



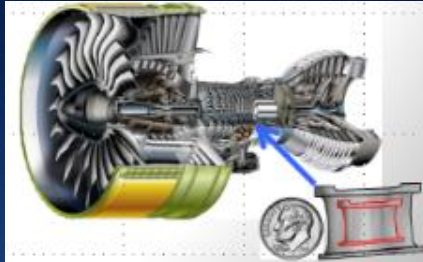
Some NASA Perspectives on H2

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H2@Airports Workshop
November 4, 2020

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/zeroa-via-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



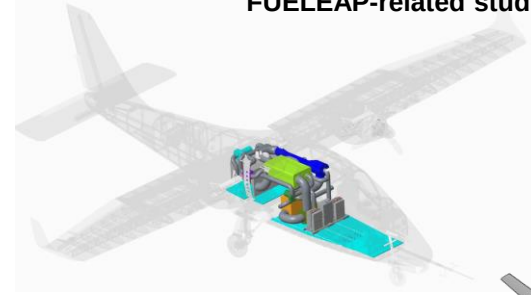
- H2 Fuel cell developments for **space applications**
 - Proton Exchange Membrane (PEM) **fuel cell power for Gemini** – 1960s
 - **Fuel cells for Apollo** (1.5 kW, 15 W/kg), **Shuttle** (12 kW, 100 W/kg) -1970s
 - Regenerative Fuel Cell (RFC) technology for **Space Station** – 1980s
 - **Non Flow Through (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)

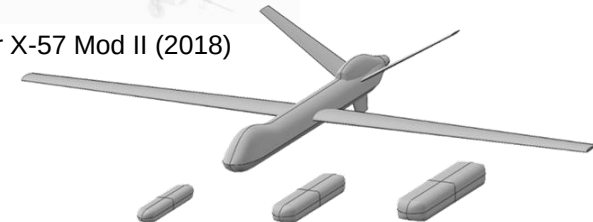


- Conducted **feasibility studies** from 2015-2018 on hybrid SOFC with onboard fuel reformation for aircraft primary propulsive power & secondary power
 - Considered **desulfurized heavy fuels** (low-sulfur diesel, jet fuel) **for ease of integration with existing distribution and airport infrastructure**
- 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)



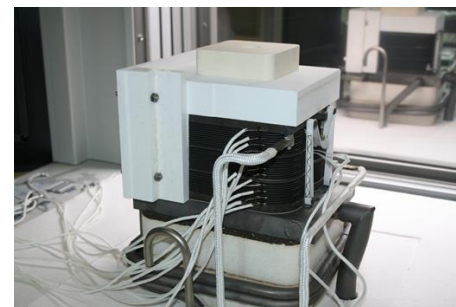
5-60kW system for UAS APU (2019)



Up to ~2MW system for PEGASUS (2020)

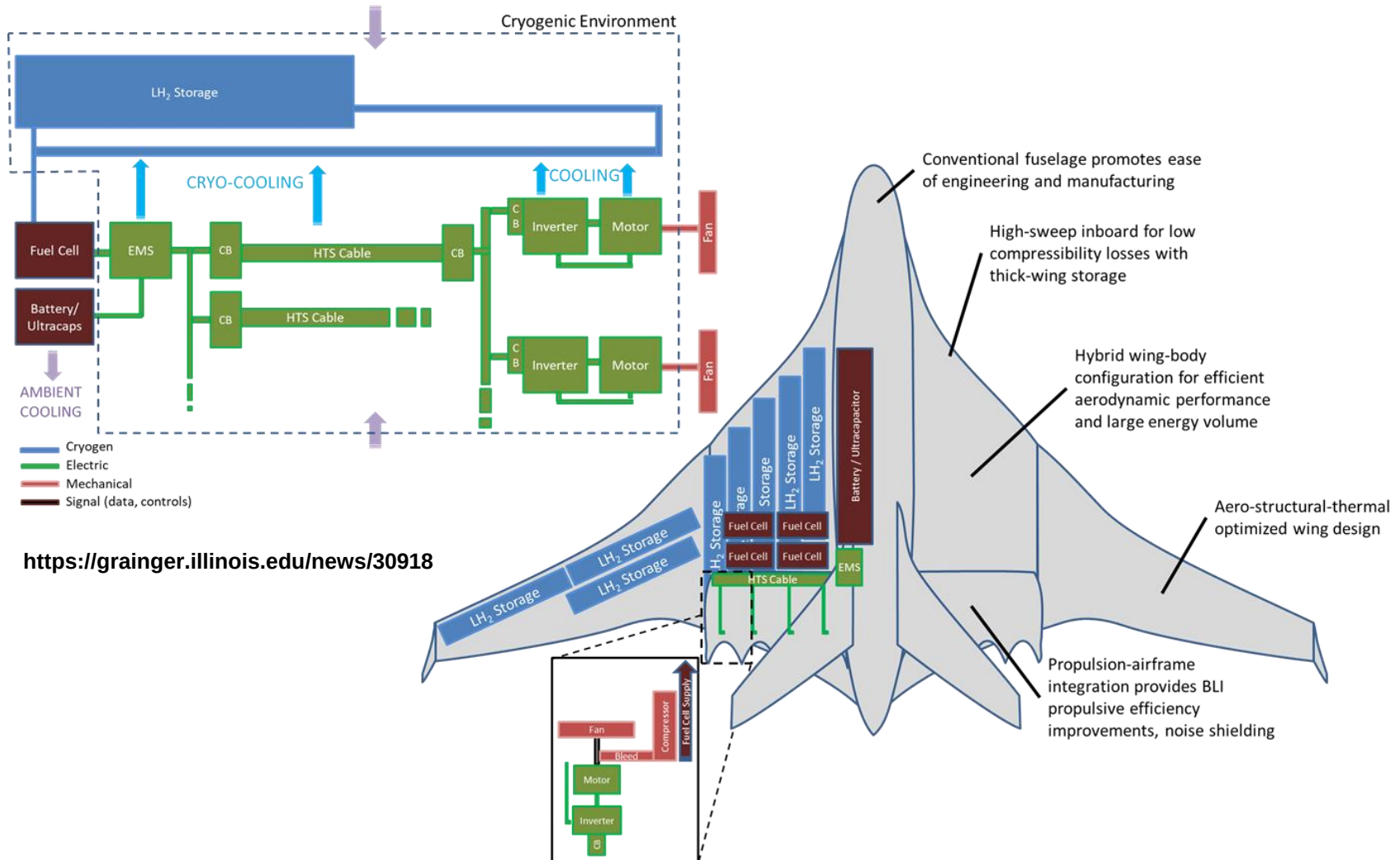


Up to ~3MW system for STARC-ABL (2020, unpublished)



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

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



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