Are Practical Electric and Hybrid Airplanes Just Around the Corner?

by Ron Gremban, CalCars Technical Lead, 4/24/2009

1. *Change of Title and Focus*

1.1. Aviation Green Prize (AGP) rules have been continuing to change.

1.1.1. The latest version arrived 2 days ago.

1.1.2. The conversion factor changed from 50 kWh/gallon to 33.7 kWh/gal – the average *net* [value used in Europe] energy content of gasoline – making electricity's mpge less advantageous than before.

1.1.2.1. Even 36.4 kWh/gal, the average *gross* [value usually used in the U.S., including by the DOE] content, would be more helpful for electrics

1.1.2.1.1. The difference is the vaporization energy of the exhaust water

1.1.3. On the other hand, the race was delayed from Sept 2010 to June 2011. Better batteries will be available, making electric *range* easier to achieve.

1.1.4. The current race formula – 1/(1/mpge + 1/mph) instead of pure speed – is strongly focused toward racing at just above the minimum 100 mph and winning on mpge, because drag increases as the cube of speed

1.1.4.1. Though, for any given airframe, not true below 130% of best L/D, this is still true when trading off all factors when designing an airframe for speed and efficiency

1.1.4.2. The winning airframe will therefore be designed for best mpge at just above 100 mph, meaning best L/D will be between 76 and 100 mph,

1.1.4.2.1. Leading to glider-like long-wing designs

1.1.4.2.2. Despite the advantage of higher speeds in helping convince travelers to fly an airplane instead of driving a car

1.1.5. The airplanes I modeled and intended to propose, though quiet, fuel efficient, and low carbon, will no longer meet the AGP's minimum mpge.

1.2. Beyond the AGP and its rules, there are good reasons for powering light airplanes electrically, once possible.

1.2.1. Cost

1.2.1.1. Batteries are still very expensive, but no more so than aircraft engines!

1.2.1.2. Electricity is a much cheaper fuel than avgas, especially once super-high oil prices return.

1.2.2. Noise is becoming a major problem, threatening to limit general aviation, especially at airports serving suburbs and towns.

1.2.2.1. Since aircraft engines cruise and climb at 65-100% of full power, quiet is more difficult to achieve.

1.2.2.1.1. Auto engines are quieter due to both lower power output 99% of the time, and bigger, heavier, more efficiency-robbing mufflers.

1.2.3. Aviation piston engines have so far been exempt from smog regulations, but:

1.2.3.1. Since regulation has now made new automobile engines 200 times cleaner, agencies need to clean up more and more other sources to continue cleaning the air

1.2.3.2. 100LL is about to go, as light aircraft add measurably to airborne lead near busy general aviation airports.

1.2.3.3. Piston aircraft still emit particulates, hydrocarbons, oxides of nitrogen, etc, at levels hundreds of times per mile that of new cars

1.2.3.3.1. At minimum, catalytic converters will be needed to help clean up aircraft piston engines – how well will they work at high altitude?

1.2.3.3.2. Diesel engines are even harder to clean up than gasoline engines.

1.2.4. Battery electric airplanes across the U.S. will already be lower carbon, because they are 2-3 times as efficient at using that energy as a piston airplane.

1.2.4.1. Though total CO2 emissions per energy content is higher now for U.S.-average electricity than for gasoline, efficiency rules:

1.2.4.1.1. Electrics around 80% efficient (grid to shaft) vs.

1.2.4.1.2. 25-30% for gasoline (tank to shaft), and

1.2.4.1.3. Around 40% for Diesel (tank to shaft)

1.2.4.2. The electric grid already has far more extra capacity, especially at night, than needed for any conceivable penetration rate of electric airplanes – enough for at least 85% of all *250 million* cars to be electric.

1.2.4.3. In contrast, for the foreseeable future, aviation biofuel use will merely slow down efforts to reduce automotive petroleum consumption

1.2.4.3.1. Low-carbon biofuel production will only exceed ground transportation requirements after near complete automotive electrification, because

1.2.4.3.2. Cellulosic and algae technology are not yet commercialized

1.2.4.3.3. Sustainable non-food feedstock limits production to 33% of existing automotive consumption,

1.2.4.3.4. Enormous investments will be required to build sufficient plant capacity, and

1.2.4.3.5. Plants must be near feedstocks because transport is too expensive.

1.2.4.4. In California, electricity is already lower-carbon than gasoline.

1.2.4.5. Many states, including CA, already have increasing renewable energy portfolio standards, and the U.S. will no doubt follow soon.

1.2.4.6. As conventional oil supplies dwindle and unconventional supplies like tar sands are increasingly tapped, the carbon emitted to make gasoline will keep increasing.

1.2.4.7. Much of the energy required for light electric airplanes could be generated by covering airport hangars with solar panels, while also improving electric utility load balancing and efficiency.

1.2.5. Reliability

1.2.5.1. Though not yet proven, electric propulsion is potentially much more reliable than piston engines.

1.2.5.2. Piston engine failures cause many fatal crashes each year.

1.3. What minimum performance is needed for a practical electric airplane?

1.3.1. My guesses as a GA pilot, former owner of an old (1966) C-172, and aviation enthusiast

1.3.1.1. These are projected minimums for some (hopefully many) pilots

1.3.1.1.1. Not what's needed to compete with piston aircraft before serious consideration of fuel costs and/or environmental factors

1.3.1.1.2. Endurance is considered to be bladder-limited to 3 hours anyway.

1.3.1.1.3. Cruise speed and endurance are rated at sea level (SL)

1.3.1.1.3.1. Endurance rated at the same cruise speed

1.3.1.1.3.2. Actual trips will require a climb to altitude, but also a descent and higher-speed, more-efficient cruising; a first-level assumption is that these things pretty much cancel out.

1.3.1.1.4. Fuel cost savings will be noted for specific designs.

1.3.1.2. Refueling will depend upon

1.3.1.2.1. As-yet-nonexistent charge stations, or

1.3.1.2.2. A high-power electrical outlet available by pre-arrangement.

1.3.1.2.3. Required power levels will be noted for specific designs.

1.3.2. Recreation

1.3.2.1. Local flying – near C-150 or LSA performance

1.3.2.1.1. 1-2-place, 200 lb/person (200-400 lb) payload (no baggage)

1.3.2.1.2. 100 mph/87 kt cruise, 8k ft ceiling

1.3.2.1.3. 1.5 hours endurance at cruise + VFR reserve

1.3.2.1.4. Overnight refueling (1-hour maximum for rentals)

1.3.2.2. Day trips – near C-172 or LSA performance

1.3.2.2.1. 2-4-place, 225 lb/person (450-900 lb) payload (minimal baggage)

1.3.2.2.2. 100+ kt cruise, 10k ft ceiling (12k+ in the West)

1.3.2.2.3. 2-3 hours endurance (230-345 miles) + VFR reserve

1.3.2.2.4. 4 hours maximum to refuel

1.3.2.3. Long distance cross-country flying – C-172++

1.3.2.3.1. 2-4-place, 250 lb/person payload (500-1000 lb)

1.3.2.3.2. 100-200 kt cruise, 12k+ ceiling

1.3.2.3.3. 2.5-3 hours endurance (288-690 miles) + VFR or IFR reserve

1.3.2.3.4. 1 hour maximum to refuel (time for a meal)

1.3.3. Business travel

1.3.3.1. Single-person travel, a stop after each leg: traveling salesman, small business owner, etc. – like recreational day trips except

1.3.3.1.1. 1-place, 250-500 lb payload (may include equipment)

1.3.3.1.2. 1-2 hours maximum refuel time due to multiple legs

1.3.3.1.3. More speed is highly desirable, as time is money

1.3.3.2. Carrying clients or associates, a stop after each leg – like single-person business except

1.3.3.2.1. 3-4-place, 250 lb/person (750-1000 lb) payload

1.3.3.3. Long distance cross-country flying – like recreational except

1.3.3.3.1. IFR reserve

1.3.3.3.2. 150+ kt cruise

1.3.4. Commuting

1.3.4.1. 1-2-place, 225 lb/person payload (225-450 lb), 100-150 kt cruise

1.3.4.2. 2-2.5 hours (more is unreasonable) at cruise (230-375 mi) + IFR reserve

1.3.4.3. 6-8 hours to refuel during work

1.4. What can hybridizing an airplane accomplish?

1.4.1. Suggested/modeled hybrid

1.4.1.1. Parallel, powered by the electric motor and/or the engine

1.4.1.1.1. Engine is used for cruise and for some climb

1.4.1.2. Motor always turns, attached directly to propeller or via PSRU

1.4.1.3. Engine, attached via a centrifugal clutch, can start and stop

1.4.1.4. Enough electric energy to climb to e.g. 10,000 ft.

1.4.1.4.1. Ground charging enables some displacement of liquid fuel

1.4.1.5. A reversing propeller to capture some energy while slowing down during rapid descents

1.4.2. Quiet airport operations, unless full power is needed for a short-field or high altitude takeoff

1.4.3. Smaller, lighter, efficient Diesel engine

1.4.3.1. Sized only for maximum cruise power

1.4.3.1.1. Especially with DeltaHawk Diesel engines, which are rated to cruise at 100% power

1.4.3.2. Higher efficiency means less weight in fuel for a given range

1.4.3.3. Motor and battery are still heavier than engine and fuel weight savings

1.4.4. Some electric energy is always held in reserve, in case of engine failure

1.4.4.1. For long life, most batteries should not normally be discharged beyond 80% anyway.

1.4.4.2. Engine failure is the cause of many fatal crashes, especially during takeoffs

1.4.4.3. Electric motors are much more reliable, and dual-power is more reliable yet

2. My modeling of electric and hybrid airplanes that are possible with today's and near-future technology (live spreadsheet to follow)

2.1. For both, I started with the fastest 4-place piston kit airframes

2.1.1. Kit airplanes get registered as amateur-built experimental, making them both modifiable and useful (can be flown most anywhere).

2.1.2. With engine size effectively limited to 350 hp, they have to be very efficient to fly at 200-250 kt.

2.1.3. Maximum L/D, though much lower than for smaller, slower glider-like airplanes, occurs at a high enough speed (e.g. 100 kt) to make the desirable 100-200 kt speeds especially efficient.

2.1.4. To get a 2-place airplane with useful range using today's batteries, 2 places and their related payload can be sacrificed.

2.1.5. As batteries improve, the airframe will remain near optimum for increasing cruise speed, range, and/or payload.