THEORY OF GLIDER FLIGHT

In 1988 the Soaring Society rewrote the *Joy Of Soaring* originally written by Carle Conway. I was asked to assist in the rewriting. The following revision is part of what I recommended. It is a good Introduction to the Theory of Glider Flight. Bret Willat

WING, FUSELAGE AND TAIL

Most gliders consist of three basic components: the wing, the fuselage, and the tail surfaces. The wing supports the glider, and the ailerons and tail surfaces provide stability and control. The fuselage performs the dual function of holding the wing and tail in proper relationship to each other and of providing cockpit space for the pilot. If one understands how the wing functions, the rest of the theory of glider flight follows naturally and logically. Understanding helps in learning the practical techniques of flight.

The way a wing works is not obvious, compared, for example, to the functioning of a wheel on a car. A wheel can be seen turning, bearing against the solid earth to apply power or to change direction. The wing works invisibly in an atmosphere that yields before the passage of the glider. But the air has substance and offers resistance, supporting the wing even as it gives way to it.

What the wing does is to drive a mass of air downward, producing an equal and opposite upward reaction upon itself in accord with Newton's 3rd law of motion. (Oddly enough, under most conditions the top of the wing contributes far more to this action than the bottom, which explains why glider pilots are so particular about wiping off the tops and less finicky about the lower surface, OK, the bottom is harder to reach.) The upward reaction on the glider is made up of two force factors: lift, which acts upward at right angles to the direction of motion; and drag, which acts rearward, or parallel to the direction of motion. The values of these two forces, expressed as a ratio, describe the glide performance of the craft at a given time. If lift is twenty times as great as drag (expressed L/D~2O:1), the glider will move forward twenty feet for each foot of altitude lost. In soaring, lift is the hero and drag is the villain.

The ability of a given wing to generate lift is in proportion to the density of the air, to speed, and to the angle at which the wing strikes the air. Denser air produces more lift because the wing has firmer substance to push against, so the reaction upon itself is greater. More speed gives more lift because the wing can deflect more air downward in a given time. Glider speed is dependent on the pull of gravity or the tug of the towrope.

The third factor in the effectiveness of a wing is the angle at which it strikes the air. This *angle of attack* is important to the pilot because he controls it directly by moving the stick fore and aft, which has the secondary effect of changing the wing's lift and drag (which means angle of descent) and the glider's airspeed.

Decreasing the angle of attack reduces lift, while increasing it generates more lift-but only up to a point. At an angle of attack in the area of 12 to 18 degrees (depending on the shape of the particular airfoil), the wing begins to lose its ability to deflect air downward and instead begins to produce a turbulent wake behind its upper surface. With only a slight additional increase in the angle of attack, lift decreases rapidly and drag 'builds up vastly, so the rate of sink increases; control is greatly reduced, and the wing is said to be *stalled.* (This is usually the condition with the control stick all the way back.) To regain lift, the angle of attack must be reduced (stick forward), returning the wing to the range of angles of attack where the air flows smoothly over the top surface and is deflected downward.

FUNCTIONS OF THE CONTROLS

Control surfaces are provided to allow the attitude of the glider to be changed about its three axis. The pilot can blend these three movements to produce any desired change in attitude. Moving the stick sideways depresses one aileron and raises the other, making the lift of the two wings unequal and rolling the glider right or left around the axis of the fuselage. Other results also appear which will be discussed later in this chapter, when we take up turning.

The vertical and horizontal tail surfaces are small airfoils which work like a wing to deflect the airflow and so produce equal and opposite reactions upon themselves. Moving the stick fore and aft moves the elevator and lowers or raises the nose of the glider so long as airspeed is adequate. A less superficial description of this action is that the elevator controls the angle of attack of the wing.

The rudder pedals are connected to the rudder in such a way that pushing the left pedal moves the glider's nose to the left. This may not seem logical when compared to the way a sled is steered; however, the use of the rudder is *not* to steer the glider but to align its fuselage so as to minimize (and occasionally to maximize) its drag. For this reason, the logic of steering is unimportant; the rudder simply yaws the glider around its vertical axis.

STABILITY

Stability of direction and bank are interrelated and complicated subjects of more interest to designers than to pilots. Few gliders will return to a wings-level glide without help from the pilot; in fact, few will long remain in that condition if left to themselves. For good reason, designers rely on the pilot to handle directional and banking stability.

Pitch stability, possessed by gliders in widely varying degrees, is of great interest to the pilot. This quality appears as a resistance on the part of the craft to flight at speeds other than that for which it is trimmed. If trimmed for 40 mph, for example, the pilot might have to exert a strong forward pressure on the stick to fly at 80 mph. Should he relax the pressure the glider would, after a series of pitch oscillations, return to 40 mph.

Gliders with high pitch stability require elevator trimming devices either on the control surface or adjustable springs in the control system to permit the pilot to fly the glider at any reasonable speed without having to hold a steady pressure on the stick. A few glider models have been deliberately designed with neutral stability and do not generate a stick load by changing speed. These gliders do not require a trim.

GLIDE PATH AND SPEED CONTROLS

When making an approach for a landing the pilot must be able to steepen his glide without gaining speed. He also needs a means to check his speed when diving to lose altitude rapidly. Several of the devices for providing this control are of interest to all glider pilots.

Spoilers, which are used on most training gliders, are devices of various styles, some perforated, which emerge from the top or bottom of the wing, or both. They may be hinged or may slide out vertically from slots in the general vicinity of the main spar. The prime purpose of spoilers is to break up the smooth flow of air over a portion of the wing, "spoiling" the lift. Secondarily, drag is increased. (Recall that L/D determines the angle of descent.)

Dive brakes are devices whose primary purpose is to increase drag. Most dive brakes are a part of the wing, and so also decrease lift. The choice of names depends on whether the accent is on decreasing lift (spoilers) or increasing drag (dive brakes). Fuselage dive brakes and drogue parachutes have no direct effect on lift, working entirely by increasing drag.

Since there are a number of sailplanes available which have drogue parachutes as supplements to spoilers and flaps, it should be noted that they are extremely effective speed-limiting devices. However, their functioning in gliders has not been 100% reliable, and a failure to open usually comes at the most inconvenient moment. Further, once deployed, they cannot be controlled or retracted and redeployed. Another handicap is that the backward pull of the chute upon the tail of the glider substantially reduces the effectiveness of both rudder and elevator. Perhaps these problems will one day be solved; meanwhile, too much reliance should not be placed upon the drogue parachute.

Flaps, which are used on some gliders, work differently from spoilers. Flaps are hinged portions of the trailing edge of the wing that, when lowered, change the camber or cross sectional curvature of the wing so as to increase both lift and drag. One type of flap has moderate up and down travel for high-speed cruising and thermalling; the function of speed control is handled by separate spoilers. Another type of flap functions in the same way for cruising and thermalling, but dispenses with the supplementary spoiler, powerful drag being provided by lowering the flap as much as 90 degrees to the chord line.

Several models of gliders have Fowler flaps, similar to those used on many airliners. Fowler flaps lower and at the same time slide backward on tracks so as to increase the area of the wing, to change its camber, and to provide a slot which smooths the airflow on the top surface of the flap. The Fowler flap increases drag moderately when partly extended for thermaling, and very greatly when fully depressed for speed control.

All the above devices tend to reduce speed, other factors remaining the same, and when designed to keep *maximum* diving speed at a safe figure, are called "terminal velocity limiting."

EFFECT OF AIR DENSITY ON PERFORMANCE

The density of the air becomes less as altitude and temperature increase. In thinner air a wing must be driven faster to produce a given amount of lift, all other things being unchanged. Fortunately, a change in air density affects the airspeed indicator in the same way as it does the wing, since they both function by the dynamic reaction of the air. Therefore, a pilot can rely on the airspeed indicator under most conditions without making a correction for density. Stalling speed, red-line speed, and glide ratios throughout the performance range of the glider are constant in terms of airspeed indicator readings. True airspeed, which is the indicated airspeed corrected for the density factor (disregarding the question of instrumental error), has a bearing on cross-country strategy and the possibility of flutter; its use in navigation is *nil* because of the irregular gait by which gliders wend their way across the land.

EFFECT OF LOADING ON PERFORMANCE

A heavily loaded glider goes forward *and down* faster than when lightly loaded. The glide ratios are the same for both loading conditions, but occur at different airspeeds. This may seem strange until one realizes that an increase in weight does not affect either lift or drag, the determining factors of glide ratio. Unfortunately, *all* the airspeeds on the performance curve of the heavily-loaded glider are higher, including stalling speed, and worst of all from the soaring standpoint, the range of thermaling speeds.

On a normal cross-country flight the heavily loaded glider makes better time between thermals but takes longer to regain the altitude lost. Both its minimum thermaling circle and its rate of sink (because of the steeper bank required) are greater than for a lightly loaded glider. When the thermals are strong the "lead sled" runs away from the "floater." When the thermals are weak, the floaters stay up and make progress while the heavy jobs are fighting simply to stay up, or perhaps are unable to do so.

Jettisonable water ballast is carried in some gliders in an effort to combine the best qualities of both types. This solution is incomplete, however, since water cannot be taken on in flight when thermals strengthen in the early afternoon.

As things stand now, no glider is ideal under all conditions. Each type is designed for certain assumed conditions and represents the designer's idea of the best compromise between speed and thermaling ability.

THE TURN

Newton's *First Law of motion* (loosely stated) says that a moving body will keep moving in the same direction until a force acts to turn it. **The force that turns the glider is the lift of the wing**.

In level flight, wing lift works upward, supporting the glider but not turning it. By banking the craft, some of the lift is stolen for the purpose of overcoming inertia and centrifugal force and thus pulling the glider around the turn. The proportional part of the lift devoted to turning and the part still devoted to vertical support vary with the angle of bank, as can be graphically described by the familiar parallelogram of forces.

While turning, the pilot must increase *total* lift so the proportional part supporting the glider continues adequate for the task. Speed, angle of attack, or both must be increased. These changes also increase total drag and steepen the glide path. Thus, a steeper bank results in a higher sink rate, an important fact to remember in the art of thermalling.

The correct way to bank a glider is with the ailerons and rudder, the rudder being used entirely to keep the fuselage streamlined. The wrong way to bank is with the rudder alone. Should a pilot push right rudder leaving the ailerons neutral, the fuselage would pivot to the right around the yaw axis. This would be skidding. A secondary effect of the skid would cause the wings to bank to the right. The lift of the wing in the banked attitude would then produce a right turn. This procedure is faulty for two reasons. The first concerns the high drag set up by the skidding fuselage which causes loss of altitude. The second concerns the effect if the wing is close to stalling, when the skidding turn may put the glider into a spin.

TOTAL DRAG

One of the major Concerns to a glider pilot is to try to reduce his drag to a minimum. The total drag of a glider in flight is composed of *INDUCED* drag and *PARASITE* drag. Parasite drag is all drag which is not directly associated with the development of lift. The wing surface, even at zero lift produces "profile" drag due to the skin friction and form. Other components of the glider much as rivets, fuselage, tail, tires etc., Contribute to drag because of their own form smoothness and skin friction.

Parasite drag increases with speed varying as the square of the velocity, ie. if you were flying at 200 mph it would have four times as much parasite drag as it would have at 100 mph. consequently, parasite drag will be of greatest importance at high speeds. At speeds just above stall, parasite drag is only 25% of the total drag. It is obvious that at high speeds the better the aerodynamic cleanness of the glider the better to obtain high speed performance.

Induced drag is the drag associated with the creation of lift. Therefore, if you increase the lift you also increase the drag. By increasing the angle of attack, you will: increase lift, increase drag, and reduce your speed. (see diagram of drag Curves)

UNDESIRED SIDE EFFECTS OF THE TURN

In turning a glider, the pilot must counteract five undesired side effects, undesired in the sense that if they did not already exist, the designer would not design them into the aircraft. During student training, the development of habit patterns to overcome these side effects, is perhaps the largest single factor in learning to fly. Success will be much easier when the student understands the causes behind his vexations.

The first side effect is called ***adverse yaw***, and is encountered when banking into or out of a turn. . Adverse yaw is the drag on the wing which is raised, this is due to the increase of angle of attack by the lowered aileron (Remember that when you increase the angle of attack; you lower the airspeed, increase the lift and increase the induced drag). To roll into a left turn, for example, the pilot moves the stick to the left. This raises the left aileron depresses the right aileron. Since the down aileron produces more drag than the other, an undesirable yawing to the right (against the direction of the turn) takes place,generating unwanted drag as the fuselage moves sideways through the air. To balance out this adverse yaw and so streamline the fuselage, the pilot applies left rudder with the left aileron. This action is called "coordinating stick and rudder", and the result is called a properly coordinated turn when the yaw string and the slip-skid ball are centered.

Adverse yaw is mild at low angles of attack but becomes severe when the wing is nearly stalled. For example, in a tight turn which is close to an accelerated stall, the application of full aileron to roll out can stall the low wingtip. The severe drag on this wing yaws the glider into a dive. If the pilot now makes the understandable error of trying to raise the glider's nose by pulling the stick even farther back the result will be a sudden spin. To recover from such an excessively tight turn, the angle of attack must first be reduced by moving the stick forward, followed by use of rudder. Once you have a lowed angle of attack use aileron/rudder to level the wings. A normal rollout results.

The ***diving tendency*** is the second "I wish it wouldn't happen" in a turn. When the glider is banked some of the wing's lift is transferred from the task of support to that of pulling the glider around the turn, as previously explained. In consequence, the rate of sink increases, stabilizing action causes the glider's nose to drop, and the airspeed increases. If the pilot does not oppose this reaction of the glider by moving the stick back, the airspeed will soon stabilize at a higher level than formerly. To maintain the same speed in the turn as in straight flight the pilot must use the elevator to keep the nose at such a position on the horizon as to hold that speed. The steeper the bank, the more back pressure on the control stick is needed.

The ***overbanking tendency*** is the third annoyance in turning. Having established the desired angle of bank, the pilot finds that he has to hold top aileron (against the angle of bank) to keep the bank from steepening. In a glider this is true in all but the shallowest banks because of the long span and normally small radius of turn. The outer wingtip moves faster than the inner, so the outer wing has more lift, causing the bank to steepen.

The fourth unwanted side effect, a ***yaw against the direction of an established turn*** (not the adverse yaw caused by aileron drag) appears because the faster-moving outer wing has more drag. Rudder in the direction of the turn is needed to balance the wing's yawing force, the amount being indicated by the yaw string or slip-skid ball. If these are centered the turn is correctly coordinated, even though the controls are crossed", which means rudder is applied on one side and aileron on the other. "Crossed controls" is a heinous sin in powered flight. ." It should be noted that the same undesired effects of a turn are in a powered aircraft, but are most noticed when in slow flight or steep turns. Most of these effects are more noticeable in the sailplane because of our long wings and slower speeds. Power pilots please note that a glider is flown so the fuselage slips through the air with minimum drag, ball/yaw string in the center, whatever position of the controls is required to accomplish this end. The same should be true in an airplane.

The fifth and last (thank goodness) side effect of turning is the ***increase in stalling speed***. As was explained earlier, during a turn the pilot applies back pressure on the stick to increase the angle of attack. Thus the glider is closer to a stalled angle than in a level glide at the same speed. Another way to look at the situation is that the load of centrifugal force is added to the weight of the glider; this higher total load on the wing raises the stalling speed. The thermalling pilot soon learns that he has to increase his airspeed as he steepens his bank in order to keep from stalling. It should be noted that the increase in stalling speed is caused by the increased wing loading rather than by the angle of bank *per se*. In the performance of aerobatic maneuvers such as a wingover the bank may be vertical and the stick is not brought back; there is no turning and no centrifugal force, and the glider's wing is not stalled even though the glider is momentarily hanging almost motionless in a vertical bank.

The following table gives an idea of the degree to which stalling speed increases with the angle of bank in a *properly executed turn*. The percentage increase is included so the reader can calculate actual values for any glider. Figures are also given for a typical trainer and a high-performance sailplane.

Angle of Bank	Load	% Increase in Stall Speed	Trainer Stalling Speed	High-performance Stalling Speed
0^0	1.0	0	31	46
30^0	1.18	8	33.5	50
45^0	1.4	18	36.5	54
60^0	2.0	40	43.5	64.5
75^0	4.0	100	62	92
90^0	A "properly executed turn" is impossible			

EFFECT OF WINDS ON TURNS

An observant beginner pilot (with instructor) making a full-circle turn at an altitude of less than a thousand feet while under strong and steady wind conditions, will be convinced that glider turns are affected by the wind. In a downwind direction, even a steep bank produces a turn of large radius over the earth and the glider goes very fast. Turning in the upwind direction, the radius of the turn is very small and the speed is visibly slowed. The student pilot *knows* that wind affects the way the glider turns because he can *see* the effect just by watching the ground. He feels that the airspeed indicator must be wrong, and that the instructor, who is saying the wind doesn't affect the way a glider turns, simply doesn't believe the evidence of his eyes.

Everything the beginner sees is “absolutely so.” It is what he cannot see, which is the motion of the parcel of air in which he is flying, that lead’s to his incorrect conclusion. He can’t even feel the strong wind that is causing his glider to behave so eccentric all compared to the expected constant-rate turn.

An analogy may clarify the situation. Consider a motorboat turning in a river. The boat, in making a constant rate turn, will soon run into its own wake, and the skipper had looked over the side and watched his path over the river-bottom, he would have seen the resultant of the circular motion of the boat and the straight motion of the river. It probably would never occur to him that a boat's turning capability is different in a river than on the placid surface of a lake because he can see all the elements that are involved, unlike our beginner pilot.

When turning in a high wind the pilot makes no change in his use of the controls. However, when he is concerned with his track over the ground, as when in the traffic pattern or on the cross-wind leg of a triangle flight, he must crab into the wind enough to compensate for the motion of the air.

It should be noted that *changes in* wind direction or velocity, as distinct from a steady wind, do affect the way a glider handles. Such conditions, occurring in thunderstorms, wave rotors, and in the disturbed air close to the ground are future discussions.