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A Pilot's Guide to the Engine-Out Glide: The Effect of Wind on Best Glide Speed

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In an effort to continue equipping pilots with the most accurate, clear, and useful information pertaining to engine-out glide performance, the author expanded the research to include the effects of wind on an airplane's v_G. The recommendations currently available for how to adjust v_G for winds will be discussed. The aerodynamic foundation of engine-out glide performance is presented to include the derivation of an analytical solution to the equation for v_G. The derivation is expanded, yielding an equation for v_G that accounts for headwinds and tailwinds. Numerical solutions to the equation and a graphical representation of the results are presented. Using the results, the author presents a method to quickly, easily, and accurately determine the effect of wind on v_G for any airplane. Suggestions are made for how pilots can use this information.

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Introduction

Best range glide speed (a.k.a. best glide, v_G), published in Pilot's Operating Handbooks (POH), is the indicated airspeed (IAS) that allows an airplane, in a specified configuration (usually with landing gear retracted, flaps up, and the propeller control in the most advantageous position), to glide as far as possible from a given altitude after the total loss of engine power. The published speed is associated with the airplane at its maximum certified gross weight (MCGW), in a wings-level glide, with zero wind. Varying from the first two conditions was addressed by Callender (2023). This paper addresses the third: the effect of wind on best glide speed. For the purpose of clarity, the published (zero-wind) best glide speed will be symbolized by v_{G_0}; whereas, the symbol for best glide speed with wind will be v_{G_w}.

Information on the effects of wind on best glide speed can be found in popular (non-academic) sources. Cahill (2019), in an AOPA article, suggested adding half of the headwind component to v_{G_0} to obtain v_{G_w}. Lanning (2019), for the online aviation news service AVweb, suggested the same, with the addition of subtracting one-third of a tailwind from v_{G_0}. In an Aviation Safety article, Wolper (n.d.) provided a non-airplane-specific background on how v_{G_0} is determined. He included that v_{G_w} is higher than v_{G_0} with headwinds and lower with tailwinds, but specific guidance for determining v_{G_w} was not provided. Jurgens (2022), from Sporty's Flight Training Central, suggested adding one-third of a headwind to v_{G_0} and subtracting one-fifth of a tailwind. SKYbrary (n.d.), an International Civil Aviation Authority (ICAO) and a Flight Safety partner organization, noted the effect of wind on glide range but did not mention an effect on best glide speed. The Federal Aviation Administration (FAA) Safety Team (n.d.) published guidance to add half of a headwind to v_{G_0} and to subtract one-fifth of a tailwind. While these sources provide inconsistent guidance on determining v_{G_w}, they agree that v_{G_w} is higher with headwinds and lower with tailwinds.

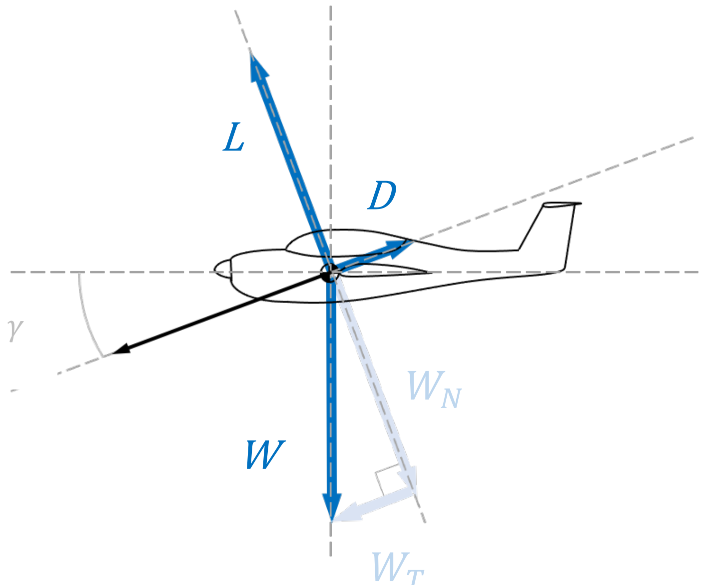
Peer-reviewed, academic articles have also addressed the effects of wind on best glide speed. Jenkins and Wasyl (1990) developed a numerical scheme with an associated graph of $v_{G_w}\ vs\ Wind$ for an example airplane (Schempp-Hirth Nimbus IIb). Bridges (1993) developed a fifth-order equation for v_{G_w} with a graph of both v_{G_w} and wind normalized by v_{G_0}. Segal, Bar-Gill, and Shimkin (2019) confirmed Bridges' solution and provided a graph of $v_{G_w}\ vs\ Wind$ for an example airplane (Cessna 172). The results in these articles for specific airplanes are practically applicable to those airplanes, but are not easily applied to other airplanes, nor are the general results for v_{G_w} palatable for pilots. This paper seeks to rectify both of these issues.

Best Range Glide Speed: Zero Wind

Identifying v_{G_0} Using Aerodynamic Forces

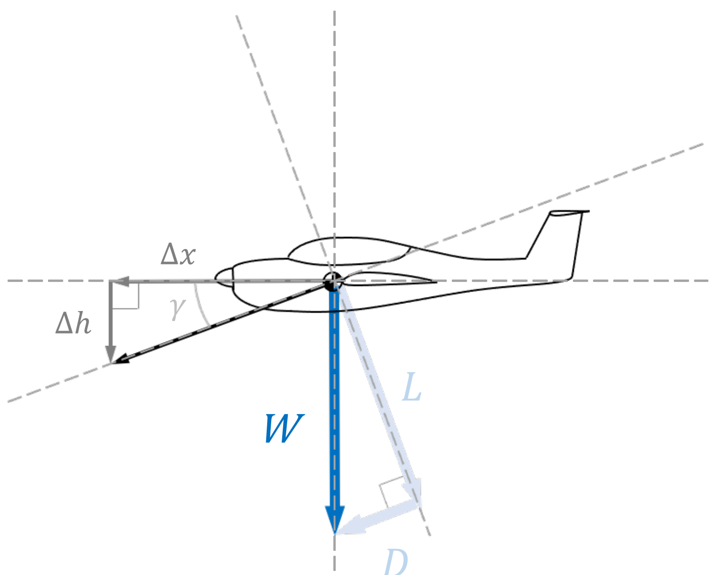
One method for identifying v_{G_0} is as follows. The forces acting on the airplane in an engine-out glide are shown in Figure 1. In the absence of thrust, a component of weight (W_T) in the direction of motion is required to counteract aerodynamic drag (D). In a steady glide, the components of weight are equal in magnitude to lift (L) and drag as shown in Figure 2.

Figure 1
Free Body Diagram of an Airplane in an Engine-Out Glide



Note. Adapted from Pilot's Guide to Maximum Glide Performance: Optimum Bank Angles in Gliding Turns (2023) by Callender, M.N.; retrieved from https://ojs.library.okstate.edu/osu/index.php/CARI/article/view/9516/8477.

Figure 2
Force Equivalencies and Distances in an Engine-Out Glide



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Geometrically similar to the force triangle formed by weight, lift, and drag is the triangle formed by the airplane's direction of motion (the black vector), the distance it covers over the ground (Δx), and the altitude it loses (Δh) while gliding. The airplane's maximum glide range (R_G) will be achieved when its glide angle is minimized (γ_{min}). Descending at the minimum angle allows the airplane to cover the most distance over the ground for each unit of altitude lost. The ratio just described is known as the glide ratio (GR), as shown in Equation 1.

$$GR = \left(\frac{\Delta x}{\Delta h}\right)_{max} \tag{1}$$

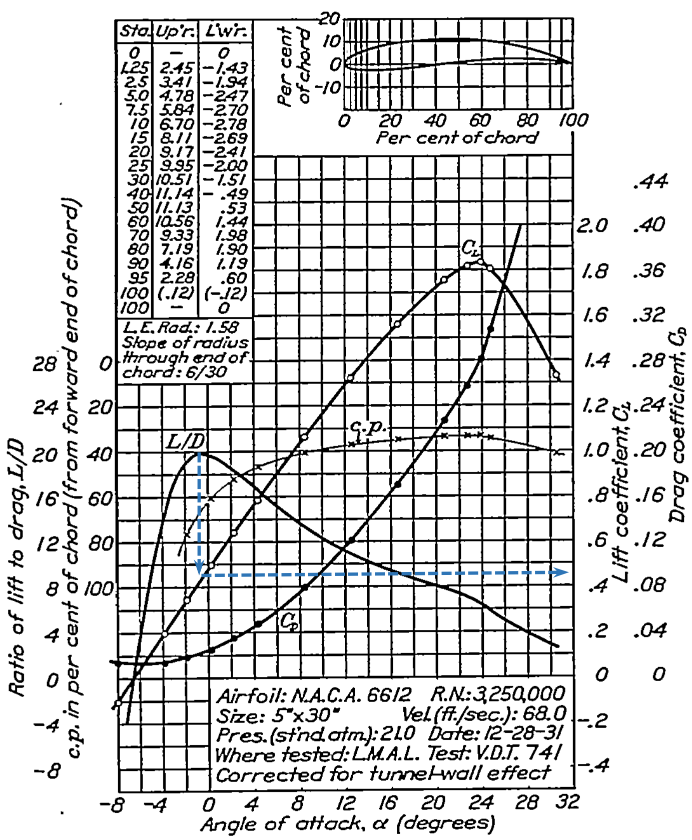
Since the force and distance triangles in Figure 2 are similar, the glide ratio can also be expressed in terms of forces as shown in Equation 2.

$$GR = \left(\frac{L}{D}\right)_{max} \tag{2}$$

This places glide performance on firm aerodynamic footing. $(L/D)_{max}$ is an important and well-known aerodynamic characteristic, found at the peak of a lifting shape's (i.e., an airfoil, a wing, or an airplane) L/D vs *angle of attack* (α) curve, an example of which is shown in Figure 3.

Figure 3

NACA 6612 Aerodynamic Characteristic Curves



Note. Adapted from The Characteristics of 78 Related Airfoil Sections from Tests in the Variable-Density Wind Tunnel, NACA-TR-460 (1933) by Jacobs, E., Ward, K.E., & Pinkerton, R.M., retrieved from ntrs.nasa.gov.

$(L/D)_{max}$ is achieved at a specific angle of attack. Using an airplane's lift coefficient $\left(C_{L_{opt}}\right)$ at this angle (e.g., following the blue arrows from $(L/D)_{max}$ in Figure 3) along with its MCGW as inputs into the lift equation, allows v_{G_0} to be calculated as shown in Equation 3.

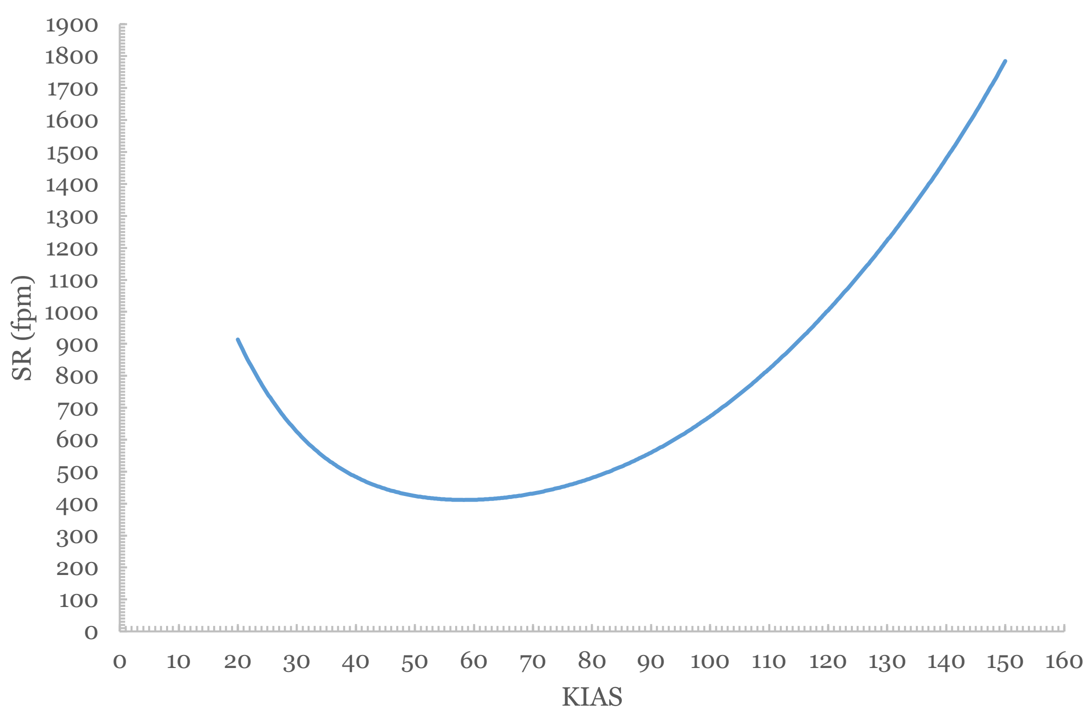
$$v_{G_0} = \sqrt{\frac{2 \cdot MCGW}{C_{L_{opt}} \rho_0 S}} \tag{3}$$

Identifying v_{G_0} Using Sink Rate Graphs

The method for determining v_{G_0} using aerodynamic forces as described in the previous section is technically correct; however, it is not the actual method used to find v_{G_0} nor is it the common way used to communicate v_{G_0} in academic and popular literature.

The sawtooth glide is a common flight test method used to obtain data necessary to identify v_{G_0}. The test is composed of a series of engine-out glides through an altitude band. The first glide is conducted at a constant airspeed, and the time to descend through the altitude band is recorded. Every subsequent glide is conducted at a different airspeed. The results of the test are the times that an airplane takes to descend through a fixed altitude band at various indicated airspeeds (IAS). By dividing the altitude band by the descent times (and appropriate unit conversions and corrections), the airplane's sink rates (SR) are calculated for various airspeeds. The results can be plotted as shown in Figure 4.

Figure 4
Example SR vs IAS Chart



The axes of a sink rate plot can be thought of in more basic mathematical terms. Sink rate is the change in altitude for a given amount of time and can be symbolized by $\Delta h/\Delta t$. Indicated airspeed is closely approximated to the airplane's ground distance covered in a given amount of time and can be symbolized by $\Delta x/\Delta t$. Figure 5 shows a sink rate plot using these symbols to represent the vertical and horizontal components of one point on the sink rate curve. With a line drawn from the origin to the point, as shown in Figure 5, the vertical and horizontal components represent the opposite (opp) and the adjacent (adj) sides of a right triangle. The tangent of the angle (θ) is calculated by Equation 4.

$$tan\theta = \frac{opp}{adj} = \frac{\Delta h/\Delta t}{\Delta x/\Delta t} = \frac{\Delta h}{\Delta x} \tag{4}$$

The result $(\Delta h/\Delta x)$ represents the altitude lost in the glide divided by the ground distance covered. This is the inverse of the right side of Equation 1. Since Equation 1 presents the condition for maximum glide range, minimizing Equation 4 also represents maximum glide range. Minimizing $tan\theta$ is accomplished by minimizing θ. This process is visualized in Figure 6. Point 1 is the original point from Figure 5. Point 2 is an SR point at a slightly higher indicated airspeed. Notice that the angle of the line from the origin to Point 2 is smaller than the line to Point 1. The angles continue to decrease for subsequent points until reaching the point of tangency (Point 3) between the sink rate curve and a line from the origin. Points at higher indicated airspeeds (i.e., Point 4) have higher angles. Since the angle of the line to Point 3 is the minimum angle, the airspeed associated with it is v_{G_0}.

Figure 5
Basic Representations of SR Point Coordinates

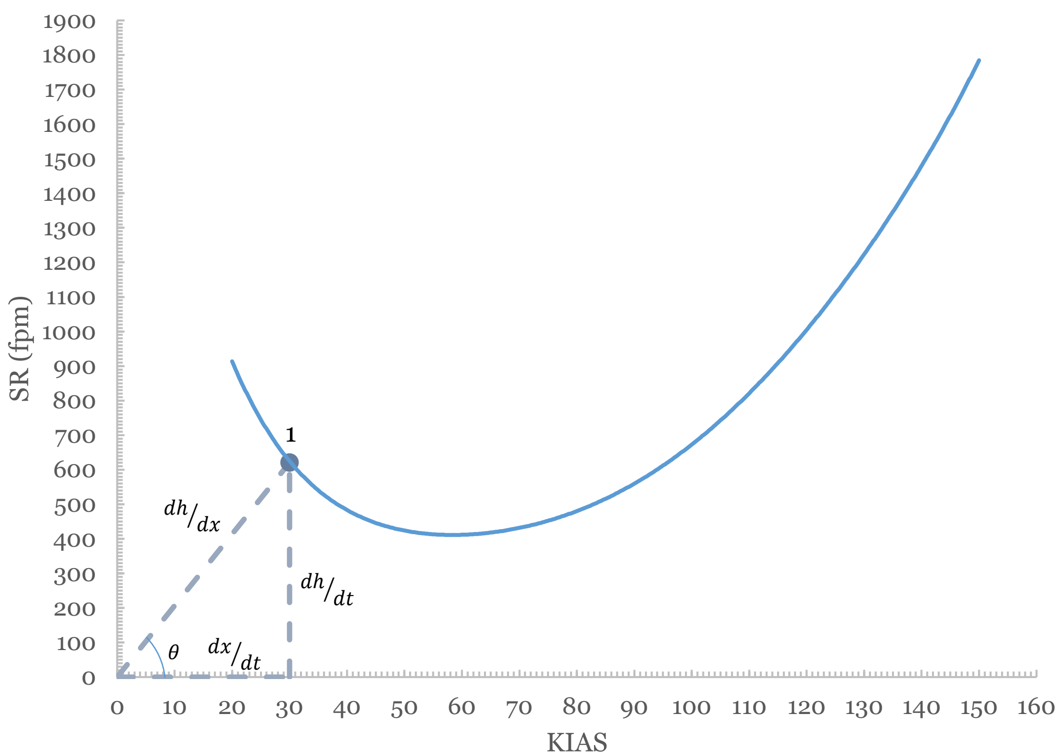
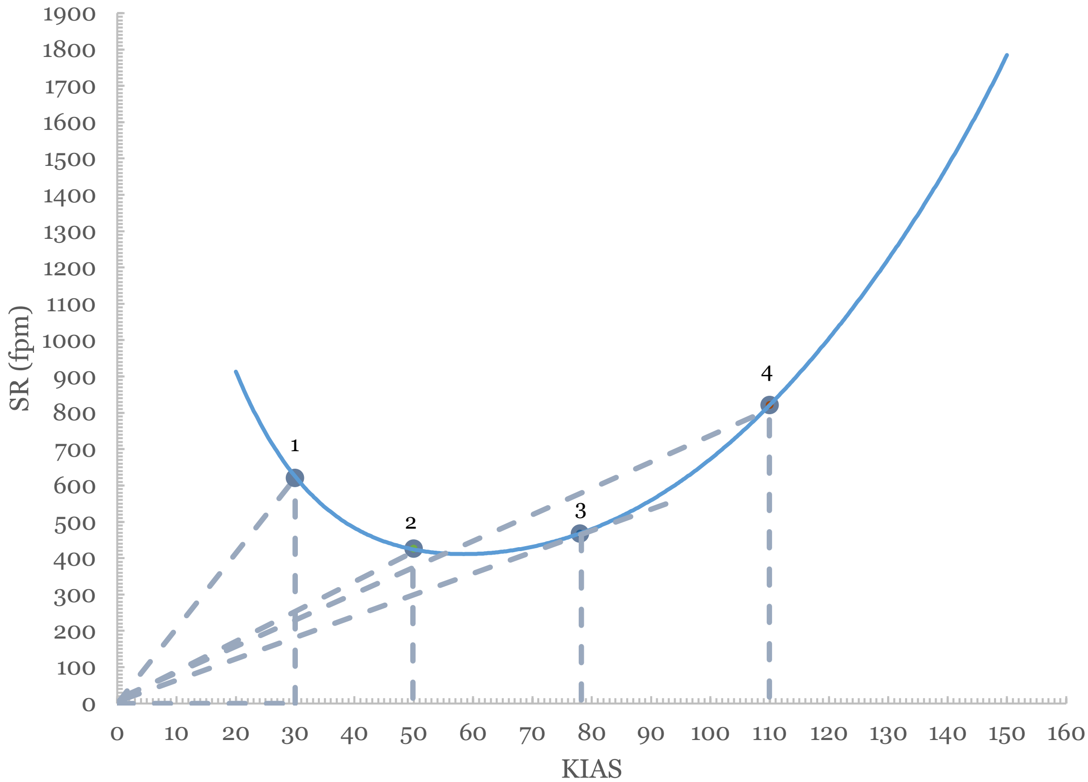


Figure 6
Identifying the SR Point with Minimal θ



v_{G_0} Analytic Solution

Basic aerodynamic principles will now be combined with the sink rate curve technique to find the analytic solution for v_{G_0}. The buildup will begin with the basic aerodynamic equation for lift coefficient that leads to the equation for drag as shown in Equations 5-8.

$$C_L = \frac{2W}{\rho v^2 S} \tag{5}$$

$$C_{D_i} = \frac{C_L^2}{\pi ARe} = \frac{4W^2}{\pi ARe\rho^2 v^4 S^2} \tag{6}$$

$$C_D = C_{D_0} + C_{D_i} \tag{7}$$

$$D = \frac{1}{2} C_D \rho v^2 S = \frac{C_{D_0}\rho v^2 S}{2} + \frac{2W^2}{\pi ARe\rho v^2 S} \tag{8}$$

The aerodynamic drag, from Equation 8, created by an airplane at a given airspeed, leads to the power required to glide at that airspeed. Power required, in the practical unit of horsepower, can be calculated using Equation 9.

$$HP_R = \frac{Dv}{550} = \frac{C_{D_0}\rho v^3 S}{(2)(550)} + \frac{2W^2}{(550)\pi ARe\rho v S} \tag{9}$$

HP_R from Equation 9, along with an airplane's weight (W), is used to calculate sink rate as a function of airspeed in Equation 10.

$$SR = \frac{33000 HP_R}{W} = \frac{(33000) C_{D_0}\rho v^3 S}{(2)(550)W} + \frac{(33000)(2)W}{(550)\pi ARe\rho v S} \tag{10}$$

This equation produces an airplane's sink rate curve like those depicted in Figures 4-6 from its basic drag characteristics (i.e. $C_{D_0}$and e), its wing's geometric characteristics (i.e. S and AR), and its weight. The equation for the tangent line from the origin to Point 3 on Figure 6 is given by Equation 11.

$$SR = mv \tag{11}$$

Since this line is on an *SR* vs *IAS* graph, its x-coordinate is airspeed (v) and its y-coordinate is sink rate. The slope is simply represented by m. At the point of tangency (Point 3 on Figure 6) between the sink rate curve (Equation 10) and the line from the origin (Equation 11), the slopes of the two are equal. The slopes of Equations 10 and 11 are found by taking their derivatives with respect to velocity as presented in Equations 12 and 13, respectively.

$$\frac{dSR}{dv} = \frac{(3)(33000)C_{D_0}\rho v^2 S}{(2)(550)W} - \frac{(33000)(2)W}{(550)\pi ARe\rho v^2 S} \tag{12}$$

$$\frac{dSR}{dv} = m \tag{13}$$

Setting these equal to one another yields Equation 14.

$$m = \frac{(3)(33000)C_{D_0}\rho v^2 S}{(2)(550)W} - \frac{(33000)(2)W}{(550)\pi ARe\rho v^2 S} \tag{14}$$

Equation 14 can then be substituted into Equation 11, resulting in a new equation for the tangent line as shown in Equation 15.

$$SR = \frac{(3)(33000)C_{D_0}\rho v^3 S}{(2)(550)W} - \frac{(33000)(2)W}{(550)\pi ARe\rho v S} \tag{15}$$

The outputs of Equation 15 for the tangent line and of Equation 10 for the sink rate curve are equal at the point of tangency. Equating the two yields Equation 16.

$$\frac{(3)(33000)C_{D_0}\rho v^3 S}{(2)(550)W} - \frac{(33000)(2)W}{(550)\pi ARe\rho v S} = \frac{(33000)C_{D_0}\rho v^3 S}{(2)(550)W} + \frac{(33000)(2)W}{(550)\pi ARe\rho v S} \tag{16}$$

Solving Equation 16 for v results in the indicated airspeed in mean sea level (MSL) conditions with zero wind that provides the most range in an engine-out glide. This solution, shown in Equation 17, is the analytic solution to v_{G_0}.

$$v_{G_0} = \sqrt[4]{\frac{4W^2}{C_{D_0}\pi ARe\rho^2 S^2}} \tag{17}$$

Equation 17 allows v_{G_0} to be calculated from an airplane's basic aerodynamic and geometric characteristics.

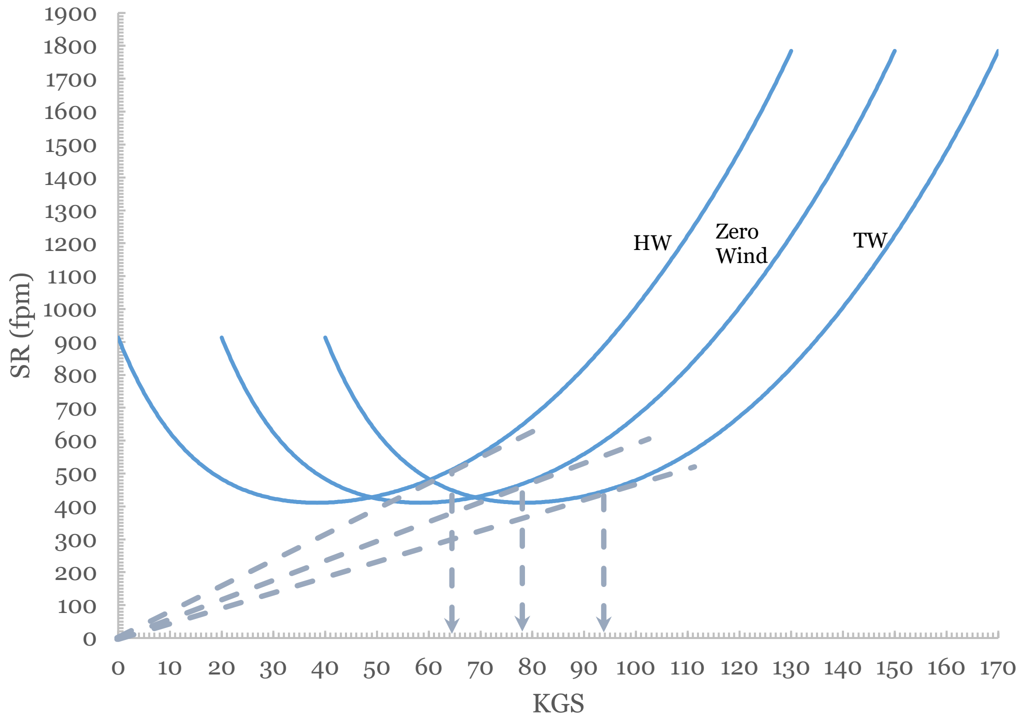
Best Range Glide Speed: With Wind

Identifying v_{G_w} Using Graphical Methods

The sink rate curve technique for finding v_{G_0} will now be applied to finding the best range glide speed with wind, v_{G_w}. Figure 6 shows that v_{G_0} was associated with the point of tangency between an airplane's sink rate curve and a line from the origin. In sea level conditions with no wind, the indicated airspeed axis is the same as ground speed. With wind, this is not the case, and since maximizing glide distance over the ground is important, finding v_{G_w} must deal with ground speed in one of two ways. The first graphical method is to draw a tangent line to an airplane's sink rate curve, not from the origin, but from the headwind or the tailwind value on the airspeed axis. The graphic representation showing the effects of headwinds and tailwinds using this method is found in current literature and was also the basis for Bridges' (1993) analytic solution. The other method is presented in this paper. It begins not by shifting the location from which the tangent line is drawn (it will begin at the origin) but by shifting the airplane's sink rate curve left or right by the amount of headwind or tailwind, respectively. This method transforms the horizontal axis from an indicated airspeed axis to a groundspeed axis. This means that the airspeed associated with the point of tangency is the groundspeed that gives the most range in the glide. Adding the headwind or tailwind magnitude to this value yields v_{G_w}. Figure 7 shows examples of shifted sink rate curves for finding v_{G_w} with headwinds and tailwinds.

Figure 7

Identifying v_{G_w} with Headwinds and Tailwinds



Note: The speeds identified by the arrows represent the ground speeds for best range for each wind condition. The wind speed must be added (HW) or subtracted (TW) in order to yield v_{G_w}).

v_{G_w} Equation Derivation

The graphical process of finding v_{G_w} by shifting the sink rate curve to the left or right for headwinds or tailwinds, respectively, can be applied to finding an analytic solution. Equation 10, representing an airplane's sink rate curve, can be shifted for wind (w) as shown in Equation 18.

$$SR = \frac{(33000)C_{D_0}\rho(v+w)^3 S}{(2)(550)W} + \frac{(33000)(2)W}{(550)\pi ARe\rho(v+w)S} \tag{18}$$

In this equation, headwinds are positive and tailwinds are negative. The same process described above, using Equations 10-16, can be followed by substituting Equation 18 for Equation 10. This process results in Equation 19.

$$(v+w)^5 - 3(v+w)^4 v + \frac{4W^2}{C_{D_0}\pi ARe\rho^2 S^2}(v+w) + \frac{4W^2}{C_{D_0}\pi ARe\rho^2 S^2}v = 0 \tag{19}$$

Equation 19 can then be simplified with the substitution of Equation 17, from the no-wind case, resulting in Equation 20.

$$(v+w)^5 - 3(v+w)^4 + v_{G_0}^4(v+w) + v_{G_0}^4 v = 0 \tag{20}$$

One of the solutions (roots) to this fifth-order polynomial, for a given wind speed, will be the groundspeed that gives the best glide range, to which the wind speed can be added to find v_{G_w}. The alternate method for visualizing v_{G_w} or for analytically deriving an equation for v_{G_w} is to have the line tangent to the sink rate curve in Figure 6 originate from the wind speed on the horizontal axis. The advantage of this method is that the speed associated with the tangent point is v_{G_w}. There is no need to add wind speed to ground speed. This method was used by Bridges (1993). Whether using Bridges' equation or Equation 20, a mathematical hurdle must be overcome. According to the Abel-Ruffini theorem, fifth-order polynomials (i.e., Equation 20) have no known analytical solution. Fortunately, they can be solved numerically (Abel, 1824). An online numerical solver was used to find the roots of Equation 20 (Wolfram Alpha, 2025). For specific v_{G_0} and w values, the appropriate root corresponding to the tangent point between the wind-shifted sink rate curve and a line drawn from the origin (with a positive slope) is the ground speed resulting in the best glide range. Adding the wind speed results in v_{G_w}.

Verification of Methods

The graphical and analytical methods for finding v_{G_0} and v_{G_w} will first be demonstrated using an example airplane. Table 1 includes the example airplane's necessary characteristics.

Table 1

Example Airplane Characteristics

$W\ (lbs)$	$S\ (ft^2)$	AR	C_{D_0}	e
2535	145.5	10.7	0.025	0.85

Applying these characteristics to Equation 17 yields the airplane's v_{G_0} as shown in Equation 21.

$$v_{G_0} = \sqrt[4]{\frac{4(2535)^2}{(0.025)\pi(10.7)(0.85)(0.00238)^2(145.5)^2}} = 131.6\ fps\ or\ 78.0\ KIAS \tag{21}$$

The characteristics from Table 1 were used to create the sink rate curve in Figure 6. Using the graphical method, the airspeed corresponding to Point 3 on Figure 6 is also $78.0\ KIAS$. Using Wolfram Alpha to find numerical solutions to Equation 20 for this example airplane for $20\ knot$ headwinds and tailwinds yield v_{G_w} values of $84.4\ KIAS$ for $20\ knot$ headwinds and $73.9\ KIAS$ for $20\ knot$ tailwinds. The graphical method depicted in Figure 7 for this airplane shows ground speeds associated with the best glide range for $20\ knot$ headwinds and tailwinds that match these values after adding and subtracting headwinds and tailwinds to convert ground speeds to airspeeds. The graphical and the analytical methods for determining v_{G_0} and v_{G_w} agree with one another.

Application

While understanding 1) the process presented in Figure 5 for finding v_{G_0} provides pilots with insight, and 2) Equation 17 allows a pilot to calculate v_{G_0} if an airplane's characteristics are available, neither of these is actually necessary. Pilots need only to consult an airplane's pilot's operating handbook (POH) or its airplane flight manual (AFM) to find v_{G_0}. What POHs don't typically include are the adjustments to v_{G_0} for airplane weights less than the maximum certified gross weight (see Callender (2023)) or the adjustments for wind. Table 2 contains v_{G_w} values for a range of wind speeds for different values of v_{G_0} obtained from solutions to Equation 20. These values can be plotted as shown in Figure 8. Each curve in Figure 8 shows the range of v_{G_w} for a given v_{G_0}(the value at the y-intercept). A pilot can first find the curve associated with an airplane's v_{G_0}. Next, the pilot can read vertically from the wind speed to the airplane's v_{G_0} curve. Reading horizontally from this point to the vertical axis yields the airplane's v_{G_w} for the selected wind speed. An example of this process is shown in Figure 8 for an airplane with $v_{G_0} = 70\ KIAS$ and a headwind of $20\ knots$. The pilot quickly and easily sees that the airplane's $v_{G_w} \approx 77\ KIAS$. Plotting the results of Equation 20 in the form of Figure 8 can be accomplished for every possible value of v_{G_0} and can include the effects of any wind speed. An example including curves, inclusive of the range of v_{G_0} seen in most general aviation airplanes, is seen in Figure 9.

Table 2
Best Range Glide Speeds with Headwinds and Tailwinds

$v_{G_w}(KIAS)$				v_{G_0}	$v_{G_w}(KIAS)$			
Headwinds (*knots*)					Tailwinds (*knots*)			
40	30	20	10		-10	-20	-30	-40
79.4	72.2	66.9	62.9	60	57.8	56.2	54.9	53.8
87.6	81.4	76.5	72.8	70	67.8	66.0	64.6	63.5
96.3	90.7	86.3	82.8	80	77.8	75.9	74.4	73.2
105.4	100.3	96.1	92.8	90	87.7	85.8	84.3	82.9
114.7	110.0	106.0	102.7	100	97.7	95.1	94.1	92.7

Figure 8

Best Range Glide Speeds with Headwinds and Tailwinds

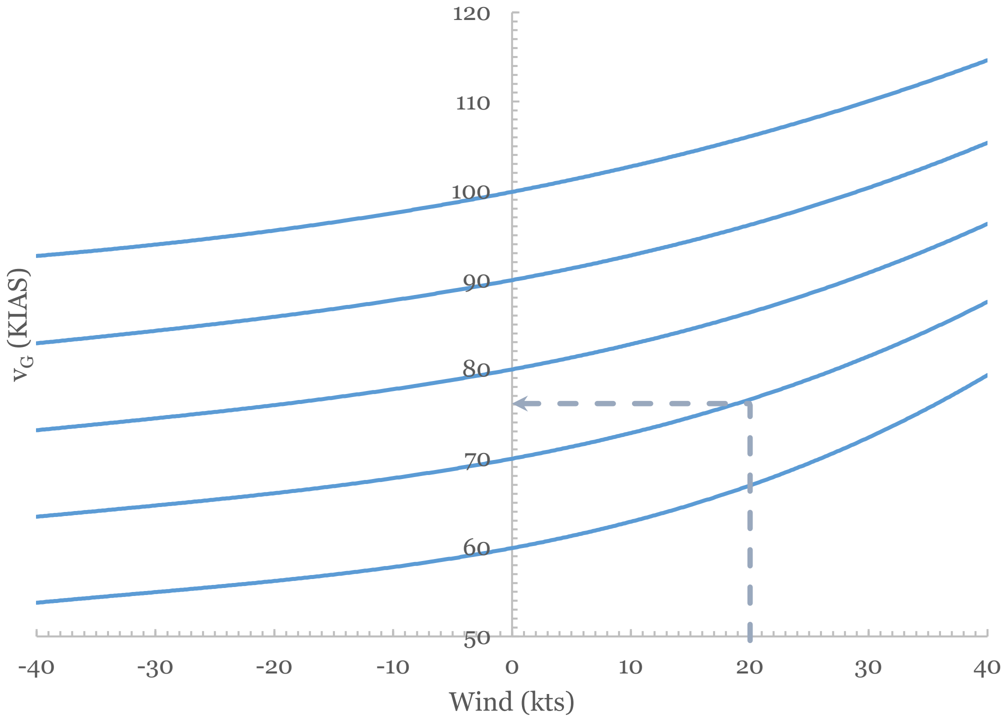
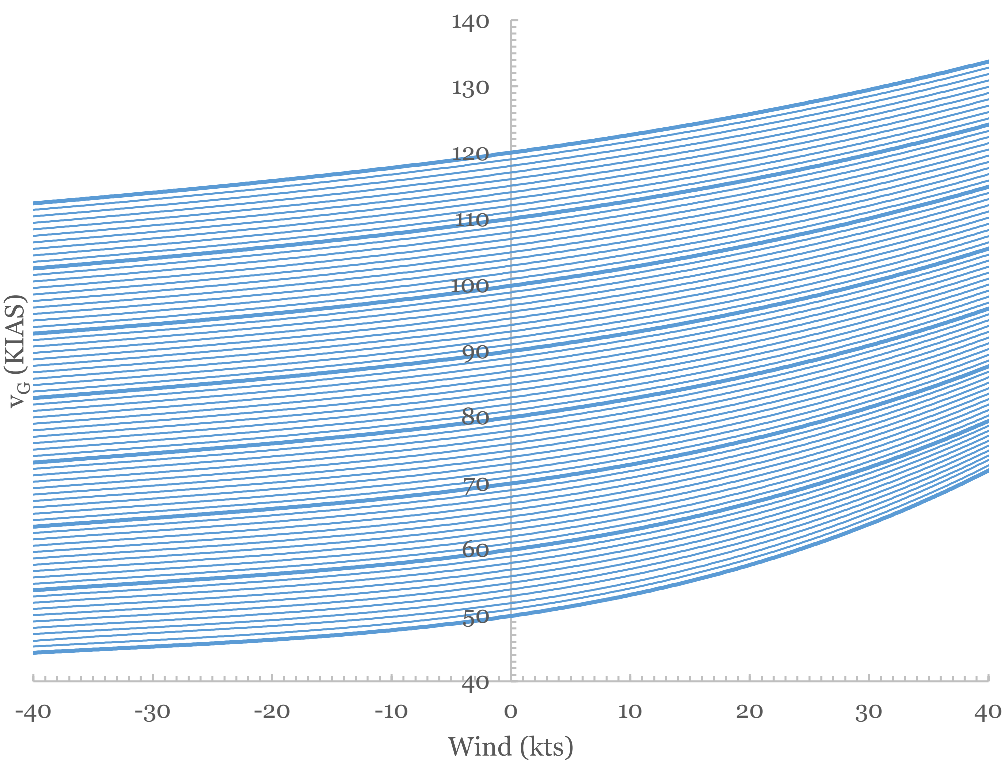


Figure 9

Best Range Glide Speed Curves for General Aviation Airplanes



Recommendations

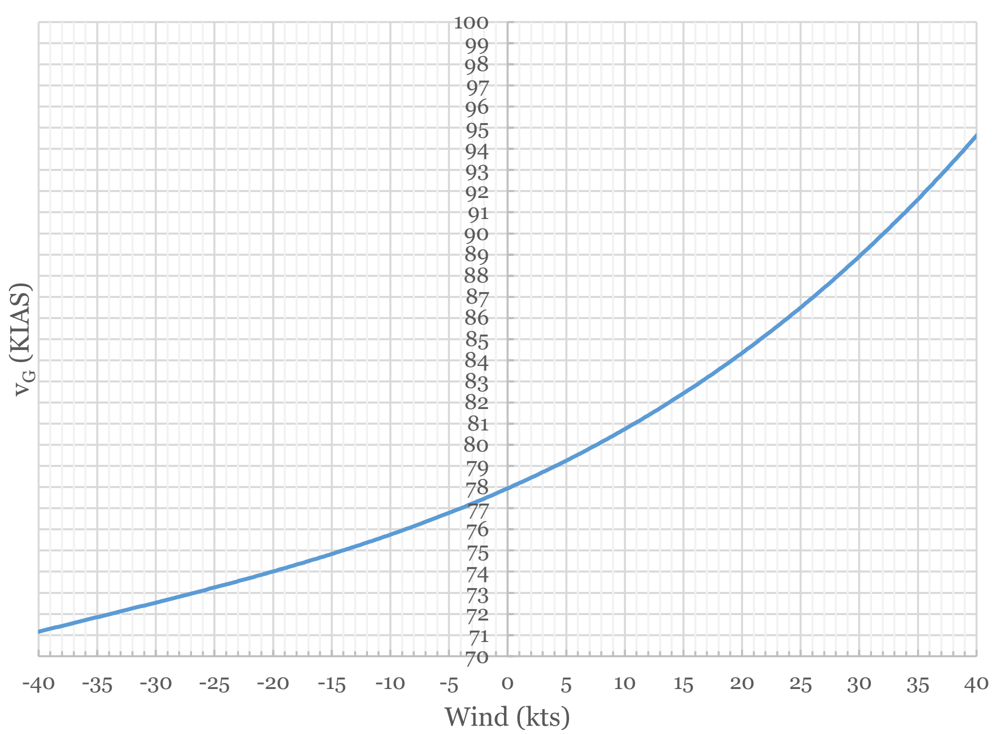
Regarding the information presented in this paper for determining any airplane's best range glide speed in any wind condition, the author makes the following recommendations.

The first recommendation is that pilot training and reference materials should adequately cover the effect of wind on an airplane's best range glide speed. As presented in the introduction, limited information on this subject is available. The information that is available is not found in commonly used pilot training/informational publications such as the FAA's Airplane Flying Handbook (AFH) or the Pilot's Handbook of Aeronautical Knowledge (PHAC), the classic Aerodynamics for Naval Aviators, nor is it found in POHs or AFMs. Non-airplane specific publications (i.e., the AFH or the PHAC) should include an explanation of the effects of wind supported by a visual similar to Figure 7, followed by either Figure 8 or Figure 9 showing v_{G_w} curves applicable to most general aviation airplanes. Airplane specific POHs or AFMs can/should do better. For the example airplane used earlier in this paper with $v_{G_0} = 78\ KIAS$, its POH could include either a table of its v_{G_w} values for various headwind and tailwind values, or it could include a visual representation of v_{G_w} as presented in Figure 10.

The next recommendation is that flight training should include the practice of determining and holding v_{G_w} in simulated engine-out glides based upon actual wind magnitude and glide direction.

Figure 10

POH Graph of v_{G_w} for an Airplane with $v_{G_0} = 78\ KIAS$



The final and potentially the most impactful recommendation is that the airplane-specific information for v_{G_w} (the equation for the specific curve from Figure 9) should be programmed into digital avionics and flight management systems. These systems can then calculate and display to the pilot the real-time v_{G_w} based upon either the reported or the calculated wind speed.

Readers who desire a graph of v_{G_w} for their airplane, similar to Figure 10, can either isolate the appropriate curve from Figure 9 and create their own airplane-specific graph or are welcome to contact the author.

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