Plane Recovery Techniques:

How to Find a Plane in Open Water

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Summary

Transoceanic flight has become a regular occurrence; there are as many as 770 transatlantic flights alone per day (1). However, when a aircraft flies over an ocean it becomes significantly more difficult to track by radar. For this reason, it is difficult to find aircraft that have lost contact with their respective control towers. Finding downed aircraft quickly is vital to the safety of passengers and faith of the consumers.

This paper discusses a model for locating downed aircraft in open water. In order to do this, the model will produce a small area in which to search for the downed craft. In order to determine where an airplane crashed, a knowledgeable human will provide the model with three variables about the aircraft before the crash: the skill of the pilot, the speed of the aircraft before loss of contact, and the flight path. Pilot skill is evaluated by rank (0 - 100) using a model of dynamic and static stability, where 0 is an unskilled novice and 100 is an incredibly skilled veteran. The actual crash location is then altered by simulated weather conditions and a pilot performance under stress.

The predictive model produces a search area where the innermost portion is the most likely crash site, banding outwards as the probability decreases. This search area gives search crews the correct area (within 20 miles) 21% of the time, and gets close (within 50 mi) 73% of the time. Additionally, the models average distance from the simulated crash site is less than 40 miles.

When searching for the missing Malaysian flight, rescue teams had to search a square area of approximately 190 miles ($\sqrt{35,000}$ miles $= 187.06 \simeq 190$ miles) (7). This model gives a search area reduced by 33,000 square miles with 73% probability of finding the downed airplane. If the given rate of searching is 18 miles per 8 hours, then it would take a team of seven rescue aircraft 23.3 hours to search the reduced area. This is a significant reduction from the 277.77 hours required to search the previous 35,000 square mile area. Thus this model reduces the required search time by 92% in 73% of crashes.

Press Release

Nearly a year after the tragic disappearance of Malaysian Airlines Flight MH370, researchers have been hard at work developing models to assist in the recovery of commercial jets which are suspected to have crashed over open water. Using a combination of physics and statistical modeling, their research has provided us with a model which can help reduce the probable search size by as much as 84%, based on weather conditions and other available information.

The International Civil Aviation Organization (ICAO) policy has recently set the standard for location transmission to 15 minute intervals, decreasing the response time to such emergencies, in most cases, as no standard guidance for this interval had been issued before. Given this time window, even without a distress signal, the airline will receive immediate alerts on planes which have not reported in at the regular interval. Air traffic controllers will be presented with any available information on the pilot, as well as the current weather and wind conditions of the last known area. Given the case file, the controllers will provide objective assessments of pilot skill and an appropriate angle of trajectory to the computer. Given these inputs, the computer will output a map with the most likely location of the plane, if it has indeed crashed, so that planes can be sent to the area immediately to begin the search.

When lives are at stake, time is of the essence. While these events are rare, we strive to respond to crises such as these as quickly as possible. With a team of highly trained rescue pilots, our crew can cover 18 miles in 8 hours. With our drastic reduction in probable search area, our team of twelve rescue craft can sweep the region in 23.5 hours. This is a significant reduction from the 167.12 hours required to search the previous average of 35,000 square miles, and applies to over 73% of the possible catastrophes.

While these improvements are significant, science never rests, and researchers are already hard at work in refining the models. In addition to accounting for other variables in the situation, they are also working to further optimize the selection and deployment of search vessels, as well as the utilization of commercial planes and ships which are already in the search area. The airline plans to invest in equipping commercial airliners with the latest technology to assist with the search as they fly along their normal path to supplement this, once the research is conclusive.

Your safety is our top priority, and we will not settle for less than a full guarantee of our passengers safe arrival. In order to maintain this high standard, we have to prepare for the worst. This research shows great signs of progress in that vein, and we will continue to update the public on this matter. Thank you for your continued patronage, and thank you for flying <insert airline here>.

Introduction

However infrequent, the loss of an aircraft undoubtedly leads to public concern. Being able to quickly and efficiently find and recover missing aircraft is invaluable in maintaining the public trust in transoceanic flight. These incidents are few and far between, which gives the problem space a tendency toward simulation and estimation rather than data analysis. This paper focuses specifically on transoceanic crash simulation, and attempts to determine a manageable area within which to search for the crashed plane. This model will provide rescue teams a way to focus their efforts, and improve their response time in the event of an emergency.

Background

Commercial transoceanic flight has been around since 1928, with blimps being the primary mode of air transportation. In the early 1930's, transoceanic airplane flights became commercialized (2). Since then, transoceanic flights have been a common form of transportation for traveling between continents. For transatlantic flights alone, there are as many as 385 each way, or 770 total per day (1). Today, most transoceanic aircraft are long-range jumbo-jets produced by Airbus or Boeing. Each generation of these planes has better tracking and fuel efficiency than the previous. These aircraft also share in their continuous efforts to improve a plane's glide-ratio. Most long-range aircraft have similar glide-ratios due to the similarity in wing structure and construction of the aircraft. A glide-ratio is a measure of an aircraft's ability to convert vertical drop to horizontal movement. A glide factor of x:1 will travel x meters forward for every one meter of vertical drop. For example, the Boeing 777 has a glide ratio of 17:1 which allows it to travel 17 meters horizontally for every meter it falls. This ratio assumes there is no thrust being added to the aircraft, and that both wings are intact. This paper uses three aircraft when determining aircraft measurement averages to use for the model: Boeing 777, Boeing 787, Airbus A380.

Boeing 777

The Boeing 777 is a member of Boeing's wide-body, long-range jet airliners. Developed in 1994, the 777 is used by several airlines including United Airlines, American Airlines, Air France, and Emirates. This aircraft has an approximated glide ratio of 17:1, which is one of the best in its class (3). This model is the parent to Boeing's next generation, the 787.

Boeing 787

The Boeing 787 is a Boeing twin-engine, wide-body, long-range jet airliner. In production since 2009, this airliner is primarily a fleet member of Air India, Japan Airlines, Air Canada, and Qatar Airways. This aircraft has an average glide ratio of 18:1 (3). This liner is also the first of its kind to reduce cabin pressure from an 8000 foot altitude to a 6000 foot altitude.

Airbus A380

The Airbus A380 is a quad-engine, double-decker, wide-body, long-range airliner. Primarily used by Emirates, Singapore Airlines, and Lufthansa the Airbus A380 has been in production since 2005. This plane has many variants, each with significant disparity between glide ratios. The lowest glide ratio for this family of aircraft is 14:1, giving it the lowest glide ratio for its class, and the highest is 17:1 (3).

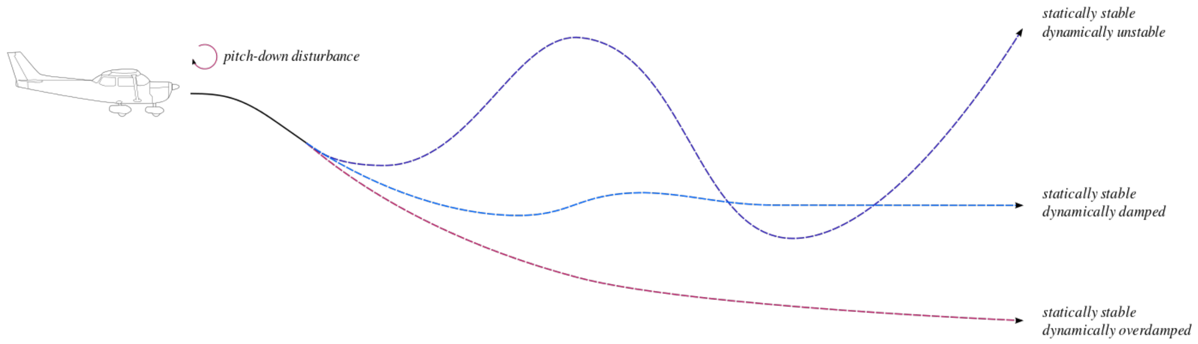


Figure 1: A visualization of varying dynamic stability's effect on aircraft trajectory (5).

In addition to glide-ratio, pilot skill is an important factor in distance before impact. This is due to an effect known as longitudinal dynamic stability. Figure 1 is a visualization of the three types of dynamic stability: unstable, damped, and overdamped. If a pilot is unskilled, and is only reacting to the instantaneous changes in altitude it is expected for the plane to follow a trajectory similar to that in figure 1 labeled dynamically unstable. This trajectory significantly reduces the distance the plane can travel before crashing. Additionally, without additional force being applied to the plane, each wave will reduce the plane's altitude, making the glide ratio a less reliable way of determining the total distance traveled.

A highly skilled pilot would be able to follow a trajectory similar to the one shown in figure 1 labeled dynamically overdamped. This path would have the plane travel significantly further than a dynamically unstable trajectory. Although skill is a determining factor in trajectory, weather conditions can affect the trajectory of a plane's descent. A skilled pilot in poor weather conditions could have a similar trajectory to an unskilled pilot in good weather.

Currently, there is no mandated communication frequency interval. However, the International Civil Aviation Organization (ICAO), an agency of the United Nations, has proposed a standard of automated position updates every 15 minutes. This implies that a plane could have flown without failure for a maximum of 15 minutes, else it would have sent out another signal. Having a standard for position updates significantly decreases the area that must be searched when a plane disappears. As of this writing, the proposal is just a recommendation, but is expected to go through a swift approval and become the standard by fall 2015 (6).

Model Descriptions

Assumptions.

While there are many factors that affect how and where a plane crashes, for the purpose of our models, this paper will only focus on the most important factors that appear to have the largest impact on crash location. To attain this goal, this paper will make the following assumptions:

- The plane was not hijacked, or taken over by someone other than the pilot during the crash.
- The skill level of the pilot during the crash has an impact on the spread of debris, and the distance between plane failure and water impact.
- The wings are intact through descent and the glide ratio of the plane is 15:1.
- Once plane failure has occurred, there is a normal distribution for which direction the plane will continue to glide before crashing. The majority (68.26%) will change the direction of travel by less than 45°(left or right) of the original direction.

Since the model becomes significantly more complicated if the pilot is not in charge of the plane between the loss of contact and crash, this model assumes the pilot maintains control over the craft throughout the crash. If a plane was hijacked, then the hijacker could take the plane in any direction they wish. More specifically, places contrary to our knowledge of the pilot's skill and conditions, rendering the current predictive model ineffective. The models use the pilot's skill level to make important decisions about the location of the crash, including distance traveled between plane failure and impact, and spread of debris. A more experienced pilot has a higher probability of being able to make a safer landing in open water, thus less of a spread of debris. In assuming the safer landing, the models assume there will be a greater distance between plane failure and impact. In trying to make a safe landing, the models assume that a pilot will concern him or herself with the stability of the plane, and not so much the direction of travel. However, the models behave such that this change in travel due to the pilot, wind, and other factors will be less than 45°left or right of the origional flight path. The model will also assume that the wings are intact through descent and that a plane has a glide ratio of 15:1 (4), as defined in the Background section.

Glide ratio is used to calculate the maximum distance a plane can travel before hitting water. The model assumes that the "best" pilot, or just an extremely lucky one, will be able to use the entire distance to slow down the plane so as to limit the impact of the crash, keeping the plane in fewer pieces. The plane is assumed to be traveling at 35000ft, so a glide ratio of 15:1 implies that the best pilot will take 100 miles to reach the water. The model includes 8 different levels of pilot skill. Each skill level reduces the distance by an additional 6.25 miles. Thus, the "worst" pilot will only have about 56.25 miles before the plane reaches the water. For a pilot to glide less than this amount before impact, there would have to be some intentionality behind it, based on research of glide-ratios. This intentionality falls into a hijacking situation, which the models assume is not the case.

The Models.

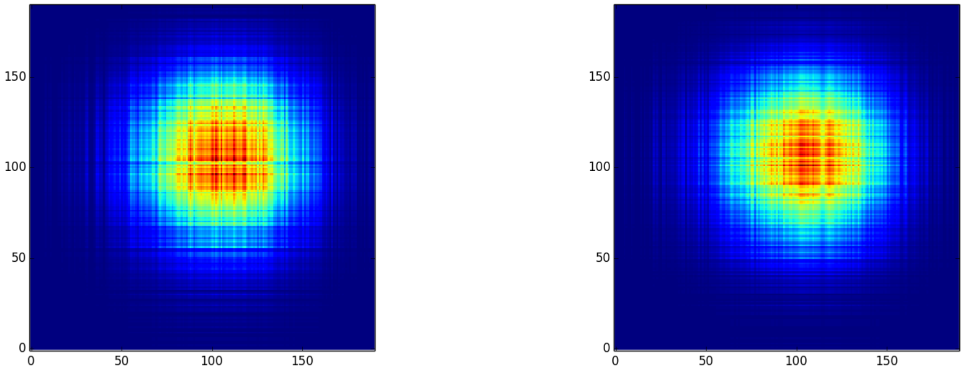
There are two main components to the models presented in this paper. The first is the actual location of the crash, and the second is the predicted location of the crash; each requires a few common elements.

Each component requires the distance between loss of contact and plane failure, skill level of the pilot, and direction of travel after plane failure.

For the purpose of this model, a 15 minute update interval will be used, since as discussed in the Background section, it is set to become standard in the coming months. This will be the interval used to help determine the distance before failure. For the purposes of this model, the time before failure is assumed to be normally distributed with a mean of 7.5 minutes and standard deviation of 2 minutes. For the basic model, an aircraft is presumed to be traveling at 558 miles per hour ($\sim$484.889 nautical miles per hour). Assuming the aircraft fails in the 15 minute interval between the last contact and next expected contact, it can travel up to 139.5 miles beyond the last known contact before the plane failure occurs. This mileage calculation does not include the miles a plane glides after the failure, as discussed above.

Skill level and direction of travel are each decided on a scale of 0 to 100 with a mean of 75, and standard deviation of 10. For the purpose of the models, it is assumed that commercial airline pilots are experienced, resulting in a higher average skill than one might expect. So, approximately 0.1% of pilots will be the absolute best, and in accordance with this distribution, approximately 68.26% will be "average" pilots, not the best, but certainly far from the worst. In the actual crash simulation, these details are combined with a normal random distribution. The level of pilot skill does not necessarily directly transition to distance covered by the aircraft during glide. There are other factors, such as the reasons behind the crash the might change the glide. In calculating the actual crash, it is assumed a pilot will act according to his or her skill level 75% of the time, and the other 25% of the time, a pilot will perform according to a normalized distribution of skill levels. This distribution is meant to account for a normal pilot "getting lucky," and a very experienced pilot having an unlucky day, favorable or unfavorable weather conditions, etc. Direction is also determined randomly with a normal distribution.

Figure 2: Heat Map of Probabilities



(a) Predicted Angle of 45°and Pilot Skill of 75%

(b) Predicted Angle of 58°and Pilot Skill of 64%

It is assumed that, on average, a plane will change direction from its original path by 45°, or less.

A user of the predictive model is defined as someone who has knowledge of the pilot's skill level and habits, and also conditions of the area in which the plane was last located. Because of this, the predictive model runs without the normal distribution probabilities listed above. The predictive model is based entirely upon the user's knowledge. In this model, a user can change factors based on their knowledge of the pilot's skill level, conditions, and how long the user believes the plane flew before encountering a failure by changing the time between last update and failure, level of pilot skill and conditions, and angle of deviation from the route. Alternatively, if the user has less than optimal knowledge of the conditions, he or she can put in a range of values for the various fields to get a wider band of possible locations.

Sensitivity Testing

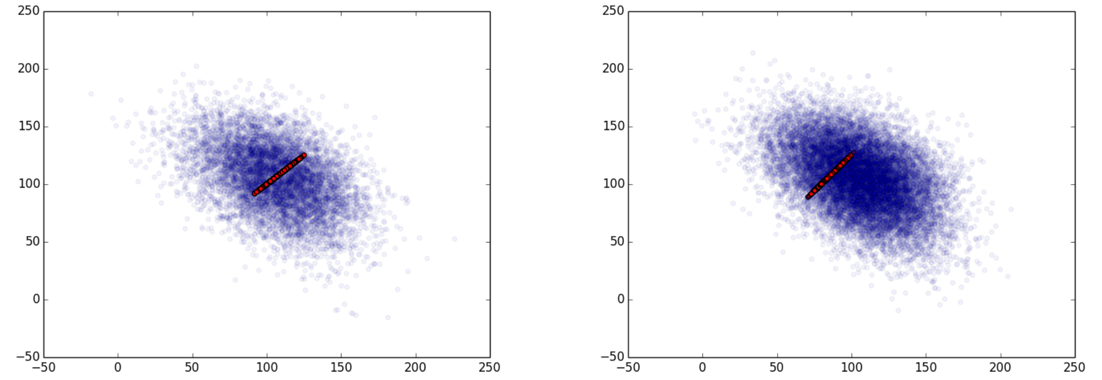
When designing this model, human variability was kept in mind. Pilot skill and the angle of trajectory of a suggested crash are both highly influential factors and require some human judgement or outside knowledge to evaluate properly. Figure 2 shows how the heat map of square miles is affected when manipulating the pilots skill from 75% to 64% and the angle from 45°to 58°. Figure 3 also shows how the predicted pilot skill will affect the spread of points. A pilot of less skill will have prediction points which vary far greater than one whose skill is higher.

The model also attempts to account for variability in time since lost contact and time of the alleged failure. With the average time since last report being 7.5 minutes as stated previously, the model accurately represents crash location inside of one reporting window. If an electrical failure happened at a time over 15 minutes before a crash actually happens, then the area of places that the plane might have crashed increases immensely. For the predictive model, it is possible to input a time greater than 15 minutes, or less than 0 minutes, if one believes the failure happened before the loss of contact. However, for the purposes of this paper, during all simulations it was assumed that a plane reports its position every 15 minutes until the point of failure in conjunction with the proposed ICAO standards.

Evaluation

Table 1 shows the statistical accuracy of the model against a given predicted location. When the pilot is assumed to be of average skill (between 75% and 80%), there is a 73% chance that they will perform to their skill level, and thus that the model will give a reasonable accuracy as to where the plane will land. For the higher and lower skill levels of pilots, there will be a greater chance of the extraordinary or the unfortunate occurring. Given these tendencies of the model, it is up to human discretion and

Figure 3: Crash Site Probabilities



(a) Predicted Angle of 45°and Pilot Skill of 75%

(b) Predicted Angle of 58°and Pilot Skill of 64%

Table 1: Results from the simulations

Trial	**Pilot Skill**	**Crash Location**	**Avg Distance(miles)**	**% Within 20 miles**	**% Within 50 miles**
0	68.25%	45°	37.9	10.7%	57.2%
1	75%	45°	38.1	21.2%	73.5%
2	81.25%	45°	38.2	21.2%	73.6%
3	87.5%	45°	38.6	10.3%	56.9%

judgement to consider the pilots objective skill. The 45°crash location represents an on course plane, traveling through our simulation from the bottom left cornet to the top right, and the accuracy for each trial is taken as the average from 8,000 iterations. If a risk is taken in assuming deviations from average with the pilot in question, it is possible that a good judgement call could lead to the quick recovery of the plane. Thus, the more knowledge one has of the pilot and conditions where the plane was last located, the more accurate the predicive model.

Conclusion

Table 1 shows that at worst, 10.3% of the time a search crew could find the plane within 20 miles, and 56.9% of the time the plane will be found within 50 miles of where the predictive model places it. Given that the average speed of a search plane is 18 miles per 8 hours (7), we would recommend deploying two search craft to search the 20 mile area around the predicted crash location and an addition 5 search craft to patrol the remaining area within the 50 mile radius. With organized cycling of search craft, the inner search area could be completely searched within 23 hours. The remaining area can be searched in as quickly as 23.3 hours by the remaining 5 searchers. If these searches were conducted simultaneously, then within 23.3 hours there is at worst a 60% chance, and at best a 73.6% chance the lost aircraft will be found. Using the previous area of 35,000 miles and the same number of aircraft searchers it would take 277.77 hours to search the area, with little to no guarantee that the plane would be found at the end of the search. This is an 92% reduction in time required to find the downed airliner.

If the lost plane was not found within the 50 mile search area, we recommend sending out boats equipped with chemical detection sensors calibrated for jet fuel. These sensors are accurate to detect jet fuel in as low of concentrations as a few parts per billion (8). These boats should search the surrounding area for traces of jet fuel to narrow down the area in which the plane can be found. Using this data, searchers could narrow down the possible crash zones.

Future Work

There are many ways in which this model could be improved upon, specifically the data that is fed into it and output from it. One such set of data would be modeling the spread and location of the debris from the crash. Using the pilot's skill to determine the glide distance, the force of the impact could also be calculated given a plane's mass and thus a debris field calculated. This would aid in the deployment of search vessels. For example, if the plane was believed to be in just a few pieces, the search efforts would need to be more concentrated. However, if the plane is believed to be in hundreds of pieces, the search effort could be more spread out through the predicted area because there is a higher probability of finding a piece in any one given area. In association with debris, the model might also consider the distance the plane was from its origins in calculating the amount of jet fuel left. If there was believed to be a higher amount of fuel left in the plane at the time of the crash, it would be more advantageous to send out boats with chemical sensors, as described above, to help with the search. However, if the plane was closer to its destination, or was believed to have run out of fuel, the additional aid of the boats with chemical sensors would not be as high. Programming these types of search aid into the model would also be a possibility for future work. The current model requires a some user decisions about the type of vessel, but the model determines the locations to send them to; however, in future models, the model will determine the most effective search vessels and locations to send them to. In conjunction with the inclusion of debris field, this allows the model to make decisions about the advantages of sending a boat with chemical sensors versus an additional plane. As time goes on, researchers can study previous crashes and submit the data to the model, so that it can continuously improve upon the accuracy of its predictions.

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