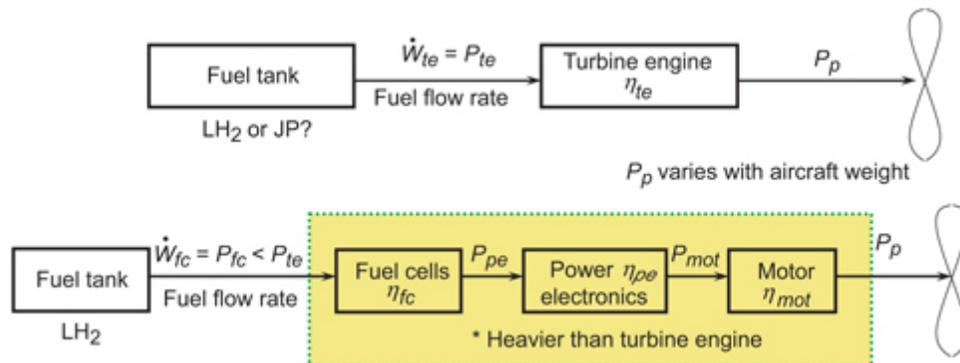# Fuel-Cell-Powered Electric Motor Drive Analyzed for a Large Airplane

Because of its high efficiency, fuel cell technology may be used to launch a new generation of more-electric aeropropulsion and power systems for future aircraft. Electric-motor-driven airplanes using fuel-cell powerplants would be beneficial to the environment because of fuel savings, low noise, and zero carbon-dioxide emissions. In spite of the fuel cell's efficiency benefit, to produce the same shaft drive power, a fuel-cell-powered electric-drive system must be definitely heavier than a turbine-drive system. However, the fuel-cell system's overall efficiency from fuel-to-shaft power is higher than for a turbine-drive system. This means that the fuel consumption rate could be lower than for a conventional system. For heavier, fuel-laden planes for longer flights, we might achieve substantial fuel savings. In the airplane industry, in fact, an efficiency gain of even a few percentage points can make a major economic difference in operating costs.

This article presents a preliminary analysis, showing how much extra propulsion system weight can be justified by a given increase in efficiency. Our simulation model, which consists of takeoff, climb, cruise, descent, and landing modules, was developed at the NASA Glenn Research Center using specifications and characteristics obtained from aircraft and engine manufacturers, Internet Web sites, and other published sources. For a comparative study, we assumed that both powerplants were fueled by liquid hydrogen (LH_2), and the Boeing 747-400 airframe with four GE CF6-80C2 engines (GE Aircraft Engines) and their characteristics were used for both systems, except that the fuselage volume change associated with most hydrogen-fueled systems was neglected.


Top: Turbine-drive system. Bottom: Fuel-cell-powered electric motor drive system. JP, jet fuel, P_{fc}, input power of fuel cell; P_{mot}, input power of motor; P_p, shaft drive power; P_{pe}, input power of power electronics; P_{te}, input power of turbine engine; $\dot{W}_{fc}$, fuel flow rate for fuel cell; $\dot{W}_{te}$, fuel flow rate for turbine engine; η_{fc}, efficiency of fuel cell; η_{mot}, efficiency of motor; η_{pe}, efficiency of power electronics; η_{te}, efficiency of turbine engine.

Long description of figure 1. Top: Diagram shows fuel tank (with liquid hydrogen or JP fuel), fuel flow rate, turbine engine, and shaft drive power (which varies with aircraft weight). Bottom: Diagram shows fuel tank with liquid hydrogen, fuel flow rate, fuel cells, input power of power electronics, power electronics, input power of motor, motor, and shaft drive power (which varies with aircraft weight).

The preceding figure shows a turbine-drive system and a fuel-cell-powered electric motor drive system. The turbine engine system directly drives the propulsor, whereas the electric motor requires fuel cells and power electronics. We first characterized each component by simple specific-power coefficients (horsepower per pound) based on the literature survey and then calculated fuel flow rate using the combustion specific energy of LH_2 for the same power to the propulsor from the two systems.

The following figure shows the simulation results for total aircraft weight as a function of time for the two systems from takeoff to landing during a 15-hr flight. Notice that the fuel cell aircraft takes off lighter (less fuel load) but lands heavier (heavier powerplant).
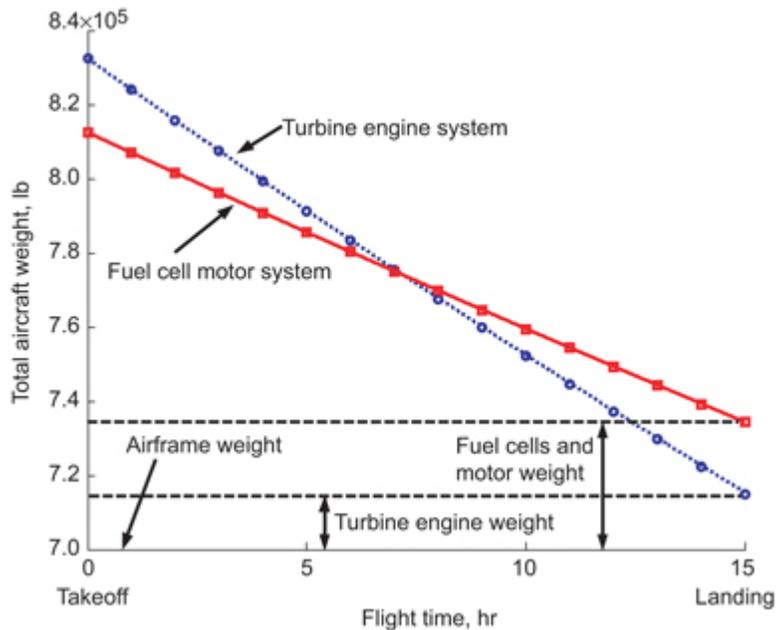
Total aircraft weight as a function of time for the two systems from takeoff to landing during a 15-hr flight.

Long description of figure 2. Graph shows airframe weight, turbine engine weight, fuel cells and motor weight, and data for turbine engine system and fuel cell motor system.

This analysis can be applied to other candidate systems to drive the propulsor, as long as each component can be approximately characterized by a simple specific power coefficient and a power efficiency from input to output. This work was supported by the Alternate Fuel Propulsion System Tech Development program.

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