CIVIL AIR PATROL

U.S. Air Force Auxiliary

Missing Aircraft Search Research

June 2009

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ATGOR STAFF NOTE 2/87

A NEW SEARCH METHOD BASED ON AN ANALYSIS OF AIR DISTRESS CASES: 1981-86

by

P.H. Saunders

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September 1987

ABSTRACT

An analysis of air distress cases covering the period 1981 to 1986 has revealed that significant changes have occurred in the distribution of crash positions relative to intended track in comparison to previous data. A new system for defining search areas based on the recent data is developed to replace the Modified Offset and Track Variable (MOTV) method currently in use. The new method produces smaller areas than MOTV without lowering probabilities of whereabouts and is simpler to apply.

ACKNOWLEDGEMENT

The author acknowledges the excellent work done by Captain A.M. Shurson of the Directorate of Air Operational Research (Reference 3) whose recommendations prompted this study. Captain Shurson carried out all the data collection and preliminary analyses.

ATGOR STAFF NOTE 2/87

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INTRODUCTION AND BACKGROUND

1. One of the fundamental tasks in the implementation of a search for a missing aircraft is the establishment of search areas. Reference 1 describes a procedure known as the Offset and Track Variable (OTV) method which establishes minimum probability areas based on Canadian aircraft crashes from 1968 to 1973. This procedure was subsequently modified to become the MOTV method which has been used effectively in Canada for several years. This method is described in more detail below.

2. Reference 2 describes a method for establishing search areas in mountainous regions of Canada where aircraft crash positions were found to exhibit different characteristics. In particular, crash sites tended to cluster close to Visual Flight Rule (VFR) routes through the mountains and were spread fairly uniformly along them. This method, known as MVFR (Mountainous VFR), has been approved and implemented for searches in mountainous regions involving VFR flights.

3. Reference 3 describes a Directorate of Air Operational Research (DAOR) study which reviewed the MOTV method using air distress cases from 1981 to 1986. The purpose of the study was to examine the more recent data to determine if the MOTV method still applied. The study showed that crash site locations relative to intended track appeared to be different from the original OTV study and the author recommended that changes be made to the present MOTV system.

4. The purpose of the study described in this report is to follow up on the recommendations from Reference 3 and propose appropriate changes to the MOTV method based on the latest data.

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THE MOTV METHOD

5. Basically, the MOTV method defines search areas relative to a missing aircraft's intended track. These areas have given probabilities of containing the crash site based on actual Canadian data. Three areas are defined by the method as described below:

a. Area 1 - a rectangular area 15nm either side of intended track commencing 15nm before Last Known Position (LKP) and extending 15nm beyond destination. This is based on a probability of whereabouts of .5;

b. Area 2 - for track lengths in excess of 100nm, a rectangular area is defined, centred on the CP[1] and based on a probability of whereabouts of .6 as defined by the OTV study but truncated at 30nm past the destination. The area includes that portion of Area 1 where overlapping occurs. In track lengths under 100nm, a rectangular area is defined, 20nm each side of track commencing at the LKP and extending 20nm past the destination; and

c. Area 3 - for tracks in excess of 100nm, a rectangular area is defined, centred on the CP and based on a probability of whereabouts of .77 as defined by the OTV study but truncated at 30nm past the destination. For tracks under 100nm, an area extending 5nm beyond Area 2. Area 3 includes that portion of Area 1 where overlapping occurs, but includes no part of Area 2. Because of the exclusion of Area 2, Area 3 actually has a probability of .17 associated with it.

These areas are illustrated in Figure 1.

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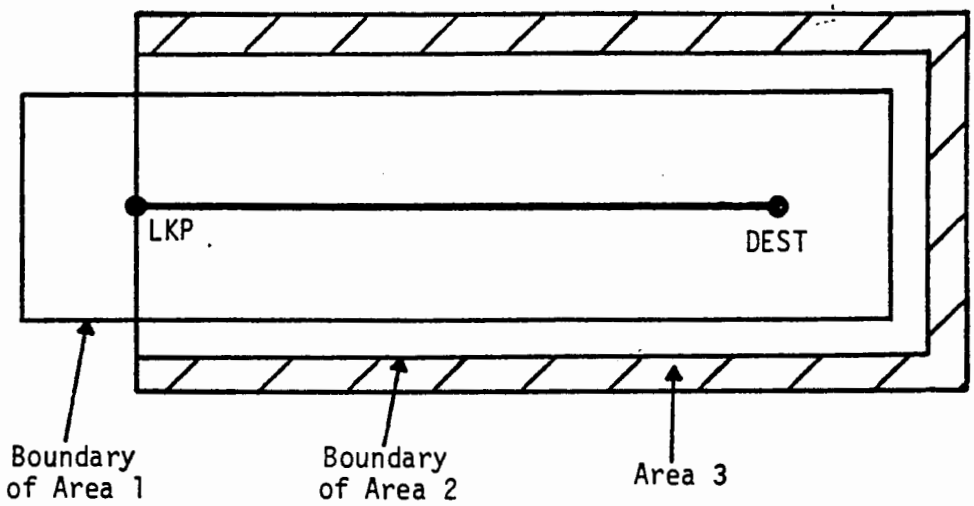
1. CP stands for Centre Point which is a point 3/4 of the way along track around which crash sites tended to cluster.

For Tracks Under 100nm



For Tracks Over 100nm

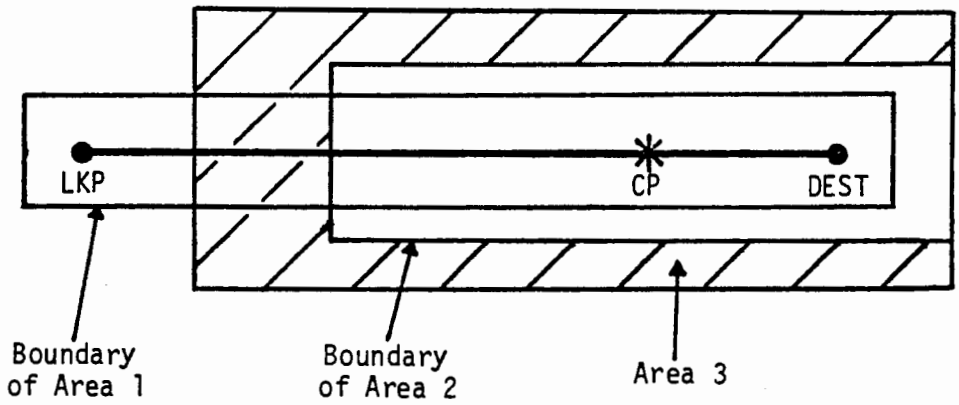


Figure 1 - Illustration of MOTV Areas

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THE DAOR STUDY

6. A total of 76 suitable cases were found from which to extract the appropriate data for the DAOR study (Reference 3). The following parameters were extracted from each case:

a. the coordinates of the Last Known Position, the destination and the crash position;

b. the intended track length;

c. the track variable which is the actual track length measured from the LKP to a line perpendicular to the intended track and passing through the crash position; and

d. the offset distance from the intended track to the crash position.

7. The conclusions obtained from a detailed analysis of the above parameters are summarized below:

a. crash positions were located closer to the intended track than in the original study;

b. there was no correlation between the offset and the intended track length, or in other words, the intended track length had no noticeable effect on how far off track a crash occurred;

c. there was a weak correlation between the actual and intended track lengths, with the centre point about .6 of the way along track. There was, however, a large spread in the crash positions along track;

.../5

d. there was a concentration of cases near the LKP and the destination; and

e. there was no correlation between the offset and actual track length.

8. As a result of the above findings, the following changes were suggested to the areas defined by MOTV:

a. the width of all three areas should be reduced;

b. the location of the Centre Point should be changed and the length components of the areas examined for a possible revision; and

c. the width components of Areas 2 and 3 should be constant (ie. they should not vary with intended track length).

9. There were purposely no hard numbers given in the DAOR study with respect to changes in the MOTV. The author left it to the SAR community to scrutinize the paper and determine the appropriate numerical changes. In the following sections of this paper possible changes to the present system will be examined.

FURTHER ANALYSIS OF THE DAOR DATA

10. The MOTV method was applied to each of the 76 cases from Reference 3. The resulting numbers of cases contained in each of the three areas are shown in Figure 2 in the form of a Venn diagram. There are overlaps between Areas 1 and 2, and Areas 1 and 3, but none between Areas 2 and 3. Figure 2 reveals the following information:

a. the number of cases found within Areas 1, 2 and 3 were 63 (83%), 50 (66%) and 10 (13%), respectively;

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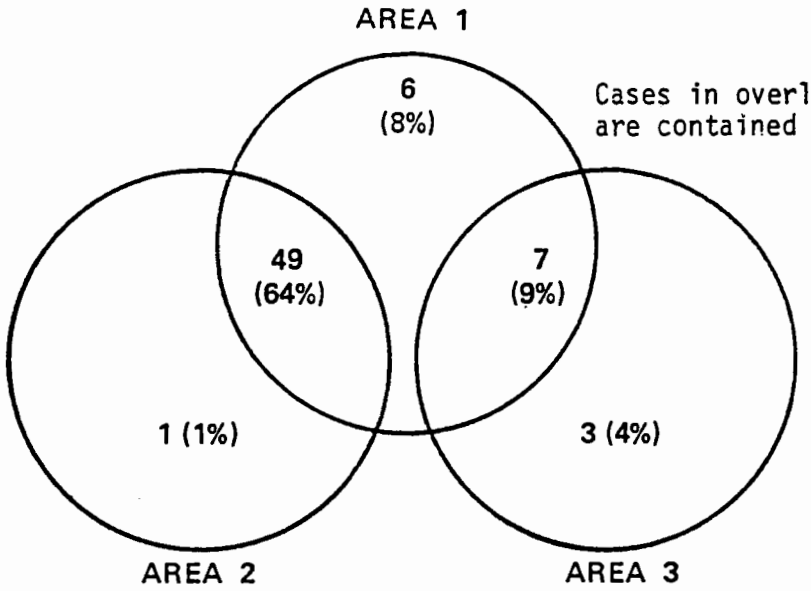

Cases in overlapping regions are contained in both Areas.

TOTALS

AREA 1 63 (83%)

AREA 2 50 (66%)

AREA 3 10 (13%)

ALL AREAS 67 (88%)

OUTSIDE 9 (12%)

Figure 2 - A Venn Diagram Showing MOTV Performance with Latest Data

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b. the total MOTV area contained 67 (88%) cases with 9 (12%) outside;

c. only one case (1%) was found in that portion of Area 2 not overlapping with Area 1;

d. only three cases (4%) were found in that portion of Area 3 not overlapping with Area 1; and

e. the expansion of the search area from Area 1 to Areas 2 and 3 is adding only four additional cases (5%) to the total.

11. It is obvious from this analysis that expanding beyond Area 1 is producing a minimal increase in the probability of containing the crash site for a substantial increase in search area. In fact, the 83% of cases found within Area 1 is higher than the 77% associated with the total area from Areas 2 and 3 of the original study. This suggests that the MOTV areas should be reduced as Reference 3 recommends.

12. Figure 3 is a histogram showing the proportion of track covered (ie. track variable divided by intended track length). Only two cases were located beyond the destination and no cases were found before the LKP. The data are grouped in tenths and in quarters. It appears that three phenomena are contributing to this distribution:

a. the near take-off/landing related cases which cluster about the LKP and destination;

b. the cases which are spread fairly uniformly along track with causation factors such as navigation errors, machanical problems and weather; and

c. the cases which tend to occur in the last half of the track as a result of inexperienced pilots 'pressing-on-regardless' under conditions when they should not.

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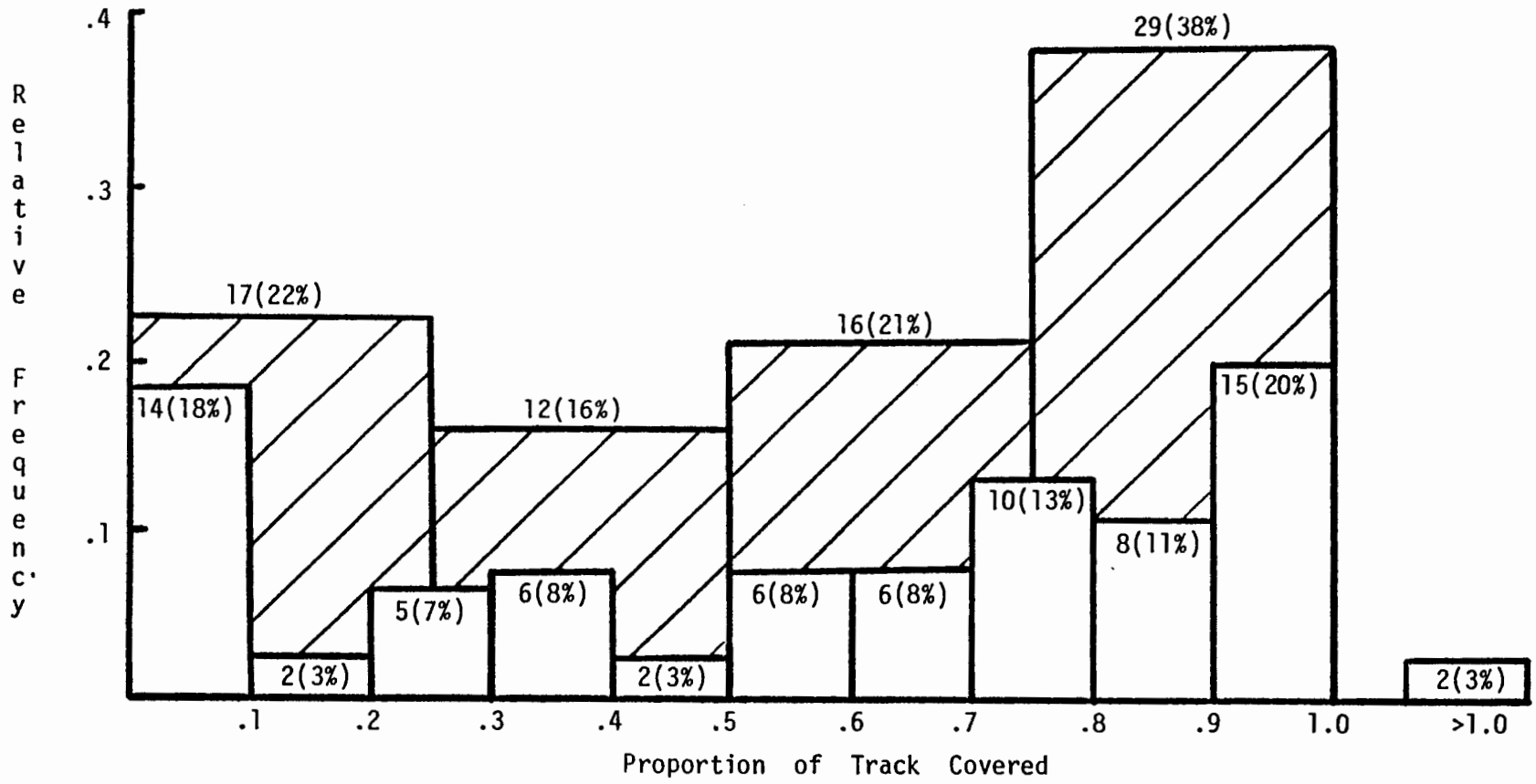

Figure 3 - Relative Frequency Histogram of Proportion of Track Covered

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13. Figure 4 shows a relative frequency histogram of offsets. Approximately 62% of cases were found within 5nm of intended track. The clustering of cases about intended track has been observed in all the previous studies, however, the degree of clustering has varied. In the original OTV study (Reference 1), the density about track was somewhat lower. In mountainous regions (Reference 2), the clustering of cases about actual VFR routes was greater.

14. The recent data suggests that crashes are occurring closer to intended track. This is despite the fact that offsets were measured from the straight line track between LKP and destination. The change is probably due, at least in part, to improvements in navigation equipment.

ESTABLISHING SEARCH AREAS

The Effect of Track Length

15. The present MOTV strategy varies with the intended track length. Not only is there a different procedure for tracks under 100nm but the dimensions of the search areas for tracks over 100nm increase significantly with increasing track length. It is a foregone conclusion that search areas must be larger for longer tracks, however, it appears from the recent data that at least the width components of such areas can be held constant over track length.

16. In Reference 3 no correlation was found between intended track length and offset at any track length grouping. The mean offset for the 28 intended track lengths under 100nm was 12.0nm while the value for the 48 tracks over 100nm was 11.2nm. Therefore, there is no justification for varying the width component of search areas for any track length grouping.

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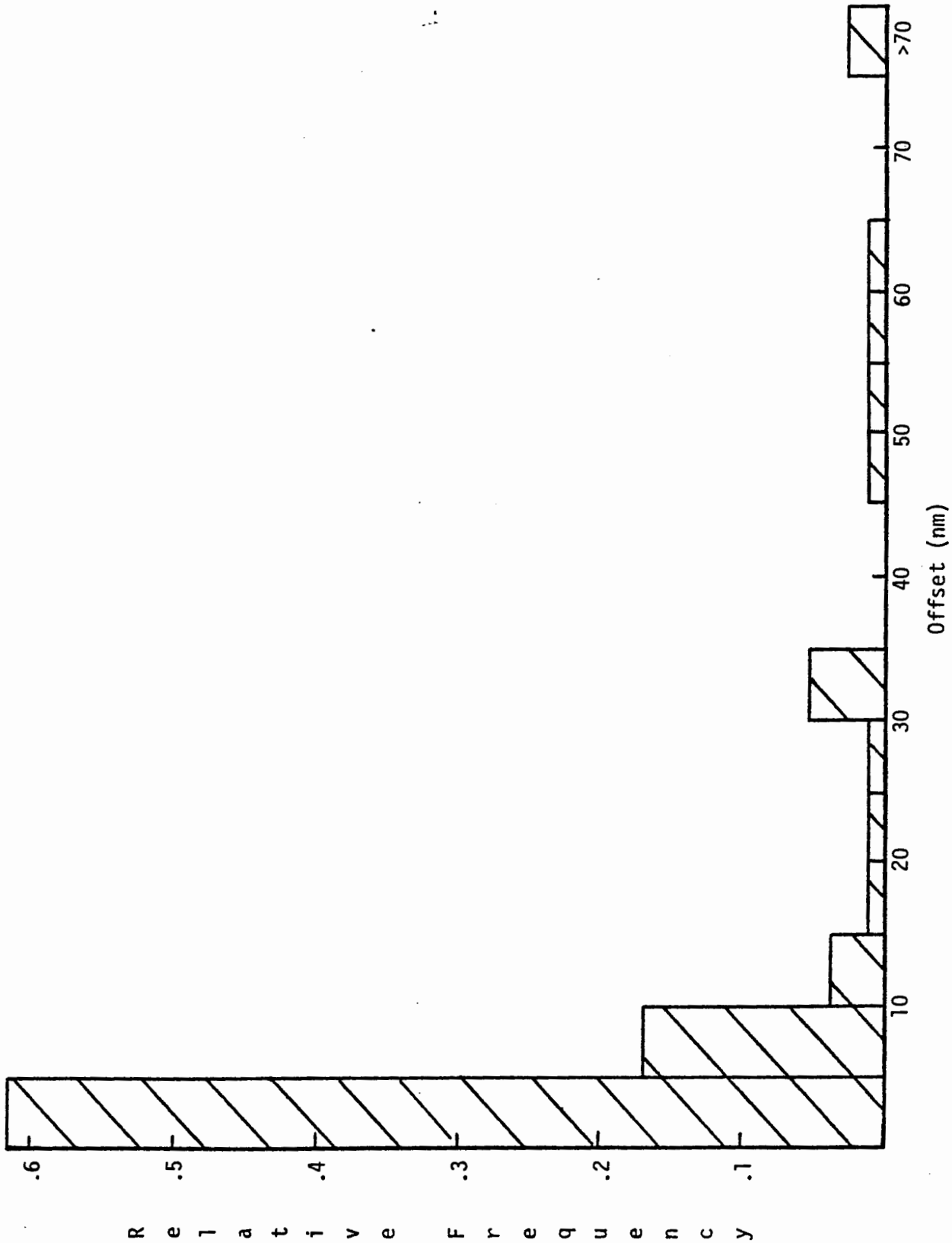

Figure 4 - Relative Frequency Histogram of Offsets

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17. In Reference 3 a correlation was found between the actual distance flown and the intended distance. The Centre Point was at about .6 of track length but with a wide variation about this point. Statistical tests were carried out to see if intended track length had any effect on the proportion of track covered. The results showed no evidence of a relationship, suggesting that the dimensions of search areas in the 'along track' direction could be based on proportions of intended track length. In other words, a certain portion of track would have similar chances of containing a crash site regardless of the intended track length.

18. For the analysis which follows, intended track length will not be a factor. Dimensions in the 'along track' direction will be specified as proportions of track length which will refer to specific intervals. For example, the proportion 6/10 of track might refer to the interval 0.4 to 1.0.

Minimum Probability Areas

19. Since the randomness of the offset versus track variable has been observed in scatter plots and tests have shown a lack of correlation, they will be treated as independent. Therefore, a joint probability function can be derived by multiplying the respective probabilities. The joint function would describe a rectangular area made up of an offset either side of track and a proportion of track length. For example, we would estimate that an area stretching along the last half of a track and 10nm either side, would have a 47% chance of containing a crash. This is based on the data from Reference 3 where 79% of cases were within 10nm of track and 59% in the last half of intended track. Combining these independent probabilities produces the joint probability as shown below:

$$.79 \times .59 = .47$$

Probability areas derived in this manner can then be minimized.

.../12

20. For a given probability of containing the crash site, many different areas can be defined. The problem is to determine the area with the minimum square mileage. The offset or width dimension poses no great problem since it is simply adjusted so that the associated probability will give the required joint probability when combined with the appropriate value for the length. However, the along track dimension which will be given as a proportion of track length could be any number of values (for example, 3/4, 1/2, 3/10, etc). Also, for any proportion of track length many different intervals would be possible.

21. For the analysis which follows, areas will be established for given probabilities of whereabouts. Where possible several different proportions of track length will be used. The optimal search area for a given probability would be the smallest one. Proportions of track will be restricted to tenths and quarters. For each proportion of track length, the corresponding track interval, having the highest probability of containing the crash site, will be used, subject to some rules discussed below. The rules are required since it is possible that several discontinuous intervals could result. For example the optimum three tenths of track from Figure 3 would be the first, eighth and tenth intervals. It would be unrealistic to divide the track so finely, especially when the data is irregular probably due to the limited sample size. Search planning strategies would also be more complex than necessary. To avoid these problems, three specific schemes were used for defining the length intervals of search areas to be used in the optimization calculations:

a. Optimal Continuous Tenths. For a proportion of track given in tenths, the continuous interval containing the greatest number of cases is used (ie. no gaps). For example, if the proportion of track were 3/10, the track interval used would be .8 to 1.0 from Figure 3 which contains 33, or 43%, of cases;

.../13

b. Optimal Quarters. For a proportion of track given in quarters, the intervals used must contain the greatest number of cases (gaps are allowed). For example, if the proportion were 1/2, the first and fourth quarters would be used which contain 46, or 61% of cases; and

c. Expand in Tenths from Centre Point (CP). This scheme was added in an attempt to produce areas similar to those formed by the original OTV study (Reference 1) where the expansion was relative to the CP. For the recent data the CP was at about .6 of track length. The areas are centred on the CP and expand in tenths toward both the LKP and destination. Since only two cases were beyond the destination these areas are truncated at the destination. For example, the length interval of the first area would be from .5 to .7 of track, the second from .4 to .8, and so on.

22. The square mileage of an area can be calculated as follows:

$$\text{Square Mileage} = \text{Track Length} \times \text{Length Factor} \times 2 \times \text{Offset}$$

where Length Factor is the proportion of Track Length covered by this area.

The objective of this analysis is to minimize the size of the search area for a given probability of containing the crash site. It is not necessary, however, to determine the actual square mileage. Since the track length and '2' in the above equation have no effect on the relative results, a parameter called Area Factor, as defined below, will be used for purposes of comparison:

$$\text{Area Factor} = \text{Length Factor} \times \text{Offset}$$

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Square mileage is easily determined using Area Factor as follows:

$$\text{Square Mileage} = \text{Area Factor} \times 2 \times \text{Track Length}$$

23. Annex A shows the detailed calculations carried out to determine Area Factors for the various probabilities of whereabouts and schemes for defining lengths of search areas. A summary of the results is given in Table I. In Table I, for each of a number of Length Factors an offset is given, which will produce an area having a specific probability of containing a crash site. The resulting Area Factors are also shown with the smallest value representing the optimal search area for a given probability. For example, using Optimal Quarters for establishing area length and a Probability of Whereabouts of .7, two areas can be defined. One area covers the first quarter and last half of track and has an offset of 26nm either side of track which results in an Area Factor of 19.5. The other area includes the entire length of track, with an offset 8nm either side of track, resulting in an Area Factor of 8.0. Obviously in this case, the search area stretching the entire length of track is the best since the Area Factor, and therefore the square mileage, is about 40% of the other area defined. In this scenario it is not possible to form a search area using less than 3/4 of track length and still maintain the .7 probability of whereabouts.

24. With one exception, the minimum Area Factors for each scheme and probability combination occur when the Length Factor is one. A Length Factor of one implies that the search area stretches along the entire length of track. The one exception occurred at a probability of .5 using Optimal Quarters for establishing length. In this case a search area encompassing the first quarter and last half of track with an offset of 5nm had a slight advantage over the full length value (Area Factors 3.75 and 4.1, respectively).

.../15

TABLE I - Area Factors for Various Probabilities of Whereabouts

			PROBABILITY OF WHEREABOUTS							
DETERMINATION OF AREA LENGTH			.5		.6		.7		.8	
Scheme	Length Factor	Interval	Offset	Area Factor	Offset	Area Factor	Offset	Area Factor	Offset	Area Factor
Optimal	.4	.6-1.0	68	27.2	----	----	----	----	----	----
Continuous	.5	.5-1.0	21	10.5	----	----	----	----	----	----
Tenths	.6	.4-1.0	14	8.4	64	38.4	----	----	----	----
	.7	.3-1.0	8	5.6	26	18.2	----	----	----	----
	.8	.2-1.0	6	4.8	10	8.0	34.5	27.6	----	----
	.9	.1-1.0	5.5	5.0	9	8.1	32	28.8	----	----
	1.0	0-1.0	4.1	4.1	5	5.0	8	8.0	14	14.0
Optimal	.50	0-.25, .75-1.0	14.5	7.25	----	----	----	----	----	----
Quarters	.75	0-.25, .50-1.0	5	3.75	8.5	6.38	26	19.5	75	56.2
	1.00	0-1.0	4.1	4.1	5	5.0	8	8.0	14	14.0
Expansion	.8	.2-1.0	6.0	4.8	10	8.0	34.5	27.6	----	----
from	.9	.1-1.0	5.5	5.0	9	8.1	32.0	28.8	----	----
CP	1.0	0-1.0	4.1	4.1	5	5.0	8	8.0	14	14.0

NOTES: 1. Schemes are defined in paragraph 21.

2. The circled Area Factors represent the minimum for each scheme and probability combination.

3. Blank entries imply that it is not possible to produce a search area of the given probability with that particular Length Factor.

4. Detailed calculations are given in Annex A.

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25. It is obvious from this analysis that search areas encompassing the entire track length are optimum for probabilities of whereabouts of .6 and higher. Because of the number of cases occurring along the entire track and particularly within the first 10% of track, the assumption of Normally distributed cases about the CP is no longer evident. Therefore, search areas expanding from the CP are no longer practical. Even if the cases which appear to be directly related to a take-off or a landing are taken out, there are still sufficient incidents in the first and last 10% of track to warrant including these areas in the primary search area.

26. The clustering of the cases close to track is somewhat surprising considering the fact that straight line tracks were assumed between LKP and destination. This suggests that pilots are tending to fly direct as opposed to following roads, rivers, railroads, etc. The cases examined in Reference 2 involving VFR flights in the mountains, on the other hand, were clustered about VFR routes such as river valleys. Bad weather and low ceilings have a much more profound effect on the ability to fly direct in the mountains than in other parts of Canada. This explains the disparity between the two data sets since weather is the major contributing factor in air distress cases.

A NEW SEARCH METHOD

27. Table II shows the percentages of cases found within expanding rectangular search areas about the intended track. For simplicity, expansion in offset is done in multiples of 5nm. Also shown in the Table are the number of additional cases contained in each area over the previous area. There is little to be gained in expanding beyond 15nm. In fact, between 15nm and 30nm only three additional cases are added, while the size of the area doubles.

.../17

TABLE II - Cases Contained Within Expanding Rectangular Areas Covering Entire Intended Track Length

OFFSET (NM)	CASES WITHIN AREA		ADDITIONAL CASES
	NUMBER	PERCENTAGE	OVER PREVIOUS AREA
5	47	62%	--
10	60	79%	13
15	63	83%	3
20	64	84%	1
25	65	86%	1
30	66	87%	1

28. Based on the recent data from Reference 3, the following two-area system is proposed which applies to any track length:

a. Area 1 - a rectangle 10nm either side of track commencing 10nm before LKP and extending 10nm beyond the destination; and,

b. Area 2 - a rectangle 15nm either side of track commencing at the LKP and extending 15nm beyond the destination.

Where en route turning points have been specified in a missing aircraft's flight plan, the areas should be adjusted so that the outside boundary of each area is an arc of 10nm for Area 1 and 15nm for Area 2, centred on the turning point. These areas are shown in Figure 5.

29. A proposed procedure and amendment for the National Search and Rescue Manual (Reference 4) is given in Annex B. Search methods are normally referred to using catchy acronyms, however, since the author is not clever enough to generate one of these, the rather unoriginal acronym 'NTAM' for New Two-Area Method is suggested.

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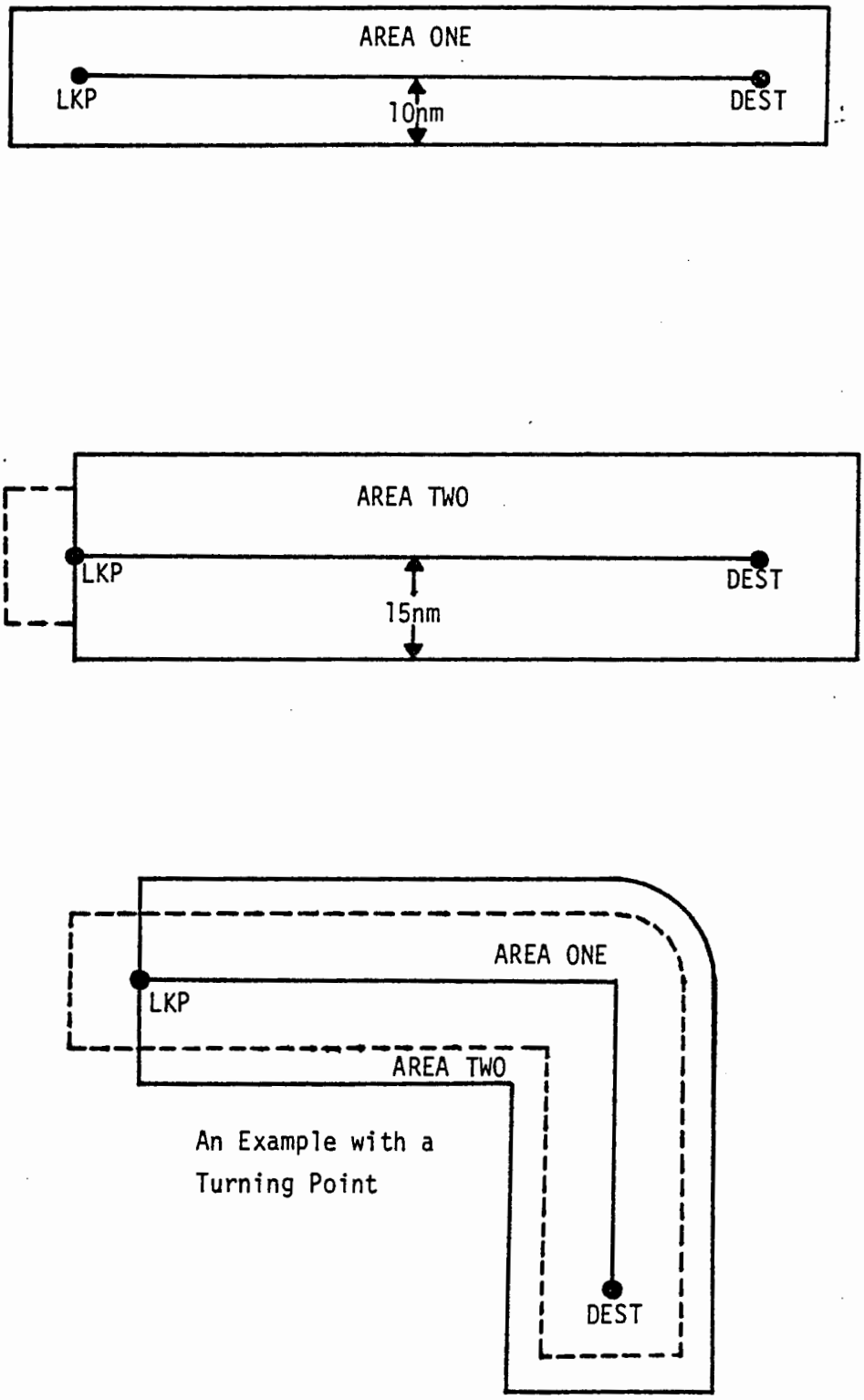

Figure 5 - Illustration of New Search Method Areas

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30. The addition of overfly and underfly areas does not increase the chances of containing a crash based on the recent data. These areas were added because of the concentration of cases in the vicinity of the LKP and destination. Since many of these cases are directly related to problems occurring shortly after take-off or during descent for landing, there is some chance that crashes will occur in these areas.

31. Besides the obvious advantage of a reduction in search area, the NTAM is also much simpler to apply as compared to MOTV. It applies to any track length and square mileages are easily obtained as shown below:

<u>Area 1</u> - Square Mileage = $(D + 20) \times 20$

<u>Area 2</u> - Square Mileage = $(D + 15) \times 30$

where D is the intended track length in nms.

32. Some limitations of the NTAM are discussed below:

a. like the MOTV, the NTAM is based only on a statistical analysis of crash site position relative to intended track. Therefore, it is meant to apply in cases when there is little else to go on besides a LKP and a destination. Any additional information on a particular case should be used by the Searchmaster to modify the predefined areas or to create new ones;

b. the NTAM applies in cases where straight line tracks are used between the LKP and destination or between any turning points specified in a flight plan. A significant deviation from a straight line, say to follow a river, road or some other physical feature, reduces the effectiveness of the NTAM. In cases like these, a possible alternative is the MVFR method (see Reference 2);

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c. no practical search method can be devised which will contain 100% of cases. In order to produce search areas that can be covered in a reasonable amount of time, a certain percentage of cases will be outside the search area. Based on the recent data, the NTAM excludes 17% of cases;

d. the crash site data may be somewhat biased since cases where the crash site was not found are not included. It is not known whether these cases would be outside search areas or well hidden within them. Since ELT (Electronic Locator Transmitter) cases are included in the database and are normally found regardless of how far the missing aircraft was off course, it is felt that the sample is representative of the true distributions; and

e. the sample size used for this study was 76 cases whereas 175 cases were used for the original OTV work, followed by an additional 63 cases in a follow-up analysis (Reference 5). However, approximately one-third of the cases involved track lengths of under 100nm which were treated separately in the OTV analysis. Also, because the OTV analysis used several different groupings of intended track lenths, the sample size for validation in any grouping is small. For the present study, because intended track length was essentially removed as a factor, all the 76 cases were used for validation. The data covers a period of nearly six years and should be representative of current trends.

SUMMARY

33. An analysis of air distress cases covering the period 1981 to 1986 has revealed that significant changes have occurred in the distribution of crash locations relative to intended tracks in comparison to

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previous data. In particular, crash sites are tending to cluster much closer to intended track regardless of intended track length. This is probably due to improvements in both land-based and airborne navigation equipment.

34. Rectangular shaped areas can be established about intended tracks which have a given probability of containing the crash location, based on the data. For probabilities of .6 or higher, the minimum areas stretch along the entire intended track length. Detailed calculations are given in Annex A.

35. A two-area system has been proposed for searches involving missing aircraft on direct flights to known destinations. The system referred to as the New Two-Area Method, or NTAM, contains about 83% of cases based on the recent data. The NTAM results in smaller search areas than the previous method and is much simpler to apply. Limitations are discussed in paragraph 32.

RECOMMENDATION

36. It is recommended that the New Two-Area Method (NTAM) by adopted for inland searches for missing aircraft in Canada, subject to the constraints discussed in this paper. A proposed amendment to the National Search and Rescue Manual is given in Annex B.

.../22

REFERENCES

1. R.P. Hypher, E.J. Emond, Captain E.C. O'Neill, Analysis of Distress Air Cases in Relation to Crash Position and Intended Track: 1968-73, ORAE Report No. 51, August 1974.

2. Paul H. Saunders, Search Planning Strategy in the Mountainous Regions of Canada, ATGOR Report R1/85, November 1985.

3. Captain A.M. Shurson, Review of the MOTV Search Method - Analysis of Air Distress Cases: 1981-86, DAOR Staff Note 87/3, February 1987.

4. National Search and Rescue Manual, B-GA-209-001/FP001, 1985-04-01.

5. K.B. Laver, Follow-Up Analysis of ORAE Report No. 51 (The OTV Search Method), ATGOR Staff Note 11/77, July 1977.

DETERMINATION OF MINIMUM AREAS

A1. In this Annex the methodology for defining areas for a given probability of whereabouts is described. It is assumed that the areas will be rectangular in shape with the length dimension along the intended track and the width dimension perpendicular to it. The terms used for the analysis are defined below:

a. 'P_W' is Probability of Whereabouts associated with an area;

b. 'ℓ' is the Length Factor which represents the proportion of the track covered by the search area. For example, a search area covering the first and last quarter of track would have a Length Factor of .5;

c. '$P_L(\ell)$' is the probability that a crash site will occur within a specified interval of track having a length factor of ℓ. For example, if the specified interval were the second half of track, $P_L(.5)$ would be the probability that a crash occurs in the interval .5 to 1.0 of track;

d. 'o' is an Offset distance in nautical miles from the intended track and represents half of the width of a search area;

e. '$P_0(o)$' is the probability that a crash site will occur within 'o'nm of intended track; and

.../A-2

f. 'A_F' is the Area Factor which is defined as follows:

$$A_F = \text{Length Factor} \times \text{Offset}$$

or

$$A_F = \ell \times o \qquad (1)$$

A_F can be used in determining square mileage as follows:

$$\text{Square Mileage} = A_F \times 2 \times D \qquad (2)$$

where D = Intended Track Length.

A2. Because the distributions of offset and actual track length were found to be independent, a joint probability function can be derived as shown below:

$$P_W = P_L(\ell) \times P_O(o) \qquad (3)$$

For a given P_W, several combinations of $P_L(\ell)$ and $P_O(o)$ can be determined to solve the equation by simple adjusting 'ℓ' and 'o'. The problem is to determine the combination that produces the minimum square mileage. Since equation (2) above always contains the factors 2 and D, and these are constant for a given case, we need only minimize A_F.

.../A-3

A3. Since no mathematical distributions were found which provided a good fit to the probability functions $P_L(\ell)$ and $P_0(o)$, it was decided to use the empirical data directly. The cumulative percentage plot for offset, shown in Figure A1, was used to approximate the function $P_0(o)$. $P_L(\ell)$ is more difficult to determine since any value of 'ℓ' could produce a number of probabilities depending on the interval of track represented. For example, if 'ℓ' were .5 the interval could be the first and last quarters, the first half, and so on.

A4. It was decided to use the data as shown in Figure 3 of the main paper, that is, grouped in tenths and quarters of track. Obviously the optimal interval of track to use for a given value of 'ℓ' would be the interval containing the largest number of cases. This, however, could result in a number of discontinuous intervals. For example, the optimal interval for an 'ℓ' of .3 would be 0-.1, .7-.8 and .9-1.0. It would be unrealistic to break a search area into sections like this especially when one considers the rather small sample size. Therefore, three different schemes were devised for establishing intervals for a given 'ℓ':

a. Optimal Continuous Tenths - for an 'ℓ' given in tenths, the continuous interval of track having the greatest number of cases.

b. Optimal Quarters - for an 'ℓ' given in quarters, the intervals containing the greatest number of cases; and

.../A-4

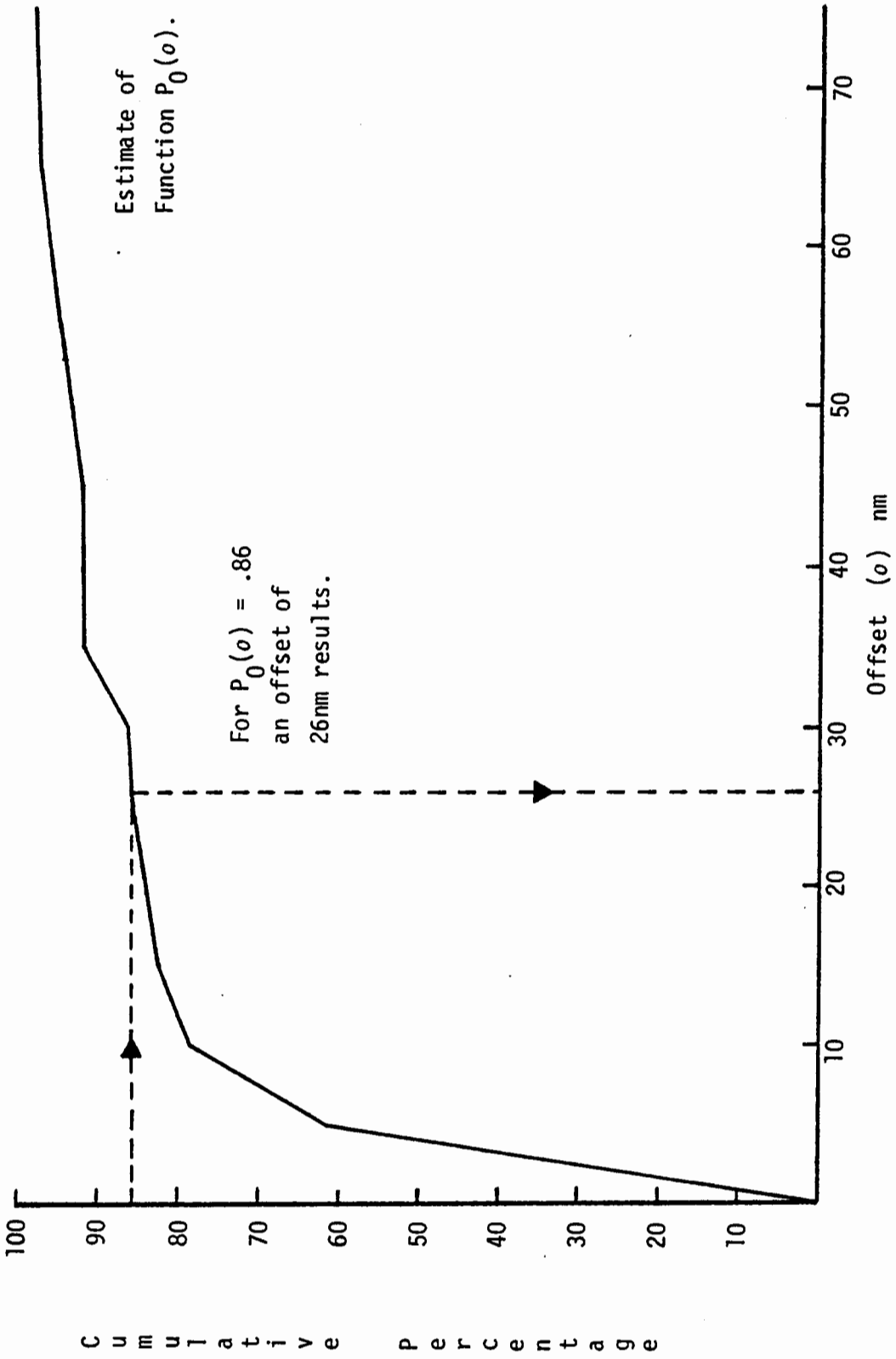


Figure A1 - Cumulative Percentage Plot of Offsets

.../A-5

c. Expansion from Centre Point (CP) - the intervals used are centred on the CP (.6) and expand in tenths in both directions from the CP. The interval is truncated at the destination, since very few cases were found beyond the destination.

The optimal intervals and associated values of '$P_L(\ell)$' and 'ℓ' for the three schemes are shown in Table A1.

A5. The procedure used for determining the minimum Area Factors for a given P_W is described below:

a. select from Table A1 all the intervals which yield values of $P_L(\ell)$ greater than P_W;

b. for each of these values, determine a value of $P_0(o)$ which will yield the given value of P_W. This is accomplished by solving equation (3) for $P_0(o)$ as follows:

$$P_0(o) = \frac{P_W}{P_L(\ell)} \qquad (4)$$

c. determine the offset 'o' from Figure A1 which will produce the values of $P_0(o)$ calculated in equation (4). This is demonstrated graphically in Figure A1; and

d. the offset determined in step c is then combined with 'ℓ' to give A_F using equation (1).

.../A-6

A6. An example of the procedure is given below:

$P_W = .7$

Scheme - Optimal Quarters

a. from the section of Table A1 dealing with Optimal Quarters, only two of the intervals produce values of $P_L(\ell)$ greater than .7 -

(1) $\ell = .75$, Interval 0-.25, .5-1.0, $P_L(.75) = .816$, and

(2) $\ell = 1.00$, Interval 0-1.0, $P_L(1.0) = .974$;

b. using equation (4) -

(1) $P_0(o) = \frac{P_W}{P_L(.75)} = \frac{.7}{.816} = .858$, and

(2) $P_0(o) = \frac{P_W}{P_L(1.0)} = \frac{.7}{.974} = .719$;

c. from Figure A1 -

(1) $P_0(o) = .858$ for $o = 26$nm, and

(2) $P_0(o) = .719$ for $o = 8$nm; and

.../A-7

d. then, using equation (1) -

(1) $A_F = \ell \times o = .75 \times 26 = 19.5$, and

(2) $A_F = \ell \times o = 1.0 \times 8 = 8.0$.

So, the minimum A_F for this example would be 8.0 which occurs when the search area extends along the entire track with an offset 8nm either side.

A7. Tables A2, A3 and A4 give the results for the three schemes listed in paragraph A4. These results are summarized and discussed in the main section of this report.

.../A-8

TABLE A1 - Length Factors and Probabilities Using Different Schemes for Determining Optimal Intervals

Optimal Continuous Tenths			Optimal Quarters			Expansion From Centre Point		
ℓ	Interval	$P_L(\ell)$	ℓ	Interval	$P_L(\ell)$	ℓ	Interval	$P_L(\ell)$
.1	.9-1.0	.197	.25	.75-1.0	.382	.2	.5- .7	.158
.2	.8-1.0	.303	.50	0-.25, .75-1.0	.605	.4	.4- .8	.316
.3	.7-1.0	.434	.75	0-.25, .50-1.0	.816	.6	.3- .9	.500
.4	.6-1.0	.513	1.00	0-1.0	.974	.8	.2-1.0	.763
.5	.5-1.0	.592				.9	.1-1.0	.789
.6	.4-1.0	.618				1.0	0-1.0	.974
.7	.3-1.0	.697						
.8	.2-1.0	.763						
.9	.1-1.0	.789						
1.0	0-1.0	.974						

.../A-9

TABLE A2 - Area Factors for Various Probabilities of Whereabouts Using Optimal Continuous Tenths for Establishing Length Factor

			PROBABILITY OF WHEREABOUTS (P_W)											
			.5			.6			.7			.8		
Length Factor(ℓ)	Interval	P_L	P_0	Offset (o)	Area Factor	P_0	Offset (o)	Area Factor	P_0	Offset (o)	Area Factor	P_0	Offset (o)	Area Factor
.4	.6-1.0	.513	.975	68	27.2	--	--	--	--	--	--	--	--	--
.5	.5-1.0	.592	.845	21	10.5	--	--	--	--	--	--	--	--	--
.6	.4-1.0	.618	.809	14	8.4	.971	64	38.4	--	--	--	--	--	--
.7	.3-1.0	.697	.717	8	5.6	.861	26	18.2	--	--	--	--	--	--
.8	.2-1.0	.763	.655	6	4.8	.786	10	8.0	.917	34.5	27.6	--	--	--
.9	.1-1.0	.789	.634	5.5	5.0	.760	9	8.1	.887	32.0	28.8	--	--	--
1.0	0-1.0	.974	.513	4.1	4.1	.616	5	5.0	.719	8.0	8.0	.821	14	14.0

.../A-10

TABLE A3 - Area Factors for Various Probabilities of Whereabouts Using Optimal Quarters for Establishing Length Factor

			PROBABILITY OF WHEREABOUTS (P_W)											
			.5			.6			.7			.8		
Length Factor(ℓ)	Interval	P_L	P_0	Offset (o)	Area Factor	P_0	Offset (o)	Area Factor	P_0	Offset (o)	Area Factor	P_0	Offset (o)	Area Factor
.25	.75-1.0	.382	--	--	--	--	--	--	--	--	--	--	--	--
.50	0-.25, .75-1.0	.605	.826	14.5	7.25	--	--	--	--	--	--	--	--	--
.75	0-.25, .50-1.0	.816	.613	5	3.75	.735	8.5	6.38	.858	26	19.5	.980	75	56.2
1.00	0-1.0	.974	.513	4.1	4.1	.616	5	5.0	.719	8	8.0	.821	14	14.0

.../A-11

TABLE A4 - Area Factors for Various Probabilities of Whereabouts Using Expansion From CP for Establishing Length Factor

			PROBABILITY OF WHEREABOUTS (P_W)											
			.5			.6			.7			.8		
Length Factor(ℓ)	Interval	P_L	P_0	Offset (o)	Area Factor	P_0	Offset (o)	Area Factor	P_0	Offset (o)	Area Factor	P_0	Offset (o)	Area Factor
.6	.3- .9	.500	--	--	--	--	--	--	--	--	--	--	--	--
.8	.2-1.0	.763	.655	6.0	4.8	.786	10	8.0	.917	34.5	27.6	--	--	--
.9	.1-1.0	.789	.634	5.5	5.0	.760	9	8.1	.887	32.0	28.8	--	--	--
1.0	0-1.0	.974	.513	4.1	4.1	.616	5	5.0	.719	8.0	8.0	.821	14	14.0

ANNEX B
TO ATGOR Staff Note 2/87
DATED September 1987

A PROPOSED AMENDMENT TO THE NATIONAL SEARCH AND RESCUE MANUAL

B1. The following pages of this Annex contain a proposed amendment to Reference 4. The amendment deals exclusively with those parts of Chapter 4 of the Reference where the MOTV method is discussed. Since paragraph and figure numbers will undoubtedly change when Reference 4 is rewritten, these numbers are not included in the proposal.

B2. A proposed change to Reference 4 based on the MVFR method has been written under separate cover.

.../B-2

SEARCH PLANNING METHODS

The manual methods include the MINIMAX computation of search areas, primarily from the US National SAR Manual, and the Canadian developed Mountainous Visual Flight Rule (MVFR) method and New Two-Area Method (NTAM). Each will be thoroughly discussed in this chapter.

Probability Area - In the absence of information to the contrary, it may be assumed that the most probable area within which a missing aircraft will be found is that along the intended track from LKP to intended destination and within a reasonable distance either side of track. A study of Canadian data which led to the NTAM and MVFR methods confirmed that definitive area sizes could be established in relation to probability of whereabouts values of an incident location.

INLAND SEARCH AREAS

Two predefined methods of determining and plotting inland search areas have been developed for use in Canada. They are:

a. the Mountainous Visual Flight Rule (MVFR) method based on empirical data collected on Canadian inland SAR incidents involving VFR flights in mountainous regions; and

b. the New Two-Area Method (NTAM) based on empirical data collected on Canadian inland SAR incidents from 1981 to 1986, excluding the data used for the MVFR study.

These methods were developed for cases where there is little information to go on besides a Last Known Position (LKP) and a destination. The MVFR method applies in cases where the intended route of the missing aircraft involves navigation by following such things as valley-floors, rivers and

.../B-3

roads as opposed to point-to-point navigation. The NTAM applies in point-to-point cases. If the searchmaster has evidence to suggest that these methods are not applicable then they should be modified subject to the concurrence of the applicable SRR Commander through the respective OIC RCC. Reasons for, and details of the modification are to be included in the SITREP.

The New Two-Area Method

Based on historical data, two definitive probability areas have been established and are categorized according to the priority with which they should be searched. The method takes into account the variations in known crash positions along track and across track, combining these variations in such a way as to assign the probabilities of coverage of a crash position by using given rectangular areas.

The use of the NTAM requires the following information:

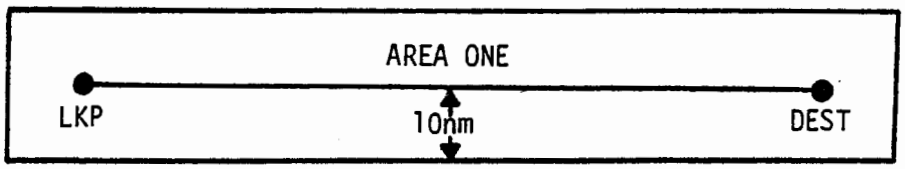
a. the Last Known Position (LKP);

b. the intended route; and

c. the intended destination.

The NTAM applies to all intended track lengths. The two areas are defined below:

a. Area One - a rectangle 10nm each side of track beginning 10nm before LKP and extending 10nm beyond destination; and



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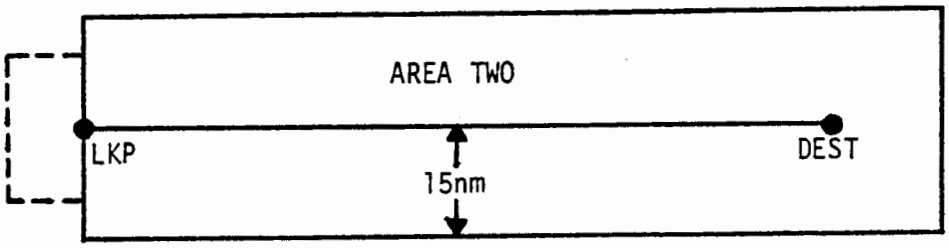
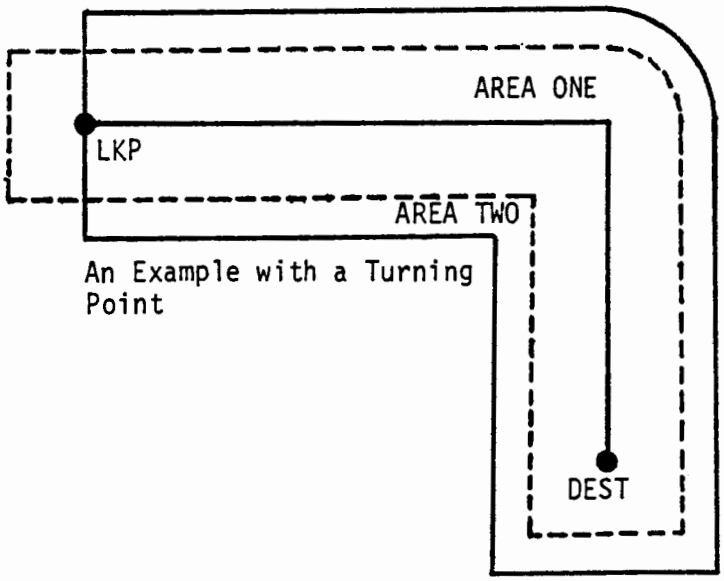
b. Area Two - a rectangle 15nm each side of track beginning at the LKP and extending 15nm beyond destination. Area Two includes that portion of Area One where overlapping occurs.



A graph providing ready reference for determining the square mileage of search areas is included on the following page.

Where an en route turning point is specified in a flight plan, the outside boundary of each area shall be an arc using the turning point as centre and a radius equal to 10nm for Area One and 15nm for Area Two (see figure below).



An Example with a Turning Point

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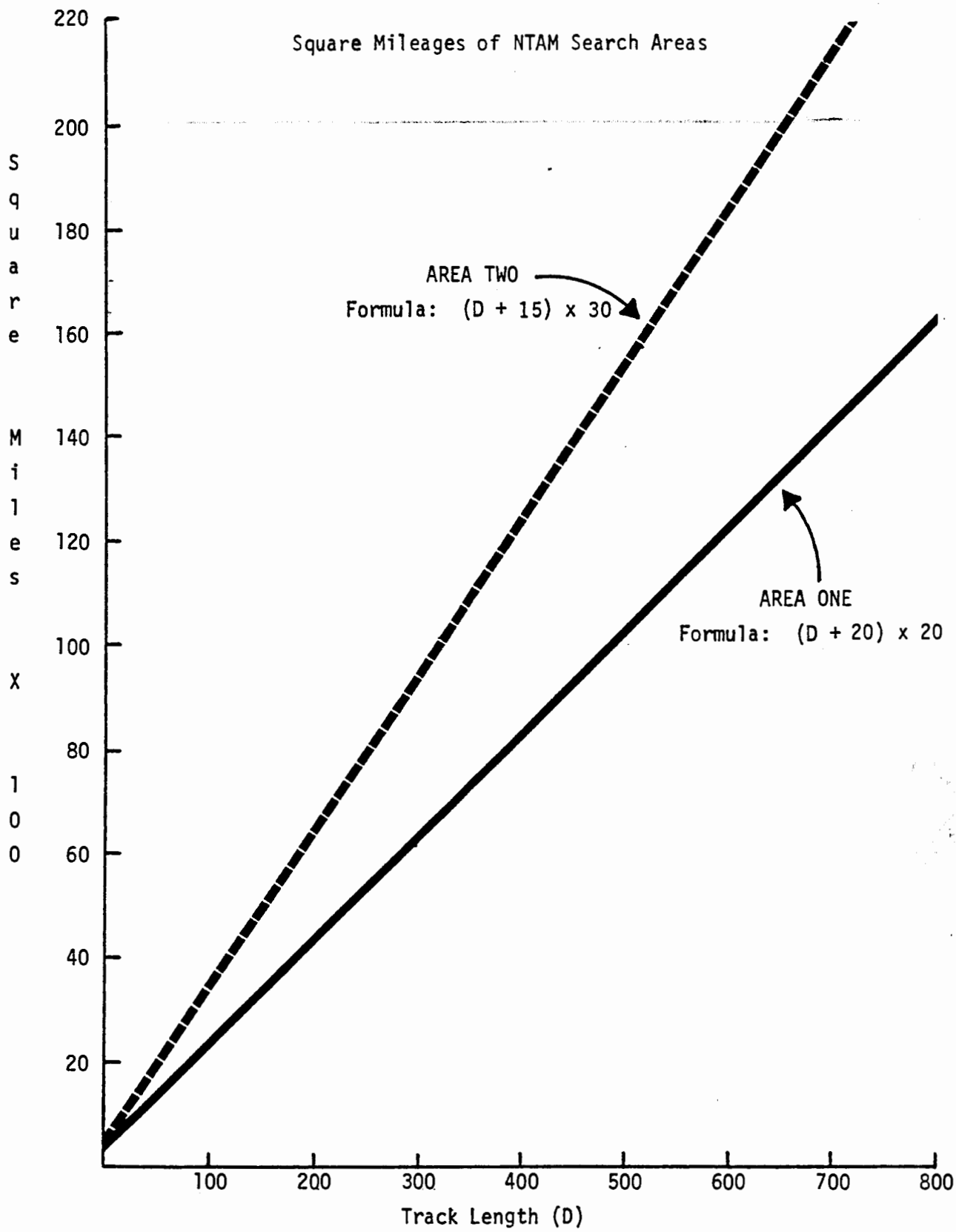
Square Mileages of NTAM Search Areas
Square Miles X 100
220
200
180
160
140
120
100
80
60
40
20
AREA TWO
Formula: (D + 15) x 30
AREA ONE
Formula: (D + 20) x 20
100
200
300
400
500
600
700
800
Track Length (D)

.../B-6

Normally there is no requirement to adjust the search areas in an inland search. Such adjustment would have to be considered, however, if any of the three basic factors listed previously should change during the search.

Probability of Whereabouts (PW) - The PW or density of crash positions based on the data varies in the along-track and off-track directions. Based on the data from 1981 to 1986 the PW is 79% for Area One and 83% for Area Two. Generally, cases tend to cluster close to intended track with the density dropping off sharply as offset increases. There are concentrations of cases in the first tenth and last tenth of track but very few cases in the underfly and overfly areas. There also tends to be more cases in the second half of track than in the first half.

Search Sequence - There is no single sequence of search types or patterns which will be suitable for all searches.

For searches where the NTAM is used, the following search sequence is suggested, unless circumstances dictate otherwise:

a. carry out track crawls along the missing aircraft's intended track and thoroughly check in the vicinity of LKP and destination;

b. carry out electronic searches and cooperating target/survivor searches, covering the entire high probability areas;

c. search Area One in the following sequence -

(1) the last quarter of track from the track outwards with equal priority along track,

.../B-7

(2) the third quarter from the track outwards with equal priority along track,

(3) the first quarter from the track outwards commencing at the LKP,

(4) the second quarter from the track outwards with equal priority along track, and

(5) the overfly area followed by the underfly area commencing at the destination and LKP respectively; and

d. expand the search to Area Two and use the same sequence as given in c above.

WHERE TO LOOK: HOW VFR FLIGHT PLANS AFFECT A SEARCH AND RESCUE RESPONSE

By

Christopher D. Holmes

A Graduate Research Project Submitted to the Extended Campus in Partial Fulfillment of the Requirements of the Degree of Master of Aeronautical Science

Embry-Riddle Aeronautical University
Extended Campus
Langley Air Force Base Resident Center
July 1999

WHERE TO LOOK: HOW VFR FLIGHT PLANS AFFECT A SEARCH-AND-RESCUE RESPONSE

by

Christopher David Holmes

This Graduate Research Project was prepared under the direction of the candidate's Research Committee Member, William Clark, Adjunct Instructor, Extended Campus, and the candidate's Research Committee Chair, Bruce Conway, Assistant Professor, Extended Campus, and has been approved by the Project Review Committee. It was submitted to the Extended Campus in partial fulfillment of the requirements for the degree of Master of Aeronautical Science

ABSTRACT

Writer: Christopher D. Holmes

Title: WHERE TO LOOK: HOW VFR FLIGHT PLANS AFFECT A SEARCH-AND-RESCUE RESPONSE

Institution: Embry-Riddle Aeronautical University

Degree: Master of Aeronautical Science

Year: 1999

This project investigates the extent to which flight plans have aided searchers in determining a search area. Most pilots enjoy flying under visual flight rules (VFR) as those rules do not require any communication and/or coordination with air traffic control. That being the case, many pilots neglect to file a flight plan with air traffic agencies, outlining their route of flight and providing contact telephone numbers. While this does not pose problems under normal operating conditions, should the pilot be forced to land or even crash, a flight plan is virtually the only method of determining the aircraft's last whereabouts. As this report will demonstrate, those who run into trouble and do not have a flight plan on file will be forced to wait several hours, if not days, before being rescued.

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CHAPTER I

INTRODUCTION

General Background of the Study

Search-and-rescue (SAR) is a time-consuming process. It takes many hours to determine if there is indeed an objective needing assistance and that having been verified, where the objective is. Time spent defining exactly where to search can impinge on a response to a SAR incident. Those involved in SAR, having faced so many situations in which the search area is ill-defined, often have elaborate procedures in place to ensure, if and when SAR resources are dispatched, those resources are sent to the correct location. Those procedures mean that someone who really is in distress simply will have to wait while the SAR "system" determines where to go. To complicate matters, searchers very often have to validate a distress call, taking additional time away from responding to an urgent case. Any procedure that can ensure searchers have a verifiable starting point can only improve the accuracy and rapidity of a SAR response.

Purpose of the Study

The Air Force Rescue Coordination Center (AFRCC) at Langley Air Force Base, Virginia, is tasked by Presidential Directive to be the focal point for all federal government involvement in SAR (Joint Publication 3-50, 1991, p. 1-4). To respond to one of the three major categories of SAR cases for which the AFRCC is responsible, the AFRCC maintains a communications watch with the Federal Aviation Administration

(FAA) for reports of missing/overdue aircraft. Determining exactly where an aircraft is, or was last known to be, involves a great deal of effort. Fixed base operators, tower controllers, AFRCC controllers, Air Route Traffic Control Center controllers, weather observers, and the like are all involved in figuring out the last position of an aircraft. In many cases, all that effort yields the simple fact the pilot neglected to close his/her flight plan upon landing at the destination. Unfortunately, forgetfulness is human nature and not easily remedied.

However, in those situations in which the pilot really is in distress somewhere, it takes a concerted effort on the part of all the agencies listed above to ensure SAR responders are sent to the correct area. A considerable amount of time is devoted to analyzing radar data and the pilot's intentions to verify a last known position. By filing a flight plan, in which a pilot details his/her point of origin, point of destination, and intended route of flight between the two, a pilot can provide immense assistance to SAR personnel. With the knowledge of where the pilot actually was in relation to where he/she was supposed to be, one can rapidly discern the two points between which the pilot went missing. Overall, this will not only reduce the amount of work AFRCC controllers must perform, but will also afford those SAR controllers the opportunity to accurately provide SAR responders the best defined, and hence manageable, area in which to search.

How The System Currently Works

Private aircraft pilots can decide, based upon their abilities, ratings, and the prevailing weather, whether to fly under visual flight rules (VFR) or instrument flight rules (IFR). The majority of the time, the weather is such that pilots can "see and avoid"

other aircraft and cloud formations and so, pilots choose to fly VFR. As long as the pilot can maintain the minimum clearance from weather as specified in the Federal Aviation Regulations, and not fly into restricted airspace (such as the airspace around busy airports like Washington Dulles), contact with air traffic control is not necessary (Nolan, 1994, p. 149). What that essentially means is that pilots can fly wherever they desire and not be required to be in radio contact with anyone. In fact, pilots often choose to fly VFR because it is the pilots themselves who determine the route and altitude, basing their decision solely on the weather and the standard "hemispheric" rule about altitude based on direction flown (Benenson, 1997, p. 52). As one author described it: "VFR flying is one of the best individual freedoms left in the United States…[One] can take a basic airplane and fly almost anywhere in the country, independently, with no government help along the way and with the success of the mission based entirely on the individual" (Collins, 1992, p. 96).

Unfortunately, this "freeform flying" coincides with most pilots forgetting to think about what happens if they run into trouble and are forced to land somewhere other than their destination or worse, crash. As contact with air traffic control (ATC) is not mandatory, no one from air traffic control is watching out for them to notice when they drop off a radar screen or fail to arrive at an airport. The sole method by which a VFR pilot's flight progress (or lack thereof) can be monitored is through a flight plan. In keeping with the spirit of the VFR rules, which allow a pilot the freedom to fly where and how he/she desires, VFR flight plans are strictly "voluntary and are used by the FAA only to assist in locating lost or overdue aircraft" (Nolan, 1994, p. 149).

Many pilots consider filing flight plans, but do not because they feel the time allotted between the estimated time of arrival and an alarm being raised is too "generous" (English, 1999, p. 12). They cannot see the utility in telling air traffic control when they'll be somewhere if no one will start looking for them until they're overdue by an hour. The logic continues that the alarm should be raised sooner, especially if a pilot has taken the trouble to precisely plan a flight and tell someone about it. In addition to that, many pilots feel the "hassle" involved if one forgets to close a flight plan is simply not worth the trouble of filing in the first place (English, 1999, p. 12). But the benefit of providing searchers some details as to where a pilot may be far outweigh any "hassles" of filing a flight plan.

Flight Plans

A flight plan is, quite simply, "a system of recording information relating to a particular airplane's operation" (Taneja, 1987, p. 35). There are three basic types:

a. VFR, filed by a pilot who intends to fly following visual flight rules, and is used for SAR purposes only;
b. IFR, filed by a pilot who intends to fly following instrument flight rules, and is used to begin air traffic control clearances and handling in addition to SAR;
c. DVFR, filed whenever a pilot intends to fly, using visual flight rules, in the Air Defense Identification Zone surrounding the US (Taneja, 1987, p. 36).

To file a VFR flight plan, all a pilot has to do is complete the Flight Plan form (see Appendix A). Apart from such basic data as the type and callsign of the aircraft, the

pilot indicates from which airport he/she is departing and at what time, at which airport he/she is arriving and at what time, and any stops or waypoints he/she plans to make or follow between the two. Virtually all VFR transactions, such as weather briefings and filing flight plans, are handled by any one of 61 ATC facilities called Flight Service Stations (FSS) nation-wide (Nolan, 1994, p. 477). The pilot provides the flight plan data either in person, or, more commonly, over the telephone to an FSS. The FSS representative then files this data into the FSS computer (Nolan, 1994, p. 439). There is no cost for filing, making flight plans a "free form of insurance" (Benenson, 1995, p. 44).

The flight plan remains dormant in the FSS computer until the pilot makes radio contact with the FSS once he/she has taken off. This is referred to as "activation" and is not automatic, relying solely on the pilot's initiation through a radio call to the servicing FSS (Nolan, 1994, p. 439). This is done to reduce the chance of a false SAR alarm. If the flight plan was activated once the pilot called it in, and the pilot decided to either not fly or delay the flight for some reason, the computer would believe the pilot overdue when he/she didn't arrive at the destination at the indicated time. By waiting until the pilot activates the plan via a radio call, FSS ensures the computer has a more accurate representation of the pilot's flight. Once the pilot arrives at his/her destination, he/she must call (radio or telephone) the servicing FSS and close the flight plan. To close a flight plan, the FSS representative merely enters the arrival time and airport into the computer. Failure to notify FSS to close (or amend) the flight plan by the estimated arrival time automatically results in the computer alerting the FSS to the fact the pilot is overdue. It is at this point that search-and-rescue operations begin.

Search-and-Rescue Response

FSS personnel, according to FAA Order 7110.10K (Flight Services), consider an aircraft overdue when "…it fails to arrive 30 minutes after its estimated time of arrival and communications or location cannot be established" (FAA 7110.10K, 1994, p. 8-1-1). These criteria have been programmed into the FSS computer to make things easier for the FSS controllers. At the time of the computer alert, the responsible FSS controllers, knowing that many pilots simply forget to close their flight plans, do their part to reduce false SAR activations by transmitting an Information Request ("INREQ") to any ATC agency that might have had contact with the aircraft. Those other agencies are then required to notify the FSS if indeed they have had contact with the objective. After one hour, if that communications search fails to determine the whereabouts of the subject aircraft, the FSS transmits an Alert Notice ("ALNOT"), an example of which may be found at Appendix B (FAA 7110.10K, 1994, p. 8-4-1). The ALNOT is sent to AFRCC for investigation. Information included therein is:

a. facility and person calling;

b. flight plan, including color of aircraft, if known;

c. time of last transmission received, by whom, and what frequency used;

d. last position report and how determined;

e. action taken by reporting facility and proposed action;

f. number of persons on board;

g. fuel status;

h. facility working aircraft and frequency;

i. last known position, estimated present position, and maximum range of flight

of the aircraft based on remaining fuel and airspeed;

j. position of other aircraft near aircraft's route of flight, when requested;

k. whether or not an Emergency Locator Transmitter signal has been heard or reported in the vicinity of the last known position;

l. other pertinent information (FAA Order 7110.65J, 1996, p. 10-3-1).

Upon receipt of the ALNOT, the watch supervisor at AFRCC assigns a controller to investigate. The controller has up to two hours to resolve two questions: whether or not the ALNOT represents a valid distress situation and what the last reported location of the objective (i.e. the aircraft) is (AFRCC, 1998, p. 2). If, by the end of that two hour point (or at any time prior to that if the controller feels he/she has answered the two criteria) the aircraft remains unlocated, the controller must dispatch SAR resources to attempt to find the missing aircraft (AFRCC, 1998, p. 2). Determining the last position of the aircraft is "essential…to have a good starting point for search planning" (Joint Pub 3-50, 1991, p. 4-3). After all, searchers must have a point at which to start! It is here, then, that the crux of this research lies.

Guiding Questions

The first question when examining AFRCC aircraft SAR data was to determine how many aircraft searches involved VFR aircraft. Then, having segregated those searches by VFR versus IFR aircraft, how many of the VFR flights were without a flight plan? Of those, how much time elapsed between the time of the aircraft's last known position (be it take-off time or a witness sighting) and when the aircraft was actually reported overdue? The next question involved calculating the amount of time elapsed between when the aircraft was reported missing to the time AFRCC dispatched search

teams (also referred to as "opening a mission"). Finally, what was the intensity of the search effort, focusing primarily on the total number of days? Of particular note in this last area will be whether or not the objective aircraft was found.

Delimitations

As mentioned before, a pilot's failure to close a flight plan is an item handled primarily by the pilot him/herself and procedures already exist by which a pilot is reminded to close his/her flight plan (witness the bottom, bold-printed, line in Appendix A). In addition, the Flight Service Stations (FSS) devote a good deal of effort to locate a VFR pilot who might have forgotten to close the flight plan. In many instances, this active searching is successful and AFRCC is never involved.

On the other hand, by accepting flight plan data, the ATC facility (FSS) has assumed responsibility for tracking the location of a particular aircraft (Illman, 1993, p. 180). Failure to provide enough detail in the flight plan, or even file a flight plan in the first place, often leads to confusion on the part of FSS and AFRCC as to the last known whereabouts of the subject aircraft. Resolving this uncertainty causes AFRCC to consume precious amounts of time. It is this area, therefore, that bears some investigation.

VFR vs IFR Aircraft

Air traffic control (ATC)'s primary responsibility is for the separation of aircraft in controlled airspace (Nolan, 1994, p. 216). In controlled airspace, "…Instrument Flight Rule (IFR) flights are required to receive [separation and other ATC] services, but VFR flights may not be" (Nolan, 1994, p. 149). It is the fact that VFR aircraft generally are not subject to the same stringent tracking and reporting requirements as IFR aircraft that

results in VFR aircraft becoming "overlooked." In fact, as detailed previously, VFR aircraft are not even required, in most instances, to contact air traffic control! VFR pilots are thus left, for all intents and purposes, to take care of themselves. While this is not generally a problem, it becomes an issue when a VFR aircraft goes overdue. If no one reports the aircraft overdue, and the pilot has not filed a flight plan to generate an automatic reaction to the fact he/she is overdue, it could be several days before a search effort is mounted. Compounding that, as discussed in the preceding sections, is the fact that no one knows with any certainty where the pilot was supposed to be. Therefore, the focus of this study is on the necessity of VFR pilots filing a flight plan.

Significance of Study

The goal of this study was to demonstrate the necessity of filing a flight plan. If VFR pilots habitually filed flight plans, it would make AFRCC's job that much more efficient in the event of a search. AFRCC controllers would know an approximate location at which to begin searching. Search teams would have a better definition (albeit broad in many cases) of a search area, allowing them to concentrate their efforts. That concentration, in turn, means a better probability of success in locating the objective.

The research question, then, was what was the average length of time taken to find a missing VFR aircraft without a flight plan versus that for a VFR aircraft on a flight plan? A corollary question was how much time did AFRCC devote to defining a search area for missing aircraft, both with and without flight plans? Finally, of those searches for aircraft without flight plans, how many of those remain unresolved?

CHAPTER II

REVIEW OF LITERATURE

There are many texts that deal with how air traffic control functions. Along the same lines, there are books on search-and-rescue, though generally one has to work in the SAR field in order to have access to that material. Due to the limited numbers of individuals who directly work SAR on a national level (about 40 at AFRCC) and the relatively few air traffic people who have dealings with SAR, there is not much in the way of literature devoted specifically to the interactions between SAR and ATC.

On the flip side, one can find a fair number of papers regarding air traffic functions and flight plans. Once again, however, there has been little, if any research, conducted along the lines of this paper. Accordingly, rather than a review of others' research, what follows is a review of closely related articles and their relation to the focus of this research project.

A Brief History of Automated Flight Plans

An article entitled "*The Federal Aviation Administration's Direct User Access Terminal Service Program*" is essentially a synopsis of the Direct User Access Terminal Service (DUATS) program's origins. In essence, the FAA introduced this program to reduce the workload on FSS personnel, as they are the predominant interfacers with VFR pilots. More germane to the area of this research, one could argue that part of the FAA's

reasoning behind the decision to implement DUATs was to subtly encourage pilots to file flight plans. After all, if filing is relatively easy and can be accomplished with a few keystrokes on a computer keyboard, pilots would be more likely to use it. Because of this, when the project was initiated, officials felt "90% of all…flight plan filing" could be accomplished through DUATS (Leps and Young, 1992, p. 311). The FAA's theory turned out to be true: DUATS was so popular that in its first year alone that it processed over two million actions (Leps and Young, 1992, p. 312). In fact, as there are now just a handful of FSS' nation-wide, DUAT automation is a virtual necessity. One would think that with such a readily available system, virtually every pilot would file a flight plan. Of concern, and curiosity, for this researcher is the reason why pilots, with such a system available, simply do not file flight plans.

While the bulk of the article is devoted to a review of the history of DUATs, the authors elicit another key area that directly relates to this research project. Pilots desiring to enter a flight plan must be licensed and have a current medical certificate in order to access the flight plan portion (Leps and Young, 1992, p. 313). The computer verifies the information entered by the pilot before the pilot is allowed to proceed (Leps and Young, 1992, p. 313). This is an important check in the entire air traffic/SAR system and could easily be one of the mitigating factors discussed later in Chapter IV. The intent is that if the pilot can't access the flight plan portion of DUATS, he/she will know he/she is not current on their license or physical and shouldn't be flying. The object is to prevent non-current or unqualified pilots from flying in the first place, especially because they may be more likely to run into trouble. Unfortunately, there is nothing to prevent the pilot from

getting annoyed at the computer and going out and flying anyway. But at least there is a check to make the pilot pause and reflect before taking off.

How Flight Plans Work

How a flight plan works is the subject of "*The Life of a Flight Plan*," an article that appeared in IFR magazine. As the magazine title suggests, its bent is towards those pilots who fly under Instrument Flight Rules and are therefore subject to air traffic control. The author therefore devotes the bulk of the article to a discussion of the movement of IFR data through the air traffic control information system. But this provides an engaging comparison to VFR information flow.

Interestingly, the amount of text dramatically illustrates the point about VFR flight plans (the focal point of this research project). Merely one paragraph is devoted to VFR flight plans. That serves to represent the point the author himself makes in the introductory sentence for that paragraph, "VFR flight plans have a less complicated life" (Haines, 1989, p. 68). VFR flight plans simply travel from the origination Flight Service Station (FSS) to the destination FSS. Again, as discussed in the previous section, VFR flight plans are simple by design: the simpler they are, the more likely pilots are to both understand and utilize them. The procedures discussed in Chapter 1 are also reiterated: that should a pilot fail to close a flight plan after the "estimated time enroute has passed," FSS controllers begin making calls to determine what happened (Haines, 1989, p. 68).

This aptly illustrates the potential difficulty (from a SAR perspective) of tracking VFR aircraft. No one is keeping tabs on a VFR aircraft's progress, and there is no automated check during the course of a flight to verify the safety of the aircraft. If a pilot runs into trouble somewhere in the middle of his/her flight, the only time the alarm will

be raised is after he/she fails to arrive at their destination. Depending on the route of flight, several hours could elapse between the actual time of distress and the time the alarm is sounded. If one is injured, those hours could very easily mean the difference between life and death. With this, one can easily see the value in filing a flight plan to reduce the amount of time in a survival situation one must endure.

Apart from these two articles, there is not much else written discussing the value of flight plans, especially in reducing the amount of time devoted to merely determining where to search. But these two articles do point out key features and theories of flight plans that relate to search-and-rescue.

Test Hypothesis

By filing a flight plan, pilots can reduce the time AFRCC controllers spend defining a search area by 24 hours. A 12-hour-or-greater differential between searches for aircraft on flight plans versus those without was considered to have met the hypothesis. This is because very little, if any, searching is conducted during hours of darkness, so a search initiated late in the afternoon on one day is essentially considered to have begun on the following day.

CHAPTER III

METHODOLOGY

Research Technique

This study was a statistical analysis. The primary focus of the analysis was on the number of hours spent defining a search area, with a secondary focus on hours spent actually searching in the field. The two categories of data compared and contrasted are the number of hours devoted to those VFR aircraft on flight plans and the number of hours given to searching for VFR aircraft without flight plans.

Research Design

AFRCC maintains a database to track its level of effort in each type of SAR scenario. The Search-and-Rescue Database (or SARDAB for short) maintained by AFRCC was the primary vehicle for obtaining data. Entries in the SARDAB go as far back as 1990. To digest that amount of data would take many months of tedious work. AFRCC has found that its workload (defined as numbers of incidents and missions) since 1990 has remained about the same. That being the case, this report concentrates on the most recent data available, namely data for 1998 and the first quarter of 1999.

Data Sources

AFRCC categorizes its activity into two areas: incident and mission. An incident is defined as when AFRCC interest is involved and AFRCC controllers are taking investigative action to determine if a distress situation does indeed exist. If controllers

are unable to make that determination, or if evidence uncovered indicates the situation is most likely distress (e.g. a crashed aircraft), the dispatch of SAR resources is defined as a "mission." There can be an incident without a mission (usually this means AFRCC controllers resolved the situation through their own investigation), but a mission does not occur without an incident. Therefore, mission data incorporates such incident times as when AFRCC first became aware of an overdue VFR aircraft.

The times used to determine the length of a SAR response, then, came from aircraft mission data contained in the SARDAB. Additionally, it was necessary to review the controller log from each mission to determine what clues controllers were able to garner as to the aircraft's whereabouts. As each log entry is marked with a date and time, the log entry may have been used as a source for the time of a response, rather than the SARDAB.

Number of Items Studied

AFRCC prosecuted 2851 missions in 1998. Merely 100 of those were aircraft missions. Of those, only 60 were missions for VFR aircraft, both with and without flight plans. However, since many missions started out as searches for ELTs and resulted in the discovery of a downed aircraft, all ELT missions, in addition to the 100 aircraft missions, had to be reviewed. Additionally, there were 623 missions in the first quarter of 1999, of which 17 were aircraft-specific. Again, though, due to the nature of ELT searches, all ELT missions for the first three months of 1999 had to be reviewed as well. Finally, there are 20 suspended missions from 1994 until 1999, each of which had to be investigated to determine if they fit the criteria of this research (i.e. involved a search for a VFR aircraft).

The specifics about each mission, including mission and incident number, along with the times that factor into each phase (e.g. last known position), are presented in Appendices C through E. There are also columns which record any mitigating factors (more on those in Chapter IV) that played a role in the mission.

Timeline

It took approximately 30 days to accurately review the SARDAB (and log where required) for each of these missions described above, record the appropriate data, and analyse the recorded data.

Selection and Description of Site

AFRCC is the central point for federal responses to SAR anywhere in the continental U.S. The FAA, in its regulations governing air traffic control (specifically Federal Aviation Regulations 7110.10K and 7110.65J), specifically names AFRCC as the focal point for SAR responses to overdue aircraft (FAA 7110-10K, p. 8-1-1). That being the case, AFRCC was the sole focus of data collection for this study.

Air Force Rescue Coordination Center (AFRCC)

The primary focus of the research was on the time expended by AFRCC controllers to locate an overdue aircraft. As any duty controller may respond to an alert by the FAA, the research examined the response from any of the 40 U.S. Air Force controllers assigned to the AFRCC (both active-duty and reserve). Particulars about the controller, including name, age, rank, and duty position, were not germane to the analysis and were not used or recorded.

In searching for overdue aircraft, AFRCC utilizes many different resources. AFRCC predominantly uses the US Air Force auxiliary, Civil Air Patrol (CAP). Other

resources typically include US Air Force combat SAR aircraft and Army National Guard helicopters. While the amount of search effort expended by these resources was an interest item of this research, other particulars about the resource (e.g. number and type of aircraft, unit of assignment) were not pertinent to the analysis and were not used or recorded.

Data Analysis Strategies

Primary analysis concentrated on times: time aircraft due to arrive at destination, time aircraft reported overdue, time AFRCC dispatched resources, and so on. All times were examined to discern whether there was an average for each phase of an aircraft search. These phases are: time elapsed between time of last known position (e.g. departure time from origination airport, radar contact, etc.) and time reported overdue; time elapsed between time reported overdue and time AFRCC dispatched resources (also referred to as “mission opening time”); and overall time elapsed between the last known position of the objective and the discovery of the objective. In the event the objective was not located, the last phase instead utilized the mission suspension time in lieu of the objective located time. Mission suspension time refers to the time all active searching terminated. Times are presented as hours and tenths of hours (e.g. 5 hours and 24 minutes as 5.4). Calculation of the tenths of hours were made utilizing the conversion table from the U.S. Air Force Technical Order 781, AFORMS Aircrew/Mission Flight Data Document.

Secondly, the total effort expended by search resources was valuable in determining the level of work needed to find an aircraft on a flight plan versus one without. That data was captured and studied, the mission opening time to objective

located time being the crux of analysis. In the case of suspended missions, the mission suspension time substituted for objective located time. Again, the goal was to discern an average.

Finally, as the ultimate goal of this research was to demonstrate the utility of filing a flight plan, all of these average times were calculated for both categories of overdue VFR aircraft searches: those on flight plans and those not. To obtain relative equality between the data sets, two filters were used. In calculating the average time to locate the objective, any missions with times greater than 200 hours or less than three (3) hours were eliminated. In the former case, this is because the objective was found later, after the official search effort was suspended. Usually the discovery was by persons who happened by chance upon the wreckage, such as hunters or hikers. In the latter case, any mission with less than three hours elapsed between the time objective went overdue and the objective was located generally meant some resource other than a federal one (e.g. county sheriff) had been alerted to the situation, and was already actively searching, prior to AFRCC learning of the situation. As such, that resource, rather than AFRCC or an AFRCC-dispatched federal unit, located the objective. The second filter used was based on the same premise, only this time for level of effort. Any mission with a level of effort less than three hours was eliminated from both sets of data for the same reasons outlined above. The refined data tables are presented with their raw counterparts in Appendices C and D.

How the Results Are Presented

Data for each phase is presented in both spreadsheet and graph form, to allow the reviewer the opportunity to see both individual data points as well as the average. Each

phase contains the graph for the “with flight plan” and “without flight plan” categories to allow for easy comparison between the two. To summarize each phase’s findings, the description of each phase is followed by a graph with both averages side-by-side for quick reference. Additionally, each phase presents both the raw and the refined averages for comparison. The level of effort for each category of search is graphed also to provide the reviewer an easy-to-read representation. In the instances in which a last known position time could not be determined from the data provided (denoted as “U” for “Unknown” in the last known position time column), the mission was segregated and placed at the bottom of each spreadsheet in the Appendices so as to allow ease of average calculations. As such, these missions were not included in the average calculations, but were used as part of the overall study.

CHAPTER IV

FINDINGS / DISCUSSION

As the data represented by the graphs in this section quite clearly demonstrate, there is a dramatic difference between the immediacy of a SAR response for an aircraft on a VFR flight plan versus that for an aircraft without one. Quite plainly, AFRCC is notified of distress situations faster and searchers find objectives quicker if a flight plan is available.

Defining the Search Area

It takes AFRCC controllers several hours to determine a search area, based on whether or not the aircraft has a flight plan. AFRCC controllers must determine a manageable search area in order to maximize search effectiveness. Without a flight plan, the unrefueled range of the missing aircraft is what defines the search area. For the majority of aircraft types for which AFRCC searches (light aircraft such as Cessna 172s or Piper PA-28s), that means the search area is a circle with a 400 nautical mile radius! An 800-nautical-mile diameter is simply untenable as a search area. Controllers must garner and analyze numerous clues in order to bring the search area down to such manageable areas as a route between two airports, a series of mountain ridges, a canyon, or the coordinates of a radar target. It is because of the significant amount of time involved in winnowing those clues that it’s not surprising, as Figure 1 on the following page shows, it takes an average of over 24 hours (28.6 to be exact) to actually dispatch

search parties on searches for aircraft without flight plans. With a flight plan, which outlines an intended route of flight, it is not surprising that the average time devoted to determining a search area is a mere 4.8 hours. When looking at refined data as shown in Figure 2, one can still see over a 12-hour difference between the average time taken to dispatch resources to search for aircraft without flight plans versus those with. Both sets of data present an unmistakable conclusion, leading to an acceptance of the hypothesis.

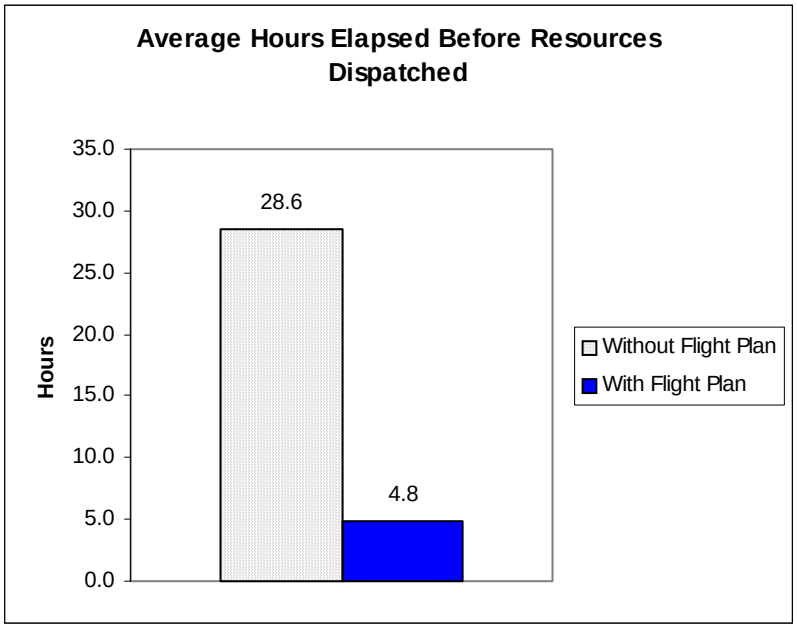

Figure 1: Average Number of Hours Before Resources Dispatched

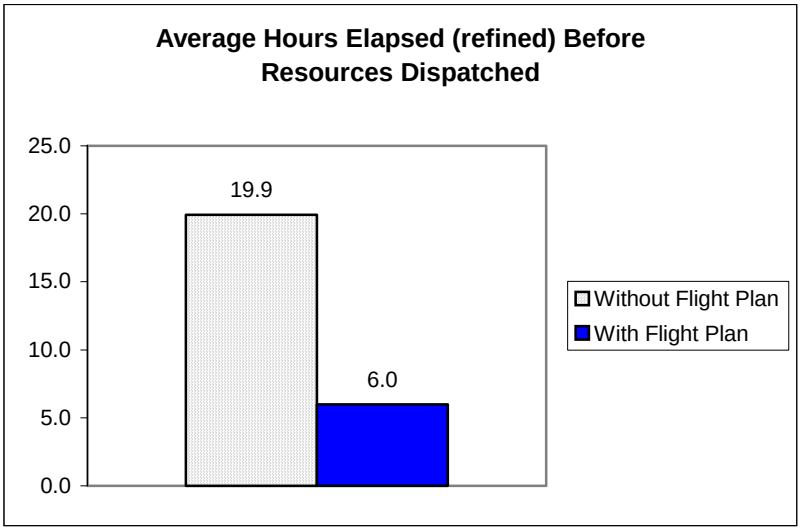

Figure 2: Refined Average Number of Hours Before Resources Dispatched

Locating the Objective

What is even more interesting is the dramatic difference in the overall average time to locate an aircraft on a flight plan (28.1) versus the average time to locate an aircraft for which no flight plan exists (82.7), as seen below in Figure 3. Of equal note is that while the refined data in Figure 4 does not show quite the same level of drama between the times, it still shows it takes AFRCC and its resources almost an entire day's worth of searching (as defined in Chapter 3) longer to find an aircraft not on a flight plan.

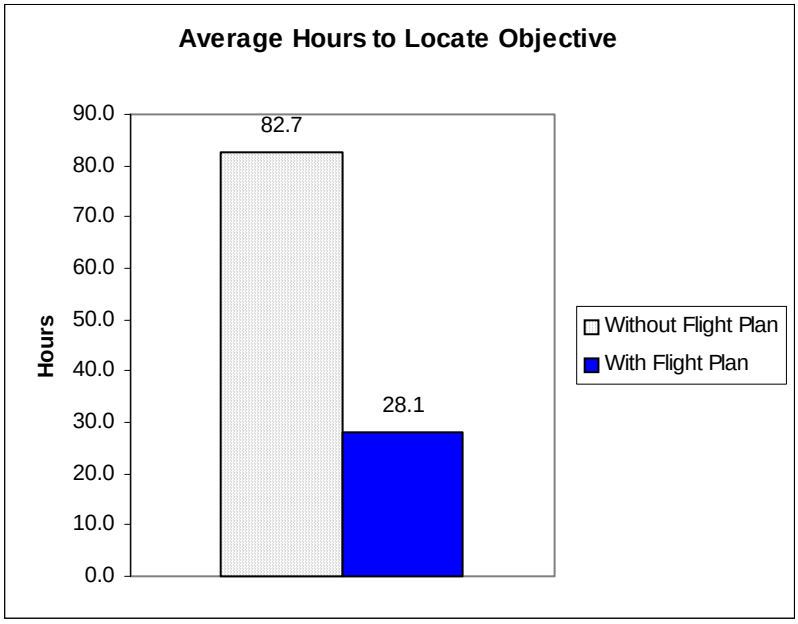

Figure 3: Average Number of Hours to Locate Objective

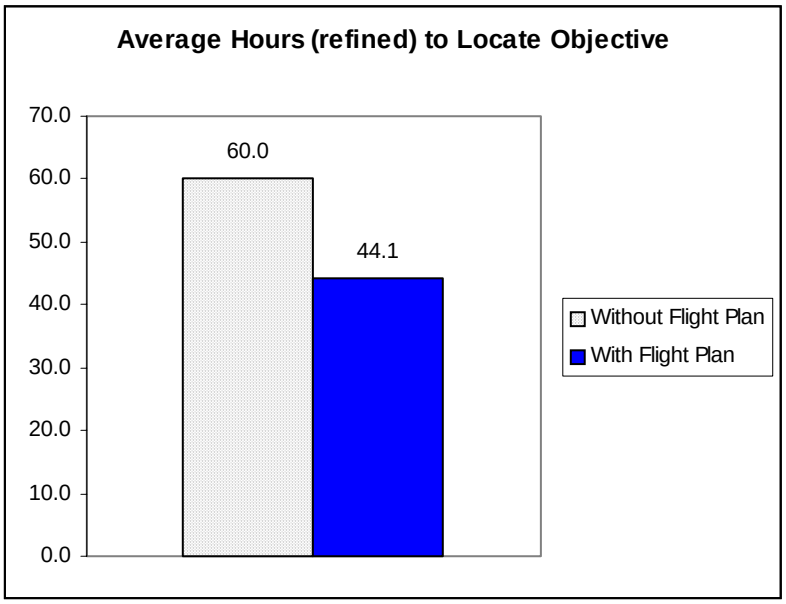

Figure 4: Refined Average Number of Hours to Locate Objective

Both sets of data make sense as, in light of what was discussed previously, a flight plan gives searchers some idea as to where the aircraft might be, allowing searchers to thus concentrate their efforts in that area. Without that information, searchers must search any and all possible areas (such as the 800 nautical mile circle mentioned above!). An excellent example is mission 98M1467, for which searchers had but two general clues to go on. The search was originally suspended, but closed some five months later after hunters stumbled upon the wreckage.

Notification Time

Not surprisingly, there is also a correlation between the amount of time before AFRCC controllers become aware an aircraft is overdue and whether the pilot has filed a flight plan. As discussed in Chapter I, failure to close a flight plan within 30 minutes of an intended arrival time results in the issue of an INREQ, the first indication of a potential problem to AFRCC. An hour later, if the aircraft still cannot be located, AFRCC is officially alerted via the ALNOT, and AFRCC controllers swing into action. As shown in Figures 5 and 6, it takes an average of 2.5 to three (3) hours between the time an aircraft goes overdue and AFRCC is notified. This makes sense as some of the delay between the 1.5 hours in the FAA regulations and the 2.5 to three hours shown in the data might be accounted for by the fact FAA personnel, attuned to the fact many pilots simply neglect to close their flight plan, devote a significant amount of time trying to locate the pilot on their own without using the formal INREQ/ALNOT SAR procedures.

On the other hand, by not filing a flight plan, no one in official aviation channels (e.g. FSS, ARTCC, etc.) is aware of an aircraft being overdue. It is only when the pilot

fails to arrive back home or to a meeting that someone raises the alarm. Many times there is a significant amount of elapsed time as the pilot's absence may go unnoticed for several hours. Additionally, as the person who notices the pilot's absence is the one who raises the alarm, that person may not be familiar with the appropriate channels. That might, in turn, mean several hours pass before the appropriate agency becomes aware of the distress situation. This explains the incredible average of 20.8 hours (below in Figure 3) elapsing between the time a non-flight-plan aircraft goes overdue and AFRCC becomes aware of the situation.

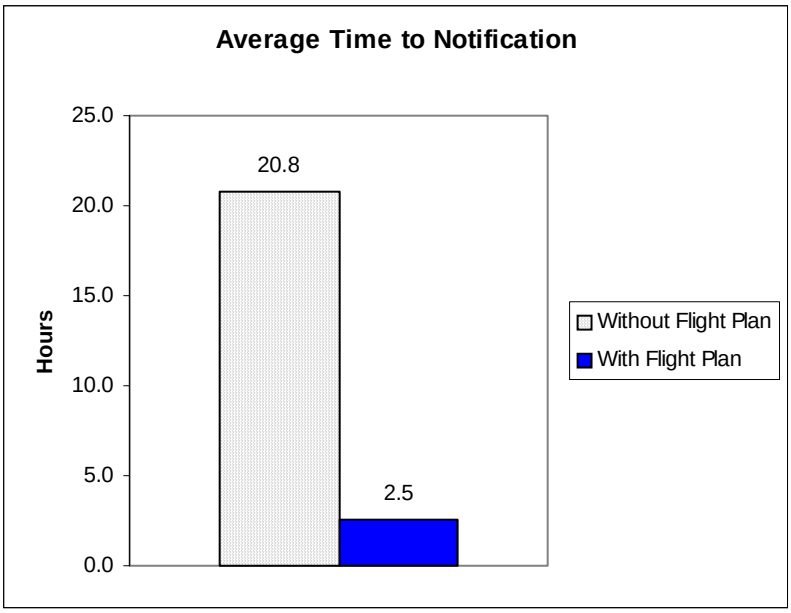

Figure 5: Average Number of Hours Before Notification

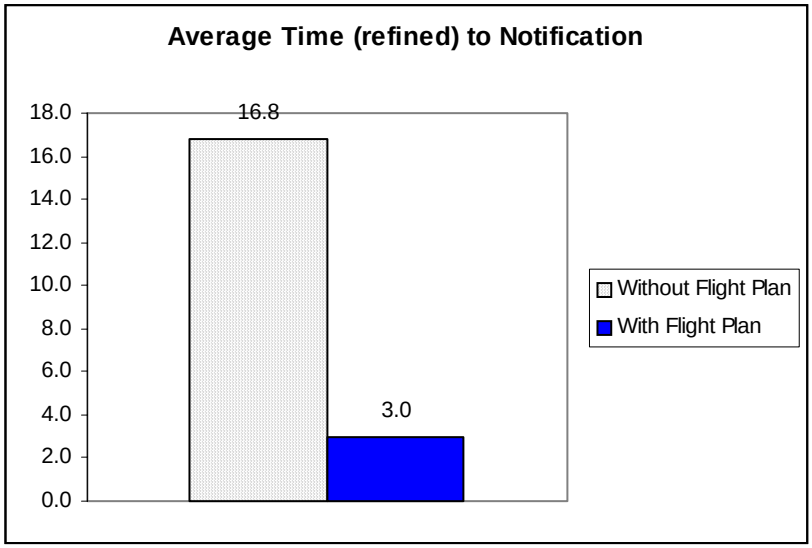

Figure 6: Refined Average Number of Hours Before Notification

Mitigating Factors

But even if a VFR pilot elects to fly without a flight plan, there are three significant factors that play a role in alerting the SAR system to his/her distress.

ELTs

The first are Emergency Locator Transmitters (ELTs), which are required by Congressional mandate to be carried aboard every non-commercial aircraft registered in the United States (NOAA, 1997). In a nutshell, ELTs are transmitters which, upon experiencing the G-forces of a crash, activate and emit an electronic tone over the standard rescue frequency of 121.5 MHz (NOAA, 1997). 121.5 (often referred to as "Guard") can and is monitored by all air traffic control facilities and airborne aircraft. In addition, the United States is a founding member of the Search-And-Rescue Satellite

Aided Tracking (SARSAT) system. The basic premise behind SARSAT is to provide, via satellite coverage, 24-hour-a-day monitoring for distress situations unhampered by weather or terrain (NOAA, 1997). AFRCC maintains a watch with the SARSAT system and investigates any SARSAT reports of activated ELTs, in addition to any reports from air traffic facilities or aircraft (AFRCC, 1997). In 11 instances (shown in Table C-1, with "Y" for "Yes" under the "ELT Initial Notification" column) , AFRCC responded to an ELT report which, during the course of AFRCC's investigation, correlated to a report of an overdue VFR aircraft. Because SARSAT provides an estimated location of the ELT (accurate to within 10-12 miles on older ELTs, .5-2 nautical miles on newer ELTs), AFRCC controllers can better define a search area and dispatch resources to the coordinates provided by SARSAT.

Of interest are seven of the nine missions at the bottom of Table C-1 for which there is no recorded last known position. This is due simply to the fact that these missions originated as ELT searches (hence the "Y" under the "ELT Initial Notification" column), but did not have any correlating missing aircraft information. The search teams happened to come across a crashed aircraft upon locating the signal source. Had the ELT not activated, it could have been several days, if not longer, before someone discovered the crewmembers missing and reported it. While each of the nine crashes resulted in fatalities, they at least highlight the value of ELTs: even if a pilot crashes and no one reports him/her missing, AFRCC will still investigate an ELT activation and locate the source.

Radio/Radar Drop Off

For 12 missions in Table C-1 (denoted with "Y" for "Yes" under the "Radio/Radar Drop-Off" column), AFRCC became aware of a distress situation because the distress pilot was in contact with an air traffic control agency and either dropped radio and/or radar contact, or declared an emergency. In those instances, not only is the notification nearly instantaneous, but playback of the radar tapes often yields a definite set of coordinates at which the aircraft was last seen. This greatly simplifies AFRCC's job, and very often searchers are sent directly to those coordinates. Although no data analysis has ever been conducted, AFRCC's experience has been that the majority of aircraft are located within one to 1.5 nautical miles of the last radar position. And, in the case of 98M0468A (bottom of Table C-1), there is no last known position because the mission was opened as a result of another aircraft hearing the pilot's "Mayday" calls over the radio. Once again, without someone cueing on a distress call, AFRCC may not have ever become aware of that pilot's situation.

Family Concern

As evidenced by the data, AFRCC initiates the majority of searches for non-flight-plan aircraft based on what is referred to as "family concern." Indicated by a "Y" for "Yes" under the "Family Concern" column in Table C-1, this is the instance detailed above, in which a family member, friend, or co-worker notes the absence of the pilot and notifies authorities. While this may help reduce the amount of time before a SAR response is generated, it does little to help AFRCC controllers quickly and accurately define a search area. Controllers endeavor to enlist the family member's help in gathering clues as to the pilot's intentions, such as retrieving the pilot's log books,

recalling flight habits, and so on. However, all that takes precious time. And, in the case of 98M0443A, often there is no last known position time because the family member who reported the pilot overdue had no idea when the pilot went flying; all he/she knew was the pilot was not home. In this instance, AFRCC controllers took a full two hours to try to determine where the pilot might have gone. Had there been some other correlating data, such as fuel on board, AFRCC controllers could have quickly developed a probable search area by comparing departure time against time reported overdue. If that total time was more than the amount of flying time afforded by the amount of fuel on board, controllers could have quickly determined this to be a genuine distress situation, estimated how far the pilot could have flown, and dispatched resources to cover that area.

Caveat

What is important about these mitigating factors is that they contribute to reducing the overall search effort by offering searchers a specific point at which to concentrate their efforts. But one must bear in mind that, even with these mitigating factors, searching from the air is difficult at best. Searchers must scour densely forested terrain or the shadows of mountain peaks and valleys to find a relatively small object. Even when the coordinates are known, it may still take some time to physically spot the wreckage. Weather, snow in particular, may cover wreckage, rendering it virtually invisible, or even preclude searching altogether. It is for these reasons that many searches, even when radar or ELT coordinates are available, still take a significant amount of time to locate the objective.

Suspended Missions

Suspended missions are missions on which AFRCC never located the objective and "suspended" all active searching after exhausting all possible leads and after making the determination there is no further, reasonable hope of the pilot's survival. This research examined the last five years' worth of suspended missions to determine if there was any correlation between the fact the objective did not file a flight plan and the fact AFRCC never located the objective. The answer came back a resounding "Yes." Of the 14 suspended missions involving VFR aircraft that are outlined in Table E-1, 71% (10 missions) were for aircraft not on a flight plan. Even with 80% of those 10 missions involving some of the mitigating factors discussed above, AFRCC was still unable to locate the objective. So while there were only two missions for VFR aircraft in 1998 for which the VFR aircraft, flying without a flight plan, was never located, compared with the 48 missions for no-flight-plan, VFR aircraft in which the objective was found, the trend is quite obvious. Without a flight plan, it remains a distinct possibility AFRCC, and its search parties, may never be able to locate the aircraft.

Level of Effort

The last point of investigation was the level of effort expended by searchers to locate aircraft in the two categories. Once again, one can easily see in Figure 7 the 54.1 hours (average) taken to locate an aircraft that did not give any indication of its intended path versus the 23.3 hours (average) taken to locate those that indicated where they were going. For the refined data in Figure 8, the average times are 40.1 for an aircraft not on a flight plan and 38.1 for an aircraft on a flight plan. Once again, this validates the hypothesis, albeit circumstantially. If AFRCC can reduce the amount of time spent

determining a search area, it can reduce the level of effort required to locate the objective as resources and time are not wasted looking in areas other than where the objective is.

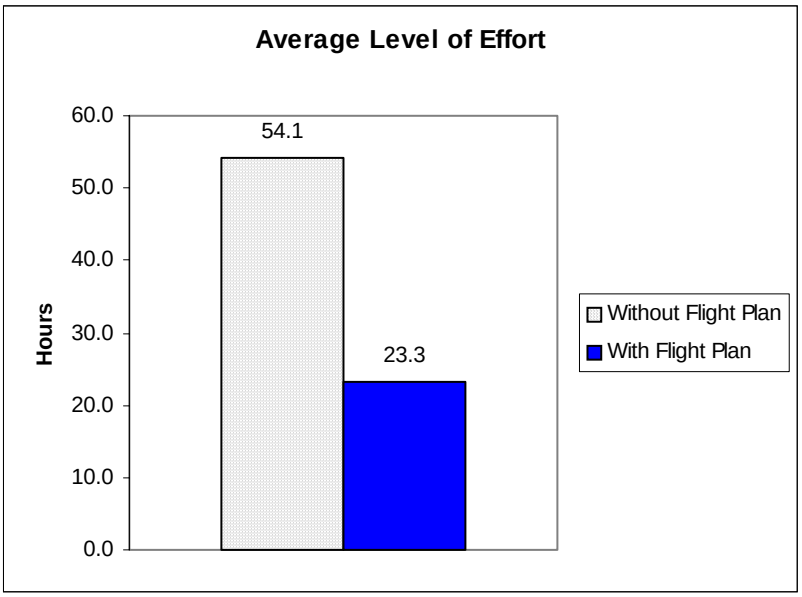

Figure 7: Average Number of Hours Searching for Objective (Level of Effort)

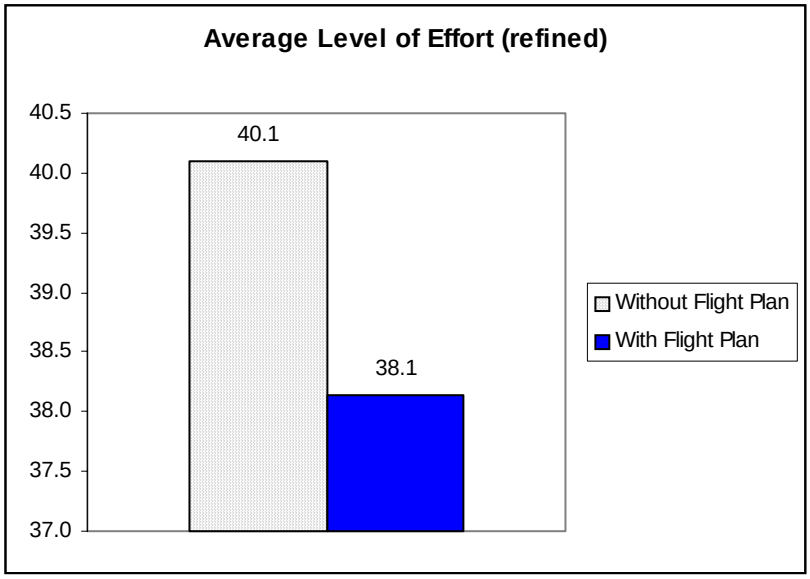

Figure 8: Refined Average Number of Hours Searching for Objective (Level of Effort)

Conclusion

It is quite plain, looking at the average amount of time in each of the phases (notification, resource dispatch, locating objective, amount of effort), that the hypothesis is indeed accepted. In other words, filing a flight plan saves at least 12 hours of SAR response time, not just in search area definition, but in the other phases as well. This data also validates the FAA's premise behind instituting flight plans in the first place: aiding search-and-rescue.

CHAPTER V

RECOMMENDATIONS

The goal of this research is to provide evidence to the flying community that VFR flight plans do indeed make sense and are valuable tools should a SAR response become necessary. As such, copies of this report and its findings will be forwarded to the FAA and to the Aircraft Owners and Pilots Association (AOPA). It is hoped that the FAA, through its public awareness campaigns, will be able to use the data contained herein to stress flight safety. The same applies for AOPA, though it is hoped AOPA would have much more of an impact due to the fact AOPA has further reaching contact with the pilot community than the FAA.

Additionally, AFRCC, as part of its SAR mission, offers numerous public presentations about its mission, capabilities, and the ways in which people (pilots in particular) can help the AFRCC help them in the event of a search. One part of that presentation (for which the author is an instructor) demonstrates the utility of filing flight plans and having emergency signaling devices (such as a crash-activated Emergency Locator Transmitter) on-board. The data used for that section is over 10 years old. This research, then, will aid AFRCC in presenting the most current data to the public, as well as educating the public on the value of flight plans.

REFERENCES

Haines, Thomas B. (1989, 1 February). The Life of a Flight Plan. IFR. pp. 65-68.

Leps, Leonard and Young, Kevin N. (1992, November). The Federal Aviation Administration's Direct User Access Terminal (DUAT) Service. 37th Annual Air Traffic Control Association Convention Proceedings. pp. 311-314.

APPENDIX A

FLIGHT PLAN FORM

Form Approved: OMB No. 2120-0026

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

FLIGHT PLAN

(FAA USE ONLY) ☐ PILOT BRIEFING ☐ VNR ☐ STOPOVER

TIME STARTED

SPECIALIST INITIALS

1. TYPE
VFR
IFR
DVFR

2. AIRCRAFT IDENTIFICATION

3. AIRCRAFT TYPE/ SPECIAL EQUIPMENT

4. TRUE AIRSPEED
KTS

5. DEPARTURE POINT

6. DEPARTURE TIME
PROPOSED (Z)
ACTUAL (Z)

7. CRUISING ALTITUDE

8. ROUTE OF FLIGHT

9. DESTINATION (Name of airport and city)

10. EST. TIME ENROUTE
HOURS
MINUTES

11. REMARKS

12. FUEL ON BOARD
HOURS
MINUTES

13. ALTERNATE AIRPORT(S)

14. PILOT'S NAME, ADDRESS & TELEPHONE NUMBER & AIRCRAFT HOME BASE

15. NUMBER ABOARD

17. DESTINATION CONTACT/TELEPHONE (OPTIONAL)

16. COLOR OF AIRCRAFT

CIVIL AIRCRAFT PILOTS. FAR Part 91 requires you file an IFR flight plan to operate under instrument flight rules in controlled airspace. Failure to file could result in a civil penalty not to exceed $1,000 for each violation (Section 901 of the Federal Aviation Act of 1958, as amended). Filing of a VFR flight plan is recommended as a good operating practice. See also Part 99 for requirements concerning DVFR flight plans.

FAA Form 7233-1 (8-82)

CLOSE VFR FLIGHT PLAN WITH _____ FSS ON ARRIVAL

APPENDIX B

ALNOT EXAMPLE

```
□SS KRCCYCYX KRCCYCYX
112038 KPIEYFYX
□ALNOT N9140X FR:V AT:MO20/A TS:160 DD:GPM TM:D111238 AE:055
RT:GPM..GGG.EMG.MLU.JAN.SJI.CEW.MAI..TLH.CTY.LAL AD:LAL TE:0600
CP:KPIEYFYX TA:111838 FB:0630 PD:RON POLLEY   COE 909 371 0988
NB:2 CR:W/GY
INFLIGHT BRIEFING 1416Z O/MLU FL075 MO20 TO LAL/PIREP
PREFLIGHT BRIEFING HBG-LAL AT 1630Z FROM GWO FSS.
ACFT NOT OG BOW/GIF/PCM  LAL AIRPORT CLSD DUE TO AIRSHOW. RAMP
CK STILL IN PROGRESS IN LAL
```

APPENDIX C

Tables of Missions for Aircraft Without Flight Plans

Table C-1

Missions for Aircraft Without Flight Plans

AFRCC Mission Number	AFRCC Incident Number	Last Known Position	Incident Opened	Mission Opened	Objective Located	VFR Flight Plan?	ELT Initial Notification?	Radio/ Radar DropOff?	Family Concern?	Total Elapsed Time to AFRCC Notified	Total Elapsed Time to Resources Launched	Total Elapsed Time to Locate Objective	Search Effort (Open to Location)
98M0092A	98I0261	1/14/98 19:30	1/15/98 01:05	1/15/98 02:03	1/15/98 14:05	N			Y	5.6	6.6	18.6	12.0
98M0094A	98I00262	1/14/98 23:36	1/15/98 02:11	1/15/98 03:22	1/15/98 08:45	N		Y		2.6	3.8	9.2	5.4
98M0131	98I0348	1/19/98 01:30	1/19/98 05:10	1/19/98 06:25	1/19/98 06:25	N			Y	3.7	4.9	4.9	0.0
98M0173A	98I0447	1/26/98 06:00	1/26/98 11:14	1/26/98 11:49	1/26/98 15:40	N	Y		Y	5.2	5.8	9.7	3.9
98M0188	98I0490	1/28/98 16:30	1/28/98 19:00	1/28/98 21:45	1/29/98 00:10	N	Y			2.5	5.3	7.7	2.4
98M0233A	98I0619	2/4/98 03:40	2/4/98 11:03	2/4/98 12:15	2/4/98 17:00	N				7.4	8.6	13.3	4.8
98M0245A	98I0651	2/5/98 23:29	2/6/98 04:40	2/6/98 07:02	2/8/98 17:45	N			Y	5.2	7.6	66.3	58.7
98M0339	98I0922	2/19/98 00:45	2/19/98 02:20	2/19/98 03:22	2/19/98 14:50	N	Y		Y	1.6	2.6	14.1	11.5
98M0374	98I1027	2/23/98 18:00	2/23/98 23:04	2/24/98 05:55	2/24/98 21:00	N	Y		Y	5.1	11.9	27.0	15.1
98M0445A	98I1210	3/6/98 03:00	3/6/98 06:10	3/6/98 06:34	3/6/98 08:51	N			Y	3.2	3.6	5.9	2.3
98M0506	98I1355	3/13/98 23:30	3/14/98 05:52	3/14/98 07:20	3/15/98 14:00	N		Y	Y	6.4	7.8	38.5	30.7
98M0684A	98I1808	4/6/98 15:00	4/7/98 07:00	4/7/98 21:48	4/11/98 01:15	N			Y	16.0	30.8	106.3	75.5
98M0715A	98I1907	4/10/98 22:00	4/11/98 15:57	4/11/98 17:00	4/12/98 15:30	N			Y	18.0	19.0	41.5	22.5
98M0784A	98I2077	4/18/98 01:00	4/19/98 12:00	4/19/98 12:14	4/19/98 13:00	N			Y	35.0	35.2	36.0	0.8
98M0774A	98I2044	4/18/98 01:05	4/18/98 01:10	4/18/98 02:19	4/18/98 02:45	N		Y		0.1	1.2	1.7	0.4
98M0841	98I2250	4/22/98 09:53	4/27/98 17:50	4/28/98 06:10	9/13/98 20:10	N			Y	128.0	140.3	562.3	422.0
98M1180A	98I3123	6/6/98 18:30	6/6/98 22:37	6/7/98 01:11	6/9/98 14:15	N			Y	4.1	6.7	67.8	61.1
98M1187	98I3142	6/8/98 01:05	6/8/98 01:23	6/8/98 01:15	6/9/98 13:30	N	Y	Y		0.3	0.2	36.4	36.3
98M1467	98I3747	6/23/98 20:00	7/3/98 00:35	7/8/98 17:07	12/19/98 17:55	N			Y	220.6	357.1	645.9	288.8
98M1442A	98I3815	7/5/98 17:24	7/5/98 18:19	7/5/98 18:58	7/5/98 21:40	N		Y		0.9	1.6	4.3	2.7
98M1658	98I4379	7/26/98 12:50	7/30/98 19:20	7/30/98 23:28	7/31/98 15:00	N			Y	102.5	106.6	122.2	15.5
98M1624A	98I4319	7/26/98 19:30	7/27/98 19:17	7/27/98 21:15	8/1/98 21:10	N			Y	23.8	25.8	145.7	119.9
98M1665	98I4401	7/31/98 17:00	7/31/98 20:20	7/31/98 21:20	7/31/98 23:04	N				3.3	4.3	6.1	1.7
98M1760	98I4639	8/3/98 01:23	8/9/98 23:03	8/10/98 21:09	8/13/98 19:30	N			Y	165.7	187.8	258.1	70.4
98M1705A	98I4480	8/4/98 13:10	8/4/98 19:27	8/4/98 21:38	8/26/98 22:59	N			Y	6.3	8.5	537.8	529.4
98M1714	98I4497	8/5/98 06:10	8/5/98 06:10	8/5/98 12:19	8/7/98 18:55	N			Y	0.0	6.2	60.8	54.6
98M1744	98I4618	8/9/98 00:31	8/9/98 00:31	8/9/98 00:40	8/9/98 03:08	N	Y			0.0	0.2	2.6	2.5
98M2142A	98I5659	9/26/98 15:33	9/26/98 16:45	9/26/98 17:47	9/27/98 22:25	N		Y		1.2	2.2	30.9	28.6
98M2194A	98I5800	10/2/98 03:00	10/2/98 04:10	10/2/98 05:45	10/2/98 16:00	N		Y		1.2	2.8	13.0	10.3
98M2283	98I6046	10/12/98 17:30	10/12/98 21:35	10/13/98 00:29	10/13/98 07:45	N	Y		Y	4.1	7.0	14.3	7.3
98M2331A	98I6180	10/18/98 22:15	10/19/98 03:00	10/19/98 04:05	10/19/98 18:20	N	Y	Y		4.8	5.8	20.1	14.3
98M2397A	98I6380	10/28/98 15:53	10/28/98 17:25	10/28/98 18:00	10/28/98 18:00	N		Y		1.5	2.1	2.1	0.0
98M2411A	98I6407	10/29/98 14:15	10/29/98 19:14	10/29/98 21:01	11/1/98 18:40	N			Y	5.0	6.8	76.4	69.7
98M2450A	98I6507	11/2/98 20:00	11/3/98 00:48	11/3/98 05:45	11/3/98 14:50	N			Y	4.8	9.8	18.8	9.1
98M2455	98I6511	11/2/98 20:00	11/3/98 05:43	11/3/98 16:09	11/3/98 18:02	N			Y	9.7	20.2	22.0	1.9
98M2488A	98I6638	11/8/98 23:00	11/8/98 23:00	11/8/98 23:27	11/9/98 08:30	N				0.0	0.5	9.5	9.1
98M2660A	98I7076	11/29/98 19:00	11/30/98 13:00	11/30/98 14:49	12/2/98 22:00	N			Y	18.0	19.8	75.0	55.2
98M2682	98I7135	12/3/98 10:44	12/3/98 12:25	12/3/98 12:45	12/3/98 13:45	N	Y	Y		1.7	2.0	3.0	1.0
98M2819	98I7535	12/24/98 21:00	12/24/98 22:22	12/25/98 00:12	12/25/98 05:00	N	Y		Y	1.4	3.2	8.0	4.8
98M2829A	98I7561	12/25/98 13:33	12/27/98 18:25	12/27/98 20:14	1/2/99 18:45	N			Y	52.9	54.7	197.2	142.5
99M0106	99I0295	1/17/99 04:40	1/17/99 06:20	1/17/99 08:15	1/18/99 15:40	N		Y		1.7	3.6	35.0	31.4
99M0198A	99I0537	1/29/99 22:21	1/29/99 23:17	1/30/99 00:35	1/30/99 20:34	N		Y		0.9	2.2	22.2	20.0
99M0244A	99I0666	2/4/99 21:51	2/5/99 20:07	2/5/99 21:11	2/6/99 17:36	N			Y	22.3	23.3	43.8	20.4
99M0308A	99I0828	2/12/99 17:26	2/13/99 01:56	2/13/99 05:00	2/14/99 22:00	N			Y	8.5	11.6	52.6	41.0
99M0484A	99I1283	3/7/99 20:30	3/8/99 22:45	3/12/99 20:30	3/12/99 22:51	N			Y	26.3	120.0	122.4	2.4
99M0540A	99I1454	3/19/99 04:31	3/19/99 05:29	3/19/99 05:29	3/19/99 08:33	N	Y			1.0	1.0	4.0	3.1
99M0604	99I1624	3/27/99 15:49	3/29/99 07:10	3/29/99 13:43	4/7/99 16:47	N			Y	39.4	45.9	265.0	219.1
									AVERAGE:	**20.8**	**28.6**	**82.7**	**54.1**
98M0685	98I1821	U	4/7/98 21:00	4/7/98 23:26	4/8/98 01:04	N	Y			#VALUE!	#VALUE!	#VALUE!	1.6
98M0765	98I2034	U	4/17/98 19:39	4/17/98 20:58	4/18/98 03:15	N	Y			#VALUE!	#VALUE!	#VALUE!	6.3
98M0904	98I2397	U	5/5/98 19:49	5/5/98 21:49	5/7/98 02:40	N	Y			#VALUE!	#VALUE!	#VALUE!	28.9
98M2258	98I5989	U	10/9/98 23:04	10/10/98 00:42	10/10/98 08:05	N	Y			#VALUE!	#VALUE!	#VALUE!	7.4
98M2844A	98I7620	U	12/30/98 21:48	12/30/98 21:48	12/30/98 23:50	N	Y			#VALUE!	#VALUE!	#VALUE!	2.0
99M0473	99I1291	U	3/10/99 03:37	3/10/99 05:03	3/10/99 11:02	N	Y			#VALUE!	#VALUE!	#VALUE!	6.0
99M0358	99I0976	U	2/21/99 04:12	2/21/99 05:27	2/21/99 07:01	N	Y			#VALUE!	#VALUE!	#VALUE!	1.6
98M0358A	98I0991	U	2/22/98 18:25	2/22/98 21:38	2/22/98 22:29	N	Y			#VALUE!	#VALUE!	#VALUE!	0.9
98M0443A	98I1208	U	3/6/98 00:53	3/6/98 02:33	3/6/98 16:25	N			Y	#VALUE!	#VALUE!	#VALUE!	13.9
98M0468A	98I1252	U	3/8/98 02:32	3/8/98 23:46	3/8/98 23:55	N				#VALUE!	#VALUE!	#VALUE!	0.2

NOTE: #VALUE! Means system unable to calculate a number based on no value assigned in "Last Known Position" column.

APPENDIX D

Tables of Missions for Aircraft With Flight Plans

Table D-1

Missions for Aircraft With Flight Plans

AFRCC Mission Number	AFRCC Incident Number	Last Known Position	Incident Opened	Mission Opened	Objective Located	VFR Flight Plan?	ELT Initial Notification?	Radio/ Radar DropOff?	Family Concern?	Total Elapsed Time to AFRCC Notified	Total Elapsed Time to Resources Launched	Total Elapsed Time to Locate Objective	Search Effort (Open to Location)
98M0024	98I0055	1/4/98 00:01	1/4/98 06:00	1/4/98 09:40	1/6/98 17:38	Y				6.0	9.7	65.6	56.0
98M0118A	98I0330	1/18/98 04:54	1/18/98 08:04	1/18/98 09:33	1/18/98 10:55	Y				3.2	4.7	6.0	1.4
98M0331	98I0912	2/18/98 20:56	2/18/98 20:56	2/18/98 21:05	2/18/98 22:58	Y				0.0	0.2	2.0	1.9
98M0754	98I2017	4/17/98 00:55	4/17/98 02:05	4/17/98 02:14	4/17/98 16:30	Y	Y			1.2	1.3	15.6	14.3
98M1166A	98I3094	6/5/98 10:47	6/5/98 19:20	6/5/98 19:20	6/6/98 15:45	Y				8.6	8.6	29.0	20.4
98M1519	98I4029	7/14/98 22:09	7/14/98 23:45	7/15/98 14:02	7/18/98 19:06	Y				1.6	15.9	93.0	77.1
98M1687	98I4435	8/2/98 12:45	8/2/98 16:55	8/2/98 20:50	8/2/98 21:14	Y				4.2	8.1	8.5	0.4
98M1790	98I4763	8/15/98 17:24	8/15/98 18:31	8/15/98 19:22	8/15/98 19:58	Y	Y			1.1	2.0	2.6	0.6
98M1994A	98I5264	9/7/98 23:56	9/8/98 00:05	9/8/98 00:23	9/8/98 03:45	Y				0.2	0.5	3.8	3.4
98M2479A	98I6595	11/6/98 22:54	11/7/98 00:44	11/7/98 05:12	11/12/98 21:13	Y		Y		1.8	6.3	142.3	136.0
98M2837	98I7580	12/28/98 00:35	12/28/98 05:37	12/28/98 06:02	12/28/98 15:50	Y	Y			5.0	5.5	15.3	9.8
99M0006	99I0013	1/1/99 21:22	1/1/99 23:42	1/2/99 00:36	1/2/99 00:38	Y				2.3	3.2	3.3	0.0
99M0123A	99I0325	1/20/99 03:00	1/20/99 04:50	1/20/99 05:55	1/20/99 17:15	Y	Y			1.8	2.9	14.3	11.3
99M0187A	99I0505	1/28/99 03:33	1/28/99 03:50	1/28/99 04:06	1/28/99 05:40	Y		Y		0.3	0.6	2.1	1.6
99M0342A	99I0939	2/19/99 01:45	2/19/99 02:25	2/19/99 05:01	2/19/99 20:00	Y		Y		0.7	3.3	18.3	15.0
									AVERAGE:	**2.5**	**4.8**	**28.1**	**23.3**
98M0449A	98I1215	U	3/6/98 18:10	3/6/98 19:14	3/6/98 19:39	Y	Y			#VALUE!	#VALUE!	#VALUE!	0.4

NOTE: #VALUE! Means system unable to calculate a number based on no value assigned in "Last Known Position" column.

APPENDIX E

Table E-1 (Suspended Missions)

Table E-1

Suspended Missions

AFRCC Mission Number	AFRCC Incident Number	Last Known Position	Incident Opened	Mission Opened	Mission Suspended	VFR Flight Plan?	ELT Initial Notification?	Radio/ Radar DropOff?	Family Concern?	Total Elapsed Time to Resources Launched	Total Mission Time	Total Time LKP to Suspend
94M1336	94I3900	6/19/94 20:28	6/20/94 00:18	6/22/94 21:50	6/28/94 11:55	Y				87.5	134.1	207.5
94M1944A	94I5866	8/28/94 18:30	8/28/94 22:37	8/30/94 11:23	8/31/94 01:05	Y				30.6	13.7	54.6
94M2787A	94I8621	12/25/94 21:30	12/26/94 19:06	12/26/94 20:00	1/2/97 16:03	N				18.6	164.1	186.6
95M0855A	95I2713	4/28/95 16:30	5/2/95 00:15	5/2/95 02:18	5/4/95 23:09	N			Y	78.7	68.9	150.7
95M1943A	95I6203	9/4/95 18:35	9/4/95 22:40	9/5/95 03:45	9/12/95 14:00	Y				19.4	178.3	187.4
96M0100A	96I0273	1/17/96 23:58	1/18/96 00:30	1/18/96 07:25	1/19/96 04:22	N				4.4	21.0	28.4
96M2507A	96I7553	11/14/96 23:15	11/23/96 05:45	11/24/96 00:12	11/28/96 23:30	N			Y	216.3	119.3	336.3
97M0761A	97I2557	4/29/97 22:00	4/30/97 00:19	4/30/97 00:36	5/2/97 04:21	N			Y	6.4	51.8	54.4
97M1920A	97I6187	9/14/97 19:30	9/15/97 20:15	9/15/97 22:45	9/25/97 05:22	N			Y	33.9	222.6	249.9
97M2516A	97I7862	12/3/97 14:40	12/3/97 20:16	12/3/97 21:10	12/7/97 01:12	N		Y		10.5	76.0	82.5
98M1429A	98I3774	7/3/98 22:00	7/4/98 01:20	7/4/98 06:19	7/9/98 21:07	Y				23.1	134.8	143.1
98M2464	98I6552	11/4/98 18:59	11/5/1998 1:35	11/5/98 08:49	11/20/98 01:43	N			Y	6.7	352.9	366.7
99M0909	99I2543	5/6/99 18:45	5/7/1999 21:07	5/7/99 23:35	5/16/99 14:00	N			Y	43.3	206.4	235.3
99M1098	99I3043	5/28/99 19:36	5/29/1999 2:45	5/29/99 22:19	6/9/99 00:01	N			Y	28.4	241.7	268.4
									AVERAGE:	**43.4**	**141.8**	**182.3**

APPENDIX F

Bibliography

BIBLIOGRAPHY

Air Force Rescue Coordination Center (1998, 23 January). Operating Instruction 10-21 [Response to FAA Notifications]. Langley Air Force Base, Virginia.

Benenson, Tom (1997, 1 March). VFR=Very Focused Responsibility. Flying. pp. 52-54.

Benenson, Tom (1995, 1 Nov). Closing a Flight Plan. Flying. pp. 44-45.

Collins, Richard L. (1992, 1 October). VFR Strategy: Flying with a Plan in Hand. AOPA Pilot. pp. 65-69.

English, Bill (1999, 1 February). The Case for VFR. IFR. pp. 11-13.

Federal Aviation Administration (1994, 28 May). Order 7110.10K, Chapter 8: Search and Rescue Procedures for VFR Aircraft.

Federal Aviation Administration (1996, 20 June). Order 7110.65J, Chapter 2: Flight Plans and Control Information.

Federal Aviation Administration (1997, 30 January). Order 7110.65J, Chapter 10: Emergencies.

Moran, Mark (1997, 8 January). SARSAT [On-Line]. Available: http://psbsgi1.nesdis.noaa.gov:808/SARSAT/homepage.html

Multiple sources (latest update 1997, November). Air Force Rescue Coordination Center (AFRCC) Basic Search-and-Rescue Controller Training Syllabus. Hampton, VA: Langley Air Force Base.

Multiple sources (1991, 1 February). The National Search And Rescue Manual, Volume I: The National Search And Rescue System (Joint Publication 3-50). Washington, D.C.: Interagency Committee on Search and Rescue.

Nolan, Michael S. (1994). Fundamentals of Air Traffic Control. Belmont, CA: Wadsworth Publishing Company.

Taneja, Nawal K. (1987). Introduction to Civil Aviation. Lexington, MA: Lexington Books.

SEARCH PLANNING GUIDANCE FOR USE IN GENERAL AVIATION MISSING AIRCRAFT SEARCHES IN THE CONTINENTAL UNITED STATES

By

John William Desmarais

Civil Air Patrol
National Headquarters
April 2000

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Last, but definitely not least, I would like to thank my parents for always being there for me and pushing me towards being the best that I could be. The example that they set for me has shown me to work hard and always do what is right and will help others. I believe this project truly represents those values.

ABSTRACT

Writer: John William Desmarais

Title: Search Planning Guidance for use in General Aviation Missing Aircraft Searches in the Continental United States

Institution: Civil Air Patrol

Year: 2000

This project reviewed the latest information on general aviation missing aircraft searches in the Continental United States (CONUS) to provide search planners useful guidance for determining the optimal search area. Most planners have been utilizing the New Two-Area Method (NTAM) developed by the Canadian Department of National Defence's Directorate of Air Operational Research (DAOR). Though this method of planning has worked, it was never validated for use in the CONUS. The author recommends that planners adjust the second area of the NTAM to search a radius of 20 nautical miles or 20% of the original track length, which ever is greater, around the last known position, turning points along the route, and the destination as this yields better results.

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CHAPTER I

INTRODUCTION

General Background of the Study

Each year several thousand aviation searches are conducted in the Continental United States (CONUS) under the control of the Air Force Rescue Coordination Center (AFRCC). Most of these searches are for Emergency Locator Transmitters (ELT) that end up being false alarms, but a small percentage of these searches are for general aviation aircraft that are actually missing. Search planners, however, do not have the luxury of knowing if the search is a false alarm or not, and must do everything that they can to prosecute the searches assigned to them efficiently and safely with the hopes of a positive outcome. These missing aircraft searches are very intensive and tie up many resources that could be used elsewhere. Anything that can be done to lessen the burden on those involved will be appreciated.

Purpose of the Study

The United States Air Force is responsible for all federal Search-And-Rescue (SAR) conducted in the inland region of the United States and the AFRCC, currently located at Langley AFB, VA, is tasked with implementing the National SAR Plan to complete these searches (Joint Publication 3-50, 1991, p. 1-4) in the CONUS. Though there are discussions of a combined or joint rescue coordination center be established for the CONUS for maritime and inland SAR, the current draft of the revised National SAR Manual, Joint Publication 3-50, reflects the same responsibilities for the AFRCC. (Draft

Joint Publication 3-50, March 2000, p. 1-4) The AFRCC does not truly have any operational assets to conduct searches and must rely on other organizations to do that, though it provides as much planning support as is reasonably possible when not on-scene. Civil Air Patrol, the Congressionally chartered Auxiliary of the United States Air Force, conducts most of the missing aircraft searches in the field for the AFRCC. The author has a vested interest in making sure that CAP has the best tools and guidance possible on these searches as he is now responsible for the development of training curricula for emergency services personnel throughout the organization.

Current Methods

Currently, search planners are predominantly using the New Two-Area Method (NTAM) to layout how searches will be planned in the United States mainly because there is nothing else available. As outlined in the National SAR School's Inland SAR Planning Course Notebook (1996), The NTAM was developed by the Canadian Department of National Defence's Directorate of Air Operational Research (DAOR). The NTAM is based on research of seventy-six missing aircraft missions conducted in Canada from 1981 to 1986. To use the NTAM requires search planners to have the Last Known Position (LKP) of the missing aircraft (which is typically the origin of the flight), the intended route of the missing aircraft, and the intended destination of the missing aircraft. From this information two areas are defined for prioritizing the search.

Area One

To establish area one, the search planner draws a rectangle 10 nautical miles each side of the track of the missing aircraft beginning 10 nautical miles before the LKP of the

missing aircraft and extending 10 nautical miles beyond the destination of the missing aircraft (National SAR School, 1996). This is depicted in figure 1 below.

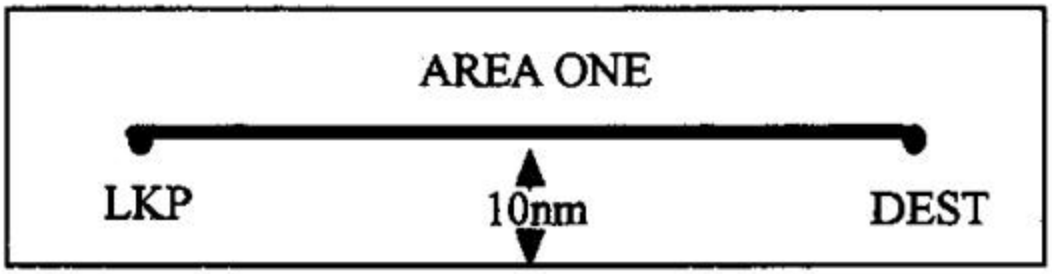

Figure 1. Area one of the NTAM as depicted in the National SAR School's Inland SAR Planning Course Notebook (1996).

Area Two

To establish area two, a rectangle is drawn 15 nautical miles along each side of the missing aircraft's track beginning at the LKP and extending 15 nautical miles beyond the destination; area two does include the portion of area one where this is overlap (National SAR School, 1996). Area two is depicted below in figure 2.

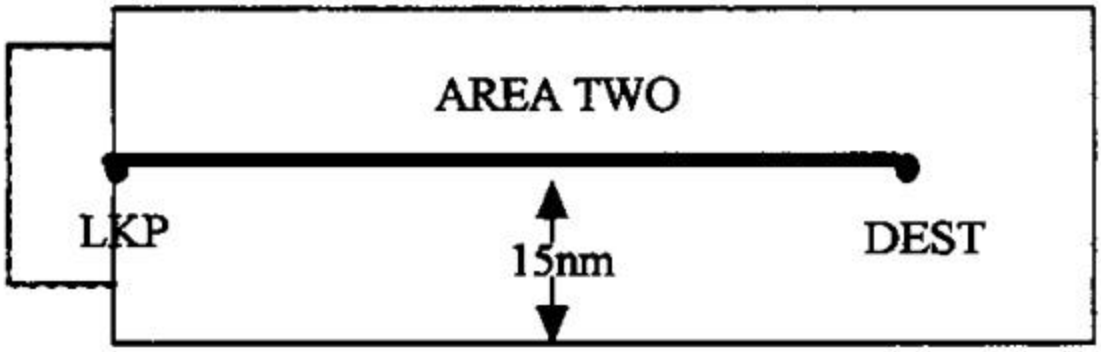

Figure 2. Area two of the NTAM as depicted in the National SAR School's Inland SAR Planning Course Notebook (1996).

En Route Turning Points

There are often known turning points along the intended route of flight that must be addressed in planning the search. Using the NTAM, this is addressed by drawing an

arc using the turning point as the center with the radius equal to 10 nautical miles for area one and 15 nautical miles for area two (National SAR School, 1996). This is depicted in figure 3 below.

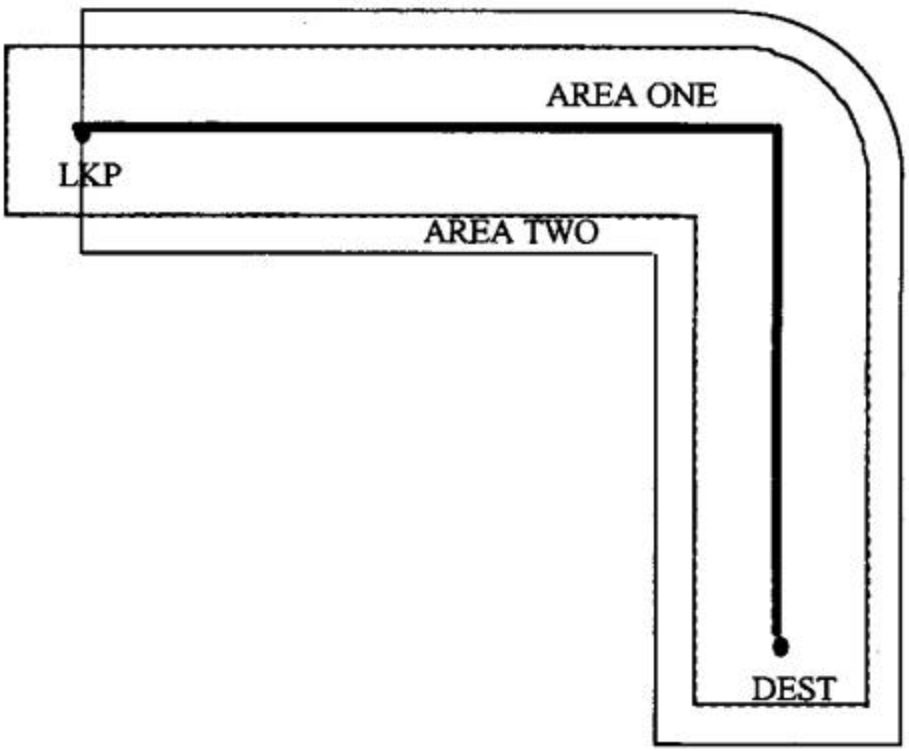

Figure 3. An example of a turning point using the NTAM as depicted in the National SAR School's Inland SAR Planning Course Notebook (1996).

Recommended Search Sequence

When utilizing the NTAM, the National SAR School recommends that searches be conducted in the following order unless the circumstances dictate otherwise (National SAR School, 1996):

First, conduct track crawls along the missing aircraft's intended tack, being especially thorough in the vicinity of the LKP and destination. Second, conduct

electronic searches and cooperating target/survivor searches, covering the entire high probability areas. Third, search area one in the following order:

a. the last quarter of the track from the track outward with equal priority along the track;

b. the third quarter from the track outward with equal priority along the track;

c. the first quarter of the track outwards commencing at the LKP;

d. the second quarter from the track outward with equal priority along the track;

e. the over-fly area followed by the under-fly area commencing at the destination and LKP respectively.

Fourth, search area two using the same sequence established for searching area one. (p. 7-29)

The above search precedence was established because most of the missing aircraft were located close to the intended track. Additionally, there were high concentrations of aircraft found in the first and last tenth of the track, and more found in the second half of the track than the first (National SAR School, 1996). There was no firm criteria established for when to expand the search areas to include area two, though if planners are prudently using available resources this would not be accomplished until area one is completely or nearly completely searched.

NTAM Results

Utilizing the missing aircraft data from the 76 missions included in the DAOR study conducted from 1981 through 1986, the Canadians found that 79% of the missing aircraft were located in area one. After further research, the Canadians found that 83% of the missing aircraft were located in area two.

Up to this point, no research has been conducted in the United States to determine if similar results should be expected or if a different method should be utilized.

Problem Statement

Knowing the basic planning guidance currently in place, it is now time for the author to formally list the problem to be explored by this study. The problem to be investigated in this study is "Should the Canadian NTAM be utilized by search planners in the CONUS or not, and if not, what better alternatives are readily available?" There are many possible criteria for deciding whether to stick with the Canadian NTAM for searches conducted in the CONUS or not, and expertise will always guide the selection of alternative methods. The author's ideas on this subject are further defined in the following sections.

Guiding Questions

The first question that must be answered is "How many missing aircraft searches were coordinated in 1999 by the AFRCC, and what information is available for each search?" To reasonably review the data available for validity using the NTAM, the LKP, intended route, and intended destination of the missing aircraft must be known.
The author reviewed the mission folders kept on file at the AFRCC for the missing aircraft missions conducted in 1999, and found a sufficient number of missions and enough information available to conduct the research. (AFRCC Mission Records, 1999)

It may be necessary to query the NTSB online database of aircraft accidents and incidents to get more data for some of the missions, but this should not be a problem. (NTSB, 2000) One hundred and fifteen missing aircraft searches of varying types were conducted in 1999. Some of these searches were initiated based on FAA Alert Notices (ALNOTs), some on reports from family or friends that the aircraft was overdue, others based on loss of radar contact, and still others because of known distress signals from Emergency Locator Transmitters (ELT) or mayday calls. With more detailed review of the above missions the author eliminated 37 missions from the study, but there were still enough remaining to reasonably compare the results to the Canadian studies conducted to develop the NTAM. The reasons for eliminating missions from study can be found in the additional questions to be answered.

The second question that has been answered is "What relevant information is normally available to mission planners that could further impact planning efforts?" Search planners must know the LKP, route, and destination as previously discussed, but there are other mitigating factors that often allow planners to focus the search efforts. Things that could focus search efforts would be things like a known flight plan, reports from concerned family or friends, radar, National Track Analysis Program (NTAP) data, or known ELT signals or distress calls in the area of possibility of the search. In fact AFRCC controllers are told in their training to learn how to prosecute missing aircraft missions that "NTAP data, when available, is possibly the best tool available to limit the search area for a missing aircraft." (AFRCC Controller Training, 1999) This type of information directs planners to focus search efforts in one area and avoid others. The only problem is that the data available is not the same for every search. Though research

shows that filing a flight plan significantly reduces the time until SAR resources are dispatched, pilots even on long cross countries still fail to file a flight plan. (Homes, July 1999, p. 2) And even though ELTs are required to be carried on board all civil aircraft in the United States according to the Federal Aviation Regulation, part 91, they do not always work since they are often destroyed in a crash. (FAA, 2000)

The third question to be answered was "Where were the missing aircraft actually located?" If the aircraft involved in the search was never located, it is not useful to this research. Also, not all missing aircraft will be found having crashed, as evidenced by the many incidents and false search missions conducted for people who simply forgot to close out their flight plan and whose planes were located at an airport by a ramp check. The only problem is that search planners do not know if an aircraft is truly missing or if the mission is a false alarm until the aircraft is found. Therefore, for the purposes of this study, these missions were left in the study.

Fourth, "Will changes to structure of the areas to be searched in CONUS yield better results than if search planners continued to use the NTAM?" The author compared the results using the NTAM with alternative designs. The author used his own background as a search planner and incident commander and his access to others with like qualifications to develop an alternative design that search planners might utilize.

Finally, "Does the available information justify search planners changing their current methods?" Time is very limited in planning searches, and anything that can be done to speed up the process is normally appreciated by all involved. The author was careful to avoid making additional unnecessary work for search planners in any

recommendations that he has made, and to try to make those same recommendations simple for search planners to implement in the field.

Significance of Study

The goal of this study was to determine the validity of using NTAM in the CONUS for conducting missing aircraft searches and to recommend changes for search planners if necessary. What makes this significant? A new method of conducting searches could reduce the time it takes to find survivors of plane crashes, and thus save lives. Additionally, even if the NTAM were determined to be the best method of conducting missing aircraft searches in the CONUS, search planners will now know this and have the data to review on hand. Every organization involved in saving lives should be looking at the legal ramifications of how their personnel conduct searches, and if their planners do not use the most efficient methods to find missing aircraft, eventually the organization will be sued and the results may not be favorable. This research gives search planners a defensible position from which to work.

CHAPTER II

REVIEW OF LITERATURE

There is very little information available on the subject of missing aircraft search in the continental United States, or anywhere else in the world for that matter. The organizations that are primarily responsible for conducting the searches for missing aircraft in the United States, the AFRCC and CAP, have been utilizing the only documented tool available to them, the NTAM. This is not written to place blame or fault on anyone, but because of budget and personnel constraints, nothing has been done to expand upon the research conducted by the DAOR for the searches conducted in the CONUS.

Regulatory Guidance in the United States

Search planning for missing aircraft searches in the United States is guided mainly by Joint Publication 3-50, The National Search And Rescue Manual. This publication, though valuable, does very little to support the planning requirements for missing aircraft searches. A large portion of the manual is devoted to maritime search, and also has guidance and responsibilities for the staff at all levels in the organizational structure of a search. Though this document provides valuable background information that can be useful to those coordinating a search, it does very little to establish guidance for true search planning for missing aircraft.

Pilots in the United States operate under Title 14 of the Code of Federal Regulations, the Federal Aviation Regulations when operating their aircraft. The Federal

Aviation Regulations in conjunction with the Airmen's Information Manual do provide survival tips and guidance for pilots after having crashed their aircraft that can help them to be located sooner by searchers. It does not however provide guidance for the search planners as to where to search.

The primary organization responsible for actually conducting searches for missing aircraft in the United States, CAP, provides regulatory guidance to it's emergency services personnel mainly in the areas of operating limitations and structure in CAP Regulations 55-1 and 60-1. These regulations also do not have any specific policies for where to begin a search. It is left up to the individual staff of the mission in conjunction with the coordinating agency, normally the AFRCC, to establish the best plan to resolve the issue. This planning normally ends up following the guidance established by the National SAR School as this school trains the majority of executive level search planners in CAP and the USAF.

National SAR School Materials

The National SAR School, located at the Coast Guard Reserve Training Center in Yorktown, Virginia, utilizes the most up to date materials available to train their students. Each student receives the Inland SAR Planning Course Notebook, which is updated with the most current information on a variety of topics ranging from legal aspects in SAR to the strategy and tactics required for missing aircraft searches. There are many emerging issues in SAR addressed at the school, and only so much time can be spent on research by the few staff members assigned at the school. The current Inland SAR Planning Course Notebook recommends the NTAM and provides background on how the NTAM was developed. The NTAM is a variant of the Offset and Track Variable (OTV) and

Modified Offset and Track Variable (MOTV) methods developed by the Canadian Department of National Defence in the 1970s and early 1980s. The NTAM is based on statistical information from 76 searches conducted in Canada in the early 1980s, and is accepted by search planners as the most reasonable approach available presently. Most of the information from the Inland SAR Planning Course Notebook on the subject is from notes and memos from the DAOR in Canada, which at present will not be released for public use outside of the DAOR.

CHAPTER III

METHODOLOGY

Subjects

The sample constitutes the 78 missing aircraft search missions of varying types coordinated by the AFRCC in 1999 that are valid for the study. These 78 missions represent approximately three percent of the 2,719 missions coordinated by the AFRCC in 1999. From discussion with the staff of the AFRCC this seemed reasonable as they would normally expect between 60 and 100 missing aircraft missions of varying types throughout any given year (C. D. Holmes, personal communication, January 12, 2000). As previously stated, there were actually 115 missing aircraft searches conducted in CONUS in 1999, but 37 of the searches did not meet the criteria for the study. It should also be noted that the AFRCC is only responsible for searches conducted in the CONUS, and the research conducted does not include searches conducted outside of the CONUS.

Instrument

To gather the required data for this project, the author used a simple database to gather the known crash site location, LKP, turning points, destination, and mitigating factors that might influence a search planner's decision like known radar plots or ELT signals. As the author reviewed the available information in more depth, greater expansion of this database was warranted to give more detailed explanations to the end-users of this research project.

Research Design

This study was primarily a statistical analysis. The author determined if it is reasonable for search planners in the CONUS to use the NTAM or if they should use some other method. This was based on data collected from the AFRCC mission folders for all missing aircraft missions of varying types conducted in 1999 as well as the NTSB Aviation Accident/Incident Database. Using the factual records of the missing aircraft missions conducted in 1999, the author first determined the percentage of missing aircraft that were found in area one of the NTAM, then area two of the NTAM, and then those found outside of the areas established by the NTAM. The author then reviewed the locations of the missing aircraft to determine if there might be a better search formula to be utilized in the CONUS and compare the results.

Procedures

First, the author collected the required information to validate the NTAM as established in the above instrument section of this chapter. This data was made readily available to the author by the AFRCC staff who were very interested in the results of this research, and the NTSB database was fairly simple to query online.

Second, the author determined how far off of the search track each aircraft was for the statistical analysis. To do so, the author used a computer software program utilized by search planners, SAR Viewpoint Version 2.1. This program has many utilities that allowed the author to plot the tracks of the missing aircraft as well as readily determine the distance from the track the missing aircraft was located at in nautical miles.

Third, the author determined the number of missing aircraft located in CONUS that were in area one using the NTAM.

Fourth, the author determined the number of missing aircraft located in CONUS that were within area two using the NTAM.

Fifth, the author determined the number of missing aircraft located in CONUS that were not within either area one or area two of the NTAM.

Sixth, based on the available information, the author determined that there are other reasonable areas that search planners could implement that might yield better results than the NTAM in the CONUS.

Finally, the author has recommended a method for search planners to effectively prosecute missing aircraft search missions within the CONUS. This not only took into account the simple distances off of track of the missing aircraft, but also other mitigating factors like known ELT or other distress signals, radar plots, or reports from witness or family members.

CHAPTER IV

RESULTS

In following the procedures established in the previous chapter the author documented the following results.

General Results

The author found the mean distance off of track for aircraft in the study to be 12.74 nautical miles. The author also found that mean distance that the aircraft in the study were found along the track was 64% of the intended track length. This can be further refined when not taking into account false missions. After removing false missions the mean distance off of track was 15.57 nautical miles while the mean distance that the aircraft were found along the track was 57% of the intended track length. A detailed table outlining the distances along and from the track by mission number can be found in Appendix A.

Results of Using the NTAM Area One

The author also found that 55 of the 78 aircraft in the study were located in area one using the NTAM. This is approximately 71% of the aircraft involved in the study. If the data is again refined to exclude false missions, 40 of the 62 aircraft were located in area one using the NTAM, approximately 65% of the aircraft located on actual missions. A detailed table listing the missions that the aircraft were located in area one of the NTAM can be found in Appendix B.

Results of Using the NTAM Area Two

The author determined that 59 of the 78 aircraft in the study were located in area two using the NTAM. This is approximately 76% of the aircraft involved in the study. After refining this data further to eliminate false missions, 43 of the 62 aircraft were located in area two using the NTAM, approximately 69% of the aircraft located on actual missions. A detailed table listing the missions that the aircraft were located in area two of the NTAM can be found in Appendix C.

Negative Results Using the NTAM

After determining the aircraft located in area one or two of the NTAM, the author calculated that 19 of the 78 aircraft in the study were not located in area one or area two using the NTAM. This is approximately 24% of the aircraft involved in the study. After removing false missions, 19 of the 62 aircraft located on actual missions were found outside of area one or two using the NTAM which is approximately 31% of the aircraft located on actual missions.

Results of Using an Alternative to the NTAM

After reviewing the results of implementing the Canadian NTAM, the author decided to try an alternative method to make a reasonable comparison. The author took a two staged approach as well. The first stage is the same as the NTAM, and the reader obviously already knows the results of that comparison. For the second stage of searching the author chose to have searches conducted within a radius of 20 nautical miles or 20% of the track length, whichever is greater, around each turning point along the route, the destination, and the LKP. Diagrams showing this revised second area are depicted in Figures 4 and 5. This resulted in 66 of the 78 aircraft in the study being

located, which is approximately 85% of the aircraft involved in the study. After eliminating the false missions, 51 of the 62 aircraft remaining were found in this area, which represent approximately 82% of the actual missing aircraft involved in the study. A table documenting the results of using this revised second area by mission can be found in Appendix D.

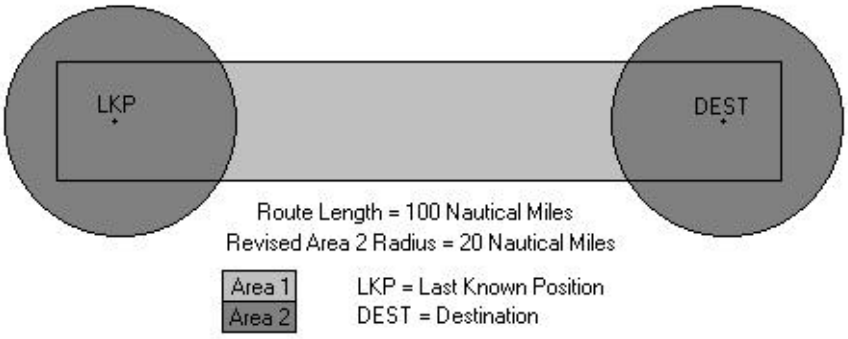

Figure 4. Revised Second Area Example One.

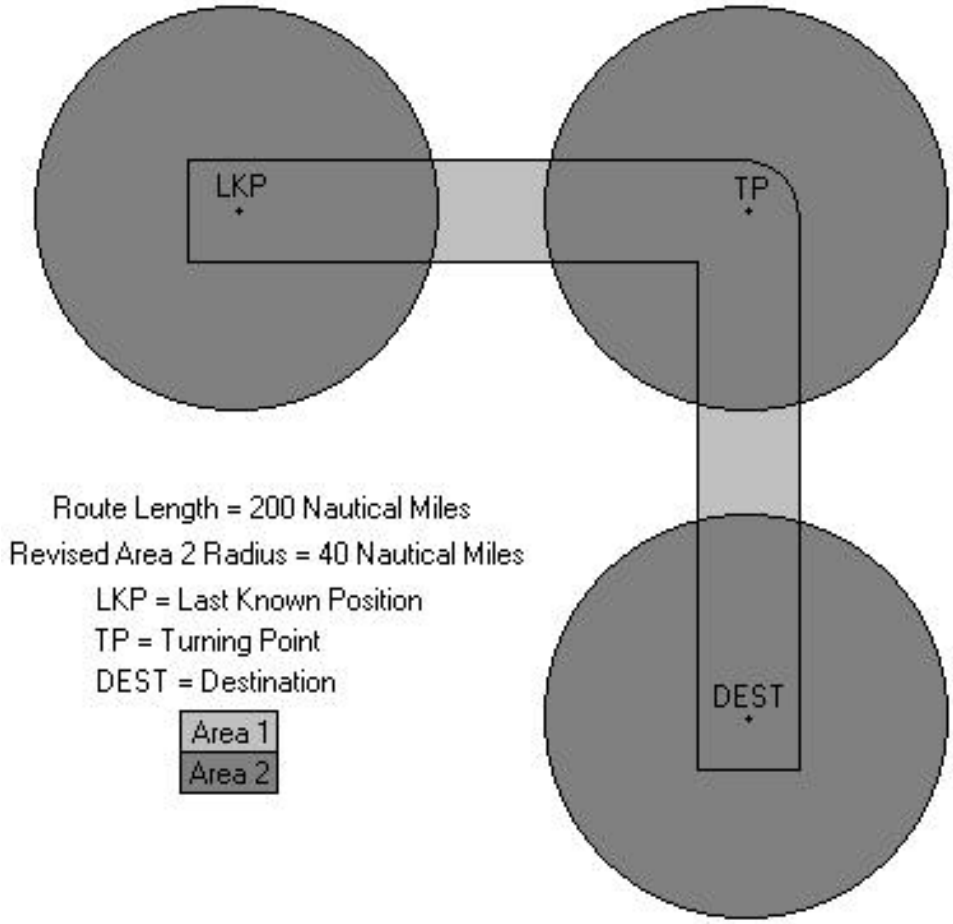

Figure 5. Revised Second Area Example Two

CHAPTER V

DISCUSSION

The results presented in the previous chapter speak for themselves on several issues, but do not clarify the research for the reader. There are several issues that readers need to be aware of as they review this research project that the author will go into more depth about in the following sections.

Limited Available Information

Though the author was able to collect enough information to conduct his research, he sometimes had a very difficult time doing so. This is not being mentioned to place blame on any organization or individuals, but does need to be brought up. Search planners are often faced with extremely limited information to work with, and that can often only be blamed on the missing pilot. Flight plans provide some useful information on where to start, but are often not detailed enough to properly limit a search area, and that assumes that the pilot even filed a flight plan. Many searches were initiated based on reports from family members or the owner of the aircraft, and often had even less information than is normally provided on a flight plan. It was blatantly obvious to the author in reviewing the data available to search planners that pilots do not expect to have an accident, and thus cut corners when providing information that could be helpful to searchers who are tasked to find them when they are lost. Several searches did not start until days after the pilot's accident because nobody noticed the aircraft and crew were overdue or missing. Additionally, even if there was data available the search planners are

forced to investigate many leads to limit the search area in the hopes of locating survivors. It is not often easy to determine if an aircraft made it to one or more of its destinations, especially if the pilot only over-flew a field, and did not land or communicate with people at that point along the route of flight. This problem is further exacerbated when definitive data from radar or NTAP may not be available or when it is it could be days before it can be processed and made available to planners. Pilots need to understand that just because you are using a transponder with a squawk code that does not mean that someone is listening or will have an exact location on you right away. The pilot and crew need to do everything that they can to help searchers should they get into trouble, and much of that can be done before they ever get into the airplane.

False verses Actual Missions

Search planners do not know if an aircraft has had an accident or has landed safely when initiating their efforts. Of the 78 missing aircraft search missions conducted in the CONUS in 1999 that were included in this project study, 16 were false alarms, or approximately 21% of the missions included in the study. In 15 of the 16 cases the aircraft was located safe on the ground somewhere along the route, and in one case an aircraft was located safe at an airport not along the route. All of these aircraft were located by searchers conducting ramp checks, and in every case the pilot had simply failed to close his or her flight plan. This is a waste of valuable resources and also forces search planners to consider this option in assigning tasks to search personnel. Many personnel conducting ramp checks could be used to search other areas of high probability on actual missions, but cannot be because they must eliminate the possibility of a false alarm.

Distance Along the Track

As noted in the previous chapter, the mean distance along the track that actual missing aircraft were located was 57% of the track length. Search planners need to have this broken down further to better understand how to focus search efforts. Table 5 below shows how many aircraft were located in 10% increments of the track length. Aircraft located before the LKP or after the destination are grouped into their own categories in the table.

Table 5

Crash Location Segment Breakdown

Distance Along Track Location	Number of Aircraft Located in Section	Percentage of Aircraft Located in Section
Before the LKP	4	6.45
LKP to 10% of Track	10	16.13
10% to 20% of Track	4	6.45
20% to 30 % of Track	5	8.06
30% to 40% of Track	4	6.45
40% to 50% of Track	1	1.61
50% to 60% of Track	3	4.84
60% to 70% of Track	2	3.23
70% to 80% of Track	1	1.61
80% to 90% of Track	5	8.06
90% of Track to Destination	12	19.35
After the Destination	11	17.74
Total Number of Actual Searches	62	

Note. This data represents the locations of actual missing aircraft within the study based on the original track, and does not include false missions.

Intended Track Length

The intended track lengths for each of the searches included in the research study varied greatly. The shortest track length was 7.53 nautical miles while the longest was

1,231.40 nautical miles. In all cases the LKP was also the origin for the flight. This is typical for the initial search planning efforts, but can make the search area much larger than it should be. The author found in his study that as additional leads were tracked down and more information made available, search planners were able to adjust the LKP and significantly decrease the size of the search area. Several of the missing aircraft were located very close to their adjusted LKP. Table 6 indicating the distanced from the adjusted LKP that the missing aircraft were located is included in Appendix E. The mean distance that missing aircraft were found from an updated LKP for actual missions was 24.72 nautical miles, with the shortest distance being right on top of the adjusted LKP to the greatest distance being 141.6 nautical miles from the updated LKP. As several of the aircraft were located at or extremely close to the updated LKP, planner should conduct hasty searches around updated LKPs as soon as possible.

NTAM Results

The results of using the Canadian NTAM were no where near as good in the CONUS as they were in Canada. For actual missions area one of the NTAM yielded a 65% found in the CONUS in comparison to the 79% found in Canada. For actual missions area two of the NTAM yielded a 69% found in the CONUS in comparison to the 83% found in Canada. In both situations this is much lower than search planner would find acceptable. This suggested to the author that there had to be a better way. A “D” is never really acceptable in any school, and this is what the Canadian NTAM was advocating for use in the CONUS. If search planners will be expected to defend their position to their peers, or possibly in court to a jury, then the method implemented in the CONUS needs to yield the same or better results than the Canadian NTAM.

Alternatives to the Canadian NTAM

There are several possible alternatives to the using the Canadian NTAM, but each has its own drawbacks. The author tried to minimize additional workload on search teams, planners, managers and searchers alike, while maximizing the number of aircraft located in the search area.

In deciding on a logical alternative the author chose to leave first area searched the same as the Canadian NTAM. This was done for two main reasons. First, many of the aircraft located in the study were found within this window, both actual and false. Second, as information is normally extremely limited at the beginning of a search, route searches along the only area of known probability, the intended route of the aircraft, is really the only alternative to waiting for more information. As it is considered better for these assets to be doing something rather than sitting idle waiting for better leads, route searches seem reasonable. Area one of the NTAM was considered acceptable by search planners. Searching an area any larger than this in the first stage was determined to be a poor decision unless it could be strongly defended.

In considering the established limitations of the search area for the first stage of the search, the author decided to look at better alternatives for area two. The only way to yield significantly better results than by using the Canadian NTAM was to either greatly increase the overall track to be searched or to search higher probability areas. Past education in crash investigation reminded the author that most aircraft accidents occur in the early or late stages of flight, and thus he decided to see if it was better to focus the second stage of the search expansion on the LKP, destination, and known turning points along the route. The author reviewed several alternatives for the second stage search.

In trying to keep the math simple for search planners, the author first review expanding the search area to 20 nautical miles around the LKP, destination and known turning points. This yielded a find rate of approximately 73% found on actual missions which is better than using the Canadian NTAM that yielded a 69% rate. The author's first choice already resulted in a better conclusion, which guided him to trying other alternatives.

First he tried establishing the second search area as a radius of 10% of the intended track length around the LKP, turning points and the intended destination. This yielded a rate of approximately 68% found on actual missions, which compared to the Canadian NTAM results was worse, but not significantly.

Then the author tried expanding the second search area to a radius of 20% of the intended track length around the LKP, turning points and the intended destination. This resulted in approximately 77% percent of the actual missing aircraft being located in that search area, which is significantly better than if using the Canadian NTAM, and also yielded better results than using the author's first alternative of a 20 nautical mile radius.

Finally, the author decided to combine his two best alternatives to see if that yielded any better results. By making the second area 20 nautical miles or 20% of the intended track length, whichever was greater, the author found that approximately 82% of the missing aircraft would have been located. This was the best alternative, and also better than using the Canadian NTAM, which is why it was chosen as the alternative example. It should also be noted that this data is based on using the original LKP for determining track length, not updated or adjusted LKPs as this could significantly reduce the area searched around the LKP, turning points, and final destination. The author did

this for two reasons. First, he noted a tendency for aircraft on longer routes tending to be farther away from the intended track, justifying a larger area being searched. Second, planners are often staging crews at several different location often great distances apart, and this allows planning to take a more forward leaning approach. More search assets may be pre-positioned in certain sections of the search area, and thus could expand into searching area two before other locations are ready to do so. It could be advantageous to move search assets to provide better coverage of the search area, but this may not be possible for a number of reasons like weather restrictions, search crew availability, or other aircraft operations or maintenance limitations.

CHAPTER VI

CONCLUSION

The Canadian NTAM, though appropriate to use when search planners have nothing else to go on, is not the best method for planning missing aircraft searches in the CONUS. The author's research indicates that alternative methods to the NTAM would yield much better results in the CONUS. Search planners should use alternative methods to the Canadian NTAM. The author will give recommended search strategy for missing aircraft searches conducted in the CONUS in chapter seven of this project.

CHAPTER VII

RECOMMENDATIONS

The author has several recommendations from conducting this research.

Search Planners

The author would like to make the following recommendation to search planners in the CONUS:

First, as early as possible in the search conduct ramp searches of the airports along the intended route of flight, especially the intended destination so as to eliminate those airports for false missions. This is a good job for the first arriving crews to perform while a more specific search area is being delineated and more resources become available. Often these resources will be en route from locations near or even co-located with the LKP, turning points along the route, or the final destination of the missing aircraft, and it is easier for them to start searching from there rather than have to turn back unnecessarily.

Second, assuming that you have no other available information other than the intended route of flight, establish your first area to be searched the same as the Canadian NTAM: a rectangular search area 10 nautical miles either side of the intended route extended 10 nautical miles beyond the intended destination and 10 nautical miles before the LKP. It is further recommended that you search that route with the following precedence:

1. The last 20% of the route, from the destination backwards searching from the track outwards with equal priority along the track;

2. The area immediately surrounding the destination after the last 10% of the route searching from the track outwards with equal priority;

3. The first 20% of the route, from the LKP forwards searching from the track outwards with equal priority along the track;

4. The area immediately surrounding the LKP before the first 10% of the route searching from the track outwards with equal priority along the track;

5. Search the remaining portions along the route from the LKP to the destination searching from the track outwards with equal priority along the track;

Note that if there is a more accurate updated LKP than the origin of the flight like NTAP data or known sightings then the area immediately surrounding the updated LKP outwards to 10 nautical miles with equal priority should be searched prior to initiating the above search sequence. If this updated LKP suggests it, eliminate areas that are no longer necessary to search.

Third, after completing a thorough search of area one, initiate a second stage search. This search expands upon the first search area to search in more detail around the LKP, turning points along the route and the destination. The second stage area of this new method expands the search area to a 20 nautical mile or 20% of the original track length, whichever is greater, radius around the original LKP, turning points, and destination. Areas of overlap with area one should be searched again as those tend to be the highest areas of probability. It is further recommended that you search this area with the following precedence:

1. The area immediately surrounding the final destination from the final destination outwards with equal priority;

2. Turning points within the last 20 percent of the original track length from the turning point outwards with equal priority;

3. The area immediately surrounding the original or updated LKP searching from outwards with equal priority;

4. Search the remaining turning points along the route from the original or updated LKP to the destination searching from each turning point outwards with equal priority;

Note that if there is a more accurate updated LKP than the origin of the flight like NTAP data or known sightings then the area immediately surrounding the updated LKP outwards to 20 nautical miles or 20% of the original track length, whichever is greater, should be searched with equal priority prior to initiating the above search sequence. If this updated LKP suggests it, eliminate areas that are no longer necessary to search.

Fourth, plan for expansion and the need for additional resources. If ramp searches and searches of the high priority areas are not successful, then a full blown search using the method recommended above is definitely required, and that will most likely be resource intensive.

Fifth, early on, set reasonable objectives for your personnel including when you plan to close or suspend your search efforts. At some point in time all leads will be exhausted, the reasonable possibility that survivors will be found does not exist, or the risk to searchers will be too great to warrant a continued search. Set reasonable limits to avoid looking for one of your own crews that exceeded their limitations.

Management and Instructors

Those responsible for managing search agencies and those teaching search managers and planners need to stay abreast of the issues involved in this study. Part of the reason that this study was conducted was because there had never been an effort in the CONUS to determine if use of the NTAM was appropriate. It was also conducted because even if it had been validated informally by search managers agreeing with the conclusions of the Canadian NTAM, nobody had truly reviewed the data recently. As technology changes rapidly, so could the areas to be searched and the guidance to search managers and planners.

For Any Reader

By reviewing the results of this study you have shown that you obviously have an interest in the subject matter for one reason or another. Consider expanding upon this study at a later date and expanding upon my work. Also consider validating or invalidating my work. There could be many changes between when I wrote this project report and when you do another study. You might find very similar or dissimilar results. Either way, your help and guidance could save lives, and these things we do so that others may live.

REFERENCES

Air Force Rescue Coordination Center. (1999). AFRCC Basic Controller Inland SAR Training and Certification, Lesson 6E. Langley Air Force Base, VA: U.S. Air Force.

Air Force Rescue Coordination Center. (1999). Mission Records and Folders. Langley Air Force Base, VA: U.S. Air Force.

Federal Aviation Administration. (2000). Federal Aviation Regulations, Part 91. Washington, DC: Federal Aviation Administration.

Holmes, Christopher D. (July 1999). Where to Look: How VFR Flight Plans Affect a Search and Rescue Response. Unpublished graduate research project, Embry-Riddle Aeronautical University Extended Campus, Langley Air Force Base, VA.

National SAR School. (1996). Inland SAR Planning Course Notebook. Yorktown, VA: U.S. Air Force.

National Transportation Safety Board. (2000). NTSB Aviation Accident/Incident Database. Washington, DC.

U.S. Department of Defense. (1991). National Search And Rescue Manual (Joint Publication 3-50). Washington, DC: Joint Chiefs of Staff.

U.S. Department of Defense. (March 2000). Draft National Search And Rescue Manual (Joint Publication 3-50). Washington, DC: Joint Chiefs of Staff.

APPENDIX A

TABLE 1

Table 1

Detailed Table of Missions

Mission Number	Track Length (NM)	Distance Along Track (NM)	Distance Along Track (%)	Distance From Track (NM)
99M0011A	61.82	48.83	79	4.10
99M0046A	166.60	49.70	30	7.11
99M0076	27.27	27.45	101	0.45
99M0106	244.10	142.20	58	24.30
99M0123A	51.48	44.44	86	1.96
99M0140A	204.90	198.53	97	8.12
99M0162	342.90	342.77	100	0.27
99M0187A	251.20	52.10	21	51.10
99M0198A	273.30	272.98	100	8.51
99M0244A	121.50	111.10	91	20.80
99M0261	445.30	0.66	0	0.25
99M0308A	270.46	(16.90)	(6)	103.90
99M0342A	326.20	129.80	40	32.50
99M0392	280.70	(0.65)	(0)	0.53
99M0427A*	519.00	519.00	100	0.00
99M0491A	8.52	8.55	100	0.30
99M0540A	120.80	47.90	40	4.17
99M0604	709.72	47.10	7	9.66
99M0657A	269.95	275.02	102	5.18
99M0729A	246.00	72.30	29	7.36
99M0794A	662.02	0.65	0	2.66
99M0851	180.00	118.80	66	3.46
99M0860A	191.20	175.50	92	0.49
99M0892	345.50	318.60	92	0.56
99M0904A	25.32	31.24	123	11.68
99M0908	57.47	0.80	1	1.02
99M0920A*	50.00	50.00	100	0.00
99M1013A*	103.20	98.66	96	28.20
99M1090A*	151.85	151.85	100	0.00
99M1119*	532.00	532.00	100	0.00
99M1152A	560.60	527.00	94	0.24
99M1179*	174.12	149.32	86	0.00
99M1180	164.60	137.50	84	28.20
99M1192	74.28	22.10	30	0.30
99M1202A	63.94	31.97	50	0.50
99M1231A	139.00	(0.26)	(0)	10.20
99M1313A	130.10	129.92	100	0.17
99M1448A	159.00	107.80	68	9.22
99M1470A	101.80	101.92	100	0.12
99M1476	329.00	338.38	103	13.99

99M1510	169.10	151.50	90	3.08
99M1539A	524.40	492.80	94	7.87
99M1566*	256.50	256.50	100	0.00
99M1603A	76.14	69.61	91	7.42
99M1614	296.50	48.30	16	17.50
99M1635*	578.60	374.59	65	0.16
99M1652*	333.20	333.20	100	0.00
99M1692	1130.90	556.70	49	21.20
99M1708A	325.90	326.19	100	0.24
99M1718A	333.32	0.45	0	0.48
99M1726A	153.80	228.60	149	145.80
99M1764	320.20	5.16	2	3.89
99M1860A	133.00	121.00	91	7.77
99M1880A*	222.81	222.81	100	0.00
99M1910A	546.00	477.50	87	36.40
99M1923	65.27	63.20	97	10.40
99M1939	340.20	286.90	84	59.80
99M2085	1231.40	160.80	13	19.20
99M2209	461.36	4.88	1	0.31
99M2210	60.16	1.95	3	1.92
99M2280A*	54.15	54.15	100	0.00
99M2282	108.10	25.90	24	2.95
99M2292	26.49	1.65	6	1.44
99M2322	371.20	139.90	38	20.10
99M2360	105.17	(86.30)	(82)	91.73
99M2373A*	60.26	60.26	100	0.00
99M2387*	105.40	105.40	100	0.00
99M2464*	59.65	59.65	100	0.00
99M2481	7.53	13.73	182	10.39
99M2509A*	373.22	373.22	100	0.00
99M2541*	54.19	0.00	0	0.00
99M2574	351.70	351.86	100	0.23
99M2611A	260.15	145.00	056	36.60
99M2621A	85.47	9.97	12	7.55
99M2636A	897.80	140.90	16	15.90
99M2684A	665.80	667.88	100	1.48
99M2703	325.90	125.40	38	43.90
99M2712	32.66	2.17	7	16.20
Total number of actual missions			62	
Total number of false missions			16	
Total number of missions			78	

Note 1. Negative numbers are shown in parentheses.
Note 2. False Missions are annotated with an asterisk (*)
Note 3. The above data was derived from the 1999 mission records of the AFRCC.
(AFRCC Mission Records, 1999)

APPENDIX B

TABLE 2

Table 2

Missions having Aircraft Found in Area One using the NTAM

Mission Number	Track Length (NM)	Distance Along Track (NM)	Distance Along Track (%)	Distance From Track (NM)
99M0011A	61.82	48.83	79	4.10
99M0046A	166.60	49.70	30	7.11
99M0076	27.27	27.45	101	0.45
99M0123A	51.48	44.44	86	1.96
99M0140A	204.90	198.53	97	8.12
99M0162	342.90	342.77	100	0.27
99M0198A	273.30	272.98	100	8.51
99M0261	445.30	0.66	0	0.25
99M0392	280.70	(0.65)	0	0.53
99M0427A*	519.00	519.00	100	0.00
99M0491A	8.52	8.55	100	0.30
99M0540A	120.80	47.90	40	4.17
99M0604	709.72	47.10	7	9.66
99M0657A	269.95	275.02	102	5.18
99M0729A	246.00	72.30	29	7.36
99M0794A	662.02	0.65	0	2.66
99M0851	180.00	118.80	66	3.46
99M0860A	191.20	175.50	92	0.49
99M0892	345.50	318.60	92	0.56
99M0908	57.47	0.80	1	1.02
99M0920A*	50.00	50.00	100	0.00
99M1090A*	151.85	151.85	100	0.00
99M1119*	532.00	532.00	100	0.00
99M1152A	560.60	527.00	94	0.24
99M1179*	174.12	149.32	86	0.00
99M1192	74.28	22.10	30	0.30
99M1202A	63.94	31.97	50	0.50
99M1313A	130.10	129.92	100	0.17
99M1448A	159.00	107.80	68	9.22
99M1470A	101.80	101.92	100	0.12
99M1510	169.10	151.50	90	3.08
99M1539A	524.40	492.80	94	7.87
99M1566*	256.50	256.50	100	0.00
99M1603A	76.14	69.61	91	7.42
99M1635*	578.60	374.59	65	0.16
99M1652*	333.20	333.20	100	0.00
99M1708A	325.90	326.19	100	0.24
99M1718A	333.32	0.45	0	0.48
99M1764	320.20	5.16	2	3.89

99M1860A	133.00	121.00	91	7.77
99M1880A*	222.81	222.81	100	0.00
99M2209	461.36	4.88	1	0.31
99M2210	60.16	1.95	3	1.92
99M2280A*	54.15	54.15	100	0.00
99M2282	108.10	25.90	24	2.95
99M2292	26.49	1.65	6	1.44
99M2373A*	60.26	60.26	100	0.00
99M2387*	105.40	105.40	100	0.00
99M2464*	59.65	59.65	100	0.00
99M2509A*	373.22	373.22	100	0.00
99M2541*	54.19	0.00	0	0.00
99M2574	351.70	351.86	100	0.23
99M2621A	85.47	9.97	12	7.55
99M2684A	665.80	667.88	100	1.48
Total number of actual missions			39	
Total number of false missions			15	
Total number of missions			54	

Note 1. Negative numbers are shown in parentheses.
Note 2. False Missions are annotated with an asterisk (*)
Note 3. The above data was derived from the 1999 mission records of the AFRCC.
(AFRCC Mission Records, 1999)

APPENDIX C

TABLE 3

Table 3

Missions having Aircraft found in Area Two using the NTAM

Mission Number	Track Length (NM)	Distance Along Track (NM)	Distance Along Track (%)	Distance From Track (NM)
99M0011A	61.82	48.83	79	4.10
99M0046A	166.60	49.70	30	7.11
99M0076	27.27	27.45	101	0.45
99M0123A	51.48	44.44	86	1.96
99M0140A	204.90	198.53	97	8.12
99M0162	342.90	342.77	100	0.27
99M0198A	273.30	272.98	100	8.51
99M0261	445.30	0.66	0	0.25
99M0392	280.70	(0.65)	0	0.53
99M0427A*	519.00	519.00	100	0.00
99M0491A	8.52	8.55	100	0.30
99M0540A	120.80	47.90	40	4.17
99M0604	709.72	47.10	7	9.66
99M0657A	269.95	275.02	102	5.18
99M0729A	246.00	72.30	29	7.36
99M0794A	662.02	0.65	0	2.66
99M0851	180.00	118.80	66	3.46
99M0860A	191.20	175.50	92	0.49
99M0892	345.50	318.60	92	0.56
99M0904A	25.32	31.24	123	11.68
99M0908	57.47	0.80	1	1.02
99M0920A*	50.00	50.00	100	0.00
99M1090A*	151.85	151.85	100	0.00
99M1119*	532.00	532.00	100	0.00
99M1152A	560.60	527.00	94	0.24
99M1179*	174.12	149.32	86	0.00
99M1192	74.28	22.10	30	0.30
99M1202A	63.94	31.97	50	0.50
99M1231A	139.00	(0.26)	0	10.20
99M1313A	130.10	129.92	100	0.17
99M1448A	159.00	107.80	68	9.22
99M1470A	101.80	101.92	100	0.12
99M1476	329.00	338.38	103	13.99
99M1510	169.10	151.50	90	3.08
99M1539A	524.40	492.80	94	7.87
99M1566*	256.50	256.50	100	0.00
99M1603A	76.14	69.61	91	7.42
99M1635*	578.60	374.59	65	0.16
99M1652*	333.20	333.20	100	0.00

99M1708A	325.90	326.19	100	0.24
99M1718A	333.32	0.45	0	0.48
99M1764	320.20	5.16	2	3.89
99M1860A	133.00	121.00	91	7.77
99M1880A*	222.81	222.81	100	0.00
99M1923	65.27	63.20	97	10.40
99M2209	461.36	4.88	1	0.31
99M2210	60.16	1.95	3	1.92
99M2280A*	54.15	54.15	100	0.00
99M2282	108.10	25.90	24	2.95
99M2292	26.49	1.65	6	1.44
99M2373A*	60.26	60.26	100	0.00
99M2387*	105.40	105.40	100	0.00
99M2464*	59.65	59.65	100	0.00
99M2481	7.53	13.73	182	10.39
99M2509A*	373.22	373.22	100	0.00
99M2541*	54.19	0.00	0	0.00
99M2574	351.70	351.86	100	0.23
99M2621A	85.47	9.97	12	7.55
99M2684A	665.80	667.88	100	1.48
Total number of actual missions			44	
Total number of false missions			15	
Total number of missions			59	

Note 1. Negative numbers are shown in parentheses.
Note 2. False Missions are annotated with an asterisk (*)
Note 3. The above data was derived from the 1999 mission records of the AFRCC.
(AFRCC Mission Records, 1999)

APPENDIX D

TABLE 4

Table 4

Results of Using Revised Second Area

Mission Number	Revised Area Two Aircraft Located
99M0011A	Yes
99M0046A	Yes
99M0076	Yes
99M0106	No
99M0123A	Yes
99M0140A	Yes
99M0162	Yes
99M0187A	No
99M0198A	Yes
99M0244A	Yes
99M0261	Yes
99M0308A	No
99M0342A	Yes
99M0392	Yes
99M0427A*	Yes
99M0491A	Yes
99M0540A	Yes
99M0604	Yes
99M0657A	Yes
99M0729A	Yes
99M0794A	Yes
99M0851	Yes
99M0860A	Yes
99M0892	Yes
99M0904A	Yes
99M0908	Yes
99M0920A*	Yes
99M1090A*	Yes
99M1013A*	No
99M1119*	Yes
99M1152A	Yes
99M1179*	Yes
99M1180	No
99M1192	Yes
99M1202A	Yes
99M1231A	Yes
99M1313A	Yes
99M1448A	Yes

99M1470A	Yes
99M1476	Yes
99M1510	Yes
99M1539A	Yes
99M1566*	Yes
99M1603A	Yes
99M1614	Yes
99M1635*	Yes
99M1652*	Yes
99M1692	Yes
99M1708A	Yes
99M1718A	Yes
99M1726A	No
99M1764	Yes
99M1860A	Yes
99M1880A*	Yes
99M1910A	Yes
99M1923	Yes
99M1939	No
99M2085	Yes
99M2209	Yes
99M2210	Yes
99M2280A*	Yes
99M2282	Yes
99M2292	Yes
99M2322	No
99M2360	No
99M2373A*	Yes
99M2387*	Yes
99M2464*	Yes
99M2481	Yes
99M2509A*	Yes
99M2541*	Yes
99M2574	Yes
99M2611A	No
99M2621A	Yes
99M2636A	No
99M2684A	Yes
99M2703	No
99M2712	Yes

Note 1. False Missions are annotated with an asterisk (*)
Note 2. The above data was derived from the 1999 mission records of the AFRCC.
(AFRCC Mission Records, 1999)

APPENDIX E

TABLE 6

Table 6

Missions in the Project Study Having Updated LKPs

Mission Number	LKP Distance to Final Location in Nautical Miles	Type of LKP
99M0011A	0.78	NTAP
99M0046A	7.95	Radar
99M0106	0.6	NTAP
99M0140A	8.41	Radar
99M0198A	6.67	Radar
99M0244A	112.2	Tower Visual
99M0308A	104.5	NTAP
99M0342A	0	NTAP
99M0657A	40.82	NTAP
99M0729A	0	Pilot Communication
99M0794A	0.78	NTAP
99M0892	23.29	Radar
99M1119	66.66	Pilot Communication
99M1152A	12.51	Radar
99M1313A	1.07	Radar
99M1476	28.41	Radar
99M1510	0.45	Radar
99M1539A	46.18	Radar
99M1566*	17.4	Radar
99M1603A	0	Radar
99M1652*	91.9	Radar
99M1692	141.6	NTAP
99M1764	6	Pilot Communication
99M1860A	1.2	NTAP
99M1880A*	220.7	Pilot Communication
99M2209	4.87	Pilot Communication
99M2280A*	37.45	Radar
99M2611A	0.6	Radar
99M2684A	2.36	Radar
Total Mean distance from LKP to Final Location		33.98 Nautical Miles
Total Mean Distance from LKP to Final Location Excluding False Missions		24.72 Nautical Miles

Note. False Missions are annotated with an asterisk (*)
Note 2. The above data was derived from the 1999 mission records of the AFRCC. (AFRCC Mission Records, 1999)

SEARCH TIME FOR DOWNED AIRCRAFT ON FLIGHT PLANS VERSUS DOWNED AIRCRAFT NOT ON FLIGHT PLANS

by

Tracy Nicole Delaney

A Graduate Project
Submitted to the Extended Campus
in Partial Fulfillment of the Requirements of the Degree of
Master of Aeronautical Science

Embry-Riddle Aeronautical University
Extended Campus
Langley Resident Center
October 2003

SEARCH TIME FOR DOWNED AIRCRAFT ON FLIGHT PLANS VERSUS DOWNED AIRCRAFT NOT ON FLIGHT PLANS

by

Tracy Nicole Delaney

This Graduate Research Project
was prepared under the direction of the candidate's Research Committee Member,
Mr. Robert Boddy, Adjunct Assistant Professor, Extended Campus,
and the candidate's Research Committee Chair,
Dr. Randall Harris, Adjunct Assistant Professor, Extended Campus, and has been
approved by the Project Review Committee. It was submitted
to the Extended Campus in partial fulfillment of
the requirements for the degree of
Master of Aeronautical Science

ABSTRACT

Researcher: Tracy Nicole Delaney

Title: Search Time For Downed Aircraft on Flight Plans Versus Downed Aircraft Not on Flight Plans

Institution: Embry-Riddle Aeronautical University

Degree: Master of Aeronautical Science

Year: 2003

This research project compared search times for downed aircraft on a Visual Flight Rules (VFR) flight plan versus downed aircraft not on a flight plan. It also compared the amount of time it took to activate search units for each case. It was found that for aircraft not on a flight plan, there was a significant increase in the time to activate search units and to locate the downed aircraft. It was also found that aircraft that requested flight following required significantly less search time to locate than those that did not. The results can be used by pilots to make an educated decision on whether to file a flight plan with the Federal Aviation Administration when flying Visual Flight Rules.

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CHAPTER I

INTRODUCTION

Background of the Problem

The search for missing aircraft in the United States (US) is a complex procedure involving numerous state and federal agencies. The US National Search and Rescue Committee (NSARC) has designated the Air Force as the US inland search and rescue (SAR) coordinator (NSARC, 2000). The Air Force has delegated this responsibility to the Air Force Special Operations Command, Director of Aerospace Operations (AFSOC/DO). The Air Force Rescue Coordination Center (AFRCC), located at Langley Air Force Base, Virginia, has been designated by the AFSOC/DO as the US inland search and rescue (SAR) mission coordinator (SMC). With this responsibility, the AFRCC receives all notifications of overdue aircraft from the Federal Aviation Administration (FAA). Each state Governor has a signed agreement with the AFSOC/DO designating the appropriate agencies to be responsible for SAR within their state borders. The AFRCC coordinates with these designated state agencies for all missing aircraft searches in the US.

The first part of every missing aircraft search is receiving the initial report of the overdue aircraft. There are four main methods that the FAA can be notified of a missing aircraft. The first is when a pilot does not close his or her flight plan within 30 minutes of the estimated time of arrival. The second is if a family member or reliable source reports that an aircraft is an hour or more overdue. The third method is when the FAA loses radio and radar contact with an aircraft. The fourth method of notification is a

satellite or airborne aircraft report of an Emergency Locator Transmitter (ELT), the distress beacon aboard an aircraft designed to activate automatically due to G-forces when an accident has occurred. Often there is more than one indication that the aircraft has gone down. The focus of this study is to investigate how the activation of flight plans relates to the time required to locate a downed aircraft.

Pilots have varied opinions on whether or not flight plans are worth filing. Some pilots prefer not to have their flights tracked. Others feel that flight plans are an important safety tool that could save their life in the event of problems. Regardless of opinion, a flight plan provides search planners two key components of a search: a defined search area and timeliness in reporting the aircraft overdue.

Researcher's Work Setting and Role

The AFRCC is the sole agency responsible for coordinating SAR for the inland region of the Continental US (CONUS). The researcher involved in this study is a certified AFRCC controller, shift supervisor, trainer, and chief evaluator for the AFRCC. She also has experience as the liaison for the Search and Rescue Satellite-Aided Tracking system that monitors distress signals and all outside agencies working with the AFRCC. She has coordinated and supervised multiple missing aircraft missions and has access and permission to use all data pertaining to aircraft searches for this study. She conducted the research at the AFRCC using the current SAR database (SARDAB).

Statement of Problem

When pilots fly an aircraft by visual flight rules (VFR), they have the choice of whether or not to file a flight plan. The purpose of the flight plan is so the FAA can track

whether the aircraft reaches its intended destination. The process of filing a flight plan, however, takes time and requires coordination with the FAA which is one reason some pilots do not file a flight plan when they fly. The focus of this study is to determine if historically there has been a difference in the amount of time it takes to locate downed aircraft on flight plans versus the time it takes to locate aircraft not on a flight plan.

Definition of Terms

When the FAA sends out a report of an overdue aircraft, they send it in the form of an Alert Notice (ALNOT) over the web-based Aeronautical Information System (AIS). A family concerned ALNOT is a report of an overdue aircraft, not on a flight plan, which was reported overdue to the FAA by family or other reliable sources. An Emergency Locator Transmitter (ELT) is the beacon on an aircraft that emits a distress signal on the frequencies of 121.5, 243.0, or 406 and can be detected by satellite or airborne aircraft upon G-force activation. A radio/radar drop-off is when the FAA has an unexpected loss of communication and radar contact on an aircraft they are tracking.

Limitations and Assumptions

This study is limited to aircraft flying within the borders of the CONUS. The data being used includes all missing aircraft from January 2000 – July 2003. It does not include all aircraft accidents. The missions involved are for those aircraft that were reported overdue and had a formal search initiated. There is no data available for aircraft that were located before a formal notification of a missing aircraft was made to the FAA. In addition, missing aircraft searches that were suspended because the aircraft were never located were not used in the data analysis. There were a few missions that also had to be

omitted because all of the pertinent information was not available. For example, some searches started out as a search for an ELT signal with no report of a missing aircraft. The search teams located a crashed aircraft, but there was no indication of how long the aircraft had been out there and no flight plan was available, thus no LKP time could be established. In addition, some missions in the SARDAB made no reference to the presence of or absence of a flight plan. Since the database for these few cases did not show any evidence of any of the information typically contained on a flight plan, it was assumed that no flight plan was filed or activated.

CHAPTER II

REVIEW OF RELEVANT LITERATURE

Flight Plans

Flight plans are filed with the FAA and provide basic information about the pilot and his or her intended flight. It is a formal document explaining the origin and destination (Kern, 1998). It also can provide the FAA with pilot contact information, requested altitude, aircraft description, departure time, and fuel on board which can all be useful in an aircraft search. The form used is the FAA Form 7233-1 shown in Figure 1, Appendix B. Flight plans are not automatically activated. The pilot has to contact the FAA to activate the flight plan (Nolan, 1999). There were a few search missions in this study where pilots of downed aircraft had originally filed a flight plan, but never activated it. In theses cases, the FAA was unaware that the aircraft was overdue until a reliable source made the report. The researcher categorized these missions as not being on a flight plan. Information contained on the VFR flight plans are transmitted from the originating flight service station (FSS) to the destination FSS. If the pilot does not close the flight plan within 30 minutes of the planned arrival time, the destination FSS starts the procedures to search for the aircraft (USDOT, 2002). Pilots flying aircraft under VFR in the US are not required to file a flight plan with the FAA (Nolan, 1999).

Elements of Aircraft Searches

The entire procedure of searching for missing aircraft is an in-depth process that is affected by numerous factors. Weather, terrain, size of search area, and the availability of searchers are all aspects that can either help or hinder the search effort. Another

significant factor is how long it takes for the FAA to be notified that the aircraft is overdue, which is what triggers the search response.

For aircraft on a flight plan that search response begins when the pilot fails to close out his or her flight plan. Thirty minutes after the aircraft's estimated time of arrival (ETA), the destination FSS considers the aircraft overdue and starts their investigation to locate the aircraft. If the aircraft has not been located within 30 minutes after the aircraft is overdue, 60 minutes after the ETA, the FSS will then send out an Information Request (INREQ) to solicit information from other FSS's and Air Route Traffic Control Centers (ARTCC) along the route of flight. The AFRCC, at this point will also check for ELT signals that were reported to be broadcasting along the route of flight. If the responses are negative within one hour of issuing the INREQ, an ALNOT is sent out. If an aircraft is not on a flight plan, the FAA will issue an ALNOT when a reliable source reports the aircraft an hour or more overdue (USDOT, 2002).

As soon as the ALNOT is issued, the AFRCC begins their investigation. The flight plan is a useful tool in providing information and assisting searchers in determining where to begin searching, but does not always limit the search area (Desmarais, 2000).

Previous Study

In 1999, Christopher Holmes, a controller at the AFRCC, investigated the same topic comparing the search times between aircraft on a flight plan with those not on a flight plan. He used data from the 77 VFR aircraft missions during 1998 and the first quarter of 1999. His results, reported in Where to Look: How VFR Flight Plans Affect a Search and Rescue Response (1999), indicated a strong correlation between filing a flight

plan and an increased SAR response time of 12 hours over those that did not file a flight plan.

Since this study was completed, there has been a significant increase in radar coverage over the US. This has been largely due to the terrorist attacks on the US, September 11, 2001. In addition, the AFRCC now has access to a radar analyst specialist that has spent numerous hours in searching for and locating refined last known radar data. This specialist has directly contributed to locating numerous missing aircraft. Desmarais (2000) stated that one of the problems in locating downed aircraft was when radar data was not available or took days to obtain. The current procedures allow for a quick response in receiving radar data in areas that have adequate radar coverage.

Because of the increased radar data available to use in searching for missing aircraft, it was important to determine if Holmes's findings in 1999 are applicable to the current SAR aviation environment.

Statement of Hypothesis

In this study, the researcher compared the search time for downed aircraft on a flight plan versus aircraft not on a flight plan. The null hypothesis tested was that the absence of a flight plan had no effect on search time for a downed aircraft.

CHAPTER III

RESEARCH METHODOLOGY

Research Design

The research technique used to carry out this study was statistical analysis on historical data. It was a correlation study to determine if there was a difference between the time spent searching for downed aircraft on a flight plan and aircraft not on a flight plan. The time being analyzed was broken down into three separate categories. The first was the time elapsed from the aircraft's last known position (LKP) (e.g. departure point, last radar contact, etc.) to the time search and rescue unites (SRUs) were activated to physically search for the missing aircraft. This time is labeled as LKP to SRU. The second time analyzed was the time from SRU activation until the aircraft wreckage was located (LOC). This time is labeled SRU to LOC. The final time analyzed was the total time from the LKP to the location of the aircraft. This time is labeled as LKP to LOC.

Sources of Data

The data was collected from the AFRCC SARDAB. This database is maintained at Langley Air Force Base, Virginia at the AFRCC and contains all pertinent data since September 1999. This database also contains all the details about each individual search. These details provided useful information to the researcher to determine why certain missions deviated from the standard.

Research Model

The data for this research project was obtained by the following method. The researcher referenced each individual search mission in the SARDAB, determined if it

met the criteria of this research project, and then obtained all of the incident numbers for the searches that applied. Since the database contains incidents for not only missing aircraft, but also for missing persons and searches that resulted in non-distress ELT signals, it was a very involved process. There were over 21,000 incidents that had to be reviewed to narrow it down to the 149 searches that applied to this research. Then the researcher went back into the SARDAB and extracted each mission number, time of the LKP, time of the SRU activation, time the aircraft was located, whether the aircraft was on a flight plan, if the initial notification was an ELT signal, if it was a family concerned ALNOT, and if it was a radio/radar drop off. Once all of the information was obtained, the following times were calculated for each incident: LKP to SRU, SRU to LOC, and LKP to LOC. The data was sorted into two separate spreadsheets shown in Appendix C. Table 1 contains the data for aircraft on a flight plan. Table 2 contains the data for aircraft not on a flight plan.

Population

The population for this study consisted of every downed aircraft incident in the CONUS from January 2000 - July 2003 that involved some type of formal search coordinated through the AFRCC. Missions that did not contain enough information or that were suspended were not included.

Data Gathering Device

The data gathering device used for this project was an excel spreadsheet. It was used to document the incident number, mission number, LKP time, SRU activation time, location time, if the aircraft was on a flight plan, if the initial notification was by ELT, if

it was a family concerned ALNOT, and if it was a radio/radar drop-off. The spreadsheet was also used to compute the LKP to SRU, SRU to LOC, and LKP to LOC.

Instrument Validity

The times listed in the SARDAB reflect the actual SRU activation times and wreckage location times. The LKP, however, varied somewhat for each mission. In some missions the only known LKP was the departure point while in other missions the last radar point was used as the LKP. This variation should not be a major factor in the analysis since it was not specific to whether or not the aircraft was on a flight plan.

Treatment of Data and Procedures

The data analysis consisted of comparing the ranked mean time of locating a downed aircraft on a flight plan with the mean time of locating a downed aircraft not on a flight plan to determine if there was a significant difference. The following times were compared: LKP to SRU, SRU to LOC, and LKP to LOC. These comparisons were made using the Mann-Whitney U test. The independent variable is the flight plan activation. If no flight plan was activated, fltplan = 1. If a flight plan was filed and activated, fltplan = 2. The dependent variables are the mean times for each category of times listed above.

Once the data collection was complete, the researcher observed that there were a lot of missions that involved aircraft that requested flight following and then dropped off radio and radar. These incidents appeared to have significantly smaller search times than aircraft that did not request flight following regardless of whether or not there was a flight plan activated. As a result of this finding, the researcher proceeded to compare the search times for aircraft that requested flight following versus those that did not. For this

comparison, the flight plan was not a factor. The times analyzed were the same as the original flight plan analysis: LKP to SRU, SRU to LOC, and LKP to LOC. The data that was previously gathered was reorganized into Appendix E. Table 3 contains data for aircraft that requested flight following and Table 4 contains data for aircraft that did not request flight following. A second null hypothesis was created. The null hypothesis tested was that the presence of aircraft flight following had no effect on search time for a downed aircraft. The comparisons were made using the Mann-Whitney U test. The independent variable is the flight following. If flight following was requested, fltfolow = 1. If there was no flight following by the FAA, fltfolow = 2. The dependent variables are the mean times for each category of times listed above.

CHAPTER IV

RESULTS

A Mann-Whitney U test was conducted using the computer-based SPSS program to evaluate the hypothesis that search time for downed aircraft not on a flight plan is not greater than downed aircraft on a flight plan. The results, listed in Appendix D, showed that the test for LKP to SRU was significant, $z = -2.207$, $p = 0.027$. The test for SRU to LOC was significant, $z = -1.983$, $p = 0.0.047$. The test for LKP to LOC was also significant, $z = -2.406$, $p = 0.016$. The null hypothesis is rejected. Total search time for downed aircraft not on a flight plan had an average rank of 78.45, while aircraft on a flight plan had an average rank of 54.00. The total search time (LKP to LOC) for missions of downed aircraft not on a flight plan ($M = 51.152$ hours, $SD = 75.3674$) on average was longer than the search time for aircraft on a flight plan ($M = 21.2202$ hours, $SD = 21.5749$). Figure 2 shows the SPSS results for the Mann-Whitney U test for LKP to SRU and the distribution of the two groups. Figure 3 shows the SPSS results for the Mann-Whitney U test for SRU to LOC and the distribution of the two groups. Figure 4 shows the SPSS results for the Mann-Whitney U test for LKP to LOC and the distribution of the two groups. For each case, fltplan = 1 indicates no flight plan, while fltplan = 2 indicates a flight plan.

Another Mann-Whitney U test was conducted to evaluate the hypothesis that search time for downed aircraft that did not request flight following is not greater than downed aircraft that requested flight following and dropped off radar. The results, located in Appendix F, showed that the test for LKP to SRU was significant, $z = -5.500$, p

= 0.000. The test for SRU to LOC was significant, z = -2.095, p = 0.036. The test for LKP to LOC was also significant, z = -3.676, p = 0.000. The null hypothesis is rejected. Total search time for downed aircraft that requested flight following had an average rank of 49.12, while aircraft that did not request flight following had an average rank of 81.53. The total search time (LKP to LOC) for missions of downed aircraft that did not request flight following (M = 54.7424 hours, SD = 77.4015) on average was longer than the search time for aircraft that did request flight following and dropped off radar (M = 15.9758 hours, SD = 11.6316). Figure 5 shows the SPSS results for the Mann-Whitney U test for LKP to SRU and the distribution of the two groups. Figure 6 shows the SPSS results for the Mann-Whitney U test for SRU to LOC and the distribution of the two groups. Figure 7 shows the SPSS results for the Mann-Whitney U test for LKP to LOC and the distribution of the two groups. For each case, fltfolow = 1 indicates flight following with radio and radar drop-off, while fltfolow = 2 indicates no flight following.

CHAPTER V

DISCUSSION

The results of this study support Christopher Holmes' research conducted in 1999, where he found that filing a flight plan does aid in the search and rescue process. Even though both of these studies demonstrated that there is a significant difference in search time between the two categories, the raw data and analysis do not explain why there is a difference. While gathering the data, the researcher observed a few reasons why flight plans prove useful in the cases examined.

The first was that flight plans typically provided a good aircraft take-off time to the AFRCC. This allowed rapid response from radar analysts. When a flight plan was not filed, the departure time was estimated only after extensive investigation. Radar analyst had to make educated decisions with the limited information given about which radar track was the actual missing aircraft.

The second factor was the timeliness of notification. The time for searchers to be activated for aircraft with no flight plan was on average 6.9 hours longer than for aircraft on a flight plan. One aircraft (mission 00M1048A) was not reported overdue until almost five days after the aircraft took off.

The last factor observed was the definition of a search area. In the searches involving a flight plan, the route of flight was already defined and could be quickly searched. In some of the searches for aircraft that were not on a flight plan, countless hours and even days were spent trying to define what the actual route of flight was. In

these incidents, valuable search time was lost because SRUs did not know where to begin searching.

CHAPTER VI

CONCLUSIONS

The hypothesis that there was no significant difference between search times from downed aircraft not on a flight plan versus aircraft on a flight plan was not supported. Even with the increase in US radar coverage and technology, it was still found that historically it took longer to locate aircraft that were not on a flight plan.

The unexpected finding was that aircraft that requested flight following seemed to have the best SRU response time and lowest search time required to locate. The total mean time to locate these aircraft (M = 15.9758 hours, SD = 11.6316) was significantly lower than the other aircraft (M = 54.7424 hours, SD = 77.4015).

The overall research plan process seemed to flow very well. One improvement in the data gathering process would have been to collect all of the required information from the SARDAB (i.e. time of LKP, time of SRU activation, etc.) at the same time that the missions were being checked to see if they fit the criteria of the study. Performing both simultaneously would have saved time and eliminated the need to access the SARDAB twice for the same incidents.

CHAPTER VII

RECOMMENDATIONS

As a result of this study, it is recommended that when pilots fly VFR, they file and activate a flight plan and consider requesting flight following as necessary.

With these results, further study on this subject is recommended in the following areas. The first is to look at survival rates of the personnel on board after a crash and compare this rate to the average hours it takes to locate downed aircraft as found in this study. This recommended investigation should include not only aircraft involved in a formal search, but for all aircraft accidents. The second is to refine the data collected for both this study and the study conducted in 1999 by Christopher Holmes to look at the effects of ELT activations and how they aided or hindered the search effort. The third recommendation is to divide the searches according to the state that conducted the search. As stated before, Governors of different states have designated different agencies in charge of search and rescue. For example, in Washington, it is the Department of Aviation, in Colorado it is Civil Air Patrol (CAP), and in Florida it is the AFRCC. It would be valuable to compare the results of this study, broken down by the different states, to compare the different search methods and the results. The final recommendation is to compare the data for CONUS searches to the data available for searches in Canada. In Canada, pilots are required to file a flight plan if the destination airport is different from the departure.

REFERENCES

Desmarais, J.W. (2000). *The graduate research search planning guidance for use in general aviation missing aircraft searches in the continental United States.* Extended Campus: Embry-Riddle Aeronautical University.

Holmes, C.D. (1999). *Where to look: How VFR flight plans affect a search and rescue respose.* Langley AFB Resident Center: Embry-Riddle Aeronautical University.

Kern, T. (1998). *Flight discipline.* New York: McGraw Hill.

National Search and Rescue Committee (NSARC) (2000). *United States National Search and Rescue Manual.* Washington DC: NSARC.

Nolan, M.S. (1999). *Fundamentals of air traffic control. (3rd Edition).* Pacific Grove, CA: Brooks/Cole Publishing Company.

US Department of Transportation(USDOT) (2002). *Flight Services. (7110.10P).* Washington D.C.:US Government Printing Office.

APPENDIX A

BIBLIOGRAPHY

International Maritime Organization and International Civil Aviation Organization (1998). *International Aeronautical and Maritime Search and Rescue Manual.* London, UK: IMO.

US Department of Transportation (2002). *Federal aviation regulations/Aeronautical information manual. (Title 14 of the Code of Federal Regulations, Part 91).* Newcastle, WA: Aviation Supplies and Academics, Inc.

APPENDIX B

FAA FLIGHT PLAN FORM

Form Approved OMB No. 2120-0026

U.S. DEPARTMENT OF TRANSPORTATION FEDERAL AVIATION ADMINISTRATION **FLIGHT PLAN**	(FAA USE ONLY) ☐ PILOT BRIEFING ☐ VNR ☐ STOPOVER	TIME STARTED	SPECIALIST INITIALS

1. TYPE	2. AIRCRAFT IDENTIFICATION	3. AIRCRAFT TYPE/ SPECIAL EQUIPMENT	4. TRUE AIRSPEED	5. DEPARTURE POINT	6. DEPARTURE TIME		7. CRUISING ALTITUDE
IFR / DVFR			KTS		PROPOSED (Z)	ACTUAL (Z)	

8. ROUTE OF FLIGHT

9. DESTINATION (name of airport and city)	10. EST. TIME ENROUTE		11. REMARKS
	HOURS	MINUTES	

12. FUEL ON BOARD		13. ALTERNATE AIRPORT(S)	14. PILOT'S NAME, ADDRESS & TELEPHONE NUMBER & AIRCRAFT HOME BASE	15. NUMBER ABOARD
HOURS	MINUTES		17. DESTINATION CONTACT/TELEPHONE (OPTIONAL)	

16. COLOR OF AIRCRAFT	CIVIL AIRCRAFT PILOTS. FAR Part 91 requires you file an IFR flight plan to operate under instrument flight rules in controlled airspace. Failure to file could result in a civil penalty not to exceed $1,000 for each violation (Section 901 of the Federal Aviation Act of 1958, as amended). Filing of a VFR flight plan is recommended as a good operating practice. See also Part 99 for requirements concerning DVFR flight plans.

FAA Form 7233-1 (8-82) CLOSE VFR FLIGHT PLAN WITH _____ FSS ON ARRIVAL

Figure 1 Federal Aviation Administration Flight Plan Form

APPENDIX C
DATA FOR FLIGHT PLAN ANALYSIS

Table 1 Data of Aircraft on a Flight Plan

AFRCC Mission Number	AFRCC Incident Number	Last Known Position Time	Incident Opened Time	Time Objective Located	VFR Flight Plan (Y/N)	ELT Initial Notification ?	Radio/ Radar Drop Off?	Family Concern ALNOT?	Elapsed Time to Resource Launched	Elapsed Time to Located Objective	Search Effot (Open to Location)	
00M0670A	00I01860	16Apr00 2219Z	17Apr00 0417Z	20Apr00 0010Z	Y	N	N	N	5.967	73.85	67.883	State Worked
00M1024A	00I02777	26May00 2039Z	27May00 0001Z	27May00 1450Z	Y	Y	N	N	3.367	18.183	14.816	
01M0110A	01I00313	20Jan01 0039Z	20Jan01 0105Z	20Jan01 0111Z	Y	N	N	N	0.433	0.533	0.1	
01M0440	01I01222	8Mar01 2217Z	9Mar01 1603Z	10Mar01 2310Z	Y	N	N	N	17.767	48.8837	31.1167	
-	01I01881	11Apr01 0450Z	11Apr01 1844Z	11Apr01 2335Z	Y	N	N	N	13.9	18.75	4.85	
01M0709A	01I01918	13Apr01 0300Z	13Apr01 0359Z	13Apr01 0915Z	Y	N	Y	N	0.98	6.247	5.267	
01M1068	01I02876	24May01 1730Z	25May01 0625Z	27May01 2030Z	Y	N	N	N	12.9167	74.9997	62.083	
01M1378	01I03686	25Jun01 0233Z	25Jun01 0930Z	25Jun01 1806Z	Y	N	N	N	6.95	15.55	8.6	
01M1717	01I04635	30Jul01 1839Z	30Jul01 2236Z	31Jul01 0130Z	Y	N	Y	Y(after)	3.95	6.85	2.9	
01M2171A	01I05781	24Sept01 1445Z	24Sept01 1844Z	24Sept01 2055Z	Y	N	N	N	3.983	6.166	2.183	
02M0056A	02I00123	9Jan02 1742Z	9Jan02 2100Z	9Jan02 2310Z	Y	Y	N	N	3.3	5.467	2.167	
02M0261A	02I00647	12Feb02 2332Z	13Feb02 1446Z	14Feb02 0015Z	Y	N	N	Y	15.233	24.716	9.483	
02M0691	02I00281	16Feb02 1110Z	16Feb02 1515Z	16Feb02 1721Z	Y	N	N	N	4.083	6.183	2.1	
02M1014	02I02539	17May02 0832Z	17May02 1054Z	17May02 1244Z	Y	Y	N	N	2.367	4.2	1.833	
02M1494A	02I03655	1Jul02 2250Z	2Jul02 0645Z	2Jul02 1329Z	Y	N	N	N	7.9167	14.6497	6.733	
02M1919A	02I04774	10Aug02 1700Z	10Aug02 2220Z	11Aug02 0745Z	Y	N	N	N	5.33	14.7467	9.4167	
02M2397A	02I06110	4Oct02 0123Z	4Oct02 0710Z	5Oct02 1930Z	Y	N	Y	N	5.783	42.116	36.333	
02M2813A	02I07291	4Dec02 0330Z	4Dec02 0554Z	4Dec02 1751Z	Y	N	Y	N	2.233	14.183	11.95	
03M0360	03I00917	28Feb03 2030Z	1Mar03 0035Z	1Mar03 1259Z	Y	N	N	Y(after)	4.0833	16.4833	12.4	
03M0369A	03I00939	2Mar03 0029Z	2Mar03 0220Z	2Mar03 0400Z	Y	N	Y	N	1.85	3.517	1.667	
03M0639A	03I01615	9Apr03 1513Z	9Apr03 2128Z	10Apr03 2034Z	Y	N	N	Y(after)	6.25	29.35	23.1	
									6.125843	21.2202	15.0944	

APPENDIX D

RESULTS FOR FLIGHT PLAN ANALYSIS

Mann-Whitney Test

Ranks

	FLTPLAN	N	Mean Rank	Sum of Ranks
RANK of LKPTOSRU	1.00	128	78.16	10004.50
	2.00	21	55.74	1170.50
	Total	149		

Test Statistics[a]

	RANK of LKPTOSRU
Mann-Whitney U	939.500
Wilcoxon W	1170.500
Z	-2.207
Asymp. Sig. (2-tailed)	.027

a. Grouping Variable: FLTPLAN

Graph

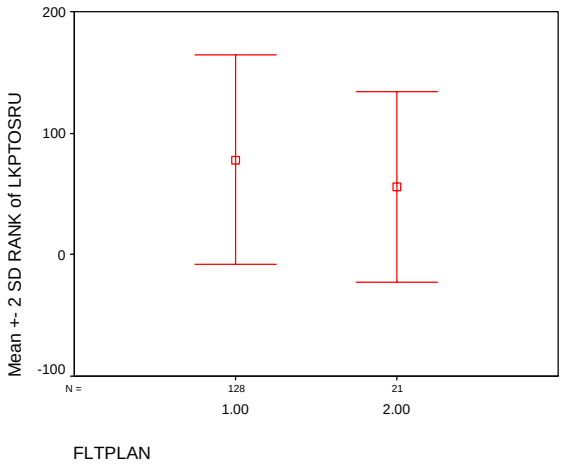

Figure 2 Flight Plan Analysis Results LKP to SRU

Mann-Whitney Test

Ranks

	FLTPLAN	N	Mean Rank	Sum of Ranks
RANK of SRUTOLOC	1.00	128	77.84	9963.50
	2.00	21	57.69	1211.50
	Total	149		

Test Statistics[a]

	RANK of SRUTOLOC
Mann-Whitney U	980.500
Wilcoxon W	1211.500
Z	-1.983
Asymp. Sig. (2-tailed)	.047

a. Grouping Variable: FLTPLAN

Graph

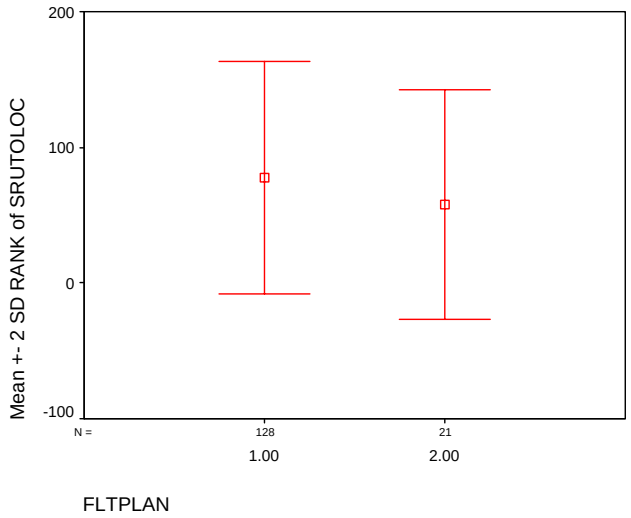

Figure 3 Flight Plan Analysis Results SRU to LOC

Mann-Whitney Test

Ranks

	FLTPLAN	N	Mean Rank	Sum of Ranks
RANK of LKPTOLOC	1.00	128	78.45	10041.00
	2.00	21	54.00	1134.00
	Total	149		

Test Statistics[a]

	RANK of LKPTOLOC
Mann-Whitney U	903.000
Wilcoxon W	1134.000
Z	-2.406
Asymp. Sig. (2-tailed)	.016

a. Grouping Variable: FLTPLAN

Graph

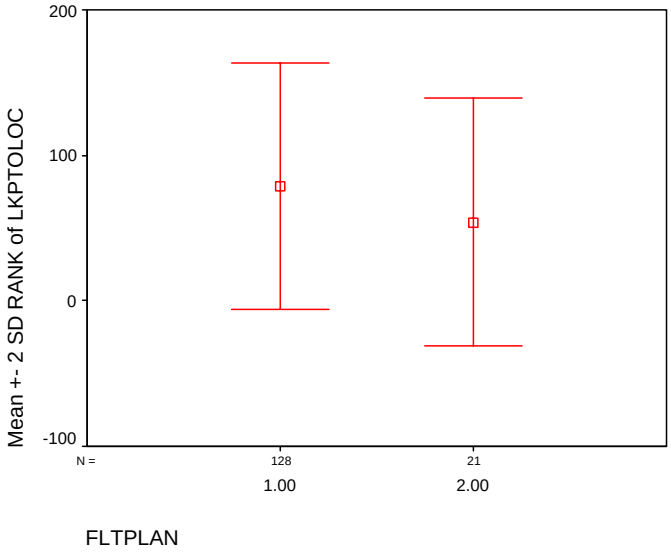

Figure 4 Flight Plan Analysis Results LKP to LOC

Mann-Whitney Test

Ranks

	FLTPLAN	N	Mean Rank	Sum of Ranks
RANK of SRUTOLOC	1.00	128	77.84	9963.50
	2.00	21	57.69	1211.50
	Total	149		

Test Statistics[a]

	RANK of SRUTOLOC
Mann-Whitney U	980.500
Wilcoxon W	1211.500
Z	-1.983
Asymp. Sig. (2-tailed)	.047

a. Grouping Variable: FLTPLAN

Graph

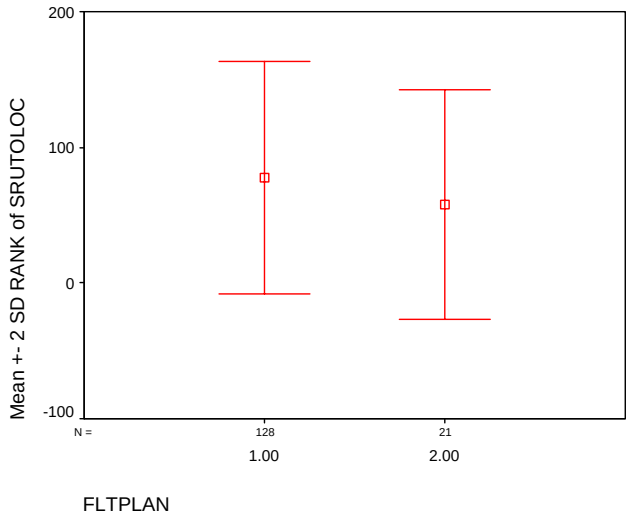

Figure 3 Flight Plan Analysis Results SRU to LOC

Table 2 Data for Aircraft Not on a Flight Plan

AFRCC Mission Number	AFRCC Incident Number	Last Known Position Time	Incident Opened Time	Time Objective Located	VFR Flight Plan (Y/N)	ELT Initial Notification ?	Radio/ Radar Drop Off?	Family Concern ALNOT?	Elapsed Time to Resource Launched	Elapsed Time to Located Objective	Search Effot (Open to Location)	
00M0019	00I00041	04Jan00 0220Z	04Jan00 0435Z	04Jan00 0630Z	N	N	Y	N	2.25	4.1667	1.9167	
00M0023	00I00053	02Jan00 1600Z	04Jan00 2344Z	06Jan00 2040Z	N	N	N	Y	55.73	100.663	44.933	
00M0035	00I00094	06Jan00 0247Z	06Jan00 1216Z	06Jan00 1745Z	N	N	Y	Y(after)	9.483	14.966	5.483	
00M0036	00I00099	06Jan00 0943Z	06Jan00 1447Z	08Jan00 1830Z	N	N	N	Y	5.067	56.7837	51.7167	
00M0072A	00I00197	12Jan00 0817Z	12Jan00 1350Z	12Jan00 1644Z	N	N	Y	N	5.55	8.45	2.9	
00M0100A	00I00282	16Jan00 2127Z	17Jan00 0700Z	17Jan00 1535Z	N	N	he initial	Y	9.55	18.133	8.583	
00M0385	00I01118	07Mar00 0033Z	7Mar00 2326Z	11Mar00 1830Z	N	N	N	Y	22.883	113.95	91.067	
00M0783A	00I02150	30Apr00 1805Z	01May00 1728Z	05May00 0005Z	N	N	N	Y	23.6167	102	78.3833	
00M0850	00I02331	08May00 1850Z	08May00 2045Z	09May00 0010Z	N	N	Y	N	1.917	5.33	3.413	
00M1028A	00I02785	27May00 0145Z	27May00 0655Z	27May00 1211Z	N	N	N	Y	5.1667	10.433	5.2663	
00M1048A	00I02843	24May00 1230Z	29May00 1300Z	02Jun00 1535Z	N	N	N	Y	119.5	219.083	99.583	
00M1221A	00I03279	15Jun00 1800Z	16Jun00 1732Z	16Jun00 1739Z	N	N	N	Y	23.533	23.6497	0.1167	
00m1416A	00I03764	08Jul00 1510Z	09Jul00 0335Z	10Jul00 0238Z	N	N	N	Y	12.4167	35.467	23.0503	
00M1412A	00I03777	09Jul00 1709Z	10Jul00 0055Z	10Jul00 1347Z	N	N	N	Y	7.767	20.633	12.866	
00M1425A	00I03786	08Jul00 2100Z	11Jul00 0045Z	12Jul00 2336Z	N	N	N	Y	51.75	98.6	46.85	
00M1513A	00I03967	18Jul00 1930Z	20Jul00 0622Z	23Jul00 1600Z	N	N	N	Y	34.867	116.5	81.633	
00M1858	00I04814	27Aug00 2333Z	29Aug00 1028Z	10Sep00 1520Z	N	N	N	Y	10.9167	303.784	292.867	
-	00I04848	29Aug00 2330Z	30Aug00 0841Z	30Aug00 1354Z	N	N	N	Y	9.1833	14.4	5.2167	Never activated VFR flight plan/State Worked
00M2066	00I05343	23Sep00 0311Z	23Sep00 0833Z	23Sep00 1919Z	N	N	N	Y	5.367	16.134	10.767	
00M2151A	00I05552	04Oct00 1635Z	04Oct00 1723Z	04Oct00 1851Z	N	N	Y	N	0.8	2.267	1.467	
00M23433	00I06230	09Nov00 2230Z	10Nov00 2206Z	18Nov00 1845Z	N	N	N	Y	23.6	212.25	188.65	
00M2597A	00I06658	03Dec00 1900Z	04Dec00 0820Z	05Dec00 1357Z	N	N	N	Y	13.33	42.9467	29.6167	
00M2602A	00I06679	04Dec00 2330Z	05Dec00 0825Z	05Dec00 2210Z	N	N	N	Y	8.9167	22.6667	13.75	
00M2609	00I06718	06Dec00 1330Z	07Dec00 1352Z	07Dec00 1900Z	N	N	N	Y	24.367	29.5	5.133	
00M2660A	00I06839	15Dec00 0415Z	15Dec00 1930Z	16Dec00 0104Z	N	N	N	Y	15.25	20.817	5.567	
00M2666	00I06849	16Dec00 0331Z	16Dec00 0331Z	16Dec00 1854Z	N	Y	N	Y	0	15.383	15.383	
00M2688	00I06899	17Dec00 2300Z	19Dec00 0309Z	21Dec00 1825Z	N	N	N	Y	28.15	91.417	63.267	
00M2710A	00I06960	22Dec00 2216Z	23Dec00 0112Z	23Dec00 1250Z	N	N	N	Y	2.93	14.563	11.633	Cancelled IFR Flight Plan
00M2729A	00I07023	28Dec00 2230Z	29Dec00 0303Z	29Dec00 1755Z	N	Y	N	Y	4.55	19.417	14.867	State Worked
01M0058	01I00175	12Jan01 0000Z	12Jan01 0451Z	12Jan01 1840Z	N	Y	N	Y(after)	4.85	18.667	13.817	
01M0089	01I00233	14Jan01 2315Z	15Jan01 0445Z	15Jan01 0805Z	N	N	N	Y	5.5	8.83	3.33	

Table 2 Data for Aircraft Not on a Flight Plan

01M0092A	01I00252	14Jan01 2300Z	15Jan01 0445Z	15Jan01 0805Z	N	N	N	Y	5.75	9.083	3.333	
01M0133	01I00374	22Jan01 2110Z	23Jan01 0619Z	27Jan01 2120Z	N	N	N	Y	9.15	120.133	110.983	
01M0148A	01I00419	24Jan01 2000Z	25Jan01 0449Z	25Jan01 1335Z	N	Y	N	Y(after)	8.817	17.584	8.767	
01M0278A	01I00808	16Feb01 0330Z	16Feb01 1400Z	24Feb01 1616Z	N	N	N	Y	10.5	204.767	194.267	
01M0285A	01I00827	16Feb01 2108Z	17Feb01 0402Z	17Feb01 2130Z	N	N	N	Y	6.9	24.367	17.467	
01M0306A	01I00881	19Feb01 0116Z	19Feb01 1450Z	19Feb01 1921Z	N	N	Y	N	13.567	18.084	4.517	
01M0305A	01I00883	19Feb01 0319Z	19Feb01 1400Z	05Mar01 1925Z	N	N	N	Y	10.683	352.1	341.417	
01M0321A	01I00926	21Feb01 0245Z	21Feb01 0927Z	21Feb01 1115Z	N	N	N	Y	6.7	8.5	1.8	
01M0351	01I00998	19Feb01 1530Z	24Feb01 0730Z	29Feb01 2310Z	N	N	N	Y	112	127.667	15.667	
01M0367	01I01055	26Feb01 2128Z	27Feb01 0835Z	27Feb01 2210Z	N	N	N	Y	11.1167	24.6997	13.583	
01M0442	01I01232	09Mar01 1508Z	9Mar01 2008Z	10Mar01 1913Z	N	Y	N	Y(after)	5	28.083	23.083	
01M0451A	01I01247	10Mar01 1200Z	10Mar01 1800Z	11Mar01 2100Z	N	Y	N	Y	6	33	27	
01M0475	01I01293	12Mar01 1840Z	12Mar01 2223Z	13Mar01 0015Z	N	Y	N	Y	3.767	5.634	1.867	
01M0533A	01I01433	20Mar01 0130Z	20Mar01 1941Z	20Mar01 2320Z	N	N	N	Y	18.183	21.833	3.65	
01M0546A	01I01453	20Mar01 1800Z	21Mar01 0956Z	21Mar01 1755Z	N	Y	N	Y(after)	15.933	23.916	7.983	
01M0551	01I01494	22Mar01 2145Z	23Mar01 0100Z	23Mar01 0225Z	N	Y	N	Y(after)	3.25	4.6667	1.4167	
01M0627A	01I01672	31Mar01 1408Z	31Mar01 2022Z	6Apr01 1920Z	N	N	N	Y	6.233	149.2	142.967	
01M0629	01I01677	31Mar01 1800Z	31Mar012220Z	1Apr01 1156Z	N	N	N	Y	4.333	17.933	13.6	
01M0668	01I01800	6Apr01 1254Z	7Apr01 2003Z	9Apr01 1515Z	N	N	N	Y	31.15	74.35	43.2	
01M0674	01I01811	7Apr01 1740Z	8Apr01 0229Z	9Apr01 2230Z	N	N	Y	N	8.8167	52.8334	44.0167	
01M0710	01I01916	10Apr01 1846Z	13Apr01 0511Z	14Apr01 1630Z	N	N	N	Y	58.4167	93.7334	35.3167	
01M0798A	01I02145	23Apr01 0438Z	23Apr01 1250Z	23Apr01 1728Z	N	N	N	Y	8.2	12.833	4.633	
-	01I02306	30Apr01 0430Z	30Apr01 0551Z	30Apr01 1200Z	N	Y	Y	N	1.35	7.5	6.15	
01M0981	01I02605	13May01 1130Z	13May01 1638Z	13May01 2115Z	N	Y	N	Y(after)	5.133	9.7497	4.6167	
01M0980	01I02606	12May01 1452Z	13may01 1500Z	26May01 1630Z	N	N	N	Y	24.133	337.633	313.5	
01M1104	01I02953	27May01 1815Z	27May01 2358Z	28May01 1730Z	N	Y	N	Y(after)	5.7167	23.2497	17.533	
01M1119A	01I02995	29May01 2115Z	30May01 0600Z	15Jun01 0001Z	N	N	N	Y	8.75	386.767	378.017	
01M1150A	01I03086	2Jun01 1508Z	2Jun01 2121Z	3Jun01 0018Z	N	N	N	Y	6.2167	9.1667	2.95	
01M1211	01I03228	7Jun01 1435Z	8Jun01 0324Z	10Jun01 1311Z	N	N	N	Y	12.8167	70.5997	57.783	
01M1588A	01I04276	18July01 1231Z	18July01 1417Z	18Jul01 1436Z	N	N	Y	N	1.767	2.0837	0.3167	
01M1616A	01I04353	21Jul01 0201Z	21Jul01 0355Z	21Jul01 1604Z	N	N	Y	N	1.9	14.05	12.15	
01m1628	01I04388	21Jul01 2104Z	22Jul01 0045Z	22Jul01 1830Z	N	Y	N	Y(after)	3.683	21.433	17.75	
01M1893	01I05121	18Aug01 2300Z	20Aug01 0315Z	22Aug01 1745Z	N	N	N	Y	28.25	90.75	62.5	
-	01I06087	14Oct01 0100Z	14Oct01 1230Z	14Oct01 1335Z	N	N	N	Y	11.5	12.583	1.083	State Worked
01M2411A	01I06323	28Oct01 0204Z	28Oct01 0800Z	28Oct01 1656Z	N	N	N	Y	5.93	14.863	8.933	
01M2440A	01I06397	01Nov01 0200Z	01Nov01 0744Z	01Nov01 2104Z	N	N	N	Y	5.733	19.066	13.333	
01M2482A	01I06479	06Nov01 0100Z	06Nov01 0525Z	06Nov01 1545Z	N	N	N	Y	4.4167	14.7497	10.333	
01M2530	01I06590	12Nov01 2200Z	13Nov01 0250Z	13Nov01 0615Z	N	Y	N	Y(after)	4.833	8.2497	3.4167	
01M2558A	01I06649	16Nov01 0700Z	17Nov01 0834Z	30Nov01 2215Z	N	N	N	Y	25.267	350.95	325.683	

Table 2 Data for Aircraft Not on a Flight Plan

01M2586	01I06721	21Nov01 1926Z	22Nov01 0558Z	23Nov01 1506Z	N	N	N	Y	10.533	43.666	33.133	Cancelled IFR Flight Plan
01M2592	01I06729	22Nov01 1750Z	22Nov01 1922Z	23Nov01 1846Z	N	N	Y	N	1.533	24.933	23.4	Requested Flight Following
01M2721	01I07096	12Dec01 2150Z	13Dec01 0205Z	13Dec01 1726Z	N	N	Y	N	4.25	19.6	15.35	
01M2740A	01I07144	14Dec01 2327Z	15Dec01 0115Z	15Dec01 1700Z	N	N	Y	Y(after)	1.8	17.55	15.75	
02M0055	02I00125	9Jan02 1700Z	9Jan02 2145Z	10Jan02 0030Z	N	Y	N	Y	4.75	7.5	2.75	
02M0085	02I00199	13Jan02 0103Z	14Jan02 1900Z	15Jan02 1316Z	N	N	N	Y	17.95	36.217	18.267	
02M0161	02I00422	28Jan02 1537Z	28Jan02 1958Z	29Jan02 1612Z	N	Y	N	Y(after)	4.35	24.583	20.233	
02M0177A	02I00459	31Jan02 0254Z	31Jan02 0553Z	31Jan02 2030Z	N	N	Y	N	4.983	19.6	14.617	
02M0396	02I00996	06Mar02 0000Z	6Mar02 0938Z	6Mar02 1215Z	N	N	N	Y	9.63	12.2467	2.6167	
02M0442A	02I01118	12Mar02 0319Z	12Mar02 0615Z	12Mar02 1705Z	N	N	N	Y	2.933	13.766	10.833	
02M0458	02I01161	12Mar02 2200Z	14Mar02 1824Z	16Mar02 1600Z	N	N	N	Y	44.4	90	45.6	
02M0465	02I01177	15Mar02 0705Z	15Mar02 0940Z	15Mar02 1800Z	N	Y	Y	N	2.5833	10.9163	8.333	
02M0643A	02I01602	6Apr02 2300Z	7Apr02 0437Z	10Apr02 1939Z	N	N	N	Y	5.6167	92.6497	87.033	
02M1115A	02I02799	28May02 0530Z	28May02 0830Z	28May02 1900Z	N	N	Y	N	3	13.5	10.5	
02M1236A	02I03063	7Jun02 0045Z	7Jun02 1912Z	7Jun02 2130Z	N	N	N	Y	18.45	20.75	2.3	
02M1351A	02I03324	17Jun02 2140Z	18Jun02 0734Z	21Jun02 0210Z	N	N	N	Y	9.9	52.5	42.6	
02M1470A	02I03604	30Jun02 0327Z	30Jun02 1226Z	30Jun02 1800Z	N	Y	Y	N	8.983	14.55	5.567	
02M1680	02I04135	18Jul02 1501Z	19Jul02 1500Z	20Jul02 0043Z	N	N	N	Y	23.983	33.6997	9.7167	
-	02I04370	27Jul02 1800Z	27Jul02 2255Z	27Jul02 2341Z	N	N	N	Y	4.9167	5.6837	0.767	State Worked
02M1910	02I04738	8Aug02 2330Z	9Aug02 0406Z	9Aug02 1430Z	N	Y	N	Y(after)	4.6	15	10.4	
02M1981A	02I04943	19Aug02 0049Z	19Aug02 1738Z	19Aug02 2147Z	N	N	N	Y	16.8167	20.9667	4.15	
02M2170A	02I05467	7Sep02 1500Z	8Sep02 1450Z	9Sep02 1610Z	N	N	N	Y	23.833	49.163	25.33	
02M2192A	02I05527	10Sep02 0351Z	10Sep02 0629Z	10Sep02 1438Z	N	N	N	Y	2.633	10.783	8.15	
02M2240A	02I05668	15Sep02 1500Z	15Sep02 1650Z	15Sep02 2302Z	N	N	N	Y	1.833	8.033	6.2	
02M2359A	02I05993	30Sep02 0235Z	30Sep02 0840Z	1Oct02 1710Z	N	Y	N	Y(after)	6.083	38.583	32.5	
02M2372	02I06039	1Oct02 2220Z	2Oct02 0250Z	2Oct02 1715Z	N	Y	N	Y(after)	4.5	18.9167	14.4167	
02M2380	02I06063	2Oct02 1145Z	2Oct02 2222Z	3Oct02 2030Z	N	N	N	Y	10.6167	32.7497	22.133	
02M2459A	02I06274	12Oct02 0003Z	12Oct02 1544Z	12Oct02 1907Z	N	N	N	Y	15.683	19.066	3.383	
02M2735A	02I07031	20Nov02 0249Z	20Nov02 0457Z	20Nov02 1320Z	N	N	N	Y	2.133	10.516	8.383	Cleared for Approach/State Worked
02M2771A	02I07136	25Nov02 0159Z	25Nov02 0745Z	25Nov02 1636Z	N	N	N	Y	5.7667	14.6167	8.85	
02M2844A	02I07373	9Dec02 1735Z	10Dec02 0149Z	11Dec02 1445Z	N	N	N	Y	8.233	45.163	36.93	
03M0055A	03I00139	8Dec02 1802Z	8Dec02 2311Z	9Dec02 1836Z	N	N	N	Y	5.15	24.5667	19.4167	
03M0146	03I00379	24Jan03 0336Z	24Jan02 0447Z	25Jan03 1808Z	N	N	Y	N	1.183	38.533	37.35	
03M0160	03I00413	26Jan03 2015Z	27Jan03 0016Z	27Jan03 0133Z	N	Y	N	Y(after)	4.0167	5.2997	1.283	
03M0228A	03I00574	6Feb03 2349Z	7Feb03 0600Z	7Feb03 1334Z	N	N	Y	N	6.183	13.75	7.567	

Table 2 Data for Aircraft Not on a Flight Plan

-	03I00680	15Feb03 0200Z	15Feb03 0432Z	15Feb03 1531Z	N	N	Y	N	2.533	8.516	5.983	State Worked
03M0335	03I00844	23Feb03 1716Z	24Feb03 2115Z	26Feb03 2307Z	N	Y	N	Y(after)	27.983	77.8497	49.8667	
03M0344	03I00870	25Feb03 2230Z	26Feb03 0500Z	26Feb03 0934Z	N	Y	N	Y(after)	6.5	11.067	4.567	
03M0375	03I00953	2Mar03 2354Z	3Mar03 0443Z	3Mar03 1905Z	N	Y	N	N	4.8167	19.1837	14.367	
-	03I00980	4Mar03 0029Z	4Mar03 0232Z	4Mar03 2159Z	N	N	Y	N	2.05	21.5	19.45	
03M0416A	03I01067	10Mar03 0133Z	10Mar03 0355Z	10Mar03 1754Z	N	N	Y	N	2.367	16.35	13.983	State Worked/Flight Following
03M0448A	03I01129	14Mar03 1737Z	14Mar03 2255Z	15Mar03 1300Z	N	N	N	Y	5.3	19.3833	14.0833	
03M0453A	03I01150	15Mar03 2119Z	16Mar03 0045Z	16Mar03 1716Z	N	N	Y	N	3.433	19.9497	16.5167	
03M0545A	03I01362	27Mar03 0130Z	27Mar03 1512Z	29Mar03 1600Z	N	N	N	Y	13.7	62.5	48.8	
03M0553A	03I01378	28Mar03 0009Z	28Mar03 0303Z	28Mar03 1432Z	N	N	N	Y	2.9	14.383	11.483	
03M0760A	03I01922	26Apr03 0011Z	26Apr03 0135Z	26Apr03 1926Z	N	N	Y	N	1.4	19.25	17.85	
03M0855	03I02167	5May03 1630Z	5May03 2322Z	9May03 0001Z	N	N	N	Y	5.867	78.517	72.65	Had Flight Plan, but never activated it!
03M0980A	03I02459	19May03 0430Z	19May03 1805Z	21May03 1745Z	N	N	N	Y	13.583	61.25	47.667	
03M1042	03I02602	25May03 0000Z	27May03 0530Z	27May03 2100Z	N	Y	N	Y(after)	53.5	69	15.5	
03M1055	03I02633	25May03 1900Z	29May03 0001Z	03Jun03 1717Z	N	N	N	Y	76.983	214.25	137.267	Coast Guard
03M1066A	03I02654	29May03 0820Z	29May03 1243Z	29May03 1826Z	N	N	N	Y	4.383	10.0997	5.7167	
03M1126A	03I02806	03Jun03 1346Z	4Jun03 0211Z	4Jun03 1319Z	N	N	N	Y	12.4167	23.5497	11.133	
03M1128	03I02810	3Jun03 1230Z	4Jun03 0430Z	4Jun03 1055Z	N	N	N	Y	16	22.4167	6.4167	
03M1237	03I03105	14Jun03 1700Z	15Jun03 0540Z	22Jun03 1434Z	N	N	N	Y	12.667	189.567	176.9	
03M1274	03I03186	18Jun03 2200Z	19Jun03 0600Z	19Jun03 0840Z	N	Y	N	Y(after)	8	10.6667	2.6667	
03M1356A	03I03375	26Jun03 0330Z	26Jun03 0950Z	26Jun03 1730Z	N	N	N	Y	6.333	13.9997	7.6667	
03M1444	03I03591	5Jul03 1504Z	5Jul03 2355Z	6Jul03 1810Z	N	N	N	Y	8.85	27.1	18.25	
03M1608	03I03986	19Jul03 2026Z	20Jul03 0420Z	20Jul03 1410Z	N	N	N	Y	7.9	17.733	9.833	
									13.07729	51.1562	38.0789	

APPENDIX F

RESULTS FOR FLIGHT FOLLOWING ANALYSIS

Mann-Whitney Test

Ranks

	FLTFOLOW	N	Mean Rank	Sum of Ranks
RANK of LKPTOSRU	1.00	30	36.12	1083.50
	2.00	119	84.80	10091.50
	Total	149		

Test Statistics[a]

	RANK of LKPTOSRU
Mann-Whitney U	618.500
Wilcoxon W	1083.500
Z	-5.522
Asymp. Sig. (2-tailed)	.000

a. Grouping Variable: FLTFOLOW

Graph

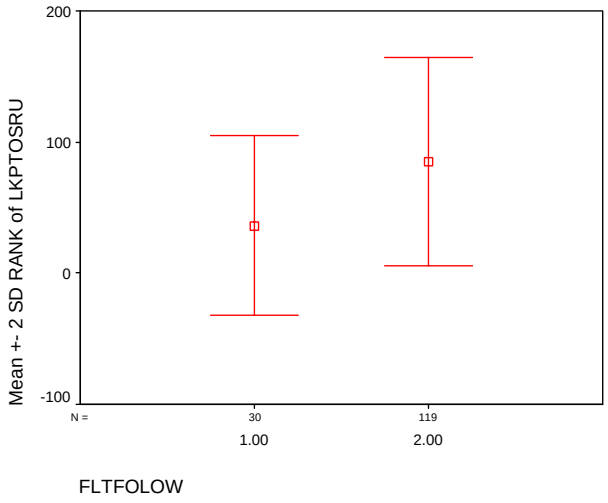

Figure 5 Flight Following Analysis Results LKP to SRU

Mann-Whitney Test

Ranks

	FLTFOLOW	N	Mean Rank	Sum of Ranks
RANK of SRUTOLOC	1.00	30	60.25	1807.50
	2.00	119	78.72	9367.50
	Total	149		

Test Statistics[a]

	RANK of SRUTOLOC
Mann-Whitney U	1342.500
Wilcoxon W	1807.500
Z	-2.095
Asymp. Sig. (2-tailed)	.036

a. Grouping Variable: FLTFOLOW

Graph

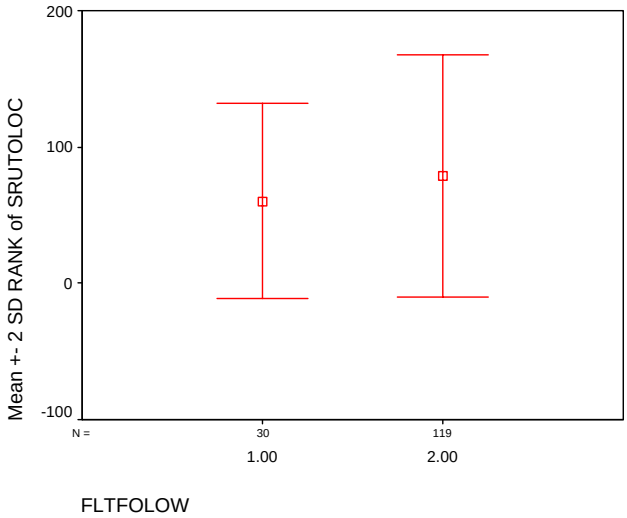

Figure 6 Flight Following Analysis Results SRU to LOC

Mann-Whitney Test

Ranks

	FLTFOLOW	N	Mean Rank	Sum of Ranks
RANK of LKPTOLOC	1.00	30	49.12	1473.50
	2.00	119	81.53	9701.50
	Total	149		

Test Statistics[a]

	RANK of LKPTOLOC
Mann-Whitney U	1008.500
Wilcoxon W	1473.500
Z	-3.676
Asymp. Sig. (2-tailed)	.000

a. Grouping Variable: FLTFOLOW

Graph

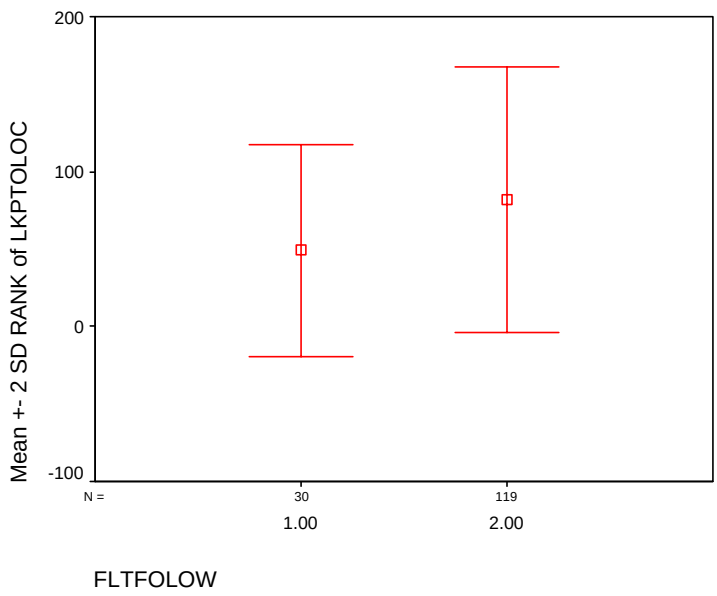

Figure 7 Flight Following Analysis Results LKP to LOC

National Aeronautics and Space Administration
Search and Rescue Mission Office
Goddard Space Flight Center

Data Collection and Analysis For NASA World Wind Search and Rescue Visualization Program

Prepared by
Robert J. Koester
dbS Productions LLC

28 February 2009

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Executive Summary

Missing aircraft incidents that resulted in search efforts and were recorded by the Air Force Rescue Coordination Center (AFRCC) have been compiled into a database. The data collected from the AFRCC and augmented by National Transportation Safety Board (NTSB) Aviation Accident Reports numbers 262 search incidents covering a time period from 2002 to 2008. Data was collected during three trips to the AFRCC and information was taken from the SARMaster program. Information was only collected from incidents when a search occurred, the incident was classified as distress, aircraft was not located on the runway, the find coordinates of the aircraft were given, and the incident records provided at least one of the following: last radar plot, route information, or Emergency Locator Transmitter (ELT) information. Additional information was obtained from the NTSB Aviation Accident and Database & Synopses reports. The total number of fields in the database number ninety-one. The principle investigator created 34 fields (mostly calculations by formula), 32 fields came from the AFRCC, 23 fields were obtained from the NTSB, and two other fields from results supplied by other software.

Radar data allowed the distance from the last plot to the crash site to be determined in 216 cases. The median (or 50%) of all crash sites are located within 0.8 nautical miles of the last radar plot. Factors that appear important in modifying the distribution of distances include type of aircraft (helicopters the furthest away and jets the closest), flying under Part 91, Instrument Meteorological Conditions (IMC) weather, pilot certification, type of flight plan, flight characteristic, and vertical changes. The most significant factors appear to be the final flight characteristic and changes in feet per minute (FPM). If the aircraft's last radar returns indicated a turn, then 95% of those aircraft were found within 3.6 nm; if the aircraft was flying straight and level then 95% were found within 65.4 nm. If the aircraft was descending at a rate of 2000 or more FPM, then 95% of the aircraft was found within 1.8 nm. This is quite different from the 95% within 101 nm for aircraft descending at a rate of 1 – 1000 FPM. Distance from the last radar site is a powerful tool that places high probability into a small area. Based upon the probability density and small size, ground searches can be justified in many cases. In addition, the study clearly identified modifying factors that require formal statistical analysis. Eventually, all of these factors need to be built into a model and a graphic interface using NASA's World Wind provided to decision makers.

The dispersion angle helps to predict where the crash site might be located based upon the last heading. Since it is the absolute difference between the last predicted heading and the actual bearing to the crash site its value ranges from 0 to 180 degrees. The median value of 159 incidents that had sufficient information was 51 degrees. Therefore, the dispersion angle can be used to further refine and predict where the aircraft will be located. Several factors were examined to determine if they altered the dispersion angles. Helicopters, visual meteorological conditions, higher rated pilots, mountainous terrain, straight flight, straight and descending flight appear to result in smaller dispersion angles. Additional work needs to be performed to look at left and right differences and help predict "ghost" plots. The dispersion angle is independent of distance so both parameters will be important to include in any model.

In flat terrain all aircraft either descend or are found at the same altitude. In mountainous terrain 72% of the aircraft descended, 6% were found at the same elevation, and 22% showed a gain in elevation of their last reported Mode C altitude. The median amount of descent was 2290 feet and the median gain in altitude was 611 feet. The phase of flight, flight characteristics, and most important of all previous vertical changes are important factors that influence the overall findings. Future work also needs to consider the Above Ground Level (AGL) in making predictions.

The radar track offset examined the distance the aircraft was found away from the projected last heading obtained from the last two radar plots for 159 incidents. The median (or 50%) of all aircraft were found within 0.4 nm of the last projected heading. In fact, 75% of the aircraft were found within 2.0 nm. Potential modifying factors include the final flight characteristics. If the aircraft radar returns indicated turning, then the track offsets distances increased. The radar track offset showed no interaction with the dispersion

angles. However, a very weak (R^2=0.39) correlation between radar track offset and distance from the last radar plot was observed.

Data collected from the NTSB accident reports proved highly valuable in adding additional fields and also in quality control. The NTSB reports often provided information that might have been missing from the AFRCC report. When the NTSB supplied a crash site coordinate it was more likely to be based upon a GPS reading taken at the point of initial impact with the ground. The NTSB was the definitive source for many of the fields used in the database. Not all of the AFRCC incidents had a NTSB report. Reports were obtained in 239 of the 262 incidents. All future work must be sure to include NTSB data.

The route offset and percentage are two of the oldest statistics used to help define the probability of containment. If no radar data is available, it is often the only meaningful way to limit the search area. Two studies have been previously conducted that looked at routes: the Canadian New Two Area Method (NTAM) and a study conducted under the auspices of the Civil Air Patrol (CAP) looking at data from the AFRCC. The NTAM study looked at 68 incidents and the CAP study looked at 62 (excluding non-distress incidents). This study examined 238 cases that had route information. The results for the most part fell between the results of the two previous studies. The median (or 50%) of aircraft are found within 4.5 nm of the planned route and along the first 63% of the route's length. Area one under the NTAM and CAP system is defined by a 10 nm box around the route. The NTAM study suggested 79% of aircraft are found within this area, the CAP study suggested only 63%, and this study found 68%. This study did differ from the two previous studies in finding that 95% of aircraft are found within 30 nm of the route. This study did not find any significant differences between the previous studies in the percentage of the route flown. As before, significant factors that might differ from the overall data were examined. Type of aircraft, type of flight plan, and terrain appear to be important factors. The most significant was the type of flight plan. Additional work needs to be done to provide useful statistics when the route is not known or the route only consists of taking off and landing at the same airfield.

The study also collected basic data on 472 Personal Locator Beacons (PLB) incidents of which 28 were classified as distress by the AFRCC. Additional information was collected on the distress incidents. The number of distress incidents is increasing and involves aircraft, boaters, and a mix of ground users activating 406 PLBs. In 72% of the distress incidents a coordinate was provided by the GPS feature of the PLB. A composite solution was calculated in 68% of the cases. PLB incidents have a high likelihood of the subject experiencing trauma or a medical problem (75%). While 61% of the cases represent non-distress and in 22% of the cases the signal simply ceases, only 11% of this category went to mission. The National Oceanic & Atmospheric Administration (NOAA) database was used to resolve 89% of these cases. Determining actual distances from the find site to the reported position was beyond the scope of this report.

This study collected, cleaned, and analyzed 262 distress incidents of missing aircraft reported to the AFRCC. The results are significant in identifying areas of high probability using several different methods. In addition, several potential factors that may increase or decrease the probability density were identified. However, these factors were not subjected to statistical testing. Furthermore, the large number of factors and how they interact is beyond the ability of most search planners and decision makers to fully understand and actually use. Therefore a comprehensive model must be built that integrates all of the factors and ultimately builds a probability of containment grid map similar to the product of the USCG's SAROP software. NASA World Wind software should play a critical role in integrating and displaying such a map. Then using World Wind's current ability to fly in actual terrain it will be possible for a search planner and search resources to better fulfill the mission of saving others.

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Acronyms and Abbreviations used

AFRCC	Air Force Rescue Coordination Center
AGL	Above Ground Level
ATP	Airline Transport Pilot
ATV	All Terrain Vehicle
CAP	Civil Air Patrol
CONUS	Continental United States
ELT	Emergency Locator Transmitter
FAA	Federal Aviation Administration
FF	Flight Following
FPM	Feet per Minute
IFR	Instrument Flight Rules
IMC	Instrument Meteorological Conditions
ISRID	International Search & Rescue Incident Database
Kts	Knots
LKP	Last Known Position
MVA	Motor Vehicle Accident
n	count
NASA	National Aeronautics and Space Administration
nm	nautical miles
NOAA	National Oceanic & Atmospheric Administration
NTAM	New Two Area Method
NTSB	National Transportation Safety Board
PDF	Portable Data Format
PLB	Personal Locator Beacon
PLS	Place Last Seen
PSR	Probability of Success Rate
RADES	84th Radar Evaluation Squadron
SBIR	Small Business Innovative Research
SD	Standard Deviation
SRTM	Shuttle Radar Topography Mission
STL	Second to Last (radar plot)
USAF	United States Air Force
VFR	Visual Flight Rules
VMC	Visual Meteorological Conditions
VOR	VHF Omni-directional Radio-range

Background

The National Search and Rescue Plan assigns NASA the role of developing and implementing aerospace technology for application to search and rescue and related activities. This role includes technical consulting on matters concerning the locating of missing aircraft when emergency beacons fail to operate. Search mission managers need to have advanced methods of determining "areas of highest probability density" where missing aircraft may have crashed after their last known position. Identification of high probability density areas help mission managers concentrate search forces, thereby conserving resources and potentially saving additional lives.

Missing aircraft missions typically account for approximately 4% of the AFRCC missions. However, they often account for a disproportionately larger amount resources and cost. The challenge of finding a missing aircraft is immense, especially when a distress signal has not been received. One of the most powerful tools, when available, is radar track data collected by the Federal Aviation Administration (FAA) and or military radar and forwarded to the Air Force Rescue Coordination Center (AFRCC). This data, when properly understood and used by search planners, may generate more confined "areas of highest probability density" where missing aircraft may have crashed.

Present methods of selecting these areas are based primarily on route of flight and track offset. They do not consider radar track data. Therefore, a detailed analysis of radar track data is needed to help define areas of highest probability. That, when teamed with NASA's World Wind satellite earth viewing technology, will serve to optimize visual search for missing aircraft when electronic means are not available.

Purpose

The purpose of this work is to perform data acquisition and analysis that aids in the development of an improved search management tool that blends results from an analysis of statistically significant past search data with aircraft radar track, terrain, and weather information. Weather and terrain are major contributors to aircraft accidents. Costly and dangerous search operations often result when potential crash locations are unknown after the aircraft is lost off radar. The blending of radar track, terrain, and weather into a computer generated visual presentation will aid search planners in identifying "areas of highest probability density". Search planners can then concentrate their efforts in those areas which will improve search efficiency, reduce search risk, and ultimately save search resources and more lives.

Basic tasks in order to carryout the purpose included building a database of incidents of missing aircraft. This work required the collection, reordering, reformatting, converting, partitioning, mapping, calculating derivative information, and similar activities using previous and any newly collected data.

Specific Tasks

This report covers six specific tasks outlined in the scope of work. For each task an overview, the methodology, results, and a brief discussion of implications follows. In addition, the report covers the overall organization of the data and additional attachments. Finally, future work is needed to accomplish the overall goals of this project. The specific tasks in this project:

- Determine the distance traveled from the last recorded radar position.
- Calculate the dispersion angle from three points: the find location, the last radar plot, and the second to last radar plot.
- Determine the relationship between the missing aircraft's last recorded radar altitude (flight altitude) and the terrain elevation where the aircraft wreckage was located.
- Determine the radar track offset based upon radar information versus route information. This statistic will provide the perpendicular distance between the find location and the aircraft's route as determined from radar data
- Collect additional data from National Transportation Safety Board (NTSB) records on aircraft accidents where search was necessary to locate missing aircraft. This will provide additional details such as Visual Flight Rules (VFR) versus Instrument Flight Rules (IFR) flight; find location from NTSB data so that previously collected data from Air Force Rescue Coordination Center data can be verified.
- Perform an analysis of the missing aircraft's route (Route Analysis) to include comparisons of data collected by other organizations, individuals and the Canadian study results which were entered in the AFRCC's SARMaster records.

Secondary Tasks

If time allowed three secondary tasks existed, all of which were accomplished:

- Travel to AFRCC to collect additional information to augment the database
- Collect Personal Locator Beacon (PLB) data
- Complete a written report

Overall Data Methodology

Data collection

Data was collected during three trips to the Air Force Rescue Coordination Center (AFRCC). The first trip was conducted in 2005 at Langley Air Force Base as part of Small Business Innovation Research (SBIR) grant 2004-02667. During this trip data was collected on 99 incidents that occurred from 2002 to 2005. The second trip to the AFRCC (now located at Tyndall Air Force Base) was conducted under NASA Work Order NNG08HA36P. New data was collected for incidents that occurred from 2005 to 2008. In addition, several new fields were added to the database in order to collect ELT, data source, and route information. The third trip to the AFRCC was conducted under this contract (GS-23F-0092K). The trip added additional cases in 2008, Personal Locator Beacon (PLB) data, and collected missing data identified during the previous data trip (chiefly route information for the 2002-2005 incidents).

The main database currently contains 262 incidents. However after applying the final data exclusion rules it contains 260 incidents used for analysis. The database is maintained in an MS Excel 2003 spreadsheet

(NTAP.xls) in a worksheet called Master. The database contains 115 fields, although some of these fields were used solely for data conversion. A separate worksheet (PLB) was created to hold the PLB data.

Data Sources

Data was collected chiefly from the AFRCC SARMaster software, file attachments found inside SARMaster, and NTSB Aviation accident reports. The file attachments collected from the AFRCC were collected under a non-disclosure agreement that limits their use and marks them as "For Official Use Only". A copy of the non-disclosure agreement is provided on the master DVD. The internet was used to obtain some supplemental information. Aircraft were placed into the appropriate category (e.g. twin engine) after viewing a photograph of the aircraft using Google images. Airport and navaids were verified using www.airnav.com, if required. Flight routes were entered into www.skyvector.com to determine the route length and also to verify all waypoints. Google Earth was used to plot the route and measure the track offset. Google Earth was also used to determine if the aircraft's find location plotted to an airport. It was also used to determine the elevation of the crash site. Coordinates were provided in at least four different systems (Decimal Degrees -- DD.DDD, Degrees Decimal Minutes -- DD MM.MMM, Degrees Minutes, Seconds -- DD MM SS.SS, or Universal Trans Mercator UTM). All coordinates were converted to the decimal degree format using Degree Format Convertor from GPSwaypoints.co.za. Conversion of coordinate files to Google Earth KML file format was done using ExpertGPS. USGS 1:24,000 topographic maps used to determine the highest ridge or mountain summit was also obtained using ExpertGPS.

Data Inclusion Criteria

All recorded incidents were collected from the AFRCC database of incidents stored in SARMaster software. Since the AFRCC area of responsibility is limited to the continental United States (CONUS), the incidents are for the most part limited to CONUS. A record is created for incidents and those incidents that result in an AFRCC mission. Data was collected from incidents (which include all missions) if they met all of the inclusion requirements. Incidents are classified as open, closed, or suspended. Only closed incidents were considered. However, some of these closed incidents represented previously suspended searches but the aircraft was found after the formal search was done. SARMaster contains a "situation" field that identifies the type of incident. Only those incidents that involved actual searches (versus rescues) for missing aircraft were selected. The software also contains a mission result field that classifies the incident as distress or non-distress (along with a few other options). Since the definition of distress was broad, only those incidents classified as distress were included. This precluded missions that were a result of a pilot failing to close out a flight plan or simply flying to another airport and failing to report. A find location for the aircraft must have been reported. Finally, in order to collect useful data from the incident, one of the following also had to be recorded: radar coordinates, route information, or an ELT signal.

In brief, the data inclusion criteria required:

- In AFRCC database (SARMaster)
- AFRCC incident number assigned
- Closed incident
- Missing aircraft
- Search occurred
- Incident classified as distress
- Find location provided (typically coordinates)
- Also provided at least one of the following
    - Radar information (last coordinates)
    - Route information
    - ELT information

Data Exclusion Criteria

After applying the data inclusion rules, only a few exclusion criteria applied. Three reasons to throw out data emerged. An entire incident would be excluded if the plane landed at an improved runway. This would be regardless of distress or non-distress. This only applied to two cases. The second exclusion criterion was conflicting information. Often information could be obtained from AFRCC fields, AFRCC comment section, NTSB reports, or online. If conflicting information existed about one of the data collection subtasks (such as route or crash site elevation) then that specific element would be excluded. Finally, data elements of an incident would be excluded if missing information existed. Therefore, throughout this report different results are based upon different numbers of cases. The number of cases a result is based upon is stated in the "count" field.

Subtasks

1. Determine distance from last radar plot to aircraft find site

Determine the distance traveled from the last recorded radar position. This will be accomplished by examining the data collected at the AFRCC. (Deliverable – Provide a CD data file that includes coordinates of last radar position, coordinates of the crash location and distance from last radar position.)

Overview

The distance traveled from the last recorded radar position was obtained from 217 incidents. In order to obtain the distance traveled from the last recorded radar position it was necessary to known the coordinates of the last recorded radar position and the find site coordinates. Radar plot coordinates were obtained from either 84th Radar Evaluation Squadron (RADES) or the FAA and recorded by the AFRCC. When radar data was reported by both sources, the RADES data was used. Find location coordinates came from NTSB aviation accident investigation reports or from AFRCC reports. When both sources reported find coordinates, the NTSB coordinates were used.

Results and Discussion

	All	In Coverage
n	**216**	**211**
25%	0.4	0.4
50%	0.8	0.8
75%	5.5	4.5
95%	45.4	37.7
Avg	7.4	6.0
SD	19.0	15.8

Table 1 Distance (nm) of find from last radar plot

In the first table the descriptive statistics of count (n), quartiles, 95%, average, and standard deviation (SD) are provided. All distances are given in nautical miles unless otherwise stated. The first column (All) represents the entire dataset. The second column excludes four cases where the radar analyst indicated that the plane was last seen at the edge of the radar coverage. The exclusion of these four cases do not change the 25% or 50%, but do shift the 75% and 95% downward. For the entire dataset it can be seen that half (median) the aircraft are located within 0.8 nm from the last radar position. This represents a significant containment of the probability of containment (or probability of area). Such a small area also indicates a high probability density. The probability density is high enough to warrant a ground search if the terrain or conditions do not allow a high probability of detection air search. Since it is doubtful that a ground search would be launched if an aircraft was last seen at the end of radar coverage the "In Coverage" column gives a better sense of the probability of area. It is possible to mount a ground search of 4.5 nm radius. It is reasonable to conduct an air search for a radius of 45 or 38 nm.

A major function of the data collect was to collect data that might help identify factors that alter these basic findings. While beyond the scope of this report to conduct statistical analysis looking for statistically significant differences or to develop a model that incorporates all of these factors, nevertheless, the actual results are presented.

The first modifying factor that was examined was the type of aircraft. The table shows the results from Helicopters, jet aircraft, propeller driven aircraft, the further divides the propeller driven into single and twin engine aircraft.

	Helicopter	Jet	Propeller	Twin	Single
n	**17**	**12**	**197**	**27**	**182**
25%	0.2	0.6	0.4	0.5	0.4
50%	3.2	1.5	0.8	1.5	0.7
75%	17.6	2.4	5.5	7.2	4.8
95%	105.7	4.2	41.0	24.6	42.5
Avg	22.0	1.7	6.8	6.2	6.8
SD	41.8	1.2	17.1	9.2	17.8

Table 2 Distance (nm) of find by aircraft type

Some clear differences appear between the various types of aircraft. Helicopter incidents show the largest standard deviation. They could be found quite close to the last radar plot (25% within 0.2 nm) or to find more than 75% of missing helicopters the search would need to be expanded beyond 17.6 nm. A working hypothesis that helicopters typically fly at low Above Ground Level (AGL) altitudes, making it easier to fly out of radar coverage long prior to the actual incident. Jet aircraft on the other hand tend to be carefully flight followed and can be at significant AGL where radar coverage is excellent. The fact that 95% of jets are found within 4.2 nm is operationally significant. While relatively minor, it does appear some difference may exist between single and twin engine aircraft (all propellers). Both the 50% and 75% rings are greater for twin engine over single engine aircraft. Considering higher speeds and better performance this would not be unexpected.

The vast majority of incident involved aircraft flying under Part 91. Only 15 incidents (that had distance from the last radar plot) involved aircraft that were not under Part 91.

	Part 91	Non
n	**195**	**15**
25%	0.4	0.4
50%	0.8	1.5
75%	4.5	14.8
95%	39.6	24.8
Avg	6.4	6.7
SD	16.6	9.0

Table 3 Distance (nm) of find by Part

A major factor in aircraft incidents is the weather. The NTSB accident report classified the weather as either Instrument Metrological Conditions (IMC) or Visual Metrological Conditions (VMC).

	IMC	VMC
n	**102**	**112**
25%	0.3	0.4
50%	0.7	1.3
75%	3.1	7.1
95%	47.9	28.9
Avg	6.3	6.5
SD	20.8	11.2

During IMC conditions it appears that the aircraft are located closer to the last radar position than during visual conditions. The 25%, 50%, and 75% are roughly half the distance. However, statistical outliers appear to be more common during IMC conditions. In addition, some overlap with pilots flying IFR or VFR is expected.

Table 4 Distance (nm) of find by Weather

Another important factor may be the pilot's experience. Experience can be measured through many different parameters. One easy measure is the type of certification the pilot holds. The levels used for this analysis included student, private certification, instrument, commercial, and Airline Transport Pilot (ATP).

	Student	Private	Instrument	Commercial	ATP
n	**6**	**59**	**53**	**46**	**20**
25%	0.2	0.4	0.3	0.4	0.5
50%	1.9	0.8	0.6	0.8	1.3
75%	7.2	6.7	2.9	4.5	12.8
95%	37.4	56.4	13.4	23.7	47.2
Avg	8.3	7.6	2.6	5.1	10.5
SD	14.6	24.4	5.4	9.3	18.3

Table 5 Distance (nm) of find my Pilot certification

The table represents the pilot's highest certification and not they type of flight activity they were engaged in (other than the student pilots). In fact of the 20 incidents involving Airline Transport Pilots none was during a scheduled passenger flight and 17 were under Part 91. It appears the instrument pilots are found the closest to the last radar plot followed by commercial pilots.

Another significant factor may involve the type of flight plan that was followed. The database recorded four types of flight plans. They included Instrument Flight Rules (IFR), Visual Flight rules (VFR), no flight plan (none), and during the flight the pilot requested flight following (FF). Since the request for flight following was made during the flight the pilot may or may not have filed a flight plan. However, since the aircraft was being directly followed, flight followed aircraft were placed with IFR aircraft for statistical analysis purposes.

	IFR	VFR	None
n	**79**	**42**	**80**
25%	0.3	0.5	0.4
50%	0.5	3.0	0.8
75%	3.1	13.1	9.6
95%	14.3	55.8	58.1
Avg	2.9	10.4	9.8
SD	5.7	22.7	24.1

Table 6 Distance (nm) of find by flight plan

Aircraft flying under IFR were found closer to the last radar plot. This result it not too unexpected since they are issued a discrete code, it is much easier to find the correct radar track for these aircraft. The differences between VFR and none are rather interesting. When no flight plan is filed it appears the aircraft is typically found closer to the last radar plot. This requires closer examination.

The NTSB report classified the flight phases of when different factors or causes of the accident occurred. With a radar track it should be possible for a skilled search planner to determine the phase of flight that is occurring at the time of the last radar plot. Some phases of the flight did not have sufficient incidents and were grouped with the next best match. The phases of flight that were examined were climb, cruise, maneuvering, descent, and approach.

	Climb	Cruise	Maneuvering	Approach	Descent
n	**14**	**31**	**42**	**94**	**17**
25%	0.5	0.4	0.4	0.3	0.1
50%	0.7	0.6	0.8	0.8	0.5
75%	5.3	7.4	7.0	3.6	2.6
95%	14.6	20.4	25.1	51.4	22.0
Avg	3.6	5.0	6.1	7.3	4.1
SD	5.5	7.7	9.5	22.1	8.9

Table 7 Distance (nm) of find by flight phase

Another important factor might be the type of terrain. Certainly mountainous terrain can cause terrain blocking and gaps in radar coverage. In addition, the causes of accidents can be different.

	Flat terrain	Mountainous
n	**88**	**128**
25%	0.4	0.4
50%	0.8	0.9
75%	6.9	4.5
95%	51.9	40.4
Avg	8.1	6.9
SD	21.9	16.8

Preliminary analysis does not suggest any major difference between flat terrain and mountainous terrain in regards to distance from the last radar plot.

Table 8 Distance (nm) of find by terrain

Since it most cases the radar data is not restricted to the last radar plot but instead tends to show the last minute, last 5 minutes, or even the entire flight; it is possible to characterize what the aircraft was doing at the time of the last plot. The terms used during this analysis was straight, straight and level, straight and climbing, straight and descending, bearing right or left, turning right or left, hooking right or left, or spiraling right or left. For this preliminary analysis only the major terms were used and right and left differences were ignored. The flight characteristics were determined by looking at a map of the plots looking at only the horizontal aspects of flight. Only straight and descending factored in a vertical component.

	Straight	Straight & Descending	Bear	Turn	Hook	Spiral
n	**67**	**14**	**10**	**13**	**34**	**13**
25%	0.7	0.1	0.1	0.5	0.3	0.3
50%	2.8	0.3	0.7	0.7	0.4	0.7
75%	13.9	0.5	1.0	2.1	1.5	6.8
95%	65.4	15.6	17.1	3.6	6.3	13.6
Avg	12.7	2.1	2.9	1.2	1.4	3.7
SD	26.4	6.8	7.1	1.2	2.4	5.0

Table 9 Distance (nm) of find by flight characteristic

Turns and hooks appear to be the best predictor of finding the aircraft nearby, all the way out to the 95%. Descending, bearing to the left or right also predicts shorter distances. Straight and descending had a significant high probability zone with 75% of the incidents within 0.5 nm. Spirals demonstrate some variability. If an aircraft was flying straight (and usually level) that proved to be a poor predictor of the distance from the last radar plot. While straight flight does appear to be a poor predictor, nonetheless both the 25% and 50% zone represent areas that could be search on the ground. In addition, it would be important to further examine if the straight and level flight represented controlled flight into terrain in mountainous areas.

Since the final flight parameters or characteristics are expected to be independent of many of the other input factors, it is expected that this factor will be an important contribution to any eventual software.

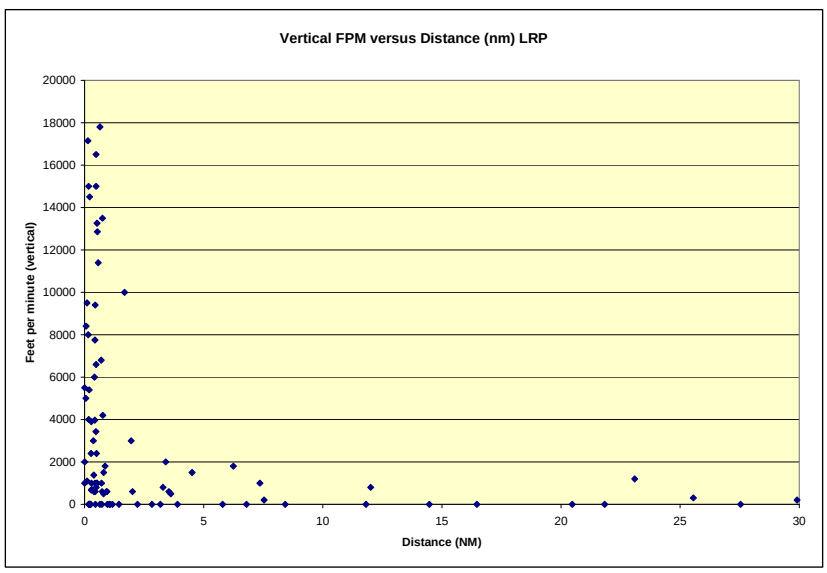
While flight characteristics looked at the horizontal characteristics of the last few plots, the Change in Feet per Minute (FPM) looked at the vertical change in the last plot. Change in FPM where obtained from Mode C transponder returns which are only precise to 100 feet. For the sake of making tables, the data was placed into bins with the first bin containing incidents where the descent in FPM was greater than 2000 feet. The

second bin contained descents of 1000-2000 FPM, the third bin 1-1000 FPM, the fourth bin the flight was level (0 FPM) and the last bin contained 8 cases where the aircraft was climbing.

	>2000	1999-1000 FPM	999-1 FPM	0 FPM	Climbing
n	**34**	**14**	**18**	**28**	**8**
25%	0.2	0.4	0.5	0.6	0.3
50%	0.4	0.6	1.5	1.8	0.9
75%	0.5	3.6	6.6	9.3	2.4
95%	1.8	15.7	101.2	27.7	6.8
Avg	0.5	3.3	15.4	7.0	1.9
SD	0.6	6.2	42.9	10.3	2.4

Table 10 Distance (nm) of find by vertical FPM rate

If the aircraft is descending at a rate greater than 2000 FPM this is an excellent predictor that the distance between the find site and the last radar plot will be small. This is not an unexpected result. For descent rates between 1000 FPM and 2000 FPM the 75% can be searched on the ground and the 95% is still a relatively small search area. Descents of 1-999 FPM often represent normal descent rates for landing. Also the limited precision of transponder reported altitudes means the plane could have been flying level but reported as descending for the last two Mode C reports. The distances are slightly greater than the median of 0.8 seen for the entire database. Level flight (0 FPM) also shows a median greater than the median value of the entire database. Only eight cases exist in the database where the aircraft was climbing. All of these cases were found relatively nearby. At this time with the small number of cases no major outliers appeared.



The data can also be viewed as a graph, which allows viewing all of the data points.

Figure 1 Relationship between find distance and FPM

Summary for Distances from last radar plot:

Distance from the last radar plot represents one of the most fundamental models used in search planning. With half of all aircraft being found within 0.8 nm this data can be used to help justify and define a ground search along with the air search. The data clearly indicates that by looking at several other input factors it will significantly influence the distances. A hook with a rapid decent would indicate the aircraft is located near the last plot. Straight and level flight might indicate the plane could be found further away.

2. Dispersion Angle

Calculate the dispersion angle from three points; the find location, the last radar plot, and the second to last radar plot. (Deliverable - Provide a CD data spreadsheet that presents the dispersion angles from the last radar position and the second to last radar position.)

Overview

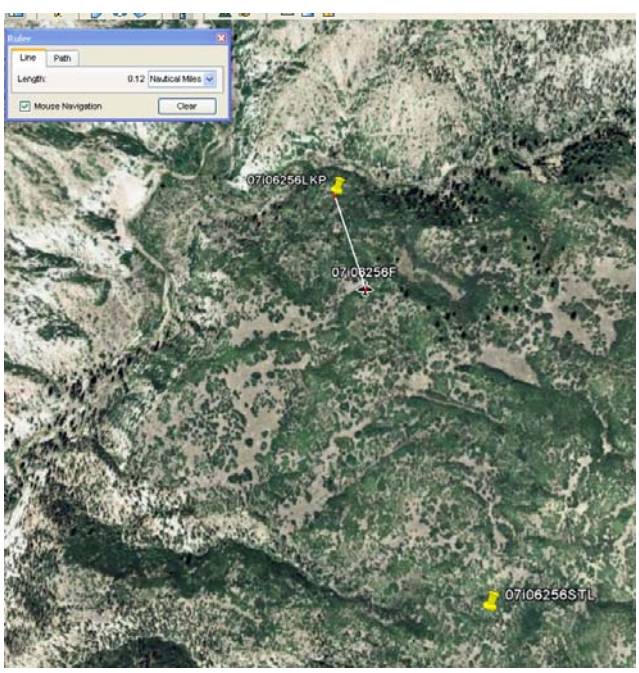
The dispersion angle represents the absolute difference between two bearings. Therefore, the largest possible difference is 180 degrees. In order to calculate the dispersion angle, three points needed to be known. The find location, last radar plot, and second to last radar plot all needed to be recorded in the database. The bearing from the last radar plot to the find location represents the "bearing." The second bearing represents the last heading of the aircraft. This was obtained in one of two ways. If the database recorded the coordinates for the last and second to last radar plot the heading was obtained by calculation. In many cases only a map of the radar plots were given and only the last radar plot had coordinates. In these cases the map was printed and the heading was manually plotted using a straight edge and compass. A total of 159 cases had sufficient information to determine the dispersion angle.

Results and Discussion

	All
Count	159
25%	22°
50%	51°
75%	112°
95%	170°
Avg	70°
SD	56

Table 11 Overall Dispersion Angle (degrees)

While the dispersion angles certainly help to narrow down the probable areas, the values are not always as high as intuition would suggest. It can be seen that 50% of the aircraft are located within 51 degrees, random chance for the 50 percentile would be 90 degrees. However, the 75% quartile shows much less clustering with the probable area being 112 degrees and the random expected value of 135 degrees. The dispersion angle does not consider if the aircraft was located to the left or right of the last heading.



In many cases the aircraft was located between the last and second to last radar plot. Two possibilities exist why this occurred. The first is that the aircraft actually changed its heading by approximately 180 degrees. The second involves an artifact of some radar systems. The radar system projects the next plot based upon current heading and when it does not actually see the real radar plot records the projected point as the last real plot. Incident 07i06256 illustrates the aircraft being located between the last two radar points. The dispersion angle for this particular incident is 178 degrees. In this particular incident the crash bearing (heading of the ground scar) was not reported by the NTSB. Such analysis is possible but was beyond the scope of this report.

Figure 2 Illustration of find between radar plots

As with the ring distances, different input factors were examined to determine if the probability distribution could be improved over using the entire database. First the type of aircraft was examined.

	All	Helicopter	Twin Engine	Single Engine	Jet Engine
Count	**159**	**9**	**14**	**128**	**6**
25%	22	9	26	24	16
50%	51	28	53	55	68
75%	112	41	80	111	110
95%	170	171	166	169	143
Avg	70	53	67	71	72
SD	56	68	56	55	65

Table 12 Dispersion angles by aircraft type

Twin engines appear no different than single engine aircraft. Jets also do not appear all that different than the overall database. Only Helicopters appear to be different. For the 25-75% the dispersion angle is a good predictor of where the helicopter will be found.

Weather conditions are always an important factor to consider. Differences between IMC and VMC are presented in the next data table.

	IMC wx	VMC wx
Count	**68**	**79**
25%	36	19
50%	72	43
75%	118	99
95%	169	168
Avg	77	63
SD	54	56

Table 13 Dispersion angles by weather

It appears that when flying in visual meteorological conditions the dispersion angle is less than when in IMC.

The type of flight certification held is examined next. Possible choices included student, private, instrument, commercial, and Airline Transport Pilot. As before, the highest level was used for analysis, it does not mean the pilot was following the rules for that particular level.

	All	Student	Private	Instrument	Commercial	Airline Transport
Count	**159**	**6**	**46**	**32**	**35**	**15**
25%	22	27	24	39	22	17
50%	51	62	60	56	51	43
75%	112	126	120	105	95	119
95%	170	137	173	161	91	167
Avg	70	72	74	71	65	66
SD	56	58	58	51	53	59

Table 14 Dispersion angle by pilot's certification

The only important difference seen is for commercial pilots. While the 25% and 50% are virtually identical with the entire database, the 75% and 95% show some important differences.

Three different types of flight plans were examined. Pilots who filed IFR or VFR plans, and those who did not file any type of flight plan.

	IFR	VFR	None
Count	**49**	**31**	**65**
25%	37	19	26
50%	67	40	57
75%	103	154	109
95%	170	174	167
Avg	74	73	71
SD	53	69	53

Table 15 Dispersion angle by flight plan

No clear differences are seen. VFR flight plans have a smaller dispersion angle for the 25% and 50%, but larger ones for the 75%. Little difference exists among any of the three at the 95%.

The phase of flight was determined from NTSB records.

	All	Climb	Cruise	Maneuvering	Descent	Approach
Count	159	9	71	33	14	16
25%	22	26	26	25	21	22
50%	51	46	56	82	28	43
75%	112	87	114	128	69	105
95%	170	135	168	174	95	173
Avg	70	65	71	79	43	66
SD	56	48	56	56	33	56

Table 16 Dispersion angle by flight phase

No clear differences appear. Descent is the most unique of all the phases.

Another important parameters is if the flight took place in mountainous terrain. The classifications used were flat/hilly, water, and mountainous. Water does not have a sufficient number of cases (4) to draw any real conclusions at this point.

	Flat	Water	Mountainous
Count	**54**	**4**	**101**
25%	30	2	21
50%	69	9	46
75%	138	34	96
95%	174	87	167
Avg	85	27	63
SD	61	41	52

Table 17 Dispersion angle by terrain

Mountainous terrain appears to have smaller dispersion angles than flat terrain.

When calculating the distance from the last radar plot one of the most significant factors was the final flight characteristic. This included straight and level flight, straight and descending, bearing to the right or left, turning to the right or left, hooking to the right or left, and spirals.

	All	Straight	Straight & Descending	Bear	Turn	Hook	Spiral
Count	**159**	**65**	**13**	**9**	**13**	**32**	**12**
25%	22	13	22	57	67	47	35
50%	51	40	29	102	96	89	48
75%	112	106	42	103	125	136	99
95%	170	174	96	167	169	170	174
Avg	70	62	37	84	97	92	75
SD	56	58	29	55	50	54	58

Table 18 Dispersion angle by flight characteristics

Some clear observations can be drawn from the final flight characteristic. Both straight and especially straight & descending result in smaller dispersion angles than the overall database. Likewise if the aircraft was turning in some manner (bearing, turning, or hooking) it is not unexpected that the last heading may not be as strong of a predictor. Examining the 50% of bearing, turning, and hooking it can be seen all of the values are at or above 90 degrees which is the expected random value. What this data analysis did not look at is the effect of turning left or right.

Finally what is the relationship between the vertical changes in FPM versus the dispersion Angle? The following scatter graph plots the relationship.

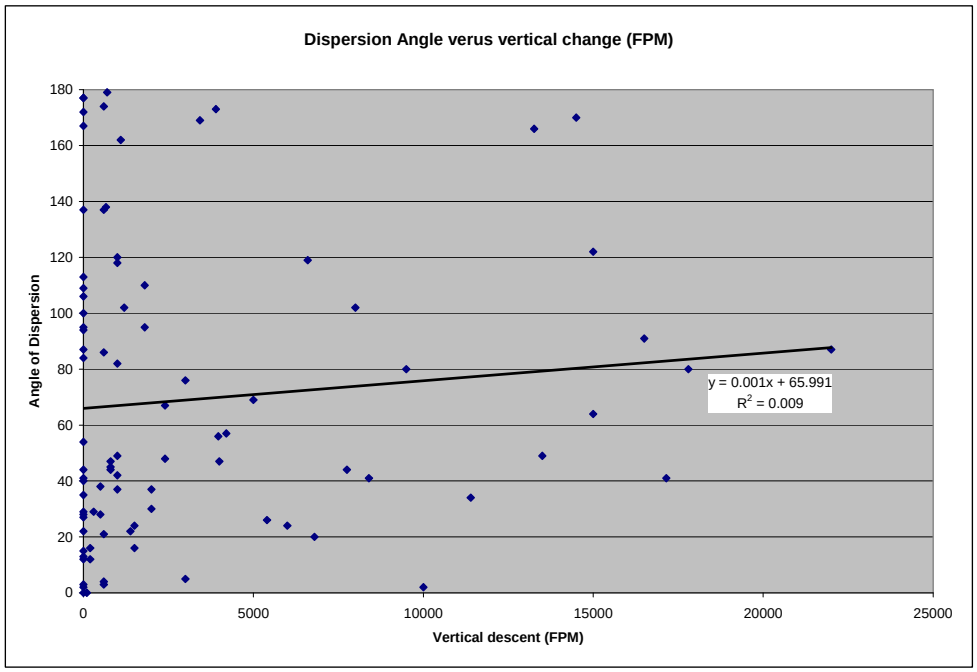


Figure 3 Dispersion Angle vs. vertical FPM

The projected trend line is nearly flat and only accounts for 1% of the variation. Therefore, it is reasonable to conclude that the angle of dispersion and vertical descent are not dependent upon each other. Therefore, any model ultimately built can include both vertical descent and Angle of Dispersion. It is also important to determine if any correlation exists between angle of dispersion and the distance from the last radar site. Once again if no correlation is found than for modeling purposes both sets of statistics can be used independently.

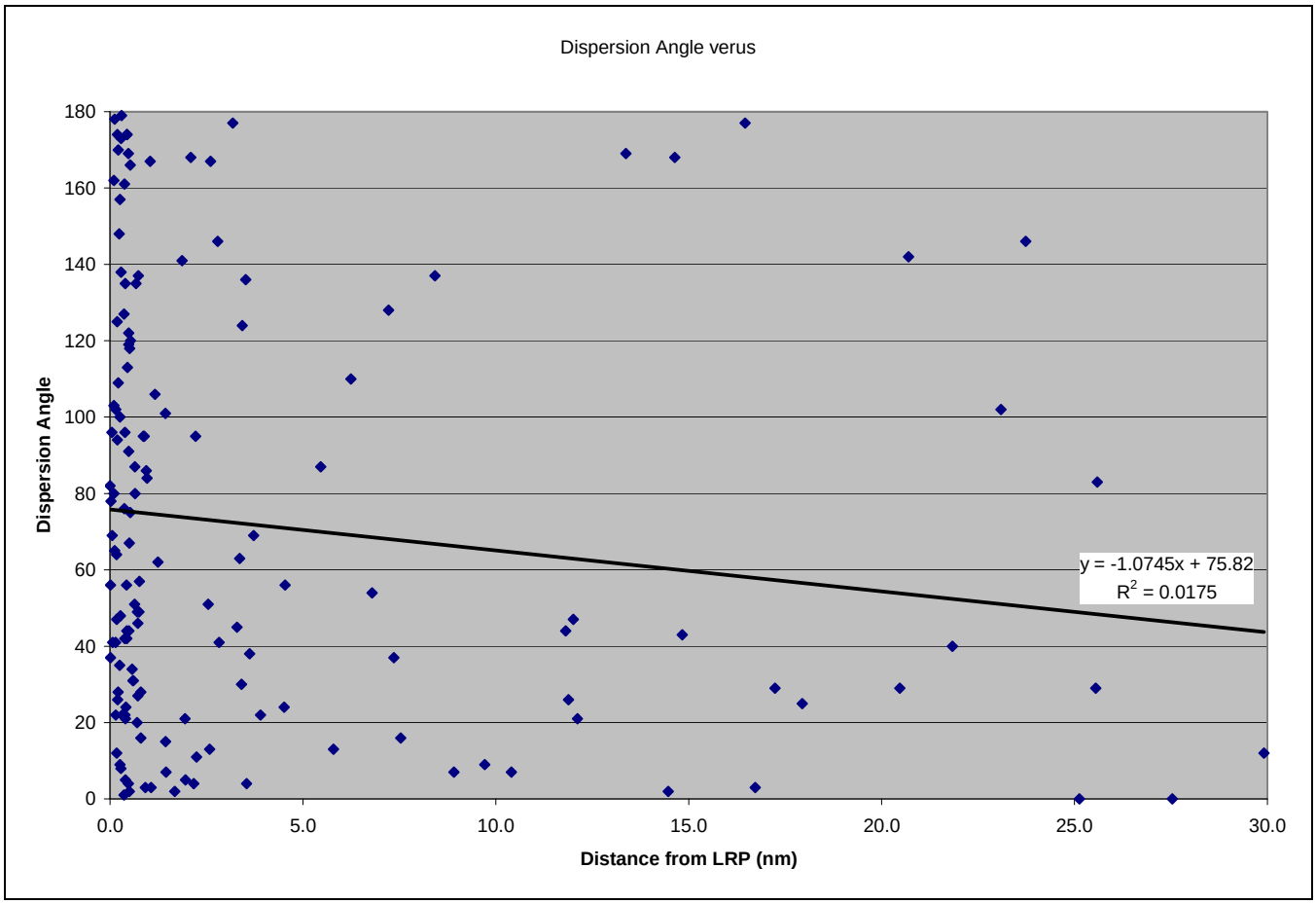


Figure 4 Dispersion angle versus find distance from last radar plot

As the trend line and R^2 factor indicates, no apparent correlation exists between the dispersion angle and the distance from the last radar position.

Summary of Dispersion Angle

The overall dispersion angles clearly show it can further define the search area. The dispersion model is independent of the distance model. Much like the distance model certain inputs that would be available to search planners can further refine the probable areas. Helicopters are much more likely to be found along the final heading than other types of aircraft, a different result than the distance model. Visual conditions and mountainous terrain also appear to be important modifying factors. The most important factor of all appears to be the final flight characteristic. Straight and straight & descending flight had small dispersion angles. If the aircraft was turning (bearing, turning, or hooking) then the dispersion angle was larger than random chance. No analysis was done of the impact of turning left or right. It certainly appears this would be critical further analysis.

3. Vertical changes

Determine the relationship between the missing aircrafts last recorded radar altitude (flight altitude) and the terrain elevation where the aircraft wreckage was located. (Deliverable – Provide a CD spreadsheet data file that relates the terrain elevation where the aircraft was located as related to the last recorded radar altitude.)

Overview

In order to determine the vertical changes from the aircraft's last position to find location only required the last reported altitude and the elevation the crash was located. The last reported altitude was recorded in the AFRCC database as Mode C information. As previously noted Mode C transponder data is reported in increments of 100 feet and is dependent upon the aircraft's altimeter being calibrated properly. The crash site elevation was determined from the aircrafts find location coordinates being plotted with Google Earth which uses NASA's Shuttle Radar Topography Mission (SRTM) elevation data. The difference between the last reported altitude and crash elevation were then calculated. A loss of altitude or descent is reported as a negative number. A gain in altitude or climbing is reported as a positive number. A total of 169 incidents had sufficient vertical data in order to make a report. In all cases, the missing data would have been the aircraft's last reported altitude.

Results and Discussion

Descended	136	80%
Same	9	5%
Ascended	24	14%
Count	169	

Table 19 Overall vertical change

For the entire database, 80% of the aircraft descended. Nine or 5% of the aircraft were found at the same elevation. The definition of same elevation was a difference of less than 100 feet between the last reported altitude and crash elevation. Of these nine cases, two represented descents (28 and 23 feet) and the remaining seven were small gains in elevation (17, 28, 47, 49, 59, 87, and 90 feet). The remaining 14% of the cases represents climbs or ascended. The median change in elevation was a descent of 1,574 feet, the average change was a descent of 2,371 feet.

It would be expected to see a difference between flat and mountainous terrain. Only mountainous terrain offers the possibility of gaining altitude and still having an impact with terrain.

	Flat	Mountainous
Ascended		22%
Same	3%	6%
Descended	97%	72%

Table 20 Vertical change by terrain

As expected no aircraft descended in flat terrain. Almost 75% of the aircraft in mountainous terrain descended and almost 25% ascended. This will be useful information for model building in the vertical dimension.

	Descended	Ascended
Count	**79**	**24**
25%	-1096	307
50%	-2290	611
75%	-3725	1169
95%	-3844	2373
Avg	-3026	816
SD	3435	779

Table 21 Vertical change amount

Looking only at mountainous terrain, the table gives the amount of change of vertical elevation. If the aircraft descended then 50% descended 2290 feet. If the aircraft ascended then 50% climbed 611 feet from the last reported altitude. Cleary the amount of descent is greater than the amount of ascent.

Helicopter	Descended	1	33%
	Same		
	Ascended	2	67%
Jet	Descended	3	75%
	Same	1	25%
	Ascended		
Single	Descended	66	73%
	Same	6	7%
	Ascended	18	20%
Twin	Descended	8	67%
	Same		
	Ascended	4	33%

Table 22 Vertical change by aircraft type

While helicopters appear to be quite different from the percentages found in other aircraft, with only three cases, no conclusions should be drawn from the results. The same statement applies to jet aircraft. Single engine and twin engine appear to have similar results that agree with the overall database. At this time type of aircraft does not appear to be a useful predictor.

IMC	Descending	34	71%
	Same	4	8%
	Ascending	10	21%
Visual	Descending	38	73%
	Same	2	4%
	Ascending	12	23%

Table 23 Vertical change by weather

The meteorological conditions do not appear to influence the percentage descending or ascending.

	IFR	VFR	None
Count	**37**	**21**	**43**
Descending	73%	67%	72%
Same	5%	5%	7%
Ascending	22%	29%	21%

Table 24 Vertical change by flight plan

The difference between IFR and VFR appears marginal. While additional statistical testing would be required to see if the slight increase in climbing under VFR is valid, operationally it would not be significant. Results are only taken from mountainous terrain.

	Climb	Cruise	Maneuvering	Descent	Approach
Count	6	50	24	9	12
Descending	67%	76%	62%	89%	67%
Same	17%	6%	4%	11%	8%
Ascending	17%	18%	33%		25%
50%	-1880	-1744	-1638	-764	-259

Table 25 Vertical change by flight phase

The phase of flight would be expected to have some affect on the vertical change. It is not surprising that during descent none of the 9 incidents showed a climb. This is partly due to the small case number. If the aircraft was maneuvering it had the greatest chance (one-third) of being found at a higher altitude. As before, all of the data was only taken from mountainous terrain incidents.

During the previous analysis one of the most significant predictors was the final flight characteristics. Since this parameter measures vertical changes the options were modified somewhat. In the following table the data was placed into one of three categories. The category "Maneuvers" includes bearing left or right, turning left or right, hooks, and spirals. The second category was for straight and level flight, while the final category is straight and climbing.

	Maneuvers	Straight and Level	Straight and Climbing
Count	**41**	**40**	**10**
Descending	76%	68%	56%
Same	10%	20%	11%
Ascending	14%	27%	44%
Median	-2049	-1064	-49

Table 26 Vertical change by flight characteristics

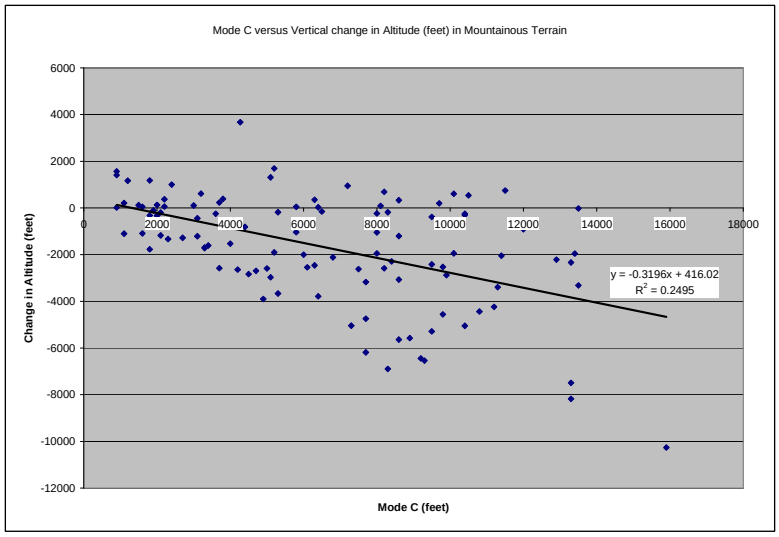
Clearly the final flight characteristics are reflected in changes in the outcomes. If the aircraft was maneuvering then it had the greatest probability (76%) of a final descent. Those aircraft flying straight and level showed the greatest probability (20%), among the three categories, of being found at the same altitude. If the aircraft was climbing it had a 44% probability of having a final ascent.

In many of the cases the actual change in FPM was known. For initial analysis five bins were created. The first bin is if the aircraft was climbing, the second is level flight, the third bin includes aircraft descending at a rate of 1-1000 FPM, the fourth is a descent rate of 1000-2000 FPM, and the last bin including a descent rate greater than 2000 FPM.

	Climbing	Level	1-1000	1000-2000	>2000
Count	**8**	**25**	**25**	**9**	**33**
Descending	63%	72%	76%	78%	94%
Same	-	4%	16%	11%	-
Ascending	38%	16%	8%	11%	6%
Median	-301	-1177	-827	-1180	-2336

Table 27 Vertical change by vertical FPM rate

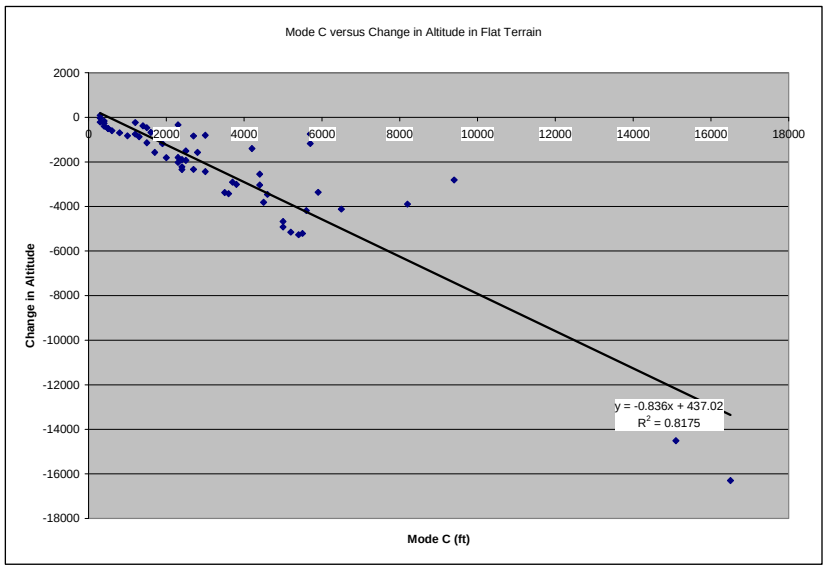
The results show a clear relationship between the vertical FPM rate and the probability the aircraft will descend or ascend in mountainous terrain.



The next scatter graph explores the possibility of a correlation between the aircraft's Mode C altitude and the eventual change in altitude.

Only a weak correlation exists (R^2=0.25). The correlation is not strong enough to have much predictive value. The simple observation might be, the higher the altitude of the aircraft, the greater the change in altitude can be. Perhaps, a better model would examine the altitude Above Ground Level (AGL) versus the change in Altitude. However, this was beyond the scope of this report. This graph looked at only mountainous terrain.

Figure 5 Vertical change versus initial Altitude



The graph shows a good correlation (R^2=0.82) between the initial Mode C altitude and the final change in altitude in flat terrain. Unfortunately, all the correlation really shows is that missing aircraft impact the ground. If AGL was used instead of Mode C it is expected a nearly perfect correlation would have been found. Unfortunately, it has little predictive value.

Figure 6 Change in altitude versus initial altitude in flat terrain

Altitude Summary

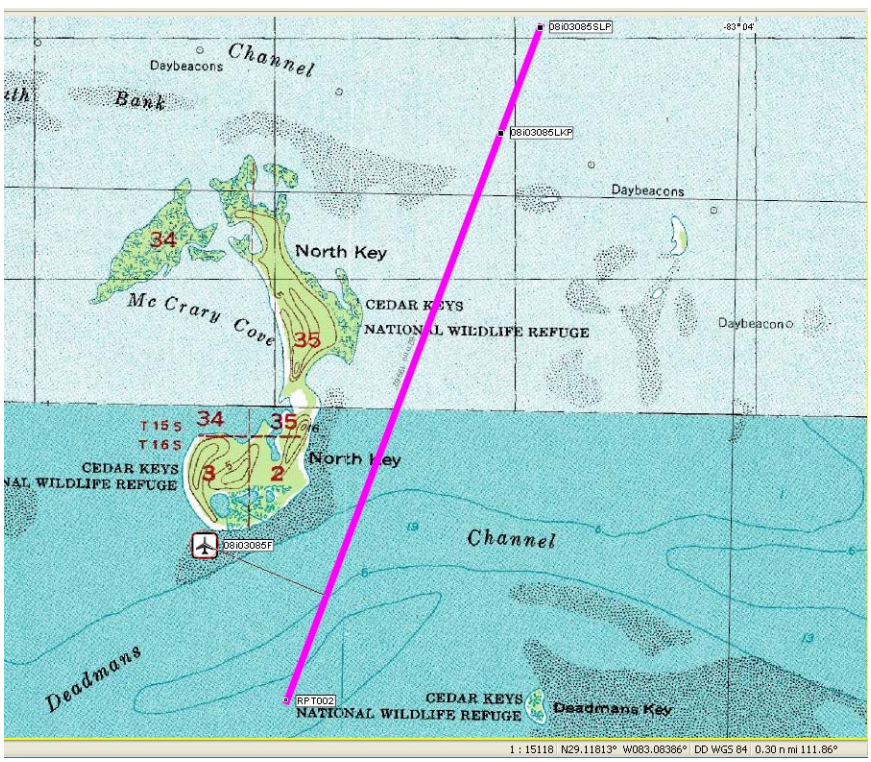
In flat terrain a missing aircraft can only be found at a lower altitude that corresponds closely with its AGL. However, in mountainous terrain probable locations become more complex. An aircraft can be found higher, lower, or at the same altitude due to rising terrain. The overall finding was that in mountainous terrain 72% of aircraft descend from the last reported altitude, 6% are found at the same elevation, and 22% are found at a higher elevation. Important influencing factors included the phase of flight, final flight characteristics, and perhaps most importantly the vertical FPM rate.

4. Radar Plot track offset

Determine the radar track offset based upon radar information versus route information. This statistic will provide the perpendicular distance between the find location and the aircrafts route as determined from radar data. Deliverable – Provide the data on a CD spreadsheet that presents the perpendicular distance from the find location and last radar Position.

Overview

If no radar information is available then the best tool a search planner has is the route of travel. The most useful statistics obtain from a route of travel is the track offset, which is the least or perpendicular distance from the find site to the expected route. However, if radar data is obtained, then this updates and often revises the route. If the aircraft continues to fly along the new route projected by the radar data, then the radar track offset should be small. In order to obtain a radar track offset it is required to have the find site coordinates, the last radar plot, and the aircraft's heading at the last radar plot. The find location and last radar plot where converted to a GPX file format and opened in ExpertGPS software. The last radar plot was selected and then using the route tool a line was drawn on the bearing of the last heading of the aircraft. Next, the distance was measured (nautical miles) from the find site to the closest point along the route (a perpendicular). This distance was the radar track offset. If the find site was located behind the last radar plot then the distance from the find site to the last radar plot was used.



A screen shot from ExpertGPS illustrates how measurements for radar track offset where taken. The purple line is the last heading established by the last and second to last radar plot. The crash site is represented by the airplane icon. The route tool is then used to draw a line from the aircraft find location to the route. The distance is then measured in nautical miles in the bottom right hand corner. In this case a distance of 0.3 nm.

Figure 7 Illustration of radar offset measurement (nm)

Results and Discussion

	All
Count	159
25%	0.1
50%	0.4
75%	2.0
95%	18.6
Avg	3.0
SD	7.8

Table 28 Overall radar plot offset

The results show that 50% of aircraft are located within 0.4 nm of the route established by the last radar heading. This can clearly help to further refine areas of higher probability. The 75% of 2.0 nm also represents a useful cluster of aircraft along the radar route.

	Flat	Mountainous
Count	52	102
25%	0.2	0.1
50%	0.4	0.4
75%	1.9	2.0
95%	19.9	18.4
Avg	3.4	2.8
SD	8.3	7.8

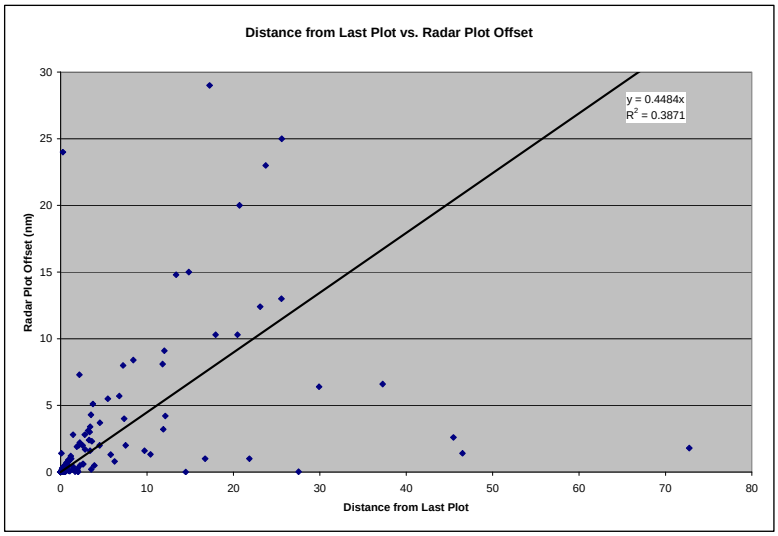
Table 29 Radar plot offset by terrain

No significant difference exists when looking at flat or mountainous terrain

	All	Straight	Straight & Descending	Bear	Turn	Hook	Spiral
Count	159	63	13	8	13	32	11
25%	0.1	0.3	0.0	0.1	0.3	0.1	0.2
50%	0.4	1.0	0.1	0.4	0.5	0.4	0.3
75%	2.0	3.0	0.4	0.9	0.9	0.7	1.8
95%	18.6	27.0	8.3	10.4	2.9	10.2	7.3
Avg	3.0	4.8	1.2	1.9	0.9	1.6	1.6
SD	7.8	11.1	3.6	4.3	1.0	4.3	2.8

Table 30 Radar plot offset by flight characteristic

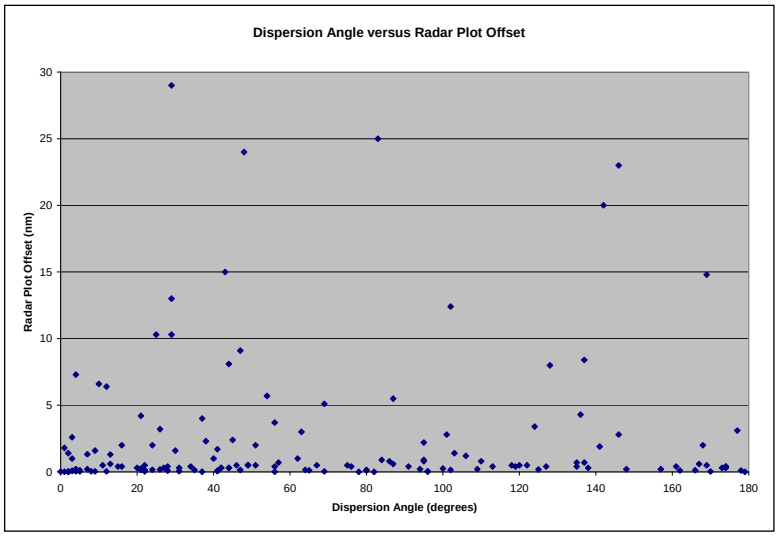
As with several of the other output statistics, the final flight characteristics do suggest some important differences. Straight and descending shows the tightest cluster of find locations near the last radar route. While, straight shows the least amount of clustering. Direction changes such as bearing, turns, and hooks, also show a tighter clustering than the overall database.



The distance from the last radar plot and the radar plot offset does show a weak correlation. A strong correlation would have meant the further away from the last radar plot the further away from the new route. However, this does not explain most of the data. More statistical analysis would be required to determine the best approach to integrating this information into a comprehensive model

.

Figure 8 Radar plot offset versus dispersion angle



The scatter graph shows no correlation exists between the dispersion angle and the radar plot track offset. Therefore, in any model building they could be used independently

.

Figure 9 Radar plot offset versus distance from last radar plot

Radar Plot Offset Summary

The radar plot offset provides yet another method to determine probable areas. It relies upon the last radar heading to create a new route of travel, then measures the distance from that route of travel. Obviously, the last heading if the aircraft is maneuvering will change. Nonetheless, it showed clustering even if the aircraft was involved in a turn. The radar plot offset does have some overlap with the distance from the last radar plot and the dispersion angle. However, since it is possible to have a small value for the distance and large value for dispersion angle, the radar plot offset can serve an intermediary role.

5. Collect data from the National Transportation Safety Board

Collect additional data from National Transportation Safety Board (NTSB) records on aircraft accidents where search was necessary to locate missing aircraft. This will provide additional details such as VFR versus IFR flight, find location from NTSB data so that verification of previously collected data from Air Force Rescue Coordination Center data can be verified. Deliverable – Provide a written report (position paper) with findings or the data can be provided on a CD spreadsheet providing it satisfies the deliverable requirement.

Overview

The NTSB maintains an online database of aviation accidents called the "Aviation Accident Database & Synopses" available at www.ntsb.gov/NTSB/Query.asp Using the aircraft's registration number collected from the AFRCC data it was possible to obtain the NTSB report. In several cases, where the registration number had been entered incorrectly or was incomplete, it was possible to use other search parameters (date, location, type of aircraft, fatalities) to locate the report. This also allowed updating the database with the correct registration number.

Results and Discussion

The NTSB issues three types of reports. The first is a preliminary report. Many of the incidents from 2008 and a few from 2007 only had preliminary reports. Later the NTSB issues a factual report and then a probable cause report. From these reports it was possible to add several fields in the database and to verify information found in the AFRCC reporting system. The fields unique to the NTSB report are:

- NTSB ID number
- Part regulation
- Flight type (personal, medical, aerial, etc)
- Light conditions (Day, Night, Night/Dark)
- Basic Weather (IMC, VMC)
- Ceiling
- Visibility
- Wind speed
- Precipitation
- Obscuration
- Total Flight hours of pilot
- Flight hours in aircraft
- Flight hours instrument
- Pilot's highest certification
- Flight Plan (IFR, VFR, none, Flight following)
- NTSB crash site elevation
- NTSB crash site bearing (magnetic)
- NTSB reported distance from last radar plot
- Flight phase
- Terrain
- Accident Cause

Since almost all of the above information (except cause, crash site elevation, crash site bearing) can be determined prior to locating the aircraft it may have predictive value. In this report several of the parameters where quickly examined using descriptive statistics to see if they influenced the outcome measurement. In many cases they do in fact influence the outcome. Unfortunately time and the scope of work did not allow looking at all of the factors.

The NTSB reports were quite useful in supplying missing information for other fields, providing insight into the incident with the extensive text, and resolving conflicting information. Any future studies should use or cross-reference the NTSB report. Not all of the AFRCC incidents had a NTSB report. The report was obtained in 239 of the 262 incidents. Reasons for a missing report included a more recent search where the report was not available at the time of data collection, a military flight; the incident did not meet the NTSB criteria for making a report, or insufficient information to locate a report.

The NTSB data is stored in two ways. First all of the reports were electronically retrieved and stored as PDF documents. The reports are placed into the appropriate year's directory. The file name is based upon the registration number with a prelim, fact, or cause added to the file name to indicate the type of report. In addition the information taken from the reports were entered into the MS Excel spreadsheet in the fields indicated above.

6. Route offset and percentage

Perform an analysis of the missing aircrafts route (Route Analysis) to include comparisons of data collected by other organizations, individuals and the Canadian study results which were entered in the AFRCC's "SARMaster" records. Deliverable – Present findings in a suitable record: i.e.; written report or if appropriate, on a CD spread sheet which presents the required data in a useable/readable form.

Overview

If radar data is not available then the most useful tool for defining a search area is the aircraft's intended route. Route analysis data as currently taught in the USAF Inland SAR School is taken from the Canadian Study often called the New Two Area Method (NTAM). John Desmarais of the Civil Air Patrol (CAP) conducted a preliminary study looking at US CONUS data that offered slightly different statistical findings. At the request of the USAF Inland SAR School, route data was collected during the last two data collection trips to the AFRCC.

Route analysis requires knowing the departure air field, any potential waypoints, destination airfield, and the aircraft's find location. As previously described in the inclusion and exclusion criteria any aircraft located at an airport or on a runway was excluded from this report. Therefore, the methodology is similar to Desmarais's report when it excludes the "false" incidents. All comparisons made to the CAP report use the results Desmarais reported after excluding false incidents.

Route data was initially collected from AFRCC information. The AFRCC reporting software has a field for collecting route information along with each waypoints coordinates. If information was missing, the incident summary comments often provided full route information. Finally, if departure or destination information was missing, then the data was taken from the NTSB report. A total of 259 of the 262 incidents had route information.

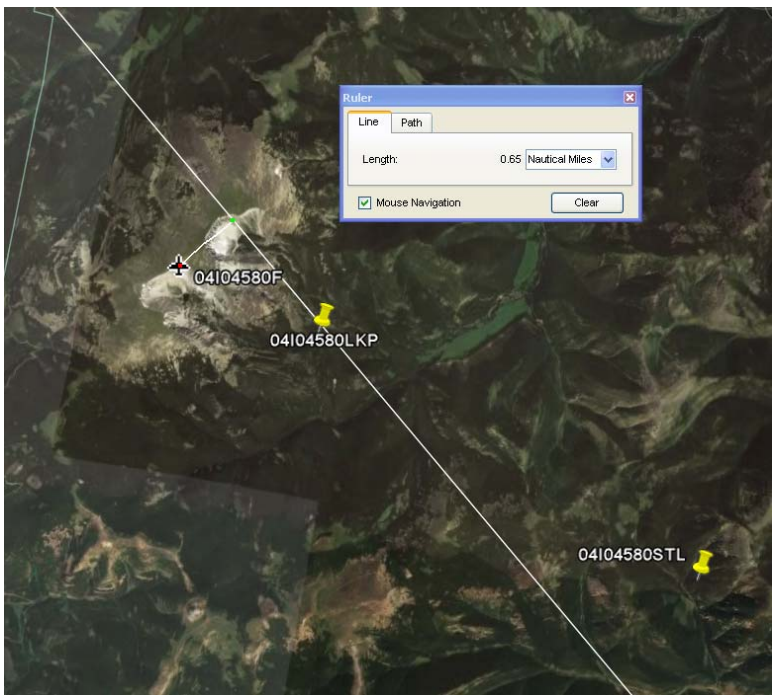
Both airports and waypoints were entered based upon the information in the AFRCC report. In cases of obscure landing fields the coordinates were captured if given. Information was usually given as either a text word (i.e. Deming Municipal Airport) or as the three digit airport code (i.e. "DMN"). In many cases the three digit code can identify either the airport or a VOR. If the VOR is located at the airport no adjustment was made. However, in many cases the airport and VOR of the same three letter code were separated by some distance. In these cases, the assumption was made that the departure and destination represent actual airfields. Therefore, a "K" was added to the three letter designator to indicate the actual airfield. Obscure place names or when the three letter needed to be matched to an airport were verified using www.Airnav.com as a resource. Airnav was able to provide codes for airports, navaids, or airspace fixes. In addition, Airnav.com provided airport coordinates if required.

The route was then entered into the online program Skyvector.com. Skyvector would plot the route on an aeronautical map; provide the distances for each waypoint, and the total distance of the route. It would also return either the three or four letter identifier along with the complete name of the airport or navaid. The length of the total route was then taken from Skyvector and entered into the spreadsheet's "Route Length (nm) field.

A route was drawn using Google Earth's route tool. This required entering the airports (using either the three letter code or airport name) and the coordinates for navaids. In a few cases, it was required to enter the coordinates for private or unmarked airfields. Within Google Earth the route was named after the AFRCC incident number. The aircraft find locations had previously been converted into a Google Earth KML file. Using Google Earth's measuring tool, the closest distance or track offset from the direct line intended

route was measured. The track offset distance was recorded in the "Route offset (nm)" field. The point of intersection of the route and perpendicular from the find site also defined the total distance the aircraft had flown of its route. This distance was entered into the "Distance along Route" field. Finally, a spreadsheet formula was used to calculate what percentage of the route had been flown. This percentage was expressed in the "Route Percentage" field. During takeoff from the departure airport, it is often required to fly in the direction opposite the destination airport or next waypoint. If a crash occurred during this phase of the flight the distance away from the departure airport would be expressed as a negative number (recall the route is direct lines drawn from between each airport or waypoint. In the case of the aircraft flying past the destination airport in order to land on the correct runway it would be possible to fly more than 100% of the route. In these incidents the route percentage will be greater than 100%.

Another common occurrence was an aircraft taking off and landing at the same airport. If an intermediate waypoint was given, then a route could be determined. If however, the route only consisted of the one airport it was not possible to create a route. In these cases no route was drawn, and no results generated. This occurred 17 times in the database. While beyond the scope of this report it would be possible to examine these incidents to determine if an alternative statistic could be generated such a ring distances.



A screenshot from Google Earth illustrates the measuring process. The aircraft icon represents the find location. The white line is the route which connected the Billings VOR (BIL) to the Great Falls VOR (GTF). In this particular incident the last radar plot (LKP) and the second to last radar plot (STL) are also seen.

Figure 10 Illustration of route offset measurement

Results and Discussion

This study will be the third to look at route information. The first study conducted in Canada is often referred to the "New Two Area Method" here abbreviated NTAM. The second study looked at AFRCC missions during 1999 and is referred here as the Civil Air Patrol (CAP) study. This study which looked at incidents from the AFRCC from 2002-2008 is referred to as the NASA study. The first results presented are the track offsets.

Study	CAP	NASA	NTAM
n	62	238	68
1nm	26%	23%	12%
5nm	45%	53%	62%
10nm	63%	68%	79%
15nm	71%	79%	83%
20nm	77%	83%	84%
25nm	84%	88%	86%
30nm	86%	95%	87%

Table 31 Route offset - three studies

The NASA study has nearly four times as much data as the NTAM or CAP study. So it has greater statistical power. The CAP and NASA study are similar in that they both collected their data from the same source (AFRCC). Although the CAP study only collected incidents that went to a mission and the NASA study used the broader incidents. The NASA study results are between the NTAM and CAP study from 1 nm track offset to 20 nm. It is common for a larger database to have results that fall between two smaller databases when the actual results are similar. Both studies advocated an area one, created by a box 10 nm all around the track line (including the departure and destination. For the NTAM area one had a 79% probability of containing the aircraft, for the CAP a 63%. The NASA study results suggest a 68% probability in area one. The NTAM study recommends that area two be a box that extends the search area out to 15 nm. This gives an area that, according to the NTAM results, has a 83% probability of containing the aircraft. Beyond this the NTAM study reported quickly diminishing returns. Going out to 20 nm only increase the probability of containment by 1% and going from 15 to 25 nm track offsets only increased the probability of containment by 3%. Based upon its results the recommendations were sound.

The CAP study found to achieve a probability of containment of 77% it needed to go out 20 nm. It achieved an increase of 14% by going from 10 nm to 20 nm, and an increase of 6% by going from 15 nm to 20 nm. It also increased the area two box further for flights that were longer than 100 nm by recommending that area two be 20% of the total route. Since this creates a variable area two, it makes direct comparison with NTAM more difficult.

The NASA study will make no recommendations at this time. Recommendations should be based upon several considerations including probability density and Probable Success Rate (PSR). Probable Success Rate is not only dependent upon the probability of containment but also on the Probability of Detection and rate at which searching occurs. Ultimately, the recommendation for search area may need to be different for different part of the country at different times of the year.

It is interesting to note that at the track offset of 25 nm and beyond the NASA study is no longer between the two other studies, but indicates aircraft start to show a tighter cluster than previously reported. The chief difference between the NTAM and NASA study is the fact data was taken from two different sources. The only difference between the NASA study and CAP study was the time period and amount of data collected. One hypothesis is that with better navigation aids available to general aviation aircraft the distances from the route have decreased. The second hypothesis is differences are due to the result of a larger database. The third hypothesis is that the two groups of data are really no different once formal statistical analysis is conducted.

	NASA	NTAM	CAP
n	**238**	**68**	**62**
Before LKP	1%	0%	6%
0 - 10%	12%	8%	16%
10 - 20%	8%	3%	6%
20 - 30%	8%	7%	8%
30 - 40%	9%	8%	6%
40 - 50%	7%	3%	2%
50 - 60%	5%	8%	5%
60 - 70%	6%	8%	3%
70 - 80%	8%	13%	2%
80 - 90%	10%	11%	8%
90 - 100%	19%	20%	19%
100%+	9%	3%	18%

Table 32 Route percentage - three studies

Another important aspect of route analysis is the percentage of the route flown prior to the accident. The table to the left uses ten percent bins along with prior to the departure airport (before LKP) and after the destination (100%+). For 9 of the 12 bins the NASA study percentages are equal or fall between the two studies. This suggests, the results might simply be explained by a greater data population. In the three cases where the percentages fell outside the two other studies the difference was only 1%, 2%, and 4%. All three studies show higher probability at departure and near the destination. In the NASA study the first 10% and last 10% (along with the bin before and the bin beyond 100%) contains 41% of the probability. From the 20% to the 80% (60% if an equal distribution) contains 43% of the probability of containment.

	All	Helicopter	Twin	Single	Jet
Count	**238**	**11**	**25**	**195**	**5**
25%	27%	23%	23%	27%	17%
50%	63%	74%	55%	66%	29%
75%	92%	85%	91%	92%	38%
95%	100%	88%	100%	101%	95%
Avg	59%	55%	56%	60%	38%
SD	37%	36%	37%	37%	33%

Table 33 Route percentage by aircraft type

The second part of the study looked at factors that might influence the route. First the type of aircraft was examined. While the number of cases of jets is quite small and cannot be statistically trusted at this point, early results suggest jet aircraft appear to have accidents during the early part of the route. It is noteworthy to mention that many of these jets were privately owned pleasure or show jets and not commercial or airline passenger aircraft. The early data suggests helicopter accidents at the destination airport are not as common as for fixed wings.

	All	Helicopter	Twin	Single	Jet
Count	**238**	**11**	**25**	**195**	**5**
25%	1.4	0.6	1.1	1.4	2.4
50%	4.5	3.8	3.0	5.0	9.0
75%	12.6	4.3	10.0	13.8	21.0
95%	36.1	14.2	37.7	36.7	45.0
Avg	10.0	4.1	9.1	10.4	14.4
SD	13.1	5.0	14.3	13.2	15.3

Table 34 Route offset by aircraft type

The next table looks at the track offsets for different types of aircraft. Once again, the number of jet cases is small. However, it appears that the track offsets are larger for jet aircraft. It also appears the offsets are slightly larger for single engine fixed wings than twin engine fixed wings. However, the difference is somewhat small and requires formal statistical testing. Finally, helicopters appear to have the smallest offset differences of the four classes.

	IMC		VMC	
	Offset	Route	Offset	Route
Count	109	109	112	112
25%	0.9	27%	1.4	31%
50%	4.7	75%	3.8	62%
75%	14.0	95%	11.9	89%
95%	35.1	100%	34.9	100%
Avg	10.1	60%	9.2	59%
SD	12.5	37%	12.8	37%

Table 35 Route by weather

The table examines any potential differences between IMC and VMC weather conditions. While subtle differences appear, nothing significant emerges.

	VFR		IFR	
	Offset	Route	Offset	Route
Count	151	151	69	69
25%	1.8	26%	0.8	27%
50%	5.2	51%	3.3	81%
75%	14.0	85%	10.2	99%
95%	36.7	100%	34.2	100%
Avg	10.5	55%	9.0	65%
SD	13.1	36%	12.6	37%

Table 36 Route by flight plan

If the aircraft was flying VFR or IFR could have a significant impact, since IFR aircraft should be flying direct from one navaid to the next. In fact, aircraft flying IFR show a tighter cluster for the track offset; enough that it may offer an explanation of the difference between the CAP and NTAM studies. If the percentages of aircraft flying IFR were substantially different (not known for either study) then a difference could easily occur. The percentage of the route also shows important differences. Twenty-six percent of the crashes occurred in the last 1 percent of the IFR route. In other words a quarter of the crashes occur during descent or landing procedures for IFR flights. VFR flights are more spread-out over the entire route.

	Climb		Cruise		Maneuvering		Descent		Approach	
	Offset	Route	Offset	Route	Offset	Route	Offset	Route	Offset	Route
Count	17	17	102	102	44	44	12	12	43	43
25%	2.1	5%	1.8	28%	2.4	38%	0.9	68%	0.2	82%
50%	3.5	17%	7.7	49%	5.0	66%	2.6	91%	1.4	98%
75%	5.5	47%	20.5	80%	15.2	95%	9.1	99%	4.5	100%
95%	18.3	100%	42.0	100%	36.7	100%	43.2	100%	16.4	101%
Avg	5.6	33%	13.0	52%	11.3	64%	8.8	76%	3.7	82%
SD	6.3	41%	14.5	31%	12.7	42%	17.2	32%	6.3	31%

Table 37 Route by flight phase

The above table is somewhat academic in nature. Without radar information it is impossible to know what phase of flight the aircraft was engaged in. If the aircraft was descending or on approach it makes sense this represented the destination. Cruising, and maneuvering could take place anywhere along the flight. Climbing shows a strong clustering towards the departure point.

	Flat		Mountainous	
	Offset	Route	Offset	Route
Count	103	103	135	135
25%	0.8	26%	1.6	29%
50%	3.5	69%	5.2	58%
75%	12.3	93%	13.0	91%
95%	35.1	100%	36.9	100%
Avg	9.2	59%	10.6	58%
SD	12.9	37%	13.1	36%

Aircraft in mountainous areas may need to depart from a straight line route in order to maneuver around mountains. The above statement is a reasonable hypothesis that would result in larger offsets compared to flat terrain. The results appear to back up the hypothesis at the 25% and 50% levels. At the 75% and 95% the results are nearly identical. The percentages along the route also appear similar.

Table 38 Route by terrain

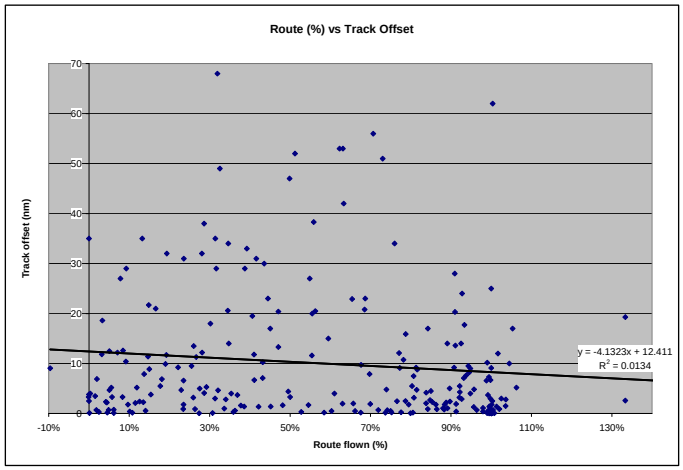


Figure 11 Route percentage versus route offset

The final question looks at the relationship between the track offset and the percentage of the route flown. No correlation between the route offset and the percentage of the route flown is seen. In the graph it is possible to observe a tight cluster that occurs at the destination airfield.

Route Summary

Two previous studies have been conducted looking at route offsets and percentage of route flown. This study has the largest number of cases and for the most part falls between the results of the previous two studies. This could either be the result of a larger population, mix of pilots flying IFR versus VFR, or changes in navigation methods. However, in this study outliers did not fly as far off the route as in the previous studies (95% of the aircraft located within 30 nm). No recommendations are made in this report of how to modify search area boxes. The raw data along with some additional analysis of probability density and Probable Success Rate can easily drive future recommendations. If radar data is not available the most powerful tool to help define a search area is route information. In a few cases when the aircraft flew out of radar coverage the route information proved more useful than the last radar position. Therefore, any eventual probability of containment map should combine both radar information and route information in some manner.

Secondary Subtasks

Trip to Air Force Rescue Coordination Center

During the second trip to the AFRCC the N number or registration number of the aircraft was obtained for the newly acquired data. This allowed searching the NTSB database for accident reports. However, this field was not collected for the 2002 – 2005 incidents. Collecting this missing information required another trip to the AFRCC. In addition, route information had not been collected for the 2002 – 2005 incidents. During the trip to the AFRCC the following was collected:

- Collected missing N number, ELT information, and Route data for 2002-2005 data.
- Collected additional new 2008 incidents
- Collected PLB data

Personal Locator Beacon data collection

Overview

While not related to aircraft incidents, currently basic statistics regarding 406 PLBs are unknown. The standards of accuracy are well published, but actual statistics from case studies have not to this author's knowledge been published for PLB use in CONUS.

A total of 472 PLB incidents were collected from the AFRCC. The data was collected from incidents from 2003 to 2008. The collected fields included the incident number, mission number, location, region, incident date, situation (all PLB), Latitude, Longitude, and mission result (Non-distress, false, ceased, handoff, or distress). For those incidents that were distress additional data was collected. These incidents are included as a separate worksheet in the spreadsheet that includes all of the aviation data. A total of 28 incidents were classified as distress. Additional fields collected on distress incidents included:

- Duration of signal (hours)
- Number of updates
- Elemental (E, A, or B)
- Latitude
- Longitude
- Satellite number
- A solution Latitude
- A solution Longitude
- Find date
- Find time
- Find Latitude
- Find Longitude
- Method to determine find location
- Number missing
- Medical outcome
- Number found alive
- Comments

Results and Discussion

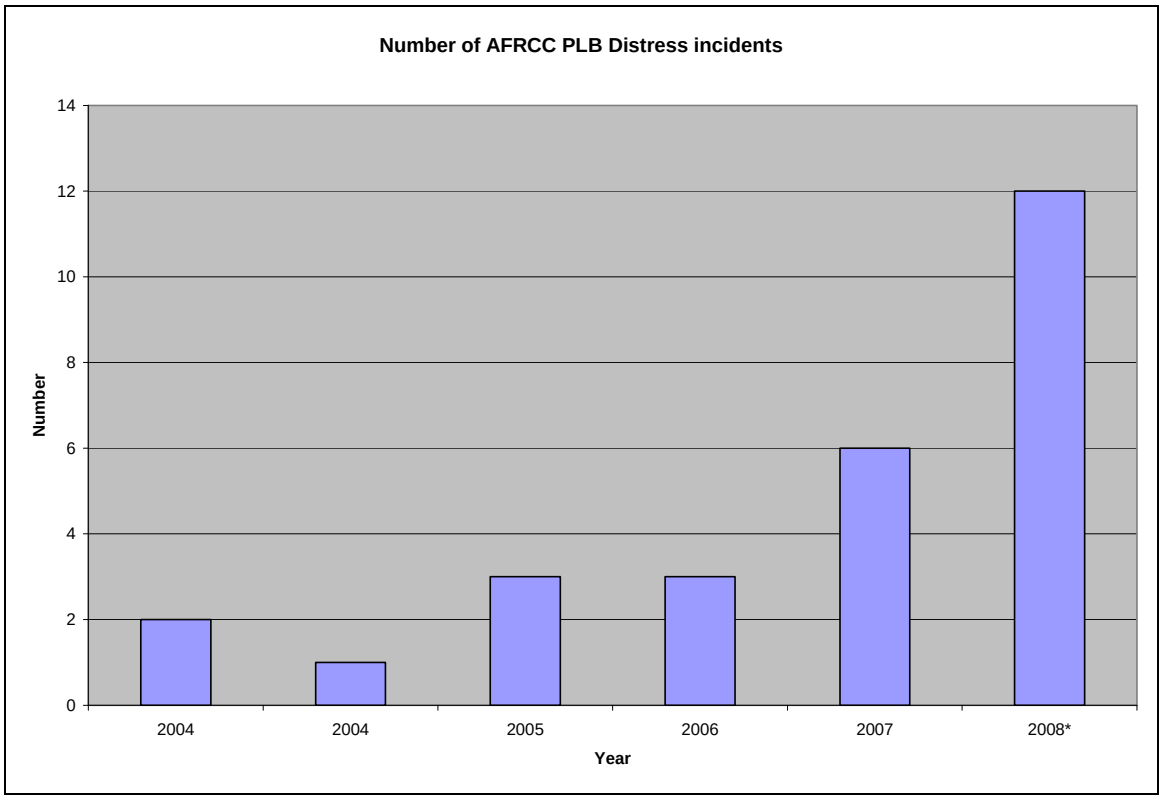


Figure 12 The yearly number of AFRCC distress incidents from PLBs. 2008 incomplete data.

The number of PLB distress incidents handled by the AFRCC is showing a clear increase. This number does not include legitimate distress handoffs that were passed to another agency. The increase is congruent with an increase in the number of PLB registrations.

Of the 29 distress incidents 27 reported the category of person in distress.

Category	Count	Percentage
Aircraft	**8**	**31%**
Fixed wing	3	12%
Helicopter	2	8%
Military Jet	3	12%
Boating	**5**	**19%**
Ground	**14**	**54%**
ATV	2	8%
Hiker	9	35%
Hunter	1	4%
MVA	2	8%

Table 39 Category of AFRCC Distress PLB

While PLBs are intended for personal use on ground, they are being used by pilots, boaters, and ground users. A majority of users are ground based with a hiker being the most common scenario. In the case of Motor Vehicle Accidents (MVA) passengers tried alternative means of communications first (cell phone, satellite phone, then PLB). In four of these cases (15%) an owner of the PLB activated the unit, not for themselves, but for another person in distress they came across. It is important for rescuer's to realize that they may not be rescuing the registered owner. PLBs issued to military aircraft personnel for their survival vest have lead to successful missions. Since a PLB requires manual activation, it is an excellent indication that at least one person has survived the initial incident.

Scenario	Count	Percentage
Lost	2	7%
Medical	5	19%
Trauma	15	56%
Stranded	5	19%

Table 40 Scenario of cause to activate PLS

Trauma was the most common reason for activating a PLB. This was often associated with falls or aircraft accidents. Medical and stranded accounted for almost 20% of the cases each. Simply being lost only accounted for 2 cases or 7%. While different than ground searches overall, using the International Search & Rescue Incident Database (ISRID), this is not unexpected since they type of person who purchases a PLB at this point tends to be well prepared and experienced.

Elemental	Count	Percentage
A	6	24%
B	1	4%
E	12	48%
EA	6	24%

Table 41 Type of data processing to obtain coordinate

Several different type methods can be used to determine the coordinates of a PLB. If the Doppler shifting is used (as in traditional 121.5 and 243 beacons) then either the A or B solution may be reported. If the PLB has, acquires, and transmits a GPS based coordinate then a E (enhanced) solution is returned. In some cases both an A and E solution were returned. If multiple satellites see the beacons signal at the same time it is possible to obtain a composite solution. This occurred in 17 cases or 68%. Processing and looking at the actual coordinates were beyond the scope of this report.

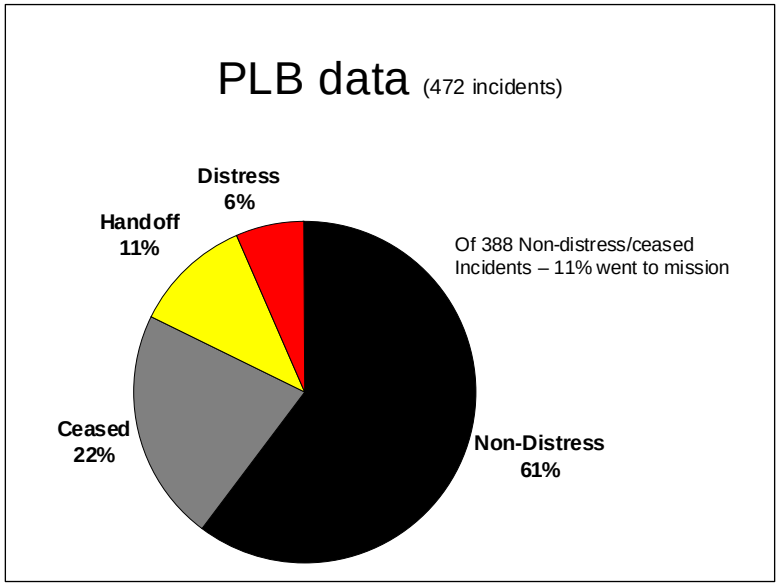


Figure 13 Distress versus non-distress status

Figure 13 looks at the overall PLB data from the AFRCC. Distress accounts for 6% of the incidents. However, the actual number of distress incidents might be higher since the status of the handoff incidents is unknown. Most of the handoff incidents were to the US Coast Guard. Still 61% were non-distress and another 22% ceased. Fortunately, with the registration database it is possible to launch a preliminary investigation prior to committing field resources. This is evidenced by the fact that of the 388 non-distress/ceased incidents only 11% needed to go to mission. In other words, 89% percent of non-distress mission could be resolved with a phone call to the PLB owner.

Report and Deliverable Organization

Five deliverables were required by the task order.

1. Provide a CD data file that includes coordinates of last radar position, coordinates of the crash location, and distance from the last radar location.

The information is contained in the MS Excel file named NTAP.xls in the worksheet called "Master". All coordinates were converted to decimal degree format. Last Radar coordinates provided from the FAA are found in field BT and BU (FAA last Lat/Long). Radar coordinates obtained from RADES are found in field BW and BX. The fields were combined and the coordinates used for all statistical analysis can be found in field BZ and CA (Last Lat/Long D.D). Crash site data was obtained from both the AFRCC and NTSB. AFRCC supplied coordinates are found in BC and BD (Find Lat/Long D.D). NTSB furnished crash site coordinates are found in fields BG and BH. The final coordinates used for analysis are found in field BI and BJ. The Distance between the last reported radar position and find location are reported in field BW of the working calculation spreadsheet called NTAP working version.xls

2. Provide a DC data spreadsheet that presents the dispersion angles from the last radar position to the crash site and from the second to last radar position.

The information is contained in the MS Excel file NTAP.xls. The bearing from the last radar position to the crash site is found in field BS (Bearing). The bearing established from the radar information (second to last radar position to the last radar position) is found in field CG (Last Bearing). The absolute difference between the bearing was calculated and shown in field CH (Dispersion angle).

3. Provide a CD spreadsheet data file that relates the terrain elevation where the aircraft was located as related to the last recorded radar altitude.

The information is contained in the MS Excel NTAP.xls file. It consists of three fields. The aircraft's last reported altitude is reported in field BZ (Mode C). The aircrafts find location elevation is reported in field AJ (Crash elevation). The difference between the two elevations are reported in field CB (Δ Mode C and crash elevation).

4. Provide the data on a CD spreadsheet that presents the perpendicular distance from the find location and last radar position.

The information is contained in the MS Excel NTAP.xls file. It is found in field CJ (Plot Offset).

5. Provide a written report (position paper) with findings or the data can be provided on a CD spreadsheet providing it satisfies the deliverable requirement of collecting additional data from the NTSB.

Data was collected and provided in several different format. Several fields in the NTAP.xls file come directly from data obtained from the NTSB reports. They are shown in Table 42 **List of database fields, count, and source of information. PI=Principal Investigator, SV=Skyvector.com, GE=Google Earth** Furthermore, all NTSB reports were downloaded as PDF documents. The document name is based upon the aircraft's registration number. The files may be found in the NTAP data directory and then in each of the appropriate year's subdirectories.

6. Present findings in a suitable record or on a CD spreadsheet which presents the route offset, percentage, and compares to previous studies.

The data is contained in the MS Excel NTAP.xls file. Relevant fields are M (actual route), N (route length), O (Route offset), P (Distance along route, and Q (route percentage). The written report and comparison to previous work is contained in the this report. More specifically, the comparisons can be found underneath the subtask 6 section.

This report provides analysis and discussion of some findings beyond the scope of the deliverables. The bulk of the additional finds and discussion take place in the discussion of the fields that follow this section. In addition, the report goes on to discuss PLB data that was collected.

The CD provides additional resources that were collected during the task. Many of the incidents had additional file documents attached to the record. These consisted of maps, images of the crash site, and/or an excel file that provided radar coordinates. A common packaged attached to the file consists of a PowerPoint presentation that shows the entire route, all of the radar plots map, a close-up of the last view radar plots overlaid on a topographic map, and then perhaps the actual radar coordinates and ancillary information. In more recent incidents more extensive use of Google Earth KML files were used. Many of these files are marked for official use only. The non-disclosure letter from the AFRCC regarding these files is attached. For this reason, the actual CD is also labeled “For Official Use Only”.

As previously stated all NTAP files that were downloaded are provided on the disk.

In addition, a few other files are attached. Since most tables and figures were generated from the MS Excel spreadsheet the file that was used to generate the figures and tables in included (NTAP working version.xls). Much of the data analysis and measurements were done using Google Earth and ExpertGPS. Therefore, the KML and GPX file used with those programs are also attached.

Database Fields

The following table summarizes the fields found in the main database.

Description	N	Type	Source	Description	N	Type	Source
Key	262	Admin	PI	Found by	257	Output	AFRCC
Incident #	262	Admin	AFRCC	Location found	74	Output	AFRCC
Location	260	Admin	AFRCC	Find Lat/Long	262	Output	AFRCC
Region	262	Admin	AFRCC	Format	262	Admin	PI
PLS Lat/Long	262	Input	AFRCC	Find Lat/Long D.D	262	Convert	PI
PLS Lat/Long D.D	262	Formula	PI	NTSB Find Lat/Long	94	Output	NTSB
Date	262	Input	AFRCC	NTSB Find Lat/Long D.D	94	Convert	PI
Time	262	Input	AFRCC	Final Find Lat/Long	262	Output	PI
Registration Number	261	Admin	AFRCC	Nm Δ	94	Formula	PI
Make Model	262	Input	AFRCC	Km Δ	94	Formula	PI
Category	262	Input	PI	Find Date	251	Output	AFRCC
Route	259	Input	AFRCC	Find Time	252	Output	AFRCC
Route length (nm)	240	Input	SV	Duration (hours)	241	Formula	PI
Route offset (nm)	238	Output	PI	Radar?	261	Admin	PI
Distance Along Route (nm)	238	Formula	PI	Source	151	Admin	AFRCC
Route Percentage	238	Formula	PI	FAA Last Lat/Long	29	Input	AFRCC/FAA
Weather 1	156	Input	AFRCC	FAA Last Lat/Long D.D	29	Formula	PI
Weather 2	38	Input	AFRCC	Plot#	64	Admin	PI
NTSB ID	208	Admin	NTSB	Last Lat/Long	219	Input	AFRCC/NTSB
Part	240	Input	NTSB	Format R	219	Admin	PI
Flight Type	237	Input	NTSB	Last Lat/Long D.D	248	Formula	PI
Light conditions	226	Input	NTSB	Nm Δ F-R	218	Formula	PI
Basic Weather	237	Input	NTSB	Km Δ F-R	218	Formula	PI
Ceiling	151	Input	NTSB	Bearing	219	Formula	PI
Visibility	235	Input	NTSB	Flight Characteristics	159	Input	PI
Wind (knots)	194	Input	NTSB	Mode 3	135	Input	AFRCC
Precipitation	84	Input	NTSB	Mode C	169	Input	AFRCC
Obscuration	60	Input	NTSB	Δ Mode C – Crash elevation	169	Formula	PI
Flight hours total	208	Input	NTSB	2nd to Last Lat/Long	92	Input	AFRCC
Flight hours in aircraft	112	Input	NTSB	2nd to Last Lat/Long D.D	92	Formula	PI
Flight hours Instrument	92	Input	NTSB	Nm Δ LR- SLR	92	Formula	PI
Pilot Certification	220	Input	NTSB	Radar bearing	116	Input	PI
Flight Plan	236	Input	NTSB	Last bearing	160	Input	PI
NTSB Elevation	124	Output	NTSB	θ Dispersion Angle	159	Formula	PI
Crash Elevation	260	Output	GE	Delta FPM	105	Input	AFRCC
Δ NTSB-Crash	124	Output	PI	Attachments	225	Admin	AFRCC/NTSB
Ridge Elevation	250	Output	NTSB	Plot offset	159	Input	PI
Crash bearing (magnetic)	117	Output	NTSB	Predicted Lat/Long	40	Input	AFRCC
NTSB distance last radar	36	Output	NTSB	Format Predicted	40	Admin	PI
Flight Activity	235	In/Out	NTSB	Predicted Lat/Long D.D	43	Formula	AFRCC/FAA
Terrain	261	Input	NTSB	Nm Δ Predicted – Find	37	Formula	PI
Cause	210	Output	NTSB	Km Δ Predicted – Find	37	Formula	PI
# Subjects on Board	260	Input	AFRCC	# ELT Updates	27	Input	AFRCC
# Alive	39	Output	AFRCC	ELT Lat/Long	45	Input	AFRCC
#DOA	234	Output	AFRCC	Interesting	33	Admin	PI
				Comments	257	Admin	AFRCC

Table 42 List of database fields, count, and source of information. PI=Principal Investigator, SV=Skyvector.com, GE=Google Earth

Key #.
The key number field was a purely administrative field used to keep the database in its original order after any sorting tasks were completed. The key number was created by the database administrator. In the future this field could be changed or deleted.

Incident #
The incident number was the number created by the AFRCC in SARMaster. The first two digits are based upon the year, the "i" indicates it is an incident number, and the last five digits indicate the incident with the first incident of the year being given a one and increasing for each new incident.

Mission #
The mission number was given by the AFRCC if an incident required an AFRCC allocation of resources. Not all incidents were given mission numbers, but all missions also have incident numbers.

Location
The location was keyed in by the AFRCC controller. It typically represents a town, city, or county that best characterizes the incident. It typically related to the place last seen (PLS) location.

Region
The region followed the same general rules as the location but specified the state.

PLS Lat and PLS Long
The coordinates of the place last seen were recorded typically in DD MM.MM format. The PLS could represent the departure airport, last radar fix, or position reported over the radio. Since all data was collected from CONUS the database does not specify (–) longitude. However, all longitudes are West.

PLS Lat D.D and PLS Long D.D
The conversion of the PLS Lat Long coordinates to the DD.DDD format. The PLS field was not used in this report. However, it has been suggested by search planners to calculate statistical rings based upon the departure airport.

Date (PLS)
The PLS date represents the day the aircraft departed.

Time z (PLS)
The time in 24 hour clock based upon Zulu time of when the aircraft departed. The time along with the date was used to determine the duration of time the aircraft was missing.

Registration Number
The registration number often referred to as the N number was used to look up NTSB reports. The number was originally provided in the AFRCC records. In some cases the number was listed incorrectly. In these cases searching on the date, type of aircraft, pilot outcome, and search region located the appropriate report in the NTSB aviation accident database. The registration number could then be corrected using the NTSB report. The N number also typically allowed a Google search with a picture of the actual aircraft.

Make/Model
The make and model of the aircraft was obtained in AFRCC records and verified in the NTSB reports. If conflicts existed the field was updated to use the NTSB report information. The information was used to determine the category of aircraft. For future studies, this field could be use to identify the ten most common type of aircraft involved in search-related accidents. The software could then allow the user to fly that particular type of aircraft using aircraft specific flight parameters.

Category
Aircraft were categorized as single engine, twin engine, jet engine, glider (no engine), Helicopter, or ultra light. The database contains the following

- 3 Glider incidents
- 14 Helicopter incidents
- 6 Jet incidents
- 213 Single engine incidents
- 25 Twin engine incidents
- 1 Ultra light incident

No analysis was done on the glider or ultra light incidents.

Route
The route was provided in the AFRCC records. Only the AFRCC records provided details on various waypoints. For unmarked airfields the records also provided coordinates. In most cases the three letter code was used. It was assumed that the first and last point would be an airfield. Therefore a K was added in the cases were the three letter code provided a VOR/DME separate from the airfield. If the route was missing the NTSB report provided the departure and arrival airports. Comment fields were added to the database where a private strip was used that can only be identified by coordinates. It was possible to determine the route for 259 incidents.

Route Length (nm)
The route and waypoints were entered into skyvector.com an online route planning tool that displays the route on aeronautical charts. The tool would also display the length of the route in nautical miles.

Route Offset (nm)
The route offset as also been called the track offset. It represents the shortest distance (perpendicular) between the route and the aircrafts find location. It answers the question, "How far off its route was the aircraft located?" The distance was measured using nautical miles to be consistent with previous work completed.

Distance Along Route (nm)
The distance along the route was determined by measuring from the departure airport to the point where the route offset perpendicular line intersected the route. In two cases the aircraft departed the runway in the opposite direction of its intended destination and crashed. In these cases the distance along the route is indicated by a negative number. It is possible for the distance along the route to be longer than the intended route itself. This most typically occurred when an aircraft was on final approach to its intended destination but the runway needed required the aircraft to fly beyond the runway.

Route Percentage (%)
The route percentage was calculated by dividing the distance along the route field by the route length field. The result was expressed as a percentage of the intended route.

Wx1 (Weather 1)
The information for this field was taken from the AFRCC reports. A wide assortments of terms were used in the AFRCC reports.

Wx2 (Weather 2)
This field provided a space when supplemental weather information was provided.

NTSB ID
The NTSB ID was obtained from the NTSB accident report.

Part
The NTSB reported which FAR part the flight occurred.

- 229 flight under Part 91
- 9 flights under Part 135
- 1 flight under Part 137
- 1 flight listed as public

Flt Type (Flight Type)
The flight type was taken from the NTSB report. Options listed included:

- Aerial 2
- Business 15
- Cargo 6
- Ferry 4
- Instructional 8
- Medical 3
- Observation 2
- Passenger 1
- Personal 188
- Positioning 5
- Public 1
- Sightseeing 1

This field was not analyzed in this report

Light conditions
The light conditions were provided by the NTSB report. They were reported as day, night, or night/dark. In this report this field was not analyzed.

Basic Wx (Basic Weather)
The basic weather conditions were provided by the NTSB report. Conditions were reported as being either visual meteorological conditions (visual) or Instrument Meteorological conditions (IMC). This field was used in analysis of several factors.

Ceiling
The height of the cloud ceiling was provided by the NTSB report. The height is given in feet. If the ceiling was unlimited then no number was given. However, if no NTSB report was present then no number would be provided either. Fortunately, lack of a NTSV report can easily be checked by if a NTSB ID was provided. The ceiling was not used in this report.

Visibility
The visibility was reported in the NTSB report with unlimited visibility being given a value of 10 miles.

Wind Kts (Wind Knots)
The wind speed at the closest ground meteorological station to the crash was provided in the NTSB report. The wind speed was given in knots.

Precip (Precipitation)
The precipitation field in the NTSB report listed if any precipitation was occurring. Terms used in the report included the following:

- Drizzle 1
- Fog 4
- Icing 14
- Rain – Light 6
- Rain – Moderate 2
- Rain – Heavy 8
- Rain – Thdrstorm 7
- Rain 14
- Snow 12

This report did not use the field in current analysis.

Obscuration
The obscuration factor was listed in the NTSB report. It was not used in the current analysis.

Flt hrs tot (Flight hours total)
The NTSB report gave the total flight hours of the pilot. This included all types of aircraft. The total flight hours ranged from 12 hours to 40,500 hours. The continuous nature of this field may assist future analysis in making predictive models. However, for this report the field was not used.

Flt hrs ac (Flight hours in aircraft)
The total flight hours in the type of aircraft the accident occurred was provided in the NTSB report. Potentially, this might be a better predictor than the flight hour total field. In this report, the field was not used.

Flt hrs Ins (Flight hours Instruments)
This field listed the total hours of instrument flying. It also included simulator time. It also was not used in this report.

Pilot Certification
The NTSB listed the various certifications the pilot held. Instead of listing all of the various certifications, the field only lists the "highest" certification attained. The following hierarchy was used:

- Airline Transport Pilot
- Commercial
- Instrument
- Helicopter
- Private
- Glider
- Student

Flight Plan
Based upon a combination of the NTSB report and AFRCC information the flight plan was coded as being any of the following:

- FF Flight Following
- VFR Visual Flight Rules
- IFR Instrument Flight Rules
- None No flight plan filed

In cases of the flight having an element of IFR then the pilot switching to VFR for the approach or landing, the flight was classified as IFR. The major consideration was the issuing of a discrete code that made it easier to determine the correct flight from radar coverage.

NTSB Elevation
The NTSB elevation was the elevation of the crash site as measured from the initial point of impact. However, not all reports clearly specified where the elevation was determined or the method to use to determine the elevation. In many cases the report mentioned the elevation was determined using a handheld GPS device. Elevation reported in feet.

Crash Elevation
The crash elevation was determined by using the find site elevation coordinates. The coordinates were converted to decimal degree format and the excel spreadsheet information was converted to a KML file using expertGPS software. The KML file was then opened in Google Earth. It was then possible to click on each crash site and zoom in on that particular coordinate. Google Earth uses NASA SRTM data, which has an accuracy of less than 10 meters. In areas of dense canopy (STS-99 flew in February 2000 so foliage in deciduous forests of CONUS would be limited) the radar often measured the height from the top of the canopy. The elevation of the crash site coordinate was displayed in Google Earth and entered as the crash elevation. The elevation was measured in feet above sea level.

Δ NTSB-Crash
This was a calculated field that provided the difference between the elevation provided in the NTSB report and the elevation determined by using the coordinates in Google Earth. There were a total of 127 elevations provided by the NTSB. The NTSB typically only gave elevations in more mountainous conditions, with 76% of the elevations from mountainous areas. The median difference was 52 feet and 75% percent of the differences were within 217 feet. Six incidents had difference greater than 1000 feet. Those incidents with differences greater than 800 feet resulted in a closer examination of the raw data in an attempt to resolve any differences.

Ridge Elevation
The ridge elevation was determined by starting at the crash site and following the fall line up until reaching either a ridge or summit. For flat any hilly areas the ridge elevation was the highest elevation in the immediate vicinity. The ridge elevation was determined using USGS 1:24,000 topographical maps viewed using ExpertGPS software. The goal was to determine what percentage of crash locations occur within a specific elevation below the highest point. The actual analysis is outside the scope of work and is not reported here.

Crash bearing
The crash bearing was provided in the NTSB report. It gives the bearing from initial impact to where the main body of the crash site exists. Bearings were also reported as magnetic bearings. The NTSB reported provided the crash bearing in 117 cases. In order to use the crash bearing the magnetic bearing would need

to be converted to the true bearing. The aircraft icon or textual information in the description box of the KML file would need to be updated. This was outside the scope of this report and was not done.

NTSB dis last radar (NTSB distance last radar)
The NTSB accident report in a few cases (36) mentioned the distance from the last radar coordinate to the crash site location. This information was collected as a cross-reference against the data collected from the AFRCC. The NTSB appeared to rely on FAA NTAP data for its source of radar information. In a few cases it appears they may have uncovered some additional radar plots that were not part of the original AFRCC case history. The NTSB reported the distances in a variety of units (feet, miles, and nautical miles) which are indicated in each cell.

Flt Activity (Flight Activity)
The NTSB accident report characterized the phase of flight the cause(s) of the accident occurred. The choices included:

- Approach 37
- Climb 15
- Cruise 107
- Descent 16
- Emergency Landing 3
- Hover 1
- Landing 3
- Maneuvering 50
- Takeoff 3

Hover was never used during the analysis. Depending upon the analysis being conducted the various terms were often grouped together. A common combining was takeoff and climb, Landing and Approach.

Terrain
The terrain was classified initially by the NTSB report which would list if mountainous terrain was a contributing factor to the incident. The initial classification left many incidents unclassified for terrain. Since every crash site was viewed using Google Earth it was possible to view the terrain directly. The most difficult judgment call to make was classifying terrain as either mountainous or hilly. After extensive research it was found no formal definition exists for hilly versus mountainous terrain. Fortunately, the need to differentiate between hilly and mountainous terrain was rare in the database. The criteria finally determined was if the terrain changes in elevation of more than 300 feet in a short distance clearly defined by a single rise it was classified as mountainous. In cases where the aircraft landed in a body of water that was found in mountainous terrain, the terrain was classified as mountainous and not water.

Cause
The NTSB would issue three different types of aviation accidents reports. The preliminary report came out first. Much of the 2008 incidents were based upon preliminary reports. Eventually the NTSB would release a factual report. Much of the data fields collected came from the factual report. Finally the NTSB would release a brief report on the main cause. The cause report would list both factors and contributing causes. In almost all the incidents multiple factors and causes would be listed. The cause field in the database lists the single most significant cause of the incident. While this field is clearly an outcome field that technically cannot be known until after the aircraft is found, examined, investigated, and studied; nevertheless experienced mission planners looking at available data may be able to infer different likely causes of the incident. This is often referred to as scenario planning. Search theory has a formal process where different scenarios can be given different weights or probabilities and each scenario may generate a different probability map. Unfortunately, it was beyond the scope of this report and initial analysis to look at each of

the possible scenarios. Nonetheless, a cause was given by the NTSB in 210 of the incident. In incidents that occurred in 2008 and 2007 the cause report was often not released at the time of data analysis.

 # Subjects (Number of Subjects on board)
The AFRCC file listed the total number of people on board the aircraft at the time of the incident.

 # alive (Number alive)
The AFRCC file listed the number of people found alive. In cases where subjects survived the initial crash but died prior to rescue they would not be listed

 # DOA (Number found Dead on Arrival)
The AFRCC file listed the number of people found dead upon the arrival of the search team. In cases where subjects survived the initial crash but died prior to rescue they would not be listed as DOA. Survival information was collected at the request of the Air Force National Search & Rescue School. However, indepth analysis is beyond the scope of this report. However, since duration and survival are discrete fields it will not take much additional effort to generate survival statistics. A top level overview shows that 260 incidents provided information on the total number of subjects on board. 39 incidents had at least one survivor or 15% and 234 incidents had at least one fatality or 90%.

Found by
The found by field typically listed the agency that located the crash site. This field was often used to help confirm the coordinates when they were questioned. In one case where the longitude had placed the crash site out in the Pacific Ocean yet the found by agency was in central California, the longitude degree was changed. This allowed both the agency and the route to come in agreement. While the field proved useful in data quality control no attempt to conduct any analysis was made.

Location found
The field refers to the find location. The AFRCC listed a wide variety of parameters. The field was used to describe geographic features, the closest town, distance from a feature, etc. The field was often used in data quality control and for verification purposes.

Find Lat and Find Long
The aircrafts find location was provided for every incident included in the database since that was a critical part of the inclusion criteria. The AFRCC used the DD MM.MM format for coordinates and was consistent in all cases. The database contains some comments in a few of the cells where issues were identified. As previously mentioned, since the entire database is from CONUS the longitudes were not expressed as negative values, even though all of West values.

Format
The format field identified the coordinate format used. In this case all of the find coordinates were in the DMM format. This field was created solely for quality control in coordinate conversion and is not included in the working version of the database

find Lat find Long D.D (Find Latitude N, Find Longitude W in DD.DDD format)
These two fields convert the DMM format find location coordinates to DD.DDD format coordinates used in the actual data analysis. This was well within the significant figures used in analysis. An automated spreadsheet (Degree Format Convertor from GPSwaypoints.co.za) was used for batch processing of the coordinate conversion. Quality control of the conversion process was conducted on several random coordinates. In addition, accurate conversion was assessed anytime the distance from the find location and last radar coordinate was greater than 5 miles.

NTSB Find Lat, NTSB Find Long (NTSB Find Latitude N, NTSB Find Longitude W)
In 95 cases the NTSB provided latitudes and longitudes in the factual accident report. Many of the accident reports stated the coordinates were obtained with a GPS receiver while at the accident site. Some accidents reports made specific mention that the point of measurement was made at the point of initial contact with the ground or vegetation. Most reports did not mention where the measurement was taken. The NTSB used a variety of formats for reporting the coordinates. It was never specified in any of the reports if the coordinates used the WGS 84 datum but in this report it is assumed that all coordinates were in either NAD83 or WGS84 which for these statistical purposes are virtually identical.

NTSB F Lat D, NTSB F Long D (NTSB Find Latitude in DD.DDD N, NTSB Find Longitude W in DD.DDD)
The next two fields were used to convert the NTSB find coordinates into DD.DDD format. Once again batch conversion was used with random quality control of the conversion process.

FF LAT DD, FF LONG DD (Final Find Latitude N in DD.D, Find Longitude W in DD.D)
These coordinate fields represented the find coordinate that was actually used in statistical analysis. If the NTSB had provided a find coordinate the NTSB find coordinate was used. If not, then the coordinate reported by the AFRCC was used.

nm Δ (Difference between the NTSB and AFRCC find locations in nautical miles)
The difference between the NTSB and AFRCC location was calculated in nautical miles. The actual calculation was done using batch processing using an MS Excel spreadsheet from GPSwaypoints.com.za. The spreadsheet used great arc circle calculations estimated to be accurate to one part in 1 million. This accuracy was well within the precision of significant figures (distances reported as either a tenth of a nautical mile or a tenth of a kilometer). This field was used as a quality control check on the data. It was found that 50% of the 95 coordinates were separated by 0.06 nm. 82% of the time the difference was within 1 nautical mile. Every case over 1 nm was individually examined to look at possible reasons or quality control issues. In one case the difference was 223 nm. Further investigation showed the AFRCC Latitude had been reported as 40 degrees while all of the other fields agreed with the NTSB reported position of 37 degrees.

km Δ (Difference between the NTSB and AFRCC find locations in kilometers)
This field reported the same distance as the previous field but instead expressed in kilometers. The kilometers were automatically generated by the spreadsheet using a conversion factor.

Find Date
The day the aircraft was found using the AFRCC data. The day was based upon zulu time.

Find Time
The time the aircraft was found using AFRCC data. The time was based upon zulu time.

Duration (hours)
The difference in hours between when the aircraft was last seen and when it was located is expressed by the duration field. The duration is reported in 240 cases. The major purpose of the duration field was for eventual survivability analysis. The field also helps to identify those searches that were initially suspended and the aircraft was subsequently located. The median duration of incidents is 14 hours.

Radar?
The NTAP field was used to indicate if usable radar data was available for the incident. A "Y" indicates a yes response. All of the incidents from 2002-2004 had radar data since the inclusion criteria required radar data when that data was collected as part of the SBIR grant. Radar data was collected from 223 incidents. The cause of a lack of radar data is beyond the scope of this report. The lack of data may indicate the aircraft was quickly located prior to the data being provided to the AFRCC or that no radar data could be obtained.

This can occur if the timeframe of takeoff is not well defined or simply because the aircraft never entered into an area with radar coverage.

Source
The source field listed the source of the radar data. Three primary sources existed. Radar data collected and analyzed by RADES is indicated by a "R". If data came from the FAA it was indicated by a "FAA". FAA data itself came from two sources. The majority of FAA cases were derived from the National Track Analysis Program (NTAP). Since originally almost all radar data was obtained through a NTAP all radar data is often referred to informally as a NTAP. In a few cases where the aircraft was being actively monitored the flight center often supplied the last coordinate. In a few cases, data came from both RADES and the FAA. Both sets of coordinates were captured

FAA Last Lat, FAA Last Long (FAA Last Latitude N, FAA Last Longitude W)
These two fields captured the latitude and longitude coordinates of the last radar position as reported by the FAA. The most typical format was DD MM.M

FAA Last Lat DD, FAA Last Long DD (FAA Last Latitude DD.D)
These two fields converted the DD MM.M format coordinates to the DD.D format.

Plot #
The Plot number field reports the number of distinctive radar plots that were obtained. The number refers to the number obtained in this database. In many cases a PowerPoint slide presentation was created that showed dozens of plot maps generated on the map. However, only the last two plots had a description or text box that gave the actual coordinates. In such a case the number of plots would be listed as two. In other cases an MS Excel spreadsheet was attached that might have given the last 100 coordinates. In other cases the AFRCC records might have contained several dozen coordinates, but since coordinates had to be manually keyed to transferred into this database often only the last 5 coordinates would be recorded.

Last Lat, Last Long (Last Latitude N, Last Longitude W)
This field contains the last radar coordinates (in whatever coordinate format the record used). In the cases where both FAA NTAP and RADES data was supplied this field contains the RADES data with the FAA data entered into the previously described **FAA Last** field.

Format R (Format Radar)
The field was used to classify the coordinate format the records used. All three of the latitude longitude formats appear in the records. This field was used to help ensure the correct spreadsheet was used for the batch conversions.

Last Lat DD.D, Last Long DD.D (Last Latitude N DD.D, Last Longitude W, DD.D)
These fields were created by the batch coordinate conversions of the previous Last Radar Plot into the decimal degree format. These were the fields used for actual analysis and in creating the KML file used for later analysis.

Nm Δ F-R (Difference between the aircraft find location and last radar in nautical miles)
The aircrafts find location coordinates and last reported radar plot coordinates were entered into the GPSwaypoint.com.za MS Excel Spreadsheet and the software provided the distance between the two points in nautical miles. At the same time the distance was also given in kilometers. A third field provided the true bearing between the last radar position and the find location. This field was the output field used for all of the distance analysis that will be reported on later and represents one of the chief products of this report.

km Δ F-R (Difference between the aircraft find location and last radar in kilometers)
This field is no different than the previous field except that distances are reported in kilometers.

Bearing
This field reports the true bearing from the last radar plot to the find location. Since the software used was designed for South African coordinates it was required to reverse the bearing provided by the software by 180 degrees. This was done by creating a temporary field within the spreadsheet that was later deleted. Results were spot checked against maps of plots on several cases to ensure quality control.

Flight Characteristics The flight field describes the general pattern seen in the last moments of the radar data information. The following descriptions were used:

- 180 turn 1
- Bear left 5
- Bear right 5
- Hook left 16
- Hook right 18
- Turn left 6
- Turn right 7
- Spiral right 5
- Spiral left 4
- Straight 46
- Straight & climbing 2
- Straight & descend 14
- Straight & level 22

Mode 3
The transponder code or Mode 3 was recorded in this field. If the plane was issued a discreet code at any phase of the flight then that particular code was entered. Even if the aircraft switched to 1200 for the landing the discreet code was still what was entered into the field.

Mode C
The Mode C field records the last reported altitude, has reported by the aircraft's transponder. This reported altitude is reported in increments of 100 feet and is dependent upon the aircrafts altimeter.

Δ Mode C and crash elevation
This field calculates the difference between the reported Mode C altitude and the elevation the aircraft was located. If the aircraft gained altitude the number is positive. If the aircraft lost elevation the number is negative. A value was obtained in 169 incidents.

2º Lat, 2º Long (Second to Last Latitude, Second to Last Longitude)
The second to last radar plot coordinates are given in this field. The purpose of the second to last radar coordinate is to determine the aircrafts last known bearing based upon the second to last and last radar plot.

2º Lat DD, 2º Long DD (Second to Last Latitude, Second to Last Longitude)
These fields were used to record the previous field converted to decimal degree format.

Nm Δ LR – SLR (Difference between last radar position and the second to last radar position in nautical miles)
The purpose of determining the difference between the second to last and last radar plot was a quality control measure. Any plots more than 2 nm apart were given individual attention to determine if any anomalies existed. A total of 92 incidents had a second to last plot. 88% of those plots were within 2 nm.

R bearing (Radar derived bearing)
The real purpose of collecting the second to last and last radar positions was to determine the aircraft's heading (bearing) at the time of the last plot. The bearing was obtained by using a MS Excel spreadsheet as previously described.

Last Bearing
The last bearing in 92 cases was derived from the previous work with the last two coordinates. However, in many cases the radar plot package consisted of a PowerPoint slide with the plots superimposed upon a map. In these cases the map that showed the greatest detail was printed out. Then using a compass and a straight edge the last heading was plotted on the paper and the degrees read off the compass. This method was used in 68 incidents to bring the total number of incidents that had a last bearing to 160.

θ Dispersion Angle
The dispersion angle was calculated as the absolute value of the difference between the last bearing (last radar heading) and the find bearing (heading from last radar plot to crash site). The dispersion angle was calculated for 159 incidents. The dispersion angle by definition could not be larger than 180 degrees.

Delta FPM (Change in vertical feet per minute)
The delta FPM was given or calculated from Mode C information given in the radar information. At least two radar plots with both altitude information and time information were required to calculate the FPM rate. A positive number indicates the aircraft was climbing. A negative number indicates the aircraft was descending. Delta FPM was available for 105 incidents.

Attachments
The attachments field was used to code if any additional information was available regarding the incident in the form of an attachment. Three codes were used to indicate the additional type of information. T=Track data, which means additional radar plot information is available. The additional information may be an excel file or word file that is stored by incident number for the file name or sub-directory name under the year the incident occurred. In some cases where only more limited data was available the additional radar data may be stored as a worksheet tab. The name of the worksheet tabs correspond to the incident numbers. M=Map data, a map is available that shows the various plots on a map. I=Image, an image of the crash site is attached.

Plot Offset
The plot offset was somewhat similar to the track offset field. In the track offset field the least distance to the expected route was measured. The plot offset is based upon the least distance to the last known heading from the last radar plot. Therefore, it required having the last radar plot, the heading from the last plot, and the find location. In those cases where the find was behind the last radar plot, then the distance from last radar plot to the find location was used. A total of 159 incidents had sufficient information to measure the plot offset.

Pred Lat, Pred Long (Predicted Latitude, Predicted Longitude)
In a few incidents (40) either RADES, CAP analyst, or the FAA provided the AFRCC with the expected find location of the aircraft. These fields recorded the predicted location.

Format P (format of predicted location)
The Format of the prediction field listed the coordinate format used.

PreLat DD, PreLong DD (Predicted Latitude DD N, Predicted Longitude DD W)
These fields were used to record the coordinates once they were converted to Decimal degree format.

Nm Δ Pre – Find (Difference between predicted location and actual find location in nautical miles)
Using the predicted location and actual find location coordinates an Excel spreadsheet returned the distance between the two points. Essentially a measure of how "good" the prediction was. Since 248 incidents had radar information, it was relatively rare for the radar forensic analyst to make a prediction. 68% of the predictions were within 1 nm and 76% were within 2 nm.

km Δ Pre – Find (Difference between predicted location and actual find location in kilometers)
This field presents the same previous information in kilometers instead of nautical miles.

 # updates (Number of ELT updates)
The field records the number of times an updated ELT position was obtained (if an ELT signal was obtained.

ELT
This field lists the coordinates of any ELT fixes. In many cases the AFRCC records only that an ELT signal was present but failed to give the position. In these cases in the ELT field instead of entering the coordinate a yes was entered. Of the 262 incidents 30 provided the ELT location and an additional 9 incidents reported that an ELT location was obtained. This indicates that an ELT signal was produced in 15% of the incidents. Analysis of ELT information was beyond the scope of this study and distances from the find location and relationship with radar information or route information was not explored.

Interesting
The "interesting" field was created at the request of NASA World Wind team. The field includes comments from the investigator on cases that had interesting, unique, or excellent learning points. Thirty-three incidents were marked as interesting.

Comments
The comments field directly copied the final summary entry in the AFRCC incident software. This field proved highly valuable in quality control, clarifying fields, and obtaining additional information.
Subtasks and Deliverables

The following fields contain potentially unique identifying information that might be considered either privileged information or information that could lead a reasonable person to determine the name of the pilot:

- Incident number
- Mission number
- Combination of Date, Aircraft type, and location (can narrow down in NTSB database)
- Aircraft Registration number
- NTSB ID
- Found by
- Radar Source (identifies RADES vs. FAA)
- Comments (Actual comments taken directly out of AFRCC SARMaster log

Suggestions for Additional Work

Overview

This report should only be viewed as the beginning of the continuum from data to implementation of fact based decision making. This report collected data from multiple sources, organized the data, and presented preliminary results. However, many tasks still remain. While key factors have been identified, they need to be confirmed using formal statistical analysis. In addition, several key factors that might influence where to look for an aircraft beyond the last radar point have not been examined yet. However, the multiple factors that influence probable areas make it critical to develop a model that integrates all significant inputs. Whether a Bayesian model or a Monte Carlo simulation (which drives the USCG SAROP probability model) is used remains to be determined. Once probability of containment values is generated then they need to be presented to the decision maker using a graphic user interface. NASA's World Wind is an ideal medium to display the final interface. Once a probability of containment is defined it is possible to use formal search theory to define how to best deploy resources. This allows progress towards the ultimate goal – to save time, resources, and most important of all, lives.

Distance from Last Radar Plot to the Aircraft

The report clearly defined that the probability of finding the aircraft close to the last radar plot is significant. In fact 50% of all aircraft are found within 0.8 nm of the last plot. This gives a potential search area of only two square nautical miles. A size easily (depending upon terrain and weather) searched on the ground, even at night. However, the study could easily be improved by examining several other factors. Radar information depends upon the radar forensic analyst finding the correct track that relates to the correct aircraft, then finding the last possible track – often from many segments that have gaps. The input of the analysts of their confidence in the track is clearly needed. The simple proxy for "confidence" in the database was the 40 incidents in which the radar analyst forwarded a formal prediction of where the aircraft might be found. Analysis of those predictions showed 68% were found within 1 nm and 76% were within 2 nm. The 75% for the overall database was 5.5 nm. This might be even more important if two or more candidate tracks are possible. While the tracks could be weighted evenly from a statistical point of view, it might be more useful to have the analyst weigh the probability.

The approach used in this study was to attempt to identify factors that result in more probability being found closer to the last radar plot. An equally valid approach is to look at factors that might identify when the last plot has nothing to do with the aircraft final location. Such a measure would help to avoid putting too much emphasis on the last radar track. The most important factor is the aircraft leaving an area of radar coverage. A formal study of all those incidents where the aircraft was not found near the last radar plot must look at radar coverage. This study already identified that straight and level flight might be another good predictor of a "non-relevant" last radar plot. However, it is noteworthy that two cases mention that the last radar plot occurred at a point of known end of coverage but the aircraft was found near those plots. Such analysis would need to define a value for what the "non-relevant" distance actually might be. The "non-relevant" distance might be different for ground-based searches and air searches. Some potential factors were not examined in this report. It would be prudent to eventually examine the actual model of aircraft, if icing conditions existed, if the aircraft entered a thunderstorm, day or night light conditions, the visibility, the ceiling, total flight hours, flight hours in aircraft, flight hour's instrument, and certain key scenarios. An examination of all factors was beyond the scope of this report.

Equally useful, would be a close examination of suspended mission (where the aircraft was eventually located). It would then be possible to identify the role a better probability of containment model or map my

play. It could also be useful in identifying factors that may need to be emphasized or considered in model building.

One of the more useful inputs was the flight characteristics field. The definition used to determine the terms needs to be further refined with the additional input of different experienced pilots. Several illustrations should be developed so that eventual users of any potential model can input the correct information. The results from the spiral category were spurious at times. This might be due to the definition of spiral allowing for both a regular descending controlled 360 degree turn and an out of control spiral. Input from the pilot community is required to better differentiate the two. Another highly useful factor in further refining the distance from the last radar plot was vertical change as measured in FPM. It was noted that the median for helicopters was 3.2 nm and the 75% 17.6 nm compared to the 0.8 and 5.5 respective values for the entire database. The working hypothesis for the difference is the fact that most helicopters fly close to the ground and can easily go out of radar coverage long before the actual incident. In one case where the helicopter had an AGL of several thousand feet it was found close to the last radar plot. Therefore, the AGL of all of the last radar plots would be looked at along with the radar coverage to build a better model.

An output factor collected from the NTSB was the cause of the incident. Typically this factor can only be thought of as an output factor, determined after the aircraft is located and following an extensive investigation. However, scenario analysis is a well accepted part of SAR theory that assigns a relative probability to each scenario and modifies the final probability of containment of each scenario. The cause of the incident can be defined as a scenario. Some scenarios such as running out of gas, engine failure, VFR only pilot entering IMC and experiencing spatial disorientation, and in-flight breakups might be predictable based upon radio communication or the nature of flight radar plots. Therefore, it will be important to discover if the cause of the incident influences the distance from the last radar plot. It was noted informally that certain accident causes are more likely to lead to the survivors.

Dispersion Angle

The dispersion angle helps to identify the probability of where the aircraft was headed after the last radar plot. The current dispersion angle is expressed as an absolute difference between the last predicted heading and the bearing at which the aircraft was located. Therefore, the measure neglects to consider if the aircraft was turning to the left or right. The flight characteristics clearly showed a difference between an aircraft that was flying straight and one that was turning. Considering right and left factors might help to significantly identify areas of higher probability.

In several cases the aircraft was found between the last radar plot and the second to last radar plot. This creates a dispersion angle close to 180 degrees. However, a known artifact of some radar systems is the addition of a ghost plot due to a cruise prediction built into the radar computer systems. It would be highly useful to identify those incidents where the aircraft was located 180 degrees to its last heading. Using the flight characteristics along with the crash site ground debris bearing (provided in the NTSB field investigation) it would be possible to determine the most likely the direction the aircraft was actually flying when it impacted the ground. From this it would be possible to further refine a model that would predict the percentage chance the last plot was in fact a “ghost” plot and the aircraft was most likely in between to two plots.

Vertical Changes

Vertical changes were only relevant in mountainous regions. The aircraft is limited to a maximum climb rate by the physics. Therefore by inputting information about the aircraft, conditions, and load weight, it should

be possible to determine the maximum climb rate. Box canyons and other mountainous conditions might be critical in determining the vertical limits of the search area. Several cases appear in the database in which the aircraft was attempting to climb. However, the details related to the type of aircraft where not examined. Lack of this type of information has lead to one suspended search. Also, as previously mentioned, it is important to look at the AGL factors and examine how they might influence vertical changes.

Route Offset and Route Percentage

The study provided new route offset and percentage information. While the study collected all the information required to revise the current NTAM suggested search areas, it did not make specific suggestions. It is recommended that an effort by the Civil Air Patrol, AFRCC, and Inland SAR School, along with the principal investigator look at the data and make relevant recommendations. In the original model prior to NTAM references made to routes longer and shorter than 100 nm. This study did not make any examination of long or short routes. However, it was noticed at an intuitive level that some differences might exist.

After talking to experienced SAR planners, they indicated a desire for information of how far the aircraft was found from the initial departure airfield. It appears in many incidents, this may be the only piece of information initially available. At first, it was thought this statistic could easily be derived from the last known position field found in the AFRCC records. Upon further investigation it was found the last known position could be the departure airport, last communication, or last radar position. It would be necessary to use the route information to obtain the coordinates of the departure airports.

The current work excluded incidents where the aircraft took off and planned to return to the same airport and did not mention any other flight destination. It would be useful to at least determine circular rings of probability around the airport.

Since radar information is not always immediately available, or in some cases may not provide a location close to the find, route information will remain important. Therefore, any model built should also consider route information and probabilities. The model should also express the probabilities with a graphic user interface that could be built into World Wind. To facilitate route information several additional features would need to be added to the World Wind interface. Since search areas based solely upon route information preclude ground searches, the level of detail would only need to be at the aircraft search scale.

Intersection with Weather Front

Syrotuck and McIver in 1975 reported the typical distances aircraft are found after intersecting with a weather front based upon 24 cases. The type of study has not been repeated since. In many of the incidents a weather front played a major role. It is possible to look at historic weather radar data and overlay the aircraft radar data into a composite picture and determine statistical methods to enhance identification of probable areas.

ELT

None of the ELT data was examined in this report. While the data was collected, the coordinates were not converted to the decimal degree format for any further analysis. With the termination of 121.5 and 243 ELT it might be necessary to gather future data from 406 ELT. Important factors to look at would include distances to the crash site and relationship between signals and survivability. Older unpublished data provided information on how the accuracy of the ELT signals improved on successive passes. Similar data

needs to be generated for 406 ELTs. This study only examined ELT data from missing aircraft. A completely different database would need to be constructed to look at all ELT data.

PLB

This study did collect and report some basic preliminary data on PLB incidents. However, coordinates were not converted to decimal degrees and the actual distances between the reported PLB and actual find was not calculated. PLB incidents appear to have good survivability compared to missing aircraft incidents. Since it does appear that PLB are being used in aircraft (in lieu of or in conjunction with ELT), it will be important for future aircraft incidents to better understand operational use of PLB in an aircraft environment.

It would also be useful to develop a model to examine factors that might predict real and false (non-distress) beacon activations. This could be helpful in making the decision to continue some additional investigation or begin launching resources. It may also help to determine what type of resources should be launched.

Survivability

Another useful model to build into any SAR program is survivability prediction. Basic survival data was collected in the database. However, no effort was made to look at factors that predict survivability. Previous research has indicated time is the biggest factor. The database and possibly additional information available from the NTSB reports could expand the database and allow better predictions. Survivability modeling is helpful in making suspension decisions or switching from rescue to recovery mode.

Conclusion

The ultimate goal of search and rescue is to locate and rescue the subject. To find the subject, search resources must be placed in the correct location. Formal search theory can help determine the placement of resources but it is dependent upon identifying how much probability of containment exists in each search grid. Therefore, it is of paramount importance to develop a model that correctly allocates probability into different areas contained in the search area. The raw data and preliminary results presented here are the foundation to achieving this goal. The next step is formal statistical analysis of relevant factors and building a mathematical model that allocates the probability. Since humans by nature are poor at visualizing probability and statistics, it is imperative to provide the information in a way that is easy to digest, visualize, and allows for making operational decisions. NASA's World Wind offers the opportunity of eventually providing a visual representation of where to search next.