Analysis of Frequency of Aircraft Impact from Overflights

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Abstract: The use of the airway-based method from NUREG-0800 to estimate aircraft impact frequency from overflights navigated by the Global Positioning System cannot account for flights that do not follow airways. To address this issue, several additional approaches are discussed in this paper. Both the average crash density and average flight hour density methods imply a constant crash density for the entire area. This can potentially be non-conservative for locations closer to flight routes or with greater influence by conditions affecting the crash likelihood. Ideally, the location-dependent crash density method can use the aircraft crash data to directly determine the aircraft impact frequency at the target location. The main problem associated with the location-dependent crash density method is that the model adopted to extrapolate the impact frequency from the historical crash sites to the target location are not substantiated by crash influencing factors. The flight density method uses a model which implements an assumption that aircraft crash is more likely to occur at locations closer to the flight routes. The model used (i.e., the impact likelihood is inversely proportional to the closest distance between the flight path and the target) represents a key source of uncertainty but may not necessarily contribute to any conservatism that may exist in the calculated result for the aircraft impact frequency. Among the methods considered, the flight density method is considered most credible.

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1. INTRODUCTION

Evaluation of the frequency of aircraft impact from overflights during the in-flight phase has become more challenging in recent years due to changes in the flight paths (even for itinerary flights) and difficulty in collecting flight frequency data. In present-day aviation, airplanes can fly using the Global Positioning System (GPS) and do not always have to follow the airways. Flight paths are primarily based on the shortest routes between the origin and destination navigated by the GPS. Therefore, the frequency of enroute overflights in the airspace nearby a nuclear facility cannot be just estimated by the air traffic along the nearby airways as specified in NUREG-0800, Section 3.5.1.6 [1].

All overflights within certain distance from the target facility should be considered. Air traffic in the airspace nearby a U.S. nuclear facility should be estimated using the U.S. Federal Aviation Administration (FAA) records on the flights crossing specific latitude/longitude boundaries, which includes not only aircraft operations into and out of a nearby airport, but also overflights through the same airspace without landing at that airport [2].

This paper describes the underlying considerations in the NUREG-0800 equation used for calculating the overflight impact frequency. It also discusses in detail how the frequency of aircraft impact from enroute overflights can be analyzed considering the type of FAA data that is available. A number of different methods that have been considered for the evaluation of aircraft impact frequency (i.e., crash density, flight density, and flight hour density methods) are described.

2. CURRENT METHODS FOR ESTIMATING IMPACT FREQUENCY FROM OVERFLIGHTS

Section II.B of the paper entitled “Analysis of the Risk of Aircraft Crash Hazard” [2] provides a detailed literature review of the analysis of aircraft impact frequency, especially during the in-flight phase. It covers the methods described in Section 3.5.1.6 of NUREG-0800 [1], Swiss Probabilistic Safety

Analysis Guideline ENSI-A05 [3], and U.S. Department of Energy (DOE) Standard on Accident Analysis for Aircraft Crash into Hazardous Facilities [4]. In addition, there are a number of risk studies that evaluated the aircraft impact frequency for commercial nuclear power plants and DOE facilities which are not available in the public domain and cannot be discussed in this paper.

Currently, the two most frequently used methods for estimating the impact frequency from overflights during the in-flight phase are the airway flight frequency method specified in Section 3.5.1.6 of NUREG-0800 and the average crash density method. This section describes each of these two methods. In addition, the location-dependent crash density method is also discussed.

2.1. Section 3.5.1.6 of NUREG-0800 – Airway Flight Frequency (Overflights Along Airways)

In accordance with Section 3.5.1.6 of NUREG-0800, the frequency of aircraft crashing into the target facility for each airway or aviation corridor that passes through the vicinity of a target facility where vicinity = 2 miles, based on Regulatory Guide 1.70, Revision 3 [5], is:

$$P_{FA} = N \cdot C \cdot \frac{A}{D} \tag{1}$$

where,

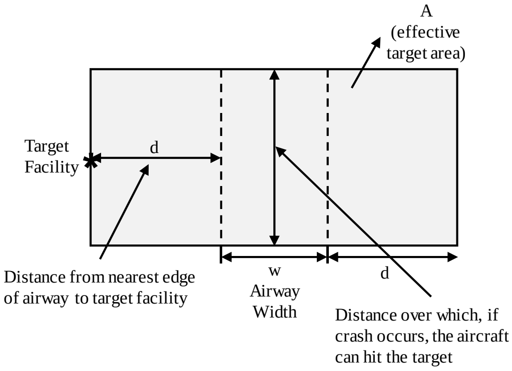
P_{FA} = aircraft impact frequency per year from flights along a specific airway
N = number of flights per year along the specific airway
C = in-flight crash rate per flight mile for aircraft using airways
A = effective area of target facility in square miles
D = width of airway in miles plus twice the distance from the nearest airway edge to the facility when the facility is outside the airway
= w + 2d
w = width of airway in miles (flights along the airway could be anywhere within this width)
d = distance in miles from the nearest airway edge to the facility when the facility is outside the airway

In Eq. (1) for the airway-based method for calculating the aircraft impact frequency, Parameter C represents the likelihood or probability of an aircraft experiencing a crash for each mile of its flight over a distance within which, if it crashes, the crashing aircraft can reach and impact the target facility. As such, a reasonable interpretation is that the factor D = A/(w+2d) represents the distance over and within which, if the aircraft crashes, the crashing aircraft can actually hit and impact the target facility.

For an aircraft along an airway to hit the target facility (with a distance “d” away from the nearest edge of the airway), the aircraft body/parts must be able to spread to a distance “d” (i.e., the distance between the nearest edge of the airway and the target facility) from the failure location. Since it is equally likely for a crashing aircraft to spread to either side of its failure location, the width of the spread of the aircraft body/parts must be “2d”.

Also, the air traffic along an airway includes a collection of flights along paths delimited by the airway. Because an aircraft along an airway can be anywhere within or across the width of the airway (“w”), we do not know the exact location of the flight path within the airway or the distance between the path of each flight (of the N flights per year) and the nearest edge of the airway from the target facility. Therefore, the total lateral spread width of the crashing aircraft (or the lateral impact range) must be “w+2d” to be able to hit the target facility. Further, to be able to hit the target facility, the total spread area for a crashing aircraft is “A”; i.e., the effective target area based on its definition. Thus, for a crashing aircraft to hit the target facility as shown in Figure 1, the flight distance within which the crash must occur is thus “A/(w+2d)”.

Figure 1: Illustration of Airway Width, Distance from Nearest Airway Edge to Target, and Effective Target Area



The impact frequency due to overflights along an airway in the vicinity of the target facility can therefore be expressed as:

$$\text{Impact Frequency} = \text{N (\# of flights/year)} \bullet \text{C (crash likelihood/flight mile)} \bullet \text{A (effective target area)} / (\text{w}+2\text{d}) \qquad (2)$$

In Eq. (2), N•C represents the number of crashes per year for each flight mile flown. A/(w+2d) represents the model which converts the crash frequency to the impact frequency. The value of this factor that converts from crash frequency to impact frequency is inversely proportional to the distance between the aircraft flight path and the target facility.

For the set of I airways/corridors meeting the analysis criteria in the vicinity of the plant, the total frequency is given by:

$$P_{FA} = \sum_{i=1}^{I} \sum_{j=1}^{J} N_{ij} \cdot C_j \cdot \frac{A_j}{(w_i + 2d_i)} \qquad (3)$$

where,

i = index for airway/corridor
I = total number of airways/corridors
j = index for aircraft type/class
J = total number of aircraft types/classes considered

As shown in Eq. (3) above, the crash rate and effective target area are dependent on the type of the aircraft.

The airway flight frequency method has been applied to the aircraft hazard analysis for almost all U.S. nuclear power plants since it is the method specified in the standard review plan for the evaluation of aircraft hazards for nuclear power plants.

The essence of the model expressed in Eq. (3) is that, for each flight, the risk of impact is characterized by the closest distance between the target facility and the flight since parameter “d” is the closest distance between the airway and the target facility.

As discussed in Section 1, the main flaw in using this method for today’s aviation system is that it only considers flights along the airways, and does not account for flights that are outside the airways, but in the vicinity of the target facility, which, if crash, can still impact the target facility.

Both parameters N and C can be determined using the actual flight data and accident data, respectively. As such, the uncertainty in these two parameters is limited to the statistical variations in the actual data.

The key source of uncertainty in the airway flight frequency method is the model used to convert from the crash frequency to the impact frequency, which is simply inversely proportional to the distance between the flight path and the target facility.

2.2 Average and Location-Dependent Crash Density Methods

As discussed in Section 2.1, the airway flight frequency method does not directly calculate the impact frequency from air traffic and accident data. Instead, it estimates the aircraft impact frequency from the data-determined crash frequency using a model that is inversely proportional to the distance between the aircraft flight path and the target facility.

2.2.1. Location-Dependent Crash Density Method

Ideally, the frequency of aircraft impact at a target facility can be estimated by using the actual aircraft crash data (including the crash events and the crash locations) to determine the location-dependent crash density first. Then, the aircraft impact frequency at the target location can be obtained by multiplying this location-dependent crash density at the target location by the effective target area. Since the aircraft impact frequency determined using this approach is intended to be derived directly from the aircraft crash data, uncertainty in the calculated result can be minimized.

However, due to the scarcity of the aircraft crash data, the historical crash sites are too scattered and widely spread out to support a statistically meaningful determination of location-dependent crash density. Because of this data limitation, two possible approaches were considered.

The first possible approach is to use the Bayesian method to estimate the distribution of the location-dependent crash frequency. In this method, a two-dimensional, prior distribution of the aircraft crash frequency can be postulated first. Using the Bayes' theorem, this distribution can then be updated with the actual crash site data. The main issue with this approach is the selection of the prior distribution of the aircraft crash frequency which is highly subjective and may not be fully supported by the key characteristics of the influencing factors for aircraft crashes.

In principle, the crash frequency at each location can be influenced significantly by many factors including weather pattern, topography, terrain-related weather conditions (e.g., frequently generated wind shear at location with steep mountain elevation drop), etc. According to the considerations of these influencing factors, one can subdivide the entire continental U.S. into many small areas, each of which entails relatively uniform characteristics of these factors that influence the crash frequency. Unfortunately, to this date, such detailed study has not been available to support the characterization of these influencing factors, classification of the geographical areas, and the specification of the prior distribution of the location-dependent crash frequency. Without substantiated by these in-depth evaluations, any use of an assumed analytical distribution as the prior distribution could essentially be arbitrary and not fully supported by the actual crash data. This kind of assumed prior distribution will no doubt contribute substantially to the inaccuracy and uncertainty in the calculated results for the aircraft impact frequency.

2.2.2. Average Crash Density Method

Due to the difficulty in developing the location-dependent crash density, some studies have used the approach to simply estimate the average crash density, which is then multiplied by the effective target area to derive the frequency of impact at the target location. This approach assumes that the crash frequency is uniform throughout the entire area within which the total number of crashes per year is divided by the total area to determine the average crash density per year. Eq. (4) below shows the mathematic representation of this approach:

$$\text{Crash density} = \text{total number of crashes} / (\text{number of crash data collection years} * \text{total crash data collection area}) \qquad (4)$$

The main drawback of the average crash density approach is that it neglects the potentially significant variation in the crash frequency from location to location. It assumes equal crash density in all areas within the crash data collection area; i.e., crash occurs equally likely anywhere within the area. This assumption is not realistic because some locations should be more likely than others because the crash density is location dependent. The average crash density method is clearly non-conservative for locations closer to the flight routes.

In one study, the total number of crashes per year in an entire country was divided by the total land area of the country to derive the average crash density per year and used for the calculation of the crash frequency per year at a specific target facility. It was stated in this study that the average crash density used was conservative for the target facility because most of the crashes occurred in the mountainous areas far away from the target facility. Using the average crash density developed in this manner for the non-mountain areas is thus considered conservative.

While the terrain may be an important factor that affects the location-specific crash frequency, there may be other factors that also contribute to the variability in the location-specific crash frequency. Blindly applying an average crash density to a specific location without fully investigating any other possible influencing factors at play could potentially underestimate significantly the aircraft impact frequency, if indeed other significant influencing factors are present nearby the target facility.

3. RECENTLY PROPOSED METHODS BASED ON AIR TRAFFIC DATA

As discussed in Sections 1 and 2.1, the airway flight frequency method only accounts for flights along the airways. Since the advent of navigation by GPS, however, aircraft can fly from Point A to Point B without following any specific airways. Therefore, for flights that do not follow the airways, they can, in principle, be anywhere in the airspace in the vicinity of the target facility. The flight path distribution could be a continuum. To ensure that all flights in the vicinity of the target facility are considered in the evaluation of the aircraft impact frequency, the method used needs to be able to include all air traffic nearby the target facility.

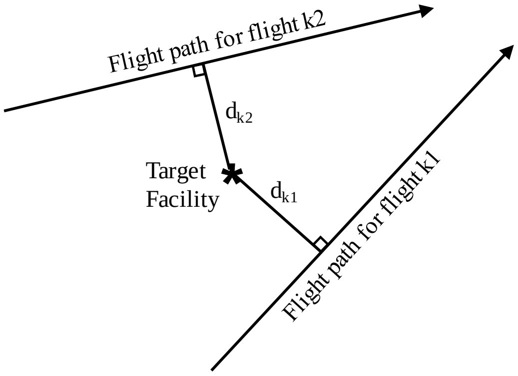
Therefore, the two methods proposed in this section (i.e., flight density method and flight-hour density method) derive the aircraft impact frequency from all air traffic data in the vicinity of the target facility.

3.1. Flight Density Method

The flight density method is an extension of the airway flight frequency method specified in NUREG-0800 for assessing the frequency of impact from flights along the nearby airways. To account for all flights in the vicinity of the target facility, the in-flight aircraft impact frequencies can be estimated using the FAA air traffic data obtained from the radar environment, which, however, is not in the form of statistics that can be readily used for the aircraft impact frequency calculation. These data from the FAA Traffic Flow Management System repository are digitalized points from the radar monitoring of the flight trajectory from airport to airport. The flights navigated by GPS are similar to the flights along airways except that they may not follow the airways even though each flight follows essentially a straight path. The FAA air traffic data must be processed by a computer program to derive the unique overflights nearby a target facility, the closest distance between the target facility and each unique flight, and the frequency of these flights.

In processing the FAA radar data, the closest distance between the target facility and each unique flight (see Figure 2) is used to determine the lateral aircraft impact range based on the model adopted by NUREG-0800. For each class of aircraft, its total frequency of crashing into a target facility can be estimated by summing the products of in-flight crash rate, effective facility target area, and the inverse of lateral aircraft impact range over all unique flights. This can be calculated for several cases of the maximum closest distance, which is used to determine the appropriate area around the facility for characterizing the aircraft impact hazard.

Figure 2: Illustration of the "Closest Distance" from Flight Path to Target Facility



3.1.1. Closest Distance between Flights and Facility – Continuous Variable Approach

For an airway, the distance between the airway and the target facility is fixed. However, since the distance between the flights navigated by GPS and the target facility can essentially be a continuous variable, Eq. (1) used to estimate the aircraft impact frequency must be modified to analyze the overflights during the in-flight phase that can be anywhere in the vicinity of the target facility.

For each individual flight navigated by the GPS, Eq. (1) reduces to the following equation since we know its exact flight path from the radar data:

$$P_k = C \cdot \frac{A}{2 \cdot d_k} \tag{5}$$

where

P_k = impact likelihood for flight k
C = crash rate, crash/mile
A = effective target area, mile^2
d_k = closest distance between flight k and target facility, mile

Since the closest point to the target facility each unique flight reached can be determined from the radar data (i.e., is known), variable "w" in the NUREG-0800 model (which is used to reflect that the flight could be anywhere within the airway width) is no longer needed as shown in Eq. (5) above.

As presented in the following, the impact frequency from all flights can thus be calculated as the sum of contributions from each individual flight:

$$f = \sum_k C \cdot \frac{A}{2 \cdot d_k} \tag{6}$$

As evidenced in Eq. (6) above, variable "N" in Eq. (1) through (3) is replaced by the summation over all unique flights.

The above equation considers only one class of aircraft. For each class or type of aircraft, its total frequency of crashing into the target facility is estimated by summing the products of inflight crash rate, effective facility target area, and the inverse of lateral aircraft impact range over all unique flights. Thus, Eq. (6) can be further defined as follows to specifically calculate the impact frequency from a specific class or type of aircraft "j" (e.g., heavy, medium, and light) passing through the airspace nearby the target facility:

$$f_j = \sum_k C_j \cdot A_j \cdot \left(\frac{1}{2 \cdot d_{jk}}\right) = C_j \cdot A_j \cdot \sum_k \left(\frac{1}{2 \cdot d_{jk}}\right) \tag{7}$$

where

index j = Class j aircraft (e.g., heavy, medium, or light aircraft)
index k = individual, unique flight k within Class j aircraft
f_j = impact frequency per year from Class j aircraft
C_j = in-flight crash rate per aircraft flight mile for Class j aircraft
A_j = effective target area (miles^2) for Class j aircraft
d_{jk} = closest distance of unique flight k (within Class j aircraft) to the target facility

The total impact frequency from all classes of aircraft is therefore:

$$f = \sum_j C_j \cdot A_j \cdot \sum_k (\frac{1}{2 \cdot d_{jk}}) \quad (8)$$

As part of the processing of the FAA radar data, the closest distance between the target facility and each unique flight is used to determine the inverse of lateral aircraft impact range, i.e., $1/(2 \bullet d_{jk})$, based on the model adopted by NUREG-0800. This model will result in greater contribution to the total impact frequency for flights closer to the target facility and smaller contribution for flights further away from the target facility.

The above calculation can be performed for a number of different cases in terms of the maximum closest distance between the target facility and the unique flights; e.g., all flights with the closest distance within 5 miles from the target facility, within 10 miles, and within 15 miles, which can be used to determine the appropriate area around the target facility for representing the aircraft crash hazard. In other words, the range of, for example, 5 miles, 10 miles, and 15 miles are simply used to determine whether a flight will be included or excluded from the calculation of the aircraft impact frequency.

Another approach in determining the boundary for including flights in estimating the aircraft impact frequency is based on the NUREG-0800 proximity criteria. As discussed in Section 3.5.1.6 of NUREG-0800, the aircraft impact risks are considered to be negligibly low if the distances between the target facility and the military training routes, federal airways, and holding/approach patterns are beyond the following:

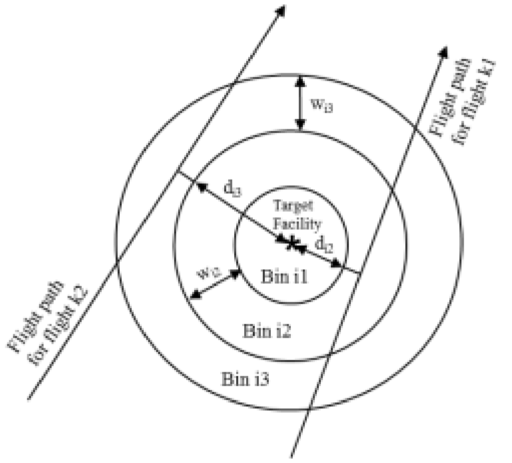
- Five statute miles from the nearest edge of military training routes
- Two statute miles from the nearest edge of a federal airway, holding pattern, or approach pattern

Assuming that the width of an airway is about 9.2 miles, the above criteria imply that the distance between the target facility and the aircraft can possibly be as much as 14.2 miles and 11.2 miles, respectively. Therefore, for the purpose of evaluating the risk of aircraft impact from enroute overflights that do not satisfy the NUREG-0800 proximity criteria, flights traversing the airspace within about at least 15 miles from the target facility should be collected and included in the evaluation.

3.1.2. Closest Distance between Flights and Facility – Discretized Bins Approach

As discussed previously in Section 3.1.1, d_{jk} in Eq. (8) could potentially be a continuous variable for flights in the vicinity of the target facility. For ease of analysis, one can also group all flights by not only the aircraft type but also their closest distances from the target facility, d_{jk} (see Figure 3). This variable, d_{jk} (closest distance to the target facility for each flight), can be discretized into a number of distance bins, each with a width and a distance to the target facility from the inner or nearest edge of the respective bin. Note that these distance bins are actually “annular distance bins” around the target facility, which are simply bins for the locations of the closest point of each of flights. In this manner, all the flights can be grouped into distance bins according to the closest distance to the target facility each flight reaches.

Figure 3: Illustration of Distance Bins



In the example of a recent study, 15 bins were defined, and each bin has a width of 1 mile. The 15 bins are defined as 0 to 1 mile to the target facility (first bin), 1 to 2 miles (second bin), …, 13 to 14 miles (14th bin), and 14 to 15 miles (15th bin).

Each flight traverses through a number of annuli around the target facility in essentially a straight line. Each annulus is a distance bin with a width. The inner most annulus that the flight traverses through is the closest point in its path from the target facility. Therefore, this flight is counted as one flight for this inner most annulus (bin) and not counted in any other annuli (bins) that it traverses through. Corresponding to each annulus (bin), there is a total number of flights and the values of "w" (annulus or bin width) and "d" (the distance from the inner edge of the annulus or bin to the target facility). Each annulus is simply the airspace within which the closest points (to the target facility) of the flights are located.

All flights sorted into the same bin/annulus are assumed to be at the same distance from the target facility even though they can be anywhere across the width of the bin/annulus. If these flights traverse through the centreline of the annulus, the distance to the target facility is (w/2)+d. The crash spread width is thus 2[(w/2)+d] = w+2d.

The binning process is simply sorting all unique flights collected and identified into the distance bins defined. This process accounts for all unique flights with no overlapping in sorting into the various bins. The flights in each distance bin are not repeated in any other bins. As such, the FAA data processing is simply identifying the unique flights, as well as counting and sorting them into different distance bins, each with a different distance from the target facility.

As such, the risk of impact from each distance bin will certainly need to be added to obtain the total risk of impact. Thus, the total aircraft impact frequency from the contributions from all distance bins can be calculated using the following equation:

$$f = \sum_j \sum_i N_{ij} \cdot C_j \cdot \frac{A_j}{(w_i + 2 \cdot d_i)} \qquad (9)$$

where

i = index for distance bin
j = index for aircraft class/type
N_{ij} = number of flights per year in bin "i" for class "j" aircraft
C_j = crash rate per flight mile for class "j" aircraft
A_j = effective target area for class "j" aircraft

w_i = width of bin "i"
d_i = distance from the inner/nearest edge of bin "i" to the target facility

Both the continuous variable and the discretized bins approaches can be implemented using a computer software to automate the processing of the air traffic data to derive the aircraft impact frequency. The discretized bins approach can provide more insights in terms of the contribution to the total impact frequency from the various distance bins, while, due to the more integrated computer processing required, the contributing parameters for the continuous variable approach may not be as transparent. However, due to the discretization error, the treatment of the closest distance as a continuous variable should provide more accurate total impact frequency, although the difference may not be significant if the distance bins are define in terms of relatively small bin width; e.g., 1 mile each.

Of course, the discretization error is smaller for finer binning structure and greater for coarser binning structure; i.e., the more bins there are, the more accurate the result is. For bins closer to the target facility (i.e., with smaller "d"), the effect of "d" due to the factor "1/(w+2d) is more prominent. As such, it may be desirable to use smaller bin width for bins with distances closer to the target facility so that the variation in the values of "d" will be the least for flights within those bins. For bins farther away from the target facility, the percentage error due to the different "d" values for flights within the same bins will be less and can afford the use of a coarser bin. So, the bin size and the number of bins are determined by how much difference it will make in the factor "1/(w+2d)" for the actual flights within the bins whose real "d" values are not totally equal.

In fact, based on a recent analysis using both approaches in which the discretized bins approach used a uniform bin width of 1 mile each, the calculated total aircraft impact frequencies are actually very close between the two approaches.

3.2. Average Flight-Hour Density Method

The average flight-hour density method utilizes the flight-hour data which can also be derived by processing the FAA radar data. With the flight-hour data, this method first calculates the flight-hour density as follows:

$$\begin{gathered}\text{Average flight-hour density within a flight data collection area} = \\ \text{(total annual number of flight-hours within a flight data collection area)} / \\ \text{(total area within the flight-hour data collection area)}\end{gathered} \tag{10}$$

Once the average flight-hour density is obtained, the aircraft impact frequency for each class of aircraft can be estimated as follows:

$$\begin{gathered}\text{Aircraft impact frequency} = \text{average flight-hour density (flight-hours/mile}^2\text{-year)} * \\ \text{crash rate (crashes per flight-hour)} * \text{effective target area (miles}^2\text{)}\end{gathered} \tag{11}$$

The crash rate (crashes per flight-hour) used in the above equation can be estimated using the National Transportation Safety Board or FAA flight accident data.

The key issue with this method is the assumption of uniform flight-hour density within a flight data collection area; i.e., the airplanes will show up anywhere in the area with equal likelihood. The flight frequency and the annual flight hours are parameters that could be highly location/direction dependent; i.e., these quantities may be concentrated in specific locations/directions and are not uniformly distributed throughout a large area.

As such, this assumption is not considered realistic because, for example, the flight-hour density should be much higher at locations near the flight routes. In other words, the flight-hour density could be diluted for large areas with variable air traffic within the airspace. This assumption is also combined in this method with the assumption of equal crash likelihood anywhere the aircraft shows up; i.e., constant crash rate which is an assumption that is commonly used and is considered acceptable on a relatively basis. Combining these two assumptions leads to essentially the same assumption as the constant crash density assumption; i.e., equal crash likelihood anywhere within the area.

Although, given an aircraft crash, the likelihood of impacting the target may not be strongly location/direction dependent, nevertheless, it is still heavily influenced by at least one characteristic; i.e., the distance of these flights or flight hours from the target location.

To sum up the total flight hours within an area and equally distributes it throughout the entire area is essentially shifting the flight hours from the concentrated locations/directions to other areas with much less flight hours. The net effect is to significantly reduce the flight hours from specific locations/directions by spreading the cumulative flight hours in those specific locations/directions to a much larger areas, which essentially is to artificially reduce the impact likelihood from selected areas.

As such, this average flight-hour density approach could be non-conservative and significantly underestimate the flight-hour density at specific locations (e.g., the direction and location-specific concentration of flights will be diluted by the average over the entire area and a diluted density could be used at locations closer to the flight routes) and thus underestimate the frequency of aircraft impact at the location of the target facility.

4. CONCLUSION

Several approaches are discussed in this paper for the analysis of the aircraft impact frequency due to overflights during the in-flight phase, including airway flight frequency, location-dependent crash density, average crash density, flight density, and average flight-hour density methods. The airway flight frequency approach can no longer be used in the present-day aviation environment because it does not account for flights outside the airways. Both the average crash density and average flight-hour density methods imply a constant crash density within the area regardless of the location of the target facility. This is not realistic in many cases and can potentially be non-conservative for locations closer to flight routes or locations with greater influence by conditions affecting the crash likelihood.

Ideally, the location-dependent crash density method can use the aircraft crash data to directly determine the frequency of aircraft impact at the target location. The main problem associated with this method is the unsubstantiated basis for the model adopted to extrapolate the impact frequency from the historical, actual crash sites to the location of the target facility.

The flight density method uses a model adopted in Section 3.5.1.6 of NUREG-0800, which implements an assumption that the aircraft crash is more likely to occur at locations closer to the flight routes and is less likely to occur at locations farther away from the flight routes. The model used to implement this assumption (i.e., the impact likelihood is inversely proportional to the closest distance between the flight path and the target facility) certainly represents a key source of uncertainty, but may or may not contribute to any conservatism that may be present in the calculated result for aircraft impact frequency.

Overall, considering the advantages and drawbacks of the methods investigated in this paper, the flight density method is considered most credible, realistic, and practical.

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