Glide Testing: a Paired Samples Experiment

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On July 23, 1983, Air Canada Flight 143—a brand new Boeing 767—grew eerily quiet as it traveled above the Canadian countryside. In ordering fuel for the flight, the pilot had made a unit conversion error and, consequently, received an insufficient fuel supply. With no airport in the vicinity, the pilot directed his aircraft at a speed of 220 knots toward an abandoned airbase in Gimli, Manitoba, and braced for an emergency landing.

What can a pilot in command of such an unintentional glider do to reach the most forgiving terrain? Upon engine failure, a powered airplane does not just fall from the sky. Rather, the craft becomes a glider, albeit a rather inefficient one. To maximize the horizontal distance traveled, or "glide distance," a pilot must use the cockpit yoke control to achieve the optimal airspeed. Furthermore, any reduction in the drag force that opposes motion through the air also will increase the glide distance. For example, the landing gear and the flaps should be retracted until needed for landing. But, what about the propeller on a propeller-driven airplane? Should the pilot let it spin freely or stop it from spinning?

Flying and Gliding

First, let's take a look at how an airplane flies. See Figure 1. Propeller-driven aircraft use an engine and rotating propeller to generate a thrust force parallel to the flight path that moves the wings through the air. Drag acts opposite to the thrust. As an airplane wing moves through the air, it creates a lift force perpendicular to the path of the airplane. Once the plane is airborne, thrust is not necessary to create the lift, but, in its absence or without an air current rising from below, the plane will descend necessarily as the weight force pulls it toward the Earth.

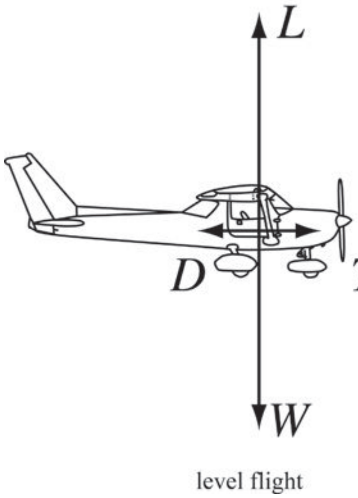

Figure 1. In level flight, the opposing forces of lift *(L)* and weight *(W)* and thrust *(T)* and drag *(D)* cancel each other.

By Newton's law of motion for straight, unaccelerated flight including climbs and descents, the lift, weight, thrust, and drag forces sum to zero. In straight and level flight, lift is approximately weight and thrust is approximately drag. With engine failure, as we see in Figure 2, the thrust goes to zero and the weight can be decomposed into the component that opposes drag, W sin , and that which opposes lift, W cos , where represents the glide angle or angle between the flight path and horizontal and W is the weight of the airplane. For small angles , we have that sin is approximately (denoted sin ~ and cos ~ 1). Letting L denote lift and D denote drag, then $L \sim D$, ~ D/L, and any reduction in drag or drag to lift ratio will reduce the glide angle and extend the glide distance.

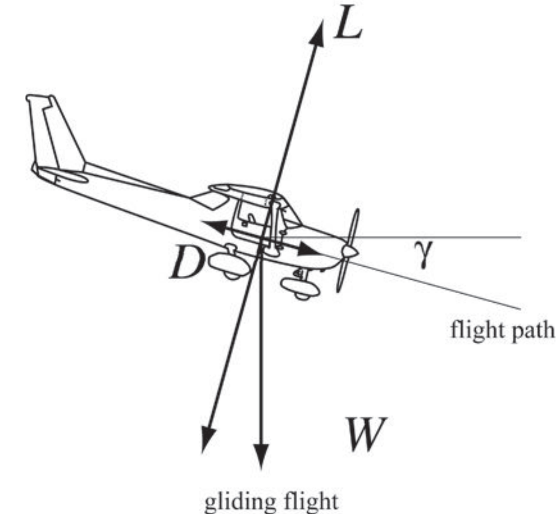

Figure 2. In gliding flight, with zero thrust in gliding flight, the components of weight parallel and perpendicular to the flight path oppose drag and lift, respectively.

Suppose an airplane experiences an engine failure at height h feet above the ground, as in Figure 3. The airplane will glide toward the ground with an airspeed—the rate traveled along the glide path—governed by the yoke control in the cockpit. Pushing the yoke forward moves the nose down and increases the airspeed, and pulling back affects the opposite. To increase the likelihood of reaching an airport or a suitable alternative place to land, the pilot needs to maximize the glide distance x. We can see that, again for small angles, $\sim \tan = h/x$, so maximizing the glide ratio x/h involves maximizing the lift-to-drag ratio L/D. For each aircraft at a specific weight, there is one airspeed, v_{bg}, or best glide airspeed, that achieves this goal.

Although manufacturers of small, single-engine aircraft are, in fact, required to make this determination, the Code of Federal Regulations does not require that

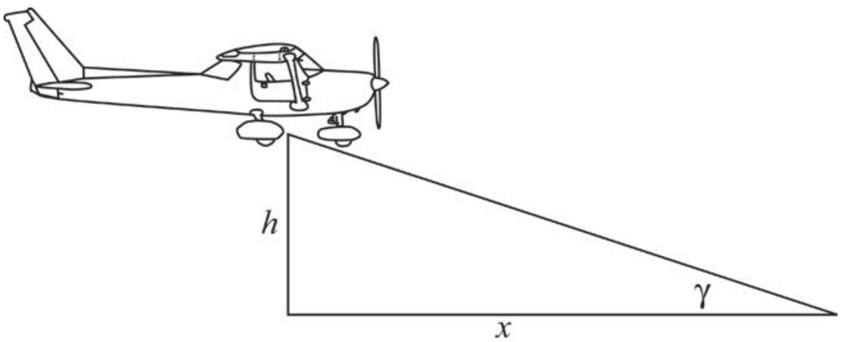

Figure 3: To maximize the glide ratio *x/h*, maximize the lift-to-drag ratio *L/D*.

v_{bg} be determined for transport category aircraft. Thus, the pilot of the "Gimli Glider," as it is now called, had to take a guess that the best glide airspeed for a Boeing 767 is 220 knots.

Stopping the Propeller

Besides holding the yoke to achieve the best glide airspeed, is there anything else a pilot can do to extend the glide? Reducing the drag force can help. Upon engine failure in a propeller-driven aircraft, the propeller will continue to turn, or "windmill," as air passes over it. Aviation literature has long reported that drag from this turning propeller is responsible for a considerable decrease in performance. In fact, twin-engine aircraft are equipped with a mechanism to stop the propeller of an inoperative engine. Although single-engine aircraft are not designed with such capability, it's reasonable to expect that drag reduction from a stopped propeller will increase the horizontal distance achieved per unit of altitude loss – the glide ratio. For single-engine airplanes, the glide ratio is approximately 10:1. Any increase in this ratio offers an unfortunate pilot beset with engine failure a greater likelihood of reaching an airport or terrain suitable for an emergency landing. By pulling the yoke control back, the pilot can force the propeller to stop by slowing the airflow over it. Once it has stopped, internal engine friction guarantees that only speeds much higher than v_{bg} will allow it to turn once more.

How much will glide ratio increase with a stopped propeller? Although Cessna Aircraft reputedly witnessed a 20% increase in the two-seat 150 model and the same for the four-seat Cessna 172, we found little information on the tests. Barry Schiff reports an increase in glide ratio in a test he conducted using the four-seat Cessna 182 in his AOPA Pilot article, "Stopping the Propeller: Buying the Most Distance When the Engine Quits."

To estimate the impact of the drag associated with a windmilling propeller, we planned 25 test flights in a 1979 two-seat Cessna 152, the successor to the 150 model, at Franklin County Airport, Sewanee, Tennessee. Sewanee is located on the edge of the Cumberland Plateau in southeast Tennessee. We selected days with calm winds so disturbances caused when higher winds meet the plateau were minimized. A matched-pairs experimental design held the promise of minimizing the effects of these and other atmospheric phenomena, assuming conditions would not vary too much for consecutive runs.

Don't Try This at Home

Stopping the propeller of a single-engine airplane is not for the faint of heart. In our tests, with the throttle closed and the plane's nose held high, the airframe of the Cessna 152 shuddered as its once invisible propeller was coaxed to a halt. The airspeed at which this is possible is much lower than the best glide airspeed, and is close to the airspeed at which a plane does, in fact, fall from the sky. After the propeller came to a halt, the nose was lowered to achieve the desired airspeed. After the test glide was completed, we lowered the nose to achieve an airspeed sufficient to start the propeller turning again. Pilots wishing to experience such a flight condition should attempt the procedure only with an instructor who has such experience in that make and model of aircraft.

The Test

Glide distance in a no-wind situation can be shown to be proportional to the time spent in the descent. Therefore, the test compares the difference in time to descend in the two conditions. We climbed above 8,000 feet mean sea level (MSL), stabilized at the best glide airspeed of 60 knots with the propeller either windmilling or stopped, and recorded the time to descend to 7,200 feet MSL. We then repeated the glide with the propeller in the other condition. The order that the propeller was either windmilling or stopped was randomized. Blinding was not possible in our experiment, as it is impossible to keep that condition from the pilot because a stopped propeller is difficult to ignore and results in an airplane that is uncharacteristically quiet. The times for 27 paired trials are shown in Table 1.

Table 1. Glide Times for 27 Trials and Their Paired Differences for all 27 trials

Trial	Windmilling	Stopped	Difference	Trial	Windmilling	Stopped	Difference
1	73.4	82.3	8.9	15	64.2	82.5	18.3
2	68.9	75.8	6.9	16	67.5	81.1	13.7
3	74.1	75.7	1.6	17	71.2	72.3	1.1
4	71.7	71.7	0.0	18	75.6	77.7	2.1
5	74.2	68.8	-5.4	19	73.1	82.6	9.5
6	63.5	74.2	10.8	20	77.4	79.5	2.1
7	64.4	78.0	13.6	21	77.0	82.3	5.3
8	60.9	68.5	7.6	22	77.8	79.5	1.7
9	79.5	90.6	11.1	23	77.0	79.7	2.7
10	74.5	81.9	7.4	24	72.3	73.4	1.1
11	76.5	72.9	-3.6	25	69.2	76.0	6.8
12	70.3	75.7	5.4	26	63.9	74.2	10.3
13	71.3	77.6	6.3	27	70.3	79.0	8.7
14	72.7	174.3	101.6				

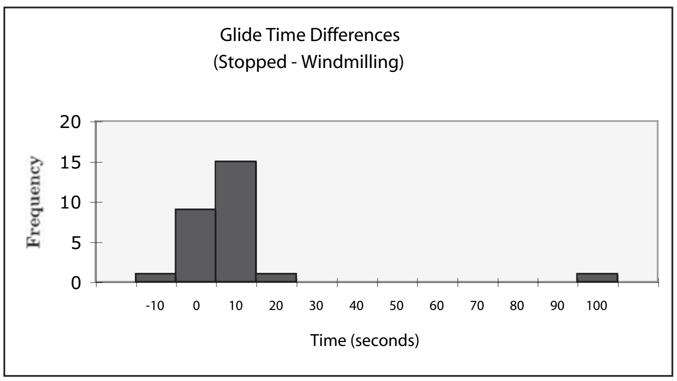

Figure 4. Histogram of glide time differences for all 27 trials

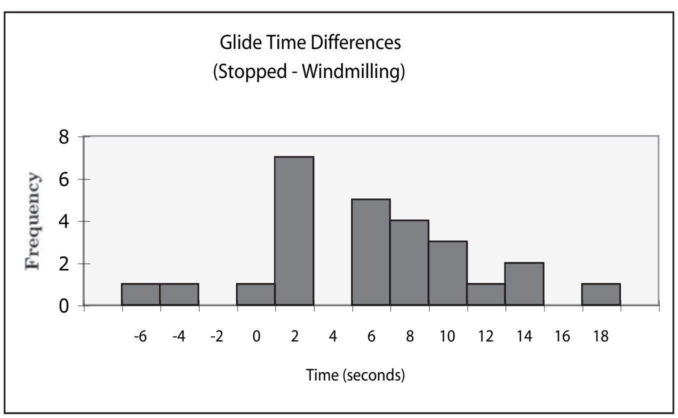

Figure 5. Histogram of glide time differences after removing trial 14

Data Analysis

Figure 4 shows the frequency of the difference in times for each pair of trials. We can see that trial 14 constitutes a distinct outlier. We knew something was amiss when we stopped the propeller and glided down 800 feet in almost three minutes, more than twice the usual time. Whether the cause was an unusual updraft from wind hitting the plateau below us or a giant hand holding us up, we wish such good luck on any pilot unfortunate enough to experience a genuine engine-out condition.

Judging trial 14 to be due to abnormal conditions and, thus, a nonrepresentative event, we can remove it from the data. Then, the data appear to be roughly symmetric with no obvious outliers, so using t-procedures is justified (see Figure 5).

Our null hypothesis is that the true mean difference in times to descend 800 feet (stopped minus windmilling) is zero versus the alternative that the difference is positive. Using Microsoft Excel's paired t-test procedure, Table 2 shows that a miniscule p-value of approximately 0.0000052 allows us to reject the null hypothesis and conclude that the airplane we tested will glide farther with a stopped propeller following engine failure.

Table 2. Data Analysis of Means for Paired Samples Using Microsoft Excel

t-Test: Paired Two Sample for Means		
	Stopped	Windmilling
Mean	77.44	71.52
Variance	24.12	25.62
Observations	26	26
Hypothesized Mean Difference	0	
df	25	
t Stat	5.49426	
one-tail probability	0.0000052	
t Critical one-tail	1.70814	

In our test, the mean increase in flight time was 5.9 seconds. A 95% confidence interval for the difference in seconds is [3.7, 8.1]. In this test, we therefore witnessed an increase in the mean glide distance of approximately 8.3%, as glide distance is proportional to time of decent.

Try This at Home

Use the data above to see if the difference we witnessed in the Cessna 152 is consistent with the 20% that was reported for other Cessna aircraft. After you have done your analysis, compare your results to our analysis on Page 13.

Conclusion

So, when the engine quits, stop that prop! We have found highly persuasive evidence that stopping the propeller does improve glide performance and the pilot of a propeller-driven aircraft may want to consider this prospect if altitude and experience permit. Incidentally, our experimental results in a Cessna 152 are consistent with trials conducted in the author's 1973 Piper Cherokee 140.

The captain of Flight 143, an experienced glider and aerobatic instructor, atoned for his mathematical slip by executing a successful emergency landing at Manitoba's air base. On the Gimli Glider, windmilling turbine fans in the jet engines—similar to propellers—created drag that hindered the plane's glide performance. Perhaps a fan-stopping mechanism on jet engines is in order. Fortunately, engine failure incidents, like those resulting from fuel exhaustion, are exceedingly rare in commercial aviation. Still, information on best glide airspeed and procedures that minimize drag would have been useful to the pilot of the Gimli Glider, or any other pilot in such unfortunate circumstances. ■

Editor's Note: *The author would like to thank William K. Kershner, who provided the Cessna 152 and the idea for the test. These results appear in his book,* The Flight Instructor's Manual.

Additional Reading

Federal Aviation Administration. (2005). *Code of Federal Regulations, Title 14: Aeronautics and Space.* Available at *http://faa.gov/regulations_policies.*

Kershner, William K. (2002). *The Flight Instructor's Manual (4th ed.).* Blackwell Publishing.

Schiff, Barry. (1995). "Stopping the Propeller: Buying the Most Distance When the Engine Quits." *AOPA Pilot,* Aircraft Owners and Pilots Association.

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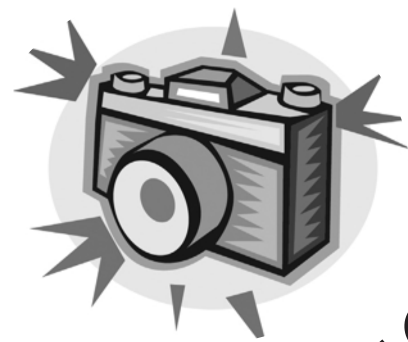
STATISTICAL SNAPSHOT



What Does a t-Test Test?

As one step in making a new drug, a pharmaceutical company uses micro-organisms to produce batches of a protein. The target yield of such batches is $_0 = 100$. It is a problem if is either too small or too large. We want to know if the target yield is being achieved.

With observed yields from $n = 10$ batches, we use the standard t-test of H_0: $= 100$ against H_A: $\neq 100$ at the 5% level, rejecting H_0 if the absolute value of

$$t = \frac{\bar{X} - {}_0}{S / \sqrt{n}}$$

exceeds 2.262. Assuming $_0 = 100$, for what values of the sample mean $\bar{X}$ and standard deviation S is H_0 rejected? You might suppose we reject mainly when a sample happens to have 'too large' a value of $\bar{X} - {}_0$.

Figure 1 plots S against $\bar{X}$ for 10,000 simulated samples of size 10 from a normal population with $= 100$ and $= 10$, emphasizing (by darker dots) the roughly 500 samples for which H_0 is wrongly rejected. Figure 1 shows that values of S that are too small can play an important role in incorrect rejection. By 'too small,' we are saying the sample standard deviation is less than the population standard deviation, when we are assuming they are equal.

An important fact about normal data is that $\bar{X}$ and S are independent. In the same figure, the cloud of all 10,000 simulated points illustrates this principle. There is no clear pattern of association between $\bar{X}$ and S. Also, their correlation is 0 within the accuracy of the simulation.