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COURSE INTRODUCTION

This training program, like other safety considerations, will not eliminate all air show accidents. However, it can help establish an understanding of the risk factors attendant to air show performances.

For some performers the concept of a good air show involves the use of the most high risk maneuvers that can be crammed into the allotted time. This is a dangerous concept that stems from an attitude on the part of the performer that he/she is in some kind of contest with other performers to show how daring he/she can be.

The professional air show performer knows that the real goal is to provide the most entertainment possible while absolutely guarding the spectator and himself/herself from unnecessary risks of harm. Traditionally, regulatory agencies such as Canada's Transport Canada (TC) and the USA's Federal Aviation Administration (FAA) have taken up the cause of public safety and have, therefore, mandated guidelines for decreasing spectator risk of harm. However, little has been done to provide the performer with the knowledge or training to control his/her own risk of harm. This is the primary purpose of this course.

RISK FACTORS:

To begin identifying risk factors, we must first consider the air show environment itself. Flying an aircraft for display or demonstration purposes in front of an audience involves a variety of psychological pressures which can impair judgment and change normal behavior patterns into patterns not evident in an individual outside the air show environment. These pressures, coupled with incomplete knowledge of the aircraft characteristics at the edge of the operating envelope, can result in unnecessary risk to the performer.

The psychological pressures arise from both internal and external sources. It is difficult to control or predict the timing, degree, or nature of externally originated pressures. Examples include a demand from an "air boss" to "hurry up and fly" or pressure to fly a routine in marginal conditions to "save" a show. Experience, knowledge of one's capability, and a thorough understanding of the technical aspects of one's routine all assist in reducing these external pressures.

Internal pressures stem from attitudes of the performer. Both the over-confident performer, who is going to "show everyone how good he is," and the under-confident performer, who knows that his training has been inadequate, are placing unnecessary pressures (risks) on themselves. Use of an airplane in front of a crowd to feed an ego or solve inferiority complexes is dangerous at best. The reason a professional show pilot flies is to entertain others, not prove something to himself/herself. Internally generated psychological pressures have no place in the air show environment.

The second area which determines risk is the pilot's knowledge of the technical factors pertaining to air show performances. It is that knowledge and skill which separates the professional air show pilot from other types of pilots. It is the difference between air show flying and being an airline pilot, an agricultural pilot, or a military pilot. Just as there are attorneys who practice corporate law rather than litigation, doctors who practice internal medicine rather than orthopedics, there are pilots who fly air shows rather than fly passengers. Each of the professions above has a basic program of learning (licenses and ratings) followed by specialty training.

Pilots, physicians and other professionals in multi-discipline professions can be trained in more than one discipline. A pilot who has not been trained in the discipline of performing at air shows should never offer himself or herself as an air show pilot.

For example, there are individuals who can be trained and proficient in both air show and agricultural flying. The key, as always, is the possession of that particular knowledge required in each specialty and the practice to remain proficient in its use.

This course is an attempt to codify and present in a logical fashion some of that special knowledge peculiar to air show flying. It is intended to be presented in such a way that its use in reducing the risk of harm to the performer is easily understood and readily adaptable to each performer's aircraft and routine.

The focus of this course is limited to performer safety and operations and does not address various other tasks associated with the proper conduct of an air show.

This document is for information purposes. The International Council of Air Shows (ICAS) does not attempt to control individual air show performers or the air show environment, and therefore cannot assume responsibility for the safety or success of individual performers.

AERODYNAMICS, TURN PERFORMANCE AND ENERGY MANAGEMENT FOR THE AIRSHOW PILOT

This review of basic aerodynamics, turn performance and energy management is intended to help pilots prepare for their oral ACE evaluation. It is not intended to be a heavy theoretical treatise. I have tried to relate the theory to important practical points and use as few equations as possible in the text, though they could not be avoided entirely. For anyone who is interested, most of the mathematics is in endnotes.

LIFT AND DRAG

1. LIFT

Figure 1 shows air flowing past an airfoil. The angle between the airflow direction (also called the relative wind) and the mean chord line of the airfoil (the line joining the leading and trailing edges) is called the angle of attack. When the airflow divides at the leading edge, some passes above the wing and some below it. Because of the curvature of the airfoil and its angle of attack, the distance from the leading edge to the trailing edge is greater along the upper surface than along the lower, so the air moving past the upper surface has to increase its velocity relative to the air moving past the lower surface so that they both arrive at the trailing edge at the same time.

Figure 1
Flow Around an Airfoil

The Swiss mathematician Daniel Bernoulli found in 1738 that when air travels in streamlines (as it does around the wing of an aircraft), its total pressure -- the sum of its static and dynamic pressures -- is constant. So when the air is accelerated past the upper surface of a wing its dynamic pressure increases (because it is moving faster) so its static pressure must decrease in proportion. This difference in static pressure between the upper and lower surfaces of the wing is what gives rise to the lifting force.

The total lift developed by a wing depends on the angle it makes with the air flowing past it: the angle of attack. Most wing sections are cambered, that is, they curve more on the upper surface than on the lower. This means that even when the angle of attack is zero -- the mean chord line is parallel to the relative airflow -- there is still a longer distance from the leading edge to the trailing edge along the upper surface than the lower. So the air still moves faster over the upper surface, there is still a pressure difference and lift is still generated. Only when the angle of attack is made negative -- typically about -4° -- does the wing stop lifting. This angle of attack is called the zero-lift angle of attack. From here up to some angle of attack usually between about 16° and 20° for conventional straight wings the lift of a given wing varies directly with the angle of attack. As the angle of attack increases the effective curvature of the upper surface becomes greater, the air is accelerated more, the static pressure drops more and more and the wing generates more lift. Double the angle of attack (don't forget we are starting from the zero lift angle of attack) and we double the lift.

The combination of the shape of the airfoil section and the angle of attack give a measure of how hard the wing is working to accelerate the air flowing past its upper surface. To make it easy to compare the efficiency of different airfoils and wings of different sizes these effects are lumped together in a parameter called the coefficient of lift, or just lift coefficient, written C_L. The only control a pilot has over the shape of his airplane's airfoil section is by raising or lowering the flaps, which is not much of an option during an airshow performance, but he has a direct C_L controller in his hand in the form of the stick. The shape of a typical curve of C_L against angle of attack is shown in figure 2.

Figure 2

Lift Coefficient versus Angle of Attack

The angle of attack at which the lift curve starts to bend to the right is where the airflow over the wing can no longer follow exactly the upper surface curvature but starts to separate. The flow separation may be felt as airframe or control buffet. As the angle of attack is increased beyond this point the flow separation will increase and the lift coefficient will peak and then decrease. The wing has stalled. In some aircraft this can happen very quickly with little or no warning, and the loss of lift can be dramatic. If the lift loss occurs asymmetrically, as it usually will, a sudden uncommanded wing drop or rolling motion will result. The maximum usable lift coefficient is called C_{Lmax}. It may be less than the value at the peak of the lift curve if the handling qualities prevent the consistent and safe use of the peak value, as in the example just given.

The lift developed by a wing also depends on the quantity of air, or the number of air molecules, flowing past it, which will be determined by a number of factors. The physical size of the wing will affect the quantity of air which at any given time is being accelerated by the camber of the airfoil. This is again a simple one-for-one relationship: double the area of the wing, and at any given time there are twice as many air molecules flowing past it, so the lift doubles.

The number of air molecules flowing past the wing is also a function of the speed of the airflow. At zero speed, there is no air flow and no lift is generated. This time there is not a direct one-for-one relationship but instead the lift depends on the square of the speed [IE]. If the speed is doubled, the lift quadruples: if the speed increases by a factor of three, the lift increases by a factor of nine.

Finally, the number of molecules being affected by the wing will vary with the air density. Nobody would expect a wing to develop any lift in the vacuum of outer space, no matter how fast it was moving or at what angle to the direction of travel. In this case we are back with the simple one-for-one relationship again: double the air density at a given speed and twice as many molecules flow past the wing in a given time, so the lift also doubles. Air density is affected by altitude, temperature and humidity, and is a very important parameter in aviation.

Air at a particular ambient density flowing at a particular speed will generate a particular dynamic pressure. Dynamic pressure is the pressure felt by the pitot side of the air speed indicator, and it is dependent on the rate at which air molecules are brought to rest and convert their kinetic energy (energy of motion) into pressure.

Climbing at a constant indicated airspeed means that the dynamic pressure stays constant and will automatically result in the true airspeed increasing at exactly the right rate to compensate for the decreasing air density. The pilot is only directly aware of the indicated airspeed and has nothing in the cockpit to alert him to his increased true airspeed[1]. Most of the time this does not matter, but it has profound consequences for turning performance and energy management.

When we collect all these variables together to find the total lift we end up with an expression that says:

Total Lift is given by half the Air Density times the Square of the True Airspeed times the Wing Area times the Lift Coefficient

which is a little cumbersome when written out in words and is more often summarized in the familiar form:

$$Lift = \frac{1}{2}\, pV^2SC_L$$

where ρ is the air density, V is the speed, S is the wing area and C_L is the coefficient of lift. The $1/2\ \rho V^2$ term, which represents the dynamic pressure, has two equivalent forms. If ρ is taken as the ambient air density, then V must be the true airspeed. If ρ is taken as the sea level standard air density, then V must be the indicated airspeed (strictly speaking the equivalent airspeed, but for our purposes and at the speeds we are dealing with the differences are small)[2E].

2. DRAG

Drag comes in two main varieties: parasite drag and induced drag[2]. The total drag is the sum of parasite and induced drag. The drag equation looks a lot like the lift equation:

$$Drag = \frac{1}{2}\, \rho V^2SC_D$$

where C_D is the total drag coefficient.

---

[1] A very few aircraft have true airspeed indicators. Rather more have Machmeters which are nearly like true airspeed indicators except that they have compensators to correct for the fact that the speed of sound changes with temperature.

Parasite drag is made up of several components, namely skin friction, form or pressure drag and interference drag, but is essentially the force that results from simply moving a body through the air. In reference to a wing alone the interference drag term is omitted and the sum of skin friction and form drag is called profile drag. It is affected by most of the same factors that determine lift: the dynamic pressure of the airflow and the size of the body, and a measure of the "efficiency" of the body at slowing the air down known as the parasite drag coefficient, C_{Do}.

Induced drag is the price we pay for lift. The pressure differential between the upper and lower surfaces of the wing forms vortices at the wing tips which dissipate considerable amounts of energy. The larger the pressure difference the stronger are the vortices and the more energy is dissipated, so induced drag will increase as the coefficient of lift increases. It turns out that the coefficient of induced drag, C_{Di}, varies with the square of the lift coefficient, or C_L^2[3]. This means that for level flight, as the airspeed increases, the induced drag goes down. It also means that in maneuvering flight the induced drag goes up VERY FAST. In fact, in a 4G turn or pullup the induced drag is sixteen times what it was at 1G. In the drag equation above, the total drag coefficient C_D is equal to the sum of C_{Do}. and C_{Di}.

Aircraft do not all generate induced drag with C_L at the same rate. The size of the wing tip vortices varies with the geometry of the wing. Long narrow wings (high aspect ratio) which are fine for sailplanes, airliners and high altitude reconnaissance aircraft, but are not very strong and do bad things to the aircraft's roll performance, generate small tip vortices and have small induced drag coefficients. Short stubby wings (low aspect ratio) which are stronger and more maneuverable and are found on fighters have proportionally much bigger tip vortices and consequently much larger induced drag coefficients. Sweepback makes matters worse.

When we add these two components of the drag as shown in figure 3 we find that one component is increasing with the square of the speed while the other is decreasing with the square of the speed. The total drag is the sum of these components. It has a large value at low speed where the effects of high lift coefficient predominate and a large value at high speed where the effects of high dynamic pressure dominate, with a pronounced decrease between these two extremes. The minimum value of the total drag occurs at the speed where the two components are equal ($C_{Do} = C_{Di}$). This speed is called the Minimum Drag Speed, or V_{md}.

Since lift is constant in level flight, when the total drag is at a minimum the lift to drag ratio (L/D) is a maximum. This is an important condition. The minimum drag speed is the speed for best range for a propeller driven aircraft, and the speed for best endurance for a jet. It is also the speed at which the excess of thrust over drag is a maximum.

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[2] There is a third variety called wave drag associated with the formation of shock waves on the airframe, but it does not have much relevance in this discussion.

[3] This relationship is not universally true. On some aircraft, especially those with very low aspect ratio wings, the induced drag goes up faster than the square of the lift coefficient. For example, in both the T-38 and the space shuttle the induced drag varies with the cube of the lift coefficient.

Another important condition for propeller driven aircraft is the speed for minimum power. It can be shown that this occurs when the coefficient of induced drag is exactly three times as large as the coefficient of parasite drag ($C_{Di} = 3.C_{Do}$). From figure 3 it can be seen that this condition will be attained at some speed below the minimum drag speed. Minimum power speed is the speed at which the excess of power over drag is a maximum.

Figure 3

Typical Drag Curve

If the weight of the aircraft is increased while everything else is held constant, then for level flight at a given airspeed the lift must be increased, which will increase the induced drag at a much faster rate ($C_{Di} = K.C_L^2$). The small increase in parasite drag resulting from the slightly different angle of attack of the whole aircraft can be ignored. The effect on the induced drag curve as before is much more pronounced at low speed, so the total drag curve moves up and to the right as shown in figure 4. This is important because while the actual weight of the aircraft would not be expected to change much in the course of an airshow routine, its effective weight changes a great deal, and changes in load factor have exactly the same effect on the drag curves as changes in weight.

To summarize the lift and drag effects for a given airplane:

- At constant angle of attack and air density, lift and drag vary with the SQUARE _____ of the TRUE AIRSPEED.
- INDICATED AIRSPEED takes changing air density into account. A given angle of attack will always generate the same lift at the same indicated airspeed.
- Induced drag varies with the SQUARE of the lift coefficient. At 2G the induced drag is FOUR times its 1G value, at 4G it is SIXTEEN times as large.

Figure 4

Effects of Weight on Drag Curves

FUNDAMENTALS OF TURNING PERFORMANCE

3. TURN RATE AND RADIUS

Consider a body travelling along a circular path, and for the time being ignore the effects of gravity. The body is moving with a velocity V, and the radius of its circular path is R. Its rate of turn, usually referred to by the Greek letter omega, Omega will increase as V increases (the body gets around the circle faster) and will decrease as R increases (it has a bigger circle to get around). Expressed in symbols:

$$\underline{Omega} = V/R$$

Newton's First Law states that a body will continue at rest or in motion in a straight line unless it is acted upon by a force. The Second Law states that: a force acting on a body produces an acceleration proportional to the force. The force produces an acceleration which acts continuously towards the center of the circle, known as the centripetal (center-seeking) or radial acceleration. When a weight is swung around on a string it is the tension in the string that exerts the force and creates the acceleration, which is, of course, proportional to the tension[4].

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It is not hard to see that for a given length of string (constant R), the faster the weight is swung the greater will be the tension and the radial acceleration. Also that for a given velocity (constant V), the longer the string the less will be the tension and the acceleration. If we now stop pretending that we are not talking about airplanes we can call radial acceleration radial G, or G_R. We can also simplify things by just referring to G, the quantity which is read from the cockpit accelerometer. It is very rarely exactly the same as G_R, but it is the only indication the pilot has[3E].

The most useful relations are those which express turn rate and radius in terms of those things which are, or should be, under the pilot's control, namely airspeed and G. It so happens that the turn rate is directly proportional to the G and inversely proportional to the speed. There is nothing very surprising about that: the harder you pull, the faster the airplane turns, and the faster it is going the larger the turn radius and the longer it takes to get round a turn[4E].

It also happens that the turn radius is inversely proportional to the G, which again is not surprising: pull harder and turn tighter. But it may be a little unexpected that the turn radius is proportional to the SQUARE of the speed: that is, if the airplane is going a LITTLE faster, it uses a LOT more airspace to turn.

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[4] This force is often miscalled centrifugal (center-fleeing) force because it seems as if the weight is exerting a force on the string, whereas it is actually the force exerted by the string on the body that is accelerating it towards the center of the circle.

4. LEVEL TURNS

Consider an aircraft in a level banked turn as shown in figure 5.

Figure 5

Forces Acting in a Level Banked Turn

The load factor is the G indicated on the cockpit accelerometer. It is equal to the lift divided by the weight. The load factor is a function of the bank angle: the steeper the bank, the greater must the load factor be for a level turn, because there will always be a 1G component of the load factor acting vertically to balance the aircraft's weight.

This confirms what you have always known, that a sustained, coordinated turn at 90° of bank is impossible because there is no component of the load factor acting vertically. In level flight the load factor is 1 which is all acting vertically, and at small bank angles there is not much "surplus" lift available to actually turn the aircraft. At small bank angles the radial G is very different from the cockpit indicated G, but as the bank angle increases the indicated G quite quickly approaches the radial G[5]. As we are not much concerned with shallow turns in this discussion it is not too inaccurate to think of the cockpit G as being the G that is turning the aircraft. These relationships will be important when we discuss turning performance[5E]

5. <u>THE V-G ENVELOPE AND CORNER SPEED</u>

Everything that can be done with an airplane is constrained within the boundaries of a flight envelope defined by the V-G (or V-n) diagram. This diagram represents the aerodynamic and structural limits of the airframe plotted against speed. A typical V-G diagram is shown in figure 6.

Figure 6

V-G Diagram

[5] At 30° of bank G_i is 1.15g, but G_R is only 0.58g. At 45° of bank G_i is 1.41g and G_R is 1g, while at 60° of bank G_i has reached 2g and G_R is 1.73g. In a 4g turn (75° of bank) G_R is 3.87g, and by the time the aircraft is pulling 6g (80° of bank) G_R has reached 5.92g.

Starting at the left hand end of the diagram, at zero airspeed the wing can develop no lift and so no g is available. The maximum lift and g available increase with the square of the speed. The speed where the g is 1 at C_{Lmax} is the 1g stall speed. The speed at which the g at C_{Lmax} equals the structural limit is called the corner speed, and it is very important in much of what follows. Above corner speed the g remains constant at the structural limit. Corner speed is the same as maneuvering speed, which is published in the operating manual for some airplanes. It is the highest speed at which a full control deflection cannot overstress the airplane because it will stall first.

The negative g portion of the diagram is similar except that most airplanes which were not purpose built for aerobatics have a structural negative g limit lower than their positive limit. Also non-symmetrical airfoils do not lift as well inverted as right side up, so the negative C_L will be lower and the negative 1 g stall speed will be higher. Sometimes the top and bottom right hand corners of the V-G diagram are cut off.

6. INSTANTANEOUS TURN PERFORMANCE

A typical set of turn performance curves is presented in figure 7[6E]. The left hand end of the plot is defined by the 1 g stall speed, at which no turn is possible (turn rate = 0) and the turn radius is infinite. As the speed increases the G available increases as the square of the speed and the turn rate increases nearly linearly with the speed and quickly approaches a line through the origin whose slope is determined by the airplane's characteristics. The turn radius decreases rapidly and approaches a line of constant turn radius whose value is determined by the airplane's characteristics.

Once the airplane is beyond corner speed things change. The G no longer increases with the square of the speed but remains constant. Now the turn radius increases with the SQUARE of the speed and the turn rate decreases with 1/V. At corner speed the airplane is capable of performing its maximum rate, maximum G and minimum radius turn.

Figure 7
Instantaneous Turning Performance

In analyzing instantaneous turning performance we are not concerned about whether the airplane can sustain its turn at the edges of the V-G envelope, only that the turn can be achieved, however briefly. The instantaneous turn envelope of the airplane is often called its lift boundary, and it is independent of engine characteristics. In the next section we shall look at the question of sustainable turn performance and what it means.

7. SUSTAINED TURNING PERFORMANCE

We have seen that no turn is possible at the 1G stall speed because all the available lift at C_{Lmax} is being used in the vertical to keep the airplane flying. At the other end of the envelope the airplane is at its maximum level flight speed and all the available power or thrust is being used to keep it there. The slightest increase in drag caused by increasing the load factor to turn will cause a deceleration. These two points anchor the ends of the sustained turning performance plot.

In between these two speeds there is both lift and excess power (thrust) available to turn or accelerate. ("Power" applies to propeller driven airplanes, in which power is essentially constant with speed. "Thrust" applies to jet aircraft which are essentially constant thrust machines and for which the arguments are similar but with some important distinctions which I shall explain as they arise.) Sustained turn performance refers to the envelopes of load factor, turn rate and turn radius between the 1G stall speed and Vmax at which the available power (thrust) exactly balances the total drag and the airplane can continue the turn indefinitely without losing or gaining height or speed. A set of typical sustained turn performance envelopes is shown in figure 8.

Figure 8

Typical Sustained Turn Performance Envelopes

It would seem reasonable to expect that the best sustained turning performance would be found at the speed for minimum power (thrust) and that is indeed true. But there is a twist. We cannot use the level flight minimum power or minimum drag speeds to predict where the best sustained turn will be, because as we found in Section 1 an increase in load factor has the same effect as an increase in weight on the total drag curves: they move up and to the right, so with increasing G the speed for minimum power (thrust) will also increase.

The sustained turn performance envelope is determined by the excess power (thrust) available throughout the speed range, so is clearly dependent on a combination of aerodynamic and engine characteristics. For this reason the sustained turn performance envelope is often referred to as the airplane's thrust boundary. Anything which affects the engine's power or thrust output will affect the sustained turn performance, so it is sensitive to density altitude and temperature effects. It goes without saying that all sustained turn performance data are obtained at full throttle.

The significance of the sustained turn performance envelope is that it represents an energy boundary for the airplane. During any maneuvers conducted inside the envelope the airplane can simultaneously turn and climb or accelerate. Outside the envelope it must lose height or speed or both.

8. VERTICAL TURNS

Vertical turns differ from level turns mainly in the fact that the gravity vector no longer exerts a consistent influence on the airplane's performance. The reading of 1G on the cockpit accelerometer during erect straight and level flight becomes -1G when the aircraft is inverted: a difference of 2G. When the airplane is pointed straight up or down the accelerometer will read zero. Thus to see what the radial G is -- the G that is actually turning the aircraft -- we must subtract 1G from the accelerometer reading when the aircraft is level at the bottom of a pullup, add 1G when it is level during an inverted pulldown, and add or subtract values between +1G and -1G when it is in other attitudes.

These gravity effects, hindering the turn when the airplane is upright and helping when it is inverted, change the shape of the instantaneous turn performance envelopes somewhat, as shown in figure 9.

When we include vertical maneuvers in an airshow routine we are almost exclusively interested in turn radius, especially during dive recoveries, split-S's and loops that may have gone wrong somewhere. The overriding concern is distance from the ground and how to avoid hitting it. It can be seen from figure 9 that when the airplane is inverted and gravity is helping the turn, the minimum radius and maximum rate (though not maximum G) no longer occur at corner speed, but at minimum airspeed. As the speed increases towards corner speed the turn rate dips and then increases again, but the radius increases continuously. Once the aircraft is past 90° nose down corner speed once more becomes the best speed to fly for minimum radius (and hence minimum height loss). Just as in level turns, once the speed is above corner speed the radius goes up very quickly. At the moment the aircraft is truly vertical its turn radius is independent of speed as long as it is still turning at C_{Lmax}.

Figure 9

Vertical Turn Performance

Figure 9 provides the clue to executing a minimum radius vertical recovery from an inverted position. The entire maneuver must be flown at $C_L$max, of course, and as long as the aircraft is inverted the speed should be as low as possible. However, not only will it be impossible to keep the speed low throughout the maneuver, but as the (inverted) dive angle increases the gravity vector provides progressively less help and the speed may be allowed to increase towards corner speed in

preparation for the upright part of the recovery. When the flight path is within about 30° of the vertical the turn radius is not very sensitive to speed, but by the time the dive angle has reduced to about 45° the aircraft should be at corner speed. Do everything possible to prevent the speed from increasing beyond corner speed as that will simply cause the turn radius to increase. The penalties for being slightly slow will be less than those for being slightly fast. Every pilot should know what his aircraft's characteristics are in a vertical dive recovery. Is there a power setting which will allow the airplane to be held on the lift boundary at corner speed, or will it accelerate beyond corner speed even with the power off? Or decelerate below corner speed at less than full power?

Figure 9 also gives some insight into the various possibilities for botching a vertical maneuver at low altitude, and explains why the simple loop is often regarded as the most dangerous maneuver in a show routine. One problem arises in misjudging the entry and pulling up at too low a speed (hot day, high density altitude, more than expected energy loss on previous maneuver, speed a few knots low - maybe the pilot didn't notice - but try the loop anyway). If the pilot does not recognize the situation and make a conscious effort to unload the airplane once he has pulled past the vertical in the climb, the reduced airspeed will tighten the loop to the point where the height over the top may be significantly lower than usual.

The situation at this point is still salvageable, but unless a minimum radius recovery is initiated while the aircraft is still inverted and can turn tightly at low airspeed, the danger is that the vertical position will be reached at a lower altitude and airspeed than the pilot is used to seeing. At this point the ground starts to look uncomfortably close and the pilot may start to pull to C_{Lmax}, but if the airspeed is below corner speed the turn radius will not be a minimum and the airplane may not be able to recover without hitting the ground. This would be especially likely to happen in an airplane which did not have the power to maintain its energy state during a loop, that is, one which would normally come out lower or slower (or both) than it went in. If the aircraft is one which needs power to achieve and hold corner speed during a dive recovery, the instinctive tendency to pull power off when faced with the ground coming up fast may in fact make the situation worse.

Excessive speed over the top of a loop or at the start of a split-S sets the airplane up for a larger than usual turn radius in the third quarter, arriving at the vertical dive position at a lower altitude and a higher airspeed than the pilot is used to seeing. If the airspeed cannot somehow be held down to corner speed the turn radius will be larger than the minimum, with obvious consequences.

It should be clear from this that the critical conditions for safe completion of a loop are set by the altitude and airspeed window when the airplane is inverted at the top. It should be equally clear that the achievement of those parameters is determined by the entry conditions and the aircraft's flight path through the first half of the loop. Given that the required entry conditions are met - which really means that the entry speed is high enough, because in airshow flying it will rarely be too high and if it is, the remedy is simple - it becomes a question of how the pilot flies the airplane.

The critical requirements are to pull hard enough in the first quarter of the loop to develop "upwardness" and build ground separation, and then to relax the pull enough in the second quarter to avoid topping out at a prematurely low altitude. It is a happy coincidence that the way to make a loop safe is also the way to make it look good from the ground. As long as the pullup g is comfortably

below the structural (or pilot) limit and the second quarter is flown comfortably below the lift boundary, there will be ample margin available for correction of errors in the third and fourth quarters. If the pilot recognizes a bad set-up over the top early enough the best solution will be to throw the maneuver away, roll out and pull the short way to the horizon. Unfortunately that is not always an option for some of the slower rolling airplanes. They become committed very soon after the nose passes through the horizon on the way down. In that case the best hope for survival will be to know the technique cold and fly it as accurately as you can.

9. ENERGY MANAGEMENT

Like drag, energy comes in two forms. Potential energy is the energy an aircraft possesses by virtue of its height above the ground. Kinetic energy is its energy of motion. If there are no energy gains or losses the two kinds of energy are completely interchangeable as long as their sum remains constant. If there were no air resistance, a bullet fired vertically upward from the ground (having kinetic but no potential energy) would slow down as it climbed, losing kinetic but gaining potential energy, until at the precise moment it reached the top of its trajectory it would have potential energy exactly equal to the kinetic energy it started with. The process would be reversed during its subsequent descent. In the atmosphere things are not quite as elegant as this, because all the time a body is in motion it is dissipating energy in the form of drag, so there can never be a perfect interchange and eventually all the original energy has disappeared in the form of heat.

An aircraft differs from a bullet in that as long as the engine keeps running it has a means of adding energy to replace what is lost to drag. But the engine can only add energy at a limited rate[7E]. So if a show routine consists of a string of energy-losing maneuvers the pilot had better plan to start with enough energy to finish the show without embarrassing him or herself. Glider pilots have no choice: they are condemned to lose energy throughout a display whatever they do, as are the pilots of Tiger Moths and other low powered airplanes. But given an aircraft with reasonable energy addition capabilities it is best to plan a display to have a sensible mix of energy losers and energy gainers.

We saw in section 2 that at the minimum power speed (best sustained turn for propeller aircraft) the induced drag is three times the parasite drag ($C_{Di} = 3C_{Do}$), and that the two are equal at minimum drag speed (best sustained turn for jets). These relationships still hold despite the increase in V_{mp}, and V_{md} under G, so it is easy to see how induced drag dominates the picture. This is especially true for the older swept-wing jets, which do not have much excess thrust at the best of times and which have the capability for very easily generating large amounts of induced drag.

Tight turns, whether in the horizontal or the vertical, are the worst enemies of energy management. Slackening a positioning turn from 3G to 2-1/2 G at 250 kts will only make a difference of 460 ft in the turn radius (166 ft at 150 kts), but may make the difference between losing and gaining energy during the maneuver. There is always a temptation to pull hard to get back on the show line as quickly as possible, but it would often be better to sacrifice a little time in the interest of maintaining a higher energy state.

DENSITY ALTITUDE

10. EFFECTS ON LIFT AND DRAG

We saw in section 1 that air density is important in generating lift and drag. Air density is affected by altitude, temperature and humidity. Increases in any of these quantities will decrease the air density. Density altitude is the equivalent altitude in a standard atmosphere at which the density would be the same as the ambient density, taking into account the effects of altitude, temperature and humidity.

We also saw in section 1 that as long as compressibility effects are ignored, all that matters as far as lift and drag are concerned is the equivalent airspeed, Ve. For our purposes Ve is essentially what the pilot reads from the airspeed indicator, and is simply the dynamic pressure of the airflow under a different name. The important effect of density altitude in this is that with increasing density altitude although the lift and drag generated at a particular indicated airspeed are unchanged, the true airspeed is increased.

11. EFFECTS ON POWER

For normally aspirated piston engines increased density altitude results in decreased charge weight, which leads to reduced power output. The relationship of power loss to density altitude is not exactly linear, but as a rough rule of thumb the power loss is approximately 3% per 1,000 ft increase in density altitude. At a density altitude of 10,000 ft (a 100°F day in Denver) the engine will be 30% down on power. Supercharged piston engines will maintain their sea level rated power up to full throttle height, after which they will be affected exactly like normally aspirated engines.

12. EFFECTS ON PERFORMANCE

Increasing density altitude gets you from every direction. First of all, to do anything at the old familiar indicated airspeeds that you've used for all those practices, the true airspeed has to be higher. Acceleration and deceleration relate to true airspeed, so it would take longer to reach the desired speed (takeoff speed, for example, or the run-in speed for the first maneuver in your display) even if the acceleration rate was the same. But it isn't, because the engine, unless it is a supercharged piston engine running below full throttle height, will be down on power. As far as takeoff performance is concerned, for example, the takeoff run will be increased by approximately a whopping 10% per 1,000 ft increase in density altitude. On our hypothetical 100°F day in Denver the takeoff roll would be doubled compared to its normal sea level value!

Some density altitude effects may be worse for propeller aircraft than for jets because a piston engine delivers approximately constant power throughout the speed range. Power is equivalent to the product of thrust and (true) velocity, so as the speed increases the thrust falls. So at the new, higher true airspeed (but same indicated speed) the power margin will be less than usual, acceleration will be slower and energy addition will be worse. This effect applies whether the engine is supercharged or not. In extreme conditions the aircraft may not be able to reach its normal indicated operating speed. Jets will be down on thrust by a roughly constant amount throughout the speed range so will also suffer acceleration and energy addition penalties.

Turning performance will be affected because all the speeds in the expressions for turn rate and radius are true airspeeds. The IAS for corner speed will be unchanged, but the TAS will be higher. Consequently the turn rate will be reduced and the turn radius will be larger. Sustained turn performance will suffer both from these and the power effects discussed above, which can lead to a trap for the unwary. For a given G, turn radius will be larger and turns will take longer. At the same time the sustained turn envelope will be reduced so the usual G levels can not be used without unaccustomed energy losses. It will take a determined and knowledgeable pilot to control his impatience, slacken the turn sufficiently to maintain the right energy balance and accept the loss of performance as inevitable.

The loss of performance in level turns has the potential for embarrassment, but the same loss of performance in vertical maneuvers, has the potential for disaster unless the pilot really understands what is going on. The first half of a loop is still where there is the most scope for setting up the second half badly. But if the second half is set up badly the increased turn radius at the higher true airspeed will at the least reduce the chances of a successful recovery.

13. DENSITY ALTITUDE CHART

A density altitude chart is reproduced in Figure 10. Copy it, cut it out and take it with you wherever your airshow travels take you. Then use it. The next section, on Flight Test Techniques, will give you some ideas on how to acquire the background knowledge you will need.

Figure 10

Density Altitude Chart

FLIGHT TEST TECHNIQUES FOR AIRSHOW PERFORMERS

14. TEST OBJECTIVES

This section contains suggestions for a small number of flight tests that every aerobatic airshow performer should carry out to ensure that he or she knows certain vital performance parameters for his or her airplane. Only then can an airshow routine be devised and flown with a high degree of confidence that not only are the safety margins adequate throughout, but that if it should ever become necessary to operate outside those margins the pilot knows exactly how the aircraft will behave.

15. HANDLING AT HIGH ANGLE OF ATTACK

Every pilot performing at air shows has an absolute duty to know how his or her airplane handles at high angle of attack even if they perform nothing more than simple flybys. Stall-spin accidents occasionally happen to aircraft waiting in orbit for their turn over the airfield, or making an over-exuberant turn off the show line after a straight and level pass. From the aerobatic pilot's point of view it makes no sense to talk of corner speed as being the speed where C_{Lmax} and the structural limit coincide if you don't know how to attain C_{Lmax} -- or even what defines it for your airplane. Is there adequate buffet warning? Indeed, is there any buffet warning? What does the airplane do at the stall? Does it drop a wing? Which one? Predictably? Violently? Does it recover when you unload it?

Start by rereading the section on stalls and spins in the aircraft handbook or operating manual.

Make sure you are completely happy with stall and spin recovery techniques. If you have not done any practice stalls and recoveries recently, you might want to get an hour or two in a similar type of aircraft with an instructor who knows what he is doing. Then, at a safe altitude, refresh yourself on the 1G stall and stall approach characteristics. Check the handling with power off and power on, and particularly note whether the airplane is sensitive to the position of the slip ball. Then move on to accelerated stalls. Start by setting up a 45° banked turn at cruise power and allow the speed to decay slowly (1 knot per second is about right) until the airplane stalls. Again pay particular attention to what the airplane does when it is in unbalanced flight (do you always fly with the ball precisely centered?).

Finally, check the handling in accelerated stalls at (different) constant speeds. This technique is called wind-up turns. Start at a speed not much above the speed atr which the airplane stalled in the constant bank angle tests. Most aircraft will probably need full power and will still have to lose height to maintain speed as the G is increased.

After this series of tests you should be able to answer all the questions that were raised three paragraphs ago. You should also have a good idea of exactly what the limitations are on high angle of attack flight in your airplane and how far you would be prepared to take it a few hundred feet above the ground. If your airplane is one that does sudden and violent things at the stall with no warning, you will have to be very careful to give yourself plenty of margin in everything you do. Look for other, perhaps less obvious cues to tell you that you are approaching the safe limits of angle of attack. If you find any, remember them well and be on the lookout for them. Otherwise, stay well away from those parts of the envelope, and as added insurance practice departures and recoveries regularly and often so that when it happens you will take the right action instinctively.

16. DETERMINATION OF CORNER SPEED

The test is quite simple: establish a turn at full power on the lift boundary at some speed obviously below the corner speed, and then allow the speed to increase, maintaining $C_L$max, until the g reaches the structural (or pilot) limit. That speed is then the corner speed. The power setting will not affect the result, but carrying out the test at full throttle will minimize the dive angle necessary to reach corner speed. The question of what G limit to use is important. Your aircraft may have a 9G structural limit but it won't do you much good if you black out at 5G. Practice at the G level you can use. If your aircraft has a published maneuvering speed you should not have to do this test, but it will still be worth a quick check to verify that you really can get maximum G and the aerodynamic limit simultaneously at the published speed.

17. DETERMINATION OF BEST SUSTAINED TURN PERFORMANCE

The quickest and simplest test method is to establish a full power, steady, level turn at some speed comfortably above where the best sustained turn performance is expected to be. This will probably be a little above the best climbing speed. Then increase the g, while maintaining a really accurate level turn, until the speed starts to decrease very slowly - less than half a knot per second. Continue the turn, keeping it level and playing the g to maintain a slow rate of deceleration. The g will peak and then decrease slowly. The speed at which it peaks is the speed for best sustained g, and

the best sustained g itself is fractionally less than what you have just been using. The slower the deceleration rate, the closer the g is to the optimum.

To do this test properly requires very accurate flying. One thing that can make it difficult is if you fly accurately enough to hit your own slipstream. If that happens the best thing is to move away a bit and start again. Remember that sustained turn performance is dependent on thrust and hence density altitude. If you repeat the test two or three times at different altitudes (with 29.92 ins set on the altimeter) and note the results, you will have a good idea of how your airplane will behave at most density altitude conditions you are likely to meet during the average airshow season.

18. DETERMINATION OF TECHNIQUE FOR MINIMUM HEIGHT DIVE RECOVERY

Enter a vertical dive at a fairly low speed (probably via a split-S), and as the airspeed approaches the previously determined corner speed, pull to the maximum g and hold it during the pullout. Observe what happens to the speed during the pullout, and adjust the power accordingly on subsequent trials until you have the nearest you can get to a setting that will maintain corner speed during the whole pullout. REMEMBER IT. If ever you are in trouble with the aircraft pointing at the ground, to have the best chance of survival go for $C_L$max, corner speed and that power setting all at the same time. Also remember that if you have to make a mistake the penalty for being a bit slower than corner speed is not as severe as the penalty for being fast, but being a lot slower won't help at all.

19. VERTICAL MANEUVERS AT HIGH DENSITY ALTITUDES

Just as it can only help to know your aircraft's sustained turn performance at different density altitudes, it is worthwhile insurance to discover how much height it takes to complete a loop or a split-S at different conditions. The effects of the V-squared relationship on turn radius may surprise you!

ENDNOTES

1. The dynamic pressure of the airflow results from the conversion of the kinetic energy of the moving air molecules into potential energy, which is felt as pressure, as they are brought to rest against the aircraft. The kinetic energy of a moving body or particle is given by the product of half its mass and the square of its speed: $E = 1/2mV^2$. The dynamic pressure therefore increases with the square of the speed of the airflow. To keep the total pressure constant the static pressure must therefore decrease at the same rate. Hence lift, which is produced by the static pressure difference between the upper and lower surfaces, also increases with the square of the speed.

2. The speed the pilot reads from the airspeed indicator is the Observed Airspeed, Vo or OAS. When corrected for instrument error, OAS becomes Indicated Airspeed, Vi or IAS. When corrected for pressure error (sometimes called position error) IAS becomes Calibrated Airspeed, Vc or CAS. When corrected for compressibility effects CAS becomes Equivalent Airspeed, Ve or EAS. Finally, when corrected for density EAS becomes True Airspeed, Vt or TAS. At the heights and speeds reached in most airshows all these corrections will usually be small or negligible except the last one, so we are justified in saying that for our purposes EAS is essentially the same as the ASI reading.

3. It turns out that G_R is related to velocity, turn rate and turn radius in the following ways:

$$G_R = V^2/R = V\underline{Omega}$$

4. Which can be seen from the following relationships:

$$R = V^2/G_R$$

and

$$\underline{Omega} = G_R/V$$

which are obtained directly from the previous equations by manipulation.

5. Mathematically, the load factor, which we can also call n_z or G_i, is related to the bank angle as follows:

$$LoadFactor = n_z = G_i = 1/\cos\Phi$$

Since the cosine of 0° is 1 and the cosine of 90° is 0, this confirms that in straight flight the load factor is 1, and rises very quickly as the bank angle increases beyond 60°-65°.

The radial G, G_R, is related to the indicated G as follows:

$$GR = \sqrt{G_i^2 - 1}$$

When these two equations are combined the relationships between load factor, radial G and bank angle are given in footnote 5.

6. These turn performance curves are based on the relationships that we have seen earlier:

$$Omega = G_R/V$$

$$R = V^2/G_R$$

and

$$G_R = \sqrt{G_i^2 - 1}$$

If we combine the last equation with the first two we can write:

$$\underline{Omega} = \sqrt{G_i^2 - 1}/V$$

and

$$R = V^2/\sqrt{G_i^2 - 1}$$

Thus for bank angles of about 65° or more it is very nearly true to say that the turn rate is proportional to the indicated G and the turn radius is inversely proportional to it.

7. Two equivalent definitions of power are that it is the rate of doing work, or the rate of energy addition. In the engineering sense, work is the product of a force and a distance, (a force moving through a certain distance) so the rate of doing work is the product of a force and a velocity.

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CHAPTER II

TEST TECHNIQUES FOR AIR SHOW SAFETY PARAMETERS

CHAPTER INTRODUCTION

This chapter is not intended to make the reader an accomplished test pilot. Nor is an extensive discussion of aeronautical engineering germane to the goal. Nonetheless, this chapter does expose the reader to some simple, practical tests and concepts that can be performed with a show airplane to arrive at useful in-flight safety parameters.

The engineering and mathematics necessary to accurately analyze aerobatic maneuvers is far beyond the scope of this chapter. A few engineering concepts will be presented for illustration purposes only. More pertinent data can be derived by each pilot spending some time in the air in his/her aircraft. This approach will also yield better results because:

A) Pilot techniques for aerobatic maneuvers vary and each pilot needs information based on his/her techniques.

B) Practically no two aerobatic aircraft are alike and, therefore, accurate engineering data is not available.

C) Actual flight tests result in a degree of confidence in the results and training benefits not possible through engineering analysis alone.

DENSITY ALTITUDE CONSIDERATIONS

Before going into test techniques for safety parameters, pilots should think in terms of always being able to pull out and miss the ground every time the nose is pointed down. This ability to pull out is related to the turning performance of the aircraft and its specific excess power, or Ps. Specifically, the capability of an aircraft to pull out of a dive is determined by:

A) Structural Strength (Vne and Max "g")

B) The maximum lift coefficient (Aircraft design)

C) Specific Excess power (Ps)

Chapter I stated that an aircraft can turn fastest if it does so at its corner velocity. A pull out from a vertical dive is a turn of one kind. It is a critical type of turn, because not pulling out has an unacceptable consequence (unlike not rolling out of a turn) and because the force of gravity is an enemy. How quickly an aircraft can regain level flight from a vertical dive is a major component in how good the aircraft is for air shows. What may be more important is how much this ability changes under various conditions of density altitude and airspeed at the start of the dive. Consider first the effect of density altitude.

Density altitude has a major effect on the distance (altitude) required to pull out from a dive. First, it affects the power available by decreasing it as density altitude increases. Second, it affects the true airspeed at which one reads the corner velocity on the airspeed indicator. To illustrate this effect on true airspeed, the following table shows the conversion factor to use in finding true airspeed from indicated airspeed for low mach numbers.

INDICATED AIRSPEED RELATION TO TRUE AIRSPEED

Density Altitude Conversion Factor

Density Altitude	Conversion Factor
Sea Level	1.0000
2,000	1.0294
4,000	1.0588
6,000	1.0909
8,000	1.1250
10,000	1.1616

TABLE 1

For example, if the corner velocity is 140 MPH (IAS), then at a density altitude of 10,000 feet, one will have a true airspeed of 163 MPH. Chapter I stated that turn radius is a function of true airspeed. Therefore, if one were to begin a pullout at 140 MPH at sea level density altitude (in Death Valley, maybe), it will take less altitude than if one were to begin a pull out at 140 MPH when the density altitude is 10,000 feet.

This is a scary thought unless one can put a handle on the relative effect of density altitude. A pilot does not want to put himself/herself in a bad situation without even knowing about it. To shed some light on the issue, Table 2 illustrates the distances (altitude) needed to pull out from a dive assuming (on the safe side) that effective radial "g" is one half "g" less than the aircraft "g".

ALTITUDE REQUIRED FOR PULL OUT FROM VERTICAL DIVE

PULL OUT FROM VERTICAL DIVE

Aircraft Load - g Units	Average Radial g	True Airspeed (MPH)							
		100	120	140	160	180	200	220	240
8	7.5	-	-	175	228	289	356	431	513
7	6.5	-	-	201	263	333	411	497	592
6	5.5	122	175	238	311	394	486	588	700
5	4.5	148	214	291	380	481	594	719	855
4	3.5	191	275	374	489	618	763	924	1099
3	2.5	267	385	523	684	866	1069	1293	1539
2	1.5	445	641	873	1140	1443	1781	-	-
1	0.5	1336	1924	2619	3420	4329	5344	-	-

TABLE 2

Looking at the example, a 4 "g" pull out from 140 MPH (IAS) at sea level will require 374 feet. At a density altitude of 10,000 feet, the same pull out will require over 489 feet or about 33% more altitude. Furthermore, this assumes that the aircraft can maintain corner velocity throughout the pull out, but the engine may not produce enough power at 10,000 feet density altitude to allow this (remember Ps). In other words, the distance could be even greater than a 33% increase.

Stated another way, an aircraft pulling out from a dive has the problem of maintaining corner velocity under conditions of reduced power available and increased true airspeed as density altitude increases. Most light aircraft cannot maintain corner velocity at max "g" even at sea level!

Obviously the point is that what is safe one day may not be safe on another day or at another place. What one needs is a way of finding some safe entry parameters (airspeed and altitude) for the plane and the maneuvers at any given density altitude. The best way to develop this safety parameter data is by individual flight tests.

There are three major types of maneuvers to investigate when testing ones airplane, using one's own pilot techniques, to find some real useable safety parameters. The three major groups of maneuvers are: vertical maneuvers, rolling maneuvers and looping maneuvers. Some maneuvers, which do not lend themselves to inclusion in these groups, will be addressed later in this chapter.

VERTICAL MANEUVERS

Perhaps the most critical phase of flight during air shows occurs when the performing aircraft is placed in a vertical climb or dive. Once the aircraft has been placed in these conditions, it either has sufficient energy to recover or it does not. The perfect piloting technique cannot prevent contact with the ground if the aircraft total energy state is not sufficient for the existing conditions of flight and aircraft characteristics such as excess power available and load limit. Therefore, the competent air show pilot must have a way of determining whether or not he/she can execute a maneuver safely before he/she commits the aircraft to the maneuver.

Consider an aircraft executing a hammerhead turn from level flight and wishing to return to level flight after completing the maneuver. The safe air show pilot would like to know the following:

1) What altitude/airspeed (i.e. energy level) does one need to execute this maneuver without gaining or losing altitude or airspeed?
2) Will this maneuver result in a net energy gain or loss for a given set of entry conditions?
3) What altitude/airspeed is needed to be able to pull out and fly to level altitude (i.e. controlled crash) in the event of:
    a) engine loss during the vertical climb?
    b) engine loss at the pivot, before rotating (slide)?
    c) engine loss at the pivot, after rotating?
4) When does the critical phase of this maneuver occur, assuming an engine failure?

To properly address these questions the air show pilot would need a complete set of engine thrust horsepower curves and a good drag polar for his/her aircraft. With these in hand, he/she could begin to tackle the extremely difficult task of analyzing this complicated flight path OR he/she could go out and get some real data by flying the maneuver. Not only will the second approach yield results in which the pilot has some confidence, but he/she may also gain from the time spent practicing the "perfect" hammerhead.

Question #1 may be answered by flying a positive entry to positive exit hammerhead at full power with entry and exit altitude the same (if possible). This should be done at various density altitudes.

One should try several speeds for each density altitude. One may find some entry speed for which return to the entry altitude is not possible. As density altitude increases, this entry speed will increase. (The reader should remember the discussions on energy from the previous chapter.) If the show time parameters are such that return to entry altitude AND airspeed are not possible, the maneuver will lose energy. If one cannot pull out to entry altitude, note at what altitude pull out is possible. This additional altitude would have to be available before starting the maneuver if such conditions prevail at the show. It is amazing how a powerful aerobatic mount can become a Piper Cub under certain conditions.

Table 3 is for a certain (all are not the same) Pitts Special S-2S. It should be reviewed.

PITTS SPECIAL: S-2S SN:002HB

HAMMERHEAD TURN, POSITIVE ENTRY & EXIT, NO ROLLS FULL THROTTLE

Entry & Exit Density Altitude	Entry IAS	Exit IAS	Energy
Sea Level	120	157	+
	140	164	+
	160	175	+
	180	184	+
4,000 Feet	120	152	+
	140	156	+
	160	160	0
	180	174	-
8,000 Feet	120	142	+
	140	150	+
	160	158	-
	180	170	-

TABLE 3

From this simple test one can gain valuable information on this maneuver. It will become evident when the maneuver can safely begin and what the resultant exit parameters will be. This data will help the performer have confidence that he/she can safely perform a hammerhead when executed at the safe levels noted during the flight test. But what about failure modes? If one is always confident that the routine has only safe hammerhead turns (will not hit the ground) in it, is that not enough? The answer lies in what degree of risk the air show performer wishes to assume. Is it safe to have no margin (i.e. entry & exit speeds and altitudes are the same) and begin the maneuver from the ground level? If so, then the performer also believes that he/she can execute the maneuver perfectly every time and that nothing will cause different parameters during exit (like engine failure or partial failure). The safe air show performer will want better odds on survival. One should consider the "what ifs".

Upon losing power in a vertical climb, the key is to transition to a glide as soon as possible. Since most aerobatic aircraft have higher drag at negative "g" loads (and energy preservation is now THE critical item) than at positive loads, it would be more advantageous to pull to a dive and then roll 180 degrees to level. However, if at all possible, keep the airspeed at or above the best glide speed at all times, since an enormous amount of altitude will be used to regain glide speed. The pilot will need to conserve enough energy to pull out of the dive and flare for landing. Below are three test points, again for the venerable Pitts S-2S, in which these failure modes were investigated.

PITTS SPECIAL: S-2S SN 002HB
ENGINE FAILURE DURING HAMMERHEAD TURN

Entry Airspeed 180 MPH
Entry Altitude 2000 Feet Density Altitude
Idle Power at "Failure"

Power Lost at Vertical	Recovery altitude: 2,500
Power Lost at Rotation	Recovery altitude: 2,700
Power Lost after Rotation	Recovery altitude: 2,900

TABLE 4

Recovery was assumed complete when a stable glide at 100 MPH was attained (from which a flare for emergency landing is possible). It may be a surprise that the instant before rotation is not the critical point. However, from this example, one can see at what altitude above ground he/she must start the hammerhead at given conditions) to be safe, even if the engine fails at the critical point in the maneuver. Armed with this data, a performer can fit a hammerhead turn into a show sequence because he/she knows the desired entry energy level at a given density altitude which will allow for a safe maneuver - even if the engine fails at a critical moment. The exit parameters, which become the entry parameters for the next maneuver, are now known.

One could develop a similar approach to other vertical maneuvers in an air show sequence, such as hammerhead turns with rolls up and/or down, "family nine" type maneuvers with or without rolls, half square loops, etc. Each maneuver will have its own parameters, although a pattern will be apparent between a plain maneuver and one with increasing numbers of rolls. Snap rolls will require more energy than slow rolls or point rolls. All of this data can be backed down into a few good "go, no-go" type criteria which helps the performer determine, for instance, to use a slow roll instead of a snap roll above certain density altitudes, or to change 3/4 rolls to 1/4 in the opposite direction under extreme conditions.

This process takes time, thought, and money, but it will yield results that give one peace of mind and make him/her a safer show pilot. One note of caution is in order. This technique should not be used for certain vertical “out of control maneuvers" such as tailslides, torque rolls, and lomcevaks. These will be dealt with later as special cases.

ROLLING MANEUVERS

The second maneuver type with the greatest potential risk to the pilot is low altitude rolls. This includes all types of rolls from slow to point to barrel to snap rolls. The common error is failure to maintain sufficient altitude during the roll, resulting in contact with the ground. Accidents during rolls occur during both level rolls and those involving an arching flight path.

Entry parameters (energy level) are just as critical for rolls as for vertical dives. Why? One should first consider the typical arching roll performed by a non-inverted Warbird. The slow roll (or point roll) consists of a pull up, the rolling portion, and the pull out. Usually, the pilot maintains a low, but positive, "g" during the maneuver which gives it the arched flight path. The trouble comes when the arch is finished before the roll! It sounds simple, but what makes the arch finish first? The answer lies partly with that now familiar term - energy. Most pilots have a rate at which they roll a plane (as fast as possible for most) and that takes so much time.

The key is to have enough time during the arch to complete the roll. What determines how much time one would have in an arching roll? The answer is the entry energy level and climb angle.

In this case, most of the energy will be in the form of airspeed and not altitude, since rolls are typically performed at minimum altitudes. So, why is entry speed the item in a roll? Well, not only will it buy more time for a given pull up angle, but it will also give a greater roll rate for most aircraft. Looking at it another way, a too slow entry results in a compound effect of shorter time available and longer time needed for the roll.

The second factor in the roll is pull up angle. This can vary from zero (level roll) to 90 degrees (see the section on vertical dives). Once again, one can find the critical parameters from aircraft data or one can do a little flight testing. A performer should know the airspeed at which a roll cannot be completed without a loss of altitude, i.e. the conditions under which a performer must lose altitude to complete the roll. This is found by testing various entry speeds and initial pull up angles.

Again, using the Pitts as the example:

Pitts S-2S
Full Power

ARCHING ROLL TYPE: 4 POINT
ALTITUDE GAIN <LOSS> DURING ROLL
Density Altitude: 2000 Feet
Entry Airspeed

Pull up angle	100	120	140	160	180
0	-230	-180	-110	-80	- 60
15	0	+ 80	+110	+300	+300
30	+210	+350	+550	+700	+700
45	+310	+450	+570	+750	+980

TABLE 5

This data is for a very low positive "g" roll. Obviously the Pitts S-2S can do level rolls due to its inverted fuel and oil system. However, the point is to show the parameter for a Pitts in this type roll. Level rolls are another test, as are snap rolls or eight point rolls. The test goal is to find entry conditions for which the roll can be done without losing altitude.

Obviously, if a person is hitting the ground in level rolls with an inverted system aircraft, what he/she needs is practice, not data! However, just because an aircraft has an inverted system does not mean that it can be used to execute a level roll from any entry condition. A little testing is in order on this point as well.

As with vertical maneuvers, a margin of safety must be determined. What if the engine fails during the roll? One should first consider techniques. The pilot should always roll to the nearest horizon to minimize the time required to be wings level (i.e. emergency landing). Therefore, the critical time will be a failure at the 180 degree (inverted) point. Once again, the performer can find the safe parameters by simulating an engine failure at various entry airspeeds and finding the minimum entry speed for which the roll can be completed and not lose altitude below the entry altitude. Various airspeeds should be tried until the pilot finds the slowest at which a recovery can be made. This is the minimum safe entry speed (again, for the density altitude tested) for the maneuvers. This must be done for all the low altitude rolls planned for any performance. A performer must know when he/she is getting near the edge.

LOOPING MANEUVERS

Failure to complete a looping maneuver by contacting the ground has taken the lives of many performers. These maneuvers give the pilot two chances to examine his/her energy state before committing himself/herself to the critical phase - the last half of the looping maneuver. The first decision point is at entry and the second is at committing the nose down in the last half of the maneuver. More good news about these maneuvers is that, unlike in vertical maneuvers, the aircraft is usually above one "g" stall speed during the entire maneuver. In other words, it can be flown immediately to a changed flight path in preparation for an emergency landing.

If these types of maneuvers are so simple and safe, why are there accidents in performing them? The answer is that aircraft can perform the first half of a loop in such a way that the last half is not possible if the goal is to exit at the same altitude at which the loop started! To learn more, the performer should go back into the air.

PITTS SPECIAL S-2S SN 002HB
Round Loop at initial 4 "g"s, Full Power
Same entry and exit altitude

Density Altitude

Entry A/S	2,000	4,000	8,000
	Exit Airspeed		
120	146	146	140
140	162	156	154
160	174	166	160
180	178	176	174

TABLE 6

As before, one can easily see the effect of various entry parameters for a loop. However, as earlier noted, there is a second chance decision point for looping maneuvers, at the top of the loop. These "second chance" parameters can be found by completing a table like that at the top of the following page on Table 7.

PITTS S-2S SN 002HB
HALF LOOP DOWN FROM INVERTED
ALTITUDE REQUIRED AT FULL POWER

Airspeed at Inverted	Altitude Required		
	2,000	4,000	8,000
60	610	640	670
70	600	660	670
80	560	650	680
90	560	640	780

TABLE 7

The final point on looping maneuvers is failure modes. Again, assuming good piloting techniques (see recovery techniques section), the critical failure is at the top of the loop. To investigate this case, one can fly the test above simulating the top of the loop entry using this technique: At engine failure simulation, the nose should be pulled down to best glide angle, the aircraft rolled to upright, and pulled out to level. Altitudes lost should be recorded. If the aircraft has a slow roll rate, it may be better to simply complete the half loop. Both techniques should be tried if in doubt.

The results of these tests should give the performer a good handle on loops. As before, the sequence should be analyzed to determine if there are some other types of maneuvers which need testing. Most aerobatic maneuvers are combinations of basic ones. Therefore, one will find that the same safety minimums apply to several maneuvers. In the end, each performer will need to keep in mind only a few numbers while performing a given show. However, there are a few maneuvers which deserve special attention. They are noted in the following pages.

OUT OF CONTROL MANEUVERS

Some maneuvers are not repeatable exactly the same way each time flown regardless of pilot technique. This results from some period of time in which the pilot is not in full control. Tailslides, torque rolls, and lomcevaks are three such maneuvers. The real danger in these is their lack of consistency. The pilot may perform several tailslides easily and then have one "stick" on him/her. That one could require considerably different entry parameters than the others.

If the pilot uses this type maneuver, he/she should test these maneuvers as others, but keep track of the worse case out of many attempts. One should use the worse case (from a data base of at least fifty as the minimum) and then add another safety margin - just in case there is an even worse case possible. Almost all of these maneuvers are energy losers. Care should be taken in using them in a sequence to make sure that the minimum entry parameters are achievable every time the maneuver is attempted. One should recognize that these maneuvers are partially out of pilot control and build in a healthy respect for the unexpected.

One last word on the subject. Spins have no place in a low altitude continuous air show sequence. They are terrible energy losers and break the rhythm and presentation of an act as well. For example, an inverted flat spin might be considered as a separate sequence. One should begin that sequence with the spin after carefully obtaining the entry parameters.

Using this testing approach, the performer can analyze and then test fly each maneuver he/she is contemplating using and determine the desired entry parameters for a given density altitude. The professional pilot should have a table for all his/her show sequence maneuvers. This can be reviewed as part of his/her preflight planning before each performance, using the appropriate density altitude, to fix in his/her mind the entry conditions for each maneuver. Some pilots may want to write some critical point (a low pull out from a vertical dive) entry parameters on their laminated sequence card in grease pencil. In this way, a quick "go, no-go" reference can be available before starting that critical maneuver.

FORMATION AIR SHOW FLYING

In analyzing formation test maneuvers for a formation team, the test aircraft must use the power setting which the leader uses in formation in order to find the correct (i.e. safe) entry conditions for each maneuver. Needless to say, a formation leader who does not know the required parameters for every maneuver is endangering the lives of all his/her team members as well as his or her own life. Wingmen would be very foolish to fly with such a leader.

CONCLUSION

The goal of the flight test program is to determine some useable maneuver entry parameters which provide sufficient energy to safely complete the maneuver and/or recover from it if the engine fails. Undertaking a basic test program will result in a better awareness of the degree of risk at all times, confidence in one's abilities and those of the aircraft, and decreased reaction time in an emergency due to familiarity with and practice of failure modes. In dealing with the FAA, Transport Canada, and Airshow Certification Evaluators, one can expect to be questioned on his or her maneuver entry parameters. Knowledge of them is one characteristic of a professional air show pilot.

CHAPTER III

DESIGNING AND FLYING A SAFE AIR SHOW

CHAPTER INTRODUCTION

It is assumed in this chapter that the pilot has aerobatic skills and wants to demonstrate them at a low altitude in front of an air show audience. It is not the intention of this chapter to teach aerobatic flying. However, the purpose is to present to the reader some concepts on safely designing and flying air show routines. Aircraft performance and pilot proficiency will determine aerobatic maneuver selection and sequence.

WIND AND WEATHER

A safe routine is one that can be flown safely in various conditions of wind and weather. There are, of course wind and weather conditions that preclude flight. However, the professional air show pilot always has several contingency flight plans for wind and weather changes, within safe flight parameters. Generally, air show routines fall into the following categories:

(1) Full Air Show - The performer can complete a full and safe air show routine that is flown well within the ceiling and visibility limitations allowed by the monitor, waiver, FAA, or Transport Canada at a particular air show site.

(2) Low Air Show - Usually flown safely in weather that has restricted ceilings and acceptable visibility. The low show will normally not include vertical maneuvers.

(3) Flat Air Show - Flown when the visibility and ceilings are so poor that aerobatic flight is not safe, proper, or allowed, however level flight is still safe and permitted. This is basically level fly-bys with noise and smoke.

The air show performer who cannot or will not develop these safe but diverse air show routines, may find that he/she is not as attractive to the air show promoter as other performers who are, within safe parameters, more prepared for all weather conditions. Of course, all flights must conform to proper, legal, and safe conditions and standards.

PERFORMER PHYSICAL CONDITION

Good pilot health and physical condition are very important for "g" tolerance and judgment during aerobatics. Practice in high "g" environment builds tolerance to high "g" loads. A reasonable exercise program is also recommended.

A performer who is mentally or physically impaired should not fly. However, what happens in the real world is sometimes quite different from the ideal. It is difficult to determine degrees of impairment. Knowing when an impairment is sufficient to compromise safety is vital to survival:

(1) Fatigue is caused by a number of everyday factors that face the professional air show performer. The most common is late night activity or an air show performance on Friday, followed by a long air show on Saturday, followed by a late night hangar get together, followed by a long day of air show on Sunday. Another common fatigue problem is too much distance and too little good weather between show sites, which bring a very tired performer to the show. Finally, there is the effect of multiple hats worn some air show pilots.

Fatigue can be exacerbated in situations in which an air show pilot doubles as the air show boss, air show director, air show promoter, or even as a volunteer in charge of obtaining and dispensing smoke oil. Performers must BEWARE of this trap. It appears on the surface to be a performer who is a "can do" sort of worker, but it can have severe consequences. A performer must be safe to fly safe.

(2) Heat - On air show day, high temperature can induce heat stroke from dehydration. Once dehydration occurs, the body may take as many as 72 hours to return to normal. Hospitalization may be required. It is extremely important that the pilot has had adequate intake of water and fruit juices throughout exposure to high temperature. This should be accomplished before thirst has set in. Once thirst has set in, the body has already become dehydrated and judgment and physical tolerance are impaired. Performers should avoid using high sugar and/or caffeine soft drinks in attempting to prevent dehydration. Use water and fruit juices.

(3) Cold - Has the pilot or wing rider been subjected to cold that might impair mental judgment? Cold exposure can cause hypothermia which will slow the pilots mental faculties to a point of extreme danger. The American fighter pilot superiority over their MiG counterparts in the

Korean conflict was in large part due to the cockpit comfort level. Plainly put, the MiG pilots reactions and mental processes were severely impaired by the cold.

Hypothermia danger signals start with body shivers. This is an attempt by the body to warm itself. Body shakes are the last line of defense the body has to maintain proper temperature. At this point, adrenaline is being manufactured to try and raise the body temperature. A pilot suffering from the shakes has already entered a state of hypothermia and should not, under any circumstances, be allowed to fly an aerobatic routine.

(4) Blood Sugar Level - Blood sugar level is an important consideration for "g" load tolerance. Low blood sugar can lower "g" tolerance considerably causing black out. However, use of sugar filled soft drinks to keep blood sugar levels high will tend to upset the blood acid/base balance and cause nausea. Eating regular, balanced meals is the best preventative.

(5) Illness - If a performer is ill, flying should be postponed. How sick is too sick? Once again, judgment is the key. Any illness will increase fatigue and decrease "g" tolerance. A performer who feels he or she may be too sick to fly, probably is. A safe routine can best be characterized as one which can accommodate the pilot's changing mental and physical conditions, wind and weather changes and time constraints placed on the performer at any particular air show. It does not involve a routine which demands constant maximum performance from either the pilot or aircraft.

The professional performer will always operate himself/herself and the machinery at less than 100% to prevent being on the edge of critical outcome at any time. There is never a question about the presence of a safety margin for a professional performer.

DESIGNING A SAFE ROUTINE

Maneuvers that lose energy:

Energy is lost through aerodynamic drag, operations against gravity or by reduction of power. When designing an air show routine, one must guard against combining energy reducing maneuvers at positions of low energy in the sequence. Under severe conditions, such as high density altitudes, continuous use of energy losing maneuvers can result in insufficient energy to recover from maneuvers.

Maneuvers that gain energy:

Energy is gained through low aerodynamic drag, operation with gravity and by an increase in power. The combination of maneuvers that gain energy with maneuvers that lose energy is the proper creation of a symmetrical and crowd appealing air show routine. The goal is to maintain a safe total energy level at all times by making the transition from one maneuver to another without losing energy in the transition itself.

G Combinations that spell trouble:

Care must be taken at all times whenever combining high G maneuvers, resulting in long periods of sustained high G loads. In addition, sustained negative G's followed quickly by high positive G loads can also lead to grayout or blackout of the pilot. Both of these conditions must be avoided in any sequence design.

Maneuvers within aircraft capabilities:

To design an air show routine directed at 100% of the aircraft capability gives no way out for less than 100% performance. Maneuvers and combinations of maneuvers must be at less than full capability to allow for the use of safety margins to correct for the unseen or unanticipated problems. In addition, maneuvers outside of the aircraft V-G diagram should never be attempted. The following aircraft and pilot limitations should be taken into consideration when planning an air show routine:

Low performance aircraft considerations: (i.e. low power to weight, low roll rate, low max G)

1. Does the aircraft have an inverted fuel and oil system?

2. Low performance aircraft will require more altitude and conservative air show maneuvers.
3. Low performance aircraft will require higher pilot proficiency and planning.
4. Low performance aircraft will require a greater safety margin if the aircraft drops behind planned speed and below planned altitude.

High performance aircraft considerations:

1. Does the aircraft have an inverted fuel and oil system?
2. Higher performance aircraft usually have higher wing loading and higher stall speeds
3. Higher performance aircraft have greater speed build up on vertical down maneuvers, requiring more altitude for recovery.
4. Higher performance aircraft have a greater range of maneuver selection.

Maneuvers within pilot capabilities:

One must also remember the 100% Rule in their role as an air show pilot. The professional air show performer will plan to have talent and energy in reserve for the unforeseen at all times.

Does the true professional plan his or her flying at less than 100% of both his or her personal capabilities and those of the aircraft? Emphatically, YES! There will always be something in reserve at all times and under all conditions.

PUTTING EXCITEMENT IN A SAFE ROUTINE

The plane's best maneuvers:

An airplane with high power to weight ratio that is highly maneuverable is often shown with fast moving routines like multiple snaps etc., while a large, more lethargic plane depends on grace, beauty, noise, and smoke for its show ability. The professional must not lose sight of the limitations of his/her equipment.

Keep it moving:

Within the safe limits of ability and the safe flight parameters of the aircraft, the professional will remember where show center is and will work to be "on stage" as much as possible during the routine.

Use of smoke, canisters, and lights:

Exhaust generated smoke, canister smoke, and lights can be used in air show routines if proper safety precautions are taken. If an air show pilot decides to use any of these devices, find the proper resources to investigate the safe use of these devices.

SAFETY IN SPECIAL MANEUVERS

High risk maneuvers are used safely by many air show performers. For the new air show performer, these maneuvers require special consideration and practice because they can present higher than normal risks to all air show pilots.

Rolls on take off:

A roll on take off requires two minimum criteria for safe performance:

1. The aircraft must reach a minimum airspeed prior to commencing the roll.
2. The aircraft must reach the correct nose up pitch of the aircraft prior to commencing the roll.

The correct combinations of airspeed and pitch will allow for safe completion of the maneuver. CAUTION! A down wind take off has the added risk of the pilot confusing ground speed for air speed.

Snap roll on take off:

A snap roll on take off requires two minimum criteria to be performed safely:

1. The aircraft must reach a minimum airspeed prior to commencing the snap roll.
2. The aircraft must reach the correct nose up pitch attitude, a climbing flight path and altitude for the safe snap roll.

The correct combination of airspeed, pitch attitude, and flight path will allow for a safe completion of the snap roll maneuver. The recovery of the snap roll requires good visual clues of the horizon. CAUTION! A down wind take off has the added risk of the pilot confusing ground speed with air-speed.

The following maneuvers require extra caution and planning to be performed safely. These maneuvers present a high risk to the new air show pilot. A brief description and consideration follows:

Hammerheads at ground level in low performance aircraft:

A hammerhead as a take off maneuver should not be considered as an opening maneuver. The speed requirements for vertical development cannot be met by most aircraft. A minimum of 500 feet above ground level should be obtained prior to pivot of the aircraft, even for high powered aircraft.

Loops:

Although the loop is one of the most basic of aerobatic maneuvers, the entry speed and altitude attained at the top of the maneuver is critical to the safe execution and completion of the maneuver. Low powered and highly wing loaded aircraft are particularly vulnerable to this criteria.

Ribbon cuts:

An airplane in stable inverted flight has a stall speed of 5% to 15% higher than the published right side up stable flight stall speed. This is due primarily to aerodynamic drag induced by reversing the positive angle of incidence of the wing. It then stands to reason that inverted flight close to the ground cannot be treated casually. This maneuver is not for all air show sites or weather conditions. Finally, the possibility of structural damage from the poles or even the ribbon should make use of this maneuver a very well planned process.

The pilot needs a good visual lead-in line such as the edge or center line of the runway. Stable altitude and airspeed control are essential. The aircraft should be positioned at least on the same level (or a few feet lower) than the ribbon to be cut. If the aircraft is higher than the ribbon, a great risk can occur if the pilot becomes fixated on the ribbon and dives to try to cut it. This can result in insufficient altitude after the ribbon is cut. Airspeed should also be high enough to withstand engine failure and still effect a safe landing.

Spins:

Spins have no place in low level routines except for the most experienced air show pilots. As an opening maneuver, the pilot can carefully position the aircraft into the desired entry conditions. Therefore, spins should only be used in the opening of a routine or after a break which allows for re-positioning.

It is suggested that several years of air show experience be attained prior to consideration of the spin in an air show routine.

Altitude is the single greatest consideration for the spin. If the pilot is going to air start the air show, plenty of time can be allowed for the proper spin altitude. If the spin is incorporated into the main body of the show routine, a break prior to the spin should be planned to attain proper entry parameters.

Wing Walking:

Training, practice and good communications are absolutely necessary in the wing walking teams. There can be no situations left to chance when anyone has the exposure to risk that a wing walker does. Tethers and/ or safety devices, and escape plans are a must, whether they are advertised or not. There must always be a way out from any situation in all show maneuvers.

Formation flight for public demonstrations:

All formation work at air shows must be preceded by extensive planning and practice. The risks to safety of flight for the solo performer are magnified in formation demonstration by the number of aircraft participating in the formation. (X)

The risk of an engine failure during the demonstration is now X times that of the solo performer. The risks that a participating pilot may be operating at less than 100% due to physiological or psychological factors is now X times as great. The risk of a human error is X times greater than the solo performer and most importantly, a new element of risk is introduced which affects both the safety of the performers and spectators alike; the risk of mid-air collision. This section addresses risk management during air show formation flight for the formation team. The importance of the selection of appropriate aircraft for formation air show demonstrations and for pilot selection and training of the individual team members must not be overlooked. For purposes of this section, it is assumed the aircraft and pilots are qualified to participate in formation air show demonstration.

Formation team organization and discipline is critical to safety of the formation demonstration. Leadership goes much further than flying number one (1) and includes responsibilities for insuring the physical and psychological fitness of each team member and airworthiness of each aircraft. Because the safe conduct of a formation flight requires a mutual dependence on the ability of each pilot to perform, interpersonal relationships between team members are important.

Formation demo sequences require careful planning for safety. Both breakaways and join-ups must be sequenced with adequate maneuvering airspace to provide a margin of safety for pilot error and excessive rates of closure.

The formation team should design and carefully rehearse emergency flight procedures to be employed when any of the formation aircraft experience an engine, structural or control-related difficulty. Emergency breakaways should be practiced and carefully designed with all team aircraft exiting away from the spectator area.

Opposing and crossing maneuvers of team aircraft have resulted in air show tragedies when one or more of the aircraft has made only a slight error in positioning.

While crossing and collision effect maneuvers are spectacular, they should be completed only when all safety criteria to complete the maneuver have been met and should include the requirement that each pilot has the required team members in sight and all team members are established on the appropriate flight path over the ground.

Pre-show site planning for formation teams is critical to the safety of the demonstration. Aerial photographs and airport diagrams should be required from the showsite and be a part of the performance contract. Aerial surveillance of the show site should be scheduled as part of the air show operations plan to allow formation team members the opportunity to visually acquire prominent terrain features and checkpoints necessary for the planned demonstration.

CHECKING A ROUTINE FOR SAFETY

Energy preservation:

The professional always has energy in the bank. The professional preserves the energy by not operating on the edge. Flight conditions that cause energy loss can put any performer in a critical position, especially at low altitude. When low, have something in the bank in the form of speed.

Pilot capabilities, skill and physical condition:

Before flying, the pre-flight must include the pilot. A careful check of the aircraft is not enough. The pilot's skill level and immediate physical state must be analyzed on the spot before the flight. One must consider the present situation and a decision to fly or not fly.

Safe for all weather:

Weather is another consideration when choosing a full show, low show, flat show, or a decision not to fly. The decision is made by the pilot with the help of the monitor and the air show boss. The performer is the pilot in command and it is incumbent on him or her to always err on the safe side.

Safe for all sites:

Each site should be surveyed in advance. If visiting the site is not possible, request airport diagrams or aerial photos. Upon arrival, survey the area to make safety decisions concerning the routine at this particular site. The performer must have the capability of altering routines for sites that would be improper or unsafe for the standard or planned routine. The professional performer must be flexible.

Safe for the spectators:

The air show spectators are the bread and butter of the industry. It makes sense not to threaten the customers with the machinery. It makes no difference what any routine entails, the aircraft should never be pointed at the crowd at any point where the debris from a mishap could reach the showline. Pyrotechnics should never be loaded or prepared in the vicinity of the air show crowd. In every case of preparation, or during any performance, good common sense should be exercised.

Use of the ACE Program Training Checklists:

The use of the ACE Program Checklists is critical. In addition, one should add items that are peculiar to his or her particular air show act. Checklists are great, but only if used and followed.

PLANNING FOR EMERGENCIES

Structural failure:

A catastrophic failure of the aircraft is something that is difficult to think through. The bottom line is survival and protection of the air show environment. The use of a parachute may be an option. In any case, there must be an attempt to lessen the impact with the ground or any object. If at all possible, one should steer into an open area. About the only hope a performer has in this case is his/her seat belt, harness, helmet, and other personal safety equipment. The best way to avoid this most serious failure is to perform good inspections and keep the aircraft within its design envelope.

Engine failures:

It is most important that airspeed (read "kinetic energy") be maintained in low level flight. The only hope for the successful outcome of any engine or power failure is to have the speed to allow time for roll out from a maneuver and selection of an open area for touchdown of the aircraft. The professional air show performer will have planned a routine during which a safe landing can be made should the engine fail at any point during the routine. If the engine does not sound right, the performer should not fly until a determination is made on the engine's condition.

Other failures:

Performers should always have a plan for any unusual occurrence such as radio, electrical, accessory, smoke or canister failures. The professional always plans for the unforeseen in every flight.

Disorientation:

This condition does not happen often, but the professional must be prepared for it. It can happen in the form of losing sense of direction coming out of one's own smoke or losing sight of the showline at a new or first time air show site. The performer should climb and pull away until completely satisfied that orientation has returned.

Blown maneuvers:

There are aerobatic standards for blown or broken maneuvers. They must not be forgotten. When a maneuver goes bad, the exit procedure is to roll to right side up and adjust pitch to the horizon. If there is a question of power application, the rule is that if the nose is above the horizon, always leave the power on. Only if the nose is below the horizon would one consider reducing power after first checking airspeed.

In designing a safe air show, the professional performer brings a safe, well rounded variety of performances to the event and provides the air show boss with the confidence that comes from the professionalism he/she can expect from the performer.

INITIAL PRACTICE OF THE AIR SHOW SEQUENCE

After maneuver selection, the air show sequence construction can begin. It is the construction and linking of maneuvers that make a safe air show sequence. This sequence of maneuvers allows the proper speed and altitude (i.e. energy) for each maneuver.

After construction of the air show sequence, aerobatic practice should begin at a minimum of 1500 feet above ground level. Using 1500 feet as the show bottom, the entire sequence should be practiced several times while study and notation are made of the speed and altitude at which each maneuver is started and finished. It is recommended that these figures be recorded in a notebook for review. If one or more portions of the sequence give altitude or performance problems, this portion of the sequence should be practiced by itself. It is this study and revision that builds the safe air show. Of particular importance is the altitude reached at the top of each and every maneuver. It is this altitude and speed that is the life blood for the next aerobatic maneuver.

After completion of the pilot's aerobatic routine, the pilot should contact an Airshow Certification Evaluator (A.C.E.). The A.C.E. will review the basic construction of the sequence and suggest any improvements necessary. The A.C.E. will then observe the pilot fly his or her routine.

After several practice flights with a 500 foot show bottom, further refinement and study of aircraft performance can be evaluated. Evaluation of engine failure at critical flight regimes can be practiced and noted. It is very important that a record be kept for pilot review and study. At the 500 foot level, the pilot can also study the effects of ground rush. Critical problem areas of the sequence become more apparent. Only when the pilot is convinced that the air show sequence has been properly constructed for the aircraft performance and pilot proficiency should the sequence be considered for the air show audience. The pilot should use this same sequence for the first air show in front of spectators.

After flying at least five air shows with a 500 foot (level III) show bottom, the air show performer may wish to be reviewed by an A.C.E. to request a level II (250 feet) certification. After flying an additional five air show sites, the performer may request a review by an A.C.E. for level I (no restrictions).

THE AIR SHOW PILOT'S GOLDEN RULE FOR A SAFE AIR SHOW PERFORMANCE

The safe and professional air show performance is the execution of months of preparation by the pilot and aircraft prior to reaching the air show site. This execution will not be rushed or changed by local authorities or by the excitement of the event.

TAKE OFF CHECK LIST ITEMS UNIQUE TO AIR SHOWS

I. Pilot and wing rider physical condition:

Heat: Has the pilot or wing rider been subjected to high heat and possible dehydration?

Cold: Has the pilot or wing rider been subjected to cold that might impair mental judgment and timing?

II. Aircraft preflight:

A) Servicing:

1. Fuel quantity and type
2. Engine oil
3. Smoke oil
4. Pyrotechnics

B) Mechanical:

1. Basic walk around

C) Altimeters:

It is suggested that the altimeter be set at zero for the show bottom that is being flown.

III. Meteorological conditions and local runway environment:

A) Wind (head wind, tail wind, on crowd, off crowd)

B) Visibility

C) Density altitude

D) Runway slope and obstructions

IV. Review of flight sequence:

A) A mental review of the sequence and conditions in a sterile environment by the pilot

V. Review of ground crew duties:

- A) Ribbon pole holders
- B) Pyrotechnics crew

VI. Execute the air show routine as briefed and practiced!