Commercially-viable Hydrogen Aircraft for Reduction of Greenhouse Emissions

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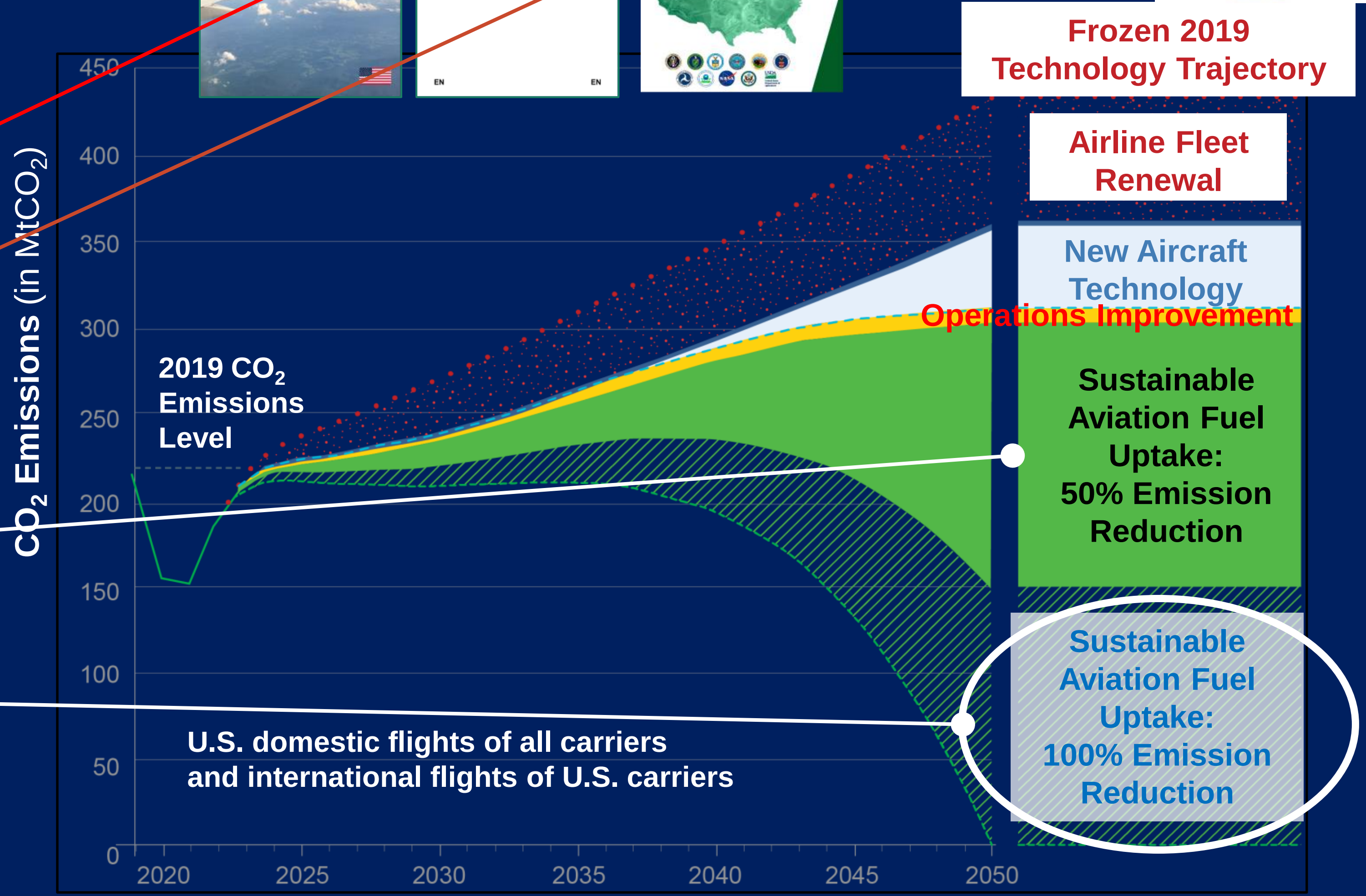
Path to Emissions-Free Aviation

- U.S. Aviation Climate Action Plan has set Sustainable Aviation Net-Zero Carbon Emissions Goals by 2050
- Europe established a strategy in 2020 and is engaging with industry for hydrogen-fueled aviation
  - A Hydrogen (H_2) Strategy for a Climate-Neutral Europe
  - Sustainable & Smart Mobility Strategy
- The *U.S. National Clean Hydrogen Strategy and Roadmap* presents a strategic framework for achieving large-scale production and use of clean hydrogen
- SAF reduces emissions and fossil fuel dependency, but transition to new approach required to achieve 2050 goals beyond SFNP (AACES 2050 study)
- Switch to renewable cryogenic fuels to eliminate carbon emissions from fuel production and aircraft propulsion (assuming sustainable fuel sources are available)

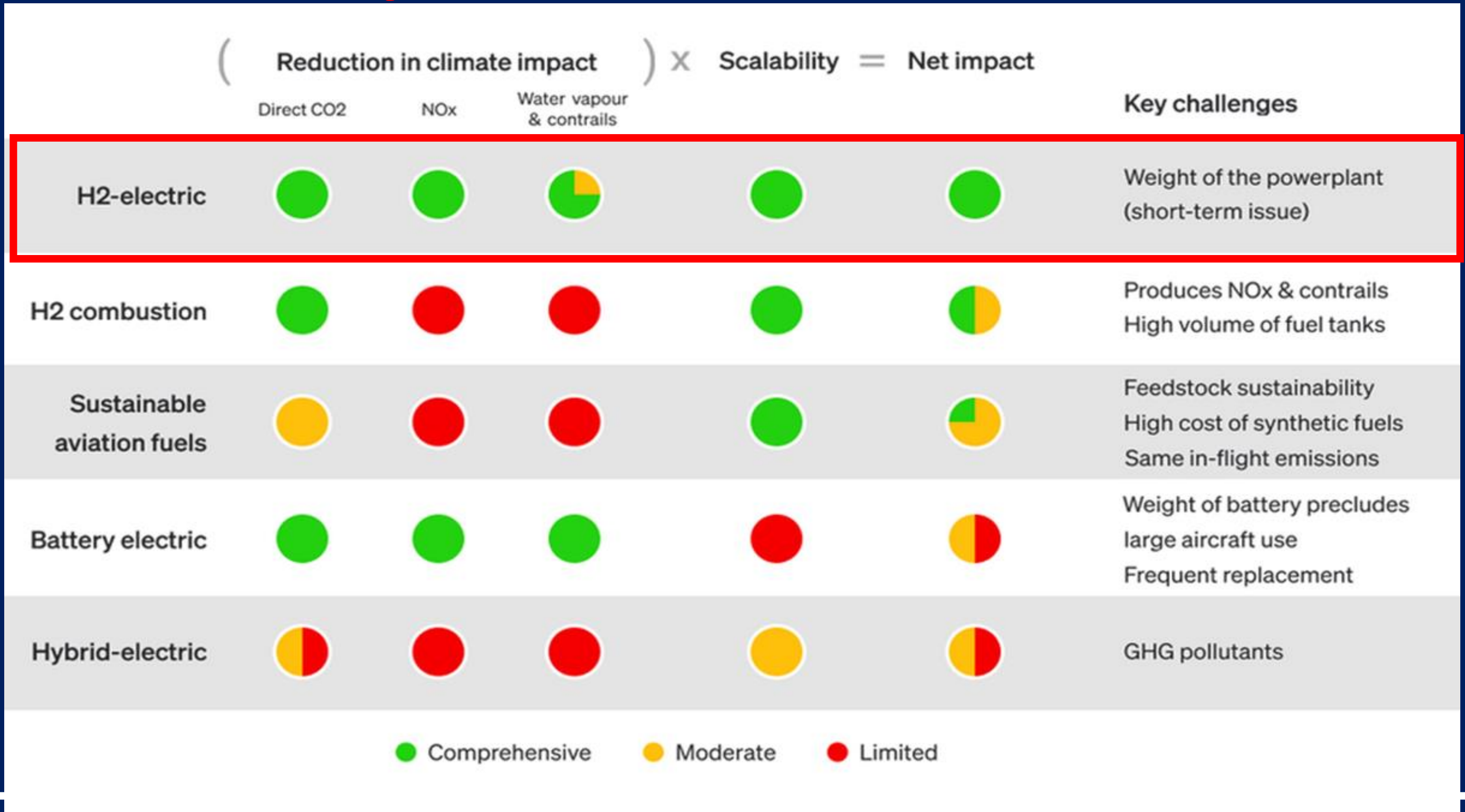


SAF = Sustainable Aviation Fuel; SFNP = Sustainable Flight National Partnership; AACES = Advanced Aircraft Concepts for Environmental Sustainability

Global climate goals by 2050 require new approach to fuels beyond Sustainable Flight National Partnership (SFNP): Renewable cryogenic fuels can enable net-zero carbon emissions

Hydrogen-Electric is the Only Scalable Zero Emission Solution

Ranking potential impacts of H2 implementation



- Establishing Airports as Hydrogen Hubs https://youtu.be/nn9rp1IHEjA

June 2023 – Paris Air Show
https://www.zeroavia.com

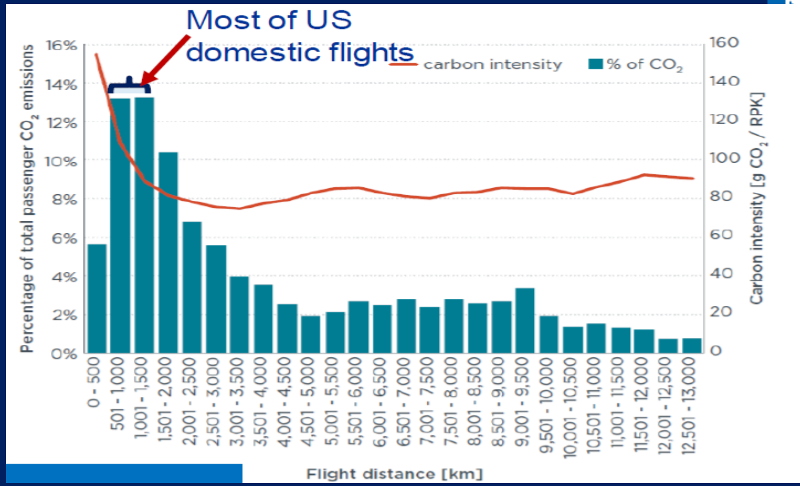
Commercially-viable Hydrogen Aircraft for Reduction of Greenhouse Emissions (CH_2ARGE)

The Opportunity:

The main focus on decarbonizing aviation is on short- and medium-range aircraft 100-300 passengers flying 1000 - 3000 km. Hydrogen is the only fuel that can provide zero carbon emissions by 2050.

How can we make Hydrogen Aircraft work in commercially viable manner?

How to use the hydrogen most effectively on the aircraft and turn it into energy?



The Strategy:

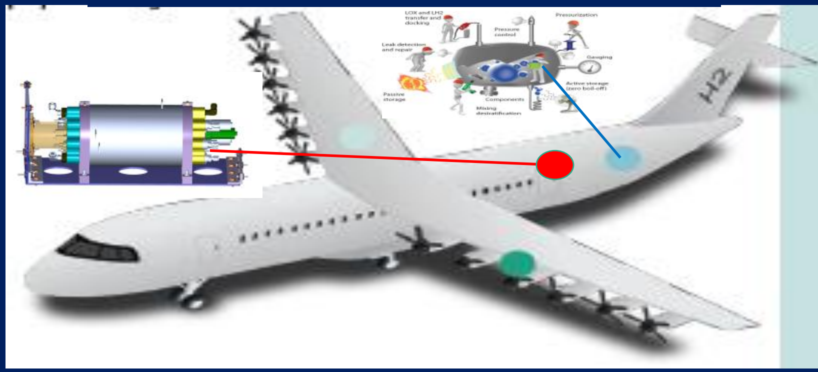
Develop integrated conceptual and experimental methodology that enable industry-wide adoption of medium-range Hydrogen Aircraft based on hydrogen-air fuel cells & cryogenic hydrogen system synthesis. Allow for the methodology maturation and identify system level closure plans and technology development targets. Develop an integrated aircraft concept of operations, exploring opportunities such as non-active time frames to simplify aircraft lifecycle requirements.

Considerations:

The <u>MAIN PRACTICAL GOAL is to increase specific energy of the whole aircraft by 2-3X</u> and will be achieved <u>at the system level by integrating</u> optimized lightweight, durable and safe composite cryotanks, on board cryofuel management system, and Fuel Cells. This requires a comprehensive system-specific studies and practical solutions in identifying advanced materials, modeling tools, & evaluation criteria.

NASA based team – capitalize on technology synergies and test facilities.

Revolutionary hydrogen fueled aircraft



Design Mission: 80-200 PAX, 500-3000 nm range.

Cruise speed Mach 0.4-0.8, Highly efficient wing

- (green) Distributed Electric Propulsion using electric motors for thrust
- (blue) LH2 tanks on wings or behind PAX cabin – added weight 4 tons
- (red) Fuel cell system and / or hydrogen burning turbines (10-25 MWt) powering electric motors

Purpose and Approach of Study – Hydrogen Aviation

- Goal: Determine approximate turbine, fuel cell system and LH_2 storage/distribution requirements for a 737-800 class aircraft capable of meeting the same mission (3500 nmi, Ma=0.8 cruise) and applicable FAR requirements as the baseline. This was essentially our team's definition of "commercially viable".

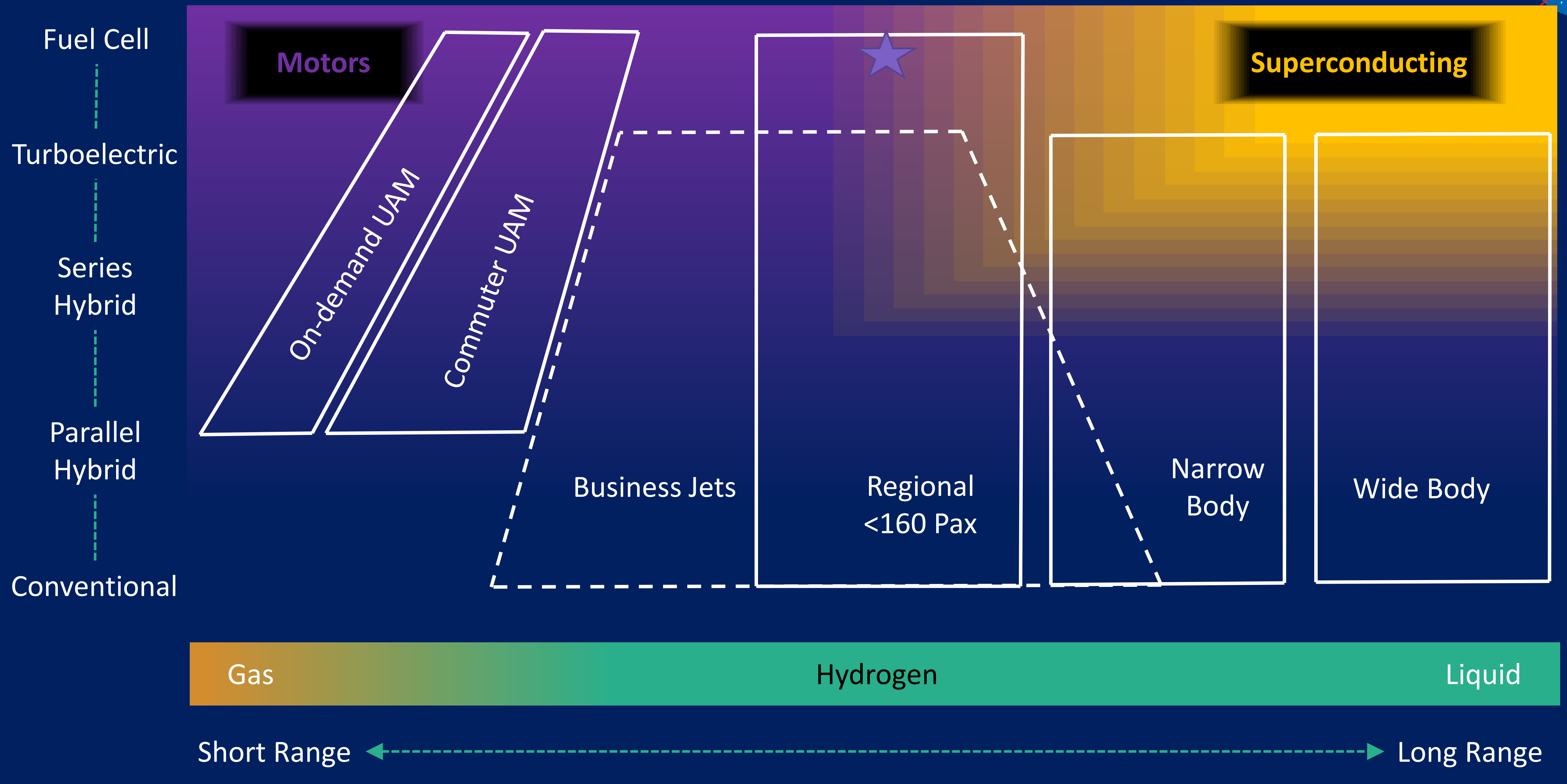
- Underlying Research Question: Could a LH_2 fuel cell powered aircraft eventually impact the dominant aircraft class in the commercial market, and not just regional/commuter aircraft and smaller?

- General Approach: Perform an iterative conceptual design study of one or more aircraft configurations. Vary power/propulsion and fuel storage component integration and technology performance levels until design closure is reached. Update concept aircraft as needed as improved component projections are obtained.

Some Key Design Parameters Include:

- Fuel cell and turbine thermodynamic efficiency, operating temperature, weight/volume per MW
- Fuel cell and turbine heat rejection approach and associated volume/weight/efficiency/drag etc.
- Level of potential "hybridization" with batteries for takeoff and ascent assistance
- Location and number of fuel tanks, fuel cell stacks, propulsors

Technology Maturation



Cryogenic Systems for Future Aviation

KSC LH_2 Sphere

Ground Storage Tanks:

- Stationary metallic tanks
- Pressure/thermal life cycle typically very long
- Conservative design (thick walled)
- Requires metallic vacuum jacket to contain insulation
- E.g.: KSC LH_2 Spheres

Ground Transportation Tank

Ground Transportation Tanks:

- Cargo tanks for rail, highway, water
- Requires metal jacket over insulation
- Static, dynamic & impact loading
- Pressure cycling
- Protection of valves, relief devices
- Subject to ASME/DOT regulations


SLS LH_2 Tank

Space Launch Vehicle Tanks:

- Much lower design safety factors than ASME/DOT (≥1.5)
- Service life ≥13 cycles
- Spray-on foam insulation lacks durability and performance

CRYOGENIC TANKS FOR FUTURE AVIATION:

Requirements:

- *Durability* – 1000s of pressure/ thermal cycles
- *Safety* – crashworthiness, reliability, maintainability, inspectability, passenger safety
- *Operations* – rapid turn-around refueling
- *Weight/Volume* – tank efficiency improves with increased diameter and reduced surface area (minimize boil-off)
- *Manufacturing Rate* – number of aircraft/ month >> other cryogenic tank applications

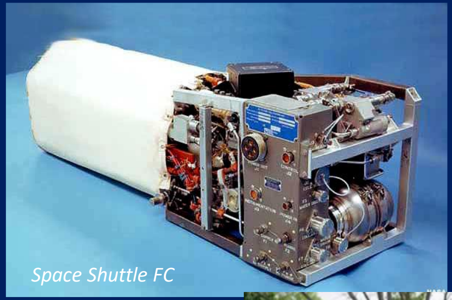
Technology Gaps:

- Materials and Structures solutions that enable viable, reliable, affordable cryogenic tanks on-board aircraft
  - Lightweight tanks and fluid systems with high pressure/thermal cycle capability
  - Lightweight, high thermal performance insulations
- Systems Analysis to assess new vehicle configurations

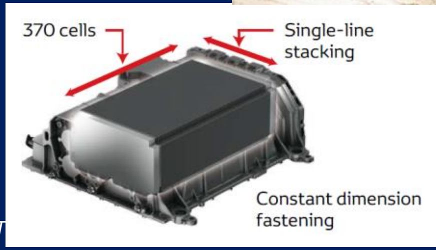
KSC = Kennedy Space Center; LH_2 = liquid hydrogen; ASME/DOT = American Society of Mechanical Engineers/Department of Transportation; SLS = Space Launch System; H_2 = hydrogen

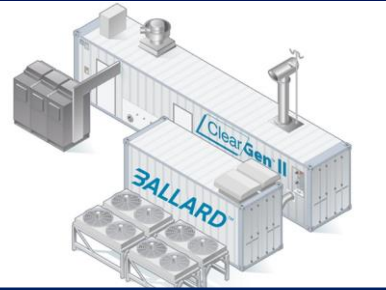
NASA experience with cryogenic fuel systems for space and ground support require development to help close gaps in the integration of cryogenic fuel systems and propulsion into aircraft

Fuel Cells for Future Aviation



Space Shuttle FC





NASA Historic Applications:

- Gemini, Apollo, Space Shuttle
- Two types of fuel cell using LH_2 & stoichiometric LO_2
- UTC alkaline fuel cell for Space Shuttle (1981 ~ 2011)
- 3 X 12kW units; each 14" x 15" x 45", 118 kgs
- Produces all onboard electrical power, drinking water
- Short service life
- 1kW NFT LT PEM module tested with ground vehicle

Automotive applications (LT-PEM):

- Several years long service life in cars, trucks, busses
- Powertrain: 100 kW (Toyota Mirai) ~ 400 kW (bus)
- Mirai FC power density: 0.83 $\rightarrow$ 2.5 kW/kg since 2008
- Standardized gas storage pressure 70 MPa: ~0.9 kWh/L (vs 1.2 for cryo)

Stationary power generation (LT-PEM & SOFC):

- 1 MW containerized PEM FC system in Martinique, France for Hydrogène de France by Ballard is the latest
- Typical SOFC <300 kW with heat & power cogeneration
- Low power density, easy fuel storage, HC fuel for SOFC

FUEL CELLS FOR FUTURE AVIATION:

Requirements:

- *Durability* – 300,000 hrs of electrical power generation
- *Large scale* – several MW size FC for a ~20 MW power system of Boeing 737
- *Safety* – crashworthiness, reliability, maintainability, inspectability, passenger safety
- *Operations* – rapid turn of power generation
- *Weight/Volume* – KW/kg high volumetric power density / gravimetrical power density
- *Manufacturing Rate* – number of aircraft/ month >> other FC applications

Technology Gaps:

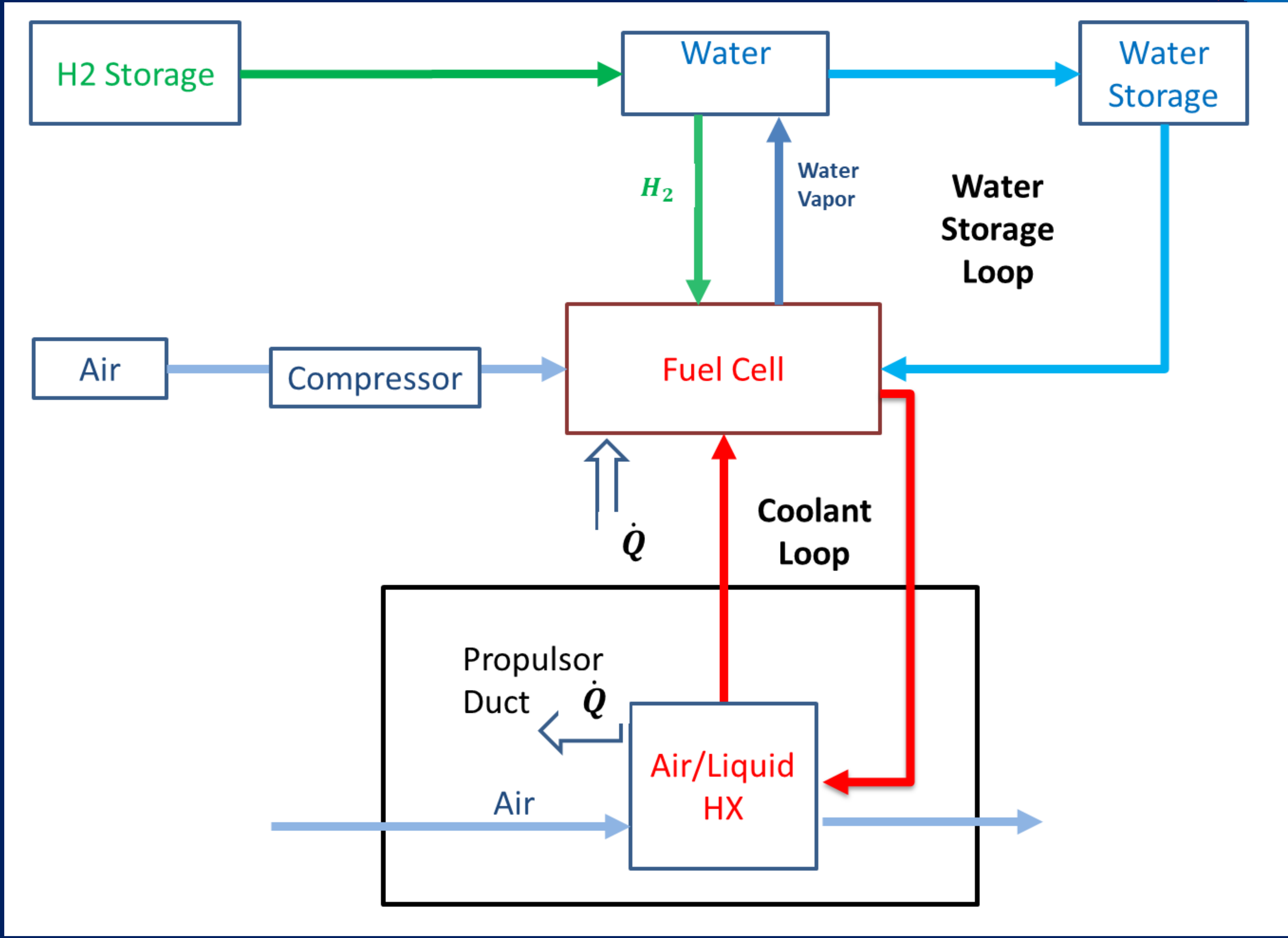
- Materials and Structures enabling solutions for scalable, durable, efficient, lightweight fuel cells
  - High power and KW/kg energy density with 300,000 hours durability and cycle rate capability
  - Introduction of High Temperature PEM FC
  - Scale up approaches for MW fuel cell stacks
  - Lightweight BOP, water and thermal management
- Systems Analysis to assess new vehicle configurations

LH_2 = liquid hydrogen; LO_2 = liquid oxygen; UTC = United Technologies Corporation; NFT = non-flow-through; cryo = cryogenic; HC = hydrocarbon

High thermal efficiency of fuel cells implies a fuel volume reduction of ~30%.
NASA experience with kW fuel cell systems for space missions can be leveraged for aviation.
Terrestrial fuel cell industry capabilities are limited to 100-500 kW range for heavy fuel cell systems and BOP.
It requires significant development to close gaps for introduction of fuel cell systems into aircraft.

Thermal Management System Considerations

- Need to reject 40% to 60% of the heat energy of the LH_2 fuel to the atmosphere
- Need to transition from LT PEM (80C) to HT PEM (200C) to achieve large temperature differential between coolant and airstream during takeoff and climb
- Heat rejection must close at zero flight speed, necessitating the placement of the heat exchanger in the propulsor duct
- At takeoff, the air is relatively hot, making heat transfer difficult
- Potential solution is to include battery power for takeoff and initial climb to reduce heat rejection requirement
- Currently working on heat exchanger conceptual design to get initial size and weight

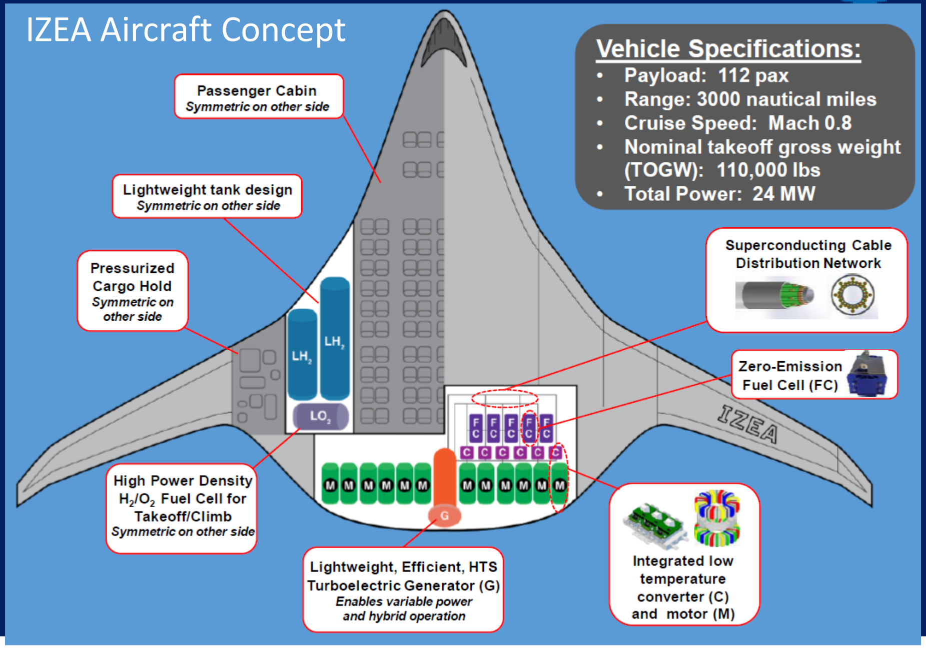


NASA University Leadership Initiative Zero Emissions Aviation Portfolio

Project IZEA – Integrated Zero Emissions Aviation

Lead by: Florida State University

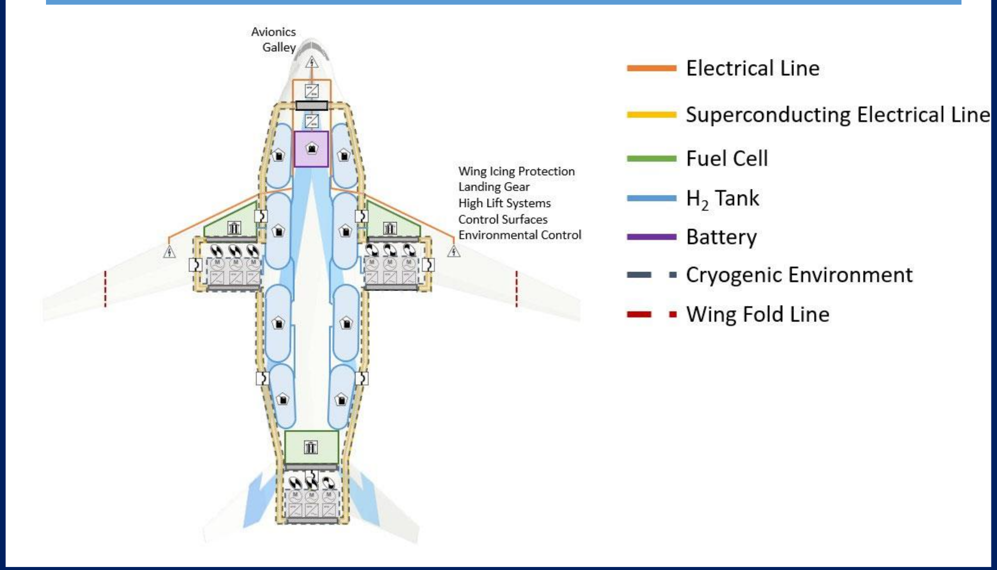
- Blended Wing Body concept
- LH_2, LO_2 Fuel Cell and H_2 Turbogenerator electric propulsion
- Superconducting power transfer from electrical sources to distributed motor-driven propulsors



Project CHEETA – Center for Highly Efficient Electrical Technologies for Aircraft

Lead by: University of Illinois Urbana-Champaign

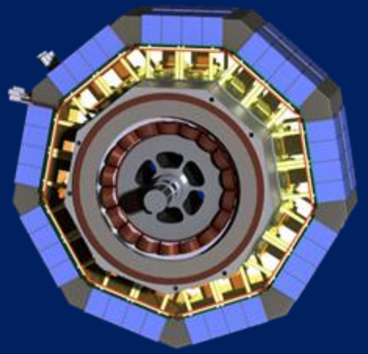
- Superconducting electric machines and high-power transfer
- Novel vehicle planform utilizing distributed electric propulsion and boundary layer ingestion – three sets of three distributed motors
- Hydrogen thermal management and storage system development



Project: Electric Propulsion - Challenges and Opportunities

Lead by Ohio State University

- Designed, Built, Tested a 1 MW Integrated Electric Machine and Inverter Drive
- Tested at NASA's NEAT Facility
- Team conducted regional electric aircraft and battery system studies



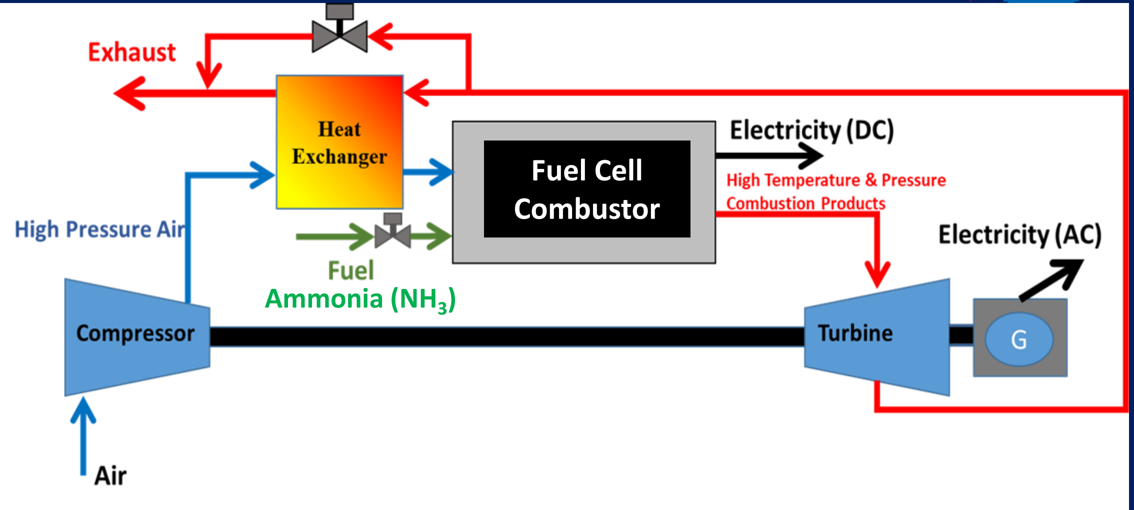
MW Machine (U. Wisconsin)
Power Electronics (Ohio State)

NASA University Leadership Initiative Zero Emissions Aviation Portfolio

Project CLEAN - Carbonless Electric Aviation

Lead by: Tennessee Technological University

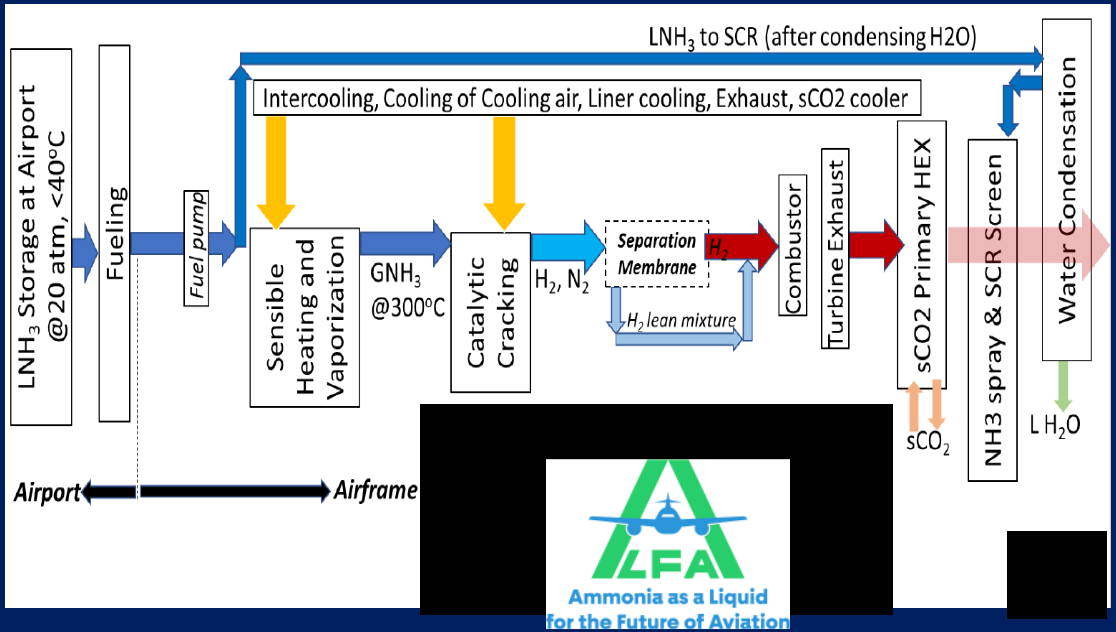
- Solid Oxide Fuel Cell Combustor which utilizes Ammonia (NH_3) as a fuel
- Combustion gas used to generate electrical power in two different ways: fuel cell and turbine-powered generator
- Electrical energy used to power motor-driven fan propulsors
- Team will study environmental impact of concept's emissions



Project ALFA – Ammonia as a Liquid for the Future of Aviation

Lead by: University of Central Florida

- Liquid Ammonia (LNH_3) is stored onboard
- NH_3 gas is partially cracked into H_2 and N_2 and burned in novel gas turbine combustor
- NH_3 used to reduce NO_x emissions through Selective Catalytic Reduction (SCR)
- Supercritical CO_2 cycle used to convert exhaust heat into electrical energy

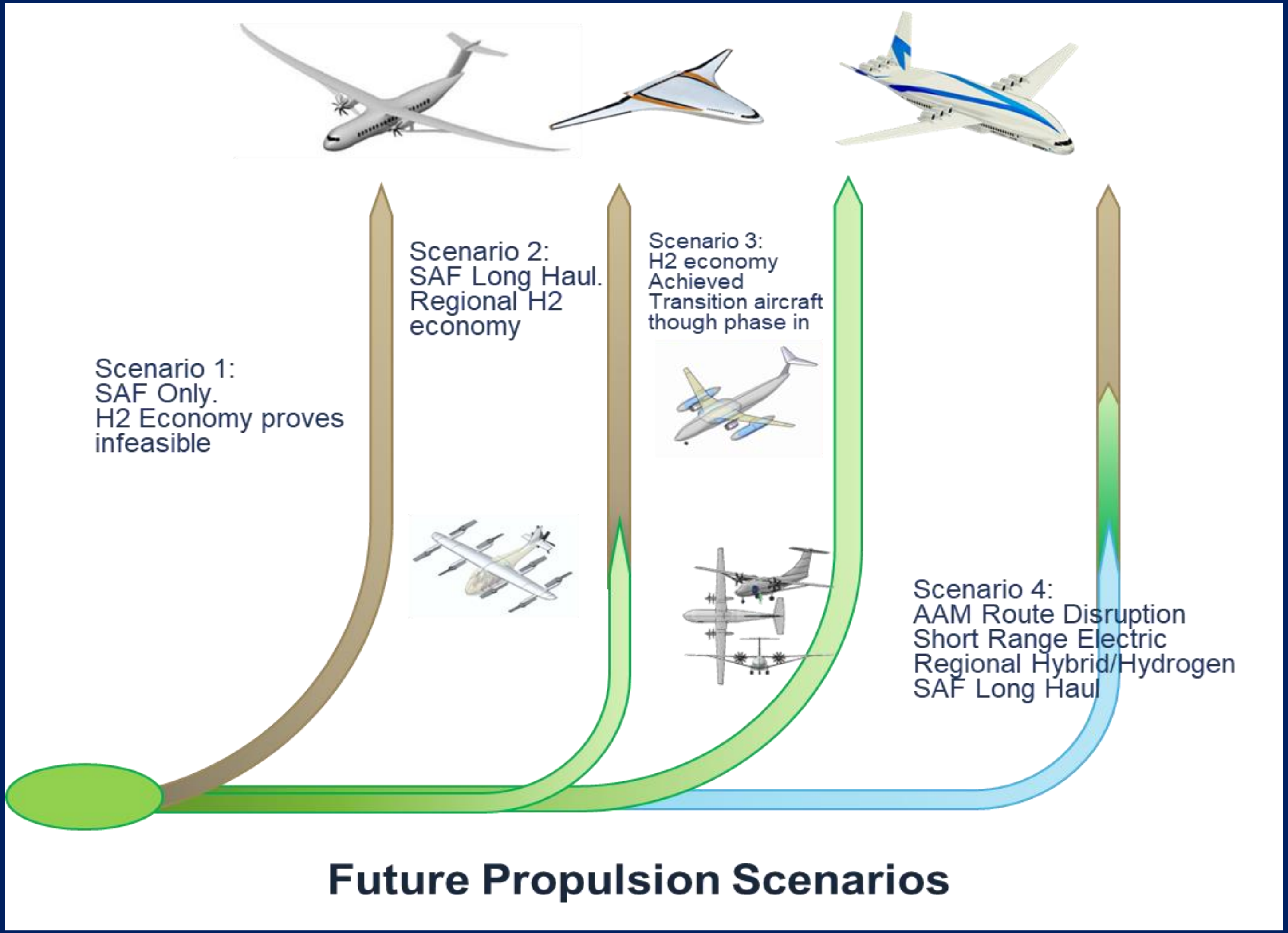


Aircraft Configuration Roadmap

Aircraft configurations may reflect different scenarios regarding Hydrogen utilization in the airspace

1. H2 Economy infeasibility leads to aircraft configurations that maximize fuel efficiency per payload mile.
2. H2 Economy limited to few regions. UAM/GA and some regional aircraft adapt to local Hydrogen utilization.
3. H2 Economy proves feasible. Aircraft configurations reflect hydrogen adoption.
4. AAM Route Disruption. Vast changes to transportation system. Short and Medium range routes using Electric or Hydrogen Power. SAF for long range routes.

Scenarios 2 and 3 may allow for single aisle class Hydrogen aircraft.

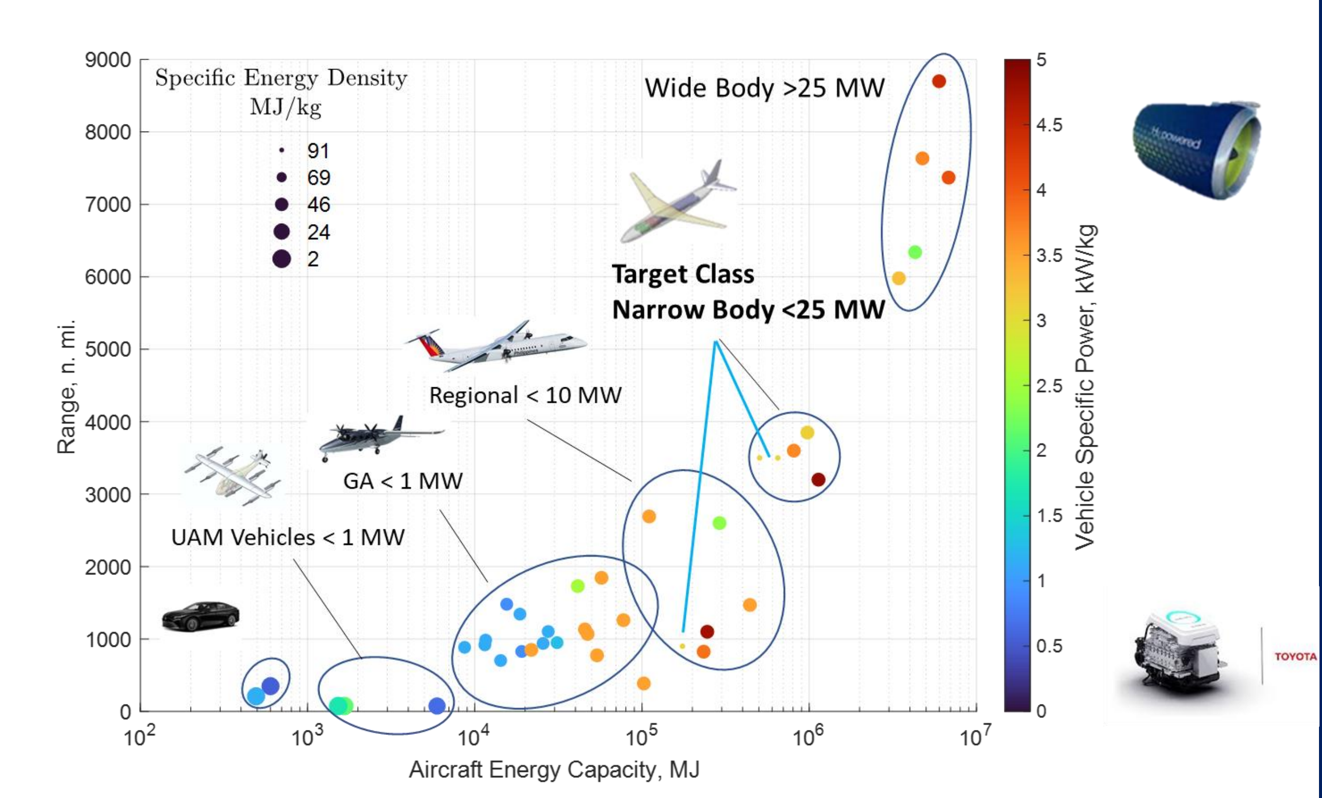


Predicted Hydrogen economy will have impact on aircraft mission requirements and resulting configuration

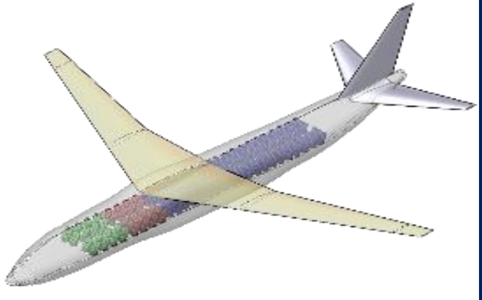
Which aircraft architecture may be good for Hydrogen?

Advances in operations and advances in structural materials are enabling the potential for LH2 fuel adoption:

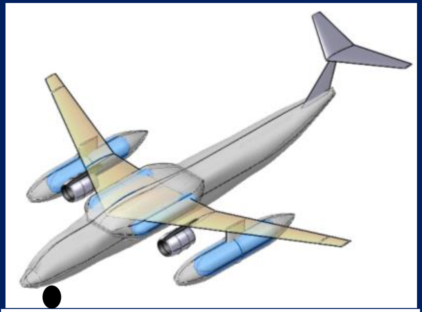
- Sub 1 MW vehicle for typical GA and UAM vehicles.
  - Vehicle specific power in line with automobile industry fuel cells capabilities.
  - Short distance allows for compressed gas or small bottle liquid LH2 story with minimal penalty.
- Commercial Regional, Narrow Body, and Wide Body class vehicles need propulsion technology systems to approach 3 kW/kg.
  - H2 Turbofans are likely near future.
  - LT Fuel Cells suffer significant weight and thrust penalties due to low grade heat.
- Target Class is Narrow Body aircraft
  - Hydrogen Turbofans (indicated by blue lines leading to small dots) show potential energy efficiency of H2 aircraft.
- Wide Body aircraft have significant volume for fuel stores.
  - The main concern is power requirements well above 25 MW and approaching 100 MW.
- Cruise flight requires significantly less power (50%) than for take off needs aircraft.



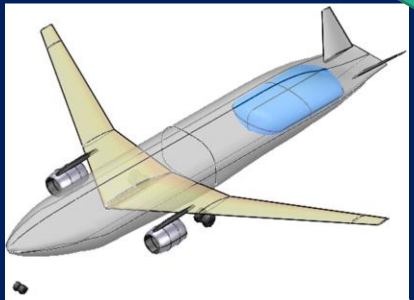
Initial Aircraft Configuration Concepts



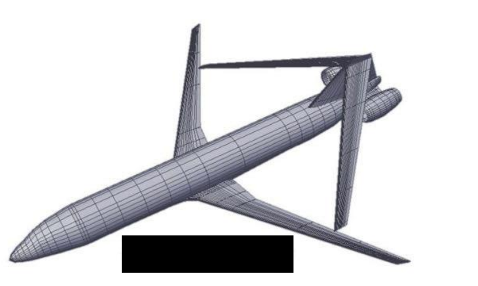
Baseline 150 PAX Aircraft



"External Tank" LH2 Carriage 150 PAX Aircraft



Internal LH2 Carriage 150 PAX Aircraft – "HWB"



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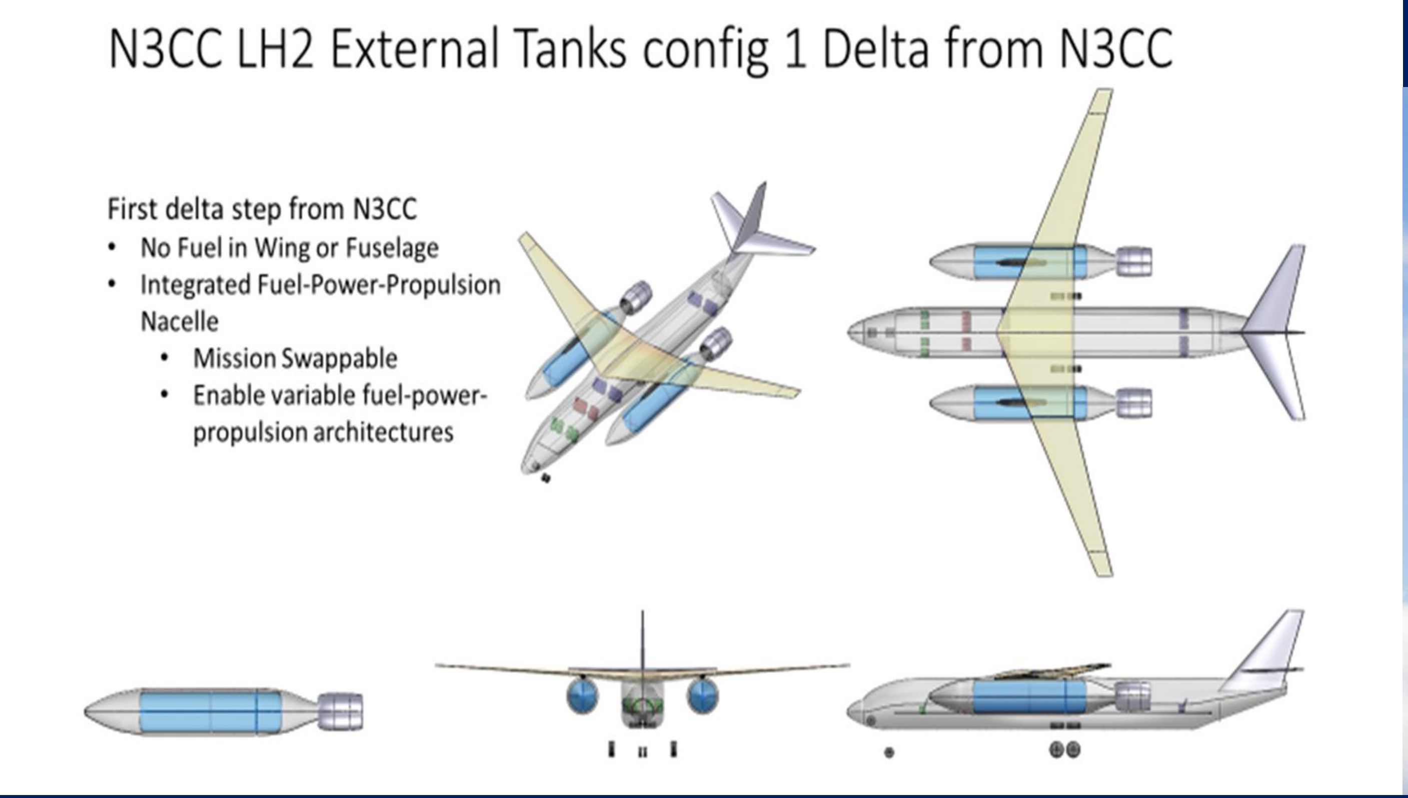
Advanced 150 PAX Aircraft for Future Study (External LH2 Carriage)

Increasing Aerodynamic Efficiency

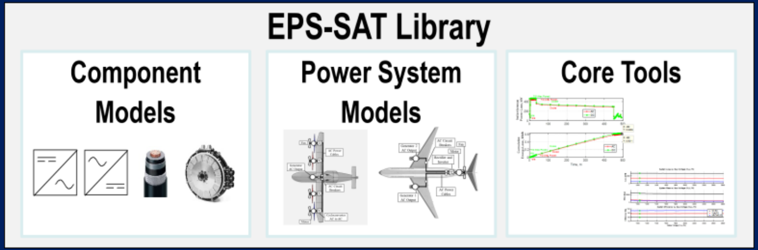
Moving Away from Traditional Designs

* Shown in alternate gas turbine engine configuration

Aircraft Configuration and Architecture



Alternate platform is LM-100J



LM-100J has a cruising speed of ~410 mph and a maximum range of ~2650 miles

NASA Team utilized a combination of analytical tools including Vehicle Synthesis Program (VSP), National Propulsion System Simulator (NPSS), FLight OPtimization System (FLOPS), Weight Analysis of Turbine Engines (WATE), and Electrical Power System Sizing and Analysis Tool (EPS-SAT) to analyze hydrogen aircraft architecture, determine and quantify key metrics, demonstrate architectural sensitivity to key metrics

Evaluation Method

- The NASA team examined a variety of concepts during this study.
    - Concepts based on conventional Tube & Wing (T&W) single aisle transports
    - Blended wing body (BWB) concepts
    - Advanced T&W hybrid wing body (HWB) concepts
- Initial evaluations examined qualitative aspects regarding vehicle serviceability and safety concerns of the concepts.
- Vehicle optimization models developed for select concepts.
- Evaluated concepts includes a Hydrogen Conventional Configuration LH2 baseline, a HWB configuration, and a Conventional Configuration with wing mounted fuel pods.

Single Aisle Mission

- Design Mission - Sizing
  - 3,500 n. mi. traveling at a 0.8 Cruise Mach and 43,000 ft. altitude
    - Typical performance analysis generally allows cruise altitude to fluctuate between 30,000 and 43,000 ft.
  - 154 passengers generating 30,800 lb. payload weight.
- Economic Mission
  - 900 n. mi. traveling at 0.78 Cruise Mach and 43,000 ft. altitude.
  - Maximum Payload*
    - Typical Jet-A fuel single aisle transport max payload is 52,000 lb.
    - Design mission LH2 fuel mass is less than difference between design and typical maximum payload weights.
      - Designs analyzed at 52,000 lb. maximum payload
      - New Max payload estimated maximum payload based on design mission fixed ramp weight.

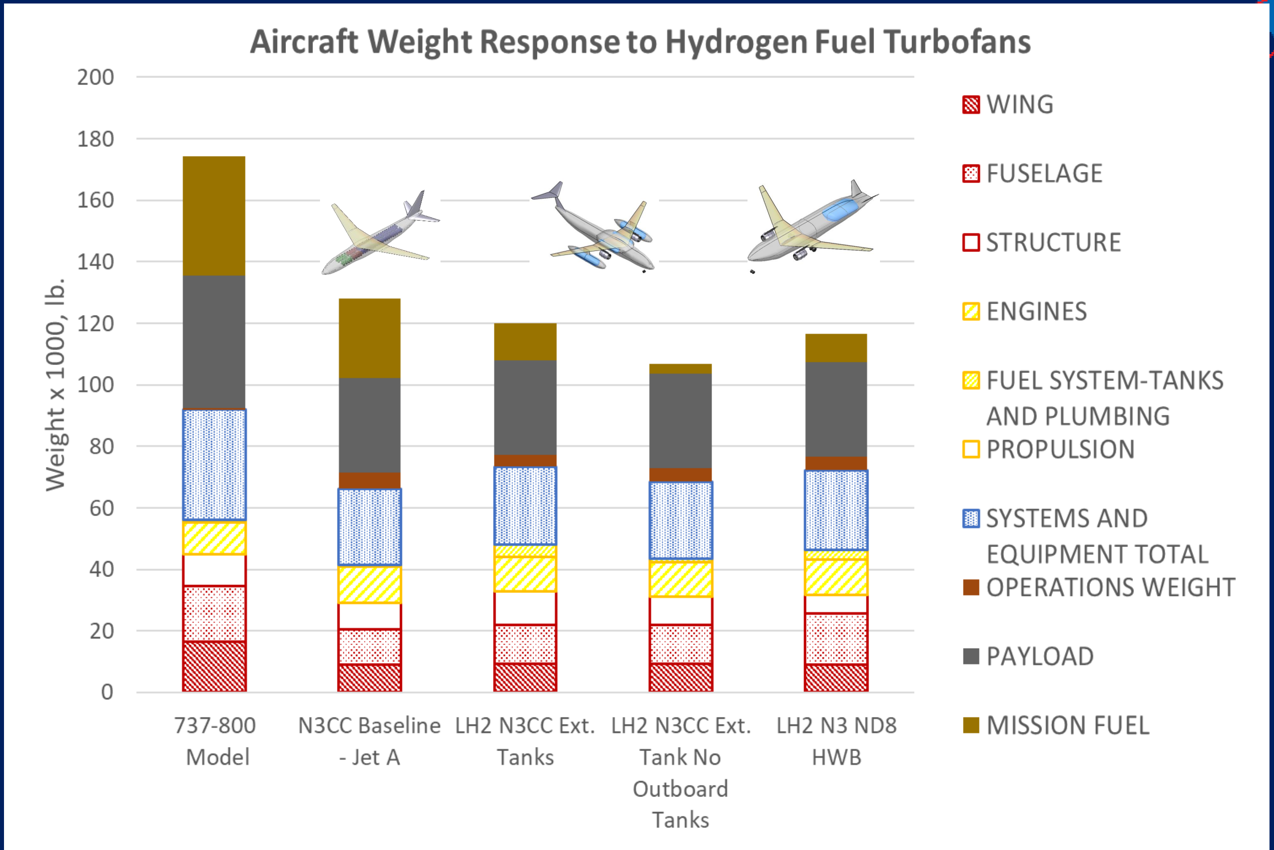
Comparison of Hydrogen Vehicle Architectures

Advances in operations and advances in structural materials are enabling the potential for LH2 fuel adoption:

- Improved Future Baseline for referencing Hydrogen Impact.
- Hydrogen fuel lowers Gross Weight, but fuel systems increase vehicle empty weight.

Configuration architectures can have impact on system performance.

- External tank drag increases fuel requirements,
  - However, this architecture aircraft down time due to tank maintenance.
- Hybrid Wide Body (HWB) designs show best performance in minimizing fuel requirements.
  - Rear only tanks introduce stability concerns.
  - Integrated tanks require long aircraft down times during fuel tank
- Exploring Alternative configurations and technologies to enable Hydrogen.



Box Wing aircraft to enable multiple fuel and engine pods while reducing drag.

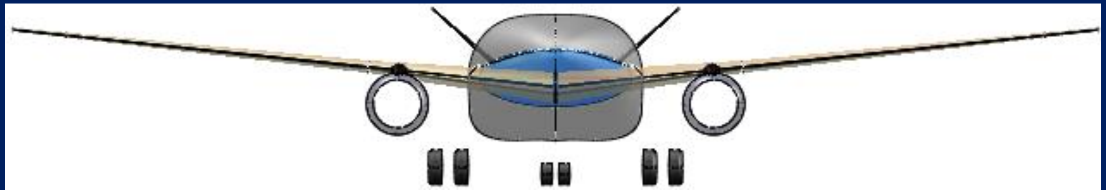
Reliable real time Virtual Cockpit potential enable forward H2 fuel stores in nose for better balancing aircraft.

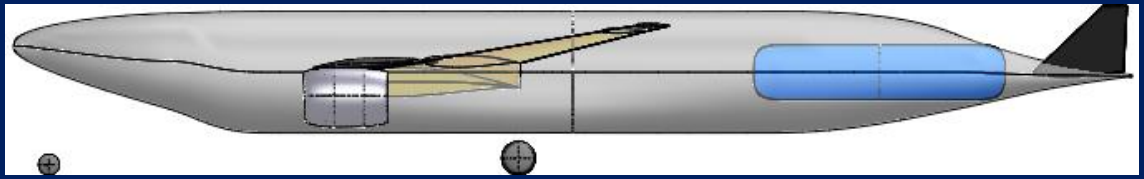
Hydrogen Hybrid Wing Body Concept

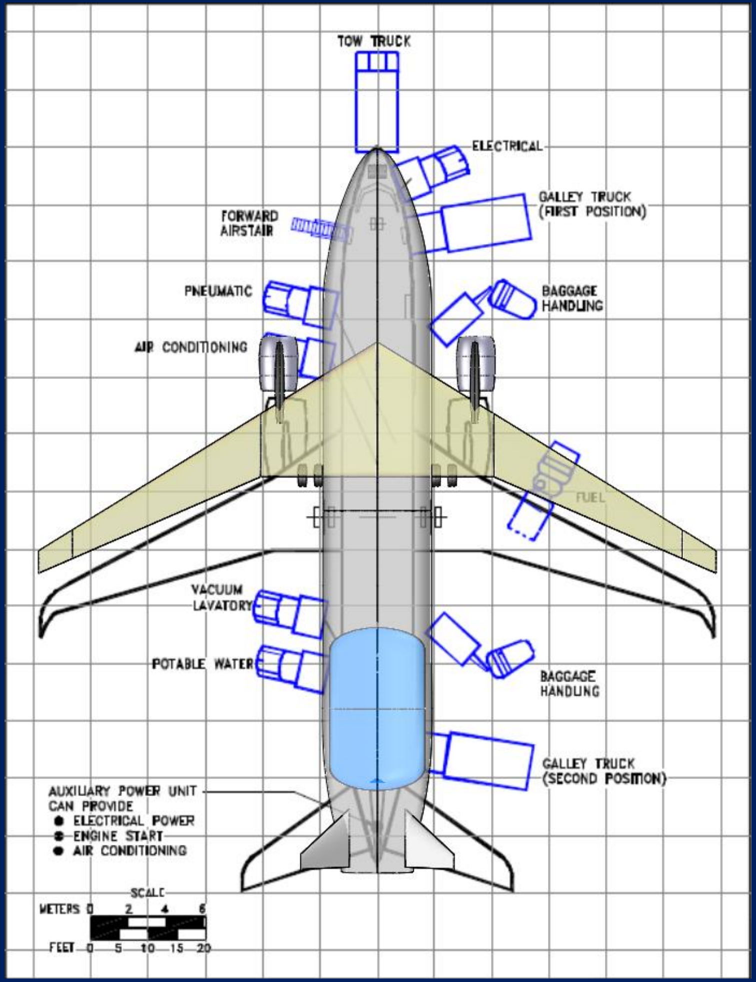
Advanced Tube & Wing Hybrid Wing Body double bubble concept.

Different variations were analyzed with a Pi Tail, rear fuselage mounted engines, and a maximum payload weight of 52, 000 lbs.

This configuration presents potential trim penalties with a large moving CG. A 5% penalty on tail surface area was applied as trim drag penalty







Hydrogen Hybrid Wing Body Concept

Advanced Tube & Wing Hybrid Wing Body double bubble concept.

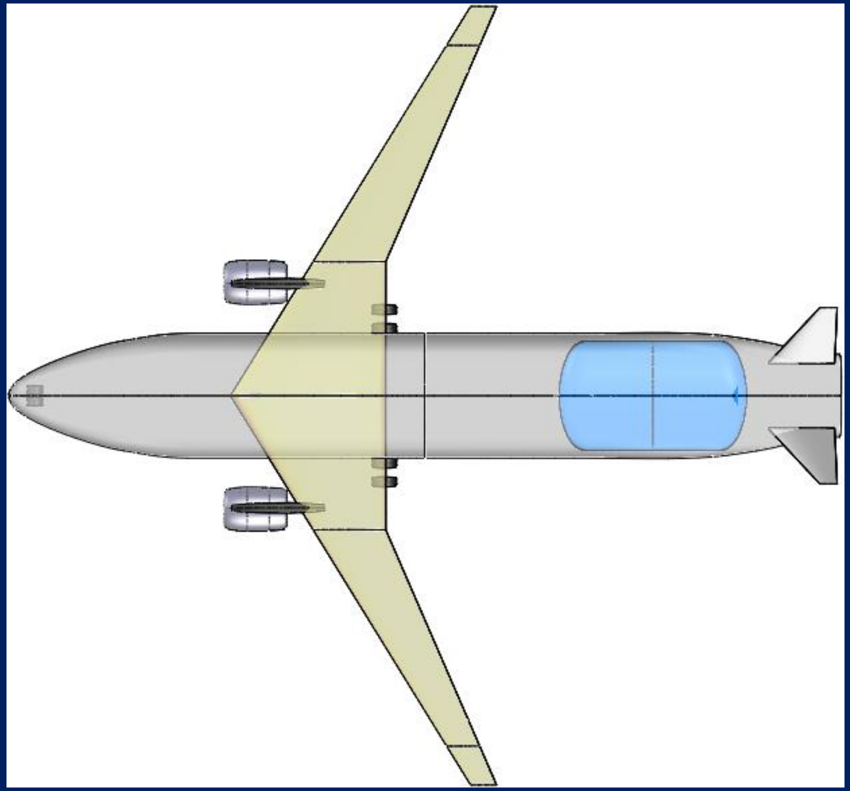
Wide body enables aft location for fuel and power systems without adding excessive fuselage length.

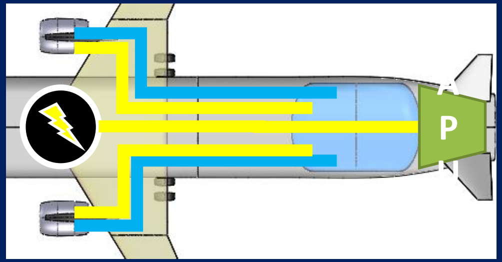
Minimizes total wetted surface of aircraft reducing vehicle weight and total drag.

Allows for different fuel-power-propulsion configurations.

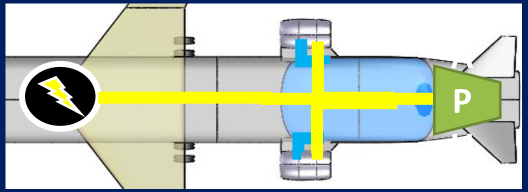
Allows for additional performance improving technologies.

Vehicle balancing increases trim drag from nose heavy weight shifting during flight





Engines on Wing



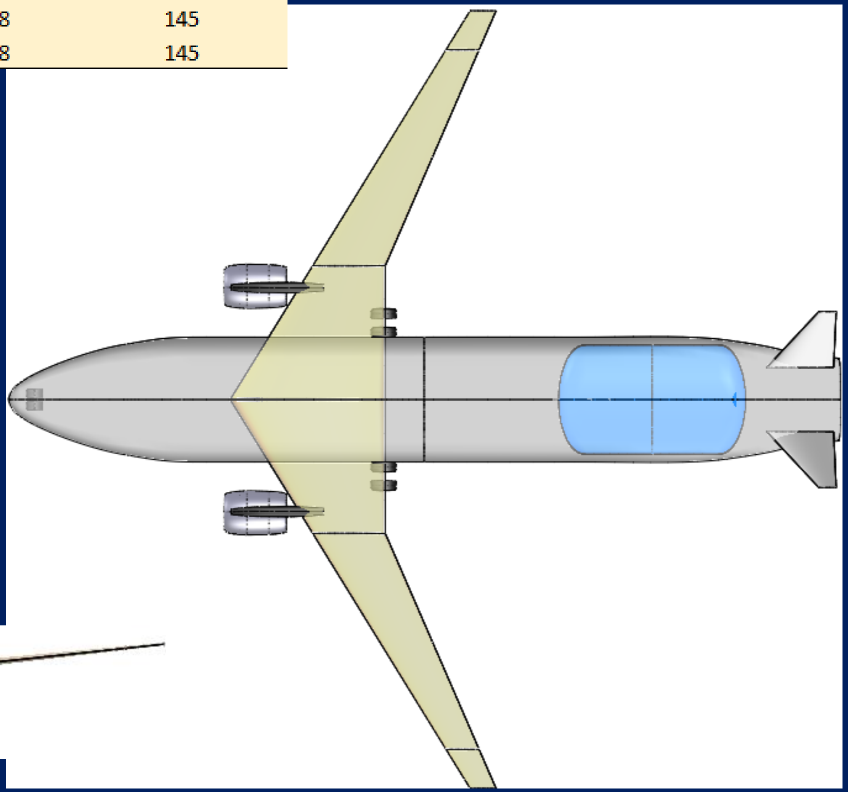
Engines on Fuselage

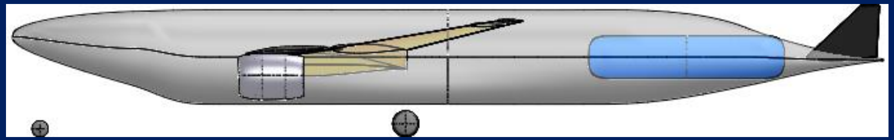
Hydrogen Hybrid Wing Body Concept

		Wing Geometry							Fuselage		Tails		Aerodynamics		
n	2023 LH2 Concepts	Span ft.	Trap. Area ft.^2	Plan. Area ft.^2	Sweep LE deg.	Taper	MAC ft.	X AC ft.	Length ft.	Diameter ft.	HT Area ft	VT Area ft.	Wetted Area ft.^2	Parasite CDf	Cruise L/D
B	N3CC - Baseline	118.8	1120	-	26	0.265232975	9.4	-	125	13	338	219	7818	0.01917	20
2	N3ND8 - 39K	118.8	1107	1288	32	0.3	13.5	52.9	126	19	217	192	8091	0.01966	19
3	N3ND8 - 52K	118.8	1109	1269	29	0.3	13.0	56.3	126	19	216	199	8030	0.01963	21
4	N3ND8 - Aft	118.8	1110	1301	32	0.3	13.8	62.8	128	19	253	220	8223	0.02002	20
5	N3ND8 - Pi Tail	118.8	1134	1315	32	0.3	13.8	50.9	118	19	579	193	8213	0.02069	18

		Objective.	Engines		Weights						Performance	
n	2023 LH2 Concepts	Econ. Fuel Burn, lb.	Thrust lb.	Fuel Type	Wing lb.	Fuselage lb.	EWT lb.	OEW lb.	Max.Payload lb.	MTOW lb.	Take Off Dist ft.	Aproach Speed kts.
B	N3CC - Baseline	6371.5	21060	Jet A	8857	11750	66285	71362	52000	127992	7999	144
2	N3ND8 - 39K	2278	20365	LH2	9090	16485	72292	76515	36852	116555	5315	145
3	N3ND8 - 52K	2581	20898	LH2	9948	16376	73745	76905	52000	132418	5228	145
4	N3ND8 - Aft	2381	20502	LH2	9325	18420	73743	77171	36477	115986	5308	145
5	N3ND8 - Pi Tail	2426	21371	LH2	9143	15031	74785	78785	37356	119445	5238	145

Fuel Load		
Max Fuel ,lbs	Fuel Volume , gal	Tank Volume , gal
27927	4168	4168
9252	15681	19602
9059	15354	19193
9006	15264	19081
9861	16714	20892

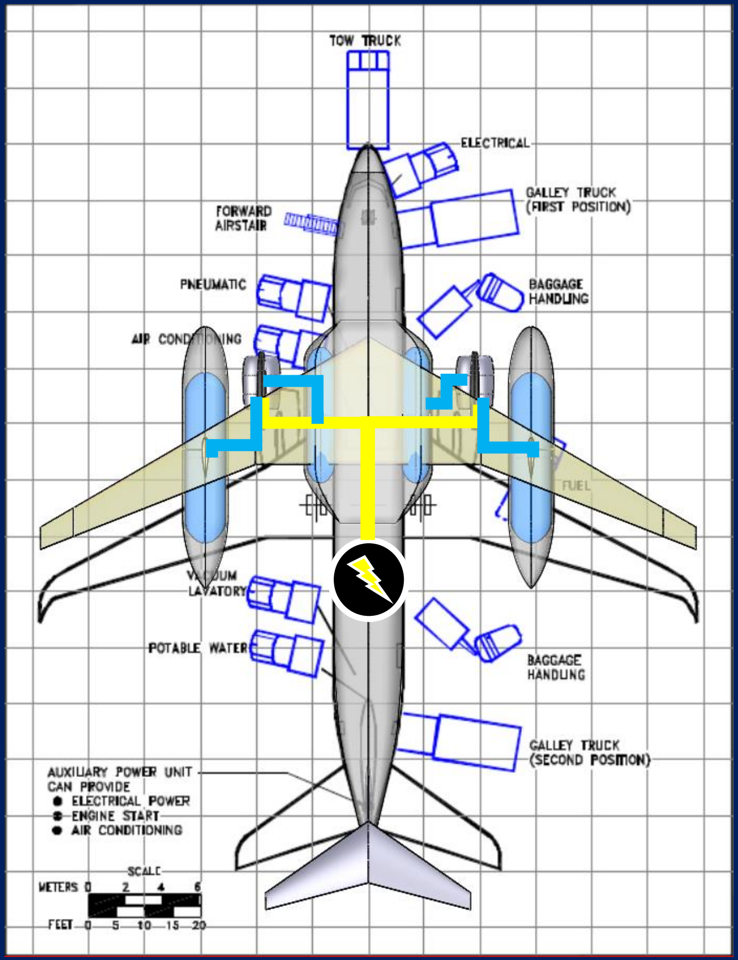




Hydrogen External Tank Concept

- Wing mounted fuel pods provide fuel storage away from main passenger cabin.
- External tanks potentially enable operational flexibility with tanks sized to the mission and potentially swappable to facilitate faster gate operations.
    - Potential family of vehicles based on route range.
- External Tank Concept may enable fuel-power-propulsion pod geometries distributing propulsion and weight across wing spans.
- Hydrogen fuel and power systems are kept away from main cabin to mitigate safety concerns.
- Additional performance enhancing technologies such as transonic truss brace wing and boundary layer ingesting fans is still possible

Concept overlaying 737-800 service layout

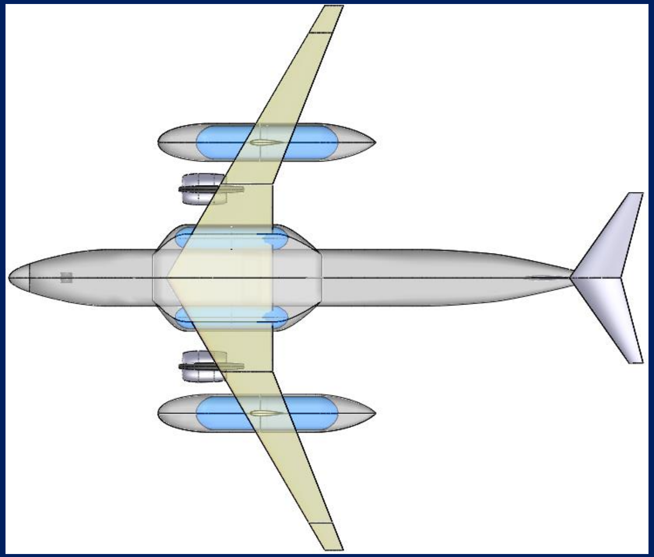


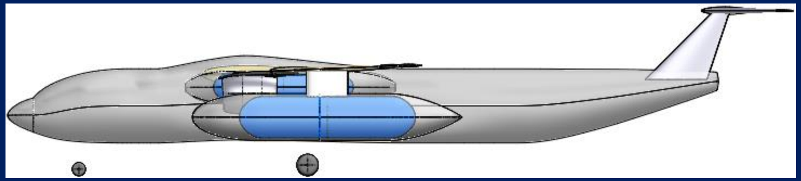
Hydrogen External Tank Concept

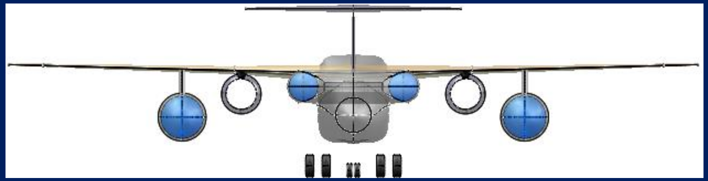
n	2023 LH2 Concepts	Wing Geometry							Fuselage		Tails		Aerodynamics		
		Span ft.	Trap. Area ft.^2	Plan. Area ft.^2	Sweep LE deg.	Taper	MAC ft.	X AC ft.	Length ft.	Diameter ft.	HT Area ft	VT Area ft.	Wetted Area ft.^2	Parasite CDf	Cruise L/D
B	N3CC - Baseline	118.8	1120	-	26	0.265232975	9.4	-	125	13	338	219	7818	0.01917	20
6	N3CC Ext. Tank 37K	118.8	1141	1307	30	0.3	20.1	45	125	15	264	164	10566	0.02386	15
6a	- W/out Outboard Tanks												8337	0.01958	20
7	N3CC Ext. Tank 52K	118.8	1141	1308	31	0.3	20.1	49.8	125	15	280	176	10407	0.02379	17
7a	- W/out Outboard Tanks												8419	0.01982	20

n	2023 LH2 Concepts	Objective.	Engines		Weights						Performance	
		Econ. Fuel Burn, lb.	Thrust lb.	Fuel Type	Wing lb.	Fuselage lb.	EWT lb.	OEW lb.	Max.Payload lb.	MTOW lb.	Take Off Dist ft.	Aproach Speed kts.
B	N3CC - Baseline	6371.5	21060	Jet A	8857	11750	66285	71362	52000	127992	7999	144
6	N3CC Ext. Tank 37K	2754	20957	LH2	9142	12793	73382	77616	38813	120317	5342	145
6a	- W/out Outboard Tanks	2359					68573	72807				
7	N3CC Ext. Tank 52K	2948	23887	LH2	9977	12799	75462	78910	52000	134939	4878	145
7a	- W/out Outboard Tanks	2318					71481	74929				

Fuel Load		
Max Fuel ,lbs	Fuel Volume , gal	Tank Volume , gal
27927	4168	4168
11903	20175	25218
3200	5424	6780
10445	17703	22129
3231	5476	6845

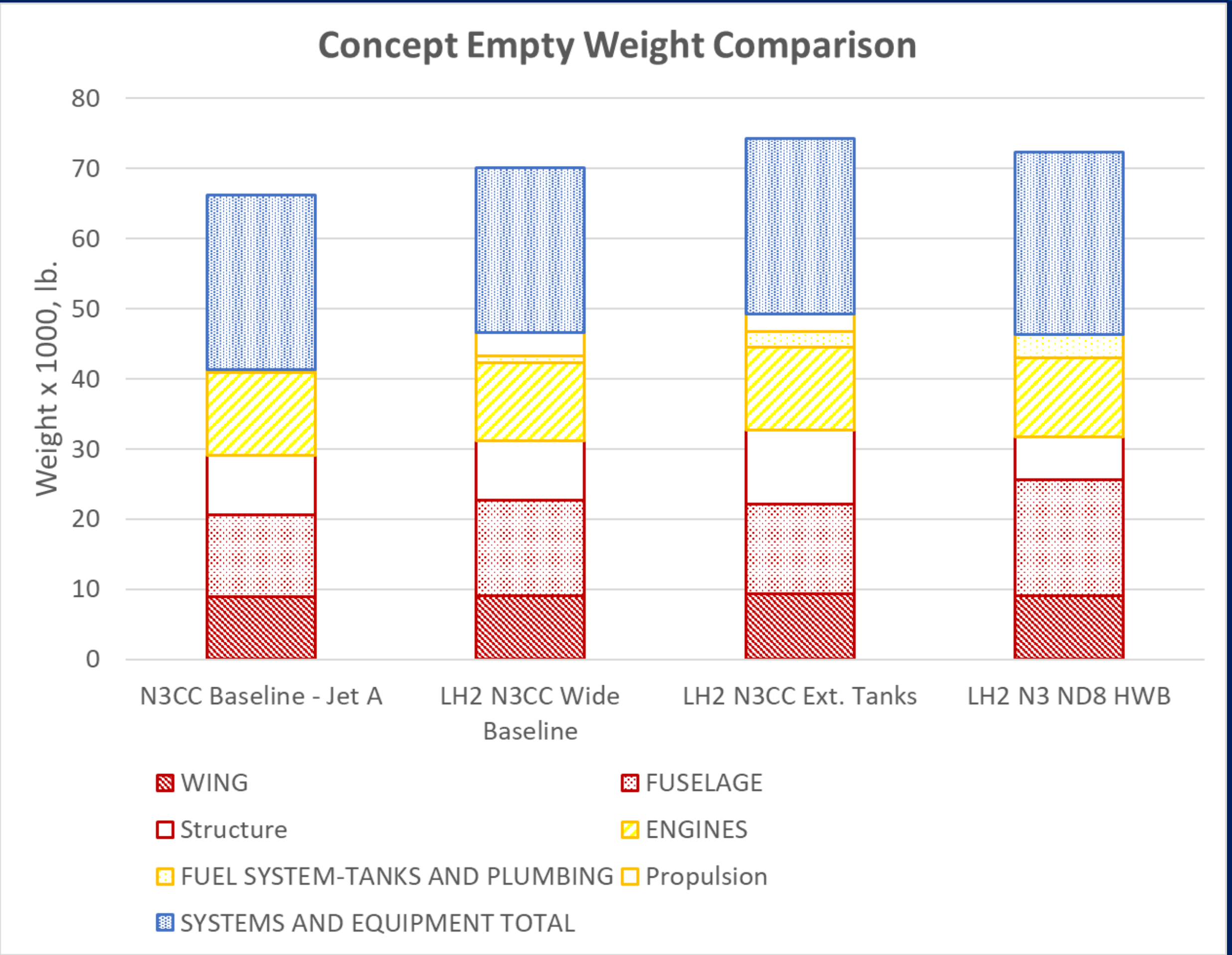






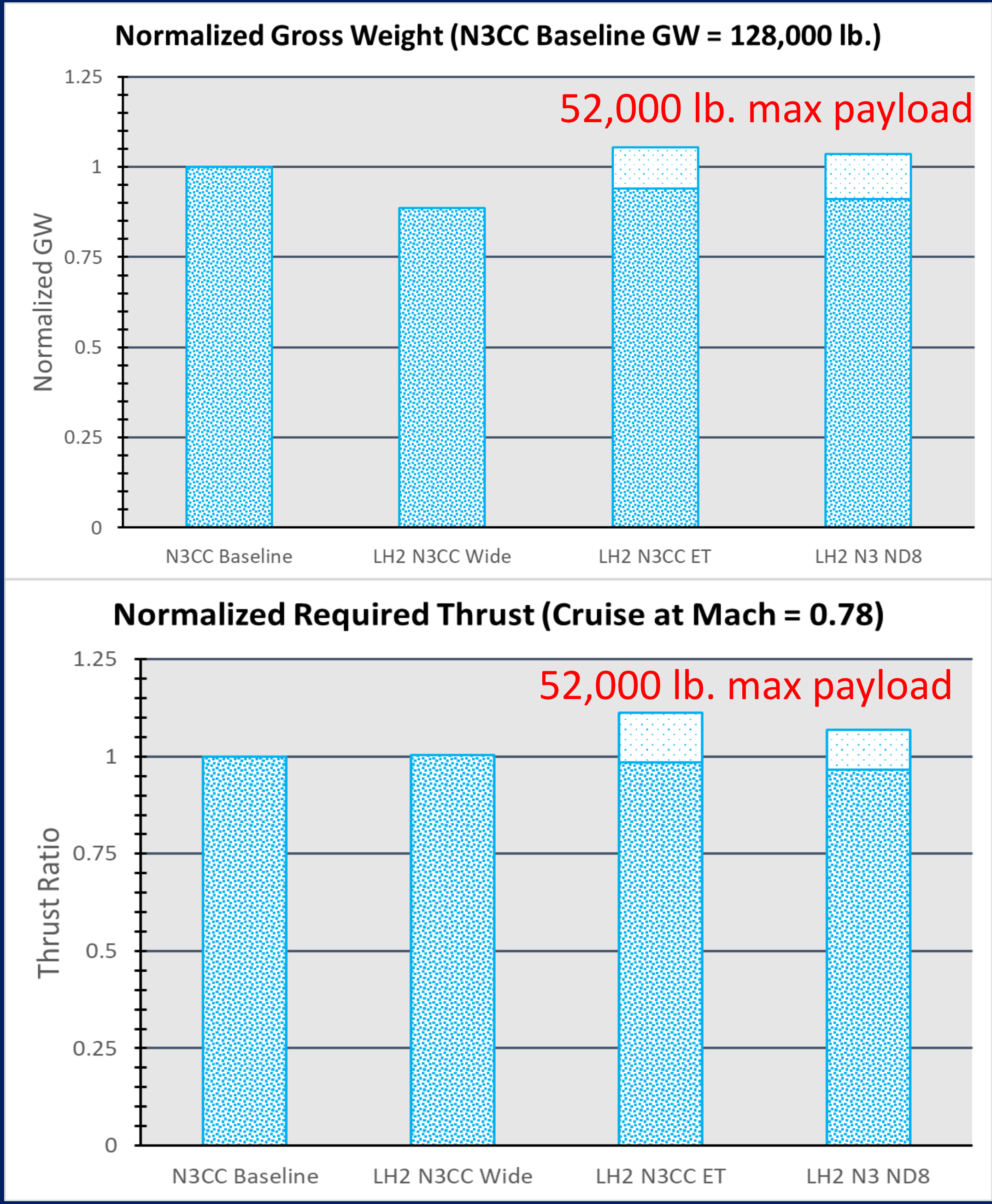
Weight Comparison

- LH2 concept empty weights are 5-17% heavier than the jet A N3CC baseline.
- The additional weight primarily comes from the increased propulsion system weight required to handle LH2 fuel.
- LH2 systems also increase the fuselage or other structural weights to accommodate LH2 fuel system.
- Wing weight remain surprisingly consistent across concepts.



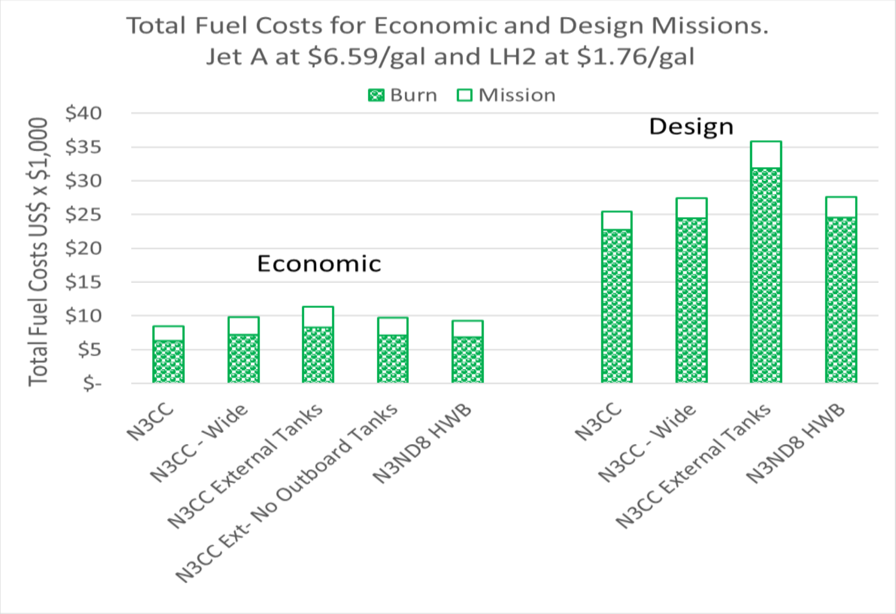
Thrust Comparison

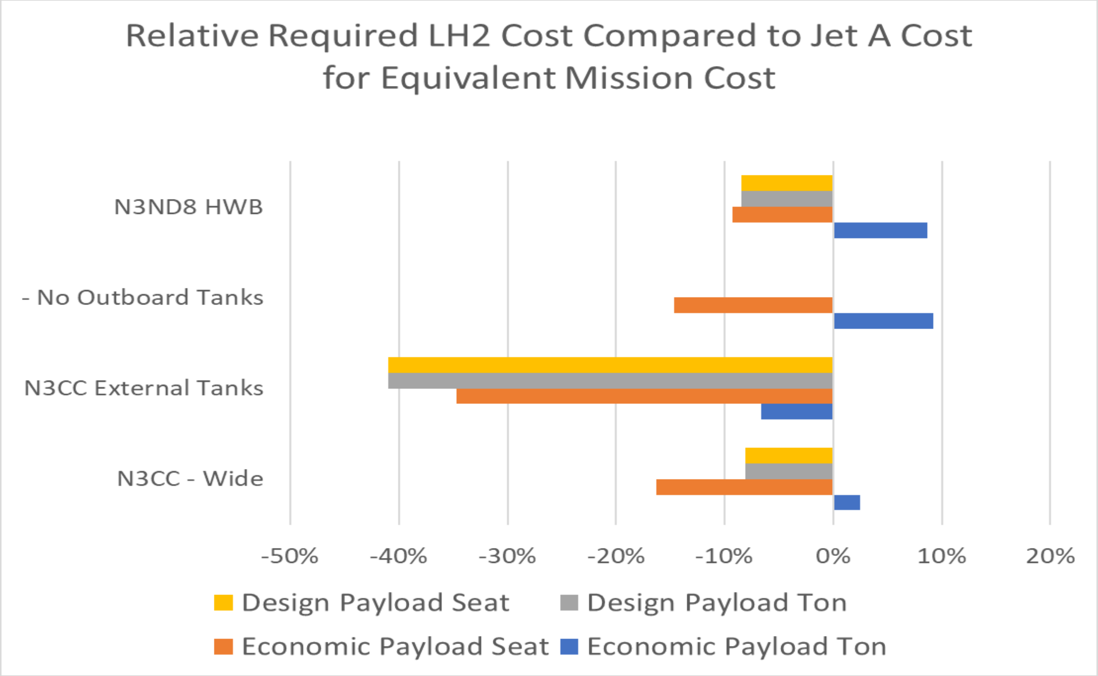
- The following charts show how transitioning to hydrogen effect the required engine thrust.
- Hydrogen require more thrust per GW compared to the baseline.
- Hydrogen concept engine thrust are comparable to baseline engine due to the lesser gross weight of Hydrogen concepts.
  - 10-15% more thrust required when concepts required to achieve 52,000 max payload.

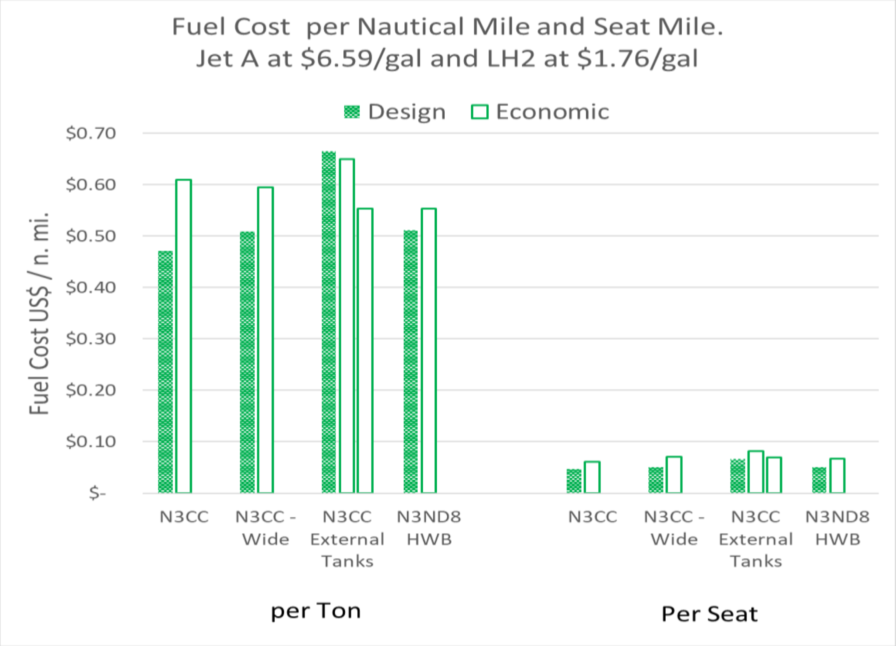


Cost Comparison

- Comparison of design and economic mission costs
- Assumes current Jet A Price of $6.59 per gal
- Assumes LH2 Price of $1.76 per gal
  - Based on US DoE study assuming airport is equivalent of LH2 distribution facility, ($6.55 per kg).
- Different Econ Mission Payloads
  - N3CC Baseline Econ Payload is 30,800 lb.
  - LH2 Concepts utilize different max weights







Hydrogen Aircraft Architecture Development Preliminary Conclusions

- For comparable missions, the liquid hydrogen aircraft empty weight is 5% - 17% more than jet fuel reference aircraft.
- The additional weight is driven primarily by the increased system volume required to handle LH2 fuel →increase vehicle empty weight with external tank drag increasing fuel requirements, fuselage length and / or other structural weights to accommodate LH2 fuel system
- The wing weight remains consistent across concepts.
- Hydrogen fuel lowers the fuel weight fraction on of the aircraft and lowers aircraft gross weight.
- Potential decrease of conventionally fueled aircraft weight with projected improvements in structures and aerodynamic technologies. Next generation concept may be more practical baseline for comparing potential hydrogen concepts.
- An internal HWB LH2 storage concept provides overall superior aerodynamic performance for the vehicle by minimizing total wetted surface of aircraft, reducing vehicle weight and total drag, minimizes fuel requirements.
- However, this configuration results in additional trim penalty (estimated at ~ 5%) due to stability concern resulting from moving center of gravity during flight forward for the aircraft. It also increases aircraft down time due to tank maintenance.
- Fuel storage on the wings is worth exploring due to enhanced safety due to location of the fuel away from the fuselage, mission flexibility with easily replaceable tanks sized to the next mission, enabling distributed electric prolusion and weight across the wing span, and being conducive to aircraft enhancing technologies such as truss brace wing and boundary layer ingestion.

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