FAKULTÄT TECHNIK UND INFORMATIK
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Lower Risk Approach for Low Emission Passenger Aircraft – Combined LH2 and Kerosene Propulsion

Airbus proposed "ZEROe" based on "disruption" and "giant leaps" but failed. What are the lessons learned?

Instead, a lower risk, low CO2 emission single aisle aircraft concept is presented. The idea is to use a conventional A320 type aircraft driven by conventional turbofan engines. 20% of the fuel tank's kerosene energy is substituted by LH2. As such, the volume of the additional LH2 tanks needed is minimized and can easily be integrated e.g., on top of the fuselage as proposed by the CRYOPLANE project already around the year 2000. The engine only needs a combined kerosene/LH2 combustor. This minimizes new technology needs and risks and stays within established experience with turbofan engines. Reliability, performance, engine life, and maintenance procedures stay the same. Emergency thrust requirements and thrust response times can be fulfilled. For a standard 900-nm-mission, CO2 emissions are reduced by approximately 50%. From airports without LH2 infrastructure, aircraft can operate with kerosene. In contrast to full hydrogen airplanes, this concept has no infrastructure limitations. This was Airbus' main excuse for not moving forward with LH2.

Background and Objectives

Consensus exists for substantial CO2 emission reductions with alternative propulsion concepts and/or more environment compatible fuels. Published concepts include electric propulsion, hybrid-electric systems, water enhanced new cycles, fuel cell systems, LH2 combustion, and synthetic fuels. All these concepts have been or are tested only at a scale of business or small commuter aircraft with maximum 1 MW to 2 MW propulsion power. Missing are real projects with regional, single aisle, or widebody aircraft. The latter need propulsion power of 20 MW or more, which requires extremely big electrical systems with cryogenic cooling, giant heat rejection systems (especially for fuel cell and water enhanced systems). Enormous fuel tank volumes are needed in case of full LH2 use. In addition, regenerative energy requirements become uneconomically high and mostly flight energy requirements (like hot reslam) cannot be fulfilled. The new complexity makes projects risky, and it will need decades to achieve the reliabilities needed for certification. The technical solution may come too late for the environment.

Looking at the emission impact (Fig. 1), CO2 reduction is most important in the long run. Cirrus cloud effects are important but get negligible the longer the considered time horizon is. This is due to the small residence time of cirrus clouds in the atmosphere.

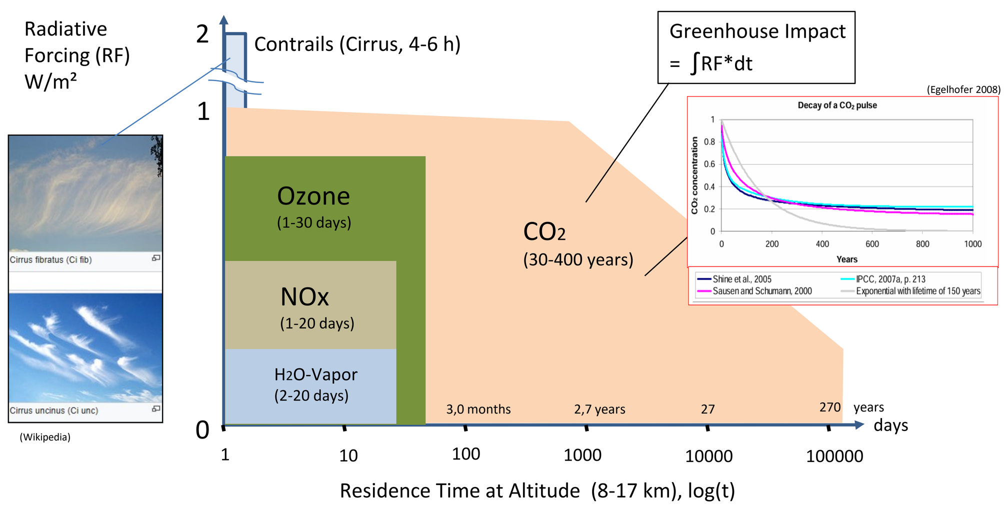
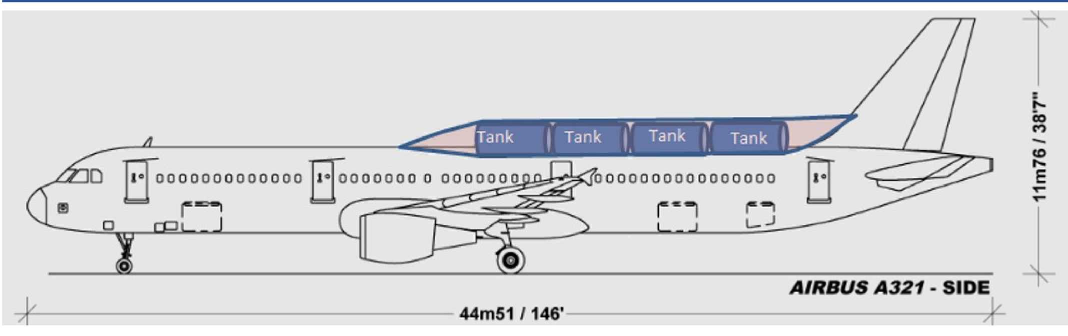


Fig. 1: The criticality of aircraft emissions considers both radiative forcing and greenhouse gas residence time in the atmosphere. CO2 dominates in the long run.

Approach

- Evaluate a minimum risk approach for C02 reduction in the single aisle and widebody class of passenger aircraft.
- Analyze mission of an A321 type aircraft with existing engines (CFM/V2500).
- Evaluate partial kerosene replacement by LH2.
- Evaluate necessary and appropriate aircraft modifications.
- Check dual fuel combustion technology requirements and readiness levels.
- Analyze flight missions (payload range) and respective CO2 reduction.

Suggested Aircraft Architecture



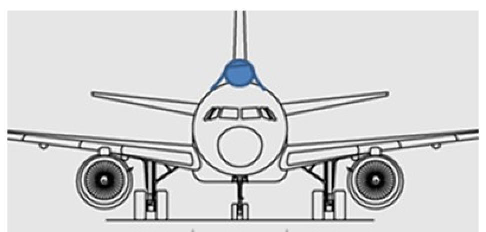


Fig. 3: Aircraft concept with roof top mounted LH2 tanks. The LH2 tanks carry 20% of the energy compared with the original tanks filled with kerosene.

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MTOW (A321, baseline):    93.5 to
Payload:                  25.0 to
Kerosene tank capacity:   19.7 to (842300 MJ = 100%)
LH2 tank capacity:         1.4 to (168460 MJ =  20%)
MTOW increase: 3.0 to ... 5.0 to
   (incl. LH2 tanks, pumps, plumbing, HEX, mounts, airframe mods)
Thrust increase:  approx. 10%   (due to drag and weight increase)
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CO2 Reduction Across Payload and Range

CO2 reduction varies depending on range (Fig. 5). 900 nm is determined as the standard mission. It is flown with a mix of LH2 and kerosene. The LH2 tanks are always supposed to be filled up totally. The CO2 reduction at MTOW is approximately 50%. As more range is demanded and more kerosene is needed, LH2 share, and CO2 reduction drops to a lower percentage.

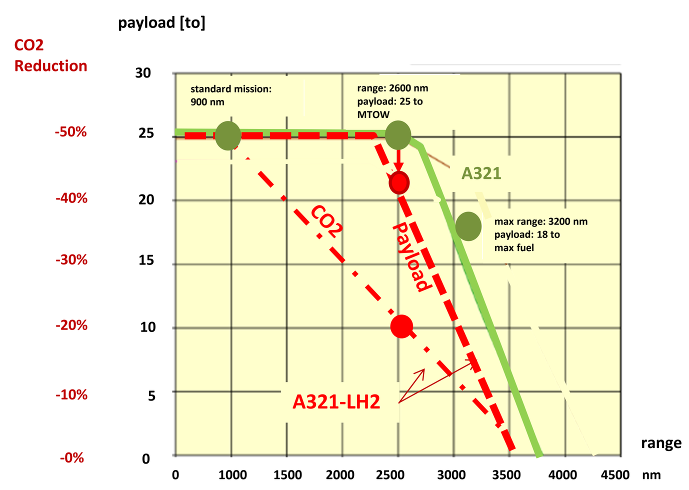
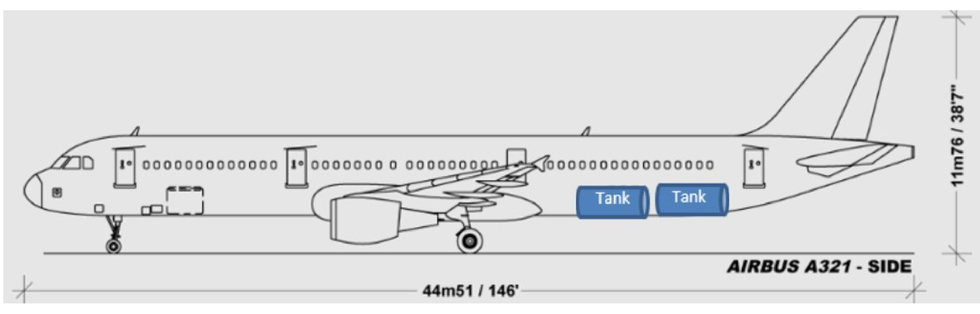


Fig. 5: Payload range diagram of the A321 (reference) and the A321-LH2. CO2 reduction (in %) due to LH2 drops with increasing range.

Dual Fuel Aircraft Concepts

The analysis is based on an existing A321 type aircraft. Aim is to minimize aircraft modifications and to apply highest safety precautions. The potential modifications considered include both fuselage mounted (Fig. 2) and roof mounted (Fig. 3) LH2 tank arrangements. The roof mounted system from the CRYOPLANE has the advantage that LH2 tanks are located outside of the pressure cabin. In case of a fire, hydrogen flames would rise away from cabin and occupants. Flight mission analysis was done for a CFM56-5 or V2500 type engine performance. The evaluation assumes to replace 20% of the kerosene by LH2 fuel of the same energy. Corresponding LH2 tank volume is approximately 20 m³ for 4 cylindrical tanks with length x diameter = 3,5 m x 1,5 m respectively. For each flight, the LH2 tanks are filled completely (if this much energy is needed). For the missing energy for the flight, kerosene is used. Consequently, the shorter the mission, the higher the CO2 reduction. See Fig. 4 for dual fuel system and dual fuel combustor.



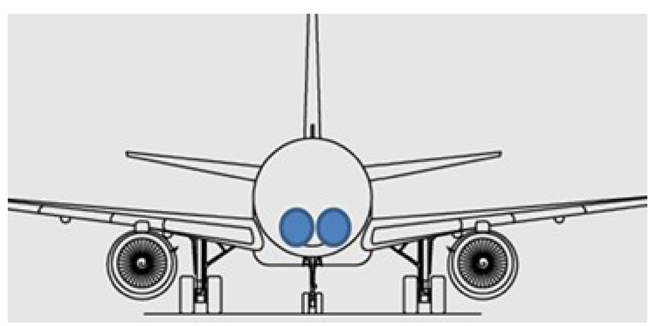


Fig. 2: Aircraft concept with fuselage mounted LH2 tanks. The LH2 tanks carry 20% of the energy compared with the original tanks filled with kerosene.

Dual Fuel System and Dual Fuel Combustor

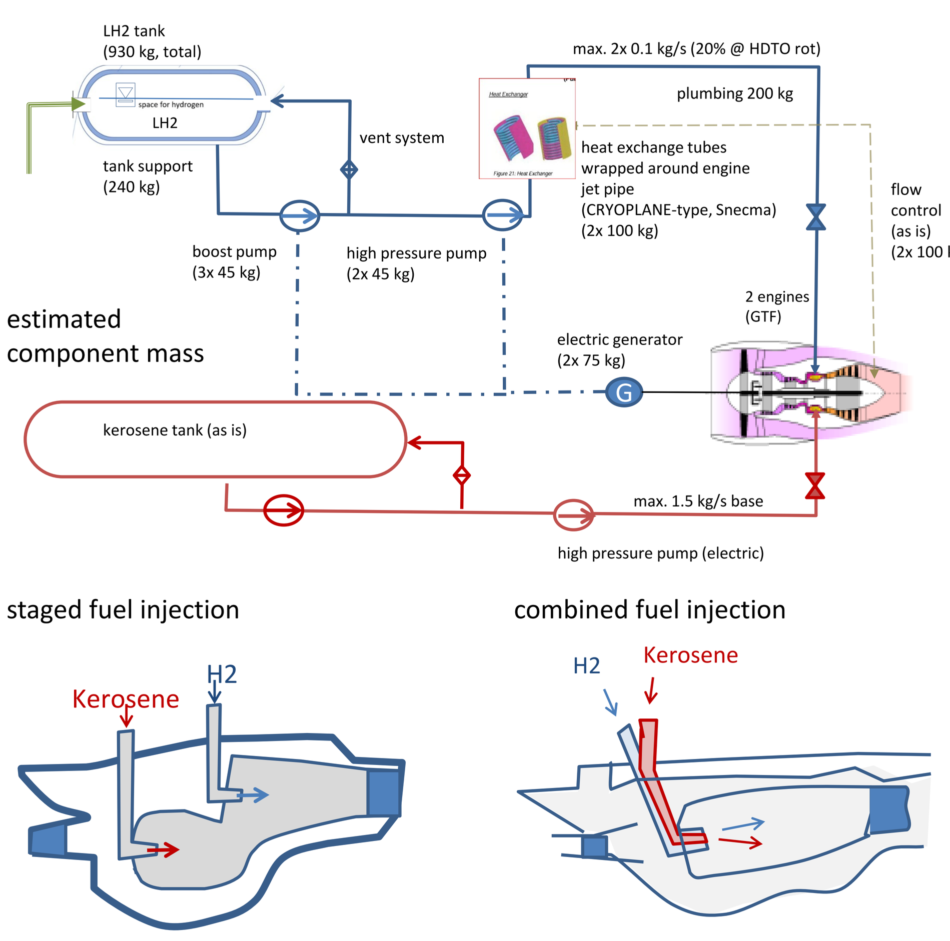


Fig. 4: Dual fuel system and dual fuel combustor arrangements

Risks and challenges:

- Combustor concept and operation strategy.
- Heat source (heat exchanger) to raise H2 temperature from -260 °C to ambient.
- LH2 plumbing (safety).

Payload and Range

The additional weight from the LH2 System (~3 to ... 5 to) would lead to a reduction in payload and/or range. Since the aircraft can carry 20% more energy this can be compensated. The additional drag from the roof mounted tanks was approximated to 5%. Together with the add weight (+5.3%), this leads to a thrust or fuel burn increase of approximately 10% (by energy) – compensated with latest Neo engines.

Technology Readiness Plan

Only one new technology will be added to the A321 aircraft. Still, technology and product development will take up to 20+ years in total. Technology requirements will address engines, aircraft, and LH2 system. See Fig. 6 and 7.

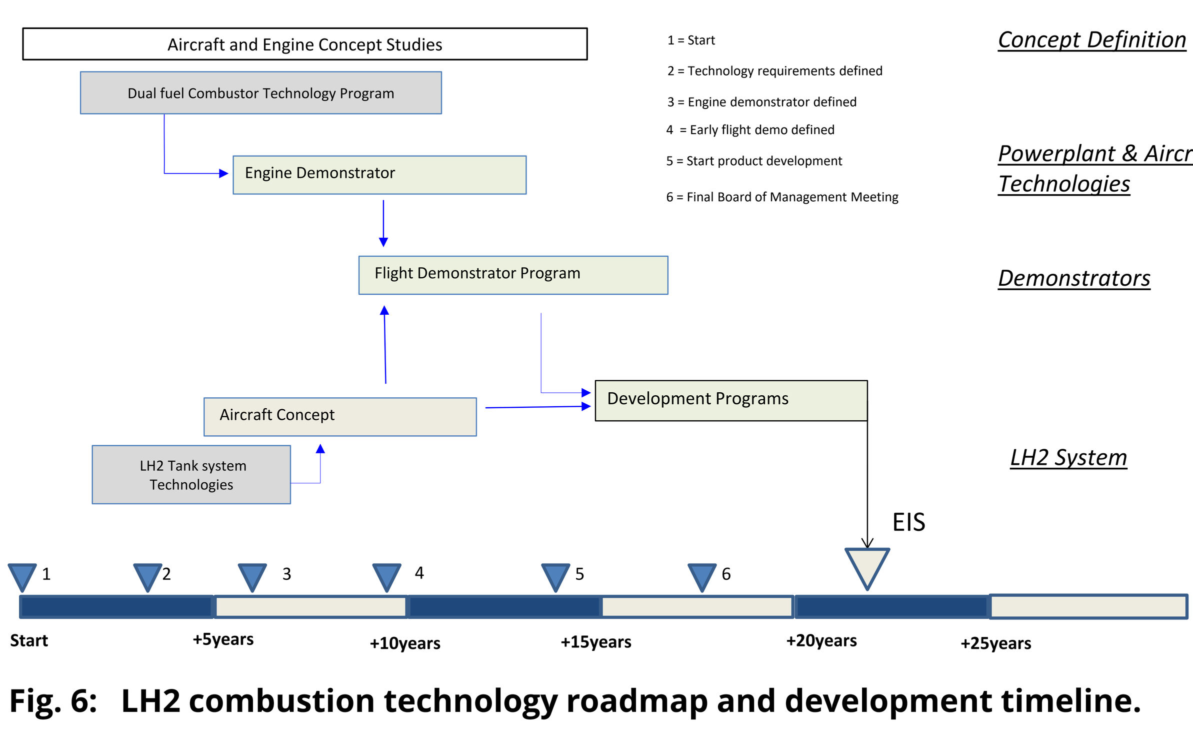


Fig. 6: LH2 combustion technology roadmap and development timeline.

Discussion

Combined kerosene and LH2 combustion could be a viable step to reduce CO2 emissions for passenger aircraft. In contrast, the introduction of 100% LH2 (for CO2 free flight) is unrealistic, because only a few airports will offer LH2 initially. Due to LH2 infrastructure limitations, aircraft must (for the foreseeable future) be able to burn both LH2 and kerosene depending on availability at airports.

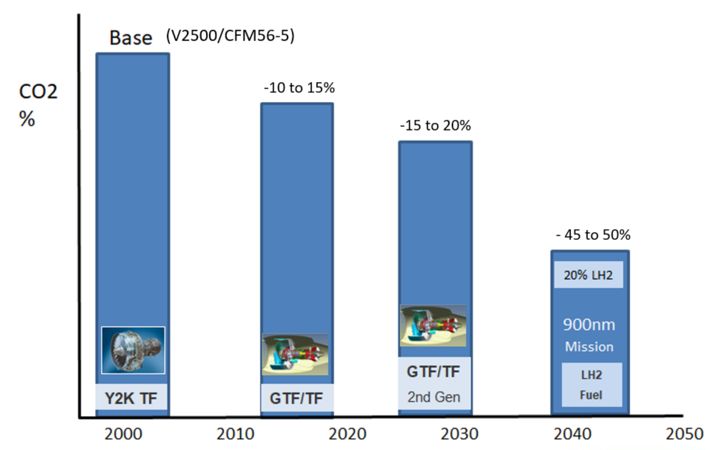


Fig. 7: Tentative roadmap towards low emission single aisle flight (A321). A similar roadmap would apply to widebody aircraft.

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