# *Thoughts* on Mush/Stall/Spin Accidents and How To Avoid Them

*By Fred E. Weick (EAA 7882)*
*2 Dolphin Dr.*
*Vero Beach, Florida 32960*

### HISTORY AND STATUS QUO

The proportion of fatal light-plane accidents in the stall/spin category has decreased substantially over the years. In the twenties,[1] thirties and early forties[2] two-thirds of all fatal accidents were in the stall/spin category. This dominant proportion dropped to slightly under one-half for the three year period following World War II,[3] and has subsequently continued to drop to under one-fourth for the three year period just preceding 1970.[3,4]

This improvement is encouraging, but these latest statistics show also that the stall/spin accident, or "failure to maintain flying speed", is still the primary cause of all the accidents, both fatal and non-fatal. Effort toward further improvement would therefore be well worthwhile, particularly since the light airplane accident rate is still high compared with those of other forms of transportation.

A recent National Transportation Safety Board report[3] shows that in 1967, 1968 and 1969 nearly all (at least 93%) of the stall/spin accidents have started from low altitudes, having been associated with take-off or landing operations, or low flying such as buzzing, aerobatics, low passes, cattle round-up, etc. Thus in a great majority of the cases fully developed spins were **not** involved but mushing flight, stalls and incipient spins were.

Another point of interest (to me at any rate) is that the NTSB report listed the Forney 415 (which included its predecessor, the Ercoupe 415, as well as its successor, the Alon) as having had a moderate number (13) of stall/spin accidents during those three years. These airplanes were designed to be spinproof and were required by the FAA to be placarded as "Characteristically Incapable of Spinning". The heading "Stall/Spin" in the report included cases involving just straight stalls, cases involving stalls in turns, cases involving incipient spins and cases involving fully developed spins. The report grouped all these together and did not differentiate between them. In order to learn just what kind of accidents these Ercoupe-type planes had I have looked up the individual briefs of each of the 13 accidents listed. Twelve of the 13 were listed as stall or stall/mush accidents. One was listed under the stall/spin heading, but the accident occurred just following take-off, the injuries were minor or none and the airplane was not destroyed. From this it would appear that the stall part of the classification would apply rather than the spin.

Two of the 13 cases involved fire after impact, and these were the only fatal ones. In the general aviation picture as a whole, about 7 of the 13 would have been fatal. The number of Ercoupe cases is of course too small to give reliable statistics.

These spinproof airplanes have effective lateral control at all angles of attack that can be maintained in flight but they are obviously **not** free from mush/stall accidents. They have the same important control disadvantage that all of the other current airplanes have — a longitudinal control that works in the way you want and expect it to under most conditions, **but must be used opposite to one's natural inclination under other vitally important conditions**.

This treacherous reverse control situation is of course well known to aeronautical engineers and knowledgeable pilots, but it is probably worth reviewing in some detail in order to assure understanding. For example suppose that we are flying level at full power and maximum speed. If we pull back on the longitudinal control a slight amount and hold it in the new position, the nose will pitch up some, the angle of attack will be increased some, the flight path will go up a fair amount momentarily and after a possible slight oscillation or two the flight path will steady down at a certain small angle and rate of climb but at a slightly lower airspeed. This appears to be natural and as it should be. If we pull back a trifle more and hold it the same thing will be repeated and both the angle and the rate of climb will be increased a little more at a further reduced airspeed. After a certain number of small steps the maximum **rate** of climb will be attained. Then if the control is held back a trifle farther the nose will still go up and the whole operation will repeat even to the increased angle of the flight path (angle of climb) but the **rate** of climb will be somewhat **lower**. A few more such steps and the maximum **angle** of climb is reached. Up to this point the results are acceptable, but what about the next step? Holding the control back the next step will pitch the nose up and will increase the angle of attack and decrease the airspeed further as it did in the previous steps, **but** the angle of climb as well as the rate of climb will be **reduced** instead of increased. This is the opposite of what one would desire in a control. And with most airplanes if the rearward control steps are continued the climb will decrease through zero and become a descent even while the wing is flying unstalled. If the longitudinal control is sufficient to stall the wing thoroughly the rate of descent can be quite high even with full power.

Thus with power full on, at angles of attack higher (and airspeeds lower) than that for the maximum angle of climb the longitudinal control does not give the results naturally desired, except possibly for a momentary flare. In this range we must train ourselves to use the controls in what seems to be the wrong or opposite sense in order to obtain the result desired.

As a second example let's start in a power-off glide at cruising speed. When we bring the longitudinal control back a trifle and hold it, the same sequence of events will occur as with power on and we will end up in steady flight at a higher angle of attack and lower airspeed, and at a flatter angle of glide and a lower rate of descent. And this also appears to be natural and as it should be. After a number of small additional steps such as this, the flattest possible glide will be reached. This will occur at an angle of attack and airspeed close to that which also gives the highest rate of climb near sea level. Now a number of additional rearward control steps will result in reaching minimum rate of descent in the glide, although the **angle** of glide will be substantially steeper than the flattest. Therefore if we want to stretch our glide to the utmost by pulling the control back and raising the nose as seems natural, this will work only up to the angle of attack for the flattest glide. Pulling back farther and raising the nose and the angle of attack more will result in a steeper glide, the opposite of what we want. So we have to train ourselves to take care of this seemingly unnatural and contradictory control response also.

It seems to me that much of our stall/spin difficulty is associated largely with this longitudinal control-reversal situation.

One of the insidious features of the use of the longitudinal control at high angles of attack and low speeds is that momentarily the nose and possibly even the flight path move in the direction desired, but the ultimate result is opposite to that desired unless we understand the reversed control situation and train ourselves to allow for it. That this is difficult and not always successful with our present day light planes, even with good experienced pilots, is shown by the accident record. As Leighton Collins pointed out in the June, 1973 issue of **Air Facts**,

> "In our experience, some people begin to hold back on the wheel at 1500 ft. in even a moderate straight stall. Now that's the time bomb in the pilot business and the goal is to be sure he's rid of it if he starts to stall inadvertently and more abruptly at 500 ft. And it should be mentioned once more that the likelihood of his ever getting into a low-altitude stall will be in turning flight, and most likely in an abruptly entered and abruptly tightened steep turn."

The stall can be induced by a slow, smooth and unnoticed easing back of the wheel while the pilot is attempting not to lose his height above the ground. It is more likely to happen in a turn where the increased angle of attack is hidden, however, and its likelihood is greatly increased by abrupt or violent maneuvers.

## WHAT FURTHER IMPROVEMENT CAN WE MAKE?

In the light of the foregoing it is apparent that we can be free of mush/stall/spin accidents if we can avoid flying at angles of attack near the stall — say, those higher than that for the maximum or steepest angle of climb. **The range of angles of attack below that for the maximum angle of climb is adequate for all flight away from the ground except for some aerobatic maneuvers.** And of course higher angles of attack are needed momentarily for a short take-off run and for touching down at low speed in a landing.

It is easy to say that the mush/stall/spin accidents can be avoided by always, when in full flight, keeping the angle of attack below that for the maximum angle of climb, but how is this to be accomplished?

With our present airplanes it is entirely up to the pilot. It depends upon his competence and his desires. There has been improvement in pilot competence in recent years, particularly in connection with instrument flight and "flying by the numbers". Further improvement along this line will depend on additional education and understanding, and improved training.

The improvement to date is certainly due to a large extent to improved piloting, but another major factor is no doubt design improvement in the airplanes themselves, such as:

1) More power and speed range so that most flight is further removed from the stall.
2) Easier stalls with less sudden roll-off.
3) Better aileron control in the region of the stall.
4) Less powerful rudders (made feasible by the tricycle gear).
5) Stall warners.

Now what additional improvement can we make in the airplane?

From the information gleaned from the records of 1967, 1968 and 1969 the problem appears to be: **how can we make the airplane help the pilot to fly always at a suitable angle of attack with a good margin from the stall?**

No doubt it would help some to provide instrumentation in the form of an angle-of-attack indicator, possibly with the points plainly marked for steepest climb, best rate of climb, flattest glide, etc. I doubt, however, that anything that a pilot must look at will help him much in a clutch when his attention is outside. Stall warners with light and horn signals are already helping the situation. And angle-of-attack indicators have been available for several years, but they have not come into general use. Possibly Langewiesche's suggestion in the June, 1973 issue of Air Facts for different sounds at certain significant angles of attack would be an additional help.

One entirely different and possibly more basic approach might be to **make the airplane itself so that it would tend firmly to hold any angle of attack for which it was set or trimmed**. With such an ideal arrangement the pilot could set the control directly for the angle of attack desired. The airplane would then continue to fly definitely at that angle of attack, and at the corresponding indicated airspeed. The trim indicator could be marked off directly in terms of indicated airspeed, and the positions for certain optimum flight conditions could be designated directly. Then if a pilot wants to fly at the speed that will give him the steepest angle of climb he merely sets the trim indicator for the point so marked and the airplane flies at that speed. In like manner, the airspeed giving the best performance could be set for the maximum **rate** of climb, or for the flattest glide.

Flying at any other speed would be obtained by merely setting the trim control to the speed desired (the entire range of speeds desired would be marked on the trim indicator). We would therefore have what might be termed a Precision Speed Control with which we merely set the trim for the speed desired and the airplane flies accordingly.

It occurred to me about thirty years ago that it might be possible to attain this state of affairs by changing the speed and angle-of-attack control from a rapidly operating one always under the immediate command of the pilot over the full range of speeds and always requiring his attention, to a slow or trimming type control which is set at the speed desired. All speed changes in ordinary flight would be made by a slow irreversible trimming control alone. Then if the speeds (or more correctly the angles of attack) for which the longitudinal control surfaces could be set ranged only between a safe margin from the stall to an acceptable high speed, and if the airplane would fly smoothly and satisfactorily within those limits and stayed at any speed desired within them, an extra responsibility would be removed from the pilot's mind. It would not amount to much under ordinary circumstances but it could make the difference between life and death under sufficiently unfavorable conditions.

The problem then is to devise a precision speed control arrangement that can be set for any desired speed from the maximum in level flight down to but not beyond, say, that for the steepest climb, and that will permit satisfactory operation in all the required phases of flight. These include taxiing, taking off, climbing, turning, cruising, gliding, approaching to a landing and landing, as well as sudden maneuvering to avoid collision.

As mentioned previously, the range of angles of attack below that for the steepest climb is adequate for all flight away from the ground except for some aerobatic maneuvers. In changing from one speed to another the acceleration takes a fair amount of time if smooth flight is to be maintained, and the slow-acting trim control fits in well with this condition. The firm trim control that would hold any desired angle of attack within these limits would therefore itself be adequate for all gentle flight away from the ground.

For unsticking in a short take off or for touching down at minimum speed in a landing, however, higher angles of attack are needed momentarily. These momentary higher angles can be obtained by an arrangement that permits overcontrolling the trim control by the usual wheel or stick, but requires an initial force of unmistakable magnitude to be overcome before the longitudinal control surface is moved from the firmly trimmed position. With this arrangement the control wheel would normally be in a fixed longitudinal position and ordinary pressure would not move it fore and aft. When the pilot needed to overcontrol momentarily he could do so, however, by pushing or pulling in excess of a predetermined unmistakable amount, say 20 or 25 pounds.

The only basic difference between this latter arrangement and the conventional present day arrangement with a tab, adjustable stabilizer, or spring system for trimming with no force required on the wheel, is that with the new arrangement no deviation can be made from the trimmed condition without application of a substantial initial force. The force should be large enough so that the pilot can hardly do it unconsciously, whereas with the present conventional arrangement in which the force increases gradually from zero, the pilot can move the control a substantial amount without always being aware of it.

The pilot presumably would be educated, trained and conditioned not to overcontrol the longitudinal trim in all normal flight away from the ground, but to rely on the trim setting to get the best performance of the type desired. He would normally overcontrol only in leaving the ground in the take-off and in contacting it again in the landing. If a sudden maneuver were required in flight, say to avoid a collision, he would overcontrol if he desired, and occasionally he might want to nudge it a bit to stop a slight oscillation in the flight path. But for all ordinary flying he would rely on the fixed trim control for obtaining the best speed and angle of attack for the performance desired. And the positions for the critical performances such as the steepest climb and the flattest glide could be marked directly on the trim control scale so that the pilot would not have to figure them out or remember them for each airplane he flies. Thus the control-reversal situation would be avoided.

Unfortunately if even with these advantages the pilot allowed himself to get caught in a bad situation in which he saw the ground "coming up at him" he might just forget his training and follow his natural inclination to pull the wheel full back regardless of the force required. It would be hoped that such a condition would be an extremely isolated one and that at least most of the present mush/stall/spin accidents would be avoided. The pilot would have to be trained to rely on the airplane trim-speed control as he has had to be trained to rely on the compass.

In 1947 I had an opportunity to make some preliminary flight trials with the fixed longitudinal trim speed-control arrangement. An Ercoupe with a special tail was used which was particularly well adapted to the situation because it would maintain very close to the same indicated airspeed for all throttle positions from wide open to fully closed. This was generally true for the ordinary Ercoupe at speeds above about 65 mph, but with the special tail it held true down to minimum speed.

This made it possible to provide a trim position scale marked directly in terms of airspeed, and which held for all throttle settings, from wide open to fully closed. The scale was in fact inscribed directly on the control wheel shaft, which was possible because each longitudinal position of the wheel represented a certain angle of attack and the corresponding indicated airspeed. This was strictly true for only one c.g. location, of course, but the c.g. range is small enough in an Ercoupe so that an average value appeared to be satisfactory.

With this combination of characteristics it is easy for the pilot to recognize that the trim unit is his forward speed control, and that at any given speed setting the throttle controls only the rate of climb or descent. The Ercoupe quadrant type throttle was designed to aid in this concept because it goes upward as well as forward as power is increased, and vice versa.

**Taxiing** — The only noticeable effect of the fixed trim device in taxiing was that it held the control wheel in a fixed position out from the instrument panel. This appeared to be a slight improvement in convenience but is of no special importance.

**Taking Off** — Before taking off the trim was set to the speed desired for the climb out. In a normal take-off, after the control wheel had been pulled back over the preload force and the plane had left the ground the control wheel was allowed to ease forward gradually to the fixed-trim position and the climb out was continued at the speed set. The take-offs were made smoothly and the following climbs were also smooth and steady.

As an experiment, some take-offs were tried by setting the trim control and letting the plane take off by itself. This worked satisfactorily if the speed was set for the best rate of climb, 65 mph. But when it was set for a low speed, such as that for the steepest climb, the ground run continued to a slightly higher speed and then when the plane did take to the air the excess speed made it zoom up somewhat and start an oscillation. This was unsatisfactory if unchecked, but it could be nipped in the bud by a slight forward nudge of the control wheel.

As long as the fixed-trim climb following take-off is steady and free from oscillations it can be made safely at the minimum trimmable speed because there is still a definitely known safe margin from the stall. In fact it can be made definitely at the speed for the steepest climb.

**Climbing, cruising and gliding** — Up in the air changing from one airspeed to another seemed easy and natural enough using the fixed-trim speed control alone. In this case a crank was used. By operating it as fast as possible it could be turned through the entire range of trim-speed settings (55 mph to 120 mph) in about 5 seconds, which was a decidedly shorter time than it took the plane to accelerate through that range. It would probably be desirable to have the normal operation of the trim change match the time required for acceleration because then there would be no oscillations. It appears likely that a regular knurled longitudinal trim wheel would be very suitable for the trim control, but it should be located in a position very convenient to the pilot's throttle hand. Possibly it would be well to fit it with a knob or small crank handle so that it could be turned more rapidly if the occasion demanded. A supplemental electric trim changer controlled with a button on the wheel would be convenient, acting at the correct speed.

At any given speed it was easy and natural to control the rate of ascent or descent with the throttle. It was necessary to make the throttle changes in a gentle and gradual manner, however, if smooth flight were to be maintained free from phugoid oscillations.

To check the effect of altitude on the trim speeds, a full-throttle climb up to 6000 feet was made with the trim

**THOUGHTS . . .**
(Continued from Preceding Page)

speed indicator set at 65 mph. The I.A.S. reading on the air speed meter remained on 65 mph all the way. At an altitude of 6000 feet level cruising runs were then made at trim settings of 60 mph to 100 mph and at each point the airspeed indicator reading agreed with the trim setting. These runs were then repeated at an altitude of 1000 feet and the same results were obtained. All of this is of course as would be expected, for the trim setting determines the angle of attack, and for a given angle of attack there is a given indicated airspeed which is the same for all altitudes. Fortunately, it is a simple relationship which makes for easy use of the fixed-trim selective speed control.

**Turning** — Turns with banks up to about $20^0$ could be made satisfactorily without moving the longitudinal control from the fixed trim position. This was true throughout the entire speed range. It is to be expected because the variation of lift required with angle of bank is a cosine function and the change is very small for small angles of bank. For a large angle of bank, however, a large increase in lift is required. This also was confirmed in the trial flights. When a steep turn was made without either moving the elevator from the fixed trim position or adding power the nose would drop and the speed would increase to the point where sufficient lift was obtained at approximately the same angle of attack in descending flight.

Medium turns with angles of bank of about $30^0$ could be made without losing altitude by merely adding a little power. For steeper turns at constant altitude the fixed trim could be brought to a lower speed setting, even to as low as it would go, and the margin of safety from the stall would still be maintained. In an extreme emergency the wheel could be pulled back over the pre-load but then of course the margin of safety would be reduced or possibly eliminated.

The air lines use very moderate banks which helps both passenger comfort and safe operation. In instrument flight the standard rate of turn of $3^0$ per second involves angles of bank under $20^0$ for almost all light airplanes. In fact, all ordinary light airplane flying could be done without exceeding an angle of bank of $20^0$, and if this practice alone were adopted the safety record would no doubt be improved substantially. There are exceptions, of course, such as mountain fields with restricted approaches, and aerobatic flight of any form, but by and large the angle of bank could be kept within $20^0$, and in general the passengers would be more comfortable and the safety would be improved.

**Approach and Landing** — The entire approach to landing was easily made by merely setting the speed control to a suitable approach speed and steering the plane in until about 20 feet above the ground. There was a tendency to come in a little low because then it was very easy to stretch the glide with a little throttle and the approach path could be controlled quite accurately.

During the last 20 feet or so of the descent to the ground the control wheel was pulled back over the pre-load from the fixed-trim position sufficiently to flare off or level off the glide path and finally to contact gently at approximately minimum speed with the wheel full back. Even when trimmed at the lowest speed available (55 mph) the plane had substantially more reserve energy than was necessary to flare off the flight path in smooth air.

**Some Remaining Questions** — One of the questions to be satisfied in flying with fixed longitudinal control is the smoothness or steadiness of flight possible considering the natural tendency for the airplane to hunt or oscillate (particularly the phugoid oscillation). In the preliminary trials such oscillations were induced by a sudden change of either trim speed or power. If a change was made fairly gradually, however, noticeable oscillations did not occur. In gusty air the bouncing around seemed about the same as when the usual pilot effort was applied to counter the gusts. On one extended trip from Maryland to the West Coast and return the fixed trim was used with ordinary comfort throughout all of the various air conditions encountered. Even so it would appear to be worthwhile for airplanes that are to be flown with fixed longitudinal trim speed control to be designed so that the oscillations are damped as much as feasible.

Another point that needs further investigation is the effect on the trim of variations in loading and the resultant c.g. travel. The plane used for the trials happened to be particularly well suited in this respect because the c.g. range was small enough so that a single average trim scale served reasonably well for all loadings. Planes with large c.g. travel would provide more of a problem. Possibly an adjustable trim scale of some kind could be used.

**Project Shelved** — Although the preliminary trials were reasonably satisfactory I shelved the project after they were completed. This was mainly on the ground that most pilots would probably not like the idea of having their complete freedom of control interfered with in any way, particularly it seems if it is intended to help them to fly more safely. We pilots naturally want to feel that our own competence is all that is needed to handle the airplane safely. And the safety does ultimately depend on the pilot — on his understanding of what he can do with his airplane, his capability of doing it, and his willingness to stay within reasonable limits. Over the past twenty-five years, however, good piloting has become much more mechanical and less "seat-of-the-pants". Pilots who fly to get places and those who get pleasure without needing to "wring it out" might now like the fixed-trim idea better than they would have in 1947. And considering that the light plane accident record is still in general poor compared with that of other modes of transportation, and that "failure to maintain flying speed" is still the primary cause for light plane accidents, I think it just might be worth looking into the fixed-trim idea again and giving it **or something like it** another try.

Happily, the Aerospace Engineering Department of the University of Michigan is interested in this as a project and arrangements are being made with the help of NASA to carry on this investigation.

## REFERENCES

1. Society of Automotive Engineers paper presented in Los Angeles, California on October 6, 1944, entitled "Four Years of Simpler Flying with the Ercoupe", by Fred E. Weick, Engineering and Research Corporation.

2. "The Dangers of the Air", by Leighton Collins, Chapter 18 of "Stick and Rudder" by Wolfgang Langewiesche, McGraw-Hill Book Company, 1944.

3. "Special Study — General Aviation Stall/Spin Accidents, 1967-1969"; National Transportation Safety Board Report No. NTSB-AAS-72-8.

4. "Safety in General Aviation", by Harold D. Hoekstra and Shung-chai Huang; Flight Safety Foundation, 1971.