**The Art of Low Power Aerobatics - Keith Shaw - Model Airplane News - Feb. 1996**

Maximize your performance with energy management

AT ANY air show, you'll see many styles of flying. The public's favorites seem to be the speed, thunder and close-quarter flying of the jet teams and the brutal precision of planes such as the Pitts, Laser, Extra and Sukhoi as they effortlessly perform intricate dances, without any apparent regard for gravity. My favorite acts, however, are those by stock or slightly modified "standard" aircraft flown on meager power, but still doing excellent aerobatics. I know that I am watching a real pilot who uses finely honed skills and senses push the plane to the limit in pursuit of performance. My heroes include Bill Barber, Art Scholl, Duane Cole and Bob Hoover, so it should be no surprise that I try to emulate them when I fly replicas of their aircraft. This type of flying requires quite a different mindset from the usual one; you spend much more time "listening" to your plane than demanding that it follow your commands. Controls are squeezed rather than slammed, while everything possible is done to minimize drag; and, surprisingly, gravity becomes a very important *ally*!

While I find the pursuit of efficiency in aerobatics extremely gratifying in its own right, there are other reasons to learn these techniques. I've seen many a crash at a crowded, noisy airfield because the pilot didn't know his engine had quit. If the pilot had been paying attention to his aircraft's speed or handling characteristics instead of to the engine noise, a safe dead-stick landing could have saved the plane. For competition fliers, a crucial flight score might be salvaged even with a bad engine run. Electric fliers will gain great rewards, because efficient flying can dramatically reduce power consumption and extend flight time.

The biggest benefit, however, will be in learning to be a better pilot. After a while, the continuous observation of the subtle visual cues and control interactions will become second nature as you develop a "feel" for the aircraft. At that point, the loop is complete, and you are now a real pilot, completely unaware of the transmitter in your hands.

## A LITTLE BIT OF PHYSICS

Please, don't he frightened! I promise not to snow you under with any equations, but there are just a couple of concepts to he discussed.

° The balance of forces. I think everyone has seen the sketch of an airplane in level flight when lift equals weight and thrust matches drag. Though this is pretty simplistic, it will serve for our purposes. Assuming the plane is in level flight, an increase in thrust will cause an acceleration, and the speed will increase until the drag rises to just equal the thrust. At this point, the forces are once again in balance, only the plane is flying somewhat faster. If the lift is increased, either by an increase in camber or an increase in the angle of attack, the plane will climb, or it could he made to carry more weight in level flight.

Unfortunately, things aren't this simple. The balance-of-forces concept implies that there is no interaction between the lift/weight and the thrust/drag components. The drag that most people think about is called “form drag”; it includes bulky fuselages, rigging, struts, exposed landing gear and engine cylinders. This type of drag gets worse as speed increases, and it's the major force that limits an airplane's top speed.

The "hidden" drag is called induced drag, and it's the penalty incurred in exchange for lift. The total lift of a wing (or any flying surface, for that matter) is dependent on its area, air speed and the airfoil's coefficient of lift (basically, a measure of how hard the airfoil must work to produce lift). The harder it has to work, the higher the lift coefficient and, unfortunately, the higher the induced drag. When a plane is flying fast, the necessary lift coefficient is quite low, so the induced drag is also low. That's why most pylon racers have very low-cambered airfoils-usually, just enough to produce the necessary extra lift for a turn. At low speeds, however, induced drag is the dominant type of drag, because the airfoil has to work very hard to create lift. To get the most efficient glide possible, sailplane designers go to excruciating lengths to choose and construct a wing that will produce the best lift-to-drag ratio. So we see that our lift force in the balance picture is coupled with the thrust/drag relationship. At slow speeds, especially near stall, induced drag can dramatically affect how a plane handles.

° Conservation of energy-the other physics lesson, and it's probably the most important tenet in flying aerobatics. A plane's potential energy is related to the height it is flying above the ground, while its kinetic energy is a function of speed.

In a perfect world without drag, the potential energy added to the kinetic energy would he a constant. This perfect plane would fly at a constant altitude indefinitely, without needing a motor. If it dove to lose altitude (decrease in potential energy), it would gain speed (increased kinetic energy) to keep the total energy constant. It would roll effortlessly and loop perfectly, and entry speed would be exactly the exit speed. For an un-powered aircraft in the real world, however, drag acts as an energy siphon that gradually decreases the plane's total energy. To even maintain a constant air speed, it would have to slowly lose altitude, and the extra drag of aerobatics would lead to even more altitude loss. As an example, a loop could be performed in two ways: by exiting at the same altitude and a lower air speed, or at a slightly lower altitude with the same air speed. But by allowing this slight altitude loss, a properly trimmed and flown glider can do any aerobatic maneuver. If we install a small power system that can just replace the energy lost owing to drag, our plane can maintain altitude and perform aerobatics. With even more power, it could gain altitude and still hold a given air speed. Of course, we could get silly and become a Sukhoi, with enough horsepower to reach terminal speed while going straight up! But rather than solving the problem with excessive energy input, we can get much of the same effect by learning to control and minimize drag and, thus, reduce our energy requirements.

## CONTROLLING DRAG

On a scale airplane, little can be done to reduce form drag, but there are several ways to reduce induced drag. As control surfaces are moved off neutral, they do not deflect the air as most people think, but they change the airfoil's camber, thereby changing the lift coefficient and unfortunately, the induced drag. If a plane has any warps, most modelers just offset the appropriate control surface. This causes induced trim drag, so it's much better to remove the warps. Similarly, if the plane is not laterally balanced (one wing is heavy), it will require aileron and rudder trim to compensate, and, of course, this means unwanted drag. So that less control throw is needed, I also always seal the hinge line on all control surfaces to make them more aerodynamically efficient.

A very major source of drag comes from having an incorrect center of gravity-usually too nose-heavy. A nose-heavy plane has to carry up-elevator trim to maintain longitudinal stability. This means that the stabilizer is lifting downward, and that creates some induced trim drag. But what's worse is that the wing must now develop even more lift to maintain level flight-incurring even more drag! A little longitudinal stability is desirable for comfortable flying, but most kits and plans are highly over-stabilized. Test your plane for correct CG using the following method (see Figure 2):

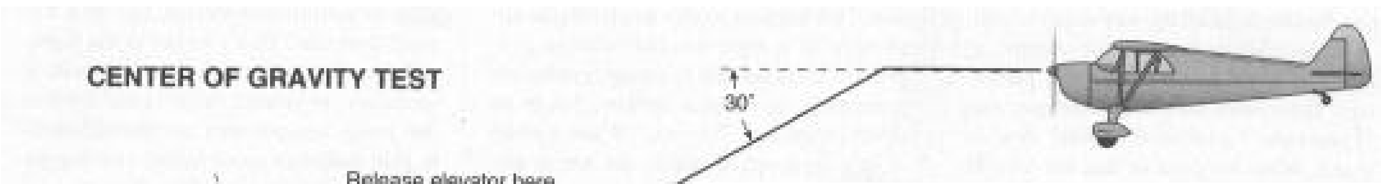
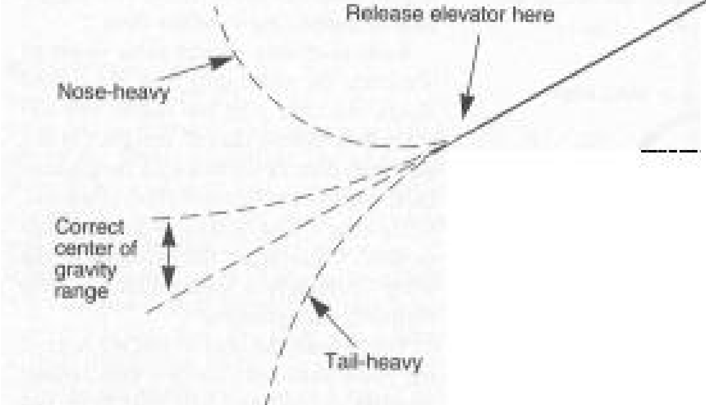

FIGURE 2

° Fly at half throttle and adjust the elevator trim until the plane can maintain hands-off level flight. Check this by making several passes without changing the throttle. You should be flying at an altitude of 100 to 150 feet.

° When the plane is nearing center stage, gently push it into a 30-degree dive, and hold it until the air speed has increased noticeably. At this point, take your hand off the stick and observe what happens.

° If the plane pulls up sharply, it's very nose-heavy. If it continues in the dive or pulls up slightly, its CG is just right. If it tries to tuck under, it's tail-heavy. A bunch of extra advantages come with having a correct CG location. The amount of elevator throw necessary for any maneuver will decrease, and that will mean less control drag. There will be virtually no need for downthrust, which is an inept attempt to "fix" an over-stabilized aircraft's tendency to nose up as power is increased.

Another source of induced drag comes from trying to convince the wing to roll. Every method works by differentially changing the lift of the wing panels. Standard ailerons deflect to increase the camber (and lift) on one panel and decrease it on the other. Of course, the change in lift also causes a change in induced drag. The problem is that the drag force creates a yaw in the opposite direction to the roll; this is known as "adverse yaw." Imagine a right roll, in which the right wing aileron goes up (decreasing lift and drag) and the left wing aileron goes down (increasing lift and drag), producing a right roll but a left yaw. If the plane is flying fast and/or has a long fuselage or a large fin, the effect is minimal. But for a slow flying plane with large wings and a short-coupled fuselage, this adverse yaw can be strong enough to turn it in the wrong direction! Not only that, the yaw also swings the fuselage out of the flight path, causing a huge increase in drag. A vast amount of effort has gone into trying to tame this demon-using tricks such as differential aileron throw; aileron/rudder coupling; specially shaped ailerons that put out a drag-increasing "foot" on the up-going motion; and various spoilers and yaw flaps. The glitch is that all of these methods only help for upright flight, but they severely worsen the problem when a plane is inverted. The all-around best method is to learn to fly coordinated rudder, keeping the fuselage in line with the flight path and drag to a minimum.

**PRACTICING SLOW FLIGHT**

When a fast, highly powered aircraft performs aerobatics, it is usually well above stall speed. Snap rolls, Lomcevaks and other violent contortions are generated by forcing a high-speed wing stall. But for low-powered airplanes, the usable speed envelope includes speeds just barely above stall, such as near the top of a loop or Immelmann. Before performing such maneuvers, it's best to practice slow flight to learn how the plane's handling characteristics change. Most modelers think that flying near stall speed is inviting certain disaster, but in truth, most planes are quite benign. Of course, extremely high wing loadings, warped wings and poorly crafted airfoils can degrade the stall handling characteristics.

To begin, fly at 150 to 200 feet while practicing a racetrack or lazy figure-8 pattern, and gradually decrease the power on each pass. Several things will become apparent at well above stall speed. Aileron authority will diminish and become sloppy, and adverse yaw will be much more noticeable, but fortunately, rudder control will usually stay solid all the way down to stall.

If the ailerons become too sloppy, try flying with rudder. Some planes, particularly those with barn-door ailerons, may experience "aileron reversal" at slow speed. What happens is that for a right-aileron turn, the down-going surface on the left wing panel effectively pushes the airfoil past stall. The loss of lift drops the left tip, making it seem to roll to the left. My Gee Bee R-l is notorious for this, so once it's turned onto final and begins to slow down, I never touch the ailerons, but fly it strictly on rudder.

Just above stall, elevator control fades, and the forward speed will rapidly drop owing to the very strong induced drag (high lift coefficient means high drag); the plane will mush forward and lose altitude. Stall recovery is best effected by applying slight down-elevator and increasing the power gradually. This decreases the induced drag and allows the wing to start lifting again, after which gradual up-elevator can be applied to return to level flight. With some practice, a plane can be flown continuously and carefully in a partial stall condition, usually with a little more power to compensate for the high induced drag.

As you become more confident, you'll appreciate the value of flying coordinated rudder to control adverse yaw, because you'll be able to turn and maneuver at much lower speeds. Flying lower will help to set these skills. It is also beneficial to do the same training inverted, particularly to help suppress the panic up-elevator response. Recovering from an inverted stall is almost the same as flying right side up, but you use slight up-elevator to get out of the stall.

Another anomaly occurs when trying to climb at slow speed: the plane tries to yaw to the left and needs right-rudder correction. This happens to any single-engine airplane with a right-handed-rotation propeller. This is not due to torque, gyroscopic precession, or circular airflow, but to an effect called the "P-factor." When a plane is in a slow-speed climb, the entire airplane-including the engine shaft-is at a high angle of attack. The descending propeller blade on the right side of the center line is at a higher angle of attack than the ascending blade, so it produces more thrust. This offsets the prop thrust to the right of the center line and yaws the plane to the left. When tail-draggers veer to the left on takeoff, it's because of the P-factor.

Kit designers try to help by building right thrust into the engine mount in an attempt to counteract the P-factor. But the yaw force is to the right when the plane is inverted, so the built-in right thrust just makes the problem worse, and it would require a lot of drag-producing left-rudder correction to overcome it. Understanding the source of these forces and learning to give the correct control inputs result in lower overall drag through maneuvers.

**SIMPLE AEROBATICS**

All basic maneuvers with the same entry and exit altitude-including loops, rolls, point rolls, figure-8s and stall turns can be done with little horsepower. The only limitation is that the air speed must not drop below stall speed anywhere in the maneuver. A nice, round loop requires an entry speed of about twice stall speed. Higher entry speeds allow an increase in loop diameter. An entry speed that's too low will result in a stall, which makes a loop out of round at the top. The classic "Cub" loop is an example of this. It's important to control the elevator smoothly to create a circular shape. The direction and amount of elevator throw will depend on a lot of factors, such as airfoil, downthrust, tail area and wind direction. Don't forget to use right-rudder correction on the upward part, if necessary, to control the P-factor. Gliders and really low-powered aircraft may need to gain sufficient speed before entering the loop by performing a shallow dive.

Rolls need only enough extra power to overcome the added drag from the control inputs. For slow rolls, top rudder will certainly help to keep the roll straight, but at a high drag cost, as we're asking the plane to knife-edge in the first and third quadrants. Knife-edge flying is done with the wings vertical while using the fuselage as the wing-certainly a spectacular but very high-drag configuration!

Try to resist the urge to pull the nose of the plane above the horizon with rudder. Smaller corrections will still help, but they'll create much less drag. In point rolls, it's important to gently squeeze the aileron controls to prevent adverse yaw from starting a yaw oscillation. This not only looks bad, but it's also very difficult to damp out. The aileron input should be more like a sine wave than a set of staccato pulses. For gliders and very low-powered planes, the loss of energy caused by control drag may be offset by performing the roll on a shallow downward line, usually no more than 5 degrees. Do not pull the nose of the plane above the horizon at any part of the roll, because the drag could increase so quickly that air speed will drop below stall speed, and the plane will literally fall out of the sky.

Cuban-8s can be done by allowing an altitude loss of about 5 feet on each half to compensate for the control losses. Even a pattern judge would have a difficult time spotting this loss. For stall turns, smoothly transition into the vertical and leave the engine at full power, not only to get the best possible height, but also to maintain rudder effectiveness. After the yaw has been initiated, the power can be reduced if you want to slow the descent.

° Snap rolls create very high drag and must be done carefully. The controls are easy: full up-elevator and aileron and rudder in the same direction for an inside snap; down-elevator and crossed aileron and rudder for an outside snap. The tricky part is gauging the correct entry speed. If the entry speed is too high, the maneuver will look like a half barrel roll and a half snap. If it is too slow, the snap will quickly degrade into a spin. Even when this is done correctly, the plane will exit at a speed just above stall at which the controls are mushy. To stop the snap with the wings level, neutralize the controls, and then add opposite rudder and a little down-elevator.

For multiple snap rolls, the drag will keep increasing, so power will have to be added to prevent the plane from transitioning into a spin. If a snap roll is incorporated into another maneuver, such as the avalanche (loop with a snap at the top), a higher entry speed will he needed to prevent the snap roll from dropping the air speed too much and causing the loop to become asymmetric.

° Spins are easy to do: at partial power, approach a stall, then add in up-elevator and rudder and ailerons in the same direction. If all you get is a spiral, try putting in rudder first, and when you see the yaw, add full up-elevator. When the wingtip stalls, dump in the ailerons. Some aircraft will spin without needing ailerons, but I find that the entry and exit are much more unpredictable and sloppy. Spin exit usually just requires that you release the controls, let the nose drop, gradually add power and return to level flight. If it's a little stubborn, keep the aileron and elevator neutralized, but feed in some rudder in the direction opposite the spin. When rotation ceases, add power and continue with the normal exit. Inverted spins are done similarly, but with down-elevator and the aileron and rudder controls crossed. Even gliders can spin, but air speed has to be a little higher because there's no prop blast on the tail. The rudder/elevator/aileron sequence seems to work best.

° Altitude-gaining maneuvers will always have a lower exit speed than they had at the start. Probably the hardest stunt to do well on low power is the Immelmann. Right when the speed is lowest and the P-factor is strongest, the plane will need to transition into inverted flight and then immediately try to do a half roll! Certainly, some extra entry speed would be very helpful, but the biggest problem is not in doing the half roll, but keeping the heading. Even though the adverse yaw tries to act like top rudder to help maintain altitude, the drag penalty is quite high and, if uncorrected, will pull the plane off heading as it approaches level flight. If we are doing - a left half roll, adding some right rudder after the wings pass the vertical position will help keep the heading. Another way to do the Immelmann involves a little cheating. It's done by doing a little less than a half loop and then starting the roll immediately. The wing will still be under positive G-force, so the adverse yaw will prevent the nose from hanging above the horizon; and it will be in the correct direction to help hold the heading. The nice thing about this method is that it does not require any rudder corrections.

° Vertical roll - one of the neatest maneuvers (usually considered a "macho-power" maneuver). With enough energy from a dive, even a glider can do one (my own record is six vertical rolls with a 2-meter slope glider). Once again, the roll part is relatively easy, but the transition back to level flight requires great care, due to very low air speed and massive P-factor effects from the prop. When pushing the nose down toward level flight, the plane is under substantial negative-G, so you'll need some left rudder to hold the heading. When the plane is level, the elevator must switch smoothly over to up, and because the plane will enter positive-G, the rudder correction has to switch to the right. Trying to hold level flight just above stall speed while trying to keep the heading and letting the plane gain speed is a fine balancing act. The "flub" that can occur is an unwanted spin caused by too low a speed and the up-elevator and right-rudder corrections. No problem! Just release the controls, do a normal spin exit, gain altitude and give it another try.

## ENERGY MANAGEMENT

Now that you have practiced the individual maneuvers, it's time to link them into a pleasing air show. Probably the most time- and space- efficient format for aerobatics is the "turn-around" layout in which maneuvers are performed at center stage and at both ends of a box. Some maneuvers are naturals for center stage; these include loops, rolls, point rolls, various figure-8s, and any maneuver that does not produce a change in direction. Direction-changing maneuvers, such as the stall turn, the Immelmann, split-S's, or half Cuban-8s, work best at the ends of the box.

The size of the box will depend on the energy available. Huge loops performed 1,000 feet away may be the standard in pattern flying, but they are rarely suitable for scale air shows. The huge maneuvers not only require vast amounts of power, but they also take longer to complete, so fewer can be done in a fixed time or energy allotment (such as with electric power). Flying closer with smaller maneuvers can look the same while saving a lot of energy; the only drawback is that errors will be more visible. A good box length is about six times the diameter of a comfortable loop. Some maneuvers can be centered to give the box some depth, but you should practice imagining a barrier on the near edge that never allows the plane any closer to the audience.

To make best use of the available energy, try to link maneuvers with matching entry and exit speeds, and practice them as a sequence. An example might be a loop at center stage, a stall turn at the turnaround, then a four-point roll, followed by a half Cuban-8. The result will be that you are in the same position on the same heading with about the same energy.

Another sequence can be created and practiced and added to the previous one, until a satisfying air-show routine emerges. If an altitude-gaining maneuver such as an Immelmann is used, the energy in the extra altitude can be invested in diving to get a higher entry speed for the maneuver that follows- a super-slow roll, avalanche, or vertical roll, or on an altitude-losing one-a spin or split-S. If the plane is getting too low, one of the turnaround maneuvers could be replaced with a climbing 180- or 540-degree turn.

The last major hurdle will be learning to fly your routine in real-life conditions-invariably crosswind or with heavy turbulence. With low power and speeds, their effects will be much more severe than normal. I suggest that you start with basic slow-flight practice and learn how the wind affects flight characteristics. Although I don't want to get into the "downwind turn" fiasco, I will tell you that making turns in a moving air mass using a plane with a finite acceleration can lead to some very exciting flying, so start with a little extra altitude. Under these conditions, I raise my base line for aerobatics by at least 30 feet. In crosswinds, the acrobatic flight line will drift, so corrections will constantly be needed. Initially, the corrections can be applied after each maneuver, but eventually, they can be blended into the maneuvers themselves. For example, an uncorrected loop in a crosswind becomes a helix, but carefully adding rudder toward the wind will keep it straight. Keep practicing in all types of weather; it will make you a much better pilot.

## FINAL THOUGHTS

Well, the path to success in flying low-powered aerobatics is before you. With much practice, careful analysis and diligent effort, you will become a real pilot. At that point, you will also know how to fly any plane in any conditions, as you'll need smaller corrections as power and speed go up.

I hope to see you at the air shows. If you have any comments or questions, you may write to me, but please include an SASE:
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