Aerodynamics Puzzler Index

The Aerodynamics Puzzler is a recurring article series in the SSA's Soaring Magazine by Steve Platt. I highly recommend it. Each article starts out with a quiz based on the aerodynamic principle at hand. Then a full detailed answer for each question and some additional insight is provided.

All SSA members have access to the entire Soaring Magazine archive and can view each of these articles at http://magazine.ssa.org (click on "Start Exploring"). These articles are reprinted with the permission of the publisher of Soaring Magazine.

Note that many topics are addressed several times with a slightly different twist each time. Be sure to reference all of the articles on the subject of your choice.

GLIDER AERODYNAMICS PUZZLER

BY STEVE PLATT

For those with a more technical bent, Steve Platt will be offering periodic "Puzzlers" for readers related to glider aerodynamics. The answers to these puzzlers lead to greater understanding of how gliders fly, and more efficient flying. See if your intuition or knowledge matches up with the answers. — Editor

Turning Flight

The glider aerodynamics puzzler is intended to stimulate your thinking about soaring and refresh your understanding of glider aerodynamics and soaring optimization. The correct answers, with detailed explanations, follow the questions. Have fun.

Questions 1–3: Most glider pilots understand the first principles of optimizing wings level glider flight, i.e. maximizing time aloft; maximizing distance in a headwind, tailwind, sink, lift, or combinations thereof; and maximizing speed between thermals (MacCready theory). What is less well understood is the impact to glider performance in turning flight.

QUESTION 1: An SGS 1-26 is flying at 35 kt and a PW-6 flying twice as fast at 70 kt. Both commence a 30 degrees bank turn at the same time. Which glider completes a 180 degrees turn first?

A. The PW-6 completes 180 degrees when the SGS 1-26 completes 90 degrees.

B. The SGS 1-26 completes 180 degrees first.

C. The PW-6 and the SGS 1-26 complete the 180 turn at the same time.

D. The SGS 1-26 completes the 180 degrees when the PW-6 completes 90 degrees.

E. The PW-6 completes 180 degrees first.

F. None of the above.

QUESTION 2: To complete a 360 degrees coordinated circling turn in ANY glider, what angle of bank and airspeed will result in the smallest loss of altitude in still air, i.e., smallest loss of energy?

A. 25 degrees of bank and level flight minimum sink speed plus 5%.

B. 35 degrees of bank and level flight minimum sink speed plus 10%.

C. 45 degrees of bank and level flight minimum sink speed plus 18.9%.

D. 55 degrees of bank and level flight minimum sink speed plus 20%.

E. 60 degrees of bank and level flight minimum sink speed plus 30%.

QUESTION 3: An SGS 1-26 and a PW-6 both complete a 360 turn (circle) using a 30 degrees bank angle and the optimum min. sink speed for the 30 degrees of bank for each glider (i.e., min sink speed + 7.5%) in still air (no lift or sink). Which glider loses more altitude completing a 360 degrees circle, the PW-6 or 126?

A. The PW-6 loses more altitude.

B. The SGS 1-26 loses more altitude.

C. The PW-6 and the SGS 1-26 lose the same altitude.

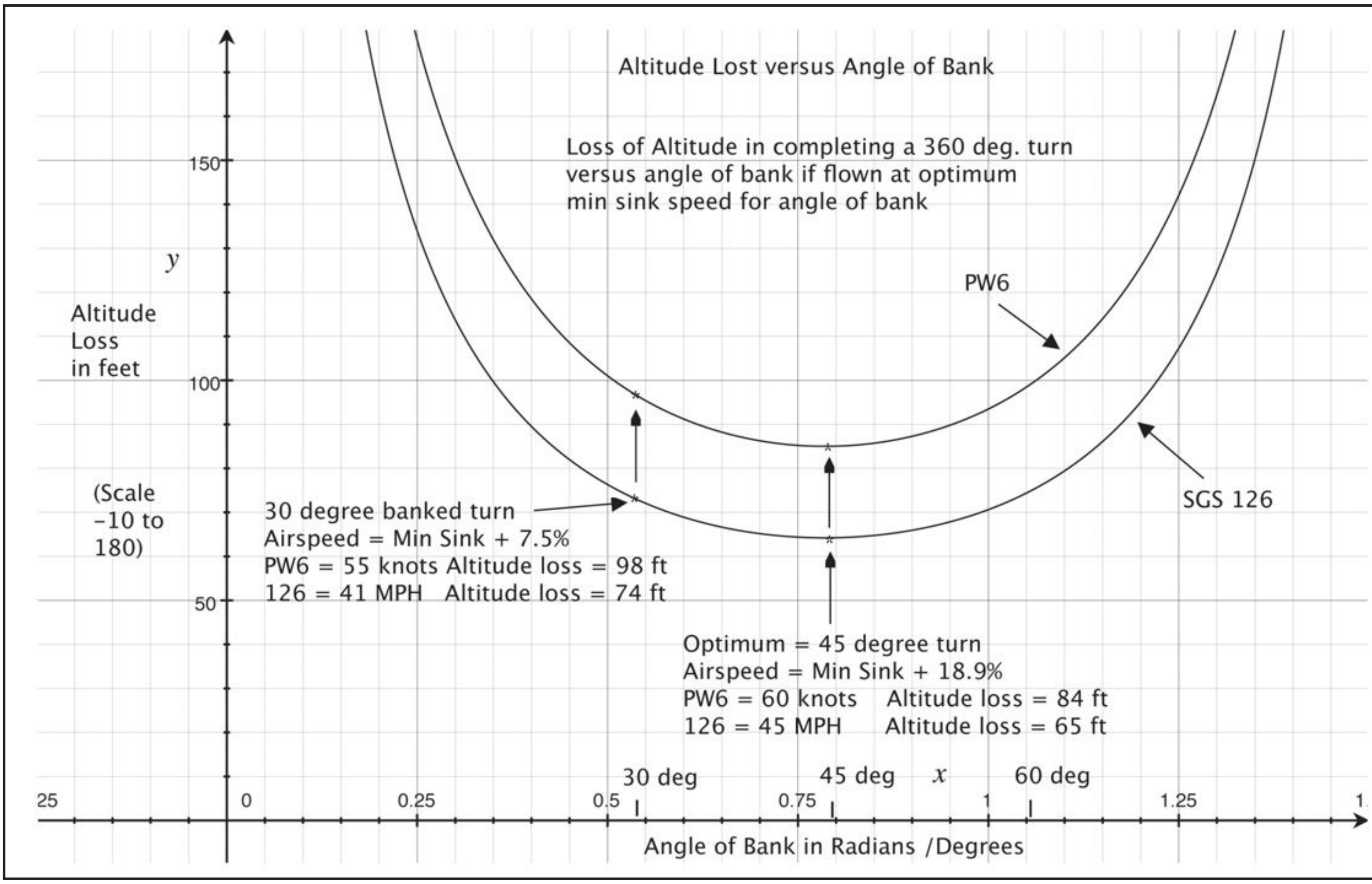
D. Neither glider loses any altitude.

Explanations

Question 1: Perhaps the most important factor to remember in turning flight is the radius of turn is proportional to the SQUARE of the airspeed. (For those interested in the details, the derivation for the radius of turn equation for all gliders – and airplanes with wings – is shown in "How to Optimize Thermaling Flight in Gliders," Appendix 1 of the May 2017 issue of *Soaring* magazine, pg 37.) The radius of turn plays a very important factor in minimizing energy loss in a turn as well as optimizing net climb rates in summer thermals. For question 1, since both the PW-6 and the 126 use the same bank angle, the only variable that affects the relative radius of turn is airspeed. Since the PW-6 airspeed is twice that of the 126, the radius of turn is FOUR times the radius of the 126. Therefore, while the PW-6 is traveling twice as fast, it must go FOUR times the distance to complete a 180 degrees turn … so, when the 126 completes the 180 degrees turn, the PW-6 is only halfway around, or at the 90 degrees point. The answer to question 1 is D. Answer B is runner up.

Question 2: The answer for question 2 is C, 45 degrees. The mathematical proof requires some calculus; however, the graph on the next page is more instructive. It shows the loss of altitude on the vertical axis to complete a 360 degrees turn versus the angle of bank on the horizontal axis for both a SGS 1-26 and PW-6. Notice that for ALL angles of bank, if flown at the optimum minimum sink speed for the angle of bank, the SGS 1-26 loses less altitude than the PW-6 and the minimum loss for both gliders (and all gliders) occurs at 45 degrees of bank.

Question 3: The wings level minimum sink speed for the PW-6 is ~50 kt with a minimum sink rate of ~150 ft/minute. Likewise, the wings level minimum sink speed for the 126 is ~ 33 kt with a minimum sink rate of ~175 ft/minute. Like question 1, if both gliders use a 30 degrees bank turn, the only variable that affects the relative radius of turn is airspeed. Since the optimum min sink speed for a 30 degrees bank turn is 7.5% above the level flight min sink speed for both gliders, the optimum speed to complete the 360 degrees turn for the PW-6 is 54 kt and 35 kt for the 126. Using the equation for radius of turn [$R = v^2 / (g^* \mathrm{Tan(ang)})$], the radius of turn for the 1-26 is 193 ft,



Above: Altitude Lost versus Angle of Bank in 360 turn.

while the radius of turn for the PW-6 is 443 ft – 2.3 times greater! So, while the PW-6 is traveling 52% faster (54 kt versus 35 kt), it must travel 130% farther, and even though the level flight sink rate of the 1-26 is greater (175 ft/min versus 150 ft/min for the PW-6) at the sink rate at 30 degrees of bank this is more than offset by the greater distance and time it takes the PW-6 to complete the circle. The answer to question 3 is A, the PW-6 loses more altitude and energy completing a 360 degrees circle than the SGS 1-26.

Lessons Learned

Airspeed is crucial in determining the radius of turn. And radius of turn is crucial in optimizing energy conservation in turning flight. Knowing the minimum sink speed for various angles of bank in turning flight (e.g. thermaling) is key to optimizing climbing flight. For example, for ALL gliders in a 30 degrees coordinated bank turn, the minimum sink speed becomes the level flight min sink speed plus 7.5%. For ALL gliders in a 45 degrees coordinated bank turn, the minimum sink speed becomes the level flight min sink speed plus 18.9%. While thermaling, it is quite easy for a high speed/high performance ship (e.g. Discus, Ventus, ASG 29, LS4, etc.) to circle outside a narrow thermal or near the boundary of the thermal, while the slow, "low performance" ship (e.g. SGS 1-26) out-climbs the high performance ships near the core of the thermal. Frequently, radius of turn matters.

Angle of Bank (Degrees)	0	10	20	30	40	45	50	60
% Increase in Minimum Sink Speed	0	0.7%	3.2%	7.5%	14%	18.9%	25%	41%
% Increase in Minimum Sink Rate	0	2.4%	9.8%	24%	49%	68%	94%	183%

Bank Angle vs. Increase in Minimum Sink Speed and Minimum Sink Rate.

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AERODYNAMICS PUZZLER

BY STEVE PLATT

Weight & Balance Effect on Performance

The glider aerodynamics puzzler is intended to stimulate your thinking about soaring and refresh your understanding of glider aerodynamics and soaring optimization. The correct answers with detailed explanations follow the questions. Have fun.

Questions 1 & 2: Glider pilots understand the effect of weight on glider performance; adding weight (ballast) shifts the flight polar down and to the right. While the best L/D glide ratio remains the same, the best L/D glide ratio speed increases. This, of course, is particularly useful for cross-country flight and competition when lift conditions are strong. Why is the speed benefit a function of the lift conditions? Because climb performance decreases with added weight. The benefit of added glide speed can easily be offset by degraded climb performance. What may come as a surprise to some is the magnitude of the change in key performance parameters with the addition or subtraction of weight (i.e., adding ballast to a single seat ship or flying a dual seat glider solo).

Question 1: For a typical dual seat, medium performance glider [with a best L/D glide ratio of ~34 at ~56 kt at gross weight (e.g., PW-6 or ASK-21)], how much can the best L/D speed decrease at minimum weight, i.e., dual ship flown solo?

A. ~5%
B. ~10%
C. ~15%
D. ~20%
E. ~25%

Question 2: For a typical two-seat, medium performance glider [with a best L/D glide ratio of ~34 at ~56 kt (e.g. PW-6 or ASK-21)], how much can climb performance improve in a typical summer thermal (i.e., Standard British Thermal with 4.2 kt of air mass lift at the core decreasing parabolically to zero at a radius of 1,000 ft) if flown solo at minimum weight versus dual at gross weight? Assume the glider is flown optimally, perfectly centered and flown at the optimum bank angle and airspeed.

A. ~10%
B. ~15%
C. ~20%
D. ~25%
E. ~30%

Explanations

Question 1: First, for ALL gliders with fixed wings (gliders that do not have "re-shapeable" wings, reflex flaps, or flaperons, etc.), the effect of a wing loading (weight) change shifts the flight polar with a simple formula: All polar coordinates shift by a factor equal to the square root of the ratio of the weight change. (References 1 & 2). The coordinates Shift Factor = $(W1/W2)^{0.5}$. This can best be seen by example. Shown in Figure 1 is the flight polar for a PW-6 at gross weight (1,220 lb, dual) and at minimum weight (900 lb, single). The coordinates Shift Factor = $(900/1220)^{0.5}$ = 0.859. Notice that while the gross weight best L/D speed equals 56 kt, at minimum weight (~900 lb) the best L/D speed decreases to 48 kt! A decrease of ~14.2%. The answer to Question 1 is C. What is also very pertinent is that the minimum sink speed decreases from 51 kt at gross weight to 44 kt at minimum weight!

Question 2: As described in the article "How to Optimize Thermaling Flight in Gliders" in the May 2017 issue of *Soaring* magazine, weight matters in optimizing net climb performance in two significant ways. First, as shown in Figure 1, both the minimum sink speed and the minimum sink rate decrease with decreasing weight. While the reduced sink rate helps at lower weights, so does the lower minimum sink speed. Shown in Figure 2, overlaid on the

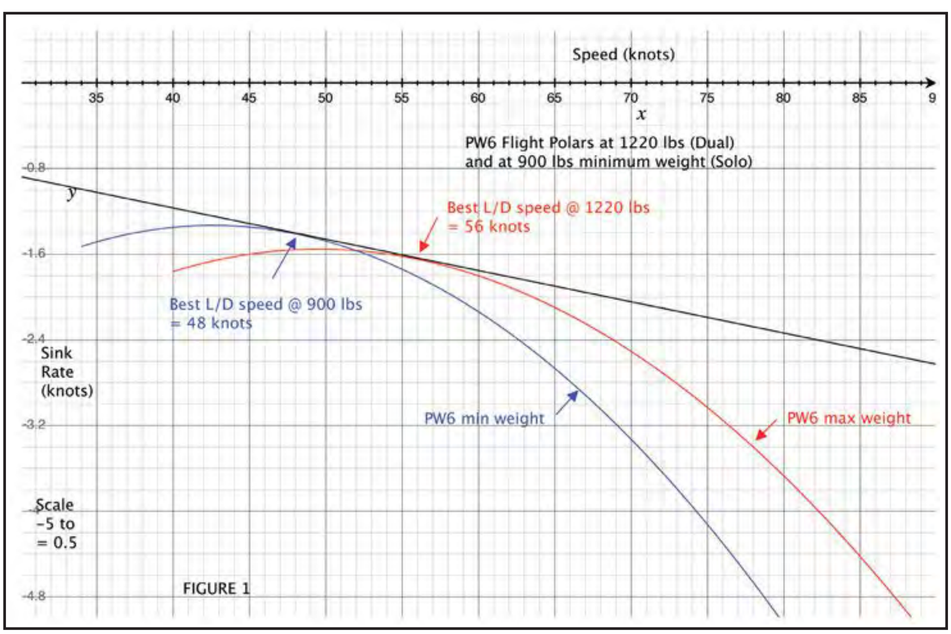

Figure 1 – PW-6 flight polars at 1,220 lb.

profile of a Standard British Thermal, is the sink rate magnitude of a PW-6 at gross weight and minimum weight as a function of the radius of turn (and therefore, as a function of the airspeed and angle of bank) if flown optimally, centered and flown at the minimum sink speed for the angle of bank). Notice that at any radius of turn, the sink rate of the minimum weight configuration is better, and, as a result, the net climb rate (i.e., the thermal profile minus the sink rate of the glider) is considerably better for ALL radii of turns. If flown optimally, the peak net climb rate at gross weight is ~1.6 kt (~160 ft/min) versus a peak net climb rate of ~2.1 kt (~210 ft/min) at minimum weight … or an improvement at the lower weight of greater than 30%! The answer to Question 2 is E. 30%.

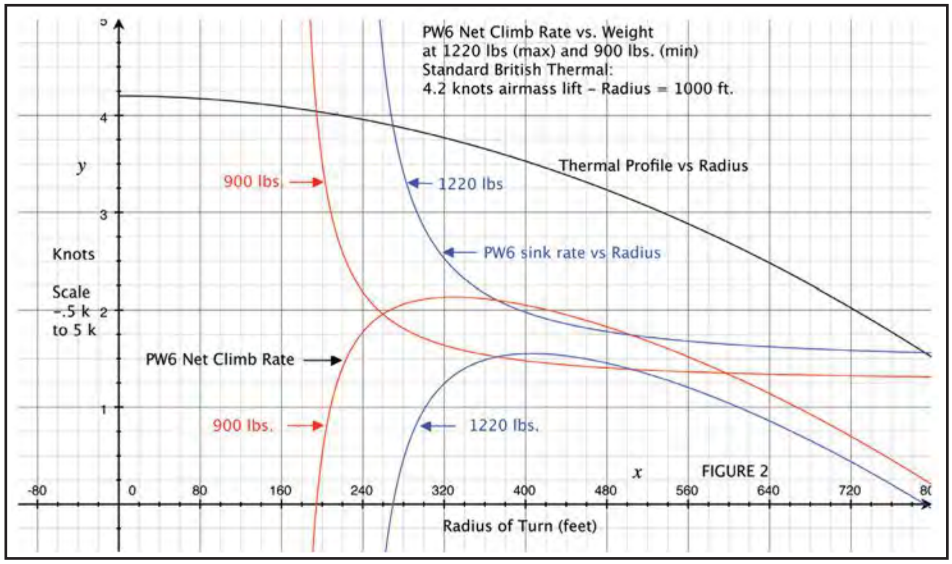

Figure 2 – PW-6 net climb rate vs. weight.

Lessons learned

Weight matters in all key glider performance parameters. While glider manufacturers typically publish the flight polar at gross weight and perhaps with ballast if an option, the flight polar at minimum weight (or for a dual ship flown solo) can be significantly different. For ALL gliders at lower weights, the level flight stall speed decreases, the minimum sink speed decreases, and the best L/D speed decreases. And for cross-country flyers, the no wind MacCready speeds decrease as well. For the PW-6 example above, the MacCready 4 speed (no wind) decreases from 70 kt at gross weight to ~62 kt at minimum weight. Not an insignificant difference. For glider pilots with installed navigation computers, it is imperative that the flight polar be entered correctly for the appropriate operating weight, or the software have a setting adjustment for the current operating weight. Otherwise, the speed to fly computations will be, by definition, incorrect.

Reference 1: Reichmann, H. (1993). *Cross-Country Soaring* (7th ed.), p 122. Hobbs, NM: Soaring Society of America. (ISBN: 1-883813-01-8).

Reference 2: Welch, A., Welch, L., & Irving, F. G. (1977). *The Complete Soaring Pilot's Handbook*, p 266. NY: D. McKay Co. (ISBN: 0-679-50718-3).

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AERODYNAMICS PUZZLER

BY STEVE PLATT

Thermaling

The Glider Aerodynamics Puzzler is intended to stimulate your thinking about soaring and refresh your understanding of glider aerodynamics and soaring optimization. The correct answers with detailed explanations follow the questions. Have fun.

Question 1

On a gorgeous Saturday morning, with an excellent thermal forecast, you are planning on a local recreational glider flight in one of your club's ships. Upon arrival at the airport one of your friends, discussing thermaling techniques, states that she can "outclimb you in any one of the club ships" and challenges you to a thermaling climb contest. She offers you the choice of the two available gliders: a Schweizer 1-26 with a best L/D of 23 and a PW6 with a best L/D of 34. The rules are simple: She will fly whichever ship you do not select. You both will enter the same thermal at the same start altitude at approximately the same time. The thermals are reported to be standard summer thermals (i.e., 4.2 kt air mass lift at the core decreasing parabolically to zero at a radius of 1,000 ft). Which ship do you select? Assuming both pilots fly their ships optimally, and both are centered, who will win and why?

A. The low performance Schweizer 1-26 will outclimb the PW6.

B. The PW6 will outclimb the Schweizer 1-26.

C. Both gliders will perform the same in the same thermal.

D. None of the above.

Explanation

Refer to figure 1. (Reference: May 2017 issue *Soaring* magazine, pg 32, "How to Optimize Thermaling Flight in Gliders"). For all gliders, the optimum bank angle and airspeed to thermal at is dependent upon several factors: the thermal strength at the core, the thermal width (radius) and profile, and the flight polar of the particular glider, especially the level flight minimum sink speed and minimum sink rate … and, of course, how well centered the glider remains. For normal thermals (i.e., strongest at the core decreasing parabolically to the periphery, as shown in figure 1), radius of turn matters. For all gliders the radius of turn is a function of the square of the airspeed and the tangent of the angle of bank as follows: radius = v^2 / (g * Tan(ang)). If a glider flown optimally (i.e., at the minimum sink speed for the chosen angle of bank) flies at too shallow an angle of bank, the radius of turn is large and the glider operates in the weakest part of the thermal close to the periphery or, worse case, circles the thermal. On the other hand, if the glider is flown at too steep an angle of bank, the sink rate increases rapidly with increasing bank angle, more than defeating the benefit of a tight radius of turn. Therefore, for each glider, and for each thermal profile, there is an optimum angle of bank and airspeed (radius) to use to maximize the net climb rate. In the case of Question 1, the Schweizer 1-26 with a level flight minimum sink speed of 38 mph (33 kt) has a significantly shorter radius of turn than the PW6 with its minimum sink speed of 51 kt. Although the level flight min. sink rate for the Schweizer 1-26 (~1.75 kt) is considerable greater than the min. sink rate of the PW6 (~1.5 kt), the tight radius of turn of the slower ship more than offsets the min. sink rate of the higher performance ship. The answer to Question 1 is A. The 1-26 will outclimb the PW6 with both ships centered and flown optimally. As an aside, notice that the peak net climb rate for the 1-26 occurs at only 22 degrees of bank while the peak net climb rate for the PW6 occurs at 34 degrees of bank. The aerodynamics of thermaling is fascinating.

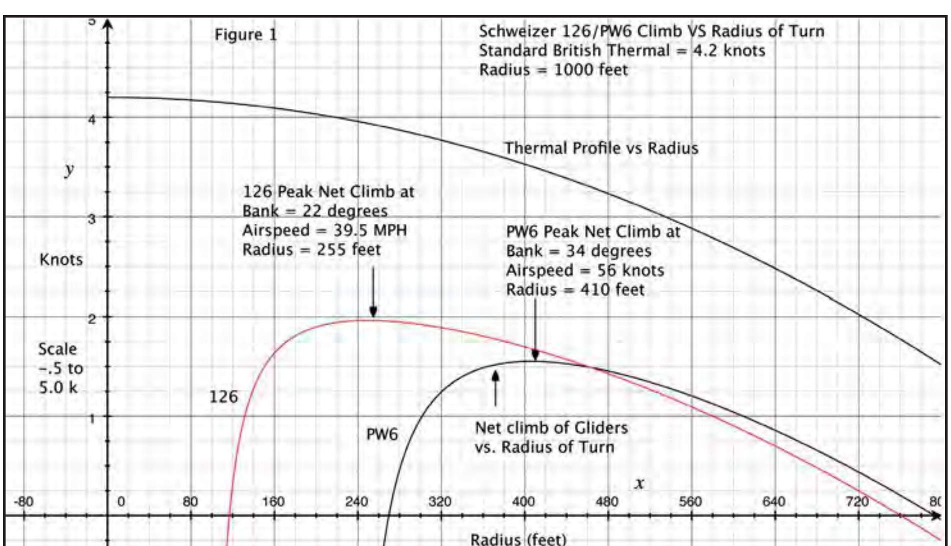

Figure 1: Lesson learned – Radius of turn matters while thermaling. Using the appropriate airspeed and angle of bank while thermaling can enhance net climb performance.

Question 2

You are on the final leg of a cross-country event flying your Super Wingbat 6000 glider. The Super Wingbat's key performance numbers for your operating weight are as follows. (The Super Wingbat's flight polar is shown in figure 2.)

Minimum sink speed = 51 kt.

Best L/D glide ratio = 34.

Best L/D speed = 56 kt.

MacCready 2 speed = 63 kt (no wind).

MacCready 4 speed = 70 kt (no wind).

MacCready 6 speed = 76 kt (no wind).

It has been a glorious day. The thermal lift has been reliable and steady, yielding a net 4 kt, and you have been able to fly with classical MacCready technique all day. As you enter what you expect will be your final thermal prior to your final glide to your home airport, your on-board $9,000 color moving map GPS Navigation computer goes blank. The battery died. You recall before the screen went blank that your final leg is into a 20 kt direct headwind. Your old reliable backup variometer continues to indicate a steady 4 kt climb. Upon reaching the necessary altitude to depart the final thermal, what is the appropriate speed to fly to maximize your average speed (i.e., minimize time) for the final glide into the 20 kt headwind? (Assumption: neutral lift/sink during final glide.)

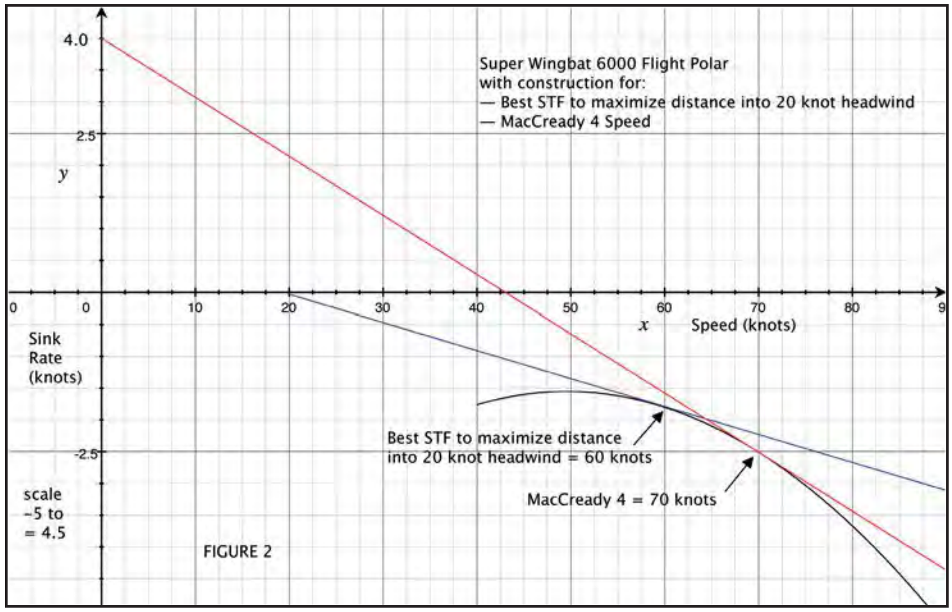

Figure 2: Best speed to fly in 20 kt headwind.

A. Best L/D speed 56 kt.

B. Best STF to maximize distance into 20 kt headwind = 60 kt.

C. Speed to fly = 70 kt.

D. Speed to fly = ~77 kt.

E. Speed to fly = ~82 kt.

Explanation

For the final climb, and the final glide, the headwind (or tailwind) must be taken into consideration for both for the minimum altitude at which the final thermal may be departed, and the optimum speed to fly to maximize average speed (i.e. minimize time). When the expected/actual net thermal climb rate is 4 kt, classical MacCready technique calls a MacCready 4 setting. Likewise, leaving a 4 kt thermal, the final glide into neutral air should be performed at a MacCready 4 setting as well. The optimum speed to fly to maximize average speed for the final climb and glide into a 20 kt headwind, AND the minimum altitude to depart the final thermal, must take the headwind (tailwind) into consideration. Normally, an onboard navigation computer can perform these calculations. However, it is useful to understand what the onboard processor is doing. The optimum speed to fly departing a

4 kt thermal into a 20 kt headwind is determined by the construction to the Super Wingbat flight polar as shown in figure 3. While the normal inter-thermal MacCready 4 speed for this glider is 70 kt (no wind), the optimum speed to fly for the final glide into a 20 kt headwind is ~77.5 kt. The answer to question 2 is D. ~77 kt.

About the author: *Steve Platt is a commercial pilot in single engine airplanes, single engine seaplanes, and gliders. He holds an instrument rating and is a Certificated Flight Instructor for airplanes, instruments, and gliders. He has logged over 4,000 flight hr including over 2,000 hr as a flight instructor. He is a retired IBM Engineering Manager and is a member of the Flight Instructor Staff at Sugarbush Soaring, Warren-Sugarbush Airport, Warren, VT.*

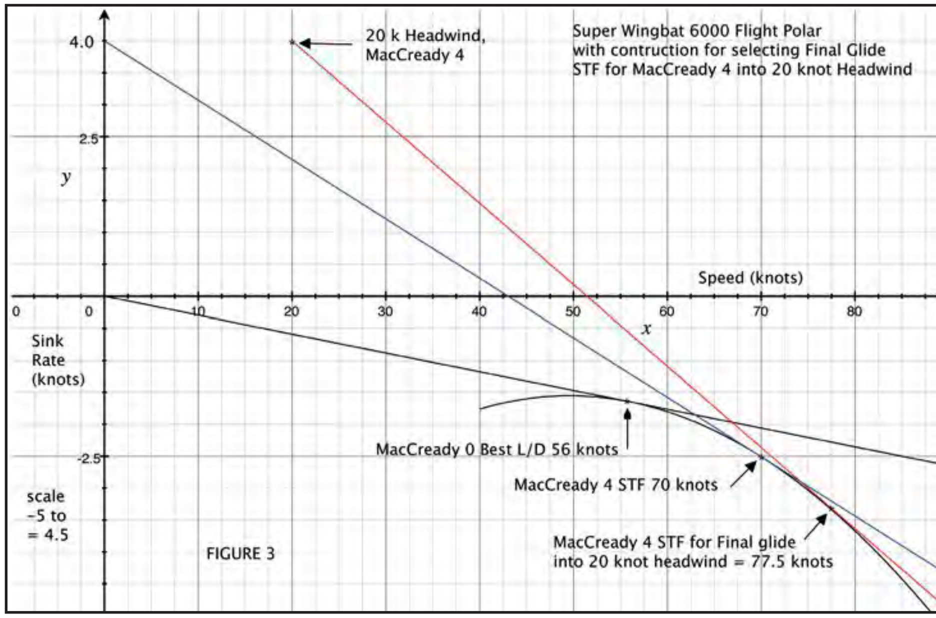

Figure 3: *Lesson learned – To optimize average speed for the final climb and final glide, the net average climb rate in the final thermal defines the appropriate MacCready setting. The final glide STF then is adjusted for the headwind (tailwind) which permits the calculation of the minimum altitude to the depart the final thermal. This can all accomplished by an appropriately programmed onboard computer. While it is quite inappropriate to be plotting tangents to flight polars in the cockpit, knowing one's flight polar and a few key parameter scenarios (i.e. key MacCready speeds and adjustments for final glides in 20 kt headwinds) can go a long way toward generating reasonably accurate speeds to fly for various scenarios when all the hardware fails. The alternative, of course, is to purchase and install a second battery!*

GLIDER AERODYNAMICS PUZZLER

BY STEVE PLATT

Race

The glider aerodynamics puzzler is intended to stimulate your thinking about soaring and refresh your understanding of glider aerodynamics and soaring optimization. The correct answers with detailed explanations follow the questions. Have fun.

Your soaring club hosts an annual "President's Cup" race. The event is an informal, fun, 35 miles, round robin event open to all members. There are three classes for low performance (best L/D glide ratio <28), medium performance (best L/D 28-37), and high performance (best L/D>37) ships so that everyone can participate, whether flying the training gliders (e.g. Schweizer 2-33, L23, PW-6) or the single-seat, high performance glass ships. Turn points are on the honor system. The event is only for fun and "bragging rights." The course is designed with conveniently located, uncontrolled, glider friendly airfields nearby. The event is designed for novices, recreational glider pilots, and student pilots with their instructors, as well as the serious cross-country and competition pilots. Each participant is given a 3,000 ft tow to the vicinity of the start gate and must proceed directly to the start. No thermaling prior to passing the start. All participants must finish at least 1,000 ft above the field prior to landing.

Question

You and your wife are the proud owners of a dual-seat PW-6. It is your wife's turn to run the race this year. She is an excellent glider pilot. In the preparation for the race, she asks you if she should fly the event solo at minimum weight (~900 lb), or with you in the back seat with some added ballast in the front to fly at max weight (~1,200 lb). The soaring forecast calls for very light winds aloft and standard summer thermals (i.e. Standard British thermals with 4.2 kt air mass lift at the core, decreasing parabolically to

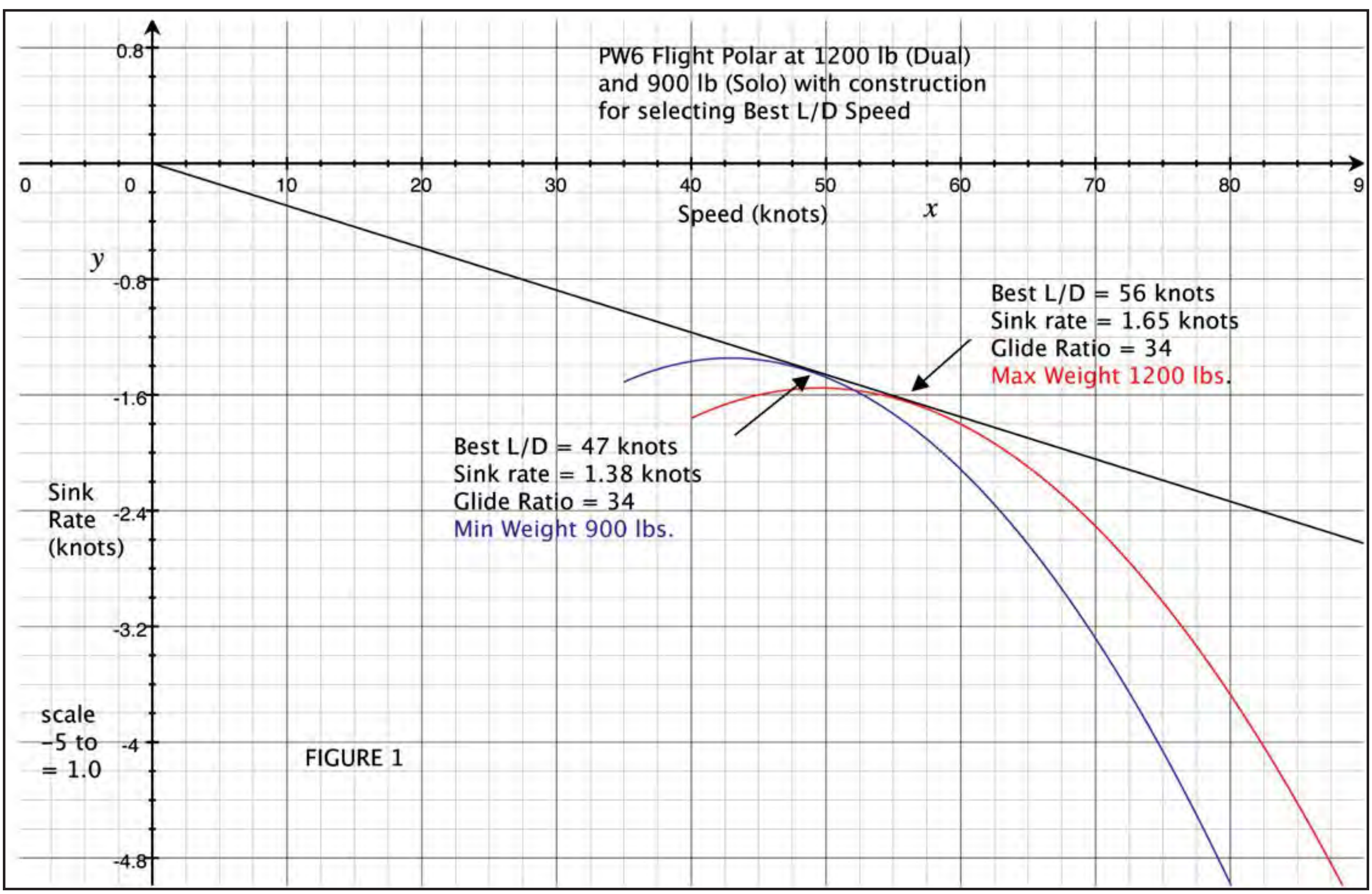

Figure 1

zero at a radius of 1,000 ft). The key performance characteristics of the PW-6 at gross weight are:

Min sink speed	51 kt
Min sink rate	148 ft/min
Best L/D speed	56 kt
Best L/D	34:1

The flight polars at 900 lb and 1,200 lb are shown in Figure 1. What do you tell your wife?

A. If flown optimally, the PW-6 should be faster around the course at max gross weight.

B. If flown optimally, the PW-6 should be faster around the course at minimum weight.

C. If flown optimally, the weight one way or the other should not matter.

Explanation

The answer to the question involves determining the tradeoff between the added speed operating at gross weight with poorer climb performance, versus the slower cruise performance at min weight with improved climb performance. To determine the climb performance difference, first the total energy (i.e. altitude required) to make it around the course must be calculated for both cases. Figure 2 shows the sink rate for both weight configurations versus radius of turn while thermaling at the minimum sink speed for each angle of bank overlaid on the profile of a Standard British thermal ... and the resulting net climb rate if centered in the thermal.

Notice that for all radii of turns, the lighter 900 lb configuration has a better net climb rate than the max weight configuration. If flown optimally, the 900 lb configuration achieves a peak net climb rate of 2.15 kt, while the max weight configuration achieves a peak net climb rate of 1.56 kt. Per classical MacCready theory, this then defines the MacCready setting for the flight, i.e. MacCready 2.1 for 900 lb and MacCready 1.6 for 1,200 lb. With the MacCready setting and the respective flight polars, the optimum speed to fly can be calculated. Shown in Figure 3 is the construction to determine the best STF to maximize average speed (no wind).

For the 900 lb weight, the best STF is 56 kt with an effective glide ratio of 30.2. For the 1,200 lb weight, the best STF is 62 kt with an effective glide ratio of 32.6. Note, in this scenario, the winds aloft are not a factor. If there were any significant headwind or tailwind component, this too would have to be taken into consideration in the determination of the best STF.

Using the effective glide ratio for each case, the total climb altitude necessary to complete the course can now be calculated. For the 900 lb weight, the total altitude required is 7,037 ft minus the 2,000 ft tow

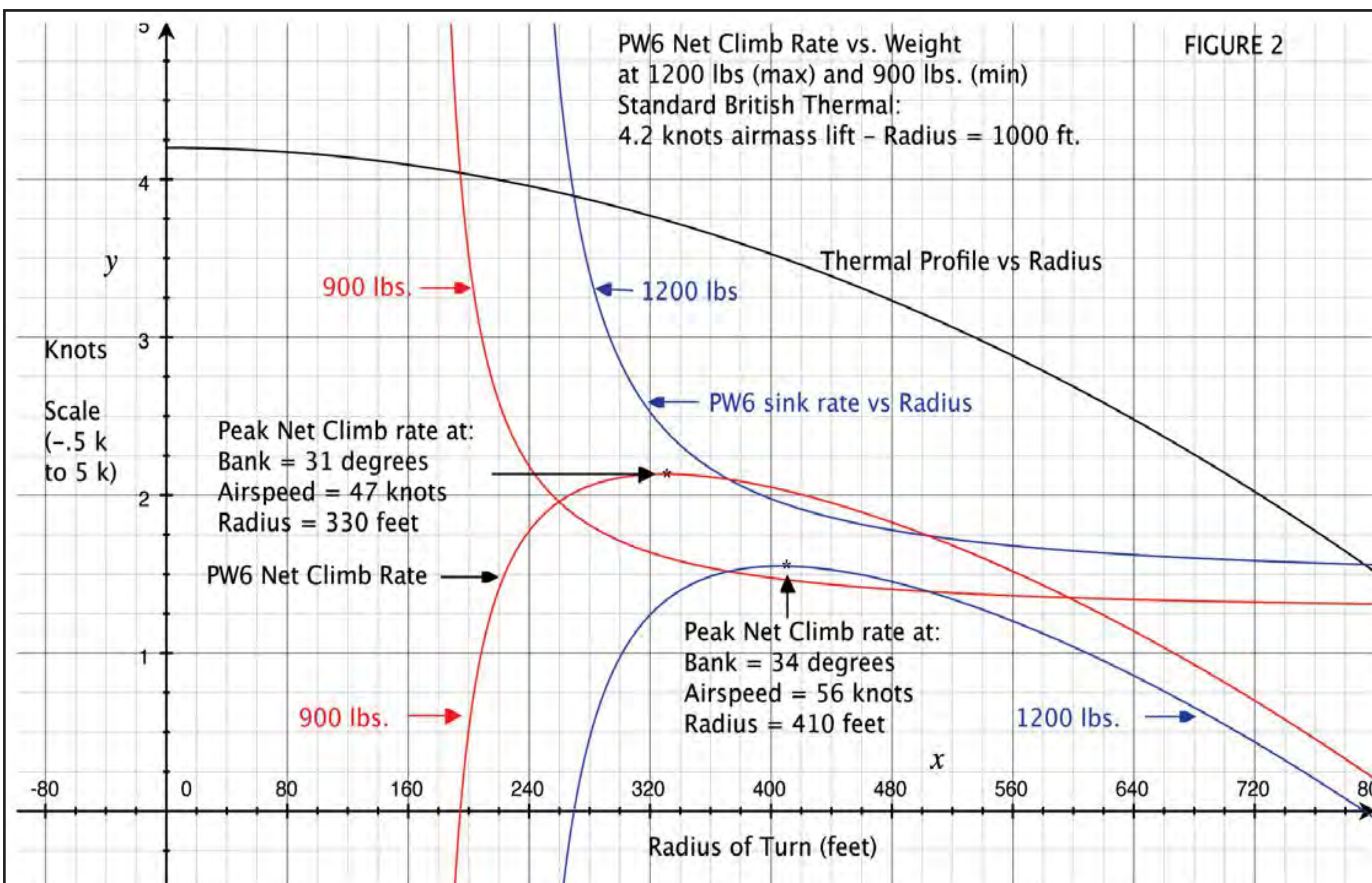

Figure 2

above the finish altitude = 5,037. For the 1,200 lb weight, the total altitude required is 6,519 ft minus the 2,000 ft tow above the finish altitude = 4,519. Therefore, if flown optimally, the climb time for the 900 lb weight is 23.14 minutes. The climb time for the 1,200 lb weight is 28.62 minutes. The time to glide the course distance, if flown at the appropriate MacCready speed, works out to be 37.50 minutes for the 900 lb weight and 33.87 minutes for the 1,200 lb weight. The total time works out to be 60.64 minutes for the 900 lb weight and 62.49 minutes for the 1,200 lb weight. Therefore, in this scenario, with only modest thermals, the advantage goes to the minimum weight configuration. No one can, or does, fly optimally 100% of the time. While this analysis is the absolute "best can do" perfect case, the results speak for themselves. The max weight configuration takes 1 minute 51 seconds longer (~3% longer) than the min weight configuration to complete the course. The answer to the question is B.

Lessons Learned

Weight matters. Decreasing weight reduces minimum sink speed and MacCready speeds, but increases climb performance. Increasing weight increases minimum sink speed and MacCready speeds, but decreases climb performance. The exact crossover decision depends upon the particular flight polar and the strength and profile of the thermals. However, as a general rule, it takes fairly strong lift conditions for the addition of ballast to provide a net benefit to average speeds. Narrow, weak thermals favor the light weight configuration. Strong, wide thermals move toward the higher weight configuration. Also, notice the difference in the min sink speeds (~7 kt) and the best MacCready STF (~6 kt) between the 900 and 1,200 lb weight configurations. Not insignificant. Weight matters in both climb performance and cruise performance. Min sink speed matters and the resultant optimum radius of turn matters while thermaling. Glider flight optimization is complex yet incredibly fascinating.

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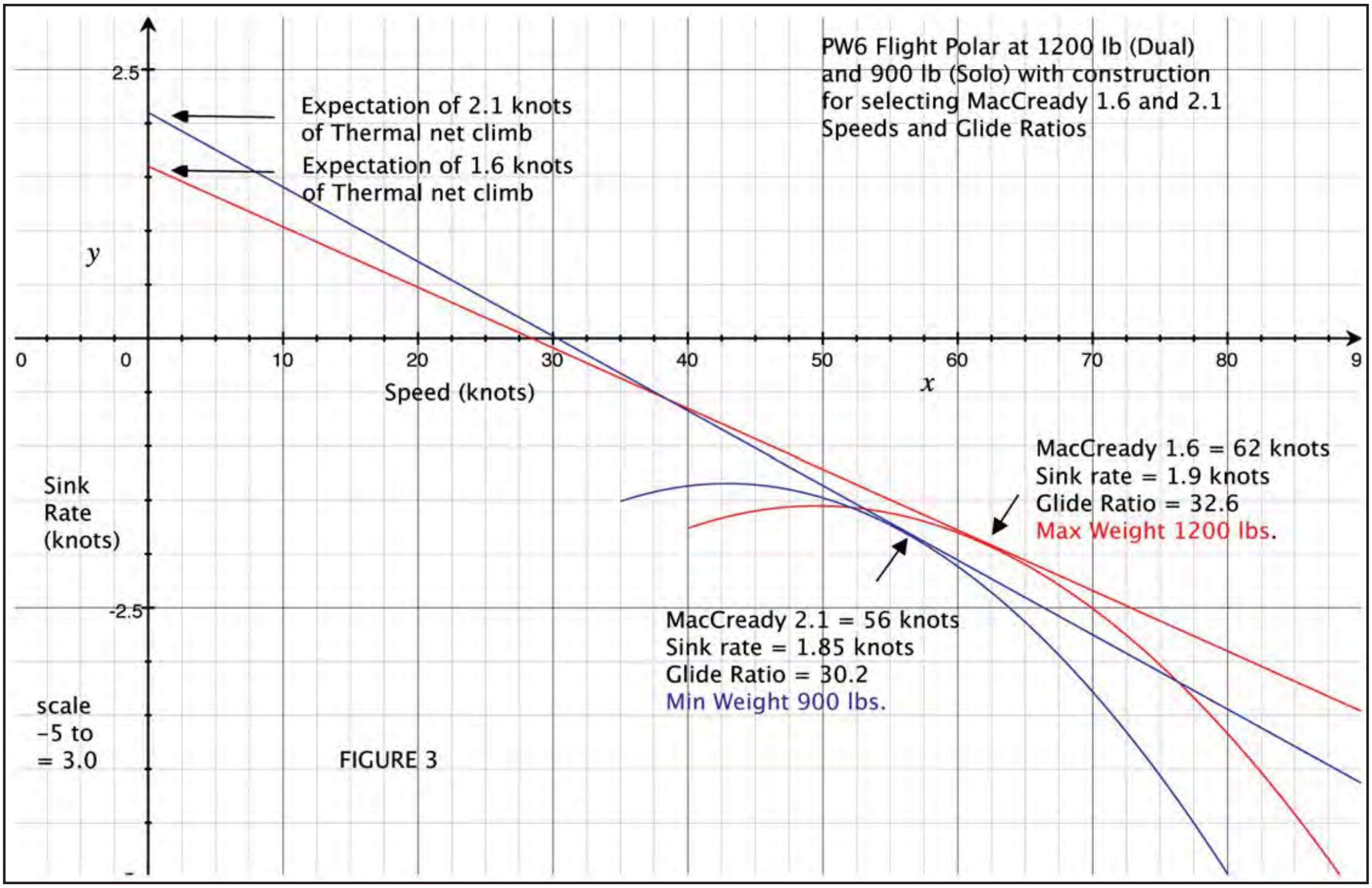


Figure 3

GLIDER AERODYNAMICS PUZZLER

BY STEVE PLATT

Winds

The Glider Aerodynamics Puzzler is intended to stimulate your thinking about soaring and refresh your understanding of glider aerodynamics and soaring optimization. The correct answers with detailed explanations follow the questions. Have fun.

Surface winds and winds aloft are a major factor in glider flight planning and operations. From the earliest flight lessons, neophyte glider pilots learn the effect of wind on both landing procedures and making it back to the airport. For some experienced glider pilots, the magnitude of the impact of headwinds/tailwinds on glider performance may come as a surprise.

You are about to fly your club's Schweizer 2-33 on a beautiful, but relatively windy day. The surface winds are blowing 10 kt, gusting 15 kt right down the runway. However, the winds aloft are forecast to be 25 kt (~29 mph) at 3,000 ft and 30 kt (35 mph) at 6,000 ft. As a reminder, the key performance numbers for the 2-33 are: Stall speed ~32 mph; minimum sink speed ~42 mph; and best L/D speed ~52 mph with a best L/D glide ratio of 23.

QUESTION 1: Flying the 2-33 into a 25 kt headwind, what is the effective glide ratio if flown at the optimum speed to fly to maximize distance into a 25 kt (~29 mph) headwind?

A. Effective glide ratio: ~ 23
B. Effective glide ratio: ~ 20
C. Effective glide ratio: ~ 15
D. Effective glide ratio: ~ 11
E. Effective glide ratio: ~ 7

QUESTION 2: Flying the 2-33 with a 25 kt tailwind, what is the effective glide ratio if flown at the optimum speed to fly to maximize distance with a 25 kt (~29 mph) tailwind?

A. Effective glide ratio: ~ 23
B. Effective glide ratio: ~ 25
C. Effective glide ratio: ~ 29
D. Effective glide ratio: ~ 35
E. Effective glide ratio: ~ 42

Question 3: While the effective glide ratio changes with headwinds/tailwinds, the glide angle changes as well. For the Schweizer 2-33 flown at best L/D speed with a glide ratio of 23-to-1, the glide angle in still air is ~2.5 degrees. As in Question 1, for the 2-33 flying into a 25 kt headwind, what is the actual glide angle if flown at the optimum speed to fly to maximize distance into a 25 kt (~29 mph) headwind?

A. Glide angle = 2.5 degrees
B. Glide angle = 3.5 degrees
C. Glide angle = 4.5 degrees
D. Glide angle = 5.2 degrees
E. Glide angle = 7.5 degrees

Explanation for question 1 & 2: Figure 1 shows the Flight Polar for the 2-33 with the construction for selecting the optimum speed to fly into a 25 kt headwind and with a 25 kt tailwind. Notice that for the headwind, the optimum STF is 54 kt (~62 mph) at a sink rate of 2.6 kt, yielding a net groundspeed of 29 kt and an effective glide ratio of only 11! For the tailwind, the optimum STF is 42 kt (48 mph) at a sink rate of 1.9 kt, yielding a net ground speed of 67 kt and an effective glide ratio of 35! The answer to question 1 is D, 11. The answer to question 2 is D, 35.

Explanation for question 3: For the 2-33 flying optimally in to a 25 kt headwind to maximize distance, the STF is 62 mph, yielding a ground speed of ~33 mph and an effective glide ratio of 11 to 1 with a glide angle of 5.2 degrees – more than twice the glide angle of the 2-33 flown optimally in still air!

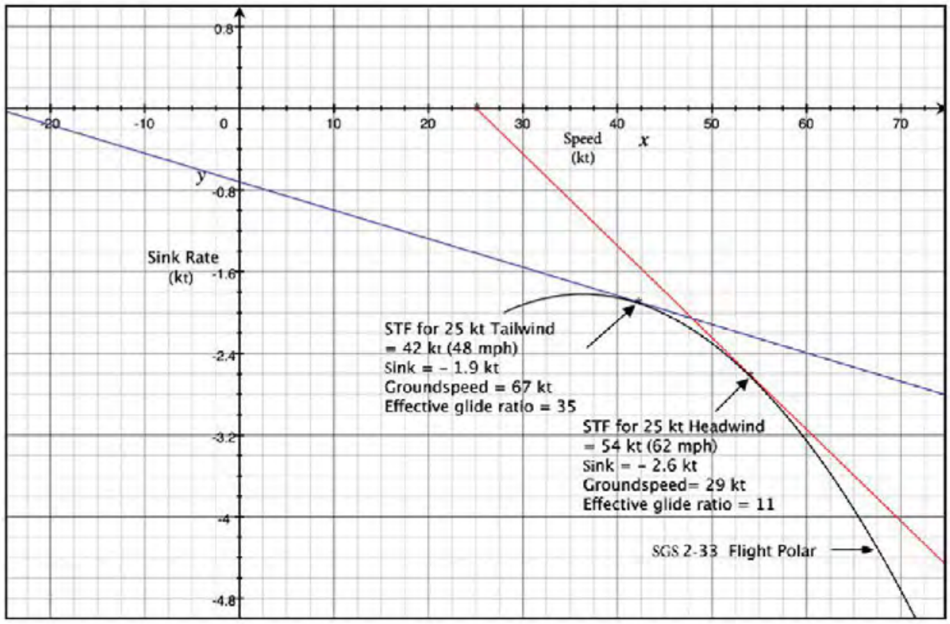


Figure 1: SGS 2-33 Flight Polar with construction for selecting optimum STF with 25 kt headwind and 25 kt tailwind.

Lessons Learned

Winds matter. For a 23-to-1 Schweizer 2-33 flying with, or against, a 25 kt wind varies the effective glide ratio from 35 to 11! The glide angle varies from 5.2 degrees to 1.6 degrees.

Likewise, when landing a 2-33 with spoilers deployed, the approach angle increases dramatically with strong headwinds when flown at an appropriate airspeed for the headwind conditions, versus landing with similar spoiler deployment in calm winds.

About the author: *Steve is a commercial pilot in single engine airplanes, single engine seaplanes, and gliders. He holds an instrument rating and is a Certificated Flight Instructor for airplanes, instruments, and gliders. He has logged over 4,000 flight hr including over 2,000 hr as a flight instructor. He is a retired IBM Engineering Manager and is a member of the Flight Instructor Staff at Sugarbush Soaring, Warren-Sugarbush Airport, Warren, VT.*

GLIDER AERODYNAMICS PUZZLER

BY STEVE PLATT

MacCready Flight 101:
How to Optimize Speed (Time)

This month, Steve presents a tutorial that precedes the Puzzler to come in July.
— Editor

All new glider pilots receive basic training in optimizing energy (altitude) to maximize distance in headwinds, tailwinds, sink, lift, and combinations thereof. For cross-country and competition pilots, knowing how to optimize speed is crucial to complete a task or remain competitive in a racing event. Paul MacCready's work in this area is to cross-country soaring flight what Newton's laws of motion are to classical physics. In the January 1958 issue of *Soaring* magazine, Paul MacCready published his method of optimizing average speeds in gliding from thermal to thermal.

Paul MacCready's work is truly impressive. It provides a basis for cross-country and competitive race pilots to optimize speed between thermals "knowing" or assuming what the net climb rate will be in the next thermal. MacCready flight optimizes TIME, not ENERGY, between thermals. MacCready flight sacrifices some altitude (energy) to go faster between thermals. Referring to Figure 1, Pilot B flies from thermal to thermal at best L/D speed. Pilot C flies at the fastest speed possible to reach the next thermal (without landing out) and begins the climb back up to the start altitude. Pilot A flies at the optimum speed (MacCready speed) to reach the next thermal and climb back to the start altitude *in the shortest amount of time*.

Pilot B reaches the next thermal to begin the climb back to the start altitude at the slowest speed but uses the least amount of energy or altitude to reach the thermal. Pilot B keeps the most energy "in the bank," i.e. remains at the highest altitude at all times. Pilot A reaches the next thermal to begin the climb back to the start altitude slower than Pilot C, faster than Pilot B, but climbs to the start altitude in the shortest total time, i.e. the glide time plus the time to climb back to the start altitude … the best average speed. Pilot C reaches the next thermal to begin the climb back to the start altitude faster than both pilots, but uses the most time to climb back to the start altitude … and reaches the start altitude after Pilot A.

Pilot C maintains the least energy "in the bank" … i.e. the lowest altitude at all times after leaving the start altitude.

Pilot A flies at the optimum MacCready speed and achieves the best average speed. Pilot B flies using the least energy. Pilot C consumes the most energy.

Flying at MacCready 1 presumes the target thermal will yield an average net climb of 1 kt back to the start altitude. Flying at MacCready 2 presumes the target thermal will yield an average net climb of 2 kt back to the start altitude. Flying at MacCready 3 presumes the target thermal will yield an average net climb of 3 kt back to the start altitude, and so on.

The Speed-to-Fly (STF) for MacCready, X, is identical to the STF to maximize distance in X kt of sink. The proof of MacCready theory is shown in a number of excellent texts (Reference 1: *The Complete Soaring Pilots Handbook* by Welch and Irving, and Reference 2: *Cross-Country Soaring* by Helmut Reichmann) and will not be repeated here. The optimum STF depends, of course, on the flight polar for the glider in question for the appropriate operating weight. For example, for the PW-6 flight polar shown in Figure 2, flight at MacCready 4 speed yields 70 kt; identical to the STF to maximize distance in 4 kt of sink.

To put MacCready flight speeds

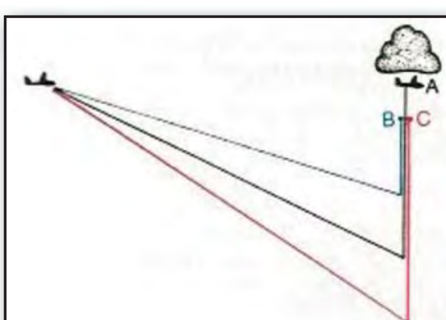


Figure 1.

in perspective, for a medium performance, 34 to 1, PW-6 glider at a max gross weight with a best L/D speed of 56 kt, flying at MacCready speeds yields:

MacCready 0 = 56 kt
MacCready 1 = 60 kt
MacCready 2 = 63 kt
MacCready 3 = 67 kt
MacCready 4 = 70 kt
MacCready 5 = 73 kt
MacCready 6 = 76 kt
MacCready 7 = 79 kt

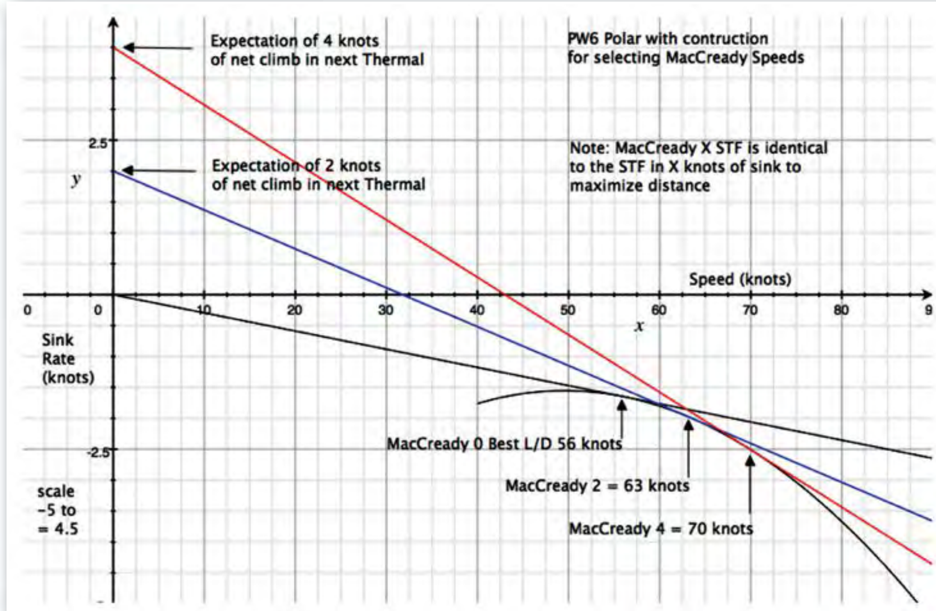


Figure 2.

The MacCready solution is independent of wind as the solution maximizes average speed thermal-to-thermal. If the air mass is moving (winds aloft), there is no impact to the thermal-to-thermal solution. However, for the final glide calculation, the winds aloft affect the final glide altitude at which the pilot may leave the last thermal for the final glide to the destination. Once again, if the final thermal has a climb rate of X, the final glide should be performed at MacCready X speed and the altitude to leave the last thermal should be based upon the effective glide ratio at MacCready X speed, with the headwind/tailwind taken into consideration (i.e. ground speed).

The practical application of MacCready theory has been tweaked over the years to deal with the real complexity of the atmosphere and, for the recreational cross-country pilot, to reduce the probability of landing out. For example, while the average net thermal lift might be 4 kt, in reality, one thermal might be 2 kt, the next thermal 4 kt, the third thermal 6 kt or other. A commonly accepted implementation of MacCready theory in this circumstance is for the glider pilot to pass up any thermal less than the MacCready setting (expected average net thermal climb rate). That is, assuming adequate altitude, pass up thermals less than the MacCready setting, and climb in thermals equal to, or stronger than, the MacCready setting. In theory, the MacCready setting is the expected average net climb in the next thermal. In reality, the MacCready setting is the weakest thermal the glider pilot is willing to stop for.

While thermal strength varies thermal-to-thermal, it also varies within a thermal. While thermal strength often increases with altitude, on occasion it also decreases at the top. A commonly accepted implementation of MacCready flight is to stay in a thermal until the climb average decreases below the MacCready setting (Reference 3: "MacCready Theory with Uncertain Lift and Limited Altitude," *Technical Soaring* 23, July 1999, by John Cochrane.)

Since MacCready flight uses energy to fly faster between thermals, the higher the MacCready setting, the more energy consumed in the glide to the next thermal, and the lower the average altitude and minimum altitude become compared to flying at a lower MacCready setting. As a result, the higher the MacCready setting, the higher the probability of landing out. One modification to pure MacCready flight used by some cross-country pilots is to lower the MacCready setting (slow down) for each reduction of 1,000 ft in altitude. For example, on a day when the average net thermal climb is expected to be 4 kt, use MacCready 4 setting when 4,000 ft above the destination finish altitude, slow to MacCready 3 at 3,000 ft above, slow to MacCready 2 at 2,000 ft above, and MacCready 1 at 1,000 ft above the destination finish altitude. This lowers the threshold to accept a thermal to climb back up in altitude and extends the glide.

For cross-country flight and competition, when thermal density and strength permit, MacCready flight facilitates the "extraction" of energy to maximize average speed. While the energy (altitude) consumption depends on the polar shape, the energy (altitude) required for a PW-6 is typical for medium performance gliders (best L/D glide ratios of ~34). From the flight polar for the PW-6 (Figure 2), the STF for MacCready 4 is 70 kt. This yields a glide ratio of ~28 (no wind), which corresponds to using 21% more altitude to go 25% faster between thermals versus flying at MacCready 0, or the best L/D speed 56 kt.

The advantage of flying at MacCready speeds is, of course, higher average speeds and shorter times en route. The disadvantage is lower minimum and average altitude en route, and for that reason, a slightly higher landout probability. For perspective, on a 50 nm cross-country in a PW-6 flying at MacCready 4 (70 kt, no-wind, glide ratio=28) versus MacCready 0 (56 kt, glide ratio=34) yields the theoretical numbers in Table 1. (Assumptions: neutral air between thermals; net lift in thermal 4 kt; straight line flight; no time consumed centering thermals; no wind – best case scenario.)

Therefore, a PW-6 on a 50 nm flight flying at MacCready 4 is 10% faster using 21% more altitude (energy) compared to flight at MacCready 0 (Best L/D).

Paul MacCready's solution to optimizing speed in cross-country flight has provided the foundation for virtually every book, article, paper, and presentation made on cross-country soaring flight for the past nearly six decades. It applies to both thermal-to-thermal and dolphin flight optimization.

About the author: *Steve is a commercial pilot in single engine airplanes, single engine seaplanes, and gliders. He holds an instrument rating and is a Certificated Flight Instructor for airplanes, instruments, and gliders. He has logged over 4,000 flight hr, including over 2,000 hr as a flight instructor. He is a retired IBM Engineering Manager and a Flight Instructor at Sugarbush Soaring Warren, VT.*

	MacCready 4	MacCready 0	Difference	% Mac 4 to Mac 0
Energy required	9,429 ft	7,765 ft	1,664 ft	+21.4 %
Time to climb	23.29 min	19.18 min	4.11 min	+21.4 %
Time of Glide	42.85 min	53.57 min	10.72 min	-20.0 %
Total Time	66.14 min	72.75 min	6.61 min	-9.0 %
Average Speed	45.36 kt	41.24 kt	4.12 kt	+10.0 %

GLIDER AERODYNAMICS PUZZLER

BY STEVE PLATT

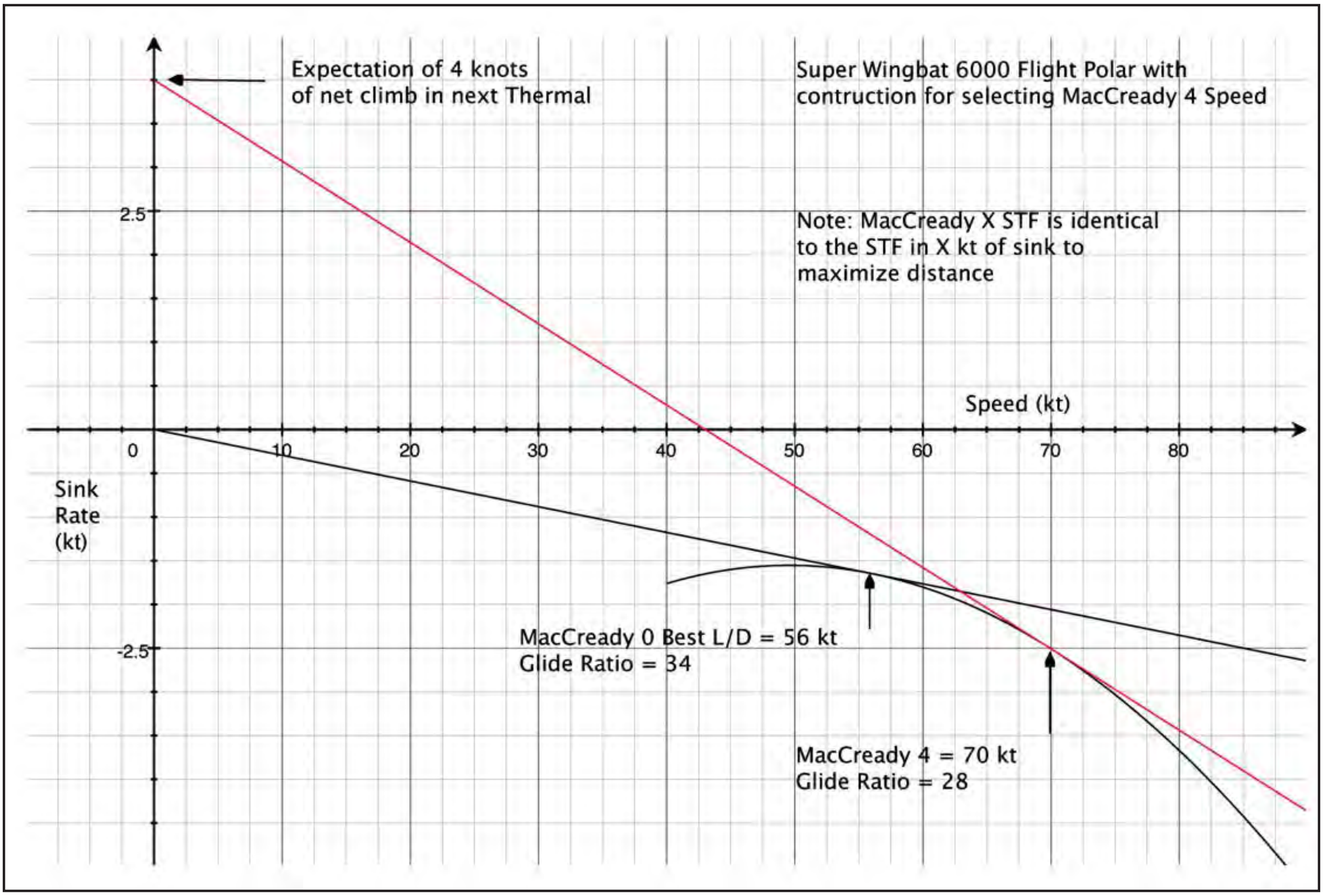
MacCready

The Glider Aerodynamics Puzzler is intended to stimulate your thinking about soaring and refresh your understanding of glider aerodynamics and soaring optimization. The correct answers with detailed explanations follow the questions. Have fun.

Glider pilots have fundamentally two choices when attempting to optimize glider flight to a destination. They can either optimize altitude (energy), or they can optimize speed (minimize time). All new glider pilots learn the basics of optimizing distance (altitude/energy) in a headwind, tailwind, sink, lift, or combinations thereof. With experience and interest in cross-country soaring and/or competition, many glider pilots become intimately familiar with Paul MacCready's solution for optimizing speed in cross-country flight. Paul MacCready first published his seminal solution for maximizing average speed in cross-country flight in the January 1958 issue of *Soaring* magazine. MacCready's work has served the soaring community exceptionally well for the past nearly six decades. Virtually every article, paper, and presentation made since that time is based on MacCready's solution.

MacCready flight optimizes average speed by using more energy (altitude) to cruise faster between thermals than the minimum energy solution. The difference is quite interesting.

On a snowy winter day, with your pride and joy Super Wingbat 6000 tucked safely away in its comfortable trailer, you decide to investigate the theoretical difference between optimized MacCready flight versus a minimum energy solution. For starters you decide to use a hypothetical 50-mile cross-country flight with no wind aloft to establish a base understanding. You assume a great thermal day with all thermals yielding a net 4 kt average climb rate. A great day. Per classical MacCready technique, you plan on cruising at MacCready 4 speed. The flight Polar for your medium performance Super Wingbat 6000, for your operating weight, is shown below in



	MacCready 4	MacCready 0	Difference	% Mac 4 to Mac 0
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Time of glide	42.85 min	53.57 min	10.72 min	- 20.0 %
Total time	66.14 min	72.75 min	6.61 min	- 9.0 %
Average speed	45.36 kt	41.24 kt	4.12 kt	+ 10.0 %

Figure 1. The key performance characteristics are:

Minimum sink speed 51 kt
Minimum sink rate 148 ft/min (1.46 kt)
Best L/D glide ratio 34
Best L/D speed 56 kt
MacCready 4 speed 70 kt

Question 1: For the 50 nautical mile flight, approximately how much additional energy (altitude) is required to fly at MacCready 4 versus MacCready 0 (best L/D speed)?

A. 10% more energy (altitude)
B. 15% more energy (altitude)
C. 20% more energy (altitude)
D. 25% more energy (altitude)
E. 30% more energy (altitude)

Question 2: If flown optimally for the 50 nautical mile flight, approximately how much does the average speed for the flight improve if flown at MacCready 4 versus MacCready 0?

A. Average speed improves 10%
B. Average speed improves 12%
C. Average speed improves 15%
D. Average speed improves 20%
E. Average speed improves 25%

Explanation Questions 1 & 2:

The figure shows the flight polar for the Super Wingbat 6000 with the construction to determine the MacCready 4 speed. The MacCready 4 speed is 70 kt, yielding an effective glide ratio of 28. The MacCready 0 speed, or best L/D speed, is 56 kt with a glide ratio of 34. Using the effective glide ratios for the 50 nm flight, the following theoretical numbers result. (Assumptions: neutral air between thermals, net lift in thermals 4 kt, straight line flight, no time consumed centering thermals, i.e. best-case scenario.)

Therefore, for a Super Wingbat 6000, flown flawlessly on a 50 nautical flight, flying at MacCready 4 is 10% faster using 21% more altitude (energy) compared to flight at MacCready 0 (best L/D).

The answer to Question 1 is C, and the answer to Question 2 is A.

Lessons Learned

For cross-country flight and competition, when thermal density and strength permit, MacCready flight facilitates the "extraction" and use of energy to maximize average speed. While the energy consumption and the results obviously depend upon the flight polar in question, if flown perfectly, the results for this medium performance Super Wingbat glider yields a 10% improvement in average speed for 21% more altitude (energy). If the thermal conditions were not as favorable (for example, 2 kt average net climb), then flight at MacCready 2 would yield different results … approximately half, or ~5% increase in average speed for ~10% more altitude (energy).

Finally, winds matter. The results will vary if flying into a headwind or with a tailwind.

About the author: *Steve is a commercial pilot in single engine airplanes, single engine seaplanes, and gliders. He holds an instrument rating and is a Certificated Flight Instructor for airplanes, instruments, and gliders. He has logged over 4,000 flight hr, including over 2,000 hr as a flight instructor. He is a retired IBM Engineering Manager and is a member of the Flight Instructor Staff at Sugarbush Soaring, Warren-Sugarbush Airport, Warren, VT.*

GLIDER AERODYNAMICS PUZZLER

BY STEVE PLATT

Energy Optimization

The Glider Aerodynamics Puzzler is intended to stimulate your thinking about soaring and refresh your understanding of glider aerodynamics and soaring optimization. The correct answers with detailed explanations follow the questions. Have fun.

All glider pilots receive basic training in the appropriate speed to fly (STF) in headwinds, tailwinds, sink, lift, and combinations thereof to maximize distance, i.e. – conserve energy. With the advent of relatively low cost onboard flight computers with GPS position information, current airspeed, altimeter, variometer inputs, and the appropriate flight polar (for the current operating weight), the onboard processor can compute all the pertinent parameters the glider pilot could ever want to know: current track, bearing to destination, speed to fly to maximize distance, speed to fly to maximize speed for a particular MacCready setting, altitude required to make a destination, winds aloft (direction and speed), and color moving map. With all this automation, it is easy for even experienced glider pilots to lose track of the basics.

Question 1: You have invited your neighbor for a local recreational flight in your soaring club's dual seat Super Wingbat 6000. The Super Wingbat flight polar is shown in Figure 1.

The key performance parameters for the Super Wingbat 6000 at your operating weight are:

Stall speed = 39 kt
Minimum sink speed = 51 kt
Best L/D speed = 56 kt
Best L/D glide ratio = 34 to 1

The Super Wingbat is equipped with only the basic airspeed, altimeter, mechanical variometer, and magnetic compass. No moving map GPS, no audio variometer, no flight navigation computer. You are on your own. You conscientiously check the weather forecast and note the winds aloft forecast. After a 2,500 ft tow, you head out upwind on a beautiful day to provide a tour of the area for your neighbor. After about an hour your passenger is ready for *terra firma*. You realize you are about 10 miles upwind of your home base but have gotten a bit low. You turn for home and decide to fly as efficiently as possible to conserve energy (altitude). Landing out would be a bit embarrassing. You estimate a 20 kt tailwind but enter an area with 2 kt of sink. With a 20 kt tailwind and 2 kt of sink, you estimate the best STF to maximize distance as:

A. Minimum sink speed (51 kt)
B. Somewhere between min sink speed and Best L/D speed (53 kt)
C. Best L/D speed (56 kt)
D. ~ 60 kt
E. ~ 65 kt
F. ~ 70 kt

Question 2: Suppose you had initially headed downwind for your flight and turn for home into a 20 kt headwind with 2 kt of sink. What would you estimate the best STF to maxi-

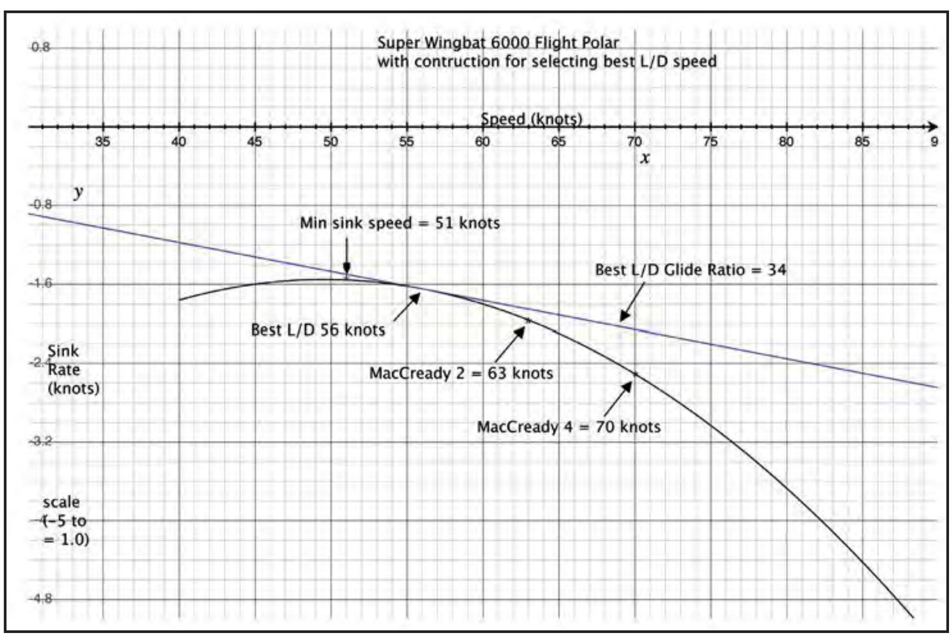


Figure 1.

mize distance with 2 kt of sink and a 20 kt headwind?

A. Minimum sink speed (51 kt)
B. Best L/D speed (56 kt)
C. ~ 60 kt
D. ~ 65 kt
E. ~ 70 kt
F. ~ 75 kt

Explanation for Question 1 and 2: The optimum speed to fly is generated by a tangent to the flight polar from the two points shown in Figure 2. The optimum speed to fly with a 20 kt tailwind and 2 kn of sink is: 60 kt. The optimum speed to fly with a 20 kt headwind and 2 kt of sink is: 69 kt. While it is quite inappropriate to be plotting tangents to polars in the cockpit, it is appropriate to understand the flight polar for the glider flown and a few key performance numbers.

As has been described in prior articles, the MacCready X STF (no wind) is identical to the optimum STF in X kt of sink. So, for example, in a headwind if the MacCready 2 speed is known (63 kt), adding ~ 1/3 of the headwind speed will yield a STF very close to the optimum STF. Likewise, in a tailwind, knowing the MacCready 2 speed and subtracting ~ 1/3 of the tailwind speed will also yield a STF very close to the optimum STF. By knowing a few key speeds generated from your flight polar (for the appropriate operating weight), a glider pilot can estimate a STF to maximize energy conservation. The answer to question 1 is D, 60 kt. The answer to question 2 is E, ~70 kt.

Lessons Learned: Knowing one's flight polar and a few key operating speeds can go a long way toward ensuring the appropriate STF is employed to accomplish virtually any mission or handle any flight condition (i.e. lift/sink, headwind/tailwind) to maximize time aloft, maximize distance, or maximize speed, particularly when all the hardware fails or is not installed.

About the author: *Steve is a commercial pilot in single engine airplanes, single engine seaplanes, and gliders. He holds an instrument rating and is a Certificated Flight Instructor for airplanes, instruments, and gliders. He has logged over 4,000 flight hr, including over 2,000 hr as a flight instructor. He is a retired IBM Engineering Manager and is a member of the Flight Instructor Staff at Sugarbush Soaring, Warren-Sugarbush Airport, Warren, VT.*

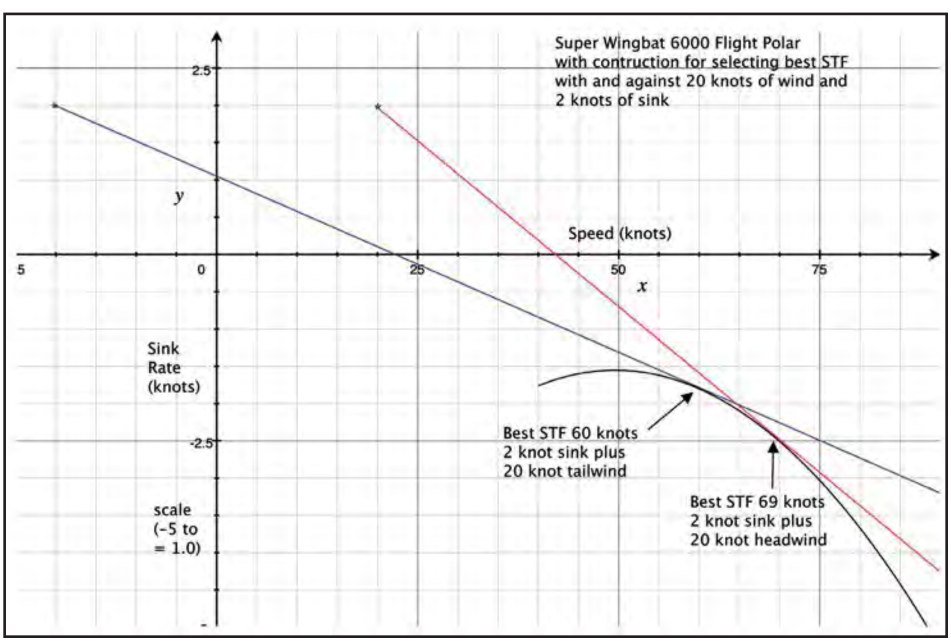


Figure 2.

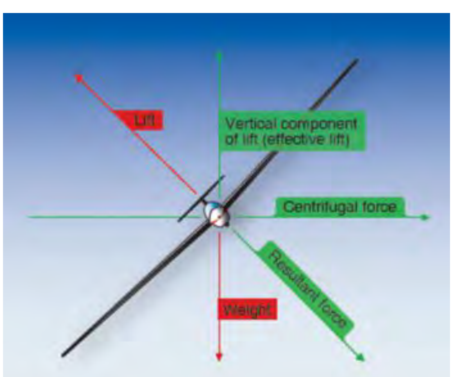
GLIDER AERODYNAMICS PUZZLER

BY STEVE PLATT, CFI-G

Radius of Turn

The Glider Aerodynamics Puzzler is intended to stimulate your thinking about soaring and refresh your understanding of glider aerodynamics and soaring optimization. The correct answers with detailed explanations follow the questions. Have fun.

Glider pilots are intimately familiar with optimizing straight and level flight depending upon the mission, e.g. maximizing time aloft with flight at minimum sink speed; or, maximizing distance (optimizing energy) with flight at the best L/D speed adjusted for current headwind/tailwind and sink/lift; or, maximizing speed with flight at the appropriate MacCready speed. In all cases, the optimum speed to fly (STF) for the particular mission must be adjusted for the current operating weight. Weight matters. What is less well understood is the effect of turning flight on glider performance.



Forces on glider during turn.

In a coordinated turn, some of the wings' lift, the horizontal component of lift, is used to overcome centrifugal force. Specifically:

Horizontal component of lift = Lift * sine(angle)

Centripetal force = W/g * V^2/R

Where angle = the angle of bank

W = the weight of the Glider

g = acceleration of gravity (32.17 ft/sec^2)

V = airspeed during the turn

R = radius of the turn

These quantities are all related through:

Equation 1: Lift* sin(angle) = W/g * V^2/R

In coordinated flight the vertical component of lift must continue to be equal to the weight of the glider, so:

Vertical component of lift = Lift * cosine(angle)

Leading to:

Equation 2: W = Lift * cosine(angle)

These two simple equations solved for R (Radius of turn) results in a fundamental equation of flight for all gliders and all airplanes with wings (refer to Table 1 for the derivation):

Radius of turn, R = V^2 / (g * tangent(angle))

The radius of turn for ALL airplanes is equal to the square of the airspeed divided by the product of the acceleration of gravity times the tangent of the angle of bank. The solution is independent of weight, and applies equally to a Boeing 777, an F-16, or an ASK 21. Increasing speed and decreasing angle of bank in coordinated turning flight rapidly increases radius of turn. Conversely, decreasing airspeed and increasing the angle of bank rapidly decreases the radius of turn, and, unfortunately, rapidly increases glider sink rate. As the bank angle increases the total lift of the wing must increase, i.e. the angle of attack of the wing and the corresponding load factor must increase to keep both the vertical component of lift equal to the weight of the airplane (plus the tail down force), and the horizontal component of lift equal to centripetal force. Increasing the angle of attack increases lift, increases the load factor, increases drag, and increases glider sink rate.

Why is all this useful to understand for glider flight? For one, glider pilots spend a significant amount of time turning in thermals. While thermaling, the radius of turn matters. Too wide a radius of turn and the glider operates in the weakest part of the thermal or, worse, circles the thermal. Too narrow a radius of turn and the sink rate increases rapidly, more than off-setting the benefit of operating close to the core of the thermal. As noted in the *Soaring* magazine May 2017 article "How to Optimize Thermaling Flight in Gliders," depending on the particular thermal strength and profile, the glider performance (especially the minimum sink speed and minimum sink rate), and, of course, how well centered the glider remains, there is an optimum bank angle and

$$\text{EQUATION 1: } Lift * \sin(angle) = (W/g) * (V^2 / R)$$
$$\text{EQUATION 1} \Longrightarrow Lift = (W/g) * (V^2 / (R * \sin(angle)))$$
$$\text{EQUATION 2: } Lift * \cos(angle) = W$$
$$\text{EQUATION 2} \Longrightarrow Lift = W / \cos(angle)$$
$$\text{Therefore: } W / \cos(angle) = (W/g) * (V^2 / (R * \sin(angle)))$$
$$\Longrightarrow R = (V^2 * \cos(angle)) / (g * \sin(angle))$$
$$\Longrightarrow R = V^2 / (g * \sin(angle) / \cos(angle))$$
$$\Longrightarrow R = V^2 / (g * \tan(angle))$$

Derivation of radius of turn formula.

airspeed (radius of turn) to fly to maximize net climb performance.

QUESTION 1: You are planning to take your neighbor for a local glider flight in your club's medium performance PW-6 glider (Best L/D = 34). Thermals have been reported as standard summer thermals, i.e. 4.2 kt of air mass lift at the core decreasing parabolically to zero at a radius of 1,000 ft. From a prior flight you know your passenger is a bit of a nervous flyer and does not like steep bank turns. You decide to limit your bank angle to 20 degrees while thermaling versus the optimum bank angle. If centered perfectly while thermaling, how much will net climb performance improve using the optimal angle of bank (and airspeed) versus 20 degrees of bank?

A. 10%
B. 15%
C. 25%
D. 50%
E. 100%

EXPLANATION: Refer to Figure 2. The black line is the thermal strength profile versus radius from the core. The red line is the magnitude of the PW-6's sink rate versus radius (i.e. versus bank angle and airspeed) if flown at the minimum sink speed for each angle of bank. The blue line is the net climb rate (black line minus red line). Notice that at 20° of bank and an airspeed of 53 kt, the radius of turn is 675 ft yielding a net climb rate of ~0.75 kt. The peak net climb rate occurs with a bank angle of 34° and an airspeed of 56 kt, yielding a radius of turn of 410 ft and a net climb rate of ~1.5 kt. Therefore, the answer to question 1 is E, 100%. The net climb rate doubles at 34° of bank and 56 kt versus 20° of bank and 53 kt.

Lesson Learned: Radius of turn, and therefore bank angle and airspeed, matters. Using the optimum airspeed and bank angle while thermaling can substantially increase net climb performance.

For most medium performance gliders, the optimum angle of bank and airspeed to thermal at for Standard British thermals is ~35° of bank at an airspeed of a 2-5 kt above the level flight minimum sink speed.

In fact, in coordinated turning flight for ALL GLIDERS at bank angle X, the minimum sink rate and the minimum sink speed increase at the identical percentage rate factors relative to their level flight min sink rate and min sink speed, given by the following equations, and plotted in Figure 3. (Reference: *The Complete Soaring Pilots*

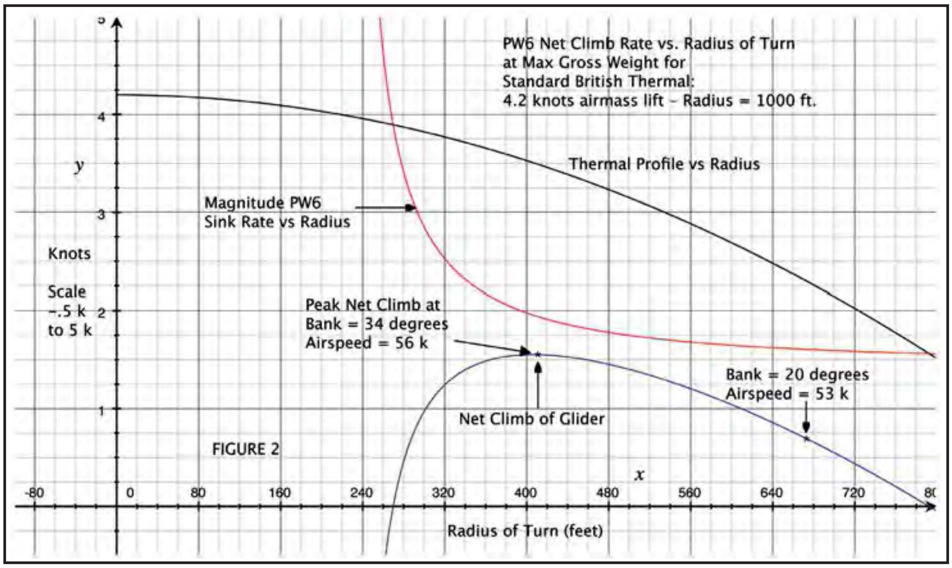


Figure 2

Handbook, by Welch and Irving, 1977, p 238, ISBN: 0-679-50718-3.)

EQUATION 3: Min Sink Rate (@ bank angle X = Min Sink Rate (Level Flight) * (1 / cosine(X))^1.5

EQUATION 4: Min Sink Speed (@ bank angle X = Min Sink Speed (Level Flight) * (1 / cosine(X))^0.5

Notice that at 45° of bank in coordinated turning flight, the min sink speed increases 18.9% over the level flight min sink speed, and the min sink rate increases by 68% over the level flight min sink rate. For a PW-6 (at gross weight) in a 45° banked turn, the min sink speed increases from 50 kt to ~ 59 kt and the min sink rate increases from 148 ft/min. to 249 ft./min! The aerodynamics of thermaling is, indeed, fascinating.

About the author: *Steve is a commercial pilot in single engine airplanes, single engine seaplanes, and gliders. He holds an instrument rating and is a Certificated Flight Instructor for airplanes, instruments, and gliders. He has logged over 4,000 flight hours, including over 2,000 hours as a flight instructor. He is a retired IBM Engineering Manager and is a member of the Flight Instructor Staff at Sugarbush Soaring, Warren-Sugarbush Airport, Warren, Vermont.*

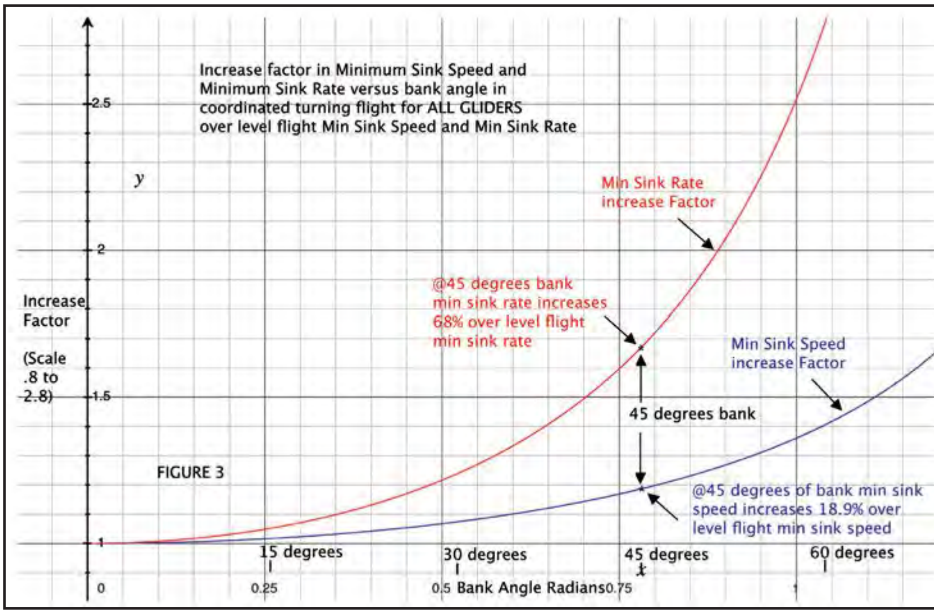


Figure 3

GLIDER AERODYNAMICS PUZZLER

BY STEVE PLATT

Turning Performance

The Glider Aerodynamics Puzzler is intended to stimulate your thinking about soaring and refresh your understanding of glider aerodynamics and soaring optimization. The correct answers with detailed explanations follow the questions. Have fun.

Glider pilots are quite cognizant of the wings-level performance of the ships they fly, particularly the published best L/D glide ratio, whether a low performance Schweizer 1-26/2-33 at 23 to 1, or a medium performance ASK 21/PW-6, etc. at 34 to 1, or a high performance Ventus, Discus, DG-1000, etc. at greater than 40 to 1. Pilots are less cognizant of the relative "turning" or "climb" performance. Yet, on a typical local or cross-country recreational glider flight, the glider pilot spends 20%-35% of the time turning (thermaling), if not more. Unless you are lucky enough to operate in an area with routine ridge lift or mountain wave, turning performance matters.

Question 1: Two gliders enter a 360° coordinated 30° banked turn in still air. Each glider is flown at its optimum minimum sink speed for a 30° banked turn. Which of the following gliders uses more altitude to complete the 360° turn?

DG-1000 versus a Schweizer 1-26
DG-1000 versus a PW-6
PW-6 versus Schweizer 1-26

Question 2: Cruise performance certainly matters, but so does climb performance. If flown optimally, i.e. at the optimum angle of bank and airspeed and perfectly centered, which of the following gliders will outclimb the other in the Standard British Thermal – a thermal with 4.2 kt of air mass lift at the core decreasing parabolically to zero at a radius of 1,000 ft?

DG-1000 versus a Schweizer 1-26
DG-1000 versus a PW-6
PW-6 versus a Schweizer 1-26
Schweizer 2-33 versus a Schweizer 1-26

Question 3: As in Question 2, what happens if the thermal is modestly stronger and slightly narrower … for example, a thermal with 6.0 kt of air mass lift at the core decreasing parabolically to zero at a radius of 750 ft? Which of the following gliders will outclimb the other?

DG-1000 versus a Schweizer 1-26
DG-1000 versus a PW-6
PW-6 versus a Schweizer 1-26
Schweizer 2-33 versus a Schweizer 1-26

Explanation for Question 1: First, the optimum speed to fly to lose the least amount of altitude for ALL gliders in a coordinated 30° banked turn is the wings level minimum sink speed plus 7.5%. Second, the sink rate for ALL gliders in a 30° coordinated banked turn increases by 24% over the wings level minimum sink rate at the current operating weight. (Reference: *The Complete Soaring Pilot's Handbook*, by Ann & Lorne Welch and Frank Irving, Published 1977 ISBN: 0-679-50718-3). Given the above and the published min sink speed and min sink rate for each aircraft, shown in Figure 1 is the altitude loss for each aircraft versus angle of bank if flown at the minimum sink speed for each angle of bank in still air.

Notice at 30° of bank, if flown optimally, the PW-6 loses the most, 96 ft; the DG-1000 loses 80 ft; and the lowly 1-26 loses the least altitude, 73 ft! Radius of turn matters. Two other observations. First, the order of altitude loss is independent of bank angle. That is, for ANY angle of bank, if flown at the minimum sink speed for that angle of bank, the 1-26 has the least amount of altitude loss. And, second, the minimum loss for ALL gliders occurs at 45° of bank and an airspeed equal to the level flight minimum sink speed plus 18.9%.

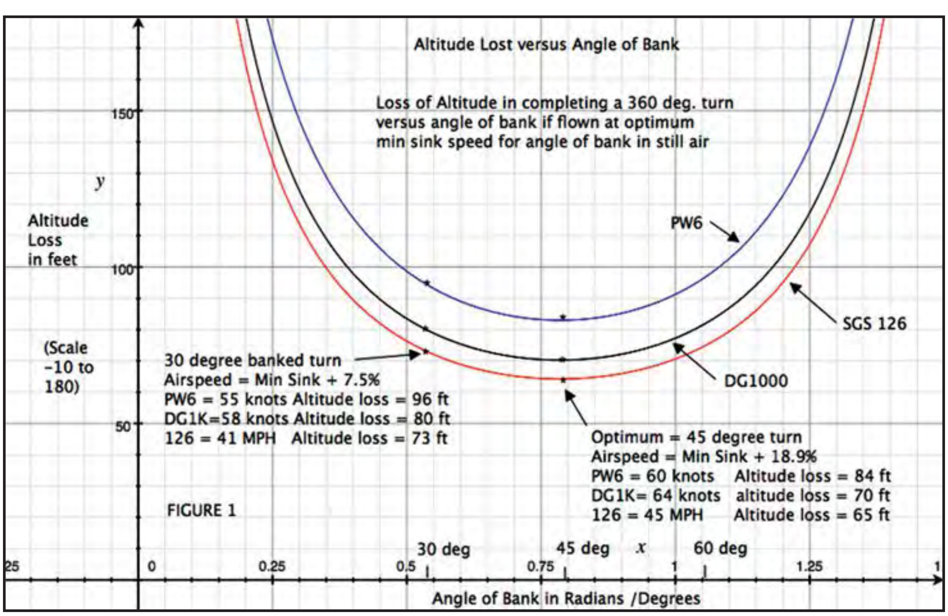
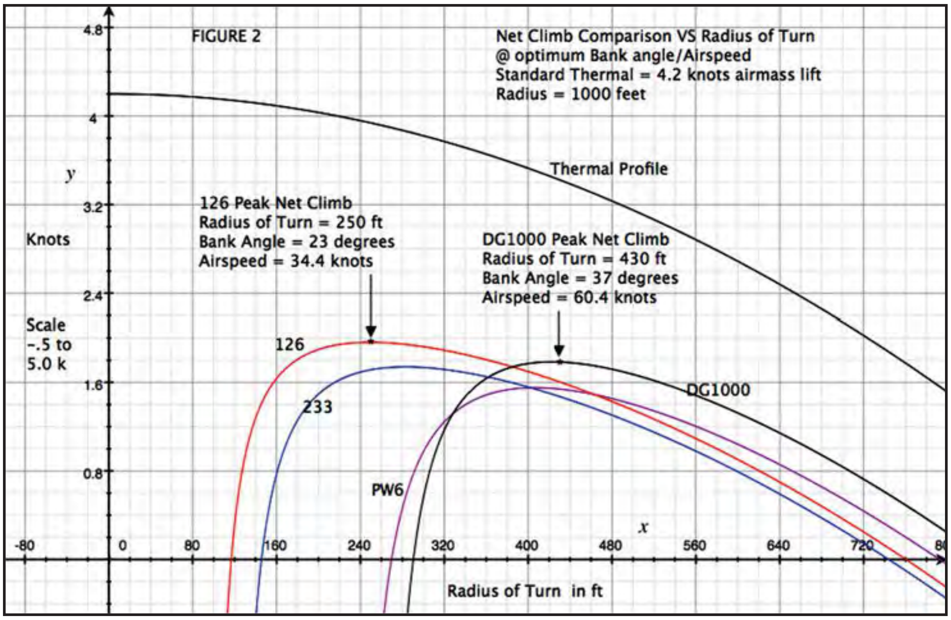


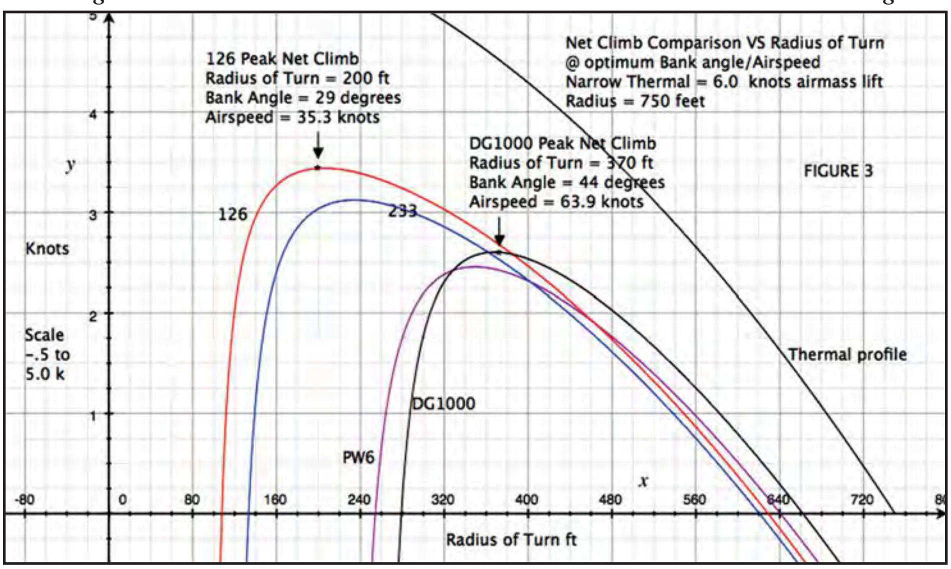
Figure 1.

Explanation for Questions 2 & 3: Shown in Figure 2 is the net climb



Above: Figure 2.

Below: Figure 3.



rate for each aircraft as a function of the radius of turn, if flown at the optimum minimum sink speed for each angle of bank and perfectly centered in a Standard British Thermal. While angle of bank and airspeed for each aircraft is different at peak, the lowly 1-26 outclimbs the other three aircraft, followed by the DG-1000, the 2-33, and the PW-6. Once again radius of turn matters. While the wings level minimum sink rate of the DG-1000 (~118 ft/min) is substantially better than the 1-26 (~177 ft/min), the inferior sink rate of the slower 1-26 is more than offset by thermaling closer to the core of the thermal. The optimum radius of turn for the Schweizer 1-26 is 250 ft, while the optimum radius of turn for the DG-1000 is 430 ft.

Notice that the peak net climb for the 1-26 occurs at a bank angle of only 23° at 34 kt, while the peak net climb rate for the DG-1000 occurs at a bank angle of 37° at 60 kt. This effect is even more noticeable for the stronger and narrower thermal shown in Figure 3. Here both the 1-26 and the 2-33 outclimb the glass ships.

Lessons Learned: Turn and climb performance matter. Radius of turn matters. Optimizing climb performance is driven by multiple parameters and is highly dependent on the strength, width, and profile of the target thermal. However, a glider's level flight minimum sink speed is a crucial parameter in determining the optimum speed to fly to maximize net climb performance while thermaling. The narrower the thermal, the more advantageous a slow minimum sink speed is. This is driven by the physics of coordinated turning flight whereby the radius of turn (R) is proportional to the square of airspeed (V), i.e.: R = (V2 /(g * Tan (ang)), where g is gravitational acceleration, and Tan(ang) is the tangent of the bank angle. Optimizing glider flight is complex and incredibly fascinating. Fly safe.

***About the author:** Steve is a commercial pilot in single engine airplanes, single engine seaplanes, and gliders. He holds an instrument rating and is a Certificated Flight Instructor for airplanes, instruments, and gliders. He has logged over 4,000 flight hr, including over 2,000 hr as a flight instructor. He is a retired IBM Engineering Manager and is a member of the Flight Instructor Staff at Sugarbush Soaring, Warren-Sugarbush Airport, Warren, VT.*

GLIDER AERODYNAMICS PUZZLER

BY STEVE PLATT

Rope Break

The Glider Aerodynamics Puzzler is intended to stimulate your thinking about soaring and refresh your understanding of glider aerodynamics and soaring optimization. The correct answers with detailed explanations follow the questions. Have fun.

You are a student pilot finishing up your Private Pilot – Glider license. Your instructor has signed you off for the checkride with a Designated Pilot Examiner. On the appointed day, the flight oral goes well and you move on to the Flight portion of the exam. It is a beautiful day with building cumulus clouds and a steady 20 kt wind blowing right down the runway. The first two flights go well. You have performed all the requested maneuvers with precision well within the practical test standard limits. You are flying a PW-6, the ship you trained in. On the third tow, after passing the departure end of the runway and reaching approximately 250 ft AGL, the DPE pulls the rope release and announces a simulated rope break. You quickly make the decision that you can safely execute an approximate 210° turn to set up a landing downwind. You immediately lower the nose and roll into a coordinated left turn. The PW-6 has the following key performance numbers at your operating weight:

Minimum sink speed: 51 kt
Minimum sink rate: 148 ft/min.
Best L/D ratio: 34 to 1
Best L/D speed: 56 kt
Normal landing speed: 60 kt

Question 1: During the turn, you want to lose the least amount of altitude (i.e., conserve energy) to ensure you can make it back to the runway for a downwind landing. What angle of bank and airspeed will consume the least amount of altitude (energy) to complete the approximate 210° turn?

A. Shallow bank: 15° with an airspeed of 51 kt (min sink speed)
B. Medium bank: 30° with an airspeed of 55 kt
C. Steep bank: 45° with an airspeed of 60 kt
D. Very steep bank: 60° with an airspeed of 65 kt
E. Rope breaks or simulated rope breaks are not allowed on Practical Flight tests

Question 2: You have executed the turn back to the airport and, using full spoilers and a necessary forward slip, positioned the glider perfectly for the downwind landing with the 20 kt tailwind, crossing the runway threshold about 10 ft in the air, identical to your normal "into the wind" landings. Given the wind conditions, how much runway would you expect to use to land downwind and come to a stop compared to a normal "20 kt into the wind" landing from the same position above the threshold with similar applied braking after touchdown?

A. 10% more runway over a normal landing
B. 30% more runway over a normal landing
C. 50% more runway over a normal landing
D. 75% more runway over a normal landing
E. In excess of 100% more runway over a normal landing

Explanation for Question 1: For all gliders, independent of make, model, etc., the optimum angle of bank to lose the least amount of altitude is 45° at an airspeed of 18.9% above the level flight minimum sink speed for the current operating weight, i.e., the minimum sink speed for a 45° coordinated banked turn. Shown in Figure 1 is the altitude consumed completing a 210° turn versus bank angle if flown at the appropriate minimum sink speed for each angle of bank. As noted in prior aerodynamics puzzlers, the minimum sink speed increases for all gliders at the same rate with increasing bank angle in coordinated turning flight.

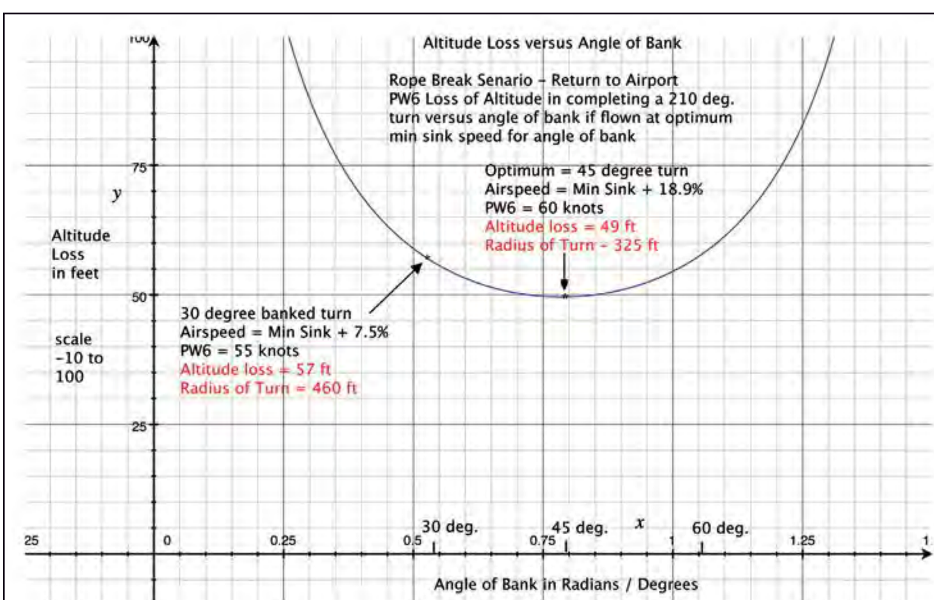


Figure 1

Notice that the minimum consumed altitude occurs at 45° of bank. While the difference between 30° of bank and 45° is not terribly great in altitude lost (approximately 8 ft), the difference in the radius of turn of 325 ft for 45° of bank, and 460 ft for 30° of bank, is significant. If clearing some trees or making it back to the airfield is an issue, every foot may count.

Explanation for Question 2: With a normal landing, as the PW-6 crosses the threshold with a landing airspeed of 60 kt, the groundspeed with a 20 kt headwind is 40 kt. On the other hand, with the tailwind landing, the ground speed is 80 kt, twice as fast. So, from the threshold at 10 ft above the runway as the PW-6 descends and levels off to touchdown at ~45 kt airspeed, the PW-6 will use up approximately twice as much runway to reach the touchdown point. However, at the touchdown point, landing into the wind, the groundspeed is only ~25 kt – while landing with the wind, the ground speed at the touchdown point is ~65 kt – greater than 2.6 times the "into the wind" touchdown speed! And since energy is proportional to velocity squared ($1/2 * W/g * V^2$, where W = weight of glider; g = gravitational acceleration (32 ft/s^2); V = velocity of glider), the energy at touchdown of the tailwind landing is 6.7 times greater! Therefore, without exceptional braking, it is highly likely the distance from touchdown to a full stop to dissipate the kinetic energy will be greater than 2 times that of a normal landing into the wind. The answer to question 2 is E, greater than 100%.

Lessons Learned: To consume the least amount of energy (altitude) while completing a circling turn, use 45° of bank at an airspeed equal to 20% (18.9% to be exact) above the level flight minimum sink speed for the current operating weight. This is the same for all gliders. When executing an actual low level rope break, or simulated rope break, a return to land downwind maneuver requires exceptional care and planning with strong wind conditions. The effective glide ratio with a strong tailwind is substantially greater than a normal "into the wind" landing, and the kinetic energy at touchdown is dramatically greater, often requiring maximum braking to stay within the runway boundaries. Note, the FAA Private Pilot Flight Test includes the option for the examiner to evaluate the applicant on "ABNORMAL OCCURRENCES" (Task G) including a rope break scenario as well as downwind landings (Task S). Fly safe.

About the author: *Steve is a commercial pilot in single engine airplanes, single engine seaplanes, and gliders. He holds an instrument rating and is a Certificated Flight Instructor for airplanes, instruments, and gliders. He has logged over 4,000 flight hr, including over 2,000 hr as a flight instructor. He is a retired IBM Engineering Manager and is a member of the Flight Instructor Staff at Sugarbush Soaring, Warren-Sugarbush Airport, Warren, VT.*

GLIDER AERODYNAMICS PUZZLER

BY STEVE PLATT

Minimum Sink Speed

The Glider Aerodynamics Puzzler is intended to stimulate your thinking about soaring and refresh your understanding of glider aerodynamics and soaring optimization. The correct answers with detailed explanations follow the questions. Have fun.

Most glider pilots are intimately familiar with the level flight performance of the ships they fly, particularly the best L/D speed and glide ratio performance in still air. Whether a Schweizer 1-26 at 23:1, a Schleicher ASK-21 at 33.5:1, or a high performance Ventus at 50:1, glider pilots usually remember the best L/D speed and glide ratio performance. Minimum sink speed, on the other hand, is a performance parameter which directly affects turning performance that is often soon forgotten. What do I mean by turning performance? The ability of any glider to complete a 360° turn using a minimum of energy, i.e., altitude, and the ability of a glider to thermal efficiently, i.e., close to the core of the thermal. Understanding minimum sink speed in coordinated turning flight is the key.

QUESTION 1: Your soaring club offers glider rides in a PW-6 and ASK-21. You are the instructor or ride pilot on duty one glorious Saturday morning. There is not a cloud in the sky or a breath of air. The wind sock is limp. A customer shows up for a 20 minute ride. There is no lift. It will be a sled ride. You decide to take the PW-6. Your strategy is to do a high tow and fly at minimum sink speed to complete the mission. The performance characteristics of the PW-6 at your operating weight are shown in Table 1.

Stall speed (kt)	38
Minimum sink speed (kt)	50
Minimum sink rate (fpm)	148
Best L/D speed (kt)	56
Glide ratio	34-to-1

Table 1: PW-6 operating characteristics.

After a relatively high tow, you release at a safe altitude to complete the flight. Your passenger is in awe of the beauty, tranquility, and smoothness of the flight. You have been flying straight at minimum sink speed to conserve energy and maximize time aloft. You will need to complete at least one 180° turn to navigate back to your pattern entry. You decide to use an approximate 30° bank turn at minimum sink speed for a 30° banked turn. During the turn, how much does the sink rate increase over the minimum sink rate in level flight?

A. Sink rate increases 16%
B. Sink rate increases 24%
C. Sink rate increases 48%
D. Sink rate increases 68%
E. Sink rate increases 78%

QUESTION 1 BONUS: How much does the minimum sink speed increase for a 30° coordinated bank turn, if the level flight minimum sink speed is 50 kt?

A. Minimum sink speed remains the same
B. Minimum sink speed increases by 3%
C. Minimum sink speed increases by 7.5%
D. Minimum sink speed increases by 12%
E. Minimum sink speed increases by 18.9%

QUESTION 2: What if you decide to use a 45° banked turn and fly at the minimum sink speed for a 45° banked turn? During the turn, how much does the sink rate increase over the minimum sink rate in level flight?

A. Sink rate increases 16%
B. Sink rate increases 24%
C. Sink rate increases 48%
D. Sink rate increases 68%
E. Sink rate increases 78%

QUESTION 2 BONUS: How much does the minimum sink speed increase for a 45° coordinated bank turn, if the level flight minimum sink speed is 50 kt?

A. Minimum sink speed remains the same

B. Minimum sink speed increases by 3%

C. Minimum sink speed increases by 7.5%

D. Minimum sink speed increases by 12%

E. Minimum sink speed increases by 18.9%

EXPLANATION QUESTIONS 1 & 2: In coordinated turning flight, the wing must work harder, i.e., lift more than in level flight, in order for the vertical component of lift to remain equal to the weight of the glider plus the tail down force, and for the horizontal component of lift to remain equal and opposite to centripetal force. The flight polar for all gliders moves down and to the right in coordinated turning flight. Shown in Figure 1 are the flight polars for a Libelle in coordinated flight at various angles of bank (Reference 1: *The Complete Soaring Pilots Handbook*, by Anne and Lorne Welch, and Frank Irving, ISBN: 0-679-50718-3). Notice the minimum sink speed displayed as small circles on each polar.

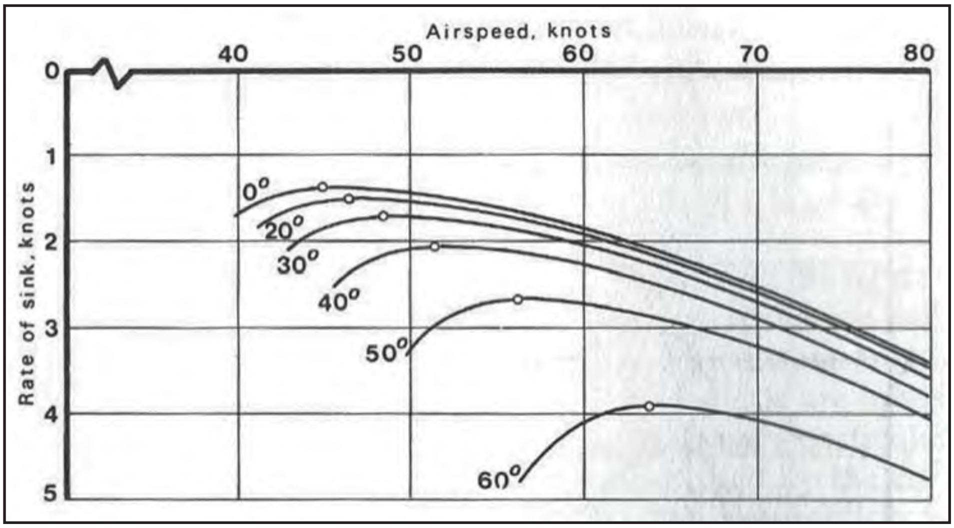


Figure 1

The increase in minimum sink speed and minimum sink rate as a percent, versus the level flight minimum sink speed and minimum sink rate for various angles of bank, is IDENTICAL for all gliders independent of make and model. Shown in Table 2 is the increase in minimum sink speed and minimum sink rate relative to the level flight minimum sink speed and minimum sink rate as a percent for various angles of bank. Notice that for 30° of bank, the minimum sink speed increases 7.5% and the minimum sink rate increases by 24%.

However, for 45° of bank, the minimum sink speed increases 18.9% and the minimum sink rate increases by 68%. Above 45° of bank, sink rate increases rapidly.

The formulae for the increase in minimum sink speed and minimum sink rate versus angle of bank are (again from Reference 1): ☛

Table 2

Angle of Bank (Degrees)	0°	10°	20°	30°	40°	45°	50°	60°
% Increase in Minimum Sink Speed	0%	0.7%	3.2%	7.5%	14%	18.9%	25%	41%
% Increase in Minimum Sink Rate	0%	2.4%	9.8%	24%	49%	68%	94%	183%

Minimum sink speed at bank angle X=(Minimum sink speed in level flight) $(1 / \text{cosine}(x))^{0.5}$

Minimum sink rate at bank angle X=(Minimum sink rate in level flight) $(1 / \text{cosine}(x))^{1.5}$

The answer to Question 1 is B. 24%, and Question 1 bonus is C. 7.5%. The answer to Question 2 is D. 68% and Question 2 bonus is E. 18.9%.

LESSONS LEARNED: Minimum sink speed is an extremely important performance parameter not only for level flight, but for turning flight as well. As described in the article "How to Optimize Thermaling Flight in Gliders" in the May 2017 issue of *Soaring* magazine, thermaling at the optimized minimum sink speed for the angle of bank chosen when properly centered will maximize net climb rates. Likewise, in an energy conservation scenario, completing a 180˚ or 360˚ turn at 45˚ of bank at minimum sink speed for a 45˚ banked turn will consume the least amount of energy (altitude) for ALL gliders. Since the radius of turn for all gliders is proportional to the SQUARE of airspeed, a relatively slow minimum sink speed facilitates thermaling with a tighter (smaller) radius of turn closer to the core of a thermal. It is for this reason that a Schweizer 1-26 can often outclimb the highest performance glass ships in many narrow thermals. Minimum sink speed and radius of turn matter. Fly safe.

About the author: *Steve is a commercial pilot in single engine airplanes, single engine seaplanes, and gliders. He holds an instrument rating and is a Certificated Flight Instructor for airplanes, instruments, and gliders. He has logged over 4,000 flight hr, including over 2,000 hr as a flight instructor. He is a retired IBM Engineering Manager and is a member of the Flight Instructor Staff at Sugarbush Soaring, Warren-Sugarbush Airport, Warren, VT.*

GLIDER AERODYNAMICS PUZZLER

BY STEVE PLATT

Thermaling

The Glider Aerodynamics Puzzler is intended to stimulate your thinking about soaring and refresh your understanding of glider aerodynamics and soaring optimization. The correct answers with detailed explanations follow the questions. Have fun.

Glider pilots spend a significant amount of time thermaling, particularly when mountain wave or ridge lift conditions are not available. On a recreational flight, as much as 25-50% of flight time may be spent thermaling. Indeed, knowing how to thermal efficiently is one of the challenges and joys of our sport. While every thermal is different in strength, shape, profile, etc., a standard thermal has been used for decades to analyze and model net climb rates for gliders as function of bank angle and airspeed. Originally proposed by H. C. N. Goodhart, the "Standard British Thermal" (SBT) is defined as a thermal with a circular cross section with air mass lift of 4.2 kt at the core decreasing parabolically to zero at a radius of 1,000 ft. (Reference: *The Complete Soaring Pilot's Handbook*, Ann & Lorne Welch and Frank Irving, 1977, Page 242 ISBN: 0-679-50718-3). While you or I may not have ever seen or been in a "Standard British Thermal," it has proven useful to study the effects of angle of bank and airspeed on net climb performance.

QUESTION 1: You are a student pilot taking up a low performance Schweizer 2-33 with your instructor for a training flight. After a 2,500 ft tow you approach what appears to be an SBT. As you enter and center the thermal, what angle of bank and airspeed will maximize your net climb rate in the thermal? (Key performance parameters for the Schweizer 2-33 are: min sink speed = 42 mph, best L/D speed = 52 mph, best L/D = 23 to 1).

A. Airspeed = 42 mph with bank angle = 20°

B. Airspeed = 43 mph with bank angle = 25°

C. Airspeed = 45 mph with bank angle = 30°

D. Airspeed = 48 mph with bank angle = 40°

E. Airspeed = 50 mph with bank angle = 45°

QUESTION 2: Similar to Question 1, you are flying your club's medium performance PW-6 glider. After a 2,500 ft tow, you approach what appears to be an SBT. As you enter and center the thermal, what angle of bank and airspeed will maximize your net climb rate in the thermal? (Key performance parameters for the PW-6 are: min sink speed = 50 kt, best L/D speed = 56 kt, best L/D = 34 to 1).

A. Airspeed = 52 kt with bank angle = 25°

B. Airspeed = 54 kt with bank angle = 30°

C. Airspeed = 55 kt with bank angle = 33°

D. Airspeed = 57 kt with bank angle = 40°

E. Airspeed = 59 kt with bank angle = 45°

QUESTION 3: Similar to Question 1, you are an experienced cross-country pilot flying a very high performance Ventus. After a 2,500 ft tow, you approach what appears to be an SBT. As you enter and center the thermal, what angle of bank and airspeed will maximize your net climb rate in the thermal? (Key performance parameters for the Ventus: min sink speed = 47 kt, best L/D speed = 56 kt, best L/D = 50 to 1).

A. Airspeed = 49 kt with bank angle = 25°

B. Airspeed = 50 kt with bank angle = 30°

C. Airspeed = 52 kt with bank angle = 35°

D. Airspeed = 57 kt with bank angle = 40°

E. Airspeed = 59 kt with bank angle = 45°

EXPLANATION QUESTIONS 1-3: The net climb rate in a thermal is a complex function of at least five variables:

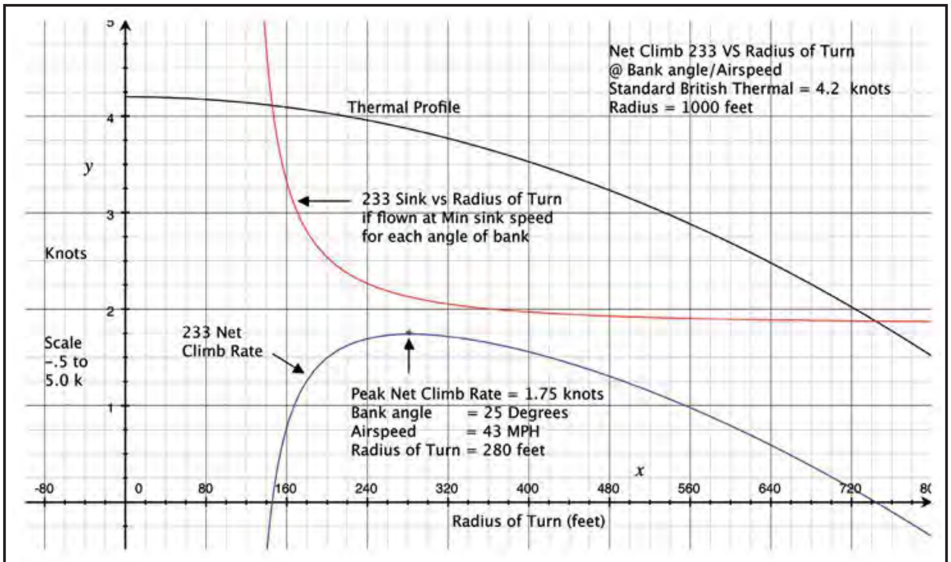


FIGURE 1

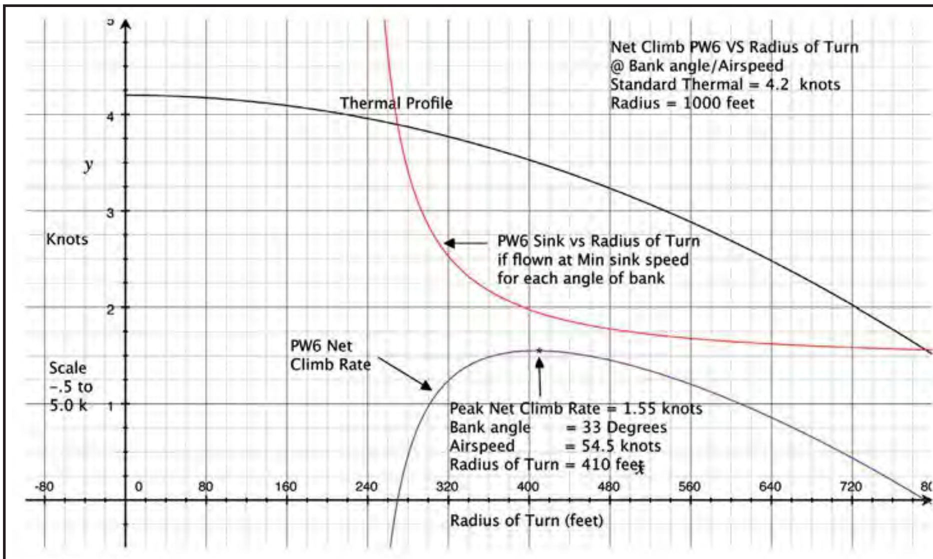


FIGURE 2

1. Thermal Strength: The peak air mass lift (vertical velocity) at the core of the thermal.

2. Thermal Profile: The shape of the thermal, i.e., the decrease in vertical lift extending out from the core of the thermal to the extremity, e.g., parabolic, linear, etc.

3. Thermal Size: The thermal width, diameter, or radius.

4. Glider Performance: The flight polar of the glider and, in particular, the wings level minimum sink speed and minimum sink rate.

5. Flightpath: How centered the glider is in the thermal.

It goes without saying that weight also affects climb performance as weight shifts the polar for ALL gliders. Increasing weight decreases net climb performance and decreasing weight improves net climb performance …. Adding ballast may help cruise performance but it definitely hurts climb performance.

Shown in Figure 1 is the profile of a Standard British Thermal as a function of radius from the core overlaid with the magnitude of sink rate for a Schweizer 2-33 as a function of radius of turn, i.e., as a function of bank angle and airspeed if flown at the optimum minimum sink speed for each angle of bank. Subtracting the 2-33 sink rate from the air mass lift yields the net climb rate as a function of radius of turn, i.e., as a function of bank angle and airspeed. Notice that for the Schweizer 2-33 perfectly centered in an SBT, the peak net climb rate occurs at a bank angle of 25° and an airspeed of 43 mph, yielding a radius of turn of 280 ft. The answer to Question 1 is B. 43 mph and 25°.

Shown in Figure 2 is the profile of a Standard British thermal as a function of radius from the core overlaid with the magnitude of sink rate for a PW-6 as a function of radius of turn … i.e., as a function of bank angle and airspeed if flown at the optimum minimum sink speed for each angle of bank. Subtracting the PW-6 sink rate from the air mass lift yields the net climb rate as a function of radius of turn … i.e., as a function of bank angle and airspeed. Notice that for the PW-6 perfectly centered in a Standard British Thermal, the peak net climb rate occurs at a bank angle of 33° and an airspeed of 54.5 kt yielding a radius of turn of 410 ft. The answer to Question 2 is C. 55 kt and 33°.

Shown in Figure 3 is the profile of an SBT as a function of radius from the core, overlaid with the magnitude of sink rate for a Ventus as a function of radius of turn, or, as a function of bank angle and airspeed if flown at the optimum minimum sink speed for each angle of bank. Subtracting the Ventus sink rate from the air mass lift yields the net climb rate as a function of radius of turn, i.e., as a function of bank angle and airspeed. Notice that for the Ventus perfectly centered in a Standard British Thermal, the peak net climb rate occurs at a bank angle of 35° and an airspeed of 52 kt, yielding a radius of turn of 340 ft. The answer to Question 3 is C. 52 kt and 35°.

LESSONS LEARNED: Optimizing net climb rates in thermals is complex. There are no simple answers. What is certain is: for a given thermal, the optimum angle of bank and airspeed varies significantly for gliders of different performance parameters. Lower performance/slower gliders

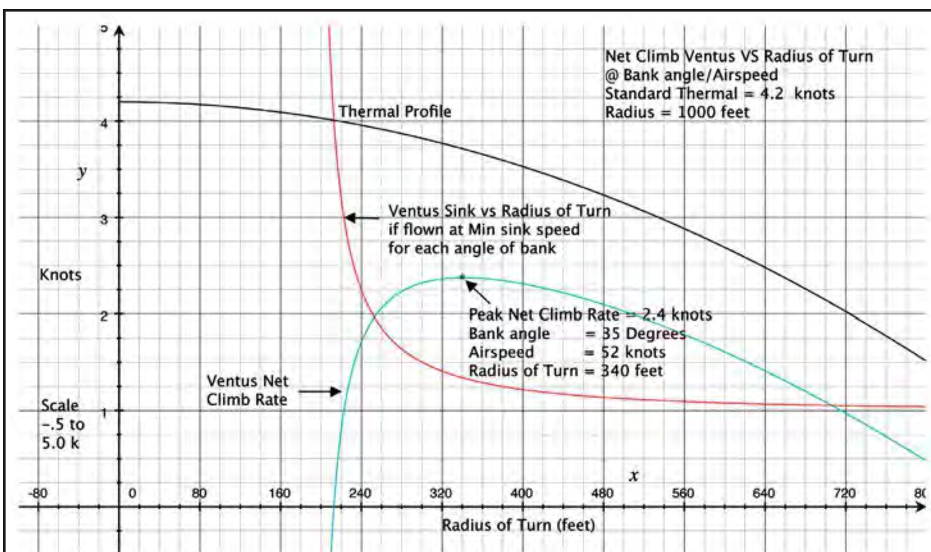


FIGURE 3

achieve optimum net climb rates with shallower angles of bank than high performance/higher speed ships. For all gliders, too shallow an angle of bank and the radius of turn is large, and the glider may circle in the weakest portion of the thermal, or worst case, circle the thermal entirely. Too steep an angle of bank, the radius of turn may be small but the sink rate of the glider increases dramatically with the higher load factor, more than offsetting the benefit of flying closer to the core of the thermal. For each glider, and for each thermal, there is an optimum angle of bank and airspeed required to maximize net climb performance, meaning that radius of turn matters. As a general rule, narrow (less than 750 ft radius) strong thermals require steeper angles of bank to maximize net climb rates, while wide (greater than 1,500 ft radius) weak thermals require shallower angles of bank to maximize net climb rates. Knowing the minimum sink speed for key angles of bank is also important.

Shown in Figure 4 is a comparison of the net climb rates for a 1-26, 2-33, Ventus, Discus, and a PW-6 versus radius of turn in an SBT. Notice that if all ships are centered perfectly and flown at their optimum minimum sink speeds for each angle of bank, the lowly Schweizer 1-26, with a peak net climb rate at only 250 ft radius of turn, is capable of outclimbing all but the Ventus! Minimum sink speed matters. Radius of turn matters. Optimizing thermaling flight is fascinating. Have fun. Fly safe.

APPENDIX

Note: All of the computer-generated net climb rates are theoretical. While the results are useful for understanding the relative performance and effects of angle of bank and airspeed on net climb performance, the models assume perfect flight — gliders are perfectly centered, flown in perfectly cylindrical thermals at the perfect minimum sink speed for each angle of bank. Highly unlikely. For those readers interested in the technicalities or plotting net climb rates for different make/models, the following equations will prove helpful:

EQUATION 1: For ALL gliders, the sink rate as a function of radius of turn (and therefore bank angle and airspeed), if flown at the optimum minimum sink speed for each angle of bank, is generated from the following equation:

$VSink(R) = VSink(0) * [\ 1 / \{\ 1 - (V_O^2 / g * R)^2\ \}^{0.5}]^{1.5}$ where:

VSink(R) = the sink rate at a radius of turn for a particular angle of bank / airspeed

VSink(0) = the level flight minimum sink rate for any glider at the operating weight

V_O = the level flight minimum sink speed at the operating weight

R = the radius of turn at a particular bank angle flown at the min sink speed for the angle of bank.

EQUATION 2: The minimum sink speed at angle of bank (x) is given by:

$Vangle = V_O * (1 / Cos\ (x))^{0.5}$ where:

Vangle = the minimum sink speed for coordinated turning flight at bank angle x

V_O = the level flight minimum sink speed at the operating weight.

EQUATION 3:

$R = (V_O)^2 / (g * Sin\ (x))$ where:

R = the radius of turn at a particular bank angle flown at the min sink speed for the angle of bank.

EQUATION 4: Model representing a Standard British Thermal, a cylindrical column of rising air with a maximum air mass rate of climb of 4.2 kt at the center, decreasing parabolically to zero at a radius of 1,000 ft:

$Thermal\ lift\ (R) = 4.2 * \{1 - (R / 1000\ )^2\}$ where:

Thermal lift (R) = the thermal strength at radius R from the center of the thermal.

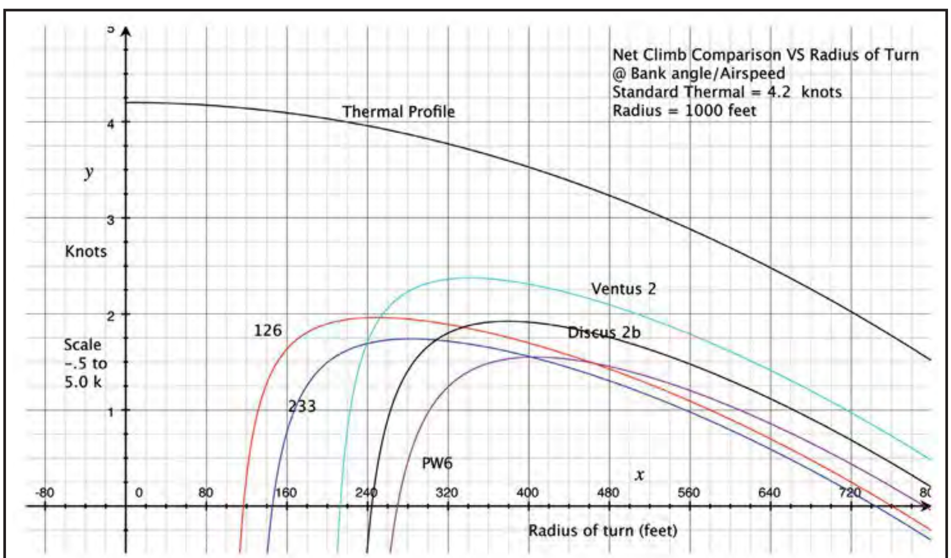


FIGURE 4

About the author: *Steve is a commercial pilot in single engine airplanes, single engine seaplanes, and gliders. He holds an instrument rating and is a Certificated Flight Instructor for airplanes, instruments, and gliders. He has logged over 4,000 flight hr, including over 2,000 hr as a flight instructor. He is a retired IBM Engineering Manager and is a member of the Flight Instructor Staff at Sugarbush Soaring, Warren-Sugarbush Airport, Warren, VT.*

GLIDER AERODYNAMICS PUZZLER

BY STEVE PLATT

Energy Management

The Glider Aerodynamics Puzzler is intended to stimulate your thinking about soaring and refresh your understanding of glider aerodynamics and soaring optimization. The correct answers with detailed explanations follow the questions. Have fun.

Glider pilots are taught from the very initial flight lessons how to manage energy. Whether flying faster into headwinds, slower with tailwinds, or thermaling efficiently, glider pilots are energy managers. Knowing how to optimize energy consumption to

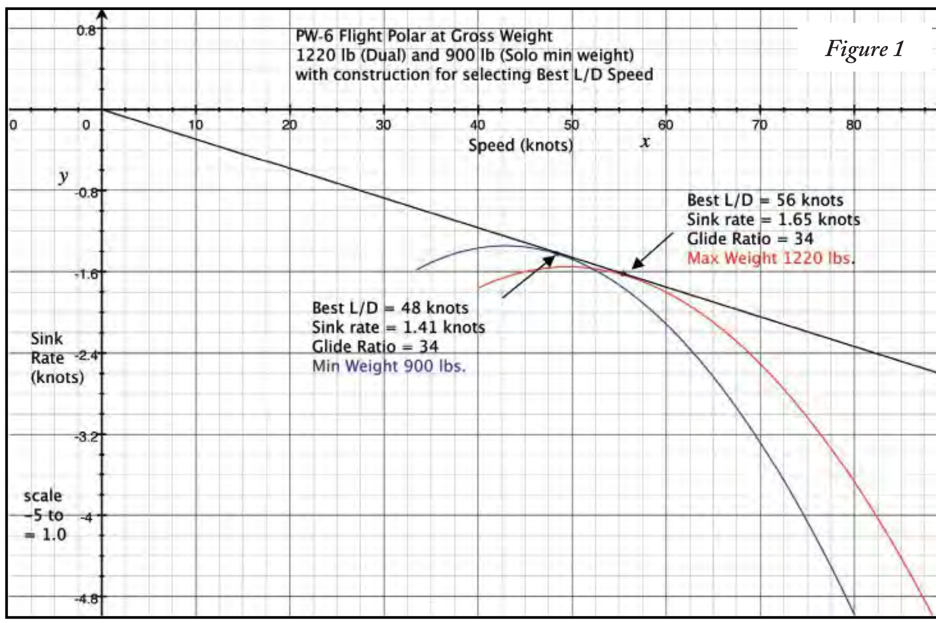


Figure 1

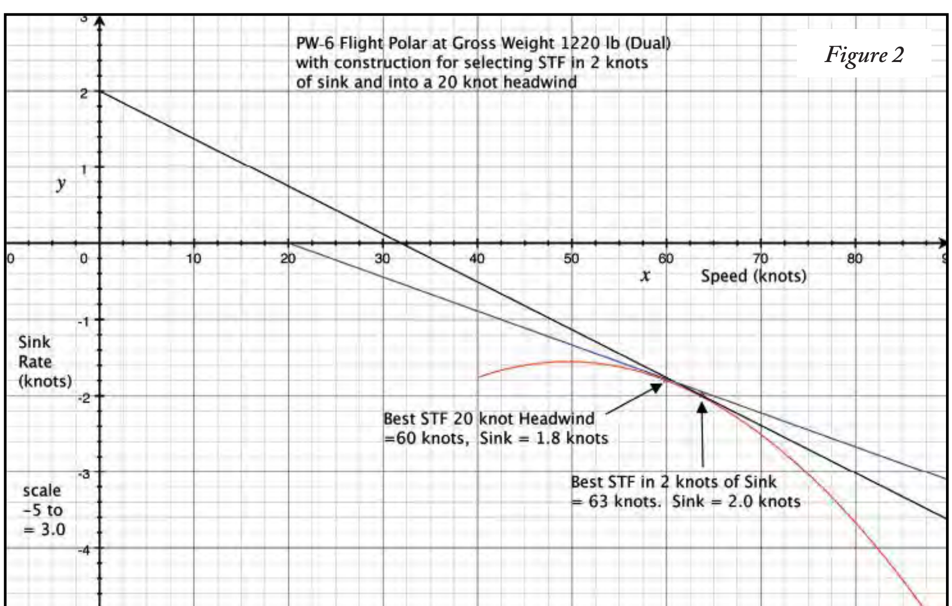


Figure 2

make a destination, maximize speed in a race, or optimize energy acquisition while thermaling, ridge flying, or in mountain wave, is key to successful soaring flight. The best glider pilots are, indeed, the best energy managers.

QUESTION 1A: You are flying a PW-6 medium performance 2-seat glider. The flight polar is shown in Figure 1 for your operating weight (max weight). You are flying to maximize energy conservation to make a destination by getting the maximum distance per foot of altitude consumed. If you fly at the optimum speed to fly (STF) to maximize distance, which of the following conditions will consume the least amount of energy (altitude) per unit distance traveled?

A. Flying in an area of 2 kt of sink
B. Flying into a 20 kt headwind
C. Either condition will consume the same altitude per unit distance travelled

QUESTION 1B: How about if you fly at the optimum STF to maximize distance into a 30 kt headwind or flying in an area of consistent 3 kt of sink, which scenario will consume the least amount of energy (altitude) per unit distance travelled?

A. Flying in an area of 3 kt of sink
B. Flying into a 30 kt headwind
C. Either condition will consume the same altitude per unit distance traveled

QUESTION 2: Optimizing energy acquisition is crucial to soaring flight. You are flying a PW-6 at max gross weight (polar shown in Figure 1). Which of the following scenarios will yield a larger net climb rate: thermaling optimally (perfectly centered at the optimal airspeed and bank angle) in a Standard British Thermal with 4.2 kt of air mass lift at the core decreasing parabolically to zero at a radius of 1,000 ft, or climbing at the optimum STF in an area of 3.5 kt of vertical air mass ridge lift?

A. Thermaling in the Standard British Thermal
B. Climbing in ridge lift
C. The net climb rate will be the same in either scenario

EXPLANATION QUESTION 1A: Shown in Figure 2 is the construction for determining the optimum STF in 20 kt of headwind and 2 kt of air mass sink. Notice that the STF to optimize distance is faster for 2 kt of sink than for a 20 kt headwind. ☛

For the case of 2 kt of air mass sink, the sink rate of the glider at the 63 kt STF is 2.0 kt, for a total of 4 kt of sink read on the variometer. (Note: the sink rate of the glider must be added to the sink of the air mass the glider is flying in). However, for the 20 kt headwind case, the sink rate of the glider at the STF of 60 kt is 1.8 kt, but the GROUND SPEED is only 40 kt in an air mass neither rising nor sinking – so the glider will take 57% longer to make the same horizontal distance traveled; the sink rate of 1.8 kt for this case must be uplifted by 50% to 2.8 kt, to be compared to the 4 kt of sink in the prior case. In summary, flying into a 20 kt headwind will consume less energy (altitude) per unit of horizontal travel than flying in 2 kt of air mass sink. The answer to Question 1A is B.

EXPLANATION QUESTION 1B: Shown in Figure 3 is the construction for determining the optimum STF in 30 kt of headwind and in 3 kt of air mass sink. As in 1A, the STF to optimize distance is faster for 3 kt of sink than for a 30 kt headwind. For the 3 kt of air mass sink case, the sink rate of the glider at the 66 kt STF is 2.2 kt, for a total of 5.2 kt of sink read on the variometer. (Again, the sink rate of the glider must be added to the sink of the air mass the glider is flying in). However, for the 30 kt of headwind case, the sink rate of the glider at the STF of 63 kt is 2.0 kt, but the GROUND SPEED is only 33 kt in an air mass neither rising nor sinking – so the glider will take 100% longer to make the same horizontal distance traveled; the sink rate of 2.0 kt for this case must be uplifted by 100% to 4.0 kt, to be compared to the 5.2 kt for the 3.0 kt of air mass sink case. Flying into a 30 kt headwind will consume less energy (altitude) per unit of horizontal travel than flying in 3 kt of air mass sink. The answer to Question 1B is B.

EXPLANATION QUESTION 2: Shown in Figure 4 is the net climb rate for the PW-6 as a function of

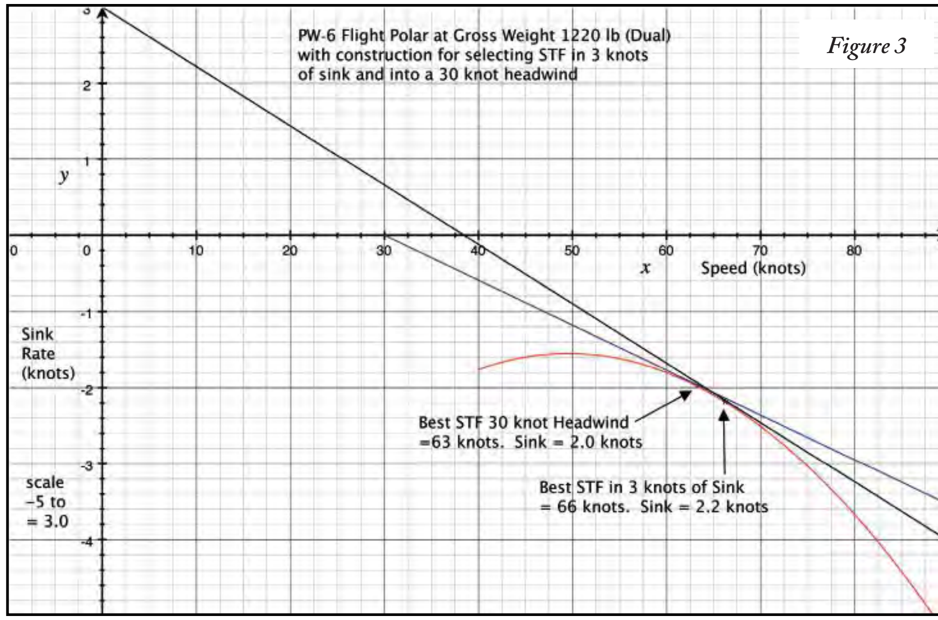


Figure 3

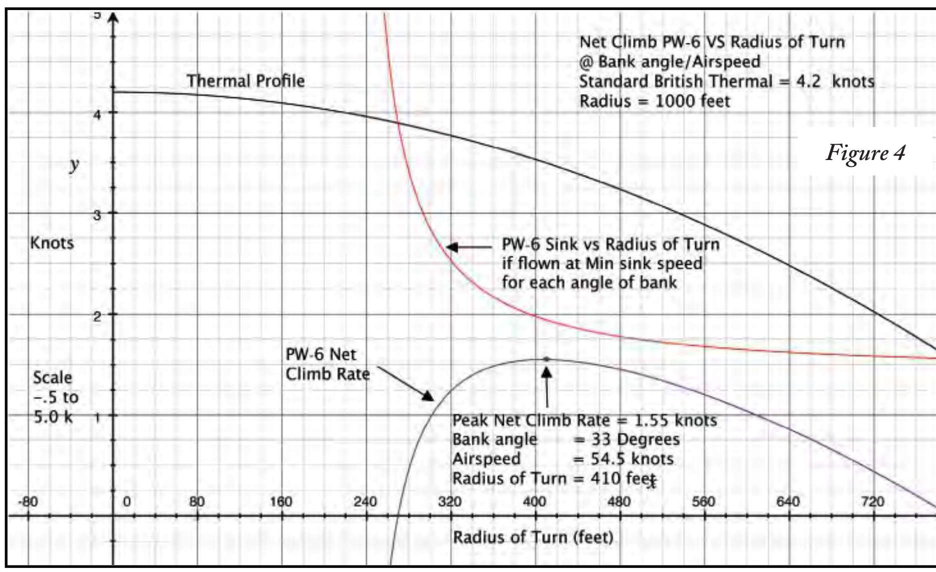


Figure 4

radius of turn in a Standard British Thermal. Notice that the peak net climb rate of 1.55 kt occurs at a radius of turn of 410 ft (i.e., at a bank angle of 33º and airspeed of 54 kt). For the ridge climb scenario, the optimum STF is the wings level minimum sink speed, which equals 50 kt at a minimum sink rate of 150 ft/min = ~1.5 kt. Therefore, the net climb rate will be the 3.5 kt of air mass lift minus the 1.5 kt sink rate of the glider, which yields ~2 kt net climb. The ridge climb scenario will outclimb the thermaling scenario, ie., 2.0 kt versus 1.55 kt.

LESSONS LEARNED: For optimizing distance, i.e. energy (altitude), the optimum STF is determined by the construction in Figures 2 and Figure 3 – the tangent to the flight polar from the "headwind point," or the "sink rate point," or the combination thereof. It is imperative to point out that the flight polar for ALL gliders is a function of weight. The flight polar must be adjusted for the current operating weight. While the change in optimal STF for single seat ships as a function of weight does not change much (except if the ship is designed to accommodate large amounts of water ballast), for two seat gliders, such as the ASK 21 or PW-6, the change in optimum STF changes significantly between maximum gross weight with 2 passengers and minimum weight with a single passenger. For example, the minimum sink speed for the PW-6 at gross weight is 50 kt. (Refer to Figure 1.) The minimum sink speed at minimum weight is 44 kt. 6 kt slower is not insignificant.

In Question 2, the key to understanding the answer is understanding minimum sink speed. For straight and level flight in ridge lift, the maximum net climb rate occurs when flying at minimum sink speed – at the minimum sink rate. Likewise, when thermaling, flying at the optimum minimum sink speed for the bank angle chosen will minimize glider sink rate and maximize climb rate for the available air mass lift. Minimum sink speed is an extremely important parameter to understand as a function of weight and as a function of bank angle. As noted in prior aerodynamic puzzlers, the percent change in minimum sink speed for various angles of bank is IDENTICAL for ALL gliders independent of make or model. I find it useful to memorize two cases: 30° of bank and 45° of bank, as it applies to all the ships I fly. (Note: Sugarbush Soaring has a Schweizer 1-26, a Schweizer 2-33, a Grob 102, an ASK 21, and two new PW-6 gliders in the fleet.) For all gliders in a coordinated 30° bank turn, the minimum sink speed increases by 7.5% and minimum sink rate increases by 24% over the level flight min sink speed and rate. Likewise, for all gliders in a coordinated 45° bank turn, the minimum sink speed increases by 18.9% and minimum sink rate increases by 68% over the level flight minimum sink speed and rate. The aerodynamics of glider flight is fascinating. Fly safe.

About the author: *Steve is a commercial pilot in single engine airplanes, single engine seaplanes, and gliders. He holds an instrument rating and is a Certificated Flight Instructor for airplanes, instruments, and gliders. He has logged over 4,000 flight hr, including over 2,000 hr as a flight instructor. He is a retired IBM Engineering Manager and a Flight Instructor at Sugarbush Soaring, Warren, VT.*

GLIDER AERODYNAMICS PUZZLER

BY STEVE PLATT

Speed to Fly

The Glider Aerodynamics Puzzler is intended to stimulate your thinking about soaring and refresh your understanding of glider aerodynamics and soaring optimization. The correct answers with detailed explanations follow the questions. Have fun.

Glider pilots take great pride in staying aloft when everyone else is "falling" out of the sky. Indeed, being able to stay aloft in weak to nonexistent lift conditions to complete the mission at hand is one of the great challenges of our sport. Whether trying to maximize time aloft, maximize distance, or maximize speed, being able to read the atmosphere and geography and knowing the optimum speed-to-fly for the mission is key. A little luck does not hurt either.

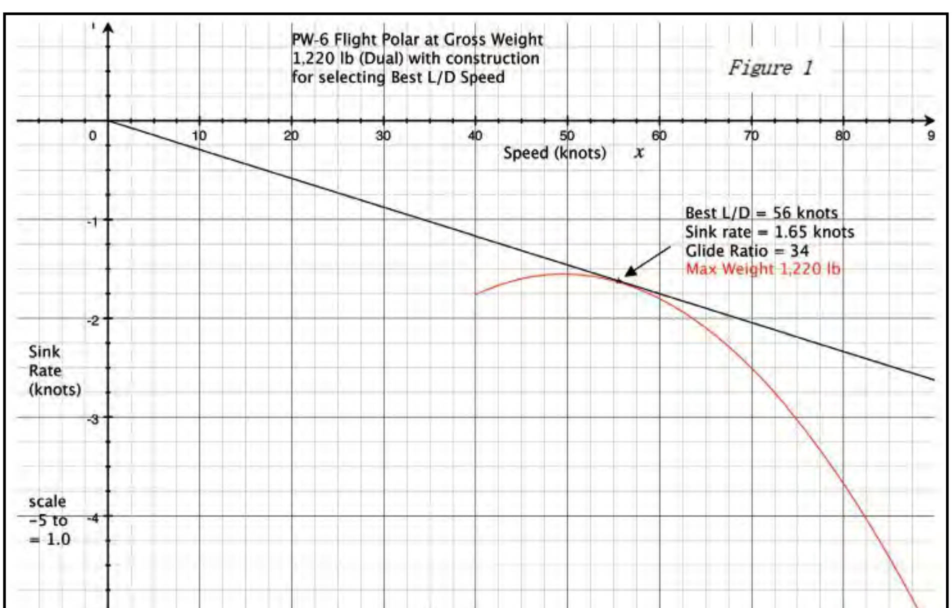
QUESTION 1: On a beautiful Saturday afternoon, you are finishing up a local recreation flight. You are flying your club's dual seat PW-6 solo at minimum weight, about 320 lb under gross weight. The manufacturer's published gross weight flight polar is shown in Figure 1. You are 5 miles from your home airport and have gotten a bit low. You decide to fly at the best speed-to-fly (STF) to maximize distance. The good news is you have a 20 kt tailwind. What is the best STF in your situation to maximize distance and conserve energy?

A. Best speed-to-fly = 42 kt
B. Best speed-to-fly = 46 kt
C. Best speed-to-fly = 50 kt
D. Best speed-to-fly = 52 kt
E. Best speed-to-fly = 56 kt

QUESTION 2: As in Question 1, suppose you have a 20 kt headwind instead of a 20 kt tailwind. What is the best STF in your situation to maximize distance and conserve energy?

A. Best speed-to-fly = 46 kt
B. Best speed-to-fly = 50 kt
C. Best speed-to-fly = 53 kt
D. Best speed-to-fly = 60 kt
E. Best speed-to-fly = 64 kt

QUESTION 3: Your soaring club holds an annual President's Cup Race for members. The course is short and designed such that landing out is highly unlikely. Your home airport is at the center of a triangular course. The event is designed only for fun and bragging rights. There are three classes based on performance such that everyone can participate, even the low performance ships (SGS 2-33s), including student pilots with their instructors. You are planning to run the course in the club's PW-6 solo at minimum weight. The manufacturer's published flight polar is shown in Figure 1. The reported net climb rates in thermals has been 2 kt from several participants. You decide to apply classic MacCready theory

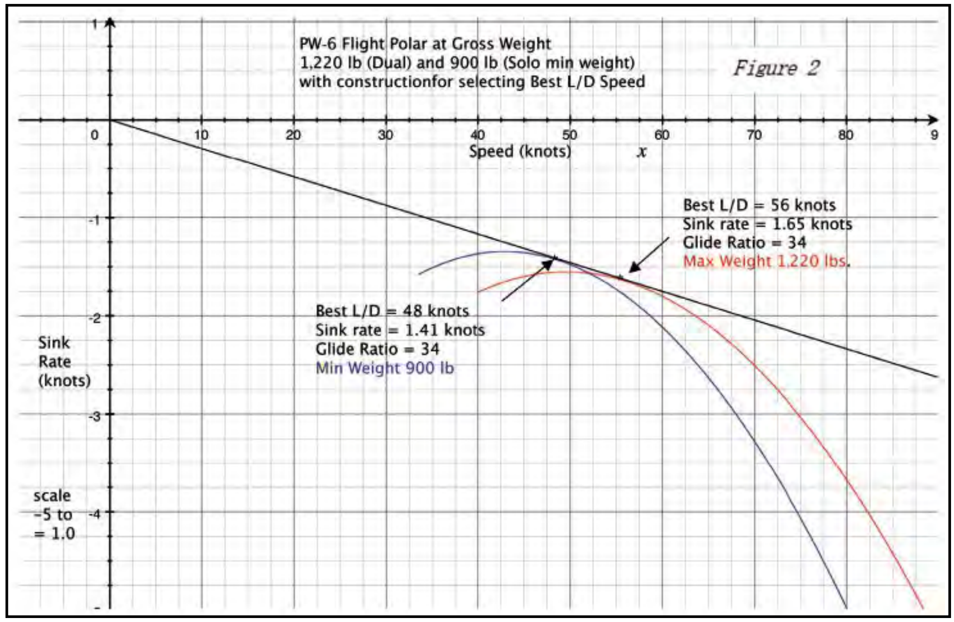


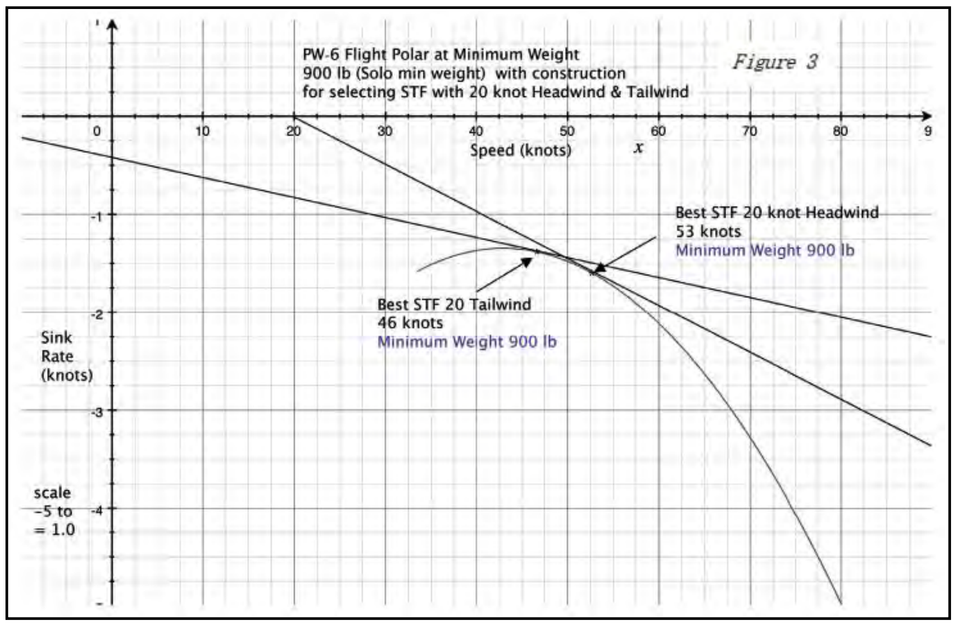
and fly at MacCready 2 speed. What is your MacCready 2 speed-to-fly?

A. Best speed-to-fly = 53 kt
B. Best speed-to-fly = 56 kt
C. Best speed-to-fly = 60 kt
D. Best speed-to-fly = 63 kt
E. Best speed-to-fly = 66 kt

EXPLANATION QUESTION 1 & 2: Weight matters. While the manufacturer's published gross weight polar is shown in Figure 1, at 320 lb under gross weight, the flight polar shifts up and to the left as shown in Figure 2. All of the key performance parameters slow down considerably. The stall speed, minimum sink speed, and best L/D speed all decrease. Technically, all the published gross weight coordinate parameters shift by a factor equal to the square root of the ratio of the actual operation weight to the gross weight. (Reference: *The Complete Soaring Pilots Handbook,* by Ann & Lorne Welch and Frank Irving, p 266, ISBN: 0-679-50718-3; and *Cross Country Soaring,* 7th edition, by Helmut Reichmann, p 122, ISBN: 1-883813-01-8.) The shift factor = $(900/1220)^{0.5}$ = 0.859. At 900 lb operational weight, the minimum sink speed reduces by ~7 kt from 50 kt to 43 kt and the best L/D speed decreases ~8 kt from 56 kt to 48 kt. Using the polar for the minimum weight configuration from Figure 2, the best STF to maximize distance is determined by the tangents to the polar for the 20 kt headwind and tailwind as shown in Figure 3. The best speed-to-fly for the 20 kt tailwind to maximize distance is 46 kt (answer B). And the best speed-to-fly for the 20 kt headwind is 53 kt (answer C).

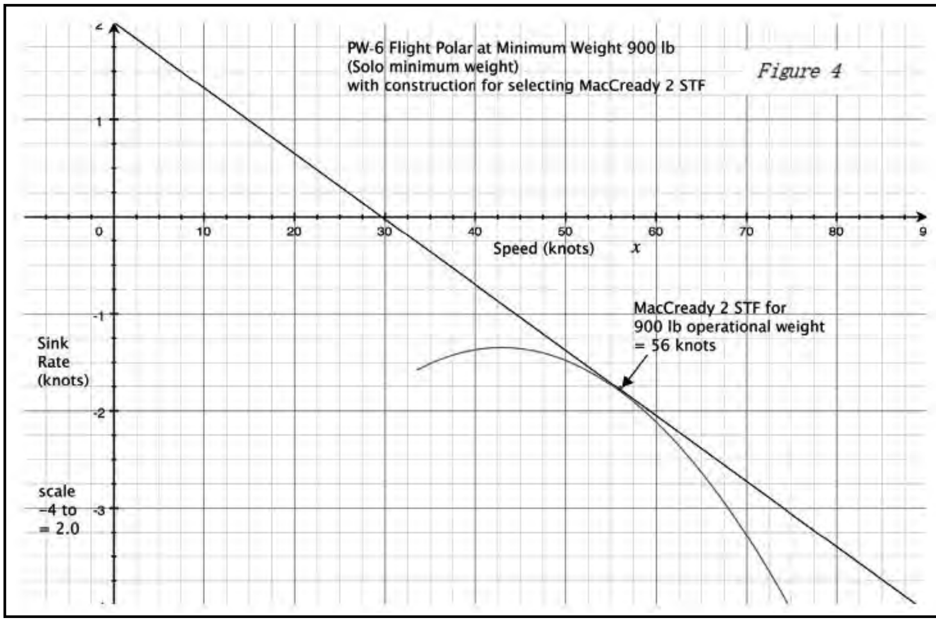
EXPLANATION QUESTION 3: Per classical MacCready flight, the best speed-to-fly to maximize average speed for thermals yielding a net climb rate of 2 kt is MacCready 2. MacCready 2 speed is determined by the construction (tangent to the minimum weight configuration polar) as shown in Figure 4. The best STF for MacCready 2 at the 900 lb operational weight is 56 kt (answer B).





LESSONS LEARNED: Know Thy Flight Polar. The flight polar for ALL gliders is a function of weight. While the manufacturers typically publish the flight polar at gross weight (and perhaps with ballast, if that is an option) the actual flight polar must be adjusted for the actual operating weight. Some sophisticated onboard navigation computers can make this adjustment if programmed properly. While the differences in key performance STF numbers for single-seat ships may be modest, for dual seat ships flown solo, the difference between minimum weight and maximum weight STF numbers can be more significant, e.g. 8 kt. Likewise, all MacCready speeds are a function of weight. Again, for single-seat ships where the min/max weight variation may be modest, the MacCready STF differences are relatively small. For dual seat ships where the min/max weight difference can be greater than 300 lb, the STF differences can be more significant.

The level flight minimum sink speed for the actual operating weight is a very important parameter to know. As described in prior "Glider Aerodynamics Puzzlers" and the *Soaring* magazine May 2017 article "How to Optimize Thermaling Flight in Gliders," the minimum sink speed is a crucial parameter in determining the optimum speed-to-fly while thermaling. The lower (slower) the minimum sink speed the smaller the radius of turn possible while thermaling – which normally yields higher net climb rates closer to the core. Glider flight optimization is, indeed, fascinating. Fly safe.



About the author: *Steve is a commercial pilot in single engine airplanes, single engine seaplanes, and gliders. He holds an instrument rating and is a Certificated Flight Instructor for airplanes, instruments, and gliders. He has logged over 4,000 flight hr including over 2,000 hr as a flight instructor. He is a retired IBM Engineering Manager and a Flight Instructor at Sugarbush Soaring, Warren, VT.*

GLIDER AERODYNAMICS PUZZLER

BY STEVE PLATT

MacCready Theory

The Glider Aerodynamics Puzzler is intended to stimulate your thinking about soaring and refresh your understanding of glider aerodynamics and soaring optimization. The correct answers with detailed explanations follow the questions. Have fun.

Your soaring club hosts an annual President's Cup Race. The race is run on a relatively short triangular course surrounding your home airport. The race is designed just for fun and bragging rights. Turn points are on the honor system. There are three classes – high, medium, and low performance ships – such that everyone may participate, even the student pilots with their instructors.

You are flying your club's PW-6 with a friend on the final leg of the race. You are a few pounds under gross weight. The flight polar for the PW-6 is shown in Figure 1 for both minimum and maximum weight. The key performance characteristics of the PW-6 at gross weight are:

Min sink speed = 51 kt
Min sink rate = 148 ft/minute (1.46 kt)
Best L/D speed = 56 kt
Sink at best L/D speed = 167 ft/minute (1.65 kt)
Best L/D glide ratio = 34 to 1

The winds aloft are light and variable, and not a factor. On the final leg, you reach what you hope will be the final thermal for a final glide to the finish line at pattern altitude. You center the thermal and start climbing. You reach an altitude of 4,286 ft MSL where your onboard flight computer (set to MacCready 0) indicates you can just make it to the finish line at pattern altitude. Pattern altitude is 2,500 ft MSL. (Your home airport elevation is 1,500 ft MSL.) You have a decision to make. You are currently exactly 10 nm from the finish line, and you have been climbing at a steady 2 kt. You can leave the thermal now and head for the finish line flying at the optimum speed-to-fly (STF) to maximize distance (conserve energy), or you can continue to climb to a higher altitude and apply MacCready theory to try to improve your speed (minimize time).

Question 1. What do you decide to do?

A. Leave the thermal as soon as possible to make it to the finish line.

B. Climb higher to the optimum MacCready departure altitude.

C. Abandon the course and land out.

Question 2. If you select B in Question 1, climb higher, and if flown perfectly, what is the optimum MacCready altitude to depart the thermal?

A. 4,200 ft MSL
B. 4,286 ft MSL
C. 4,428 ft MSL
D. 4,500 ft MSL
E. 4,628 ft MSL

Question 3. If you select B in Question 1, how much time will you save by applying MacCready flight versus leaving the thermal as soon as possible and flying at the best STF to maximize distance?

A. Nothing. MacCready flight will not work in this scenario.

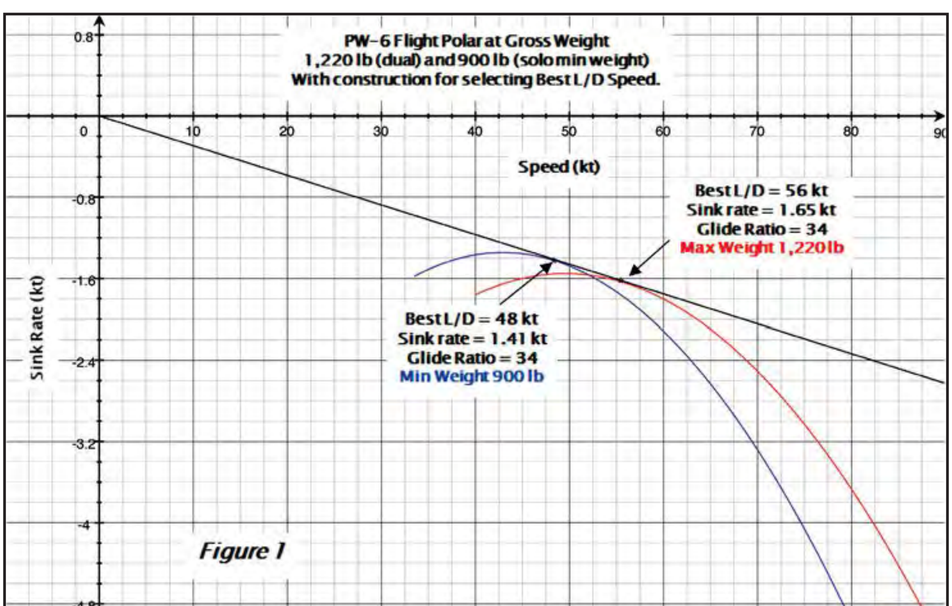


Figure 1

B. 20 seconds
C. 30 seconds
D. 56 seconds
E. 1 minute, 56 seconds

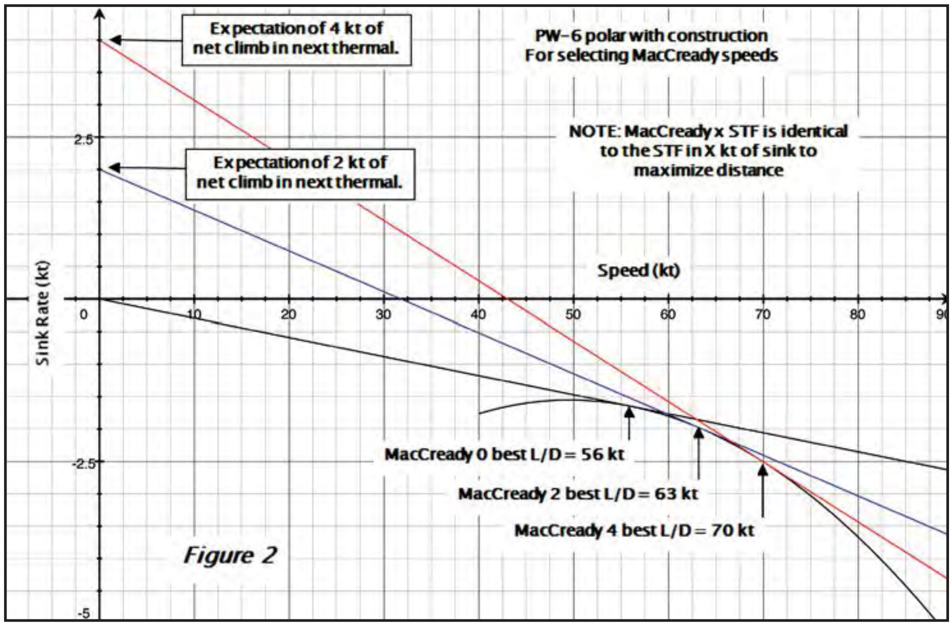


Figure 2

Explanation Questions 1-3:

Paul MacCready's solution for maximizing speed, first published in the January 1958 issue of *Soaring* magazine, has served the test of time over the past six decades. The MacCready solution (refer to the article "MacCready Flight 101: How to Optimize Speed (Time)" in the June 2018 issue of *Soaring* magazine) minimizes the time (i.e. maximizes average speed) for the glide from one thermal to the next thermal, and the climb back to the start altitude. The solution is independent of the winds aloft.

The MacCready solution states that the best STF to minimize time between thermals and climb back to the start altitude is dependent on the expected average climb rate in the thermal returning to the start altitude. If the net climb rate in the thermal is 2 kt, as is the case in this example, the best speed to fly is MacCready 2. And the MacCready 2 speed to fly is determined by the construction to the flight polar (for the current operating weight) as shown in Figure 2. The best STF to maximize average speed is the MacCready 2 speed of 63 kt. The best speed to fly to maximize distance, i.e., leave the thermal with the least amount of energy (altitude) is the best L/D speed of 56 kt. (With headwinds or tailwinds, the STF would have to be adjusted to accommodate the winds aloft.) Since flying at 63 kt (MacCready 2) versus 56 kt (MacCready 0) requires more energy, additional altitude is required and the glider must climb a little longer in the thermal.

In this example, with 10 nm to fly to the finish line at the best L/D speed of 56 kt, the glide ratio is 34 to 1. Therefore, 10/34 nm or 1,786 ft above the pattern altitude is required to make it to the finish line exactly at pattern altitude. With the pattern altitude at 2,500 ft MSL, when flying at best L/D speed, the PW-6 may leave the thermal at 4,286 ft if flown perfectly. (Note, for simplicity, we are assuming neither additional lift nor sink in the final glide). With 10 nm to fly at 56 kt, the time to reach the finish line will be 10/56 hr, or 10 minutes and 43 seconds.

On the other hand, to fly at MacCready 2 speed of 63 kt, the glide ratio degrades to 31.5. Therefore, the altitude required to fly at 63 kt is 10/31.5 nm or 1,928 ft. An additional 142 ft of altitude (energy) is required to fly at 63 kt versus 56 kt to just make it to the finish line at pattern altitude. The answer to Question 2 is C, 4,428 ft MSL. Now, the time to climb the additional 142 ft at the 2 kt climb rate is: 42 seconds. The time to reach the finish line at 63 kt is 10/63 hr, or 9 minutes and 31 seconds. Adding the additional climb time, the total time becomes 10 minutes and 13 seconds. Climbing higher before departing the final thermal and flying at the optimum MacCready Speed reaches the finish line 30 seconds faster than at best L/D speed!

Lessons Learned: MacCready flight optimizes average speed, not energy. While the thermal-to-thermal MacCready solution is independent of wind, for the final glide, the headwind/tailwind must be taken into consideration for the minimum departure altitude calculation. If you are not in a race, or in a hurry, or concerned about having enough energy to make a particular destination, flying at the best STF to maximize distance will conserve energy (i.e. altitude). Similar to best L/D speed, minimum sink speed, and stall speed, all MacCready speeds are a function of weight. While the difference in MacCready speeds for single-seat gliders between minimum and maximum weight is usually less critical (unless there is an option for large amounts of water ballast), for dual seat ships the difference in MacCready speeds flown solo at minimum weight versus dual at gross weight can be as much as 7-8 kt. If you are trying to maximize speed in a race, it may be appropriate to adjust your MacCready speeds for the current operating weight. As they say: Know thy flight polar. Fly safe.

About the author: *Steve is a commercial pilot in single engine airplanes, single engine seaplanes, and gliders. He holds an instrument rating and is a Certificated Flight Instructor for airplanes, instruments, and gliders. He has logged over 4,000 flight hr including over 2,000 hr as a flight instructor. He is a retired IBM Engineering Manager and a Flight Instructor at Sugarbush Soaring, Warren, VT.*

GLIDER AERODYNAMICS PUZZLER

BY STEVE PLATT

Turning Flight Performance

The Glider Aerodynamics Puzzler is intended to stimulate your thinking about soaring and refresh your understanding of glider aerodynamics and soaring optimization. The correct answers with detailed explanations follow the questions. Have fun.

Optimizing glider flight involves both optimizing level flight, i.e. maximizing time aloft, distance, or speed, AND optimizing turning flight, i.e. maximizing energy acquisition while thermaling or conserving energy in turning flight. Optimizing turning flight is complex and generally less well understood.

QUESTION 1:

Two identical gliders (same flight polar and operating weight) enter a coordinated 360° turn. Glider A uses 45° of bank and an airspeed of 70 kt. Glider B uses 27° of bank and an airspeed of 50 kt. Which glider has the larger radius of turn?

A. The fast Glider A has a larger radius of turn.

B. The slow Glider B has a larger radius of turn.

C. Glider A and Glider B have the same radius of turn.

QUESTION 2

In Question 1, which glider completes the 360° turn first?

A. The fast Glider A finishes the turn first.

B. The slow Glider B finishes the turn first.

C. Glider A and Glider B finish the turn at the same time.

EXPLANATION QUESTIONS 1 & 2

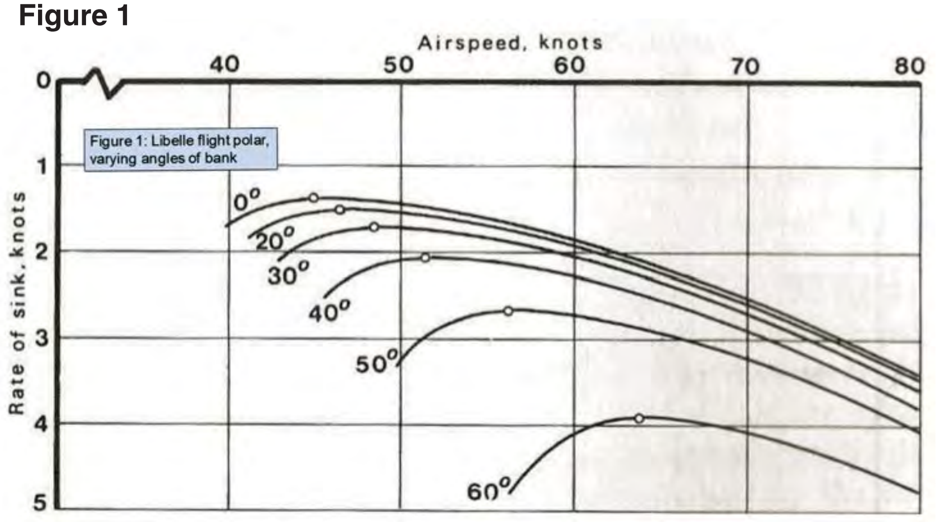
Key to understanding Turning Flight is understanding two relationships. The first is radius of turn as a function of airspeed and bank angle, and the second is the impact of wing loading on glider performance, i.e. the effect of angle of bank in coordinated turning flight on glider sink rate. Let's look at both. First, the radius of turn for ALL airplanes with wings is given by a fundamental equation of flight. The relationship is identical whether flying a Schweizer 1-26, an F-16, or a Boeing 777. The radius of turn is equal to the square of airspeed divided by the product of the acceleration of gravity (32.17 ft per second squared) times the tangent of the angle of bank.

Radius = V^2 / (g * Tan(angle of bank))

(Refer to the derivation of this equation in the "Glider Aerodynamics Puzzler," *Soaring* magazine, November 2018, p 34.) There are two variables in this equation: airspeed and angle of bank. Both are important, but changes in airspeed affect radius of turn "faster" because of the square function in the numerator. I like to use the following example to portray the effect: Two identical gliders enter a 30° banked turn. The first is flying slowly at 45 kt. The second is flying twice as fast at 90 kt. Which airplane reverses direction first? The answer is: The slow glider will complete the 180° turn while the fast glider is only at HALF way around at the 90° point. Why? Because the radius of turn of the fast glider is FOUR times that of the slow glider, and while the fast glider is flying twice as fast as the slow glider, it has 4 times the distance to travel. If you accidentally fly into a boxed canyon with narrow walls and you have to turn around to escape – slow down! While thermaling, achieving the optimum radius of turn, with the appropriate airspeed and bank angle, will maximize net climb rates.

Now let's look at the other key factor in turning flight: the effect of angle of bank and wing loading on glider sink rate. Figure 1 shows the effect on the flight polar for a Libelle at various angles of bank. (Reference: "The

Figure 1



Angle of Bank (degrees)	0	10	20	30	40	45	50	60
Increase in Minimum Sink Speed (%)	0	0.7	3.2	7.5	14	18.9	25	41
Increase in Minimum Sink Rate (%)	0	2.4	9.8	24	49	68	94	183

Table 1: Percentage increase in minimum sink speed and sink rate.

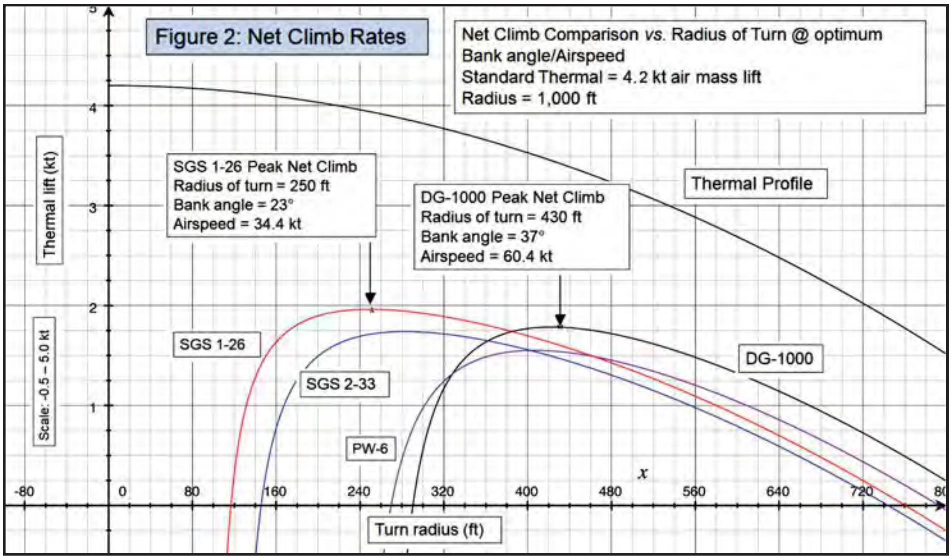
Complete Soaring Pilot's Handbook," by Welch and Irving, 1977, p 239, ISBN: 0-679-50718-3.) As the bank angle increases, the wing must "work harder," i.e. lift more, in order for the vertical component of lift to remain equal to the weight of the glider plus the tail down force, and for the horizontal component of lift to remain equal to centripetal force. As the bank angle increases, so does the angle of attack. As the angle of attack increases, lift increases and so does drag. As drag increases, the sink rate of the glider increases. As in Figure 1, the entire flight polar for all gliders moves down and to the right with increasing bank angle. In fact, the percentage increase in minimum sink speed and minimum sink rate (little circles) over the level flight minimum sink speed and minimum sink rate, IS IDENTICAL for all gliders. The percentage increase in minimum sink speed and minimum sink rate over the level flight parameters is shown in Table 1. Together, these two factors, radius of turn and sink rate versus bank angle, are the reason why, for every thermal profile, there is an optimum angle of bank and airspeed to maximize net climb rates.

For a given thermal profile, flying too fast and with too shallow an angle of bank, the radius of turn is large, and the glider either circles the thermal or operates in a weaker portion of the thermal. On the other hand, flying too steep and too slow, the radius of turn may be narrow, but sink rate of the glider (per Table 1) increases rapidly, more than offsetting the benefit of operating closer to the core of the thermal. As a general rule, for the idealized Standard British Thermal, with 4.2 kt of air mass lift at the core decreasing parabolically to zero at a radius of 1,000 ft, the optimum angle of bank varies from about 25° of bank for the very slow aircraft (like the Schweizer 1-26) to 40° of bank for very high performance gliders with considerably higher level flight minimum sinks speeds.

In Figure 2, the net climb rates of a Schweizer 1-26, Schweizer 2-33, PW-6, and DG-1000 are shown as a function of radius of turn for a Standard British Thermal. In each case, the glider is flown at the optimum minimum sink speed for the angle of bank. Notice that, for the Schweizer 1-26, the peak net climb occurs at a radius of 250 ft resulting from a bank angle of 23° and the minimum sink speed for a 23° bank of 34.4 kt (40.6 mph). However, for the DG-1000, the peak net climb rate occurs at a radius of 430 ft, resulting from a bank angle of 37°

and the minimum sink speed for a 37° bank of 60.4 kt. As an aside, notice that the SGS 1-26 can outclimb all of the ships, including the DG-1000, if flown optimally. Radius of turn matters.

As for the answer to Question 1, entering the airspeed and bank angle for both Glider A and Glider B into the radius of turn equation results in a radius of turn of 433 ft for Glider A, and 433 ft for Glider B. The answer is C. The radius is the same. For Question 2, since the radius and therefore the distance traveled is the same, the faster glider, A, will finish first.



LESSONS LEARNED

The relationship between radius of turn, driven by bank angle and airspeed, and increasing sink rate, driven by wing loading (bank angle), are the two parameters that must be selected properly in order to optimize turning flight. When thermaling, the width and profile of the thermal is a prime factor in deciding what angle of bank and airspeed to deploy. The narrower the thermal, the steeper the bank required to reach maximum net climb rate. However, just as using too shallow a bank angle yields circling in a weaker part of the thermal, using too steep an angle of bank is also counterproductive. Remember from Table 1, for a 45° bank coordinated turn for ALL gliders, the minimum sink rate increases by 68% over the level flight minimum sink rate – and that is if the 45° banked turn is flown at the minimum sink speed for a 45° bank (which is 18.9% above the level flight minimum sink speed). Any other speed, the glider sink rate will be even greater!

For example, for a glider with a level flight, minimum sink rate of 125 fpm at 40 kt, in a 45° coordinated banked turn, the minimum sink rate would increase to 210 fpm at 48 kt. For a Schweizer 2-33 in a 45° banked turn, the glider sink rate increases to over 3 kt! It had better be a fairly narrow and strong thermal to justify banking 45° in a 2-33! Lastly, knowing the percent increase in minimum sink speed for various angles of bank (Table 1) is key to optimizing net climb rates while thermaling. Glider aerodynamics are complex but incredibly fascinating. Have fun. Fly safe. SP.

About the author: *Steve is a commercial pilot in single engine airplanes, single engine seaplanes, and gliders. He holds an instrument rating and is a Certificated Flight Instructor for airplanes, instruments, and gliders. He has logged over 4,000 flight hr including over 2,000 hr as a flight instructor. He is a retired IBM Engineering Manager and a Flight Instructor at Sugarbush Soaring, Warren, VT.*

GLIDER AERODYNAMICS PUZZLER

BY STEVE PLATT

Winds

The Glider Aerodynamics Puzzler is intended to stimulate your thinking about soaring and refresh your understanding of glider aerodynamics and soaring optimization. The correct answers with detailed explanations follow the questions. Have fun.

Glider pilots usually are intimately familiar with the best Lift-to-Drag (L/D) glide ratio performance of the ships they fly. However, when trying to reach a particular destination while flying to conserve energy (altitude) at the optimum Speed to Fly (STF) to maximize distance, the winds aloft play a crucial role in determining what the optimum STF is, and what the resulting effective glide ratio will be.

QUESTION 1: The flight polars for both a 23:1 Schweizer 1-26 and a medium performance 34:1 PW-6 are shown in Figure 1. If the Schweizer 1-26 is flying with a 20 kt tailwind and the PW-6 is flying with a 20 kt headwind, and both ships fly at the optimum STF to maximize distance, which glider will have the higher effective glide ratio with their flight conditions?

A. The Schweizer 1-26.

B. The PW-6.

C. It's independent of the winds aloft.

D. Will be the same for both.

QUESTION 2: In Question 1, what is the best STF to maximize distance (maximize the effective glide ratio) for the Schweizer 1-26 with the 20 kt tailwind, and the PW-6 with the 20 kt headwind?

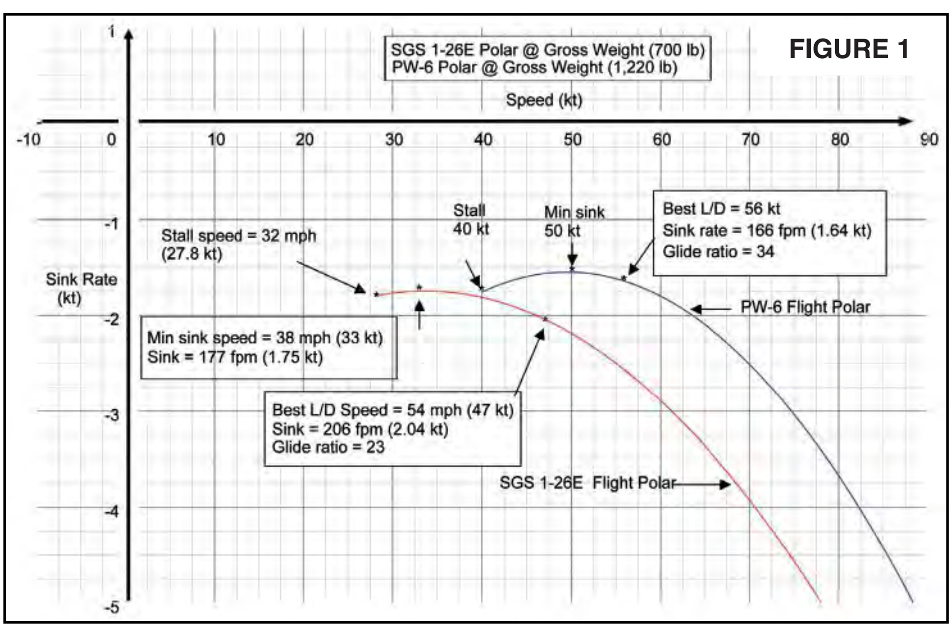
QUESTION 3: Suppose a high performance Discus-2 is flying into a 20 kt headwind at the best STF to maximize distance and a Schweizer 1-26 is flying with a 20 kt tailwind at the best STF to maximize distance. Which glider has the best effective glide ratio with their flight conditions?

A. The Schweizer 1-26.

B. The Discus.

C. It's independent of the winds aloft.

D. Will be the same for both.



QUESTION 4: In Question 1, suppose the winds aloft are only 10 kt and the Schweizer 1-26 is flying with a 10 kt tailwind and the PW-6 is flying into the 10 kt headwind. If both ships fly at the optimum STF to maximize distance, which glider will have the better effective glide ratio?

A. The Schweizer 1-26.

B. The PW-6.

C. It's independent of the winds aloft.

D. Will be the same for both.

EXPLANATION QUESTIONS 1 & 2: Shown in Figure 2 is the construction for determining the best STF for the Schweizer 1-26 with a 20 kt tailwind, and for the PW-6 in a 20 kt headwind. The best STF for the 1-26 is 43 kt yielding a ground speed of 63 kt, which results in an effective glide ratio of 33.7. The best STF for the PW-6 into a 20 kt headwind is 59.5 kt yielding a ground speed of 39.5 kt, which results in an effective glide ratio of 21.9. In effect, with a 20 kt tailwind, a 1-26 has the performance of a PW-6 in still air — and a PW-6 with a 20 kt headwind has the performance of a 1-26 in still air. The answer to question 1 is A.

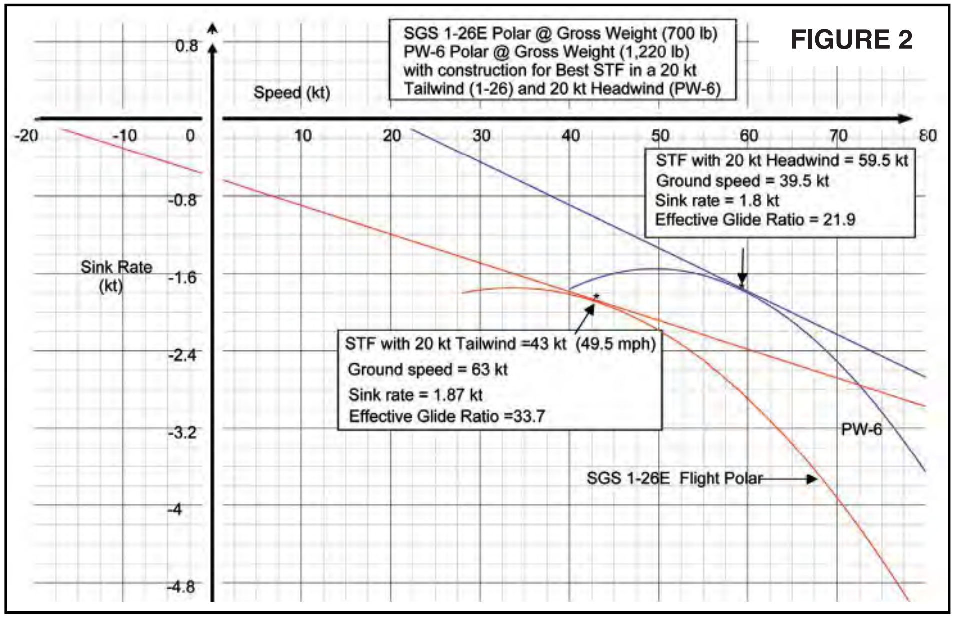
EXPLANATION QUESTION 3: Shown in Figure 3 is the construction for determining the best STF for the Schweizer 1-26 with a 20 kt tailwind, and for a Discus in a 20 kt headwind. The best STF for the 1-26 is 43 kt yielding a ground speed of 63 kt, which results in an effective glide ratio of 33.7. The best STF for the Discus is 62.5 kt yielding a ground speed of 42.5

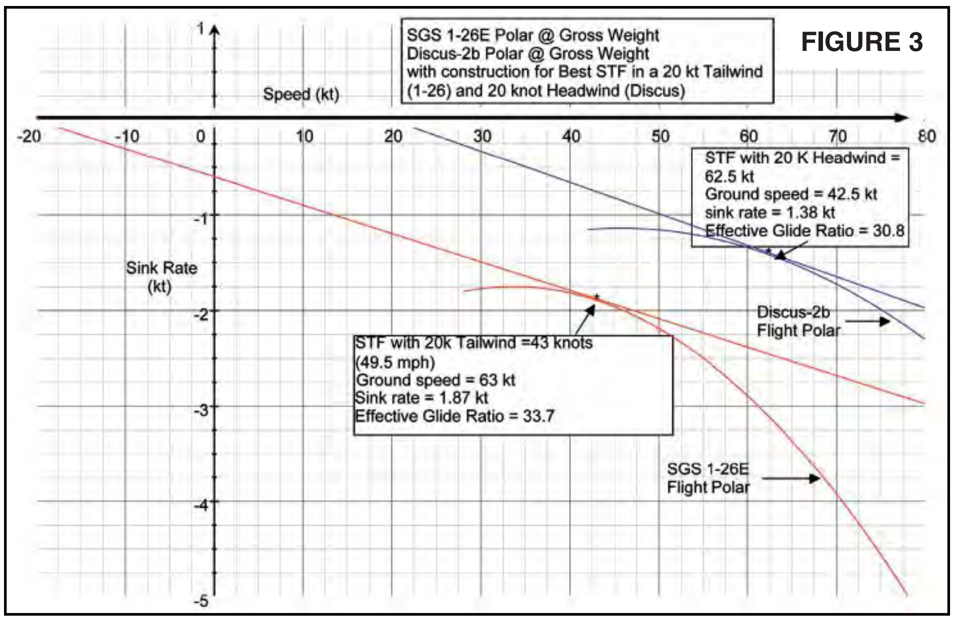
kt, which results in an effective glide ratio of 30.8. Once again, a 1-26 with a 20 kt tailwind has a better effective glide ratio than the high performance Discus with a 20 kt headwind.

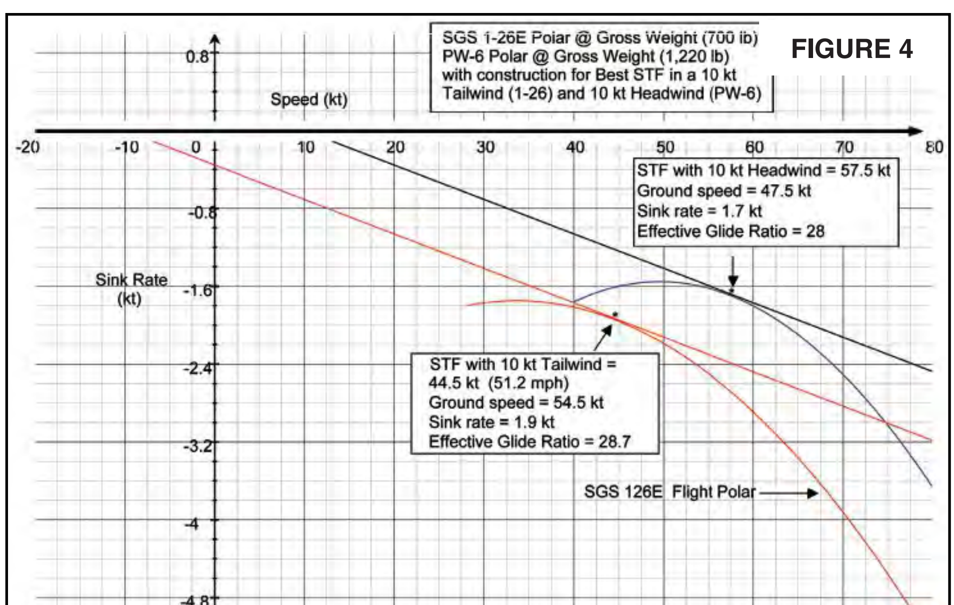
EXPLANATION QUESTION 4: Shown in Figure 4 is the construction for determining the best STF for the Schweizer 1-26 with a 10 kt tailwind, and for the PW-6 in a 10 kt headwind. The best STF for the 1-26 is 44.5 kt yielding a ground speed of 54.5 kt, which results in an effective glide ratio of 28.7. The best STF for the PW-6 is 57.5 kt yielding a ground speed of 47.5 kt, which results in an effective glide ratio of 28. Once again, a 1-26 with a 10 kt tailwind has a slightly better effective glide ratio than the PW-6 with a 10 kt headwind!

LESSONS LEARNED: Winds matter. Even modest winds matter. With strong winds aloft, e.g. 30-35 kt, even the sleekest high performance 45/50:1 glass ships can have an effective glide ratio of no more than that of a Schweizer 1-26/2-33 in still air! For safe flight, glider pilots must always understand the current and forecast winds aloft for any planned flight. Glider aerodynamics are fascinating. Fly safe.

About the author: *Steve is a commercial pilot in single engine airplanes, single engine seaplanes, and gliders. He holds an instrument rating and is a Certificated Flight Instructor for airplanes, instruments, and gliders. He has logged over 4,000 flight hr including over 2,000 hr as a flight instructor. He is a retired IBM Engineering Manager and a Flight Instructor at Sugarbush Soaring, Warren, VT.*







GLIDER AERODYNAMICS PUZZLER

BY STEVE PLATT

Stall Speed

The Glider Aerodynamics Puzzler is intended to stimulate your thinking about soaring and refresh your understanding of glider aerodynamics and soaring optimization. The correct answers, with detailed explanations, follow the questions. Have fun.

The stall speed for most gliders is typically published at gross weight. However, the actual operational stall speed is a function of several parameters.

QUESTION 1: Your soaring club has several two seat training aircraft – a Schweizer SGS 2-33, an ASK 21, and two PW-6 gliders. The PW-6 glider has a published gross weight stall speed of 40 kt. You are a student pilot signed off for solo flight in the PW-6. You will be taking the PW-6 up on a practice flight solo at minimum weight, 900 lb, versus gross weight of 1,220 lb.

What will happen to the wings level stall speed at your operating weight?

A. Remain at 40 kt
B. Decrease to 38 kt
C. Decrease to 36 kt
D. Decrease to 34 kt
E. Decrease to 30 kt

QUESTION 2: On your solo training flight, you plan on practicing several maneuvers including steep bank turns at a safe altitude. If you make an approximately 60° steep bank turn and increase the wing loading by a factor of two, what will happen to the instantaneous accelerated stall speed?

The accelerated stall speed will:

A. Remain the same
B. Increase by 10% over the level flight stall speed
C. Increase by 20% over the level flight stall speed
D. Increase by 40% over the level flight stall speed
E. Increase by 100% over the level flight stall speed

QUESTION 3: While the stall speed is typically published at gross weight, is the stall speed at all related to the center of gravity (CG) loading if the glider is loaded within the certificated CG envelope?

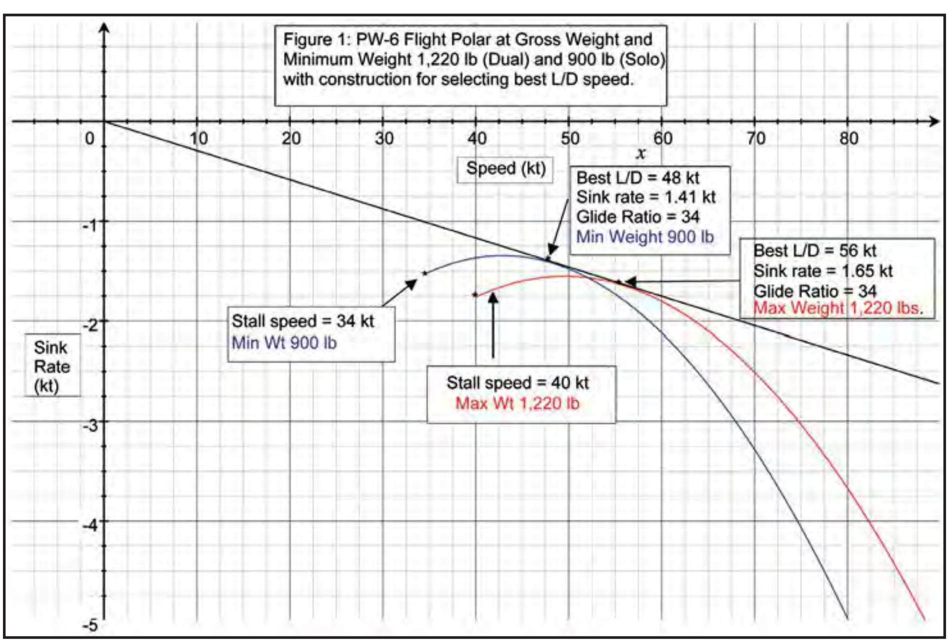
A. The stall speed is independent of the CG location
B. The stall speed is a strong function of the CG location
C. The stall speed is a weak function of the CG location

QUESTION 4: An acquaintance of yours with an aerobatic certificated glider with a wings level, 1 g, stall speed of 40 kt tells you that she can routinely pull 4 g while performing an approximately 75° banked turn, commencing the turn at 70 kt. Is this maneuver possible?

A. Yes. An aerobatic glider should be stressed for more than 4 g
B. No. Not possible

EXPLANATION QUESTION 1: Weight matters. The flight polar for all gliders shifts up and to the left for decreasing weight, and down and to the right for increasing weight. (Refer to Figure 1.) For ALL gliders for a different wing loading (weight), the flight polar coordinates shift by a factor equal to the square root of the ratio of the weights. (Reference 1: *Complete Soaring Pilot's Handbook;* Ann and Lorne Welch, and Frank Irving, 1977, page 266, ISBN: 0-679-50718-3. Reference 2: *Cross-Country Soaring*; Helmut Reichmann, 7th Edition, 1993, page 122, ISBN: 1-883813-01-8). Accordingly, the gross weight stall speed of 40 kt will decrease by a factor of $(900/1220)^{0.5}$, which becomes 0.859 x 40, which equals 34 kt.

EXPLANATION QUESTION 2: In coordinated turning flight, the wing must work harder. The wing's lift must increase such that the vertical component of lift remains equal to the weight of the aircraft (plus the



tail down force), and the horizontal component of lift remains equal and opposite to centripetal force. Since the vertical component of lift in a banked turn is equal to the cosine of the angle of bank times the wing's lift, in a 60° banked turn, the vertical component of lift is only half of the wing's total lift, i.e., the cosine of 60 is equal to 0.5.

Therefore, for the 60° banked turn, for the vertical component of lift to remain equal to the weight of the airplane (plus the tail down force), the total lift of the wing must double. For the total lift of the wing to double, the angle of attack must increase substantially. And since lift of any wing is a function of airspeed, the slower the airspeed, the higher the angle of attack required to generate the necessary lift. This applies until, of course, the critical angle of attack is reached or exceeded, whereupon the wing stalls.

The instantaneous, accelerated stall speed of any wing increases by a factor equal to the square root of the load factor, or g-load. Therefore, in a coordinated 60° banked turn with a load factor of 2, the accelerated stall speed becomes 1.41 (square root of 2) times the stall speed, and the stall speed increases by 41%. For the PW-6 at minimum weight, with a 1 g stall speed of 34 kt, the accelerated stall speed becomes 48 kt in a 2 g turn. However, at gross weight, the PW-6 accelerated stall speed increases to 56 kt.

EXPLANATION QUESTION 3: The level flight stall speed for all conventionally configured gliders (and airplanes) is a weak function of the CG location. Within the approved CG envelope, the CG location affects the tail down force modestly and, therefore, affects the lift required slightly. A rearward CG decreases the tail down force and slightly decreases the stall speed. A forward CG increases the tail down force and slightly increases the stall speed.

EXPLANATION QUESTION 4: While the aerobatic aircraft may be stressed and certificated to 6 g, the maneuver described CANNOT be performed starting at an airspeed of 70 kt. The glider will stall first, before reaching 4 g. Indeed, a normal coordinated 75° turn (not diving) would require the wing loading to increase by a factor of 4 – a 4 g turn. However, at 4 g, the accelerated stall speed increases by a factor of 2 (square root of the g-load) over the 1 g stall speed. Therefore, at 4 g, the accelerated stall speed would be 80 kt (40 kt x 2). Since the maneuver is started at 70 kt, as the pilot begins to roll into the 75° banked turn and increases the wing loading with considerable back pressure on the stick, the critical angle of attack will be reached at approximately 3.1 g. The glider will stall before reaching 4 g. If the maneuver were started at considerably over 80 kt, then 4 g could be reached. However, the airspeed during the maneuver would have to remain over 80 kt at 4 g not to stall.

LESSONS LEARNED: Weight matters. Wing loading matters. The published, gross weight stall speed of any aircraft is just the starting point. The actual operational stall speed of any glider and airplane is a function of both current operating weight and wing loading. For the PW-6, the 1 g, wings level, stall speed varies from 40 kt at gross weight to 34.4 kt at minimum weight. In a 60° bank, 2 g, coordinated turn, the stall speed increases to 56.4 kt at gross weight. For an aerobatic aircraft pulling 4 g, the stall speed doubles. The instantaneous, accelerated stall speed for any glider (or airplane) increases by a factor equal to the square root of the operational g-load over the 1 g stall speed. Glider aerodynamics is fascinating.

About the author: *Steve is a commercial pilot in single engine airplanes, single engine seaplanes, and gliders. He holds an instrument rating and is a Certificated Flight Instructor for airplanes, instruments, and gliders. He has logged over 4,000 flight hr including over 2,000 hr as a flight instructor. He is a retired IBM Engineering Manager and a Flight Instructor at Sugarbush Soaring, Warren, VT.*

GLIDER AERODYNAMICS PUZZLER

BY STEVE PLATT

Ballast

The Glider Aerodynamics Puzzler is intended to stimulate your thinking about soaring and refresh your understanding of glider aerodynamics and soaring optimization. The correct answers with detailed explanations follow the questions. Have fun.

Glider pilots are quite familiar with the effects of weight on glider performance, i.e., increasing weight increases stall speed, minimum sink speed, best L/D speed, and all MacCready speeds … and, unfortunately degrades climb performance. The 64-thousand-dollar question is "When is the lift strong enough to justify adding ballast to improve net average speed?"

QUESTION 1: Your girlfriend is an outstanding glider pilot and a member of your soaring club. She is planning a 50 miles cross-country, on a glorious Saturday afternoon, in the club's PW-6 glider. The weather is perfect. Blue sky, scattered clouds, and very light winds aloft. Her plan is to fly out 25 nm to a nearby uncontrolled airport and back. Her goal is to break her record time for this flight. She plans on taking a 3,000 ft tow above your home airport (elevation 1,500 ft MSL, pattern altitude 2,500 ft MSL) before starting her clock. The thermals have been reported as standard summer thermals, i.e., standard British thermals with 4.2 kt of airmass lift at the core decreasing parabolically to zero at a 1,000 ft radius. She asks you the following question: "Assuming I fly perfectly, that is, perfectly centered in all thermals at the optimum airspeed and bank angle to maximize net climb rates, and I cruise between thermals at the optimum MacCready speed between thermals, should I fly solo at minimum weight, or take you along in the backseat plus a little ballast in the front seat to fly at gross weight? Which way will give me a higher average speed?" The PW-6 polars for minimum weight (900 lb) and gross weight (1,220 lb) are shown in Figure 1.

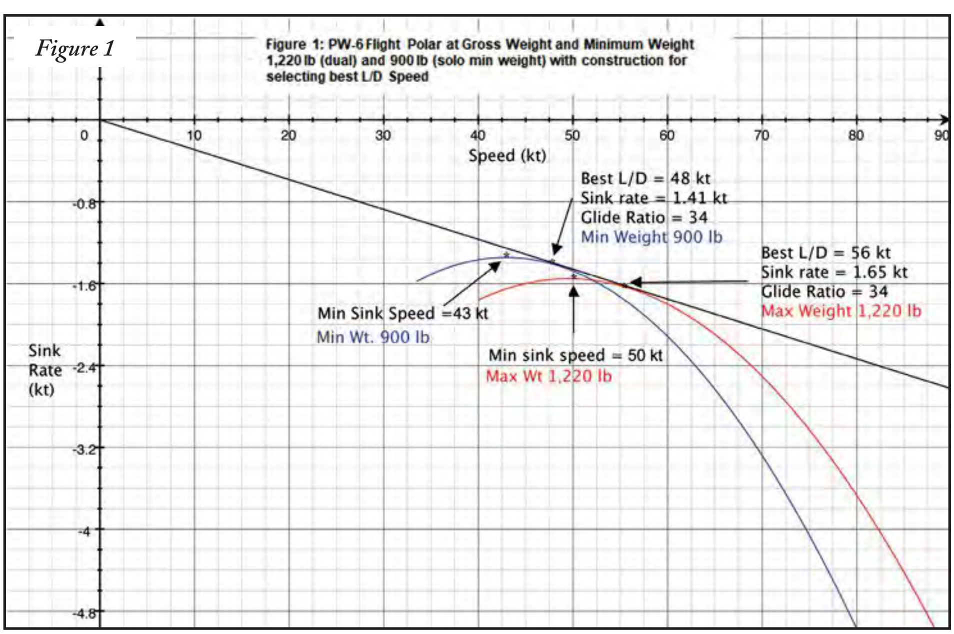


Figure 1

Figure 1: PW-6 Flight Polar at Gross Weight and Minimum Weight 1,220 lb (dual) and 900 lb (solo min weight) with construction for selecting best L/D Speed

What do you tell her?

A. Go at minimum weight without me. While your cruise speed will be slower, you will climb faster and have a better average speed.

B. Let's go at maximum weight. While your climb will be a little slower, your cruise speed will be faster, and you will have a better average speed.

C. Either way the average speed will be the same.

D. I do not have a clue which way is better.

QUESTION 2: In Question 1, if you selected answer A or B, how much faster will the optimum configuration be?

A. 30 seconds faster

B. 1 minute faster

C. 2 minutes faster

D. 4 minutes faster

EXPLANATION QUESTION 1 & 2: The analysis for this proposed flight can be modeled as one climb to an appropriate height and a final glide to pattern altitude. In order to figure out what altitude will be required, the first step is to figure out what the optimum MacCready speed will be for each configuration and the resultant effective glide ratio. Then, the necessary altitude can be computed, as well as the time to climb. Step 2 is to calculate the net average climb rate for both configurations in a standard British thermal if flown optimally. Shown in Figure 2 is the net climb rate for the PW-6 at both minimum and maximum weight as a function of radius of turn. Notice that the peak net climb rate for the minimum weight configuration is 2.1 kt and occurs at a radius of turn of 330 ft. The peak net climb rate for the gross weight configuration is 1.6 kt and occurs at a radius of turn of 410 ft. With the peak net climb rates established, the optimum MacCready settings are now known, and the re-

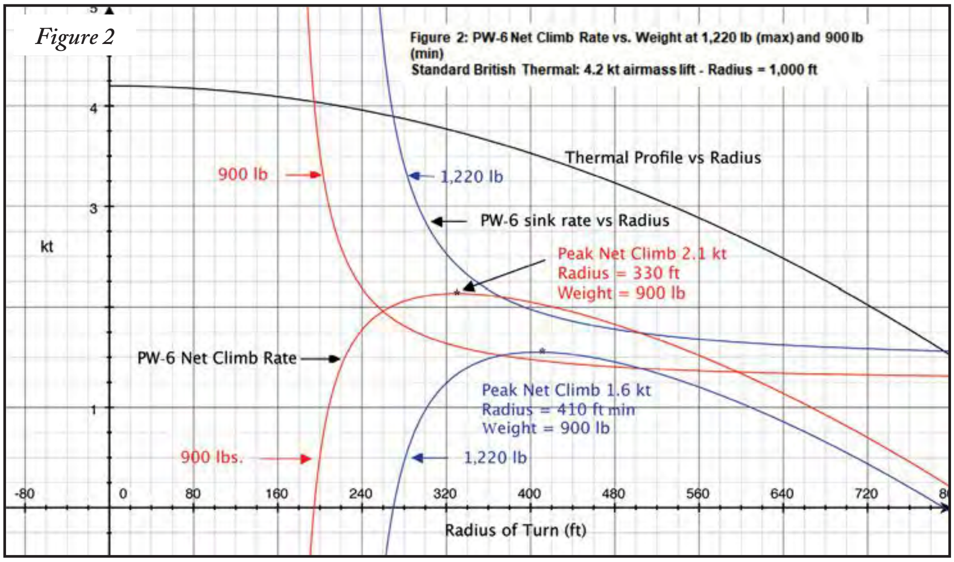


Figure 2

sulting MacCready speeds and glide ratios can be computed from Figure 3. Note that for the minimum weight configuration, the optimum MacCready 2.1 STF is 56 kt, yielding a glide ratio of 30.2 to 1. For the maximum weight configuration, the optimum MacCready 1.6 STF is 62 kt, yielding a glide ratio of 32.6 to 1.

With the effective glide ratios known, the altitude required to complete the 50 nm trip can be computed. For the minimum weight case: 50 nm * 6,072 / 30.2 = 10,053 ft. Subtracting the 2,000 ft tow above pattern altitude, a total of 8,053 ft of altitude (energy) must be acquired by climbing at 2.1 kt, resulting in a total climb time of 37.9 minutes, or 37 minutes 54 seconds. With a cruise speed of 56 kt, the cruise time for 50 nm is 53.57 m, or 53 m 34 s, resulting in a total flight time of 91 m 28 s. For the maximum weight case, the altitude required to complete the 50 nm trip is: 50 nm * 6,072 / 32.6 = 9,313 ft. Subtracting the 2,000 ft tow above pattern altitude, a total of 7,313 ft of altitude (energy) must be acquired by climbing at 1.6 kt, resulting in a total climb time of 45.16 m, or 45 m 9.9 s. With a cruise speed of 62 kt, the cruise time for 50 nautical miles is 48.39 m, or 48 m 23 s, resulting in a total flight time of 93 m 33 s.

Therefore, in this scenario, if flown optimally, the minimum weight configuration wins by 2 m 5 s, yielding an average speed of 32.8 kt versus an average speed for the gross weight configuration of 32.1 kt. The answer to question 1 is A: Go at minimum weight, and Question 2 is C: 2 min faster.

LESSONS LEARNED: While this scenario is highly unrealistic (no one flies perfectly 100% of the time and not all thermals are standard British thermals), the analysis remains valuable. Weight really matters. Adding ballast in order to cruise faster only yields a net benefit when the thermal strength is sufficiently strong to overcome the degradation of climb performance at higher weights. The crossover point is clearly dependent on the specific glider's flight polar. However, as a general rule, for medium performance gliders, it takes net climb rates substantially greater than that capable from a standard British thermal to justify intentionally adding weight. In parts of the country where thermal strength can peg the variometer, adding ballast may, indeed, optimize average speed. Glider aerodynamics is fascinating. Have fun. Fly safe.

About the author: *Steve is a commercial pilot in single engine airplanes, single engine seaplanes, and gliders. He holds an instrument rating and is a Certificated Flight Instructor for airplanes, instruments, and gliders. He has logged over 4,000 flight hr including over 2,000 hr as a flight instructor. He is a retired IBM Engineering Manager and a Flight Instructor at Sugarbush Soaring, Warren, VT.*

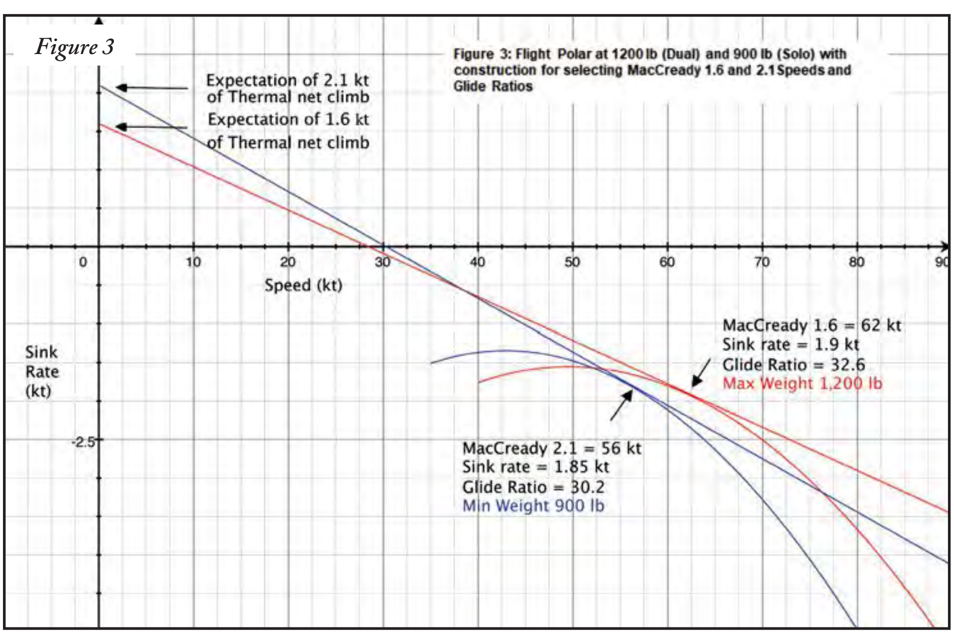


Figure 3

GLIDER AERODYNAMICS PUZZLER

BY STEVE PLATT

Energy Strategy

The Glider Aerodynamics Puzzler is intended to stimulate your thinking about soaring and refresh your understanding of glider aerodynamics and soaring optimization. The correct answers with detailed explanations follow the questions. Have fun.

Soaring, as a sport, is as much a mental exercise as it is physical stick and rudder skills, if not more.

Knowing what to do when is critical to optimizing glider flight. Indeed, glider pilots in competition or on a recreational flight are tacticians and strategists reading the atmosphere and terrain to accomplish the mission safely and efficiently. Soaring is a mental sport.

QUESTION 1: You are on the final leg of your club's annual round-robin cross-country race. You are flying your club's PW-6 glider at gross weight with your neighbor for ballast. The flight polar for the PW-6 at your operating weight is shown in Figure 1. The thermals have been modest, yielding an average net climb rate of 1.6 kt. The winds aloft are light and variable and are not a factor. You are 10 nm from the finish line, which for this event is midfield crosswind at or above pattern altitude.

The pattern altitude is 2,500 ft MSL. The airport elevation is 1,500 ft. You are at 3,393 ft MSL when your onboard navigation and flight computer indicate you can just make it to the finish line if you fly at best L/D speed (MacCready 0). There is a typical summer thermal halfway to the airport, 1 or 2 degrees off the direct line course at about 5 nm from your current position. The question is: How do you optimize your speed (minimize time) to the finish line?

You consider three options. *Option 1* is to fly at best L/D speed all the way to the finish line in a final glide WITHOUT stopping at the thermal 5 nm out. *Option 2* is to fly at best L/D speed to the thermal 5 mi out, gain the necessary altitude, then fly at an appropriate (faster) MacCready speed to the finish line. *Option 3* is to fly at an appropriate MacCready speed from 10 miles out to the thermal 5 miles out, then climb in the thermal for the minimum required to perform the final glide at the appropriate MacCready speed. Which option do you select?

1. Fly at best L/D speed all the way to the finish line in a final glide, no stopping to thermal.
2. Fly at best L/D speed to the thermal 5 nm out, climb as required, then fly at the appropriate MacCready speed to the finish line.
3. Fly at the appropriate MacCready speed to the thermal 5 miles out, climb as required, then fly at the appropriate MacCready speed to the finish line.
4. Some other option.

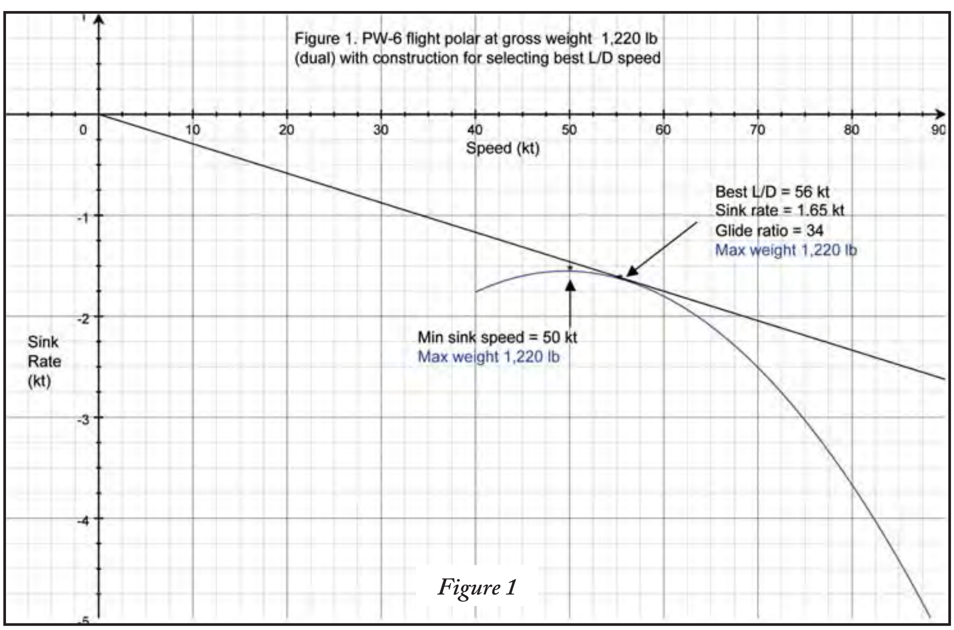


Figure 1

EXPLANATION QUESTION 1: For *Option 1*, with a best L/D speed of 56 kt, the time to complete 10 nautical miles is: 10/56 = 0.179 hr = 10.71 min = 10 min 43 s.

For *Option 2*, the time to get to the thermal 5 miles out is: 5/56 = 5 min 21 s. Assuming the average climb rate remains 1.6 kt, the appropriate MacCready speed to fly (STF) is MacCready 1.6. Shown in Figure 2 is the construction to determine the MacCready 1.6 STF and glide ratio. With the glide ratio reduced from 34-to-1 to 32.6-to-1, an additional 38 ft of altitude (energy) is required for the final 5 nm glide at MacCready 1.6 speed of 62 kt. Acquiring a minimum 38 ft of altitude requires a minimum of one turn in the thermal, which, if flown optimally, will take ~30 s to complete. The time for the last 5 nm at 62 kt takes 5/62 hr or 0.08 hr or 4.84 min, which is 4 min

50 s. This gives an *Option 2* total time of: 5 min 21 s plus 30 s plus 4 min 50 s, which yields 10 min 41 s.

Now for *Option 3*: Since net climb rate has been 1.6 kt, it is reasonable to assume the final thermal will yield 1.6 kt net climb rate. Therefore, MacCready 1.6 is the appropriate STF. The time to complete 10 nm at the MacCready 1.6 speed of 62 kt is: 10/62 = 0.161 hr = 9.68 min = 9 min 41 s. The time to climb the additional 76 ft necessary to complete the final leg at MacCready 1.6 speed and finish at pattern altitude requires 1 turn in the final thermal for an additional time of ~30 s, yielding a total time of 10 min 11 s.

In summary, *Option 1*, flying at best L/D speed without stopping to thermal, yields 10 min 43 s. *Option 2,* flying at best L/D to the thermal, then thermaling for 1 turn, then completing the course at MacCready 1.6 speed, yields 10 min 41 s. However, *Option 3*, flying at MacCready 1.6 speed to the thermal, climbing for 1 turn, then finishing at MacCready 1.6 speed, yields 10 min 11 s - 30 s faster than *Option 2* and 32 s faster than *Option 1*!

LESSONS LEARNED: MacCready STF works, but it is important to remember the definition. MacCready flight optimizes the time from a starting altitude to the next thermal AND the climb back to the starting altitude. Or, conversely, the climb from a starting altitude to a higher departure altitude and the cruise to the original starting altitude. MacCready flight works equally well in the final glide with one additional consideration. For *en route* cloud-to-cloud flight, the MacCready solution is independent of the winds aloft. However, for the final glide to the destination, while the MacCready STF remains the same, the departure altitude must take into consideration the winds aloft. The effective glide ratio, with the winds aloft taken into consideration, must be used for the final glide departure altitude calculation.

The additional energy (altitude) to fly at the appropriate MacCready speed can be acquired at the beginning of a final glide or in the middle. It does not matter. The optimum STF solution remains the same. While this example assumes perfect flight for ease of math (highly unrealistic), the analysis is still useful. From 10 nm out, the MacCready solution beats the best L/D solution by 30 seconds. Not insignificant.

Paul MacCready's solution for optimizing average speed is brilliant. It has served the test of time for over six decades. Glider aerodynamics are indeed fascinating. Fly safe.

About the author: *Steve is a commercial pilot in single engine airplanes, single engine seaplanes, and gliders. He holds an instrument rating and is a Certificated Flight Instructor for airplanes, instruments, and gliders. He has logged over 4,000 flight hr including over 2,000 hr as a flight instructor. He is a retired IBM Engineering Manager and a Flight Instructor at Sugarbush Soaring, Warren, VT.*

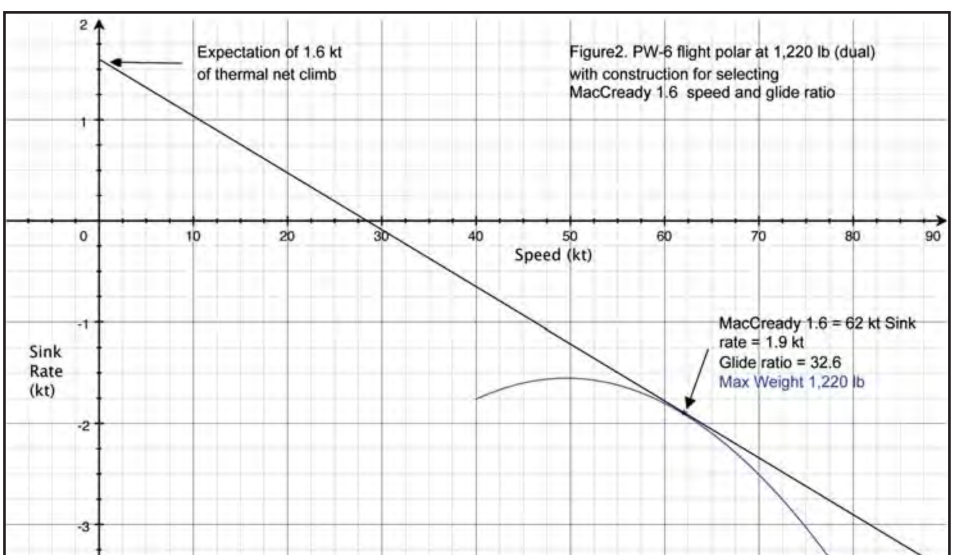


Figure 2

GLIDER AERODYNAMICS PUZZLER

BY STEVE PLATT

Winds

The Glider Aerodynamics Puzzler is intended to stimulate your thinking about soaring and refresh your understanding of glider aerodynamics and soaring optimization. The correct answers with detailed explanations follow the questions. Have fun.

It is a glorious Saturday with not a cloud in the sky. Totally blue. A gorgeous day to fly, but there does not appear to be any obvious thermal lift. However, there are strong west to east surface winds of 20 kt gusting 25 kt. The winds aloft forecast calls for winds of 25 kt out of the west up to 3,000 ft MSL. Your home airport is located in a valley at 1,500 ft MSL. 5 nm east of the airport is the peak of a ridgeline running north to south. The land rises from the valley to the peak of the ridgeline at an approximately 7° average slope. The peak of the ridgeline runs at approximately 2,500 ft MSL. The winds are perfectly orthogonal to the ridgeline. You suspect there will be excellent ridge lift along the windward side of the ridgeline. You decide to take your club's 2-place PW-6 glider with a friend to demonstrate ridge soaring. Your plan is to take a 3,000 ft tow to 4,500 ft MSL and release approximately 1/2 nm to the windward side of the ridge. You will be operating at just under gross weight. The flight polar for the PW-6 is shown in Figure 1.

QUESTION 1: If the winds aloft forecast is indeed correct, will there likely be enough ridge lift to sustain flight for the PW-6 flying north-to-south and south-to-north along the ridgeline?

A. No
B. Yes
C. I don't have a clue

QUESTION 2: On the return trip from the ridgeline to the airport, what will the effective glide ratio of the PW-6 be if flown optimally into the 25 kt headwind?

A. 34 to 1
B. 30 to 1
C. 26 to 1
D. 22 to 1
E. 19 to 1

QUESTION 3: Suppose you decided to take your club's Schweizer SGS 2-33. Do you suspect there will be enough ridge lift to sustain at least level flight along the ridge in the Schweizer SGS 2-33?

A. No
B. Yes
C. I don't have a clue

QUESTION 4:

For the SGS 2-33, on the return trip to the airport, if there is no other sink or thermal lift *en route*, can the SGS 2-33 make it back to the airport at normal pattern altitude?

A. No
B. Yes
C. I don't have a clue

EXPLANATION QUESTION 1: If the airmass is moving west to east at 25 kt when it encounters the 7° up sloping terrain, the airmass will follow the slope at least close to the surface. Therefore, within ~500 ft of the terrain, the vertical component of the sloping airmass will be no greater than 25 kt times the sine of 7°, which

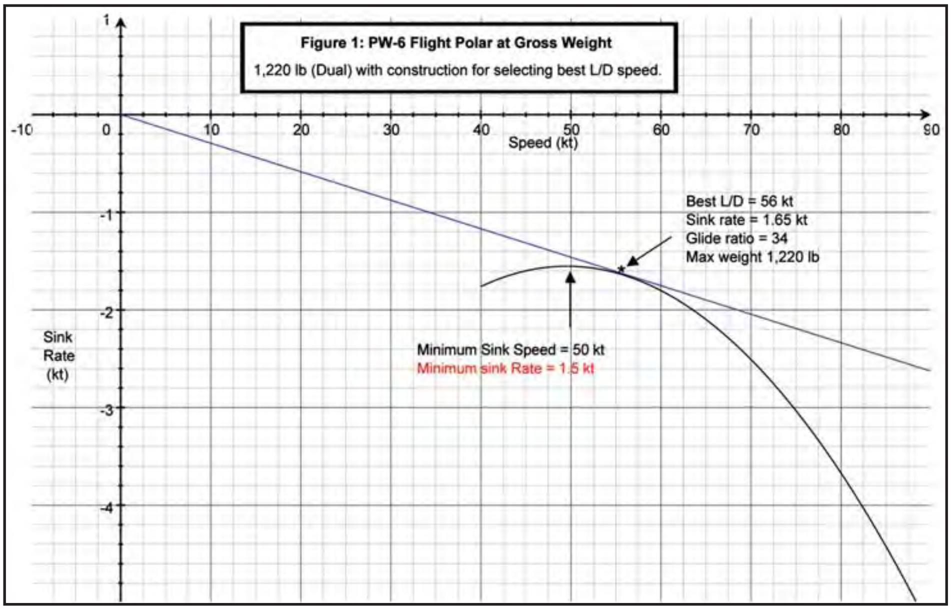
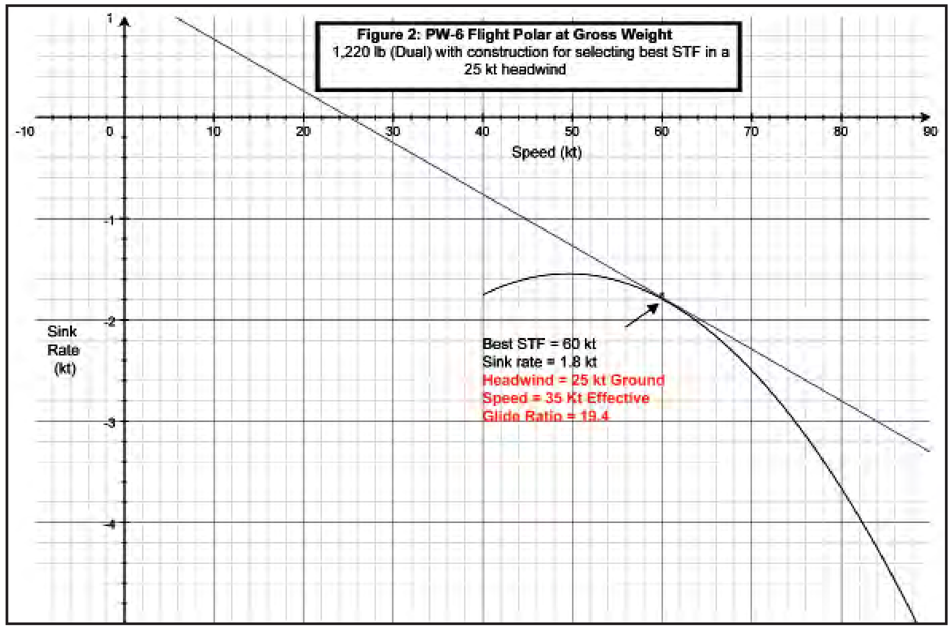


Figure 1: PW-6 Flight Polar at Gross Weight

1,220 lb (Dual) with construction for selecting best L/D speed.

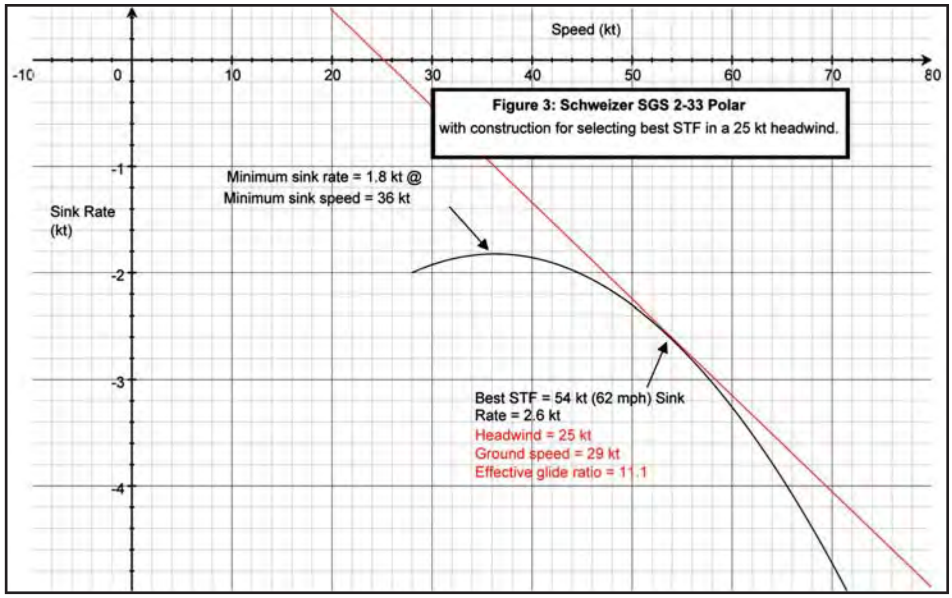
equals 25 x 0.122, which equals 3 kt. Now, this effect decreases with altitude above the terrain. My experience indicates that the vertical component of the slope following airmass decreases about 50% at 1,000 ft above the terrain of the theoretical number close to the surface. So, in this example, flying safely 1,000 ft above the terrain, I would expect the vertical lift component to be approximately 1.5 kt. Since, from Figure 1, at minimum sink speed the PW-6 has a sink rate of ~1.5 kt, I would expect the PW-6 to have a reasonable chance to just maintain altitude flying safely along the ridge.

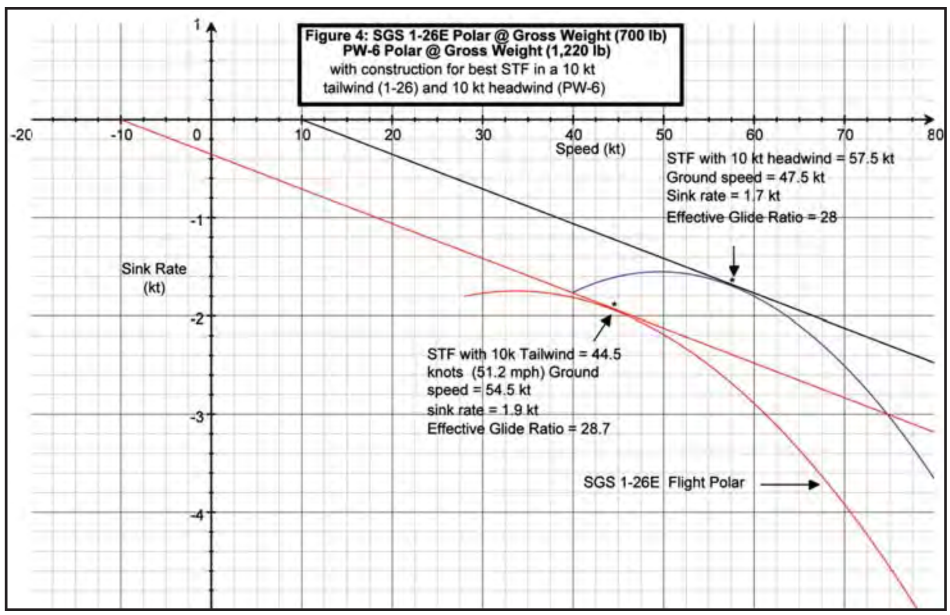


EXPLANATION QUESTION 2: Shown in Figure 2 is the construction for determining the optimum STF (Speed To Fly) for the PW-6 to maximize distance, i.e., the best effective glide ratio, into a 25 kt headwind. The optimum STF is 60 kt, resulting in an effective glide ratio of 19.4 to 1. Any other airspeed will yield an inferior effective glide ratio.

EXPLANATION QUESTION 3: From the flight polar of the Schweizer SGS 2-33, shown in Figure 3, the sink rate of the SGS 2-33 flown at minimum sink speed is approximately 1.8 kt. With projected airmass ridge lift of 1.5 kt at 1,000 ft above the ridge, it is unlikely the SGS 2-33 will be able to maintain altitude without getting uncomfortably close to the ridge.

EXPLANATION QUESTION 4: Shown in Figure 3 is the construction for the SGS 2-33 to determine the best STF to maximize distance into a 25 kt headwind. The best STF is 54 kt (62 mph), yielding an effective glide ratio of 11.1 to 1. With approximately 4.5 nm miles from the ridgeline to the airport traffic pattern, if flown optimally, the SGS 2-33 will consume 2,461 ft of altitude returning from the ridgeline. If the SGS 2-33 leaves the ridge to return to the airport upon reaching 4,000 ft MSL altitude (500 ft below the release altitude), if flown optimally (at the best STF into a 25 kt headwind), the SGS 2-33 CAN just make it back to the airport at pattern altitude, but the pucker factor may be quite high.





LESSONS LEARNED: Winds matter. Strong winds are required to set up good ridge lift conditions. However, strong winds aloft are a double-edged sword. The effective glide ratio of all gliders decreases substantially when flying into a strong headwind. However, even relatively light winds aloft can meaningfully affect glider performance. To put the issue into perspective, refer to Figure 4, where a low performance 23 to 1 (still air) Schweizer SGS 1-26 has a better effective glide ratio with a 10 kt tailwind than a medium performance 34 to 1 (still air) PW-6 with only a 10 kt headwind!

Winds aloft matter. Knowing the winds aloft, magnitude and direction, is an absolute prerequisite to a proper preflight. Going soaring without knowing the winds aloft is like flying a power plane without knowing how much fuel is in the tanks. Fly safe.

About the author: Steve is a commercial pilot in single engine airplanes, single engine seaplanes, and gliders. He holds an instrument rating and is a Certified Flight Instructor for airplanes, instruments, and gliders. He has logged over 4,000 flight hr including over 2,000 hr as a flight instructor. He is a retired IBM Engineering Manager and a Flight Instructor at Sugarbush Soaring, Warren, VT.

GLIDER AERODYNAMICS PUZZLER

BY STEVE PLATT

Glider Aerodynamics Puzzler #25 (Turning Efficiency)

The Glider Aerodynamics Puzzler is intended to stimulate your thinking about soaring and refresh your understanding of glider aerodynamics and soaring optimization. The correct answers with detailed explanations follow the questions. Have fun.

Most glider pilots take great pride in their ability to manage energy. On a recreational flight on a day when there appears to be minimal lift, most glider pilots experience some amount of glee when they can stay up all afternoon when everyone else is "falling out of the sky". And if they are flying a Schweizer 1-26 versus the 45:1 *Super Wingbat 6000*, all the better. Conserving energy, and flight efficiency, are the secret. While most glider pilots are quite knowledgeable about optimizing *straight and level* flight – i.e., maximizing time aloft, maximizing distance, or maximizing speed depending upon the mission – optimizing *turning* flight is another story.

Question 1: For a coordinated 30° banked turn, for any glider, if flown at the minimum SINK SPEED for the angle of bank, how much does the glider SINK RATE increase over the level flight minimum SINK RATE?

A. 8% more than the level flight minimum sink rate

B. 16% more than the level flight minimum sink rate

C. 24% more than the level flight minimum sink rate

D. 32% more than the level flight minimum sink rate

E. 40% more than the level flight minimum sink rate

F. I do not have a clue

Question 2: For a coordinated 30° banked turn, for any glider, by what percentage does the minimum SINK SPEED increase over the level flight minimum SINK SPEED?

A. 0% the minimum sink speed is identical to the level flight minimum sink speed

B. 3% more than the level flight minimum sink speed

C. 7.5% more than the level flight minimum sink speed

D. 10% more than the level flight minimum sink speed

E. 15% more than the level flight minimum sink speed

F. I do not have a clue

Question 3: For a coordinated 45° banked turn, for any glider, if flown at the minimum SINK SPEED for the angle of bank, how much does the glider SINK RATE increase over the level flight minimum SINK RATE?

A. 9% more than the level flight minimum sink rate

B. 19% more than the level flight minimum sink rate

C. 29% more than the level flight minimum sink rate

D. 48% more than the level flight minimum sink rate

E. 68% more than the level flight minimum sink rate

F. I do not have a clue

Question 4: For a coordinated 45° banked turn, for any glider, by what percentage does the minimum SINK SPEED increase over the level flight minimum SINK SPEED?

A. 0% the minimum speed is identical to the level flight minimum sink speed

B. 4% more than the level flight minimum sink speed

C. 9% more than the level flight minimum sink speed

D. 19% more than the level flight minimum sink speed

E. 25% more than the level flight minimum sink speed

F. I do not have a clue

Question 5: You need to reverse direction and you want to conserve energy … or, you are in a rope break scenario shortly after takeoff (above 200 ft AGL) and you have decided it is safe to make an approximately 210° turn and return to the runway, what angle of bank and airspeed will lose the least amount of altitude for ALL gliders?

A. 20° of bank and level flight minimum sink speed

B. 30° of bank and level flight minimum sink speed plus 5%

C. 35° of bank and level flight minimum sink speed plus 7.5%

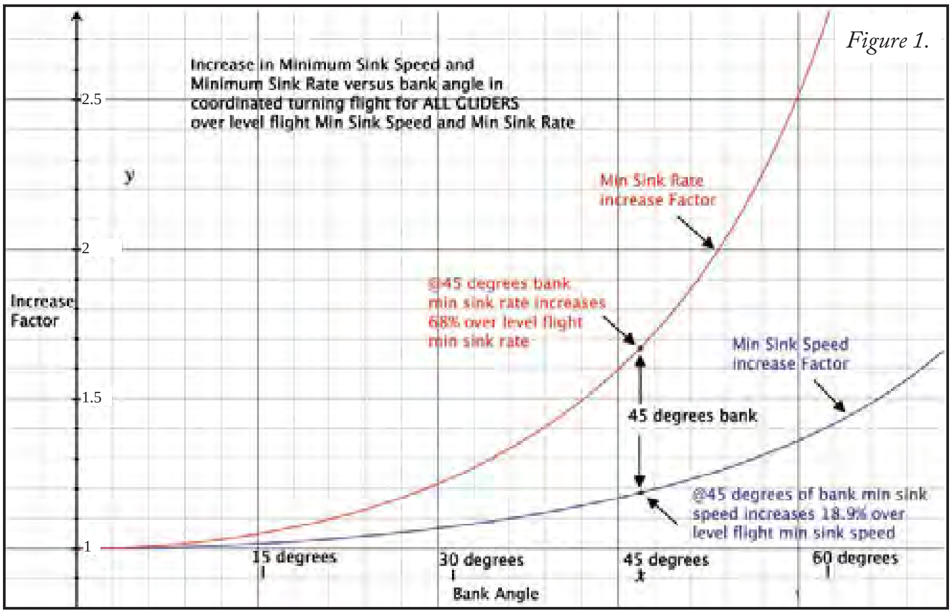
D. 45° of bank and level flight minimum sink speed plus 18.9%

E. 60° of bank and level flight minimum sink speed plus 20%

F. I do not have a clue

Explanation Questions 1-4

Newton's Laws of Physics apply equally to all gliders in level or turning flight. The percentage increase in minimum sink speed AND the percentage increase in minimum sink rate at a particular bank angle in coordinated flight IS IDENTICAL for all gliders independent of make and model.



Shown in Figure 1 is the increase factor in Minimum Sink Speed (Blue curve) and the Increase factor in Minimum Sink Rate (Red curve) versus Angle of Bank in coordinated turning flight for ALL gliders over their level flight Minimum Sink Speed and Minimum Sink Rate.

The equations plotted are:

Minimum Sink Speed (@ Bank Angle x) = Minimum Sink Speed (level flight) * $(1/\cos(x))^{.5}$

Minimum Sink Rate (@Bank Angle x) = Minimum Sink Rate (level flight) * $(1/\cos(x))^{1.5}$

For those readers interested in the Mathematical derivation, please refer to: *The Complete Soaring Pilots Handbook*, by Ann and Lorne Welch and Frank Irving, 1977, Chapter 16 "Theory of Glider Performance", p 238.

The curves in Figure 1 are interesting, but the data in Table 1 is, perhaps, more informative.

Notice that for a 30º coordinated banked turn the minimum sink speed increases by 7.5% and the minimum sink rate increases by 24%. For a 45º coordinated banked turn the minimum sink speed increases by 18.9% and the minimum sink rate increases by 68%!! And for those pilots that enjoy practicing 2G turns, in a coordinated 60º banked turn the minimum sink speed increases by 41% and the minimum sink rate increases by a whopping 183%!! These percentages are IDENTICAL for all Gliders. The percent change factors must be applied to the minimum sink speed and minimum sink rate for the current operating weight. Remember, the min sink speed and min sink rate are a function of weight. All flight polars shift up and to the left for decreasing weight and down and to the right for increasing weight. And, the numbers in the

Angle of Bank	0º	10 º	20 º	30º	40º	45º	50º	60º
% Increase in Minimum Sink Speed	0	0.7%	3.2%	7.5%	14%	18.9%	25%	41%
% Increase in Minimum Sink Rate	0	2.4%	9.8%	24%	49%	68%	94%	183%

Table 1, Change in Glider Minimum Sink Speed and Minimum Sink Rate as a Function of angle of Bank table assume perfect flight … i.e. for each angle of bank the minimum sink speed for the particular angle of bank is flown. Any other speed for that angle of bank will have even more sink!

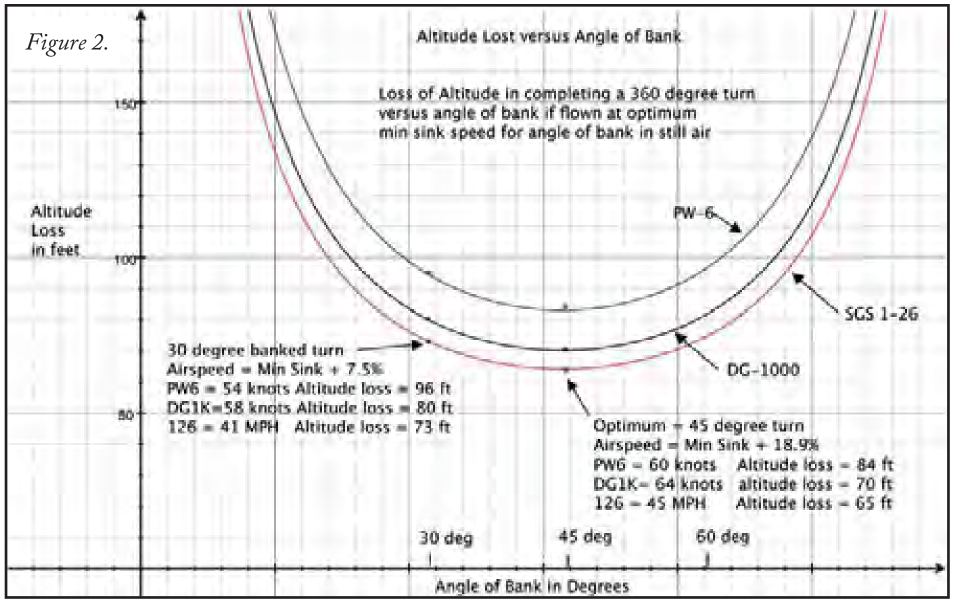
Answers are: Question 1: C; Question 2: C; Question 3: E; Question 4: D.

Explanation Question 5

Answer Question 5: D. The optimum bank angle and airspeed to lose the least amount of energy (altitude) in a completed turn for ALL gliders is 45° of bank and an airspeed equal to the level flight minimum sink speed (for the current operating weight) plus 18.9% (approximately 20%). Refer to Figure 2, which shows altitude loss while completing a 360° turn versus angle of bank for various gliders. Notice that the minimum altitude loss for ALL aircraft occurs at 45° of bank and an airspeed equal to the level flight minimum sink speed plus 18.9%. It is also interesting to point out that the lowly Schweizer 1-26 loses less altitude than the glass ships! Radius of turn matters.

LESSONS LEARNED: Except perhaps when working a thermal, turning flight is horribly inefficient. In a coordinated banked turn, the wings' lift must increase as the horizontal component of lift must remain equal and opposite to centripetal force, and the vertical component of lift must remain equal to the weight of the glider plus the tail down force (for conventional configured Gliders). Increasing lift means increasing the angle of attack which increases drag and increases glider sink rates. The optimal angle of bank and airspeed for ALL glider to lose the least amount of altitude in completing a turn (180°, 360°, etc.) is 45° of bank and an airspeed equal to the minimum sink speed in level flight (for the current operating weight) plus 18.9% (20% close enough). Remembering these numbers could prove most useful in an emergency situation.

Figure 2.



Except for acquiring energy in a thermal, or turning for mandatory navigational purposes, for energy conservation, turning flight in gliders is ill advised. Glider Aerodynamics is fascinating. Fly safe.

About the author: *Steve Platt is a commercial pilot in single engine airplanes, single engine seaplanes, and gliders. He holds an instrument rating and is a Certificated Flight Instructor for airplanes, instruments, and gliders. He has logged over 4,000 flight hours including over 2,000 hours as a flight instructor. He is a retired IBM Engineering Manager and a Flight Instructor at Sugarbush Soaring, Warren VT.*

GLIDER AERODYNAMICS PUZZLER

BY STEVE PLATT

Flight Polars

The Glider Aerodynamics Puzzler is intended to stimulate your thinking about soaring and refresh your understanding of glider aerodynamics and soaring optimization. The correct answers with detailed explanations follow the questions. Have fun.

Your soaring club recently purchased a PW-6 dual-seat glider. After a thorough checkout with one of the club's Flight Instructors, your wife is preparing to take the ship solo for a recreational flight. In reviewing the Pilot Operating Handbook (POH) she can only find the manufacturer's flight polar for Gross weight (1,220 lb) where the key speeds are shown as: Minimum Sink speed = 50 kt; Best L/D speed 56 kt. She will be operating solo at just above Minimum weight (900 lb).

Question 1: What will happen to the Minimum Sink SPEED at a 900 lb operating weight?

A. Remain 50 kt
B. Decrease to 48 kt
C. Decrease to 46 kt
D. Decrease to 43 kt
E. Decrease to 40 kt

Question 2: What will happen to the Minimum Sink RATE at a 900 lb operating weight?

A. No change
B. A minimal change: less than 5% reduction in min sink rate
C. A minimal change: between 5% and 10 % reduction in min sink rate
D. A 10% reduction
E. A 14% reduction
F. A 18% reduction

Question 3: What will happen to the Best L/D SPEED at a 900 lb operating weight?

A. Remain 56 kt
B. Decrease to 54 kt
C. Decrease to 52 kt
D. Decrease to 50 kt
E. Decrease to 48 kt
F. Decrease to 46 kt

Question 4: Your wife likes to enter your club's annual round-robin race. She asks you what happens to the Gross weight MacCready 4 speed of 70 kt, if she operates the PW-6 solo at minimum weight during the race and she needs to fly at MacCready 4 speed?

A. The MacCready speeds do not change with weight
B. The MacCready speeds increase by the square root of the ratio of Gross weight to operating weight.
C. The MacCready speeds decrease by the square root of the ratio of operating weight to the Gross weight.
D. The MacCready 4 speed decreases from 70 kt to 63 kt.
E. The MacCready 4 speed increases by 7 kt

Explanation questions 1- 3:

My two all-time favorite reference books describing the Physics of Glider Flight Performance are: *The Complete Soaring Pilot's Handbook* by Ann and Lorne Welch and Frank Irving, 1977 (ISBN: 0-679-50718-3) and Helmut Reichmann's classic *Cross-Country Soaring*, 7th Edition, published by the Soaring Society of America in 1993 (ISBN: 1-883813-01-8). For those glider pilots interested in the nuances of glider flight optimization, these books will be welcome additions to your library. They are generally available used on Ebay or Amazon.

All flight polars move up and to the left with decreasing weight, and conversely, down and to the right with increasing weight. On Page 122 of Reichmann's book, he describes, mathematically, the effect of changes in wing loading (i.e. operating weight) on the movement of flight polars for all gliders.

The bottom line is: All the coordinates of a flight polar, at a given weight, shift by an amount equal to the square root of the ratio of the weights for a new weight (new wing loading). So, for Question 1, the answer is D: if the Minimum Sink speed at Gross weight (1220 lb) is 50 kt then the Minimum Sink speed at 900 lb will be: 50 * $(900/1220)^{.5}$ which equals (50 * 0.859), which equals 43 kt … i.e. the Minimum Sink speed declines by 14% from gross weight to minimum weight.

Likewise, for Question 2, the answer is E: the Minimum Sink RATE at minimum weight decreases by the same factor – 14% – from the Minimum Sink RATE at Gross weight.

For Question 3, the answer is E. Since ALL coordinates of a flight polar shift by the same square root of the ratio of weights, the Best L/D speed also shifts down by the same factor. So, the Best L/D speed at Minimum weight moves from 56 kt to 56 * $(900/1220)^{.5}$ which equals 48 kt.

Explanation Question 4:

Shown in Figure 1 is the flight polar for the PW-6 at Gross weight and Minimum weight, and the constructions for determining the MacCready 4 speed-to-fly at both weights. Notice the MacCready 4 speed-to-fly decreases from 70 kt for Gross weight to 63 kt at 900 lb, so the answer is D. ALL MacCready speeds are a function of weight. Indeed, if a pilot unknowingly applied the MacCready 4 Gross weight speed of 70 kt to the 900 lb minimum weight wing loading condition, they would be flying, unknowingly, at about MacCready 6 speed!

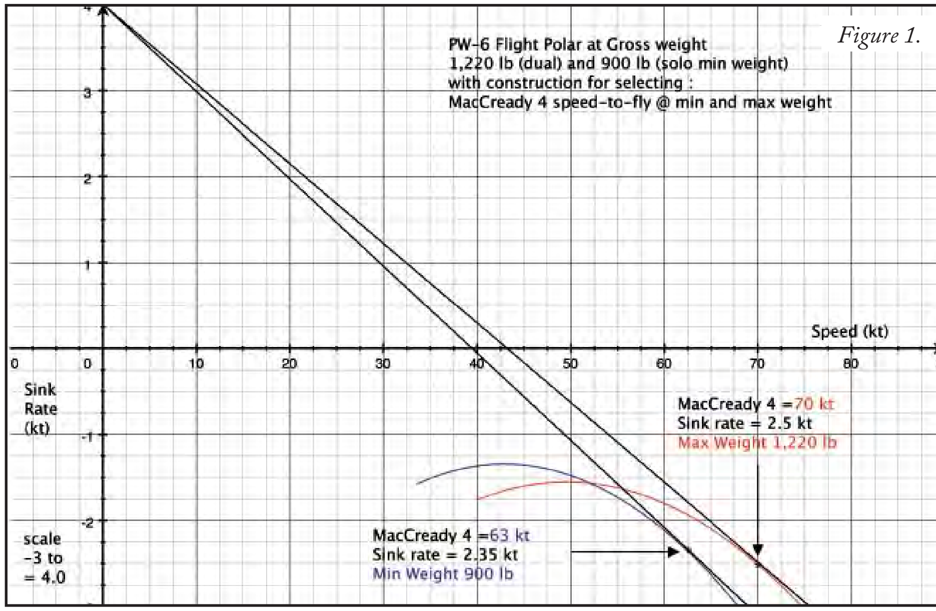


Figure 1.

Shown in Figure 2 is the flight polar of an SZD-55 at an operating weight of 740 lb, and when flown with maximum ballast at a maximum weight of 1,100 lb. Notice the Best L/D speed increases a whopping 13 kt from 60 kt to 73 kt, nearly a 22% increase!

LESSONS LEARNED: Weight matters. The flight polar for all gliders shifts up and to the left for decreasing weight and down and to the right for increasing weight. For changes in weight the shift factor is equal to the square root of the ratio of weights. For single seat gliders a difference of 10 or 20 lb is not significant. However, for dual seat ships flown solo at minimum weight, or single seat ships flown with maximum ballast, the difference can be huge.

Glider aerodynamics is fascinating. Fly safe.

Digitizing and Modeling Polars:

I have been asked by several readers how I digitize and plot the Flight Polars used in the Glider Aerodynamics Puzzler. The answer is I follow the Helmut Reichmann method. In his book, *Cross-Country Soaring* (first published in Germany in 1975), Reichmann describes how to model any flight polar by using a section of a quadratic equation of the form:

Sink = $(a * v^2) + (b * v) + c$, where v is airspeed and a, b, and c are constants.

Any glider's Flight Polar may be represented very accurately by this quadratic equation, and the coefficients a, b, and c may be calculated by selecting three polar coordinate pairs:

s1/v1, s2/v2, and s3/v3 from the Manufacturer's Published flight Polar, usually provided at gross weight … and using the three equations below as described in Reichmann's book. To achieve maximum accuracy in areas of interest, I have selected the three data pairs as: Minimum Sink speed, Best L/D speed, and Best L/D speed plus 10-25 kt depending upon the ship. By definition, the quadratic curve must pass exactly through these coordinates.

a = ((v2-v3)*(s1-s3)+(v3-v1)*(s2-s3)) / ($v1^2$*(v2-v3)+$v2^2$*(v3-v1)+$v3^2$*(v1-v2))

b = (s2-s1-a*($v2^2$-$v3^2$)) / (v2-v3)

c = s3 - a*$v3^2$ - b*v3

Once the coefficients a, b, and c are known, the quadratic equation can now be easily plotted using any PC graphing program (e.g. Grapher on Apple). By using the data pairs to calculate the coefficients, the modeled polar is quite accurate in the area of interest … i.e. from a few kt below Minimum Sink speed to Best L/D speed plus 25 kt.

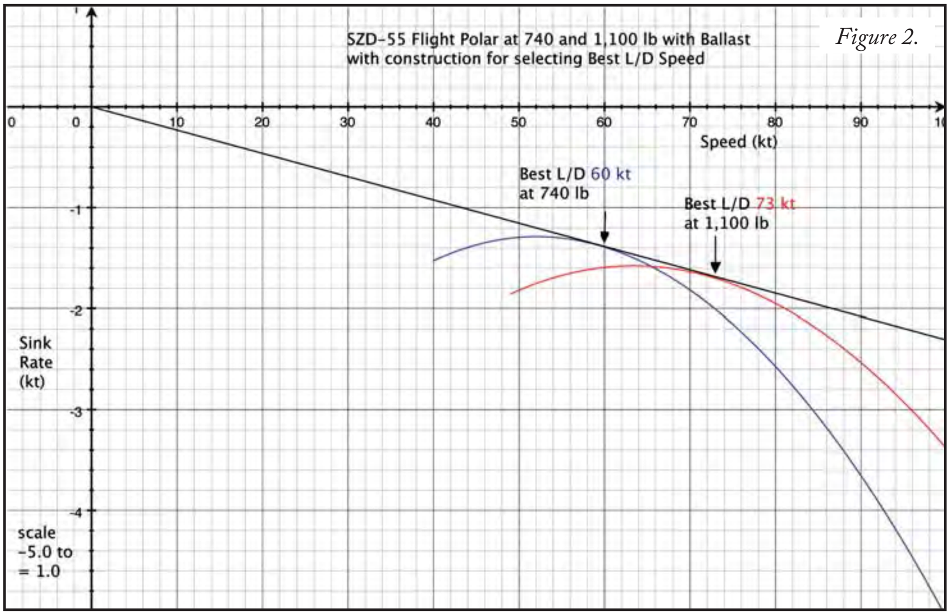


Figure 2.

With the flight polar modeled with a simple equation, the *coup de grace* is the polar for ANY other weight can be easily generated by multiplying all the coordinates of the polar by the shift factor discussed earlier … i.e. the square root of the ratio of the weights.

About the author*: Steve Platt is a commercial pilot in single engine airplanes, single engine seaplanes, and gliders. He holds an instrument rating and is a Certificated Flight Instructor for airplanes, instruments, and gliders. He has logged over 4,000 flight hours including over 2,000 hours as a flight instructor. He is a retired IBM Engineering Manager and a Flight Instructor at Sugarbush Soaring, Warren VT.*

GLIDER AERODYNAMICS PUZZLER

BY STEVE PLATT

Weather

The Glider Aerodynamics Puzzler is intended to stimulate your thinking about soaring and refresh your understanding of glider aerodynamics and soaring optimization. The correct answers with detailed explanations follow the questions. Have fun.

The state of the atmosphere plays a crucial role in glider operations. Indeed, it is the energy of the sun that allows gliders to remain in the air for hours at a time. Knowing how to read the atmosphere is an important part of being a glider pilot. While you do not have to have an advanced degree in meteorology to be a glider pilot, it certainly does not hurt.

QUESTION 1. It is a glorious midsummer afternoon with blue sky, scattered cumulus clouds, light winds and warm moist air. The current surface air temperature is 24° C with a dew point of 19.5° C. What do you estimate the cloud bases to be above ground?

A. 1,000 ft AGL
B. 2,000 ft AGL
C. 3,000 ft AGL
D. 4,000 ft AGL
E. 5,000 ft AGL

QUESTION 2. For a typical summer day with warm moist air at the surface, what is the temperature lapse rate for a parcel of air per 1,000 ft of altitude?

A. -0.5° C per 1,000 ft
B. -1.0° C per 1,000 ft
C. -2.0° C per 1,000 ft
D. -3.0° C per 1,000 ft
E. -4.0° C per 1,000 ft

QUESTION 3. For a typical summer day with warm moist air at the surface, what is the dew point lapse rate for a parcel of air per 1,000 ft of altitude?

A. -0.5° C per 1,000 ft
B. -1.0° C per 1,000 ft
C. -2.0° C per 1,000 ft
D. -3.0° C per 1,000 ft
E. -4.0° C per 1,000 ft

QUESTION 4: You are returning from a recreational glider flight in your club's PW-6 dual seat glider. You are operating at just under gross weight with your neighbor along for the flight. The flight polar for the PW-6 at your operating weight is shown in Figure 1. The Best L/D speed is 56 kt and yields a 34:1 glide ratio. You have encountered sustained headwinds of 25 kt and decide to operate at the Best Speed to Fly (STF) to maximize distance and conserve energy. What is the best STF with the 25 kt headwind and what will be the effective glide ratio?

A. 56 kt with an effective glide ratio of 34:1
B. 60 kt with an effective glide ratio of 30:1
C. 64 kt with an effective glide ratio of 24:1
D. 66 kt with an effective glide ratio of 20:1
E. 60 kt with an effective glide ratio of 19:1

EXPLANATION QUESTIONS 1-3: ANSWERS ARE C, C, A. Refer to Figure 2. While the lapse rate varies with humidity, for typical warm moist summer air the temperature lapse rate is -2.0° centigrade per 1,000 ft of altitude. The dew point lapse rate is -0.5° centigrade per 1,000 ft. Therefore, with a surface temperature of 24° C and a dew point of 19.5°, the temperature-dew point spread is 4.5° C. As the warm moist parcel of air rises, the temperature and dew point approach at a rate of 1.5° C per 1,000 ft.

After rising 3,000 ft the temperature-dew point spread reaches zero, whereupon the moisture in the super

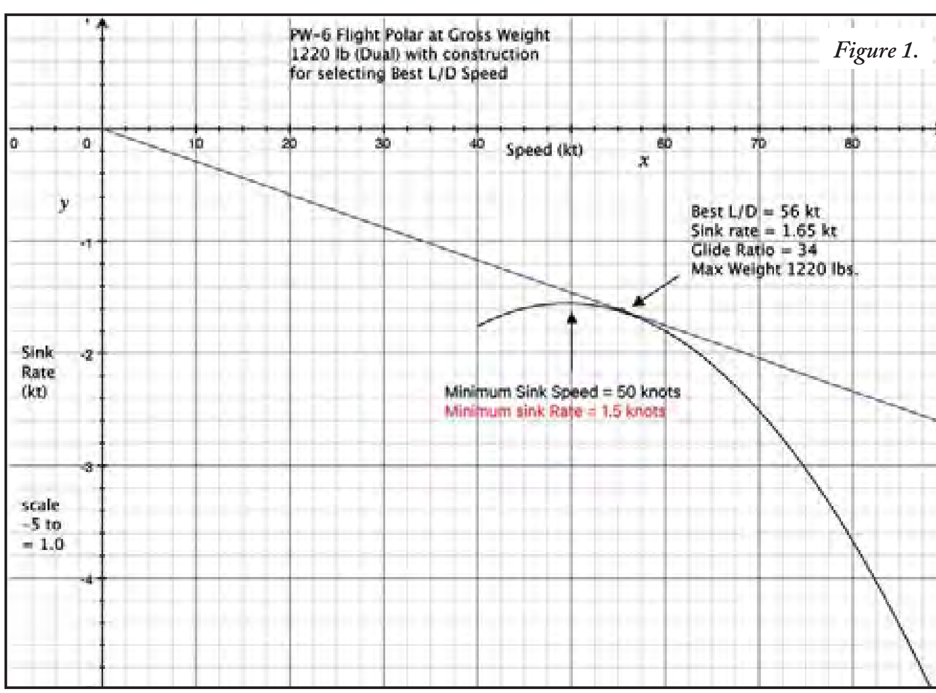


Figure 1.

saturated parcel of air condenses and forms liquid water vapor clouds … giving off the latent heat of condensation. Indeed, it is the latent heat of condensation that is the secret sauce of soaring and the reason why cumulus clouds billow. As the water vapor and air rises inside the building cumulus cloud, "fresh" air is "sucked-in" the bottom of the cloud … and so, glider pilots have an excellent source of rising air below the clouds initiated by the sun and accelerated by the latent heat of condensation. The ultimate demonstration of the energy from the latent heat of condensation is a thunderstorm. The atmosphere is amazing….

EXPLANATION QUESTION 4: ANSWER: E. Shown in Figure 3 is the construction for determining the best speed to fly into a 25 kt headwind to maximize distance and conserve energy (altitude). Note the best STF is 60 kt yielding an effective Glide ratio 19.4 to 1. The effective glide ratio is calculated by dividing the sink rate of the glider at the best STF into the GROUND SPEED of the glider which is the airspeed of the glider minus the headwind speed … or 60 kt minus 25 divided by 1.8 kt sink rate … which equals a 19.4:1 EFFECTIVE glide ratio.

LESSONS LEARNED: The state of the atmosphere, i.e., weather, is obviously crucial to glider operations. Knowing the temperature-dew point spread is useful in estimating cloud bases if more accurate observations and measurements are not available. Knowing the magnitude and direction of surface winds and winds aloft is critical to successful (and safe) glider operations. The effective glide ratio of any glider is strongly influenced by winds aloft magnitude and direction. Even a modest 15 kt wind aloft can make a huge difference in glider performance. Fly safe and have fun.

About the author*: Steve Platt is a commercial pilot in single engine airplanes, single engine seaplanes, and gliders. He holds an instrument rating and is a Certificated Flight Instructor for airplanes, instruments, and gliders. He has logged over 4,000 flight hours including over 2,000 hours as a flight instructor. He is a retired IBM Engineering Manager and a Flight Instructor at Sugarbush Soaring, Warren VT.*

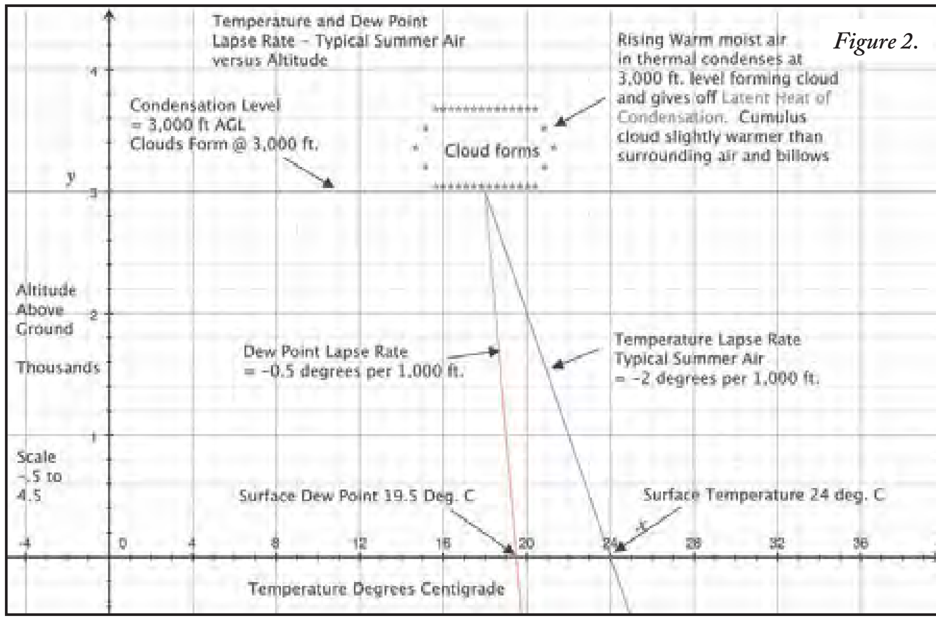


Figure 2.

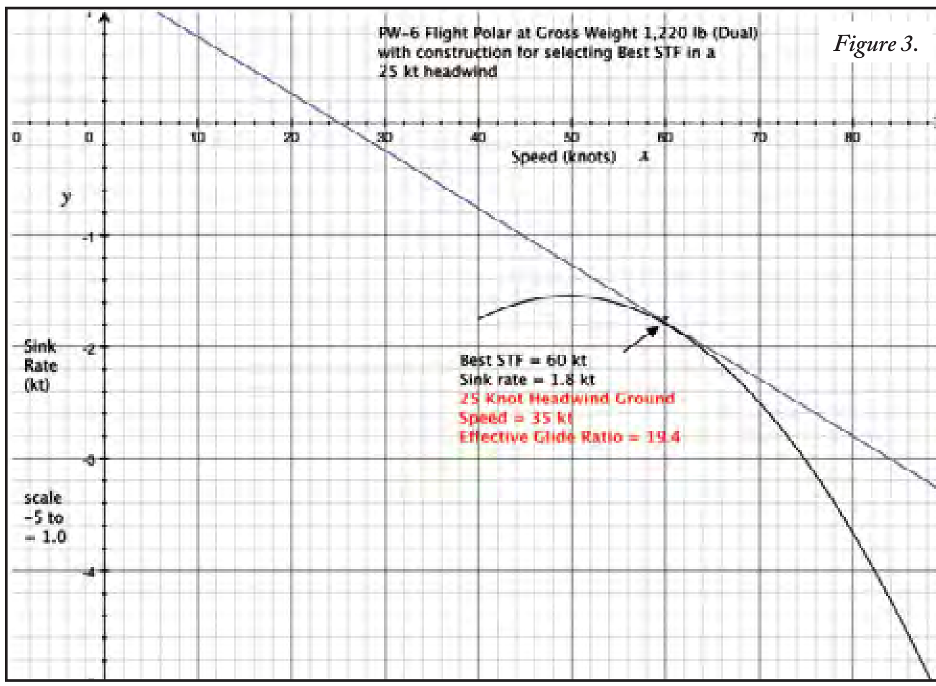


Figure 3.

GLIDER AERODYNAMICS PUZZLER

BY STEVE PLATT

Speed to Fly

The Glider Aerodynamics Puzzler is intended to stimulate your thinking about soaring and refresh your understanding of glider aerodynamics and soaring optimization. The correct answers with detailed explanations follow the questions. Have fun.

Knowing the best "Speed to Fly" to accomplish a particular mission is critical to optimizing glider flight. While all glider pilots usually have memorized the manufacturer's published best L/D glide ratio and speed for the ships they fly, the actual optimum Speed to Fly is dependent on several variables. Let's look at some examples:

QUESTION 1: You are flying your club's PW-6 two seat glider solo, at the 900 lb minimum weight, on a recreational flight. The published flight polar for the PW-6 is shown in *Figure 1*. The published Best L/D glide ratio is 34:1 at 56 kt. You are on your final leg to your home airport flying east bound 10 nm out. You have a 20 kt direct tailwind helping you along. You conclude you have enough altitude (energy) to make it safely home without stopping to thermal but decide to fly at the best Speed to Fly to conserve energy. In this scenario what is the best speed to fly with a 20 kt tailwind?

A. 56 knots, the published Best L/D Speed.
B. 50 knots, the published Minimum Sink Speed
C. 64 knots the MacCready speed for a 20 kt tailwind
D. 53 knots
E. 47 knots
F. 43 knots

QUESTION 2: Like Question 1, you are flying the PW-6 solo, at minimum weight, eastbound 10 nm out with a 20 kt tailwind, except this time you cross a ridge line running north to south and encounter sustained airmass sink of 2 kt in the lee of the ridge line. Again, you believe you have sufficient altitude to make it comfortably home without stopping to thermal. However, in an abundance of caution you decide to fly at the best speed to fly to conserve energy (altitude). What is the optimum speed to fly with a 20 kt tailwind and 2 kt of sink?

A. 56 knots the published Best L/D Speed
B. 50 knots the published Minimum Sink Speed
C. 43 knots the published Minimum Sink speed adjusted for weight
D. 64 knots the MacCready speed for a 20 kt tailwind
E. 52 knots
F. 60 knots

QUESTION 3: Like Question 1, you are flying the PW-6 solo at minimum weight eastbound 10 nm out with a 20 kt headwind. As you approach the North to South ridge line you encounter 2 kt of sustained sink. Again, you believe you have sufficient altitude to make it comfortably home without stopping to thermal. However, in an abundance of caution you decide to fly at the best speed to fly to conserve energy (altitude). What is the optimum speed to fly with a 20 kt headwind and 2 kt of sink?

A. 56 knots the published Best L/D speed
B. 50 knots the published Minimum sink Speed
C. 58 knots
D. 63 knots
E. 70 knots

QUESTION 4: You plan on entering your club's President's Cup race this coming weekend in the PW-6 glider shown in *Figure 1.* You have not made the decision whether you will fly solo at minimum weight or take a

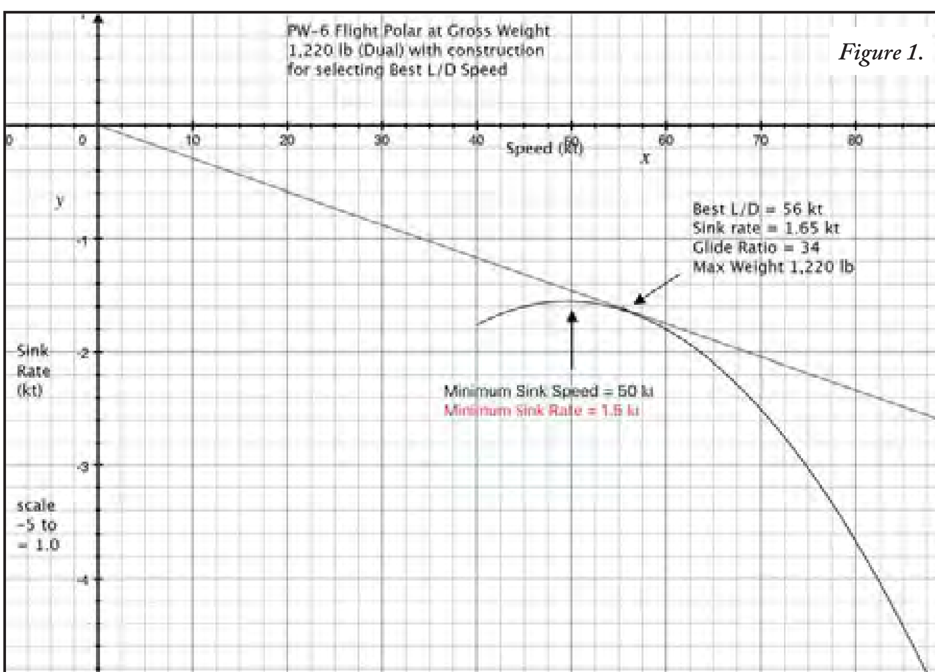


Figure 1.

friend along at gross weight. The forecast is for outstanding weather with excellent lift conditions. You want to be prepared to fly at the appropriate MacCready speed as needed. What is the MacCready 4 speed for the PW-6 at Gross weight and Minimum weight … or does weight not matter? How about wind? Are MacCready speeds a function of current wind conditions?

A. The MacCready 4 speed at Gross weight and Min weight is 70 knots. Weight does not matter.
B. The MacCready 4 speed at Gross weight and Min weight is 63 knots. Weight does not matter.
C. The MacCready 4 speed at Gross weight is 70 knots and 63 knots at Minimum weight.
D. The MacCready 4 speed at Gross weight is 74 knots and 67 knots at Minimum weight.
E. The MacCready 4 speed at Gross weight is 78 knots and 70 knots at Minimum weight.

EXPLANATION QUESTIONS 1-3: ANSWERS ARE E, E, D. The optimum Speed to Fly (STF) to conserve energy is a function of several variables. Current Operating weight and operating conditions … i.e. whether in a headwind/tailwind,

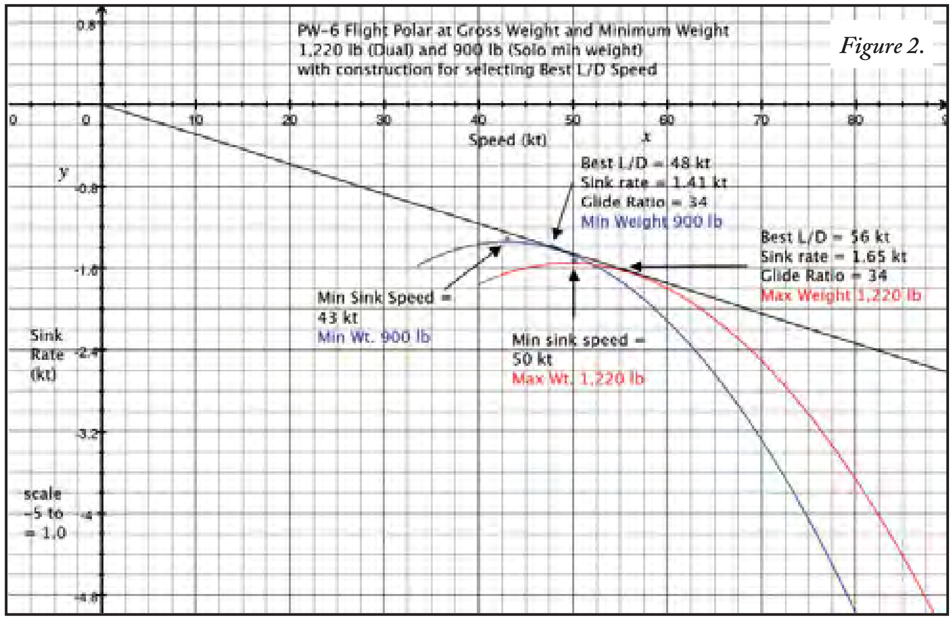


Figure 2.

and/or lift or sink. Manufacturers' published flight polars, usually provided at Gross weight, are only the starting point.

Before we can answer Questions 1-3 we must first calculate the flight polar for the CURRENT OPERATING WEIGHT to calculate the optimum STF. As described in prior Glider Aerodynamics Puzzlers, the flight polar at any (allowed) weight may be determined by shifting all the polar coordinates of the published flight polar by a factor equal to the square root of the ratio of the weights. Shown in *Figure 2* is the appropriate flight polar for the PW-6 flown at Minimum weight … i.e. 900 lb (blue polar). The flight polar shift factor for the PW-6 between gross weight (1,220 lb) and minimum weight (900 lb) is the square root of 900/1220 or .859.

For Question 1, the red line in *Figure 3* is the construction for determining the Best Speed to Fly with a 20 kt tailwind using the minimum weight flight polar (the tangent line commences at a point on the x axis at -20 kt). Notice the Best STF is a very modest 47 kt.

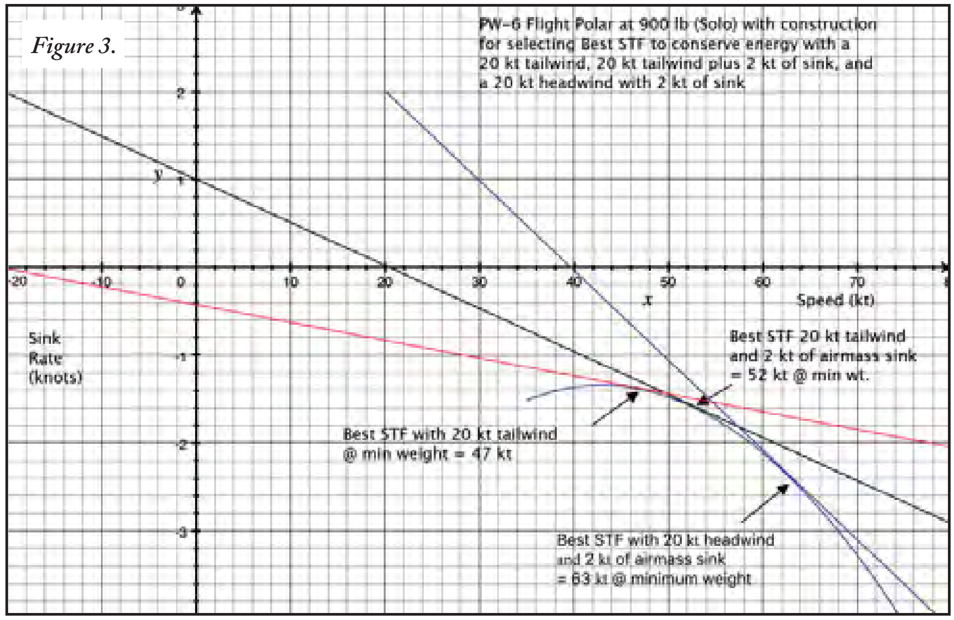


Figure 3.

For Question 2, again using the Minimum weight Flight polar, the black line in *Figure 3* is the construction for determining the best STF with a 20 kt tailwind and 2 kt of airmass sink (the tangent line commences at a point located at x = -20 kt AND y = +2 kt). Notice the Best STF is 52 kt.

And finally, for Question 3, the blue

line shown in *Figure 3* is the construction for determining the best STF with a 20 kt headwind and 2 kt of sink (the tangent line commences at a point located at x = +20 kt AND y = +2 kt). Notice the best STF is 63 knots.

EXPLANATION QUESTION 4: ANSWER: C. Shown in *Figure 4* is the construction for determining the MacCready 4 speeds for the PW-6 at both Gross weight and Minimum weight (the tangent lines commence at a point located at y = +4). The MacCready 4 speed at gross weight is 70 kt. The MacCready 4 speed at minimum weight is 63 kt. There is a 7 kt difference in MacCready speeds due to weight. If the 70 kt gross weight MacCready speed were used inadvertently at minimum weight it would be equivalent to flying at approximately MacCready 6 speed! MacCready speeds are independent of winds.

LESSONS LEARNED: Weight and current operating conditions — i.e. winds aloft and air mass sink or lift — matter in determining the optimum speed to fly to conserve energy (altitude). The flight polar for the current operating weight must be used to reach the correct answer. While no one expects pilots to be plotting tangents to flight polars in the cockpit, glider pilots should be intimately familiar with the performance of the ships they fly at the appropriate operating weight and under varying operating conditions, particularly into headwinds and/or in areas of sustained sink. The effective glide ratio of a Schweizer 2-33 with a 25 kt headwind and with 2 kt of airmass sink is around 10:1 if flown at the best STF. At any other speed the effective glide ratio is even worse. As for MacCready, all MacCready speeds are a function of weight and independent of winds aloft. Have fun, fly safe.

About the author: *Steve Platt is a commercial pilot in single engine airplanes, single engine seaplanes, and gliders. He holds an instrument rating and is a Certificated Flight Instructor for airplanes, instruments, and gliders. He has logged over 4,000 flight hours including over 2,000 hours as a flight instructor. He is a retired IBM Engineering Manager and a Flight Instructor at Sugarbush Soaring, Warren, VT.*

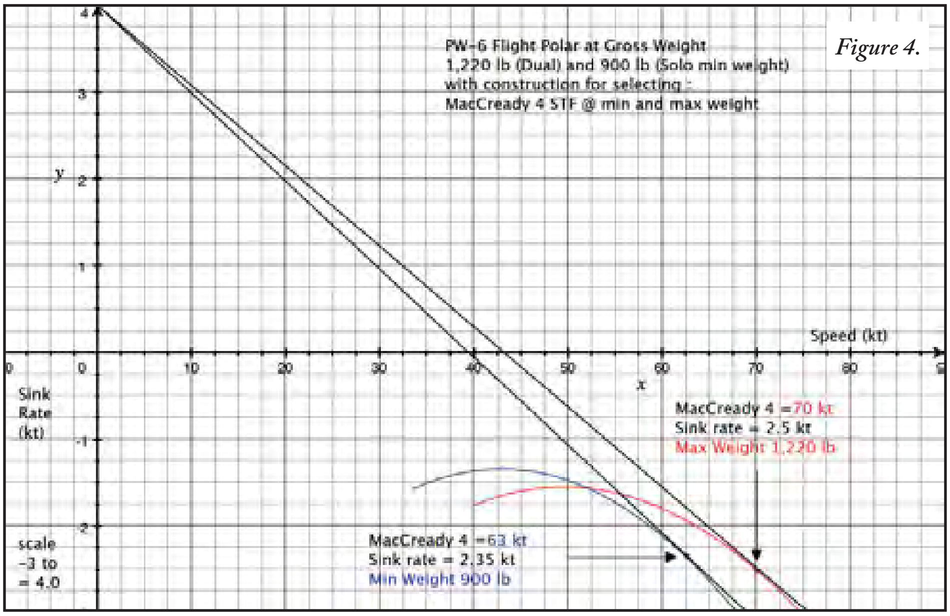


Figure 4.

GLIDER AERODYNAMICS PUZZLER

BY STEVE PLATT

Crosswinds

The Glider Aerodynamics Puzzler is intended to stimulate your thinking about soaring and refresh your understanding of glider aerodynamics and soaring optimization. The correct answers with detailed explanations follow the questions. Have fun.

All pilots receive training in crosswind takeoffs and landings prior to certification. Indeed, crosswind landings are one of the more difficult maneuvers for student pilots to master. Even for experienced long-time pilots, it is the rare pilot that intentionally practices crosswind landings with or without an instructor. Sadly, crosswind related accidents and incidents account for a significant fraction of the annual accident rate. Staying "current" is more than completing three takeoffs and landings.

QUESTION 1: For General Aviation aircraft, what is the minimum "maximum demonstrated crosswind component" the FAA requires for certification?

A. 8 kt
B. 10 kt
C. 20 kt
D. 0.20 x V_{S0} (stall speed)
E. 0.25 x V_{S0}

QUESTION 2: If the glider manufacturer's published "maximum demonstrated crosswind component" is 11 kt, is it even possible to land the glider with an 18 kt direct crosswind?

A. Yes
B. No
C. Maybe

QUESTION 3: Your home airport is using Runway 22. The current surface winds are 280° at 12 kt gusting to 18 kt. You are planning on flying your club's Super Wingbat 6000 glider. You recall the "maximum demonstrated crosswind component" for the aircraft as 11 kt. Will the current winds exceed the "maximum demonstrated crosswind component" of the aircraft?

A. Yes
B. No

QUESTION 4: You are returning to land in an ASK 21. You have just completed a base to final turn and recognize the 25 kt steady winds aloft on short final are 90° to the landing runway.

The surface winds are a direct crosswind reported as 10 kt gusting 15 kt below the 60-foot trees paralleling both sides of the runway. You normally land with an IAS of 60 kt with light winds but decide to add 5 kt due to the winds. Your plan is to hold 65 kt on short final.

With a 65 kt IAS and a direct 90° 25 kt crosswind, what will your wind correction angle or crab angle have to be to have your course remain on the extended centerline?

A. 10°
B. 13°
C. 16°
D. 20°
E. 23°

Explanation QUESTION 1: ANSWER: D. The certification requirements for General Aviation airplanes requires a minimum demonstrated crosswind landing with a 90° crosswind component of a modest 0.2 V_{S0}. The manufacturer may publish a "maximum demonstrated crosswind" component higher than 0.2 V_{S0} if demonstrated during certification testing. However, an important part of the "max demonstrated" definition is that "the airplane must be satisfactorily controllable without requiring exceptional piloting skill or strength." The published "max demonstrated crosswind" IS NOT necessarily a design limit. For perspective, most gliders have a "demonstrated crosswind landing" limit of approximately 10–12 kt. (Reference: Glider Flying Handbook). The max demonstrated crosswind component for a Cessna 152 is 12 kt. For a Cessna 172 it is 15 kt. For a Grob 103 it is 11 kt. For a Boeing 737 it is ~35 kt (for a dry runway).

Explanation QUESTION 2: ANSWER: A. The maximum demonstrated crosswind component is not a design limit. With great caution, it is possible for skilled pilots to land their gliders above the manufacturer's published "max demonstrated crosswind component" wind speed. However, the pilot must be on their "A" game.

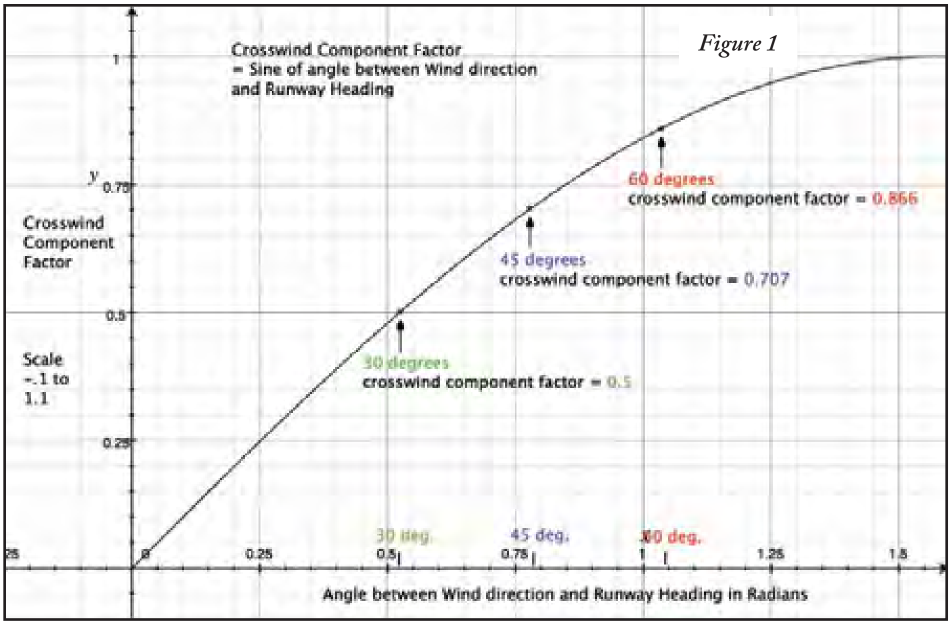


Figure 1

Explanation QUESTION 3: ANSWER: A. The crosswind component is calculated as the sine of the angle between the wind direction and the runway centerline times the magnitude of the wind. While student pilots can calculate the crosswind component with their E-6B circular "computers", most experienced glider pilots do not carry an E-6B in their flight bag or on-board equipment. Shown in *Figure 1* is a graph of the sine of an angle from 0° to 90° with the factors for 30°, 45° and 60° highlighted.

For winds 30° off the centerline the crosswind component is 0.500 times the wind magnitude.

For winds 45° off the centerline the crosswind component is 0.707 times the wind magnitude.

For winds 60° off the centerline the crosswind component is 0.866 times the wind magnitude.

If the Wind speed and angle off the runway centerline is known, *Figure 2* can be used to calculate both the headwind and crosswind components. For many pilots simply memorizing the crosswind component factors is easier to estimate the crosswind component than carrying an E-6B or pulling out your cell phone calculator. With the winds 60° off the centerline for your flight, the crosswind factor is

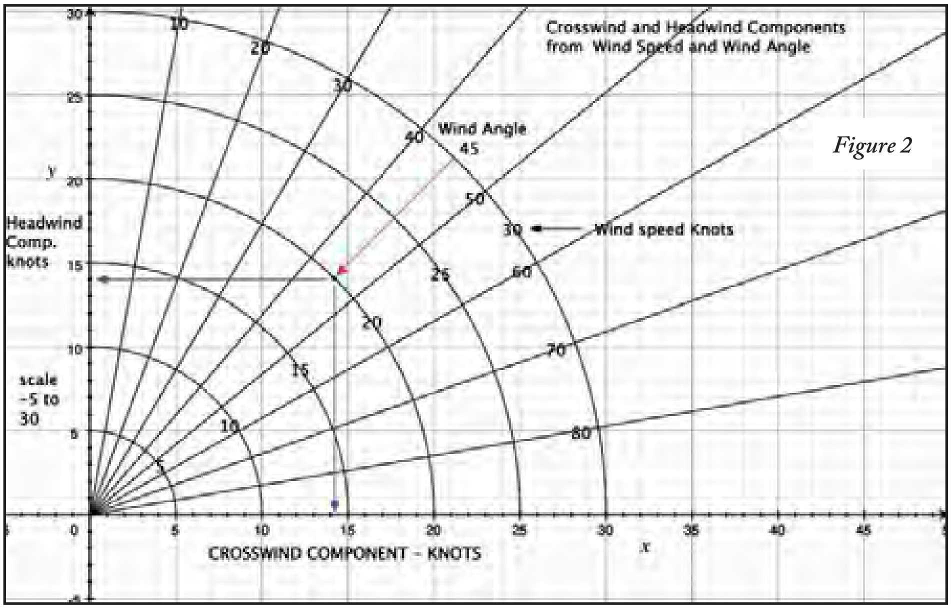


Figure 2

0.866. For the winds 12 kt gusting 18 kt 60° off the centerline, the crosswind component will be 10 kt gusting 16 kt. The gusts will clearly exceed the "max crosswind component" number. Landing may be a challenge!

EXPLANATION QUESTION 4: ANSWER: E. For the ASK 21 to remain on the extended centerline, the sine of the wind correction angle (wca) times the indicated airspeed must be equal to the crosswind.

Therefore,

sin(wca) = crosswind/airspeed or,

sin(wca) = 25/65 = 0.385.

The Wind correction angle must be 23° to remain on course on the extended centerline, because the sine of 23° is .385.

LESSONS LEARNED: For most gliders the maximum demonstrated crosswind landing speed is a very modest number in the range of 10 to 12 kt. When attempting landing with crosswinds above the manufacturer's published maximum demonstrated crosswind, you have become, by definition, a "test pilot". While the manufacturer's published max demonstrated crosswind number is not necessarily a design limit, or the absolute maximum crosswind that a skilled pilot can successfully land in, it is a limit that most Glider pilots would be wise to adhere too. And, of course, the winds do not have to be orthogonal to the landing runway to have a significant crosswind component. In fact, a 20 kt magnitude wind 45° off the runway centerline will exceed the max demonstrated crosswind number for most gliders. Extreme caution must be exercised with strong crosswind landings. Sadly, every glider season a significant fraction of landing accidents/incidents are caused by unsuccessful crosswind landings. Please be careful. Fly safe.

***About the author**: Steve Platt is a commercial pilot in single engine airplanes, single engine seaplanes, and gliders. He holds an instrument rating and is a Certificated Flight Instructor for airplanes, instruments, and gliders. He has logged over 4,000 flight hours including over 2,000 hours as a flight instructor. He is a retired IBM Engineering Manager and a Flight Instructor at Sugarbush Soaring, Warren, VT.*

BY BRITTON BLUEDORN

Calculating Still Air Best Cruise Speed

This article reintroduces a concept that isn't covered in much detail in our older texts: the Still Air Best Cruise Speed (BCS). Is "best cruise" the same as maximum L/D? No, maximum L/D is the speed for best *range* in still air.

For gliding flight, BCS is toward the high-speed end of the glide polar, where speed is maximized in the most efficient manner. Understanding BCS may help you compare glider performance and help visualize compromises in speed versus range. After all, the high-speed portion of the polar is what wins races and has been the emphasis of new glider design for some time now. This article will show you how to calculate the BCS for your glider.

As glider pilots we obsess over our glide polars. We can quickly identify select speeds like minimum sink speed and speed for max L/D, and we know our sink rates at high speed. We compare aircraft polars to one another and examine the effects of wing loading on polar shapes. We use this analysis to calculate speed-to-fly tables, circling polars, and in some cases make purchase decisions. As the glide polar provides the basis of the fundamental characteristics, comprehending the different speeds is important for varying phases of the flight; depending on whether the pilot wants to maximize time, distance, or velocity.

During our basic glider training, we learn key concepts such as Minimum Sink speed to extend our time aloft, or speed for maximum efficiency (L/D) to provide us the maximum distance we can travel in still air. From there our learning typically progresses into more advanced cross-country techniques: MacCready speed-to-fly, lift bands, probability/landout risk-based decisions, etc. But there remains a very basic still air speed to be considered before the advanced topics are discussed, the speed for best velocity in still air or BCS, which *maximizes the product of speed and gliding efficiency*.

To keep things as simple as possible we'll explain how to calculate the BCS, which can be thought of as weighting the all-important L/D parameter as a function of velocity.

Figure 1 is the advertised glide polar for an ASW 27 corrected to a wing loading of 10 pounds per square foot (psf), which is a partial load of water ballast for a good summer day of flying. Minimum Sink speed is around 48 kt.

The resulting L/D plot (*Figure 2*) shows maximum L/D occurring at about 60 kt. Note the *y*-axis shows L/D instead of Sink Speed.

At this step we simply multiply the points of the L/D curve by their corresponding speed. This provides a weighting factor to the L/D results based on what we value: speed. On the high-speed end, as the L/D is coming down and velocity is coming up, an optimum appears from the product of the two. The resulting *Figure 3* depicts the still air BCS and the corresponding "velocity-range" (Mach*L/D) parameter that we'll discuss.

The speed at the optimum shown, around 89 kt, is the BCS for this specific wing loading. Flying at this speed (in still air) you are at the most efficient high-speed portion of the glide polar. You are keeping L/D as high as you can while maximizing speed. ☛

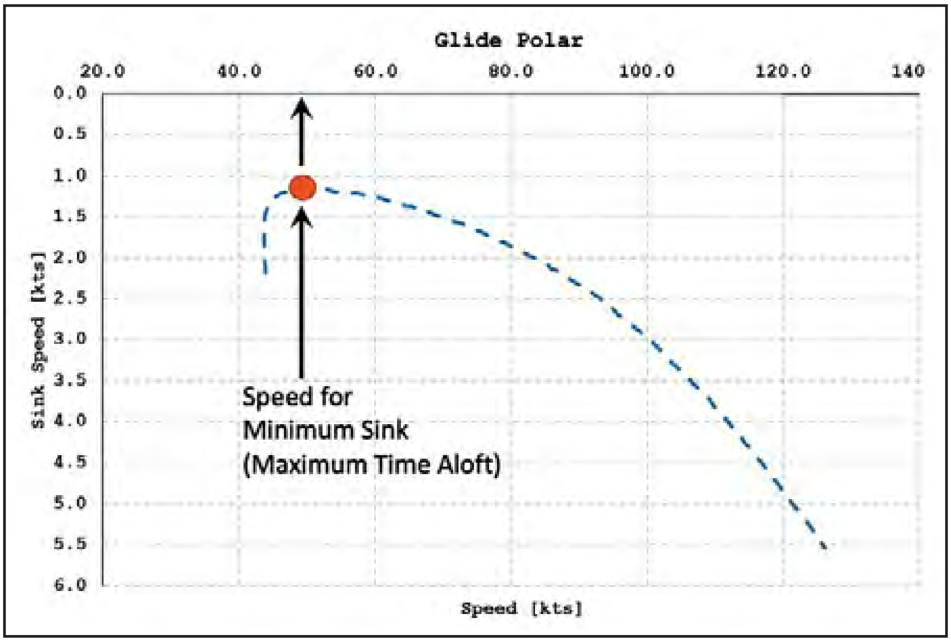


Figure 1: Glide Polar ASW 27, 10 psf.

This concept adds another still air "best speed" to our list of quotable speeds:

- Best time aloft – min sink speed
- Best range – max L/D speed
- Best cruise speed – max of velocity x L/D

Figure 3 uses Mach number to keep the left axis unitless, but multiplying L/D by speed in your favorite units will work just as well. Note the values on the left axis are a bit confusing when looking at only one glider (we'll compare more gliders shortly). The left axis depicts a concept of "velocity-range" used in industry for straight and level cruise comparisons. By constructing this graph we've boiled down this measure into our gliding vernacular (i.e., not level flight). The important concept is there exists a speed which provides an optimum, which we can use for comparisons of "still air best cruise speed" between gliders.

So, is this process new? No. Does it provide additional insight into your normal flying style? Maybe. Is it pedantic? Absolutely. Is it useful to acknowledge this speed? Certainly. It becomes the basis for the more advanced cross-country and racing topics (MacCready, Reichmann, Cochrane, etc.).

This procedure graphically depicts the concept the racing community and manufacturers often emphasize: it's not max L/D that wins races, but rather high-speed cruise efficiency. Carefully choosing the associated wing loading for projected weather can unlock potential advantages against your competitors. This easy to construct cruise graph (L/D curve multiplied by speed) can then provide the basis for future glider comparisons.

Figure 4 compares three generations of gliders: a Libelle 201, the referenced ASW 27, and an approximation of a modern 18-meter racing glider. All polars have been corrected to be near the higher end of their wing loading range for a good soaring day. Not only are performance and flight speeds increasing over time, but the BCS can clearly be seen, and is fairly flat near the peak for each generation. Our latest generation 18-meter glider is obviously more efficient at the optimum BCS (near 90 kt) for this specific wing loading comparison. Also note the wing loading trend is depicted on each graph by the arrows. *Figures 4a* and *4b* show the expected pure shift of the curve with varying wing loading, whereas *Figure 4c* depicts an expansion of the curve with increasing wing loading (which is left for the reader to prove to themselves).

Acknowledging a BCS exists, even at an academic level, provides the basis for further advanced texts and attempts to quantify and optimize flight in this region. For example, since the velocity-range parameter becomes fairly flat near the optimums in *Figures 3* and *4c*, one can surmise that attempting to optimize this region in a varying airmass would be dynamic at

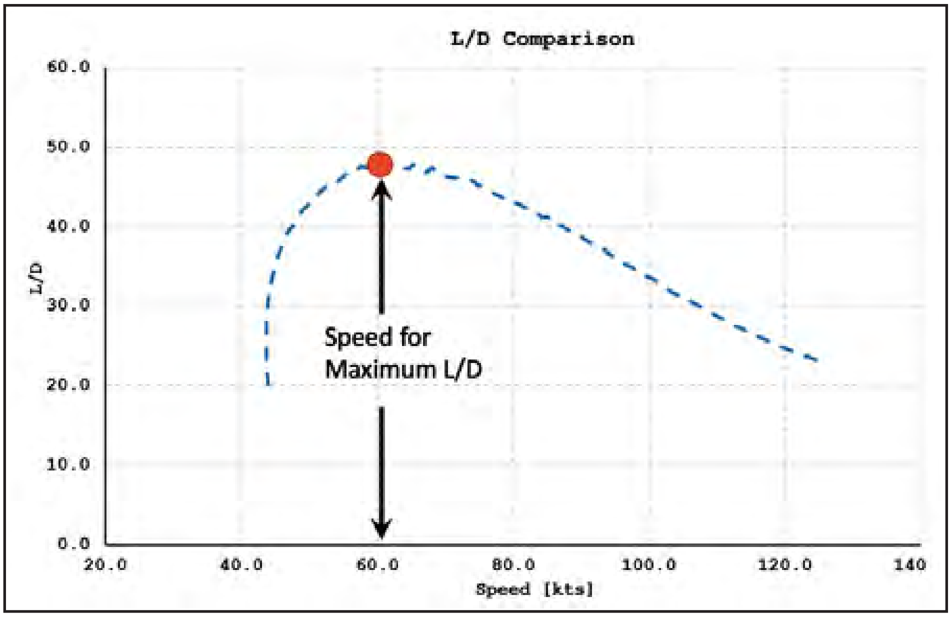


Figure 2: Resulting L/D, ASW 27, 10 psf.

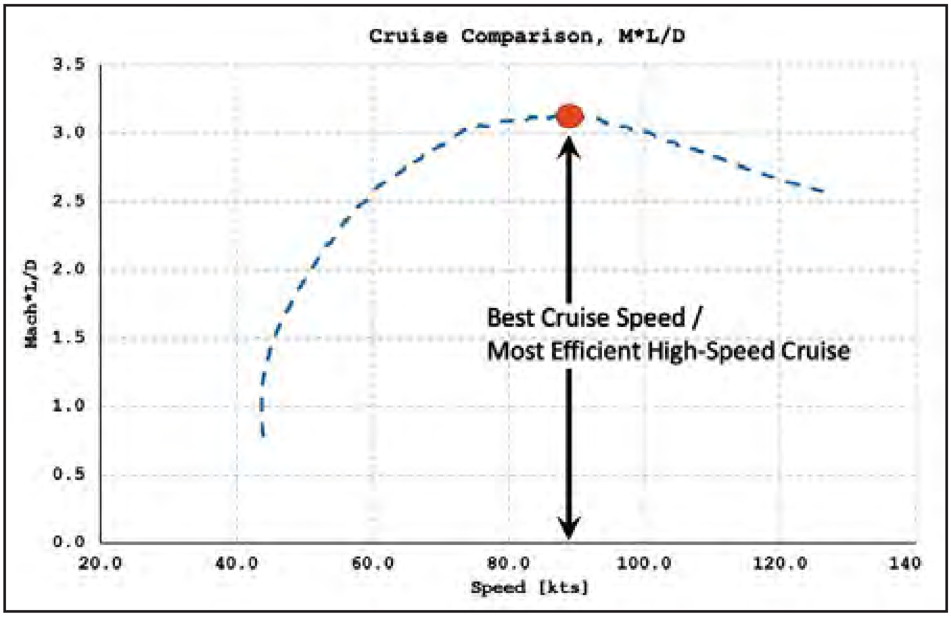


Figure 3: Cruise Graph, ASW 27, 10 psf. This is calculated by multiplying the corresponding x- and y-axis points from Figure 2.

best. This gives credence to the theory that flying 5 kt faster or slower than perfection doesn't greatly impact your overall results over the course of the day, so you might as well fly faster if conditions allow.

This author recommends manufacturers begin disclosing their BCS, providing a clear basis for product bragging rights and future comparison purposes. Of course, the associated wing loading or mass needs to be referenced to anchor any claims.

In summary, comprehending the three different "best" speeds from the glide polar is important to successfully use them in different phases of the flight, depending on whether the pilot wants to maximize time, distance, or velocity. Finally, the reader can use their referenced BCS as a litmus test for quantifying each cross-country flight; ask yourself: can I 'best' my still air best cruise speed on today's cross-country flight? This might become a new measure of merit for all of us.

Author's note: All glide polars were digitized from manufacturers' advertised polars. No data smoothing was performed so any slight wiggles in the curves are author generated. Special thanks to Chris Dowell and Tom Serkowski for proofreading.

***About the author**: Britton Bluedorn is a lead aerodynamicist on Lockheed Martin advanced projects with hardware flying today. He caught the glider flying bug at age 15 and has since been devoted to the never-ending search for understanding on how things fly and how to improve them. Along the way he earned a BS and MS in Aerospace Engineering (with a highlight of a summer internship at the Schempp-Hirth factory). He currently holds a commercial glider and private pilot SEL certificate and enjoys flying his ASW 27 (and the wife's DA40), always striving for long, fast, and high flights.*

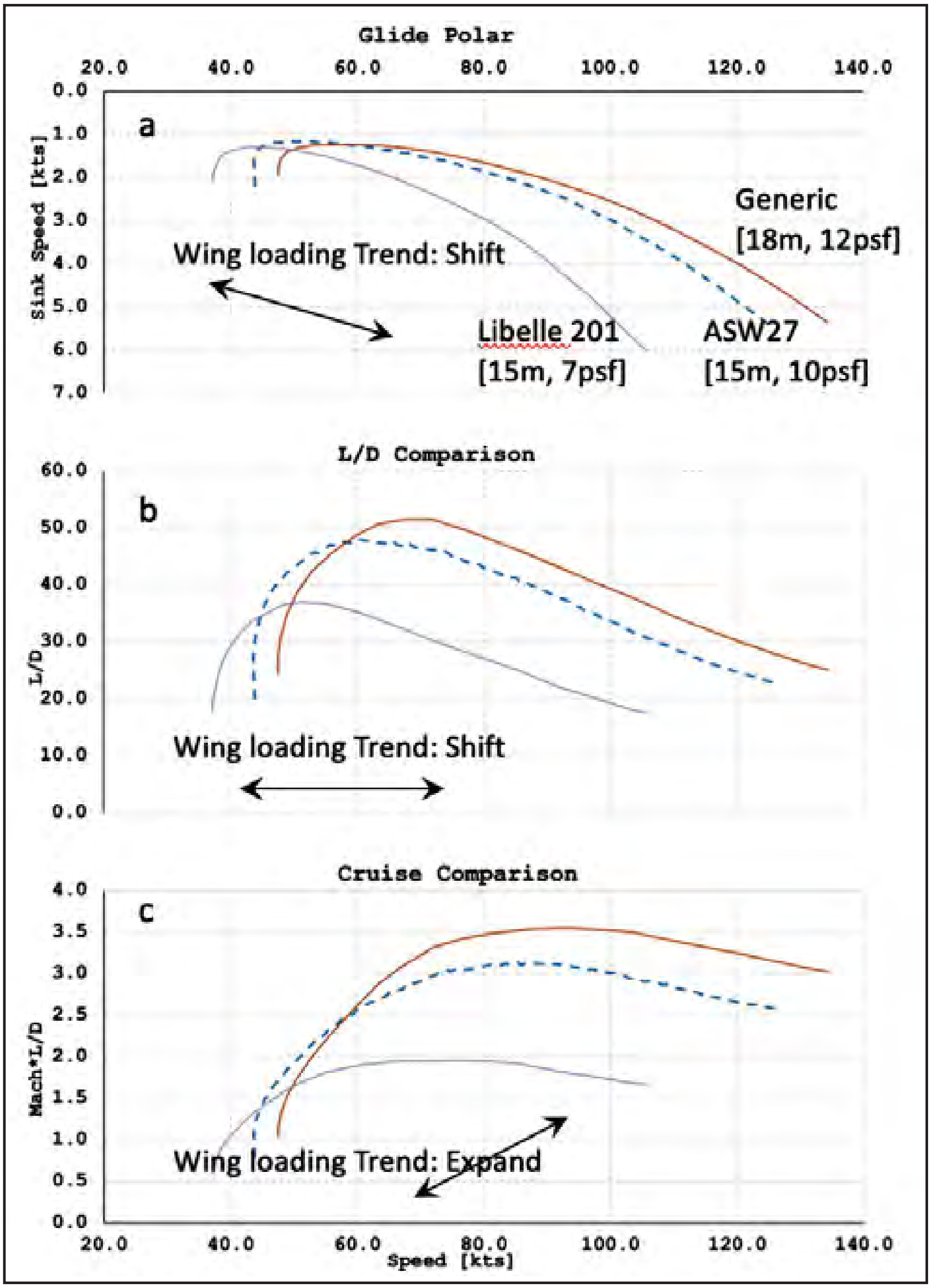


Figure 4: Polar, LD, Cruise Graphs for Libelle 201, ASW 27, Latest Gen 18m.

GLIDER AERODYNAMICS PUZZLER

BY STEVE PLATT

Climb Rate

The Glider Aerodynamics Puzzler is intended to stimulate your thinking about soaring and refresh your understanding of glider aerodynamics and soaring optimization. The correct answers with detailed explanations follow the questions. Have fun.

Optimizing the net climb rate in thermals is perhaps more art than science. However, there are a few first principles that will help most glider pilots get closer to the optimum. For every thermal, depending upon its strength, radius, and profile, there is an optimum bank angle and airspeed to optimize net climb rates. If the angle of bank is too shallow and/or flown too fast, the radius of turn is large and the glider circles in the weaker portion of the thermal or circles outside the thermal entirely. On the other hand, if the bank angle is too steep, the sink rate of the glider is too great and gives up more than is gained by being closer to the core of the thermal. Indeed, there is a sweet spot for every thermal. Let's look at the physics and consider some of the variables.

QUESTION 1: It is a beautiful summer Saturday morning. Three of your soaring club's ships are already in the air: a Schweizer 1-26, a Schweizer 2-33, and a medium performance PW-6. All three ships find an early morning thermal. The thermal is relatively narrow with airmass lift at the core of 4.2 kt decreasing parabolically to zero at a radius of 500 ft. If all three ships circle in this thermal optimally — i.e., perfectly centered and at the optimum airspeed and bank angle for each ship — how will their resulting net climb rates compare?

A. The PW-6 will out climb the 2-33 and the 1-26 … and the 1-26 will out climb the 2-33.
B. The PW-6 will out climb the 2-33 and the 1-26 … and the 2-33 will out climb the 1-26.
C. The 2-33 will out climb the 1-26 and the PW-6 … and the PW-6 will out climb the 1-26.
D. The 2-33 will out climb the 1-26 and the PW-6 … and the 1-26 will out climb the PW-6.
E. The 1-26 will out climb the 2-33 and the PW-6 … and the 2-33 will out climb the PW-6.
F. The 1-26 will out climb the 2-33 and the PW-6 … and the PW-6 will out climb the 2-33.

QUESTION 2: It is now 2 pm. The same three ships are up again, and this time find a typical summer thermal — i.e., a Standard British thermal with airmass lift at the core of 4.2 kt decreasing parabolically to zero at a radius of 1,000 ft. If all three ships circle in this thermal optimally — i.e., perfectly centered and at the optimum airspeed and bank angle for each ship — how will their resulting net climb rates compare?

A. The PW-6 will out climb the 2-33 and the 1-26 … and the 1-26 will out climb the 2-33.
B. The PW-6 will out climb the 2-33 and the 1-26 … and the 2-33 will out climb the 1-26.
C. The 2-33 will out climb the 1-26 and the PW-6 … and the PW-6 will out climb the 1-26.
D. The 2-33 will out climb the 1-26 and the PW-6 … and the 1-26 will out climb the PW-6.
E. The 1-26 will out climb the 2-33 and the PW-6 … and the 2-33 will out climb the PW-6.
F. The 1-26 will out climb the 2-33 and the PW-6 … and the PW-6 will out climb the 2-33.

Explanation for QUESTION 1: ANSWER: E. Shown in *Figure 1* is a plot of the profile of the morning ther-

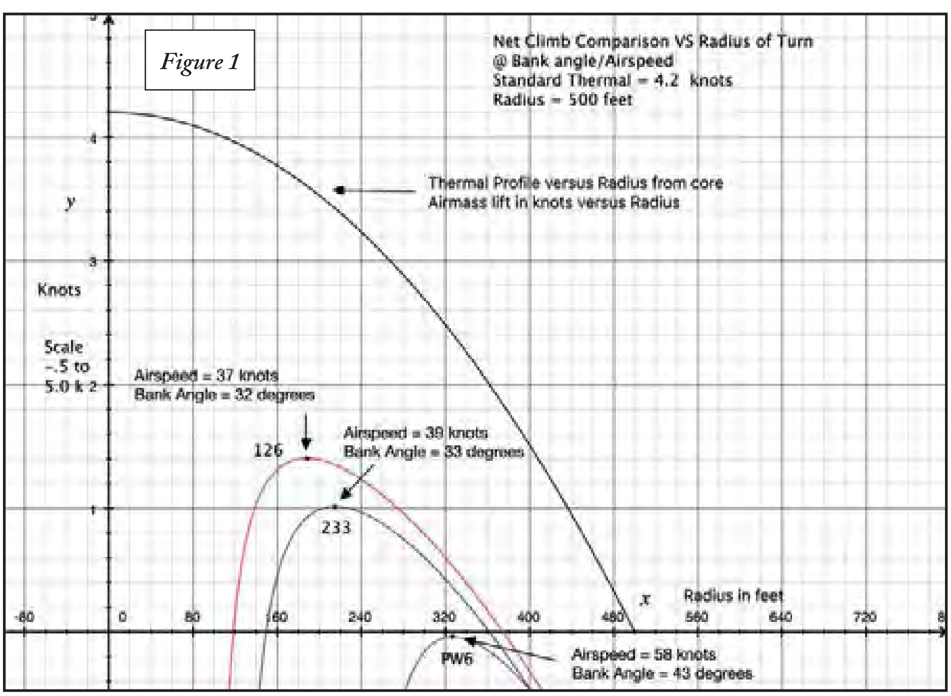
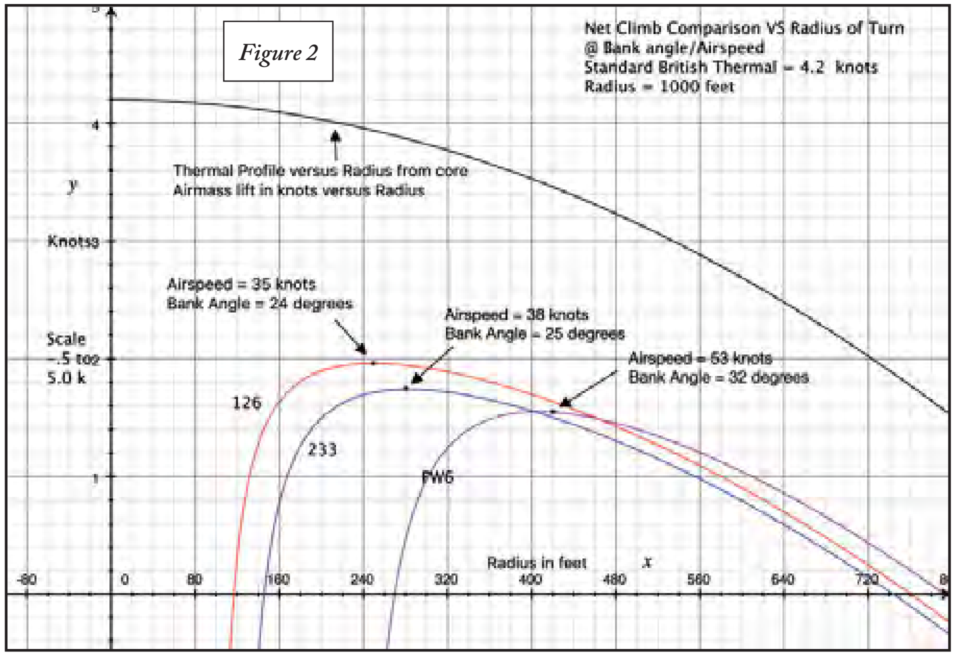


Figure 1

mal in QUESTION 1 and the resulting net climb rates of all three ships versus radius of turn if flown optimally — i.e., perfectly centered and at the optimum airspeed and bank angle for each ship. Notice that the 1-26 is capable of out climbing both the 2-33 and the PW-6, and the 2-33 is capable of out climbing the PW-6. Notice that the optimum net climb rate occurs at a different radius of turn, bank angle, and airspeed for each ship. Indeed, the PW-6 can barely maintain zero climb rate while the 2-33 can achieve a 1.0 kt net climb rate while the 1-26 can achieve 1.4 kt! Also, notice the angle of bank at optimum net climb rate is approximately 10˚ steeper for the faster ship … i.e., 43˚ of bank versus ~33˚ of bank for the slower gliders.



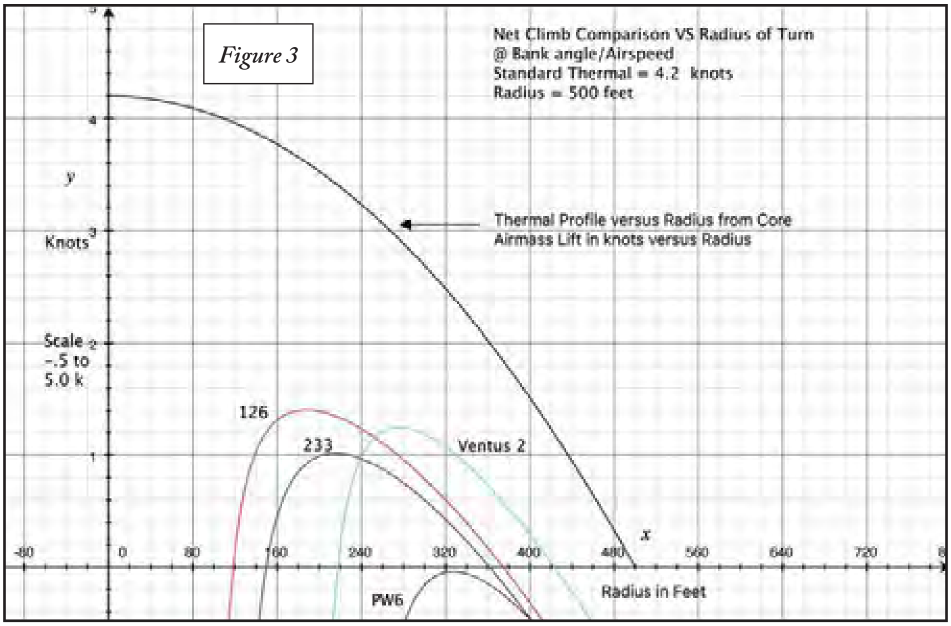
Explanation for QUESTION 2: ANSWER: E. Shown in *Figure 2* is a plot of the profile of the afternoon thermal (Standard British thermal) in QUESTION 2 and the resulting net climb rates of all three ships versus radius of turn if flown optimally — i.e., perfectly centered and at the optimum airspeed and bank angle for each ship. Notice, once again, the Schweizer 1-26 can out climb both the 2-33 and the PW-6 … and the 2-33 can just barely out climb the PW-6. But again, the optimum net climb rate occurs at significantly different radius of turns. Indeed, the optimum radius of turn for the 1-26 is not quite half that of the PW-6. And again, the optimum angle of bank is shallower for slower gliders (e.g., 24˚ of bank for the 1-26 and 25˚ of bank for the 2-33) and steeper for faster gliders (e.g., 32˚ for the PW-6.)

LESSONS LEARNED: Radius of turn matters! And, therefore, bank angle and airspeed matter. To optimize net climb rates, there exists an optimum bank angle and corresponding airspeed for each thermal profile. Narrow strong thermals will require steeper angles of bank and faster airspeed to reach the optimum net climb rate. While weak, wide thermals will require shallower bank angles and slower airspeed to reach the optimum net climb rate, flying at the minimum sink speed for the angle of bank selected will optimize net climb rates. Slower gliders have an inherent advantage while thermaling. They can operate at shallower bank angles for a particular radius of turn than faster ships. Remember, the radius "R" of turn for all gliders (and airplanes with wings) in coordinated turning flight is proportional to the square of airspeed — i.e., $R = V^2 / (g * \mathrm{Tan(bank\ angle)})$.

In narrow thermals, if flown optimally, the slow Schweizer 1-26 can out climb nearly everything!

Refer to *Figure 3*, where the net climb rate of a high-performance Ventus 2 is compared to the Schweizer 1-26 in a narrow thermal — i.e., with airmass lift of 4.2 kt at the core decreasing parabolically to zero at a radius of 500 ft. The Schweizer is capable of out climbing the Ventus 2!

Glider Aerodynamics is fascinating. Have fun. Fly safe.



DISCLAIMER: The author is painfully aware the results shown in *Figures 1, 2*, and *3* are, indeed, idealized models based upon the Physics of flight with unrealistic assumptions — i.e., gliders are flown optimally 100% of the time at the minimum sink speed for the angle of bank and are perfectly centered in perfectly cylindrical thermals. However, while no glider pilot thermals optimally 100% of the time, and I have never experienced a perfect Standard British Thermal, the analysis is still instructive in demonstrating the first principles involved in optimizing net climb rates.

About the author: *Steve Platt is a commercial pilot in single engine airplanes, single engine seaplanes, and gliders. He holds an instrument rating and is a Certificated Flight Instructor for airplanes, instruments, and gliders. He has logged over 4,000 flight hours including over 2,000 hours as a flight instructor. He is a retired IBM Engineering Manager and a Flight Instructor at Sugarbush Soaring, Warren, VT.*

GLIDER AERODYNAMICS PUZZLER

BY STEVE PLATT

Winds

The Glider Aerodynamics Puzzler is intended to stimulate your thinking about soaring and refresh your understanding of glider aerodynamics and soaring optimization. The correct answers with detailed explanations follow the questions. Have fun.

The surface winds and the winds aloft significantly affect glider operations and performance. Whether crosswind takeoff or landing, or enroute flight, the surface winds and winds aloft matter.

QUESTION 1: A medium performance PW-6 with a 34:1 best L/D glide ratio in still air is flying into a 10 kt headwind. A low performance SGS 1-26 with a 23:1 best L/D glide ratio is flying with a 10 kt tailwind. Which glider has a better Effective Glide ratio?

A. The SGS 1-26 has a better Effective Glide ratio than the PW-6
B. The PW-6 has a better Effective Glide ratio than the SGS 1-26
C. They both have the same Effective Glide ratio
D. I don't have a clue

QUESTION 2: A PW-6 is 5 miles east of the airport on a final glide, flying at the Best Speed to Fly to maximize distance into a 10 kt headwind. At the same time an SGS 1-26 is 5 miles west of the airport on a final glide flying at the Best Speed to Fly to maximize distance with a 10 kt tailwind.

Which glider makes it to the airport first? In other words, which glider has the faster Ground Speed?

A. The SGS 1-26 has the faster ground speed and makes it to the airport first.
B. The PW-6 has the faster ground speed and makes it to the airport first.
C. Both gliders reach the airport at the same time.
D. I don't have a clue.

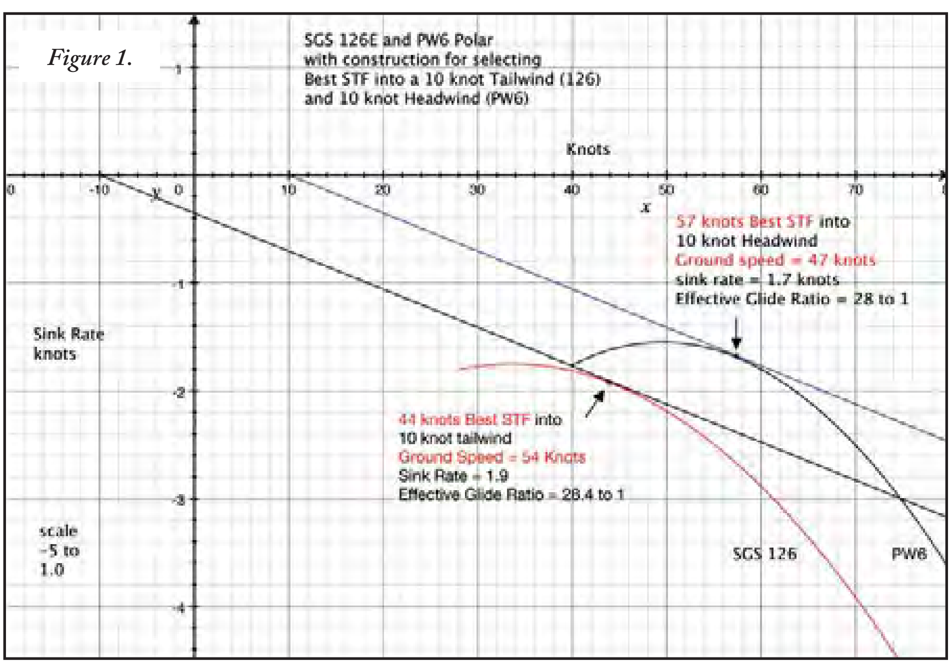


Figure 1.

QUESTION 3: A high performance Discus with a 45:1 best L/D glide ratio in still air is flying into a 10 kt headwind. A low performance SGS-126 with a 23:1 best L/D glide ratio is flying with a 10 kt tailwind. Which glider has a better Effective Glide ratio?

A. The SGS 1-26 has a better Effective Glide ratio than the Discus
B. The Discus has a better Effective Glide ratio than the SGS 1-26
C. They both have the same Effective Glide ratio
D. I don't have a clue

QUESTION 4: A Discus is 5 miles east of the airport on a final glide flying at the Best Speed to Fly to maximize distance into a 10 kt headwind. At the same time an SGS 1-26 is 5 miles west of the airport on a final glide flying at the Best Speed to Fly to maximize distance with a 10 kt tailwind.

Which glider makes it to the airport first? In other words, which glider has the faster Ground Speed?

A. The SGS 1-26 has the faster ground speed and makes it to the airport first.
B. The Discus has the faster ground speed and makes it to the airport first.
C. Both gliders reach the airport at the same time.
D. I don't have a clue.

Explanation for QUESTION 1: ANSWER: A. QUESTION 2: ANSWER: A. Shown in *Figure 1* are the flight polars for both the SGS 1-26 and PW-6 as well as the construction for determining the best Speed to Fly (STF) in a 10 kt headwind for the PW-6 and the best STF with a 10 kt tailwind for the SGS 1-26. Notice that the best STF to maximize distance for the SGS 1-26 is 44 knots resulting in a ground speed of 54 kt and an effective Glide ratio of 28.4:1. The best STF to maximize distance for the PW-6 is 57 kt resulting in a ground speed of 47 kt and an effective glide ratio of 28:1. The SGS 1-26 has a faster ground speed and a better Effective Glide ratio with only a 10 kt tailwind than the PW-6 with a 10 kt headwind!

Explanation for QUESTION 3: ANSWER: B. QUESTION 4: ANSWER A. Shown in *Figure 2* are the flight polars for both the SGS 1-26 and Discus as well as the construction for determining the best STF in a 10 kt headwind for the Discus and the best STF with a 10 kt tailwind for the SGS 1-26. The best STF to maximize distance for the Discus is 60 kt resulting in a ground speed of 50 kt and an Effective Glide ratio of 37:1. The SGS 1-26 has a faster ground speed with a 10 kt tailwind than the Discus with a 10 kt headwind but the Discus continues to have the better Effective Glide ratio than the SGS 1-26.

Lessons Learned: Winds matter. The Effective Glide ratio of all gliders is a strong function of the winds aloft. Even a 10 kt headwind significantly reduces glider performance. A 25 kt headwind dramatically reduces glider performance. For example, the Effective Glide ratio of a 34:1 PW-6 (in still air) reduces by over 40% to ~19:1 in a 25 kt headwind if flown optimally! And, of course, ground speed decreases in headwinds as well. Indeed, most gliders flying into a modest 20 kt headwind will reduce ground speed by over 30%. Any glider pilot that goes soaring without knowing the winds aloft, both magnitude and direction, has not done an adequate preflight. Going soaring without knowing the winds aloft is like taking up a power plane without knowing how much fuel is on board (if any). Have fun. Fly safe.

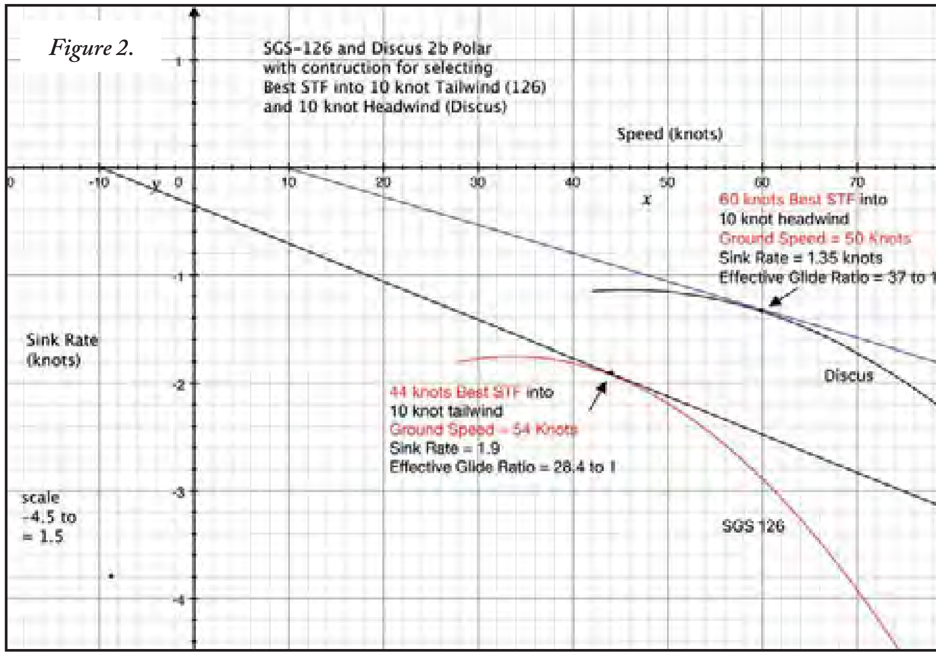


Figure 2.

About the author: *Steve is a commercial pilot in single engine airplanes, single engine seaplanes, and gliders. He holds an instrument rating and is a Certificated Flight Instructor for airplanes, instruments, and gliders. He has logged over 4,000 flight hours including over 2,000 hours as a flight instructor. He is a retired IBM Engineering Manager and a Flight Instructor at Sugarbush Soaring, Warren, Vermont.*

GLIDER AERODYNAMICS PUZZLER

BY STEVE PLATT

Landing

The Glider Aerodynamics Puzzler is intended to stimulate your thinking about soaring and refresh your understanding of glider aerodynamics and soaring optimization. The correct answers with detailed explanations follow the questions. Have fun.

I like to tell my students "Every landing in a glider is different." Unlike powered airplanes with available thrust, where independent of the headwind component, the glide slope on an ILS is 2.5°. Likewise, the "glide slope" at airports installed with Visual Approach Slope Indicators (VASI) is approximately 3°. For powered aircraft, the sight picture and approach angle, with rare exceptions, is pretty consistent. However, for gliders it is a different story. Let's look at the numbers.

QUESTION 1. On a gorgeous Saturday morning you are up with a student in a Schweizer 2-33. After practicing maneuvers and a "sled ride" back to the airport you enter the pattern to land. The wind is dead calm, not a whisper. Your student makes an excellent landing using an airspeed on final of 55 mph (48 knots) and a decent rate of ~ 700 ft/min. Later the same day in mid-afternoon the surface winds come up and are now blowing 20 knots right down the runway. You return to land after an instructional flight with another student. Your student advises she plans to use 60 mph on final because of the surface headwind. She executes an excellent pattern, anticipates the winds, and holds an appropriate crab angle on base leg. She turns final and holds her target airspeed of 60 mph and sets up an ~700 ft/min descent rate to another excellent landing. Compared to the morning approach angle, how much does the afternoon approach angle have to change?

A. No glide path angle change is necessary. The sight picture will be the same.
B. The approach angle will decrease 5%. The sight picture will change.
C. The approach angle will increase 5%. The sight picture will change.
D. The approach angle will increase by 15%. The sight picture will change.
E. The approach angle will increase by 25% The sight picture will change.
F. The approach angle will increase by 35%. The sight picture will change.
G. The approach angle will increase by 45 %. The sight picture will change.

QUESTION 2. A friend returns to land after a short cross-country flight. He is flying his Super Wingbat 6000 high-performance glider. It has a best L/D glide ratio near 50 to 1. With the 20-kt headwind right down the runway he sets up his landing approach using 65 kt and ~700 ft/min descent rate. Compared to the Schweizer SGS 2-33 landing into the 20-kt headwind what will be the difference in the approach angle of the Super Wingbat 6000 and the Schweizer 2-33?

A. No Difference in approach angles. Both will have the same sight picture.
B. The 2-33 approach will be 0.5° steeper than the Super Wingbat 6000 approach
C. The 2-33 approach will be 1.0° steeper than the Super Wingbat 6000 approach
D. The 2-33 approach will be 2.0° steeper than the Super Wingbat 6000 approach
E. The 2-33 approach will be 2.5° steeper than the Super Wingbat 6000 approach
F. The 2-33 approach will be 3.5° steeper than the Super Wingbat 6000 approach

Explanation

Whether the winds are calm or blowing 20 knots down the runway, the Instrument Landing System (ILS) glideslope is ~2.5°. Powered aircraft adjust for the headwind component by adding power. The “sight picture” on final, i.e. the approach angle, with an ILS or visual approach slope indicator is the same.

Not so for gliders. The approach angle is significantly different for gliders with headwinds versus no wind when using a consistent descent rate profile. Landing Gliders is more challenging than landing powered aircraft in strong winds. Because of the winds, “every glider landing is different”.

QUESTION 1: ANSWER G In the morning, with an approach speed of 55 mph (47 kt) and a descent rate (speed) of 700 ft/min (or 7 kt), the approach angle is the arc sin of 7/47, or arc sin of 0.149 which equals 8.6°. However, in the afternoon, with an approach speed of 60 mph (52 kt) and a GROUNDSPEED of 32 knots (with the 20-kt headwind) the approach angle is the arc sin of 7/32, or arc sin of 0.219 which equals 12.6°. There is a 4-degree increase in approach angle in the afternoon versus the morning with the 20-kt headwind using exactly the same descent rate! The approach angle increases by 46.5% with the 20-knot headwind!!

QUESTION 2: ANSWER F The Super Wingbat 6000 with a 20-kt head wind and holding 65 knots airspeed (groundspeed of 45 knots) with a descent rate of 700 ft./min has an approach angle of arc sin of 7/45, or arc sin of 0.155 which equals 8.9˚. For a 20-kt headwind for the SGS the approach angle of 12.6˚ must be 3.7˚ steeper than the 8.9˚ approach angle of the Super Wingbat 6000 with the same wind and descent rate!!

LESSONS LEARNED: First an anecdote. I share this event not to embarrass anyone but rather as a "lesson learned" for all of us. A number of years ago an extremely experienced member of our soaring club returned from a cross-country flight in his high-performance sail plane. At the time he had thousands of hours and thousands of miles of glider cross-country experience. He was a Power pilot as well, with airplane Single engine, Multi-engine, Instrument airplane and CFI-G license/ratings. He was also a tow pilot. He was not an active CFI in the club.

Late that afternoon, after landing his high-performance ship into the 20-kt headwind, he volunteered to take one of our youth Line Crew Members for his earned lesson in one of the club's Schweizer 2-33's. After a ~30-minute flight, he returned to land. Since it was the last flight of the day, one of the other line crew members radioed to the crew and requested they "land long" to facilitate putting the aircraft away for the evening. The winds were still blowing 20 kt down the runway.

As the 2-33 reached the point on downwind where I thought they needed to turn base leg under the existing wind conditions, the glider continued on downwind. I wondered what they were doing. When they finally turned base leg, I thought to myself that they would not make it to the runway. Not only did they not "land long," or make it to the runway, they were still 100 ft short of the runway after the rollout!! Fortunately, the approach to the runway has a 500-ft mowed grassy area prior to the runway start. While the pilot in command was highly embarrassed, there was no harm done to the aircraft or crew. When questioned "what happened" the pilot confessed he was so accustomed to the sight picture of his high performance 50-1 glider landing at 70 kt indicated air speed with 20 kt of wind, he failed to account for the performance difference of the much slower Schweizer 2-33 aircraft. Lesson learned.

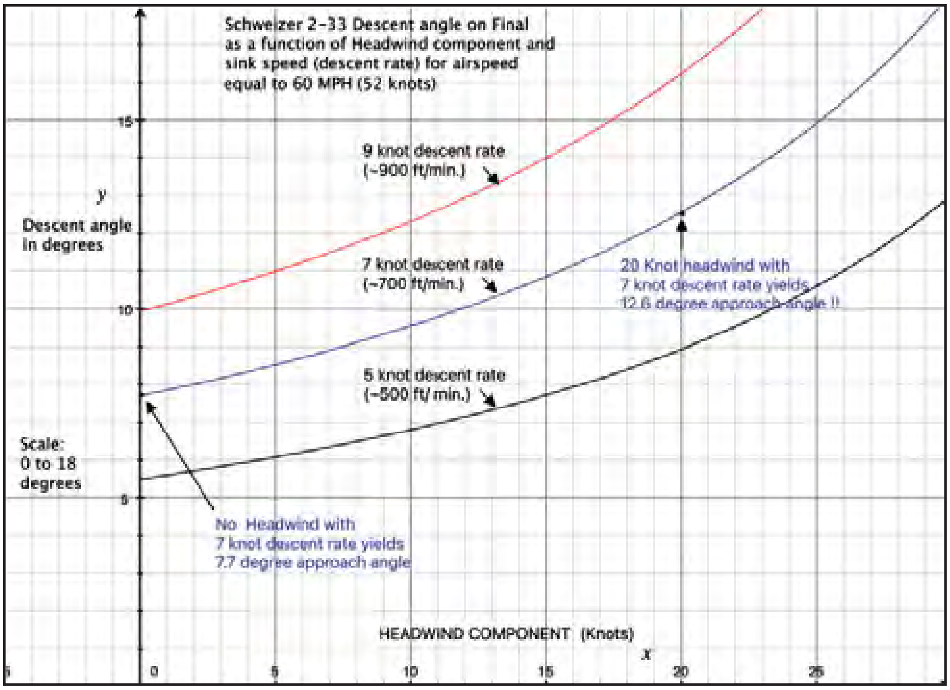


Figure 1: Schweizer 2-33 descent angle as a function of headwind.

The approach angle landing for ALL gliders must be steeper with strong headwinds. For low performance (slow) gliders (e.g., Schweizer 2-33 and 1-26) the approach angle must be considerably steeper with strong headwinds. The approach angle may increase by over 50% versus no wind conditions. Shown in Figure 1 is a graph indicating the actual approach angle as a function of headwind speed for a Schweizer 2-33 (or any glider) flown at 60 mph (52 kt) airspeed for varying decent rates. Notice that with no wind and a decent rate of 7 kt (~700 ft/min) the approach angle is 7.7˚. However, with a 20-kt headwind and a GROUND SPEED of 32 kt and the descent angle is 12.6˚!

Gliders land differently than powered aircraft. *Every* landing in a glider is different. The sight picture changes as a function of the wind conditions. While I may be prejudiced, it is for this reason that I believe experienced glider pilots are among the best stick and rudder pilots in the world. Have fun. Fly safe.

About the author: *Steve is a commercial pilot in single engine airplanes, single engine seaplanes, and gliders. He holds an instrument rating and is a Certificated Flight Instructor for airplanes, instruments, and gliders. He has logged over 4,000 flight hours including over 2,000 hours as a flight instructor. He is a retired IBM Engineering Manager and a Flight Instructor at Sugarbush Soaring, Warren, Vermont.*

GLIDER AERODYNAMICS PUZZLER

BY STEVE PLATT

Minimum Sink

The Glider Aerodynamics Puzzler is intended to stimulate your thinking about soaring and refresh your understanding of glider aerodynamics and soaring optimization. The correct answers with detailed explanations follow the questions. Have fun.

The minimum sink speed is one of the Speeds-to-Fly (STF) that all glider pilots should understand and exploit when appropriate. The Minimum Sink Speed plays a crucial role not only in staying aloft for the longest time but also in thermaling.

QUESTION 1. Your wife is planning on taking up your club's PW-6 dual seat glider solo for a recreational flight. The manufacturer's published gross weight flight Polar is shown in *Figure 1*. At gross weight (1,220 lb) the Minimum sink speed is 50 kt and the Minimum Sink Rate is 150 ft/minute. She will be operating the PW-6 solo at minimum weight (911 lb). She asks you what the Minimum Sink SPEED will be at her operating weight?

A. The Minimum Sink Speed is independent of weight
B. The Minimum Sink Speed increases 5 kt to 55 kt
C. The Minimum Sink Speed decreases 7 kt to 43 kt
D. The Minimum Sink Speed decreases 5 kt to 45 kt
E. The Minimum Sink Speed decreases 3 kt to 47 kt

QUESTION 2. Your wife then asks you what happens to the Minimum Sink RATE at her operating Weight?

A. The Minimum Sink Rate is independent of weight.
B. The Minimum Sink Rate increases 14 feet/minute
C. The Minimum Sink Rate decreases 20 feet/minute
D. The Minimum Sink Rate decreases 14 feet/minute
E. The Minimum Sink Rate decreases 10 feet/minute

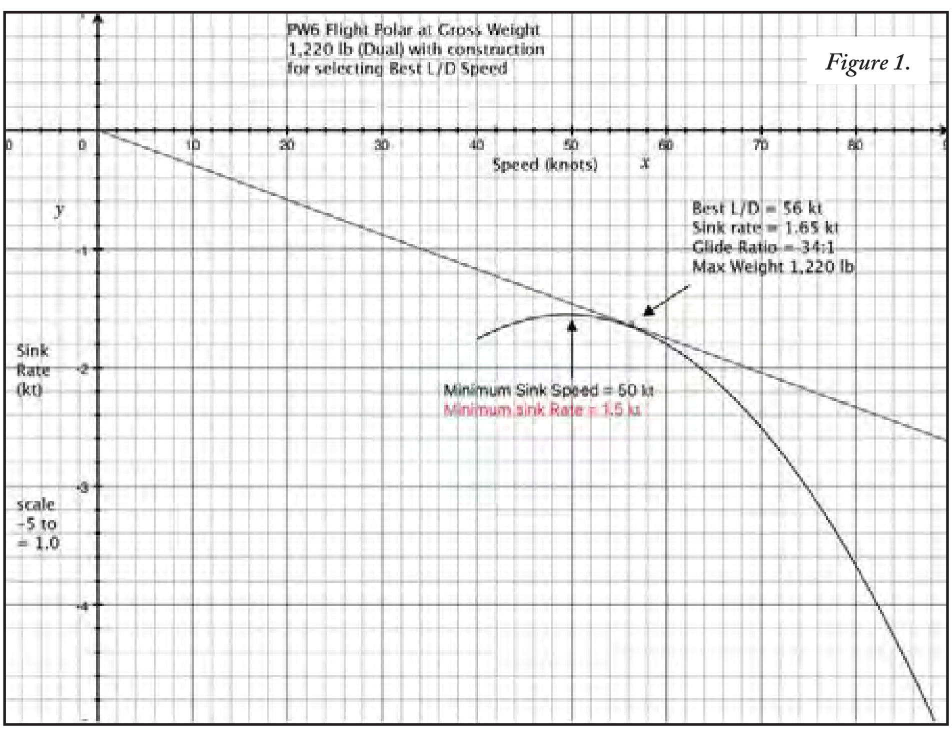


Figure 1.

QUESTION 3: Your wife's next question is: "What happens to the Minimum Sink SPEED in a coordinated 30° banked turn?".

A. The Minimum Sink Speed is independent of bank angle
B. The Minimum Sink Speed increases by a percentage equal to the square root of the bank angle
C. The Minimum Sink Speed increases by 5%
D. The Minimum Sink Speed increases by 7.5%
E. The Minimum Sink Speed increases by 12%

QUESTION 4: Your wife's final question is: "What happens to the Minimum Sink RATE in a coordinated 30° banked turn?"

A. The Minimum Sink Rate is independent of bank angle
B. The Minimum Sink Rate increases by a percentage equal to the square root of the bank angle
C. The Minimum Sink Rate increases by 10%
D. The Minimum Sink Rate increases by 16%
E. The Minimum Sink Rate increases by 24%

QUESTION 5: The stall speed of your club's ASK 21 at gross weight is 39 kt with a minimum sink speed of 45 kt. Can the ASK 21 at gross weight thermal in a narrow thermal with a bank angle of 45° and an airspeed of 45 kt (level flight minimum sink speed)?

A. Yes
B. No
C. Maybe
D. I don't have a clue ☛

Explanation

QUESTION 1: ANSWER C The flight polar for ALL gliders shifts up and to the left for decreasing weight (and down and to the right for increasing weight). All the flight polar's coordinates (i.e. x/y coordinates) shift by factor equal to the square root of the ratio of the weights. Therefore, for the PW-6 flown solo at 911 lb minimum weight versus a gross weight of 1,220 lb, the flight polar shifts by a factor equal to $(911/1{,}220)^{0.5}$ which equals 0.864 as shown in *Figure 2*. In other words, the Minimum Sink SPEED decreases by 13.6%, or by 7 kt to 43 kt!!

QUESTION 2: ANSWER C The Minimum Sink RATE also decreases by 13.6%, or by 20 ft/min to 130 ft/min.

QUESTION 3: ANSWER D and QUESTION 4: ANSWER E The flight polar for ALL gliders shifts down and to the right for coordinated turning flight at various angles of bank. Shown in *Figure 3* are the flight polars for a Standard Libelle at 695 lb and various angles of bank. The Minimum Sink SPEED at bank angle X° increases by a factor equal to:

*Min Sink SPEED (at Angle of bank X) = Min Sink SPEED (0 -level flight) * (1/ Cosine (X))*$^{0.5}$

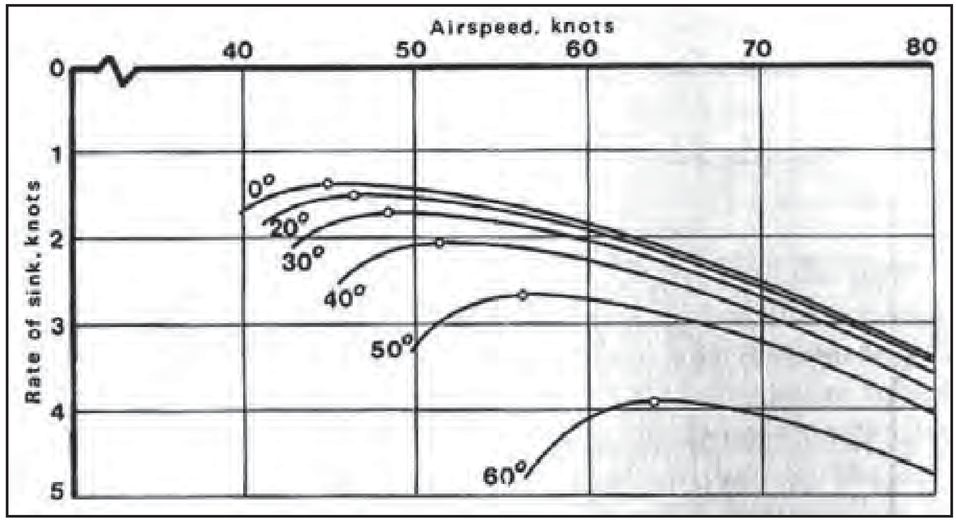
and, the Minimum Sink RATE at bank angle X° increases by a factor equal to:

*Min Sink RATE (at Angle of bank X) = Min Sink RATE (0 -level flight) * (1/ Cosine (X))*$^{1.5}$

Shown in Table 1 is the result of these equations for several common angles of bank.

For a coordinated 30° banked turn in ANY glider the minimum sink SPEED increases by 7.5% and the minimum sink RATE increase by 24% over the level flight Minimum Sink SPEED and the Minimum Sink RATE.

QUESTION 5: ANSWER B Can the ASK 21 at gross weight thermal in a narrow thermal with a bank angle of 45° and an airspeed of 45 kt (level flight minimum sink speed)? The answer is NO because the ASK 21 will stall. For ALL airplanes and gliders in a 45° coordinated banked turn the stall speed increases by a factor equal to the square root of 1 divided by the cosine of the angle of bank, or $(1/\cos(45))^{0.5}$ which equals 1.189 or, increases by 18.9%. Therefore, for the ASK 21 at



Libelle sink rates at various angles of bank. Reference: **The Complete Soaring Pilot's Handbook** *by Ann and Lorne Welch and Frank Irving, Page 238, 1977, ISBN: 0-679-50718-3.*

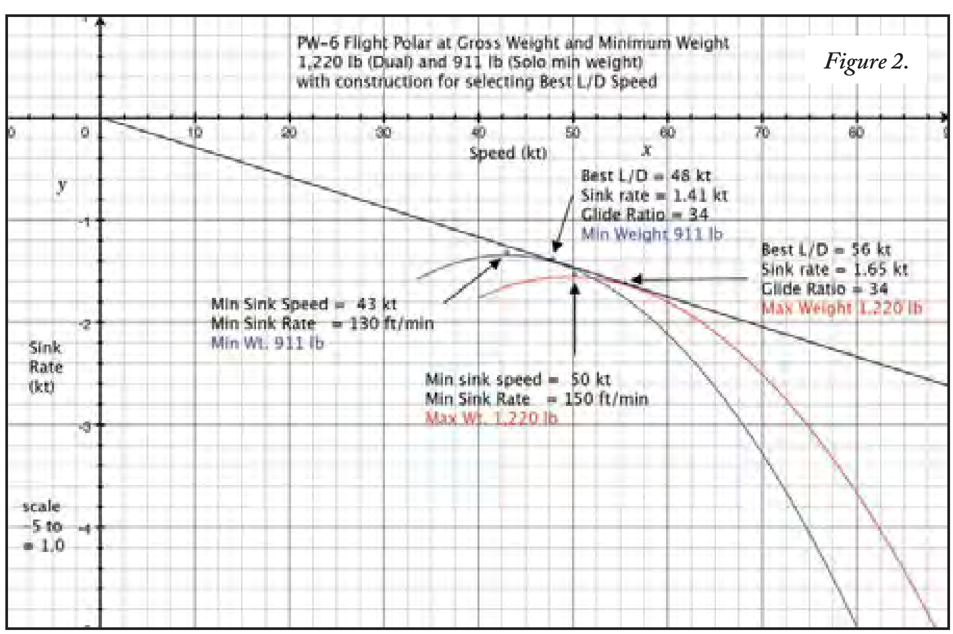


Figure 2.

gross weight in a 45˚ banked turn the stall speed increases from the level flight stall speed of 39 kt to 46.4 kt (39 * 1.189). If the ASK 21 attempts to slow to 45 kt in a coordinated 45˚ banked turn the glider will exceed the critical angle of attack and stall.

Angle of Bank (˚)	0	10	20	**30**	40	**45**	50	**60**
% Increase in Minimum Sink Speed	0	0.7%	3.2%	**7.5%**	14%	**18.9%**	25%	**41%**
% Increase in Minimum Sink Rate	0	2.4%	9.8%	**24%**	49%	68%	94%	**183%**

Table 1: Change in Glider Minimum Sink Speed and Minimum Sink Rate as a function of Angle of Bank.

LESSONS LEARNED: The Minimum Sink Speed is an important speed to understand and utilize both for maximizing time aloft and for optimizing thermal flight. The Minimum Sink Speed is both a function of weight as well as a function of the angle of bank in coordinated turning flight (i.e. thermaling). For decreasing weight, the Min Sink SPEED and Min Sink RATE both decrease by a factor equal to the square root of the ratio of the lower weight divided by the published known (gross) weight.

However, in coordinated turning flight the Min Sink SPEED and Min Sink RATE both increase from the level flight Min Sink SPEED/RATE for the current operating weight as shown in Table 1. Two useful points to memorize are for 30˚ and 45˚ coordinated banked turns — where for 30˚ banked turns the Min Sink SPEED increases 7.5% and the Min Sink RATE increases by 24% over the level flight numbers — and for 45 ˚ banked turns the Min Sink SPEED increases by 18.9% and the Min Sink RATE increases by 68% over the level flight numbers! Except for acquiring energy while thermaling, or for mandatory navigational turns, if you want to conserve energy, avoid turning! Glider Aerodynamics is fascinating. Have Fun. Fly safe.

About the author: *Steve Platt is a commercial pilot in single engine airplanes, single engine seaplanes, and gliders. He holds an instrument rating and is a Certificated Flight Instructor for airplanes, instruments, and gliders. He has logged over 4,000 flight hours including over 2,000 hours as a flight instructor. He is a retired IBM Engineering Manager and a Flight Instructor at Sugarbush Soaring, Warren, Vermont.*

GLIDER AERODYNAMICS PUZZLER

BY STEVE PLATT

Speed to Fly Turning

The Glider Aerodynamics Puzzler is intended to stimulate your thinking about soaring and refresh your understanding of glider aerodynamics and soaring optimization. The correct answers with detailed explanations follow the questions. Have fun.

Most glider pilots have good understanding of the best speed to fly (STF) to optimize time aloft, distance or speed. Selecting the best STF while turning is less well understood. Let's look at three examples.

QUESTION 1: You are flying your club's PW-6 glider solo at minimum weight (~900 lb). The manufacturer's published flight polar at gross weight is shown in *Figure 1*. On takeoff, upon reaching approximately 250 ft AGL the rope breaks. You quickly decide you have enough altitude to complete an approximately 210˚ turn to land on the departure end of the runway. In this scenario what is the best angle of bank and airspeed to complete the approximately 210˚ turn and lose the least amount of altitude?

A. 30˚ bank and level flight minimum sink speed.

B. 45˚ bank and level flight minimum sink speed.

C. 45˚ bank and level flight minimum sink speed for your operating weight.

D. 60˚ bank and level flight minimum sink speed for your operating weight plus 18.9%

E. 45˚ bank and level flight minimum sink speed for your operating weight plus 18.9%

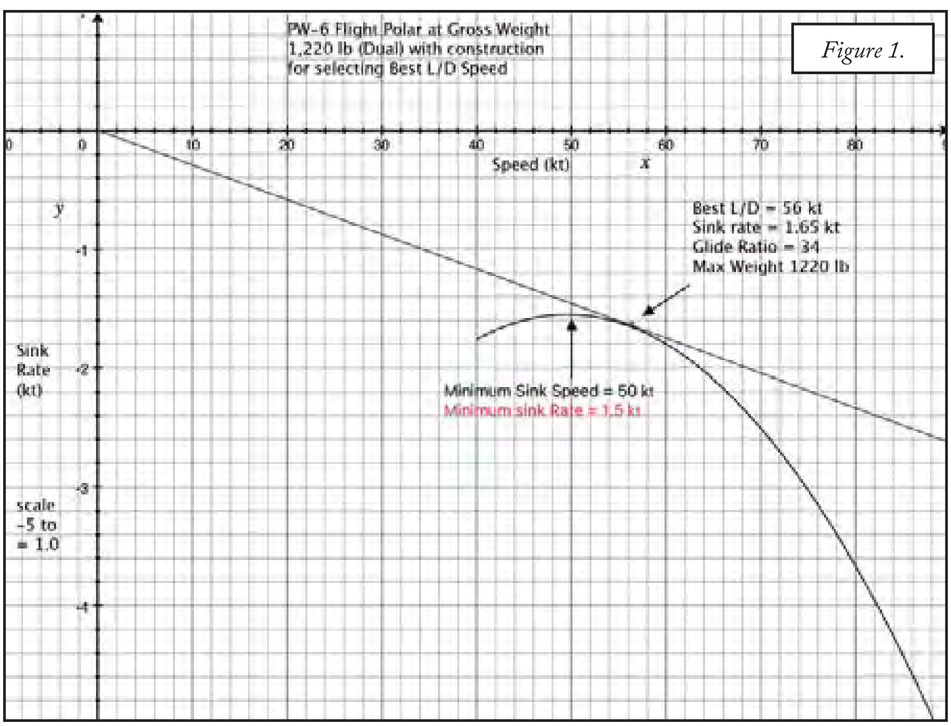


Figure 1.

QUESTION 2: You are flying your club's PW-6 solo at minimum weight on a local recreational flight. For the last thermal you averaged a net 2.1 kt during the climb. The thermal appeared to have the characteristics of a typical summer thermal with 4.2 kt of airmass lift at the core decreasing parabolically to 0 at a radius of 1,000 ft. As you return to that very same thermal what bank angle and airspeed will optimize the net climb rate?

A. 25˚ of bank at minimum sink speed.

B. 30˚ of bank at level flight minimum sink speed plus 7.5%

C. 30˚ of bank at level flight minimum sink speed for your operating weight plus 7.5%.

D. 40˚ of bank at level flight minimum sink speed for your operating weight plus 14%.

E. 45˚ of bank at level flight minimum sink speed for your operating weight plus 18.9%.

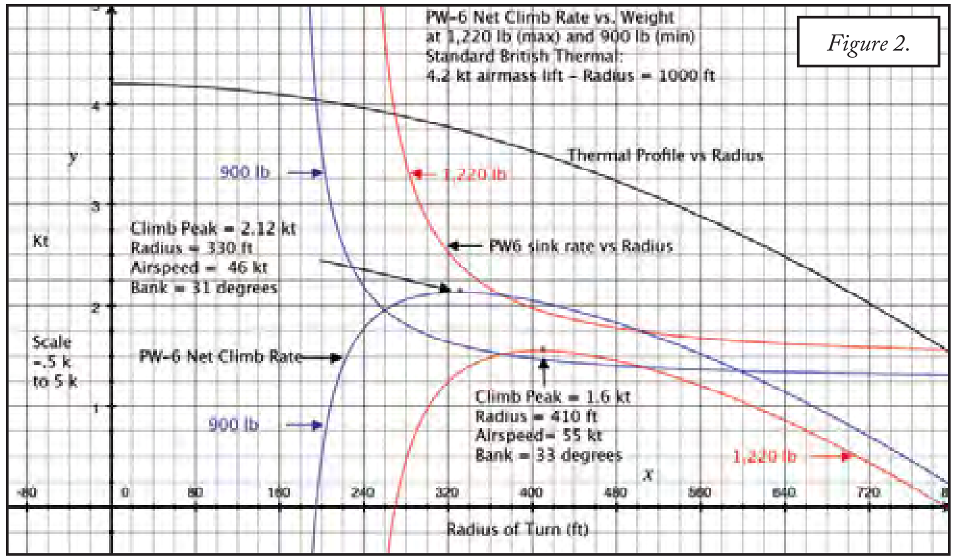
QUESTION 3: You are flying your club's PW-6 solo at minimum weight in a local "out and back" race. The thermals have been excellent yielding a net 3 kt of climb during the race. Accordingly, you fly at the appropriate McCready speed of 70 kt. As you approach the only turn point, where a 180˚ turn is required, you consider two techniques for completing the turn to optimize time, i.e., maximize average speed. First you consider maintaining 70 kt and roll into a 45˚ bank turn to keep your speed around the turn point. Your second thought is to pull up abruptly to 55 kt while rolling into a 45˚ bank turn upon completing the turn then lowering the nose to return to 70 kt. Which of the two options will consume the least amount of time and provide the highest average speed?

A. Maintain 70 kt around the turn.

B. Slow to 55 kt while rolling into the turn then return to 70 kt upon completing the turn.

Explanation

QUESTON 1: ANSWER E. In the rope break return to the airport scenario, the angle of bank and airspeed to use to lose the least amount of altitude (energy) during the turn is 45° of bank at the minimum sink speed for a 45° banked turn at you operating weight … which in this case equals the level flight minimum sink speed at your operating weight plus 18.9 %. At gross weight the minimum sink speed is 50 kt. However, at the 900 lb operating weight the flight polar shifts up and to the left by a factor equal to the square root of the ratio of the minimum weight to the gross weight or $(900/1{,}220)^{.5}$ which equals 0.86. Therefore, the level flight minimum sink speed at 900 lb lowers from 50 kt at gross weight to 43 kt at 900 lbs … and in a 45° bank turn the minimum sink speed becomes 43 kt x 1.189 which equals 51 knots.



QUESTION 2: ANSWER C. For every thermal there is an optimum bank angle and airspeed to maximize net climb rates. For the PW-6 thermaling in a typical summer thermal the optimum angle of bank is ~30° at an airspeed of minimum sink speed for a 30° banked turn … which equals the level flight minimum sink speed plus 7.5%. If the thermal is flown too shallow the radius of turn is wide and the glider operates in a weaker part of the thermal. If the glider is flown too steeply, the radius of turn is closer to the core of the thermal but the sink rate of the glider is too great. And so,

there is a sweet spot for every thermal. For typical summer thermals as shown in *Figure 2*, with airmass lift equal to 4.2 knots at the core decreasing parabolically to zero at a radius of 1,000 ft, the optimum angle of bank for slow aircraft (e.g. SGS 1-26 and 2-33) works out to be ~25° of bank. For medium performance gliders (like the PW-6 and ASK 21) the optimum angle of banks works out to be approximately 30-35° of bank … and for high performance ships the optimum angle of bank works out to be 35-40°. In all cases the optimum STF is the minimum sink speed for the angle of bank flown.

QUESTION 3: First, it is important to remember the radius of turn for all gliders (and airplanes with wings) in coordinated turning flight is proportional to the SQUARE of airspeed. Specifically the radius of turn is equal to:

$R = V^2 / (G * \text{Tan ANG})$

Where V is airspeed, G is the acceleration of gravity (32.17 ft./sec^2), and ANG is the angle of bank.

Therefore, in the case of maintaining 70 kt around the turn, the radius of turn works out to be: R = 433 ft. Since the distance travelled during the turn is Pi * R, the time to complete the 180° turn at 70 kt works out to be 11.5 seconds.

On the other hand, slowing quickly to 55 kt to complete the turn the radius of turns works out to be approximately 267 ft and the time to complete the turn is 9.1 seconds. However, it takes a second or two to slow to 55 kt and a second or two to speed back up to 70 kt … so the answer is not obvious … what do you think?

LESSONS LEARNED: Optimizing glider flight requires optimizing level flight and turning flight. For all gliders independent of make and model, to lose the least amount of altitude (energy) while turning requires a 45° bank turn at an airspeed equal to the level flight minimum sink speed for the current operating weight plus 18.9%. The optimum STF while thermaling is equal to the minimum sink speed for the angle of bank flown. The optimum angle of bank while thermaling depends on upon the specific flight polar for the current operating weight as well as the profile of the thermal. However, for medium performance gliders like the PW-6 or ASK 21, for typical summer thermals, the optimum angle of bank is between 30-35° depending upon operating weight. Finally, the radius of turn for all gliders in coordinated turning flight is proportional to the square of airspeed. Glider aerodynamics is fascinating. Fly safe.

About the author: *Steve Platt is a commercial pilot in single engine airplanes, single engine seaplanes, and gliders. He holds an instrument rating and is a Certificated Flight Instructor for airplanes, instruments, and gliders. He has logged over 4,000 flight hours including over 2,000 hours as a flight instructor. He is a retired IBM Engineering Manager and a Flight Instructor at Sugarbush Soaring, Warren, Vermont.*

GLIDER AERODYNAMICS PUZZLER

BY STEVE PLATT

MacCready

The Glider Aerodynamics Puzzler is intended to stimulate your thinking about soaring and refresh your understanding of glider aerodynamics and soaring optimization. The correct answers with detailed explanations follow the questions. Have fun.

Paul MacCready is best known among glider pilots for his technique for maximizing speed while racing. However, he was also a talented aeronautical engineer and accomplished glider pilot. He was the U.S. National Open Class soaring champion in 1948, 1949, and 1953. He was the first American World Soaring champion in 1956. He won the First Kremer Prize for Human Powered Flight … and he won the Second Kremer Prize for Human Powered flight across the English Channel.

He created the solar-powered Gossamer Penguin and Solar Challenger. In addition to defining the "MacCready Theory" on Speed to Fly to maximize speed thermal to thermal, he invented the MacCready "Speed Ring". Clearly a talented individual. Let's take a look at MacCready speeds.

QUESTION 1: You are planning on entering your club's President's Cup local race. You want to be prepared to fly at the appropriate MacCready speed for your club's PW-6 glider . The Flight Polar at gross weight for the PW6 is shown in *Figure 1*. What are the MacCready 2 and MacCready 4 speeds at gross weight?

A. MacCready 2 speed = 56 kt, MacCready 4 speed = 62 kt
B. MacCready 2 speed = 60 kt, MacCready 4 speed = 68 kt
C. MacCready 2 speed = 63 kt, MacCready 4 speed = 70 kt
D. MacCready 2 speed = 68 kt, MacCready 4 speed = 76 kt
E. MacCready 2 speed = 70 kt, MacCready 4 speed = 78 kt

QUESTION 2: What is the MacCready 0 speed at gross weight?

A. MacCready 0 speed is the minimum sink speed = 50 kt
B. MacCready 0 speed is the Best L/D speed = 56 kt
C. MacCready 0 speed = 60 kt
D. MacCready 0 speed = 64 kt
E. There is no MacCready 0 speed

QUESTION 3: The winds aloft are expected to provide a 20-kt headwind on the final leg of the race. What effect does a 20-kt headwind have on the MacCready speeds?

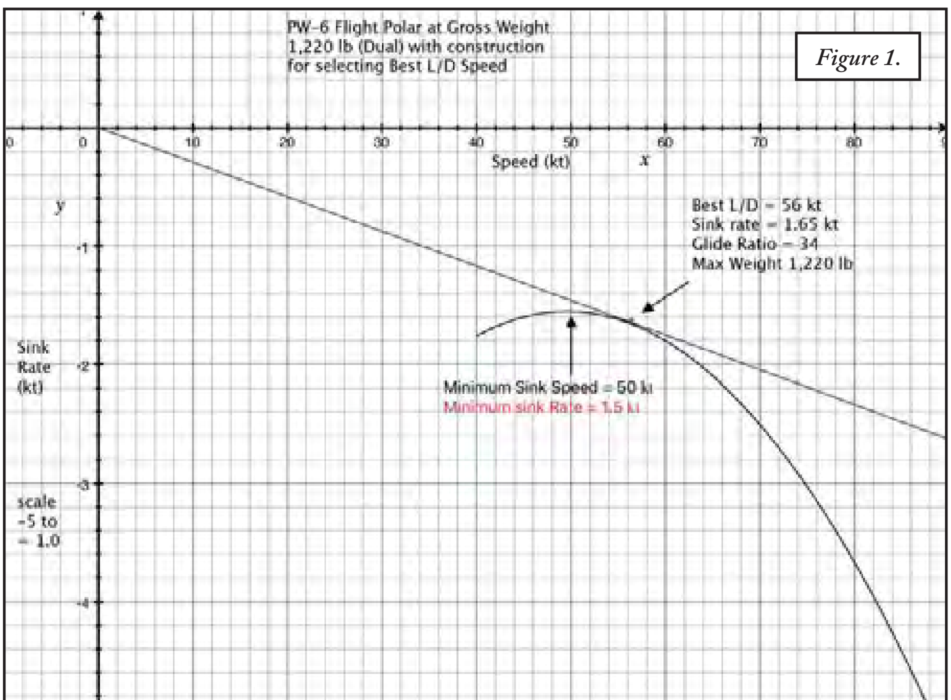


Figure 1.

A. None. The MacCready speeds are independent of the winds aloft.
B. Add approximately 15% of the headwind component speed to the MacCready speed
C. Add approximately 25% of the headwind component speed to the MacCready speed
D. Add approximately 33% of the headwind component speed to the MacCready speed
E. Subtract approximately 25% of the headwind component speed from the MacCready speed

QUESTION 4: You are planning on operating the PW-6 shown in *Figure 1* solo at minimum weight.

What happens to MacCready speeds at minimum weight … approximately 300 pounds under gross weight?

A. The MacCready speeds are independent of weight
B. The MacCready speeds increase with decreasing weight
C. The MacCready speed decrease with decreasing weight

Explanation

QUESTION 1: ANSWER C. Shown in *Figure 2* is the construction for determining the MacCready 2 and MacCready 4 speeds for the PW-6 at gross weight. Notice the MacCready 2 speed equals 63 kt and the MacCready 4 speed equals 70 kt. The MacCready X speed is determined by a line drawn from x kt up on the Y axis tangent to the Flight polar for the operating weight. Note, the MacCready X speed IS IDENTICAL to the best Speed to Fly in X kt of airmass sink to maximize distance!

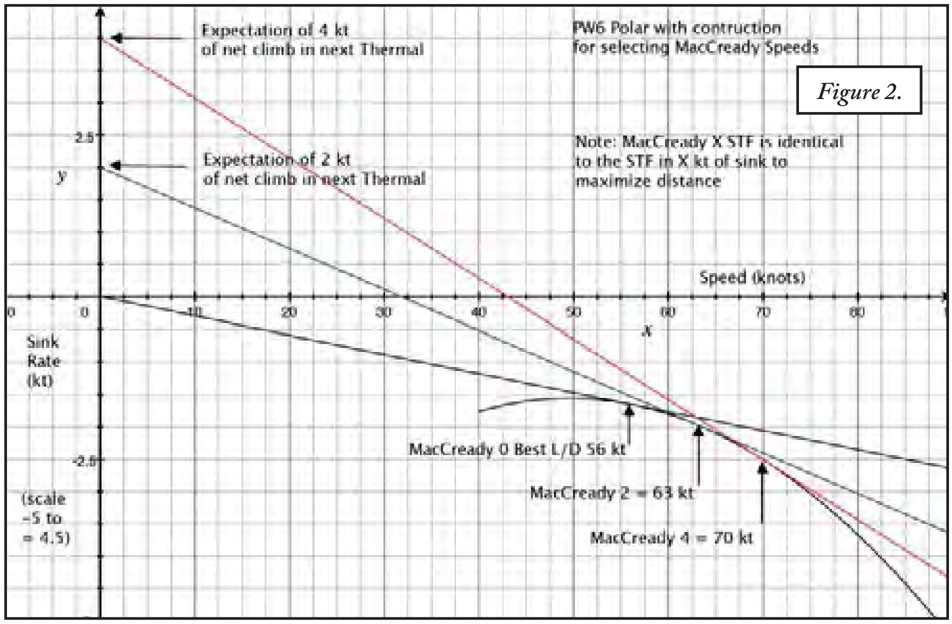


Figure 2.

QUESTION 2: ANSWER B. The MacCready 0 speed is equal to the Best L/D speed.

QUESTION 3: ANSWER A. All MacCready speeds are independent of the winds aloft. The MacCready speed optimizes speed thermal to thermal independent of whether the the entire airmass is moving or not.

QUESTION 4: ANSWER C. All MacCready speeds are a function of weight. Shown in *Figure 3* is the construction of the MacCready 4 speed for the PW-6 at gross weight and minimum weight. Notice, the MacCready 4 speed decreases from 70 kt at gross weight to 63 kt at minimum weight. If a glider pilot accidentally uses the Gross weight MacCready

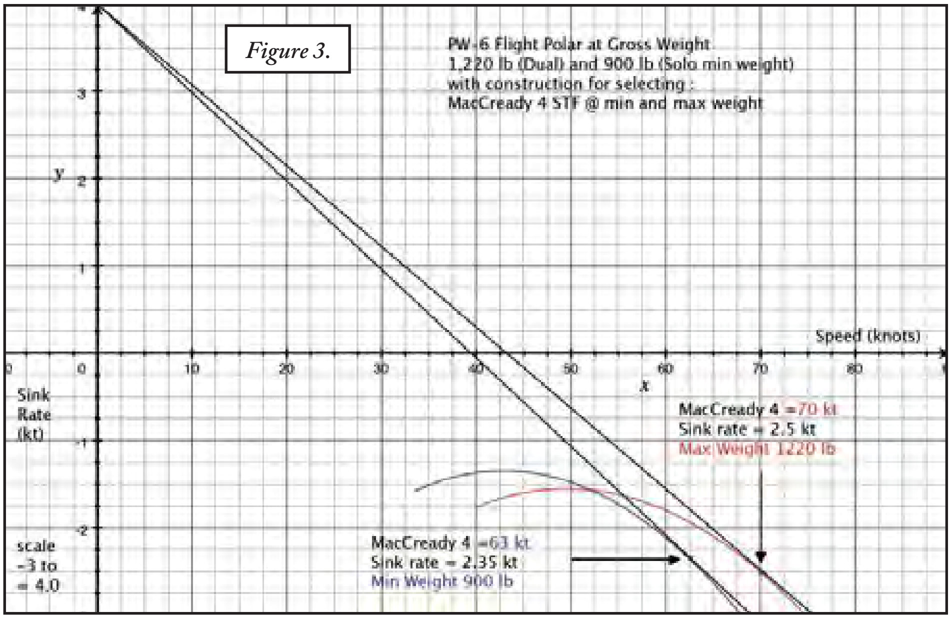


Figure 3.

4 speed while flying at minimum weight, they will in effect be flying at approximately MacCready 6 speed! Weight matters.

LESSONS LEARNED: MacCready speeds optimize the speed from thermal to thermal including the climb back to the start altitude. All MacCready speeds are a function of weight. All MacCready speeds are independent of the winds aloft. The winds aloft DO effect the altitude required to commence the final glide, as the ground speed must be used in that calculation. Paul MacCready's technique for maximizing speed has served the test of time for over six decades. Have fun … Fly safe.

About the author: *Steve Platt is a commercial pilot in single engine airplanes, single engine seaplanes, and gliders. He holds an instrument rating and is a Certificated Flight Instructor for airplanes, instruments, and gliders. He has logged over 4,000 flight hours including over 2,000 hours as a flight instructor. He is a retired IBM Engineering Manager and a Flight Instructor at Sugarbush Soaring, Warren, Vermont.*

GLIDER AERODYNAMICS PUZZLER

BY STEVE PLATT

Polar Modelling

The Glider Aerodynamics Puzzler is intended to stimulate your thinking about soaring and refresh your understanding of glider aerodynamics and soaring optimization. This month I divert from the usual format of aerodynamic questions followed by answers with detailed explanations.

Reichmann's Formula

I have been asked by several readers to explain how to model glider flight polars, i.e., digitize/computerize manufacturer's published flight polars so that they may be easily and properly adjusted for different operating weights and wing loadings. The simple answer is to use the Helmut Reichmann technique first published in the 1970's and included in his classic book *Cross-Country Soaring*. I have a copy of the 7th edition published by the Soaring Society of America in 1993. The book is simply outstanding and would be a welcome addition to any glider pilot's library.

What Reichmann describes, and proves, is how a quadratic equation of the form shown below can very accurately model any manufacturer's published flight polar:

$$S = a * V^2 + b * V + c$$

where S = glider sink rate; V = glider Airspeed and a, b, and c are constants. The constants are calculated by selecting three data points (three pairs of x/y coordinates) from the manufacturers published flight polar and inserting them in the equations below: *(see yellow box at bottom of page).*

Shown in Figure 1 is the actual example for an ASW 15 provided by Reichmann in his book using the three data points: best L/D speed, never exceed speed, and a speed halfway in between. Notice that the plotted quadratic equation in the area of interest is virtually identical to the manufacturer's flight polar for the ASW 15. Except for high-speed racing gliders, I recommend using: Minimum Sink speed, Best L/D Speed, and Best L/D Speed plus 20 knots for the three data points defining the quadratic equation. This ensures excellent accuracy from slow speed through high-speed cruise.

While calculating the coefficients a, b, and c manually is tedious, entering the equations into a small program or spreadsheet allows the coefficients to be generated quickly by computer.

Flight Polars for Non-published Weights

The 64-thousand-dollar question is: *How to generate flight polars for different weights (i.e., wing loading) other than provided by the manufacturer's published curve, usually at gross weight?* The answer is again provided by Helmut Reichmann in *Cross-Country Soaring* (p. 122) where he explains how for any glider for different wing loadings (weights) all the flight polar coordinates shift by a factor equal to the square root of the ratio of the weights.

That is, for decreasing weight the Flight Polar moves up and to the left … and for increasing weight the Flight Polar moves down and to the right. All the Manufacturer's published coordinates shift by the same factor … the square root of the ratio of the weights.

Therefore, once the quadratic equation model is generated for the published weight and plotted, it becomes a simple exercise to multiply all the coordinates by the shift factor for any

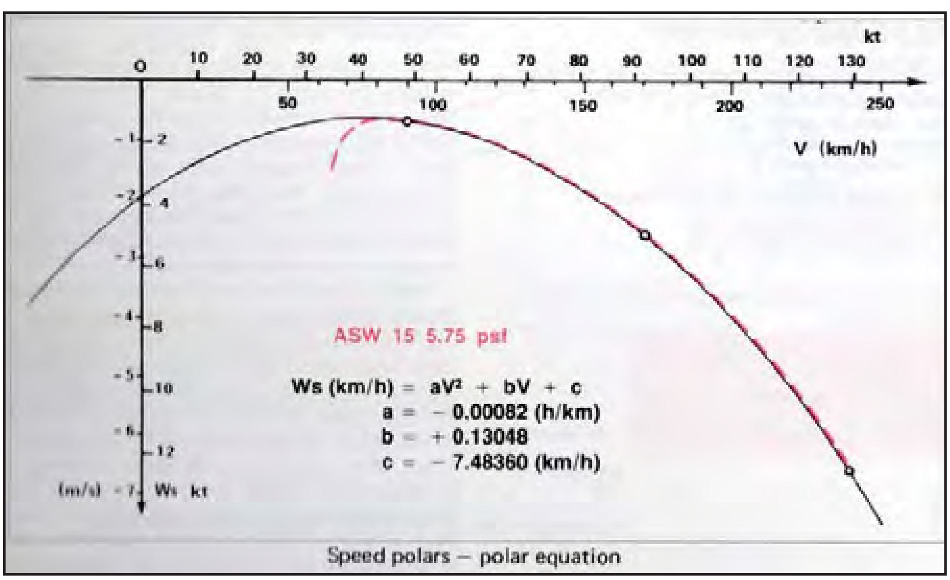


Figure 1.

$$a = [(V2–V3) * (S1–S3) + (V3–V1) * (S2–S3)] / [V1^2 * (V2–V3) + V2^2 * (V3–V1) + V3^2 * (V1–V2)]$$

$$b = [S2 – S3 – a * (V2^2 – V3^2)] / (V2 – V3)$$

$$c = S3 – a * V3^2 – b * V3$$

other weight (wing loading) to generate a new polar at the new weight. Shown in *Figure 2* is the flight polar for the PW-6 plotted using its quadratic equation at gross weight (red), then shifted for the minimum weight operating condition (blue). Since the "shift factor" is the square root of the minimum weight (900 lbs) divided by the gross weight (1,220 lbs) the shift factor is $(900/1{,}220)^{0.5}$ … which equals 0.86. In other words, all the coordinates of the gross weight Polar are decreased by 14% for the minimum weight Flight Polar.

While the difference in performance numbers for a single seat glider flown 10 lbs lighter, or heavier, makes little difference, the difference in performance numbers for a dual seat glider flown solo at minimum weight, or a single seat glider flown with maximum ballast can be very significant. In the case of the PW-6 glider shown in *Figure 2*, the difference between the Best L/D speed at gross weight (56 kt) and minimum weight (48 kt.) is 8 kt! And for the SZD-55, shown in *Figure 3*, the difference in Best L/D speed flown at 740 pounds and at 1,100 pounds with maximum ballast is an amazing 13 kt!

Lessons Learned

Helmut Reichmann's work some five decades ago made major contributions to the art and science of soaring. Any glider's published flight polar may be easily modeled with a simple quadratic equation then utilized to generate a flight polar for any other wing loading using a very simple shift factor … i.e., the square root of the ratio of the weights. To accurately optimize glider flight, the flight polar for the CURRENT operating weight must be used. Small weight changes make little difference. However, for dual seat ships flown solo using the gross weight polar, or for single seat ships using the non-ballast polar with heavy ballast, is guaranteed to lead to large errors in the optimum Speed to

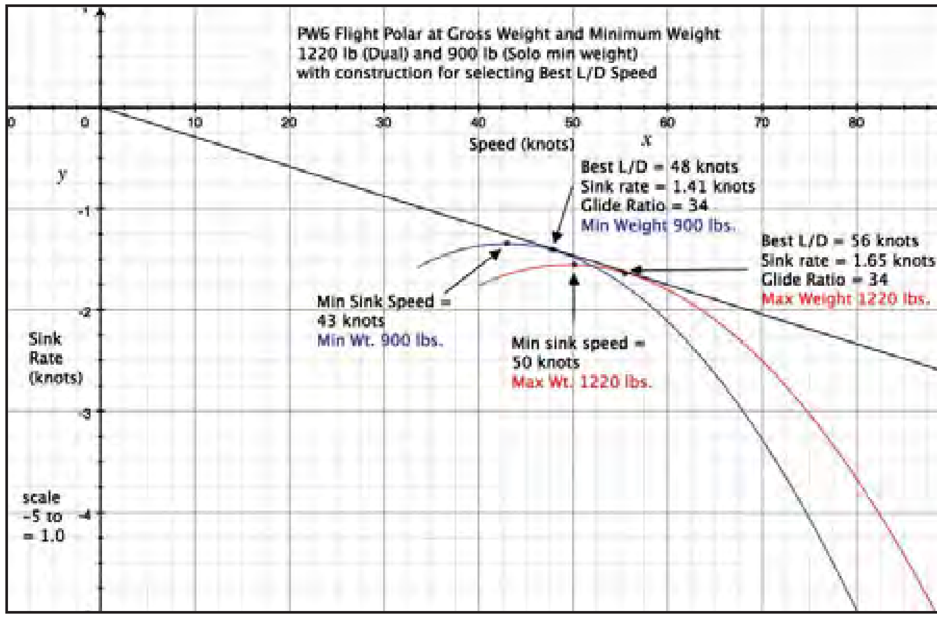


Figure 2.

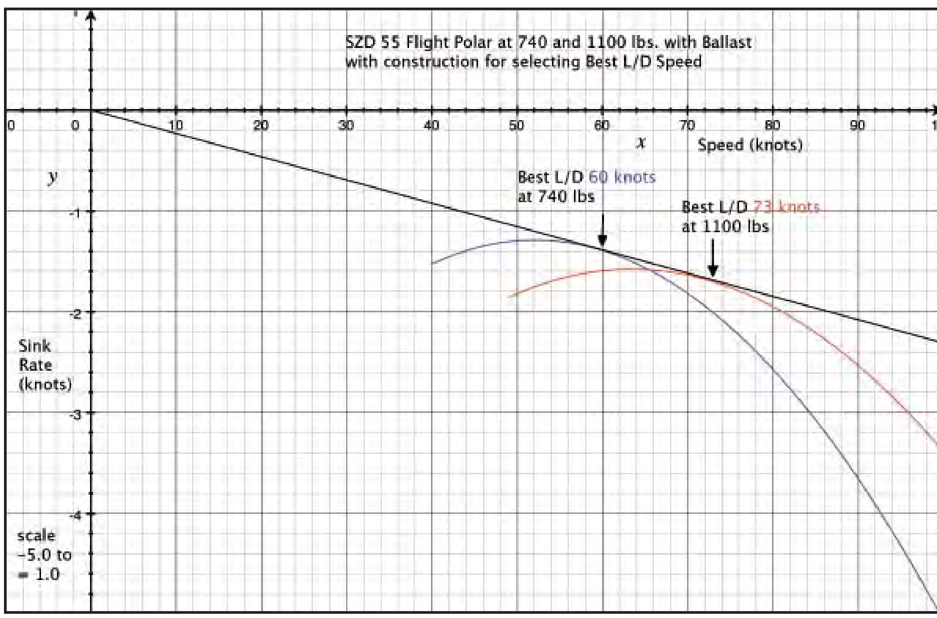


Figure 3.

Fly. Glider Aerodynamics is fascinating. Fly safe.

About the author: *Steve Platt is a commercial pilot in single engine airplanes, single engine seaplanes, and gliders. He holds an instrument rating and is a Certificated Flight Instructor for airplanes, instruments, and gliders. He has logged over 4,000 flight hours including over 2,000 hours as a flight instructor. He is a retired IBM Engineering Manager and a Flight Instructor at Sugarbush Soaring, Warren, Vermont.*

GLIDER AERODYNAMICS PUZZLER

BY STEVE PLATT

Conserving Energy

The Glider Aerodynamics Puzzler is intended to stimulate your thinking about soaring and refresh your understanding of glider aerodynamics and soaring optimization. The correct answers with detailed explanations follow the questions. Have fun. In the May issue of *Soaring* the Glider Aerodynamics Puzzler focused on MacCready Flight and MacCready Speeds. This issue focuses on the Speed to Fly (STF) to conserve energy (i.e. maximize distance) in headwinds, tailwinds, lift and sink … and combinations thereof.

QUESTION 1: On a glorious Saturday afternoon you are flying your Club's PW-6 at just under gross weight. While flying into a 20 kt headwind approaching a ridge line you encounter 2 kt of sustained airmass sink. The flight polar for the PW-6 is shown in *Figure 1*. What is the the best STF to maximize distance with a 20 kt headwind and 2 kt of sink?

A. 56 kt
B. 60 kt
C. 64 kt
D. 69 kt
E. 74 kt

QUESTION 2: Later in the day on a second flight you are flying the PW-6 solo at minimum weight (approximately 900 lb). This time you have a 20 kt tailwind. What is the best STF to maximize distance with a 20 kt tailwind at minimum weight?

A. 43 kt (minimum sink speed)
B. 47 kt
C. 49 kt
D. 54 kt
E. 56 kt

QUESTION 3: You are flying a Schweizer 2-33 with your instructor at just under gross weight. The 2-33 has a Best L/D glide ratio of 23 to 1 in still air. If the 2-33 is flown optimally at the best STF to maximize distance into a 25 kt headwind what will the resulting effective glide ratio become?

A. 23 to 1
B. 21 to 1
C. 19 to 1
D. 15 to 1
E. 11 to 1

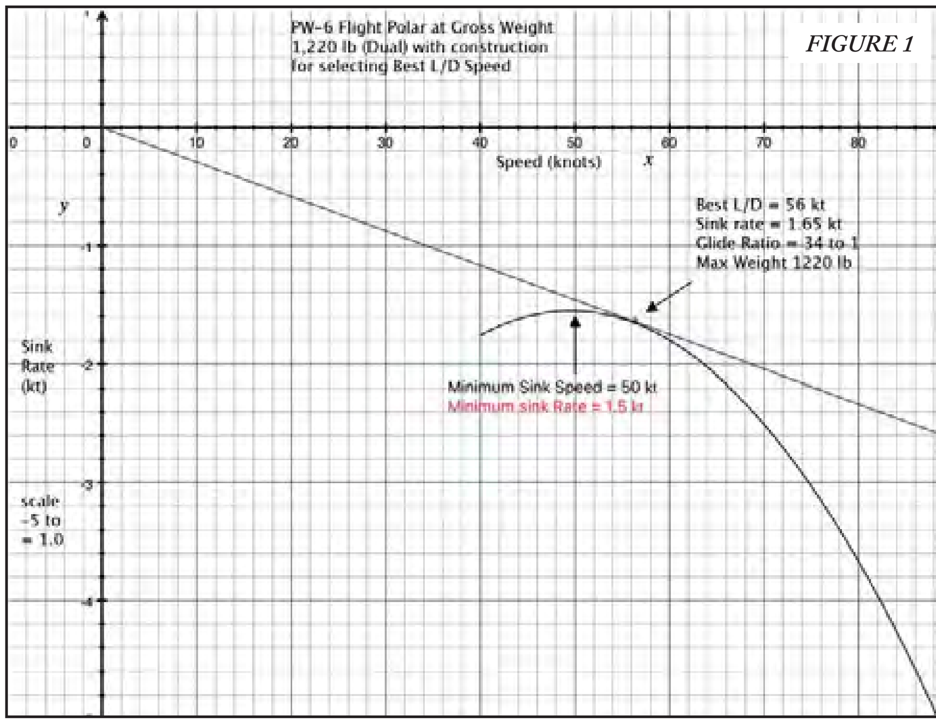


FIGURE 1

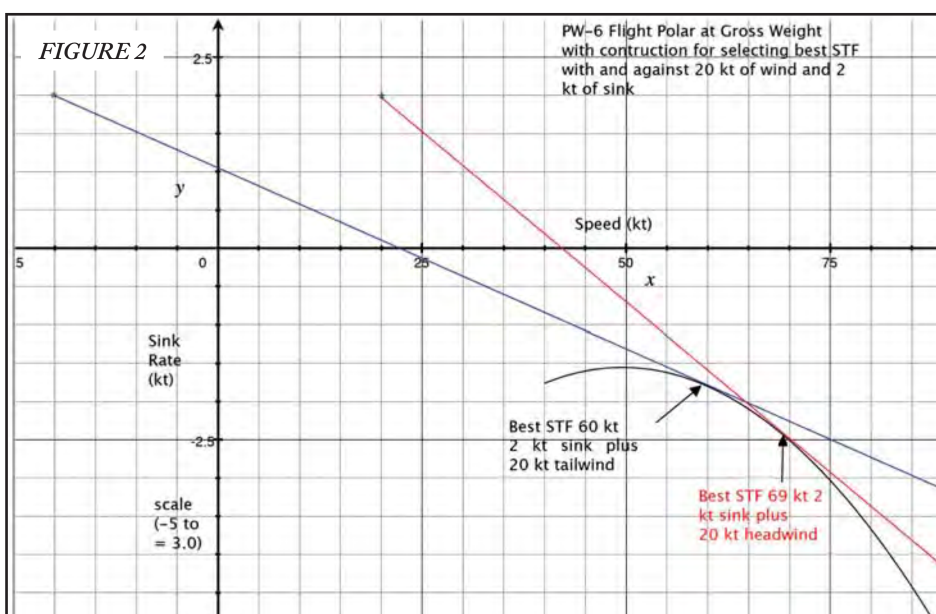


FIGURE 2

QUESTION 4: Your instructor in QUESTION 3 asks you to make a 180° turn. Now you are flying the 2-33 with a 25 kt tailwind. If the 2-33 is again flown optimally at the best STF to maximize distance what will the resulting effective glide ratio become?

A. 23 to 1
B. 28 to 1
C. 32 to 1
D. 35 to 1
E. 39 to 1

Explanation

QUESTION 1: ANSWER D. Shown in *Figure 2* is the construction for selecting the best STF in a 20 kt headwind and 2 kt of sink. Notice the best STF is 69 kt. *In general, the best STF at any wind speed and airmass lift/sink combination is determined by drawing a tangent to the flight polar (for your current operating weight) from a x/y coordinate point equal to wind speed on the x axis and the sink (lift) on the y-axis.*

QUESTION 2: ANSWER B. Shown is *Figure 3* is the construction for selecting the best STF in a 20 kt tailwind. Since the PW-6 is operating at minimum weight in question 2, the flight polar for the minimum weight operating condition must be used (blue polar). The best STF is 47 kt.

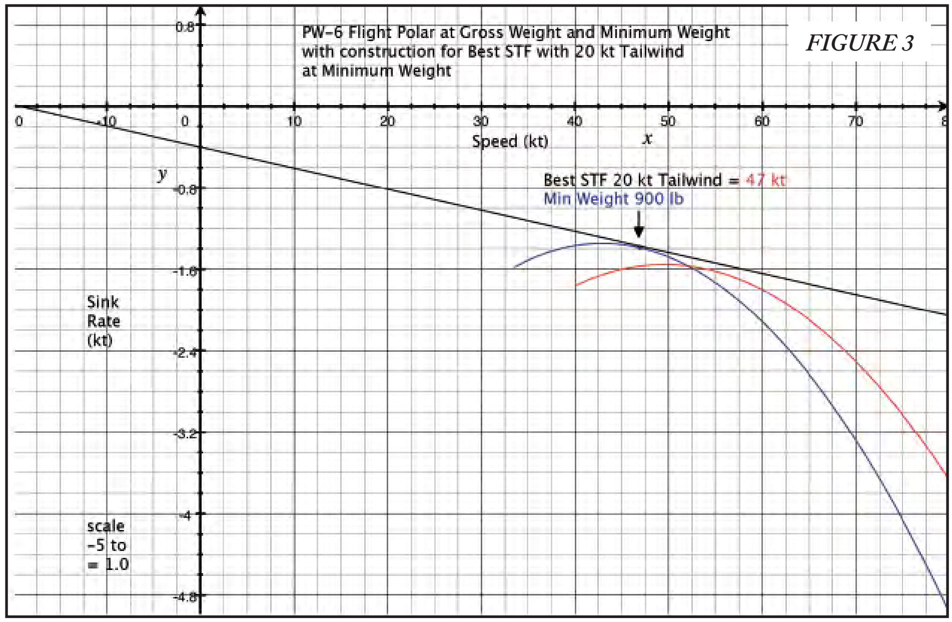
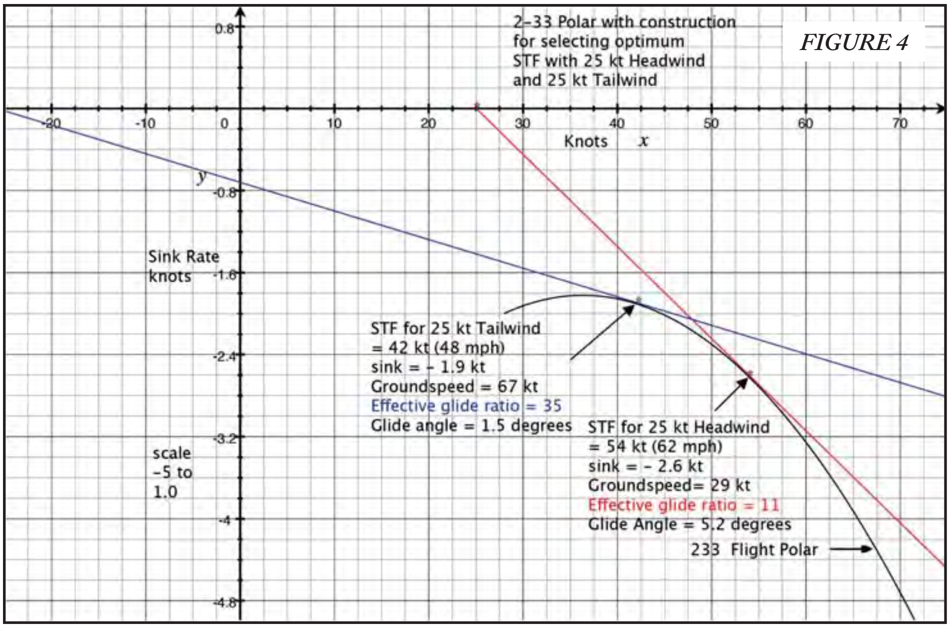


FIGURE 3

QUESTION 3: ANSWER E. QUESTION 4: ANSWER D. Shown in *Figure 4* is the construction for selecting the best STF for the SGS 2-33 in a 25 kt headwind and 25 kt tailwind. Notice the Best STF in a 25 kt headwind is 54 kt (62 MPH) yielding an effective glide ratio of 11 to 1 … and the best STF in a 25 kt tailwind is 42 kt (48 MPH) yielding an effective glide ratio of 35 to 1! ☛

Lessons Learned

Whether flying a Schweizer 1-26 or a high-performance Discus, the winds aloft have a dramatic effect on glider performance. Indeed, with only a 20 kt tailwind a Schweizer 1-26 has a better effective glide ratio (33.7 to 1) than a Discus with a 20 kt headwind (30.8 to 1)! If the winds aloft are blowing 25 kt (i.e. *Figure 4*), the effective Glide ratio of a Schweizer 2-33 varies from 11 to 1 to 35 to 1 depending upon the direction of flight! Incredible! Winds matter. Glider aerodynamics is fascinating. Fly safe.



About the author: *Steve Platt is a commercial pilot in single engine airplanes, single engine seaplanes, and gliders. He holds an instrument rating and is a Certificated Flight Instructor for airplanes, instruments, and gliders. He has logged over 4,000 flight hours including over 2,000 hours as a flight instructor. He is a retired IBM Engineering Manager and a Flight Instructor at Sugarbush Soaring, Warren, Vermont.*

GLIDER AERODYNAMICS PUZZLER

BY STEVE PLATT

Stalls

The Glider Aerodynamics Puzzler is intended to stimulate your thinking about soaring and refresh your understanding of glider aerodynamics and soaring optimization. The correct answers with detailed explanations follow the questions. Have fun.

All glider pilots receive initial and recurrent training in stall awareness and recovery. While the 1 G wings level stall speed is usually well understood, a wing may stall in any attitude and at virtually any airspeed. The wings level stall speed is just the beginning.

QUESTION 1. You are flying your Super Wingbat 6000 glider with a friend on a glorious Saturday afternoon. Your friend asks you to demonstrate an accelerated stall. After clearing turns, and at a safe altitude and in a safe area, you roll into a coordinated 60˚ banked turn and pull 2 G's. The wings level (1 G) stall speed of the Super Wingbat 6000 at your operating weight (gross weight) is 40 kt. In a 60˚ bank turn pulling 2 G's at what airspeed with the Super Wingbat stall?

A. 46 kt
B. 48 kt
C. 52 kt
D. 56 kt
E. 60 kt

QUESTION 2. Suppose the Super Wingbat 6000 is operated solo at minimum weight of 900 lb versus the gross weight of 1,220 lb and the same accelerated stall maneuver is repeated, i.e. a 60˚ banked turn pulling 2 G's, at what airspeed will the Super Wingbat stall?

A. 46 kt
B. 48 kt
C. 52 kt
D. 56 kt
E. 60 kt

QUESTION 3: You are flying the Super Wingbat 6000 at gross weight at 56 kt. You commence a maneuver that increases the wing loading of the glider. How much would the wing loading have to increase at an airspeed of 56 kt for the wing to reach the critical angle of attack and stall? In other words, what would the G load have to be to stall the wing at 56 kt?

A. 1.6 G's at stall
B. 1.8 G's at stall
C. 2.0 G's at stall
D. 2.2 G's at stall
E. 2.4 G's at stall

QUESTION 4: You are flying an aerobatic glider during an airshow. Your glider has a wings level 1 G stall speed of 40 kt at your operating weight and is certificated to positive 6 G's. Flying at 75 kt you rapidly roll into a very steep, 78˚, coordinated banked turn at 4 G's. Is this maneuver possible?

A. Yes
B. No
C. Maybe

Explanation

QUESTION 1: ANSWER D. As the wing loading increases, (i.e., the G load increases), the angle of attack increases and the stall speed increases. The accelerated stall speed is equal to the 1 G stall speed times the square root of the G load. Therefore, in Question 1 with a 2 G load factor, the accelerated stall speed becomes 40 kt times the square root of 2, or 40 x 1.41 which equals 56 kt.

QUESTION 2: ANSWER B. In Question 2, the Super Wingbat 6000 is operated at minimum weight, 320 lb under gross weight. The flight polar for all Gliders moves up and to the left for decreasing weight. All of the coordinates of the gross weight flight polar reduce by a factor equal to the square root of the ratio of the minimum weight to the gross weight…and in this case reduces by a factor of the square root of 900 divided by 1,220…which equals 0.86. The 1 G level flight stall speed at the minimum weight becomes 40 kt times 0.86 which equals 34 kt. Therefore, in a 2 G turn, the accelerated stall speed at minimum weight becomes 34 kt time the square root of 2, or 34 kt times 1.41 which equals 48 kt.

QUESTION 3: ANSWER C. For the accelerated stall speed to increase from 40 kt to 56 kt, the square root of the G load would have to be equal to the ratio of 56 divided by 40…which equals 1.4. Therefore, the G load would have to be 1.4 squared…which equals 2 G's.

QUESTION 4: ANSWER B. This maneuver is not possible because with an airspeed of 75 kt the wing will stall before reaching 4 G's. At 4 G's the accelerated stall is two times the 1 G stall speed which equals 80 kt. Therefore, rolling into the 78° steep banked turn, the aerobatic glider would stall upon reaching 3.5 G's.

Lessons Learned

There are three key lessons from this puzzler.

1: The wings level 1 G stall speed is just the beginning. Any wing may be stalled at virtually any attitude and at nearly any airspeed.

2: The 1 G stall speed is a function of weight: the operating weight stall speed equals the gross weight stall speed times the square root of the ratio of the operating weight to gross weight.

3: Lastly, the instantaneous accelerated stall speed is equal to the square root of the wing's instantaneous G load times the 1 G stall speed for the current operating weight.

Glider aerodynamics is fascinating. Fly safe.

About the author: *Steve Platt is a commercial pilot in single engine airplanes, single engine seaplanes, and gliders. He holds an instrument rating and is a Certificated Flight Instructor for airplanes, instruments, and gliders. He has logged over 4,000 flight hours including over 2,000 hours as a flight instructor. He is a retired IBM Engineering Manager and a Flight Instructor at Sugarbush Soaring, Warren, Vermont.*

GLIDER AERODYNAMICS PUZZLER

BY STEVE PLATT

Radius of Turn Thermalling

The Glider Aerodynamics Puzzler is intended to stimulate your thinking about soaring and refresh your understanding of glider aerodynamics and soaring optimization. The correct answers with detailed explanations follow the questions. Have fun.

The radius of turn while thermalling is a crucial factor in optimizing net climb rates. For a given thermal, knowing the angle of bank and airspeed to deploy to yield a radius of turn that optimizes the net climb rate is valuable knowledge for all glider pilots. The relationship between glider bank angle, airspeed, sink rate and radius of turn is key.

Question 1: A typical summer thermal, sometimes referred to as a "Standard British Thermal," is defined as a thermal with airmass lift at the core of 4.2 kt decreasing parabolically to zero at a radius of 1,000 ft. If a low performance (23:1) SGS 1-26 and a medium performance (34:1) PW-6 glider both commence thermalling in a Standard British thermal, and both are flown optimally, i.e. perfectly centered and at the optimum bank angle and airspeed for each ship, which glider will out climb the other?

A. The SGS 1-26 will out climb the PW-6
B. The PW-6 will out climb the SGS 1-26
C. They will climb at the same rate
D. I do not have a clue

Question 2: A medium performance PW-6 glider at gross weight enters a typical summer thermal, i.e., a Standard British Thermal with airmass lift at the core of 4.2 kt decreasing parabolically to zero at a radius of 1,000 ft. If the PW-6 is flown optimally — perfectly centered and at the optimum bank angle and airspeed to maximize the net climb rate — what will be the optimum angle of bank?

A. 20° of bank
B. 25° of bank
C. 33° of bank
D. 40° of bank
E. 45° of bank

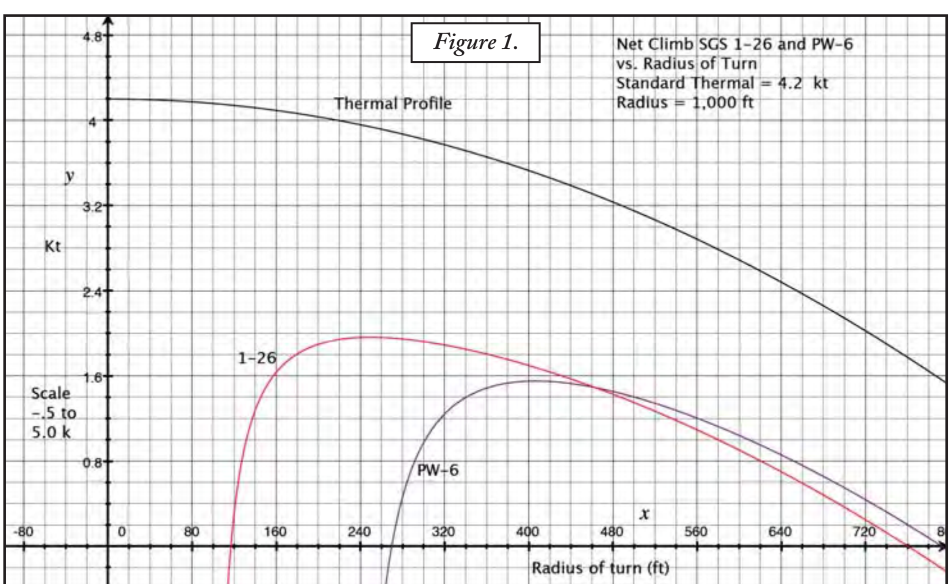


Figure 1.

Question 3: If a Discus 2b enters a Standard British Thermal with air mass lift at the core of 4.2 kt decreasing parabolically to zero at 1,000 ft and is flown optimally — perfectly centered and at the optimum bank angle and airspeed to maximize the net climb rate — what will be its radius of turn?

A. 280 ft
B. 380 ft
C. 480 ft
D. 580 ft
E. 680 ft

Question 4: You are thermalling your Super Wingbat 6000 in a typical summer thermal. You have been perfectly centered and operating at a 30° bank angle at the minimum sink speed for a 30° banked turn. However, you decide your radius of turn is a little too large and you want to reduce the radius of turn to operate closer to the thermal's core. So, you increase your bank angle by 10°, to 40°. To optimize your net climb rate how should you change your airspeed?

A. Increase airspeed
B. Decrease airspeed
C. No change in airspeed required
D. Fly at level flight minimum sink speed

Explanations

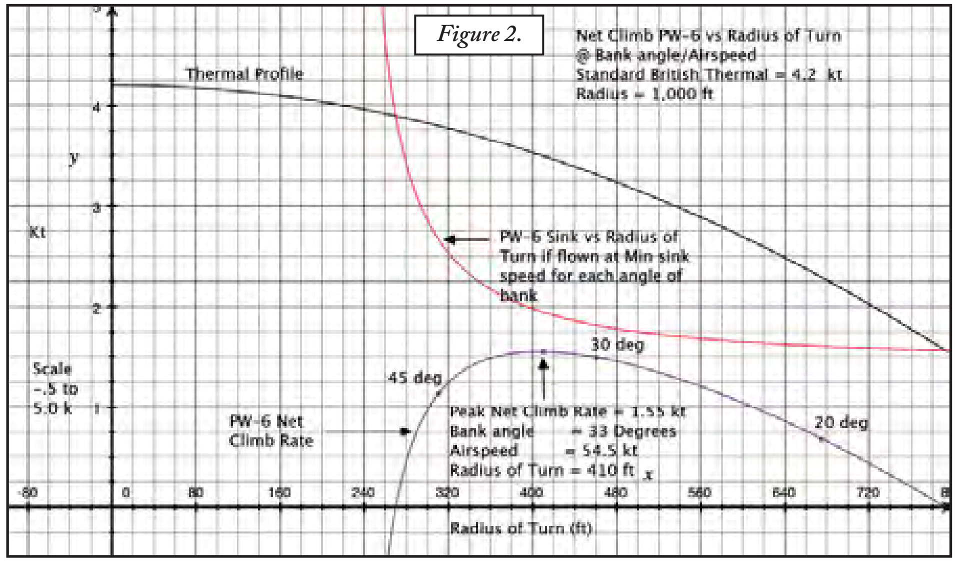
QUESTION 1: ANSWER A. Shown in *Figure 1* is the net climb rate comparison versus radius of turn of both the SGS 1-26 and the PW-6 if flown optimally in a Standard British Thermal, i.e., at the minimum sink speed for the angle of bank flown. Notice the optimal radius of turn for the SGS 1-26 is 240 ft yielding a net climb rate of just under 2 kt. The optimum radius of turn for the PW-6 is 410 ft yielding a net climb rate of around 1.5 kt. The Schweizer 1-26 can easily out climb the PW-6 if flown optimally. Radius of turn matters.

QUESTION 2: ANSWER C. Shown in *Figure 2* is the climb profile of the PW-6 versus radius of turn. Notice that the peak net climb rate occurs at a radius of turn of 410 ft for a bank angle of 33° at the minimum sink speed for a 33° banked turn, which is 54.5 kt.

QUESTION 3: ANSWER B. Shown in *Figure 3* are the net climb rates versus radius of turn of several gliders (SGS 1-26, SGS 2-33, Ventus 2, Discus 2b, and PW-6) if flown optimally in a Standard British Thermal. Notice the maximum net climb rate for the Discus 2b occurs at a radius of turn of 380 ft.

QUESTION 4: ANSWER A. The radius of turn while thermaling (or while turning in general) is equal to the airspeed squared divided by the product of the acceleration of gravity times the tangent of the angle of bank; or

$R = V^2 / (g * Tan(angle\ bank))$.



Angle of Bank	0°	10°	20°	30°	40°	45°	50°	60°
% Increase in Minimum Sink Speed	0	0.7%	3.2%	7.5%	14%	18.9%	25%	41%
% Increase in Minimum Sink Rate	0	2.4%	9.8%	24%	49%	68%	93%	183%

Table 1: Change in glider minimum sink speed and minimum sink rate as a function of bank angle in coordinated turning flight for ALL gliders.

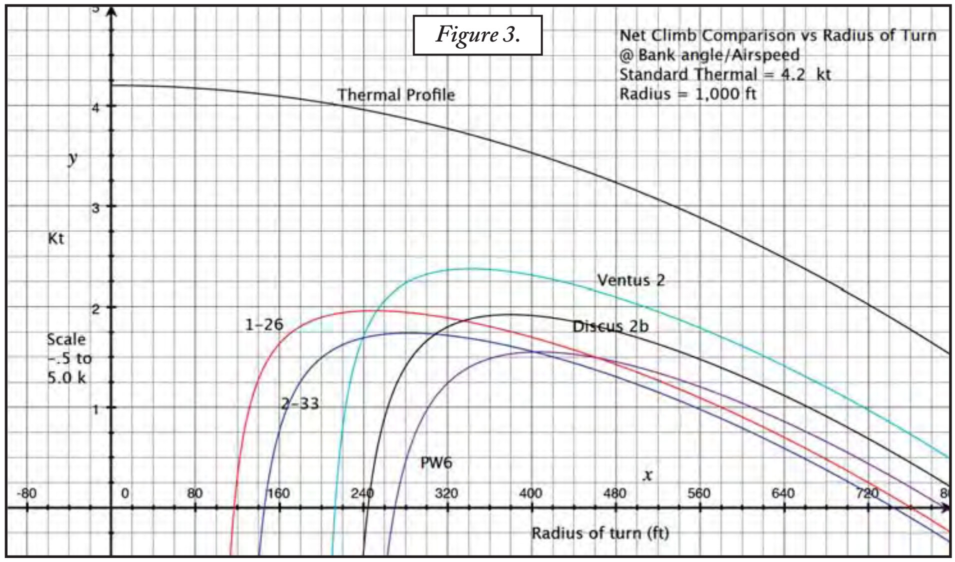
The optimum net climb rate occurs at the minimum sink speed for the angle of bank. The minimum sink speed increases for increasing bank angles given by the equation:

$$\text{Min Sink (angle)} = \text{Min sink (level)} * (1/\text{Cosine (angle)})^{0.5}$$

or as shown in *Table 1*. Therefore, if the angle of bank is increased from 30° to 40°, airspeed must increase from 7.5% above the level flight min sink speed to 14% above the level flight minimum sink speed to achieve maximum net climb rates.

Lessons Learned

The radius of turn while thermalling plays a crucial role in optimizing net climb rates. For every thermal there is an optimum bank angle and airspeed to maximize net climb rates. If the bank angle is too shallow the radius of turn is wide and the glider operates in a weaker portion of the thermal. If the bank angle is too steep the glider operates closer to the core of the thermal, but the sink rate of the glider increases dramatically. For every thermal there is a sweet spot that optimizes net climb rates. In all cases the optimum airspeed is equal to the the minimum sink speed for the angle of bank flown. Glider aerodynamics is fascinating. Have fun and fly safe.



Disclaimer: The results shown in *Figures 1, 2* and *3* are from idealized computer models assuming perfect glider flight, that is, gliders are perfectly centered and flown at the optimum minimum sink speed for the angle of bank in perfect Standard British Thermals. While I have never seen a perfect Standard British Thermal and no-one flies perfectly 100% of the time, the results remain useful in understanding the effects of radius of turn on net climb rates.

About the author: *Steve Platt is a commercial pilot in single engine airplanes, single engine seaplanes, and gliders. He holds an instrument rating and is a Certificated Flight Instructor for airplanes, instruments, and gliders. He has logged over 4,000 flight hours including over 2,000 hours as a flight instructor. He is a retired IBM Engineering Manager and a Flight Instructor at Sugarbush Soaring, Warren, Vermont.*

GLIDER AERODYNAMICS PUZZLER

BY STEVE PLATT

Minimum Sink Speed Turning

The Glider Aerodynamics Puzzler is intended to stimulate your thinking about soaring and refresh your understanding of glider aerodynamics and soaring optimization. The correct answers with detailed explanations follow the questions. Have fun.

Minimum sink speed is a critical speed that glider pilots must exploit often. While most glider pilots have an excellent understanding of how to optimize straight and level flight regarding time aloft, distance flown, or speed, knowing how to optimize turning flight is less well understood. Let's examine a few examples.

Question 1: You are flying your soaring club's dual seat Super Wingbat 6000 at gross weight (1,204 lbs.). You are up with a friend practicing maneuvers. The minimum sink speed for the Super Wingbat 6000 at gross weight is 50 kt. You want to complete a 360° turn and lose the least amount of altitude. What airspeed and bank angle should you use?

A. 50 kt and 30° of bank
B. 48 kt and 45° of bank
C. 52 kt and 45° of bank
D. 54 kt and 30° of bank
E. 59 kt and 45° of bank

Question 2: Later in the day, you are up again in the Super Wingbat 6000. This time you are solo flying at minimum weight (911 lbs). You again perform a 360° turn and want to lose the least amount of altitude. What airspeed and bank angle should you use?

A. 50 kt and 30° of bank
B. 48 kt and 45° of bank
C. 52 kt and 45° of bank
D. 54 kt and 30° of bank
E. 59 kt and 45° of bank

Question 3: You are flying your Super Wingbat 6000 at gross weight on a recreational flight. You normally like to make 30° bank turns while maneuvering and want to conserve energy. In a 30° bank turn what airspeed will consume the least amount of altitude?

A. 50 kt
B. 48 kt
C. 52 kt
D. 54 kt
E. 59 kt

Question 4: You are up flying the Super Wingbat 6000 with a student pilot at gross weight. You want to demonstrate to your student at a safe altitude and in a safe area a "rope break and return to the airport" maneuver. What airspeed and bank angle do you use to demonstrate the maneuver to lose the least amount of altitude completing the approximately 210° turn?

A. 50 kt and 30° degrees of bank
B. 48 kt and 45° degrees of bank
C. 52 kt and 30° degrees of bank
D. 54 kt and 45° degrees of bank
E. 59 kt and 45° degrees of bank

EXPLANATION TO QUESTIONS 1-4: The answer to all four questions requires the application of the proper minimum sink speed and bank angle. For all gliders, minimum sink speed is a function of both weight and bank angle in coordinated turning flight. First, regarding weight, the flight polar for all gliders shifts up and to the left for decreasing weight, and down and to the right for increasing weight. All the coordinates of the flight polar shift by a factor equal to the square root of the ratio of the weight…i.e. the square root of the ratio of the CURRENT operating weight to the published max gross weight. Second, Minimum sink speed increases with increasing bank angle given by the formula:

*Min Sink (angle) = Min Sink (level) * (1/Cosine (angle))*$^{0.5}$.

Angle of Bank	0°	10°	20°	30°	40°	45°	50°	60°
% Increase in Minimum Sink Speed	0	0.7%	3.2%	7.5%	14%	18.9%	25%	41%
% Increase in Minimum Sink Rate	0	2.4%	9.8%	24%	49%	68%	94%	183%

Table 1.

While the formula is interesting, the results in *Table 1* are more informative. For example, for all gliders in a coordinated 30° banked turn, the minimum sink speed increases by 7.5% over the level flight minimum sink speed at the current operating weight. Likewise, for all gliders in a coordinated 45° banked turn, the minimum sink speed increase by 18.9 % over the level flight minimum sink speed at the current operating weight.

Explanations

QUESTION 1: ANSWER E. To lose the least amount of altitude in completing a 360° turn the bank angle should be 45° and the airspeed the minimum sink speed in a 45° turn, which equals the level flight minimum sink speed (50 kt) plus 18.9% which equals 59 kt.

QUESTION 2: ANSWER C. Since the minimum sink speed is a function of weight, first the minimum sink speed at minimum weight (911 lbs) must be determined. All the coordinates of the flight polar (including the minimum sink speed) decrease by a factor equal to the square root of the ratio of the weights. Therefore, the reduction factor is the square root of 911 (min weight) divided by 1204 (gross weight) or $(911/204)^{0.5}$ which equals 0.87. The minimum sink speed decreases by 13% at minimum weight, or decreases from 50 kt to 43.5 kt. Since the minimum sink speed in a 45° turn increases by 18.9%, the optimum speed to fly at minimum weight in a 45° banked turn to lose the least amount of altitude becomes 43.5 x 1.189 or 52 kt.

QUESTION 3: ANSWER D. In a 30° banked turn the optimum speed to fly to lose the least amount of altitude is the minimum sink speed for a 30° banked turn…which equals the level flight minimum sink speed plus 7.5%. Since the minimum sink speed at gross weight is 50 kt, in a 30° banked turn the minimum sink speed becomes 50 x 1.075 which equals 54 kt.

QUESTION 4: ANSWER E. Like Question 1, to lose the least amount of altitude while turning requires a 45° banked turn at the minimum sink speed for a 45° banked turn…which equals the level flight minimum sink speed at your current operating weight (gross weight) which is 50 kt plus 18.9%…or 50 x 1.18 which equals 59 kt.

Lessons Learned

Minimum sink speed is an important speed for optimizing several glider maneuvers. For all gliders, minimum sink speed is a function of both weight and angle of bank in coordinated turning flight. Minimum sink speed decreases with decreasing weight by a factor equal to the square root of the ratio of the weights. Minimum sink speed increases for increasing bank angles in turning flight as shown in Table 1. In a 30° banked turn the minimum sink speed increases by 7.5% and the minimum sink rate increases by 24% over the level flight numbers. In a 45° banked turn the minimum sink speed increases by 18.9% and minimum sink rate increases by 68%. Glider aerodynamics is fascinating. Fly safe.

About the author: *Steve Platt is a commercial pilot in single engine airplanes, single engine seaplanes, and gliders. He holds an instrument rating and is a Certificated Flight Instructor for airplanes, instruments, and gliders. He has logged over 4,000 flight hours including over 2,000 hours as a flight instructor. He is a retired IBM Engineering Manager and a Flight Instructor at Sugarbush Soaring, Warren, Vermont.*

GLIDER AERODYNAMICS PUZZLER

BY STEVE PLATT

Energy

The Glider Aerodynamics Puzzler is intended to stimulate your thinking about soaring and refresh your understanding of glider aerodynamics and soaring optimization. The correct answers with detailed explanations follow the questions. Have fun.

Glider pilots are energy managers. Whether acquiring energy in a climb, or dissipating energy in a descent, glider pilots strive to most efficiently exploit or acquire energy.

However, glider pilots are subject to the laws of physics, particularly Newton's Laws of Motion and the Law of Conservation of Energy. Potential energy (altitude) can be converted to kinetic energy (airspeed), but the sum of the two must remain constant. More precisely, the kinetic energy (airspeed) of a glider plus the heat energy generated from drag must be exactly equal to the potential energy (altitude) given up.

Question 1: You are gliding your ASK 21 in neutral air (no lift or sink) at gross weight (approximately 1,300 lbs) at 60 kt. You raise the nose to slow to 50 kt. Approximately how much altitude will you gain upon reaching 50 kt?

A. 25 ft
B. 35 ft
C. 50 ft
D. 75 ft

Question 2: You are gliding your ASK 21 in neutral air (no lift or sink), this time at a weight of approximately 1,000 lbs (300 lbs lighter than in question 1) at 60 kt. You raise the nose to slow to 50 kt. Will you gain more altitude, less altitude, or about the same altitude as in Question 1 with lower weight?

A. Gain the same altitude
B. Gain less altitude
C. Gain more altitude

Question 3: You are gliding your ASK 21 in neutral air (ie. no lift or sink) at gross weight (approximately 1,300 lbs.) at 50 kt. You lower the nose to speed up to 60 kt. At a minimum how much altitude must you give up to reach 60 kt?

A. 25 ft
B. 35 ft
C. 50 ft
D. 75 ft

Question 4: You are gliding your ASK 21 in neutral air (no lift or sink) at 50 kt. But this time you are at 1,000 lbs. You lower the nose to speed up to 60 kt. Approximately how much altitude must you give up to reach 60 kt?

A. 25 ft
B. 35 ft
C. 50 ft
D. 75 ft

Explanations

Questions 1-4: The change in potential energy (altitude) must equal the change in kinetic energy (airspeed) plus any of the losses due to drag (heat). Kinetic Energy is given by the equation: $1/2 * w/g * v^2$ where w = weight, V= airspeed and g = the acceleration of gravity (32.17 ft/sec^2).

QUESTION 1: ANSWER C. Ignoring the small amount of energy lost as heat: the difference in energy between 50 kt and 60 kt must equal the gain in potential energy so:

$\frac{1}{2}(w/g\ V_f^2) - \frac{1}{2}(w/g\ V_s^2) = w * H$

Since weight (w) appears on both sides of the equation and cancels out, the height gain must equal to:

$$H = (V_f^2 - V_s^2) / 2 * g$$

substituting the numbers yields H = 48.9 ft (approximately 50 ft).

QUESTION 2: ANSWER A. Question 2 is interesting because in the equation above weight (w) appears on both sides of the equation and cancels out; therefore weight does not matter…i.e.…in slowing from 60 kt to 50 kt the same amount of altitude will be gained independent of weight!

QUESTION 3: ANSWER C. Question 3 is virtually identical to Question 1 in reverse. In this case the gain in energy by speeding up plus the small amount of energy consumed as heat due to drag must be equal to the potential energy (altitude) given up: Again, ignoring the small amount of energy lost as heat, the answer will be the same, approximately 50 ft.

QUESTION 4: ANSWER C. Like Question 2, because weight (w) appears on both sides of the equation and cancels out, in speeding up from 50 to 60 kt the same amount of altitude will be lost independent of weight!

Lessons Learned:

In neutral air, the kinetic energy of a glider "falling" plus the heat generated from drag, must be exactly equal to the potential energy (altitude) given up. Two gliders of different weights flying at the same speed entering a climb will gain the same altitude upon reaching the target speed. Likewise, two gliders of different weights flying at the same speed entering a descent will give up the same amount of altitude upon reaching the target speed. The Physics Law of Conservation of Energy applies in both cases. Glider aerodynamics is fascinating. Have fun. Fly Safe.

About the author: *Steve is a commercial pilot in single engine airplanes, single engine seaplanes, and gliders. He holds an instrument rating and is a Certificated Flight Instructor for air- planes, instruments, and gliders. He has logged over 4000 flight hours including over 2000 hours as a flight instructor. He is a retired IBM Engineering Manager and a Flight Instructor at Sugarbush Soaring, Warren, Vermont.*

GLIDER AERODYNAMICS PUZZLER

BY STEVE PLATT

Landing

The Glider Aerodynamics Puzzler is intended to stimulate your thinking about soaring and refresh your understanding of glider aerodynamics and soaring optimization. The correct answers with detailed explanations follow the questions. Have fun.

Gliders land differently than powered planes. Instrument Landing Systems (ILS) at airports worldwide have an approach angle of approximately 2.5°. Likewise, airports with Visual Approach Slope Indicators (VASI) have approach angles between 2.5° and 3°. Powered planes on final normally fly with approach angles of 2.5° to 3°. Glider final approaches are entirely different. Let's look at the numbers.

QUESTION 1: You are flying your Club's Schweizer SGS 2-33 on short final. The wind is dead calm. Not even a light breeze. You set up your final approach using an airspeed of 55 mph with a 700 ft/min descent rate. What is your final approach angle?

A. 3°
B. 5°
C. 8°
D. 11°
E. 15°

QUESTION 2. Later in the day, the winds come up. You take up the Schweizer SGS 2-33 again to practice landings. The winds have come up and are now blowing 10 kt (11.5 mph) right down the runway. On landing you set up a final approach using an airspeed of 60 mph (because of the winds) with a descent rate of 700 ft/min. What is your final approach angle?

A. 3°
B. 5°
C. 8°
D. 11°
E. 15°

QUESTION 3. On another day you are again flying the SGS-233. On this day the winds are blowing 20 knots (23 mph) right down the runway. As you come in to land, because of the winds, you decide to hold an airspeed of 65 mph with a descent rate of 700 ft./min. What is your final approach angle?

A. 3°
B. 5°
C. 8°
D. 11°
E. 15°

Explanation

The approach angle in all three questions is approximately equal to the arc sine of the descent rate divided by the ground speed.

QUESTION 1: ANSWER C. Since 60 mph equals 88 ft/sec, in Question 1, the ground speed is 55 mph which equals 80.66 ft/sec, or 4,840 ft/min. Therefore, the approach angle is equal to the arc sine of 700 ft/min divided by 4,840 ft/min, which equals 8.3°.

QUESTION 2: ANSWER C or D. In Question 2 the ground speed is close to 48.5 mph (60 mph - 11.5 mph) which equals 71.1 ft/sec, or

4,268 ft/min. Therefore, the approach angle is equal to the arc sine of 700 ft/min divided by 4,268 ft./min, which equals 9.4˚.

QUESTION 3: ANSWER D. In Question 3 the ground speed is close to 42 mph (65 mph - 23 mph) which equals 61.6 ft/sec, or 3,696 ft./min. Therefore the approach angle is equal to the arc sine of 700 ft/min divided by 3,696 ft/min, which equals 10.9˚.

LESSONS LEARNED: Powered aircraft on final approach can pretty much maintain their typical approach angle of 3˚ by applying power independent of the headwind component. Gliders cannot. Gliders can only steepen the approach angle to maintain their desired approach speed and descent rate to make it to the runway threshold. A glider's approach angle is a strong function of the headwind component. While the approach angle of a powered aircraft on final approach on an ILS is 2.5˚, a gliders approach angle is typical 3-4 times steeper depending upon the headwind component and the performance of the glider. For gliders, the sight picture on final (the approach angle) varies considerably more than for powered aircraft!

Without a throttle supplying power/thrust, glider pilots must adapt to wind conditions far more so than powered aircraft. That's why I honestly believe active glider pilots are the best pilots in the world.

About the author: *Steve Platt is a commercial pilot in single engine airplanes, single engine seaplanes, and gliders. He holds an instrument rating and is a Certificated Flight Instructor for airplanes, instruments, and gliders. He has logged over 4000 flight hours including over 2000 hours as a flight instructor. He is a retired IBM Engineering Manager*

and a Flight Instructor at Sugarbush Soaring, Warren, Vermont.

GLIDER AERODYNAMICS PUZZLER

BY STEVE PLATT

Bank Angle

The Glider Aerodynamics Puzzler is intended to stimulate your thinking about soaring and refresh your understanding of glider aerodynamics and soaring optimization. The correct answers with detailed explanations follow the questions. Have fun.

Whether in a Boeing 747, an F-16, or an PW-6, the rate of turn of all airplanes and gliders in coordinated turning flight is a function of bank angle and airspeed. New power pilots and instrument rating students quickly learn the approximate bank angle and airspeed to use to achieve a standard rate turn; that is, 3° per second. Likewise, glider pilots quickly learn the approximate bank angle and airspeed to use while thermaling to maximize net climb rates. The relationship between bank angle and airspeed is very important for all pilots to understand and exploit.

QUESTION 1: You are flying your club's PW-6 in neutral air (no lift or sink) at gross weight (approximately 1,200 lbs.). At gross weight the PW-6 has a minimum sink speed of 50 knots and a best L/D speed of 56 knots. Which of the following bank angles and airspeed will yield the highest (fastest) rate of turn?

A. 30° of bank at 60 knots
B. 35° of bank at 65 knots
C. 30° of bank at 50 knots
D. 35° of bank at 50 knots
E. 40° of bank at 60 knots

QUESTION 2: You are flying your club's PW-6 in neutral air (no lift or sink) at gross weight (approximately 1,200 lbs.). Which of the following bank angles and airspeed will yield the slowest rate of turn?

A. 30° of bank at 60 knots
B. 35° of bank at 65 knots
C. 30° of bank at 50 knots
D. 35° of bank at 50 knots
E. 40° of bank at 60 knots

QUESTION 3: You are flying your club's PW-6 in neutral air (no lift or sink) at gross weight. You commence a 35° banked turn and maintain 55 knots. Is the resultant rate of turn a function of weight? Would the rate of turn be the same, lower, or higher, if you were flying at minimum weight (approximately 900 lbs.)?

A. The rate of turn would be the same
B. The rate of turn would be lower (slower)
C. The rate of turn would be higher (faster)
D. I do not have a clue

QUESTION 4: A Schweizer 2-33 enters a 30° banked turn and maintains 60 mph (52 knots). A high performance Super Wingbat 6000 enters a 45° banked turn at the same time and maintains 70 knots. Which aircraft completes a 180° turn first, the Schweizer 2-33 or the Super Wingbat 6000?

A. The Schweizer 2-33 completes the 180° turn first
B. The Super Wingbat 6000 completes the 180° turn first.
C. Both aircraft complete the 180° turn at the same time

Explanation

QUESTION 1-4: First, the radius of turn of all airplanes and gliders in coordinated turning flight is proportional to the SQUARE of airspeed and is given by the Equation 1:

$$R = (V^2) / (G * Tan(angle))$$

where R is the Radius of Turn, V is airspeed, G is the acceleration of gravity (32.13 ft./sec²), and angle is the angle of bank. This equation is a fundamental equation of flight and applies to all airplanes and gliders in coordinated turning flight.

Applying Equation 1 to each of the bank angle/airspeed combinations, the radius of turn is first calculated. Then circumference of the turn circle (ie. distance) is divided by the speed to calculate the time to complete a 360°

turn.; yielding the rate of turn in degrees per second as follows:

30° of bank at 60 knots yields 10.60 degrees/second

35° of bank at 65 knots yields 11.75 degrees/second

30° of bank at 50 knots yields 8.75 degrees/second; slowest

35° of bank at 50 knots yields 15.29 degrees/second; fastest

40° of bank at 60 knots yields 15.26 degrees/second

QUESTION 1: ANSWER D. 35° of bank at 50 knots yields the fastest rate of turn.

QUESTION 2: ANSWER A. 30° of bank at 60 knots yields the slowest rate of turn. (Corrected from original)

QUESTION 3: ANSWER A. Weight does NOT enter into the calculations. The rate of turn will be the same independent of weight. In fact, for the same bank angle and airspeed in coordinated turning flight a Schweizer 1-26 and an ASK-21 will have the same rate of turn.

QUESTION 4: ANSWER A. The radius of turn for the Schweizer 2-33 using Equation 1 works out to be 314 ft and the time to complete the 180° turn is 11.2 secs. The radius of turn for the Super Wingbat 6000 works out to be 434 feet and the time to complete the 180° turn is 11.55 seconds. The Schweizer 2-33 completes the 180° turn first.

LESSONS LEARNED: The rate of turn is dependent upon bank angle and airspeed. For ALL make and models, INDEPENDENT of weight, the rate of turn will be the same for a specific bank angle and airspeed. Likewise, the radius of turn is dependent only on the bank angle and airspeed given by the fundamental equation of flight:

*R = (V2) / (G * Tan(angle))*

A Schweizer 1-26 and an ASK 21 will have the same rate of turn when making a 30° banked turn at 50 knots. Glider aerodynamics is fascinating. Have fun. Fly safe.

About the author: *Steve Platt is a commercial pilot in single engine airplanes, single engine seaplanes, and gliders. He holds an instrument rating and is a Certificated Flight Instructor for airplanes, instruments, and gliders. He has logged over 4000 flight hours including over 2000 hours as a flight instructor. He is a retired IBM Engineering Manager and a Flight Instructor at Sugarbush Soaring, Warren, Vermont.*

GLIDER AERODYNAMICS PUZZLER

BY STEVE PLATT

Crosswinds

The Glider Aerodynamics Puzzler is intended to stimulate your thinking about soaring and refresh your understanding of glider aerodynamics and soaring optimization. The correct answers with detailed explanations follow the questions. Have fun.

Crosswind landings are one of the most challenging maneuvers for new student pilots to master. Even for long time pilots that fly infrequently, crosswind landings can be a challenge. In my experience, except for the mandated FAA Flight Reviews, it is the rare pilot, that intentionally goes out on their own, or with an instructor, to intentionally practice crosswind landings. Indeed, each year crosswind landing incidents account for a significant fraction of documented accidents. Many crosswind landing incidents where no damage results (except to the pilot's ego), are not reported nor need to be.

However, crosswind landings usually separate the skilled pilots from the less than skilled pilots. All pilots should know what the maximum demonstrated crosswind landing specification is for the aircraft they fly.

QUESTION 1: What is the maximum demonstrated crosswind landing specification for a Schweizer 2-33?

A. 8 mph
B. 10 mph
C. 12 mph
D. 14 mph
E. 16 mph

QUESTION 2: What is the maximum demonstrated crosswind landing specification for an ASK 21?

A. 8 knots
B. 10 knots
C. 12 knots
D. 14 knots
E. 16 knots

QUESTION 3: What is the maximum demonstrated crosswind landing specification for a PW-6U?

A. 8 knots
B. 10 knots
C. 12 knots
D. 14 knots
E. 16 knots

QUESTION 4: Just for fun, what is the maximum demonstrated Crosswind landing specification for a Boeing 737-800 airliner?

A. 24 knots
B. 28 knots
C. 33 knots
D. 35 knots
E. 40 knots

Explanation

QUESTION 1-4: First, during aircraft certification, the FAA requires the manufacturers to demonstrate a minimum crosswind landing capability. This requirement is a relatively modest 0.2 x V_{so}…i.e. 20% of the stall speed. For example, if the gross weight stall speed of a glider were 40 knots, the demonstrated crosswind capability during certification would only have to be a very modest 8 knots.

Most manufacturers publish a number higher than the minimum required for certification, but rarely is the number higher than 12 knots. Whatever number is ultimately published, it must have been demonstrated during certification. In North America, and for that matter throughout the world, surface winds at airports are routinely at or above 15 knots. It comes as a surprise to many pilots that the published demonstrated crosswind component for many aircraft are as low as they are.

The published maximum demonstrated crosswind component for a Cessna 150 is 12 knots. For a Cessna 172 it is 15 knots. For a PW-6 glider it is 12 knots. For a Boeing 737-800 it is 35 knots on a dry runway.

QUESTION 1: ANSWER B. The Schweizer 2-33 has a published maximum demonstrated landing crosswind component of 10 mph (8 knots)

QUESTION 2: ANSWER A. The ASK 21 has a published maximum demonstrated landing crosswind component of 8 knots (10 mph)

QUESTION 3: ANSWER C. The PW-6U has a published maximum demonstrated landing crosswind component of 12 knots (14 mph).

QUESTION 4: ANSWER C. The Boeing 737-800 has a published maximum allowable landing crosswind component of 33 knots on a dry runway or 30 knots on a wet runway. However, in their operating manuals many air carriers limit the maximum crosswind component to 25 knots on a dry runway…. and even lower on a wet runway!

Please fill out and return your Safety postcards!

Lessons Learned

The FAA required minimum Demonstrated Crosswind component during certification is an extremely modest 20% of Vso. The Manufacturers published maximum demonstrated crosswind component, while usually higher than the minimum required for certification, rarely exceeds 12 knots if demonstrated during certification. The point is, when the crosswind component is greater than 12 knots, by definition, according to the manufacturer, you are now a test pilot! Have fun, fly safe.

About the author: *Steve Platt is a commercial pilot in single engine airplanes, single engine seaplanes, and gliders. He holds an instrument rating and is a Certificated Flight Instructor for airplanes, instruments, and gliders. He has logged over 4000 flight hours including over 2000 hours as a flight instructor. He is a retired IBM Engineering Manager and a Flight Instructor at Sugarbush Soaring, Warren, Vermont.*

GLIDER AERODYNAMICS PUZZLER

BY STEVE PLATT

Glide Ratio

The Glider Aerodynamics Puzzler is intended to stimulate your thinking about soaring and refresh your understanding of glider aerodynamics and soaring optimization. The correct answers with detailed explanations follow the questions. Have fun.

The best L/D glide ratio for most gliders varies from 23:1 to ~ 50:1. The best L/D glide ratio for most general aviation airplanes is in the 10-1 to 12-1 range. What is particularly interesting is the best L/D glide ratio of modern airliners.

QUESTION 1: What is the best L/D glide ratio of a Boeing 747?

A. 12 to 1
B. 15 to 1
C. 17 to 1
D. 19.5 to 1
E. 22 to 1

QUESTION 2: What is the best L/D glide ratio of a Boeing 727?

A. 12 to 1
B. 15 to 1
C. 17 to 1
D. 19.5 to 1
E. 20 to 1

QUESTION 3: What is the best L/D glide ratio of an Airbus A320?

A. 12 to 1
B. 15 to 1
C. 17 to 1
D. 19.5 to 1
E. 20 to 1

QUESTION 4: What is the best L/D glide ratio of a Boeing 757?

A. 12 to 1
B. 15 to 1
C. 17 to 1
D. 19.5 to 1
E. 20 to 1

QUESTION 5: From 39,000 feet how far can a fully loaded Boeing 787 glide, if flown optimally, with both engines off? Ignore the winds aloft.

A. 35 statue miles
B. 50 statue miles
C. 80 statue miles
D. 110 statue miles
E. 145 statue miles

EXPLANATION QUESTIONs 1-4: What comes as a surprise to many, is the fact that the best L/D glide ratio for modern airliners is quite good. The best L/D glide ratio for a Boeing 747 is 15 to 1. The best L/D glide ratio for a Boeing 727 is 17 to 1. The best L/ D glide ratio for an Airbus A320 is 17 to 1 and the best L/D for a Boeing 787 is an amazing 20 to 1.

EXPLANATION QUESTION 5: With a best L/D glide ratio of approximately 20 to 1, a fully loaded Boeing 787 at 39,000 feet can glide 147 miles if flown optimally. Indeed, a Boeing 787 at 39,000 feet over Albany New York, could easily glide with both engines out to LaGuardia airport in New York City with altitude to spare!

LESSONS LEARNED: The best L/D glide ratio for most gliders varies between 23:1 and 50:1. The best L/D glide ratio for general aviation airplanes is in the range of 10:1 to 12:1. The best L/D glide ratio for modern airliners ranges from 15:1 to 20:1. The engine out glide range for most airliners at cruise altitudes is in over 100 nautical miles.

As for airliners as gliders, a number of incidents have occurred over the years. One of the more amazing incidents occurred in 1983 when an Air Canada Boeing 767, flight 143, enroute from Montreal to Edmonton, ran out of fuel at 41,000 ft over Red Lake Ontario due to a refueling error and glided approximately 145 miles to an emergency landing at a former Royal Canadian Air force base in Gimli, Manitoba! With both engines out and little hydraulic pressure, the main landing gears came down and locked under gravity, however, the nose gear did not lock. The 767 skidded to a stop on its nose. There were no serious injuries to passengers or persons on the ground, and relatively minor damage to the aircraft. The airplane was repaired and returned to service. The 767's nickname became the "Gimli Glider". Amazing. Fly safe.

About the author: *Steve is a commercial pilot in single engine airplanes, single engine seaplanes, and gliders. He holds an instrument rating and is a Certificated Flight Instructor for airplanes, instruments, and gliders. He has logged over 4000 flight hours including over 2000 hours as a flight instructor. He is a retired IBM Engineering Manager and a Flight Instructor at Sugarbush Soaring, Warren, Vermont.*

GLIDER AERODYNAMICS PUZZLER

BY STEVE PLATT

Climb Rate

The Glider Aerodynamics Puzzler is intended to stimulate your thinking about soaring and refresh your understanding of glider aerodynamics and soaring optimization. The correct answers with detailed explanations follow the questions. Have fun.

A frequent discussion and debate among glider pilots while hangar flying is: "what is the optimum angle of bank and airspeed to deploy while climbing in a thermal?". While listening to these discussions and debates I have heard everything from 25 degrees of bank to 45 degrees of bank….and airspeeds all over the place. The actual answer depends upon a number of factors including the aircraft flown as well as the profile of the thermal. First some questions:

QUESTION 1: For a Schweizer 1-26, what is the optimum bank angle and airspeed to achieve a peak net climb rate in a Standard British thermal (defined as a thermal with 4.2 knots of airmass lift at the core decreasing parabolically to to zero at a radius of 1000 ft)?

A. 20° of bank; airspeed 38 MPH
B. 24° of bank; airspeed 40 MPH
C. 30° of bank; airspeed 40 MPH
D. 35° of bank; airspeed 45 MPH
E. 40° of bank; airspeed 50 MPH

QUESTION 2: For a Schweizer 2-33, what is the optimum bank angle and airspeed to achieve a peak net climb rate in a Standard British thermal?

A. 20° of bank; airspeed 38 MPH
B. 25° of bank; airspeed 44 MPH
C. 30° of bank; airspeed 40 MPH
D. 35° of bank; airspeed 45 MPH
E. 40° of bank; airspeed 50 MPH

QUESTION 3: For a PW-6, what is the optimum bank angle and airspeed to achieve a peak net climb rate in a Standard British thermal?

A. 20° of bank; airspeed 38 MPH
B. 25° of bank; airspeed 44 MPH
C. 30° of bank; airspeed 45 MPH
D. 32° of bank; airspeed 61 MPH
E. 40° of bank; airspeed 50 MPH

EXPLANATION QUESTIONS 1-3: Let's look at the numbers and some examples. Shown in *Figure 1* are the net Climb rates for a Schweizer 1-26, a Schweizer 2-33, and a PW-6 versus radius of turn, if flown optimally at the minimum sink speed for each angle of bank in a Standard British Thermal.

QUESTION 1: ANSWER B. The peak net climb rate occurs for the SGS 1-26 at 35 knots (40 MPH) and 24° of

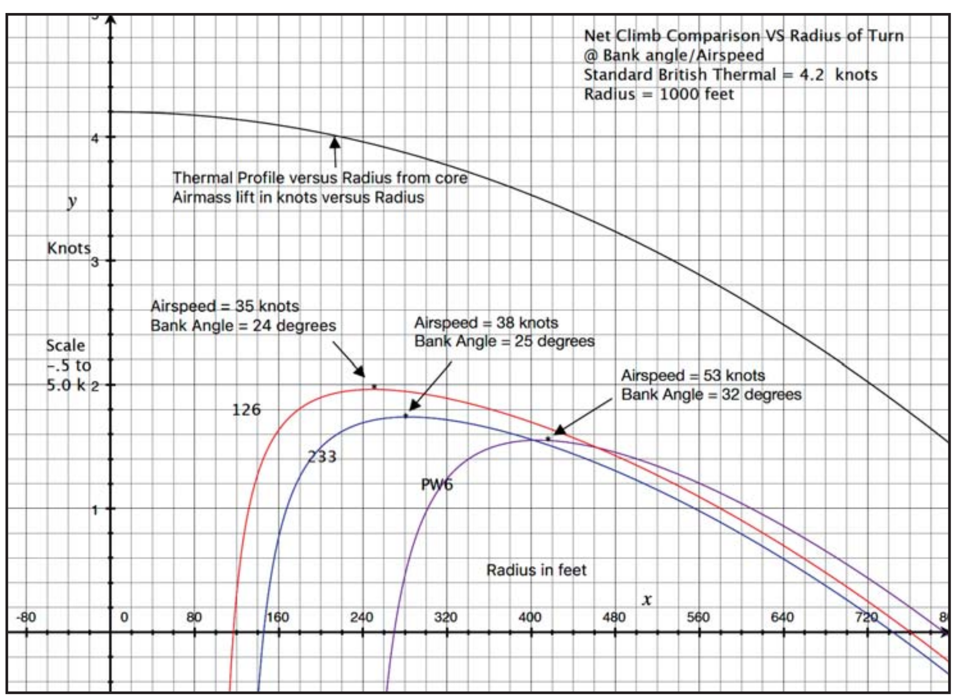


Figure 1.

bank. QUESTION 2: ANSWER B. The peak net climb rate for the SGS 2-33 occurs at 38 knots (44 MPH) and 25° of bank. QUESTION 3 ANSWER E. The peak net climb rate for the PW-6 occurs at 53 knots (61 MPH) and 32° of bank.

Shown in *Figure 2* and *Figure 3* are the net climb rates for an HpH 304C glider and for a Ventus 2, versus radius of turn in a Standard British thermal. Notice that the peak net climb rate for the HpH 304 occurs at a bank angle of 33° and an airspeed of 50 knots…while the peak net climb rate for the Ventus occurs at a bank angle of 35° and 52 knots. The faster the glider, the steeper the bank angle to achieve peak net climb rates. In all cases, the speed to fly while thermaling is the Minimum Sink Speed for the angle of bank flown.

LESSONS LEARNED: The optimum bank angle and airspeed to deploy while thermaling depends upon the glider at hand and the thermal profile…ie…the width and strength of the thermal. However, for typical summer thermals, for low performance gliders…e.g. an SGS 1-26 or SGS 2-33, a good starting point is 25° of bank. For medium performance gliders, like the ASK 21 or PW6 gliders, 30-35° of bank is a good starting point. For the highest performance gliders, like a Ventus 2, 35° of bank will yield the best net climb rate. The optimum angle of bank varies from 25° of bank to 35° of bank depending upon the performance (speed) of the glider flown. In all cases, the optimum speed to fly is the minimum sink speed for the angle of bank flown. And since the minimum sink speed in a 30° banked turn increases by 7.5% above the level flight minimum sink speed at your current operating weight, the optimum speed to fly while thermaling will be approximately 4 knots above the minimum sink speed in level flight at your current operating weight.

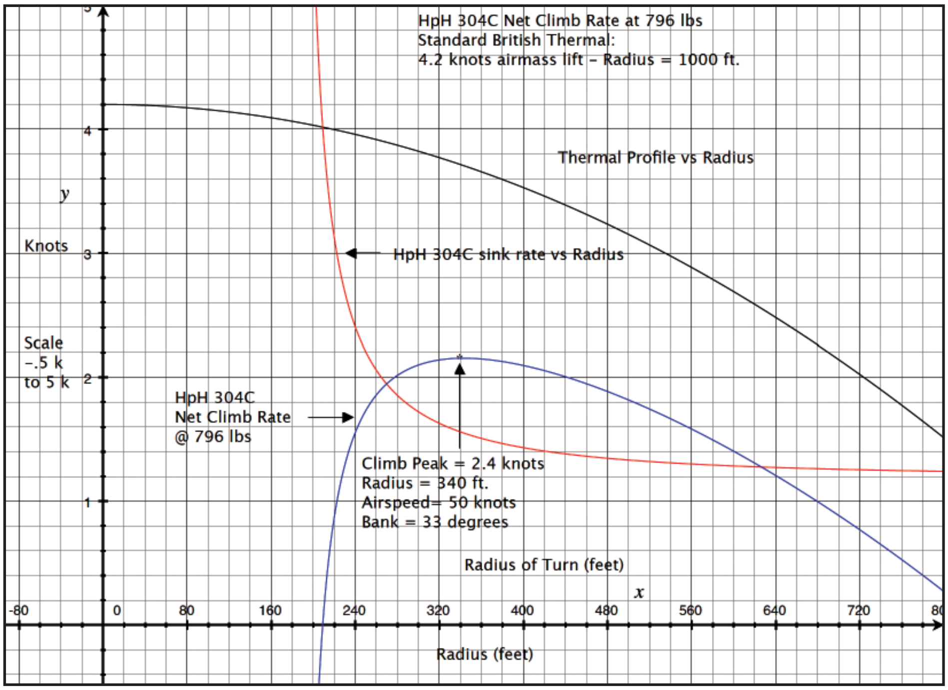


Figure 2.

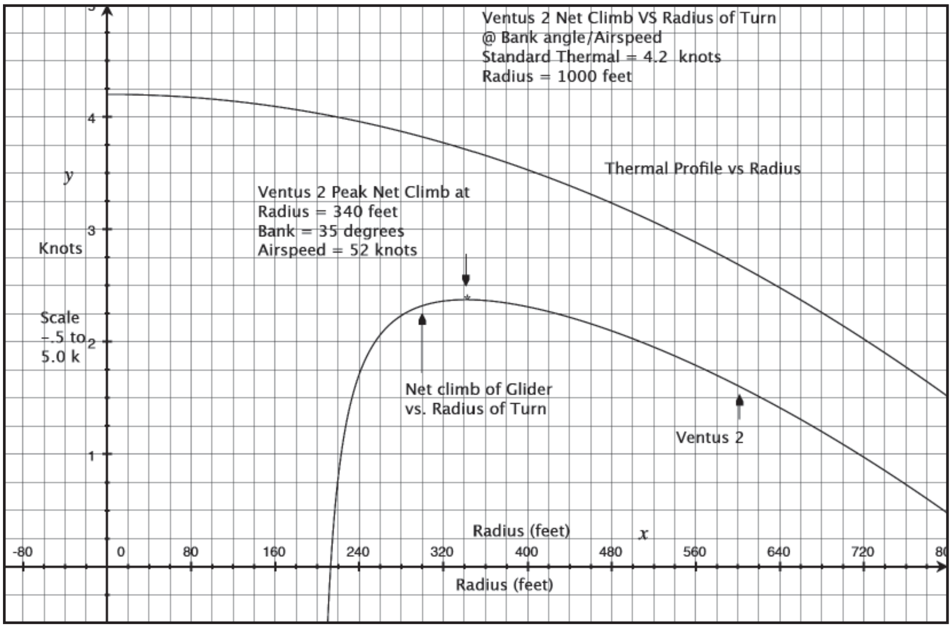


Figure 3.

Glider aerodynamics is fascinating. Have fun. Fly safe.

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BY STEVE PLATT

Radius of Turn

The Glider Aerodynamics Puzzler is intended to stimulate your thinking about soaring and refresh your understanding of glider aerodynamics and soaring optimization. The correct answers with detailed explanations follow the questions. Have fun.

Powered aircraft on cross-country flights turn relatively infrequently. On takeoff, perhaps a turn, maybe two, leaving the pattern for the on-course heading. With GPS, most powered flights, more frequently than not, fly direct to the destination. Upon reaching the destination, turns are limited to turning crosswind, turning downwind, turning base, and turning final. And, most of the turns are limited to around 90°. Not a lot of turning. Powered aircraft fly wings level most of the time.

Steep banks at slow airspeed mean smaller circles (i.e. smaller radii). Photo by Roy Bourgeois.

Not so with gliders. Gliders spend a lot more time turning. In fact, knowing how to optimize turning flight while thermaling is crucial to optimizing net climb rates. Achieving the optimum radius of turn is key. And while you do not have to be a classical physicist to be a great glider pilot, you do need to understand the relationship of radius of turn to airspeed and angle of bank. Let's take a look:

QUESTION 1: You are flying an ASK 21 at max gross weight. Which will reduce the radius of turn more, increasing the bank angle from 25° to 30°, or slowing the airspeed from 55 kt to 50 kt?

A. Increasing the bank angle from 25° to 30°
B. Slowing the airspeed from 55 kt to 50 kt
C. The decrease in Radius of turn will be the same for either.

QUESTION 2: In Question 1 does the weight matter? If the ASK 21 were at minimum weight would the radius of turn be different for a given bank angle and airspeed?

A. Weight matters
B. Weight does not matter

QUESTION 3: In Question 1 does the make and model matter? For a given bank angle and airspeed is the Radius of turn dependent upon the Make and Model?

A. No
B. Yes
C. It depends

QUESTION 4: An ASK-21 flying with an airspeed of 50 kt commences a coordinated turn with a bank angle of 25 degrees. A Ventus flying with an airspeed of 55 kt commences a coordinated turn with a bank angle of 30 degrees. Which glider has a smaller (shorter) radius of turn?

A. The ASK-21 has a shorter radius of turn

B. The Ventus has a shorter radius of turn

C. Both aircraft have the same radius of turn

EXPLANATION QUESTIONS 1-4: Whether the aircraft is a Boeing 747, a Cessna 172, or Schweitzer 2-33, in coordinated turning flight, the radius of turn is only a function of the airspeed and angle of bank. Weight and make and model do not enter into the equation. While you don't have to be a mathematician to be a great glider pilot, it is, however, worthwhile to understand the Radius of turn equation for all airplanes and gliders in coordinated turning Flight:

Radius of turn = $V^2 / g * Tan(angle)$

The radius of turn is equal to the airspeed squared divided by the product of the acceleration of gravity (g = 32.13 ft/sec^2) times the tangent of the angle of bank. This equation is a fundamental equation of flight. It applies to all aircraft with wings in coordinated turning flight.

ANSWER QUESTION 1: For the ASK 21, applying the radius of turn equation with an airspeed of 55 kt (or 92.8 ft/sec.) and a bank angle of 25°, the radius of turn works out to be 574 feet. Applying the radius of turn equation with an airspeed of 50 kt and a bank angle of 25° the radius of turns equals 474 feet. However, the ASK-21 with an airspeed of 55 kt and a bank angle of 30° yields a radius of turn of 464 feet. Increasing the bank angle from 25 to 30 degrees yields a slightly shorter radius of turn than slowing from 55 to 50 kt. Answer: A.

ANSWER QUESTION 2: Weight does not matter. A Boeing 747 and a Citation jet will have the same radius of turn if flown at the same airspeed and bank angle in coordinated turning flight. Answer: B.

ANSWER QUESTION 3: Weight does not matter, nor does the specific make and model…only airspeed and bank angle determine the radius of turn in coordinated turning flight. Answer: A.

ANSWER QUESTION 4: Applying the radius of turn equation with an airspeed of 50 kt and 25° of bank, the ASK 21 has a radius of turn of 474 feet. Applying the radius of turn equation with an airspeed of 55 kt and 30° of bank, the Ventus has a radius of turn of 464 feet. The Ventus has a shorter radius of turn. Answer: B.

LESSONS LEARNED: The radius of turn for ALL aircraft with wings is proportional to the square of airspeed and is given by the fundamental equation of flight:

Radius of turn = $V^2 / g * Tan(angle)$

If you must reverse direction quickly slow down! Obviously, a Piper cub can easily out turn an F16! Glider aerodynamics is fascinating.

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