

Flying Training

T-6 Advanced Handling Characteristics

May 2002



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Chapter 1

INTRODUCTION TO AHC

Introduction. All aircraft are designed to operate within a given set of flight parameters, commonly called “the envelope.” Teaching students while operating the aircraft near the edge of the envelope can yield brief excursions (departures) requiring pilot recognition and a positive recovery to quickly and safely return to controlled flight. The AHC flight profile will safely and deliberately explore specific excursions from controlled flight you could encounter while flying with a student. Armed with this knowledge and experience, you will be better able to maximize aircraft flying performance, recognize potential departure scenarios and recover from actual departures. As an added benefit, familiarity with the aircraft limits through AHC training instills the confidence necessary for safe and effective student training.

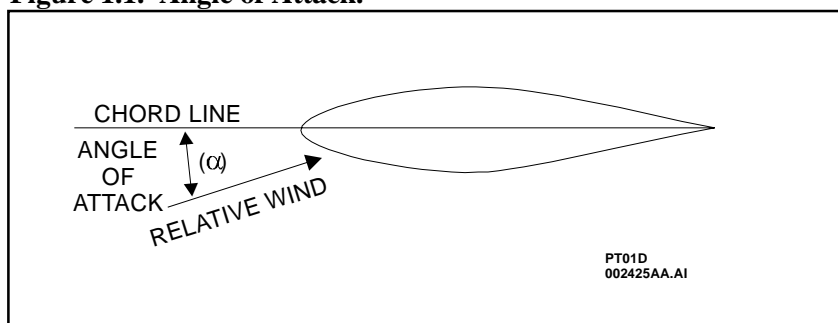
Knowledge of aircraft limits is no less important than knowledge and awareness of your own limits and those of your student. Exceeding your own limitations through overconfidence, timeline pressures, fatigue, or simply having a bad day, can lead to shortcuts and mistakes. Pushing your limits results in ineffective training and potentially unsafe situations. Likewise, pushing your students past their own physical or emotional limitations serves little purpose and breeds frustration and negative training. A professional military aviator must be constantly aware of their limits. There is no value gained by exceeding the aircraft limitations, your own limitations, or your student’s limitations. Calling “knock-it-off” when a limit is approached or is about to be exceeded will ensure an effective and positive learning environment and could keep you from becoming a mishap statistic.

Flying a propeller-driven aircraft with a 1,100 shaft horsepower engine results in strong gyroscopic forces. The relationship of power to spins and stalls is complex: it depends on many factors, including angle of attack, the amount of roll coupled with yaw, and rotational speed. While some are more dominant than others, it is the sum total of all these effects together that creates the reactions we see.

Aerodynamic Terms:

Angle of Attack (AOA). The angle between a reference line on the aircraft (usually the chord line) and the relative wind direction. AOA (α) is depicted in **figure 1.1**.

Figure 1.1. Angle of Attack.



Aerodynamic Coupling. An aerodynamic characteristic affecting dynamic stability which results when disturbance about one axis causes a disturbance about another axis, e.g., a rolling motion resulting from rudder deflection.

Body Axis System. The body axis system is the system by which the axes of flight or aircraft movement are determined. The aircraft body axis system is shown in **figure 1.2**.

Departure. The phase of flight during which the aircraft goes from controlled to uncontrolled flight. The departure boundary is depicted in **figure 1.3**.

Figure 1.2. Body Axis System.

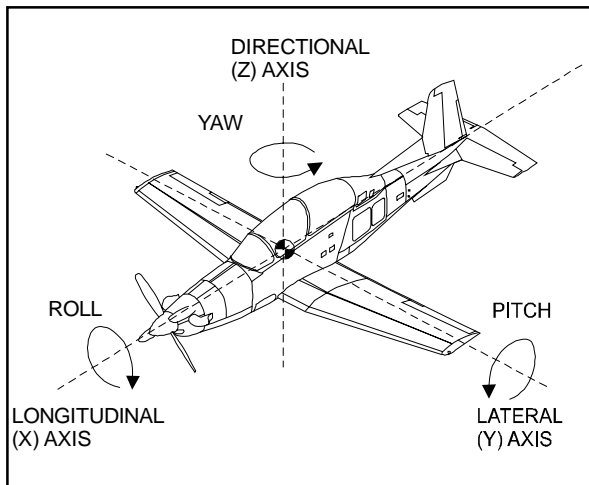
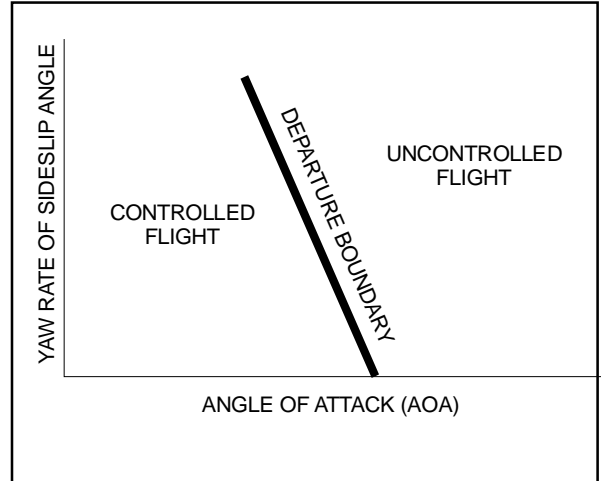
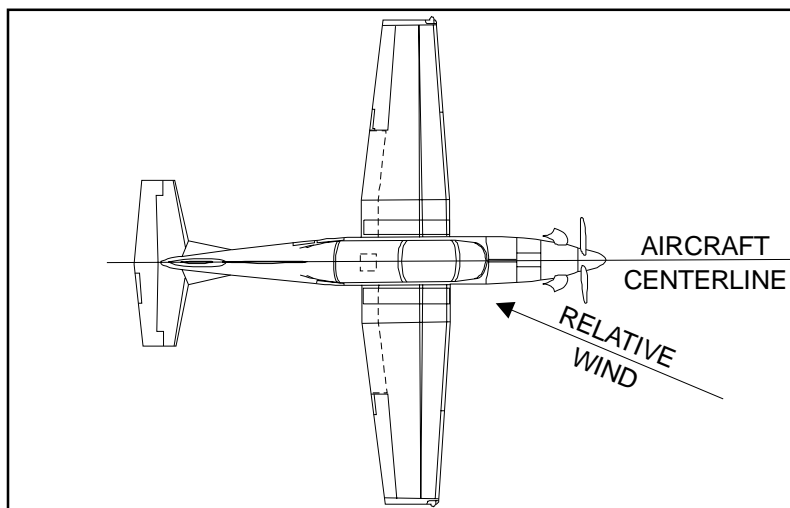


Figure 1.3. Departure Boundary.



Moment of Inertia (I). With respect to any given axis, the moment of inertia is a measure of resistance of a body to angular acceleration. $I(x)$, $I(y)$, and $I(z)$ are moments of inertia about respective body axes.

Figure 1.4. Sideslip Angle



Sideslip Angle. Sideslip angle is the relationship between the displacement of the aircraft centerline from the relative wind rather than from a reference axis. Sideslip angle is depicted in **figure 1.4**.

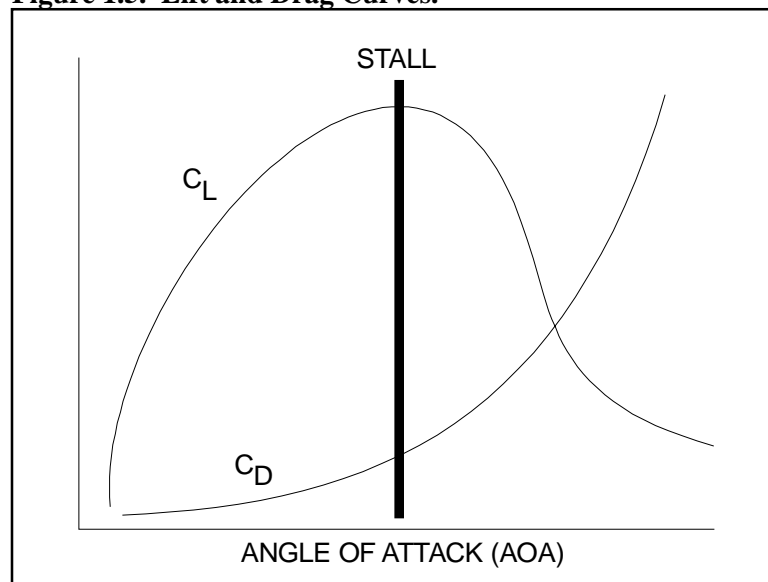
Stall. That AOA beyond which a further increase in AOA will not produce a corresponding increase in lift.

Yaw Rate. Rate of change of yaw angle or, how fast the nose of the aircraft is moving across the horizon. It is measured in degrees per second (deg./sec.).

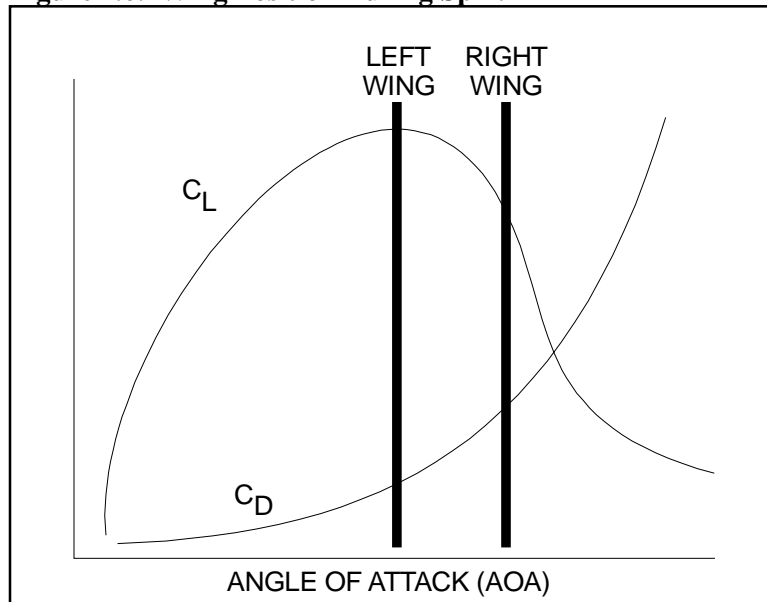
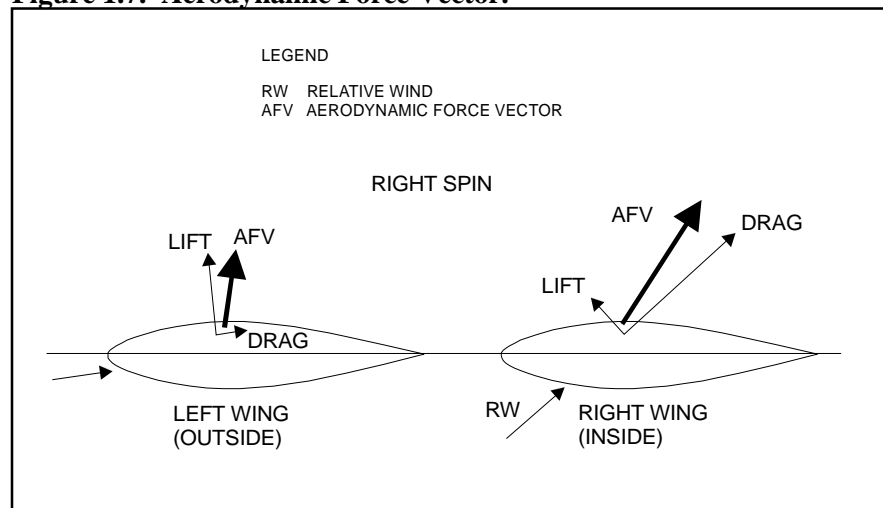
Aerodynamics:

There are two necessary prerequisites for a spin: a stall in combination with a yawing moment. You may recall the relationship between the coefficient of lift and drag curves vs. angle of attack (**figure 1.5**). The coefficient of lift (C_L) drops off sharply as the angle of attack exceeds the stalling angle of attack, while the coefficient of drag (C_D) increases. In discussing the T-6A spin, we will be dealing with post-stall gyration, so we will be working with the portion of the curves to the right of the stalling angle of attack.

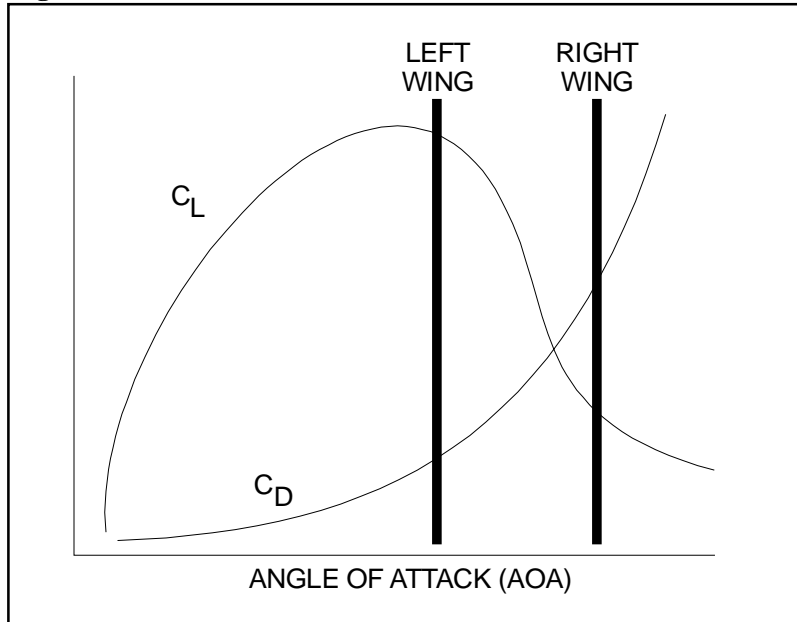
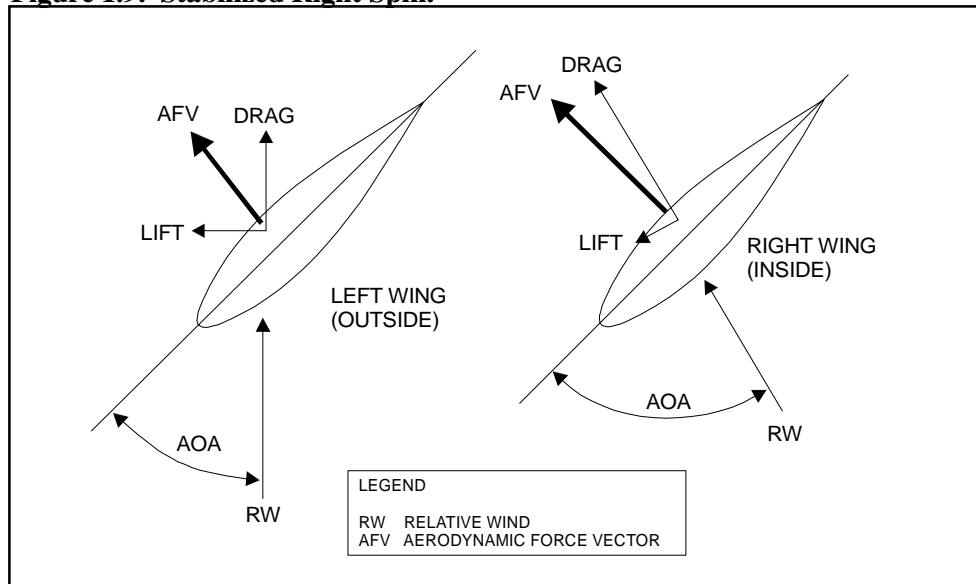
Figure 1.5. Lift and Drag Curves.



The second prerequisite for a spin, a yawing moment, causes a differential angle of attack between the wings. In the case of a planned spin entry, we induce the yaw with rudder. In an inadvertent situation, this yaw could also be induced by adverse yaw, torque, gust loading, etc. If the aircraft is stalled with the yawing moment to the right, the right wing will have a higher angle of attack. **Figure 1.6** plots the C_L/C_D location of each wing during the spin. Transposing this to force diagrams on the wings, we see the resultant forces. **Figure 1.7** illustrates the left wing at 14 degrees angle of attack (the approximate flaps UP stalling angle of the T-6A wing) and the right wing slightly higher at a slightly higher angle of attack at the start of the spin. The resultant lift and drag forces have been exaggerated in order to illustrate the point. The reduced lift on the right wing will cause a rolling motion to the right and the increased drag will result in a yawing motion to the right. The overall loss of lift will result in a descent with the nose lowering. It becomes extremely difficult to separate the rolling and yawing moments as the nose lowers, so we will simply be referring to the combination of the two as a rotational moment.

Figure 1.6. Wing Position During Spin.**Figure 1.7. Aerodynamic Force Vector.**

In a right spin, as the nose lowers and the spin becomes fully developed, the angles of attack continue to change significantly. The angles of attack increase, however, the difference between the angles of attack of the right and left wing become greater and contribute to greater stall and yaw. **Figure 1.8** shows the C_L/C_D curves and **figure 1.9** shows auto-rotational forces vector diagrams for a stabilized spin. In the exaggerated force diagrams, it is obvious that the left or outside wing will generate greater lift and less drag than the right wing. The resultant force would be forward or in the direction of rotation. Although the right wing also generates a forward force, which would be in opposition to the rotation, it is not as great as the pro-rotational force generated by the left wing. The net result is autorotation.

Figure 1.8. Auto-rotational Forces.**Figure 1.9. Stabilized Right Spin.**

The rudder works in a recovery to both break the stall and counter the rotation. Due to the position of the relative wind in a spin, the dorsal fin area of the vertical tail tends to block out a portion of the vertical tail and rudder, reducing its effectiveness as an airfoil. The vertical tail then acts as a flat plate with the resultant aerodynamic force parallel to the relative wind. **Figure 1.10** clearly illustrates that pro-spin rudder will minimize the tail area, which acts in resistance to the relative wind, while opposite rudder will maximize the resistance and the resultant aerodynamic force. The resultant aerodynamic force can be resolved into its horizontal and vertical components: the horizontal component creating an anti-spin or anti-rotational force and the vertical component creating a tail-up or nose-down force. Both components are maximized with the application of opposite rudder. **Figure 1.11** shows that the horizontal stabilizer

tends to blank out the lower portion of the rudder. The more effective portion of the rudder is the portion near the top.

Figure 1.10. Horizontal and Vertical Components of Auto-Rotational Forces.

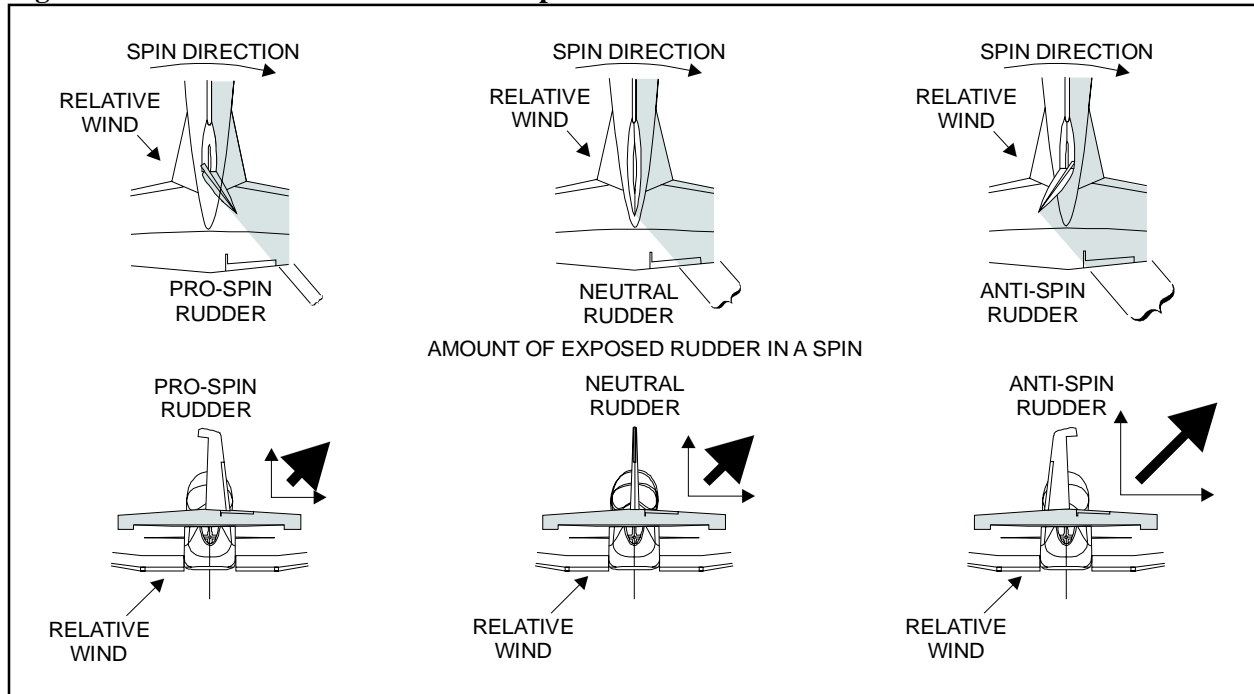
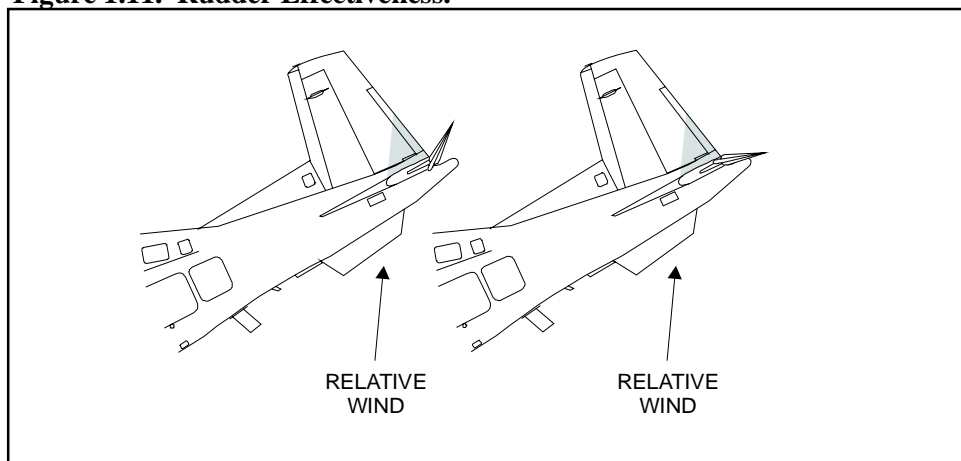
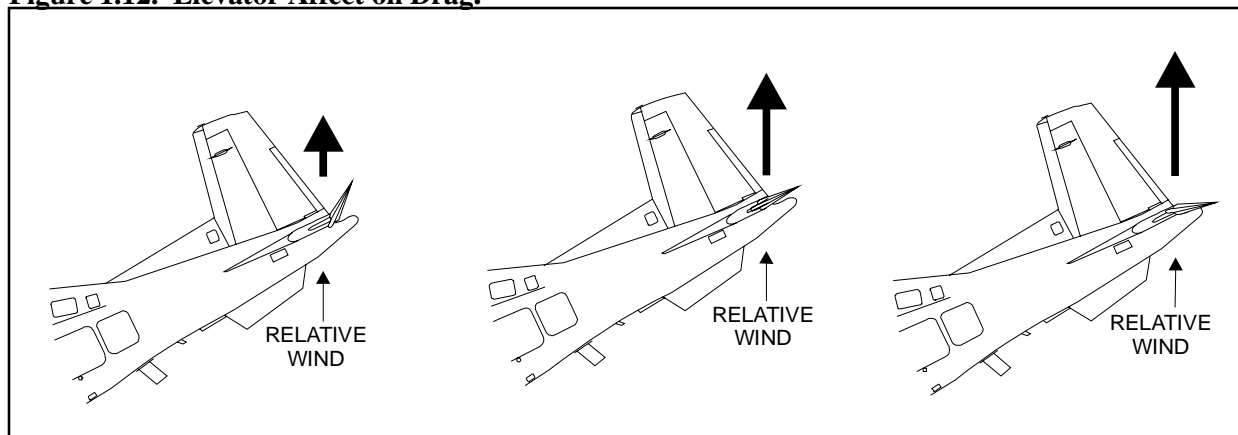


Figure 1.11. Rudder Effectiveness.



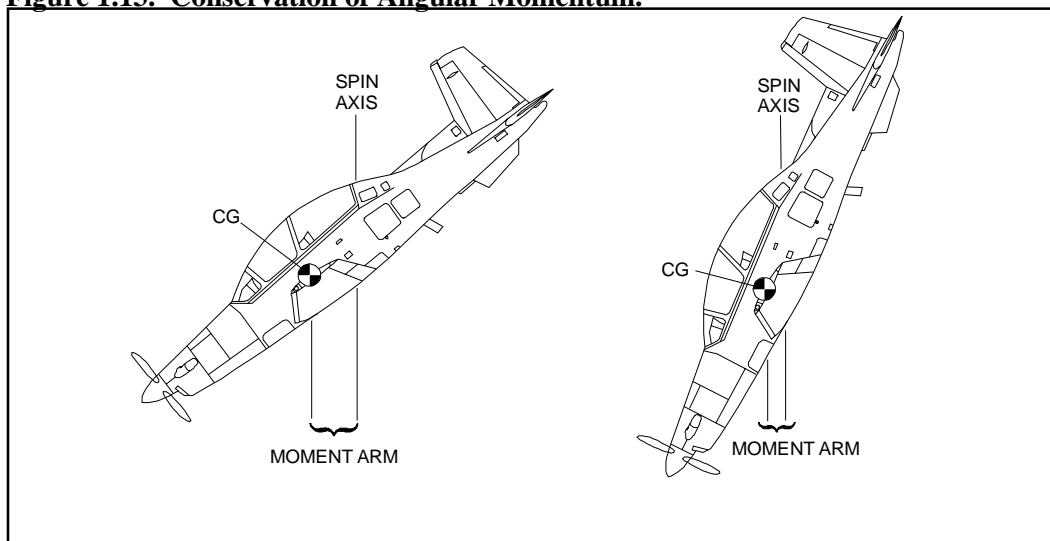
In a stabilized spin, the horizontal stabilizer and elevator are stalled due to the excessive angle of attack (**Figure 1.12**). This results in the development of very little lift, but a great amount of drag. This drag will be maximized with full down elevator and minimized with full up elevator. This drag is also trying to lift the tail or lower the nose.

Figure 1.12. Elevator Affect on Drag.



As the pitch attitude in the spin becomes steeper due to the increased nose down force from the rudder and/or the elevator, the rate of rotation increases. This increase is due to the conservation of angular momentum. As the pitch rate becomes steeper, the center of mass of the aircraft, 'moves closer to the spin axis. The shorter moment arm necessitates an increased angular velocity in order to maintain the angular momentum. This is similar to a spinning ice skater. As a spinning skater brings his arms in, the spin rate increases for the same reason. **Figure 1.13** may make this easier to visualize and understand. Full nose up elevator results in the flattest pitch up attitude with the slowest rotation rate. Any stick position other than full aft will result in a steeper pitch attitude and an increased rotation rate. This is why any spin with other than full aft stick is considered an accelerated spin. If the pitch attitude reaches 90 degrees nose down, the spin, of course, would be broken. However, as the pitch attitude slowly becomes more nose down, the center of gravity experiences a greater and greater acceleration away from the spin axis. In other words, as the pitch attitude slowly becomes steeper, the increased rotation rate causes greater resistance to increasing pitch attitudes. This is why if you move the stick forward excessively slowly you will feel an increased force against stick movement.

Figure 1.13. Conservation of Angular Momentum.



The preceding information can be applied to predict and explain the reaction noted in the pitch and rotational rates for any changes in elevator and/or rudder position during a spin. For instance when opposite or recovery rudder is applied, the nose will lower and the rotational rate will initially increase as the center of mass moves closer to the spin axis. The rotation rate will then slow down as the anti-rotational force of the rudder becomes effective in decreasing the rotational momentum. Before concluding our discussion of T-6A spin aerodynamics, there are a few additional areas worth mentioning.

Instrument Readings:

The turn needle will always indicate the direction of a spin, even when spinning inverted. The slip indicator (inclinometer or ball) portion of the turn and slip indicator will give no useful information when spinning.

The airspeed indicator during a spin is not accurate since the pitot tubes are not aligned with the relative wind. However, an air-speed indication of approximately 120 KIAS is a fairly reliable indication of a stabilized spin (erect, IDLE power, elevator full aft, ailerons neutral, pro-spin rudder). AOA in an erect spin will indicate a full stall.

Power Effects:

One effect of power on the stall and spin characteristics is the result of the high-energy, spiral slipstream from the propeller wrapping around the aircraft and impinging upon the wing root, fuselage, and tail surfaces. The spiral slipstream changes with power and airspeed. The addition of power energizes the air flowing over the tail surfaces, making them more effective at slow speeds. In the T-6A, the spiral slipstream will induce a slightly higher angle of attack on the left wing root and tail surfaces and a slightly lower angle of attack on the right wing root and tail surfaces.

Another effect of the propeller is that the downward-moving propeller blade has a higher angle of attack than the upward-moving blade. This moves the aerodynamic center of the propeller to the right of the shaft on a clockwise-rotating propeller, causing the aircraft to yaw left as angle of attack or power is increased. This is why increasing right rudder is required to maintain coordinated/balanced flight as you slow down or add power.

The torque reaction in a propeller-driven aircraft acts opposite the direction of rotation of the propeller. In the case of the T-6A, the aircraft will tend to roll to the left as a result of torque.

Gyroscopic reactions, called “precessions”, occur when a force is applied to displace a spinning mass such as the propeller, or in the case of a spin, the aircraft as a whole. Precession causes an applied force to act in a plane 90 degrees from that in which it was applied, translating in the same direction as the rotation. **Figure 1.14** shows typical reactions from a clockwise-turning propeller which include:

If the nose is yawed to the left – the nose will tend to pitch up.

If the nose is yawed to the right – the nose tends to pitch down.

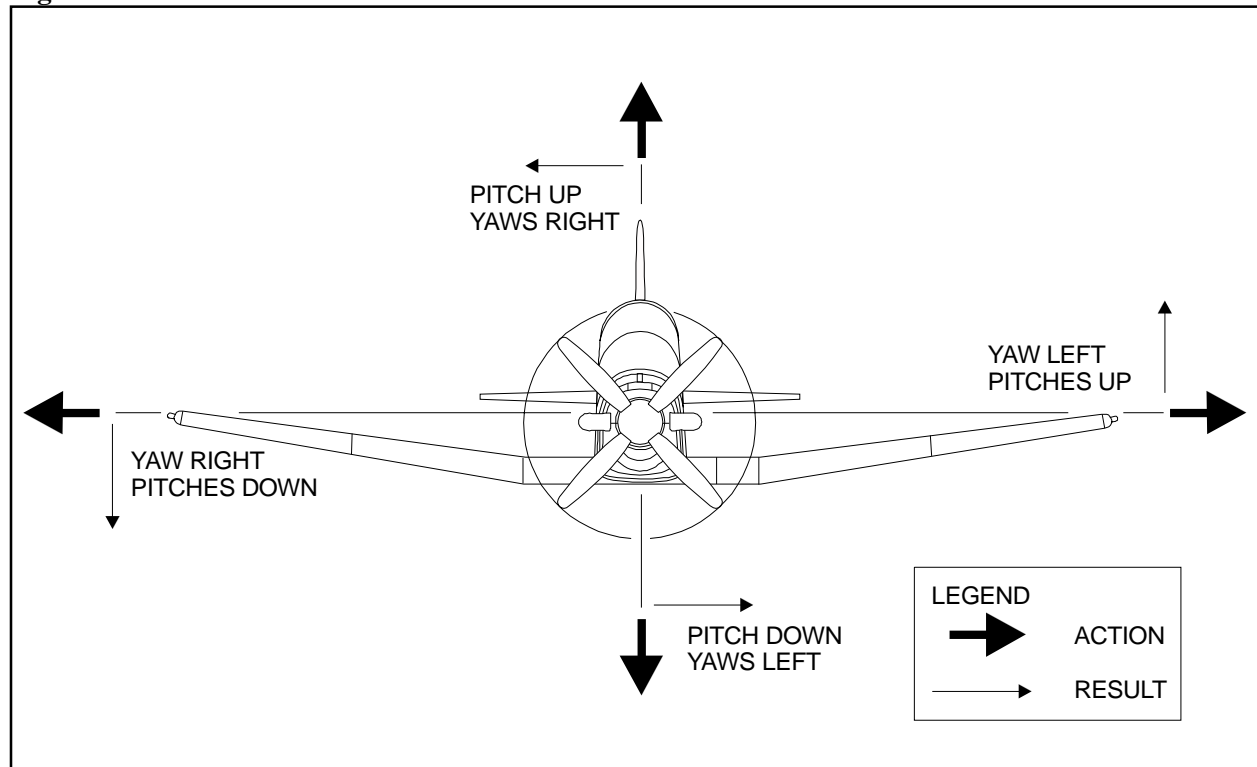
If the nose is pitched down – a left yaw tends to develop.

If the nose is pitched up – a right yaw tends to develop

These reactions depend on the rate of movement about the pitch or yaw axis. Increased rates tend to increase the effect. This explains why a pilot who abruptly corrects aircraft deviations (pitch, bank, yaw)

will end up frustrated with the adverse effects of precession. The relatively large propeller on the T-6A and high rpm result in more precession effect than an aircraft with a lighter, smaller propeller turning at slower rpm. Applying this knowledge to erect spins in the T-6A means right spins result in the nose pitching down and a slightly faster roll rate compared to left spins, where the nose pitches up and the roll rate is slowed. This pamphlet will refer to the sum total of these reactions as “power effects.”

Figure 1.14. Power Effects.



Flight test evaluation of power-on spins is limited. Flight test did evaluate the failure to reduce power during a normal spin turn entry by performing the entry and first spin turn with full power and then reducing power to IDLE for an additional five turns. Full power entries to the right exhibited only slight differences in pitch attitude when compared to IDLE power entries. Full power entries and the first turn to the left demonstrated significantly greater pitch excursions. In either case, reducing power to IDLE quickly stabilized the spin in the normal IDLE power spin mode. Additionally, “inadvertent” spins were evaluated to one turn with full power. Inadvertent spins are those spins in other than a normal spin configuration. Takeoff and landing configurations with full power were evaluated to one turn. Full power configured spins to the right are difficult to initiate due to torque. Full power configured stalls to the left demonstrate slightly greater pitch excursions than IDLE power entries in the same configuration. All recoveries from these spins were initiated using IDLE power.

Mass Distribution. Aircraft mass distribution (inertia) must also be considered when discussing precession. An aircraft resists acceleration about any axis where a lot of mass is distributed. The T-6A can be considered to have an approximately equal mass distribution about the fuselage and wings or “neutral loading”. Rudder tends to be the primary spin recovery control for a neutrally loaded aircraft.

Stability. The T-6A’s longitudinal stability makes it resist entering inadvertent accelerated stalls. However, at lower than required power settings, airspeed can decay and AOA can build, resulting in an insidious flat stall that is not easily detected without referencing instruments. Care should be taken to

monitor airspeed, AOA and power to prevent the sink at low altitudes. When using power in stall recovery, be aware that it will pitch, yaw, and roll the aircraft. Be prepared to step on right rudder to counter this effect, and keep the aircraft in balanced flight. Remember that adding yaw to a stall will induce the spin.

Spin Resistance. The T-6A is resistant to spins and requires a deliberate effort to enter a spin. Relaxing back pressure and/or neutralizing rudder during entry can cause the spin to stop or “pop out”. Applying recovery procedures produces prompt recovery to a near vertical attitude. A typical erect spin will lose approximately 400-500 feet per turn and will recover 45-65 degrees nose low. Altitude loss during the spin and spin recovery will vary from 1400-2400 feet when recovery is initiated within one turn after entry. Recovery is prompt. For altitude planning, a good rule of thumb is to allow for 1000 feet of altitude loss for each turn planned before recovery initiation (e.g. 6 turn spins require 6000 feet total altitude above 10,000 feet AGL).

Chapter 2

RELATED TOPICS

Defensive Positioning. Defensive positioning is the flight instructor technique of refusing to allow the aircraft, student or themselves to get into an out of control situation. Defensive positioning does not mean “riding the controls”. Instead, it is important that the instructor “shadows” the controls, and is aware of his student’s inputs. This is especially important during critical phases of flight at low altitudes. A good example of defensive positioning is “guarding” the rudder pedals during ELP training to prevent a slip from becoming a skid without your immediate recognition. Defensive positioning awareness will improve your reaction time by allowing you to “feel” an improper input and act correctly.

Unintentional Spin Characteristics. During intentional spin entries, parameters such as altitude, pitch attitude, stick position, and power setting are fairly consistent. Those constraints breed familiarity, so when one or two parameters are changed the pilot can easily become disoriented in an inadvertent entry. The following variables could affect either the entry characteristics or the view seen from the cockpit.

Gross Weight. Although you may notice slight variations in spin characteristics at varying gross weights, flight testing shows these differences are negligible.

Fuel Imbalance. Flight testing revealed spin and spin recovery characteristics were not noticeably affected when performing spin maneuvers with 50 pounds of fuel imbalance in right or left wing heavy configurations.

Configuration. Landing gear and flaps extended (TO or LDG) – Flight testing in this configuration is not complete. Unintentional configured spins (one turn) will recover within two turns after recovery procedures are applied.

Speed Brake. Has no significant effect.

Power Setting. MAX power will delay the spin recovery, particularly to the left. Flight testing revealed these spins required more turns to recover and lost more altitude during the recovery than spins at idle power. This tendency emphasizes the need to immediately reduce power to idle when any unintentional spin is identified.

Trim Aid Device (TAD). Has no significant effect.

Inverted Spins:

Refer to Section VI of the flight manual on inverted spins. Aerodynamically, the inverted spin is quite similar to the erect spin in that both require a stalled AOA and a yawing motion. In order to enter an inverted spin, the stall must be at a negative AOA. An inverted stall is more difficult to enter than an erect stall although it can be done either deliberately or inadvertently. Flight test data revealed that while recovery from an inverted spin was easily accomplished, the spin itself proved to be very disorienting to the pilot. Pilots are more sensitive to motion about the

longitudinal axis than the vertical axis, and are consequently more likely to interpret an inverted spin in the direction of roll rather than direction of yaw. Regardless of whether the aircraft is spinning erect or inverted, the turn needle will always deflect fully in the direction of spin and is the only reliable indication of spin direction.

During flight tests, the T-6A consistently entered a right, power-on, inverted spin when releasing the flight controls with the nose 60 degrees above the horizon at max power and 50 KIAS. The aircraft recovers easily when using the recommended inverted spin recovery procedures outlined in Section VI of the flight manual. Testing also revealed that failure to reduce power to idle during an inverted spin would likely prevent recovery.

Inverted spins were also attempted from a wings level inverted stall position. In most cases, the aircraft entered a steep nose down spiral and recovered immediately upon neutralizing the flight controls.

It is essential to emphasize these flight characteristics since you will be flying with students, often at high AOA and, in the case of aerobatic training, at flight regimes similar to those described in the preceding paragraphs. A student pilot attempting a loop or Immelmann, for example, could easily become disoriented and arrive at a nose high attitude with a high AOA and decreasing airspeed. A wary instructor pilot should recognize the potential for departure from controlled flight in these instances and recover. Simply reducing the power to idle and neutralizing the controls should prevent the aircraft from entering an inverted spin. However, if timely action is not taken and the aircraft enters an inverted spin, you can be assured that recovery will be prompt after initiating inverted spin recovery procedures. In the event that you are completely disoriented and are not sure you are spinning or in a spiral, the best course of action is to check power at idle, neutralize controls, and verify cockpit indications. Remember, in an inverted spin, the AOA will indicate pegged below zero, and the turn needle will be fully deflected in the direction of spin. In an inverted spiral, the airspeed will be building rapidly through 140 KIAS, and the turn needle will be fully deflected in the direction of spin.

Spirals:

The high-speed spiral is characterized by a nose low attitude, high roll rates and rapidly increasing airspeed. It may easily be confused with a spin if the pilot relies solely on the interpretation of outside references and fails to accomplish a proper analysis of the cockpit flight instruments. Should the pilot misinterpret a high-speed spiral as a spin, it is highly unlikely that anti-spin inputs will effect a successful recovery.

The cockpit indications differ significantly from those of a steady state, erect spin. The aircraft is not stalled; therefore, AOA will not be pegged as in an erect spin. Airspeed will most likely be rapidly building through 140 KIAS. The rate of descent will exceed that of a steady state spin because of the high airspeeds ultimately attained through this flight regime. The turn needle will, however, be fully deflected in the direction of the roll. Flight manual out-of-control recovery procedures should be utilized if a high-speed spiral is encountered. The key to a safe recovery lies in the expeditious recognition of the aircraft's actual flight condition. The pilot must be able to accomplish a proper analysis of the flight instruments and not rely solely on outside references.

Unintentional Departures. Review Section VI of the flight manual on Departures from Controlled Flight. Applying the proper departure recovery technique depends on accurately analyzing the situation. Incorrect analysis and improper control inputs could result in the pilot worsening the situation and delaying recovery. Departure from controlled flight can be a confusing and extremely disorienting experience. Visual and “seat of the pants” cues are not always sufficient to analyze the departure. In these situations, you must immediately initiate the flight manual Departure Recovery. The T-6A has proven its willingness to recover by simply reducing the power to idle and neutralizing the controls – “Idleize and Neutralize”. Reducing power to IDLE and neutralizing the stick and rudder are the control inputs that will avoid aggravating the departure and start the recovery process. With stick, rudder, and PCL in the proper recovery position, the pilot is free to continue analyzing the situation. Be patient and allow the process to work. Using defensive positioning, knowing your limits, and maintaining situational awareness should prevent a departure from controlled flight.