\Delta t)}(X) \mid A_{[t,t+\Delta t)}^{[d,d+\Delta d)}(X))$ is the probability X becomes a groundling fatality in [t, t+Δt) given that X stays within [d, d+Δd) for that time interval. Bayes' theorem yields:

$$P(B_{[t,t+\Delta t)}(X) \mid A_{[t,t+\Delta t)}^{[d,d+\Delta d)}(X)) = \frac{P(A_{[t,t+\Delta t)}^{[d,d+\Delta d)}(X) \mid B_{[t,t+\Delta t)}(X))}{P(A_{[t,t+\Delta t)}^{[d,d+\Delta d)}(X))} P(B_{[t,t+\Delta t)}(X)) \qquad (4)$$

The left hand side represents the spatial variability of the risk in the dimensions time and distance to an airport. The distance conditional groundling mortality rate is:

$$h_{X,d}(t) = \lim_{\Delta d \to 0}\left(\lim_{\Delta t \to 0} \frac{P\left(B_{[t,t+\Delta t)}(X) \mid A_{[t,t+\Delta t)}^{[d,d+\Delta d)}(X)\right)}{\Delta t} \right), \qquad (5)$$

and the general groundling mortality rate is:

$$\lambda_X(t) = \lim_{\Delta t \to 0} \frac{P\left(B_{[t,t+\Delta t)}(X)\right)}{\Delta t}. \qquad (6)$$

Define the following distribution functions:

$G_{X,t}(d)$: The probability that X is within distance d of an airport at time t given that X becomes a groundling fatality at time t.

$F_{X,t}(d)$: The probability that X is within distance d of an airport at time t.

We assume that the corresponding densities exist:

$$g_{X,t}(d) = \frac{\partial}{\partial d} G_{X,t}(d), \tag{7}$$

$$f_{X,t}(d) = \frac{\partial}{\partial d} F_{X,t}(d). \tag{8}$$

The functions $G_{X,t}(d)$, $F_{X,t}(d)$, $g_{X,t}(d)$ and $f_{X,t}(d)$ can, under appropriate assumptions, be estimated from data. The following expression can be derived by first applying Bayes' Theorem according to (4) and then calculating the limit in (5):

$$h_{X,d}(t) = \frac{g_{X,t}(d)}{f_{X,t}(d)} \lambda_X(t) \tag{9}$$

We are interested in:

The risk that an individual becomes a groundling fatality in 2000 given that this individual stays at distance d from the nearest airport for the whole year. Notation: $P(B_{2000}(X) \mid A^{d}_{2000}(X))$

The risk is hypothetical because nobody stays at exactly distance d of the nearest airport for a year, but it is the most reasonable measure to quantify the current spatial variability of the risk. Assuming that each of the quantities on the right hand side of (11) are constant within the year 2000, then the hypothetical risk for groundling fatality in 2000 can be calculated as:

$$P\left(B_{2000}(X) \mid A^{d}_{2000}(X)\right) = \int_{2000}^{2001} h_{X,d}(t)\,dt = \frac{g_{X,2000}(d)}{f_{X,2000}(d)} P\left(B_{2000}(X)\right) \tag{10}$$

This expression is used to quantify the spatial variability of the groundling fatality risk by estimating each of the quantities on the right hand side. The groundling risk in 2000 to a random individual X, ($B_{2000}(X)$), is estimated in the previous subsection as 1.3 10^{-8} (see equation 4). The fatality density function in 2000, $g_{X,2000}(d)$, is estimated in subsection 3.2 and a spatial population distribution function with respect to airports is derived in subsection 3.3[3].

In this study we separately analyzed three different airport groups, the busiest 100, 250, and 2250 airports denoted as the Top100, Top250 and Top2250 airport lists. We describe our analysis for the Top100 airport list, and present only the results for the Top250 and Top2250 lists, for details see (Rabouw 2000). The crash density function, $g_{X,2000}(d)$ for distance d to a Top100 airport, and the corresponding histogram are presented in Figure 4. The density function is of the form $e^{-a \times d} + b$ and the area under $g_{X,2000}(d)$ for $d \leq 10$ equals 0.39.

Figure 4 The fatality density function $g_{X,2000}(d)$ with distance d to a Top100 airport.

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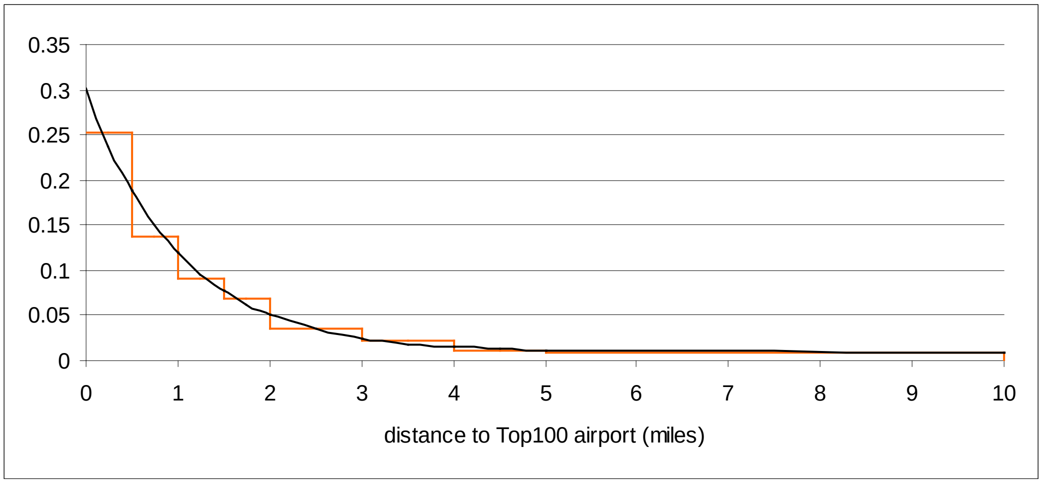
[3] For purposes of this analysis, we assumed that all ground fatalities occurring further than 10 miles from the nearest airport were not airport-related, and quantified these as the baseline risk of planes falling out of the sky and killing people. These risks are very small, but they are not zero.



Equation (10) also requires a population density function parameterized by the distance to a Top100 airport. The distribution function $F_{X,t}(d)$ with distance d to a Top100 airport, can be interpreted as follows (X is random U.S. resident):

$F_{X,t}(d) = P\{X \text{ is within distance d of an airport at time t}\}$

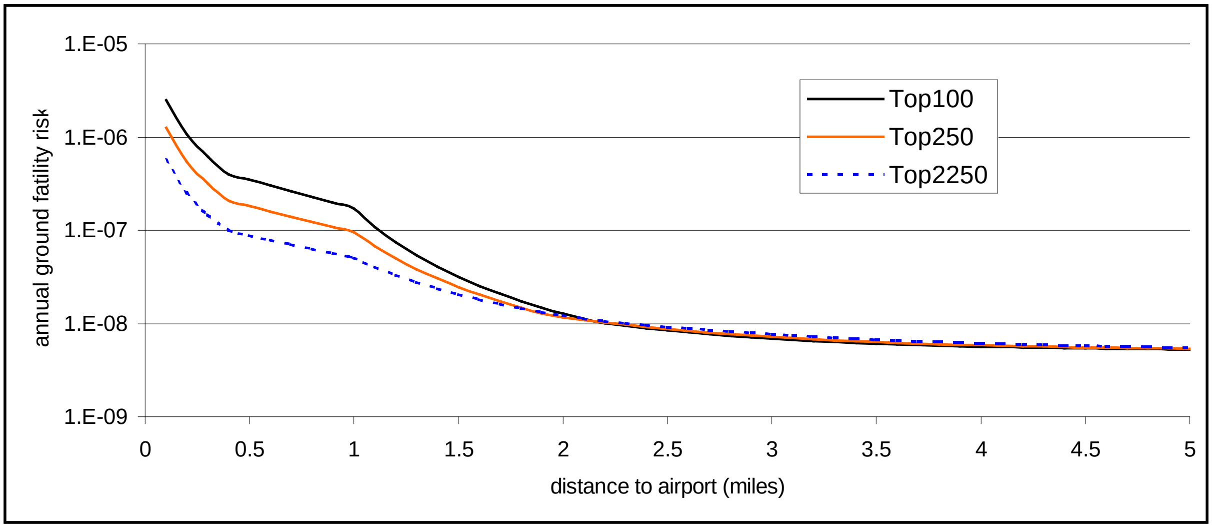
The distribution function $F_{X,2000}(d)$ is approximated as follows:

$F_{X,2000}(d) \approx$ P(Random 1990 U.S. resident X is living within d miles of a Top100 airport)

4. Results and Conclusions

Figure 6 presents the results for the three airport lists. We conclude that the risks of groundling fatalities are significantly higher in the vicinity of an airport. The spatial variability of the exposure associated with the dimension distance to an airport is approximately a factor of 100. The variability of the exposure to the groundling fatality risk mainly applies to the first 2 miles around an airport. The estimate of the average annual exposure within 0.2 miles of a Top100 airport exceeds 10^{-6}.

Figure 5 Variability of the risk of groundling fatalities in the dimension distance to an airport represented by the quantity $P\left(B_{2000}(X) \mid A^{d}_{2000}(X)\right)$ for the Top100, Top250 and Top2250 airports.



The limitations of our model include our reliance on residence locations for the spatial distribution of population around airports and our lack of consideration of the dynamics of flight paths and specific airport considerations. In 1993, the RAND corporation estimated 0.6 expected groundling fatalities at Schipol airport in the Netherlands for the year 2003 using a scenario-based method that developed a two dimensional crash distribution based on 53 crashes worldwide and applied this distribution around Schipol.[7] Schipol's airport activity is comparable to the 25-th highest ranked US airport, and we estimate a total of 0.99 expected groundling fatalities for all of the top 100 US airports in 2000. Thus, comparing our estimate of 0.99 for all top 100 US airports to the estimate of 0.6 for Schipol alone leads to questions about whether Schipol is significantly more risky than US airports or whether the RAND method might be overestimating the risk. We note that while there are several limitations to our model, it differs from the RAND method in that our model does take into account the pilot's ability to avoid population concentrations in the final seconds before a crash and the actual experience with crashes that have occurred in the US. We believe that understanding the spatial variability of risk around airports is critical both in managing airport risks and in risk communication.

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