Selection of Off-Field Landing Sites

Lincoln Stoller
Tenger Research, LLC
148 Dubois Rd, Shokan, NY 12481USA

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Abstract
This article uses Baysian statistics to produce guidelines on selecting 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 when 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 incipient (suggest 'preparatory') stage.

I present arguments using simple Baysian logic that is easily put into practice. The result is an approach that better integrates an awareness 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-field1[a]. In most cases the aircraft involved were destroyed.

Of these 24 cases 18 appear to be primarily due to the pilot's 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 cross wind.

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

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's difficult to know how far back to go in the chain of decisions the pilot made leading up to their landing out. An analysis could go back as far back 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'll 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'll refer to this as our "land-out consideration point." Most authors generally agree that this is the point when one drops below 3,000' AGL, or when one drops below a conservative glide slope to a safe landing area.

Baysian 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 you've gotten some statistics on the likelihood of constituent events you can assemble statistics for the larger events. The process of building statistics for groups from the statistics of their elements is called Baysian statistics.

Baysian statistics is intuitive and we do it all the time. It becomes complicated just where any statistics becomes complicated, namely when your 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's say that 5% of those people who become soaring pilots get involved with competitive soaring. And lets 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's then natural to ask "what's the chance of a soaring pilot experiencing a damaging accident at any point in their career?" This is a problem in Baysian statistics.

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

The answer goes like this: there is a 95% chance that you'll be a non-racing pilot who experiences a 5% accident rate, and a 5% chance that you'll be a racing pilot that experiences a 20% accident rate. The result that we're 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 one has to be precise about what you 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 soar plane.

The land-out risks

Baysian 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'll 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'll 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 East we usually have fields surrounded by forest. The average forest height is about 80' 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' in its smallest dimension. Using simple trigonometry we can figure the distance that we can be from 80' 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' AGL. At this height we are just able to see a 400' field over the top of an 80' tree as long as we are no further than a distance R from it. 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', 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' 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'll be able to spot a land-out site from 3,000' AGL (or at whatever altitude we begin looking for land-out sites). I'll guess that most pilots would require this probability to be about 95%.

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

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

Assumption #3 — Know the safe terrain

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

An essential component of a "safe harbor" is that we can reach it. This means that we won't 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.*

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've 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're flying along our route and we've dropped to our land-out consideration point of 3,000'. 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.
2. We find lift and ascend above our land-out consideration

altitude.

3. We do not find a field or lift and we proceed toward L1.

4. We do not find a field or lift. We do not proceed toward L1 but stay on some other course.

These four cases are a general description on the initial situation for any pilot when they reach their land-out consideration altitude. And because we've 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 last 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 that 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 at a high altitude 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 altitude 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 altitude at 1,500', 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're 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 that we've assumed that the area we've 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 statistical reason that the probabilities are not linked is that we're evaluating the probabilities of each area as we pass over it.

Even the original 95% becomes an overestimate of our safety as the situation deteriorates. It's 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 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 an good landing site, the greater their chance of finding a good site. The truth is just the opposite:

Point #1: Decreasing safety

As you lose altitude, in an unchanging situation, your 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,

A conservative glide slope is the best L/D of the plane 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[7].

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're entering an off-field landing situation, then chances are that our conservative assumptions are justified. If entering an off-field landing situation because we've dropped below 3,000', then we may still be well above the glide slope to the safe harbor. On the other hand, we may be trying 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 head winds and possible sink that we build into our conservative estimate of L/D we should include a "wandering" factor. This factor plays a greater or lesser role in proportion to whether our desired course follows the course between our safe harbors.

When your desired headings are close to the headings to your safe harbor sites, then you can adopt a more optimistic

L/D, and hence a more lenient glide envelope. On the other hand, if your desired heading is significantly different from the heading to your safe harbors, then you should adopt a more pessimistic L/D. This will enable you to deviate from the safe harbor heading with a greater margin of safety.

Point #2: Include a wandering factor

Your glide envelope should include a "wandering" factor that reflects how closely your desired route takes you over your safe harbor points.

Guidelines for field selection

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

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

If you do not immediately see a potential landing site, then it will be safest if you change your heading so as to remain within the glide slope to L_1. Any other heading will be less safe.

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[8]. He suggests that when a suitable field is found and there remains sufficient altitude to look for lift, that the downwind side of the field is a good place to explore for lift.

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

Point #3: Where to look for lift

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

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

1. If over dangerous terrain, then immediately change course and head toward your safe harbor.
2. If you are not prepared to accept the risks of landing away from your 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 (note envelop is the verb and envelope the noun) of your safe harbor.
3. Immediately scan the areas 90º to the left and right of your current course. If you do not see a likely land-out site, then turn 180º and survey the area behind you. If you still do not see a likely land-out site after having surveyed the full 360º area, then make certain that you maintain a course that keeps you within the glide envelope of your safe harbor.
4. Remain on a course that keeps you within the glide envelop of your predetermined safe harbor until you are either lifted out of this situation, or you land.

Concluding Remarks

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

1. As you lose altitude your chances of locating a safe landing site decrease.
2. When your desired course differs from the course to a safe landing site, and when you have dropped to glide path to the safe landing site, then you should change course to the safe landing site.
3. You should modify your conservative glide slope to compensate for the amount of wandering you expect to do in search of a thermal.
4. If you do not plan and follow a course that keeps you within glide slope of a safe landing site, then this analysis indicates you are not controlling the odds of preserving your safety.

References

[1]Piggott, Derek, *Gliding Safety*, Knauff & Grove, 1998. pp. 58 ff.

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[3]Knauff, Thomas, *After Solo*, Knauff & Grove, 1995, pp. 126 ff.

[4]Gertsen , Kai, *Off-Airport Landings*, April 2003 revision, self published, pp. 7 ff.

[5]Carswell, Dean, *Cross-Country Manual for Glider Pilots*, Soaring Books & Supplies, c. 2003, pp. 30 ff.

[6]Petmecky, Phil, *Breaking the Apron Strings*, Soaring Books & Supplies, c. 2003, pp. 6.

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

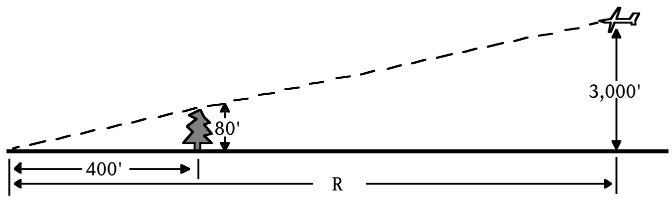

Figure 1 The situation that will describe our situation whenever we enter a low-altitude condition, according to our assumptions.

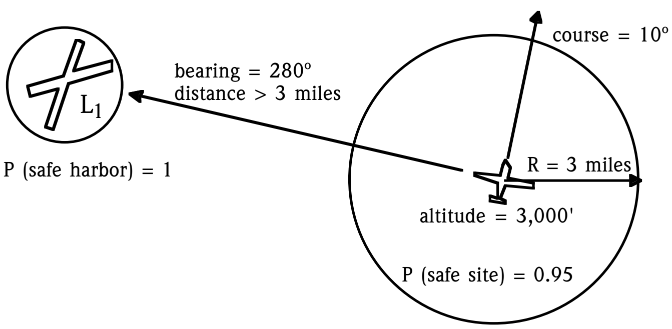

Figure 2 The change of course suggested upon entering a potential land-out situation.

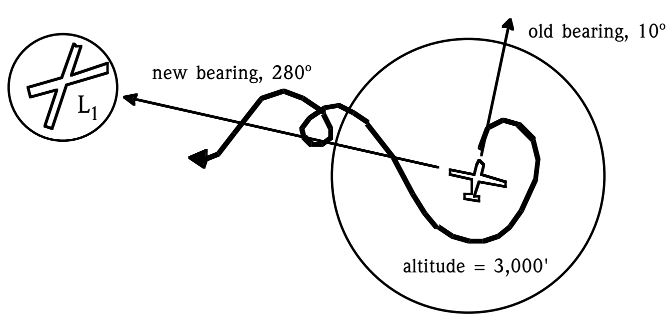

Figure 3 The change of course suggested upon entering a potential land-out situation.