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STATISTICAL ANALYSIS OF REAL FLIGHT TRACKS FOR THE RISK ASSESSMENT OF A NEW TAKEOFF-ROUTE

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ABSTRACT

Because of the reshaping of a departure route of Munich airport in 1999 a new evaluation of the frequency of air crashes with regard to a neighbouring nuclear facility has been necessary. The evaluation has been made by statistical analysis of real flight data and with the method used in the risk analysis for licensing the plant [1]. The comparison of both methods resulted in a better suitability of using real flight data and an overestimation by using the universal valid state of the art and showed the benefit of an individual way of view. In both cases arose no contradiction to the existing plant license.

KEY WORDS

Air crash, nuclear facility, airport, statistical analysis, risk analysis, data, probability, frequency, distribution

INTRODUCTION

In connection with airports subjects like noise pollution or probability of air crashes have been discussed by the public and local authorities. Object of the following account is the frequency of air crashes on a nuclear facility in the neighbourhood of a Munich airport departure route. An evaluation of the frequency of air crashes for several aircraft categories was performed for this plant for licensing and in this context also the probability of air crashes was discussed. This estimation was done with the method used in the risk analysis for licensing the plant [1] under consideration of the local conditions of the air traffic. In this calculation the increase of the air traffic of 5 % per year until the year 2010 was taken into account. In 1999 a new departure route was developed due to the noise protection of the population. The task consisted in checking the effects of this new departure route on the frequency of air crashes on the nuclear facility.

METHODOLOGY

Previous method and results

The reshaping of the departure route has affected only the takeoffs of the big scheduled planes, therefore the category "aircraft with a lift-off weight > 20 t" is relevant to outcome. The frequency of air crashes during takeoff has been determined by equation (1) [1]. Accordingly the frequency of air crashes w_L is calculated as follows:

$$w_L = w \cdot h_L \cdot d_L \cdot b \qquad (1)$$

The probability of flights over the nuclear facility w has been depicted as a Normal distribution and is determined by equation (2) [1].

$$w = \int_{x_k - a/2}^{x_k + a/2} \frac{1}{\sqrt{2\pi}\,\sigma} \cdot e^{-\frac{x^2}{2\sigma^2}}\, dx \qquad (2)$$

with

w_L : frequency of air crashes for scheduled planes per year
w : probability of flights over the nuclear facility at takeoffs
h_L : frequency of air crashes at air traffic routes in cruising (≙ $2{,}5 \cdot 10^{-12}$/flight-kilometre and flight)
d_L : flight density of the concerned air traffic route per year
a, b : expansion of the nuclear facility in kilometre (a or b respectively ≙ edge length of a rectangle representing the

expansion of the nuclear facility (≙ 0,054 kilometre))

s : standard deviation from the guideline (by [1] 0,926 kilometre)

x_k : minimal distance between centre of the location and the guideline

For the category "aircraft with lift-off weight > 20 t" a frequency of air crash at takeoff was determined about $2{,}7\cdot10^{-14}$ /a for the year 2010. The total frequency of air crashes (takeoffs, landings and flights over the nuclear facility) run up to $4{,}1\cdot10^{-11}$ /a (inclusive of an extra security charge to $3\cdot10^{-10}$ /a).

Reshaping of the departure route and changes of the parameters

Before reshaping the departure route described a continuous left turn after takeoff and a following flight on radial 327° of the beacon Munich. The ideal line ran in a distance of 5 kilometres to the nuclear facility. After reshaping the departure route now describes a left turn, afterwards a short straight flight about 3 kilometres ("track") in south direction and finally a further left turn with following flight on radial 323° beacon Munich (Fig. 2-1). Because of the shift in south direction the ideal line has come closer to the nuclear facility. Moreover there have been great changes of the calculated flight expectation area.

A takeoff including a "track" is much more inexact than a takeoff on a radial of a beacon. For this reason a opening of the flight expectation area on both sides of the ideal line about 15 ° has been calculated according to the used methods for calculating a flight expectation area. Thus a widening of the flight expectation area in south direction has resulted. Subsequently the nuclear facility has been located inside of the area of located flights since the reshaping. Because of the new situation it was supposed that an increased risk of air crashes could results from these new conditions.

On the other hand the navigation and supervision system NeSS (New SIDs and STARs, means New Standard Instrument Departures and Standard Arrival Root) was used and increasingly the FMS (Flight Management System) too. But the FMS is used only on voluntary base. By these systems a more exact flight of curves and a stronger concentration at the ideal line has been got and the number of the starting aircrafts which fly through the airspace of the nuclear facility has been reduced.

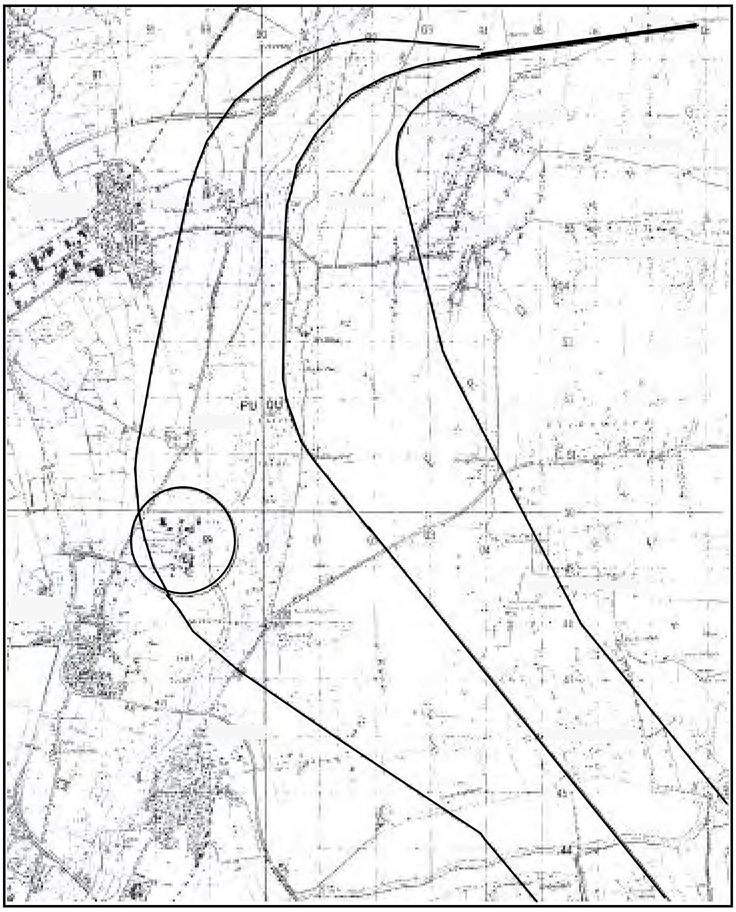

Figure 2-1: Ideal line and flight expectation area of the reshaped departure route from 15.07.99

New calculation of frequency of air crashes

The frequency of air crashes will be calculated by equation (1). The expansion of the nuclear facility in kilometre has not been changed. There have been following changes of the parameters:

The latest findings [2] show that the frequency of air crashes in the takeoff phase is nearly twice higher than in cruising. Because of this fact the previous frequency of air crashes at air traffic routes in cruising with the value $2{,}5 \cdot 10^{-12}$ per flight-kilometre and flight has been doubled. The flight density per year dL has been updated by current data survey. 2432 flights on the departure route were identified in the period of 04.08.1999 and 02.09.1999. That's a yearly flight density about 30.000 aircrafts in 1999. With an increase of 5 % per year the flight density in 2010 will come to 51.000 aircrafts. Now the probability of flights over the nuclear facility by takeoffs has been calculated in two ways. First with the method previously used, afterwards on base of a data survey which had been made in 1999.

New calculation of the probability of flights over the nuclear facility with the previous method

Because of the shift in south direction the ideal line has come closer to the nuclear facility. The minimal distance between centre of the location and the ideal line has been shorted by 2 kilometres from 5 kilometres to 3 kilometres. The other parameters, expansion of the nuclear facility *a* and the deviation from the ideal line σ, have stayed unchanged.

New calculation of the probability of flights over the nuclear facility on base of data survey and analysis

The DFS Munich had made records about the air traffic on the reshaped departure route between 04.08.1999 and 02.09.1999 and has made them available for further analyses. The records included sum plots with the departures of one day and single plots of flights over the nuclear facility. Figure 2-2 shows the sum plot of the 07.08.1999 for example.

Figure 2-2: Sum plot of the departures, Saturday, 07.08.99 from 00:00 to 21:16 MESZ

There have been 13 flights above the nuclear facility, but they all took place in a level more than 5000 ft. above ground. 5000 ft. above ground is the level for jet planes, where the pilots are not longer bound on the departure route and can head for their destinations directly. So these flights over the nuclear facility haven't been taken into further consideration.

In the first step it could be shown that it is not possible to describe the data by a single distribution function. It was already obvious from mere visual inspection of the flight data that a superposition of different distribution-types had to be discussed.

To be as transparent as possible the Student's t-distribution and a Normal distribution was used again.

1) t-distribution for variances $\sigma 2 \neq 1$ and expected values $\mu \neq 0$, defined through

$$\boldsymbol{t}(\boldsymbol{x},\boldsymbol{n},m,s) := \frac{\Gamma(\frac{\boldsymbol{n}+1}{2})}{\Gamma(\frac{\boldsymbol{n}}{2}) \cdot \sqrt{\boldsymbol{np}} \cdot s} \cdot \left(1 + \frac{(\boldsymbol{x}-m)^2}{s^2 \cdot \boldsymbol{n}}\right)^{-\frac{\boldsymbol{n}+1}{2}} \qquad \text{(F1)}$$

2) Normal distribution

$$\boldsymbol{N}(\boldsymbol{x},m,s) := \frac{1}{\sqrt{2p} \cdot s} \, \boldsymbol{e}^{-\frac{(\boldsymbol{x}-m)^2}{2s^2}} \qquad \text{(F2)}$$

With the help of a chi-squared goodness-of-fit test it has been checked whether 2 t-distributions, a t-distribution together with a Normal distribution or a combination of 2 Normal distributions could explain the observed movements (error of first order 5%) and with which parameters this approximation was possible. This leads to a non-linear optimisation problem with 6 to 7 variables. Therefore the solutions found are not necessarily global optima, but at least locally optimal. This was sufficient for the exactness required for this application. An example is shown in figure 2-3.

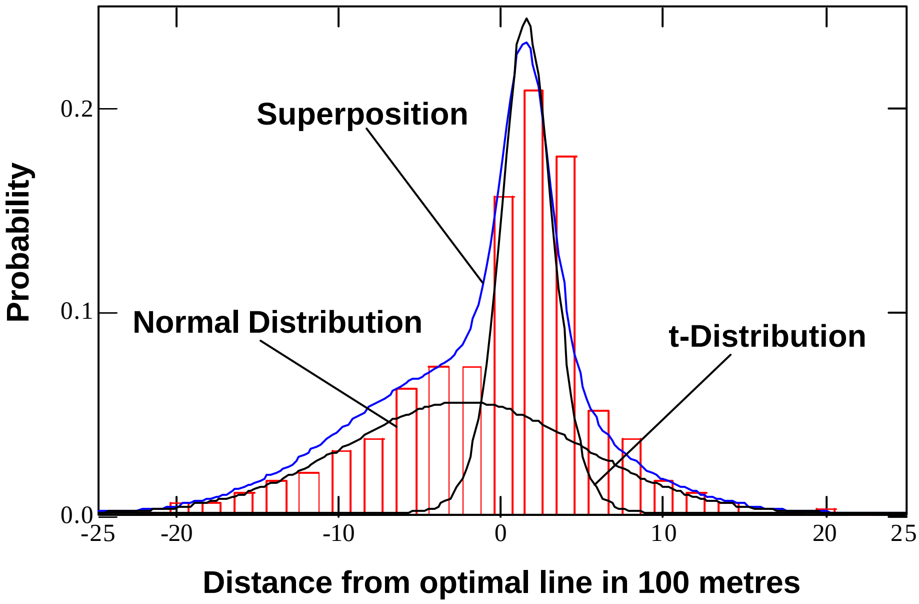

Figure 2-3: Linear superposition of the two identified distribution types

For this superposition a reasonable argumentation has been found. As mentioned before the FMS is increasingly used by the pilots. This could be the cause for the "narrow" distribution close to the reference track. On the other hand the pilots are not obliged to use the FMS. So the "broader" distribution could well be traced back to flights without the use of FMS.

RESULTS

For the category "aircraft with lift-off weight > 20 t" following values resulted (Table 3-1) With the previous method according to equation (2) the probability of flights over the nuclear facility came to 1,2·10-4 /a. With the method based on data analysis a mean value of $2{,}7\cdot10^{-7}$ for the probability of flights above the nuclear facility at takeoffs was got. On the assumption that the probability of flights above the nuclear facility apply to the level of 5000 ft. and below, it will be a conservative assumption. Further the table shows the results for the frequency of air crashes according to equation (1) for the years 1999 and 2010.

Table 3-1: Probabilities of flights over and frequencies of air crashes during takeoff phase in the category "aircraft with lift-off weight > 20 t"

Method	Probability of flight over	Frequency of air crashes for 1999 (30.000 starts/a)	Frequency of air crashes for 2010 (51.000 starts/a)
Result based on data analysis	$2{,}7\cdot10^{-7}$ /a	$2{,}1\cdot10^{-15}$ /a	$3{,}6\cdot10^{-15}$ /a
Result according to previous method	$1{,}2\cdot10^{-4}$ /a	$9{,}8\cdot10^{-13}$ /a	$1{,}7\cdot10^{-12}$ /a

DISCUSSION

The following figure 4-1 shows the Normal distribution used in the first risk analyses because of the lack of real data in comparison with the actual determined distribution function resulted from empirical data and the resulting probabilities of flights over the nuclear facility w. The found fits were clearly superior to the previous method.

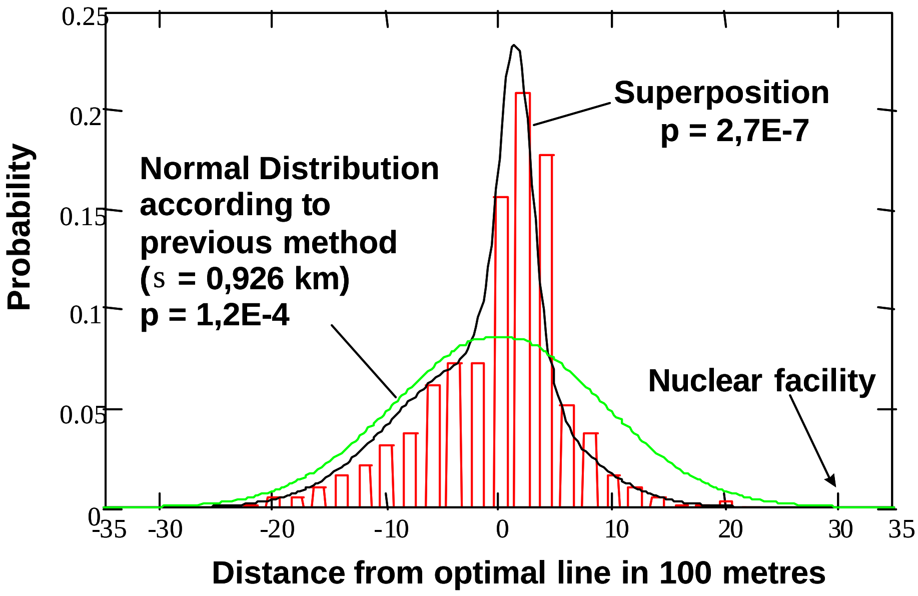

Figure 4-1: Comparison of Normal distribution and the superposition

The Normal Distribution of the previous method clearly does not fit the data and therefore overestimates the resulting probability of air crashes. The fit shows a steeper decline in direction to the plant and leads to a even reduced probability, although the planes moved closer to the plant than before.

Both probabilities were calculated according to equation (1). Table 4-1 shows the results of the different scenarios in discussion:

Table 4-1: Frequency of air crashes during takeoff phase in the category “aircraft with lift-off weight > 20 t”

Scenario	**Frequency of air crashes**
Reshaped route, 30.000 starts/ a for 1999	
Result based on data analysis Result according to previous method	$2,1 \cdot 10^{-15}$ /a $9,8 \cdot 10^{-13}$ /a
Reshaped route, 51.000 Starts/ a (prognosis for 2010)	
Result based on data analysis Result according to previous method	$3,6 \cdot 10^{-15}$ /a $1,7 \cdot 10^{-12}$ /a
Old route: Result of the former analysis for 2010	$2,7 \cdot 10^{-14}$ /a

The reshaped route has come closer to the nuclear facility as well as the nuclear facility has been included into the flight expectation area. The comparison shows that although this facts the result based on data analysis has been one order lower than the result for the old route of the former analysis whereas the result according to the previous method has been two orders greater than the result of the former analysis.

Considering the results based on data analysis following total frequency for air crashes in this category has been determined (Table 4-2):

Table 4-2: Total frequency of air crashes in the category “aircraft with lift-off weight > 20 t”

Frequency of air crashes in the category "aircraft with lift-off weight > 20 t”	**Frequency of air crashes**
Fly over	$3,3 \cdot 10^{-11}$ /a
Takeoff	$3,6 \cdot 10^{-15}$ /a
Landings	$7,7 \cdot 10^{-12}$ /a
Total	$4,1 \cdot 10^{-11}$ /a
Plant license Total frequency for air crashes in the category “Planes with lift-off weight > 20 t”	$3 \cdot 10^{-10}$ /a

As it can be seen, there is no contradiction to the existing license.

CONCLUSIONS

Obviously the Normal distribution is unsuitable to describe the real data. In [1] it has been noticed that the Normal distribution was chosen because of the lack of statistic data and also deviations from the Normal distribution are possible. In this case such a deviation has been found. As showed an analysis based on the Normal distribution leads to an overestimation of the probabilities of flight over.

So the use of mere data analysis for practical purposes is demonstrated in this example. It could be concluded by similar arguments that also other “risks” could be treated as well, e. g. the exposition to noise, which was the starting-point for the reshaping of the departure route.

REFERENCES

[1] Deutsche Risikostudie Kernkraftwerke, Fachband 4, Gesellschaft für Reaktorsicherheit, Verlag TÜV Rheinland, 1980

[2] Safety Report (JET) 1998, IATA, Montreal-Geneva