How manufacturers determine an aircraft's maximum allowable (redline) airspeed. Three types of loads imposed on planes play crucial part

That DEADLY 'REDLINE'

by ROBERT T. SMITH • AOPA 85503

The operating speed range of an airplane is from its stalling airspeed up to its never-exceed-airspeed, commonly referred to as the "redline" airspeed. The stalling speed is the lower limit while the "redline" speed is the upper limit.

No sane pilot would ever allow his aircraft to operate close to either limit except that stalls are practiced (at a safe altitude) when checking out in a new airplane. But almost no one "practices" flying up to the redline airspeed intentionally. Is it possible for a pilot to fly near the "redline" airspeed unintentionally? We say, "Perhaps it is," but we temper this with a proper definition of redline airspeed.

The redline airspeed shown on the airspeed indicator is the maximum allowable airspeed, the airspeed that is never to be exceeded under any conditions. The redline airspeed is determined as that airspeed at which the loads imposed on the aircraft by aerodynamic forces equal the maximum allowable load for which the aircraft was designed. It is impossible to discuss airspeeds without considering loads. Loads imposed on an aircraft in flight may roughly be grouped in three categories; (1) normal loads, (2) maneuver loads, and (3) gust loads.

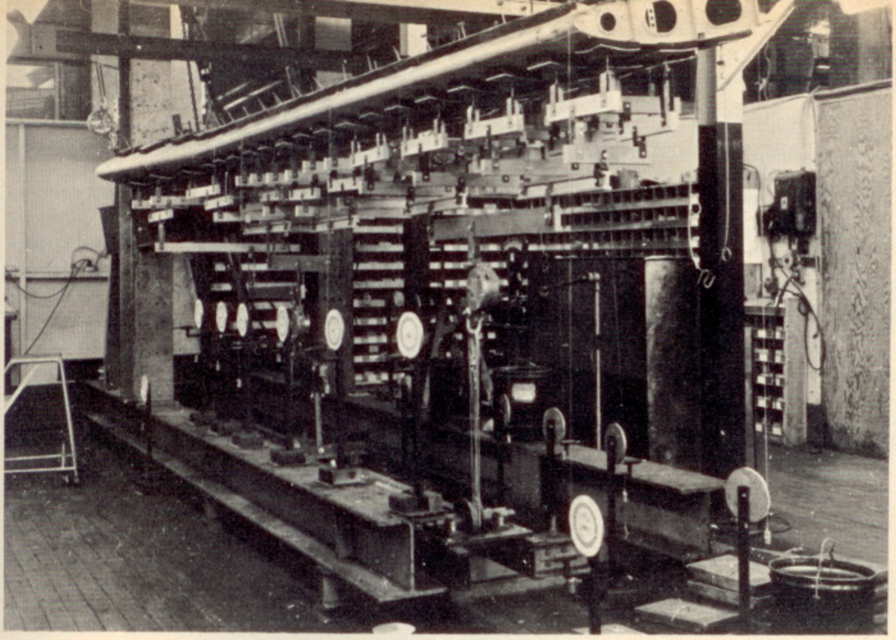
All of us know that an aircraft in straight and level flight has a load of 1 G imposed on it. G stands for the force applied to an object by gravity, which, at a force of 1 G, is equal to the weight of the object. Thus, gravity exherts a pull of 1 G on an object. Gravity pulls downward toward the center of the earth. An airplane in flight has many forces working on it, not all of which are gravity. However, these forces are expressed in G units, or gravity units, simply for standardization. All loads concerning aircraft are expressed in units of G. Structural limits are set at certain G units, aerodynamic loads are expressed in G; in short, all loads applied to aircraft are expressed in units of G.

An aircraft in straight and level flight has a downward load of 1 G imposed by the earth's gravity which is opposed by a lifting force developed by the wing equal to 1 G to prevent the airplane from dropping. The engine produces thrust which is opposed by an equal amount of drag. The airplane is in stable flight at 1 G. There are two types of G operating on an airplane, positive and negative. Positive G forces are those which tend to bend the wings upward; negative G forces are those which tend to bend the wings downward. The positive G forces are by far the most critical.

As we all know, the wing develops lift. This lift is expressed in pounds of force pulling upward on the wing. In straight and level flight this lift force equals the weight of the airplane, or 1 G. Lift is directly proportional to airspeed and at high airspeeds the wing develops more lift than at low airspeeds. Forces acting on the airplane as a result of the lift

V-n Diagrams for Piper Comanche 250

Based on a Piper Aircraft engineering department drawing, the V-n diagram at the right for the Piper Comanche 250, at a gross weight of 2,900 pounds, is typical of all V-n diagrams. G forces are shown on the vertical scale at left, with airspeed shown on the horizontal line within the "envelope." The aircraft's structural integrity must be demonstrated for all major points on the V-n diagram. The curving line on the upper lefthand corner of the V-n diagram is the stalling speed line caused by increasing maneuver loads as mentioned in the text. Author has added an "Angle of Bank—Coordinated Turn" line above the curved line on the V-n diagram for reader's convenience. The angle of bank line is not normally included on a V-n diagram. Airspeed shown at bottom of the yellow arc (180 m.p.h. on the Piper Comanche 250 V-n diagram at right) is also referred to as maximum Airspeed, Level Flight on older aircraft.



Piper Comanche wing undergoes structural testing to prove its strength for various points on V-n diagram.

Piper Aircraft photos

generated by the wing may be referred to as normal loads.

If an airplane is to be turned, it must be "tilted" or banked to one side so that the lift generated by the wings will pull to one side to cause the airplane to turn. When this is done, the vertical (gravity opposing) component of the lift vector is reduced so the airplane will begin a descent. The pilot pulls back on the control wheel in order to increase the wings' angle of attack to develop more lift so that the vertical component of lift will be sufficient to maintain a level altitude. When this is done, the total lift vector is now much greater than when the wings were level. This additional lift imposes an additional load on the wings.

This additional load may be referred to as the maneuver load. Maneuver loads come into play in turns, in abrupt pull-ups, and in any maneuver where the wings must develop more than 1 G of lift.

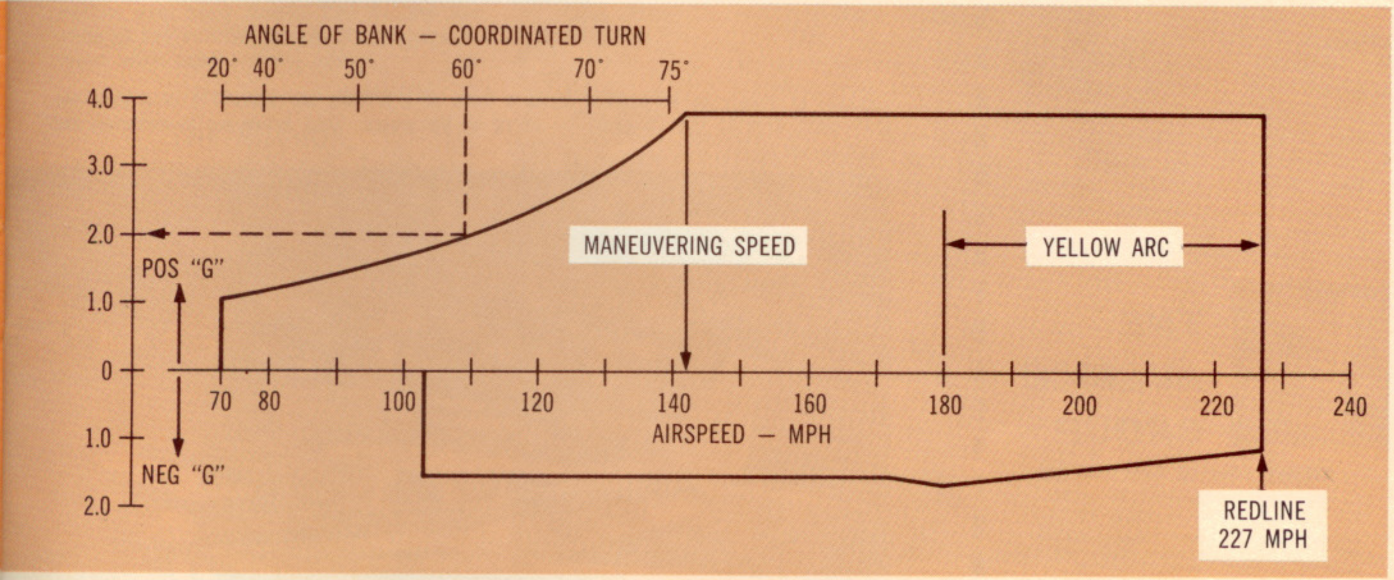
The third load imposed on an aircraft structure is the gust load which is the additional load caused by flying in gusty or turbulent air. For aircraft certificated in the "normal" category, the designer must allow for a gust load equal to that imposed by a vertical current of air moving at 30 feet per second (f.p.s.) up to the design cruising speed of the aircraft. This gust load must be in addition to maneuver and normal loads. For "normal" category aircraft, such as the Piper *Comanche* 250, the total of all these loads must not exceed 3.8 G positive and 1.52 G negative. (NOTE: all figures are for the Piper *Comanche* 250 at a gross weight of 2,900 pounds). The designer is required to provide an aircraft structure capable of withstanding 3.8 positive and 1.52 negative G in the case of the Piper *Comanche* 250.

Above the design cruising speed, the gust load may be assumed to be only 15 f.p.s., which means that we are assuming the air will be much smoother. However, our airspeed doesn't control how rough the air is! So, at high airspeeds, we must operate in smooth air, and if the air becomes rough, we must slow down.

Since a gust load equal to that imposed by a 30 f.p.s. vertical current is quite severe, we limit the airspeed so that the total of gust load and cther loads will not exceed 3.8 positive G. and 1.52 negative G. As everyone knows, the stalling speed of an airplane increases with an increasing angle of bank. This increase in stalling speed is due to an increase in G load on the airplane as the airplane is banked.

As we know, the wing must support the weight of the airplane. In straight and level flight, the weight of the airplane is equal to 1 G. As the angle of bank is increased in a coordinated turn, the G load increases which means the wing is required to support more "weight." In order to support this additional weight, more airspeed is required in order to generate more lift. At an angle of bank of 60° (see dashed line on accompanying diagram), the G loading is 2, and for the Piper *Comanche* 250, for example, the airspeed required to support the airplane is 109 m.p.h.

As the angle of bank is decreased, the airspeed required to develop sufficient lift to maintain level flight decreases until, for the Piper *Comanche* 250, it is 73 m.p.h. with 0° bank (wings level). Conversely, as the bank is increased, the airspeed required to maintain level flight increases until it is approximately 139 m.p.h. at 75° angle of bank. The airspeed continues



to increase above this value until, at an angle of bank of 90°, it is infinity, which simply means no airplane can make a coordinated turn of 90° of bank.

From the stalling speed of the airplane with its wings level (73 m.p.h. for the Piper *Comanche* 250 at 2,900 pounds, gear and flaps up), up to the limit positive G load for which the aircraft is designed, we have a smooth curved line which reflects the airspeed and G load imposed on the airplane simply from the maneuver load. In this speed range (73 m.p.h. up to 142 m.p.h. for the Piper *Comanche* 250—see accompanying diagram) any additional load, such as a gust load, will cause the aircraft to stall. Should we maneuver the aircraft in this speed range, and encounter rough air, the additional load imposed by the rough air (gust load) would not cause structural damage because the aircraft would stall before its limit load of 3.8 G was reached.

The maximum airspeed on the curved line is 142 m.p.h. for the Piper *Comanche* 250, and this is the maximum airspeed at which the aircraft can be maneuvered (steep turns, abrupt pullouts, etc.) safely. Above 142 m.p.h. in the *Comanche* 250, it is possible to encounter a combination of maneuver and gust loads that may cause structural failure before a stall occurs. This does not preclude normal turns (up to about 30° of bank), normal climbs, and normal descents above 142 m.p.h., but it *does* preclude steeply banked turns, and any abrupt maneuver. In other words, above the maneuvering speed of 142 m.p.h., the Piper *Comanche* 250 should not be flown abruptly, or roughly, or banked in steep turns.

The maneuvering speed for your aircraft will be found in its flight manual, and has the same meaning for your aircraft that 142 m.p.h. has for the Piper *Comanche* 250.

If you fly an older aircraft, check with the local FAA office. They have specs on all aircraft, and these specs include the maneuvering speed. You might want to post this airspeed on your instrument panel.

Continuing above the maneuvering speed we enter an area where the aircraft is expected to be flown in normal flight, without excessive maneuvering, and is expected to be able to withstand a gust load of 30 f.p.s. Neither the maneuvering speed nor the normal flight area is clearly indicated on the airspeed indicator except that the upper limit of the 30 f.p.s. gust load area is shown.

The yellow arc on the airspeed indicator indicates the area in which the gust load is assumed to be 15 f.p.s. or lower. The bottom edge of the yellow arc is the upper limit of the 30 f.p.s. gust load area. Up to and including the airspeed shown at the bottom of the yellow arc (180 m.p.h. for the Piper *Comanche* 250), the aircraft has sufficient strength to withstand a gust load of 30 f.p.s., plus normal airloads associated with normal flight, but *not* including additional loads imposed by maneuvering flight.

The yellow arc is a "caution area." In this area the normal loads are such that a gust load of only 15 f.p.s. could cause the total load to exceed the structural limit of 3.8 positive and 1.52 negative G. Any maneuvering loads imposed when the aircraft is being flown in the yellow arc on the airspeed indicator could cause the total load to very quickly exceed the aircraft's structural limit. For this reason, any time the aircraft is flown in the yellow arc on the airspeed indicator, it should be in smooth air in normal flight.

While flying with the airspeed needle in the yellow arc, if a pilot suddenly finds himself in rough air, he should immediately slow the aircraft until the needle is below the yellow arc. It might be good to visualize the yellow arc as the area in which the aircraft must be in smooth air.

The upper limit of the yellow arc is the redline speed of the aircraft. Flight above the redline is tampering with death. Above the redline speed, normal loads are so high that any slight additional load caused by maneuvering or rough air could lead to structural failure.

There is a fairly widespread feeling that the manufacturer provides a generous "pad" of safety above the redline speed. A few pilots will take advantage of this so-called pad. Unfortunately, they do not realize the pad may already have been used up. Variations in workmanship during production, variations in materials used, and variations in known aerodynamic data may already have taken up the pad of safety.

You may be sure the manufacturer has dived the aircraft above the redline airspeed, but the general practice is to go only about 10% above the marked redline speed, and this 10% is used only to take care of the variables of workmanship, materials, and aerodynamic data already mentioned. The pilot who knowingly exceeds the readline is venturing into an area that even the test pilots may not have investigated.

In practice, the airspeeds we have mentioned are plotted on a graph against the forces and loads we have mentioned on what is called a V-n diagram (see accompanying V-n diagram for Piper *Comanche* 250). This diagram shows the aircraft's structural integrity for all normal regimes of flight, and the manufacturer is required to demonstrate that the aircraft is capable of withstanding all forces and loads within the envelope of the V-n diagram. A safety factor is added to the loads on the V-n diagram, but this safety factor is intended, as we have already mentioned, to take care of variables in the design and construction of an airplane to insure that all production aircraft will at least meet the criteria shown on the V-n diagram. Exceeding the limits shown on the V-n diagram is a little like playing Russian roulette with five of the chambers loaded and one empty!

In summary, an airplane may be maneuvered up to and including its maneuver airspeed. Above this airspeed it should be flown in normal flight without excessive maneuvering or abrupt changes in aircraft attitude. At the beginning of the yellow arc on the airspeed indicator, the aircraft should be in smooth air, and if rough air is encountered while flying in the yellow arc, slow down. The yellow arc ends at the redline speed. Never experiment with that redline speed. ●

The pull of gravity on an aircraft exerts a force of 1 G when the aircraft is in straight and level flight, such as this Comanche, or sitting on the ground. Load forces due to maneuvers and rough air add up the "G's"

THE AUTHOR

Articles by Robert T. Smith, author of "That Deadly 'Redline'," have appeared in The PILOT frequently during the past several years. Born in Griffin, Ga., Smith is a veteran of the U.S. Air Force, first serving as an airplane mechanic, later as a pilot on the Boeing B-47 "Strato-Jet." After leaving the Air Force, he taught Air Force students at Bartow Air Force Base, Fla., until that base was closed down in 1960. He is a former member of Lockheed's Flight Test Analysis Department in Marietta, Ga. The author of several books on antique airplanes, Smith resides in Smyrna, Ga.