Using the Polar

Understanding the aerodynamic performance of fixed-winged aircraft is crucial to an aviator if maximum utility and safety is to be achieved. The drag polar is the primary tool for determining the glide performance parameters. While expressing aircraft performance with the polar chart is normally limited to texts for glider pilots, a study of drag polar fundamentals will benefit airplane pilots. This discussion will cover the method of constructing a polar, interpreting performance parameters from the polar, and using that information to enable the aviator to maximize aircraft performance in flight.

Polar Fundamentals

The information needed for the construction of the polar is acquired experimentally. A two-column table is made with predetermined regular airspeed increments in one column. The sailplane (or airplane {power-off}) is flown in smooth air at those incremental airspeeds from stalling speed to V_{NE} (potentially), and the corresponding sink rates are noted in the second column. This is repeated as necessary to ensure that the data is accurate. The data points are then plotted and a best-fit curve is drawn. The result for an LET L-23 Super Blanik sailplane is shown in **Figure 1**:

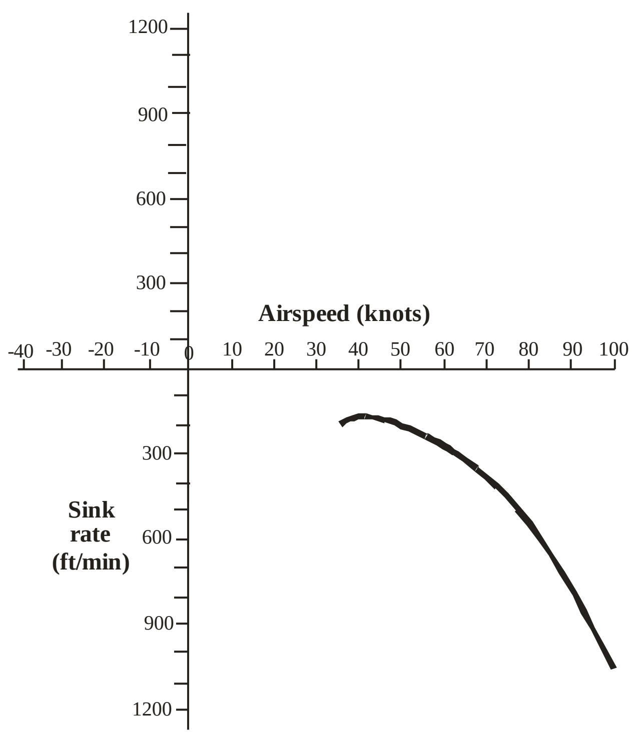

Figure 1

In this case the sink rate was noted for 5-knot airspeed intervals from stall in the clean configuration to 100 knots. The left end of the curve is the stall airspeed, and the right end is the highest airspeed evaluated (V_{NE} for this aircraft is 124 kt).

Now it's time to interpret the polar and use it for practical purposes. A line is constructed that is parallel to the X axis and tangent to the curve as shown in **Figure 2**.

The point on the airspeed axis where the line touches the point of tangency is the minimum sink airspeed, and the corresponding sink rate for this flight condition is indicated on the Y axis.

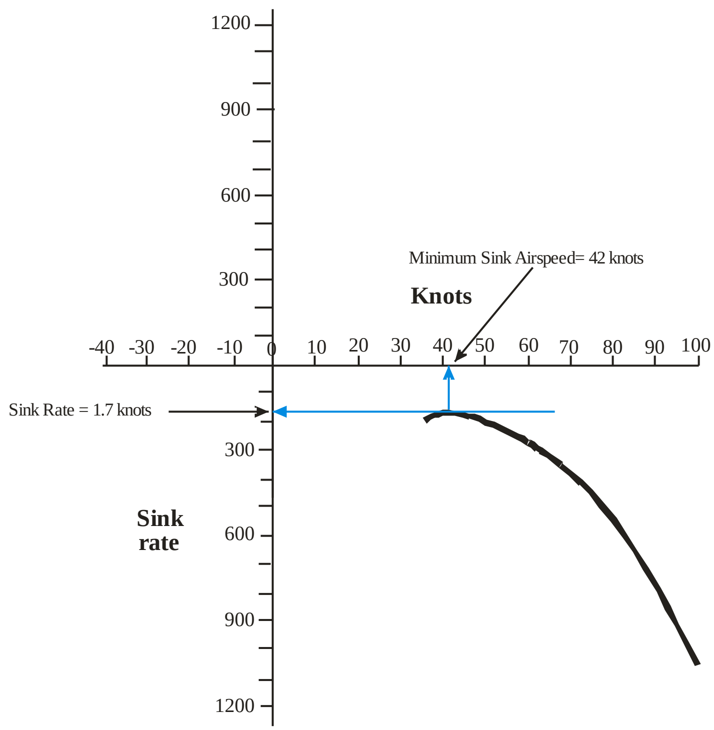

Figure 2

Although this speed is used in sailplanes for thermalling, it's more appropriate to think of this as an airspeed that maximizes *time*. Any time the aviator is operating in a favorable flight condition, this is the *speed-to-fly*. The wise aviator recognizes the favorable condition and wants to maximize the amount of time spent in that condition, thereby reaping the maximum amount of benefit provided by that condition. In addition to being a thermalling airspeed, minimum sink airspeed is the most appropriate choice for flying in a tailwind. Simply stated, aircraft efficiency is maximized by flying at an airspeed that will allow it to remain in a favorable flight condition for longest *time* possible.

When the goal is to maximize the *distance* covered, it is necessary to fly at the airspeed that yields the best ratio of lift/drag, commonly verbalized as "*best L-over-D*." The determination of this airspeed is illustrated in **Figure 3**.

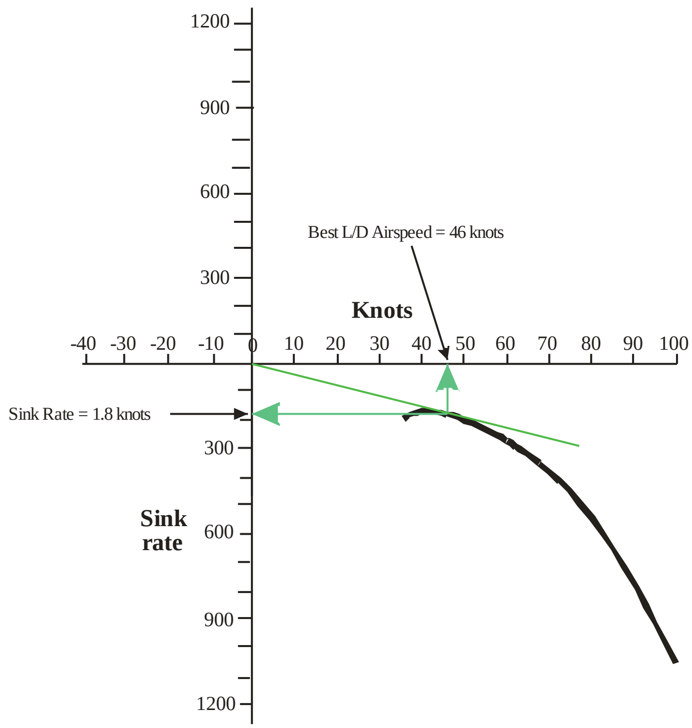

Figure 3

A line is drawn from the origin through the point of tangency on the drag curve. The airspeed corresponding to that point is the best L/D airspeed. The sink rate naturally will be higher than when flying at minimum-sink airspeed, but the distance travelled *per foot of altitude expended* will be the greatest possible.

Notice that the units on the Y-axis are expressed in knots *and* feet per minute. This is mathematically possible because 100 feet/minute x 60 minutes = 6000 feet/hour. Since one nautical mile is approximately 6000 feet, then 100 ft/min = 1 knot. This conversion to common units is useful for expressing the glide ratio of an aircraft. In the case of the L-23 used in this example, 46 kt/1.8 kt = 25.5555 or approximately 26. When flown at best L/D airspeed, this aircraft should glide 26 feet for every foot of altitude lost in the effort. When describing the performance characteristics of this aircraft, it is commonly said to have an L/D of 26.

Aviation texts that are written for operators of airplanes usually illustrate the relationship between airspeed and drag with a graph similar to the one in **Figure 4**, where the blue curve represents parasite drag, the red curve represents induced drag, and the green curve represents the of the addition of the two curves or total drag. Best L/D airspeed occurs where the parasite drag curve and the induced drag curve cross. Because of the exponential relationship between airspeed and drag, any increase in airspeed beyond L/D_{max} causes an increase in parasite drag that is greater than the decrease in induced drag. Airspeeds lower that L/D_{max} creates an inverse situation, and total drag is increased.

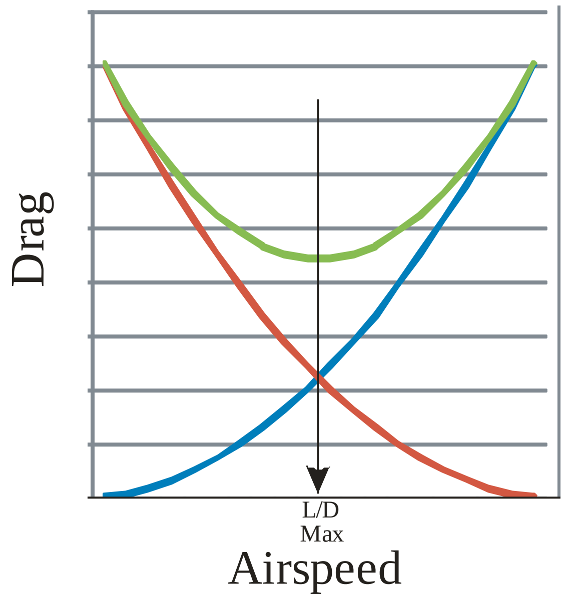

Figure 4

While the best L/D airspeed is the most efficient speed-to-fly with regard to distance, it is valid <u>only</u> in a no-wind scenario. The speed-to-fly with a headwind component can be determined with the polar as shown in **Figure 5**.

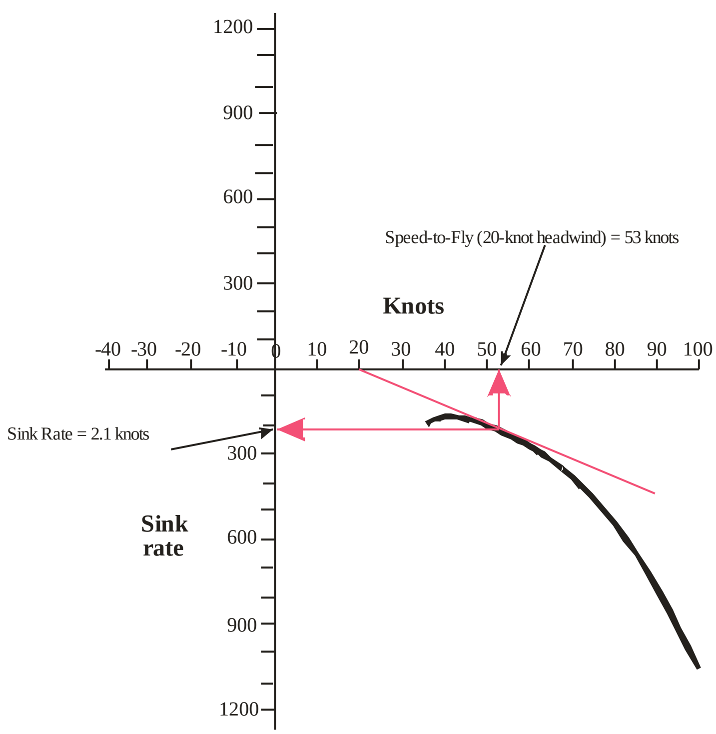

Figure 5

First, the headwind component is determined by estimation or through the use of the groundspeed function of a GPS, 20 knots in this example. Then construct a line that extends from the point on the positive side of the airspeed axis that corresponds to the headwind component through the point of tangency on the curve. That point projected upward to the X-axis yields the speed-to-fly in a 20-knot headwind component. Although the sink rate is 30 fpm greater at this airspeed, the total distance covered is the greatest possible.

Experimentation with this technique at various headwind components yields a rule of thumb for practical use: the appropriate speed-to-fly with a headwind is best L/D plus 50% of the headwind component.

The negative side of the airspeed axis demonstrates how speed-to-fly with a tailwind can be determined in the same fashion, as illustrated for a 20-knot tailwind component in **Figure 6**. Notice that, regardless of how large the tailwind component becomes, the speed-to-fly will never be less than the minimum-sink airspeed.

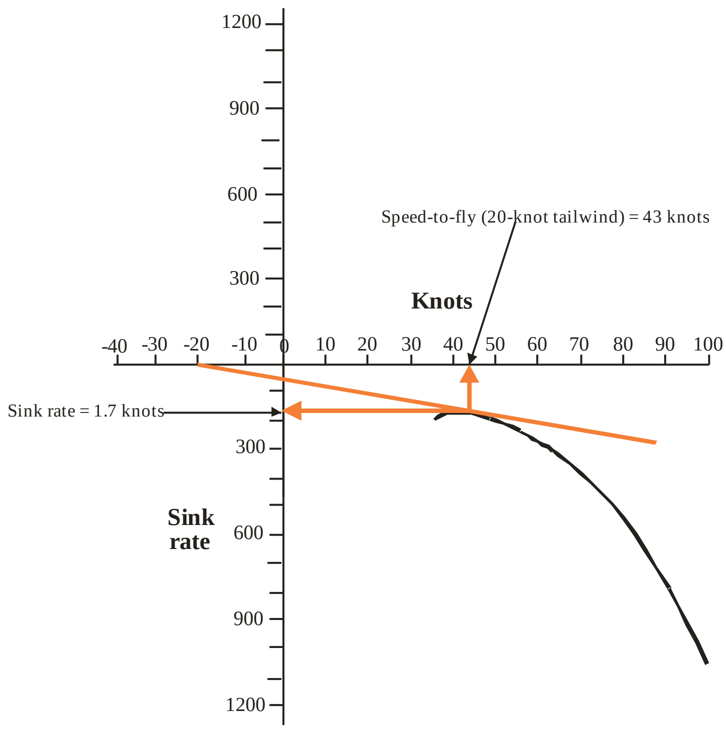

Figure 6

A sailplane pilot who encounters sink must select another speed-to-fly in order to maximize performance. In the polar shown in **Figure 7**, sink is measured on the upper side of the Y-axis. In this example, a sink rate of 5 knots is indicated on the sailplanes variometer. A tangential line that originates at that point yields a speed-to-fly of 69 knots while in this sink condition. While the price for this action is high, a 3.5-knot descent rate in this case, the area of sink is transitioned rapidly, minimizing the overall effect of sink on the sailplane. Additionally, when the pilot increases pitch to reduce airspeed to a more appropriate speed-to-fly when the area of sink has been crossed, the excess airspeed can be converted to altitude, regaining *some* of the advantage lost by utilizing this technique.

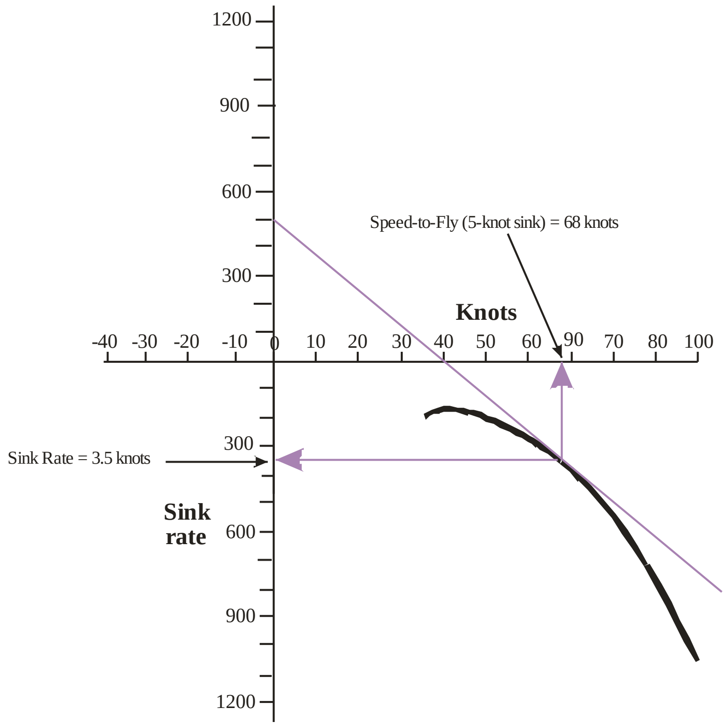

Figure 7

Practical Use of the Polar in Airplanes

Although the focus of the foregoing portion of this article has been on the relatively ideal aerodynamic realm of soaring, rendering it of interest to a small portion of the aviation world, the polar can be of practical use in the operation of any fixed-wing aircraft.

The most obvious practical use of an enhanced knowledge of drag characteristics provided by understanding of the polar is improved pilot performance in engine-out scenarios. Best-glide airspeeds are included in the Emergency Procedures section of all Pilot Operating Handbooks and Airplane Flight Manuals. The authors of this material *assume* that their audience has limited exposure to the advanced aerodynamic concepts provided by study of the drag polar, so only one specified airspeed is presented as the recommended airspeed to fly in the event of an engine failure. The best way to determine the best-glide airspeed for a given airplane is to generate experimentally a polar for each individual aircraft, but this may not be practical, especially for rental airplanes. So the next best approach is to accept the published best-glide airspeed as the best L/D airspeed and apply the polar principles to derive a speed-to-fly for each engine-out situation. For example, when gliding into a headwind, increasing the published best-glide airspeed by 50% of the estimated headwind component would maximize the gliding distance. Conversely, if the aviator determines that a downwind glide is the best option, a glide speed that is *slightly* lower than the published would yield the maximum glide distance.

Take another look at the polar with the units of measurement restated in **Figure 8**. In sailplanes, altitude equals potential energy, just as fuel available in the tanks of an airplane represents the potential energy waiting to be converted to the kinetic energy of forward motion. So the units on the Y-axis of the polar can be expressed as any form of energy that can be exploited to attain airspeed. The point on the airspeed axis that corresponds to the point of tangency on the curve is expressed at V_Y, best rate-of-climb airspeed.

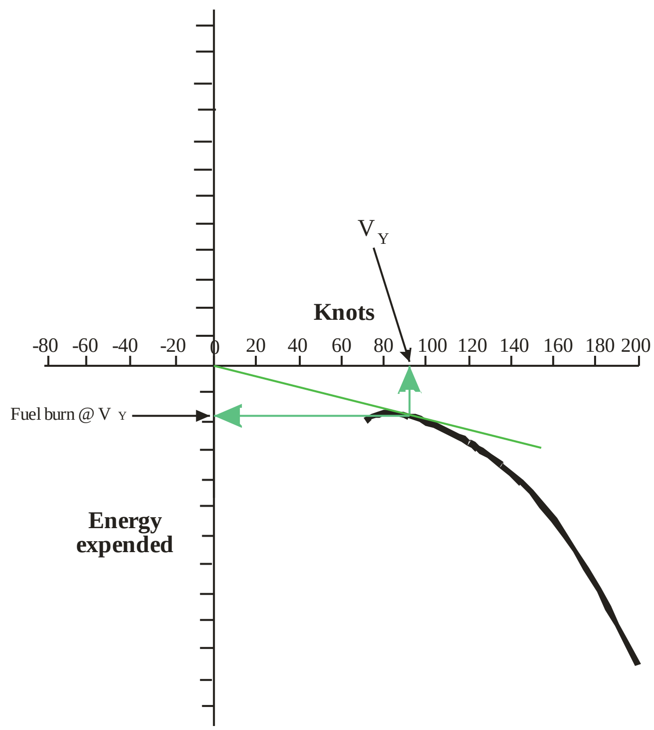

Figure 8

Persons taking the airman knowledge test for Airline Transport Pilot (Airplane) will encounter a question in the following format:

Which procedure produces the minimum fuel consumption for a given leg of the cruise flight?

A. Increase altitude for a headwind, decrease altitude for a tailwind.
B. Increase speed for a tailwind.
C. Increase speed for a headwind.

Adaptation of the polar principles discussed earlier illustrates why answer **C** is correct. When flying an airplane over a leg into a headwind, and fuel consumption is a primary consideration, increase power and lower angle of attack to increase airspeed by 50% of the headwind component (if possible) on the upwind leg. Although the *rate* of fuel consumption (gph or pph) will be greater in this configuration, the *total* fuel consumed for the upwind leg will be less than it would be is the original cruise airspeed had been maintained throughout the leg. Conversely, when flying a leg in a tailwind, reducing the normal cruise airspeed by 25% of the tailwind component (if reasonable) will yield comparable benefits. Expressed simply, choose airspeeds that will minimize the time spent flying in a detrimental condition, and that will maximize time spent flying in a beneficial condition.

Application of Polar Fundamentals to Multiengine Airplanes

Insight provided by study and understanding of the polar is especially valuable to the operators of multiengine airplanes when flying with one engine inoperative.

The airspeed indicator of every twin engine airplane is marked with a blue radial, indicating the value of V_{YSE}, or best rate-of-climb airspeed for single engine operations. Examination of the flight manual for all multiengine airplanes reveals that the value of V_Y, or normal best rate-of-climb airspeed, is identical to (or very close to) the blue-line airspeed. This is because these values are determined by construction of a polar for the *airframe*, and is essentially unaffected by outside factors, including the operational status of the engines. Note also that blue line is an *indicated* airspeed, thus it is unaffected by changes in air density that result from changes in altitude or atmospheric conditions.

When faced with an engine-out scenario, naturally the multiengine pilot's initial priority is to maintain control of the aircraft, shut down and secure the offending engine, and configure systems according to the manufacturer's recommendations. Once that has been accomplished, the successful outcome of the flight is dependent on the pilot's aeronautical decision-making abilities. Knowledge of polar principles will dramatically increase the quality of these decisions.

First, a pitch attitude must be established that will yield V_{YSE}, or best L/D airspeed with a single engine operating. As previously stated, the *airframe* is configured for greatest efficiency.

Second, the propeller on the operating engine must be properly set. Since the propeller is an airfoil, it has a polar of its own. Its airspeed, measured in RPM, must be set with the propeller control to a best *thrust over drag* condition in order to maximize its efficiency. Since V_{YSE} is the best rate-of-climb airspeed for the airframe, it follows that the climb RPM setting represents the most efficient propeller condition. This setting is *normally* 2300 RPM. Viewed philosophically, the inoperative-engine side of the airplane is falling. The multiengine pilot's job in this scenario is to make the operating side climb at the same rate or better. If a constant altitude can be maintained with the operating propeller set to best climb RPM at full throttle, the airplane is at its absolute single-engine ceiling. If altitude cannot be maintained, this aircraft configuration will yield the most efficient drift-down condition until the reaches its absolute single-engine ceiling.

Third, the pilot must choose the most practicable alternate field and establish a course that will achieve that goal. If the aircraft's altitude is sufficient to clear all obstacles along the route to the alternate field, the throttle should be set to a manifold pressure that will maintain that altitude. If obstacles along the route require a significant climb, the pilot will need to select a more suitable alternate.

Next, pilot will need to determine the existing wind conditions along the chosen route. This is most easily accomplished with the use of a GPS receiver. In the case of a headwind, V_{YSE} minus the GPS groundspeed readout equals the headwind component. If a GPS is not available, the headwind/tailwind component must be determined by other means.

Finally, the pilot must determine the best speed-to-fly for the existing flight condition. This is where knowledge of the polar provides the wise aviator with the strategy that will maximize the chances of a successful termination of the flight.

Engines, including aircraft engines, are machines that convert fuel into heat, which can be measured in calories (a calorie is the amount of heat required to increase the temperature of one milliliter of water on degree Celsius, a very small amount). The byproduct of this process is the work of producing thrust. Every engine, when it is new, has the capacity to produce a finite number of calories from a finite volume of fuel. When that finite number is reached, the engine's life is totally expended, and failure occurs. The rate at which these calories are produced varies with the operating conditions. That rate is extremely high for the operating engine of a multiengine airplane during single-engine operations.

When a pilot is proceeding to an alternate airport on a single engine, the number of calories the operating engine is capable of producing is unknown. What *is* known, however, is that the number is finite. The pilot must use those remaining calories efficiently if the flight is to be concluded successfully. **Figure 9** below shows the polar redrawn to plot airspeed against energy in the form of engine life in calories.

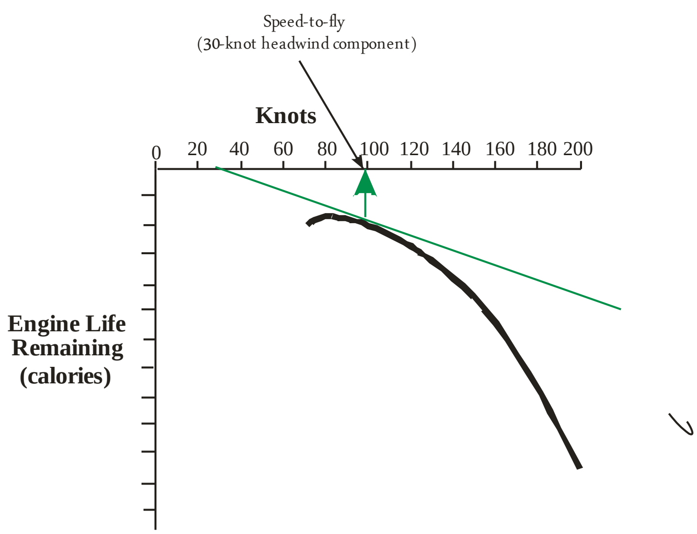

Figure 9

The polar chart shows the informed selection of a speed-to-fly, with a 30-knot headwind component on the course to the alternate. In this case, assuming the aircraft is below its absolute single-engine ceiling and the operating engine has excess power available, the pilot should reduce pitch and increase throttle to increase airspeed by one-half the headwind component, if possible. Operating the airplane in this manner will result in the lowest possible number of calories being produced while proceeding to the alternate. If the headwind component is so strong that this increase is clearly impossible, the pilot should probably select a different alternate with less formidable wind conditions.

Naturally, if a no-wind or a tailwind condition is encountered, the flight should be conducted at V_{YSE}.