Liquid Hydrogen Aviation: Why the Fuel of the Future Requires the Aircraft of the Future

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Abstract

Liquid hydrogen (LH2) represents a promising pathway toward reducing aviation's dependence on conventional hydrocarbon fuels, but its physical and operational characteristics require substantial changes to aircraft design. Although hydrogen provides significantly greater specific energy by mass than conventional jet fuel, its low volumetric energy density and cryogenic storage temperature create challenges involving tank volume, insulation, structural integration, fuel distribution, thermal management, and aircraft center of gravity. Historical programs such as the U.S. Air Force's Project Suntan demonstrated both the feasibility and complexity of hydrogen-powered flight, while contemporary research and demonstrations by organizations including Airbus and H2FLY are advancing hydrogen combustion, fuel-cell propulsion, and cryogenic storage technologies. Future hydrogen aircraft may therefore incorporate enlarged fuselages, distributed propulsion, box-wing or blended-wing-body configurations, and other clean-sheet designs optimized specifically for LH2. Successful implementation will additionally require extensive airport infrastructure, specialized refueling systems, certification standards, and reliable low-carbon hydrogen production. Liquid hydrogen consequently represents not merely an alternative aviation fuel, but a technological transition capable of reshaping aircraft architecture, propulsion systems, airport operations, and the broader aviation energy infrastructure.

Keywords: liquid hydrogen, hydrogen-powered aviation, aircraft design

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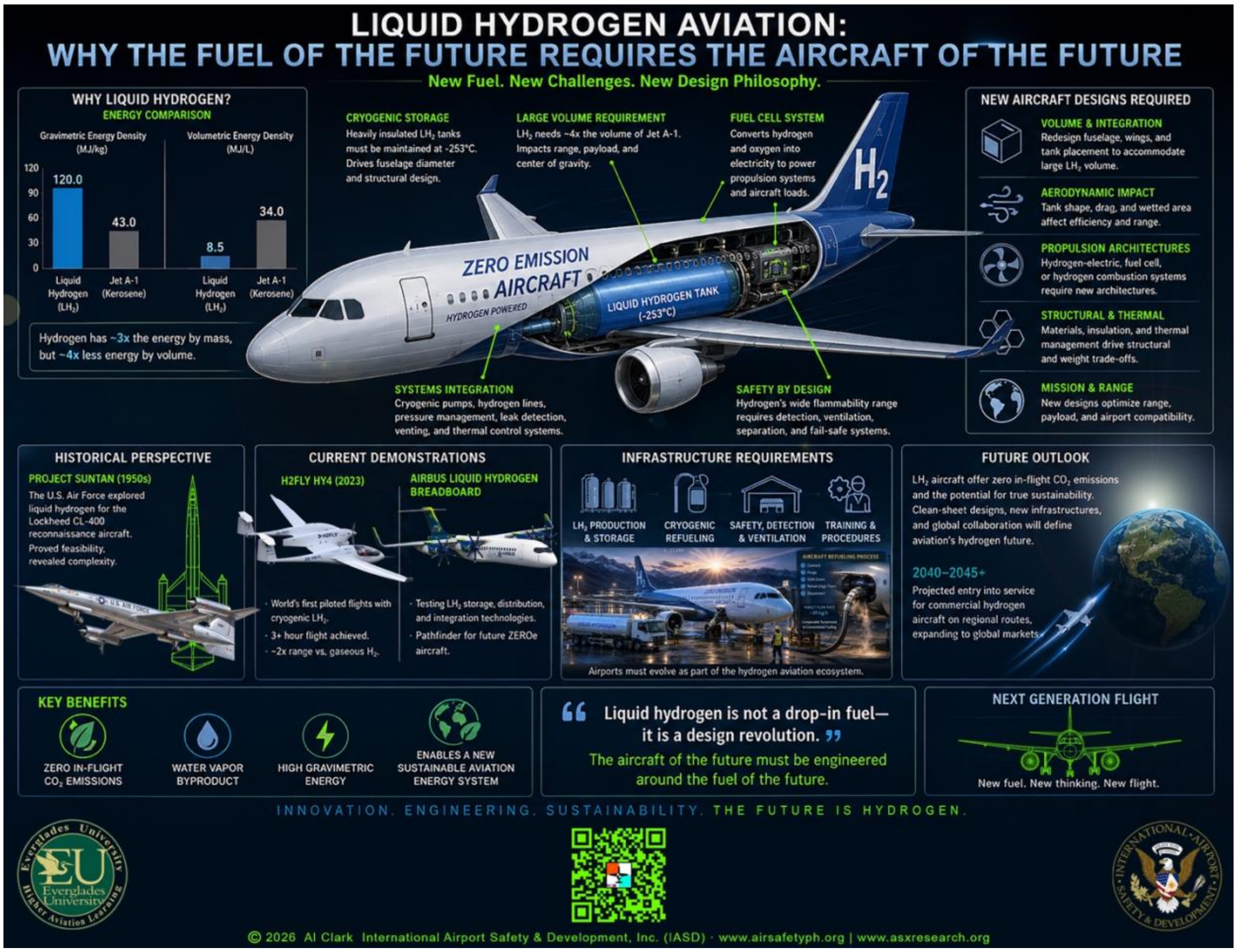
Figure 1.

Liquid hydrogen aviation: Aircraft design, propulsion, infrastructure, and sustainability considerations for future hydrogen-powered flight.



Why would liquid hydrogen require new aircraft designs?

Liquid hydrogen would require fundamentally new aircraft designs because it behaves very differently from conventional Jet A fuel. Although hydrogen has exceptionally high specific energy by mass—roughly three times that of kerosene—it has very low volumetric energy density. Even as a cryogenic liquid, an aircraft requires roughly four times the tank volume needed for an equivalent quantity of conventional fuel, and the hydrogen must remain near −253°C. Traditional transport aircraft store kerosene efficiently inside relatively thin, irregularly shaped wing tanks; liquid hydrogen instead requires heavily insulated, pressure-capable cryogenic vessels that favor cylindrical or near-spherical geometries. Consequently, designers cannot simply substitute hydrogen for kerosene in an existing Boeing 737 or Airbus A320. The tanks affect fuselage diameter, passenger and cargo volume, center of gravity, structural loading, aerodynamic drag, and ultimately the overall aircraft configuration. Dries Verstraete, Pierre Hendrick, Pericles Pilidis, and Kristina Ramsden (2010) identified lightweight, highly insulated cryogenic tanks as one of the principal enabling technologies for hydrogen-powered transport aircraft and demonstrated why aircraft-specific LH2 tanks differ substantially from terrestrial or space applications.

The challenge is not new. Serious research into hydrogen aviation dates to the 1950s, most notably the U.S. Air Force’s classified Project Suntan, which investigated the Lockheed CL-400 reconnaissance aircraft as a liquid-hydrogen-powered successor to the U-2. The proposed aircraft was an extraordinary purpose-built design approximately 49 meters long, with a fuselage roughly three meters in diameter partly because it had to accommodate approximately 9,700 kilograms of liquid hydrogen. Pratt & Whitney even developed and tested the Model 304 hydrogen-burning turbojet for the project. Suntan was ultimately canceled, but it demonstrated remarkably early that hydrogen propulsion was technically possible while simultaneously demonstrating that the aircraft and its supporting infrastructure could not simply follow conventional petroleum-fueled practice. Later military analysis reached similarly cautious conclusions: William T. Mikolowsky and Leland W. Noggle (1978) examined liquid hydrogen for very large U.S. military aircraft and found that the fuel presented substantial economic and operational disadvantages compared with synthetic hydrocarbon fuels available at the time. Thus, the military has indeed tackled the concept, and historically the U.S. Air Force was actually among the pioneers of hydrogen-aircraft research.

Tank design remains perhaps the most difficult aircraft-level problem because an LH2 tank must simultaneously be extremely light, thermally efficient, structurally strong, crashworthy, and capable of handling pressure changes and fuel boil-off. Arturo Gomez and Howard Smith (2019) demonstrated that LH2 tanks become major structural design drivers for commercial aircraft, particularly because the fuel requires approximately four times the storage volume of kerosene and therefore forces changes to aircraft geometry, aerodynamic efficiency, and payload accommodation. Weiqiang Xu, Qianqian Li, and Minjie Huang (2015) likewise demonstrated the importance of lightweight super-insulated tanks in their study of a high-altitude, long-endurance aircraft; their insulated support arrangement reduced heat leakage through the support structure by more than 85 percent. These requirements also introduce systems absent from ordinary kerosene aircraft: cryogenic pumps and plumbing, pressure-management and venting systems, hydrogen-leak detection, specialized refueling connections, thermal-management equipment, and physical separation between hydrogen components and ignition sources. The result is not merely a new fuel system but an aircraft whose structure, systems architecture, and safety philosophy must be designed around the fuel.

Current practical demonstrations show that these challenges are solvable on a smaller scale. In 2023, Germany’s H2FLY completed the world’s first piloted flight campaign of an electric aircraft powered by cryogenically stored liquid hydrogen. Its HY4 demonstrator completed four LH2-powered flights, including one lasting more than three hours; H2FLY reported that replacing compressed gaseous hydrogen with liquid hydrogen could approximately double the aircraft's potential range from 750 to 1,500 kilometers. Research is now moving toward larger regional aircraft. Jona Eissele, Stefan Lafer, Cristian Mejía Burbano, Julian Schließus, Tristan Wiedmann, Jonas Mangold, and Andreas Strohmayer (2023) developed a conceptual 50-passenger hybrid-electric regional aircraft using liquid hydrogen and fuel cells for a projected 2040 entry into service. Their work illustrates an important point: exploiting hydrogen effectively requires simultaneous optimization of propulsion, tank placement, thermal management, electrical systems, aerodynamics, and aircraft geometry rather than treating hydrogen as a conventional drop-in fuel.

Among major manufacturers, Airbus is presently one of the most prominent companies explicitly tackling this problem through its ZEROe program. Airbus initially investigated hydrogen combustion, turboprop, turbofan, blended-wing-body, and fuel-cell architectures, but in 2025 selected hydrogen fuel-cell technology as the principal propulsion direction for its future ZEROe aircraft. Its current concept uses four hydrogen-electric propulsion pods, while Airbus and Air Liquide have developed a Liquid Hydrogen BreadBoard to investigate onboard LH2 storage and distribution. Airbus is also pursuing Cryoprop, a two-megawatt-class superconducting electric propulsion demonstrator in which liquid hydrogen contributes to the cryogenic cooling system. This illustrates why a clean-sheet aircraft becomes attractive: once hydrogen supplies fuel, provides a cryogenic heat sink, powers fuel cells, and interacts with high-power electrical propulsion, the optimum architecture may look substantially different from today’s tube-and-wing airliners. Giuseppe Palaia, Karim Abu Salem, and Erasmo Carrera (2024), for example, investigated a liquid-hydrogen-powered box-wing aircraft and found that unconventional geometry provides opportunities to address the payload, range, and tank-integration penalties imposed by LH2.

The implications extend beyond the aircraft itself because airports would also require new infrastructure. Liquid hydrogen cannot simply be pumped through existing Jet A hydrant systems. Airports would need cryogenic storage, liquefaction or hydrogen-delivery arrangements, specialized refueling equipment, leak and fire detection, ventilation and separation zones, trained personnel, emergency procedures, and internationally standardized handling requirements. Airbus is participating in the European GOLIAT program, running from 2024 through 2028, which is specifically developing scalable LH2 refueling equipment, aircraft refueling couplings, airport ground-handling procedures, certification approaches, and demonstrations involving the HY4 aircraft at Stuttgart, Rotterdam, and Lyon. The aircraft and airport therefore become parts of one hydrogen system rather than independent technological problems. This also explains why implementation will probably begin with limited regional networks or designated hydrogen-capable airports rather than immediate fleetwide replacement of kerosene aircraft: manufacturers need an aircraft, but airlines simultaneously need reliable supplies of low-carbon hydrogen and airports capable of safely handling it.

The future of liquid-hydrogen aviation therefore depends less on whether hydrogen can make an airplane fly—the historical record and modern demonstrations have already answered that question—and more on whether it can be made operationally, economically, and environmentally competitive at commercial scale. Hydrogen offers enormous gravimetric energy advantages and the possibility of eliminating in-flight carbon dioxide emissions, but its volume, cryogenic temperature, tank mass, boil-off behavior, infrastructure requirements, and safety considerations reshape virtually every part of an aircraft. Future configurations could consequently include enlarged conventional fuselages with fore-and-aft tanks, hydrogen-electric regional aircraft, distributed propulsion, box-wing designs, and eventually blended-wing-body aircraft whose internal volume is particularly attractive for bulky LH2 storage. Current research increasingly treats 2040–2045 as a plausible timeframe for more mature hydrogen-aircraft architectures rather than assuming immediate large-scale adoption; for example, Felix Fritzsche, Daniel Silberhorn, Vincenzo Nugnes, Tim Burschyk, and Michael Kotzem (2026) developed DLR liquid-hydrogen medium-to-long-range concepts around a 2045 entry-into-service scenario and showed how tank integration affects mass, aerodynamics, trim, and energy consumption. Ultimately, liquid hydrogen requires new aircraft because realizing its environmental advantages demands designing the airplane around hydrogen from the beginning rather than attempting to force hydrogen into an aircraft designed around kerosene.

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