The Coming Multi-Tier Propulsion Era for Sustainable Aviation

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Past Decades

• **All Gas Turbines for All Tiers**

  • For more than 6 decades, all tiers of flight vehicles have used gas turbine engines burning kerosene.
  • Turboprops from Piper Meridian to Airbus A400M
  • Passenger jets from Cirrus Vision SF50 to Airbus A380
  • Combat jets from Cessna AT-37 to Boeing B-52 and Lockheed SR-71
  • Helicopters from Hughes OH-6A to Sikorsky CH-53K
Piper Meridian: 500 hp turboprop

Credit: Alan Lebeda, airliners.net
Airbus A400M: 44,000 hp turboprop

Credit: Peng Chen, Wikimedia Commons
Cirrus Vision: 5 passengers
Airbus A380: 555 passengers

Credit: P.loos, French Wikipedia
Cessna A-37B: 14,000 lb MTOW Mach 0.7

Credit: TSGT Ken Hammond, Wikimedia Commons
Boeing B-52H: 488,000 lb MTOW

Credit: Balon Greyjoy
Lockheed SR-71 Mach 3+

Hughes OH-6A: 250 hp

Credit: US Army
Sikorsky CH-53K: 22,500 hp

Credit: Lance Cpl. Molly Hampton, US Marines
Future Decades

• **Multiple Tiers Driven by Range, Sustainability**
  - Multiple Tiers of Quite Different Propulsion Systems
  - Driven by the critical need for sustainability
  - No single propulsion system meets the needs any longer
Six Major Tiers of Propulsion

- Battery Multi-Rotor eVTOL, inspired by drones
  - Range as low as 22 miles
- Battery Multi-Rotor eVTOL, with wings for cruise
  - Range up to 150 miles
- Battery winged airplane
  - Range up to 300+ miles
- Hydrogen fuel cell winged airplane
  - Range up to 800 miles
- Liquid hydrogen gas-turbine winged airplane
  - Range up to 2,000 miles
- Sustainable Aviation Fuel SAF gas-turbine winged airplane
  - Range up to 9,000 miles
eHang 216: Battery multirotor eVTOL
Volocopter
VoloCity: Battery multirotor eVTOL

Credit: Volocopter
Joby S4: Battery tilt-rotor eVTOL

Credit: Joby
Autoflight Prosperity: Battery lift-plus-cruise eVTOL
eViation Alice: Battery winged airplane 9 passengers, 285 miles

Credit: eViation
Elysian E9X: Battery winged airplane 90 passengers, 500 miles (?)
Universal Hydrogen demo Q-300: Fuel cell winged airplane 800 miles

Credit: Universal Hydrogen
Airbus Hydrogen gas-turbine concept: 2,000 miles

Credit: Airbus
Boeing 777-9: SAF Winged Airplane: 9,000 miles
Already Multiple Course Corrections and Outright Failures

- Batteries have not improved much, despite PowerPoint decks and numerous claims
- Zunum, backed by Boeing, closed down, as did Kittyhawk
- Many battery-powered projects have reduced their expected range, such as eViation Alice (700 nm to 400 nm to 250 nm) and Heart ES-30 (now 200 km on batteries only)
- Several battery-powered projects have added hybrid turbogenerators, such as Heart Aero and Elysian
- Ballooning budgets have made funding a bigger challenge
- Certification uncertainty and delays are a major concern
Heart ES-19 before reality

Credit: Heart Aerospace
Heart ES-30 after reality

Credit: Heart Aerospace
Heart ES-30
Breaking News This Week:
GE Catalyst 1,300 hp?

Credit: Heart Aerospace
Some Winners After Major Shakeouts

• Most of the Competitors Today will Fail
  • Industry analysts now tracking just over 1,000 projects
  • Market space for only 1 or 2 dozen, most likely
  • But the need for sustainability is strong, only getting stronger
  • So those winners will be embraced by the World
  • The aviation industry will be transformed
  • But several years will be required for SAF, hydrogen, and battery development and volume production
Results for Sustainability

- Over All, Most Energy Will Still Come from Kerosene in Gas Turbines
  - Larger, longer range airliners consume most of the fuel
  - Thus, SAF, sustainable aviation fuel, is still the key
  - Requires major investments in processing refineries
  - Requires major investments in feedstock development
  - But a substantial proportion of the flights – possibly the majority -- will use batteries or hydrogen
  - Energy for aviation likely to be more expensive
  - The expense will be accepted, to achieve sustainability
Closing

• Thank You!
• Questions?