Overview of Hydrogen-Powered Air Transportation

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Nomenclature

ACI-ATI	Airports Council International-Aerospace Technology Institute
BAC	Boeing Airplane Company
LCC	Lockheed California Company

1 Introduction

The aviation industry is growing at a rapid pace. By 2030, air travel is expected to increase by 5% (Baroutaji et al., 2019). The aviation industry accounts for roughly 12% of all carbon dioxide emissions generated by the transportation industry (Baroutaji et al., 2019). According to the Kyoto Protocol, the global carbon rate increases by 2% every year (Klug & Faass, 2001). Kerosene, a fossil-based fuel, is used as fuel in the aviation sector today. Fossil-based fuels are not environmentally friendly. In addition, the use of a fossil-based fuel in the aviation sector makes a sustainable economy unsustainable due to fossil-based fuels are not renewable energy sources. In order to ensure aviation's long-term sustainability and reduce

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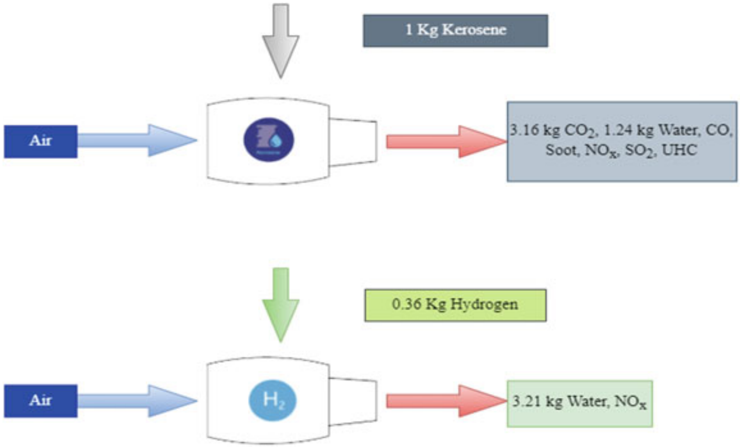

Fig. 1 Mass energy and emission comparison between kerosene and hydrogen fuel

environmental damage, it's become vital to switch to fuels made from environmentally friendly and renewable resources.

Hydrogen fuel is the most promising fuel for ensuring aviation's long-term sustainability and reducing environmental damage. Hydrogen is one of the universe's most plentiful elements. With the exception of hydrocarbons, it cannot be destroyed, and it simply transforms from water to hydrogen and back to water during consumption (Momirlan & Veziroglu, 2005).

Hydrogen has a high specific effect due to its low molecular weight. This means that with 1 kg.s^{-1} of hydrogen, 450 kg-force thrust is obtained (Cecere et al., 2014). When comparing hydrogen with kerosene, it is clear that hydrogen has approximately three times the energy per unit weight of petroleum and is much more environmentally friendly (Van Zon, 2008). It is shown in Fig. 1.

This article contains an overview of the research utilizing hydrogen energy in airports and aircraft, as well as its future sustainability.

2 Hydrogen-Powered Aircraft and Airports

The aviation industry is known for its high levels of safety and security. The Hindenburg disaster in aviation history has generated a sensitivity to hydrogen (Klug & Faass, 2001). The explosion of the hydrogen contained in the airship and its subsequent destruction in a matter of seconds is an iconic moment in aviation history. As a result of the disaster, the aviation industry was negatively affected.

Hans Joachim Pabst von Ohain is the first one to power a turbojet engine with hydrogen in 1936 (Töpler & Lehmann, 2015). It is not because hydrogen fuel is environmentally friendly that it is used (Töpler & Lehmann, 2015). It was chosen because it produces a high reaction and allows for combustion with a lean mixture

(Töpler & Lehmann, 2015). Then he tried the hydrocarbon-based gasoline (Töpler & Lehmann, 2015). Serious research in the aviation industry began in the 1970s (Clean Sky 2, 2020).

2.1 NASA "Hydrogen Airport" Project

Korycinski (1978) analyzed two NASA (National Aeronautics and Space Administration) hydrogen airport studies. At Chicago O'Hare International Airport (Airport1), BAC simulated the utilization of LH_2, while LCC simulated the utilized of LH_2 at San Francisco International Airport (Airport2). Subsonic commercial aircraft with a capacity of 400 passengers and a distance of 5500 nautical miles have been used in this scenario. The reason for investigating at large commercial aircraft as part of the research is that they used a quarter of the fuel used in civil air travel in the United States in 1975. The two airports' wide-body aircraft traffic was used to assess fuel needs, which were then used to measure the size and capacity of international airports for liquid H_2 production, storing, and delivery. The simulation was assumed in the years 1990–1995. Table 1 shows the characteristics of the airport hydrogen liquefying facility (Korycinski, 1978).

LH_2 ground fuel system expenses are roughly to be \$304 million in Airport2 and \$469 million in Airport1 (Korycinski, 1978).

2.2 Tupolev T-155 Project

According to Schmidtchen et al. (1997), the Tupolev T-155 project was performed in the 1980s (Fig. 2). It made its first flight in 1988. It was discovered through this experiment that the unit weight energy of H_2 is 2.8 times more than that of kerosene (Schmidtchen et al., 1997). Furthermore, it has been noted that when hydrogen fuel is used, the turbine output temperature is 37 K lower, which increases engine life and performance (Cecere et al., 2014). To produce an equivalent amount of energy as kerosene, LH_2 needs four times the volume, and low-temperature requirements such as 20 K have increased the cost (Cecere et al., 2014). This is attributable to the fact that the LH_2 system requires additional insulation and cooling systems (Cecere et al., 2014). Due to the high cost of liquid hydrogen, the project was canceled. Later, the

Table 1 Characteristics of airport hydrogen liquefying facility (Korycinski, 1978)

Airport	Maximum output		Hydrogen liquefying	
	Ton.day^{-1}	(tonne.day^{-1})	Size ton.day^{-1}	(ton.day^{-1})
Airport2	846	768	250	227
Airport1	800	726	268	243

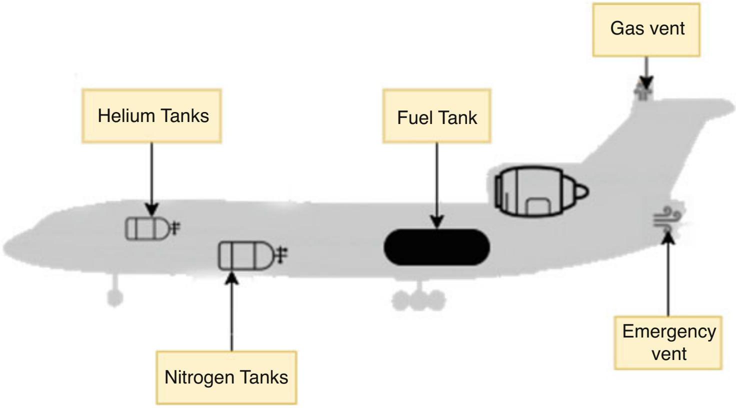

Fig. 2 TU-155 liquid hydrogen aircraft design

information gathered from this experiment was utilized in the Airbus company's Cryoplane project (Cecere et al., 2014).

2.3 Swiss Group "Hydrogen in Air Transportation" Feasibility Study

The Swiss Group conducted a preliminary investigation of a cargo jet utilizing liquid hydrogen as fuel at Zurich Airport between 1980 and 1984 (Alder, 1987). A feasibility study for refueling 15–30 tons of LH_2 per day was done (Alder, 1987). A route has been established between California, Europe, and Saudi Arabia. Zurich Airport was selected as the European hub (Alder, 1987). Three alternative possibilities were considered (Alder, 1987). It is shown in Fig. 3.

In each case, liquid hydrogen was more expensive than kerosene. Jet A fuel cost LH_2 is by a factor of 2.2–3.8 more expensive (Alder, 1987). The high cost of liquid hydrogen compared to kerosene negatively affected the sustainability of this project (Alder, 1987).

2.4 German-Russian "Feasibility Study": Cryoplane Based on A310 Defined

Pohl and Malychevc (1997) investigated a project on the use of hydrogen in civil aircraft undertaken under German-Russian cooperation between 1990 and 1993. The base aircraft for passenger aircraft configuration studies was a first-generation LH_2, an Airbus A310. In the purely tourism-related configuration, this medium-range wide-body aircraft has a maximum takeoff weight of 150 mt and a passenger

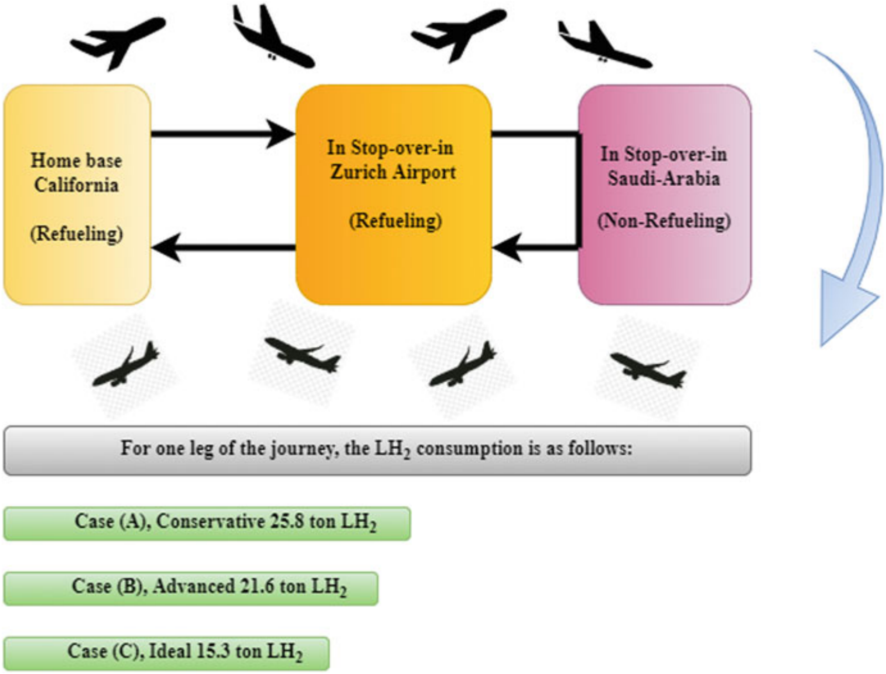

Fig. 3 Three alternative possibilities

capacity of 243. It is propelled by two PW-4152 engines, each having a static thrust of 52,000 pounds. Because the fuel volume is four times that of a jet fuel aircraft and the cryogenic heating rate necessarily requires extremely efficient tank isolation and pressurization, conventional wing tanks are not suitable for LH_2 aircraft. The fuselage-mounted tank arrangement was determined to be the best alternative for replacing an existing aircraft for hydrogen operating condition after considering achievement, operational expenses, ability to handle, and protection. Four different fuel tanks are positioned on the hull's upper side (Pohl & Malychevc, 1997). It is shown Fig. 4.

For a conventional aircraft, the design range requires 15,600 kg of LH_2, which is equivalent to 37,000 kg of kerosene (Pohl & Malychevc, 1997). With the exception of the cryogenic fuel system, the aircraft's systems are largely unchanged (Pohl & Malychevc, 1997). Major structural modifications include wing reinforcements, fuselage midsection, and fuselage upper surfaces due to tank mounting (Pohl & Malychevc, 1997). If indeed the energy-related cost of LH_2 is less than 110% of that of jet fuel, it can be considered cost-competitive (Pohl & Malychevc, 1997).

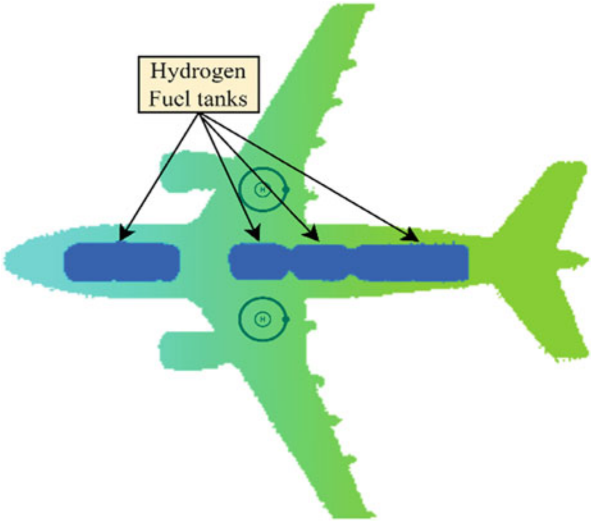

Fig. 4 Liquid hydrogen fuel tank design

2.5 Airbus Cryoplane Feasibility Study

The Airbus company investigated the use of liquid H_2 as a fuel in aircraft between 2000 and 2002 (Airbus, 2002). For this study, both conventional and nonconventional configurations were used. Seven different aircraft configurations were used to simulate the use of liquid hydrogen fuel. These aircraft include the business jet, rural propeller aircraft, rural jet aircraft, mid-range aircraft, extended-range aircraft, and also very large long-range Aircraft. Various tank configurations were made according to the aircraft category. The optimal tank arrangement was chosen for each category. The most important point in the tank configuration is the aircraft's center of gravity. It occupies four times more volume than liquid hydrogen kerosene. As a result of this situation, the empty weight of the aircraft is 25% higher than that of kerosene aircraft. The maximum take of weights decreases due to light LH_2. Using bulky tanks increases DOC (direct operating costs) by 25% for 1000 nm (Airbus, 2002).

The minimum changes to be made for the LH_2 aircraft are categorized in Fig. 5.

As a result, when compared to liquid hydrogen fuel, kerosene has a lower cost. Depending on the price of hydrogen and kerosene fuel, DOC (direct operating costs) is predicted to be approximately equivalent in 2040 (Liquid Hydrogen Fuelled Aircraft, 2002).

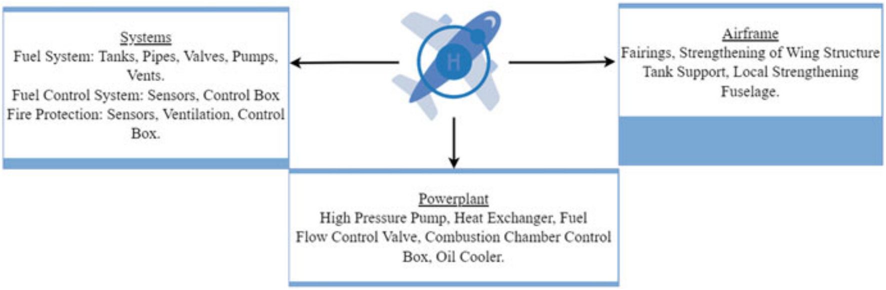

Fig. 5 Minimum change for LH_2 aircraft Cryoplane

Fig. 6 Hydrogen fuel cell powered commuter segment aircraft

3 Future Aspect of Hydrogen-Powered Air Transportation

Fuel cell assisted aircraft (Clean Sky 2, 2020): If aircraft were powered by fuel cells, hydrogen would be refueled at airports, and the hydrogen fuel cell would then start generating electrical energy from the electrical and chemical reaction of hydrogen with oxygen in the air, powering the electrically powered propellers while only emitting water vapor as a by-product. In the next decades, commuter segment (19 passengers and 500 km range) aircraft will be able to use hydrogen fuel. A hydrogen aircraft is powered by a fuel cell, which also handles motors and provides battery energy planning and infrastructure to satisfy transitory loads. To provide thrust, every electric motor gets to drive an impeller (Fig. 6). It reduces the climate effect in the range of 80–90%. Related to the cost per seat available kilometer, the cost rises by 0–5% (CASK). It is foreseen that it will take place physically within 10 years (Clean Sky 2, 2020).

Several ways can be considered for a hydrogen-powered airport (ACI-ATI Report, 2021). LH_2 airport consists of subsections such as production, liquefaction, storage, distribution, and transportation. Firstly, hydrogen production, liquefaction, and storage can be done from the airport. Secondly, a production facility is built near

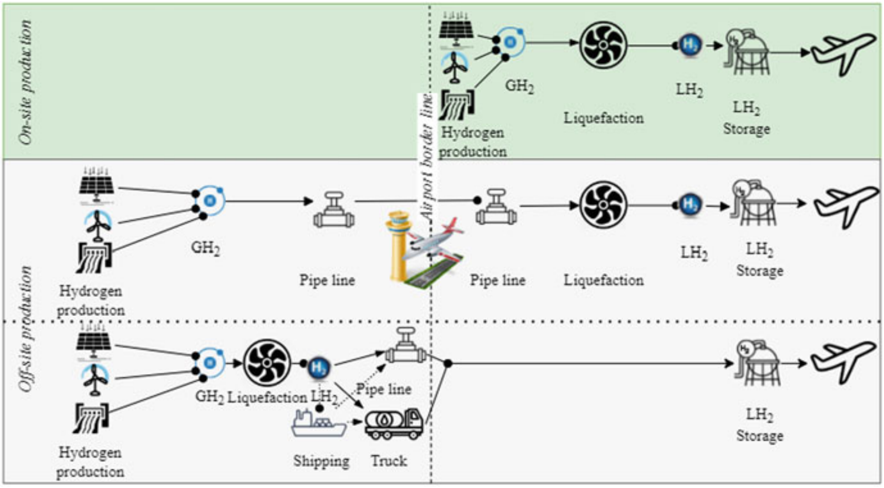

Fig. 7 Three primary hydrogen supply chain/pathways into the airport

the airport, gas hydrogen is transported to the airport via pipelines, and liquefaction is done from the airfield. Another way is to produce at a different location, liquefy hydrogen, and transport it to the airport by pipelines, trucks, and ships. Storage is carried out at the airport (ACI-ATI Report, 2021). It is shown in Fig. 7.

4 Conclusion

In this study, comprehensive studies on LH_2 are included. These are the following: NASA "Hydrogen Airport" Project, Tupolev T-155 Project, German-Russian "Feasibility Study"-Cryoplane Based on A310 Defined, and Airbus Cryoplane Feasibility Study. The common problem that came across in these studies is that the cost of LH_2 fuel is much higher than kerosene fuel. The most emphasized issue in the studies investigated is the cryogenic storage of hydrogen.

In terms of applicability for a few decades, they are commuter segment (19 passengers and 500 km range) aircraft operating with hydrogen fuel cells. Related to the cost per seat available km in, the cost rises by 0–5%. (CASK). It is foreseen that it will take place physically within 10 years. It is predicted that the use of liquid hydrogen will increase in 2040 depending on fuel prices.

This article contains an overview of the research on hydrogen as a fuel in airports and aircraft, as well as its future feasibility. More research is considered necessary to increase the effectiveness of hydrogen fuel.

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