Engine Upgrade Performance?

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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 285 bhp IO-520 engines there is the temptation to upgrade to a 300 bhp 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 $8000. What performance increase does the increased cost buy you? For example, what increases in cruise speed and rate-of-climb can be expected from the increased horsepower of the IO-550.

Currently there is considerable discussion about the different certification standards for the IO-520 and the IO-550. Both engines were certified *without* accessories attached (FAR 33.45/49). The IO-520 was certified at 285 bhp ±2.5% 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 275 bhp power 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 from an IO-520 is 275 bhp and the estimated maximum installed brake horsepower 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 ($300 + 0.05 \times 300 - 3 = 312$).

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. The corresponding increases in rate-of-climb compared to that for 275 bhp are: 265/−79, 275/0, 285/79, 300/197, 315/317 fpm. If we plot the increase in rate-of-climb against the change in brake horsepower compared to 275 bhp as a base, as shown in Figure 2, 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 (less than 3%). 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

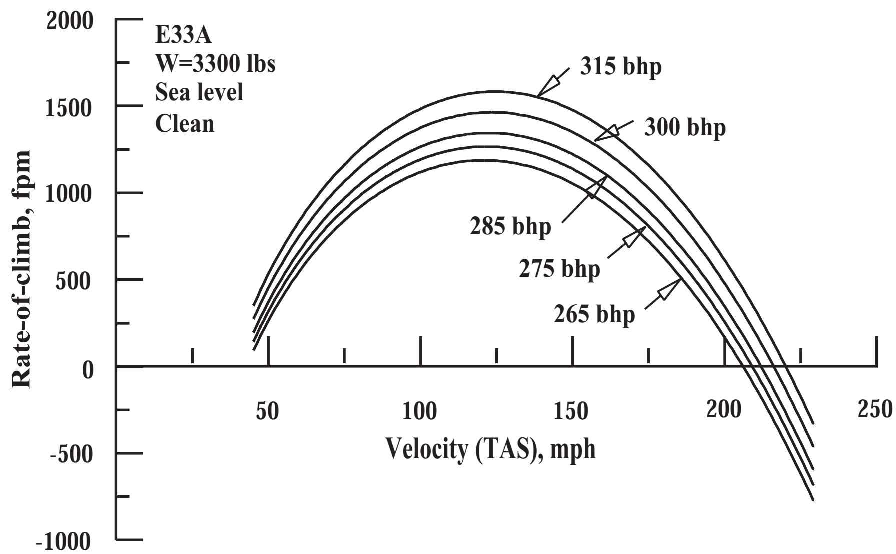

Figure 1. Rate-of-climb vs velocity.

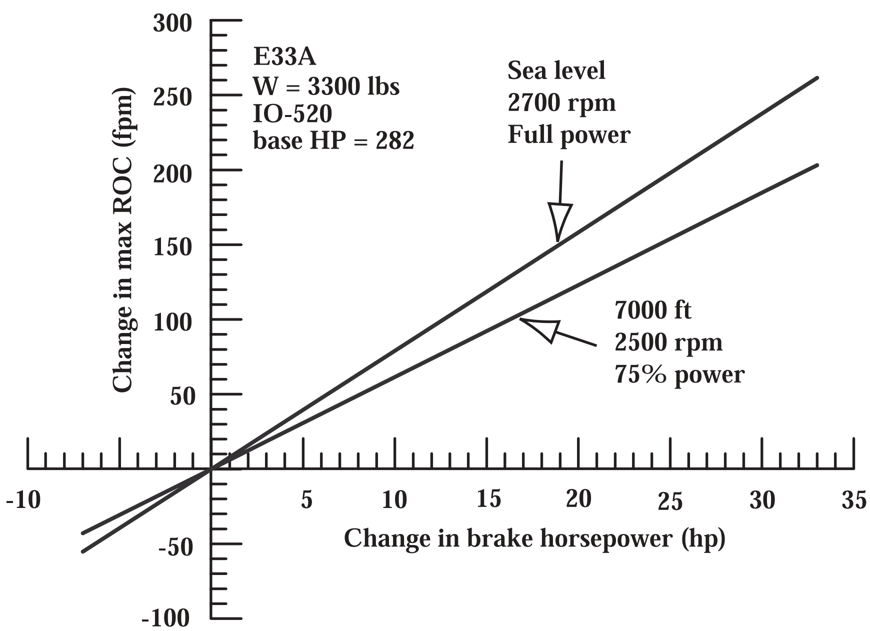

Figure 2. Change in rate-of-climb vs brake horsepower.

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 (275 bhp) to a nominal IO-550 (297 bhp) we have

$$\begin{aligned}\Delta RC &= \frac{\Delta ThP_a}{W} = \frac{\eta \Delta BHP_a}{W} \\ &= \frac{(0.79)(22)}{3300}(550)(60) = 173.8 \text{ fpm}\end{aligned}$$

where the 550 and the 60 are conversion factors so that the result comes out in feet per minute.

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. The respective increases in maximum sea level velocity compared to that for 275 bhp are: 265/−3, 275/0, 285/3, 300/7, 315/11 mph. Figure 3 shows the change in maximum velocity at sea level against the change in brake horsepower. Notice that it is not quite a straight line. Can we explain this? Yes – you knew I was going to say that 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

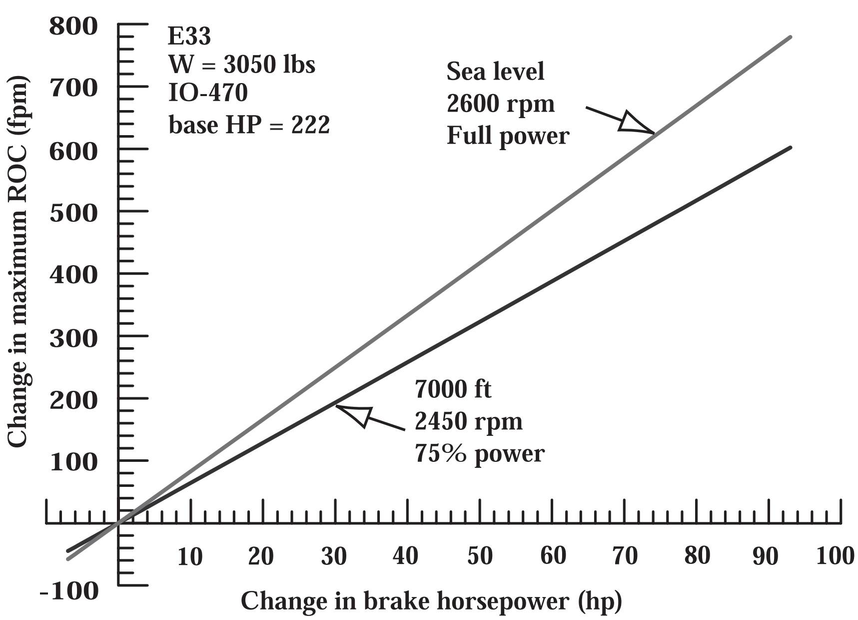

Figure 3. Change in velocity vs brake horsepower.

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 parasite drag, i.e., the first term, is dominant. As a first approximation we neglect the second term. Thus, the equation further simplifies to

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

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

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

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 line in Figure 3 is not quite straight – it is a piece 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 88%. Let's rewrite the equation taking these factors into account. The result is

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

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 is 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 (275 bhp) to a nominal IO-550 (297 bhp) we have

$$\begin{aligned} V_{\text{new}} &= \sqrt[3]{\frac{BHP_{\text{new}}}{BHP_{\text{old}}}}\; V_{\text{old}} \\ &= \sqrt[3]{\frac{297}{275}}\; V_{\text{old}} \\ &= \sqrt[3]{1.08} = 1.026 \end{aligned}$$

or 2.6%. For 75% power at 6000 feet that equates to 5 mph ($198 \times 1.026 - 198 = 5$)! Five mph corresponds closely to the value in Figure 3 for a change in horsepower of 22 bhp ($297 - 275 = 22$).

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 $(1.08 - 1.0)/3 = 0.026$ or 2.6% which, to any reasonable precision, is the same number we obtained from the exact calculation above. Isn't math interesting?

