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Improved Assessment of Aviation Hazards to Ground Facilities Using a Geographical Information System

G. M. Sandquist
D. M. Slaughter
C. Y. Kimura

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G. M. Sandquist and D. M. Slaughter
CENTER for Excellence in Nuclear Technology, Engineering & Research, University of Utah
Salt Lake City, Utah 84112
(801) 581 7372

C. Y. Kimura
Fission Energy and Systems Safety Program
Lawrence Livermore National Laboratory
Livermore, California 94551
(510) 423 1745

ABSTRACT

A computer based system for performing probabilistic safety assessments (PSAs) of aircraft crashes to ground structures is under development. The system called ACRA (aircraft crash risk assessment) employs a GIS (geographical information system) for locating, mapping, and characterizing ground structures; and a multiparameter data base system that supports the analytical PRA (probabilistic risk assessment) model for determining PSAs for aircraft crashes. The Salt Lake International Airport (SLC) is being employed as the base case for study and application of ACRA and evaluation of the projected safety assessment.

I. INTRODUCTION

The close proximity of airports and aircraft approach and departure paths has increased the exposure of the public to health risks from the environmental effects of noise, visual impairment, emissions, and particularly to safety risks from possible aircraft crashes. Recently, the Federal Aviation Administration (FAA) has reduced previous limits on takeoff and landing at many major US airports so traffic will increase and so will risks. Historically, the probability of aircraft crashes resulting in injury or death to persons on the ground is less than 1E-6 crashes per flight in the US. However, the increased level of aircraft operations and relaxed restrictions in aircraft operations in the vicinity of airports may increase this risk, particularly at airport environs with high aircraft traffic and large surrounding populations.

Kimura[1] has described how risks from aviation traffic near ground facilities have been determined, quantified, modeled, and assessed in the past and how significant improvements to these assessments have been realized by examining actual traffic patterns at selected high aircraft activity airports. Recently an improved analytical model and computer code have been developed which more accurately estimate crash frequencies and provide a mechanism for estimating operational data necessary for producing accurate assessments. Furthermore, aircraft operation and accident data have been updated and additional parameter data have become available to better support and validate the model.

This study describes how these enhanced models, increased data, and methodology improvements have been incorporated into the computer based aircraft crash risk assessment (ACRA) system currently under development. The operating airport chosen to test the utility of this risk assessment system is the Salt Lake International Airport (SLC) located near Salt Lake City, Utah. The Airport is identified here for convenience by the acronym, SLC which is the designation assigned to the Airport by the International Air Transport Association (IATA).

II. AIRCRAFT RISK MODEL

The US Nuclear Regulatory Commission[2] first quantified the risks that aircraft flights might pose to nuclear power plants located in the US. This quantitative risk articulation used the standard probabilistic risk assessment (PRA) methodology presented in NUREG-0800 and developed for the WASH 1400 , methodology studies. The assumptions and subsequent analysis made using NUREG-0800 were very conservative and modifications for improving the NUREG have been proposed and evaluated by many others including Hornyik[3], Solomon[4], and Smith[5].

However, all of the various (PRA) models employ the common assumption that the frequency that an airborne aircraft will strike a particular building or facility is acceptably modeled and quantified by the following four measurable factors:

- number of flights or operations in the specific location of interest
- site specific frequency of an aircraft accident or the expected crash rate
- probability that the aircraft will impact a particular location where a building or ground facility is located
- effective impact area and collision energy (penetration and damage volume) delivered to the building or facility

The annual frequency of aircraft crashes, F, is given by the following integral expression involving the joint probability density function $f(x,y)_{ijk}$:

$$F = N\,P \iint_{AF} f(x,y)_{ijk}\,dx\,dy \qquad (1)$$

where

- F annual frequency of an aircraft crash into a given ground grid cell
- N annual number of aircraft operations near or affecting the building or facility
- P generic probability of an aircraft crashing per operation (e.g., landing, takeoff) expressed as crashes per distance flown, or hour flown, or per flight

The double integral represents the crash probability into a given ground structure as a function of the effective target area A, impact angle, impact velocity, and other crash-specific parameters given the occurrence of a crash. Equation (1) accounts for the observation that the crash location joint probability density function, f(x,y) is dependent on various crash kinematics parameters such as crash impact angle, aircraft speed, aircraft type, and other parameters.

This model for aircraft crash frequency provides the mathematical basis for quantifying risk using the computer based PSA system, ACRA (acronym for Aircraft Crash Risk Assessment) currently under development and testing for SLC.

II. DESCRIPTION OF SALT LAKE INTERNATIONAL AIRPORT

The SLC (Salt Lake International Airport) currently has four operational aircraft runways and numerous major buildings, taxiways, fuel storage tanks, and support facilities. Commercial air traffic is served by runways:

- **16R/34L** (3659 m long and 46 m wide) began operation in late 1995
- **16L/34R** (2925 m long and 46 m wide)
- **17/35** (2925 m long and 46 m wide)
- **14/32** (1614 m long and 46 m wide) mostly serves general aviation traffic and air taxi flights.

The SLC also possesses numerous ground structures which house significant numbers of the people during certain portions of the day. Other facilities such as petroleum storage areas and areas with high densities of parked automobiles, hazardous material storage areas, and other features that pose risk to public health and safety in the event of an aircraft crash to that area or facility.

Collecting and incorporating in the assessment system all of the site specific data associated with these ground features and in the nearby surrounding areas is a data intensive task. But this is required to perform accurate site specific risk assessments using the ACRA system. The most efficient manner of accomplishing this task of accumulating and manipulating the data effectively to perform risk assessment is the construction and use of efficient and manageable data bases. ACRA uses specialized computer software and an associated data base referred to as a Geographical Information System or GIS to accomplish this task.

This paper describes the ACRA system and the GIS supporting the system and how ACRA utilizes the data to calculate the aircraft risk to ground facilities. Much of the actual statistical and operational data required for modeling the SLC using the GIS in ACRA is presented in companion papers by Kimura[1,6].

III. SALT LAKE INTERNATIONAL AIRPORT OPERATIONAL DATA

The Salt Lake International Airport (SLC) is a major, commercial airport served by a FAA staffed tower. In 1994, 42 certified route air carriers performed 90,510 aircraft departures with 7,828,969 enplaned passengers and 87,754 revenue freight tons. Delta Airlines is the dominant air carrier in the area with a major domestic hub established at SLC. Delta performed 56,988 departures in 1994 carrying 5,610,399 enplaned passengers which represents 63% of the total aircraft departures and 72% of the enplaned passengers at SLC. General aviation operations comprised 25 percent and military aviation operations made up the remaining 3 percent of the total aircraft operations at SLC.

For the period 1987 to 1994, the Boeing 727, 737 and 757 constitute the dominant commercial aircraft types and provides 85 percent of the total certified air carrier departures from the SLC. New long range wide body aircraft types such as the Airbus A.330 and A.340, and the Boeing 777 may be slowly introduced at SLC if it develops into a major international airport. However, Los Angles, San Francisco, and Denver Airports also compete in this international air transportation passenger market. An aircraft risk analysis using the certificate air carrier aircraft type survey based on the 1987 to 1994 time period used here will probably be applicable for several years even with the introduction of the short haul aircraft types at SLC.

The next term needed in the calculation of the aircraft crash frequency into a facility is the probability of an aircraft crash occurring during takeoff or landing operations. The consequences to ground structures for aircraft accidents occurring during taxing or ground phase operations are not considered as crash candidates in this study. Also, accidents that result in only serious injuries or fatalities to persons in the aircraft or on the ground, but do not result in substantial damage to the airframe, are not considered as crash candidates for ACRA risk assessment.

The average US crash rates for the 1978-1994 period as compiled by the National Transportation Safety Board (NTSB) with aircraft destruction or major airframe damage is a follows:

- Part 121 Air carriers
  - 1.6 E-6 crashes/aircraft-hr
  - 3.9 E-9 crashes/aircraft-mile
  - 2.2 E-6 crashes/departure

- Part 135 Air carriers
  - 1.8 E-5 crashes/aircraft-hr
  - 7.1 E-8 crashes/aircraft-mile
  - 1.2 E-5 crashes/departure

The crash rate for SLC based on the limited number of crashes which have occurred near SLC is 2.8E-6 per flight. This is slightly higher than the average crash rate reported in 14 CFR 121 (Title 14, Part 121 of the US Code of Federal Regulations) air carriers of 2.2E-6 per departure. It is assumed that the accident rate given by the NTSB (i.e., 2.2E-6 crashes per departure) for all 14 CFR 121 air carriers can be applied to aircraft operating in the vicinity of SLC and the ACRA data base is a reasonable approximation of the actual crash rate at SLC.

IV. GIS BASED ACRA RISK ASSESSMENT MODEL

The various geographic data bases used by ACRA are developed and manipulated as data layers that are conformably mapped to accurately overlay the reference ground feature data layer. The ground data layers define the basic grid cells that are used to control and characterize the metric for all other data layers. Each overlay layer may be selectively viewed and processed by the computer as respective aerial plan views over these ground layers. The complete set of the several aerial data layers generates the vertical volumetric air space cells that contain the airborne aircraft traffic movement under assessment.

The GIS ground data layers are composed of two different sets of layer data base grids developed for ACRA as follows:

- **Far-field data base grid** which incorporates the FAA flight control patterns within the airport control areas and the major ground features within the metropolitan Salt Lake City area where the population is located that may be impacted by aircraft crashes
- **Near-field data base grid** which contains the aircraft runway and taxiways, the landing and approach pathways and other immediate airport environs.

The far-field grid provides a macroscopic plan view of the area surrounding the airport and the airspace above this airport from which aircraft incidents could reasonably occur and result in a crash of the aircraft resulting in injury and death to persons on the ground. Typically, the far-field grid data base is composed of a few thousand rectangular ground grid cells (usually one quarter square kilometer in area). The ground features (e.g., buildings, structures, equipment, population density, etc.) are situated within a ground grid cell to provide mean data values for risk assessment. Significant characterizable ground features include shopping centers, schools, sports arenas, industrial plants, residential areas, fuel storage depots or refineries, a restricted flight zone over the Camp Williams (National Guard) Site about 25 km south of the SLC, and two small municipal airports near the SLC.

For the SLC, the far field grid size is 22 km by 40 km (3520 grid cells each 1/4 square km in area) and encloses most of the populated areas and significant ground features in the Salt Lake metropolitan area. The far-field data base for SLC encompasses a population of about 1.85 million people and permits a comprehensive assessment of the risk to health and safety for essentially all people living with the metropolitan area surrounding the SLC. The mean population in the far field area is 2102 people per square km with a standard deviation of 1740 people per square km. A simple scan and assessment of the maximum consequences from a single large commercial aircraft crash to a vital ground structure in the far-field grid could produce about a thousand injuries and fatalities.

The near-field grid utilized by ACRA for SLC addresses aircraft incidents in final landing and takeoff operations in the SLC airport-terminal area which result in aircraft crashes posing risk of injury and death to persons in the immediate environs of the airport. For the SLC there are 1800 near-field grids that overlay the 4 major runways. The basic ground grid cell is a square 100 meters on edge which permits detailed consequence analysis and risk assessment for each major ground feature at SLC. Complete coverage of these major features is provided by a matrix of 60 by 30 grid cells (i.e., a total aerial coverage of 6 km by 3 km) and encloses both airport terminals, parking lots and garages, postal delivery and shipping terminals, fuel storage, and other associated airport activities and facilities.

ACRA performs a risk assessment to the ground base population by selecting sequentially each of the vertical grid volumes within the near or far-field mapping. In this air space volume the probabilities of the presence of a particular type of aircraft, its direction and speed (i.e., velocity vector) are determined for the standard flight path as prescribed by FAA for the given aircraft type (B-727, 737, 757). The data bases influencing the probability of an incident leading to the crash of the aircraft to the ground are then interrogated (e.g., probability of another aircraft within a collision path, mechanical failure, flight crew errors, weather conditions such as icing or wind shear, etc.) and the probability of the aircraft crashing to the ground over the appropriate distribution of the ground cells is determined. This process is repeated for each vertical grid volume and the total risk to persons at each ground cells is summed to provided as the total annual risk for that given type of aircraft. When all vertical cells are evaluated the total risk is summed for each ground cell and displayed. The total distribution of risk to the public is displayed on the geographical ground map of ACRA. Color variations in the computer display (intense red to white) permit an immediate risk assessment survey for various levels of risk. Actual numerical risk data is also available for printout from the data base for any specified grid location.

V. CONCLUSION

The ACRA system[7], a computer based system for performing probabilistic safety assessments (PSAs) of aircraft crashes to ground structures, is being tested and evaluated using the Salt Lake International Airport (SLC) [8] as a base case. Use of a GIS[9] data base and data management system have proven to be invaluable in incorporating the many expanded features provided by the model. Both the near and far-field grids permit the detailed analysis of the ground structure location, characteristics, associated flight paths, schedules and risk posed to ground structures within both grids. This comprehensive risk assessment may serve as a basis for review of current landing and takeoff patterns for the SLC.

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