The Proficient Pilot

Volume 2

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Chapter 4 **Flying in Turbulence**

Most of the time, turbulence is only a mild annoyance, but occasionally, it can attack with a vengeance, assaulting the aircraft unmercifully. For those inside, this can lead to fatigue, nausea, and injury. Deterioration of vision also may be experienced, because turbulence excites an airplane's natural vibrations, making it almost impossible for a pilot to read the instruments.

Considering the hazardous potential of turbulence, it is unfortunate that so little advice is available to those who find themselves being flung about the sky like a leaf in the wind. Oh, yes, pilots are told to stow loose objects that could become unguided missiles and to tighten their seat belts and shoulder harnesses. They are then cautioned to fly the aircraft at its published maneuvering speed (V_A).

Unfortunately, such well-intended advice can lead to breaking the airplane. This is because V_A most often is not the best turbulence-penetration speed. This might sound like heresy to those who have been taught that flying at V_A is guaranteed to protect an airplane against damaging structural loads, but it nevertheless is true.

To appreciate why V_A frequently is not the best speed to use in turbulence, it first is necessary to understand what maneuvering speed really is and how it is determined.

Pilots know that stall speed increases in proportion to the square root of the applied load factor. For example, stall speed doubles during a 4-G maneuver (because the square root of four is two) and triples when the load factor is nine.

Most general aviation, Normal-category airplanes are certified to withstand 3.8 Gs, a limit load factor that must not be exceeded. (When pinned to the wall, designers concede that even though a load factor of

3.8 Gs is "within limits," numerous exposures to such an extreme can result in airframe fatigue and ultimately deformation and damage.)

One way to prevent exceeding the limit load factor is to make sure that an aircraft stalls first. This is because a stall is a form of aerodynamic relief and prevents additional maneuvering loads from being applied. The airspeed that guarantees a stall at the limit load factor is called maneuvering speed and usually is determined by multiplying the flaps-up, power-off stall speed by the square root of 3.8 Gs, which is 1.95. For example, a Cessna 172XP Hawk has a "clean" stall speed of 54 knots (the bottom of the green arc on the airspeed indicator) and a published maneuvering speed of 105 knots (determined by multiplying 54 by 1.95). In other words, a Hawk XP being flown at 105 knots would stall at precisely 3.8 Gs.

For those not wanting to suffer through the mathematical derivation of V_A, suffice it to say that there is a theoretical basis for claiming that flight at maneuvering speed prevents an airplane from being overstressed. But this applies only when the control surfaces are rapidly deflected to their limits. In the case of turbulence, however, there is a significant difference between theory and reality.

Although the concept of V_A seems plausible, there are two reasons why it fails as protection against overstressing the airframe. First of all, pilots doing battle with turbulence are usually flying with power. And as every pilot knows, the power-on stall speed of an airplane is significantly lower than its power-off stall speed. Consequently, an airplane being flown with power at its maneuvering speed does not stall at 3.8 Gs. Something more than this limit load factor must be applied before the aircraft will stall and shed the applied Gs. And it is this "something more" in the way of load factor that can be the G that breaks the airplane's back.

A second and perhaps more significant reason not to use V_A when penetrating heavy turbulence is the effect that gusts have on airspeed. Because all turbulence is a form of wind shear (or vorticity), pilots recognize that this often causes airspeed to fluctuate. Gusts that strike from ahead of the aircraft (increasing headwind shear) have the effect of increasing airspeed so that a pilot attempting to maintain V_A, most likely will exceed this target speed. How much V_A is exceeded depends, of course, on the intensity of the turbulence and the horizontal component of the gusts.

During studies conducted by Great Britain's Royal Air Force some years ago, it was determined that light turbulence can cause airspeed fluctuations of 5 to 15 knots. Similarly, moderate turbulence can cause fluctuations of 15 to 25 knots, and severe turbulence can result in airspeed variations of more than 25 knots. In extreme turbulence, rapid fluctuations well in excess of 25 knots can be expected.

Consequently, a pilot should penetrate turbulence at least 10 knots below V_A to account for the stall-delaying effects of power. He also should reduce airspeed several knots more to compensate for the effect of horizontal wind shear (depending on gust intensity).

Pilot's operating handbooks for many aircraft specify a single maneuvering speed, one that is valid only when the aircraft is at its maximum-allowable gross weight. This speed, however, is not applicable at lighter weights when stall speeds are reduced. For example, the Hawk XP's V_A of 105 knots is valid only for a gross weight of 2,550 pounds (the maximum allowable). At 2,150 and 1,750 pounds, maneuvering speed is reduced to 96 and 87 knots, respectively. In other words, maneuvering speed decreases as gross weight decreases because a lightly loaded aircraft is accelerated more easily by gusts than one that is heavily loaded.

Although V_A can be computed for various gross weights (it is proportional to the square root of the actual aircraft weight divided by the square root of the maximum-allowable gross weight), it is easier to approximate using a rule of thumb. For the typical lightplane, reduce the published V_A by 2 knots for each 100 pounds below maximum-allowable gross weight.

All of these factors demonstrate that the safest turbulence-penetration speed usually is significantly less than the published maneuvering speed. Reducing airspeed below V_A has other benefits, too. Because the G load produced by a given gust is directly proportional to airspeed, going slower reduces the G load and makes the ride more bearable. Reducing airspeed also decreases the frequency of gust encounters because it takes longer to fly from one gust to the next—in other words, the slower the better.

“Wait a minute,” someone will say, “flying too slowly in turbulence increases the risk of an accelerated stall as the aircraft is pounded by G-producing gusts.”

Quite true, but the stall induced by a gust usually is very brief. The wings stall and recover almost before the pilot has an opportunity to realize what is happening. A pilot is not likely to jeopardize safety unless he manhandles the controls, is close to the ground, or is flying an airplane with undesirable stall characteristics. Research pilots who intentionally fly through fully developed thunderstorms (in properly equipped aircraft) report that flying substantially below V_A is a key to survival.

One can carry a good thing too far, however. Flying too slowly can result in poor control responsiveness and a succession of high-speed stalls. The best target speed in turbulence is well below V_A, well above stall, and largely a matter of experimentation and judgment. (Unless the aircraft has a designated turbulence-penetration speed, V_B, a good speed to use in heavy turbulence is 1.6 or 1.7 times the “clean” stall speed.)

Just as reducing airspeed decreases the G load produced by a given gust, so does increased wing loading have a similar effect. In other words, flying an airplane with a light wing loading through a given gust results in more of a G load than when flying through the same gust in an airplane with a heavy wing loading. This is one reason why the pilot of a Cessna 310R—which has a wing loading of 31 pounds per square foot—

might report light turbulence while a pilot flying through the same turbulence in a Cessna 172—which has a wing loading of only 13 pounds per square foot—reports moderate turbulence. This explains also why a pilot report of turbulence is virtually useless unless aircraft type is mentioned. (The wing loading of a Boeing 747, for example, is so high that the aircraft is much more resistant to vertical acceleration than is a lightplane. This is why the aircraft is certified with limit load factors of only -1.0 to +2.5 Gs.)

It is not surprising that heavy wing loading suppresses the G load produced by a given gust. After all, the smaller a wing is in proportion to aircraft weight, the more difficult it is for a gust to displace (accelerate) the aircraft. An aircraft with a relatively large wing area is accelerated more easily. Also, heavier aircraft generally provide the most comfortable ride because their inertia makes them less likely to be displaced by gust action; the gusts, however, usually appear to be sharper in these aircraft.

Because most light airplanes are certificated from -1.52 Gs to +3.8 Gs, many conclude that these aircraft can accept more than twice as much positive load as they can negative load. This misconception results from a simple misinterpretation of the numbers. When an aircraft is accelerated to +3.8 Gs, it experiences a net change from its normal, 1-G flight of only 2.8 Gs. On the other hand, a negative load of 1.52 Gs is a change of 2.52 Gs from level flight. In other words, most light aircraft can tolerate about as much of a downward gust (negative acceleration) as they can an upward gust (positive acceleration).

Airplanes are protected from excessive negative Gs in the same way they are protected from excessive positive Gs. The wing stalls before any damage can be done (as long as airspeed is less than V_A). The negative-G stall occurs because a sufficiently powerful downward gust makes the wing "feel" as if it were being flown inverted at too large an angle of attack. The only significant difference between a negative-G stall and a positive-G stall is that everyone on board is momentarily lifted from their seats and pressed against their restraints until the negative load is relieved. (Some aircraft actually are more docile during a negative-G stall than when stalled conventionally.)

When an aircraft is flown into severe or extreme turbulence, gust loads are punishing and potentially destructive. Unfortunately, many pilots compound the problem by rapidly jerking and shoving the controls in an effort to maintain a reasonably level attitude. The effect of this, however, is to create maneuvering loads that combine with gust loads to make the total G load greater than necessary. Although a pilot understandably is filled with anxiety (and possibly fear) at such a time, he must make every effort not to contribute to the hazard. The controls should be moved deliberately yet smoothly. There should be no attempt made to maintain altitude (unless the airplane is about to strike something more solid than a gust). Nor should the pilot chase airspeed; needle fluctuations can be so erratic that he might pull when he should push and simply compound the problem.

If a pilot elects to escape turbulence by turning, a shallow bank angle should be maintained despite the eagerness to reverse course. The Gs created during any maneuver, including those produced during a steep turn, add to those resulting from turbulence; aircraft have been damaged by pilot-induced loads.

Even jetliner manufacturers recognize that the greatest flight-path deviations caused by turbulence require timid control inputs. This is why the Boeing 747 autopilot, for example, has a turbulence mode. When this mode is engaged, the autopilot does no more than maintain attitude. Additionally, flight control input from the autopilot is reduced by 50 percent to prevent overstressing the aircraft.

Because most general aviation autopilots do not have a turbulence mode, they should not be used when the going gets rough because their flight control inputs might be excessive.

Pilots seem obsessed with maintaining a specific altitude. Although this is normally admirable, such a goal should be discarded in heavy turbulence. Attempting to maintain altitude not only can be futile and induce damaging loads, it also can work against the pilot. This is especially true when flying through vigorous convective turbulence.

When an aircraft enters a powerful updraft, a pilot tends to lower the nose (to maintain altitude) and perhaps reduce power. This not only violates the first rule of flying in turbulence (maintain attitude), but also is counterproductive. For one thing, an updraft should be used to advantage to gain altitude because just as night follows day, downdrafts ultimately follow updrafts. The altitude gained from an updraft then is available for sacrifice when the downdraft is encountered. Also, lowering the nose increases airspeed (another hazard in turbulence) and reduces time spent in the updraft, time that could be used to gain additional "free" altitude.

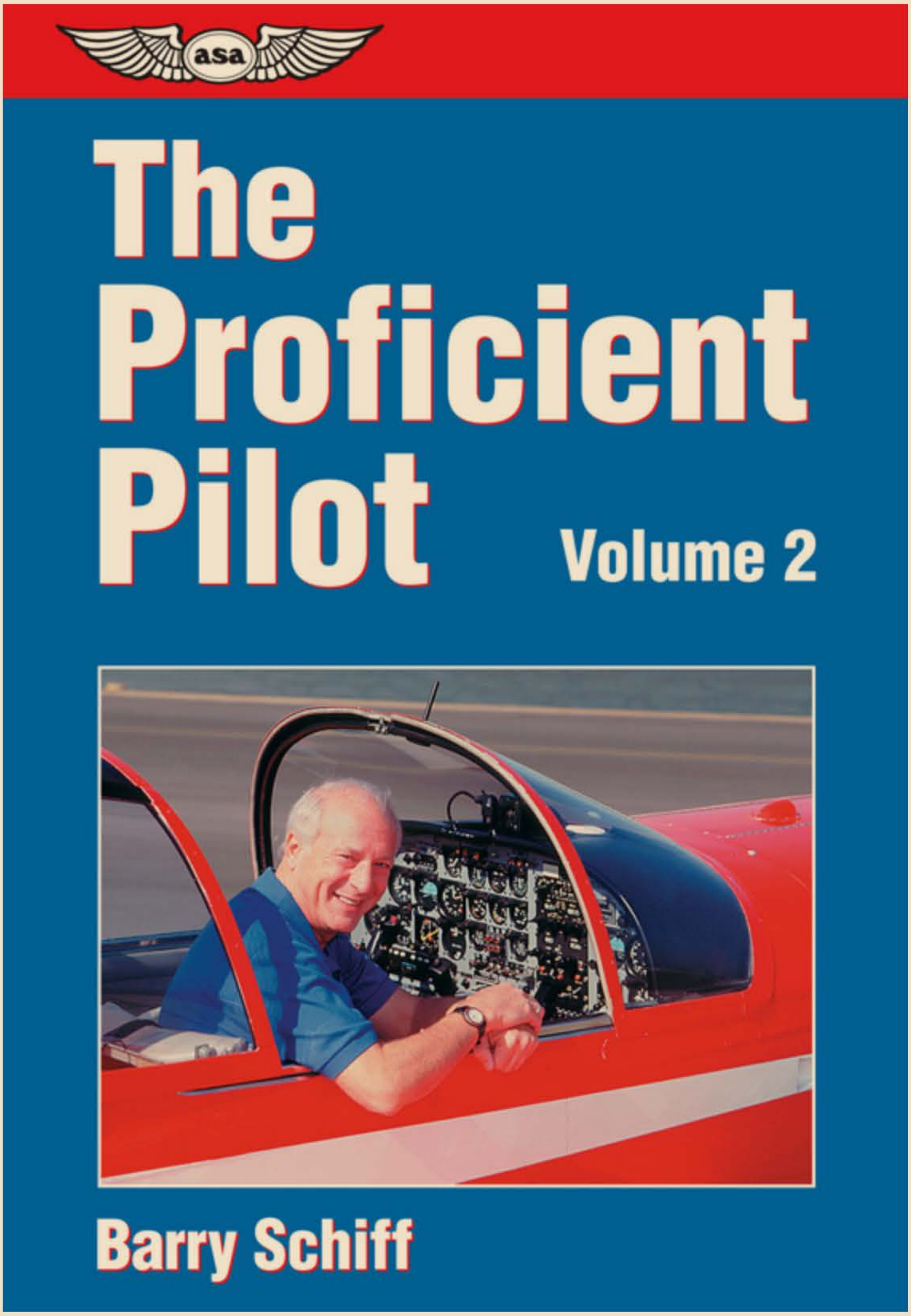
When the transition to a downdraft finally occurs, a pilot's instinct is to raise the nose (to maintain altitude). Because this results in airspeed decay, more time than necessary is spent in the downdraft. Instead, maintain target airspeed and traverse the area as quickly as possible so as to minimize the downdraft's detrimental effect. (Fighting a summer downdraft by raising the nose and adding power also can result in an overheated engine.)

By maintaining attitude and going with the currents (instead of against them), the flight is safer, more comfortable, and more efficient. Purists who argue that a specific VFR cruise altitude must be maintained in accordance with the hemispherical rule should recognize that this regulation applies only when maintaining altitude. When climbing and descending, such a rule obviously is inapplicable. If severe turbulence is encountered when on instruments, a pilot always has the option of exercising emergency authority and allowing altitude to vary as necessary, but please keep air traffic control informed of such regulatory deviations.

A discussion of flight into turbulence is not complete without mentioning V_{NO}, an airplane's maximum structural cruising speed. This speed is shown at the beginning of the yellow arc (or "top of the green") on airspeed indicators. The precise definition of V_{NO} has become mathematically complex over the years, but it is approximately the maximum speed at which an airplane can safely endure a sharp-edged, 30-fps vertical gust. In theory, such a gust is the most intense a pilot is likely to encounter in other than severe conditions. But as an aircraft is taken deeper into the yellow caution range, tolerable gust intensity decreases significantly.

Although a Normal-category airplane is built to withstand its negative limit load factor at V_{NO}, airframe tolerance for these negative Gs fades to zero between V_{NO} and the redline (V_{NE}). Consequently, airspeed above V_{NO} should be avoided when turbulence is even remotely anticipated; the yellow arc is strictly for smooth-air operations.

Because abiding by limit load factors is so essential to one's health and well-being, it seems odd that pilots are not provided with a means of determining when these outer limits are being approached. The only instrument normally available is the Mark IV gluteus maximus. A pilot desiring more than seat-of-the-pants accuracy might consider installing a G-meter. Many of these self-contained, inexpensive instruments not only indicate G load, but also record the maximum positive and negative G loads encountered during each flight. A G-meter not only can fill one of those blank spots on the instrument panel, it also is invaluable to a pilot seriously concerned about maintaining the airplane's structural integrity. It is obvious that if a pilot does not know when he is approaching the outer limits, he soon may find himself beyond, where even test pilots fear to tread.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