Glider performance during launch phase and during free flight phase depends on many factors. The design of the glider itself is one factor. Weather, wind, and other atmospheric phenomena also affect glider performance.

FACTORS AFFECTING PERFORMANCE

Glider performance during launch depends on the power output of the launch mechanism and on the aerodynamic efficiency of the glider itself. The three major factors that affect performance are density altitude, weight, and wind.

DENSITY ALTITUDE

Air density directly affects the launch performance of the glider. As the density of the air increases, the engines power output of the launching vehicle (towplane, ground tow, or self-launch glider) and the aerodynamic lift of the glider's wings increase. When air density is less dense, the launch performance decreases. **Density altitude** is the altitude above mean sea level (MSL) at which a given atmospheric density occurs in the **standard atmosphere**. It can also be interpreted as **pressure altitude** corrected for nonstandard temperature differences.

PRESSURE ALTITUDE

Pressure altitude is displayed as the height above a standard datum plane, which, in this case, is a theoretical plane where air pressure is equal to 29.92 inches of mercury (in. Hg). Pressure altitude is the indicated height value on the altimeter when the altimeter setting is adjusted to 29.92 in. Hg. Pressure altitude, as opposed to **true altitude**, is an important value for calculating performance as it more accurately represents the air content at a particular level.

The difference between true altitude and pressure altitude must be clearly understood. True altitude means the vertical height of the glider above MSL. True altitude is displayed on the altimeter when the altimeter is adjusted to the local atmospheric pressure setting.

For example, if the local altimeter setting is 30.12 in. Hg., and the altimeter is adjusted to this value, the altimeter indicates exact height above sea level. However, this does not reflect conditions found at this height under standard conditions. Since the altimeter setting is more than 29.92 in. Hg., the air in this example has a higher pressure, and is more compressed indicative of the air found at a lower altitude. Therefore, the pressure altitude is lower than the actual height above MSL.

To calculate pressure altitude without the use of an altimeter, remember that the pressure decreases approximately 1 inch of mercury for every 1,000-foot increase in altitude. For example, if the current local altimeter setting at a 4,000-foot elevation were 30.42, the pressure altitude would be 3,500 feet. (30.42 - 29.92 = .50 in. Hg. x 1,000 feet = 500 feet. Subtracting 500 feet from 4,000 equals 3,500 feet).

The four factors that affect density altitude the most are atmospheric pressure, altitude, temperature, and the moisture content of the air.

ATMOSPHERIC PRESSURE

Due to changing weather conditions, atmospheric pressure at a given location changes from day to day. When barometric pressure drops, air density decreases. The reduced density of the air results in an increase in density altitude and decreased glider performance. This reduces takeoff and climb performance and increases the length of runway needed for landing.

When barometric pressure rises, air density increases. The greater density of the air results in lower density altitude. Thus, takeoff and climb performance improves, and the length of runway needed for landing decreases.

ALTITUDE

As altitude increases, air density decreases. At altitude, the atmospheric pressure that acts on a given volume of air is less, allowing the air molecules to space themselves further apart. The result is that a given volume of air at high altitude contains fewer air molecules than the same volume of air at lower altitude. As altitude increases, density altitude increases, and glider takeoff and climb performance is reduced.

TEMPERATURE

Temperature changes have a large affect on density altitude. When air is heated, it expands and the molecules move farther apart, creating less dense air. Takeoff and climb performance is reduced, while the length of runway required for landing is increased.

The effects are different when the air is cool. When air-cools, the molecules move closer together, creating denser air. Takeoff and climb performance improves, and the length of runway required for landing decreases.

The effect of temperature on density altitude can be very great. High temperatures cause even low elevations to have high-density altitudes, resulting in reduced takeoff and climb performance. Very cold temperatures, on the other hand, can result in density altitudes that are far below those at sea level. In this dense, cold air, takeoff and climb performance is enhanced considerably.

MOISTURE

The water vapor content of the air affects air density. Water vapor molecules, consisting of two hydrogen atoms and one oxygen atom, have a relatively low molecular weight. Water vapor molecules in the atmosphere displace gas molecules with higher molecular weights. Therefore, as the water vapor content of the air increases, the air becomes less dense. The result is increased density altitude and decreased takeoff and climb performance.

Relative humidity refers to the amount of water vapor contained in the atmosphere. It is expressed as a percentage of the maximum amount of water vapor the air can hold. Perfectly dry air (air that contains no water vapor) has a relative humidity of 0 percent, while saturated air (air that cannot hold any more water vapor) has a relative humidity of 100 percent.

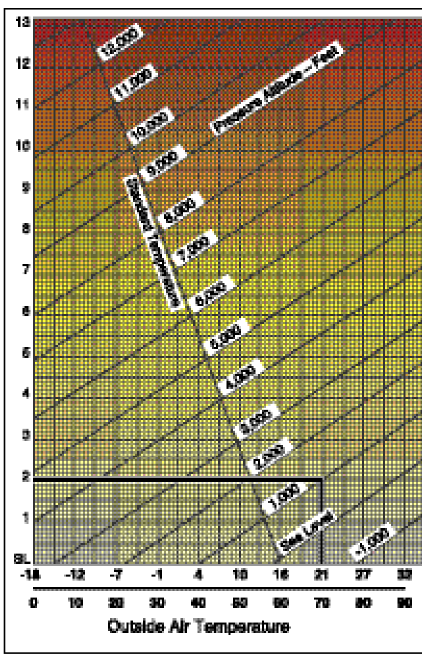
The amount of water vapor that an airmass can sustain is affected by temperature. Cold air can hold a relatively small amount of water as vapor; warm air can hold much more. Increasing the temperature of an airmass by 20°F doubles the amount of water the airmass can hold as water vapor. Increasing the temperature of an airmass by 40°F quadruples the amount of water the airmass can hold. Increasing the temperature of an airmass by 60°F causes an eightfold increase and so on.

By itself, humidity usually is not considered an important factor in calculating density altitude and glider performance. Nevertheless, high humidity does cause a slight decrease in glider takeoff and climb performance. At relatively low temperatures, the effect of humidity is very slight because the total amount of water vapor the airmass can hold is relatively small. At relatively high temperatures, on the other hand, the effect of humidity is more significant because the total amount of water vapor the airmass can hold is many times larger. There are no rules-of-thumb or charts used to compute the effects of humidity on density altitude. Expect a minor decrease in takeoff performance when humidity is high.

HIGH AND LOW DENSITY ALTITUDE CONDITIONS

Every pilot must understand the terms “high density altitude” and “low density altitude.” In general, high density altitude refers to thin air, while low density altitude refers to dense air. Those conditions that result in a high density altitude (thin air) are high elevations, low atmospheric pressure, high temperatures, high humidity, or some combination thereof. Lower elevations, high atmospheric pressure, low temperatures and low humidity are more indicative of low density altitude (dense air). However, high density altitudes may be present at lower elevations on hot days, so it is important to calculate the density altitude and determine performance before a flight.

One way to determine density altitude is to use charts designed for that purpose. [Figure 5-1] For example, assume you are planning to depart an airport where the field elevation is 1,165 feet MSL, the altimeter setting is 30.10, and the temperature is 70°F. What is the density altitude? First, correct for nonstandard pressure (30.10) by referring to the right side of the chart and subtracting 165 feet from the field elevation. The result is a pressure altitude of 1,000 feet. Then, enter the chart at the bottom, just above the temperature of 70°F (21°C). Proceed up the chart vertically until you intercept the diagonal 1,000-foot pressure altitude line, then move horizontally to the left and read the density alti-



Altimeter Setting	Pressure Altitude Conversion Factor
28.0	1,824
28.1	1,727
28.2	1,630
28.3	1,533
28.4	1,436
28.5	1,340
28.6	1,244
28.7	1,148
28.8	1,053
28.9	957
29.0	863
29.1	768
29.2	673
29.3	579
29.4	485
29.5	392
29.6	298
29.7	205
29.8	112
29.9	20
29.92	0
30.0	-73
30.1	-165
30.2	-257
30.3	-348
30.4	-440
30.5	-531
30.6	-622
30.7	-712
30.8	-803
30.9	-893
31.0	-983

Figure 5-1. Density Altitude Chart.

tude of approximately 2,000 feet. This means your self-launching glider or towplane will perform as if it were at 2,000 feet MSL on a standard day.

Most performance charts do not require you to compute density altitude. Instead, the computation is built into the performance chart itself. All you have to do is enter the chart with the correct pressure altitude and the temperature. Some charts, however, may require you to compute density altitude before entering them. Density altitude may be computed using a density altitude chart or by using a flight computer.

WINDS

Wind affects glider performance in many ways. Headwind during launch results in shorter ground roll, while tailwind causes longer ground roll before takeoff. Crosswinds during launch require proper crosswind procedures. [Figure 5-2]

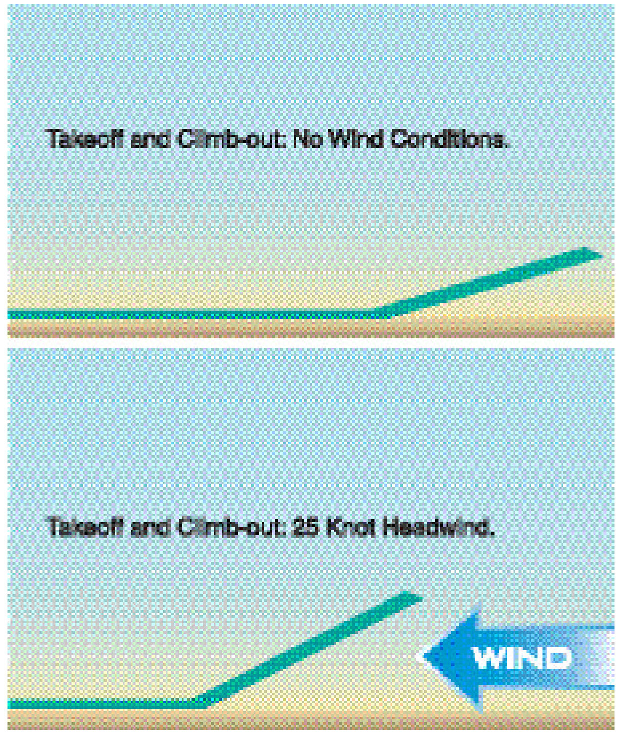


Figure 5-2. Wind effect on takeoff distance and climb-out angle.

During cruising flight, headwinds reduce the groundspeed of the glider. A glider flying at 60 knots true airspeed into a headwind of 25 knots has a groundspeed of only 35 knots. Tailwinds, on the other hand, increase the groundspeed of the glider. A glider flying at 60 knots true airspeed with a tailwind of 25 knots has a groundspeed of 85 knots.

Crosswinds during cruising flight cause glider heading (where the glider nose is pointed) and glider track (the path of the glider over the ground) to diverge. When gliding toward an object on the ground in the presence of crosswind, such as on final glide at the end of a cross-country flight, the glider pilot should keep the nose of the glider pointed somewhat upwind of the target on the ground. For instance, if the crosswind is from the right, during final glide the nose of the glider is pointed a bit to the right of the target on the ground. The glider's heading will be upwind (to the right, in this case) of the target, but if the angle of crab is correct, the glider's track will be straight toward the target on the ground. [Figure 5-3]

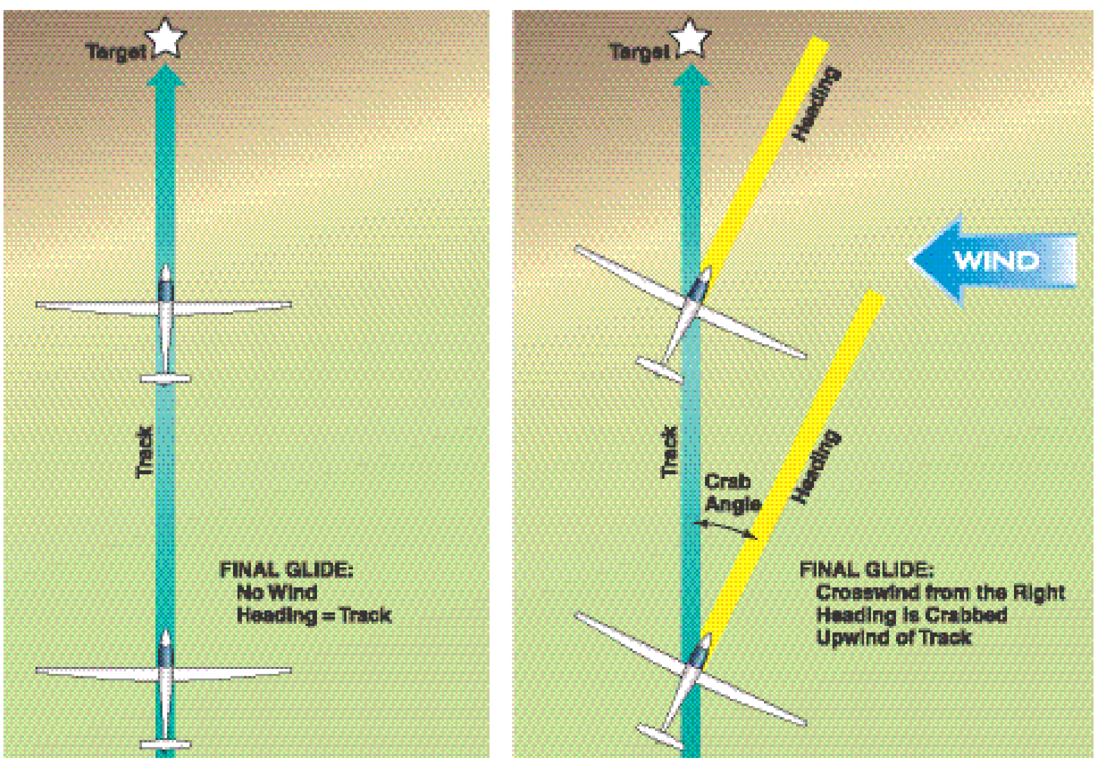


Figure 5-3. Crosswind effect on final glide.

Headwind during landing results in a shortened ground roll and tailwind results in a longer ground roll. Crosswind landings require the pilot to compensate for drift with either a sideslip or a crab. [Figure 5-4]

Some self-launch gliders are designed for extended periods of powered cruising flight. For these self-launch gliders, maximum range (distance) for powered flight and maximum duration (elapsed time aloft) for powered flight is primarily limited by the self-launch glider's fuel capacity. Wind has no effect on flight duration but does have a significant effect on range. During powered cruising flight, a headwind reduces range, and a tailwind increases range. The Glider Flight Manual/Pilot's Operating Handbook (GFM/POH) provides recommended airspeeds and power settings to maximize range when flying in no-win, headwind, or tailwind conditions.

WEIGHT

In gliding, increased weight decreases takeoff and climb performance, but increases high speed cruise performance. During launch, a heavy glider takes longer to accelerate to flying speed. The heavy glider has more inertia making it more difficult to accelerate the mass of a glider to flying speed. After takeoff, the heavier glider takes longer to climb out because the

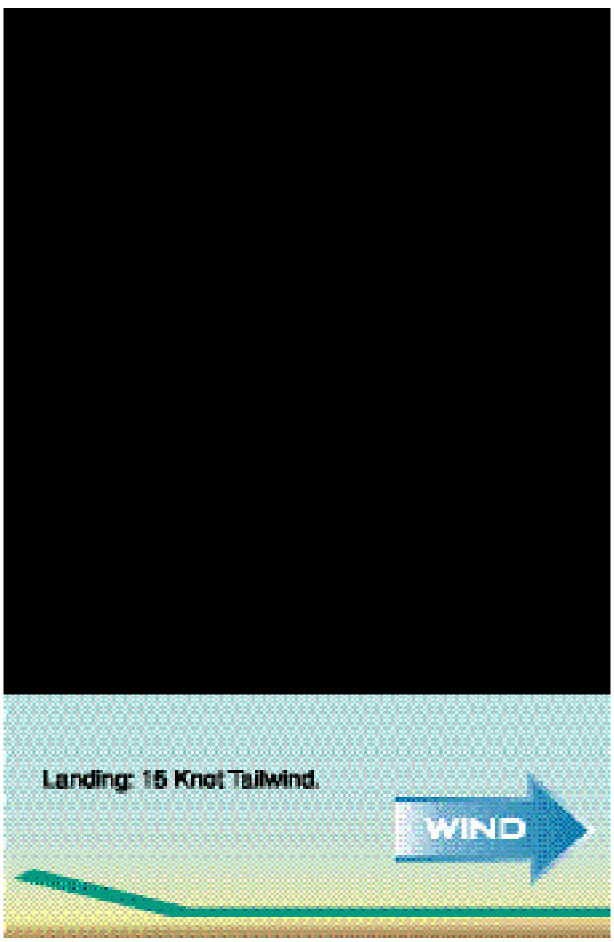


Figure 5-4. Wind effect on final approach and landing distance.

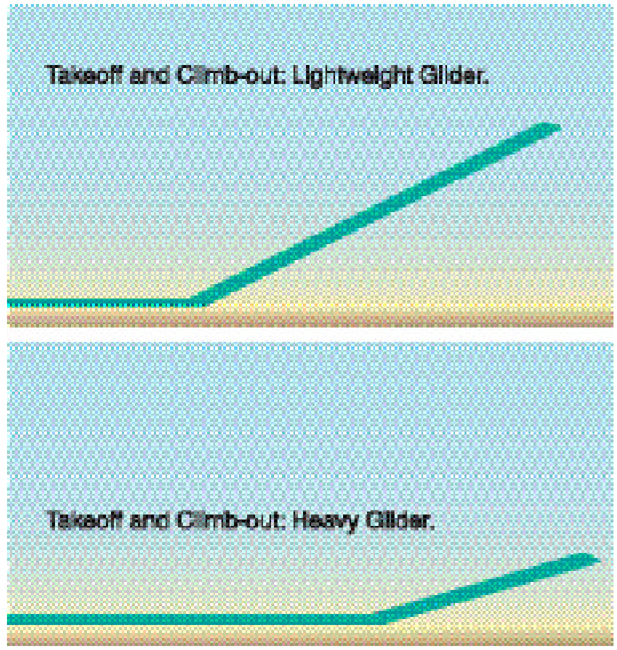


Figure 5-5. Effect of weight on takeoff distance and climbout rate and angle.

heavier glider has more mass to lift to altitude than does the lighter glider (whether ground launch, aerotow launch, or self-launch). [Figure 5-5]

The heavy glider has a higher stall speed and a higher minimum controllable airspeed than an otherwise identical, but lighter, glider. The stall speed of a glider increases with the square root of the increase in weight. If weight of the glider is doubled (multiplied by 2.0), then the stall speed increases by more than 40 percent (1.41 is the approximate square root of 2; 1.41 times the old stall speed results in the new stall speed at the heavier weight).

When circling in thermals to climb, the heavy glider is at a disadvantage relative to the light glider. The increased weight of the heavy glider means stall airspeed and minimum sink airspeed is faster than they would be if the glider were operating at a light weight. At any given bank angle, the heavy glider's faster airspeeds mean the pilot must fly larger diameter thermaling circles than the pilot of the light glider. Since the best lift in thermals is often found in a narrow cylinder near the core of the thermal, larger diameter circles generally mean the heavy glider is unable to exploit the strong lift of the thermal core, as well as the slower, lightweight glider. This results in the heavy glider's inability to climb as fast in a thermal as the light glider. [Figure 5-6]

The heavy glider can fly faster than the light glider while maintaining the same glide ratio as the light glider. The advantage of the heavier weight becomes apparent during cruising flight. The heavy glider can

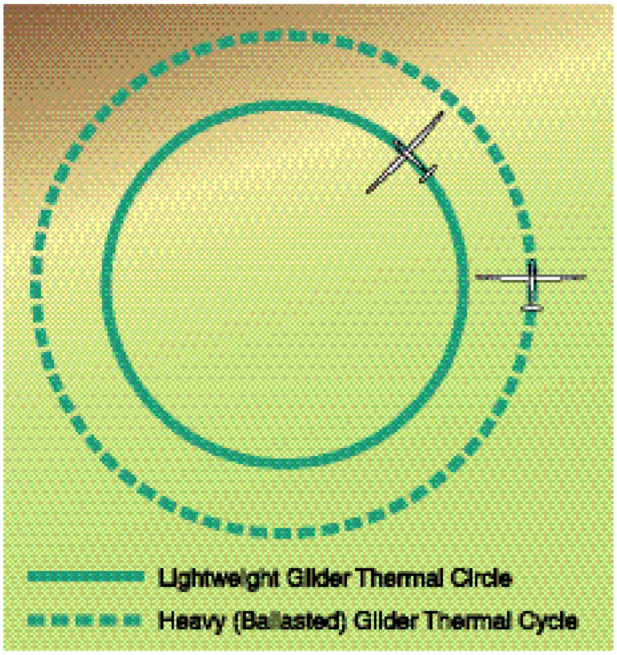


Figure 5-6. Effect and added weight on thermaling turn radius.

fly faster than the light glider and still retains the same lift/drag (L/D) ratio.

If the operating weight of a given glider is increased, the stall airspeed, the minimum controllable airspeed, the minimum sink airspeed, and the **best L/D airspeed** will be increased by a factor equal to the square root of the increase in weight. [Figure 5-7]

The addition of **ballast** to increase weight allows the glider to fly at faster airspeeds while maintaining its L/D ratio. The table in Figure 5-7 shows that adding 400 pounds of water ballast increases the best L/D airspeed from 60 knots to 73 knots. The heavy glider will have more difficulty climbing in thermals than the light glider, but if lift is strong enough for the heavy glider to climb reasonably well, the heavy glider's advantage during the cruising portion of flight will outweigh the heavy glider's disadvantage during climbs.

Water is often used as ballast to increase the weight of the glider. However, the increased weight will require a higher airspeed during the approach and a longer landing roll. Once the cross-country phase is completed, the water ballast serves no further purpose. The pilot should jettison the water ballast prior to entering the traffic pattern. Reducing the weight of the glider prior to landing allows the pilot to make a normal approach and landing. The lighter landing weight also reduces the loads that the landing gear of the glider must support.

Rate of Climb

Rate of climb for the ground-launched glider primarily depends on the strength of the ground-launch equipment. When ground launching, rates-of-climb generally are quite rapid, and can exceed 2,000 feet per minute if the winch or tow vehicle is very powerful.

When aerotowing, rate-of-climb is determined by the power of the towplane. It is important when selecting a towplane, to ensure that it is capable of towing the glider considering the existing conditions and glider weight.

Self-launching glider rate-of-climb is determined by design, powerplant output and glider weight. The rate-of-climb of self-launch gliders may vary from as low as 200 feet per minute to as much as 800 feet per minute or more in others. The pilot should consult the GFM/POH to determine rate-of-climb under the existing conditions.

FLIGHT MANUALS AND PLACARDS

AREAS OF THE MANUAL

The GFM/POH provides the pilot with the necessary performance information to operate the glider safely. A GFM/POH may include the following information.

- Description of glider primary components.
- Glider Assembly.
- Weight and balance data.
- Description of glider systems.
- Glider performance.
- Operating limitations.

OPERATING WEIGHT	STALL AIRSPEED	MINIMUM SINK	BEST L/D AIRSPEED
800 Pounds	36 Knots	48 Knots	60 Knots
1200 Pounds	44 Knots	58 Knots	73 Knots
1600 Pounds	50 Knots	68 Knots	83 Knots

Figure 5-7. Effect of added weight on performance airspeeds.

PLACARDS

Cockpit **placards** provide the pilot with readily available information that is essential for the safe operation of the glider. All required placards are located in the GFM/POH.

The amount of information that placards must convey to the pilot increases as the complexity of the glider increases. High performance gliders may be equipped with wing flaps, retractable landing gear, a water ballast system, drogue chute for use in the landing approach, and other features than are intended to enhance performance. These gliders may require additional placards. [Figure 5-8]

PERFORMANCE INFORMATION

The GFM/POH is the source provided by the manufacturer for glider performance information. In the GFM/POH, glider performance is presented as terms of specific airspeed such as stall speed, minimum sinking airspeed, best L/D airspeed, maneuvering speed, rough air speed, and V_{NE}.

Some performance airspeeds apply only to particular types of gliders. Gliders with wing flaps, for instance, have a maximum permitted flaps extended airspeed (V_{FE}).

Manuals for self-launch gliders include performance information about powered operations. These include rate-of-climb, engine and propeller limitations, fuel consumption, endurance, and cruise.

GLIDER POLARS

In addition, the manufacturer provides information about the rate of sink in terms of airspeed, which is summarized in a graph called a polar curve, or simply a polar. [Figures 5-9].

The vertical axis of the polar shows the sink rate in knots (increasing sink downwards), while the horizontal axis shows airspeed in knots. Every type of glider has a characteristic polar derived either from theoretical calculations by the designer or by actual in-flight measurement of the sink rate at different speeds. The polar of each individual glider will vary (even from other gliders of the same type) by a few percent depending on relative smoothness of the wing surface, the amount of sealing around control surfaces, and even the number of bugs on the wing's leading edge. The polar forms the basis for **speed-to-fly** and final glide tools that will be discussed in Chapter 11–Cross-Country Soaring.

Minimum sink rate is determined from the polar by extending a horizontal line from the top of the polar to the vertical axis. The **minimum sink speed** is found by drawing a vertical line from the top of the polar to the horizontal axis. [Figure 5-10]. In this example, a minimum sink of 1.9 knots occurs at 40 knots. Note that the sink rate increases between minimum sink speed and the stall speed (the left-hand end point of the polar). The best glide speed (best L/D) is found by drawing a tangent to the polar from the origin. The best L/D speed is 50 knots. The glide ratio at best L/D speed is determined by dividing the best L/D speed by the sink rate at that speed, or 50/1.9, which is approximately 26. Thus, this glider has a best glide ratio in calm air (no lift or sink and no headwind or tailwind) of 26:1 at 50 knots.

The best speed-to-fly in a headwind is easily determined from the polar. To do this, shift the origin to the right along the horizontal axis by the speed of the headwind and draw a new tangent line to the polar. From the new tangent point, draw a vertical line to read the best speed-to-fly. An example for a 20 knot headwind is shown in Figure 5-11. The speed-to-fly in a 20 knot headwind is found to be 60 knots. By

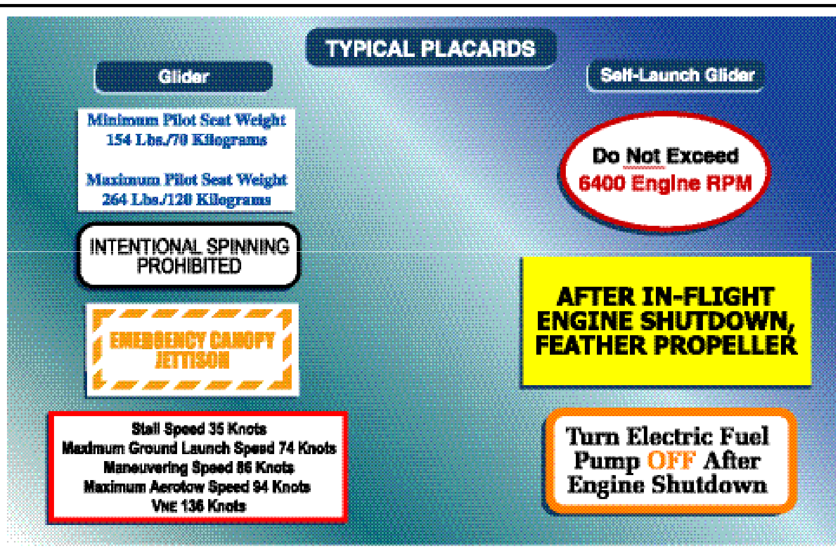


Figure 5-8. Typical placards for non-motorized and self-launch glider.

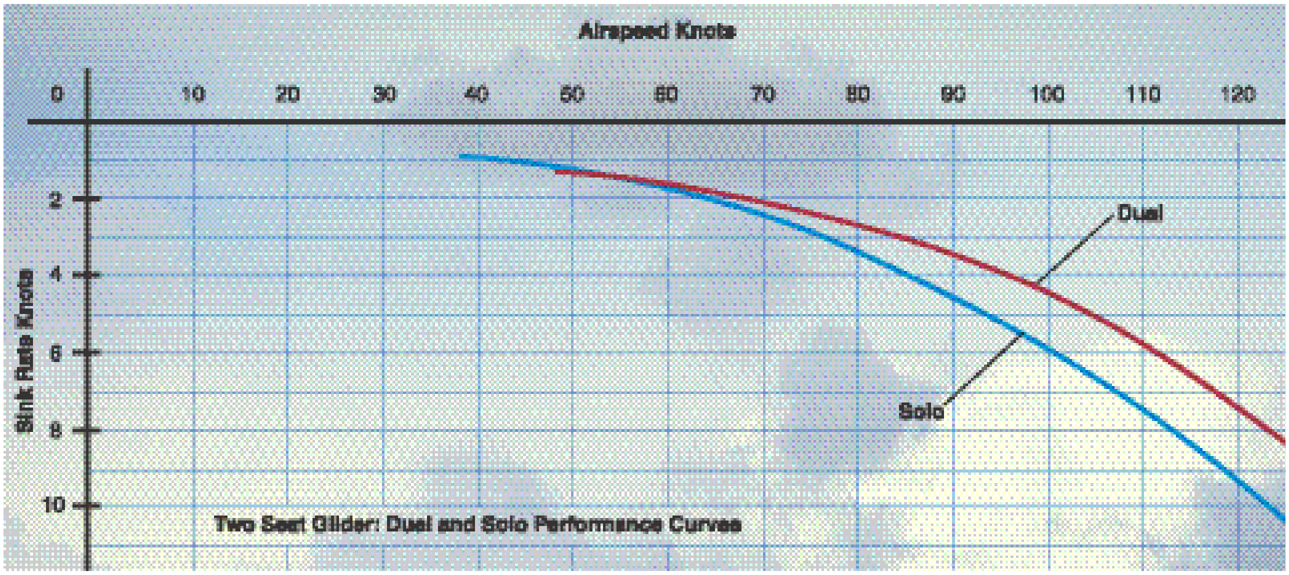


Figure 5-9. Dual and solo performance curves for a two-seat glider.

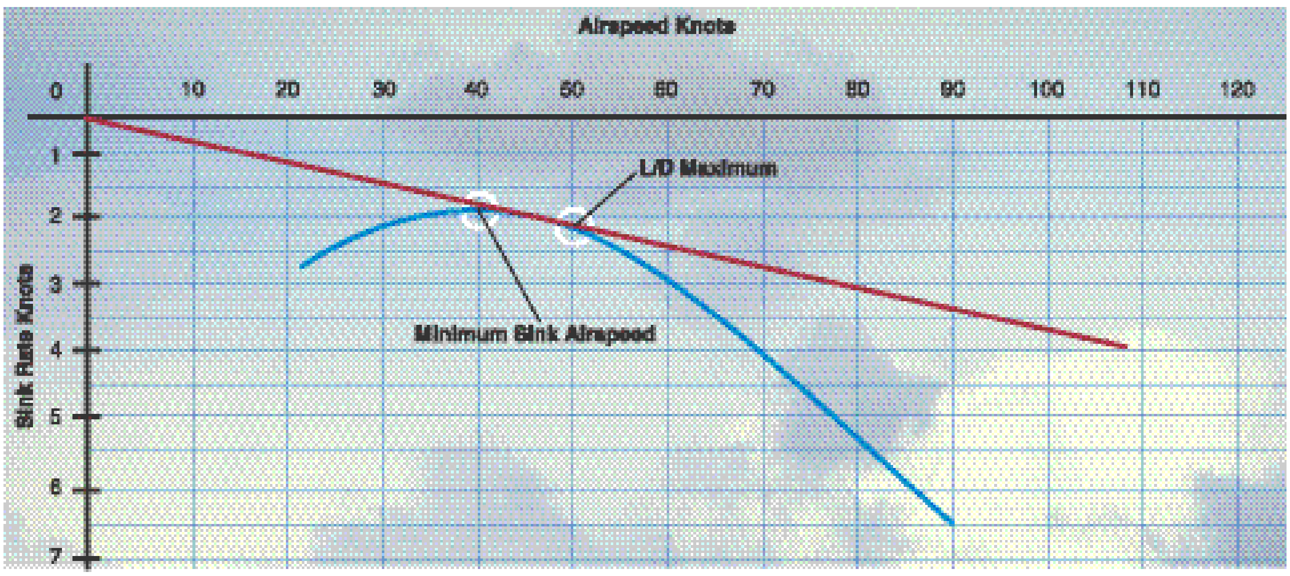


Figure 5-10. Graphic depiction of minimum sink airspeed and maximum L/D speed.

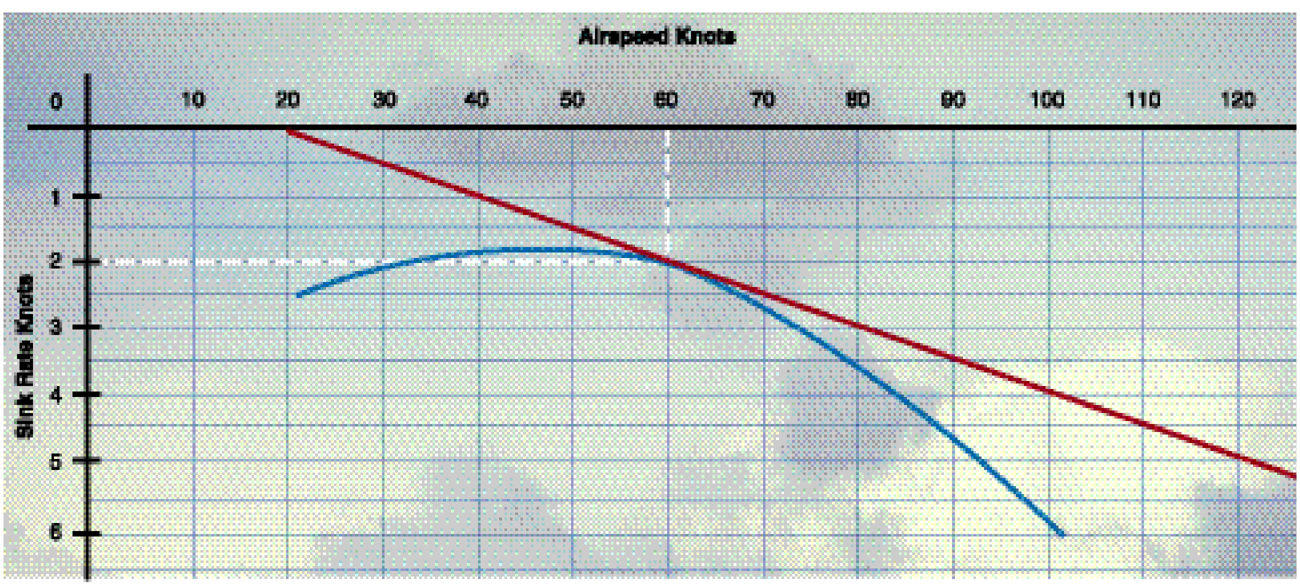


Figure 5-11. Best speed-to-fly in a 20-knot headwind.

repeating the procedure for different headwinds, it is apparent that flying a faster airspeed as the headwind increases will result in the greatest distance over the ground. If this is done for the polar curves from many gliders, a general rule of thumb is found, namely, add half the headwind component to the best L/D for the maximum distance. For tailwinds, shift the origin to the left of the '0' mark on the horizontal axis. The speed-to-fly in a tailwind is found to lie between minimum sink and best L/D but never slower than minimum sink speed.

Sinking air usually exists between thermals, and it is most efficient to fly faster than best L/D in order to spend less time in sinking air. How much faster to fly can be determined by the glider polar, as illustrated in Figure 5-12 for an air mass that is sinking at 3 knots. The polar graph in this figure has its vertical axis extended upwards. Shift the origin vertically by 3 knots and draw a new tangent to the polar, then draw a line vertically to read the best speed-to-fly. For this glider, the best speed-to-fly is found to be 60 knots. Note that the variometer will show the total sink of 5 knots as illustrated in the figure.

If the glider is equipped with water ballast, wing flaps, or wingtip extensions, the performance characteristics of the glider will be depicted in multiple configurations. [Figures 5-13, 5-14, and 5-15]. Comparing the polar with and without ballast [Figure 5-13] it is evident that the minimum sink is higher and occurs at a faster speed. With ballast, therefore, it would be more difficult to work small, weak thermals. The best glide ratio is the same, but it occurs at a higher speed. In addition, the sink rate at higher speeds is lower with ballast. From the polar, then, ballast should be used under stronger thermal conditions for better speed between thermals. Note that the stall speed is higher with ballast as well.

Flaps with a negative setting as opposed to a '0' degree setting during cruise also reduce the sink rate at higher speeds, as shown in the polar [Figure 5-14]. Therefore, when cruising at or above 70 knots, a –8 flap setting would be advantageous for this glider. The polar with flaps set at –8 does not extend to speeds slower than 70 knots since the negative flap setting loses its advantage there.

Wing-tip extensions will also alter the polar, as shown in [Figure 5-15]. The illustration shows that the additional 3 meters of wing span is advantageous at all speeds. In some gliders, the low-speed performance is better with the tip extensions, while high-speed performance is slightly diminished by comparison.

WEIGHT AND BALANCE INFORMATION

The GFM/POH provides information about the weight and balance of the glider. This information is correct when the glider is new as delivered from the factory. Subsequent maintenance and modifications can alter weight and balance considerably. Changes to the glider that affect weight and balance should be noted in the airframe logbook and on appropriate cockpit placards. Maximum Fuselage Weight: 460 pounds

Weight is the force with which gravity attracts a body toward the center of the earth. It is a product of the mass of a body and the acceleration acting on the body. Weight is a major factor in glider construction and operation; it demands respect from all pilots. The pilot of a glider should always be aware of the comsequences of overloading.

LIMITATIONS

Whether the glider is very simple or very complex, designers and manufacturers provide operating limita-

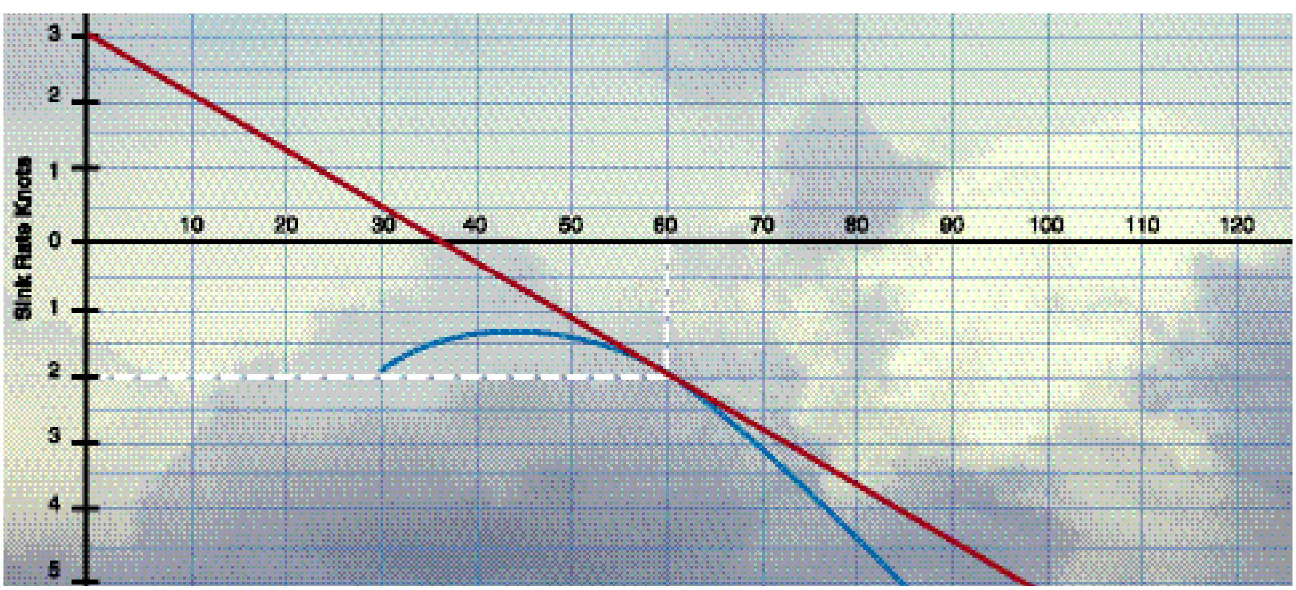


Figure 5-12. Best speed-to-fly in sink.

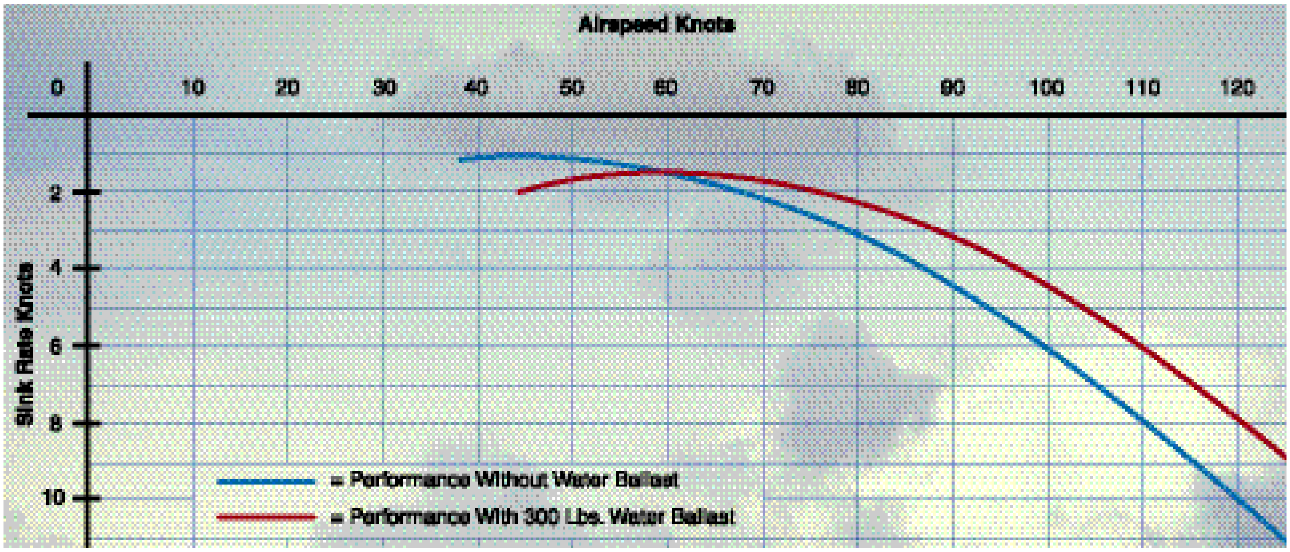


Figure 5-13. Effect of water ballast on performance polar.

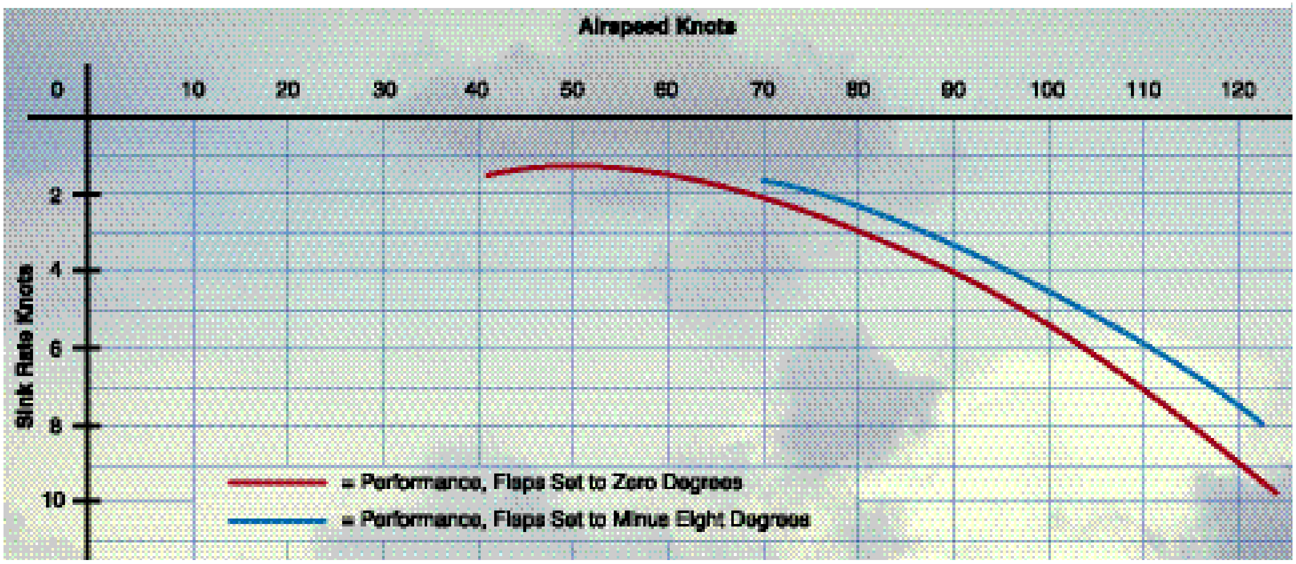


Figure 5-14. Performance polar with flaps at 0° and minus 8°.

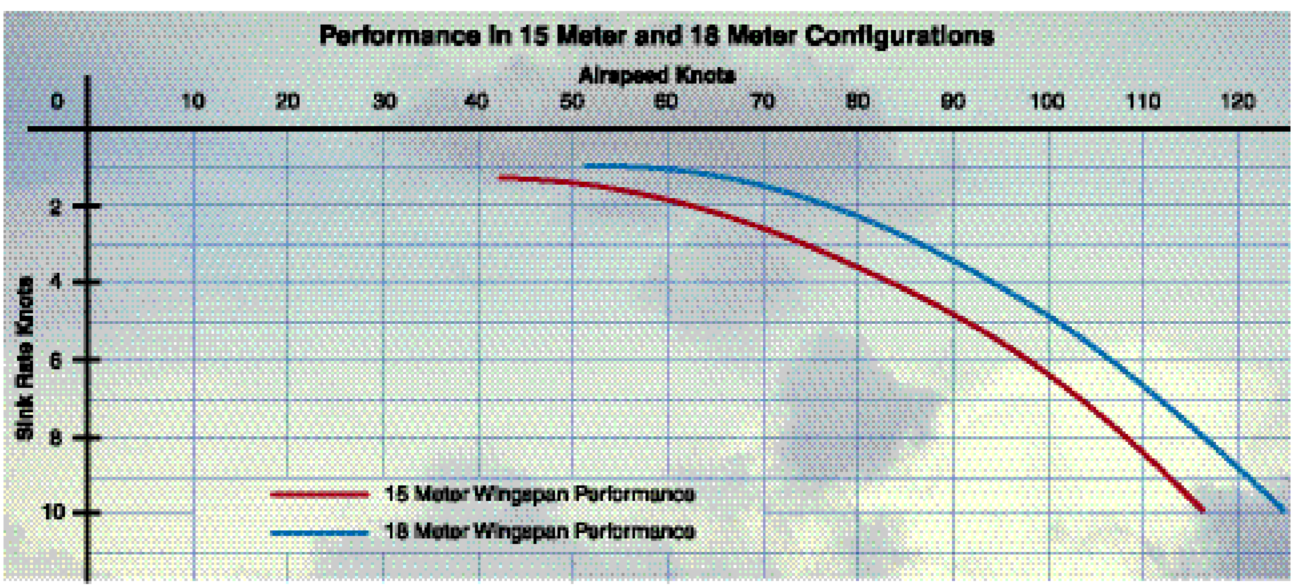


Figure 5-15. Performance polar with 15 meter and 18 meter wingspan configurations.

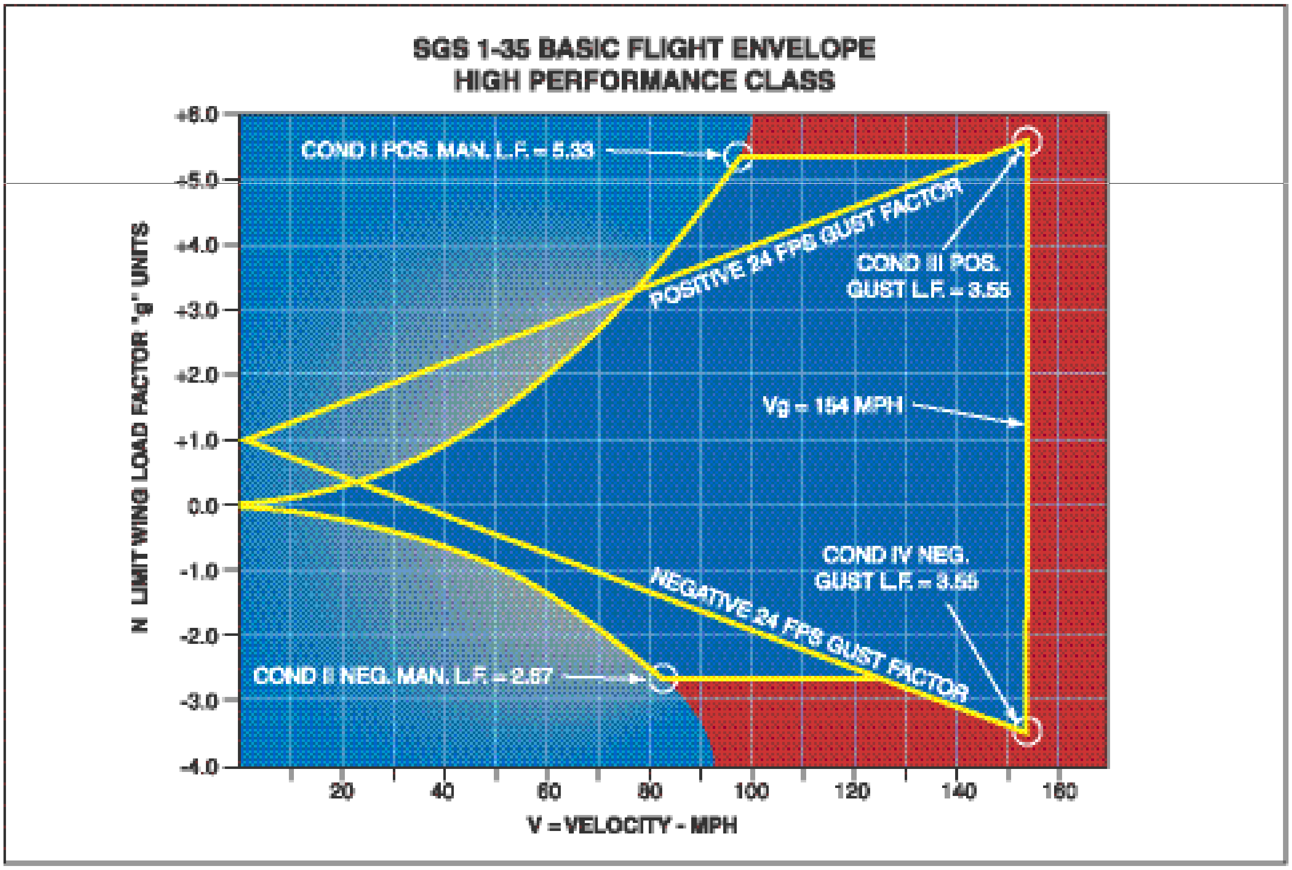


Figure 5-16. VG Diagram.

tions which must be complied with to ensure the safety of flight.Weight is a major factor in glider construction and operation; it demands respect from all pilots. The pilot of a glider should always be aware of the consequences of overloading.The V-G diagram provides the pilot with information on the design limitations of the glider such as limiting airspeeds and load factors. Pilots familiarize themselves with all the operating limitations of each glider they fly. [Figure 5-16]

TERMS AND DEFINITIONS

The pilot should be familiar with terms used in working the problems related to weight and balance. The following list of terms and their definitions is well standardized, and knowledge of these terms will aid the pilot to better understand weight and balance calculations of any glider.

- Arm (moment arm)—is the horizontal distance in inches from the reference datum line to the center of gravity of an item. The algebraic sign is plus (+) if measured aft of the datum, and minus (–) if measured forward of the datum.
- Ballast—is a removable weight installed to meet minimum balance conditions to comply with center of gravity limitations. Ballast may also be in the form of water used to enhance the performance of the glider.
- Center of gravity (CG)—is the point about which a glider would balance if it were possible to suspend it at that point. It is the mass center of the glider, or the theoretical point at which the entire weight of the glider is assumed to be concentrated. It may be expressed in inches from the reference datum, or in percent of mean aerodynamic chord (MAC).
- Center-of-gravity limits—are the specified forward and aft points within which the CG must be located during flight. These limits are indicated on pertinent glider specifications.
- Center-of-gravity range—is the distance between the forward and aft CG limits indicated on pertinent glider specifications.
- Datum (reference datum)—is an imaginary vertical plane or line from which all measurements of arm are taken. The manufacturer establishes the datum. Once the datum has been selected, all moment arms and the location of CG range are measured from this point.
- Empty weight—is the weight as established by the manufacturer, and which may be modified by addition or deletion of equipment.
- Fuel load—is the expendable part of the load of the self-launch glider. It includes only usable

fuel, not fuel required to fill the lines or that which remains trapped in the tank sumps.

- Maximum gross weight—is a weight limitation established by the manufacturer that must not be exceeded. Some gliders may have two maximum gross weights, one with ballast and one without.

- Mean aerodynamic chord (MAC)—is the average distance from the leading edge to the trailing edge of the wing. Some GFM/POHs present the acceptable CG range as a percent of the Mean Aerodynamic Chord (MAC).

- Moment—is the product of the weight of an item multiplied by its arm. Moments are expressed in pound-inches (lb.-in). Total moment is the weight of the airplane multiplied by the distance between the datum and the CG.

- Moment index (or index)—is a moment divided by a constant, such as 100, 1,000, or 10,000. The purpose of using a moment index is to simplify weight and balance computations of gliders where heavy items and long arms result in large, unmanageable numbers.

- Standard weights—have been established for numerous items involved in weight and balance computations. These weights should not be used if actual weights are available. Some of the standard weights are:

  Gasoline..6 lb./US gal
  Oil..7.5 lb./US gal
  Water..8.35 lb./US gal

- Station—is a location in the airplane that is identified by a number designating its distance in inches from the datum. The datum is, therefore, identified as station zero. An item located at station +50 would have an arm of 50 inches.

- Useful load—is the weight of the pilot, passengers, baggage, ballast, usable fuel, and drainable oil. It is the empty weight subtracted from the maximum allowable gross weight.

CENTER OF GRAVITY

Longitudinal balance affects the stability of the longitudinal axis of the glider. To achieve satisfactory pitch attitude handling in a glider, the CG of the properly loaded glider is forward of the Center of Pressure (CP). When a glider is produced the manufacturer provides glider center-of-gravity limitations, which must be complied with. These limitations are generally found in the GFM/POH and may also be found in the glider airframe logbook. Addition or removal of equipment, such as radios, batteries, flight instruments, or airframe repairs, can have an effect on the center of gravity position. Aviation maintenance technicians must record any changes in the weight and balance data in the GFM/POH or glider airframe logbook. Weight and balance placards in the cockpit must also be updated.

PROBLEMS ASSOCIATED WITH CG FORWARD OF FORWARD LIMIT

If the center of gravity is within limits, pitch attitude control stays within acceptable limits. However, if the glider is loaded so the CG is forward of the forward limit, handling will be compromised. Nose heaviness will make it difficult to raise the nose on takeoff and considerable back pressure on the control stick will be required to control the pitch attitude. Stalls will occur at higher than normal airspeeds and will be followed by a rapid nose-down pitch tendency. Restoring a normal flight attitude during stall recoveries will take longer. The landing flare will be more difficult than normal, or perhaps even impossible, due to nose heaviness. Inability to flare could result in a hard nose-first landing.

The following are the most common reasons for CG forward of forward limit.

- Pilot weight exceeds the maximum permitted pilot weight.

- Seat or nose ballast weights are installed but are not required due to the weight of the pilot.

PROBLEMS ASSOCIATED WITH CG AFT OF AFT LIMIT

If the glider is loaded so the CG location is behind the aft limit, handling is compromised. The glider is said to be tail-heavy. Tail heaviness can make pitch control of the glider difficult or even impossible.

When the glider is tail-heavy recovering from a stall may be difficult or impossible. When the stall occurs, the tail-heavy loading tends to make the glider nose continue to pitch upward, increasing angle of attack and complicating stall recovery. In extreme cases, recovery from stall or spin may be difficult or even impossible.

The following are the most common reasons for flight with CG located behind permissible limits.

- Pilot weight is less than the specified minimum pilot seat weight and trim ballast weights necessary for the lightweight pilot are not installed in the glider prior to flight.

- Tailwheel dolly is still attached, far aft on the tailboom of the glider.

- Foreign matter or debris (water, ice, mud, sand, and nests) has accumulated in the aft fuselage of the glider and was not discovered and removed prior to flight.

- A heavy, non-approved tailwheel or tail skid was installed on the aft tailboom of the glider.

- Improper repair of the aft fuselage of the glider resulted in an increase in aft weight of the fuselage that was not recorded in the glider airframe logbook, or not reflected in cockpit placards, or both.

SAMPLE WEIGHT AND BALANCE PROBLEMS

Some glider manufacturers provide weight and balance information in a graphic presentation. A well-designed graph provides a convenient way to determine whether the glider is within weight and balance limitations.

In Figure 5-17, the chart indicates that the minimum weight for the front seat pilot is 125 pounds, and that the maximum is 250 pounds. It also indicates that the maximum rear seat pilot weight is 225 pounds. If each pilot weighs 150 pounds, the intersection of pilot weights falls within the envelope and the glider load is within the envelope and is safe for flight. If each pilot weights 225 pounds, the rear seat maximum load is exceeded, and the glider load is outside the envelope and not safe for flight.

DETERMINING CG WITHOUT LOADING CHARTS

The CG position can also be determined by calculation using the following formulas:

Weight multiplied by Arm equals Moment

Weight x Arm = Moment

Total Moment divided by Total weight equals CG position in inches aft of the reference datum.

Total Moment • Total Weight = CG

The computational method involves the application of basic math functions. The following is an example of the computational method.

Given:

Maximum Gross Weight....................1,100 lb.
Empty Weight......................................600 lb.
Center-of-Gravity Range..........14.8 – 18.6 in.
Front Seat Occupant.............................180 lb.
Rear Seat Occupant..............................200 lb.

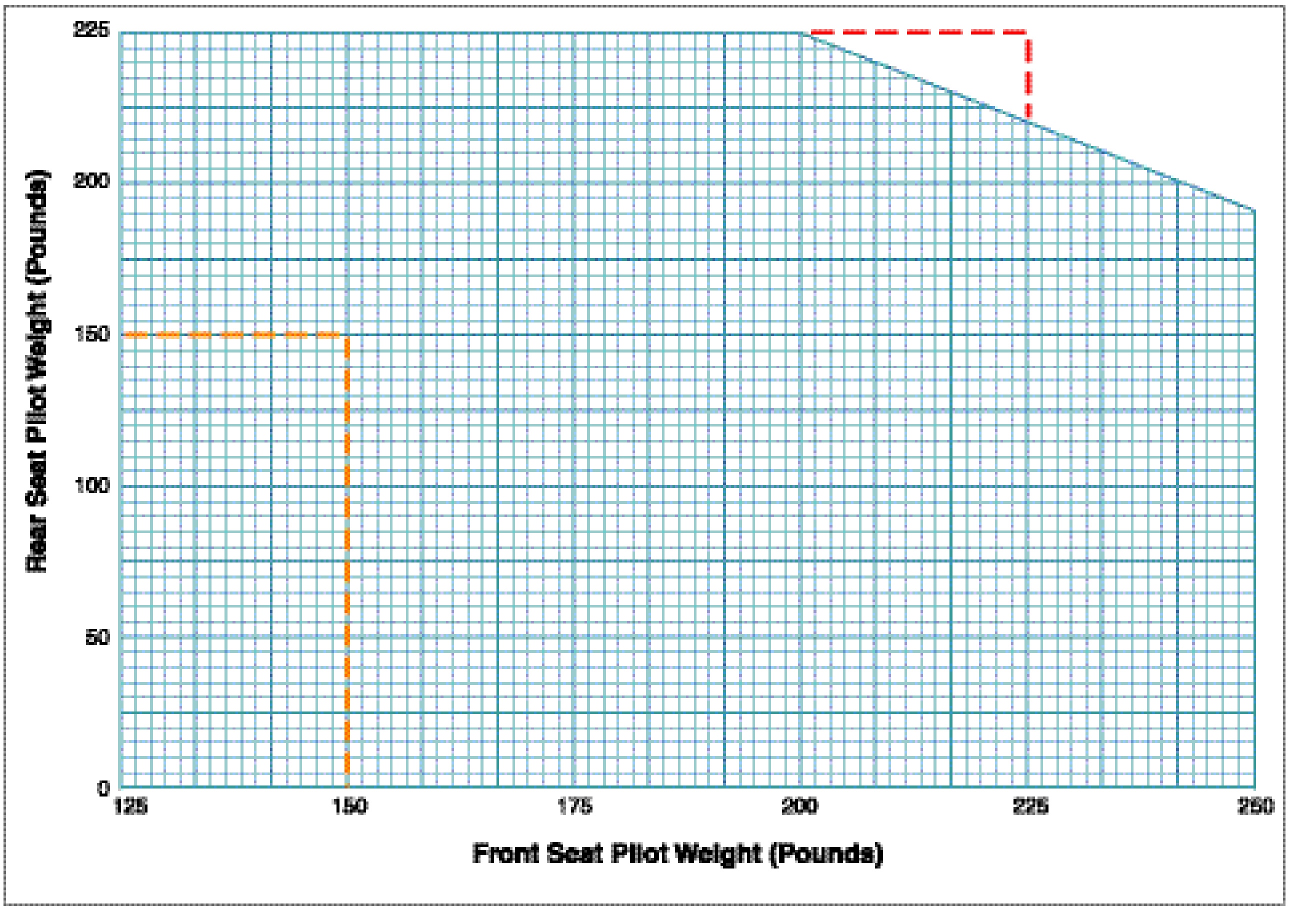


Figure 5-17. Graphic presentation of weight and balance envelope.

To determine the loaded weight and CG, follow these steps.

Step 1—List the empty weight of the glider and the weight of the occupants.

Step 2—Enter the moment for each item listed. Remember "weight x arm = moment." To simplify calculations, the moments may be divided by 100.

Step 3—Total the weight and moments.

Step 4—To determine the CG, divide the moments by the weight.

NOTE: The weight and balance records for a particular glider will provide the empty weight and moment as well as the information on the arm distance. [Figure 5-18]

In Figure 5-18, the weight of each pilot has been entered into the correct block in the table. For the front seat pilot, multiplying 180 pounds by +30 inches yields a moment of +5400 inch/pounds. For the rear seat pilot, multiplying 200 pounds by -5 inches yields a moment of -1000 inch/pounds.

The next step is to find the sum of all weights, and record it: 980 pounds. Then, find the sum of all moments, and record it: +16,400 inch/pounds.

Now we can find the Arm (the CG position) of the loaded glider. Divide the total moment by the total weight to discover the CG of the loaded aircraftglider. So, +16,400 divided by 980 = +16.73 inches from datum. [Figure 5-20]

We now know the total weight (980 pounds) and the CG location (+16.73 inches from datum) of the loaded glider. The final step is to determine whether these two values are within acceptable limits. The GFM/POH lists the maximum gross weight as 1,100 pounds. The operating weight of 980 pounds is less than 1,100 pounds maximum gross weight. The GFM/POH lists the approved CG range as between +14.80 inches and +18.60 inches from datum. The operating CG is +16.73 inches from datum and is within these limits. We have determined that the weight and balance are within operating limits.

BALLAST WEIGHT

Ballast weight is non-structural weight that is added to a glider. In gliding, ballast weight is used for two purposes. Trim ballast is used to adjust the location of the center of gravity of the glider so handling characteristics remain within acceptable limits. Performance ballast is loaded into the glider to improve high-speed cruise performance.

Removable trim ballast weights are usually made of metal and are bolted into a ballast receptacle incorporated in the glider structure. The manufacturer generally provides an attachment point well forward in the glider cabin for trim ballast weights. These weights are designed to compensate for a front seat pilot who weighs less than the minimum permissible front seat pilot weight. The ballast weight mounted well forward in the glider cabin helps place the CG within permissible limits.

Some trim ballast weights are in the form of seat cushions, with sand or lead shot sewn into the unit to provide additional weight. This type of ballast, which is installed under the pilot's seat cushion, is inferior to bolted-in ballast because of the propensity to shift position. Seat cushion ballast should never be used during acrobatic or inverted flight.

EFFECTS OF WATER BALLAST

Sometimes trim ballast is water placed in a tail tank in the vertical fin of the fuselage. The purpose of the fin trim ballast tank is to adjust CG location after water is added to, or drained from, the main wing ballast tanks. Unless the main wing ballast tanks are precisely centered on the center of gravity of the loaded aircraftglider, CG location shifts when water is added to the main ballast tanks. CG location shifts

ITEM	WEIGHT (POUNDS)	ARM (INCHES)	MOMENT (INCH/POUNDS)
EMPTY WEIGHT	600	+20	12,000
FRONT SEAT PILOT	180	+30	+5,400
REAR SEAT PILOT	200	-5	-1,000
	980 Total Weight	+16.73	+16,400 Total Mom.

Figure 5-18. Weight and balance: front and rear seat pilot weights and moments.

again when water is dumped from the main ballast tanks. Adjusting the amount of water in the fin tank compensates for CG shifts resulting from changes in the amount of water ballast carried in the main wing ballast tanks. Water weighs 8.35 pounds per gallon. Because the tail tank is located far aft, it does not take much water to have a considerable effect on CG location. For this reason, tail tanks do not need to contain a large volume of water. Tail tank maximum water capacity is generally less than two gallons of water.

Although some older gliders employed bags of sand or bolt-in lead weights as performance ballast, water is used most commonly to enhance high-speed performance in modern sailplanes. Increasing the operating weight of the glider increases the optimum speed-to-fly during wings-level cruising flight. The higher groundspeed that result provide a very desirable advantage in cross-country soaring and in sailplane racing.

Water ballast tanks are located in the main wing panels. Clean water is added through fill ports in the top of each wing. In most gliders, the water tanks or bags can be partially or completely filled, depending on the pilot's choice of operating weight. After water is added, the filler caps are replaced to prevent water from sloshing out of the filler holes.

Drain valves are fitted to the bottom of each tank. The valves are controlled from inside the cockpit. The tanks can be fully or partially drained while the glider is on the ground to reduce the weight of the glider prior to launch, if the pilot so desires. The ballast tanks also can be partially or completely drained in flight—a process called dumping ballast. The long streaks of white spray behind a speeding airborne glider are dramatic evidence that the glider pilot is dumping water ballast, most likely to lighten the glider prior to landing. The filler caps are vented to allow air to enter the tanks to replace the volume of water draining from the tanks. It is important to ensure that the vents are working properly to prevent wing damage when water ballast is drained or jettisoned. [Figures 5-19 and 5-20]

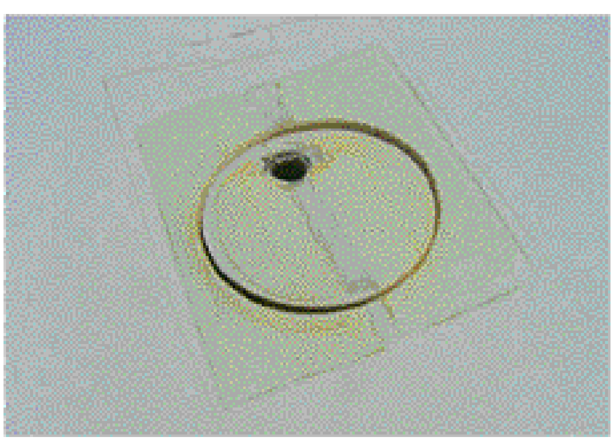


Figure 5-19. Water ballast tank vented filler cap.

It is important to check the drain valves for correct operation prior to flight. Water ballast should drain from each wing tank at the same rate. Unequal draining leads to a wing-heavy condition that makes in-flight handling, as well as landings, more difficult. If the wing-heavy condition is extreme, it is possible the pilot will lose control of the glider.

Ballast drains should also be checked to ensure that water ballast drains properly into the airstream, rather than leaking into the fuselage and pooling in the bottom of the fuselage. Water that is trapped in the fuselage may flow through or over bulkheads, causing dislocation of the CG of the glider. This can lead to loss of control of the glider.

The flight manual provides guidance as to the length of time it takes for the ballast tanks to drain completely. For modern gliders, it takes about 3 to 5 minutes to drain a full tank. When landing is imminent, dump ballast early enough to give the ballast drains sufficient time to empty the tanks.

Use of water ballast when ambient temperatures are low can result in water freezing the drain valve. If the drain valve freezes, dumping ballast is difficult or impossible. If water in the wings is allowed to freeze, serious wing damage is likely to occur. Damage occurs because the volume of water expands during the freezing process. The resulting increased volume can deform ribs and other wing structures, or cause glue bonds to de-laminate. When weather or flight conditions are very cold, do not use water ballast unless anti-freeze has been added to the water. Prior to using an anti-freeze solution, consult the glider flight manual to ensure that anti-freeze compounds are approved for use in the glider.

A glider carrying large amounts of water ballast has noticeably different handling characteristics than the same glider without water ballast. Water ballast:

- Reduces the rate of acceleration of the glider at the beginning of the launch due to the increased glider weight.
- Increases the length of ground roll prior to glider liftoff.
- Increases stall speed.
- Reduces aileron control during the takeoff roll, increasing the chance of uncontrolled wing drop and resultant ground loop.
- Reduces rate of climb during climb-out.
- Reduces aileron response during free flight. The addition of large amounts of water increases lat-

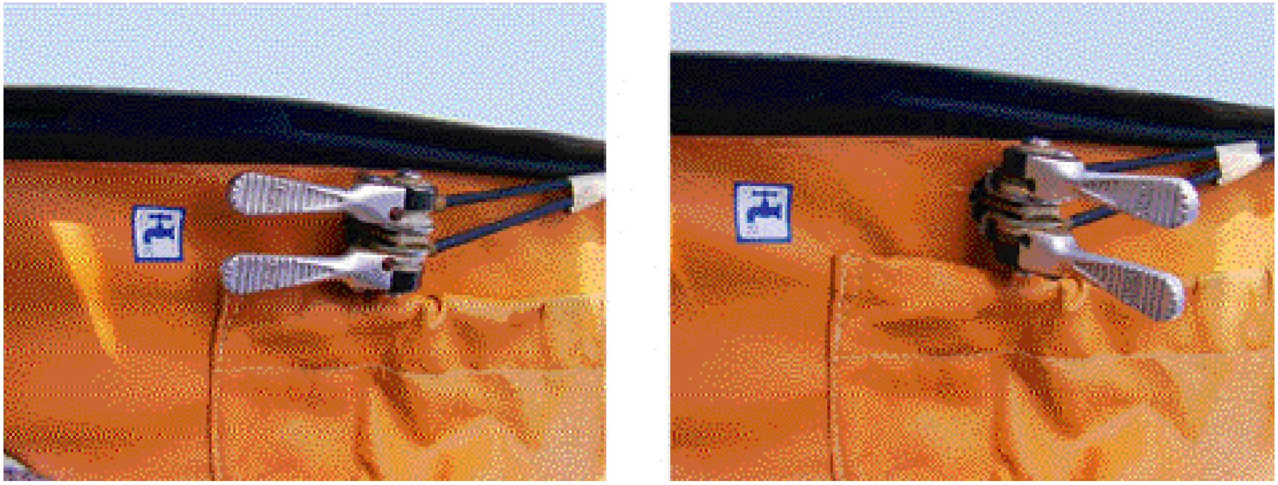


Figure 5-20. Water ballast drain valve handles.

eral stability substantially. This makes quick banking maneuvers difficult or impossible to perform.

Water ballast is routinely dumped before landing to reduce the weight of the glider. Dumping ballast:

- Decreases stall speed.
- Decreases the optimum airspeed for the landing approach.
- Shortens landing roll.
- Reduces the load that glider structures must support during landing and rollout.

The performance advantage of water ballast during strong soaring conditions is considerable. However, there is a down side. The pilot should be aware that water ballast degrades takeoff performance, climb rate, and low speed handling. Before committing to launching with water ballast aboard, the pilot should review operating limitations to ensure the safety of flight will not be comprised.