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OVERFLIGHT LETTER

APR 1 0 1989

Mr. Ralph Stein, Associate Director
Office of Systems Integration and Regulations
Office of Civilian Radioactive Waste Management
U. S. Department of Energy, RW-24
Washington, D. C. 20545

Dear Mr. Stein:

SUBJECT: MINUTES FROM FEBRUARY 8, 1989 MEETING ON OVERFLIGHTS OF THE HIGH-LEVEL NUCLEAR WASTE REPOSITORY

Enclosed is a copy of the minutes from the February 8, 1989 meeting among the U. S. Nuclear Regulatory Commission (NRC) staff and representatives from the U. S. Department of Energy (DOE), the U. S. Air Force, the State of Nevada, and Nye County, Nevada. The minutes were jointly prepared by the NRC staff and representatives from DOE. As can be seen from the minutes, the meeting was informational, and discussions centered on the NRC staff's concerns about overflights of the Yucca Mountain, Nevada, high-level nuclear waste repository.

If you have any questions, please feel free to contact Mr. Joseph Holonich of my staff at FTS 492-3403 or (301) 492-3403.

Sincerely,

ORIGINAL SIGNED BY

John J. Linehan, Director
Repository Licensing and Quality
Assurance Project Directorate
Division of High-Level Waste Management

Enclosure: As stated

cc: R. Loux, State of Nevada
M. Baughman, Lincoln County, NV
S. Bradhurst, Nye County, NV
D. Bechtel, Clark County, NV
C. Gertz, DOE/Nevada

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LPDR	ACNW	PDR	

OFC :HLPD	:HLPD	:	:	:	:	:
NAME:JHolonich/mc	:JLinehan	:	:	:	:	:
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ENCLOSURE

SUMMARY OF NRC-DOE-AIR FORCE MEETING
ON OVERFLIGHTS OF YUCCA MOUNTAIN

Summary:

On February 8, 1989, members of the U. S. Nuclear Regulatory Commission (NRC) staff met with representatives from the U. S. Department of Energy (DOE), the U. S. Air Force (USAF), the State of Nevada, and Nye County, Nevada. The purpose of the meeting was to provide background information on NRC concerns about overflights of NRC-licensed facilities. Attachment 1 is a list of attendees. The Yucca Mountain candidate repository site is near a flight path used by planes from the neighboring Nellis Air Force Base (NAFB). The flight path is an access route for planes flying to the NAFB range north of the site. DOE currently restricts Air Force overflights of the Nevada Test Site abutting the Yucca Mountain site.

At the outset of the meeting, both DOE and USAF officials spoke of the good working relationship they had developed with each other. They expressed confidence in their ability to work out a mutually satisfactory arrangement to permit easier USAF access to the NAFB range without jeopardizing the safety of repository operations. DOE's Yucca Mountain Project Office (YMP) said that the Project has worked out an agreement with NAFB on overflights during site characterization. The USAF has agreed to stay at least 500 feet above Yucca Mountain during the overall site characterization program, and at least 1500 feet above the site during the time that construction crews are on location. In addition, the USAF had initially had major concerns about overflight restrictions but has developed a good cooperative relationship with DOE over the site. The USAF went onto say that it could develop a system for assuring continued access to the NAFB range.

The NRC staff made it clear at the meeting that it has not developed a position on what regulatory controls are needed for overflights of a repository during licensed operations. The only existing staff positions apply to the review of nuclear power plant license applications. The staff positions are to assure that the risks due to aircraft hazards are sufficiently low, and, if they are not, evaluate the applicant's plant design to assure that it is protected against the potential effects of aircraft impacts and fires. The NRC staff distributed copies of the section of the NRC Standard Review Plan (NUREG-0800) criteria concerning the applicant's assessment of aircraft hazards and two other guidance documents referenced in that publication. NRC staff also agreed to provide a list of reference documents on aircraft hazard assessment methods and copies of the shorter documents.

A copy of the reference list is contained in Attachment 2 and copies of the documents are contained in Attachment 3.

The NRC staff explained its criteria for the analysis of aircraft hazards for the licensing of reactors. This included a general explanation of the background of the 10^{-7} per year probability criterion for aircraft accidents resulting in radiological consequences greater than the 25 rem individual dose limit in 10 CFR Part 100, Appendix A. The NRC staff covered the regulatory background for the minimum distance-from-plant and maximum frequency-of-flight-operations requirements under which the probability of aircraft accident consequences could be assumed to be less than 10^{-7} per year by inspection. In addition, a description of some of the design basis considerations that shaped the development of the guidance, and how the staff applied the guidance in several reactor licensing cases was given.

In a preliminary discussion, the staff noted that the design basis requirements in the guidance for reactor licensing may be conservative for a repository. It was suggested by the NRC staff that in developing aircraft hazard assessment methods for a repository, DOE might want to consider, among other things, the potential consequences of an airplane crash on the site. The consequences would depend on such factors as, for example, how much waste inventory would be on the surface of the site, and the area that would have to be decontaminated if the maximum credible amount of this inventory were released. The NRC staff also suggested that DOE might want to take into account the nature of the engineered structures at the site surface, particularly with respect to their resistance to impacts and susceptibility to fire hazards.

DOE noted that it is currently planning lag storage for 750 to 3,000 metric tonnes of heavy metal equivalent at the site, but has not decided on the design of the cask for this storage.

The State of Nevada representative noted that in reviewing an application at Yucca Mountain, NRC would probably also have to consider the effect of an aircraft accident on the underground facility through the potential impact of a crash at a ramp or ventilation shaft. The NRC staff agreed that this was a valid point.

In a discussion of the relationship of the current and proposed flight corridors to the NAFB range and the Yucca Mountain site, the USAF said that the closest tactical approach comes about three miles from the site, but there are probably unintentional overflights several times a week. The USAF also stated that there is some low-altitude manuevering, and live ordinance is carried in the vicinity. However, it did state that the current overflight restrictions for the Yucca Mountain site characterization program are not a problem. The principal USAF concern is that the requirement to avoid the Nevada Test Site forces planes returning from the NAFB range to fly a longer distance when they are low on fuel. The USAF has prepared an environmental assessment for a new route for night operations planned to begin this fall and continue until the repository becomes operational.

John J. Linehan 4/3/89

John J. Linehan, Director
Repository Licensing and Quality
Assurance Project Directorate
Office of Nuclear Material Safety
and Safeguards
U. S. Nuclear Regulatory Commission

Ralph Stein 4/4/89

Ralph Stein, Associate Director
Office of Systems Integration and
Regulations
Office of Civilian Radioactive
Waste Management
U. S. Department of Energy

ATTACHMENT 1

Attendee List
February 8, 1989 Meeting

NRC

R. Virgilio
B. J. Youngblood
R. MacDougall
J. Linehan
K. Campe
J. Bunting
D. Gupta
J. Pearring

USAF

Col. C. L. Meyer
Col. L. Heiser
Lt. Col. J. Taylor
Lt. Col. F. Arneman
Lt. Col. C. Brammeier

DOE

R. Stein
C. Gertz

State of Nevada

C. Johnson
M. Murphy

Nye County, Nevada

E. Holstein

Science Applications International, Corp.

W. Andrea
P. Austin

ATTACHMENT 2

Reference List

Bernero, Robert M., USAEC, "Supplemental Testimony on Aircraft Hazard," Three-Mile Island Nuclear Station -- Docket No. 50-289, October 26, 1973

Bloch, P.B., et. al., USNRC, Initial Decision (On all Remaining Issues), Atomic Safety and Licensing Board, In the Matter of Consumers Power Co. (Big Rock Point Nuclear Power Plant), Docket No. 50-155-OLA, August 29, 1984

Chandler, L.J., and Treby, S.J., "NRC Staff Posthearing Memorandum Regarding Aircraft Crash Probability Issue," Before the Atomic Safety and Licensing Appeal Board, In the Matter of Metropolitan Edison Co., et. al., (Three-Mile Island Nuclear Station), Docket No. 50-320, April 30, 1980

Fontecilla, H.B., USNRC, "Calculation of Target Area for Aircraft Impact," (memorandum for possible use in Three-Mile Island 2 Appeals Board Hearings), December 12, 1978

Kennedy, R.P., et. al., Sandia National Laboratories, Capacity of Nuclear Power Plant Structures to Resist Blast Loadings, USNRC, NUREG/CR-2462, Sept., 1983

Kot, C.A., et. al., Argonne National Laboratory, Effects of Air Blast on Power Plant Structures and Components, USNRC, NUREG/CR-0442, October, 1978

Kot, C.A., et. al., Argonne National Laboratory, Evaluation of Aircraft Crash Hazards Analyses for Nuclear Power Plants, USNRC, NUREG/CR-2859, June, 1982

Krug, H.E.P, USNRC, "Testimony on Aircraft Operations in Response to a Request from the Board," Before the Atomic Safety and Licensing Board, In the Matter of Pacific Gas and Electric, (Diablo Canyon Nuclear Power Station Unit Nos. 1 and 2), Docket Nos. 50-275 and 50-323 (undated)

Niyogi, P.K., et. al., "Safety Design of Nuclear Power Plants Against Aircraft Impacts," (proceedings from unnamed conference, ca. 1977)

Phillips, D.W., Criteria for the Rapid Assessment of the Aircraft Crash Rate onto Major Hazards Installations according to their Location, United Kingdon Atomic Energy Authority Safety and Reliability Directorate, July, 1987

Pinkel, I.I., Consultant, USAEC, "Appraisal of Fire Effects from Aircraft Crash at Zion Power Reactor Facility," July, 17, 1972

Price, H.J., Director of Regulation, USAEC, Letter to Edward J. Bauser, Executive Director, Joint Committee on Atomic Energy, U.S. Congress, on military training flights, May 11, 1971

Roberts, T.M., "A Method for the Site-Specific Assessment of Aircraft Crash Hazards," United Kingdom Atomic Energy Authority Safety and Reliability Directorate, July, 1987

San Diego Gas and Electric Co., "Probability of a Military Aircraft in Low-Level Flight Impacting the Sundesert Plant," (Appendix 2.2A of Sundesert Nuclear Plant -- Preliminary Safety Analysis Report) March, 1977

Solomon, K.A., and Okrent, D., "Airplane Crash Risk to Ground Population," Hazard Protection, (Journal of the System Safety Society) Vol. 11, No. 3, Jan.-Feb., 1975

USNRC, "Summary of Meeting Held on August 27, 1975," (memorandum on meeting with San Diego Gas and Electric Co. concerning, inter alia, aircraft activities in vicinity of Sundesert reactor site) Sept. 4, 1975

USNRC, "Aircraft Crash Probabilities," Nuclear Safety, Vol. 17, No. 3, May-June, 1976

Voit, D.E., "The Relationships bwetween Airport Location, Air Traffic, and Nuclear Power Plant Sites and Their Possible Interaction," Public Health Service, U.S. Department of Health, Education, and Welfare (Draft report, ca. 1970)

Wall, Ian B., "Probabilistic Assessment of Aircraft Risk for Nuclear Power Plants," Nuclear Safety, Vol. 15, No. 3, May-June, 1974

ATTACHMENT 3

October 26, 1973

THREE MILE ISLAND NUCLEAR STATION - DOCKET NO. 50-289

SUPPLEMENTAL TESTIMONY ON AIRCRAFT HAZARD

BY

ROBERT M. BERNERO

Contention #2

The facility should be so constructed, prior to operation, so as to withstand a direct impact from a 707 Jet airplane crash or from the crash of a super jet. It is contended that the probability of a 707 or super jet crashing into the facility is significantly high enough to warrant such protection. It is further contended that if the facility is not designed to withstand the impact from the aforesaid aircraft, adequate monitoring systems must be provided and adequate arrangements with nearby airports must be made in order to avoid flight patterns of said aircraft near or over the facility.

INTRODUCTION

The evaluation of the potential interaction between the Three Mile Island Nuclear Station and aircraft using the Harrisburg International Airport was performed by the Regulatory staff as part of the construction permit consideration. As a consequence of that evaluation Three Mile Island Unit 1, was constructed with special design features to protect vital areas of the plant from impact and fire effects of the crash of most of the aircraft using the airport, that is, aircraft weighing no more than 200,000 lbs. Consequently, the risk analysis discussed later in this testimony is concerned only with heavy aircraft, those weighing more than 200,000 lbs. During the Regulatory staff review of Three Mile Island Unit 1, for the operating license, the aircraft hazard evaluation was reviewed to ensure its adequacy. I participated in that review of the aircraft hazard evaluation. A summary of the evaluation was presented in Section 3.6 of the staff Safety Evaluation Report on Three Mile Island Unit 1, dated July 11, 1973. This testimony is intended to define that evaluation in greater detail with particular address of the concerns identified in the intervenors' Contention 2.

HARRISBURG INTERNATIONAL AIRPORT

The Harrisburg International Airport is located alongside the Susquehanna River on the East bank with the long, single runway parallel to the river. The river takes a bend to the right before reaching Three Mile Island. Consequently, the Three Mile Island nuclear plants lie about 2.5 miles along and about 1.5 miles to the right side of the extended centerline of the runway.

Harrisburg International Airport handles scheduled and nonscheduled passenger and cargo flights, general aviation, and some military cargo traffic. Originally designed as an Air Force base, Harrisburg International Airport is capable of handling flights by the largest aircraft in use today. The October 15, 1973 edition of the Official Airline Guide (published by Reuben H. Donnelly) shows scheduled passenger flights mostly by twin-engined aircraft, including the propellor-driven Beechcraft and Convair models and the jet-engined McDonnell Douglas DC-9 and Boeing 737. A number of the three-engined Boeing 727 jet aircraft also make scheduled flights to Harrisburg International Airport as well as one four-engined aircraft, TWA Flight 16 (a Boeing 707), which uses the airport daily. Table I shows the weights of some of the aircraft which use the Harrisburg International Airport now.

I also consulted with the Facility Manager at Harrisburg International Airport to determine how much other traffic, of large aircraft, currently uses the airport. The number of cargo and charter flights of size comparable to or greater than the Boeing 707 averages about three or four movements (takeoff or landing) per day. The aircraft involved are Boeing 707's, McDonnell Douglas DC-8's, and a few Convair 880's; these are all approximately 300,000 lb. aircraft. In addition, one charter operator is expected to bring a Boeing 747 into the airport occasionally, and the U.S. Air Force sometimes lands a Lockheed C-5A. Considering all of these large aircraft movements, it was estimated that there are now about 2000 movements per year (5-6 movements per day) at Harrisburg International Airport of aircraft weighing more than 200,000 lbs. These constitute about 2 or 3 percent of the total traffic.

TABLE I

TYPICAL AIRCRAFT WEIGHTS

Aircraft Type	No. and Type of Engines	Weight (lbs)*
Beechcraft King Air	2 Prop.	10,000
Gates Learjet	2 Jet	12,000
Lockheed Jetstar	2 Jet	40,000
Convair 600	2 Prop.	50,000
Grumman Gulfstream	2 Jet	55,000
McDonnell Douglas DC-9	2 Jet	100,000
Boeing 737	2 Jet	100,000
Lockheed Electra	4 Prop.	120,000
Boeing 727	3 Jet	150,000
Boeing 720	4 Jet	200,000
Boeing 707	4 Jet	300,000
McDonnell Douglas DC-8	4 Jet	300,000
Boeing 747**	4 Jet	700,000
Lockheed C-5A**	4 Jet	700,000

*Approximate mean of loaded takeoff and landing weights.
**Occasional use expected (see text)

AIRCRAFT HAZARD ANALYSIS

The aircraft hazard analysis of a nuclear power plant such as Three Mile Island Unit 1, is concerned with the possibility that an aircraft might strike the plant and, either by direct impact effects or by attendant fire, cause a release of radioactivity to the environment in excess of the design basis. Therefore, the vulnerable areas of the plant which merit concern are the reactor coolant pressure boundary, the spent fuel in storage, and those plant systems which are needed for safe shutdown of the plant. These vital portions of the plant are ordinarily enclosed by some protecting structure such as the reactor containment building which surrounds the reactor coolant system. It is possible that a crashing aircraft might breach one of these enclosures without causing the significant release of radioactivity with which we are concerned. However, because of the difficulties in properly analyzing the course and consequences of such an event, it is customary to make the conservative assumption that any breach of the enclosing structure is potentially damaging.

The aircraft hazard or risk analysis therefore requires establishment of the protective capabilities of the structures which enclose the vital areas of the plant and then an assessment of the likelihood of a crash on these structures by an aircraft which exceeds those capabilities. The Regulatory staff agreed in the construction permit review that it was acceptable to design the plant so that vital areas are protected by structures capable of withstanding impact at the worst angle of incidence on the weakest point by an aircraft weighing 200,000 lbs. and travelling at 200 knots. It is probable that the structures can withstand the impact of much larger aircraft without penetration if they strike at an angle to the surface of the structure or at some point other than the weakest. Special fire protection systems were also required to cope with the large quantities of fuel which might be spilled and ignited. The 200-knot impact velocity was selected as a reasonable upper limit for aircraft involved in takeoff or landing accidents. The 200,000 lbs. weight is characteristic of a Boeing 720, a four-engined jet, and this size limit was expected to include most of the aircraft which use the Harrisburg International Airport. The details of the structural analysis and the fire protection systems are presented in the Final Safety Analysis Report by the applicant and the Safety Evaluation Report by the Regulatory staff; they will not be addressed here.

Accepting the 200,000 lb. capability of the key structures, the risk or probability of impact by a larger aircraft was calculated by using the equation:

$$P = D \times A \times M$$

where: P is the probability

D is the distribution function

A is the target area

M is the number of movements

Or, in words, the probability is the product of the likelihood of an aircraft crashing in an area near an airport runway, the size of the vulnerable area, and the number of movements by aircraft of significant size.

The distribution function was claculated on the basis of ten years' accident statistics drawn from data provided by the National Transportation Safety Board of the U.S. Department of Transportation. The data for air carrier crashes during the period 1956 to 1965 were used and a distribution of crash probability as a function of distance from the end of the runway was calculated. The crash distribution is listed in Table II and, as indicated, is based on fatal crashes which occurred on takeoff or landing within a 60^0 arc of the projected path of the runway. Attention was confined to those crashes which caused fatalities because it was believed that these included all the crashes where the lack of aircraft control or ignorance of position and heading were sufficient to make collision with a large power plant a possibility. As previously noted, the Three Mile Island Nuclear Station is about 2.5 miles beyond the end of the runway and about 1.5 miles to one side, putting it just at the side of a 60^0 arc. Going to Table II we therefore identified 0.96×10^{-8} per square mile per aircraft movement as the crash distribution function appropriate to the Three Mile Island calculation. It should be pointed out that the use of 1956-1965 data is also somewhat conservative since, with improvements in equipment and control procedures, successive years have shown lower accident rates.

The target area of the Three Mile Island Nuclear Station for this calculation was taken as 0.01 square miles per nuclear unit or 0.02 square miles for the station. This value for the target area was established

TABLE II

CRASH DISTRIBUTION

DISTANCE FROM END OF RUNWAY	PROBABILITY ($\times 10^8$) OF A FATAL CRASH PER SQUARE MILE PER AIRCRAFT MOVEMENT
	U.S. AIR CARRIER
0-1 Mile	16.7
1-2 Mile	4.0
2-3 Mile	0.96
3-4 Mile	0.68
4-5 Mile	0.27
5-6 Mile	0.0 1/
6-7 Mile	0.0
7-8 Mile	0.0
8-9 Mile	0.14
9-10 Mile	0.12

1/No crashes occurred at these distances within a 60° flight path.

by a conservative evaluation of the area exposed to impact when considering conservative angles of incidence on a typical nuclear power plant. It includes allowance for aircraft which might strike the ground adjacent to a vital structure and skid into it. A sense of the conservatism of this target area may be obtained by comparing it, 0.01 square miles or 280,000 square feet, to a simple projected area for the largest single vital structure of the Three Mile Island plant, the reactor building, which stands about 160 feet above grade with a 140 foot diameter and presents a side view area of about 22,000 square feet. It should also be noted that using this large target area is additionally conservative because the impact rating of the structure was based on the 200,000 lb. aircraft striking the structure at the weakest point as well as at the worst angle. Taking into account impacts at stronger points on the structures or at different angles would give either a higher structural rating or a smaller target area for use in the calculation.

The number of aircraft movements used in the calculation was 2400 per year. This was originally established by estimating a total of 80,000 movements per year by all aircraft and postulating that 3% of that traffic would be aircraft weighing more than 200,000 lbs. Compared to the current level of heavy aircraft traffic, about 2000 movements per year, the value used in the calculation is about 20% conservative. There is further conservatism of a factor of about two since, depending on the wind direction, only about half of the takeoffs and landings on the runway would have a route in the direction of the facility. An additional conservatism is involved in that the calculation assumes that all these movements pass over the power plant, no discount of either the number of movements or the crash distribution is made to reflect the fact that the plant is far to one side of the runway path, over which aircraft would not be likely to travel.

Combining all the preceding terms, the probability of a potentially damaging crash was calculated:

$$P = D \times A \times M$$
$$= 0.96 \times 10^{-8}/\text{movement}/\text{mi}^2/\text{yr} \times 0.02\ \text{mi}^2 \times 2400\ \text{movements}$$
$$= 5 \times 10^{-7}\ \text{per year (considering both plants)}$$

CONCLUSIONS

Probabilities calculated in this manner are not intended to be precise values of probability with high confidence levels. Rather, they are intended to be upper bound estimates of the probability of an event which can be used to assess how seriously that event may affect the health and safety of the public. A probability less than 10^{-6} per year calculated by this conservative model, is considered acceptably low for a potentially damaging aircraft crash. Therefore, I consider the probability of 5×10^{-7} per year for a potentially damaging aircraft strike calculated for the Three Mile Island Nuclear Station acceptably low. I must emphasis that such a probability is not the probability of a major radiological accident but is rather only the probability of a potentially damaging aircraft strike. Having concluded that the calculated probability of 5×10^{-7} per year is acceptably low, I have further concluded that no arrangements were necessary to avoid flight patterns of heavy aircraft near or over the Three Mile Island plants.

No traffic growth prediction studies were performed because, in my judgement, the repeatedly conservative bases and the result calculated indicate that even a tenfold increase would not be critical. Moreover, I don't believe that the Harrisburg area, with a population in the range of a hundred thousand rather than millions, is likely to generate so great an increase for large size aircraft traffic in the future.

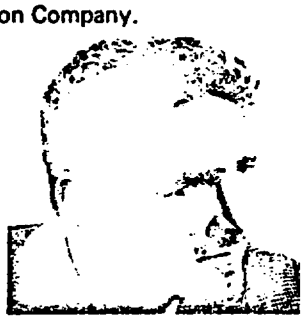
The aircraft hazard analysis was based on a heavy aircraft traffic of 2400 movements per year, about 20% greater than the current traffic, as well as the other conservative bases indicated. The applicant has agreed to monitor the airport traffic and report on it to the AEC at least annually. This is sufficient to detect changes important to the safety of the plant in time to permit appropriate consideration.

hazard prevention

JOURNAL OF THE SYSTEM SAFETY SOCIETY

volume 11 number 3
january/february 1975

DR. KENNETH ALVIN SOLOMON, (B.S. in Engineering at UCLA, 1971; M.S. in Engineering at UCLA, 1971; and Ph.D. in Engineering at UCLA, 1974), is currently a staff engineer in the Engineering and Consulting Division of NUS Corporation, Sherman Oaks, California. His special areas of interest include: General Risk Assessment, Methods of Probabilistic Safety Analysis, Nuclear Reactor Reliability, and Nuclear Reactor Kinetics. He is also a part-time post-doctorate scholar with UCLA. He was formerly a consultant to NUS Corporation, a director of Igor Bazovsky and Associates, a research engineer with Jet Propulsion Laboratories, and a nuclear engineer with Southern California Edison Company.



DR. DAVID OKRENT is professor of Engineering and Applied Science at the University of California, Los Angeles. He received an M.E. degree from Stevens Institute of Technology and the M.S. and Ph.D. (Physics) from Harvard University. Dr. Okrent worked at Argonne National Laboratory for twenty years, pioneering in fast reactor physics and safety. Dr. Okrent was a Guggenheim Fellow in 1961-62; is a Fellow of the American Physical Society and the American Nuclear Society; was a member of the U.S. delegation to all four Geneva Atoms for Peace Conferences; received the first Argonne Universities Association Distinguished Appointment Award in 1970; was chairman of the Math and Computations Division, ANS; currently is chairman of the ANS Technical Group for Nuclear Reactor Safety; and is a member of the USAEC Advisory Committee on Reactor Safeguards, having served as ACRS chairman in 1966.

AIRPLANE CRASH RISK TO GROUND POPULATION

By Kenneth Alvin Solomon and David Okrent

(The preliminary study was supported by the U.S. Atomic Energy Commission, Division of Research, under Contract No. AT(04-3)-34 P.A. 205 Mod. 2.)

ABSTRACT

Analysis of national aircraft accident statistics yielded an average value of 4 x 10-9 as the approximate probability, per square mile, per operation, of a crash within a five-mile radius of a typical airport. Taking into account the appropriate annual air traffic results in average values of 1.6 x 10-3 and 4 x 10-4 for the probabilities, per square mile, per year, of a crash averaged over the five-mile radial region for Los Angeles International Airport (LAX) and Hollywood-Burbank Airport (BUR), respectively.

Using these crash probabilities and considering both resident and transient populations, estimates of expected annual mortalities were 0.8 fatalities per year, per eighty square miles around LAX and 0.5 fatalities per year, per eighty square miles around BUR (this eighty square-mile region corresponds to about five-mile radius around the airport).

The study identified nine sites in the vicinity of LAX at which large numbers of people are frequently brought together. Maximum occupancies varied from several hundred to many thousands of persons. Probabilities of accidental aircraft impact while occupied, per year, per target site, varied from 1.6 x 10-6 to 3.5 x 10-4. Three of these sites were large sports facilities – analysis for one of them, Hollywood Park Race Track, is presented later in detail. The probability of an aircraft impact on Hollywood Park is estimated as 6.6 x 10-5 per year. The probability that such an accident will occur while the facility is occupied is estimated as 1.3 x 10-5. Maximum mortalities, based on capacity occupancy of 50,000 people and a hypothetical, direct impact by one of the largest aircraft in service, is estimated as 32,000 people; this is a much lower probability event than the average crash. It is estimated that the average crash into the grandstand during occupancy would result in 5,000-6,000 mortalities.

Twenty-five sites of frequent high occupancy in the vicinity of BUR were identified and investigated. Maximum occupancies vary from 450 to 5000 persons. Probabilities of impact while site is occupied vary from 2.8 x 10-7 to 4.0 x 10-5 per year, per target site.

The values derived in this study are based on extrapolated statistics from existing data on prior aircraft crashes in the vicinity of airports throughout the United States. The results stated in this study are subject to an element of uncertainty due to a variety of assumptions, one of which is that LAX and BUR are typical large airports.

INTRODUCTION

Air travel is one of the great conveniences of our time. Airline passengers are generally well aware of the hazards of flying and the accident record of aircraft. The risk involved is accepted in the decision to fly and willingly borne by the traveler. The general public may be less well aware of potential risks to population in the vicinity of airports, particularly with regard to low probability events with very high consequences.

High consequence events are made hypothetically possible by the patterns of land use which tend to appear near airports. Typically, airports have been located at some distance from urban centers but tied-in to the local transportation system with high volume access corridors. Access to transportation, among other factors, has made these areas attractive to developments such as sports facilities which tend to concentrate large numbers of people in a very small area. Thus, the existence of such facilities creates the possibility of an aircraft crash during full occupancy which would have severe consequences comparable to many other catastrophes.

The analysis gave detailed consideration to two specific airports: Los Angeles International (LAX), and Hollywood-Burbank (BUR). The environs of these airports were carefully surveyed to determine average local residential populations and to identify sites with frequent temporary high occupancy rates. Detailed analysis and computations were carried out to approximate crash probabilities, ranges of expected consequences in the event of crashes, and expected annual mortalities. LAX and BUR were selected for study because of their proximity to where the study was conducted. The values derived in this study are subject to an element of uncertainty due to the variety and degree of assumptions made.

METHODOLOGY

The methodology of this risk assessment was designed to meet the goal of providing a realistic analysis with an emphasis on low probability events with very high consequences. These events are the possible accidental impact of aircraft on facilities in which large numbers of people are gathered together at the time of impact. Realistic analysis of such events demands consideration of such factors as: probability of aircraft crash and its variation with geometric relationship to intended flight path; geometric relations between flight paths in use and sites with high consequence potential; patterns of population density near airports and their variation with time; and the probable structural damage and attendant threat to occupants resulting from an aircraft impact. Two specific airports were chosen for the analysis and consideration of the relevant factors was based upon currently prevailing conditions. The study required several distinct analyses which are presented in the next section.

It was necessary to identify the most important parameters affecting variation in the probability of aircraft impact and represent the effect of these parameters in a mathematical model. Relations were inferred from study of crash statistics, and the formulation and the calibration of the model is presented.

Detailed surveys were made of population densities and patterns in the vicinity of the airports. Sites with frequent high occupancy level included sports facilities, theaters, office complexes, shopping centers and industrial facilities. Population statistics also are presented.

Part of the next section is devoted to presentation of important characteristics of the two airports used for the study, LAX and BUR. Orientation of runways, day and night flight patterns and similar characteristics were considered in the analysis.

Determination of the probable physical damage to impacted structures is a complex problem. Relevant factors include size, velocity and impact angle of the aircraft as well as the strength of the structure impacted. Structural analysis was required to estimate the extent of physical damage in the event of an impact and hence, by inference, the relative number of fatalities and injuries to occupants. Methodology used in the analyses is presented. One case, Hollywood Park, is considered in detail as an illustration of the application of the method.

Finally, results of all the analyses were integrated to produce estimates of crash probabilities and expected casualties for the cases considered. These computations are illustrated for selected cases, and detailed results are tabulated for all cases considered.

Where data were unavailable, it was necessary to fill the deficiency by assumptions. One very important assumption is that LAX and BUR are typical, commercial United States airports.

ANALYSIS

SYMBOLS AND DEFINITIONS – Several functional relationships are developed in this analysis of aircrash probabilities:

$PT(r,z,\phi,\theta,t)$ = probability of a plane crash per target area,

$D_d(r,\theta,t)$ = peak population density,

$D_c(r,\theta,t)$ = continuous population density,

r = the distance from the crash point to the runway,

z = the height of a target structure,

ϕ = the glide crash angle,

θ = the angle defined by the landing or takeoff path and the line drawn from the runway to the crash point,

t = the time of day of the crash.

It has been shown that:

$PT(r,z,\phi,\theta,t) = (A''+A') \,.\, A_oR(r)\Theta(\theta)T(t) = (A''+A') \,.\, P(r,\theta,t)$ where:

$P(r,\theta,t)$ = probability of a plane crash per square mile,

$A''+A'$ = target area (TA) of structure (square miles) and is a function of z and ϕ,

$\Theta(\theta)$ = θ dependence of the aircrash probability (dimensionless),

$T(t)$ = the time dependence of crash probability,

$R(r)$ = functional dependence of crash probability on r (distance from runway).

ADDITIONAL SYMBOLS USED:

A = aircrash probability per square mile, averaged over the ten square miles immediately adjacent to the runway.

A_o = aircrash probability per square mile, averaged over the square mile concentric about $r=1$ mile and $\theta=0^\circ$.

A'' = base area (ab) of target structure, in square miles

A' = shadow area of target structure (in square miles).

$A'=(az)/\tan\phi$ where ϕ = glide angle, z = height of structure.

a,b = dimensions of base of target structure.

N = number of yearly aircraft operations.

$p(t)$ = total population in any region as a function of time.

$R_L(r)$ = the functional dependence of crash probability at a distance r from the touchdown point on the runway.

$R_T(r)$ = the functional dependence of crash probability at a distance r from the takeoff point on the runway.

d = destruction coefficient = the ratio of the number of mortalities in the structure to the total population of the target structure: $0 \leq d \leq 1$.

i = injury coefficient = the ratio of the number of injuries in the structure to the number of people in the structure: $0 \leq i \leq 1$, where $0 \leq d + i \leq 1$

SUBSCRIPTS:

c = continuous or average or residential population.

d = dicrete or peak or crowd population.

MATHEMATICAL MODEL OF AIRCRASH PROBABILITY – The probability that an aircraft will crash into a structure is a function of many variables. The calculation of crash probabilities is based on empirical data and historical records. An analytical expression for crash probability has been derived, based on observed dependencies of aircraft accidents on specific parameters, such as time of day, distance from the runway, etc. In the calculations the assumption has been made that all the parameters are independent and the probability equation is therefore separable.

The aircrash probability per year, per target area, is the product of Equation and N, the number of yearly overheat operations.

FUNCTIONAL DEPENDENCIES OF CRASH PROBABILITY – To determine the specific form of Equation it is necessary to establish the functional relation between crash probability and the various parameters in the equation (see Figure 1). This ha[illegible]one in a previous study by careful evaluation of [illegible] statistical data, and checking the derived models against observations.

θ-DEPENDENCE – The angle θ is the angle defined by the landing path and the line drawn from the runway to the crash point. Most previous methods used to calculate crash probabilities assumed essentially no θ-dependence. Statistics show, however, that the greatest probability for aircrash occurs when the aircraft is on the landing or takoff path. A recent study derived a functional relation for θ-dependence.

r-DEPENDENCE – The results of many surveys on airplane crashes indicate that crash probability increases (for landing) as the plane approaches the runway, and decreases (for takeoff) as the plane departs from the runway.

Specifically, the surveys show that it is about as likely for a plan to crash within five miles of the runway (while landing) as five or more miles away. But it is about two times more likely that the plane will crash one mile from touchdown than two miles from touchdown.

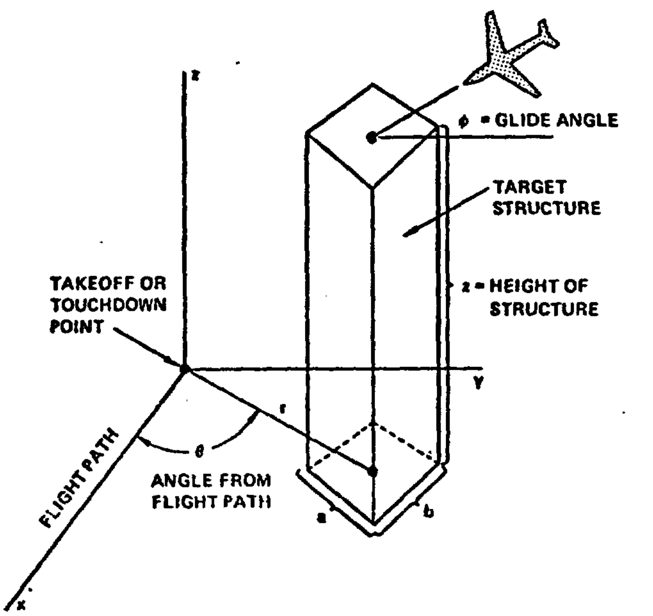
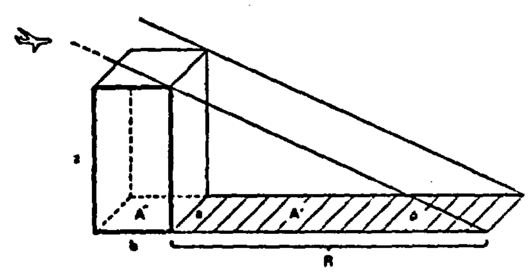


Figure 1. Spherical Coordinates Used to Calculate Crash Probabilites.

Other statistics indicate that, for takeoffs, the crash probability is about three times greater for one mile distance than for two miles. The functional relations for crash probability dependence on r, for takeoff and landing, inferred from statistical data, are derived in a previous study.

DEPENDENCE ON TARGET AREA AND GLIDE ANGLE, φ – The probability of an aircrash into a structure depends on the height of the structure (z), the base area of the structure (ab), and the glide crash angle of the plane (φ) (see Figure 2). If the height of the structure were zero, the crash probability would be proportional to the area of ground occupied by the structure. With zero height, any glide crash angle terminating outside this area would result in no impact with the structure. As the height of the structure increases, however, the likelihood of impact also increases. A line drawn parallel to the aircraft flight path, extending from the top of the structure to the ground, marks the limit of a shadow area (A'). Any glide path at this or a smaller glide angle that intersects the earth within this shadow area would result in impact with the structure. The height of a structure and its shadow area are thus both related to crash probability. For any given angle φ, a greater structural h[illegible] will give a larger shadow area (A'). The effective target area can be defined as the sum of the base area of the structure (A", = ab) and the shadow area (A' = az/tanφ). A previous study derived the φ-dependence.

TIME DEPENDENCE – An airplane is more likely to crash in poor weather than in good weather and is more likely to crash during the night than during the day. For the entire U.S., the vast majority of all air operations occurs during daylight hours. Approximately eighty percent of all air traffic accidents occur during daylight hours. The fact that any single flight is more likely to crash at night than during the day is considered a second-order effect, compared to the fact that many more flights occur during daylight hours.



B_o = AIRCRASH PROBABILITY FOR BASE AREA A" (ASSUMING NO BUILDING PRESENT)
B = AIRCRASH PROBABILITY FOR BASE AREA A" PLUS SHADOW AREA A'
A" = ab
A' = (az)/tanφ
φ = GLIDE ANGLE OF AIRCRAFT (ASSUMED φ = 20° UNLESS STATED OTHERWISE)
B = B_o(A" + A')/A"
φ=5° B = 3.8 B_o for z = 75 FT AND b = 1/16 MILE ~ 330 FT
φ=20° B = 1.7 B_o for z = 75 FT AND b = 1/16 MILE ~ 330 FT
A" + A' = TARGET AREA

Figure 2. Calculation of Aircrash Probability, B, as a Function of Height of Structure, z, and Angle of Glide of Aircraft, φ.

The time dependence of aircrash probabilities derived in this study is based on accident statistics, and is empirical. As an example of the technique employed, consider the probability of an aircrash into Hollywood Park, near Los Angeles Airport (LAX).

Daylight in Los Angeles (in summer) extends from approximately 5:30 a.m. to about 7:30 p.m. and in winter, about 7:30 a.m. to about 5:30 p.m. Hollywood Park is occupied about one third of the year (late spring into early summer) and is crowded with people from about 10 a.m. to about 6 p.m. The Park, when open, is thus occupied during 70-75 percent of the total daylight hours. Hence, if it is assumed that Hollywood Park is involved in an aircrash accident, the probability that the Park is crowded at the time of the accident is:

(1/3 of year) x (80% of accidents during daylight) x 75% chance that Park is open during the day) = approximately 20%.

Since the Park sometimes has dusk and night events, there may be a total of about a 25 percent chance that a plane would crash into the Park while it is occupied. The twenty percent figure has been used for calculations involving Hollywood Park, in this study. The above empirical method was used in calculating the time dependence of crash probability for other crash points.

This twenty percent probability will be referred to as a twenty percent capacity factor relative to overhead flights (i.e., the Park has about a twenty percent chance of being crowded when there is an overhead or nearly overhead flight).

NORMALIZATION COEFFICIENT A_o – A_o is the open field crash probability, per square mile, per operation, concentric about the square mile where r = 1 mile and θ = 0°. The average value for A_o, calculated for all commercial airports in the U.S., for 1[illegible]72, is approximately 1.5 x 10-7 per flight, per square mile.

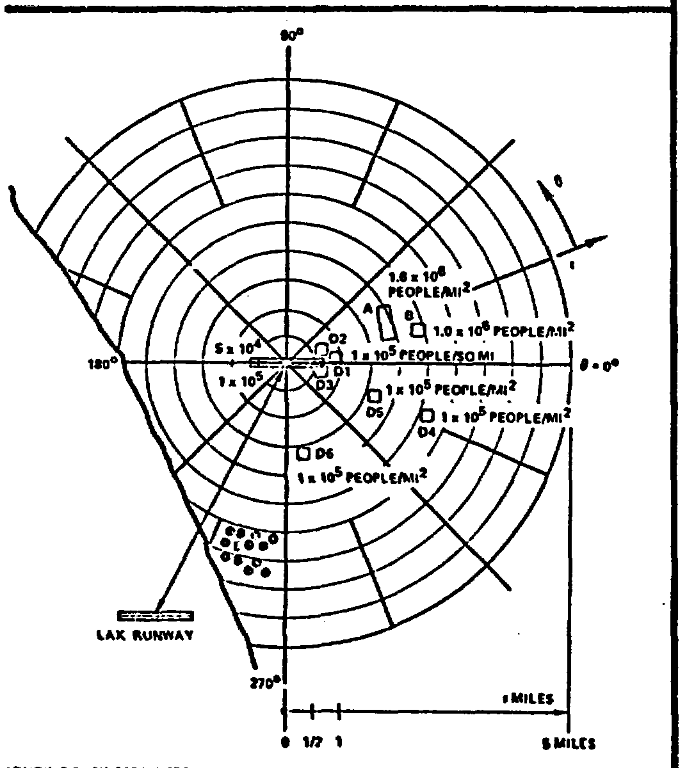
COEFFICIENT A – A is the open field crash probability, per operation, per square mile, averaged over the ten square miles immediately adjacent to the runways, where $0.5 < r < 1.5$ miles and $0° < \theta < 360°$. A has been calculated for the years 1965-1972 (inclusive), and is estimated to be 2.0 x 10-8 per flight, per square mile.

POPULATION DENSITY – The location of any point relative to the location of the runway can be described by spherical coordinates. Consider the center of coordinates to be the touchdown point on the runway; then any other point can be located by knowing r, the distance from the touchdown point of the landing plane to the point of interest; θ, the angle inscribed by the landing path and a line drawn from the point of interest to the touchdown point; and t, the time.

The population density, $D(r,\theta,t)$, is not only a function of position, (viz, r,θ), but also of time of day or week, (viz, t), since people change their location throughout the day. The total population density can be defined by $D(r,\theta,t)$. Then, the total population per region at time t is defined by $p(t)$ where the region of interest is the area defined by $a \leq r \leq b$, and $0 \leq \theta \leq 2$. In particular:

$$p(t) = \int_0^{2\pi}\int_a^b D(r,\theta,t)\,r\,dr\,d\theta$$

In order to calculate $D(r,\theta,t)$ we must divide our analysis into two parts. In the first analysis, we must consider those areas that are very highly populated, (e.g., race tracks, baseball stadiums, theaters, shopping centers, and so on). These areas are usually very heavily populated only at certain times. Let us define these areas of very high density population as $D_d(r,\theta,t)$, where the subscript d stands for discrete point. $D_d(r,\theta,t)$ is obtained from aerial photographs, maps and by surveying the area by car for areas of high population density (see Figure 3). Table 1 lists the high population density areas for such points as Hollywood Park, The Forum, office buildings and various other locations.



*DURING BUSINESS HOURS

SEE TABLE ? FOR LETTER KEY

CENTER OF RUNWAY AT r = 0 MILES, LAX AIRPORT

Figure 3. High Population Density, $D_d(r,\theta,t^*max)$, People/Square Mile Adjacent to LAX

Point of Interest	Total Population at Point p(t), People	Reference	Population Density at Point, People/Sq. Mile	r (Miles)	[illegible]	θ (Degrees)	Time When Most People Are Present
A Hollywood Park	50,000	(13,17)	1.6×10^6	2	75	10	[illegible]
B Forum	16,000	(11,18)	1.0×10^6	2	60	60	[illegible]
C [illegible]	80,000	(13)	1.6×10^6	8 1/2	45	[illegible]	[illegible]
D Office Complex 1	2,000	(13,14,18)	1.0×10^5	1	120	0	
2	1,000	(13,14,18)	5.0×10^4	1/2	30	80	[illegible]
3	3,000	(13,14,16)	1.0×10^5	1/2	[illegible]	[illegible]	[illegible]
4	4,000	(13,14,16)	1.0×10^5	2 1/2	[illegible]	[illegible]	[illegible]
5	[illegible]	(13,14,16)	1.0×10^5	1 1/2	100	[illegible]	
6	3,400	(13,14,16)	1.0×10^5	1 1/2	[illegible]	[illegible]	
E [illegible]	[illegible]			3	[illegible]	[illegible]	

TABLE 1. High Population Density Areas, $D_d(r,\theta,t)$ Adjacent to LAX

Areas of high population density are usually about .01 to .06 square miles in target size and could have a value of $D_d(r,\theta,t)$ from about 50,000 people per square mile up to almost 2,000,000 people per square mile.

From Cornell's formula, the simple model to calculate the distance that an airplane travels across the ground from the point of impact to the point where the plane stops (assuming there are no obstructions in its path), is given by the effective scabbing distance, X_{eff}:

$$X_{eff} = (6.3 \times 10^{-6})\left(\frac{V_o^2}{K}\right) \text{ miles,}$$

where V_o is the crash velocity of the plane and K is a velocity dependent parameter.

For V_o = 400 mph, then K = 4 and X_{eff} = 0.2 miles and

For V_o = 500 mph, then K = 1.5 and X_{eff} = 0.8 miles.

The scabbing area (in square miles) is assumed equal to the wingspan of the aircraft (in fractions of a mile) times the scabbing distance in miles.

Fuel is ejected from the crashed plane at V_o miles per hour and in general is ejected a distance somewhat greater than the effective scabbing distance, Xeff.

The average population density, $D_c(r,\theta,t)$ is determined from surveys of residential areas. Figure 4 graphs $D_c(r,\theta,t)$ for 12 midnight. From 6 p.m. to 6 a.m. one would expect $D_c(r,\theta,t)$ to be at its maximum, since the family members are most likely to be at home. $D_c(r,\theta,t)$ is assumed to decrease by a factor of one half during daylight. When calculating $D_c(r,\theta,t)$ the values of $D_d(r,\theta,t)$ were of course not averaged into the results.

$D_d(r,\theta,t)$ is usually many times larger during the day since people come in from other parts of the city to work and go to sports events. There are many more flights during the day than at night. The population density of people per square mile for peak population areas in the vicinity of BUR has been derived. There have been 25 strategic points determined. The maximum total population at each of those points has been determined as well.

The average (or residential) population density of people per square mile as a function of location for the eighty square miles isotropic about BUR runway at a time (6 p.m. to 6 a.m.) when the largest number of people are present has been determined.

The population density (both discrete and continuous) varies between 0 people per square mile (on the runway) to over 10,000 people per square mile.

DESCRIPTIONS OF LOS ANGELES INTERNATIONAL AND HOLLYWOOD-BURBANK AIRPORTS – The Los Angeles International Airport (LAX) is located near Inglewood, California, about fifteen miles WSW of downtown

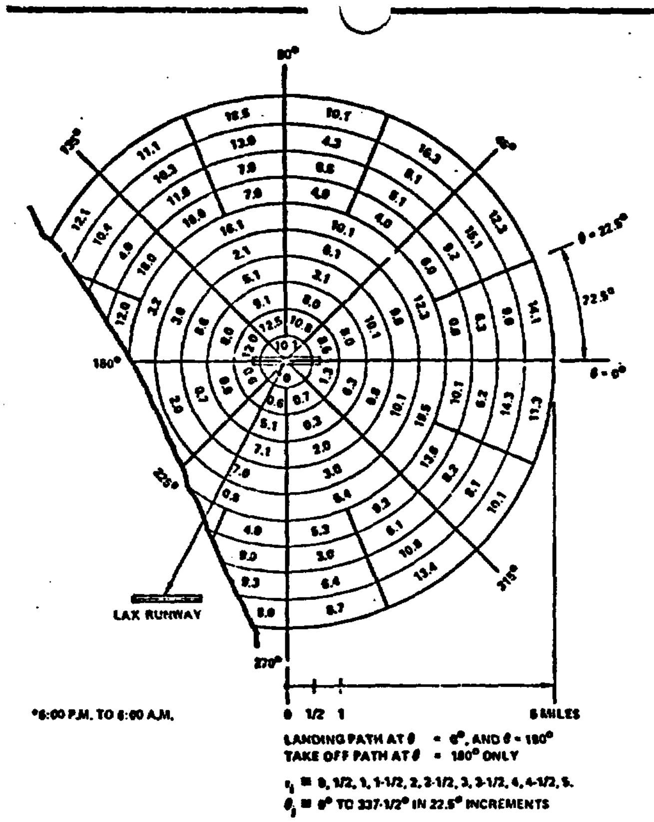


Figure 4. Population Density, Dc(r,θ,t*max), (1000's of People /Square Mile) for (ri,θj). Adjacent to LAX

Los Angeles. The center of geographical coordinates of LAX is at longitude 118°32' 30" W and latitude 34°01' 15" N. There are approximately 400,000 to 500,000 operations per year at LAX. In the calculations of this study 400,000 operations were assumed.

Hollywood-Burbank Airport (BUR) is located approximately four miles NW of Burbank, California. The geographical coordinates are longitude 118°21' 25.5" W and latitude 34°12' 5.7" N. The elevation of the airport is 775 MSL.

STRUCTURAL DAMAGE DUE TO AN AIRPLANE CRASH AND CALCULATION OF DESTRUCTION COEFFICIENT – The purpose of this section is to determine how much damage is done to a structure when an airplane is postulated to hit it and, in particular, to calculate a destruction coefficient. The destruction coefficient, d is defined as the ratio of the number of mortalities when the target structure is struck to the total number of people in the structure at the time. Of course, the destruction coefficient, d, has a numeric value between zero (no mortalities) and one (all people in the structure are mortalities). Other coefficients can be calculated also; the injury coefficient, i, is defined by the ratio of the number of people injured to the total number of people in the structure. Clearly, $d + i \leq 1$ where r_0, ϕ_0 and θ_0 represent a fixed location and t_0 is a particular time. The monetary damage can be described in terms of a monetary damage coefficient, m, which is assumed to be equal to the numeric value of the destruction coefficient d, where m varies between 0 and 1 and represents the percent of the total worth of the structure that is destroyed.

Most data on structural damage are obtained from two fundamental sources. The first source is papers on military projectile damage due to bullet-like projectiles. Unfortunately, some problems result in scaling up the dimensions of bullets to the dimension of aircraft and scaling down the mass and velocity of bullets to the mass and velocity of aircraft. The second source of information is a group of studies on aircraft impact into nuclear reactor buildings. The scaling problem here arises because nuclear reactor containment structures are much stronger than grandstands or office building structures.

Initially an analytic model is developed to represent the accident involving an airplane and a structure. Structural size, structural type, airplane size, airplane type and amount of fuel on the airplane are all use as parameters in the analytic model. A collision glide angle of 20° is assumed. The analytic model is then applied to the structures in the area surrounding LAX and BUR airports.

In order to develop the analytic model, it is important to consider three modes of structural damage when an airplane strikes a target structure. The first type of damage is identified as the performation mode, where the aircraft perforates the structural component upon impact. The second type of damage is caused by a collapse mode, where the structural member yields considerably at all restraints. The load corresponding to the collapse mode is obtained by using yield line theory. In this mode of damage, the structural component loses all of its integrity, and the falling debris from the aircraft or structure may enter the structure. The third type is identified as the cracking mode, where the concrete of the structure cracks under impact. The loads corresponding to this mode are obtained by making use of elastic analysis. Thus, the load obtained by using this criteria will not cause extensive deformations. In this mode of damage only one portion of the structure reaches the ultimate moment capacity and thus the structure as a whole may still have considerable reserve capacity to counteract the load.

Depending on the function of the structure (i.e., whether it is a grandstand, a building or an oil storage area), one might be interested in evaluating the perforation mode, collapse mode or cracking mode of damage.

AIR OPERATIONS – About one third of the 400,000 yearly operations at LAX involve either 747s, L-1011s or DC 10s. The remainder of the operations involve medium size commercial airliners such as 707s and 727s. At Burbank all operations involve 707 and 727 size airplanes and smaller planes. When a plane is taking off, it carries more fuel than when it is landing, and thus it is far more likely to cause a large fire if a crash occurs on takeoff.

At LAX there are 400,000 operations per year and about half are over land. There are about 100,000 operations at Hollywood-Burbank Airport; all are over land.

IDEALIZATION OF AIRCRAFT AS A PROJECTILE – It is known that the weight of the engine or engines of the aircraft is proportional to the weight of the entire aircraft. Most airplane penetration data are expressed in terms of engine weight rather than aircraft weight. For very small aircraft (four passengers or less), the fuselage offers little resistance upon impact and the majority of the structural damage is done when the engine hits the target area.

In this study, for the purposes of computation of perforation thickness, only the engine weight is used. It is believed that the damage obtained using the momentum, mass and energy of the engine (or engines) and scaling up to the momentum, mass and energy of the aircraft give more conservative results than those obtained by using the characteristics of the fuselage.

CALCULATION OF DESTRUCTION COEFFICIENT: d – The destruction coefficient is determined for various types of structures (grandstands, oil tanks, office building, theaters, apartment buildings and shopping centers) by integrating the methodology discussed above.

Since the velocity of an airplane is essentially constant within five miles of an airport, the destruction coefficient is a function only of the type of plane, the type of structure hit, and the mode of flight at the time of the crash. The destruction coefficient is normalized to have a maximum value of 1; d=1 implies that the entire structure is demolished and all the people in the structure are killed. A value of 0.50 implies that only half the people are fatalities when the plane hits the structure, and so on. Of course, a plane that is taking off contains more fuel than one that is landing, so a crash of a plane taking off could cause more serious fire damage.

The destruction coefficients are used to calculate the number of mortalities per year due to airplane crashes within a five-mile radius of LAX and BUR.

A recent study illustrates how to calculate the destruction coefficient, d, for the most serious possible air crash over Hollywood Park. The method is applied to all structures near both LAX and BUR and the destruction coefficients are listed in Table 2.

The destruction coefficients listed in Table 2 are average upper bound values. A ninety percent confidence interval can be calculated to be approximately $1/2d < d_{approx.} < 2d$.

In other words, with ninety percent certainty, a 747 crashing into Hollywood Park while attempting to take-off will have a destruction coefficient between 0.10 and 0.40. The possibility of d being 0.63 (maximum upper bound for d for Hollywood Park) is very slight.

CALCULATION OF THE NUMBER OF GROUND MORTALITIES DUE TO A POSTULATED AIRCRAFT CRASHES NEAR LAX – The number of yearly fatalities, F, on the ground, as a result of aircrash is equal to the product of: 1) the crash probability per operation per square mile, 2) the target area in square miles, 3) the average destruction coefficient for the structure or structures in the target area, 4) the number of overhead or near overhead yearly operations, and 5) the total population in the target structure or structures.

Type of Airplane	Private Home	Small Apartment House	Large Apartment House	Destruction Office Building	Coefficient Shopping Center	Theaters [illegible]	Hollywood Park Grandstands	Forum	Coliseum	Approx. of Affected Area (sq. ft.)	[illegible]
Plane Landing											
Small private or shuttle type	1.00	0.90	.40	0.05	0.03	0.35	0.04	0.08	0.08	3.0x10 4	(a)
Medium 707, 727	1.00	1.00	1.00	0.20	[illegible]	0.80	0.08	0.16	0.14	6.0x10 5	(b)
747, DC10	1.00	1.00	1.00	.80	0.08	0.96	0.10	0.29	0.13	9.0x10 5	(c)
Plane Taking Off											
Small private or shuttle type	1.00	0.75	1.00	0.37	[illegible]	0.37	0.05	0.12	[illegible]	5.0x10 4	(a)
Medium 707, 727	1.00	1.00	1.00	0.40	0.11	0.96	0.12	0.24	0.21	8.0x10 5	(b)
747, DC10	1.00	1.00	1.00	0.75	0.16	1.00	0.29	0.30	0.19	7.0x10 6	(d)

Notes
(a) Navy airplane crash, March 1973 near San Francisco. Also private plane crashes in L.A. 1968-1973.
(b) References 1, 2, 3, 4, 5, 6
(c) Russian SST crash, Paris air show, June 1973
(d) [illegible]

Table 2. Destruction Coefficient, d, for a Direct Hit.

APPLICATION OF METHOD TO NUMBER OF MORTALITIES FOR STRATEGIC TARGET AREAS NEAR LAX – Table 3 summarizes the number of mortalities at Hollywood Park assuming a direct hit by a jumbo plane to the center of mass of the grandstand. The grandstand and adjacent areas are considered to contain the maximum number of people (about 50,000).

The majority of all operations over Hollywood Park are landing operations. The probability of a plane crashing into the square mile area adjacent to Hollywood Park (while landing) is 1.1 x 10-8 per operation, per square mile. Assuming that the target area size of Hollywood Park is .03 square miles and that 200,000 landing air operations per year at LAX pass over or adjacent to Hollywood Park, then the probability that a landing airplane of any commercial size will crash into the Hollywood Park target area, per year, for all operations in a year is:

$$(.03)(200,000)(1.1 \times 10^{-8}) \cong 6.6 \times 10^{-5}.$$

The value of crash probability of 6.6 x 10-5 per target area, per year, for all landing operations is averaged for all types of aircraft. Since about one third of all operations at LAX involve either DC-10s, L-1011s, or 747s, (i.e. Jumbo Jets), then the air crash probability for all DC-10, L-1011 and 747 operations per year, per target area, at Hollywood Park is (1/3) (6.6 x 10-5)≅2.2 x 10-5. The remaining operations involve smaller 4.4 x 10-5 for the target area at Hollywood Park. Since there are about 200,000 yearly landing operations over Hollywood Park and only about 1,000 to 3,000 yearly takeoff's over the Park, then the probability of a plane crashing into the park while landing is about two order of magnitude greater than while taking off.

$$\left(\begin{array}{c}\text{Probabilities of crash}\\ \text{per year for a 747, L 1011, or}\\ \text{DC 10 into Park while park is}\\ \text{crowed}\end{array}\right) \times \left(\begin{array}{c}\text{Number of mortal-}\\ \text{ities per hit of}\\ \text{747, L 1011, and}\\ \text{DC 10.}\end{array}\right) = \left(\begin{array}{c}\text{Expected number of}\\ \text{mortalities per year}\\ \text{due to 747's, L 1011's}\\ \text{and DC 10's}\end{array}\right)$$

	landing	takeoff	landing	takeoff	landing	takeoff
direct hit	0.2×10^{-6}	0.5×20^{-8}	21,600	31,500	4.3×10^{-3}	1.5×10^{-5}
average hit	4.2×10^{-6}	0.3×10^{-7}	6,000	10,000	2.4×10^{-3}	3.0×10^{-4}
					6.7×10^{-3}	3.2×10^{-4}

Using similar methods, the mortalities due to all plane crashes was estimated.

Table 3. Expected Number of Mortalities per Year at Hollywood Park Due to L 1011's, DC 10's or 747's Hitting the Park While the Park is Occupied.

The expected yearly mortality rate due to potential plane crashes into Hollywood Park is about 4.9 x 10-2 for all size aircraft and about 6.7 x 10-3 for just jumbo jets.

Figure 5 compares the probability of an aircrash into Hollywood Park, per year, when the Park is occupied with the expected mortality toll per crash. For calculation purposes it is assumed that the park holds 50,000 people at the time of the crash. The comparison is made for an average crash and for the most serious direct hit.

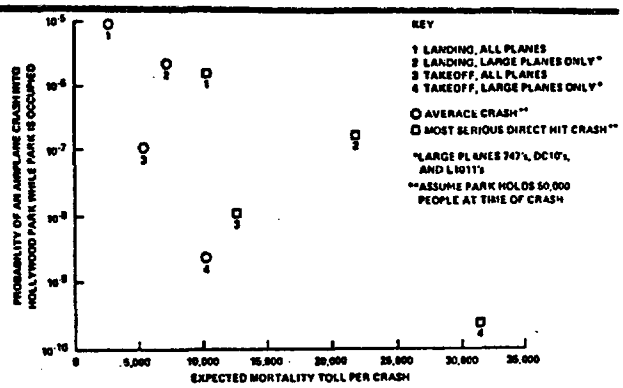


Figure 5. Probability of an Airplane Crash Into Hollywood Park Per Year While Park is Occupied Versus Expected Mortality Toll per Crash.

Table 4 lists the probability of planes crashing into other strategic points and the average number of mortalities per year as a result.

The average crash probability is 4.0 x 10-9 per operation, per square mile within a five-mile radius of LAX. The average crash probability within a five-mile radius of LAX for all operations is 16 x 10-4 per square mile. The average population density for the eighty square miles isotropically surrounding LAX is 4.7 x 103 people per square mile. The average destruction coefficient is assumed to be equal to 0.1 and the effective scabbing area for an average crash is assumed to be 0.013 square miles. Hence, the expected yearly mortality in the eighty square miles isotropically surrounding LAX is:

$$\left(\frac{1.6 \times 10^{-3}}{\text{year mi}^2}\right) \times \left(\frac{4.7 \times 103 \text{ people}}{\text{mi}^2}\right) \times (80 \text{ mi}^2)(0.1)(0.013 \text{ mi}^2 \text{ effective scabbing area})$$

$\cong 0.8$ people in entire 80 square mile area per year

RESULTS FOR HOLLYWOOD-BURBANK AIRPORT – The crash probabilities and mortalities per year calculated by the same methods for Hollywood-Burbank Airport are summarized in Table 5. When the consequences are summed over all targets, it is estimated that the expected annual mortalities to ground population arising from commercial airline crashes within a five-mile radius of Burbank is 0.5 fatalities per year.

LOCATION r (miles)	STRATEGIC POINT θ (0 From Flight Path)		PROBABILITY OF PLANE CRASH FOR ALL OVERHEAD OPERATIONS, FOR TARGET AREA, PER YEAR, WHILE OCCUPIED	AVERAGE NUMBER OF MORTALITIES PER YEAR AT SITE
2	10	Hollywood Park	1.3×10^{-5} †	$(4.1 \text{ to } 7.0) \times 10^{-3}$
2	10°	Forum	1.0×10^{-5}	$(1.0 \text{ to } 2.0) \times 10^{-3}$
8 1/2	45°	Coliseum	1.2×10^{-6}	$(3.0 \text{ to } 6.0) \times 10^{-5}$
		Office Building Complex*		
1	0°	(1)	3.5×10^{-4}	$(6.1 \text{ to } 7.0) \times 10^{-6}$
1/2	10°	(2)	4.6×10^{-5}	$(5.8 \text{ to } 6.3) \times 10^{-6}$
1/2	3°	(3)	4.6×10^{-5}	$(5.3 \text{ to } 6.0) \times 10^{-6}$
2 1/2	340°	(4)	3.1×10^{-5}	$(2.8 \text{ to } 5.1) \times 10^{-6}$
1 1/2	270°	(5)	2.0×10^{-6}	$(2.0 \text{ to } 8.0) \times 10^{-6}$
1 1/2	280°	(6)	3.8×10^{-6}	$(1.8 \text{ to } 4.0) \times 10^{-6}$
3	260°	Oil Refinery**	1.6×10^{-6}	$(1.0 \text{ to } 1.8) \times 10^{-7}$

(1) Sheraton Hotel (10 stores plus three other smaller buildings (96th St. and Aviation Blvd.)

(2) Many small stores, markets, and a bank (Sepulveda Blvd and Manchester Blvd.)

(3) Two buildings (one is 6 stories and one is 15 stories) (Airport Blvd. & Century Blvd.)

(4) Several large buildings (Crenshaw Blvd. and Imperial Blvd.)

(5) Hughes building ten stories (Imperial Blvd. and Sepulveda Blvd.)

(6) Airport Blvd. (10 stories and Medical Building (13 stories)

* See map to identify location of office buildings

** People die as a result of inhalation of fumes due to fire in oil and gasoline tanks.

*** Multipuly by the number of operations per year and target area size to get the total yearly aircrash probability per target area

† For Hollywood Park Crash Probability per target area for the entire year (occupied or not) is 6.6 x 10-5 – most overhead flights occur during Hollywood Park busy hours. For the Coliseum the crash probability per target area for the entire year is 7.0 x 10-7 since many Coliseum events are during non-peaked air traffic times (after sundown), the probability that an airplane crashes into the Coliseum while people are at the Coliseum is 1.2 x 10-6 for all 200,000 yearly, overhead landing operations.

Table 4. Likelihood of Crash and Number of Mortalities per Year for Strategic Points Near LAX.

LOCATION r miles	θ degrees	STRATEGIC POINT	PROBABILITY OF A PLANE CRASH FOR ALL OVERHEAD OPERATIONS, FOR TARGET AREA OF INTEREST, PER YEAR, WHILE THE TARGET STRUCTURE IS OCCUPIED	AVERAGE NUMBER OF MORTAILITIES PER YEAR AT STRATEGIC POINT
4.75	227	1. Mayfair Shopping Center	4.8×10^{-7}	$(3.3 \text{ to } 6.3) \times 10^{-6}$
3.80	227	2. Shopping Center	8.1×10^{-7}	$(7.3 \text{ to } 9.8) \times 10^{-6}$
2.10	260	3 McCambridge Recreation	1.8×10^{-6}	$(1.1 \text{ to } 3.2) \times 10^{-4}$
3.65	260	4. Burbank H.S.	8.4×10^{-7}	$(7.5 \text{ to } 9.6) \times 10^{-4}$
2.35	245	5. Bank/Markets	1.8×10^{-6}	$(1.2 \text{ to } 3.3) \times 10^{-4}$
1.80	227	6. Market	4.8×10^{-6}	$(3.3 \text{ to } 6.3) \times 10^{-6}$
1.25	215	7. Market	9.3×10^{-6}	$(7.8 \text{ to } 1.6) \times 10^{-5}$
0.80	100	8. Shopping Center	4.0×10^{-5}	$(2.5 \text{ to } 4.9) \times 10^{-3}$
1.40	100	9. Market	2.8×10^{-5}	$(2.1 \text{ to } 3.6) \times 10^{-4}$
1.80	100	10. Stores	10.2×10^{-6}	$(9.3 \text{ to } 13.7) \times 10^{-5}$
2.20	100	11. Valley Plaza Center	8.5×10^{-6}	$(7.6 \text{ to } 9 \times 10^{-3}$
3.20	100	12. Coldwater Shopping	4.8×10^{-6}	$(3.3 \text{ to } 6.3) \times 10^{-3}$
3.60	100	13. Many Stores	2.8×10^{-6}	$(2.1 \text{ to } 3.6) \times 10^{-5}$
4.20	100	14. Apt. Bldgs.	1.6×10^{-6}	$(1.9 \text{ to } 3.4) \times 10^{-4}$
3.70	85	15. Many Stores	3.4×10^{-6}	$(2.8 \text{ to } 3.9) \times 10^{-5}$
3.85	85	16 Shopping Center	3.3×10^{-6}	$(2.7 \text{ to } 3.8) \times 10^{-3}$
2.75	70	17 Many Stores	12.7×10^{-6}	$(11 \text{ to } 14) \times 10^{-4}$
2.20	80	18. Apt. Bldg	12.7×10^{-6}	$(11 \text{ to } 14) \times 10^{-4}$
2.20	67.5	19 Laurel Plaza May Co.	4.8×10^{-6}	$(3.3 \text{ to } 6.3) \times 10^{-3}$
2.45	120	20 Temple-Market	8.5×10^{-7}	$(7.6 \text{ to } 7.9) \times 10^{-5}$
3.25	125	21. Shopping Center	1.8×10^{-7}	$(2.1 \text{ to } 3.6) \times 10^{-4}$
2.80	120	22 Temple	7.5×10^{-7}	$(6.4 \text{ to } 8.1) \times 10^{-6}$
3.70	115	23 Market	3.8×10^{-7}	$(3.1 \text{ to } 4.4) \times 10^{-5}$
3.45	110	24 Shopping Center	2.8×10^{-7}	$(2.1 \text{ to } 3.6) \times 10^{-4}$
3.30	140	25. Theater	2.8×10^{-7}	$(2.1 \text{ to } 3.6) \times 10^{-5}$

sum equals total number of mortalities per year at high population density points

Table 5. Likelihood of Crash and Number of Mortalities per Year for Strategic Points Near Hollywood Burbank Airport.

CONCLUSIONS

National aircrash statistics lead to an estimate of 4 x 10-9 as the probability of a crash, per square mile, per operation, within a five-mile radius of an airport. For Los Angeles International Airport (LAX), and Hollywood-Burbank Airport (BUR), the probability of a crash, per square mile, (within a five-mile radius) per year is 1.6 x 10-3 and 4.0 x 10-4 respectively (due to the large number of operations at the airports). Expected mortalities within the five-mile radius based on these estimates are 0.8 and 0.5 per year, LAX and BUR, respectively.

Dense population sites (such as Hollywood Park) contain large crowds at peak time and the probability of a crash into such a site, per year, while the Park is occupied is 1.3 x 10-5. If the Park contained 50,000 people at the time of the hypothetical crash, the maximum mortality figure expected is 32,000. An average crash while the Park was occupied is expected to result in 5,000 to 6,000 mortalities.

LIST OF PUBLICATIONS AND PRESENTATIONS (cont'd)
By: Kenneth A. Solomon

PRESENTATIONS

19. SMIRT Conference, London Imperial College, September 1, 1975, "Weld Inspection Procedures".

20. ANS Conference, New Orleans, Louisiana, June 11, 1975, "CACS Reliability in the HTGR".

21 RAMS Conference, Washington, D. C., January 29, 1975, "Contingency System Optimization for Nuclear Power Plants".

22. ANS Student Conference (Best Paper Award), University of Idaho, Pocatello, Idaho, April 1972, "Nuclear Reactor Stability".

ACCEPTED FOR PUBLICATION OR PRESENTATION

23. "Reliability of the Core Auxiliary Cooling System" to Nuclear Engineering and Design.

24. "General Risk Assessment" to Hazard Prevention Journal, D. M. Layton, Editor.

25. "Hazard of Meteorites to Nuclear Reactors", to Hazard Prevention Journal, D. M. Layton, Editor

26. "Risk of the Chemical Industry", to Hazard Prevention Journal, D. M. Layton, Editor.

LIST OF PUBLICATIONS AND PRESENTATIONS

By: Kenneth A. Solomon
April 1975

PUBLICATIONS

1. Transactions, 3rd International Conference on Structural Mechanics in Reactor Technology, (SMIRT), London, Imperial College, September 1975, "Weld Inspection Procedures", by K. A. Solomon, D. Okrent and W. E. Kastenberg.

2. Transactions, American Nuclear Society (ANS) Conference, New Orleans, Louisiana, June 1975, "CACS Reliability in The HTGR", by K. A. Solomon, D. Okrent and W. E. Kastenberg.

3. "Development of Flaws in Nuclear Reactor Pressure Vessel Welds", by K. A. Solomon, D. Okrent and W. E. Kastenberg, UCLA-ENGR 7496, February 1975.

4. "Prediction of Core Auxiliary Cooling System Availability and Reliability", by K. A. Solomon, D. Okrent and W. E. Kastenberg, UCLA-ENGR 7495, February 1975.

5. "Airplane Crash Model", by K. A. Solomon and D. Okrent, Hazard Prevention Journal, Volume 11, No. 3, Jan/Feb. 1975, D. M. Layton, Publisher.

6. "Estimates of Hazards to Nuclear Reactors from Random Impact of Meteorites", by K. A. Solomon, R. C. Erdmann and D. Okrent, Nuclear Technology, January 1975.

7. Transactions, 1975 Annual Reliability and Maintainability Symposium, (RAMS), Washington D. C., January 1975, "Contingency System Optimization for Nuclear Power Plants", by I. Bazovsky and K. A. Solomon.

8. "Risk Benefit Study", UCLA/NSF grant, contributing author to Quarterly Reports, June, 1973 to present.

9. "Nuclear Power Plant Reliability", by K. A. Solomon, Ph. D. Dissertation, UCLA, School of Engineering and Applied Science, December 1974.

10. Contributed to AEC Study WASH 1400, "Reactor Safety Study", June 1974.

11. "Potential Hazards to a Nuclear Reactor from the Random Impact of Meteorites", by K. A. Solomon, R. C. Erdmann, T. E. Hicks, and D. Okrent, UCLA-ENG-7426, March 1974.

12. "The Risk of Catastrophic Spills of Toxic Chemicals", by J. A. Simmons and R. C. Erdmann, edited by K. A. Solomon et al., UCLA-ENG-7425, March 1974.

13. "Airplane Crash Risk to Groung Population", by K. A. Solomon, T. E. Hicks, R. C. Erdmann and D. Okrent, UCLA-ENG-7424, March 1974. – Available from MRS. Betty Hillman, UCLA Engr. Reports GROUP, Boelter Hall – UCLA, L.A. 90024

14. "MHD topping Cycles", Jet Propulsion Laboratory Report, JPL 1200-59, May 18, 1973.

15. Transactions, ANS Calculational Physics Topical Meeting, University of Michigan, Ann Arbor, Michigan, April 1973, "Fault Tree Analysis of Reactor Safety Systems with Application to the Residual Heat Removal System of a BWR", by R. C. Erdmann, D. Okrent, P. Godbout, and K. A. Solomon.

16. Transactions, Western-Midwestern Meeting of the student branches of the ANS, Pocotello, Idaho, April 1972, "Nuclear Reactor Stability".

17. "Linear Stability of Fast and Thermal Reactors", by K. A. Solomon and W. E. Kastenberg, Nuc. Sci. & Engr.: 49:99-108, 1972.

18. "Methods of Determining Oscillations and Linear Stability of a Nuclear Reactor using Space Dependent Kinetics", M. S. Thesis, UCLA, School of Engineering and Applied Science, September 1971.