Statistical Analysis of Several Terminal Area Traffic Collision Hazard Factors

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An 11 hr sample of air traffic, comprising 584 tracks recorded at Atlanta during peak periods of August 1967, is analyzed to examine the statistical characteristics of range-guard intrusions and airspace conflicts in a terminal area. The number of intrusions (of an imaginary 3-naut mile, 500-ft range guard surrounding each aircraft) and number of conflicts (of the projected airspace for two aircraft) for a track exhibit Poisson variations with track duration. The hourly rate of intrusions follows the gas model square-law variation with traffic density, but the hourly conflict rate, contrary to the gas model, decreases with greater traffic density.

1. Introduction

IN this paper, an 11-hr sample of aircraft flight tracks from the Atlanta terminal area, is analyzed with respect to aircraft range-guard intrusions and airspace conflicts.†

To warn a pilot of possible airspace conflicts, pilot warning indicators (PWI) are under development.[5] Computer-aided displays are being considered to indicate airspace conflicts to an air-traffic controller and/or pilot.[6] But for evaluating air traffic equipment, as well as operations, the analyst is lacking a verified model of airspace conflicts for air traffic.

Studies of airspace conflicts, lacking track data, have been forced to postulate the so-called gas model wherein aircraft speeds and headings are assumed to be planar random. As pointed out by Raisbeck et al.[7] this assumption is unrealistic because air traffic in both space and time is highly nonuniform.

In Refs. 1–3, and elsewhere, the Atlanta flight tracks have been used in the evaluation of PWI concepts. The purpose of the present paper is to show statistical trends of conflict factors for this sample of traffic data.

2. Flight Track Data

The 11 hr of flight-track data used in this study were recorded at Atlanta over a 5-day period in August 1967 during peak hours of the morning, afternoon, and evening. Table 1 summarizes the traffic statistics for the 11 hr. The period contains 584 tracks having a total track duration of 94.92 hr, and a mean track duration of 9.8 min (585 sec).

The data were collected by the FAA using the Airport Radar Terminal System (ARTS). Details of data acquisition and reduction are given in Refs. 1, 8, and 9. Weather conditions during this period were generally overcast at from 400 to 10,000 ft. For the most part, the flights were operating under instrument flight rules[9] (IFR).

Received January 11, 1971; revision received June 18, 1971. This research was supported in part by the former NASA Electronics Research Laboratory, Cambridge, Mass., under contract NAS 12-698 with A. S. Richardson Jr., and D. Brayton as project monitors. R. W. Simpson of MIT served as technical consultant.

Index categories: Air Navigation, Communication, and Traffic Control Systems; Aircraft Flight Operations.

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† The term airspace conflict is used here to be synonymous with collision hazard in Refs. 1–3. A terminology for airspace conflicts has not been agreed upon, but the term hazard conveys to many a greater degree of risk than intended here. We are concerned with aircraft separations in time (20 sec) and distance (several naut miles) an order of magnitude greater than for NMAC incidents. Reference 4 does apply the term conflict to NMAC incidents, so conflict is taken as a categorical term, the degree of risk being implied in the present report by the acceleration-hazard criterion (Sec. 3).

3. Range-Guard Intrusions

Intrusions Per Track

For a measure of aircraft proximity, the 3-naut mile horizontal separation standard used in the terminal area for IFR flight and ±500 ft altitude, corresponding to IFR 1000-ft separated flight levels, are selected to define a range guard surrounding each aircraft, as shown in the sketch of Fig. 1. Intrusions of this range guard are counted. Aircraft flying under visual flight rules (VFR) are not required to maintain this separation, so an intrusion is not a fair measure of hazard for this mixed traffic sample, but only of aircraft proximity.

Hour-10 is selected for analysis of intrusions having a high-density traffic with 63 tracks recorded, 11.3 aircraft per radar scan, and a high arrival-departure ratio (43/20). There are 38 intrusions of the 3-naut mile, 500-ft range guard, counting 2 intrusions per aircraft pair. The number of intrusions per

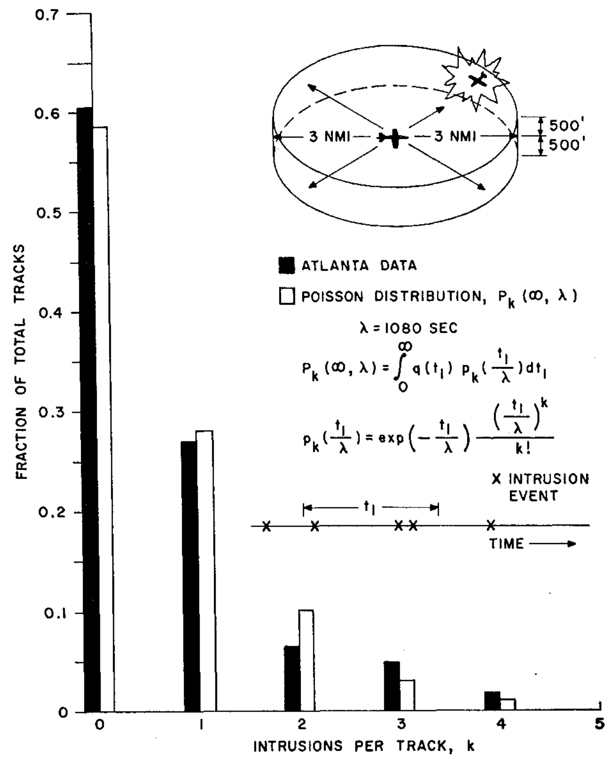


Fig. 1 Bar graph of tracks experiencing *k* intrusions of 3-naut mile, 500-ft range guard, hour-10 tracks.

Table 1 Statistics of Atlanta ARTS data

Hour Number	Day[a]	Local Time[a]	Total Number Tracks	Arrival/Departure Ratio	Average Number A/C Per Radar Scan[a]
2	Monday	15 : 20 16 : 20	42	33/9	8.5
3	Monday	19 : 55 21 : 00	55	20/35	5.6
4	Tuesday	9 : 00 10 : 00	55	47/8	12.4
5	Tuesday	15 : 15 16 : 25	57	35/18	6.9
6	Tuesday	20 : 00 21 : 00	41	20/20	5.0
7	Wednesday	10 : 00 11 : 00	69	32/34	9.4
8	Wednesday	15 : 20 16 : 20	52	37/14	7.6
9	Wednesday	20 : 00 21 : 15	41	21/20	5.7
10	Thursday	10 : 15 11 : 15	63	43/20	11.3
11	Thursday	19 : 00 20 : 00	62	44/15	12.7
13	Friday	9 : 00 10 : 00	47	42/4	12.2
Total			584		

[a] From Ref. 10.

track is plotted in Fig. 1: 60% of the tracks experience no intrusions, 27% one, etc.

Consider the intrusions to be random events in time, given by the Poisson function. Assume that each flight track is a portion of an infinite flight track with a mean time between intrusions, λ. Then, the Poisson probability function

$$p_k(\bar{t}_1) = \exp(\bar{t}_1)\,\bar{t}_1{}^k/k! \qquad (1)$$

where $\bar{t}_1 = t_1/\lambda$, describes the probability of a track with duration t_1 experiencing k intrusion events.

Let $q(t_1)$ represent the fraction of tracks with durations between t_1 and $t_1 + dt_1$, normalized so

$$\int_0^\infty q(t_1)dt_1 = 1 \qquad (2)$$

The Poisson cumulative probability density function

$$P_k(t_1, \lambda) = \int_0^{t_1} q(t)p_k(t/\lambda)dt \qquad (3)$$

is the Poisson probability of the tracks with durations up to t_1 having k intrusion events.

For Hour-10, λ is 1080 sec (18 min). The Poisson cumulative function $P_k(\infty, 1080\text{ sec})$ is compared with the Atlanta data in Fig. 1. The agreement is good, the largest difference being only 0.035 (equivalent to 2 tracks) for $k = 2$.

It is concluded that these intrusions of the 3-naut mile, 500-ft range guard are essentially random in time, following a Poisson variation with track duration.

Traffic Density Effect

The effect of traffic density upon the intrusion time for each traffic hour is shown in Fig. 2. Here the duration of each intrusion is measured in units of 3-sec-spaced epochs (the data rate). The total intrusion epochs for each hour is plotted vs the mean number of aircraft recorded in the terminal area per radar scan for the hour $\bar{N}$ which is the mean traffic density. The best power-law fit of $\bar{N} - 1$ is 1.90, with a correlation coefficient r of 0.74 (± 1 is perfect correlation and 0 is no correlation (1). It is concluded that the intrusion time increases essentially as the square law for the gas model of random traffic.

4. Airspace Conflicts

Conflict Criterion

The definition used here for an airspace conflict was introduced in Refs. 2 and 3, and is called the "acceleration-hazard criterion." Briefly, the flight path for each aircraft is projected ahead for an escape time t_e making allowance for turns, speed changes and climbs or dives, as sketched in Fig. 3. In the horizontal plane, Fig. 3a, a $\frac{1}{2}$-g acceleration in any direction would allow for an equilibrium bank angle up to 27° or speed change up to $\pm\frac{1}{2}$-g. In altitude, Fig. 3b, a maximum flight path angle γ_{max} of $\pm 10°$ anticipates all typical climb or dive rates.

The definition of a conflict is critical to the results. Escape times of 20 to 60 sec have been employed elsewhere.[6] Here 20 sec is used for t_e, which is assumed to allow a pilot and controller time to assess the conflict and perform an escape

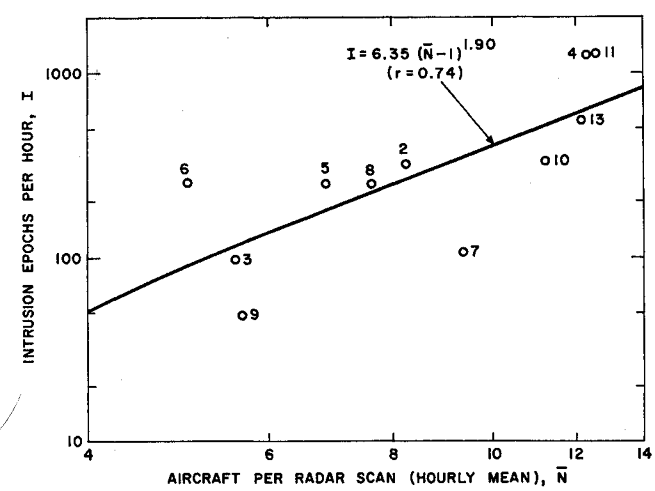


Fig. 2 Range-guard intrusion epochs per hour vs average number of aircraft per radar scan, hour number indicated.

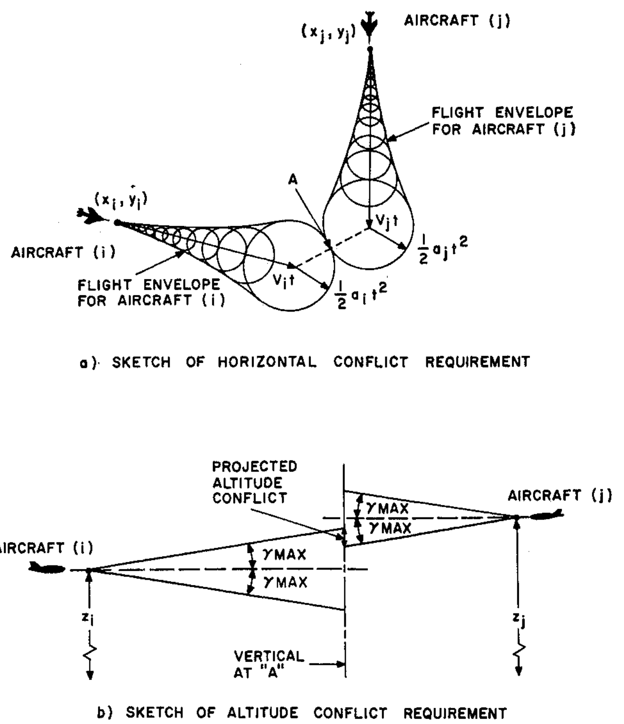


Fig. 3 Sketch illustrating acceleration-hazard criterion used to define airspace conflict.

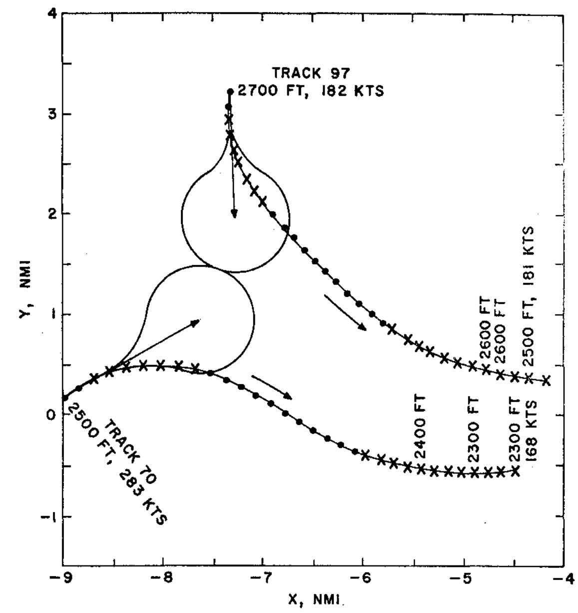


Fig. 4 Flight tracks during typical airspace conflict encounters.

maneuver where required. Holt et al.[6] estimate 28 to 35 sec is required for the systems considered, which would enlarge a typical envelope for the aircraft in the present traffic nearly a factor of two or more in the flight direction. Tighter control might allow reducing the envelope width, but, so long as blunders are possible, it seems evident the criterion must admit both left and right turns.

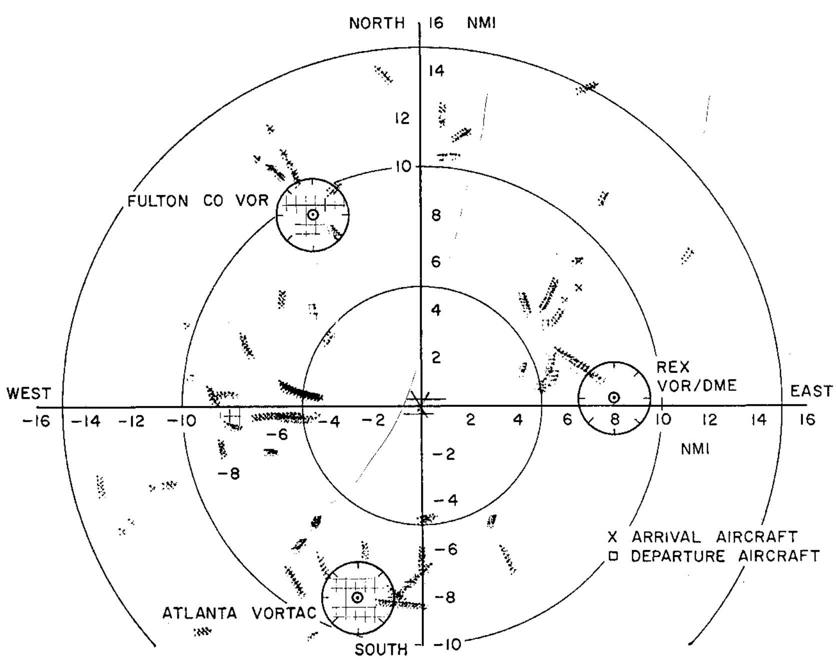
Typical conflict encounters are plotted in Fig. 4 for two aircraft approaching parallel runways. Each cross represents a conflict epoch and each dot a nonconflict epoch. The projected flight envelopes are shown at the first conflict epoch. After 7 conflict epochs the tracks are nearly parallel and separated by 1.7 naut miles, so the encounter ends. After 11 more epochs, track 70 does a slight left turn towards its runway, for a second encounter.

Conflict Locations in the Terminal Area

The Atlanta terminal area extends about 30 naut miles from the airport. Nearly all of the airspace conflicts occurred in the inner region shown in Fig. 5. The location of each aircraft during a conflict epoch is indicated—a cross for an arrival aircraft and a square for a departure aircraft.

Aircraft generally enter from the NE, SE, SW or NW heading toward one of the VOR stations. The aircraft enter a trombone pattern west of the airport, by heading west on a downwind leg 5 naut miles north or south of the airport, turning to a base leg, and returning eastward on the approach. The tracks terminate at the outer marker, about 4 naut miles

Fig. 5 Location of aircraft during airspace conflict epochs, 11 hours of Atlanta data.



from the airport. Departure aircraft takeoff eastward, generally turning left or right.

The conflicts group around the VOR stations, the base leg and approach, which are recognized as problem areas for NMACs[4] and midair collisions.[6] Arrival aircraft are involved in most of the encounters except near the departure point where arrivals and departures are involved about equally.

Conflicts per Track

There are a total of 63 airspace conflict encounters in the 11 traffic hours. One encounter is defined as a continuous sequence of conflict epochs for an aircraft—two encounters being counted for an aircraft pair; because of the speed-range interest of Refs. 1–3, aircraft with speeds over 235 knots are not counted in encounters, reducing the number slightly. The mean flight time between entering a conflict encounter λ is 5424 sec (90.4 min).

The distribution of conflict encounters over the tracks is shown in Fig. 6. Of the 584 tracks, 90.6% experience no conflict encounter, 8.0% one encounter, and 1.4% two encounters.

The Poisson model for random encounters is compared with the Atlanta data using Eq. (3), the distribution of track durations for the 11 hr and λ equal 5424 sec. The agreement is excellent, the largest difference being only 0.01.

It is concluded the probability of a track experiencing a conflict encounter follows the Poisson random event model in time. The dependence of the mean flight time between conflicts λ upon traffic factors is not known.

Traffic Density Effect

The effect of the traffic density on the airspace conflict rate is shown in Fig. 7, where the hourly conflict encounter rate H_E is plotted vs $\bar{N}$. The solid line represents the best linear fit, which shows a decreasing trend with the higher traffic density. Flight safety is concerned more with the hours having high conflict rates; the broken line is the envelope of hourly peak conflict rates, which falls off sharply with increasing traffic density.

The gas model would indicate a conflict rate increasing as the square of the traffic density. This relationship is used frequently in predicing future rates of midair collisions and near midair collisions (e.g. Ref. 6). The reason for the decreasing trend of the conflict rate is not explained, although it may reflect a change in the flight patterns used, variation in controller attention, or adherence by the pilots to directives.

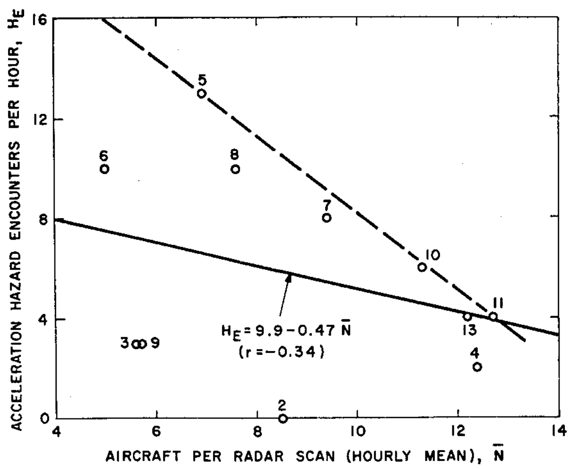


Fig. 7 Airspace conflict encounters per hour vs average number of aircraft per radar scan, hour number indicated.

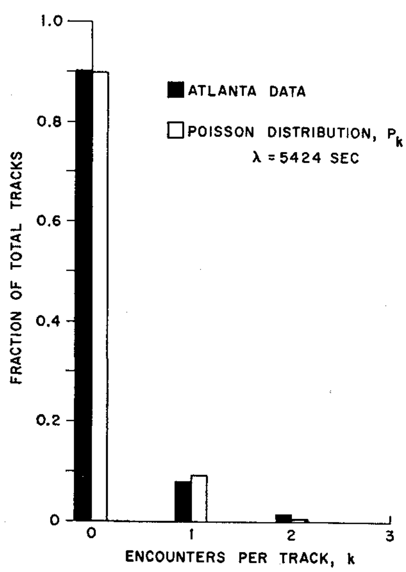


Fig. 6 Bar graph of tracks experiencing *k* airspace conflict encounters, 11 hours of Atlanta data.

5. Conclusions

From this examination of 11 hr of flight tracks from a single terminal area, it appears that intrusions of the 3 -naut mile, 500-ft range guard and airspace conflicts occur as random events in time exhibiting a Poisson variation with track duration. The airspace conflicts take place as expected near the navigation points (VOR stations) and near the final approach to the runways. The hourly rate of intrusions seems to follow the gas model square-law increase with traffic density, whereas the airspace conflict rate shows a definite decreasing trend. The factors involved causing this conflict trend are not known, but the result does challenge the random traffic model of air traffic for such uses as predicting midair collision rates.

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