LANCAIR COLUMBIA 400 SPIN RECOVERY TESTING

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ABSTRACT

The Columbia 400 was derived from the spin-resistant Columbia 350. The change from normally aspirated engine to turbocharged engine of the same power and the extended operational envelope (FL250) required a change from spin resistance to spin recoverable. To make the Columbia 400 spin recoverable under all conditions, an extensive spin test program was flown during which many different aerodynamic modifications were tested. This presentation will discuss some of the things that worked or did not work and some of the lessons learned.

INTRODUCTION

The Columbia 400 is a four-seat, composite, turbocharged airplane with a gross weight of 3600 lb and 98 gal usable fuel. This paper continues the story started by Len Fox during the 2004 Symposium. After the loss of the first test airplane, a second Columbia 400 was prepared for spin testing with a redesigned spin recovery system. The goal was to find a configuration in which the Columbia 400 would meet the requirements for 14CFR 23.221 for one turn spin recovery while retaining the 'looks' of the airplane and with the least amount of changes to the airframe / molds. About 50 different configurations were tested during the 1.5 years of the Lancair spin program. These tests were considered high risk, the spin recovery chute was successfully used four more times.

Figure 1 Columbia 400

REDESIGNED SPIN RECOVERY SYSTEM

The redesigned recovery system was mounted on the left side of the aft fuselage for most of the tests. The spin recovery chute was deployed by a spring loaded pilot chute, which pulled the main chute out of its bag. The aerodynamic effect of the side mounted spin boom was investigated, it was equivalent to a slight rudder deflection to the side it was mounted on. To fly coordinated with the left side spin boom installed, more right rudder than normal was needed while with the right side spin boom very little right rudder was needed at full power. The spin recovery characteristics were best without a spin boom, slightly degraded with the left side spin boom (slightly longer recovery turns) and worst with the right side spin boom (right hand spins were worst). Tuft tests showed that the spin boom shielded a small area of the vertical tail and rudder, where it was mounted.

The first spin chute used for deployment on the airplane that was lost was a ribbon chute with a nominal diameter of 11.3 ft. The recovery time was about 3 turns with this chute. This chute was successfully used one more time but was then lost after it was cut away. The next spin chute was of a nominal diameter of 2.5 m (8.2 ft) with slots in only one row ($C_{D\ average}$ = 0.83) The recovery times with this and subsequent spin chutes of similar size were below one turn. The spin chute activation was observed from the chase airplane once. From a right spin the bag was pulled to the right, well clear of the tail. The canopy opened quickly after the pilot chute had stretched it fully aft of the airplane. For the design of the bag attached to the spin boom containing the chute it should be considered that the chute deploys sideways in a spin. On our deployments the opening of the bag would only allow the chute to come out straight aft, this resulted in the sides of the bag being torn several times or the mounting plate being ripped off and lost.

Figure 2 Left Side and Right Side Spin Boom with Chute

After several deployments the line attaching the chute to the airplane showed evidence of chafing at the D-ring. The equipment was sent to a local parachute rigger who had been packing the spin chute for us and had built the chute bags. He cut the chafed end off and stitched a new loop. No one noticed that the thread he used was not the same strength as the original stitching, but weaker.

Figure 3 Chute Attachment

During the next deployment, this stitching failed, fortunately after the spin rotation was stopped, but just before the pilot could cut the chute away. This confirmed that the loads during chute deployment are lower than with the airplane descending with the chute fully deployed on its tail.

MODIFICATIONS AND TEST RESULTS

The first changes from the spin resistant Columbia 300/350 configuration were:

- Rudder chord was increased (Figure 4)
- Rudder leading edge is round instead of square
- Ventral fin added (no “step” breaking continuity of bottom line to fuselage).
- Rudder deflection increased to ±30º (from ±17º)
- The elevator was shortened and its deflection increased
- New stall strip locations
- CG limits moved 4% MAC aft
- New larger cowling (1” longer)

During the series of tests in this configuration we learned that in general a light airplane (less inertia) recovered quicker than a heavy airplane (fuel had most effect). Full elevator forward was required for consistent recoveries in combination with opposite rudder. Power on recoveries were quicker than power off, opposite aileron recoveries were quicker than neutral aileron, flaps down recoveries were quicker than flaps up. In some cases with full flaps it would not even spin. Spins up to 18,000 ft worked well, but it went into an unrecoverable spin at 25,000 ft, HVY/AFT, right turn, delayed rudder input, and the spin chute was used. The same condition to the left, which was tested first, was recoverable and passed.

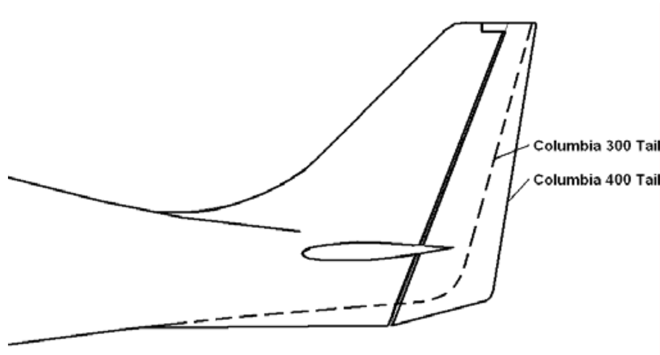

Figure 4 Comparison Columbia 300 with 400 Tail

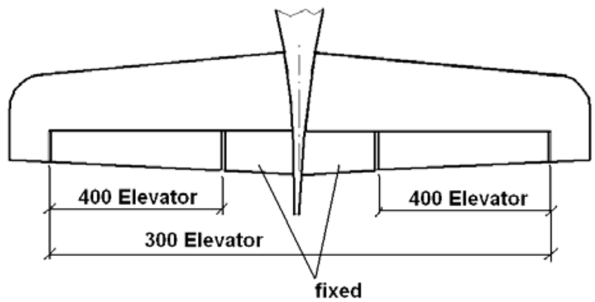

Figure 5 Elevator Comparison

At this point we realized that our test airplane was not perfectly symmetrical (right spins worse than left spins). We accepted this as the worst case, knowing that production airplanes would be straighter. In addition we increased many control surface gaps to up to 0.5", which reduced the effectiveness of the controls further. That way we could allow larger tolerances in production.

During the preliminary spin resistance tests prior to making the decision to go spin recoverable we tested winglets for their potential to improve spin resistance. The winglets (various sizes and shapes were tested) were beneficial for spin resistance, but not enough to pass 23.221. Afterwards the winglets were tested in spins and were found to increase the recovery time over no winglets by about ½ turn. This was probably because they reinforced the effect of the wing cuffs, which add lift at high angles of attack at the outboard wing. This is undesirable for spin recovery.

The next modification, horizontal tail strakes (Figure 6) produced mixed results. In some cases recoveries were quicker (mid weight / AFT

CG), in others they were slower (HVY/AFT), it was not consistent. They did not seem to have an effect on the pitch attitude in spins as we had hoped. They were removed for subsequent tests.

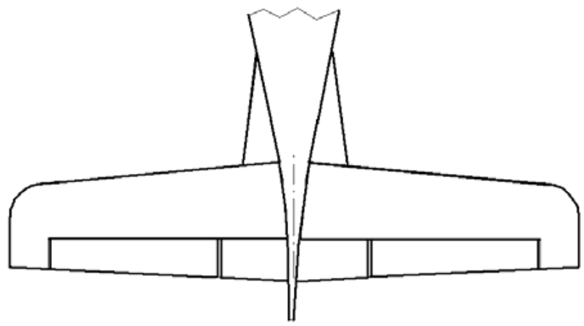

Figure 6 Horizontal Tail Strakes

The airflow at the vertical tail was investigated in normal flight and yawed flight, to look for ways to make it more effective and to investigate why the airplane would take longer to recover from right spins (1/4 to ½ turn more compared to left spins).

Figure 7 Left Rudder Sideslip and Right Rudder Sideslip

In normal flight at all speeds down to stall speed the airflow would be roughly parallel to the fuselage longitudinal axis. In yawed flight with rudder deflections, the airflow changed until it was about parallel to the vertical tail leading edge. This led to another modification we called a vertical tail fence, like a stall fence on a swept wing, which was attached to the leading edge of the vertical tail at about mid span .

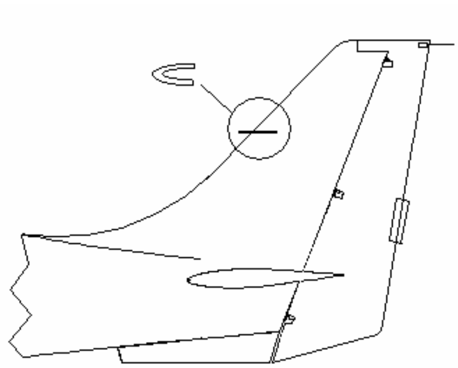

Figure 8 Vertical Tail Fence and Stepped Ventral Fin

Spin tests with the vertical tail fence showed that it increased rudder authority, both for spin entry and recovery. This had two effects. The airplane would enter the spin quicker and get to a higher turn rate at one turn. The rudder was then also more effective for terminating the rotation, so the end result, the recovery turns, remained about the same. The vertical tail fence was not pursued but it may have been beneficial had we intended to certify this airplane as recoverable from multi-turn spins.

Tuft tests of the vertical tail during spins with a video camera showed that the airflow at the vertical tail above the horizontal tail was turbulent / separated on both sides. Underneath the horizontal tail the airflow remained attached and nearly parallel to the fuselage longitudinal axis on both sides. Our efforts in improving spin recovery were then focused on the lower part of vertical tail and rudder.

To shorten the ventral fin, its front edge was cut off (as in Figure 8). With the “stepped” ventral the airplane proved to be better recoverable than with the previous version. Various leading edge shapes of this ventral were tested (round, pointy, square), but the results were not consistent. We then proceeded with the shape we thought gave the best results.

We were still getting somewhat inconsistent recoveries, where the recovery turn results varied by ½ turn for the same configuration. We eventually found one reason for this to be the pilot not bothering to fly coordinated during climb to the test altitude due to high rudder forces, which resulted in a fairly large fuel imbalance (fuel migrated outboard on one side) due to the large expansion space even with full tanks. Coordinated flight prior to spin tests resulted in more consistent recoveries. The other factor which caused inconsistent recoveries was the yaw rate at one turn. Many of the modifications we tested had an influence on the yaw rate during the first turn. The slower the yaw rate was when recovery controls were applied the faster it would recover.

The configuration with large rudder and stepped ventral would pass all tests except delayed rudder to the right. In this test elevator forward was applied at one turn, and opposite rudder half a turn later. This allowed the airplane to get further into the spin, and it would not respond to the rudder input. This case was worst at high altitude (FL250), where the inertia forces in spins were larger in proportion than the aerodynamic forces. Full fuel and high altitude proved to be the worst combination for spin recovery. In some cases the airplane would recover from a steady spin (> 6 turns) after descending to lower altitude, in other cases it would not and the spin chute had to be used. The use of power, speed brakes or any other control inputs had no effect in a steady, fully developed spin. With this airplane, 3 out of 4 non-recoverable spins occurred to the right. We were then trying to determine the reason for the asymmetry and how to make it recoverable in spite of it. Most efforts focused on adding vertical area aft of the CG or making the existing area more effective. This was not enough. It was then decided to remove the nose wheel pant and therefore remove directionally destabilizing area in front of the CG. Without the nose wheel pant the LC41 passed all spin tests below 18,000 ft and was certified for this configuration and altitude.

Next a smaller nose wheel pant was built and spin-tested in the hope that it would have less effect on recovery. The opposite turned out to be true; with the small nose wheel pant recoveries took longer than with the standard large nose wheel pant.

Figure 9 Small and Standard Nose Wheel Pant

It was then attempted to reduce the amount of side force in spins caused by the nose wheel pant and cowling by attaching “Spin Strips” onto them in various locations. These were intended to stall the airflow in yawed flight and therefore reduce the side force created by those otherwise rounded parts. The shape of the spin strips was varied from L-profile to triangular, the locations were varied in height and length. The spin strips were tested separately and together on cowling and nose wheel pant. In general the recovery times were reduced and about the same as without the nose wheel pant. Spin entries seemed slower. Both together were not an improvement over either the cowling strips or nose wheel pant strips by themselves. Longer cowling spin strips did not improve recoveries over the size shown in Figure 10. Delayed rudder was tested eventually, and it failed (recovery after >6 turns without the use of the spin chute).

Figure 10 Nose Wheel Pant Strips and Cowling Spin Strips

For another modification the nose wheel pant was removed and short taillets (Figure 11) were installed on the bottom surface of the horizontal tail at the tips. The recoveries (flaps up, power off, including delayed rudder) were similar to slightly better than without taillets. Then the leading edge angle of the taillets was cut back to an angle of 45º. The same tests were performed, but left delayed rudder, flaps up, power off at 17.5k was not recoverable and the spin chute was used.

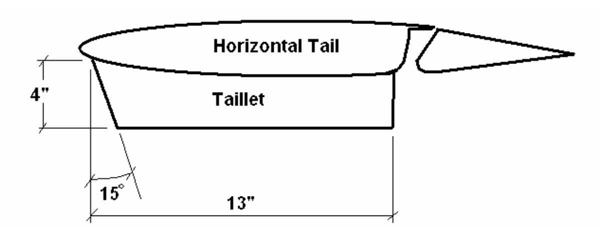

Figure 11 Short Taillets

Figure 12 Long Taillets

A different version of taillets was installed on the horizontal tail (Figure 12). The flaps up, power off, normal recoveries were better than before. Tests were continued with power on, flaps up and delayed rudder, which worked to the left but failed with >5 turns to the right. It recovered without the use of the spin chute. The taillets were removed.

At this point we were very frustrated with the results. Management finally consented to let us to modify the wing, specifically the cuffs, which we believed were the main reason why we were having so much trouble getting consistent recoveries. The whole airplane had been tufted and a camera was mounted in various locations showing the airflow during spins. This way we knew that the wing from the cuff outboard (left wing in a right spin) had partly attached flow in a steady spin. This was driving the spin with more force than any of the modifications we had tried could oppose. The left wing was worse than the right wing, which accounted for us having more unrecoverable spins to the right than to the left. The airplane surfaces had been measured with a laser tracking method prior to starting the spin tests, so we knew that there were small differences in airfoil contour along the leading edge left to right wing on this airplane.

The standard nose wheel pant was reinstalled and all other mods removed. The effect of the wing cuffs was then reduced by adding 12" long stall strips on the cuff leading edges. This improved the consistency of left and right recoveries considerably (left spin recoveries were typically ¼ turn, right spin recoveries were typically 3/4 turn, this changed to ½ turn for both). With the nose wheel pant installed it passed all tests up to an altitude of 18,000 ft including the delayed rudder case. It still failed the delayed rudder case to the right at 25,000 ft, the spin chute had to be used again. At this point the airplane was still covered with tufts and had a small video camera mounted on top of the fuselage. The cuff stall strip length was increased to 18”. It passed all tests including high altitude delayed rudder.

Figure 13 Cuff Stall Strips, taped on

The tufts and camera were removed and the tests repeated. It failed delayed rudder to the right, but recovered after 4 ½ turns. The cuff stall strips were increased to 24” length and this time all spin tests passed at all altitudes. The stall characteristics still met 23.201 and 23.203 requirements. This was the configuration that is now certified to 25,000 ft.

In an effort to find an indication if an airplane is aerodynamically unsymmetrical like our test airplane, by other means than actually spinning it, I developed a yaw angle test which seems to correlate with the spin characteristics. I measured the yaw angle in steady side slips with full rudder deflection, left and right, power off at different speeds and at one speed at different power settings.

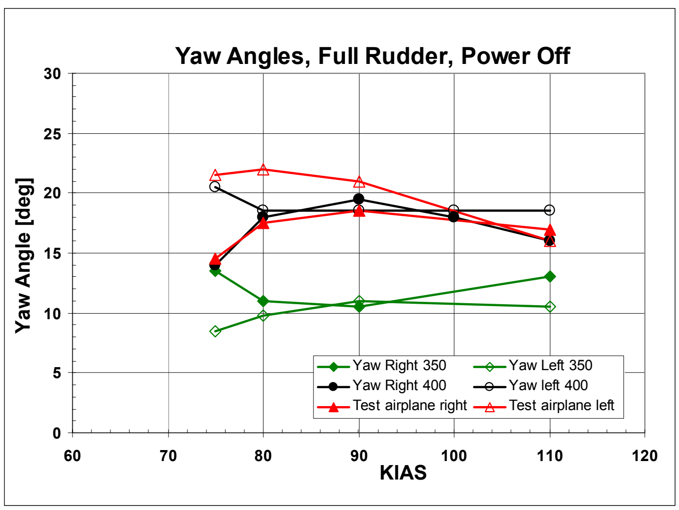

Figure 14 Yaw Angles Power Off

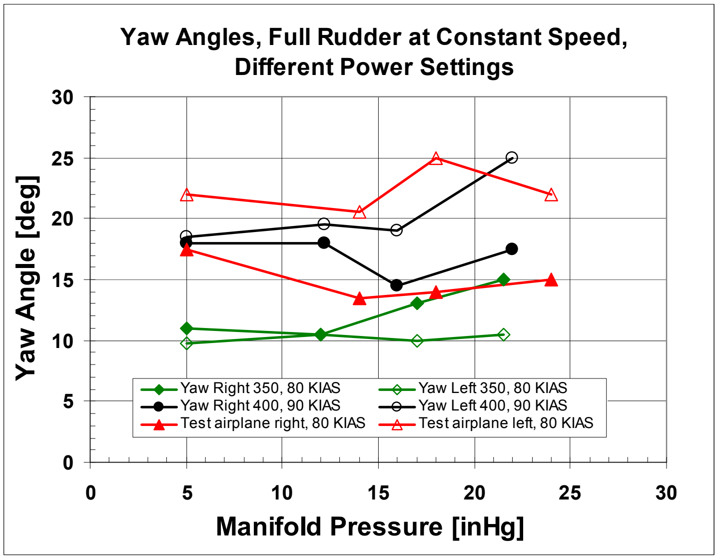

Figure 15 Yaw Angles Power On

In Figure 14 and 15 the yaw angles measured on representative Columbia 350's and 400's are compared with the spin test airplane. At higher power settings a difference left and right can be expected due to propeller slip stream effects, but power off it should be about the same left and right. The spin test airplane yaw angles are significantly different left and right, especially power off at slow speeds. The reason why left and right power off yaw angles below 80 kts are so different has no been determined yet.

CONCLUSION & LESSONS LEARNED

- Using a spin resistant airplane as the starting point made the job of making it spin recoverable a lot harder.
- The wing leading edge airfoil shape has a lot of influence on the stall / spin behavior. Small deviations in the contour can have a large effect on spin recovery. The effect of test equipment and wool tuft needs to be investigated, it may influence spin recovery in either negative (spin boom) or positive (tufts) manner. On some airfoils leading edge contamination from bugs or rain can also have an effect.
- For certification flights the worst airplane aerodynamically should be tested. In our case, if our test airplane would have been aerodynamically perfect, we would have stopped the program after the first few iterations with the first configuration that passed all spins. We would not have known that a production airplane with deviations would

most likely have been unrecoverable, or would have to spin test every production airplane with deviations.

- Any changes to proven equipment as essential as the spin chute should be carefully reviewed, and not just by one person.
- For the purpose of buildup flights low risk to high risk we used the configuration flaps up, power off, full fuel, for the first spin tests. We did not anticipate that this would be one of the worst cases. We changed this for subsequent flights with modifications to full flaps, mid fuel, power off.
- The spin chute was recovered every time except once, when it was cut away above FL200 and 60 kts wind. A chase plane can follow it and document the location where it lands, but even if that is not the case, the spin test pilot can record the location and wind where he cut it away and it can then be found by searching from the air as long as it has a distinct color.