

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



Credit: Cirrus

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+



Credit: Tech. Sgt. Michael
Haggerty, US Air Force

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



Autoflight Prosperity: Battery lift-plus-cruise eVTOL



eViation Alice:
Battery
winged airplane
9 passengers,
285 miles



Elysian E9X:
Battery
winged airplane
90 passengers,
500 miles (?)



Credit: Elysian

Universal Hydrogen demo Q-300: Fuel cell winged airplane 800 miles



Credit: Universal Hydrogen

Airbus Hydrogen gas-turbine concept: 2,000 miles



Boeing 777-9: SAF Winged Airplane: 9,000 miles



Credit: Boeing

Stumbles along the way

- **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 ?**