Modeling the Spatial Distribution of Aircraft on Visual Flight Rules

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Introduction

THIS Note summarizes an FAA-supported pilot program to develop models which estimate the average and peak instantaneous aircount (IAC) of aircraft flying on visual flight rules (VFR). The IAC are distributed spatially, similar to a checkerboard effect, over the cross-sectional area of each state in the continental United States (CONUS) for a typical VFR day in 1980. VFR aircraft are primarily general aviation (GA) aircraft and they constitute the bulk of all in-flight aircraft (at least 85%). Knowledge of aircraft densities helps to estimate the size of replacements for the enroute air traffic control computers. Peak density is especially important to the design of aircraft collision avoidance devices.

An earlier model estimated the average IAC of VFR aircraft over each Air Route Traffic Control Center, of which there are 20 covering the CONUS.[1,2] The new models described here will be referred to collectively as the VFR spatial model. Without this model, it would be necessary to process radar data on all in-flight VFR aircraft in order to obtain their peak and average spatial distribution. This approach is not only enormously costly and time-consuming, but it would also require the solution of several formidable technical problems.[2]

Development of the Spatial VFR Model

The overall approach in estimating the spatial distribution of VFR aircraft is similar to the approach in Ref. 2. A major point in the model development is that over a 24-h day, the number of VFR aircraft leaving and entering any large geographic area are about equal. The principal input to the VFR spatial model is the annual number of GA itinerant operations for each state in the CONUS. This input was extracted from an airport data tape provided by the FAA's National Flight Data Center. The tape also contains other information, collected in 1980, about each airport in the U.S. (e.g., latitude and longitude, number of based aircraft, whether towered or nontowered). The model is summarized by the equation

$$I = OFt/(2)(365)(AB) \qquad (1)$$

where I is the daily average number of itinerant VFR aircraft per square nautical mile over any large area, A; O is the annual number of general aviation itinerant operations within the area (obtained by programming the FAA data tape); F is the fraction of these operations that are VFR operations; t is the average flight time of a VFR aircraft; and B is the number of busy hours in a typical VFR day. Numerical values for F, t, and B were computed in Ref. 2. For convenience, only state areas will be used.

The peak VFR model, derived in the Appendix, is

$$P = 2I \qquad (2)$$

where P is the peak density over each state and I is defined in Eq. (1).

Results

Using Eqs. (1) and (2), the average and peak traffic densities of VFR aircraft are obtained. Table 1 summarizes them as well as the average and peak IAC for each state in the CONUS. The densities are believed to be conservative because they assume private aircraft are distributed uniformly over the cross-sectional area of each state. In mountainous states they cannot be uniformly distributed. It should be noted that the term "average," as used here, means the daily number of aircounts averaged over a year.

Evaluation of Spatial Model Output

In order to test the reasonableness of the model's output, a comparison was made between model predictions and measurements of air traffic density over the Los Angeles Basin, made by Lincoln Laboratory[3] during the time interval 11:30-11:49 a.m., Pacific Standard Time, Nov. 21, 1976 (the Lincoln Laboratory data are one of the few known sources of reliable field counts). Lincoln Laboratory measured a peak air traffic density of about 0.029 aircraft per square nautical mile. By Eq. (2), the average density is 0.015. This density was forecasted to be 0.019 aircraft per square nautical mile in 1980, by the following method: Since most aircraft (90-95%) in the Los Angeles Basin fly VFR, VFR forecasts are required.

Table 1 VFR spatial aircounts for each continental state[a]

State[b]	Average count[c]	Average density[d]	Peak count[e]	Peak density[f]
Alabama	71	0.002	142	0.004
Arkansas	98	0.002	196	0.005
Arizona	161	0.002	322	0.004
California	1278	0.011	2556	0.021
Connecticut	61	0.016	122	0.032
Delaware	16	0.010	32	0.021
Florida	352	0.008	704	0.016
Georgia	109	0.002	218	0.005
Iowa	93	0.002	186	0.004
Illinois	196	0.005	392	0.009
Indiana	110	0.004	220	0.008
Kansas	105	0.002	210	0.003
Kentucky	58	0.002	116	0.004
Louisiana	102	0.003	204	0.006
Massachusetts	116	0.019	232	0.037
Maryland	68	0.009	136	0.017
Maine	42	0.002	84	0.003
Michigan	176	0.004	352	0.008
Minnesota	109	0.002	218	0.003
Missouri	113	0.002	226	0.004
Mississippi	58	0.002	116	0.003
North Carolina	98	0.002	196	0.005
New Hampshire	28	0.004	56	0.008
New Jersey	131	0.022	262	0.044
New York	208	0.006	416	0.011
Ohio	176	0.006	352	0.011
Oklahoma	169	0.003	338	0.006
Pennsylvania	148	0.004	296	0.009
Rhode Island	23	0.025	46	0.050
South Carolina	65	0.003	130	0.006
Tennessee	103	0.003	206	0.006
Texas	458	0.002	916	0.005
Virginia	103	0.003	206	0.007
Vermont	11	0.002	22	0.003
Washington	174	0.003	348	0.007
Wisconsin	115	0.003	230	0.005
West Virginia	38	0.002	76	0.004

[a]Typical VFR day in 1980. [b]Missing states have an average density of 0.001 or less. [c]Daily average IAC of VFR aircraft over a state. [d]Daily average IAC divided by state area (aircraft per square nautical mile). [e]Daily peak IAC of VFR aircraft over a state. [f]Daily peak IAC divided by state area (aircraft per square nautical mile).

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The FAA forecasts the number of registered general aviation aircraft for each FAA region.[4] It is assumed that their growth rate in the Western Region (California, Arizona, and Nevada) is the same as for the Los Angeles Basin. It can be demonstrated that the number of in-flight VFR aircraft is proportional to the number of registered general aviation aircraft, leading to the above forecast estimate.

In order to make a meaningful comparison between measured and predicted data, the predicted 1980 air traffic density for the Los Angeles Basin, 0.019, was projected to an air traffic density for California using the following method:

$$\frac{\text{Number over state}}{\text{state area}} = \frac{\text{Number over basin} + \text{Number outside basin}}{\text{Basin area} + \text{Non-basin area}} \tag{3}$$

Rearranging terms on the right-hand side of Eq. (3) and assigning symbols:

$$N_s/A_s = (D_B)(X)/(Y) \tag{4}$$

where

$$X = 1 + (N_s - N_B)/N_B \tag{5}$$

$$Y = 1 + (A_s - A_B)/A_B \tag{6}$$

where N_s is the average or peak number of aircraft over California, A_s the area of California, A_B the area of the Los Angeles Basin, N_B the average or peak number of aircraft over the Los Angeles Basin, and D_B the measured air traffic density over the Basin. Use $N_s = 1278$ aircraft (average), $A_s = 119{,}832.20$ n.mi.^{2}, $N_B = 157$ (average) aircraft,[2] $A_B = 5654.87$ n.mi.^{2}, $D_B = 0.019$ aircraft per square nautical mile (average). The values for N_B and D_B are for 1980. Substitution of these numerical values into the right-hand side of Eq. (4) yields $N_s/A_s = 0.007$ average aircraft per square nautical mile as the projected air traffic density over California. This projection is based only on the measured air traffic density over the Los Angeles Basin. The average air traffic density over California predicted by the spatial model (Table 1) is 0.011 average aircraft per square nautical mile. The difference between the two densities is about 46%. Given the qualitative nature of these calculations, this difference is reasonable and, assuming it is similar in other states, is adequate for planning purposes.[2] However, the difference is probably overestimated. The data in Ref. 3 were collected in November, when GA activity is slightly lower than the average number of daily operations used in Eq. (1), by about 6%, determined by using seasonal correction factors.[5] The average density predicted by the model is therefore lowered to 0.010 for November. Consequently, the difference between measured and predicted densities is reduced from 46 to 37%. However, the day-to-day variation in the measurements was about 30%, implying an effective difference of 7%.

The comparison between measured and predicted peaks is similar to the above and leads to the same numerical differences. It is reasonable that the spatial model's average (peak) density is greater than the measured (peak) density because 1) air traffic predicted by the model include both transponder and non-transponder equipped VFR aircraft, whereas air traffic measured by Lincoln Laboratory included only aircraft with transponders; and 2) natural barriers such as mountains occlude some transponder signals so that not all in-flight aircraft over the Los Angeles Basin were counted.[3] The model ignores these barriers—it counts all aircraft. It would be fallacious to suggest that the model's predictions have been completely verified, but the fact that there is reasonable agreement in one important test case—California—is encouraging. The Appendix contains an assessment of the reasonableness of the model to estimate peak aircounts.

Conclusions

The model to estimate the average and peak spatial distribution of VFR aircraft appears to be potentially useful, based on a preliminary evaluation of the output. Evaluation of the model should not be based on only one such comparison. Therefore comparisons between measured and predicted air traffic densities will be made for many more data samples obtained on different days of the year from diverse geographical areas. The model is economical in that its basic input, annual number of general aviation itinerant aircraft, is readily available, thereby avoiding costly data collection procedures.

Appendix: Derivation of Peak Model, Eq. (2)

On a typical VFR day, VFR traffic is active over a period of about B hours (B usually equals 12) although peak traffic persists for a time interval much less than B hours. However, for simplicity, the peak model widens the peak to the full window of activity without distorting its amplitude. The average number of peak VFR operations per unit time is

$$O' = O/B \tag{A1}$$

where O is the daily number of operations, defined by

$$O = A + D \tag{A2}$$

and A and D are the number of arrival and departure operations, respectively. Over a full day they are equal,[2] i.e.,

$$A = D \tag{A3}$$

Therefore

$$O' = 2D/B \tag{A4}$$

Since there is about one in-flight aircraft for every arrival and departure,[2] the instantaneous peak VFR aircount is

$$P' = (D/B)t \tag{A5}$$

where t is the average time of a VFR flight. In the original model, the average aircount I' is defined by[2]

$$I' = Dt/2B \tag{A6}$$

Dividing Eq. (A5) by (A6) gives the final result:

$$P' = 2I' \tag{A7}$$

Equation (A7) is essentially the same as Eq. (2) if both sides of the former equation are divided by the area of the state and the prime notations dropped.

Scarcity of field data makes it difficult to verify Eq. (A7), but it is possible to infer its reasonableness because the same equation should also be applicable in a terminal area, where data are available. Data on general aviation itinerant tower operations[6] indicate that the ratio of daily peak operations to average daily operations is, for most GA towers, also about 2. In Ref. 6, data were compiled on daily operations, whereas this section computes instantaneous counts, but since these are proportional to daily operations, comparison between the derived proportionality constant in Eq. (A7), and the measured peak to average ratio in Ref. 6, is probably a reasonable one.

References

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[3]Harman, W.H., "Air Traffic Density and Distribution Measurements," FAA Rept. No. RD-78-45, May 1979.
[4]"FAA Aviation Forecasts, FY 1981-1992," FAA Rept. No. AVP-80-8, Sept. 1980, Table 7.
[5]"FAA Aviation Forecasts, FY 1979-1990" FAA Rept. No. AVP-78-11, 1978, p. 82.
[6]Weiner, A., "Tower Airport Statistics Handbook—Calendar Year 1978," FAA Rept. No. AVP-79-2, 1979.

Ground Contamination by Fuel Jettisoned from Aircraft in Flight

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Introduction

THE term "fuel jettisoning" refers to the discharge of unburned fuel directly into the atmosphere by an airborne aircraft. Fuel jettisoning usually occurs as the result of an in-flight emergency or unforeseen operational requirement and is performed to reduce the aircraft's gross weight and facilitate a safe, expeditious landing. Jettisoning incidents, although infrequent, involve considerable quantities of fuel. Depending upon the aircraft, the fuel released in a single incident can range from a few thousand liters to well over 50,000 liters.[1] The jettisoned fuel readily breaks up into small droplets and begins to evaporate. From an environmental standpoint, the principal concern is what fraction of the fuel reaches the ground before it can evaporate and disperse. A previous analysis[1] showed that the effect of the evaporated fuel vapors in the atmosphere is negligible. If liquid fuel reaches the ground, however, there is a potential for negative environmental consequences such as crop damage or water pollution.

The Air Force has been investigating the environmental ramifications of fuel jettisoning for several years. Air Force aircraft jettison fuel nearly 1000 times a year, and the fuel released to the atmosphere by these aircraft amounts to more than 7000 metric tons (16 million pounds) per year —averaging 26,000 liters (7000 gal) per day.[1] Fortunately, the fuel discharged by Air Force aircraft is generally JP-4, a highly volatile fuel which is readily evaporated and dispersed, minimizing ground contamination by liquid fuel.[2,3] On the other hand, Jet A, the fuel currently in use by commercial aircraft in the United States, is a kerosene-type fuel much less volatile than JP-4. Recently the Air Force has converted many of its NATO aircraft to JP-8, a military fuel very similar to Jet A. Any fuel jettisoning involving these fuels can be expected to entail greater ground contamination than that involving JP-4 owing to the lower tendency to evaporate. In recent years, Air Force aircraft in NATO have jettisoned fuel approximately 80 times per year, for a total of over 500 metric tons (over a million pounds) of fuel per year.[1] Commercial aircraft also jettison fuel, but complete records are not kept. Maintenance reports provided to the FAA by the commercial airlines[4] show 485 records of fuel jettisoned over the 5-yr period ending March 1980. Unfortunately, these records do not indicate the amount of fuel jettisoned, and only fuel jettisoning incidents associated with aircraft maintenance are included, not those occasioned by weather or scheduling imperatives. Nevertheless, we can conclude that the level of fuel jettisoning by commercial aircraft is significant. The purpose of this study was to determine the increased likelihood of ground contamination from commercial jet fuel and JP-8 as compared to JP-4.

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Procedure

In order to assess the differential impact of fuel jettisoning involving JP-4 and Jet A/JP-8, a computer model was employed which simulates the evaporation and free-fall of fuel droplets in the atmosphere. This model was developed and validated during a previously reported study of the drop formation and evaporation of JP-4 fuel jettisoned from an aircraft in flight.[2,3] The model, which is described in detail in Ref. 3, breaks up a droplet's fall into a series of small time intervals. During each interval the distance of fall and loss of mass are calculated, providing the initial conditions for the next interval. This stepwise approximation continues until the droplet impacts on the ground or evaporates completely. To simulate fuel jettisoning, the model is run for a series of droplets based on actual experimental measurements of the fuel droplet size distribution produced by aircraft fuel jettisoning.[3] A detailed composition of the jettisoned fuel must be input into the model for use in the evaporation calculations. The model then keeps track of the changing composition as the more volatile components evaporate preferentially, leaving the denser, slower-evaporating components behind. In previous reports,[1-3] only a composition for JP-4 was used. In this study the effect of changing the jettisoned fuel composition to that of a representative Jet A fuel[5] (shown in Table 1) was determined.

Results

The predictions of the fuel droplet evaporation and free-fall model for JP-4 and JP-8/Jet A are compared in Figs. 1

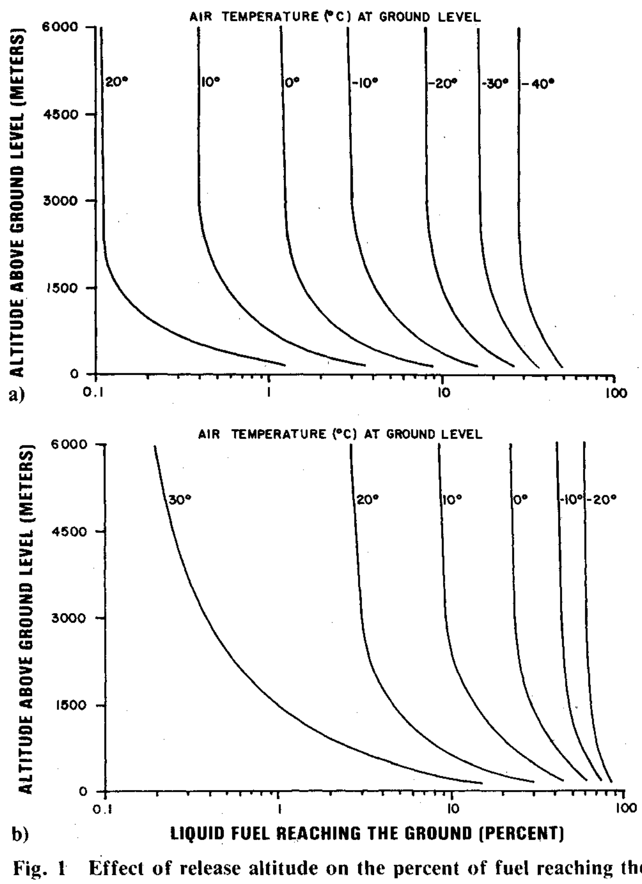

Fig. 1 Effect of release altitude on the percent of fuel reaching the ground. a) JP-4, b) JP-8/Jet A.