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Parameter Selection for Hydrogen Passenger Aircraft Preliminary Sizing

1 Basic Hydrogen Parameters

Hydrogen parameters compared to kerosene parameters are given in Table 1 (Seeckt 2010).

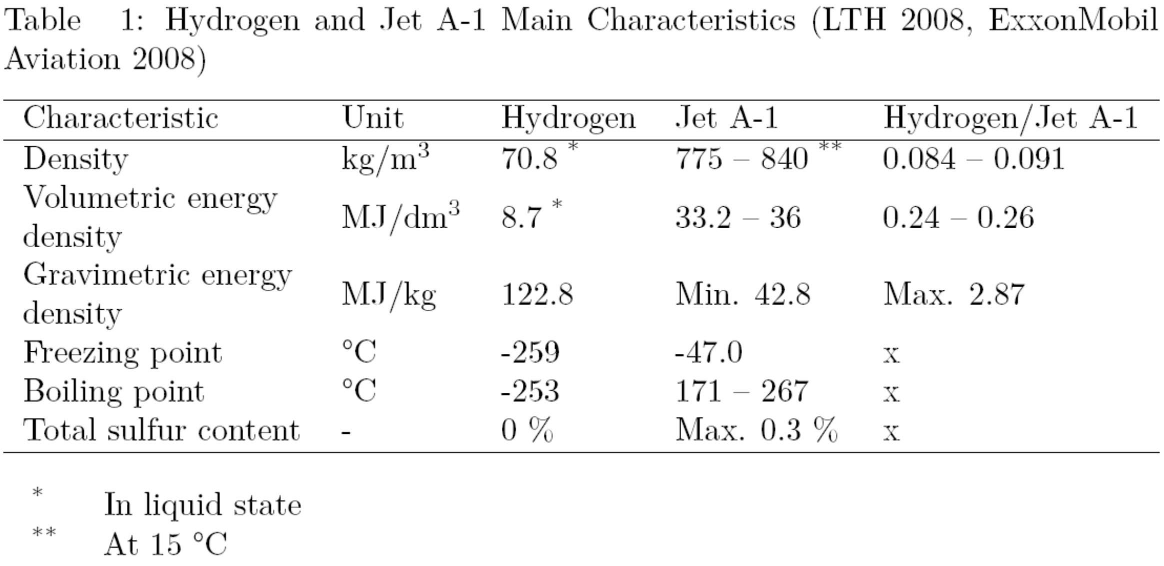

Table 1: Hydrogen and Jet A-1 Main Characteristics (LTH 2008, ExxonMobil Aviation 2008)

Characteristic	Unit	Hydrogen	Jet A-1	Hydrogen/Jet A-1
Density	kg/m³	70.8 *	775 – 840 **	0.084 – 0.091
Volumetric energy density	MJ/dm³	8.7 *	33.2 – 36	0.24 – 0.26
Gravimetric energy density	MJ/kg	122.8	Min. 42.8	Max. 2.87
Freezing point	°C	-259	-47.0	x
Boiling point	°C	-253	171 – 267	x
Total sulfur content	-	0 %	Max. 0.3 %	x

* In liquid state
** At 15 °C

2 Specific Fuel Consumption of Hydrogen Jet Engines

Hydrogen has 2.87 times more energy per mass (kg) than kerosene (Jet A-1). The inverse means that its mass is 1/2.87 = 0.35 or only 35% for the same energy. This also means that the Specific Fuel Consumption, *c* (SFC) of a hydrogen jet engine is only 35% of that known from a kerosene jet engine. This has nothing to do with the propulsive or thermodynamic efficiency of the engine. It is just a result from the gravimetric energy of the fuel in use.

If we decided on the technology of a jet engine, based on Bypass Ratio, μ (BPR) and Overall Pressure Ratio (OPR), we get approximately the Specific Fuel Consumption of the LH2 engine based on the kerosene engine (index: K) from

$$c_{LH2} = k_{c,LH2} \cdot c_K \quad \text{with} \quad k_{c,LH2} = 0.35 \tag{1}$$

3 Operating Empty Mass Ratio of Hydrogen Aircraft

Modern kerosene passenger aircraft have integral fuel tanks. The fuel is filled directly into the structure. This design principle is lighter than a design with LH2 fuel tanks that need to withstand internal pressure and need to be well insulated in order to keep the temperature below -253 °C. In addition the tanks have a volume 4 times as large as comparable kerosene tanks. The larger tanks are heavier already due to their size. Furthermore, the large tanks also need a larger and heavier aircraft with more structure around the tanks. The additional structure could be the structure of tanks in separate pods e.g. attached to the wings, or a stretch of the fuselage to house the tanks.

The structural efficiency of an aircraft is expressed by the Operating Empty Mass, m_{OE} (OEM) divided by the maximum take-off mass, m_{MTO} (MTOM). This ratio is increase in case of hydrogen powered aircraft.

$$\left(\frac{m_{OE}}{m_{MTO}}\right)_{LH2} = k_{OEM,LH2} \cdot \left(\frac{m_{OE}}{m_{MTO}}\right)_{K} \quad \text{with} \quad k_{OEM,LH2} \quad \text{from Table 2} \tag{2}$$

Normally, aircraft design statistics are based on the parameters of real aircraft. In case of LH2 passenger aircraft (so far) none exist. As a substitute, parameters are averaged from the aircraft designed to much detail in the frame of the Green Freighter (GF) project. Additionally, parameters of other well documented hydrogen passenger aircraft studies could be included later in a update of this statistic.

Table 2: Factor for the Operating Empty Mass Ratio $k_{OEM,LH2}$

aircraft similar to ...	**average $k_{OEM,LH2}$**	**Source**
ATR-72	1.102	Seeckt 2010a
Airbus A320	1.140	Dib 2015
Lockheed C5	1.020	Seeckt 2010b
Average	1.087	

4 Maximum Glide Ratio of Hydrogen Aircraft

The maximum glide ratio, $E_{max} = (L/D)_{max}$ is reduced when an aircraft shows relatively more wetted area immersed in the flow. This follows from

$$E_{max} = k_E \sqrt{\frac{A}{S_{wet} / S_W}} \quad . \tag{3}$$

Hydrogen aircraft show more wetted area due to tanks in pods or a fuselage stretched to house the large tanks. In preliminary sizing, when the details of the aircraft and the wetted area of all of its components are not yet known, it is possible to include the effect in the parameter k_E.

$$k_{E,LH2} = k_{k,E,LH2} \cdot k_{E,K} \quad \text{with} \quad k_{k,E,LH2} \quad \text{from Table 3} \tag{4}$$

Table 3: Factor for the maximum glide ratio $k_{k,E,LH2}$

aircraft similar to ...	**average $k_{k,E,LH2}$**	**Source**
ATR-72	0.982	Seeckt 2010a
Airbus A320	0.968	Dib 2015
Lockheed C5	0.974	Seeckt 2010b
Average	0.975	

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