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Research Paper

LIQUID HYDROGEN AS AVIATION FUEL AND ITS RELATIVE PERFORMANCE WITH COMMERCIAL AIRCRAFTS FUEL

Shreyas Harsha[1]*

With huge amount of concern directing towards the use of conventional type of aviation jet fuel which consists of unleaded kerosene (Jet A-1) and Naphta-Kerosene (Jet-B) as the base, which leads to many problems such as global warming, formation of smog and various breathing problems, the idea of using Liquid Hydrogen as an alternative to Jet Fuel seems the best solution. Hydrogen shows the potential to considerably reduce the emissions of aircrafts, annulling the increase in emissions due to the growth of commercial aviation. It is possible to produce large quantities of hydrogen in an environmentally compatible and affordable manner. The only main concern, the use of Hydrogen as aviation fuel faces is the initial infrastructural cost and funding the research for better production of liquid fuel in a much more efficient manner, as the ideas still remains in its premature stages. Work has been done to predict the performance of a hydrogen fueled commercial aircraft, termed as LH2-400, relative to an energy-equivalent conventional Boeing 747-400 aircraft. Safety wise, aircrafts running on commercial kerosene fuel pose a bigger threat in case of an aircraft crash when compared to Hydrogen based aircraft. Through the experiments performed by Boeing, it goes on to state that, LH2-400 aircraft performed better in the beginning of an experimental cruise, while its performance deteriorated towards the end of the cruise, though the overall performance were almost similar. The liquid hydrogen aircraft has the potential to drastically reduce the operating cost of commercial aircrafts.

Keywords: Aircraft, Liquid hydrogen, Alternate fuel, Economy, Cryogenics, Hydrogen technology

INTRODUCTION

Liquid Hydrogen fueled aircrafts are capable of performing the same mission as a commercial aircraft, but with the use of less or same amount of energy, with smaller impact on the environment, as much safer than the commercial aircraft. But at the same time, it needs huge amount of infrastructure, finance and investment in money and time in the areas of; adaptation of hydrogen technology by commercial airliners and setting up of the hydrogen infrastructure at the airport. Before

[1] SRM University, Kattangulthur, Chennai, India.

introducing this technology in real life by the airliners, considerable time needs to be dedicated by the government, aircraft manufacturers and the energy companies on the viability of this technology, listing out in details its Pros and Cons. Hence Boeing came forward and modified one of their Boeing 747-400 aircraft to run on Liquid Hydrogen and named it LH2-400, for the sole purpose of testing and comparing it with the commercial aircraft which uses kerosene based jet fuel.

BACKGROUND DISCUSSION

It is estimated that the aircraft energy efficiency can improve by approximately 0.62% per year from the year 2006 to 2050, yielding at massive 24% total reduction in the use of energy per aircraft by the end of year 2050. While at the very same time, commercial aviation is expected to grow by 35 per year through 2050, offsetting, and any gain that could have been achieved by the 24% improvement in aircraft energy efficiency. Since emissions are relative to energy use, the combination of air traffic growth and increased efficiency nets a 2.36% per year increase in emissions between 2006 and 2050.

The emissions produced from kerosene based aircraft, are very pungent to the people around the airport and produce Smog, which is one of the prime reasons for limiting expansion of runways and airports. However burning of hydrogen in a jet engine produces carbon emissions with minimal amount of nitrogen oxide, water vapour and few other contrails. Although, nitrogen oxide is one of those gases that are responsible for global warming, the harmful effects produced by nitrogen oxide are minimal when compared to carbon emissions.

Hydrogen aircrafts have the potential to reduce global warming by 60% to 90%. This reduction only includes the emissions from the aircraft, and does not include the emissions while producing Hydrogen. Also, Hydrogen can be produced with almost zero emissions by using sources like solar, nuclear, hydroelectric and wind power.

According Energy Information Administration (EIA), there are made three price case prediction of hydrogen and kerosene jet fuel. The three cases are High-price case, reference case and Low-price case. Reference case is based on oil supplies being in plentiful with no anomalies to affect the demand and supply. The low price case is based on the oil supplies being much more than predicted and High price case being with oil supplies being in less plentiful. The average cost of three cases put together is predicted (by EIA) to be $1.66 per gallon by 2030.According to the survey conducted by the Department of Energy of USA (DOE), the cost of Hydrogen in 2010 was $1.50 per gasoline gallon equivalent. The gasoline gallon equivalent (gge) is approximately equal to a kilogram of hydrogen on an energy basis. At present Hydrogen can be produced via natural gas at $2.00/gge. With the recent research underway in electrolysis, compression, liquefaction, storage and delivery, it will contribute to reductions in the cost of hydrogen. Hydrogen can also be produced using biomass, biological and photochemical processes.

The energy per unit mass and energy per unit volume as referenced to gasoline, gives a rough idea of the viability of hydrogen as aviation fuel. For example, a kilogram of gasoline is energy equivalent to about 0.4 of a kilogram of hydrogen. A gallon of gasoline is energy equivalent to 3.7 gallons of liquid hydrogen. Thus for the hydrogen to be feasible, it greatly depends on the system it is being used in and how it is stored.

HISTORY OF HYDROGEN IN AVIATION

Hydrogen- fueled aircrafts were researched by the NACA-Lewis Flight Propulsion laboratory in the 1950's. In 1956, a US Air Force B-57 medium bomber was modified to carry liquid hydrogen fuel along with the conventional Jet fuel. The Liquid Hydrogen was stored in a wing tip tank and was boiled by an air-to-hydrogen heat exchanger that fed the gaseous hydrogen in to the engine combustor. During takeoff and landing, the aircraft burned Jet fuel in both engines. During the cruise the aircraft switched to hydrogen fuel in the modified engine. The Liquid Hydrogen fuel provided 21 minutes of flight. This was the first ever flight of an aircraft flow with Liquid Hydrogen as its fuel. Motivated by environmental and energy supply issues in Russia, Russian aircraft manufacturer's Tupolev modified a Tu-154 to run one of its three engine on Liquid Hydrogen. This aircraft was named Tu-155. The 4000 cubic feet cryogenic fuel tank was added to the real of the fuselage. The fuel pump was pneumatically powered to avoid the hazard of a spark from an electric motor. The combustion chamber, fuel injection nozzles and engine controls were the only engine modification made to the aircraft.

On June 19, 1988, the first aircraft made its maiden flight solely fueled by hydrogen. The 40 gallon fuel tank provided about 1-2 hours of operation. A study performed mainly by the Lockheed-California Company, found that commercial transports designed specifically for Liquid Hydrogen fuel will achieve lower energy based fuel burn per passenger- mile than the conventional kerosene-type jet fuel.

CONFIGURATION

The central configuration change for liquid hydrogen fueled transport is due to the large volume required by the fuel tank. The tank must be well insulated to prevent the boil off of Liquid Hydrogen. It must be structurally efficient so that the overall aircraft weight is not compromised. Thus the most efficient shape to meet hr structural and thermal efficiency requirements is spherical; however a cylinder is the best compromise with manufacturing and aerodynamic consideration. The insulation thickness is an important factor in designing the fuel tank, as the cryogenic temperature of liquid hydrogen of –150 °C or below is to be maintained at all the time. Closed cell cryogenic foam is used as the fuel tank insulation with a think aluminum skin for protection.

The various configurations available for the tank are: above the payload, above and aft of payload, and fore and aft of the payload section. In the above and aft of payload configuration, the tanks are placed above and behind the passenger compartment. In the fore and aft configuration, the forward tank is placed in between the cockpit and forward passenger compartment bulkhead and the aft tank between the aft passenger structures. The tanks can be integral or non-integral parts of the fuselage structure. In the structurally integral tank, the inner walls of the tank play the role of containing the liquid hydrogen fuel and acting as the main fuselage structure. According to study, the fore and aft tank is suitable for medium and long range aircraft; while an above and aft tank is suitable for short range missions.

PROPULSION

Several full turbine engine cycle analyses have been performed on hydrogen fueled aircraft engines and studied. There were only minute changes to the hydrogen fueled aircraft engine like the addition of heat exchanger and slight changes in the cycle. According to the results obtained from the study, it shows that the Specific Fuel Consumption (SFC) for takeoff and cruise conditions is about 65% lower than kerosene fueled engine. This is achieved because of the higher energy density per unit mass of liquid hydrogen. The liquid hydrogen fueled engines us an average of 2.85% less energy during takeoff and 0.81% less during cruise, meaning liquid hydrogen uses about 1-2% less energy than the kerosene fueled aircraft engine. This results in production of extra thrust from the energy available. Liquid hydrogen fueled engines can operate with a slightly lower entry temperature, resulting in longer engine life and lower maintenance cost.

SAFETY

Because of specific chemical properties of hydrogen, a liquid hydrogen fire last for a much shorter duration than a kerosene fire. Thus, in case of an aircraft fire, a kerosene fueled aircraft is going to be affected more than a hydrogen fueled aircraft. For a large hydrogen fueled aircraft, the fire would last up to 15-25 seconds only. At the same time, the intensity of heat from a kerosene fire is much higher. Thus in case of a long fire in a kerosene fueled aircraft, it is possible for the fuselage to collapse, while in case of a hydrogen fueled aircraft, the fuselage will remain intact. Moreover, the radius of a hydrogen fire is smaller when compared to a kerosene fire.

The biggest safety issue of hydrogen is detecting and minimizing hydrogen leaks. Also gaseous hydrogen is odorless and colorless, preventing detection by human senses. Therefore continuous monitoring where hydrogen leaks or accumulation could cover is required along the length of the hydrogen storage system. Liquid Hydrogen adds the complexity of cryogenic system for storage, transportation and detection.

DESIGN CHALLENGES

The density of liquid hydrogen is much lower than that of kerosene, 70.85 kg/m^3 vs 810 kg/m^3. Therefore, for the same energy content, hydrogen aircraft requires about 4 times the fuel volume of the kerosene aircraft. The combination of large volume requirement, cryogenic insulation, and an efficient pressure vessel shape are the prime driving force in the liquid hydrogen aircraft configuration design. Due to the required thickness of the fuel tank, it can no longer be stored in the wings, and thus needs to be a part of the fuselage. The combination of a much larger fuselage size and the same size or smaller wing leads to an aircraft with a much larger ratio of fuselage wetted area to wing wetted area than that of a conventional kerosene aircraft. This increases the overall skin friction drag and compressibility drag of the aircraft, thus reducing the Lift to Drag Ratio(L/D) of the aircraft. The extra insulation also results in addition of empty weight to the aircraft. In summary, the extra insulation of tank, leads to lowering of L/D ratio of aircraft, increase in aircraft's Empty Weight Fraction (EWF). This result in extra energy being required by the kerosene fueled aircraft, but gets compensated by the far lower fuel weight of liquid hydrogen.

CONCLUSION

This paper has shown the possibility of hydrogen fueled aircrafts as an alternative fuel and also the relative performance between kerosene and liquid hydrogen aircraft. The liquid hydrogen aircrafts has a much lower fuel weight than an equivalent kerosene aircraft, but the added weights and bulk of cryogenic fuel tanks offsets this weight somewhat. The actual point at which a liquid hydrogen aircraft becomes profitable as a kerosene aircraft depends, in addition to fuel prices, on the performance of the liquid hydrogen aircrafts.

The main conclusion that can be drawn from this paper is that fuel burn performance is a motivation towards developing liquid hydrogen aircraft. The largest hurdle to the operation of liquid hydrogen aircrafts is the infrastructure need to fuel them. Hydrogen can be produced in an economically positive and environmentally friendly manner.

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