Air Show Performers Safety Manual

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Contents

Chapter 1: **Aerodynamics, Turning Performance and Energy Maneuverability for the Air Show Performer**

Chapter 2: **Test Techniques for Air Show Safety Parameters**

Contents Continued

Chapter 3: **Designing and Flying a Safe Air Show**

Air Show Performers Safety Manual

Introduction

The ICAS Air Show Performers Safety Manual was originally developed by members of the ICAS ACE Committee more than 20 years ago. This document was distributed widely throughout ICAS and the North American air show community, but – for reasons that are not entirely clear – stopped being shared approximately 15 years ago.

Recently, the document was retrieved from a file at ICAS headquarters, reviewed by knowledgeable individuals for relevance and currency, and is now being widely distributed once again to help air show performers benefit from the insight contained in it. With only a few minor changes and updates, the entire document is virtually unchanged from the original document generated in the early 1990s.

For some, the technical jargon and mathematical equations will help to support and clarify some of the points made in the text. For others, the jargon and equations will be off-putting, suggesting that the information is inaccessible or difficult to understand. We encourage those with the latter reaction to push through the text. You'll quickly realize that the material is very useful whether or not you understand the math or the jargon. Indeed, the entire document could easily be presented without the math, physics and engineering and still be enormously useful.

Like other safety programming, this document 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 and the USA's Federal Aviation Administration have taken up the cause of public safety and have, therefore, mandated guidelines for decreasing spectator risk of harm. However, much less has been done to provide the performer with the knowledge or training to control his/her own risk of harm.

This document is an attempt to codify and present in a logical fashion some of that special knowledge peculiar to air show flying. The information in this document will 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 document is limited to performer safety, and does not address various other tasks associated with the proper conduct of an air show.

ICAS expects to periodically update, correct and add information to this document. Subsequent revisions will be made and distributed on a regular basis from this point forward.

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. Low-level aerobatic flying is specific to the show site, pilot, aircraft, weather conditions and a host of other factors. The information contained in this document will be helpful to some, but it is intended to complement – not replace – practice, dual instruction, one-on-one coaching, and good judgment.

Finally, ICAS would like to thank the ICAS members who originally worked to produce this document more than two decades ago, particularly Michael Van Wagenen, Leo Loudenslager, T. J. Brown, and Dave Hoover. Thanks also to Rob Harrison and Francisco Franquiz who both contributed to updating, correcting and refining portions of this more recent version of the publication.

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 weather 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 and 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 become proficient in both air show and agricultural flying. The key, as always, is the possession of that particular knowledge base required in each specialty and the practice to remain proficient in its use.

Chapter 1:

Aerodynamics, Turning Performance and Energy Maneuverability for the Air Show Performer

Introduction

Imprecise, inaccurate or incorrect descriptions of basic maneuvering principles, or the maneuvers themselves, frequently lead to misconceptions that hinder the progress of air show pilots working to improve their skills. It is important, therefore, for air show pilots (experienced or not), instructors and Aerobatic Competency Evaluators (ACEs) to have a thorough understanding of aerodynamic and maneuvering principles to be able to effectively improve or teach their skills.

This chapter is concerned with aerodynamics, turning performance and energy maneuverability. It is presumed that the reader will have acquired a general knowledge of these topics in his or her previous experience. Therefore, in some areas, a wide range of subjects will be covered briefly, but in sufficient depth to provide a useful review. A great deal of attention will be focused on apparently simple subjects to insure a complete knowledge of the principles involved. Hopefully, this will provide the reader with a solid foundation and standard vocabulary on which to build discussions of air show sequence determination and the safety limitations of both the aircraft and the pilot.

PART A: BASIC AERODYNAMICS

Not all pilots will have an input into the preliminary design of high performance aerobatic machines, however, every pilot should be familiar with design considerations to fully appreciate the capabilities of his/her aircraft. Specifically, one should understand the principles of turning performance and energy maneuverability. To do this, a foundation in the laws of aerodynamics is absolutely necessary.

As a performer, instructor or ACE, one will need to understand these principles and relate them to “seat of the pants” cues and instrument readings. One misconception can lead to many wrong moves. The objective of this chapter is to understand the theory of flight, the forces that act on an aircraft, the effect of certain design characteristics, and the mathematical relations that describe aircraft performance.

Bernoulli’s Equation

In order to understand fully the theory behind energy maneuverability, it is necessary to understand the fundamentals of lift and its resultant forces. These concepts are part and parcel to every conversation one might have regarding flying, whether as a performer, instructor, or an ACE. One must have a sound working knowledge of these fundamentals. Rather than trying to learn high level mathematics, the reader is encouraged to read this chapter on basic aerodynamics with an eye toward refreshing the memory on these basic laws of aerodynamics. For that specific purpose, this chapter presents a review of the derivation of the lift equation, resultant lift forces.

All of the external aerodynamic forces on a surface are the result of air pressure or air friction. Since friction effects are limited to the immediate vicinity of the surface and are not the predominate force, they have been excluded from discussion for now.

An easy way to see the effects of airflow and the resultant pressures is to look at flow in one end of a closed tube in the shape of a venturi. Since we have a closed tube, all flow in one end must exit the other end. This concept sounds somewhat obvious and easy to comprehend, however, it is the cornerstone of lift. The airflow at each cross section of the tube has a certain velocity, static pressure and density. As the air moves to the next cross section of the venturi, certain changes must take place. The law of continuity of mass flow says that the flow of air through the tube is constant, i.e. all that goes into one end must go out the other.

"Energy" is the engineer's way of describing the ability do to work (i.e. electric energy can make a motor run; chemical energy can be generated from gasoline and make your car go). In this case, we are concerned with the energy of a moving stream of air. The first engineer to describe the energy of a moving stream of fluid (gasses and liquids are considered "fluids" by engineers) was Daniel Bernoulli in 1738.

Bernoulli's principle teaches us that the total energy is unchanged from one end of the venturi to the other. Developing this further, energy is considered in two forms: potential energy and kinetic energy.

The total amount of energy contained in the moving stream discussed above, flowing continuously through our venturi, may be divided into Kinetic Energy and Potential Energy, or K.E. and P.E.

$$E_{tot} = K.E. + P.E.$$

E_{tot} = Total Energy

Kinetic Energy depends on the mass of the air in our airstream and how fast it is moving.

$K.E. = \frac{1}{2} mV^2$

where m = mass (slugs)

and V = velocity (ft/sec)

For a cubic foot of air of mass M, Density $(\rho) = \frac{\text{Slugs}}{\text{ft}^3}$

Therefore,

$K.E./ft.^3 = \frac{1}{2} \rho V^2 = q$ (pressure caused by motion or dynamic pressure)

Potential energy is related to static pressure. Its magnitude is determined by how much air there is above an object exerting force onto the object. Combining the above terms, one gets:

$$H = q + p = \frac{1}{2} \rho V^2 + p$$

Where

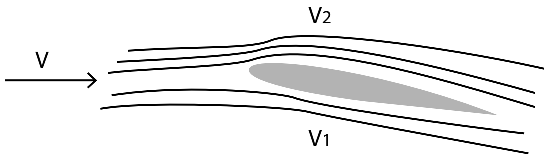
H is total pressure (psi)
p is static pressure (psi)
q is dynamic pressure or $\frac{1}{2}$ p V^2

Bernoulli, therefore, stated the total pressure equals the static pressure plus the dynamic pressure and is constant throughout the system.

Development of the Aerodynamic Forces

We have seen that, since the total energy in a moving airstream is constant, as the speed of the air increases, the pressure drops. In your mind's eye, picture the hypothetical venturi above is moving through the air, rather than moving through a stationary venturi. The effects are the same. Now, picture instead an airfoil moving through the air. You can see that, as the air speeds up over the top of the airfoil, the pressure is decreased. The lower pressure creates a force on the airfoil. It is this force, which we call lift, which allows us to fly. The pressure distribution over the airfoil determines the forces applied to the airfoil, and thus the speed, direction of flight, and movement of the airplane to which the airfoil is attached.

One should imagine the bottom of the venturi modified to assume the shape of an airfoil. If one were to incline the airfoil, one would get a change in the pressure distribution. The velocity of the air over the upper surface must be greater than the lower surface as depicted in Figure 1. The static pressure on top is less and this pressure differential causes an upward lift on the wing. The same pressure differential could exist by increasing the curvature of the upper surface without inclining the airfoil.



The closer streamlines (from wind tunnel tests) indicate V_2 is higher than V_1.

FIGURE 1

The location of the maximum thickness, the camber or shape, and the location of the maximum camber all determine such things as stall, lift and drag characteristics of an airfoil. (Though a cambered airfoil is shown here, most aerobatic airplanes use symmetrical airfoils, that is, airfoils with a flat mean camber line. The principles are the same.) Figure 2 depicts the definitions of the following airfoil terminology:

1. **Chord Line** – a straight line between the leading edge and the trailing edge of an airfoil.

2. **Mean Camber Line** – a line described by points which are equidistant from the upper and lower surfaces of the airfoil.

3. **Camber** – measure of the curvature of an airfoil, that is, the height above or below the chord.

4. **Location of Max Camber** – helps define airfoil shape and locate the maximum pressure differential.

5. **Thickness** – another important measurement for airflow characteristics.

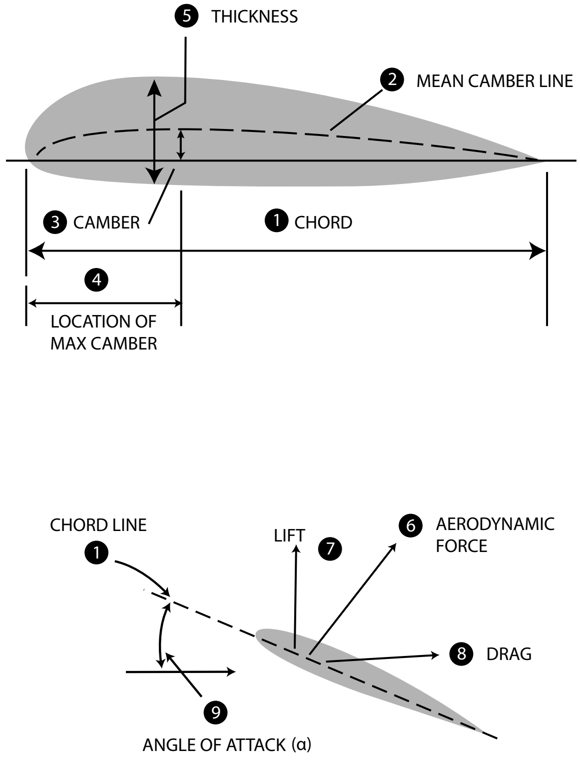


FIGURE 2

6. **Resultant Aerodynamic Force** – the vector summation of all the aerodynamic forces acting on an airfoil. Its point of application is at the center of pressure.

7. **Lift** – the component of the aerodynamic force which is perpendicular to the relative wind.

8. **Drag** – the component of the aerodynamic force which is parallel to the relative wind.

9. **Angle of Attack (AOA)** – angle between the relative wind and the chord line.

Many years ago, the National Advisory Committee for Aeronautics (forerunner to the National Aeronautics and Space Administration) developed an extensive database that assigned a number to an airfoil that describes the shape of the airfoil. For example, a 3412 wing means that the max camber is 3% of the chord length, the location is 40% back on the chord line and the max thickness is 12% of the chord length.

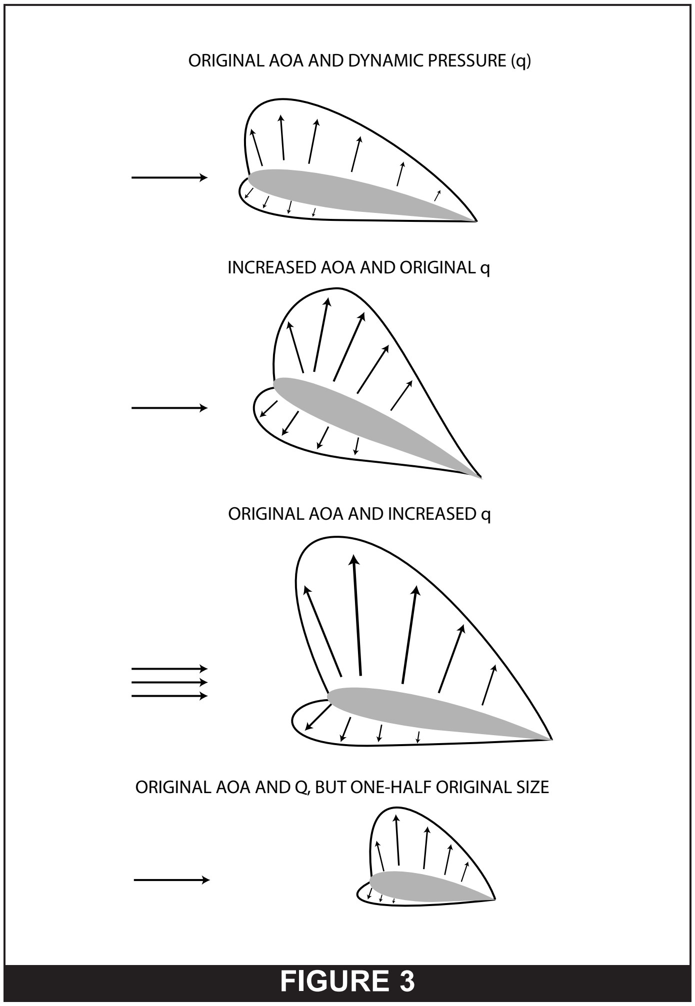


FIGURE 3

Lift

From the lift equation,

$L = C_L \frac{1}{2}\rho V^2 S$ where

C_L = the coefficient of lift,

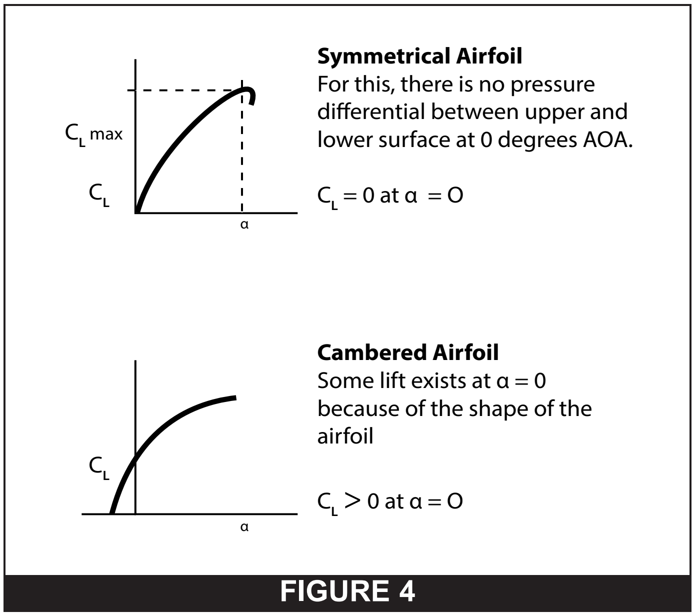
$\frac{1}{2} \rho V^2$ = dynamic pressure

S = wing area

By examining the lift equation, one can see the effects of varying different factors in the equation as shown in Figure 3. By increasing the velocity, one increases lift as a function of the square of the velocity; or, if the velocity is doubled, then the total lift force generated is increased by a factor of four. The lower the pressure altitude, the higher the density of air; therefore, the higher the total lift force generated.

Since one normally examines an airfoil's performance characteristics at a given airspeed (V) and density altitude (p), assuming a constant airfoil area (S), the primarily lift variable is the Coefficient of Lift. From the above discussion, one knows the factors affecting Coefficient of Lift are Angle of Attack (AOA) and airfoil shape. Figure 4 shows the effect of AOA on the Coefficient of Lift for both the Symmetrical and cambered airfoils.

Aspect Ratio (AR) is a term used to describe the planform shape of an airfoil and is another factor which affects the lift coefficient. AR is a measurement of how broad or narrow a wing is. It is ften described as the ratio of the span to the average chord, but since the average chord is somewhat difficult to arrive at, it is more practically defined as the span squared divided by the wing area (S).



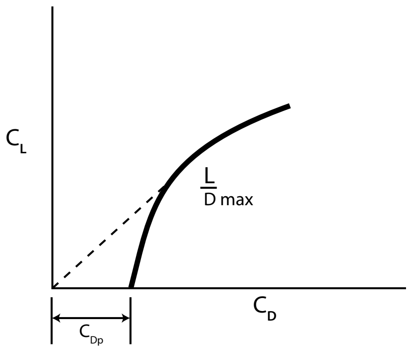
Symmetrical Airfoil
For this, there is no pressure differential between upper and lower surface at 0 degrees AOA.

$C_L = 0$ at $\alpha = 0$

Cambered Airfoil
Some lift exists at α = 0 because of the shape of the airfoil

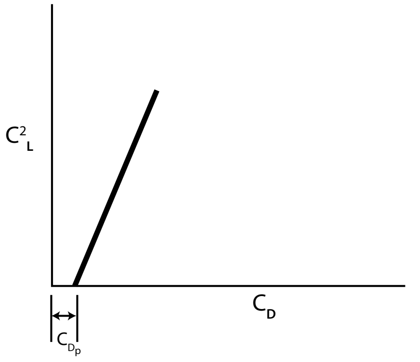
$C_L > 0$ at $\alpha = 0$

FIGURE 4



Drag Polar or Lift vs Drag Curve
This curve is almost parbolic in shape
at $C_L = 0$,
$C_D = C_{D_p}$ because $C_{D_i} = 0$

FIGURE 5



This is the form you will find most often
in performance manuals and reports.

FIGURE 6

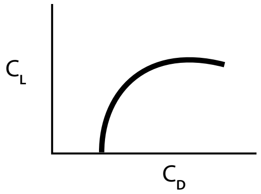


FIGURE 7

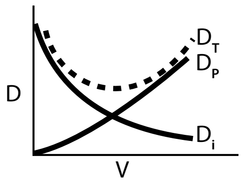


FIGURE 8

Drag

If a vehicle is going to fly, it must overcome the resistance to its motion through the air. This resistive force acting in a direction opposite to the direction of flight is called aerodynamic drag. Total drag is the sum of many component drags. There are three types of drag: Induced (drag due to lift); Wave (drag due to supersonic flights); and Parasite (all else). In our case, Wave Drag is not a factor.

Parasitic Drag includes all other drag components, such as Interference drag or drag caused by the mating of parts such as the wing to the fuselage. The sum of Parasitic Drag and Interference Drag, if measured separately, is less than that if measured together.

Profile Drag is a measure of the resistance to flight caused by air on the profile of the aircraft. It is subdivided into skin friction and pressure drag. Most of these factors are, to a certain extent, constant and predictable. The drag most accountable to performance is the one controlled by the pilot and that is drag due to lift or Induced Drag – D_i.

The drag that most affects performance of the the airplane is Induced Drag, or drag due to lift.

The relationship between lift and drag can be expressed as a drag polar diagram (See Figure 5 above.)

The drag coefficient equation is developed in the same manner as the lift coefficients.

$C_D = C_{D_p} + C_{D_i}$ where

C_D = coefficient of total drag

C_{D_p} = coefficient of parasite drag

C_{D_i} = coefficient of induced drag

Without any lift being generated, induced drag is zero; however, profile drag still exists due to the speed of the airfoil. Figures 5 and 6 demonstrate this by showing the relationship of lift to drag. Notice that, as lift is increased, drag begins to increase as an exponential factor of lift. The point of maximum lift to drag occurs at the intersection of a line from the origin to a point of tangency of the curve. This chart also shows the penalty for high angle of attack (AOA) maneuvering in terms of drag. Note that, past the point of L/D max, increases in lift result in incrementally higher increases in drag. The flatter the top portion of the curve, the more pronounced the increase in drag.

This increase in drag generated by high lift is due to the effects of induced drag (induced drag varies with the square of lift). One of the primary determinants of the magnitude of induced drag is the Aspect Ratio of the airfoil. Induced drag varies inversely with the Aspect Ratio of the airfoil. Airplane configurations designed to operate at sustained high lift coefficients are optimized with high aspect ratio wings. While the high aspect ratio will minimize induced drag, long, thin wings increase structural weight, have relatively poor stiffness characteristics and relatively high profile drag at higher airspeeds. This results in low aspects ratio wings for high performance aircraft.

Summarizing drag in level flight: parasite drag is predominant at high speed while induced drag is predominant at low speed. Increasing the aspect ratio decreases drag for constant lift. Most importantly, drag increases with lift as shown in Figure 7. Finally, the total drag for a given set of flight parameters is the summation of parasite drag and induced drag as shown in Figure 8. When the pilot wants more lift (i.e., wants to turn), he/she pays the price with induced drag.

PART B: TURNING PERFORMANCE

Turning performance is perhaps the most effective means of determining the capability of the aircraft in the air show arena. It provides a mechanism for the serious safety conscious pilot to ascertain the proper air show safety margins. By understanding what the factors are in the rate and radius equations and that those factors are laws of physics and don't change, a performer can build an adequate foundation upon which to determine an effective air show sequence.

Total G. vs. Radial G

Before beginning the discussion on turning performance, there are some terms and definitions that need to be clarified in order to have a common base upon which to understand the performance capability of the aircraft.

Since G loading directly affects the effective gross weight, if G is varied, so are the resultant forces and structural considerations. Aircraft are designed to stay together up to a certain structural limit. This limit is the upper G limit or the design limit load factor.

There is normally an aerodynamic limit in an airframe design beyond which some controllability problems arise. These are normally stall, roll-off, departures, excessive AOA, etc. This limit is called the maximum lift coefficient. The Coefficient of Lift Max and wing loading (weight divided by the wing area or W/S) combine to define the ability of the aircraft to develop the aerodynamic loads, or available G, necessary for maneuvering flight.

In some situations below a certain velocity (sustained turn velocity), thrust is the limitation on maximum turn at constant altitude. Above that velocity, excess thrust determines the amount of excess power available for accelerating and/or climbing once G-limit is achieved.

In Figure 9, the total sum of forces acting on an aircraft in a turn is depicted. It is assumed the velocity will remain constant in this turn, so there will be no net force going into or out of the turn (or thrust equals drag.). The lift force can be written as an acceleration upward. When lift is divided by mass, the result is the amount of acceleration upward caused by the lift force or cockpit

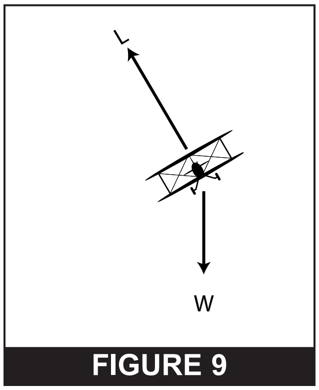


FIGURE 9

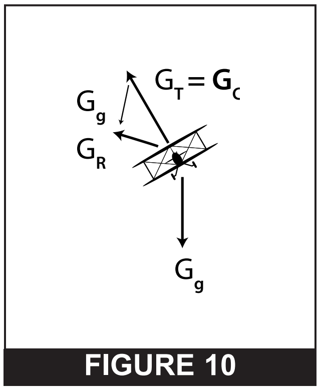


FIGURE 10

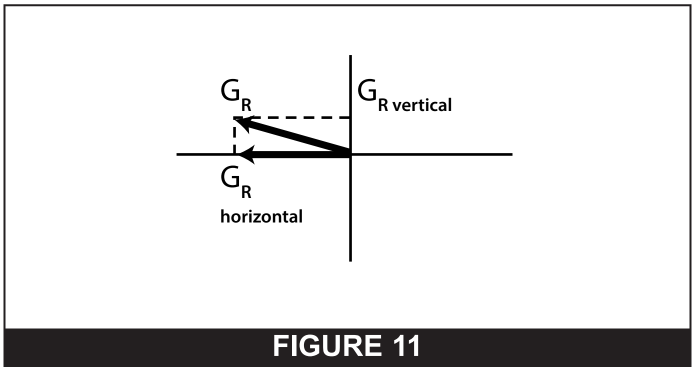


FIGURE 11

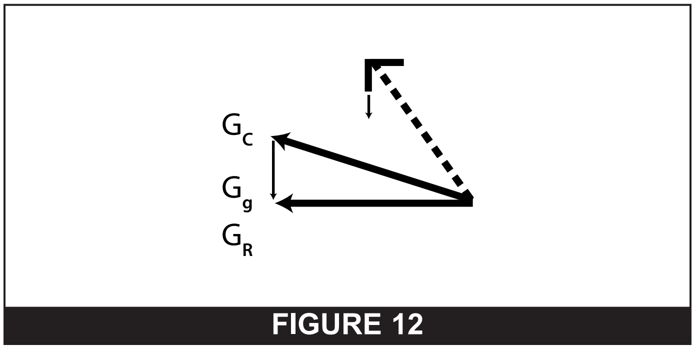


FIGURE 12

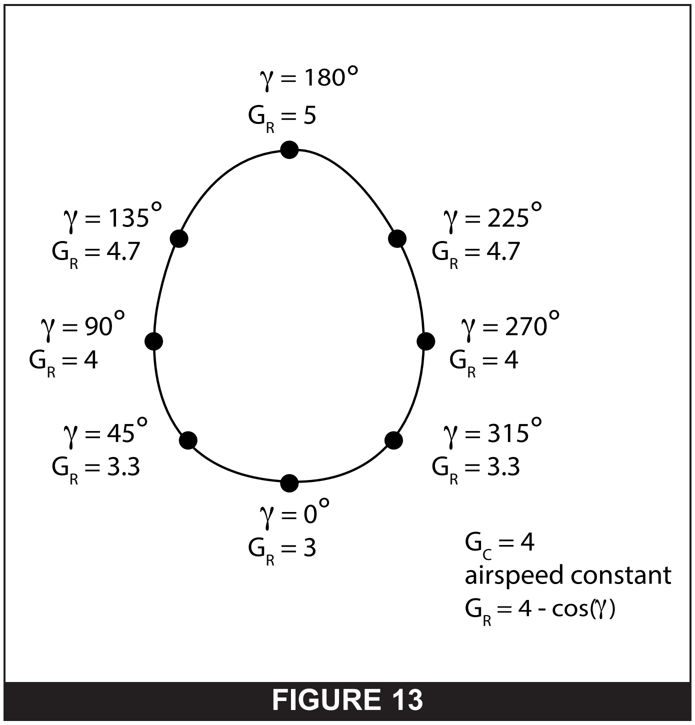


FIGURE 13

G (G_c). In the same manner, weight can be converted to acceleration due to gravity which is herein called G_g. This will always be equal to a value of one. The resultant or net force acting on the aircraft is then found by the addition of these two vectors. This vector summation is shown in Figure 10. The resultant vector is shown as G_R. This vector defines the plane of the turn or plane of motion of the aircraft and is called radial G or G_R.

In Figure 10, the plane of the turn will result in a slight climbing turn. By resolving the G_R vector into vertical and horizontal components, it is obvious there are vertical and horizontal components to the turn as shown– in Figure 11. To ease complexity of analyzing the turn, the bank is increased so that there is no vertical component of G_R as shown in Figure 12. This can also be done by decreasing the magnitude of G_c. Now the turn will be entirely in the horizontal plane. Since the angle between G_R and W is 90 degrees, the Pythagorean theorem can be used to determine the value of G_R. Simply stated:

$$G_c^2 = G_g^2 = G_R^2$$

Since $G_g = 1$,

$G_c^2 = 1 + G_R^3$ and solving for G_R

$$G_R = \sqrt{G_c^2 - 1 \text{ for a level turn}}$$

The traditional method of depicting the resultant vector analysis is the Energy Maneuverability "Egg" as shown in Figure 13. The reader will note that in a 4 G loop the G_R varies from 3 G's at the bottom of the loop to 5 G's at the top of the loop. Furthermore, note that any time the lift vector is oriented below the horizontal, there is an additional portion of G_g aiding the turn.

Turn Radius

Newton's Law states "for every action there is an equal and opposite reaction" and further, "for every force there is an equal and opposite force" (the dark side). Newton further postulated that a body traveling in a circular path must be constantly accelerated toward the center of the turn. This acceleration is a function of the tangential velocity and the radius of the turn and is equal to:

$G_R = \frac{V^2}{R}$ where

V = Velocity
R = Radius

The horizontal component of lift, or L_H, is the force that produces the centrifugal force (CF). The radial G or G_R and centrifugal acceleration (G_{cent}) are equal and opposite in a level turn.

Since centrifugal force results from normal acceleration, it is equal to the product of the mass times the acceleration or F = Ma. Therefore, combining the two equations for G_R and G_{cent} which are equal and opposite forces, we can solve for G_R:

$$CF = Ma = \frac{MV^2}{R} = \frac{WV^2}{gR}$$

Since CF = G_R, then

$$G_R = \frac{CF}{W} = \frac{WV^2}{WgR}$$

Therefore:

$$G_R = \frac{V^2}{gR}$$

Solving for radius R:

$R = \frac{V^2}{gG_R}$ Measured in feet;

Equation for Turn Radius of Any Aircraft

Where

V = true air speed (TAS) (Ft/sec)
G = 32.2 ft/sec^2
G_R = Radial G

Therefore, for any turn, it remains only to determine the magnitude of the "turning" or radial G and true airspeed for the radius of turn ~~to~~ be calculated. It must also be noted and emphasized that the radius of any turn depends solely on velocity and radial G. No other variable such as wing loading or gross weight is a factor. Also note, that for a vertical turn $G_R = G_c - \cos$ (of the flight path angle or pitch attitude) as shown in Figure 13 depicting the "Energy Maneuverability Egg."

Consequently, one can see that at a constant velocity and a constant G_c, radius will increase as dive angle decreases (cosine of 0° is 1 and of 90° is 0, so the bottom number is larger for 90° than it is for 0° and the radius will get larger as the pitch angle decreases to 0).

Turn Rate

Turn rate is simply how fast one transfers across the sky or how fast one covers a certain number of degrees. Turn rate is defined as w and is the angular velocity as expressed in the formula:

$$\omega = \frac{V \text{ in ft/sec}}{R \text{ (Radius) in ft}} \qquad \text{stated in Radians/Second}$$

One radian is that segment of the circumference equal in length to the radius. There are 57.3 degrees in a radian.

Since, in the equation for turn radius,

$$R = \frac{V^2}{gG_R}$$

Substituting this in the equation for ω:

$$\omega = \frac{VG_R g}{V^2} = \frac{G_R g}{V} \qquad \text{expressed in Radians/Second}$$

Converting to degrees/second simply requires multiplying by the 57.3 degrees/radian; therefore to express the equation in degrees/second:

$$\omega = \frac{G_R g}{V} \text{ x } 57.3 \text{ expressed in degrees/second}$$

Since the force of gravity, g, and the conversion from Radians/ Second to degrees/second are constant, they can be shown as a constant K = (57.3) (32.2) = 1,845 or:

Turn Rate Equation For Any Aircraft

$$\omega = \frac{K\,G_R}{V}$$

Note that – like radius – turn rate is solely dependent upon true airspeed and radial G. The greater the G available for a given velocity, the greater the rate of turn will be in degrees per second.

Look at a representative example of a Pitts Special at sea level indicating 145 knots, in a 6 G turn at a bank angle of 83 degrees and determine the turn rate and radius. The reader should determine the G_R for a G_c of 6 which is done in the equation:

$$G_R^2 = G_c^2 + G_g^2 - 2G_cG_g \cos 83°$$

Since Gg = 1

$$G_R = \sqrt{G_c^2 + 1 - 2G_c \cos 83°}$$

Substituting for the example:

$$G_R = \sqrt{G_c^2 + 1 - 2G_c \cos (83°)} \text{ solving}$$

$$G_R = \sqrt{37 - 12\ (.1428)}$$

$$G_R = 5.95$$

Therefore, solving for Radius (R),

$$R = \frac{V^2}{gG_R} = \frac{[(145)(1.69)]^2}{(32.2)(5.95)} = 313.4 \text{ feet}$$

Solving for turn rate (ω),

$$\omega = \frac{K\,G_R}{V} = 1845 \frac{5.95}{(1.69)(145)} = 44.9 \text{ deg/sec}$$

The only thing in the above example that is peculiar to aircraft type is the ability of the aircraft to attain and sustain G_c of 6 at 145 knots at sea level.

What does all this mean to the air show pilot? Turn radius remains about the same for a given velocity up to corner velocity (this term will be discussed later). This is due to the relationship of G_c and velocity. As previously discussed, Gc is equal to lift divided by weight or in equation form:

$$G_c = \frac{L}{W} = \frac{(1/2\,\rho V^2 S)}{W} \frac{C}{L}$$

The above shows that G_c (or available G) increases as the square of the velocity up to the max available G or the placard limit. That is to say, as V doubles, G_c increases 4 times. Also $G_R = G_c + G_g$, meaning that G_R increases as the square of the velocity. Therefore:

$$\text{Since } R = \frac{V^2}{32.2G_R}$$

then the increase in G_R reduces the impact of increasing V on radius.

Turn rate increase is equal to:

$$\omega = \frac{K\,G_R}{V} \text{ and } G_R = \frac{V^2}{gR}$$

As the velocity doubles, G_R increases by four. Thus G_R increases much faster than V up to the placard limit and turn rate increases dramatically to the point of max G. The ratio of G_R/V rapidly decreases as velocity continues to the placard limit, but G remains constant at the placard limit.

A plot of G available (G_C) versus velocity is seen in Figure 14. Referring to the turn rate and radius formulas, one can see that as velocity increase, available G increases and, therefore, radius decreases slightly and rate increases. However, once the placard limit is reached, available G becomes a constant and the increase in velocity increases radius and decreases rate.

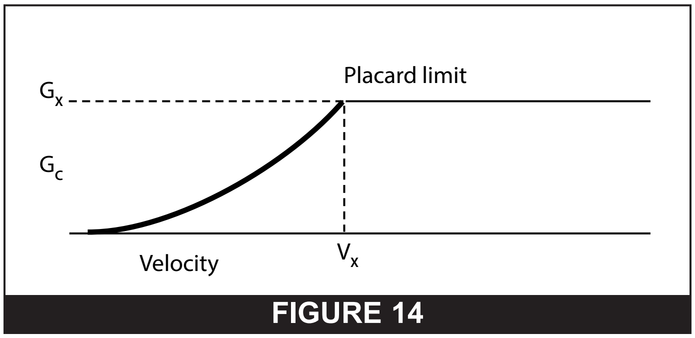


FIGURE 14

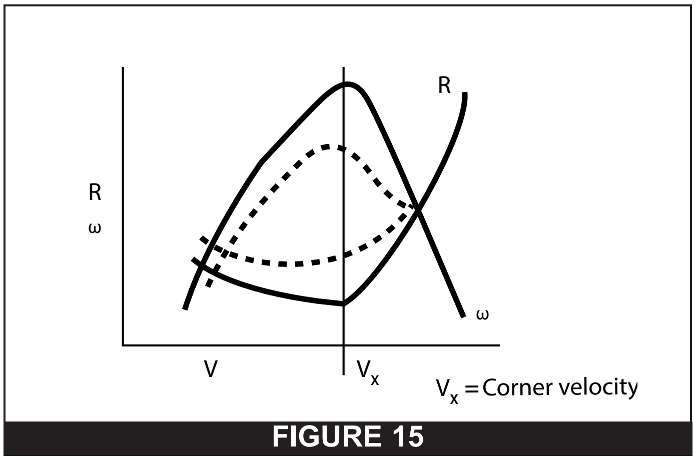


FIGURE 15

A plot of turn rate and radius are seen in Figure 15. V_X is the point where placard is reached, and – in most aircraft – where one gets the quickest (highest ω), tightest (lowest R) turn. This velocity is defined as the corner velocity and is used in analyzing instantaneous maneuverability.

The quickest, tightest turn represents a maximum performance capability and is therefore instantaneous because of the high energy bleed-off associated with this type of turn. This energy bleed-off is measured in specific excess power (P_S) and for most aircraft is negative for the quickest, tightest turn. This concept will be discussed in more detail in the next chapter.

The dotted line in Figure 15 represents a sustained turn performance plot of rate and radius to velocity. Although the tightness of this turn is not as great as the maximum performance turn, it can be sustained indefinitely. Because of the airspeed and subsequent rate decay with a maximum AOA turn, the average rate for the total duration of that turn may be lower than that of a sustained G turn. It is to be determined by the pilot which turn is needed to have the desired result. The retention of energy is critical in designing the maneuvers of a safe air show routine and these concepts then become quite important.

In review, turn rate and radius are based solely on G available and velocity. Turn rate and radius can be used to instantaneously analyze aircraft performance via the G-V diagrams and determining the corner velocity for that aircraft.

PART C: ENERGY MANEUVERABILITY

This section of Chapter 1 examines various ways to determine the three-dimensional maneuvering potential of the aircraft. Energy Maneuverability (EM) has evolved over a period of years dating back to the Richthofen days where different methods were used to determine the advantages and disadvantages of one aircraft versus another when compared on paper. Since then, EM has emerged as an art form to determine the maneuvering capability of an aircraft in real terms that the pilot can use in the cockpit. While usually reserved for training fighter pilots in the arena of aerial combat, it can be used quite effectively in the air show arena as well.

Wing Loading

The turn performance of an aircraft may be analyzed by examining the ratio of gross weight to the wing surface area, or wing loading.

In the formula for turn rate:

$$w = K \frac{G_R}{V}$$

turn rate (w) is directly proportional to the radial G loading (G_R). Assuming $G_R = G_C$, from the classic lift equation,

$$L = C_L qS = \frac{G_c}{W} \text{ where}$$

W = gross weight

S = surface area of the wing

C_L = coefficient of lift

q = dynamic pressure

G_c = G loading (cockpit G)

One can see that in solving for G_c that:

$$G_c = C_L \frac{q\,S}{W} = C_L \frac{q}{\frac{W}{S}}$$

W/S is the gross weight of the aircraft divided by the surface area of the wing or wing loading. Note then, that wing loading is inversely proportional to the load factor and also to the turn rate. That is, the smaller the wing loading, the greater the turn rate. It then becomes important to note that a lighter aircraft will perform better.

Advanced aerodynamics, such as lifting body effects (which change the C_L of the aircraft) and high lift devices, will change wing loading somewhat. However, wing loading will always be a good method to help determine the performance of the aircraft.

Power/Thrust-to-Weight-Ratio

The Power/Thrust-to-weight ratio is another method used to analyze the capability of an aircraft to accelerate and sustain turn rates. This ratio is derived by dividing the aircraft's gross weight into the total installed power/thrust. This is called the power-to-weight ratio. Obviously, a larger power-to-weight ratio indicates a better acceleration and sustained turn capability.

Energy Maneuverability (EM)

This method of rating performance grew out of an extensive analysis of aerial combat and uses a variety of combat performance charts to graphically provide comparisons throughout the entire flight envelope.

Briefly, the theory states that – to accomplish the ultimate objective in aerial combat – all conventional fighters must achieve a position within the firing parameters of their weapons. As one might expect, the ability to achieve this position in a visual engagement depends upon an aircraft's maneuverability, which is defined as the ability to move and/or rotate about all axes. Maneuverability depends directly upon a measurable quantity: energy. An airplane at a low energy state has less maneuvering potential than one at a higher energy state. One valuable way of evaluating performance potential for creating a safe high performance air show routine is to evaluate energy states and rates of change of energy states.

The total mechanical energy of an aircraft is the algebraic sum of three particular types of energy: kinetic, potential and rotational.

Kinetic energy results form the linear motion of the airplane and is expressed by the equation:

$$Ek = \frac{MV^2}{2} \text{ where}$$

M = mass
V = velocity (TAS)

Potential energy or "stored" energy represents the potential increase in kinetic energy if the mass of the airplane were to fall toward the earth, accelerating at 1 G (32.2 ft/sec^2). Potential energy may also be thought of as the energy needed to raise the airplane to its particular altitude above the ground. Potential energy is expressed by the equation:

E_p = mgh where
m = mass
h = altitude
g = acceleration due to gravity (32.2 ft/sec^2)

Rotational energy is a function of angular velocity as the aircraft rotates ~~aro~~und any or all of the three axes. However, the value of rotational energy is extremely small compared with kinetic and potential energy and for practical purposes is considered to be zero.

Total mechanical energy is then expressed as:

$$E_t = E_k + E_p + E_{rot}$$

or

$$E_t = \tfrac{1}{2} mV^2 + mgh + 0$$

Specific Energy (E_S)

Total energy by itself is not an accurate measure of maneuverability because of the inertia associated with weight. A 747 weighing 500,000 pounds will possess more total energy than an Extra 300 weighing 1,500 pounds, but the Extra 300 is clearly more maneuverable. In order to get an accurate indication of maneuverability, total energy is divided by the gross weight of the aircraft. This is called the "specific energy" or E_S. Expressed in equation form:

$$E_S = \frac{E_t}{W} = \frac{\tfrac{1}{2} mV^2 + mgh}{mg} \quad \text{where}$$

W = weight = mg therefore,

$$E_S = \frac{V^2}{2g} + h \text{ expressed in feet}$$

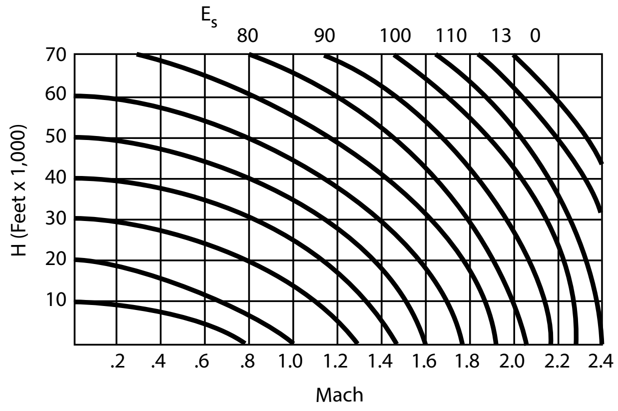


FIGURE 16

E_S techniques are used to create contour lines of constant E_S on a chart, which represent the combination of kinetic and potential energy, according to the equation, to produce that particular E_S as shown in Figure 16.

The contour lines may be thought of as describing the theoretical acceleration of an airplane, or any other mass, from a particular height until it hits the ground. For example, if a T-6 (a rock or any other inert mass) falls from 50,000 feet and zero airspeed, 10,000 feet lower, at 40,000, it will have accelerated to 0.8 Mach. At sea level, it will hit the ground at slightly more than 1.6 Mach (disregarding drag).

Going the other way, the E_S contours may be thought of as describing the maximum zoom altitude that can be attained from any given altitude/velocity combination. For example, if that same T-6 could accelerate to 360 knots at sea level, it could then zoom to zero airspeed at slightly more than 8,000 feet. One should note that these values are theoretical and apply to objects in a pure vacuum, so that – in an actual ballistic zoom – aerodynamic drag will cause maximum zoom altitudes to be slightly lower, while in zero AOA dives, the aircraft will accelerate slightly slower than the E_S contours indicate. By simply superimposing the steady state flight envelopes of a particular aircraft onto the contour graph, an analysis can be performed on the E_S levels. In order to get an accurate picture of the E_S levels, several steady state flight envelopes would need to be superimposed simultaneously, usually from 1-G out to corner velocity for the G level anticipated … perhaps around 6 G's.

Specific Power (P_S)

The rate of change in energy with respect to time is called "power." For the same reason one is interested in specific energy (energy per pound of weight), one should be interested in specific power (power divided by weight). This power may also be considered "excess thrust," and the descriptive term "specific power" is normally used and is known as P_S. P_S then refers to the ability of the airplane to change its energy state by accelerating or climbing.

Expressions for P_S may be developed in several different ways. The most straightforward is to use calculus and to take the derivative of E_S with respect to time:

$$P_S = \frac{d(E_S)}{dt} = \frac{d}{dt}\left(\frac{(V^2+h)}{2g}\right) \text{ and solving}$$

$$P_S = \frac{V}{g}\frac{dV}{dt} + \frac{dh}{dt} \text{ Measured in ft/sec where}$$

$\frac{dV}{dt}$ = rate of change of velocity with respect to time or acceleration, and

$\frac{dh}{dt}$ = rate of change in altitude with respect to time or climb rate (vertical velocity)

To express this in a more usable equation, one must consider an aircraft in an accelerated climb. The acceleration (or deceleration) of the aircraft along the flight path results from the unbalanced force along the flight path. This force is the sum of all the individual forces acting along the flight path and can be shown in equation form after multiplying by the velocity (V) and dividing by the weight (W). This can be expressed as follows:

$$P_S = \frac{V\,(T-D)}{W}$$

where T = thrust (lbs)

From this, one can see the P_S for aircraft (climbing, diving, accelerating or decelerating) is a function of thrust, drag and velocity. Careful consideration of P_S shows that it is indeed a valid indication of aircraft performance. The reader should notice that, at higher altitudes where power is greatly reduced, P_S decreases. In high-G turns where induced drag is high, P_S will be lower. At high speed, P_S increases, but is limited by increasing parasite drag. These are the factors that actually distinguish the performance of an aircraft and can be measured.

Conclusions

The intent of this chapter has been to explain some of the mathematical relationships between the factors that dictate performance. A solid understanding of these factors and what control the pilot has will allow him/her to design an exciting air show routine while preserving adequate safety margins.

When performing down vertical snap rolls, it is nice to know what the available G is in relation to the corner velocity as the ground starts looking bigger very quickly. Furthermore, the turn rate and radius numbers can be easily translated into safety margins. Knowing that rate and radius depend solely on airspeed and G will further allow one to understand the kinds of maneuver sequences the aircraft can safely perform. Knowing the P_S levels during a specific maneuver also translates into safety margins. Performing a maneuver from ground level that is at a negative P_S tells the pilot that when he/she completes that maneuver, he/she will have lost airspeed, because to lose altitude will severely cut short the air show routine.

A continual review of these concepts and mathematical relationships will allow the performer/instructor/ACE to maintain the ability to critique his/her air show routine and help in the credible explanation of these critical concepts.

Chapter 2:

Test Techniques for Air Show Safety Parameters

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. But 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 illustrative 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.

PART A: 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 P_s. Specifically, the capability of an aircraft to pull out of a dive is determined by:

A) Structural Strength (V_{ne} and max "G")
B) The maximum lift coefficient (aircraft design)
C) Specific Excess power (P_s)

Chapter 1 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, Table 1 (above) 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 ft	1.0294
4,000 ft	1.0588
6,000 ft	1.0909
8,000 ft	1.1250
10,000 ft	1.1616

TABLE 1

For example, if the corner velocity is 140 MPH indicated air speeed (IAS), then at a density altitude of 10,000 feet, one will have a true airspeed of 163 MPH. Chapter 1 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 (see page 16) 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."

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 P_s). 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

Altitude Required for Pull Out from Vertical Dive

Pull Out from Vertical Dive

Aircraft Load - 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

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 one's 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.

PART B: 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 (See Table 3 on page 17). 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 t 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 alti-

PITTS SPECIAL: S-2S SN:002HB

HAMMERHEAD TURN, POSITIVE ENTRY & EXIT, NO ROLLS

FULL THROTTLE

Entry & Exit Density Altitude	Entry IAS (mph)	Exit IAS (mph)	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

tude, 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.

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 engineer 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 (See Table 4, page 20) are three test points, again for the venerable Pitts S-2S, in which these failure modes were investigated.

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 parame-

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

ters, 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 ¾ rolls to ¼ rolls 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.

PART C: 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 lower 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

Pitts S-2S **ARCHING ROLL TYPE: 4 POINT**
Full Power **ALTITUDE LOSS/GAIN DURING ROLL**
Density Altitude: 2000 Feet

	Entry Airspeed (units = mph)				
Pull up angle (units = degrees)	**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

speeds and initial pull-up angles. Table 5 uses the Pitts as the example.

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 attitude.

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.

PART D: 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.

As before, one can easily see the effect of various entry parameters for a loop (see Table 6). 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 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 deter-

PITTS SPECIAL S-2S SN 002HB
ROUND LOOP AT INITIAL 4 “G”S, FULL POWER
SAME ENTRY AND EXIT ALTITUDE

	Density Altitude (units = feet)		
Entry A/S (units = mph)	**2,000**	**4,000**	**8,000**
	Exit Airspeed (units = mph)		
120	**146**	**146**	**140**
140	**162**	**156**	**154**
160	**174**	**166**	**160**
180	**178**	**176**	**174**

TABLE 6

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

	2,000	4,000	8,000
Airspeed at Inverted (units = mph)	**Altitude Required (units = feet)**		
60	**610**	**640**	**670**
70	**600**	**660**	**670**
80	**560**	**650**	**680**
90	**560**	**640**	**780**

TABLE 7

mine 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.

PART E: 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 database of at lease 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.

PART F: 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 Aerobatic Competency 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 3:
Designing and Flying a Safe Air Show

Introduction

It is assumed in this chapter that the pilot has aerobatic skills and wants to demonstrate them at 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.

PART A: 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.

PART B: PERFORMER PHYSICAL CONDITION

Good pilot health and physical condition are very important for "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 result in the performer arriving at the show site already fatigued. Finally, there is the effect of multiple hats worn by 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 – and has had! — 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 pilot's 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 pilot's reactions and mental processes were severely impaired by 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 blackout. 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.

PART C: 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 way to create 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 following 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 greater safety margins 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 should always be something in reserve at all times and under all conditions.

PART D: 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.

PART E: 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 altitude, a climbing flight path and altitude for the safe snap roll.

The correct combination of air speed, pitch altitude, 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 centerline 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 affect 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 even considering the addition of a spin to an air show routine.

Altitude is the single greatest consideration for the spin. If the pilot is going to air start the air show with a spin, 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

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

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 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 demonstrations.

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 tem 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 show site 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.

PART F: 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.

PART G: 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, thorough 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.

PART H: 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 the altitude and speed that is the lifeblood for the next aerobatic maneuver.

After completion of the pilot's aerobatic routine, the pilot should contact an Aerobatic Competency Evaluator. The ACE will review the basic construction of the sequence and suggest any improvements necessary. The ACE 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.

PART I: 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 with his/her 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.

PART J: AIR SHOW TAKE-OFF CHECKLIST

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 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!