180° Turnback Webinar Response to Questions

During this September 22, 2020, webinar, we were asked dozens of detailed questions regarding some of the factors that affect the outcome of this maneuver. Many of these factors can be considered during preflight planning and then used during the decision-making process in deciding whether to attempt a 180° turn back to the runway following a takeoff engine failure.

We would strongly encourage you to fly the test cards described in the webinar at EAA.org/TestCards and then scan these results in an email to FTM@eaa.org. We've received over a dozen completed sets of test cards already, and we plan to share these very interesting results with the EAA community in the future. The optimum response to this very interesting issue is continuing to evolve, especially with your input, and we sincerely appreciate your interest!

The responses to questions have been grouped and summarized below.

Choice of Bank Angle / Stall

Tradeoffs during the turn back to the runway include bank angle (G) and the airspeed the turn is performed at. These tradeoffs will be the subject of an upcoming article in *Sport Aviation*, so stay tuned for additional information coming in response to a number of several great questions raised during our September 22 webinar on this subject, including the following:

- One asked why we modeled a 45-degree bank turn, what about more or less?
- Another hypothesized that the turn takes longer at 30 degrees of bank but loss of lift is greater at 45.
- Still another noted that a steeper bank would result in less altitude loss and also keep you closer to the runway because of reduced turning radius.

So what's the right way to think about the turning portion of the turnback maneuver? A few rules of thumb:

- The turn rate is significant in that the longer an aircraft spends in a descending turn, the greater the altitude loss. Compare in the figure below 90 knots at 30 degrees to 60 knots at 45 degrees for the combined bank angle and airspeed effect: a reduction in turn radius of (1246-316)= 930 feet, with the lower speed and higher bank resulting in 2.5 times the turn rate. This is a major contributor to total altitude lost. If you want to try some of your own numbers you can use this website calculator: http://www.aviationwebdevelopment.com/samples/rateandradiusofturncalculator.aspx

Bank angle	Airspeed			
	60	75	90	120
	Turn radius (in feet)			
30	553	863	1246	2212
45	316	498	717	1276
	Turn rate (in degrees/second)			
30	10.5	8.4	7.0	5.3
45	18.2	14.5	12.1	9.1

- Aerodynamicists have indeed proven that altitude loss is greater past 45 degrees of bank, and that in the vast majority of cases, the optimum bank angle is between 40-50 degrees, balancing high descent rates at high bank angles with lower total time in the turn.
- With the tighter radius of turn you end up *laterally* closer to the runway *centerline* at the end of the turn, meaning the total degrees of turn to line up with the runway is less, so less total altitude lost in turning. This is a fairly small factor.

So is best glide, Vg, a safe speed for a 45-degree bank turn? Can we or should we be slower than Vg in the turn to minimize the turn radius? The answer is difficult to generalize, depends on the aircraft, and again is best determined by knowing what your power off stall speed is at 45 degrees of bank (go check it in flight) and ensuring you maintain ***at least*** 5 percent margin above that speed in the turn. In most aircraft Vg will meet this criteria. What you will also learn by flying the 45 degree bank power off turn is that you will need greater nose-down pitch to maintain your target speed in the turn.

Vx vs Vy

Every choice in preflight planning involves making tradeoffs. For example, reducing fuel load reduces takeoff gross weight, resulting in a shorter takeoff roll and improved climb performance, but it reduces the range of the aircraft and may require additional fuel stops.

Vx is defined as the best angle of climb speed (e.g., maximum angle of climb over the ground), and Vy is defined as the best rate of climb speed (e.g., maximum altitude gained during a period of time).

The Flight Test Manual (FTM) test cards are designed to determine Vy, and can also be used to determine Vx. The climb speed to be used immediately after takeoff has many factors to consider.

Many questions were received regarded the choice of Vx vs Vy as the initial climb speed. Some of the tradeoffs between these two choices are:

Vx

- Vx should be used when there is an obstacle to clear, and then a choice can be made whether or not to accelerate to Vy

- Climbing at Vx can significantly reduce the down range distance the aircraft covers during initial climbout
- Using Vx slightly reduces the down range distance by eliminating the distance to accelerate to Vy
- Vx may adversely affect engine cooling
- Vx is closer to the aircraft's wings level stall speed, and should be used with caution, especially during gusty or turbulent conditions
- Vx reduces visibility over the nose
- A turn at Vx back to the runway has a smaller turn radius than a turn at Vy (but is closer to the stall speed)
- Some pilots are not as comfortable climbing at Vx as they are at Vy
- For a C-172, climbing at Vx (59 KIAS) instead of Vy (73 KIAS) reduces the distance from the runway by 1380 ft/minute downrange.

Vy

- Vy provides a greater margin over the wings level stall speed
- Vy provides slightly more time to react to an unexpected engine failure
- Vy provides improved visibility over the nose during climb out
- Vy is closer to Vg (best glide speed) in higher performance aircraft, allowing for easier transitions to a glide if required
- Vy provides better engine cooling

Right now, the Takeoff Advisor uses whatever speed a pilot has tested for (Vy or Vx). The pilot might even choose to create two profiles, one with Vx and the other with Vy. Whether a Vx or Vy profile is optimum for a specific aircraft requires further testing and study.

Rule of Thumb Questions

The altitude where you can successfully complete a 180-degree turn following engine failure varies with many different factors, including wind, temperature, and aircraft weight. There is no single rule of thumb that you can count on, but consider as a mental starting point your ability to make a 180-degree turn from the downwind (1,000 feet AGL), with power at idle, and land from that approach. If there are no good places to land straight ahead after takeoff, starting a turn toward favorable areas is recommended, which reduces the amount of turn needed to return to the takeoff runway.

If you are flying from a non-towered airport, keep in mind the current FAA guidance, contained in AC60-99B:

> **11.8 Turning Crosswind.** Airplanes remaining in the traffic pattern should not commence a turn to the crosswind leg until beyond the departure end of the runway and within 300 feet below traffic pattern altitude. Pilots should make the turn to the downwind leg at the traffic pattern altitude.
>
> **11.9 Departing the Pattern.** When departing the traffic pattern, airplanes should continue straight out or exit with a 45-degree left turn (right turn for right traffic pattern) beyond the departure end of the runway after reaching traffic pattern altitude. Pilots need to be aware of any traffic entering the traffic pattern before commencing a turn.

If you are flying from a tower-controlled airport, with no good places to land if the engine fails, you can request a turn after takeoff to increase your ability to return to the takeoff runway.

To develop the Takeoff Advisor, testing is done at altitude with the engine at idle. For most piston-engine airplanes, there is a small amount of end play on the crankshaft. When the engine is producing thrust, the crankshaft will be at the forward limit of the end play and the propeller will be pulling the airplane through the air. With the engine at idle, it will be at the aft limit of the end play and no longer producing thrust. Testing will be similar to a completely failed engine with a wind-milling propeller.

In a large percentage of cases where the engine failed on takeoff, the problem was fuel-related. The engine continued to windmill after it failed. In some cases, there was a complete mechanical failure, the engine seized, and the propeller stopped. If this happens, there will be additional drag compared to a windmilling propeller. The actual drag due to the propeller will vary between aircraft equipped with fixed pitched props or constant speed props, and whether the propeller continues to rotate or is able to be feathered (or moved to high pitch/low RPM). Because every airplane is different, and due to the risk involved in testing with a stopped propeller, the Takeoff Advisor guidance will intentionally be conservative.

General Technique Questions

One of the new test cards has you test your aircraft during an engine out 180-degree turn, and a 360-degree turn. The altitude lost in these turns is a very important consideration for engine out glides in any phase of flight and would be very useful when descending over an emergency field. The Takeoff Advisor uses this data to develop an “altitude lost/degree of turn” factor which is used for all heading changes following an engine failure. In most cases, an actual return to the airfield following an engine failure requires a turn of approximately 190-220 degrees of heading change (in no wind conditions). Many pilots offset their after-takeoff climb on the downwind side of the runway, which reduces the total distance required to turn back considerably in a strong crosswind. If not offsetting due to crosswind, any turnback towards the takeoff runway should be made towards the crosswind to reduce the overall distance traveled.

The Takeoff Advisor is designed to be more accurate than Brian Schiff’s rule of thumb, and to utilize actual flight test data from your own aircraft and your own skills. While safety factors must be applied to the final calculation of measured data (based on the variations seen in the measurements), we must also be careful not to apply too many factors such that the pilot is only left with the option of landing straight ahead. In this case, the pilot’s only other alternative is to land in the suburbs.

It is also important to note that, in a certified aircraft, the pilot’s operating handbook publishes best-case performance for a brand-new aircraft, brand-new engine, at maximum gross weight, at standard sea-level conditions. These tests were flown by a highly experienced test pilot performing multiple runs, rejecting data that was not flown perfectly. Similar results are published for some kit aircraft. It is very likely that the actual performance of most aircraft in actual use will have significantly reduced performance, especially at non-sea level density altitudes, and therefore using actual data for your aircraft/engine combination should result in a more realistic result. The Takeoff Advisor does not currently have any data that adjusts glide performance with an actual engine failure (versus a windmilling engine), and obtaining this data obviously significantly increases the risk level of flight test. In any case, some margin of safety should always be applied to any preflight planning to compensate for unknown factors.

The actual glide speed of the aircraft is not significant in performance, it is the aircraft's glide angle. The same is true for the climb speed — the climb angle is the significant factor, not the actual speed for Vx or Vy.

Should a 180-degree turn be attempted with partial power? If the aircraft is capable of making the turn with a complete engine failure, a partial power loss should result in an improved likelihood of success. However, this question is very much dependent on the specific aircraft/engine combination and cannot be answered for all aircraft types.

A STOL kit would allow the aircraft to takeoff in a shorter distance, and climb at slower airspeed (and probably a better climb angle). However, STOL kits tend to have more drag, so actual flight test data looking at climb and glide performance would be necessary to see how the total result would affect your ability to return to the runway.

Some pilots asked about the use of flaps during the glide: in general, the glide angle decreases (worse performance) with flaps, especially at higher flap deflection angles. It would be a good idea to know your own aircraft's performance with flaps, as it may be very useful in eliminating excess altitude during an engine failure after the runway is made. In any case, flaps result in a lower stall speed and are useful if extended just before touchdown in an emergency situation.

The Takeoff Advisor

Takeoff Advisor allows you to define ANY departure route. It also allows you to choose to crab into the wind to maintain a course or to maintain heading and drift with the wind. A departure course of flying into the crosswind could easily be constructed with Takeoff Advisor; it also projects ALL glide paths to ALL runways, not just the straight-out departure and return.

Currently, no data exists showing the difference in performance following an engine failure during the initial climb for various types of aircraft. One of the new test cards asks pilots to perform a test without a delay, and repeat the test with the results of a delayed response following an unexpected engine failure. The results of these tests will be provided in future outputs from this project.

<u>Data Recording Questions</u>

Can I use something else to record my turnback besides ForeFlight?

We would like to receive data from as many airplanes as possible and welcome working with all pilots to adapt our data processing to your devices. Here are a few guidelines to follow.

<u>Equipment Required to Record your Turnbacks</u>

The procedure "Recording Your Turnbacks" says to use one of the following to record your flight:

• *ForeFlight with attached Sentry (Wi-Fi), Stratus (Wi-Fi), GDL 50 (Bluetooth), or a similar external device that provides GPS/AHRS data (see Foreflight manual).*

• *G1000 using an SD card to store the flight data (see G1000 manual).*

• *A similar device that will record GPS and AHRS data at a rate of 1 record per second.*

Many pilots have asked if other EFBs or other devices could be used other than ForeFlight, or a G1000. The answer is yes, and we have already worked with pilots to accept their recordings. There are only a few requirements that need to be met to make the data useful to the data analysis tools:

1. The device needs to accurately capture data at a rate of at least 1 "record" per second (see Data Capture Rate below). Higher data capture rates are OK as well.
2. Each data record should contain the following information:
   - Timestamp — Date, Time (hour, minutes, seconds) with at least 1 second resolution. Decimal seconds are preferred.
   - Latitude / Longitude — The location of the airplane at that moment.
   - Altitude — MSL altitude.
   - Course — The course along the ground. Should reference true north.
   - Speed_kts — The speed along the ground in knots.
   - Bank Angle — (optional)
   - Pitch Angle — (optional)

Format of the Data

The data can come in the form of a .CSV file, or a KML File, or any other format. It just needs to be text (human-readable) so a proper driver can be written to read the data and convert it to our standard output.

Data Capture Rate

The recording procedure contains the warning not to use ForeFlight alone, but to use it connected to an external device such as a Sentry or Straus.

• *NOTE: ForeFlight must be connected (via Wi-Fi or Bluetooth) to an external device to record the rapid turnbacks smoothly. It cannot be used alone without the external device connected for this exercise.*

Using a device which cannot capture data at a high rate accurately will result in turnback recordings that are "jittery" when viewed in Google Earth. For example:

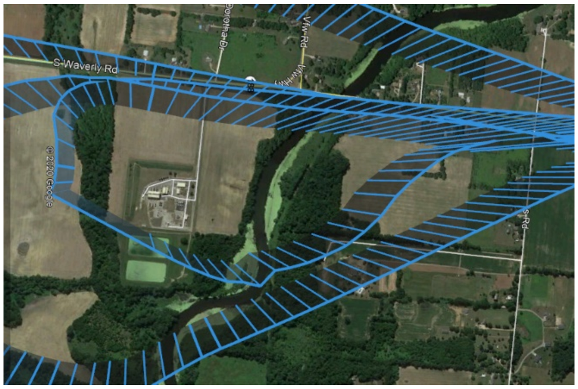

Figure 1. ForeFlight alone

Figure 2. ForeFlight with Sentry

We have tried both ForeFlight alone and ForeFlight connected to a Scout. Both have shown to be inadequate. During the rapid, tight turnbacks, Foreflight alone (or ForeFlight with the Scout) are not able to give accurate location readings. The path of the flight appears to be "jittery" around the turn. Using ForeFlight with a Sentry (for example), will result in smooth curves during the turnback.

To test your device, try recording a turnback maneuver, and if possible, display the data on Google Earth (not in the manufacturer's display since the data path may be smoothed to make it look good). If the turnback curves appear smooth, the data capture rate is adequate.

If you have any specific questions or would like to send in sample data for us to evaluate, please contact RickM@InflightMetrics.com.

Can Takeoff Advisor be applied to homebuilt aircraft and light-sport aircraft?

We hope to receive data from as many airplane types as possible including homebuilt aircraft and light-sport aircraft, and have already received some. We think it would be extremely valuable to the flying community to provide data showing the differences between various types of airplanes' abilities to perform the turnback maneuver successfully.

So far, Takeoff Advisor currently has a limited number of airplanes in the database. The actual flight data of these limited number of airplanes were used to develop the model. Now that it's been shown that the model can be used to describe real flight data, we hope to significantly expand the data for all types of general aviation airplanes.

Additionally, the concept of Takeoff Advisor is to allow a pilot to measure the basic flight characteristics of their airplane and input them into the app. This allows Takeoff Advisor to be used for any type of general aviation airplane including home-builts and even one-of-a-kind planes. By putting the performance characteristics of your own airplane into Takeoff Advisor you would be reflecting your skill sets at the time (of altitude lost during a turn, for example) and the airplane's actual performance.

Also, if you would like to explore various turnback techniques, such as using Vx instead of Vy for the climb, or 30-degree banks instead of 45-degree banks for the turnback, Takeoff Advisor will allow you to put in various profiles. You can then visualize the differences.

Which criteria most affect the outcome?

This is an excellent question. There have been many discussions, papers written, and testing of aircraft around the question of the optimal turn and how to minimize the altitude lost in the turn. With these studies, there are discussions around whether or not the increased risk of a higher bank turn results in a significant benefit for turnbacks. Other papers focus on the effects of using Vx vs Vy to increase the climb angle.

The Takeoff Advisor model shows that several factors must come together to result in a successful return to the runway. The major factors include the takeoff distance, the climb angle, the distance traveled due to the startle effect, the altitude lost in the turn, the glide angle, and the runway length we are trying to reach. One could argue that they are all important, as the links in a chain. If any one is sub-optimized, the plane might not make it back.

But to more precisely answer the question, we will consider typical numbers from a Cessna 172 and try to show which of the parts of the flight affect the outcome the most. Variations to each part of the flight will be compared to the distance we can improve the return by optimizing the turn (i.e. by comparing the distance gained to the runway using two different bank angles). Although the values used may not be exactly precise for a given airplane (even these values are for a theoretical typical 172), the calculations serve to illustrate the relative sensitivity each factor has compared to each other. The reader can apply their own values to see if they get similar results.

Take a typical (yet hypothetical) set of values for a 172 with a given scenario:

- Takeoff distance 700 feet
- Climb angle 5.71 degrees (1:10 climb ratio)
- Climb IAS 73 knots
- Startle time 5 seconds
- Altitude lost in a 30-degree bank turn 400 feet
- Altitude lost in a 45-degree bank turn 350 feet
- Glide angle 4.76 degrees (1:12 glide ratio)
- Runway length 4,000 feet
- Altitude that power was lost 1,000 feet

Note: Again, the reader can substitute their own values, especially the altitude savings for the 45-degree bank vs the 30-degree bank. Here we are using a 50-foot savings by using the 45-degree bank.

If the savings in altitude is 50 feet by executing a 45-degree bank instead of a 30-degree bank, at a 1:12 glide ratio, the plane would land 600 feet closer to the runway.

Using the 600-foot difference to compare the other factors, we can now calculate how the other factors would have to vary to yield a 600-foot equivalent distance.

Some factors have a one-to-one relationship: If the takeoff distance was 600 feet more, the plane would land 600 feet further from the end of the runway; an 86 percent increase in the normal distance, in this example.

If the runway was 600 feet shorter, the plane would land 600 feet shorter from the end of the runway.

To go 600 feet further by increasing the startle time, at 73 knots, the startle time would need to be increased by 4.87 seconds. This would be approximately a 100 percent increase from the 5 second typical startle time.

But what would the airplane's climb angle need to be reduced by to result in a 600-foot further distance from the runway at 1000 feet? The angle would only have to be decreased to 5.39 degrees (1:10.6 climb ratio) from the normal 5.71 degrees (1:10 climb ratio) to make the 600-foot distance; a difference of only 0.320 degrees. The distance from the runway, for a given altitude, is extremely sensitive to the climb angle. This is probably the most sensitive factor.

In the example shown in the presentation, we showed that two Cessna 172's experienced a difference of 1.3 degrees climb angle even at the same Vy, resulting in approximately a 3,000 foot difference in distances from the runway at 1000 feet. This would far outweigh any gains by optimizing the altitude lost in the turn. Although every factor is important, if the climb angle is sub-optimal, all other factors may not matter.

Likewise, to land 600 feet further from the runway, the glide angle would only need to decrease from 4.76 degrees (1:12 glide ratio) to 5.19 degrees (1:11 glide ratio) a difference of 0.43 degrees. This factor would be the second most sensitive.

One additional note: Wind also highly affects the return to the runway. In the above example, a wind of only 2.2 knots would also result in a 600-foot difference in the distance back to the runway.

This example serves to illustrate that although all factors work together to give a final result of where the plane lands, some may be far more sensitive to change than others. In this example with climb and glide ratios of 1:10 and 1:12 the angles are fairly small, resulting in a large sensitivity to change. For other model planes where the climb angles are much higher, other factors may be more sensitive to change. Before over-focusing our optimizations around any one factor we should consider its sensitivity compared to the other factors.

NTSB Data Clarification – Does the NTSB Database include events with no injuries?

The NTSB database contains airplane accident events that resulted in harm to either the pilot, passengers (or other persons), or airplane. With each event, the database tracks the level of injury to the pilot, passengers, or others as well as the severity of harm to the airplane. It does not contain events in which there was no harm to the people involved or the aorplane.

So those who turned back at a low altitude and did not stall still may have sustained injuries to the people or airplane. These are recorded in the database. The data shows that the fatality rates for these cases (no stall) were low, even though other damage was done.

Identifying the number of successful turnbacks can be difficult since there is no obligation on the part of the pilot to report an event that does not result in damage to the airplane or persons.

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