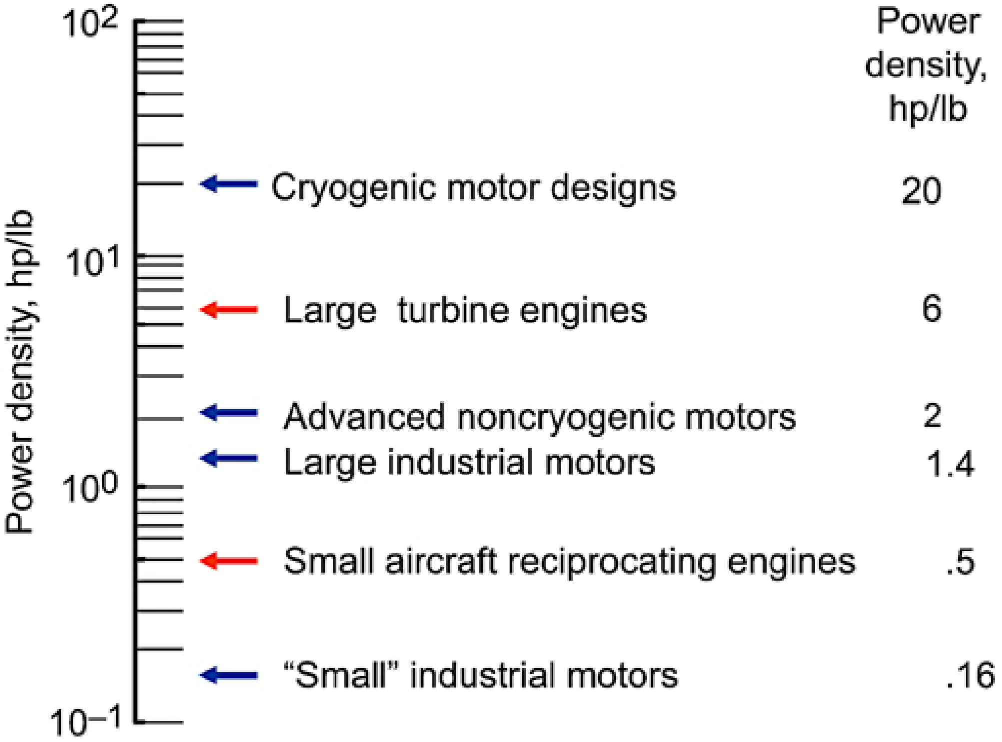
Power Requirements Determined for High-Power-Density Electric Motors for Electric Aircraft Propulsion

Future advanced aircraft fueled by hydrogen are being developed to use electric drive systems instead of gas turbine engines for propulsion. Current conventional electric motor power densities cannot match those of today's gas turbine aircraft engines. However, if significant technological advances could be made in high-power-density motor development, the benefits of an electric propulsion system, such as the reduction of harmful emissions, could be realized.



Power-density comparison of engines and motors.

Long description of figure 1. Various electric motors (cryogenic, large turbine, advanced noncryogenic, large industrial, small aircraft reciprocating, and "small" industrial) and aircraft engine power densities (20, 6, 2, 1.4, 0.5, and 0.16 horsepower per pound, respectively) are plotted for comparison.

In evaluating the power requirements for replacing gas turbine engines with electric motors, it is important to compare their relative current and potential power densities (see the preceding graph). Comparing a turbofan engine with an electric-motor-driven-fan system requires some decisions on how much power the motor must produce, as well as how much of the turbine engine is actually replaced. This comparison is not a straightforward “apples to apples” comparison, and great attention must be made when converting power and weight variables into equivalent power-density terms. Consequently, researchers at the NASA Glenn Research Center addressed several issues relating to this comparison.

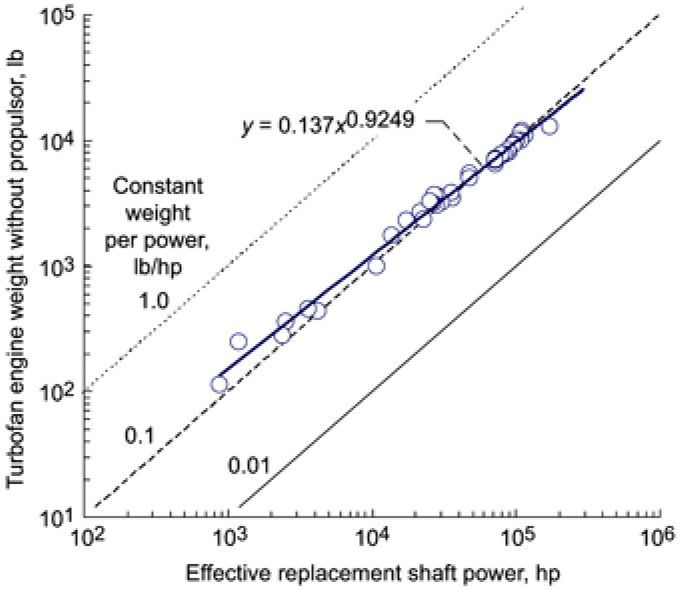
The first issue was that the published weights of turbine engines usually include the propulsor, that is, the propulsive fan and related components, such as the fan frame, brackets, supports, exit guide vanes, and containment. These propulsor components would all be required with an electric motor drive. Our first step in making an appropriate comparison of motors and turbofan engines, therefore, is to subtract the propulsor weight from the total weight of a turbofan engine. From some proprietary data we have for actual propulsor weights for large turbofan engines, the average fraction of total engine weight represented by the propulsor components is 30 percent. This factor was used to estimate the propulsor weight for all the midrange engines in our survey, even though the actual propulsor weight would vary with bypass ratio and other variables. Actual values were used for the large engines for which we had data.

A second issue was that the power delivered to the propulsive fan, which a motor would have to supply, is not typically published. Instead, the total turbofan engine thrust T_{tot} (sea-level static takeoff thrust) is published. This total thrust is the sum of the thrust from the fan and the thrust from the jet. From some proprietary data, we derived a typical relation. For engines between 15,000- and 100,000-lb thrust, the power P_{fan} (in horsepower) delivered to the fan through the fan shaft is 1.25 times the total engine static sea-level takeoff thrust in pounds.

The remaining issue was how to deal with the jet thrust of a turbine engine, which does not exist for an electric-motor-driven fan. If an electric motor were to drive the fan used in a particular turbofan engine (at the same speed and with the same torque), the resulting thrust would be lower than the total thrust of the turbofan engine including its jet. We chose a factor of 0.8 to estimate the fan thrust T_{fan} from the total turbofan engine thrust T_{tot}: that is, $T_{\mathrm{fan}} = 0.8\ T_{\mathrm{tot}}$.

Although this factor would be expected to vary from 0.8 with the bypass ratio and other variables, we used it for all the engines in our survey. Hence, we consider a replacement effective power output of the turbofan engine to be 1.25 times the fan horsepower. This power reasonably represents the power that an electric motor would have to produce to give the same thrust as a turbine engine. This would be accomplished with a somewhat larger fan than for a comparable one used in a turbofan engine.

The resulting replacement power per weight, or power density, requirements for the electric propulsion system is thus obtained (see the following graph) when all of the factors above are applied to an engine, or engine class, of interest. This power and weight relationship can be expressed as $\mathit{weight} = 0.137(\mathit{power})^{0.9249}$.



Turbofan engine weights (without the propulsor weight) as a function of effective replacement shaft power.

Long description of figure 2. This plot, using hollow blue circles with a blue line, shows the weight versus power required to replace gas turbine engines with high-power-density electric motors over a wide range of power levels. Constant weight per power is shown for 1.0, 0.1, and 0.01 pounds per horsepower.

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