Selection of Off-Field Landing Sites

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Abstract

This article uses Bayesian statistics to produce guidelines on selecting an an off-airport landing site.

Introduction

About 25% of reported glider accidents are due to pilots' inability to locate land-out sites. Numerous authors provide guidelines for selecting off-airport landing sites[1-5], but little applies to the early stages of a land-out situation. In addition, most advice is provided as a formula while the situation often calls for decision making.

In this article I argue that finding a good off-field landing site is best accomplished using a strategy that combines route planning and navigating, with an understanding of one's chances of finding a good land-out site when still in the preparatory stage.

I present arguments using simple Bayesian logic that are easily put into practice. This results in a better integration of awarness of landing-out with the task of route finding.

How serious is the problem of off-field selection?

Of the 73 glider accidents reported in the US to the NTSB between January 2001 and September 2003, 24 of these were due to failures in attempts to land off-field[a]. In most cases the aircraft involved were destroyed.

Of these 24 cases 18 appear to be primarily because of the pilots' failure to find a suitable off-field landing site. Suitable, that is to say, with respect to the pilots' abilities. In only 5 of these cases did the reports indicate the sites chosen were appropriate and the accident due to other causes, such as a crosswind.

Therefore, we can say that nearly 25% of all glider accidents reported in this period were because of the pilot's inability to locate a suitable land-out site.

The cause of accidents

Soaring is a complex activity and landing off-field is one of its more complicated problems. Off-field landings are accidents in themselves, whether they result in damage or not. Damaging off-field landings are really two accidents that occur in succession: the necessity to land off-field, and incurring damage in the process.

There will always be two things to analyze: the decision to land off-field, and the landing itself. The root cause of the damage could be an error in either area, or in both.

It is difficult to know how far back to go in the chain of decisions the pilots made leading up to their landing out. An analysis could go back as far as the flight plan that preceded becoming airborne, or to an evaluation of previous experience. And because the land-out is the culmination of so much decision-making, an analysis of it runs the risk of becoming an analysis of everything.

I will take the simpler approach that begins with the assumption of a reasonable flight plan. My analysis of the cause of land-out accidents begins at that point where one starts planning for the possibility of landing out. I will refer to this as our "land-out consideration point." Most authors generally agree that this is the point when one drops below a height[b] of 3,000 feet above ground level (AGL), or when one drops below a conservative glide slope to a safe landing area.

Bayesian statistics

Statistics provide indications of the likelihood of things happening in groups. When considering events that consist of other events one needs to consider various elements in their turn. Once we have gotten some statistics on the likelihood of constituent events then we can assemble statistics for the larger events. The process of building statistics for groups from the statistics of their elements is called Bayesian statistics.

Bayesian statistics is intuitive and we do it all the time. It becomes complicated just where any statistics become complicated, namely when the definitions and assumptions become confused. For our needs, however, the problem is clear and the statistics are simple.

Consider this example that involves completely invented numbers. Let us say that 5% of those people who become soaring pilots get involved with competitive soaring. And let us say that on average, over a person's entire soaring career, the likelihood of their having an accident that causes notable damage is 20% if they engage in any racing, and 5% if they do not race. It is then natural to ask "what is the chance of a

[a] This analysis is based on the information currently available on all reports found when searching the US National Transportation Safety Board's (NTSB) web site for glider accident reports in the US. The web site URL is http://www.ntsb.gov/ntsb/query.asp.

[b] Throughout this article I use the word "height" to denote altitude above ground level.

soaring pilot experiencing a damaging accident at any point in their career?" This is a problem in Bayesian statistics.

The answer goes like this: there is a 95% chance that you will be a non-racing pilot who experiences a 5% accident rate, and a 5% chance that you will be a racing pilot that experiences a 20% accident rate. The result that we are looking for is obtained by weighting the relative accident rates by the likelihood of you being in either group. In this case we have:

Career Accident Rate = ((.05*.2) + (.95*.05))
= .058 or 5.8%

As with all statistics we have to be precise about what we are saying. For example, we are not saying that competitive soaring pilots are more accident prone. Nor are we talking about the risk one takes in stepping into a sailplane.

The land-out risks

Bayesian statistics tells us that if we want to pick the safest option, then we must first calculate the safety of all the options. To accomplish this we must have generally useful means for:

1. describing all of the options,
2. calculating the safety of each option,
3. determining the safest option.

Describing all of the options

The following assumptions describe the situation that I believe we would like to find ourselves in when we enter a potential land-out situation. I will assume that we are always within glide slope of a known field on which we are certain of a safe landing. This can be any intermediate site along our route. I will refer to the this is our "safe harbor", and its location as "L_1".

Assumption #1 — There is a safe harbor

> *I assume that there will always be a known safe harbor within a conservative glide slope from any position along our route.*

When flying over unfamiliar terrain we can only see details on the ground sufficiently well within a certain distance so as to evaluate their suitability as landing sites. This distance is determined by the terrain, vegetation, and weather.

In the Eastern USA we usually have fields surrounded by forest. The average forest height is about 80 ft. and, seen from a distance, trees of this height will obscure a certain amount of ground that lies beyond them.

To be acceptable as a landing site a field needs to be at least 400 ft. in its smallest dimension. Using simple trigonometry we can figure the distance that we can be from 80 ft. trees and still be able to see fields of this size. This is shown in Fig. 1.

In Fig. 1, I assume that we are looking for land-out spots when we drop below 3,000 ft. AGL. At this height we are just able to see a 400 ft. field over the top of an 80 ft. tree as long as we are no further than a distance R from it[c]. The simple formula for equal ratio of the sides of similar triangles tells us that 80/400 = 3000/R. From which we calculate R = 15,000 ft., or about 3 miles.

Assumption #2 — 3 mile view of the ground.

> *We have a useful field of view of about 3 miles in any direction when at 3,000 ft. in which we can evaluate gross features of potential landing fields. This assumes clear weather.*

In order for the terrain below us to be considered "safe" there must be a good probability that we will be able to spot a land-out site from 3,000 ft. AGL (or at whatever height we begin looking for land-out sites). I will guess that most pilots would require this probability to be about 95%.

This means that when we spend a minute or two over safe terrain examining the options within a radius of 3 miles, there is a 95% chance that we will find a suitable field.

This does not mean that we will see a land-out site in any direction 95% of the time, or that 95% of the land around us is landable, or that there actually are good land-out sites hidden somewhere below us 95% of the time. Rather, it relates only to what we can reasonably discern with our limited view in a limited amount of time.

Areas that do not meet this criteria would be considered dangerous to fly over. Such terrain would include mountains, canyons, lakes, forests, and cities.

In areas where safe land-out areas are plentiful, such as central USA and parts of England, one's safe harbor may be a particular field or an area of fields. It may be easier to keep track of where the safe land-out sites are not. In any case it is assumed that the pilot knows the location of safe landing sites, and that one is currently above the glide path to them.

Assumption #3 — Know the safe terrain

> *We will always know the locations of safe terrain ahead of time, and we strive to remain over such terrain.*

An essential component of a "safe harbor" is that we think we can reach it. This means that we do not expect to be forced to a premature landing in dangerous terrain. We are reasonably assured of this if we use a conservative glide slope to L_1 and we ensure that only safe terrain lies between us and L_1.

Assumption #4 — Avoid dangerous terrain

> *Only safe terrain (as defined with reference to circles of 3 mile radius) lies between us and L_1.*

[c] I am not implying that one might land on a 400 ft. field by dropping over an 80 foot obstruction. Fig. 1 merely shows the geometry required to see this field from a distance. Landing in a field of this size would require an unobstructed approach from another direction.

Evaluating our options

Using these four assumptions we can draw Fig. 2 that shows our land-out options at any time or place along our route.

Here we have written the probability of finding a safe landing site as "P". The safe harbor at L_1 has a P of 1 (this is the definition of a safe harbor). According to Assumption #3 we will be able to find a field that offers a safe landing within 3 miles of our current location with a probability P = 0.95.

Now consider that we are flying along our route and we have dropped to our land-out consideration point of 3,000 ft.. Our route is along a 10º course. Our safe harbor is on a 280º bearing. We would like to continue on our route. What do we do?

As we continue to descend one of the following things is certain to happen:

1. We find a safe field within a circle of R = 3 miles and descend toward it. This might become a new safe-harbor, as discussed later.
2. We find lift and ascend above our land-out consideration height.
3. We do not find a field or lift and we proceed toward L_1.
4. We do not find a field or lift. We do not proceed toward L_1 but stay on some other course.
5. We encounter strong sink that forces us toward landing at an unfamiliar location.

These five cases are a general description of the initial situation for any pilot when they reach their land-out consideration height. And because we have defined L_1 as a field that is within our glide slope we know that we are safe in either of the first three cases.

However, we usually want to continue on our course and there is a good chance that our safe harbor is not directly in front of us. For this reason the fourth case is an important case to consider.

Selecting a course

The risks and benefits of staying on course

We are now heading across safe terrain and we are either remaining within the glide slope to L_1, or we are not. If we remain within glide slope of L_1 then we are safe. How safe are we if we move out of the glide slope to L_1? We focus on this special case.

In theory, our route has been planned as a hop-scotch from the glide envelope of one safe harbor to the next. However, there is no reason for us to travel directly over each safe harbor. If we are far above their field elevations, then we could travel many miles to either side of these airfields.

Unexpected conditions may change our altitude so that we find ourselves reaching our land-out decision height while on a heading well away from the nearest safe harbor.

In this situation we are heading across safe terrain but moving out of the glide slope to L_1. Given a glide slope of 20:1 we will travel about 6 miles before we reach pattern height at 1,500 ft., which is the commitment point for an off-field landing.

Traveling 6 miles will take us to the center of the next circle of 3 mile radius. If the chance of finding a safe landing site was 95% in the first 3-mile radius, then the chance of finding a safe landing site somewhere within the first or the second of these areas is 1 - (0.05*0.05) = 99.75%. However, in the situation we are describing the probability of finding a safe landing site in the next 3-mile radius area remains 95%, which is the same as in the last such area.

The reason for this is that we have assumed the area we have just flown over did not have a suitable land-out site. As we put that area behind us it has no bearing on the likelihood of safe landing sites in the next area. The reason that the land-out probabilities are not linked is that we are evaluating the probabilities of each area separately, as we pass over it.

Even the original 95% becomes an overestimate of our safety as the situation deteriorates. It is an overestimate because of the diminishing time available to locate and confirm a good site, and the increasing pressure as we approach the pattern commitment point. The point is that continuing on a course that takes us out of the glide slope to L_1 makes the situation increasingly unsafe. This is shown in Fig. 3.

This is an important point. Some pilots may subscribe to the mistaken idea that the longer time they spend over terrain that they had judged to be safe without finding a good landing site, the greater their chance of finding a good site. The truth is just the opposite:

Point #1: Decreasing safety

As we lose altitude, in an unchanging situation, our chances for locating a safe landing site decrease.

What heading is a safe heading?

This section addresses the following questions:

- How closely must we fly on a heading directly toward our safe harbor in order for this to remain a safe option for landing?
- To what extent can we fly off on different headings in our search for lift, promising fields, or in an attempt to make progress toward our original goal?

These questions are answered by considering what we mean by the glide envelope.

The glide envelope is an inverted cone, or funnel, that is centered on our safe harbor at L_1. The bottom of the funnel is coincident with the pattern entry point for this landing site. The angle of the funnel's sides reflect a performance estimate based on a conservative L/D. This is shown in Fig. 4.

A conservative glide slope is the best L/D of the glider divided by a safety factor to account for likely adverse influences. The safety factor depends on flying conditions, piloting experience, and the land-ability of the surrounding terrain. The standard safety factor is 50%. Phil Petmecky raises this to 75% in the case of an experienced pilot over predictable and friendly terrain[6].

The degree to which we can deviate from a direct heading to our safe harbor is proportional to our height above the glide envelope. When we have extra height we can make excursions away from a direct heading. On the other hand, when we approach the glide envelope we should cease these excursions and head directly toward the safe harbor.

If we are entering an off-field landing situation, then chances are that our conservative assumptions are justified. If we are entering an off-field landing situation because we have dropped below 3,000 ft., then we may still be well above the glide slope to the safe harbor. On the other hand, we try to jump from one safe harbor to another and find ourself right at the lower edge of the glide envelope.

Since we want to search for lift while we search for a safe land-out site we should build this desire into our estimate of our L/D. This means that in addition to headwinds and possible sink we should include a "wandering" factor in our conservative estimate of L/D. This factor plays a greater or lesser role in proportion to whether our desired course follows the course between our safe harbors.

When our desired headings are close to the headings to our safe harbor sites, then we can adopt a more optimistic L/D, and hence a more lenient glide envelope. On the other hand, if our desired heading is significantly different from the heading to our safe harbors, then we should adopt a more pessimistic L/D. This will enable us to deviate from the safe harbor heading with a greater margin of safety.

Point #2: Include a wandering factor

Our glide envelope should include a "wandering" factor that reflects how closely our desired route takes us over our safe harbor points.

Guidelines for field selection

There are three things we can say about Assumption #4 in which our desired heading is not the same as our safe harbor heading. These are:

When we reach 3,000 ft. we should become aware of possible land-out sites in all directions around us. If we have not been keeping careful track as we have been flying, as we probably have not, then we should make a 180º turn to evaluate the terrain behind us. Even if we have, the new view afforded to us from this perspective could well reveal landing sites we missed when looking from the other direction.

If we do not immediately see a potential landing site, then it will be safest if we change our heading so as to remain within the glide slope to L_1. Any other heading will be less safe. This change of heading is shown in Fig. 5.

Adding a safe landing site "on the fly"

How should our strategy change in the event that we locate a suitable off-field site, a site that is not one of our predetermined safe harbors? The answer to this question depends on our level of experience in evaluating sites and executing off-field landings given current conditions.

There is an art to evaluating potential land-out sites that involves weighing serious and often hidden risks. One needs to know the slope and texture of the surface. What it is composed of or what is growing in it, what obstructions surround it, and what surface wind and lift prevail in the area. These issues are separate from the skill required to plan the approach and execute a landing at the field. A successful off-field landing requires that one succeed in both picking a field and landing at it.

If you are confident in betting on the safety of landing at a newly discovered off-field site, then you can designate this as a safe landing site. You can then proceed with the strategies given here by provisionally adding this to your list of pre-existing safe landing sites. However, a newly discovered field will probably never be as safe a landing site as a known safe harbor. Not only are there risks that remain hidden from view at a distance, factors can also change day by day. The most obvious being that a field empty and clear one day may have people or equipment on another.

Treating a newly discovered field as if it were a safe harbor, even a provisionally safe harbor, requires assumptions in addition to those about the field itself. These include the assumption that we will be able to relocate the field as we wander around in its vicinity looking for lift – something that might be problematic in hilly terrain. We are also assuming that we will be able to keep track of our relationship to the glide slope to this field. This gets more difficult the farther we are from the field, or the lower our height.

Using a flight computer that allows us to punch in and keep track of a new landing site on the fly could help in both these respects. Nevertheless, unanticipated off-field landing sites will generally offer lower safety margins than our predetermined safe harbors, assuming that we are still above the glide to those safe harbors.

It may be worth repeating the obvious: if we have fallen below glide slope to any of our safe harbors, then find and focus on a safe landing site. Once we have fallen below glide slope to a safe harbor these landing sites can no longer be assumed the safest alternative.

Point #3: Leave riskier off-field sites for emergencies

It would probably be best for a pilot new to cross country flying to play a conservative game by limiting his or her safe harbors to proven landing sites. Leave the riskier off-field sites for emergency landings.

Searching for lift

From the point of view of wanting to find lift, one of the best places to look is on the lee side of fields suitable for landing, according to Tom Knauff[7]. He suggests that when a suitable field is found and there remains sufficient height to continue the search for lift, that the downwind side of the field is a good place to explore.

From a safety point of view looking for lift is the same as looking for a landing site. That is because either finding lift or finding a safe landing site will provide safety. Because of this we should look for lift along our new course line in the direction of L_1. This is another important point that is generally overlooked in the standard guidelines.

Point #4: Where to look for lift

Look for lift in the same direction we look for landing sites. Namely, to either side of the course toward our safe harbor.

We can now list the following guidelines for what to do when we reach land-out consideration height.

1. If over dangerous terrain, then immediately change course and head toward our safe harbor.
2. If we are not prepared to accept the risks of landing away from our safe harbor, which is usually the case in a non-competition or a club ship situation, then change course to avoid flying out of the glide envelope of our safe harbor.
3. Immediately scan the areas 90º to the left and right of our current course. If we do not see a likely land-out site, then turn 180º and survey the area behind us. If we still do not see a likely land-out site after having surveyed the full 360º area, then make certain that we maintain a course that keeps us within the glide envelope of our safe harbor.
4. Remain on a course that keeps us within the glide envelop of our predetermined safe harbor until we are either lifted out of this situation, or we land.

Concluding Remarks

This analysis of the incipient land-out situation brings to fore the following points:

1. As we lose altitude our chances of locating a safe landing site decrease.
2. When our desired course differs from the course to a safe landing site, and when we have dropped to the glide path to the safe landing site, then we should change course to the safe landing site.
3. We should modify our conservative glide slope to compensate for the amount of wandering we expect to do in search of a thermal.
4. Be cautious in judging the safety of landing at any newly discovered off-field site.
5. If we have not planned or do not follow a course that keeps us within glide slope of a safe landing site, then this analysis indicates we are not controlling the odds of preserving our safety.
6. If we find ourselves forced to land at an unfamiliar location, either because we failed to follow a good plan, or our good plan failed, then we should have experience in landing at unfamiliar sites. If there is one area in which standard training fails, it is this: learning to land off-field is best accomplished by doing it.

Acknowledgements

Thanks to Tony Firmin for comments on the manuscript.

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[7]Knauff, Thomas, "Preventing Landing Accidents", presented at the 8th Annual FAA Soaring Safety Seminar. Available on video from Knauff & Grove.

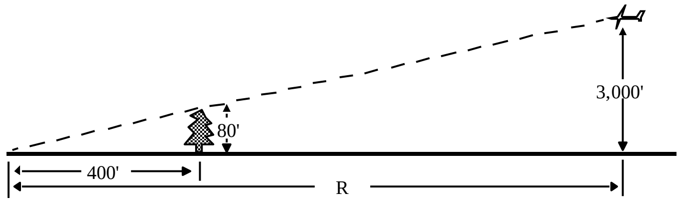

Figure 1 Our land-out options at any time or place along our route.

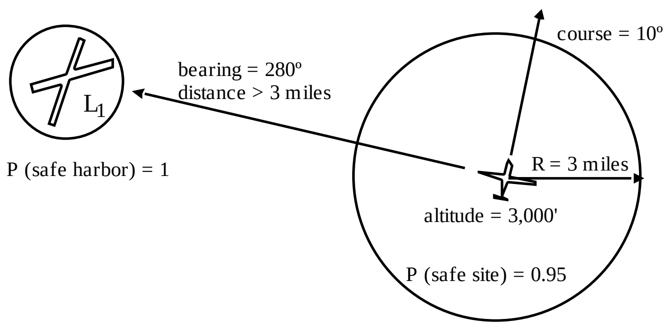

Figure 2 Our land-out options at any time or place along our route.

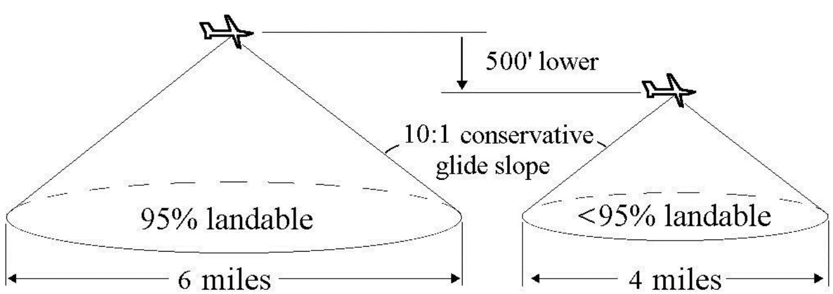

Figure 3 As one loses altitude, the diminishing time available to locate and confirm a good site lowers ones chances of finding a good site even when the general quality of the terrain remains unchanged.

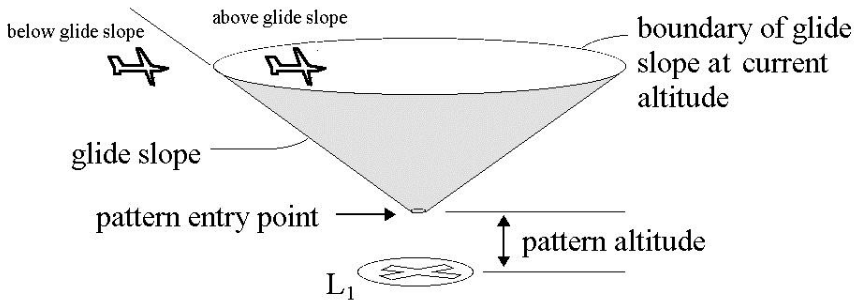

Figure 4 The bottom of the funnel is coincident with the pattern entry point for this landing site. The angle of the funnel's sides reflect a conservative L/D.

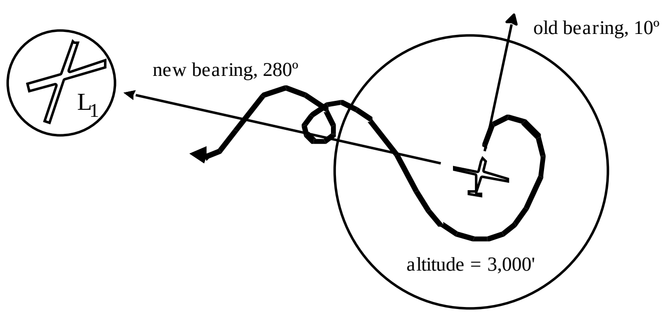

Figure 5 The change of course suggested upon entering a potential land-out situation.