NASA Meeting on Cryogenic Fuel Systems for Aircraft

Overview of Previous Workshops and Studies

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NASA Glenn

Outline

U.S. Aviation Climate Action Plan (and what aviation to focus on)

Throw out some ideas (get the ball rolling) – what do we know from previous efforts (and what is NASA's role?)

- Airframe focus
- Propulsion focus
- Fuel System focus

Wrap-up (Q&A)

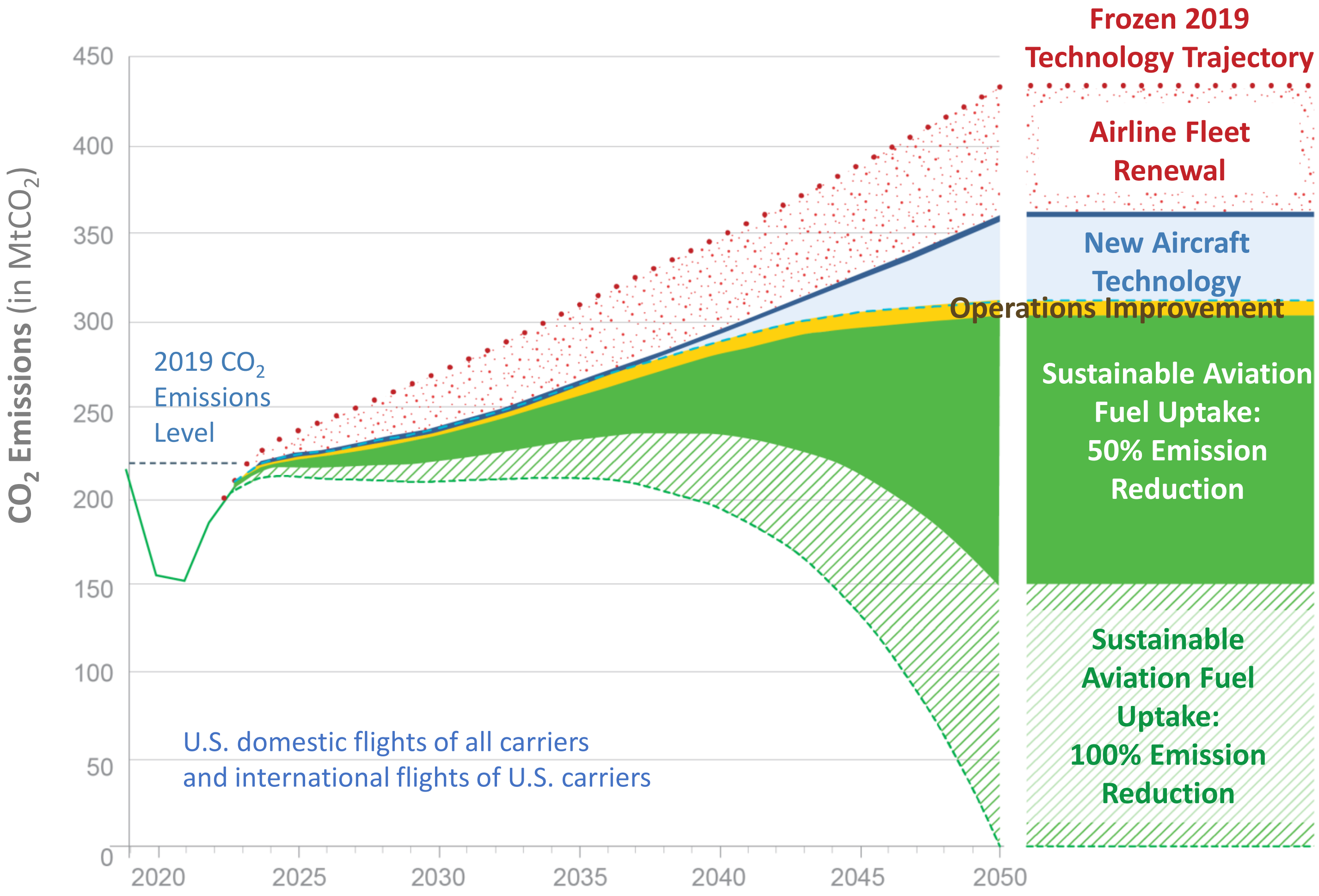
Caveat: This may look NASA-centric, but done to limit permissions, copyrights, etc.
Links to additional work near end of presentation and in the backup charts

U.S. Aviation Climate Action Plan

U.S. Aviation Climate Action Plan is aligned with

- U.S. economy-wide goal
- International Civil Aviation Organization
- Air Transport Action Group

U.S. aviation goal is to achieve **net-zero greenhouse gas emissions by 2050**

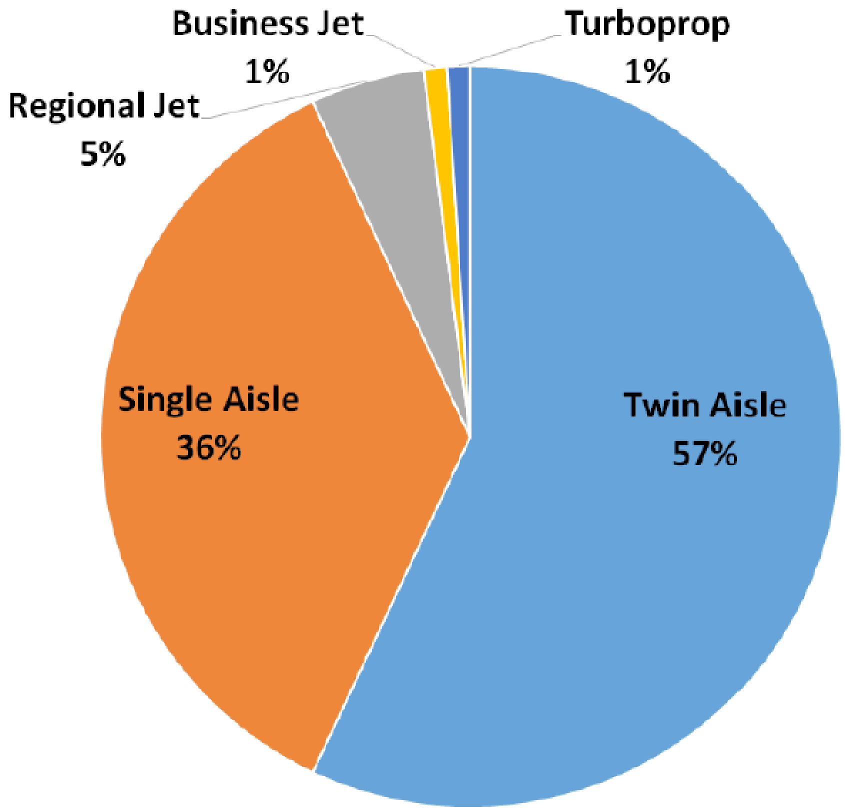


Based on Fig 3 in https://www.faa.gov/sites/faa.gov/files/2021-11/Aviation_Climate_Action_Plan.pdf

U.S. Aviation Climate Action Plan (2)

It is obvious which segments of the global civil aviation fleet use most of fuel (and produce the most climate impact) So it helps to focus our efforts on certain vehicle classes

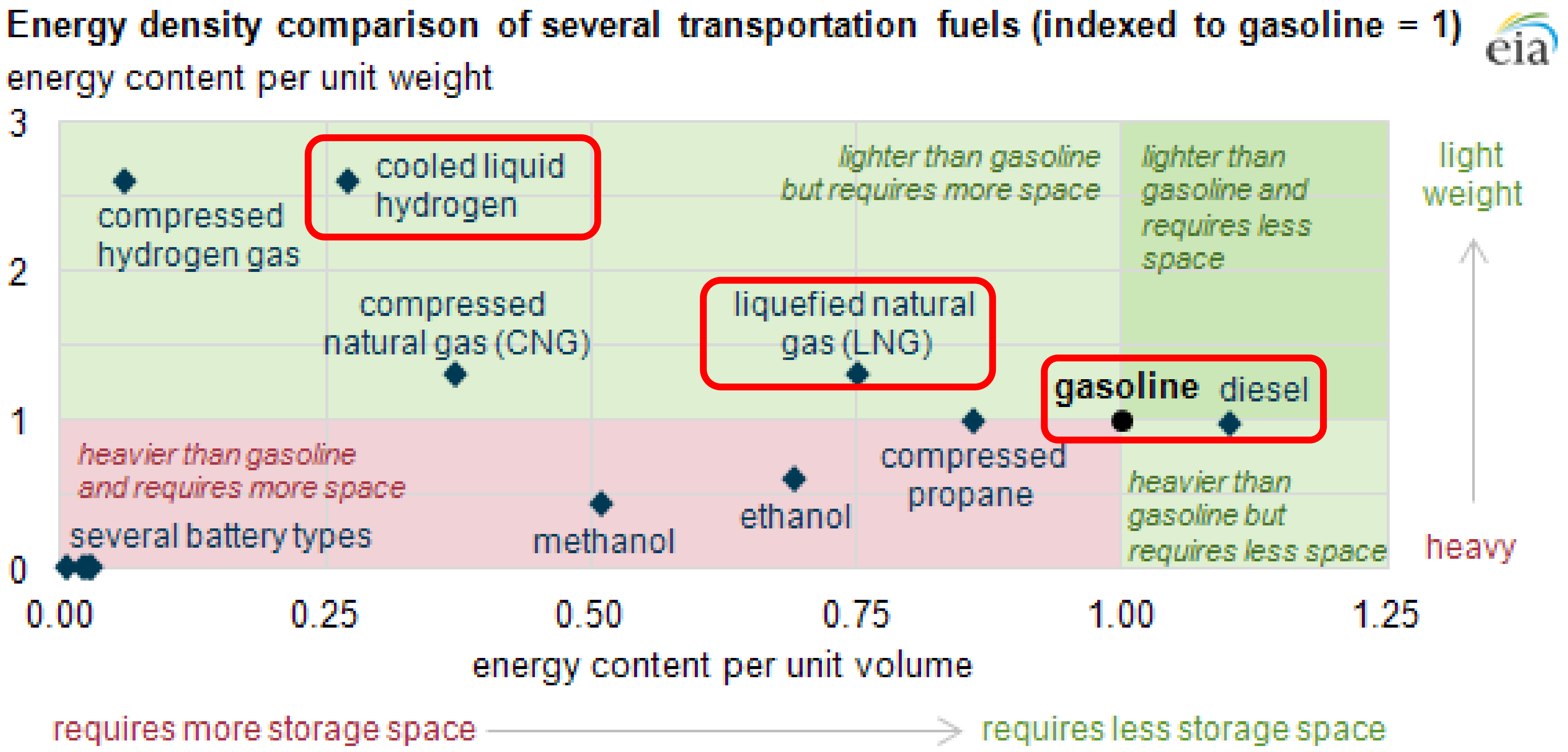
Single aisle and twin aisle aircraft are also highly sensitive to fuel energy density and volume. These aircraft designs have become highly optimized around Jet-A fuel.



Global civil aviation fuel consumption, THE NATIONAL ACADEMIES PRESS: Commercial Aircraft Propulsion and Energy Systems Research: Reducing Global Carbon Emissions (2016) http://www.nap.edu/23490

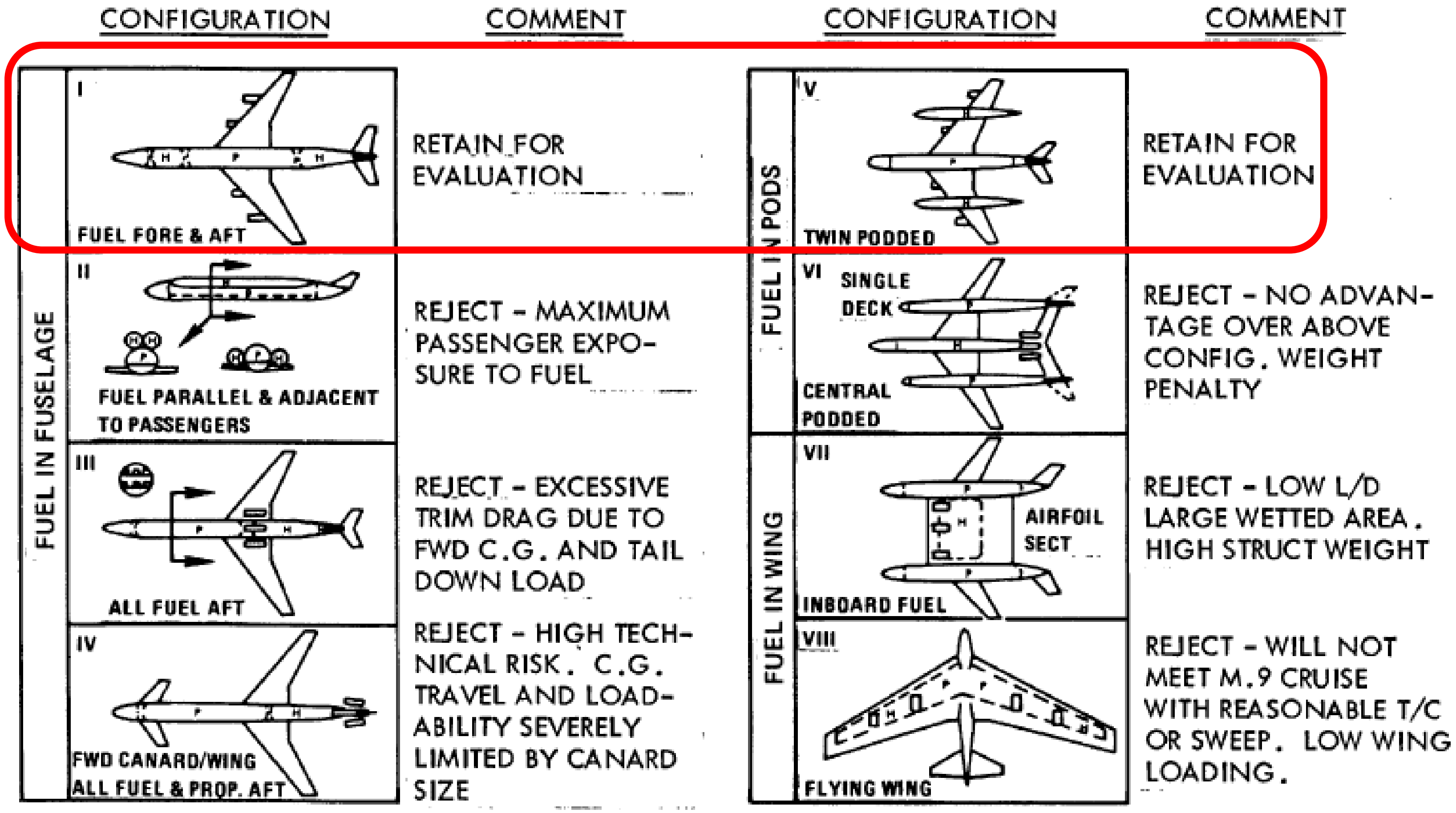
Possible solutions – (previous experience, NASA’s role?)

Focus on methane and hydrogen: cryogenic liquid (volume)



https://www.eia.gov/todayinenergy/detail.php?id=9991

Airframe focus (1 - NASA older – 1970s)



NASA CR-132558: “STUDY OF THE APPLICATION OF HYDROGEN FUEL TO LONG-RANGE SUBSONIC TRANSPORT AIRCRAFT” by G.D. Brewer, R.E. Morris, R.H. Lange, and J.W. Moore (1975) https://ntrs.nasa.gov/api/citations/19790025036/downloads/19790025036.pdf

Airframe focus (2 - NASA older – 1970s)

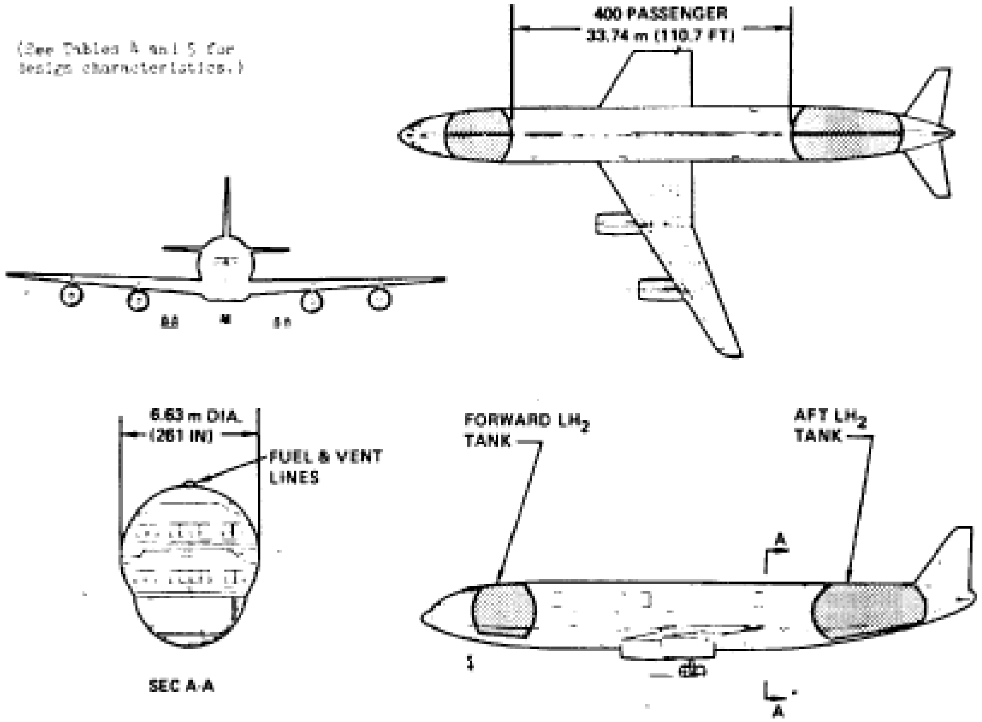


Figure 5. LH_2 Passenger Aircraft - Internal Tank Configuration

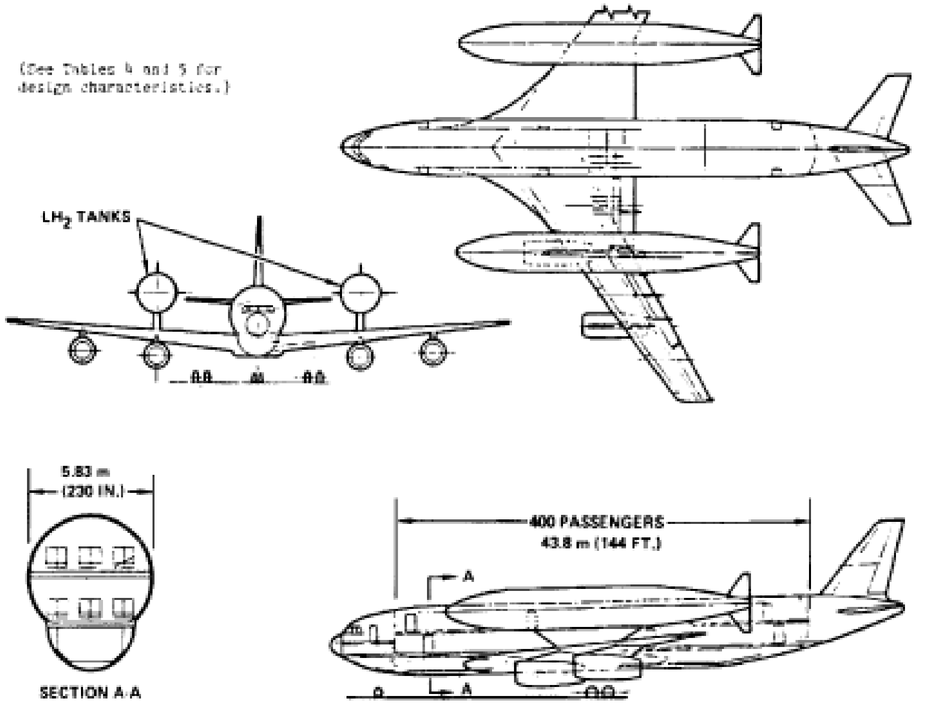
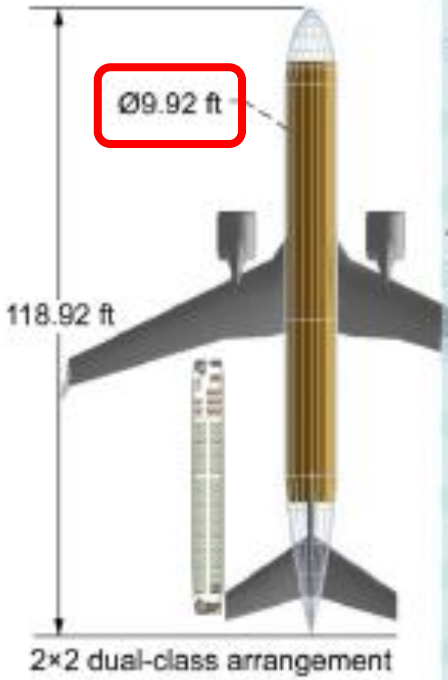


Figure 6. LH_2 Passenger Aircraft - External Tank Configuration

NASA CR-132558: “STUDY OF THE APPLICATION OF HYDROGEN FUEL TO LONG-RANGE SUBSONIC TRANSPORT AIRCRAFT” by G.D. Brewer, R.E. Morris, R.H. Lange, and J.W. Moore (1975) https://ntrs.nasa.gov/api/citations/19790025036/downloads/19790025036.pdf

Airframe focus (3 - NASA revisit – circa 2000s)

Design mission: 2200 nmi (maximum)
maximum TOGW
0.80 cruise Mach number



JP		LH_2
34,900	A_{cruise}, ft	37,100
6,710	TOFL, ft	4,990
1.58	maxCL	1.58
13.79	$L/D_{takeoff}$	14.71
14.58	L/D_{cruise}	13.82
110,948	TOGW, lb	102,432
23,421	Fuel, lb	8,962
20,327	Payload, lb	20,327
61,914	OEW, lb	64,412
7,833	Propulsion weight, lb	9,891
1,025	SW, ft^2	1,093
93.1	SPAN, ft	96.2
8.46	AR	8.46
18937	Thrust, lb	21086
0.871	ESF	0.973
0.669	SFC_{cruise}, lb/hr/lb	0.244
74011	CO_2, lb	0
68	NOx, lb	4

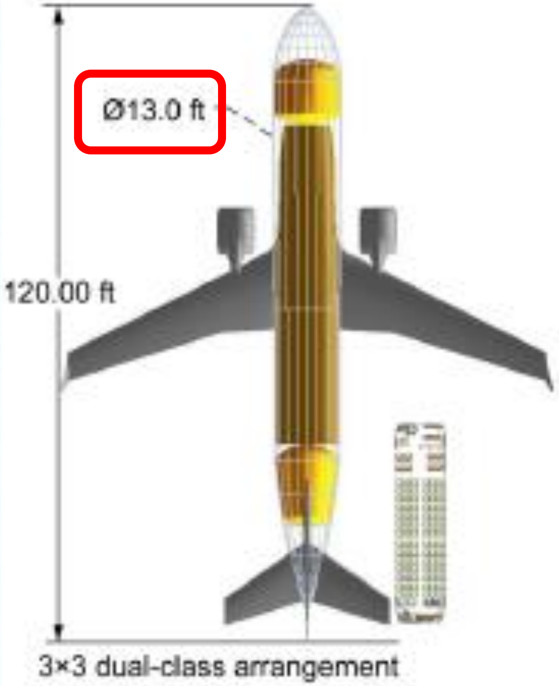
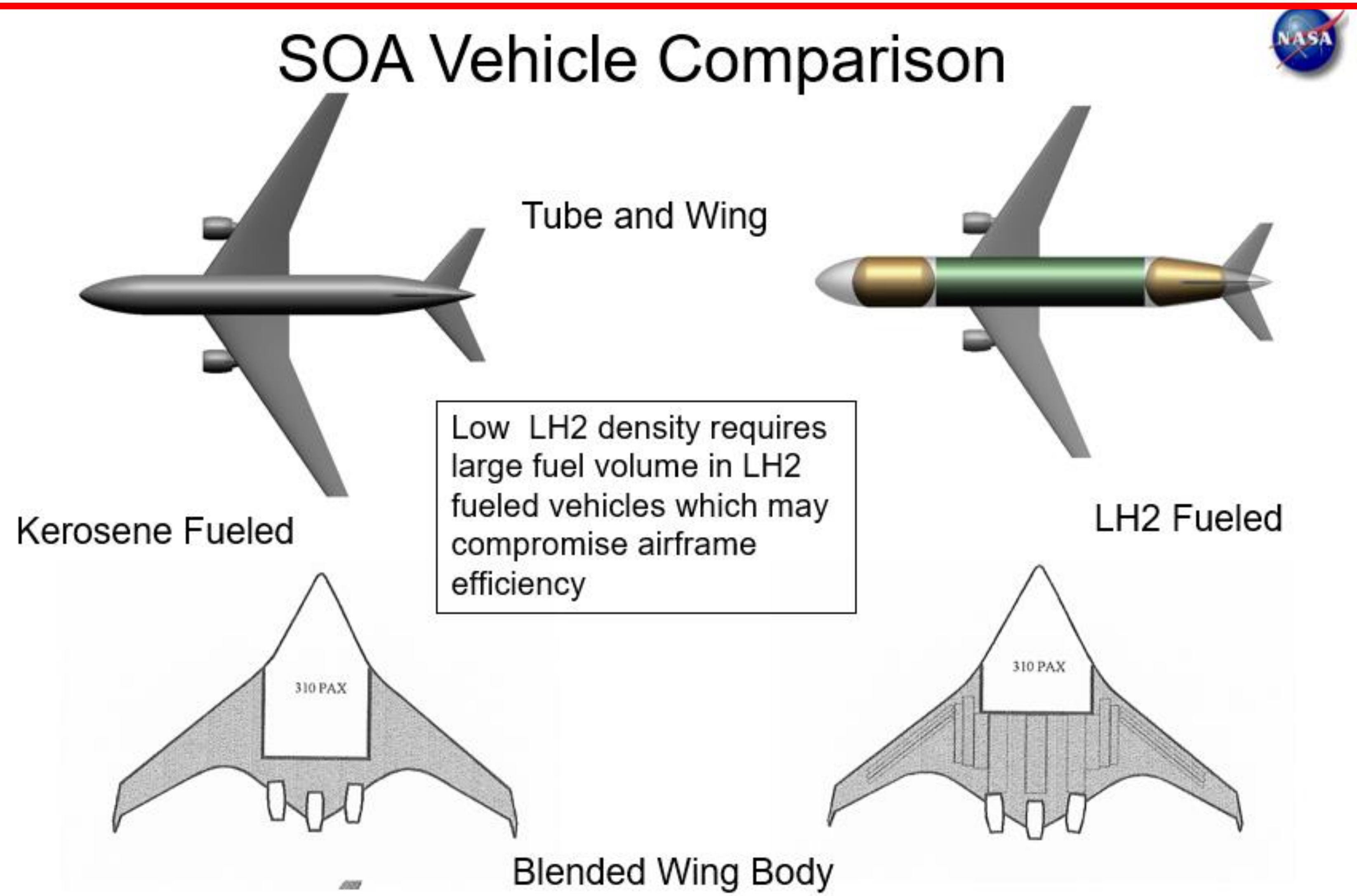


Figure 15.—Baseline kerosene (JP) versus liquid hydrogen (LH_2) gas-turbine size and overall parameters for 100-passenger aircraft (takeoff gross weight (TOGW), takeoff field length (TOFL), coefficient of lift (CL), lift over drag (L/D), operating empty weight (OEW), reference wing area (SW), altitude ratio (AR), engine scale factor (ESF), specific fuel consumption (SFC)).

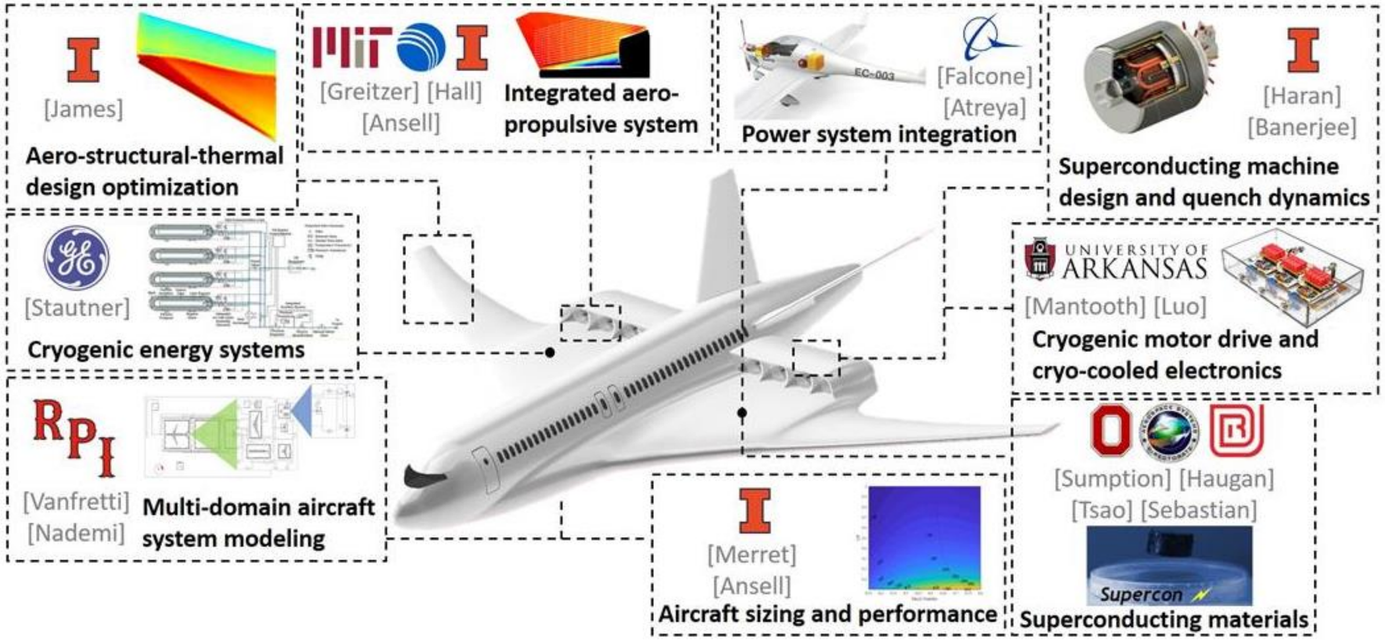
NASA TM-2009- 215487, "Propulsion Investigation for Zero and Near-Zero Emissions Aircraft", by Snyder, et. Al
https://ntrs.nasa.gov/api/citations/20090023315/downloads/20090023315.pdf

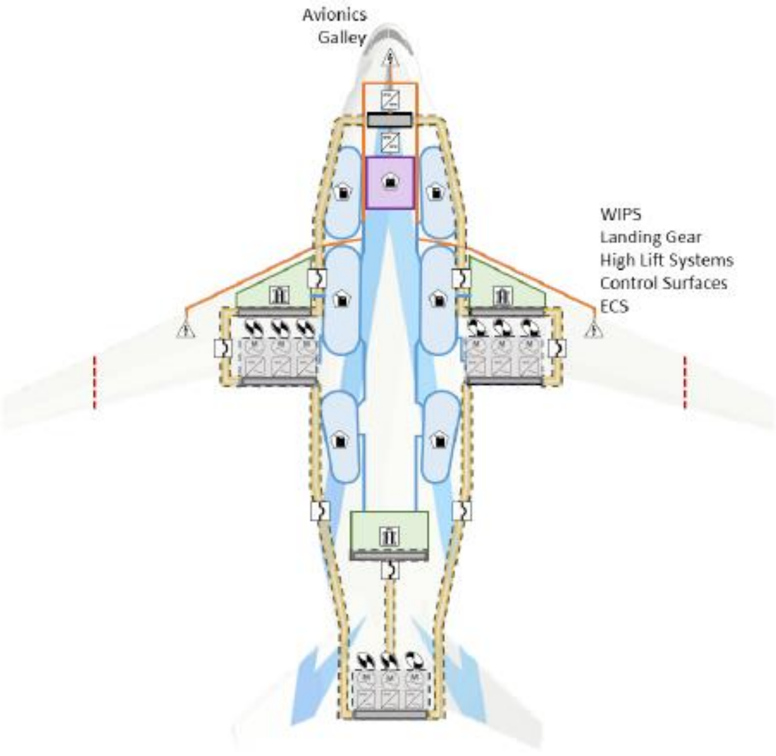
Airframe focus (4 - NASA revisit – circa 2000s)



Airframe focus (5 - NASA [2020s, ongoing] studies)

- Present H2 aircraft studies under University Leadership Initiative (ULI) https://nari.arc.nasa.gov/uli
- Center for High-Efficiency Electrical Technologies for Aircraft (CHEETA) https://cheeta.illinois.edu/





Propulsion focus (1 - hydrogen fuel cell & turbofan, 2000s)

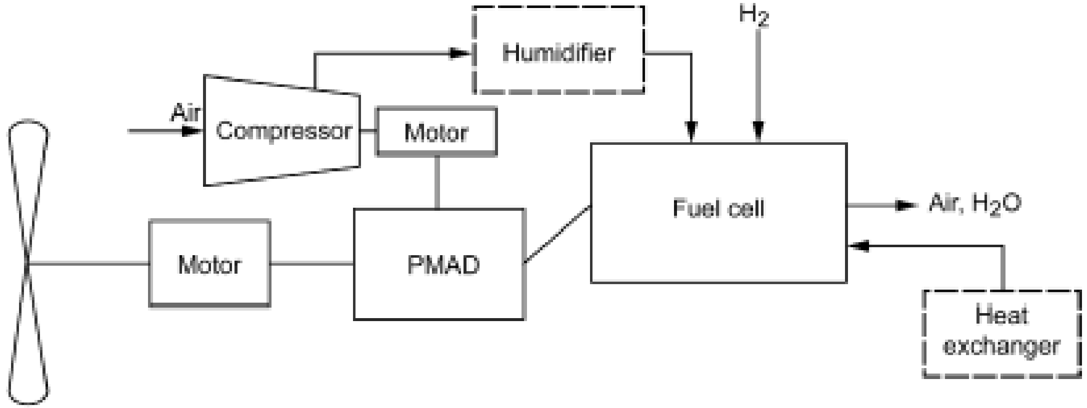


Figure 6.—Fuel cell propulsion and power system (power management and distribution (PMAD)).

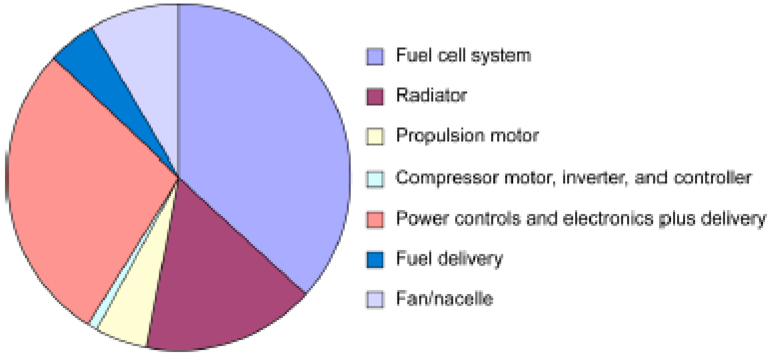


Figure 14.—Final relative masses of hydrogen fuel cell propulsion system components.

NASA TM-2009- 215487, “Propulsion Investigation for Zero and Near-Zero Emissions Aircraft”, by Snyder, et. Al https://ntrs.nasa.gov/api/citations/20090023315/downloads/20090023315.pdf

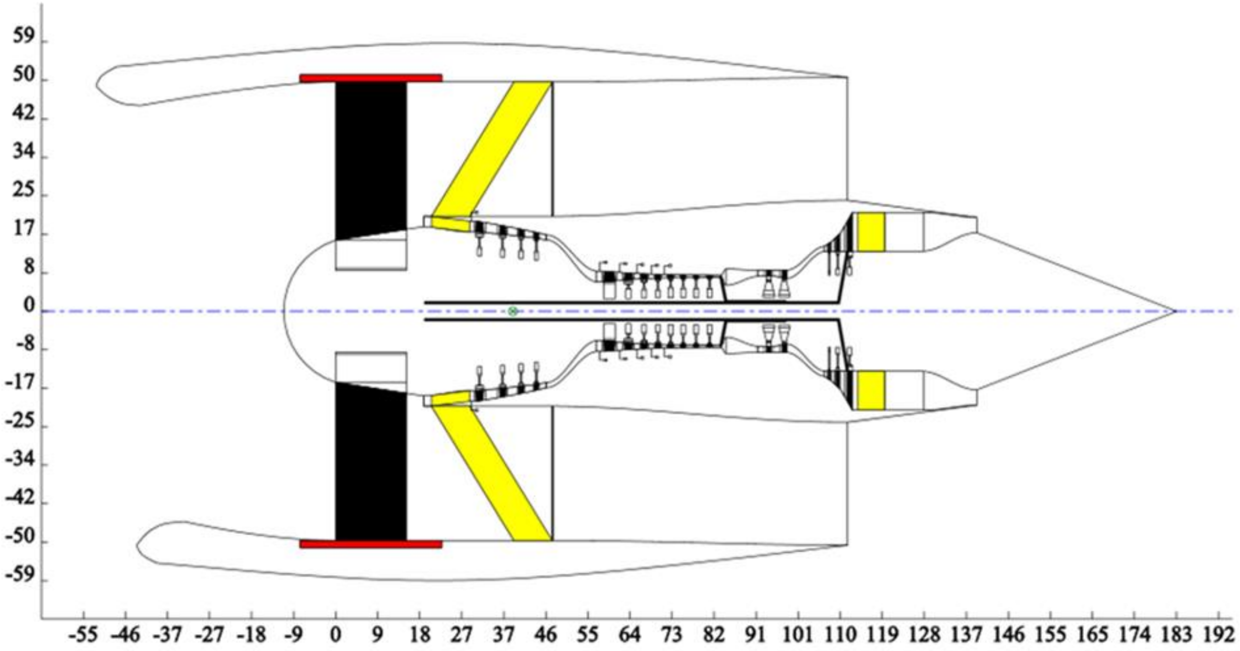


Figure 2. Cross section of N+3 Engine (dimensions in inches).

NASA TM-20210021504, “Effects Of Energy Capture And Recovery On An N+3 Technology Level Reference Propulsion System”, by C.A. Snyder, https://ntrs.nasa.gov/api/citations/20210021504/downloads/TM-20210021504.pdf

Propulsion focus (2 - solid-oxide fuel cell within advanced turbofan + electric motor)

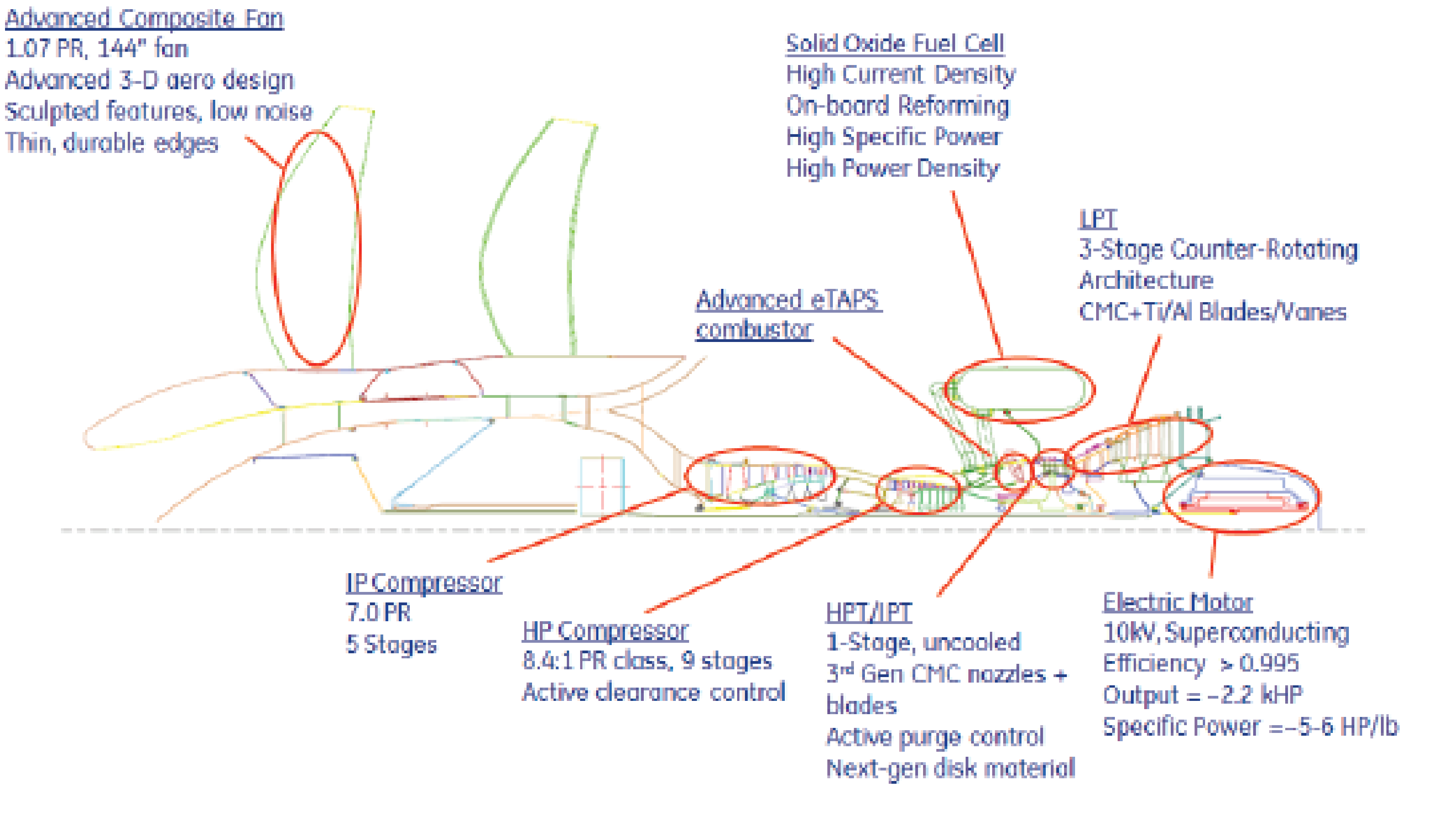
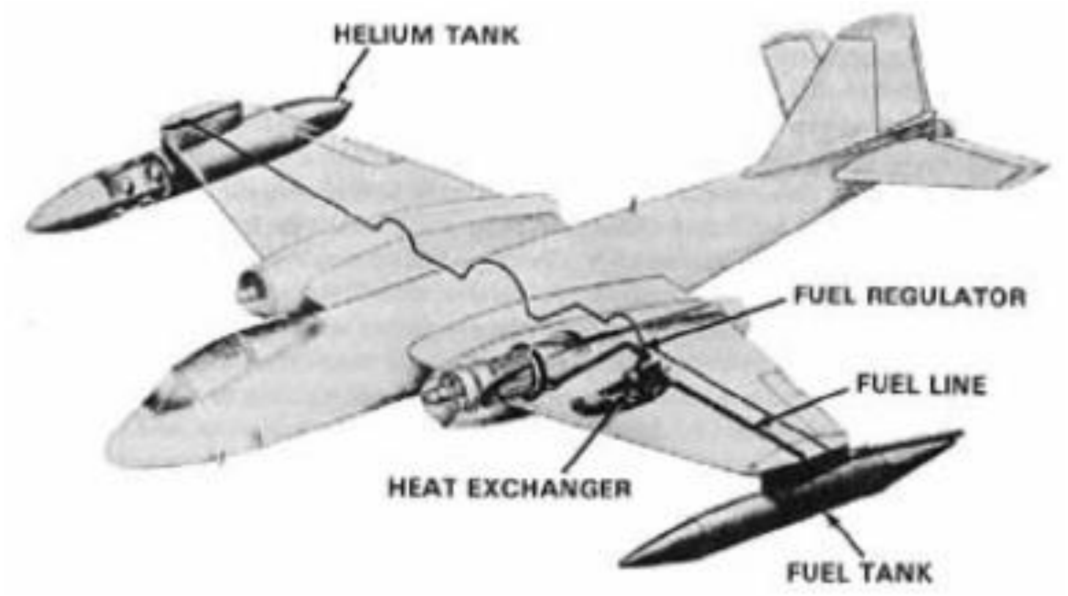


Figure 3 - LNG+2045GT+SOFC+UDF Concept Layout

Integrate fuel cell within turbofan engine, PLUS electric motor with battery assist to reduce fuel burn.

NASA CR-2012-217556, "Subsonic Ultra Green Aircraft Research Phase II: N+4 Advanced Concept Development", by Bradley, Marty K.; Droney, Christopher K. (Boeing) https://ntrs.nasa.gov/api/citations/20120009038/downloads/20120009038.pdf

Fuel system focus (1 – 1950s-70s)



1955-59, NACA Lewis (now NASA Glenn), Project Bee. B-57B modified to permit one engine to burn JP-4 or hydrogen (NASA SP-4404 Liquid Hydrogen as a Propulsion Fuel, 1945-1959, John L. Sloop)

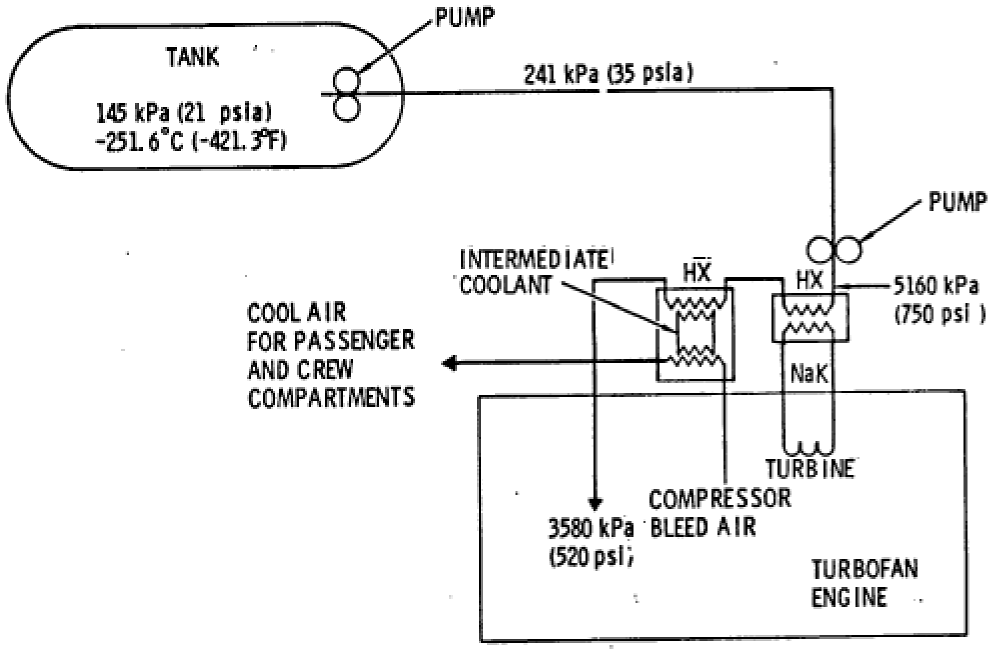
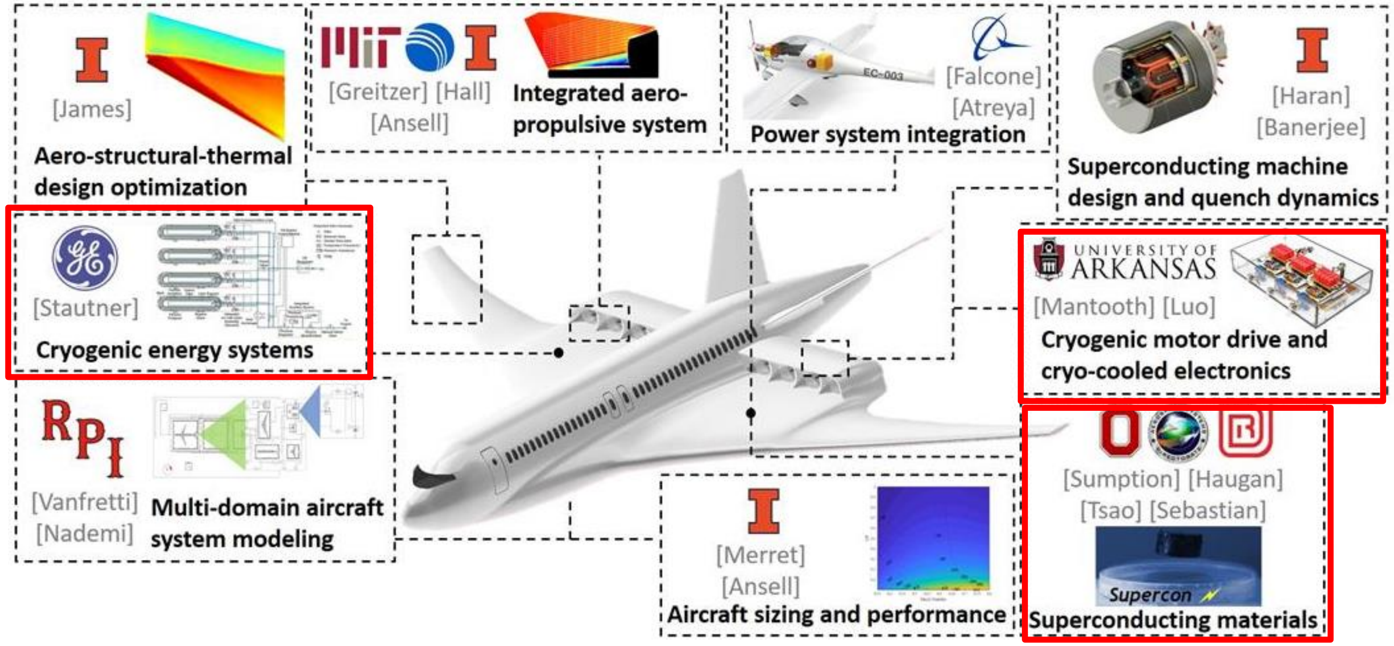


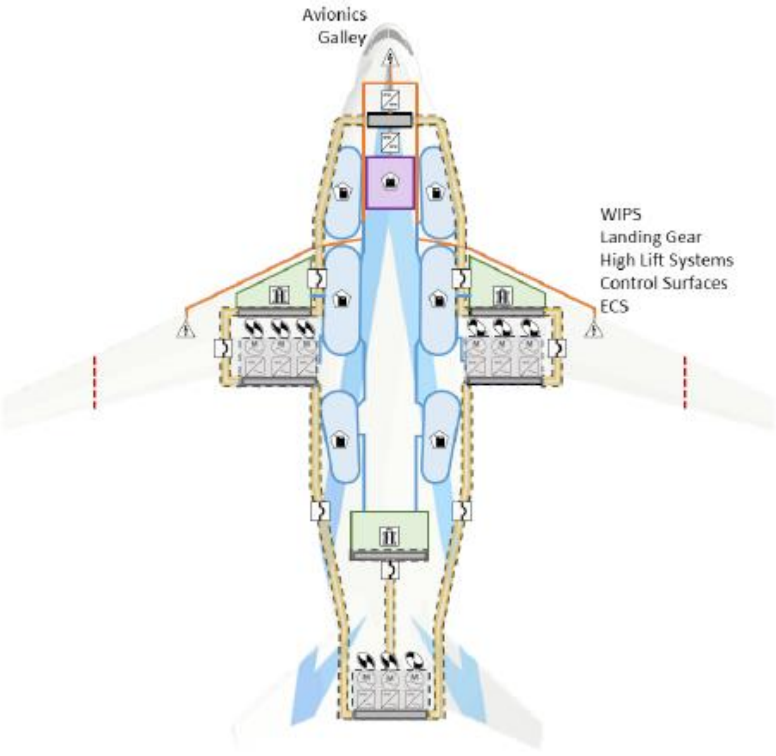
Figure 1. Hydrogen Fuel System Elements

NASA CR-132558: "STUDY OF THE APPLICATION OF HYDROGEN FUEL TO LONG-RANGE SUBSONIC TRANSPORT AIRCRAFT" by G.D. Brewer, R.E. Morris, R.H. Lange, and J.W. Moore (1975)
https://ntrs.nasa.gov/api/citations/19790025036/downloads/19790025036.pdf

Fuel system focus (2 – 2020s CHEETA includes fuel system modeling)

- Present H2 aircraft studies under University Leadership Initiative (ULI) https://nari.arc.nasa.gov/uli
- Center for High-Efficiency Electrical Technologies for Aircraft (CHEETA) https://cheeta.illinois.edu/





Synergies?

With so many (new?) components and possible things to explore to meet this urgent need:

- What thoughts and ideas are out there? (Identify opportunities)
- Capture possible synergies of these systems
- Which ones should NASA explore? (What makes the most sense?)

We have some experience:

- Past aeronautics-based studies
- A lot of space-based experience, how best to use?
- How to best capture our expertise?

There are also other sources of ideas and work to leverage:

Workshops and Activities on Cryogenic Fuels

Recent Workshops on cryogenic fuels

- Vertical Flight Society H2-Aero Workshop (March 29-31, 2022)
  - https://vtol.org/events/2022-h2-aero-symposium-and-workshop
  - Included GH2 and LH2 as fuel and a range of vehicle sizes
- DOE Liquid Hydrogen Technologies Workshop (Feb 22-23, 2022)
  - https://www.energy.gov/eere/fuelcells/liquid-hydrogen-technologies-workshop
  - Included LH2 production, delivery, distribution, storage & applications
- DOE H2@Airports Workshop (Nov 4-6, 2020)
  - https://www.energy.gov/eere/fuelcells/h2airports-workshop
  - Assessed SOA for electric aircraft and airport applications using hydrogen fuel cells

Upcoming Workshops on cryogenic fuels

- U.S. Air Force is conducting the first inaugural workshop in November 2022 to explore LNG options for aviation

Workshops and Activities on Cryogenic Fuels

Current activities that include cryogenic fuels

- DOE Hydrogen Program
  - https://www.energy.gov/sites/default/files/2022-04/fc-expo-2022-doe-h2-overview-h2-shot-update.pdf
  - H2@Scale, Hydrogen Shot, National Hydrogen Strategy and Roadmap
- FAA
  - ASCENT Project 52 includes assessing LH2 as aviation fuel (https://ascent.aero/)
  - Hydrogen Fuel Cell Research
- U.K. and European Union (EU) programs
  - Aerospace Technology Institute (ATI) FlyZero (https://www.ati.org.uk/flyzero/)
  - U.K. Hydrogen Strategy (https://www.gov.uk/government/publications/uk-hydrogen-strategy)
  - EU Clean Aviation (https://www.clean-aviation.eu/)
  - EU Green Deal and Hydrogen Strategy (https://energy.ec.europa.eu/topics/energy-systems-integration/hydrogen_en)
- Industry efforts
  - A range development and demonstrations are underway using LH2 for fuel cells and gas turbines

Further NASA University Leadership Initiative (ULI) efforts

ULI Round 5 (Current activities just kicking off) https://nari.arc.nasa.gov/ULIround5

- IZEA – Integrated Zero-Emission Aviation using a Robust Hybrid Architecture
  - PI: Louis Cattafesta (Florida State University)
  - News Release: NASA selects FAMU-FSU College of Engineering to help develop sustainable aviation system
- Zero-Carbon Engine Core with Supercritical Carbon Dioxide Power Cycle for Onboard Power
  - PI: Jayanta Kapat (University of Central Florida)
  - News Release: UCF to Lead $10M NASA Project to Develop Zero-Carbon Jet Engines

Thanks for your attention.

Questions?

Backup charts

Additional information (individual reports):

- PERFORMANCE ANALYSIS OF EVOLUTIONARY HYDROGEN-POWERED AIRCRAFT, White Paper, International Council on Clean Transportation (ICCT) (Jan 2022). https://theicct.org/publication/aviation-global-evo-hydrogen-aircraft-jan22/
- "H2 / DeCarbonization studies: history and ongoing", by Christopher A. Snyder (October 2021). Presented at NARI Systems Analysis Symposium 2021. (Includes several links noted earlier and some comments for these links.) Video and all NARI symposium presentations at: https://nari.arc.nasa.gov/NASA_Systems_Analysis2021. This specific presentation available on NASA Tech Report server: https://ntrs.nasa.gov/citations/20210023506
- Waypoint 2050 by Air Transport Action Group (ATAG) (Sep 2020). "New analysis details aviation climate pathways." https://www.atag.org/component/news/?view=pressrelease&id=120
- "Hydrogen A future fuel for aviation?", Roland Berger (March 2020). Comprehensive view of hydrogen within and outside aviation; identifies and discusses pros and cons. https://www.rolandberger.com/en/Insights/Publications/Hydrogen-A-future-fuel-for-aviation.html
- Boeing N+4 Workshop, Includes LH2 and LCH4 (June 2011)
  - Under NASA Contract NNL08AA16B – NNL11AA00T – Subsonic Ultra Green Aircraft Research – Phase II, N+4 Advanced Concept Development
  - https://ntrs.nasa.gov/api/citations/20120009038/downloads/20120009038.pdf (noted previously)