Rogers Aerospace Engineering & Consulting
817 Holly Dr. E.
Annapolis, MD 21409
410-271-1968 (c)
www.nar-associates.com

G-58 Baron
Vortex Generator Level Flight Performance
Before and After Flight Tests

Purpose

The purpose of the level performance flight tests was to evaluate the increase in drag resulting from installation of a Micro Aerodyanmics Inc. Micro VG Kit on a G-58 Beechcraft Baron and to estimate the effect on cruise true airspeed.

The Micro VG Kit consists of 66 wing mounted vortex generators installed just aft of the boot line and 34 rudder mounted vortex generators. The rudder VGs are installed on both sides of the rudder. Eighty vortex generators are added on the underside of the horizontal stabilizer. Strakes are installed on the outside of each engine nacelle.

The Aircraft

The aircraft is a 2005 Model G-58 Beechcraft Baron. The aircraft is powered by two Continental IO-550C engines rated at 300 BHP at sea level on a standard day. The aircraft is equipped with Hartzell three blade propellers (PHC-J3YF-2UF/FC7663(K)-2R). The aircraft is equipped with a Garmin G-1000 EFIS (Electronic Flight Information System)

The Flight Tests

All flight tests were conducted by the same pilot and flight test engineer. All loose equipment in the aircraft was either removed or carefully weighted. The same equipment was aboard the aircraft for all flight tests.

Flight tests were conducted before and after the installation of the Micro Aerodynamics Inc. vortex generator kit (Micro VGs). Flight tests occurred on three different days: The first flight was used to establish a baseline without VGs installed. The second and third flights were conducted to establish the effects of VGs on the parasite drag and aircraft efficiency.

Takeoff weight on the first flight test was 5434.8 lbs. Takeoff weight on the second flight test was 5422.8 lbs. The takeoff weight on the third flight test was 5376 lbs. During the flights, while data was being taken, the weight decreased as fuel was consumed. Fuel remaining was carefully recorded to allow determination of the actual aircraft weight for any given data point. At take off, the center of gravity was mid-range aft of the datum and varied during the flight tests. All flights were conducted at a pressure altitude of 5500 feet for a range of power available from 43% to 75% as determined using the Continental IO-550 power curves corrected for temperature. The engine was consistently leaned to 100° F rich of peak EGT for best power available.

True airspeed was determined using GPS and the horseshoe heading technique. The horseshoe heading technique uses the GPS ground speed observed in steady level flight during three legs each at a 90° heading from the previous leg to eliminate the effect of wind (see www.nar-associates.com/technical-flying/horseshoe_heading/horseshoehead_screen.pdf for an explanation). The aircraft autopilot in heading mode and with altitude hold engaged was use to minimize both altitude and heading excursions. On each leg, both the aircraft indicated airspeed (IAS) and GPS ground speed were allowed to stabilize prior to data acquisition. As a crosscheck, a second GPS ground speed was taken approximately 30 seconds later. A box pattern at headings of 0°, 90°, 180° and 270° were used for each data point. Data from the four legs is then combined to yield the true airspeed (TAS) for each three legs and the results averaged. This also allows discarding the results from an obviously incorrect leg triplet.

Additional Flight Tests

During the second and third flights two additional flight tests were performed to evaluate the effect of VGs when executing a power approach and during landing and the initial segment of a go-around. The power approach configuration (PA) is gear down, flaps approach (18.3°), cowl flaps and all vents closed. The landing configuration (LNG) is gear down, flaps full (33.7°), cowl flaps open, all vents closed. Flap deflection was measured with a digital inclinometer 5 inches outboard of the fuselage at the flap/wing junction.

Results

The equivalent parasite drag area, f, is a measure of all the drag not associated with the production of lift. Parasite drag is most important in the high speed range, e.g., during cruise. The Oswald aircraft efficiency factor, e, is a measure of the induced drag of the aircraft, particularly of the efficiency of the wing. The induced drag is most important at high lift coefficients, i.e., in the slow speed range, e.g., maximum range speed, approach, landing and slow flight on the backside of the power curve.

The values for f and e are determined by plotting the thrust horsepower multipled by the true airspeed versus the true airspeed to the fourth power. Thrust horsepower is brake horsepower times the propeller efficiency. The result should be a straight line. The slope (inclination to the horizontal axis) is used to determine f. The *larger* the slope (higher inclination) the *higher* the value of f and hence the *larger* the parasite drag.

The intercept of the line with the vertical axis is used to determine the Oswald aircraft efficiency factor e. The greater the slope, the larger f, i.e., the more drag. The *higher* the line intercepts the vertical axis the *lower* the value of e and hence the less efficient the aircraft. Additional details and explanation are available at http://www.nar-associates.com/technical-flying/flttst/eftrueairspeed_screen.pdf

The results for all flight tests, reduced to sea level on a standard day at the aircraft gross weight of 5500 lbs, are shown in Figure 1. Clearly, the data is linear.

Vortex generator effect on the clean configuration

Looking first at the clean configuration the results clearly show that the parasite drag (f) increases when the vortex generators are added. In the clean configuration the value of f increases from 5.4723 ft^2 to 5.7266 ft^2 , an increase of 4.6% as shown in Figure 1 and in Table 1.

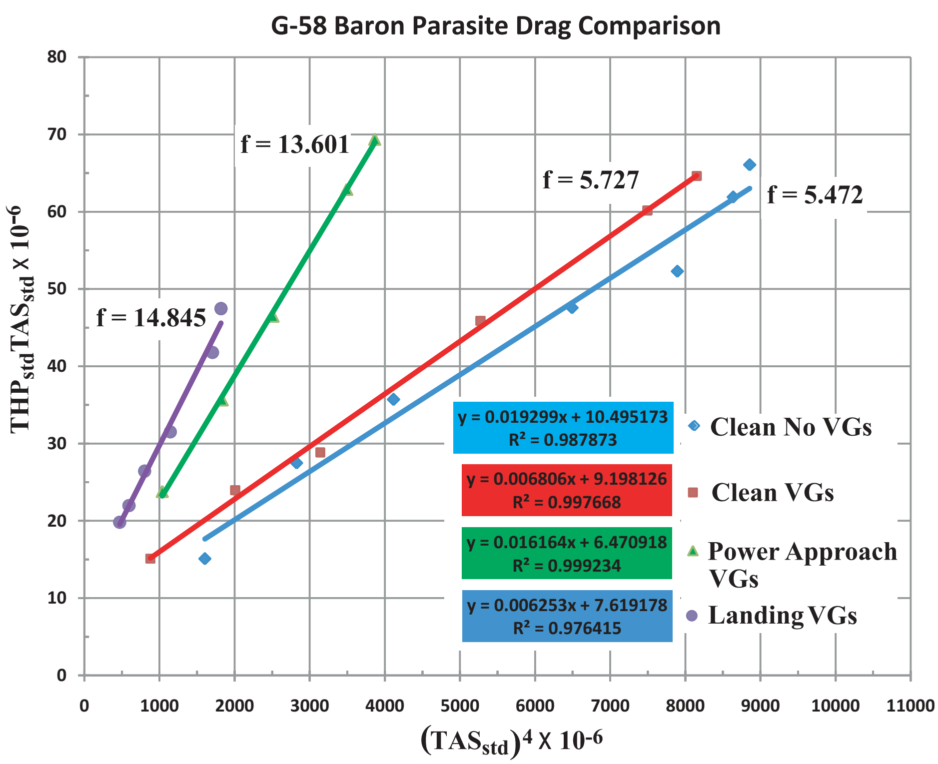

Figure 1. G-58 Baron parasite drag comparison with and without VGs, standard day at sea level and 5500 lbs.

Table 1 VG Effects On Parasite Drag, f, and Aircraft Efficiency e

Configuration	f	Delta f	% Increase	e	Delta e	% Decrease
Clean Without VGs	5.4723	0	0	0.804	0	0
Clean With VGs	5.7266	0.2543	4.6	0.614	-0.190	23.6

A 4.6% increase is significant because the parasite power required to maintain level flight increases directly with the increase in parasite drag (f).

Using the values of f and e from the Table 1, Figure 2 illustrates the effect of the vortex generators on the power required to maintain steady level cruise flight at a pressure altitude of 6000 ft on a standard day at a weight of 5200 lbs . Clearly, the additional drag of the vortex generators results in an increase in power available to maintain a given true airspeed speed. Alternatively, the cruise true airspeed is decreased for a given power available.

Vortex generator effect on cruise airspeed

Figure 3 shows the decrease in true airspeed with vortex generators installed for a given power available for a typical cruise altitude of 6000 ft on a standard day. For example, at 75% power available, which loosely corresponds to full throttle and 2500 RPM, the cruise true airspeed is decreased by approximately 5.4 KTAS.

Notice that the decrease in cruise true airspeed is larger for lower BHP available, i.e., at lower true airspeeds than at higher true airspeeds. At the higher true airspeeds the change in parasite drag dominates, while the change in induced drag has little effect. However, at lower true airspeeds induced drag is dominant. Hence, the aircraft efficiency, e, is dominant while the change in parasite drag has little effect. Notice also, that the percentage change in the value of e is significantly larger than that in f.

Vortex generator effect on rate of climb

The velocity for maximum rate of climb decreases as the fourth root of the ratio of f with and without vortex generators. In this case, the effect is small, i.e., a reduction of approximately 1%.

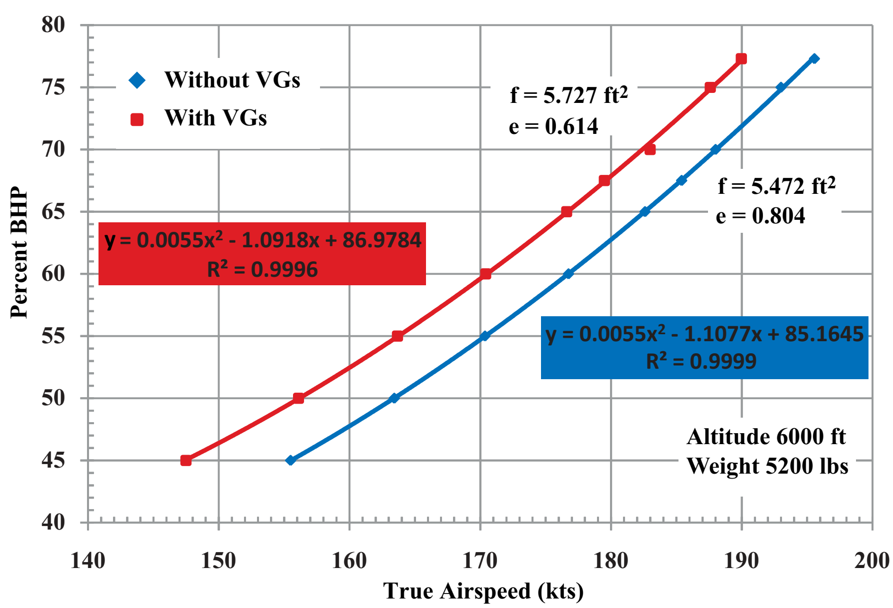

Figure 2. Percent brake horsepower versus true airspeed; standard day at 6000 ft at a weight of 5200 lbs .

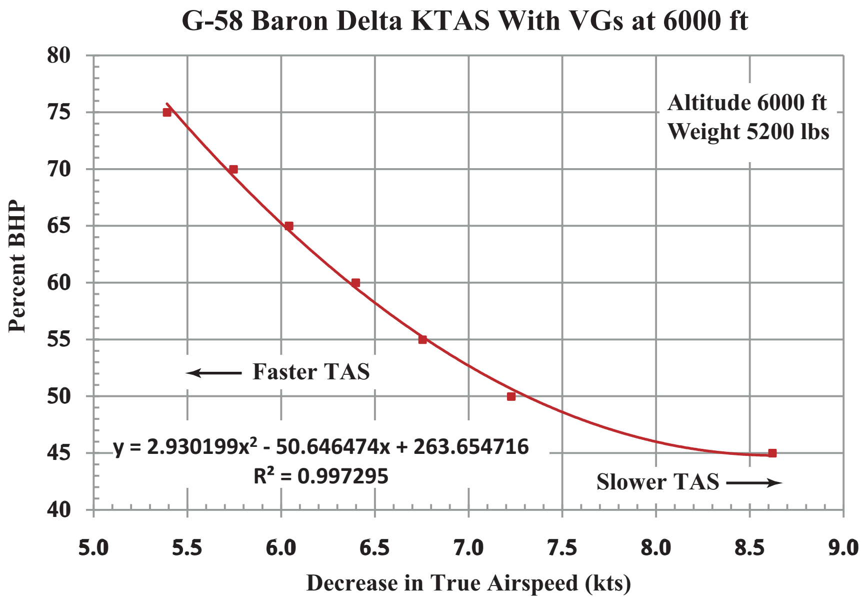

Figure 3. Decrease in true airspeed for a given brake horsepower available at 6000 ft on a standard day.

For a given weight and power available the reduction in rate of climb is directly proportional to the increase in power required as a result of the increase in drag caused by the vortex generators. Figure 4 presents an estimate of the decrease based on the flight test results. The decrease in rate of climb at the speed for maximum rate of climb is estimated as 160 fpm.

Vortex generator effect on lift to drag ratio

The velocity for maximum lift drag ratio (maximum glide and maximum range speed) decreases as the square root of the ratio of the f with and without vortex generators. In this case, the effect is small, i.e., a reduction of approximately 2%.

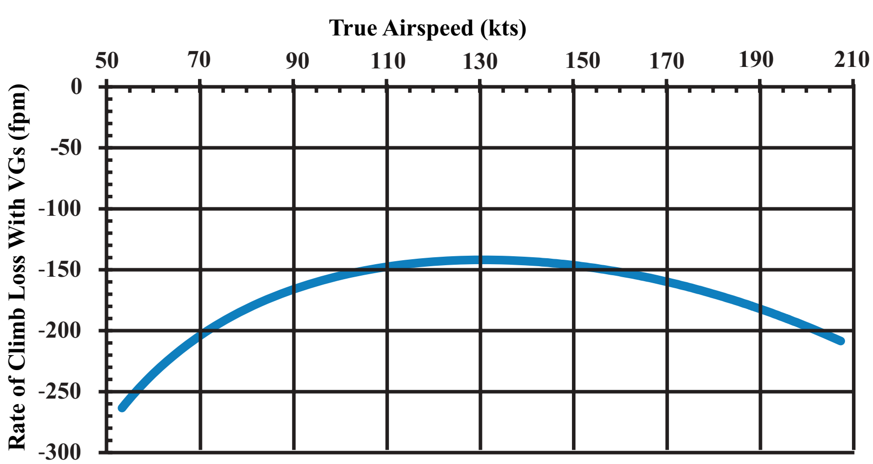

Figure 4. Rate of climb decrease with VGs installed; standard day, sea level, maximum power.

Vortex Generator Installed Flight Tests

Figure 1 also shows the effects on parasite drag with VGs installed when flaps and gear are extended, i.e., in the power approach (PA) and landing (LNG) configurations. Based on data from this limited series of flight tests the calculated theoretical change in the speeds for maximum rate of climb and maximum lift to drag ratio referenced to the clean no vortex generators installed configuration are give in Table 2. The no vortex generator installed clean configuration speeds should be multiplied by the values in columns five and six of Table 2 to approximate the speeds for the clean configuration with vortex generators installed as well as for power approach (PA) and landing (LNG) configurations with vortex generators installed.

Table 2 Configuration Effects On Parasite Drag

Configuration Baseline Clean	f	Δf No VGs	% Increase No VGs	$V_{R/C_{\max}}$ No VGs	$V_{L/D_{\max}}$ No VGs
Clean Without VGs	5.4723	0	0	1.0	1.0
Clean With VGs	5.7266	0.2543	4.6	0.9887	0.9775
PA With VGs	13.6007	8.1284	148.5	0.7964	0.6343
LNG With VGs	14.8450	9.3727	271.3	0.7792	0.6071

Effect of aircraft configuration and density altitude

Figure 5 shows the effect of aircraft configuration and density altitude on both the rate of climb and the true airspeed for maximum rate of climb.[†] As previously mentioned, Figure 5a illustrates that the true airspeed for maximum rate of climb is not significantly affected by the installation of vortex generators. However, compared to the clean configuration the maximum rate of climb is reduced by approximately 8% by the installation of vortex generators. True airspeeds are used here because the G1000 system has the ability to display true airspeed in real time.

In both the PA (gear down, flaps approach, cowl flaps open) and LNG (gear down, flaps full, cowl flaps open) both the rate of climb and the speed for maximum rate of climb are significantly reduced. Compared to the clean configuration *with vortex generators installed* the maximum rate of climb is reduced by approximately 18% in the PA configuration and by approximately 38% in the LNG configuration. Furthermore, the speed for maximum rate of climb is reduced by approximately 27% from approximately 113 KTAS to approximately 89 KTAS. Both the reduction in maximum rate of climb and the speed for maximum rate of climb in the PA and LNG configurations have implications for a missed instrument approach and/or a balked landing. In both cases, appropriate speed control is significant.

Figure 5b depicts the effect of density altitude on maximum rate of climb and the speed for maximum rate of climb. First, note that the true airspeed for maximum rate of climb does not change significantly from the sea level case. However, as expected, the available rate of climb decreases.

[†]The rate of climb shown in Figure 5 is somewhat higher than shown in the POH. This is attributed to the fact that the propeller efficiency curve for the Hartzell propeller installed on the aircraft is not available. Hence, the propeller efficiency curve was built up using the method described in Perkins and Hage *Airplane Performance Stability and Control* adjusted to give approximately 88.5% efficiency in cruise. Hence, only percentage changes are given.

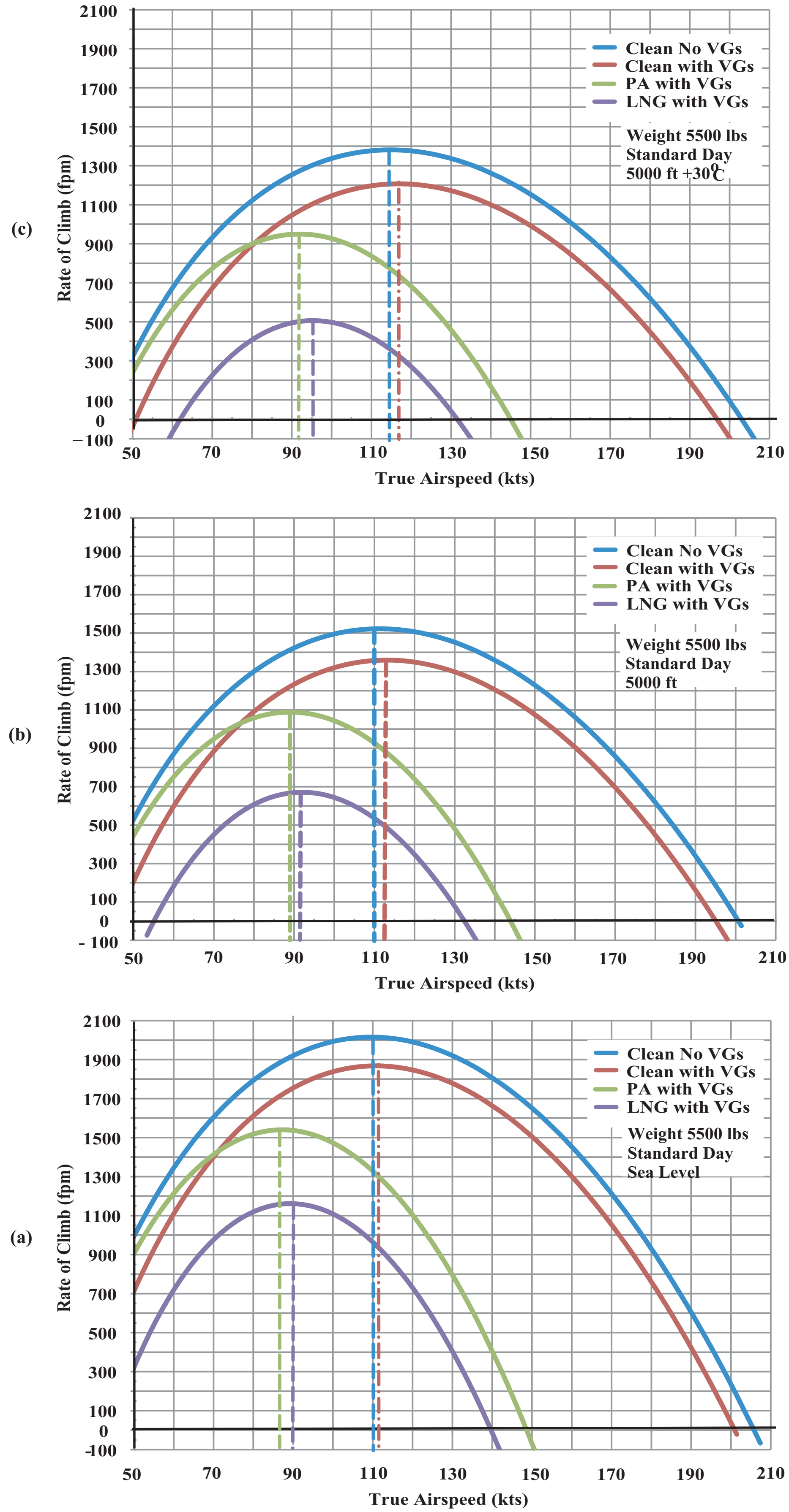

Figure 5. Effect of aircraft configuration and density altitude on rate of climb and maximum rate of climb speed; (a) sea level, standard day, (b) 5000 ft standard day, (c) 5000 ft +30°C.

With the vortex generators installed in the clean configuration the maximum rate of climb at 5000 ft is reduced by approximately 32%. With the vortex generators installed the maximum rate of climb in the PA configurations is reduced by approximately 25% compared to the clean configuration with vortex generators installed. In the LNG configuration the maximum available rate of climb is *halved* compared to the clean configuration with vortex generators installed.

Looking now at Figure 5c shows the effects of increased temperature above that for a standard day. Compared to the standard day clean configurations with vortex generators installed, a +30°C day reduces the maximum rate of climb by approximately 13%. The increased temperature reduces the maximum rate of climb in the PA and LNG configurations by 15% and 32% respectively.

Conclusions

1. Addition of vortex generators increases the drag of the aircraft.

2. The increased drag results in an estimated reduction in cruise airspeed of approximately 5.4 KTAS at a typical cruise altitude of 6000 ft . At slower speeds, e.g., for maximum range, the reduction in airspeed can be as much as 8.5 KTAS. The actual speed for maximum range does not decrease significantly. However, it takes additional power and hence additional fuel to maintain that speed with a resulting decrease in range.

3. Installation of vortex generators decreases the rate of climb in the clean configuration by an estimated 150 fpm.

4. Analysis of the results of the flight tests with vortex generators installed shows that in the clean configuration the speed for maximum rate of climb does not change significantly with and without vortex generators.

5. Analysis of the results of the flight tests with vortex generators installed shows that speed for maximum rate of climb is not significantly different in the PA and LNG configuration.

6. Analysis of the results of the flight tests with vortex generators installed shows that significant reduction in rate of climb in the PA and LNG configurations occurs with increasing density altitude. For example, at 5000 ft the rate of climb in the LNG configuration is *halved*.

The results from the level flight performance flight tests are, as anticipated, mostly negative, e.g., lower cruise speed, less rate of climb and less range, etc. Anticipated positive results will result from the stall and single engine flight tests, e.g., lower lift off speed, lower stall speed, and improved controllability. It is the owner/operators judgement as to whether the positive results outway the negative results.

