Tip Tank Flight Tests

by David F. Rogers

Tip tanks are an apparent attractive addition to nearly any Bonanza that is used for long range flight. The two principal STCs are from Beryl D'Shannon and J. L. Osborne. The D'Shannon tanks add 15 gallons a side, while the Osborne tanks add 20 gallons a side. This increased fuel capacity translates to approximately two additional hours of fuel for the fiberglass D'Shannon tanks, and nearly three additional hours for the aluminum Osborne tanks at typical cruise altitudes and speeds. Both STCs offer a modest gross weight increase, although with a change from utility category (4.4 gs) to normal category (3.8 gs) when the tanks contain fuel.

The tip tanks affect the aerodynamic characteristics of the aircraft. In particular, they increase both the aerodynamic damping in yaw and roll, resulting in a decrease in the frequency of the Bonanza dutch roll mode. The result is a perceived reduction in the characteristic Bonanza 'tail wag'. They also decrease the roll rate of the aircraft, especially when the tanks are full. The result is that the aircraft feels 'heavier' in roll.

The tanks increase the parasite drag of the aircraft and hence decrease the speed attainable at any given power setting. However, the tanks also act to decrease the intensity of the tip vortex and hence decrease the induced drag of the aircraft. An interesting question is how do these two effects interact? Is the net result a decrease in drag and thus an increase in speed, or an increase in drag and thus a decrease in speed for any given power setting?

Recalling the power required equation

$$P_r = \underbrace{\frac{\sigma\rho_{\text{SL}}}{2} f V^3}_{\text{parasite}} + \underbrace{\frac{2}{\sigma\rho_{\text{SL}}}\frac{1}{\pi e}\left(\frac{W}{b}\right)^2\frac{1}{V}}_{\text{effective induced}}$$

where

- b is the wing span;
- e is the so called Oswald efficiency factor;
- f is the equivalent flat plate area or the equivalent parasite drag area;
- W is the weight of the aircraft;
- V is the true airspeed (TAS);
- ρ_{SL} (rho sea level) is the density at sea level;
- σ (sigma) is the ratio of the density at altitude to that at sea level ρ/ρ_{SL}

or simplifying to

$$P_r = \underbrace{\text{Const}\, fV^3}_{\text{parasite}} + \underbrace{\text{Konst}\,\frac{1}{e}\Big(\frac{1}{b}\Big)^2\frac{1}{V}}_{\text{effective induced}}$$

where Const and Konst are constants, we can anticipate the results. Specifically, note that the first term in the equation, the parasite power required, involves the equivalent parasite drag area, f, and is proportional to the cube of the true airspeed, V. Because f increases when tip tanks are added we expect that adding tip tanks will decrease the true airspeed at high cruise airspeeds and power settings.

However, the second term, the effective induced power required, involves the Oswald efficiency factor, e. The Oswald efficiency factor is increased by the effect of the tip tanks. The induced drag is also decreased. Hence, the effective induced power required is reduced. Because the effective induced power required is inversely proportional to the velocity, it is most important at low true airspeeds which correspond to high wing lift coefficients and high induced drag. Notice that this term is also inversely proportional to the wing span, b. If the tip tanks increase the effective wing span, then the effective induced power required is reduced.

If the increase in parasite power required occurs at high true airspeed while the decrease in effective induced power required occurs at low true airspeed, then there must be some true airspeed at which the effects are equal and cancel each other. Typically, an aircraft designer wants that true airspeed to be the design cruise true airspeed.

To answer this question, comparative flight tests were carried out on two model E33A Bonanzas – N7960R (CE-270) and N2255A (CE-280). Both aircraft have essentially the same empty weight at 2151 lbs for N7960R and 2142 lbs for N2255A, including the weight of six gallons of unusable fuel and ten quarts of oil. N7960R is equipped with Beryl D'Shannon tip tanks; N2255A is not. Both aircraft had recently overhauled McCauley 3-blade propellers. Both aircraft had approximately 100 hours on recently installed IO-520BB factory remanufactured engines.

The flight tests were conducted at a pressure altitude of 6000 feet. The horseshoe heading technique† was used to determine the true airspeed from GPS ground speed at brake horsepower settings from 42.5% to 75% for N2255A and from 44% to 74.5% for N7960R. A stroboscopic Proptach was used to measure propeller RPM, and the aircraft instrument was used to measure manifold pressure in order to determine power available. Mixture was set to correspond to best power, i.e., approximately 100° rich of peak. Takeoff weight was 2952 lbs for N7960R and 3209 lbs for N2255A. During the flight tests, weight varied from 2960 lbs to 2897 lbs for N7960R and from 3186 lbs to 3097 lbs for N2255A. Outside air temperature (OAT) varied from 59° F to 62° F for the N7960R flights, with most flights occuring with an OAT of 62° F; for N2255A the OAT was constant at 33° F. Manifold pressure varied from approximately 19"Hg to 23"Hg in 1"Hg increments, while propeller speed varied from approximately 2000 to 2500 RPM in 100 RPM increments. The results of these flight tests are shown in Figure 1. No weight or temperature corrections have been applied to the TAS data.

† http://www.nar-associates.com/technical-flying/
horseshoe_heading/horseshoehead.pdf

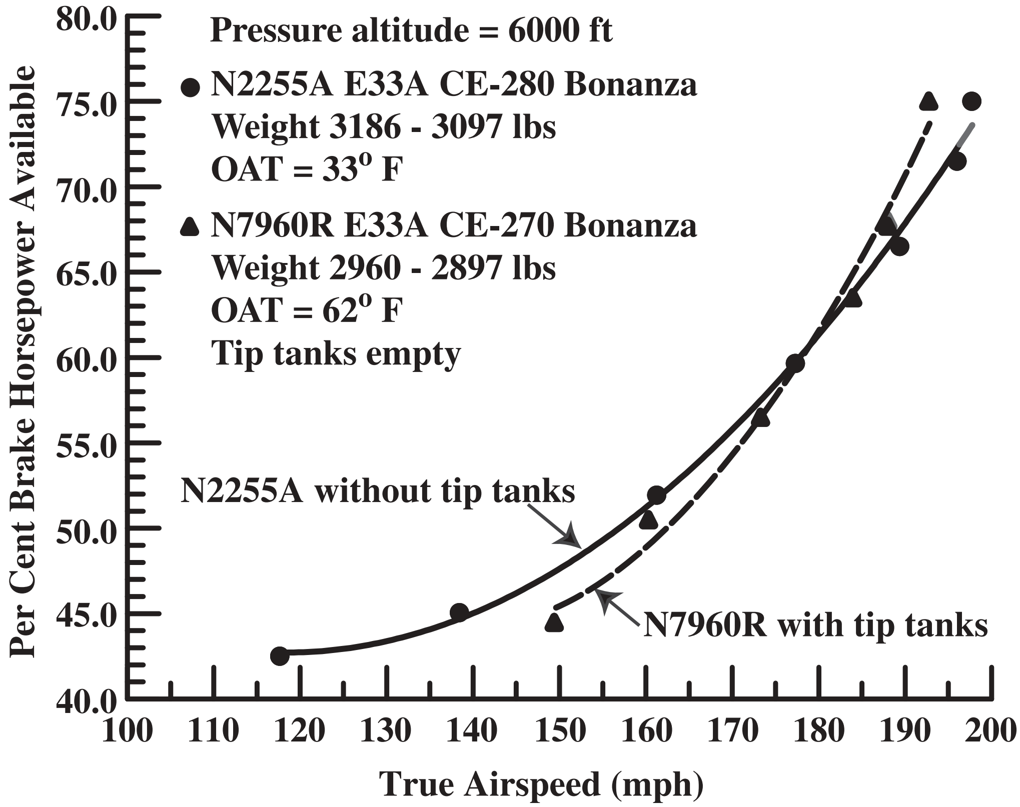

Figure 1. Flight test results.

Looking at Figure 1 we immediately see that the results are as expected. Specifically, adding tip tanks decreases the TAS at high speed because of the increase in parasite drag and increases the TAS at low speeds because of the reduction in induced drag. Furthermore, careful examination shows that the cross-over point is at approximately 58–60% brake horsepower available. Sure enough, if you check the POH you'll find that on a warm summer day full throttle and 2300 RPM yields approximately 60% power between 6000 and 8000 feet. Also, recalling our discussion of the most efficient way to waste fuel calls for approximately 59% power at approximately 8300 feet (see the WBS Newsletter, August 2003 pp. 14-15). Hence, adding the Beryl D'Shannon tip tanks results in little or no loss in TAS at typical medium cruise altitudes and powers. However, if you typically cruise at lower altitudes and higher power, then there will be a small but non-negligible loss in TAS. If you typically cruise at higher altitudes where the full throttle available power is lower, then you might see a small increase in TAS.

Notice also that the results shown in Figure 1 for N2255A provide confidence in the data. Specifically, at 65% power on a standard day, where the OAT is 42° F at 6000 feet for a gross weight of 3100 lbs the POH yields a TAS of 186 mph. Under approximately the same conditions, the data for Figure 1 also yield a TAS of 186 mph.