Are Practical Electric and Hybrid Airplanes Just Around the Corner?

(what I added to my model early this morning surprised me when I awoke)

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Are Practical Electric and Hybrid Airplanes Just Around the Corner?

Change of Title and Focus

• I delayed writing this talk until yesterday, as Aviation Green Prize rules were continuing to change
  – Conversion factor changed from 50 kWh/gallon to 33.7 kWh/gallon, making electricity’s mpge less advantageous
  – The race has been delayed from Sept 2010 to June 2011
    • Better batteries should be available, making electric range -- which is what my modeling focused on -- much easier
  – Instead of pure speed, the race formula is now 1/(2/passenger-mpge + 1/mph)
    • Strongly biased toward fuel efficiency, since drag increases as the cube of speed
      – This is true during the design process even if not at best glide speed
    • I believe the winner will
      – Fly an LSA-sized airframe at just above 100 mph
      – By powered by a high-efficiency turbo-Diesel engine
        » Diesel engine exhaust has especially toxic emissions that are difficult to clean up
      – Employ a glider-like long-wing design
  – The electric airplanes I modeled, though quiet, fuel efficient, and low carbon, will no longer meet the AGP’s minimum mpge.
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There are good reasons for electric airplanes ASAP

• **Cost**
  – At the shaft, electricity is less than 1/5 the cost avgas
  – Though batteries are hugely expensive, so are the aircraft engines they can replace

• **Noise – an increasing problem at GA airports**

• **Aircraft engines pollute**
  – Aircraft piston engines have not been cleaned up at all. In contrast, new auto engines are around 200x cleaner than before, making each piston aircraft a ‘gross polluter’ in comparison
  – 100LL is now actually on its way out, due to airborne lead near GA airports
  – Particulates, hydrocarbons, oxides of nitrogen, etc, must eventually be regulated
  – Studies show that electric power is cleaner than the best of today’s auto engines

• **Electric airplanes will immediately be lower carbon**
  – Because 2-3 times as efficient as ICE
  – Average U.S. electricity now higher CO2 per kWh than gasoline, but not for long
    • CA already twice as low
    • Many states have renewable portfolio standards – soon the U.S?
  – Plenty of electric capacity available
  – Hangars could be covered with solar panels
  – Low carbon biofuels will have limited availability for the foreseeable future

• **Reliability – potentially much higher, though not yet proven**
  – Potential to be safer than twins, which don’t actually have a better engine-out safety record than singles (due to loss of control from sudden off-axis thrust)
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What minimum performance is needed for a practical electric airplane?

- My guesses as a GA pilot & former C-172 owner
  - For some, not all pilots
  - Not what’s competitive without fuel & environment considerations
  - Endurance bladder-limited to 3 hours anyway
  - Cruise speed and endurance rated at sea level (SL)
    - Endurance rated at the same cruise speed
  - Refueling will depend upon
    - As-yet-nonexistent charge stations, or
    - A high-power electrical outlet available via pre-arrangement
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Recreational Flying

- **Local flying – near C-150 or LSA performance**
  - 1-2-place, 200 lb/person (200-400 lb) payload (no baggage)
  - 100 mph/87 kt cruise, 8k ft ceiling
  - 1.5 hours endurance at cruise + VFR reserve
  - Overnight refueling, except <1 hr for rentals

- **Day trips – near C-172 or LSA performance**
  - 2-4-place, 225 lb/person (450-900 lb) payload
  - 100+ kt cruise, 10k+ ceiling (12k+ in the West)
  - 2-3 hours endurance (230-345 mi) + VFR or IFR reserve
  - 4 hours maximum to refuel

- **Long distance cross-country flying – C-172++**
  - 2-4-place, 250 lb/person payload (500-1000 lb)
  - 100-200 kt cruise, 12k+ ceiling
  - 2.5-3 hours endurance (288-690 mi) + VFR or IFR reserve
  - 1 hour max to refuel (time for a meal)
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• **Business Travel**
  - Single-person travel, a stop after each leg
    - Like recreational day trips, except
    - 1-place, 250-500 lb payload (may include equipment)
    - 1-2 hours maximum refuel time due to multiple legs
    - More speed is highly desirable, as time is money
  - Carrying clients or associates, a stop after each leg
    - Like single-person business, except
    - 3-4-place, 250 lb/person (750-1000 lb) payload
  - Long distance cross-country flying
    - Like recreational, except IFR reserve and 150+ kt cruise

• **Commuting**
  - 1-2-place, 225 lb/person payload (225-450 lb), 100-150 kt cruise
  - 2-2.5 hours (more is too long a commute) at cruise (230-375 mi) + IFR reserve
  - 6-8 hours to refuel during work

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What can hybridizing an airplane accomplish?

• **Suggested/modeled hybrid**
  – Parallel, powered by the electric motor and/or the engine
  – Motor always turns, direct or via a PSRU
  – Engine, attached via a centrifugal clutch, can start & stop
  – Enough electric energy to climb to e.g. 10k ft
    • Ground (PHEV) charging enables some fuel displacement
    – A reversing propeller can capture energy during descents

• **Quiet airport operations**
  – Except when full power needed for short field or high altitude takeoffs

• **Smaller, lighter, efficient Diesel engine**
  – Sized only for cruise power (especially DeltaHawk)
  – Higher efficiency also means less weight for fuel

• **Some electric energy is always held in reserve for an emergency**
  – For long life, normal discharge is by only 80%
  – Fewer engine-failure-induced fatal crashes
  – Electric power is more reliable, and dual-power is more reliable yet
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My modeling (live spreadsheet to follow)

• For both electric and hybrid, I started with the fastest 4-place piston kit airframes
  – Kit airplanes get registered as amateur-built experimental
    • Modifiable and can be flown most anywhere
    – Must be efficient to be fast
    – Maximum L/D occurs at usefully fast speeds
    – 2 places and associated payload can be sacrificed for sufficient range with today’s batteries
    – As batteries improve, will the airframe remain near optimum for increasing either…
      • Cruise speed and range, or
      • Payload?
### Are Practical Electric and Hybrid Airplanes Just Around the Corner?

#### Worksheet for possible electric aircraft to enter the NASA/CAFE high-efficiency 2-place airplane contest

<table>
<thead>
<tr>
<th>Aircraft characteristics</th>
<th>Velocity XL-RQ</th>
<th>Velocity XL-RG</th>
<th>Velocity Hybrid</th>
<th>Lancair IV</th>
<th>Lancair IV Electric</th>
<th>Lancair IV Electric, actuator for slowed flight</th>
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<th>Van's RV-10</th>
<th>Van's RV-10 Hybrid</th>
<th>Van's RV-10 Electric, optimized for slowed flight</th>
<th>Van's RV-10 Electric, optimized for slowed flight</th>
<th>Piplasted Slices</th>
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<th>Cessna C-172M</th>
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<td>14) Climb to 3,000 ft</td>
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