Some NASA Perspectives on H2

Presented by
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H2@Airports Workshop
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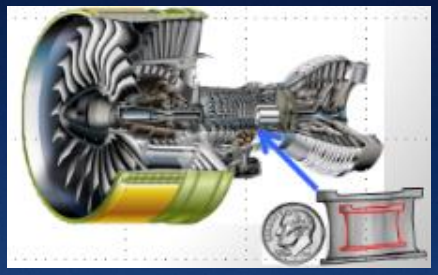
NASA Subsonic Transport Strategy

Focus on 4 Key Technologies



Small Core Gas Turbine
5%-10% fuel burn benefit

Electrified Aircraft Propulsion
Up to 5% fuel burn and maintenance benefit

High Rate Composite Manufacturing
4x-6x manufacturing rate increase

Transonic Truss-Braced Wing
7%-10% fuel burn benefit

Ensure U.S. industry is the first to establish the new “S Curve” for the next 50 years of transports

NASA Perspectives on H2

- H2 offers **opportunity** as a **clean energy carrier**
- NASA has **explored H2 applications for air transportation in past decades**, which helped to highlight benefits and challenges
- Noted **recent increase in interest associated with H2-powered concepts** and research in the air transportation community
- NASA's current research portfolio includes some **investigation of H2 energy storage and hydrocarbon conversion for fuel cells on electric aircraft**, though no current emphasis on other H2-related challenges
- Need to consider off-aircraft challenges: the **cost/ energy/ environmental impact of H2 production**; the **cost of developing H2 infrastructure**; characterization of **contrails and their atmospheric impacts**

Since NASA's H2 interest has related to vehicle-level technology development and integration, we are happy to see workshops focused on solving the challenges of H2 airport infrastructure

Examples of Renewed Interest in H2

ZeroAvia Commercial H2 Flight

https://www.nacleanenergy.com/articles/39133/zeroavia-completes-world-first-hydrogen-electric-passenger-plane-flight

Airbus H2 Transport Concepts

https://www.airbus.com/newsroom/press-releases/en/2020/09/airbus-reveals-new-zeroemission-concept-aircraft.html

Alaka'i H2 Concept for UAM

https://www.wired.com/story/alaka i-flying-car-air-taxi-evtol-hydrogen/

NASA's History with H2

- H2 Fuel cell developments for **space applications**
  - Proton Exchange Membrane (PEM) **fuel cell power for Gemini** – 1960s
  - **Fuel cells for Apollo** (1.5 kW, 15 W/kg), **Shuttle** (12 kW, 100 W/kg) -1970s
  - Regenerative Fuel Cell (RFC) technology for **Space Station** – 1980s
  - **Non Flow Through (NFT-RFC) technology** to capture water – early 2000s
  - **Multi-fuel Solid Oxide fuel Cell (SOFC)** to reduce weight (300W/kg)

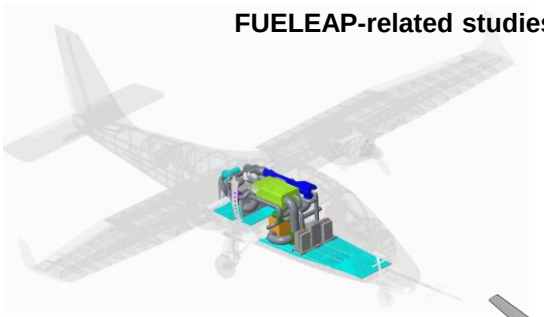
- H2 Fuel cell developments for **aero/automotive applications**
  - DOE/NASA GRC **alternative energy technology** program – 1970s
  - **"Quiet Green Transport"** - hydrogen fuel cell powered aircraft – 2000s
  - **Emissionless Aircraft Study** with MSE Technology Application Inc - 2002
  - RFC for unmanned electric aircraft – **LEAP aircraft flown** in 2005
  - **Zero NOx emissions aircraft study** with hydrogen PEM fuel cells – 2009
  - Hydrogen **fuel cell powered UAV** study – 2009

- Comparison of **fuel cells vs combustion**
  - Current fuel cells are **5 to 10 times heavier** than a gas turbine engine
  - Fuel cell estimated cruise specific fuel consumption (**sfc) 20-30% better than combustion**

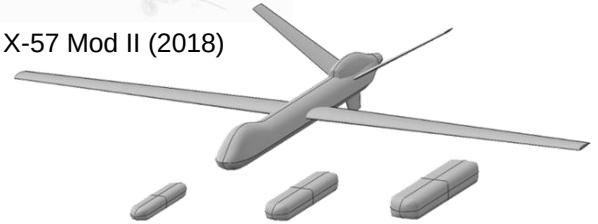
Recent Interest: Fostering Ultra-Efficient, Low-Emitting Aviation Power (FUELEAP)

- Conducted **feasibility studies** from 2015-2018 on hybrid SOFC with onboard fuel reformation for aircraft primary propulsive power & secondary power
  - Considered **desulfurized heavy fuels** (low-sulfur diesel, jet fuel) **for ease of integration with existing distribution and airport infrastructure**
- Developed **hybrid SOFC architecture** with Boeing, leveraging partner's research on low-leakage power system design
  - Total architecture (including balance of plant) goal of **> 300 W/kg dry, > 60% net efficiency** referenced to fuel LHV
- Developed **automated, long-duration SOFC ground test facility at GRC**
  - Partnered with AFRL to leverage ongoing SBIR on high-efficiency SOFC
  - GRC facility cleared for unattended, long-duration operation

FUELEAP-related studies



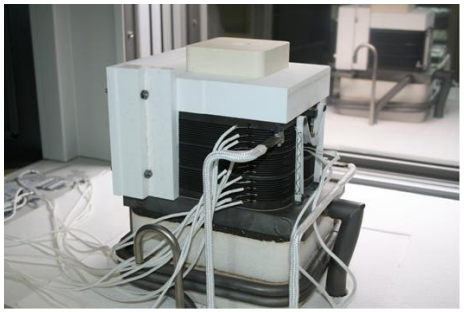
120kW system for X-57 Mod II (2018)



5-60kW system for UAS APU (2019)

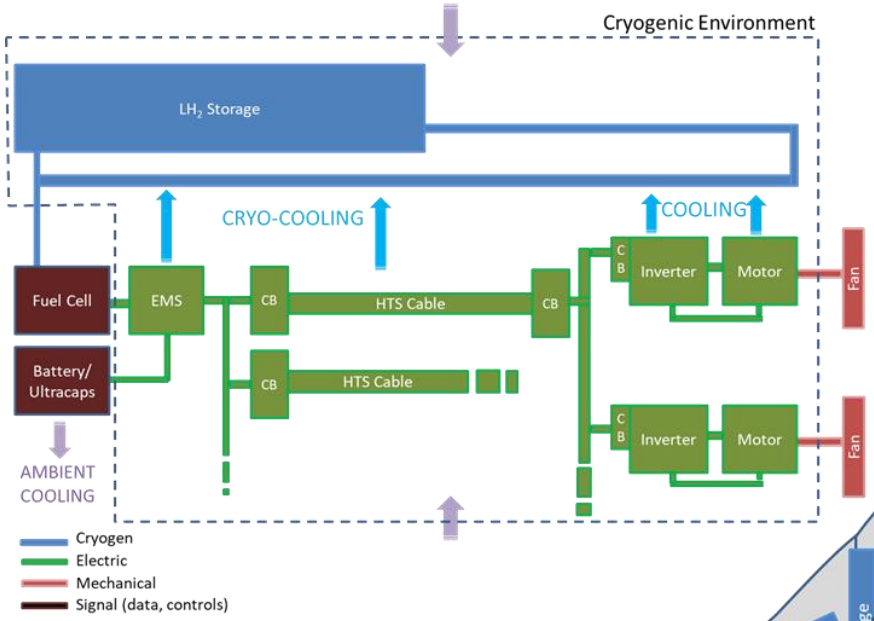
Up to ~2MW system for PEGASUS (2020)

Up to ~3MW system for STARC-ABL (2020, unpublished)

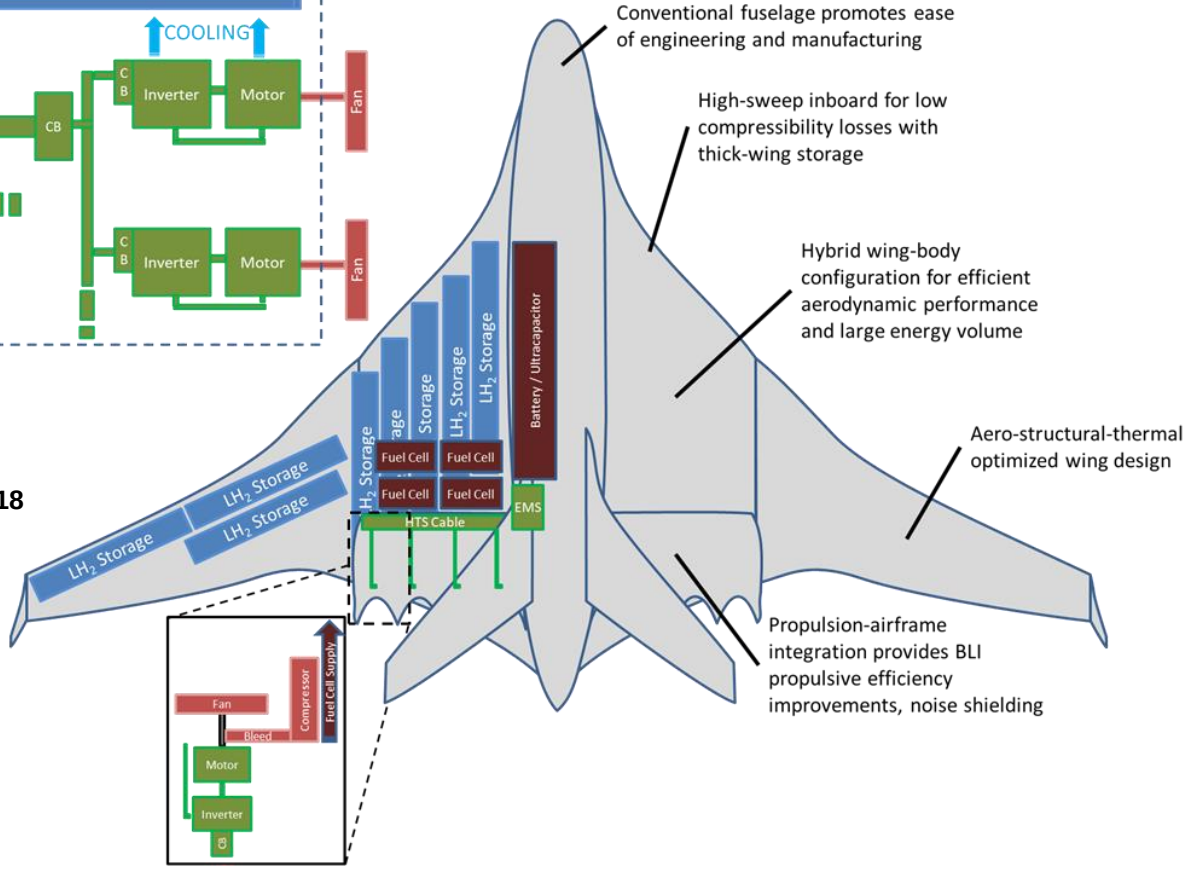


700W SOFC in GRC long-duration test facility (2018)

Current Interest: Center for Cryogenic High-Efficiency Electrical Technologies for Aircraft (CHEETAH)



https://grainger.illinois.edu/news/30918



NASA is funding a 3-year ULI project exploring the use of cryogenic LH2 energy storage for all-electric transport aircraft applications

H2 Challenges

- Some pertinent **vehicle** challenges
  - **Onboard storage of LH2** – size, weight, managing boil-off
  - **Onboard storage of GH2** – size, weight, safety
  - Increased **complexity** of systems associated with **H2 combustion in a gas turbine**
  - **Fuel cell integration** – size, weight, complexity (including balance of plant)
  - **Fuel cell pressurization** – increased balance of plant needs, leakage

- Some pertinent **transportation system** challenges
  - **Airport facilities** – production, storage, delivery, safety
  - **Scalability for airport operations** (e.g, 1976 NASA/Lockheed research into LH2 at SFO)
  - **Impact on ground/flight operations** – managing fueling, boil-off, etc.
  - Interaction with **surrounding infrastructure** (e.g. power grid)
  - **H2 production** – energy requirements, emissions, transportation
  - **Atmospheric impact of contrails**, particularly at higher altitudes

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Questions