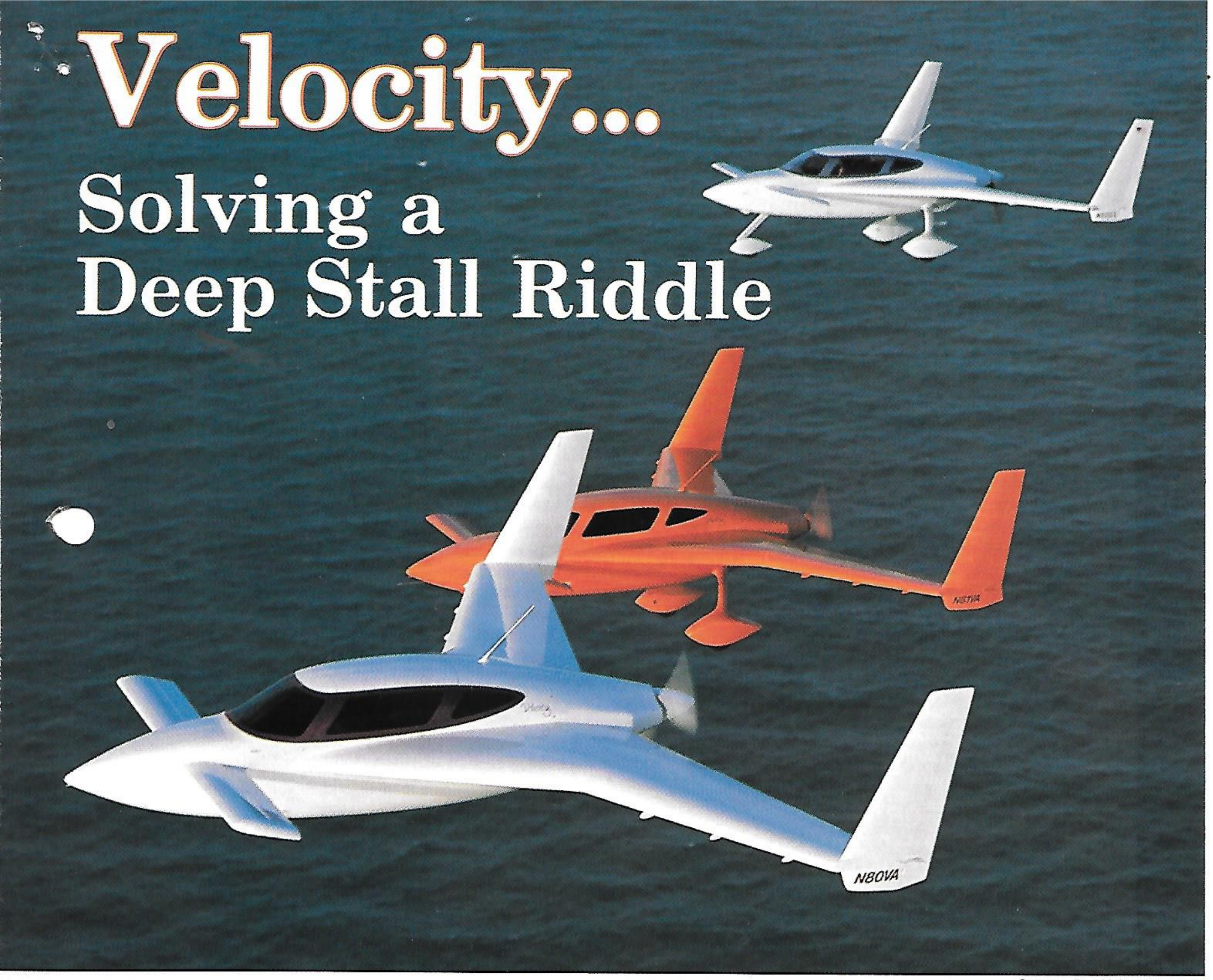
Velocity...
Solving a Deep Stall Riddle



Courtesy Dan Maher

By JACK COX

Danny Maher's 4-place Velocity first appeared in SPORT AVIATION in November of 1985 . . . in the form of a picture in Hot Line, with some basic specs. The following April the first article on the design appeared, an interview EAA director Billy Henderson taped with Danny shortly before Sun 'n Fun '86. The airplane made its public debut at Lakeland a short time later, and was mobbed from the time the engine was shut down. Neil Hunter built the first kit version in 8 months and had it at Sun 'n Fun in 1987. It differed from the prototype in that it had a fixed nose gear instead of the VariEze/Long-EZ type retractable gear. Coming at a time when Burt Rutan was creating a big void by getting out of the homebuilt business, and satisfying the desire for four place seating that burns in the hearts of so many builders, Danny Maher's sleek canard pusher seemed to have a bright future . . . as bright as the wild, Totally Orange Velocity he flew to Oshkosh in 1988.

Then two remarkable incidents took place that cast a long shadow of doubt on the design. First, Neil Hunter got into a high angle of attack situation from which he could not recover . . . and rode his Velocity down into a canal near his Florida home. Inexplicably, the airplane had become aerodynamically "locked" in a flat attitude and had descended at an unnaturally low rate of sink all the way down to the water. Neil tried everything he could think of to get the nose down and get the airplane flying again, but to no avail. Miraculously, the descent was so slow that Neil was able to survive the impact with only relatively minor injuries.

In an attempt to find out what had happened and why, Danny had Carl Pascarell try to duplicate the incident in the Totally Orange company Velocity . . . and he succeeded . . . in spades! At a high angle of attack, Carl also found himself suddenly "locked" in a flat, descending situation, and like Neil, he found there was nothing he could do to break the airplane out of its aerodynamic hammerlock. He even opened the gull wing cabin door and leaned out over the nose as far as he could in an effort to get the nose down . . . but it didn't work. Amazingly, Carl says that he could stick out a hand and feel hardly any air rushing against it as the Velocity descended ever nearer the ocean off St. Augustine. Although he was wearing a 'chute, he ultimately chose to ride the airplane down . . . and suffered no injuries! Ol' Totally Orange suffered only superficial damage on its bottom surfaces as it pancaked into the water . . . and was flying again in a very short time.

Obviously, something very unusual was taking place. Both Neil Hunter and Carl Pascarell were highly competent and experienced pilots, but neither had ever experienced anything like this . . . and both had pretty well exhausted their ideas for a solution on the way down to their spectacular splats in the water. Although there was apparently no danger of a Velocity getting into such an aerodynamic "lock" as long as it was flown at usual attitudes (as opposed to the FAA's definition of "unusual" attitudes) and within its normal weight and balance envelope, the situation was now known to be repeatable, so something had to be done. If it could happen to two different Velocities, Danny had to assume it could happen to all of them. Not a personality capable of shying away from a problem, he characteristically met it head on.

One of the first things he did was to contact Jim Patton, the recently retired Chief of Flight Operations at NASA Langley, who had headed up the widely publicized general aviation stall/spin program that, among other things, had come up with the leading edge cuffs used so successfully on the VariEze and the Questair Venture. Jim's report on the work he would subsequently do for Danny picks up the narrative at this point . . .

A PILOT REPORT:

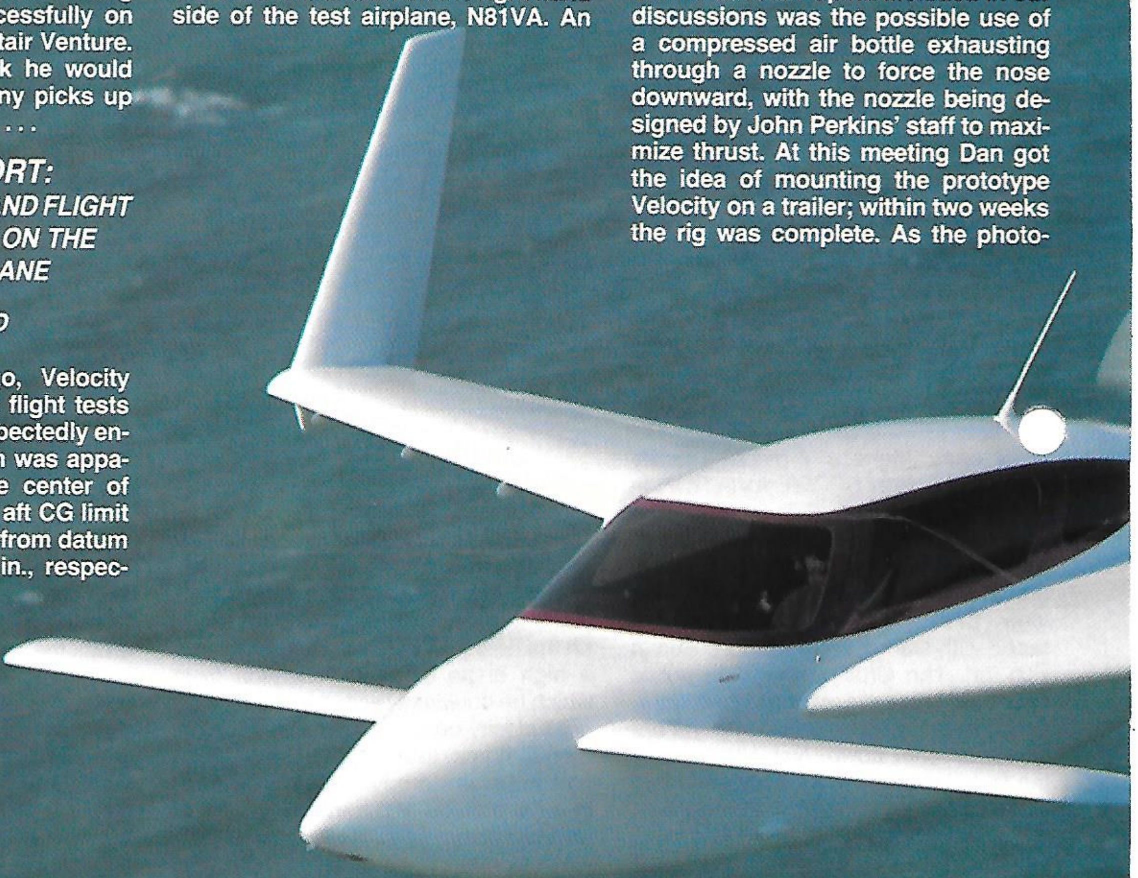
HIGH ALPHA GROUND AND FLIGHT TESTS CONDUCTED ON THE VELOCITY AIRPLANE

BACKGROUND

About 1-1/2 years ago, Velocity N81VA, while undergoing flight tests at St. Augustine, FL, unexpectedly entered a "deep stall" which was apparently unrecoverable. The center of gravity (CG) was near the aft CG limit (forward and aft CG limits from datum are 114.09 in. and 120.5 in., respectively). The airplane had been modified by attaching an aluminum gap seal beneath the canard elevator. The pilot had a parachute but elected to ride the airplane to the water because the descent rate appeared very low and there was no discernible forward motion. The pilot was unhurt on impact and the airplane received only light damage (it was flying again in 3 weeks). I was contacted by Mr. Dan Maher, President of Velocity Aircraft, in July 1990 and was asked to lend what help I could in eliminating the deep stall as a potential problem for Velocity kit builders. Dan had already advised Velocity builders to move the aft CG limit forward until more could be learned about the problem.

APPROACH

Naturally, a precondition for continued flight testing of the Velocity in the high alpha range was to develop reasonable assurance of recovery by other means than primary controls. Before calling me, Dan designed and installed a 210 lb. translating weight, movable fore and aft on the right hand side of the test airplane, N81VA. An electric motor, controlled by a fore and aft lever, drove a sprocket-chain arrangement to move the weight. The weight could be quickly and easily selected by the pilot to pre-marked positions, changing the CG at will from ahead of the forward CG limit to the aft CG limit. This was certainly a convenient way to quickly get acquainted with the airplane, evaluating the entire CG range in one flight, and a beautiful tool for conducting stability and control tests, but we still didn't have complete assurance that moving the weight forward would allow recovery from a deep stall entered at aft CG. I consulted with my friends at NASA Langley who I knew to have long experience in this area, Messrs. Paul Stough and Long Yip; also, Dan and I flew to Raleigh, NC, to talk about possible ways of defining the problem with Dr. John Perkins and his staff, the Aeronautical Engineering Department, North Carolina State University. These are the same people who designed the outer droops and slots on the Questair Venture for stall improvement and the composite nosegear strut on the Questair Spirit. Included in our discussions was the possible use of a compressed air bottle exhausting through a nozzle to force the nose downward, with the nozzle being designed by John Perkins' staff to maximize thrust. At this meeting Dan got the idea of mounting the prototype Velocity on a trailer; within two weeks the rig was complete. As the photo-



graphs show, the airplane could be rotated to about 70 degrees nose-up to reflect deep stall conditions. The pivot points were on the vertical CG; the airplane could be moved fore and aft and locked on the pivots for any CG within the airplane limits. The following 5 CG positions were set up for the trailer tests (expressed as inches aft of datum): 115.5, 117.0, 118.5, 120.0, and 121.5. The pivots contained bearings to allow free rotation. A trailer-mounted actuation switch was installed to move the canard elevators for stall or recovery. It was clear from the deep stall incident at St. Augustine that the descent rate was only 15 to 20 mph; so the trailer tow speed did not have to be very fast; the small pick-up we had was adequate. In most cases, the elevators could not fly into deep stall; airplane was rotated upward by hand and recovered when necessary by pulling downward on a line attached to the nose gear strut. We tufted the upper wing surfaces, fuselage, and canard to get some idea of where the stall occurred and how it progressed. An indicator from an ultralight airplane was used to monitor airspeed, and an inclinometer was installed and calibrated to indicate pitch angle. This "outdoor wind tunnel" immediately began yielding extremely interesting data; data which qualitatively corresponded with what we knew about the high alpha characteristics of the Velocity. There is no question that such things as ground effect, unsteady winds, and crosswinds would have some effect on the data; but we always got such repeatable results that it quickly became apparent these effects were relatively small and could be ignored for the purposes of our testing.

Jim Patton

Imagine the consternation of neighbors seeing this apparition roaring down the runway!

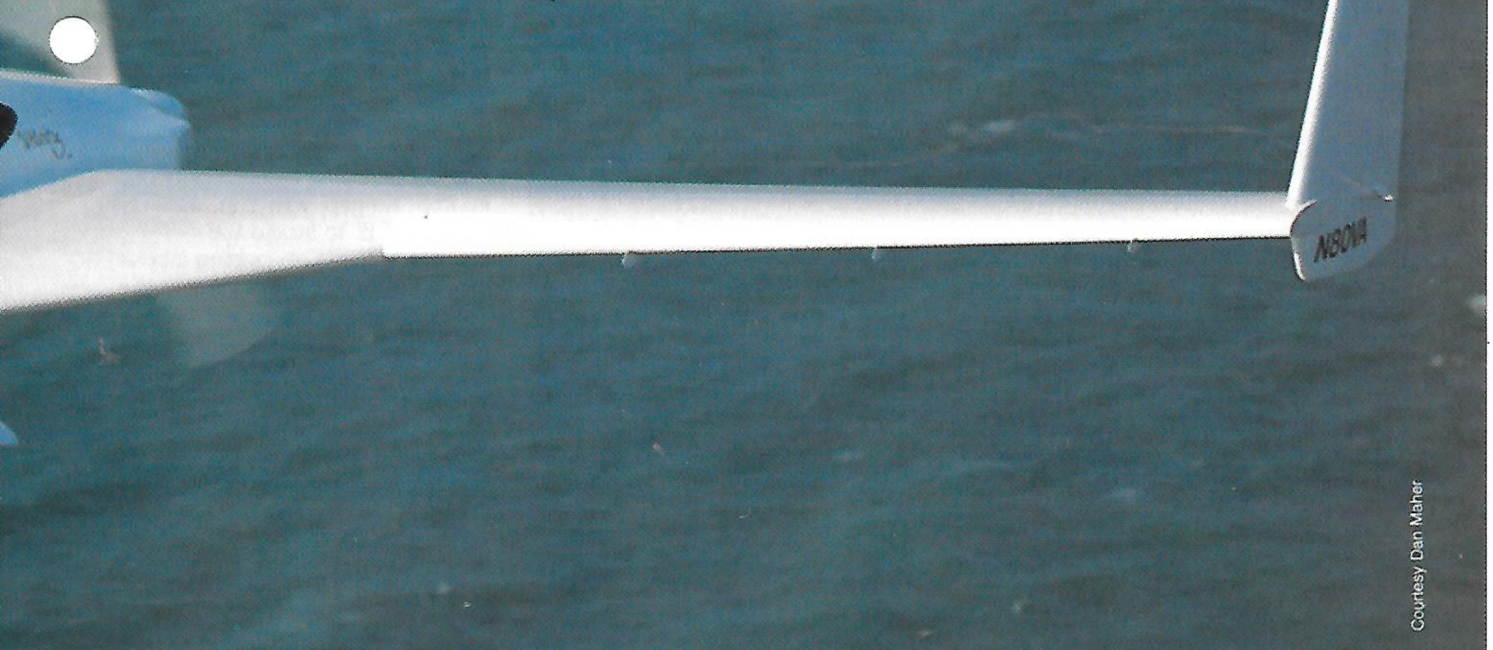
A video camera was mounted in the cabin of the flight test airplane to view the instrument panel during tests and serve as a record of airplane behavior during stalls.

RESULTS

Trailer Tests

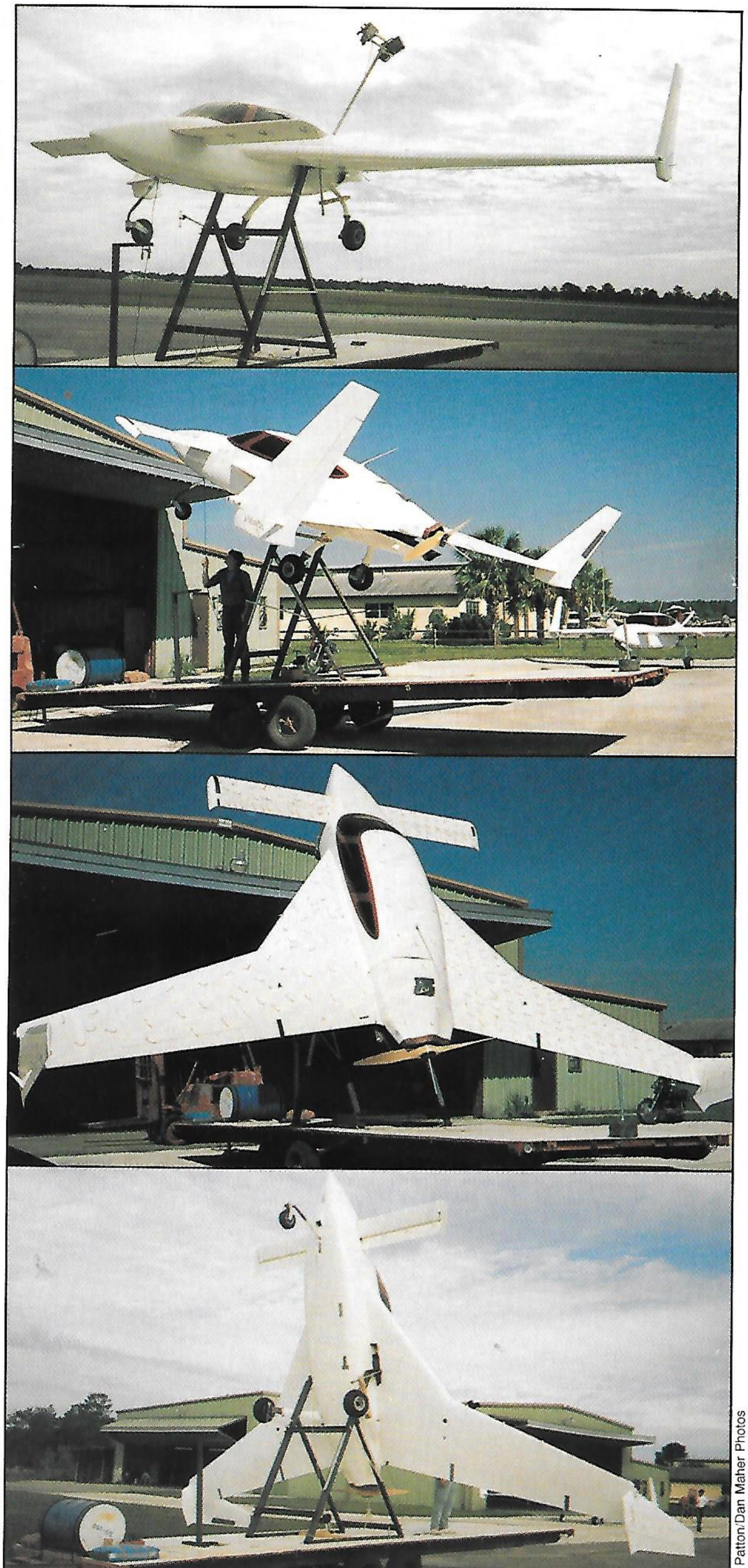
Stall Speeds - Stall speeds attainable with the tow truck were 45 to 50 mph, compared to about 70 mph in flight. Stalling angles at the 45 to 50 mph tests were the same at 30 mph; ground test stalling angles are probably very close to inflight angles.

Original Configuration - The canard stall occurred at about 20 degrees pitch angle, the wing at about 18 degrees, and the strakes at about 26 degrees, according to tuft behavior. Three vortilons were mounted on each wing lower LE as shown in the photo. As the



Courtesy Dan Maher

The Velocity is one slick looking machine with the retractable gear.



Jim Patton/Dan Maher Photos

The Velocity in several angles of attack on the test rig. The video camera records the effects on the tufts.

airplane was rotated through about 26 degrees (strake stall angle), a pitchup tendency was noted for CG locations forward of 118.5 in. and a pitchdown tendency for CG's aft of 118.5 in., indicating that the center of pressure for strake lift after main wing stall was behind the CG at locations forward of 118.5 in. and vice versa.

With full airplane nose up (ANU) elevator at a CG of 118.5, about 10 lb. push was required to rotate the airplane up into a deep stall of about 40 degrees alpha. When full airplane nose down (AND) elevator was applied, the airplane pitched down slowly to level flight. At CG's of 117.0 in. and forward, considerable push force was required to rotate the airplane up to angles above 40 degrees, and recovery occurred even with full ANU elevator. At CG's of 120.0 in. and aft, the airplane could be flown into deep stall with elevator cycling to cause oscillations. A pull force on the nose gear line, up to 70 lbs. at the most aft CG, was required for recovery, with full AND elevator.

To evaluate deep stall recovery capability, the airplane was rotated to a 62 degree angle at a CG of 114.0 in. and released; it rotated back to level even with full ANU elevator. Note that full forward travel of the weight resulted in a CG of 111.0 in.

Aerodynamic Configurations Tested - Of the configurations listed below, photographs are available only for the leading edge droops, or "cuffs", as they will be termed in this report. All cuffs had the same cross-section, arbitrarily chosen.

1. 60 in. cuffs, extending inboard from wingtip.
2. 40 in. cuffs, extending inboard from wingtip.
3. 34 in. cuffs, extending inboard from wingtip.
4. 22 in. cuffs, extending inboard 36 in. from wingtip.
5. 22 in. cuffs, extending inboard 60 in. from wingtip, with 2 in. wide chines, elevator T.E. to strake L.E.
6. 21 in. cuffs, extending inboard 60 in. from wingtip.
7. 2 in. wide chines, elevator T.E. to Fake L.E.
8. 21 in. cuffs, extending inboard 62 in. from wingtip, fence on inboard end of cuff.
9. 21 in. cuffs, extending inboard 62 in. from wingtip, fence on outboard end of cuff.
10. 24 in. strake L.E. spoilers, triangular XC, 1/2 in. height, 1 in. base.
11. Enlarged plywood vortilons, same wing location as originals.

12. Vortex generators, just forward of strake round-down.

13. Ventral fins (2), 8 x 18 in., lower engine cowling.

Configurations (1), (2), (9) and (3) provided the best recovery to marginal, in that order. All other configurations were either ineffective or of so little help that they were not considered for flight test. The protection from locked-in deep stall resulted from the outboard wing sections retaining attached airflow and lift, thus providing a pitchdown recovery moment up to high angles, beyond the strake stalling angle.

Flight Tests

Weight and Balance - The airplane was weighed for each pre-marked position of the translating 210 lb. weight with the pilot, parachute, and flight test fuel aboard. Results were as follows (CG given in inches):

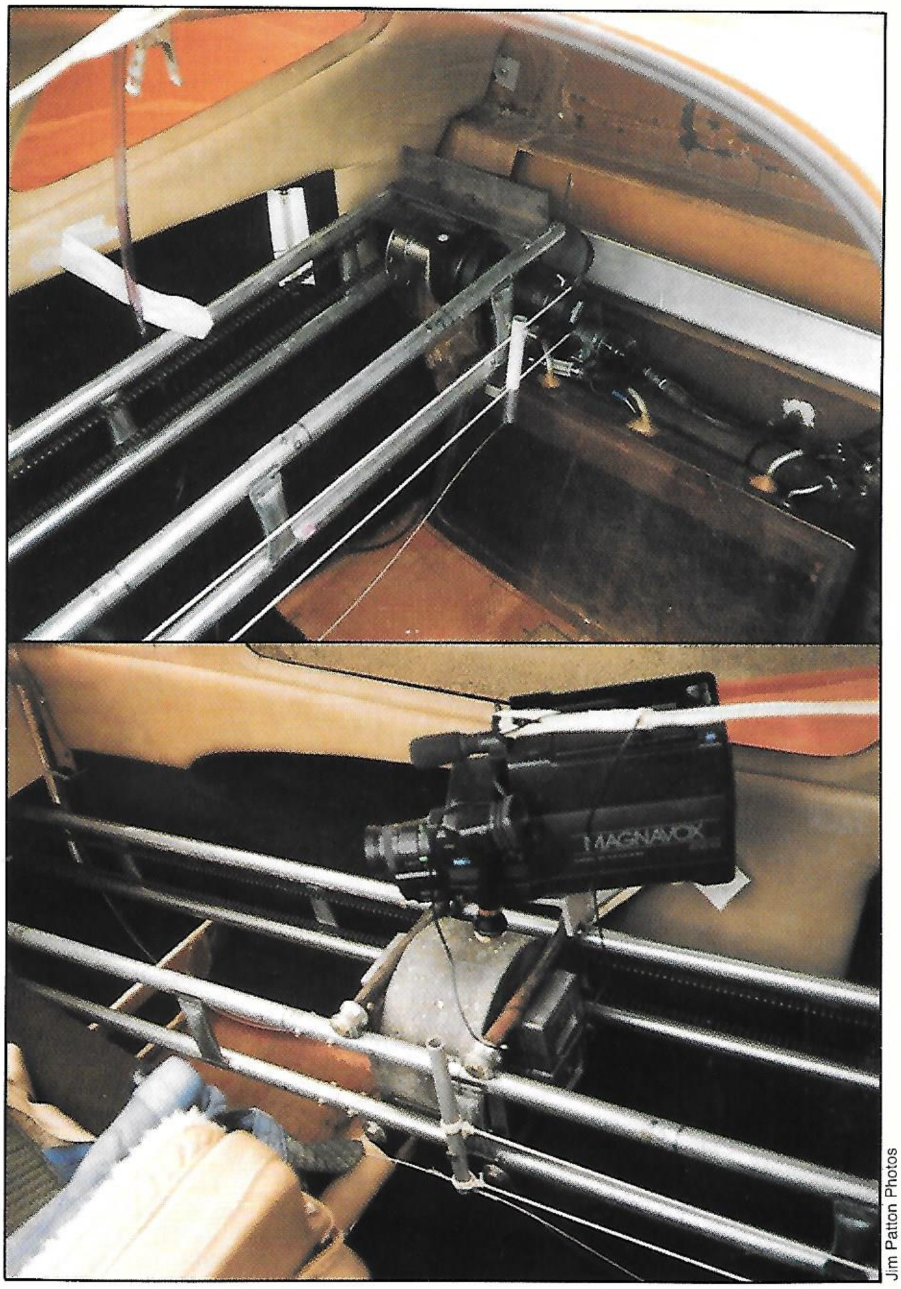
Position 0 - 112.37 in.
Position 1 - 113.71 in.
Position 2 - 115.0 in.
Position 3 - 116.22 in.
Position 4 - 117.44 in.
Position 5 - 118.73 in.
Position 6 - 119.95 in.
Position 7 - 121.23 in.

First Flight (Original Configuration) - Test altitude was 12,000 ft. for all stall entries. On 02/13/91, from 1040 to 1135 EDT, abused stall tests were conducted by first attaining full aft stick, then pumping the stick forward and against the aft stop to obtain the largest possible pitch oscillation amplitude. CG positions (3) and (4) were evaluated in this manner, with no departure or cue of impending departure. At CG position (4), the "pitch buck" accompanying full aft stick hesitated at the peak before pitching down again; after increasing pitching amplitude through several cycles, the airplane hesitated for a longer period at the top of a cycle; this was accompanied by noticeable high frequency buffet buildup, which felt like wing airflow separation buffet. At the peak of the next cycle, the airplane suddenly pitched up to between 45 and 60 degrees (verified by chase pilot), the airspeed dropped to zero, and the nose then pitched slowly down toward the horizon. I immediately applied full forward stick and full throttle (it had been determined previously that recovery would be first attempted without use of the translating weight). The airplane responded slowly to recovery controls, pitching nose down to about a 30 degree diving attitude. Altitude at pitchup was 11,600 ft.; recovery to level flight was 20 seconds after pitchup, at 10,000 ft.

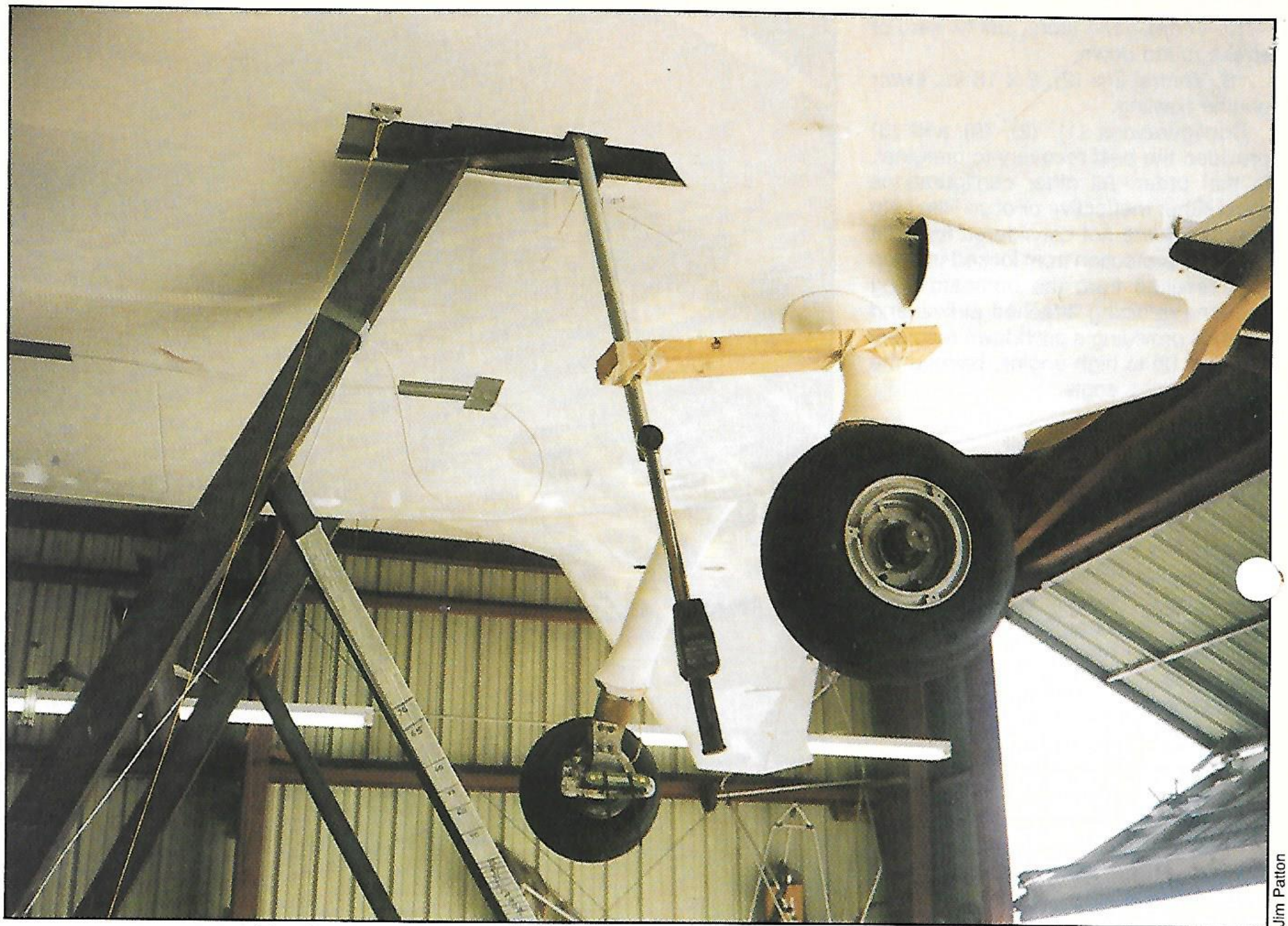
Second Flight - This flight was conducted on the same date from 1340 to 1435 EDT to evaluate flight characteristics at more aft CGs. Beginning with the weight at Position 5 and progressing to more aft CG at each succeeding test point, airspeed was slowly reduced to obtain full aft stick. The airplane was allowed to stabilize at each test point, but no attempt was made to abuse the stall. At Positions 6 and 7, the "pitch buck" disappeared and an increasing level of buffet was present with aft CG movement. Also, the stick force gradient became very light; the airplane behaved as if it were very close to the neutral point.

Third Flight - Leading edge cuffs of 34 in. were fitted on the outboard wingtips. The flight was conducted from 0940 to 1040 EDT on 02/14/91. Testing was begun as before, at CG Position 5. As the "pitch buck" was reinforced, a hesitation accompanied by a momentary rise in buffet level at the peak resulted in aborting the flight on my judgment that only a slight improvement had been effected.

Fourth Flight - Leading edge cuffs of 60 in. were fitted on the outboard wingtips. On 02/21/91, from 0950 to 1125 EDT, a combination photo and test flight was flown. The stall attempts were begun at CG Position 5. As on the previous flight, the airplane hesitated at the top of the reinforced "pitch bucks"; it was found that when forced further, the airplane would suddenly pitch up 20-30 degrees, then pitch more slowly back to level flight, with no severe drop off in airspeed and little or no altitude loss. This same behavior occurred for



The electric motor driven sliding weight device installed in the Totally Orange Velocity. The video camera records instrument readings for subsequent study.


Jim Patton

Details of the mounting of the Velocity on the trailer angle of attack test rig.

Positions 6 and 7.

Discussion - It is believed that the pitchups on Flight 4 occurred when the main inboard wing stalled at about 18 degrees. The strakes continued flying to about 26 degrees; the center of lift on the strakes was ahead of the CG and would therefore cause pitchup. The pitchup moment was apparently greater than the pitchdown moment from the still-flying outboard wings. Then when the strakes stalled, the pitchdown moment from the wings took over. During the NASA Stall-Spin Program, it was found that for the straight-wing test airplanes, inboard wing stall was at about 18 degrees and the outboard cuffed wings continued flying until about 35 degrees alpha.

WING DESIGN CHANGE

Immediately following the deep stall incident mentioned early in this report, Dan Maher redesigned the Velocity wing by extending the trailing edge and changing the aft inboard camber slightly, and he reports that recent tests of the new wing installed on the prototype trailer-mounted airplane show that there is no unrecoverable deep stall with this new configuration. The outboard wing LE cuffs will therefore not be required for kits now being shipped.

CONCLUSIONS

1. The Velocity kits preceding the above change will receive leading edge cuffs as tested on the fourth flight.
2. It is believed that the pitchups on the fourth flight were caused by the strake lift existing after main inboard wing stall, which overpowered the pitchdown moment from the still-flying outboard wings; the pitchdown to controlled flight occurred when the strakes stalled.
3. Further trailer testing should be done to develop an understanding of the reason for the low descent rate existing in the deep stall condition. It is possible that a very large, strong vortex was formed above the wing which could not be detected by surface tufting. It is my understanding that Mr. Witold Kasper has demonstrated this phenomenon in flight.

- James M. Patton, Jr.
Test Pilot

* * * *

In addition to the testing described in Jim Patton's report, the Velocity has been subjected to a flutter analysis and, with the new wing, a new structural load test.

"I have done as much as I can possibly do with the resources I have and the intelligence that we have among us . . . so, finally, I feel good about selling the plane to people I know and care fc Danny Maher says.

The trailer test system will continue to be utilized because Danny, Jim and everyone else connected with the project want to know what is happening in that aerodynamic "locked" or deep stall condition with the original, un-modified wing that permits such a slow vertical descent (see sidebar).

Danny is also going to continue to use his weight shifting test rig, and will make it available to others who want to investigate the far corners of their CG envelope . . . and beyond.

RETRACT OPTION

Danny is so pleased with the retractable gear developed for the Velocity by Duane and Scott Swing (Composite Development) that he is now promoting its use by his Velocity builders. About half his recent customers are opting to use it. The gear is no heavier than the standard fixed gear and adds 12 to 15 knots to the design's top speed.

Jim Patton

One of the cuffs tried on the original Velocity wing. A 60 inch cuff kept the airplane from getting into the deep stall condition and has been made available to builders of early kits. A new Velocity wing, now a part of kits, does not need the cuffs.

VELOCITY 173

The latest news out of the Velocity camp is a new version of the airplane, the Velocity 173.

The significance of the model designation "173" is that it comes right after 172 . . . as in Cessna 172. A welcomed step in a direction away from all-out speed, the Velocity 173 is intended to be a docile airplane any Cessna 172 pilot can step into and fly. It will have a heavy duty landing gear to allow operation from unpaved runways, and with more wing and canard span and a thicker airfoil, it will fly down to around 58 mph. Top speed will still be up around 180-190 mph, however, and with thicker strakes, standard fuel will be about 100 gallons.

Danny Maher, like a lot of EAAers today, believes that with the factories virtually out of the certificated lightplane business and so many homebuilt designers concentrating on the top end of the performance scale, a big segment of the airplane market is being ignored . . . the docile Cessna 172/Piper Cherokee class of airplanes that has been the mainstream of general aviation for so long. With his Velocity 173, Danny intends to offer the utility and gentle flying characteristics in a package that includes a modern look and significantly greater top end performance . . . or better economy.

At Sun 'n Fun in April, Danny said if everything went as planned, he would have the Velocity 173 at Oshkosh '91.

KASPER VENDICATED?

In the July 1973 issue of SPORT AVIATION, an article entitled **The Revolutionary Kasper Wing** told of retired Boeing engineer Witold Kasper's experiments and theories on what he termed "vortex lift." Briefly, he claimed that with a flying wing glider he had designed and built, he could . . . at high angles of attack . . . induce a spanwise vortex of air above the wing that produced enough lift to significantly reduce the craft's rate of descent, allowing bird-like landings. Mr. Kasper acquired various patents on devices to induce and contain this vortex . . . and demonstrated the phenomenon at airshows in the northwest for many years. Later an ultralight was developed incorporating his concepts, and its parachute-like, near vertical descents were demonstrated many times at Oshkosh in the early 1980s.

There had already been examples of some sort of similar lift phenomenon at work. For decades, free flight modelers had been installing "dethermalizers" on their airplanes to keep them from disappearing over the far horizon. It consisted of a fuse that would be lit just before release of the model . . . that would burn through a rubber band holding down the trailing edge of the horizontal tail. When released, the horizontal tail, hinged and spring loaded at the leading edge, would pop up into a vertical position, putting the model into a deep stalled condition. Amazingly, the models would descend to the ground in a flat attitude . . . as stable as a rock . . . and so slowly that normally no damage would be incurred. A few years ago, a NASA contractor experimented briefly with a similar set-up on a glider, mechanically actuated by the pilot, and found that it reacted exactly as do the model airplanes . . . and Witold Kasper's swept wing gliders.

What is the actual mechanism at work here? Is it "vortex lift", as Witold Kasper theorizes? Such a phenomenon, controlled at will by the pilot, could be a safety device that might, for example, save pilots and their passengers experiencing engine failures at night or in instrument conditions, so it would be beneficial to us all if NASA spent some of our tax dollars thoroughly investigating whatever it is that is continuing to crop up in incidents like Carl Pascarell's strange descent into the Atlantic Ocean.

DEEP STALL
. . . Continued!

Editor's Note: Following is one of several letters received on the article "Velocity . . . Solving A Deep Stall Riddle" and is presented here for the additional information it provides on the subject.

* * * *

I just finished reading your fine article, "VELOCITY . . . Solving A Deep Stall Riddle." The developers are to be complimented on their approach to determining the causes of their problem. However, your article leads me to suspect that they may not be completely aware of how serious Deep Stall can be. Perhaps this letter can lend some further understanding, and also warn others out there of the possible situation that exists for all airplanes.

We'll begin back when Deep Stall was first discovered by British Aircraft Corp. as a result of the crash of one of the first BAC 111's during certification testing. I was an aerodynamicist at Douglas Aircraft working on the design of the DC-9 at the time. We received word of the crash the same day. The story sent a chill through the air in our department. The BAC 111 had rotated into a second mode of stability at (I recall) approx. 30,000 ft. altitude and descended to the ground in a "belly first" attitude. All attempts to cycle engine thrust, change aircraft configuration, and move controls failed to return the aircraft to forward flight so it could recover from its plunge. The saga was radioed to the ground as it took place by the unfortunate crew.

We went straight to the wind tunnel with the DC-9 and discovered that our "short-coupled T-tailed" configuration could be made to fly stably in two modes: nose first (min. drag mode) and belly first (max. drag mode). For simplicity let's call the first the Dart Mode and the second the Parachute Mode, since these terms essentially describe what is happening.

To relieve everyone's anxiety, the DC-9 was cured of its Parachute Mode tendencies by making the horizontal tail approximately one-third the area of the wing! For obvious reasons this story was given little publicity. Perhaps that is why Deep Stall still remains a mystery to most. The facts should be known to prevent others from stumbling into this dangerous arena.

I have always assumed that the Deep Stall phenomenon was peculiar to short-coupled T-tailed aircraft where the horizontal tail is rendered ineffective by the separated rolling wave of air from the fully stalled wing. Apparently this is not the only case. The canard version has now been discovered. Increasing the horizontal tail size is not the cure, so we had better realize what is going on.

Deep Stall is an understated description of the phenomenon. It's more than just a stall. The aircraft rotates many degrees beyond the stall into a new stability bucket with a different "nose" (belly) and a different "tail" (fully stalled wing and tail surfaces). It is not the same airplane we designed at all! The farther the rotation into the new stability bucket the more stable the Parachute, and the more difficult the task of forcing the aircraft back into the Dart Mode.

Free falling parachutists are probably the ultimate users of these two modes of stability. The classic "arms spread, knees bent" configuration stabilizes them in the Parachute Mode (max. drag, min. descent speed, 120 plus/minus mph). Folding their arms and straightening their legs rotates them into the Dart Mode (min. drag, max. descent speed, 180 plus/minus mph). The two mode phenomenon can be both good and bad.

If you have a low enough wing loading, such as free flight model airplanes and the Velocity, the Parachute Mode can be used to safely lower the aircraft to the ground. If you have high wing loading, forget it!

Also please note that the infamous "Flat Spin" is a close relative of the Deep Stall, wherein the spin itself provides the stability for the Parachute Mode. The flat spin and the deep stall both result in non-recoverable rapid descents and should be avoided at all costs.

By now everyone should be getting the drift that the Parachute Mode of flight stability is a concern for all aircraft. You just don't want to get stable (read: locked in) in this mode. Some aircraft avoid this unhappy situation by snap rolling. Some, such as the Ercoupe, maintain some forward speed and "mush" to the ground precluding ever entering deep stall. Some cleverly placard around the approach to deep stall. Keep your airplane nose heavy so the center of gravity cannot be surrounded with fully stalled wings and tails acting as parachutes and you may be O.K. Hinge your horizontal tail so it will flip up and most any (especially high wing) airplane becomes a parachute.

If your airplane has the two modes of stability, proper recovery probably requires a drastic configuration change. For instance, a canard configuration could let the canard float up (feather) dumping its parachute effect and allowing the aircraft to nose over into the Dart Mode.

Just remember this. In the Parachute Mode of stability all normal aerodynamic forces and moments are thrown out the window. You are not flying, you are falling. You are riding in a parachute held in check only by drag. You are locked into this mode by an array of forces from spin stability to fully stalled wing and tail surfaces acting as little parachutes, to **low** CG, etc. To recover from this predictment you must shed some stabilizing forces (or add destabilizing forces) forward and allow the others to rotate you back into the Dart Mode, just as the free fall parachutist does. In other words, tip over your parachute. You can't do this by raising or lowering flaps or landing gears, moving the CG a few inches, or wiggling the control surfaces. Changing the power only makes you a powered parachute and moves your crash site over a little bit.

These are not insurmountable problems we are discussing. The basics have been understood for quite some time. The only change is the proliferation of new designers rediscovering old problems. Thanks to the EAA and your magazine we can pass the word quickly and preclude some unnecessary accidents, not to mention save time and money reinventing the wheel.

- Barry E. Jones
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