Engine Upgrade Performance

IO-470 to IO-550

by David F. Rogers
email: dfr at nar-associates.com
First appeared in the Newsletter of the Australian Beechcraft Society, June 2003.

Your engine is at TBO or beyond. It is now time to consider an overhaul, a factory remanufactured engine, or even an upgrade to a larger engine. For those of us with the 225 bhp IO-470 or the 285 bhp IO-520 engines there is the temptation to upgrade to a larger engine. For those with the IO-520 upgrading to the IO-550 is tempting. For those with the 225 bhp IO-470 the tempation is to upgrade to either an IO-520 or go all the way to the IO-550.

Based on research, the difference in installed cost of a factory remanufactured IO-520 and an STC'd factory remanufactured IO-550 is approximately $8,000. The upgrade from an IO-470 to either an IO-520 or IO-550 is quite a bit more expensive. One STC holder estimates about $38,000 for the IO-520 upgrade because it needs new exhaust manifolds and pipes, cooling baffles, hoses, air duct, heat shield, engine mounts, air box assembly, alternator conversion, the tachometer and manifold gauges remarked and recalibrated as well as possibly new mixture, throttle and propeller cables, vacuum pump and propeller governor. It may be possible to use the existing propeller but, if not, than a new one is required at an additional $8,000. The price includes an exchange factory remanufactured engine and the core upgrade charge. Installation is extra. No additional gross weight increase is currently available. In round numbers the upgrade will cost between $46,000 and $50,000 USD. The upgrade from the IO-470 to the IO-550 definitely includes a new propeller so figure on $50,000 because of the increased core upgrade charge and a more expensive STC. The most recent STC does not require the addition of cowl flaps. However, based on experience flying an A-36 with an IO-550 conversion, I think I'd add them anyway. What performance increase do these increased costs buy you? For example, what increases in cruise speed and rate-of-climb can be expected from the increased horsepower?

Currently there is considerable discussion about the different certification standards for the IO-470/IO-520 and the IO-550. These engines were all certified *without* accessories attached (FAR 33.45/49). The IO-470 and the IO-520 were certified at 225 bhp and 285 bhp $\pm 2.5\%$ respectively while the IO-550 was certified at 300 bhp $+5\%$ -0%. The accessories on these engines are: alternator, vacuum (pressure) pump and air conditioner, if fitted. All other operational parts of the engine, e.g., fuel pump, magnetos, oil pump, etc. were attached when certified. With few aircraft fitted with air conditioners, that really leaves just the alternator and vacuum (pressure) pump to absorb power. The vacuum (pressure) pump absorbs negligible power and in daylight cruise the alternator absorbs perhaps three brake horsepower. Subtracting 2.5% and the alternator loss leaves an estimated minimum of 216 bhp for the IO-470 ($225 - 0.025 \times 225 - 3 = 216$) and 275 bhp for the IO-520 ($285 - 0.025 \times 285 - 3 = 275$).

Additional power losses result from back pressure in the exhaust system and pressure loss in the air intake system. However, the exhaust system on these engines is fundamentally an open stack which results in minimum back pressure. Notice also that the air intake is cleverly positioned such that the propeller acts as a 'pump' to increase the intake pressure as the blades pass across the intake – higher intake pressure results in more air in the cylinders and thus more power from the additional fuel that can be burned. The net result of the these two effects is probably neutral, i.e., no net power loss or gain.

Consequently, the estimated minimum installed brake horsepower for an IO-470 is 216 bhp and for the IO-520 is 275 bhp and the estimated maximum installed brake horsepower for the IO-470 is 228 bhp ($225 + 0.025 \times 225 - 3 = 228$) while for the IO-520 the maximum is 289 bhp ($285 + 0.025 \times 285 - 3 = 289$). Similarly the estimated minimum installed brake horsepower available from an IO-550 is 297 bhp ($300 - 3 = 297$) and the estimated maximum installed brake horsepower is 312 bhp ($300 + 0.05 \times 300 - 3 = 312$). Subtracting the 3 bhp for the alternator yields a nominal 222 bhp for the IO-470, 282 bhp for the IO-520 and 297 bhp for the IO-550.

Figure 1 shows the calculated rate-of-climb versus TAS for a model E33A for 265, 275, 285, 300 and 315 brake horsepower at a gross weight of 3300 lbs at sea level on a standard day. If we plot the increase in rate-of-climb against the change in brake horsepower, as shown in Figure 2 for the IO-520 at 3300 lbs compared to 282 bhp as a base and in Figure 3 for the IO-470 at 3050 lbs on a base of 222 bhp, we see that the rate-of-climb is directly related to the change in horsepower. Can we explain this? Yes.

Recall that the rate-of-climb is calculated as the difference between thrust power available, ThP_a, and power required to maintain steady level flight, P_r, divided by the aircraft weight, W. Recall also that the thrust power available, ThP_a, is the engine power at the propeller shaft, P_a, times the propeller efficiency, η (eta), i.e. $ThP_a = \eta P_a$. Thus, our rate-of-climb equation is

$$RC = \frac{ThP_a - P_r}{W}$$

At the velocities for maximum rate-of-climb propeller efficiency is about 79%.

For the small changes in power available, the velocity for maximum rate-of-climb does not change significantly (about 3% for the IO-520 and about 7% for the IO-470 to IO-550 conversions). Consequently, the power required does not change significantly. Let's assume that the power required is constant, after all the airframe has not changed. Using the

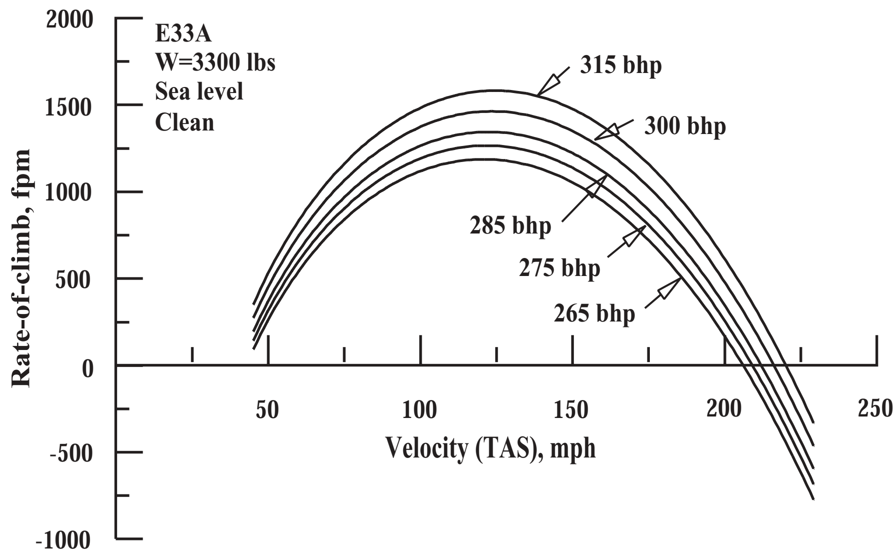

Figure 1. Rate of climb vs velocity.

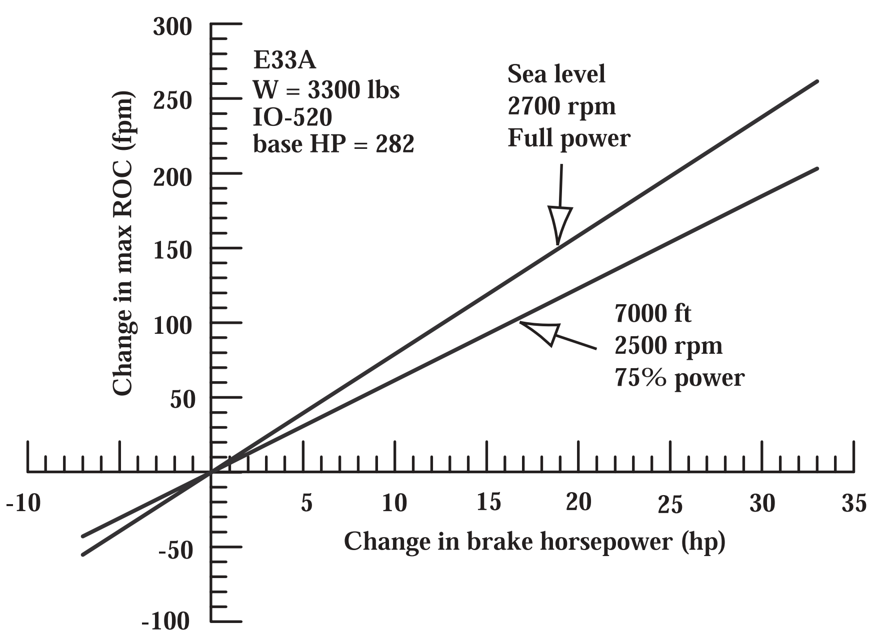

Figure 2. Change in rate-of-climb vs change in brake horsepower; IO-520 at 3300 lbs.

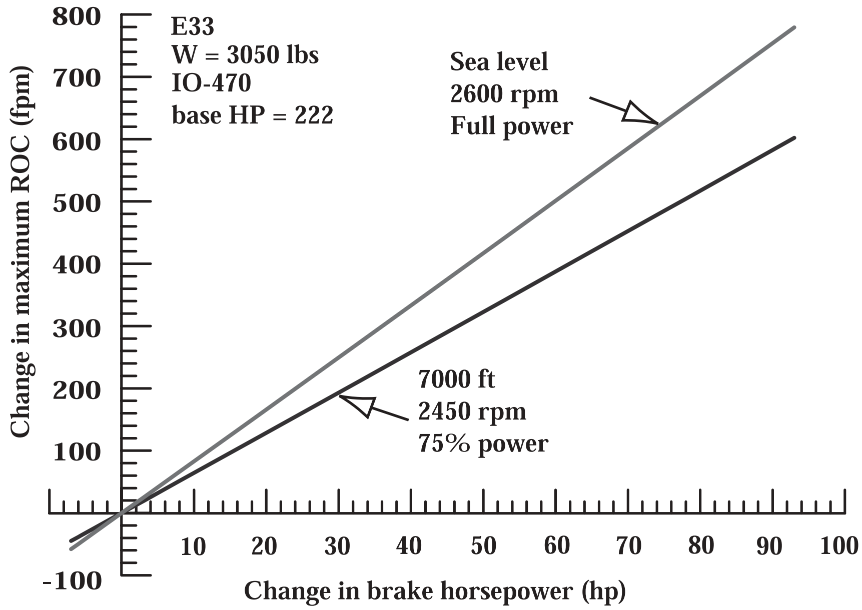

Figure 3. Change in velocity vs brake horsepower; IO-470 at 3050 lbs.

above equation twice, once for the original power available and once for the new power available and subtracting allows us to calculate the incremental change in rate-of-climb for an incremental change in thrust power available

$$\text{rate-of-climb change} = \frac{\text{thrust power avail. change}}{\text{weight}}$$

or

$$\Delta RC = \frac{\Delta ThP_a}{W} = \frac{\eta \Delta BHP_a}{W}$$

where ΔThP_a represents the change in thrust horsepower available and ΔBHP_a represents the change in brake horsepower available.

Thus, if we calculate the increase in sea level maximum rate-of-climb for an upgrade from a nominal IO-520 (282 bhp) to a nominal IO-550 (297 bhp) we have

$$\Delta RC = \frac{\Delta ThP_a}{W} = \frac{\eta \Delta BHP_a}{W}$$
$$= \frac{(0.79)(15)}{3300}(550)(60) = 119 \text{ fpm}$$

where the 550 and the 60 are conversion factors so that the result comes out in feet per minute. This is approximately the value shown in Figure 2.

Similarly the increase in sea level maximum rate-of-climb for an upgrade from a nominal IO-470 (222 bhp) to a nominal IO-520 (282 bhp) is

$$\Delta RC = \frac{\Delta ThP_a}{W} = \frac{\eta \Delta BHP_a}{W}$$
$$= \frac{(0.79)(60)}{3050}(550)(60) = 513 \text{ fpm}$$

and for a nominal IO-550 (297 bhp) is 641 fpm which again are approximately the values shown in Figure 3.

Figure 1 also shows the increase in maximum speed at sea level. Note that when the rate-of-climb is zero the aircraft is in level flight. Thus, the intersection of the rate-of-climb curve with the horizontal zero rate-of-climb line is the maximum level flight velocity. Figure 4 shows the change in maximum velocity at sea level against the change in brake horsepower for both the IO-520 at 3300 lbs gross weight and Figure 5 shows the results for the IO-470 at 3050 lbs gross weight. Notice that the change is not quite a straight line. Can we explain this? Yes – you knew I was going to say that, because I want to show you some more math, didn't you?

Remember that in steady level flight the thrust power available is equal to the power required and that the power required is made up of two parts; parasite power required and induced power required or

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

Here we are only interested in velocity so the equation simplifies to

$$Thp_a = P_r = \underbrace{\text{Constant}\, V^3}_{\text{parasite}} + \underbrace{\frac{\text{Konstant}}{V}}_{\text{effective induced}}$$

where Constant and Konstant are constants.

Now, at high velocities the second term, i.e., the effective induced power required is small and can be neglected as a first approximation.†

Thus, the equation further simplifies to

$$ThP_a = P_r \approx \underbrace{\text{Constant}\, V^3}_{\text{parasite}}$$

which means that if the thrust horsepower available increases, the velocity only increases as the cube root of the increase in thrust horsepower available, i.e., the new velocity is approximately

$$V_{\text{new}} = \sqrt[3]{\frac{\text{ThP}_{a\,\text{new}}}{\text{ThP}_{a\,\text{old}}}}\, V_{\text{old}}$$

This is rather discouraging. For example, to double the maximum velocity the thrust horsepower must be increased by a factor of *eight* because the cube root of eight is two ($2 \times 2 \times 2 = 8$). By the way, this is why the lines in Figures 4 and 5 are not quite straight – they are pieces of a cubic curve.

Most of us do not fly at sea level at maximum power but rather cruise at six to ten thousand feet at 55% to 75% brake horsepower available. Here the propeller efficiency is about 85–88%. Let's rewrite the equation taking these factors into account. The result is

$$V_{\text{new}} = \sqrt[3]{\frac{\eta c BHP_{\text{new}}}{\eta c BHP_{\text{old}}}}\, V_{\text{old}} = \sqrt[3]{\frac{BHP_{\text{new}}}{BHP_{\text{old}}}}\, V_{\text{old}}$$

†Note that for typical Bonanza cruise velocities this assumption underestimates the increase in velocity. However, it does illustrate the fundamental difficulty in increasing the speed of an aircraft.

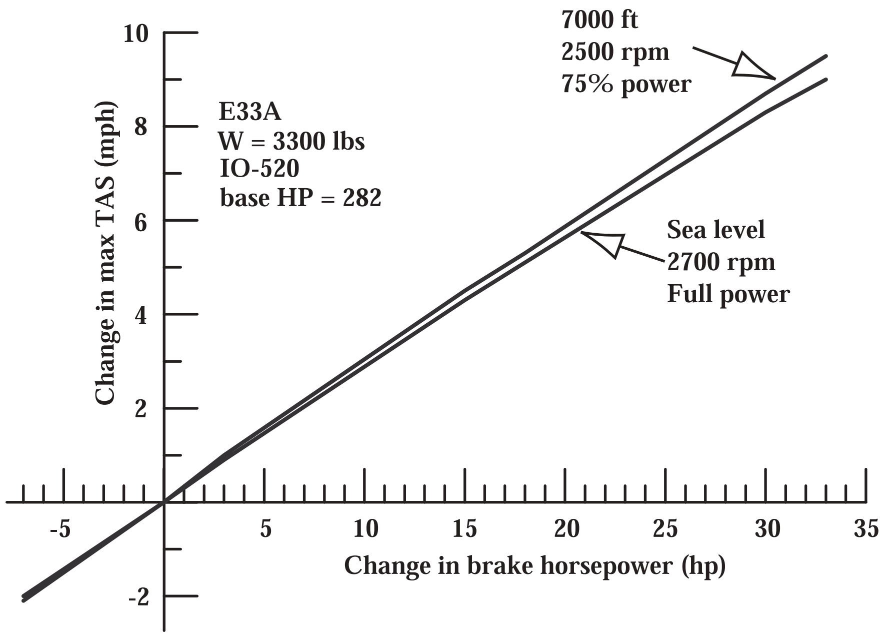

Figure 4. Effect of power available change on maximum and cruise velocity for an IO-520 at 3300 lbs.

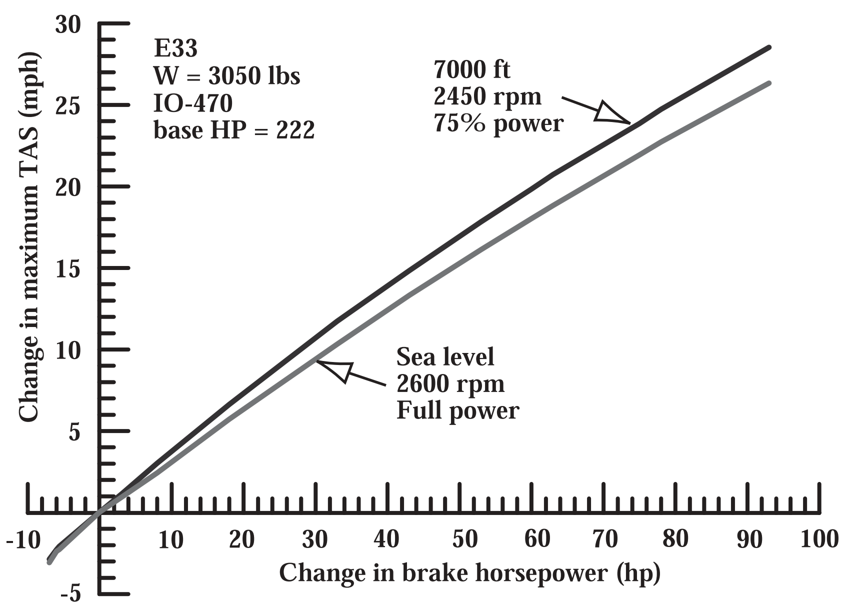

Figure 5. Effect of power available change on maximum and cruise velocity for an IO-470 at 3050 lbs.

where c is the percentage of available power in cruise. Here we see that, except for minor and negligible variations in propeller efficiency, the result is independent of the propeller efficiency and percent power, Thus, the change in velocity can be approximated by looking at the change in brake horsepower only.

Thus, if we calculate the increase in cruise velocity for an upgrade from a nominal IO-520 $(285 - 3 = 282$ bhp) to a nominal IO-550 $(300 - 3 = 297$ bhp) we have

$$\begin{aligned} V_{\text{new}} &= \sqrt[3]{\frac{BHP_{\text{new}}}{BHP_{\text{old}}}}\, V_{\text{old}} \\ &= \sqrt[3]{\frac{297}{282}}\, V_{\text{old}} \\ &= \sqrt[3]{1.053} = 1.017 \end{aligned}$$

or 1.7%. For 75% power at 7000 feet that equates to 3.5 mph $(200 \times 1.017 - 200 = 3.5$ mph) which somewhat under estimates the more exact value in Figure 4 for a change in horsepower of 15 bhp $(297 - 282 = 15)$.

Similarly the increase in cruise velocity for an upgrade from a nominal IO-470 (222 bhp) to a nominal IO-550 (297 bhp) we have

$$\begin{aligned} V_{\text{new}} &= \sqrt[3]{\frac{BHP_{\text{new}}}{BHP_{\text{old}}}}\, V_{\text{old}} \\ &= \sqrt[3]{\frac{297}{222}}\, V_{\text{old}} \\ &= \sqrt[3]{1.34} = 1.10 \end{aligned}$$

or 10%. For 75% nominal power at 7000 feet that equates to approximately 18 mph $(179 \times 1.10 - 179 = 17.9)$ which under estimates the sea level value obtained from Figure 5 for a change in horsepower of 75 bhp $(297 - 222 = 75)$.

One last comment. How do you calculate a cube root. On a calculator, but you don't have a calculator with a cube root function. In that case, a good approximation for these small differences from 1.0 is to subtract 1.0 from the number and divide the result by 3. Here, let's try that using the example above $(1.053 - 1.0)/3 = 0.0173$ or 1.73% which, to any reasonable precision, is the same number we obtained from the exact calculation above. The result for the cube root of 1.34 is $(1.34 - 1.0)/3 = 1.13$ which over estimates the result. Can you explain why this second estimate is not quite as good as the first? Well, yes because while 0.053 is small compared to 1.0, 0.34 is not and we assumed the the approximation was good for small differences from 1.0. Isn't math interesting?

