



FIGHTER FORMATION FUNDAMENTALS



Fighter Formation Aircrews,

As promised, this text was produced in a continuing effort to not only improve our overall performance as fighter pilots, but more importantly our safety. In this light, I decided to write on a subject not directly connected with formation. With the airshow season coming closer, this discussion will cover fighter turn performance. Over the years we have lost more P-51 aircrews to turn related accelerated stall than any of us care to remember. Due to the P-51's laminar flow wing. It exhibits accelerated stall characteristics much like that of a modern jet fighter. The following discussion will examine some basic aerodynamic principles in high performance aircraft and how to use the V-G diagram to help determine your aircraft's limitations.

Flying jet fighters in today's air combat arena is demanding, challenging and very rewarding. To be successful however, it is mandatory that the fighter pilot be totally familiar with all aspects of his airplane's performance. Turn performance is one of the most important of these aspects for his life may depend on his ability to maximum perform the aircraft's turn performance limitations can be equally important to your longevity. We've all been there. The airshow airboss that is changing the scenario mid-stream or demands a certain action with little regard for the aircrews attempting to accomplish the feat. In cases such as these, often times you will immediately be faced with decisions on how to comply and then what to do. A common example of this episode is the turn reversal after a low airshow pass commonly referred to as the "duster turn". While a lightly wing loaded Stearman may accomplish this with impunity, the heavily wing loaded P-51 requires a little more contemplation, room and airspeed. These low to the ground, G-induced, high turn rate events are what this discussion is all about.

TURN PERFORMANCE

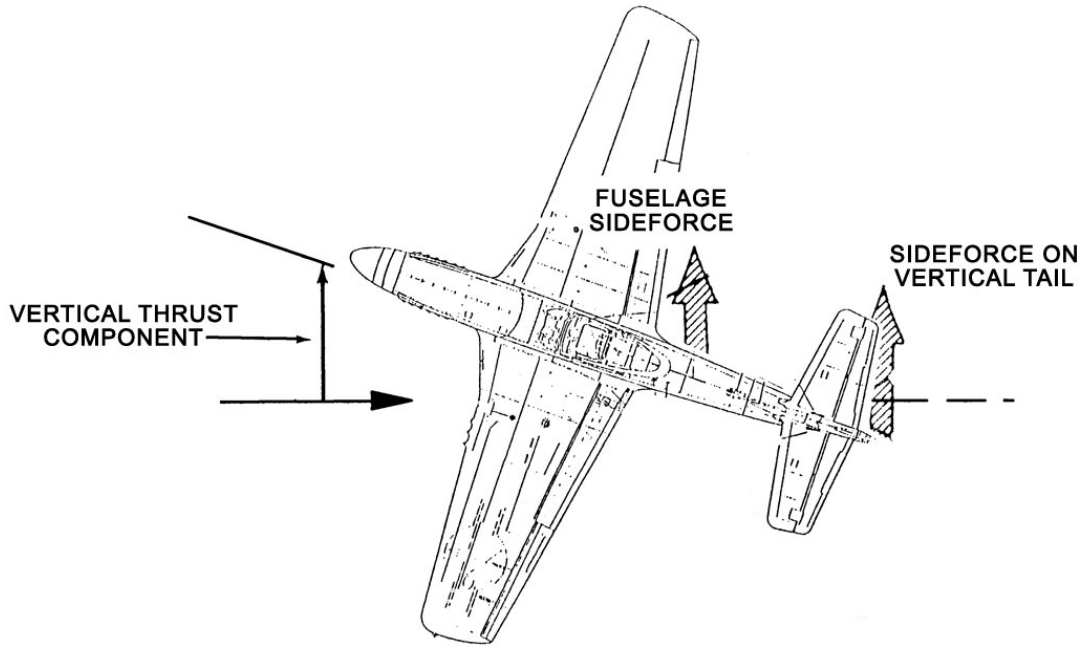
Turn performance is the ability of an aircraft to change the direction of its motion in flight. This direction is defined by the velocity vector, which may be visualized as an arrow pointing in the direction of aircraft motion and having a length proportional to the speed of that motion. Maneuverability is defined as the ability of a fighter to change the direction of its velocity vector. The term therefore, may be used synonymously. Maximum performance turns may be classified as one of two types: instantaneous and sustained. Instantaneous refers to the aircraft's maximum turn capabilities at any given moment under the existing flight conditions (speed, Altitude). A particular capability may last for only an instant before flight conditions change, resulting in a change in instantaneous turn capability. Sustained turns are those, which the aircraft is able to maintain for an extended period of time.

Any turn may be measured in three ways. One convenient measure of aircraft turn performance is load factor, which is actually a component of the centrifugal acceleration generated by the turn. This acceleration is usually expressed in terms of Gs, with one G unit being the equivalent of the nominal acceleration of gravity. Therefore in a G turn, the pilot will weigh three times his normal weight. Turn rate is another important performance measure. This is the angular rate of change of the velocity vector, usually expressed in degrees per second and in a level turn would equate to the rate of change in the aircraft's course. Turn radius, the third important measure of turn performance, is generally expressed in feet or miles.

An aircraft in a turn is subjected to an unbalanced force acting toward the center of rotation. This unbalanced force is called centripetal force and it produces an acceleration toward the center of rotation known as radial acceleration. In wings level, constant altitude flight, the lift equals the weight of the airplane and is opposite to it in direction. In turning flight, the lift is not opposite, in direction, to the weight. Only the vertical component of the lift, called effective lift, is available to offset the weight. Thus, if constant altitude is to be maintained, the total lift must be increased until effective lift equals weight.

"flying fighters is not a matter of life or death - it's much more important than that"

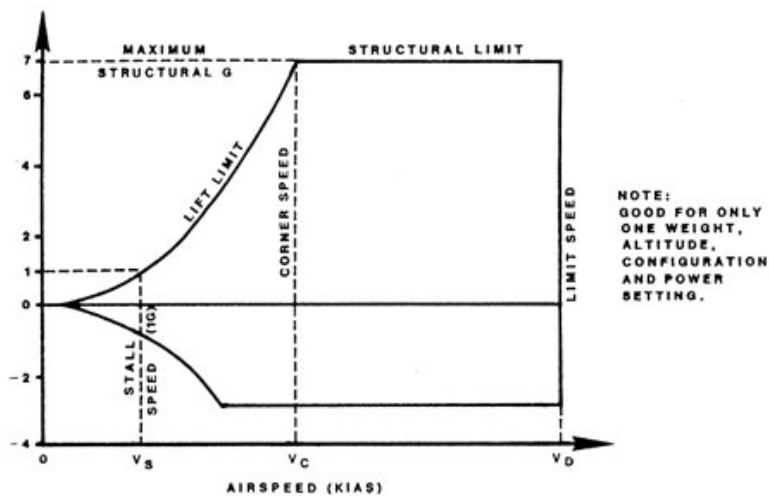
Gs required for an aircraft to maintain altitude in a coordinated turn are determined by the bank angle alone. Type of aircraft, airspeed, or factors have no influence on the load factor. As bank angle increases, the load also increases up to 90 degrees of bank where load factor would be infinity and thus impossible to attain. This assumes the wing alone provides all the lift. Yet we have all witnessed the four-point roll with a stop at the knife-edge 90 degree point. The secret is that lift is provided by parts of the airplane other than the wings. If the nose of the aircraft is held above the horizontal, the vertical component of the thrust will act as lift. The fuselage is also producing some lift by AOA. The vertical tail and rudder will also develop lift.



STALL & THE V-G DIAGRAM

The P-51 as any airplane develops slow speed stall at the stall AOA. At this AOA, the value of the lift coefficient is a maximum so the stall occurs at CL_{max} . Stall speed depends on the square root of the G loading. All other factors are constant for the same altitude. One of the most common and important tools for determining your aircraft's turn performance related to stall is the V-G diagram. This diagram is a graphical plot of load factor capability versus airspeed. This relationship is what this dissertation is all about – saving our lives! The V-G diagram for a fighter such as the P-51 contains a great deal of information in a compact, efficient and visually accessible form.

THE V-G DIAGRAM



The vertical axis is load factor in G units. When you are operating in the upper half (positive) of the diagram, you will be pushed down into the seat, while in the lower half (negative) you will be pushed upward away from the seat. The horizontal axis is airspeed, specifically MPH or KIAS. This is the speed shown on the airspeed indicator and is based on impact pressure. The left side of the V-G diagram, or lift limit, indicates the maximum load factor this fighter can generate at a specified airspeed. The curvature of this boundary primarily reflects the variation of lift capability with the square of the airspeed value. Along this line, the aircraft is operating at maximum positive lift in the upper half of the diagram and maximum negative lift in the lower half. Conventional aircraft are physically unable to operate to the left of this aerodynamic boundary. The upper and lower boundaries of the diagram depict the structural strength limits of the aircraft in the positive and negative directions.

The intersection of the positive aerodynamic boundary (lift limit) and structural limit defines a speed that is crucial to fighter performance and equally important to P-51 flying. This is known as “corner velocity” or “maneuver speed”. At this airspeed, a fighter attains maximum instantaneous turn performance. **At any airspeed below this speed, the airplane cannot be overstressed.** It will stall before the limit load factor is reached. Above this speed, however, the aircraft can exceed the limit load factor before it stalls. At corner, the aircraft’s limit load factor will be reached at the lowest possible airspeed. Bank angle and velocity play a role in corner velocity. High bank angles and slower airspeeds produce small turn radii and high rate of turn. **Corner speed is the airspeed at which highest bank angle can be achieved at minimum airspeed. Thus, minimum turn radius and maximum rate of turn will be realized at this speed.**

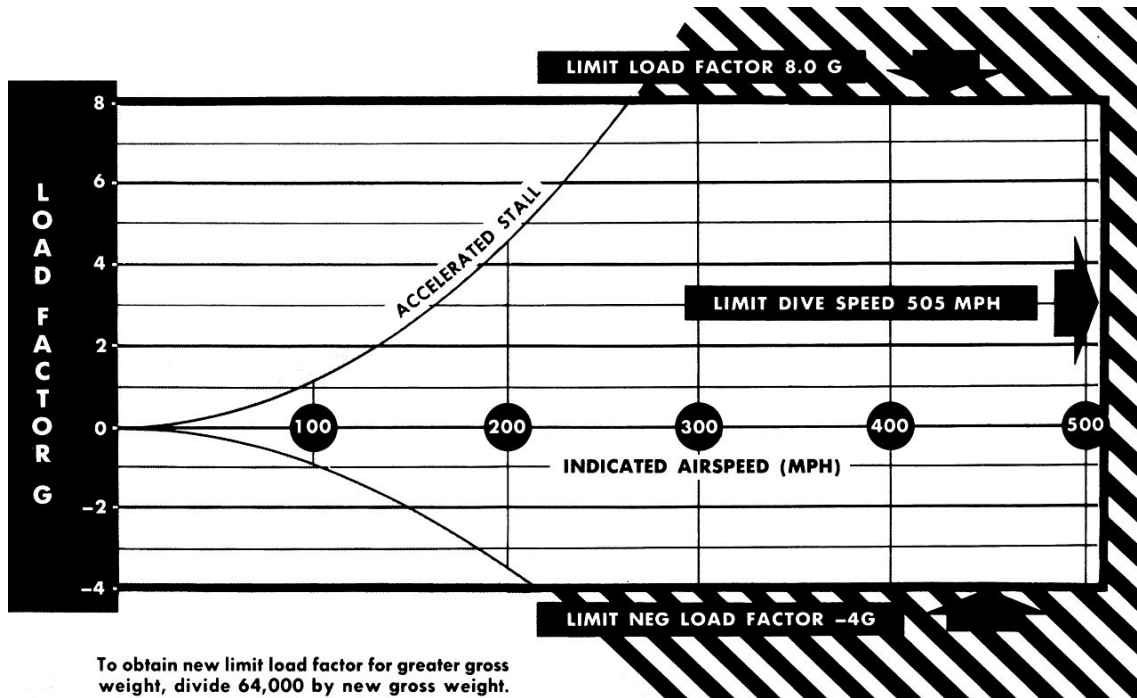
With all this said, how does it all really apply to us? Personally, I have committed several benchmarks of every fighter’s V-G diagram I have flown to memory. For the P-51, you will notice by the diagram below that 159 MPH=2.2G, 200 MPH=4.5G, 260 MPH=8G (approx. corner). Bear in mind that these figures are for 8000 LB gross weight and will change as weight increases or decreases. See the note under the diagram. If we assume, however, that in most airshow operations we are operating below to well below 8000 lbs then these benchmarks and the V-G diagram itself represents a comfortable pad. If you are very familiar with your V-G diagram it will prevent you from inadvertently demanding more from your fighter than it is able to give you. Low altitude in the airshow environment is no place to practice your stalls. Remember that in the event an excessive load is induced, there is only one course of action! As we preached in the F-4 community: **UNLOAD FOR CONTROL!** Airspeed is life in these airplanes. It can be converted to altitude if necessary and if used and monitored judiciously will save your skin.

P-51 V-G DIAGRAM

T.O. No. 1F-51D-1

OPERATING FLIGHT LIMITS

Based on design gross weight (8000 Pounds) or less



I hope this discussion has been informative and helpful. Have fun this new year – fly smart and fly safe.

Check Six,

Bradley C. Hood
Fighter Formation Qualification Program