Vortex Generator Flight Tests — Stall Effects

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Vortex generators (VGs) are usually associated with multiengine, STOL or military aircraft. On multiengine aircraft, e.g., a Baron, the principal attraction is a significant improvement in single engine handling qualites. Recently, a number of STCs have become available for single engine aircraft including one from Beryl D'Shannon (BDS) for the Bonanza. Vortex generators work by re-energizing the flow in the boundary layer, that thin layer of air of reduced airspeed right next to the surface. It is separation of the boundary layer from the upper surface of the wing that causes stall. Re-energizing the flow in the boundary layer delays stall and increases the stall angle of attack. The result is a higher wing lift coefficient and hence a lower stall velocity. Used in front of or on control surfaces, e.g., ailerons, the vertical tail/rudders or the horizontal tail, they increase control effectiveness at slower speeds.

The BDS kit consists of 39 VGs installed approximately 10% behind the leading edge of each wing. Eleven VGs are installed on each wing ahead of the inboard and outboad ends of the ailerons, and 12 VGs are installed on each side of the vertical tail ahead of the rudder for a total of 124 VGs in two different sizes (see Figure 1). The STC installation instructions are very clear and detailed. Detailed templates are provided to precisely locate the VGs on both the wing and the vertical tail (shown in Figure 2). Complete installation was accomplished in approximately eight hours. The installed VGs are shown in Figures 3 and 4. An optional 100 lb. gross weight increase is available. However, the STC for the gross weight increase changes the aircraft from utility category (4.4 gs) to normal category (3.8 gs) when operating at the increased gross weight.

Stall characteristics The straight tail and the later V-tailed Bonanzas have two stall/spin strips

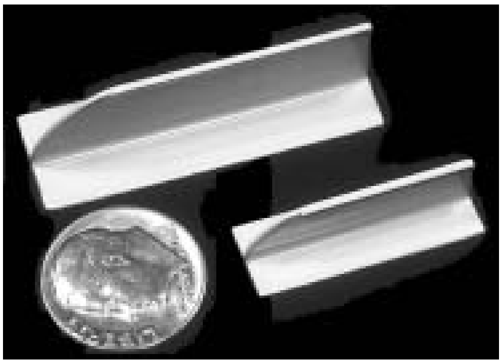

Figure 1. Vortex generators.

Figure 2. Vertical tail installation templates. VGs layed out on the horizontal tail for installation on the vertical tail.

Figure 3. Vortex generators installed on vertical tail.

mounted on the inboard section of the wing (see Figure 5). The inboard stall/spin strip (black arrow), mounted at the crank of the wing, activates at a higher angle of attack than the outboard six inch long stall/spin strip that looks like a small piece of angle iron (white arrow).

As the aircraft is pitched up the airflow comes from underneath the outboard stall/spin strip. If the airflow comes from underneath the sharp edge of the stall/spin strip, the local airflow immediately behind the stall/spin strip separates from the wing and flows aft in a narrow turbulent stream. Because, as shown in Figure 5, the elevator balance horn is located immediately behind the small outboard stall/spin strip, the narrow stream of separated turbulent air impinges on the horn and shakes the elevator and hence the control yoke — in effect it acts as an aerodynamic stick shaker.

As the aircraft continues to pitch up at a moderate rate, the inboard stall/spin strip located at the crank of the wing activates. Here a stronger locally separated turbulent flow is generated which, as Figure 5 indicates, impinges on the center of the elevator and literally shakes the entire aircraft with

Figure 4. Vortex generators installed on wing.

a significant up and down pitching motion. If the aircraft continues to pitch up at a moderate rate, a full stall occurs. Hence, with moderate or faster pitch-up rates there are two significant warnings of an impending stall. This constitutes good design.

Flight tests without VGs The no VG flight tests were conducted by a single pilot at pressure altitudes from 4000 to 8000 feet. Takeoff weight was 2861 lbs. The weight during the flight tests varied

Figure 5. Stall/spin strips.

from 2839 to 2746 lbs. The center of gravity was 80 inches aft of the datum. Tests were conducted at bank angles from zero to thirty degrees both to the left and to the right. Power off tests were conducted at idle power in descending glides. Power on tests were conducted both at full throttle and 2700 RPM and in the power approach configuration (2300 RPM and approximately 23 inches of manifold pressure or full throttle). All tests were conducted using a slow approach to stall, i.e., a deceleration of one knot per second or less as specified in FAR 23.201. Fuel burn was from the left tank.

In the power off clean configuration (gear and flaps retracted), flight test results show that for zero bank angle the aircraft stalls at 61+1/–0 miles per hour indicated airspeed (MIAS). Noting that the POH shows negligible airspeed correction at 60 mph, at the test weight the POH gives a stall speed of 66.7 MIAS at 2800 lbs. The most likely explanation for the difference in stall speeds is the FAR requirement that the value in the POH be for the worst case (FAR 23.49), which is typically for the center of gravity at the forward limit of 77 inches.

In both right and left 20° banks, stall occurred at 64 MIAS, while in right and left 30° banks stall occurred at 69±1 MIAS. In all cases a mild wing drop (typically to the right) occurred or the aircraft gently bobbled up and down while descending. In all cases, solid aileron control was maintained up to and into the stall. This is not surprising, in view of the fact that both experimental tuft and analytical studies show that on the Bonanza wing stall begins at the trailing edge 1–2 feet outboard of the root and smoothly progresses forward and outward on the wing. The flow on the wing in the region of the ailerons does not begin to separate until the stall is nearly fully developed on the inboard portions of the wing. Stall recovery was initiated by returning the control column to a neutral position. Power was not added.

In the power off dirty configuration (gear and flaps extended) flight test results show that for zero bank angle the aircraft stalls at 53+0/−1 MIAS. In 20° left and right banks stall occurs at 55+0/−1 MIAS, while in a 30° left bank stall occurred at 59 MIAS. At stall a mild left wing drop or gentle bobble occurred. Aileron control was good.

At full power at 7500 feet pressure altitude (22 inches MP and 2700 RPM) in the clean configuration with zero bank angle, stall occurred at an average of 55 MIAS while climbing in excess of 500 fpm. Full right rudder was required. In the power approach configuration (full throttle – 21.5 inches MP and 2300 RPM) at 7800 feet, gear and flaps extended with zero bank angle, stall occurred at 54 MIAS. Full right rudder as well as some right aileron was required to overcome a left turning tendency. Good control was maintained. Prior to the stall the aircraft continued to climb. Upon stall the aircraft rolled to the right. In 20° left and right banks the aircraft also stalled at 54 MIAS. Again, full right rudder as well as some right aileron was required to overcome a left turning tendency. Good control was maintained. Prior to the stall the aircraft continued to climb. Upon stall a mild left wing drop occurred.

Flight tests with VGs The flight tests with the VGs installed were conducted under the same conditions as those without VGs installed. In the power off clean configuration for zero bank angle the aircraft stalled at 53 ± 1 MIAS with the VGs installed, which represents a reduction of 8 MIAS compared to without VGs. The stall was not as well behaved as without the VGs installed. The resulting wing drop was more aggressive. The stall warnings generated by the stall/spin strips were significantly decreased. The most likely explanation for the decreased stall warning is that the VGs cause the separated flow from the stall/spin strips to reattach to the wing until significantly higher angles of attack. At these higher angles of attack the wing stalls more abruptly with the VGs installed.

In the power off dirty configuration with VGs installed the aircraft stalled at 50±1 MIAS, which represents a reduction of 3 MIAS compared to without VGs installed. In this configuration stall occured with the column full aft. Using 25° of trim, i.e., all available trim, was insufficient to reduce the stick force to zero. With the ball centered, the aircraft bobbled upon stalling. This observation, along with the small difference in stall speed with the VGs installed and the full aft column, *suggests* that, using the slow stall technique, a fully developed stall *may not* have occurred because of lack of elevator power. Vortex generators on the underside of the horizontal stabilizer ahead of the elevators to increase elevator power may be indicated. Aileron control was solid.

At full power (22 inches MP, 2700 RPM, OAT of 45° F at 7600 feet pressure altitude) in the clean configuration with zero bank angle, stall occurred at 52 ± 1 MIAS while the aircraft was climbing. Full right rudder and partial right aileron was insufficient to prevent a left turning tendency. In the dirty configuration with zero bank angle stall occurred at 47 ± 1 MIAS. Full right rudder with partial right aileron was necessary. Aileron control was solid. During stall, significant wing drop of as much as 45° occurred.

In the power approach configuration (23 inches MP and 2300 RPM) gear and flaps extended with an OAT of 50° F at 7500 feet pressure altitude with zero bank angle the aircraft stalled at $50 + 1/{-2}$ MIAS while climbing. With the same power settings in the clean configuration stall occurred at $53 + 1/{-2}$ MIAS. Again, right rudder and aileron were required to prevent a significant left turning tendency both clean and with gear and flaps extended. In the dirty configuration left and right banks between 10° and 30° resulted in a stall velocity of 51 ± 1 MIAS independent of bank angle. Wing drops of up to 45° were experienced. Both in the full power and the power approach configurations the deck angle was estimated as $25 - 30°$.

Summary The Bonanza, as originally equipped, has excellent low speed handling and stall characteristics with good multiple stall warnings provided by two stall/spin strips. As a result, the aircraft has good short field characteristics.

At the test conditions, the VGs reduced the power-off stall speed in the clean and dirty configurations by 13% and 6% respectively. In the dirty power approach configuration a 7% decrease was found. For all test cases good aileron and rudder control were maintained. Previously, without the VGs install, I was quite happy to come down short final at 85-90 MIAS for a short field landing. With the VGs, 75-80 MIAS is quite comfortable although I generally use 82 MIAS because the stall warning horn activates at 80 MIAS. These results make a good short field aircraft even better.

As with anything, the reduction in stall speed comes with a price. Specifically, VGs adversely affect flying qualities near stall, especially aerodynamic stall warning. Furthermore, the actual stall is more aggressive as indicated by significant wing drop. However, if you need to get in and out of short fields or just want that extra margin above stall, the cost may be acceptable.

Because of recent flight restrictions, characteristics at the optional 100 pound gross weight increase were not tested. A separate article will discuss the effect of vortex generators on cruise speed.