# AIRCRAFT SIMULATIONS USING HYDROGEN AS AN ENERGY CARRIER
## *TRA105—Fuel Cell Systems Tracks Project*

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## INTRODUCTION

*The aviation industry accounts for a growing share of total greenhouse gas emissions. As a result, there is an urgent need to reduce the industry's carbon footprint. One way to achieve this is by using batteries for energy storage and electricity for propulsion. Electric aircrafts are currently being studied to provide zero emissions and easy access to a large number of locations in Sweden. A limitation in today's use of electric aircraft is the power density of batteries. An alternative to the batteries is to use hydrogen as fuel in the aircraft. Hydrogen fuel cells offer a clean and efficient way to produce electricity for propulsion, and the only by-product is water.*

Image Credits: Heart Aerospace

## METHODOLOGY

*The data from the conceptual design for an electric aircraft being developed at Chalmers as a part of a CARAT project shown will be used for calculations.*

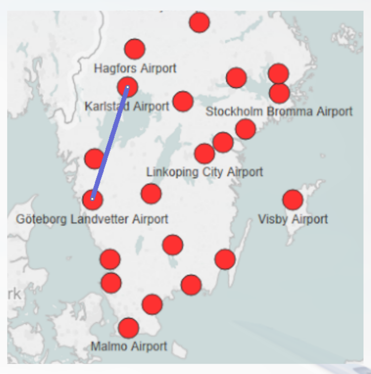


Figure 1: Flight path and airports in Sweden

***Parameters and Assumptions:***
*Cruise height: 13000ft (3962.4m)*
*Lower heating value for H2: 120 MJ/kg*
*Temperature at cruising height: -10° Celsius*
*Total distance: 206 Km*
*Reference area: 37.7 sq m*
*Mass of aircraft: 8618 kg*
*Assumed passenger weight: 95 kg*
*Number of passengers: 19*
*Pressure at ground: 105037 Pa*
*Temperature at ground: 9.6° Celsius. (Based on average temperature in Borås Sweden)*
*Cd=0.11; Cl=1.53.*

Angle of attack ($\alpha$) considerations:
Lift coefficient:
$$c_L(\alpha) = 0.1020.\alpha + 0.1020$$
Drag coefficient:
$$c_D(\alpha) = 0.0005.\alpha^2 - 0.0008.\alpha + 0.0284$$
Constant speed at level flight:
$$L = mg, D = F_N$$

| Segment | Speed (m/s) | Flight path angle, $\gamma$ (deg) |
|---|---|---|
| Climb | 92 | 4.0 |
| Cruise | 94 | 0.0 |
| Descent | 79 | -3.0 |
| $\eta_{prop}$ | | 87.0 % |
| $\eta_{motor}$ | | 90.0 % |
| $\eta_{controller}$ | | 98.0 % |

*Lift and drag forces are developed from basic aerodynamic relations according to:*
$$L = c_L.q.S \qquad D = c_D.q.S \qquad q = \frac{\rho V^2}{2RT}$$
*where S is the reference area and q is the dynamic pressure, which for high-speed flows is cast in the density free form.*
*Constant speed, constant climb gradient flight:* $F_N = \frac{L.sin\gamma + D.cos\gamma}{\cos(\alpha+\gamma)}$ *and* $D.sin\gamma + mg = L.cos\gamma + F_N.sin(\alpha+\gamma)$

*These equations can be integrated to eliminate the net thrust. An iterative solution for $\alpha$ can then be developed having assumed a fixed value for $\gamma$.*
*Distance to climb and descent :* $\frac{Cruise\ Height}{\tan(\gamma)}$ *and Total cruise distance:* $D_{Total} - (D_C + D_D)$

*Considering the above equations, and considering the efficiencies of the propeller, motor, and controller, we get the power requirement for our flight during climb, cruise, and descent. We also got an estimate of the time taken for the journey.*

Image Credits: Eviation Alice

## AIM

*The aim of the project is to evaluate the possibility of developing an electric aviation route between Gothenburg and Karlstad, a distance of 206 km (Road distance 248 km), with relatively available fuel cell technology.*

## SCOPE

- *Thorough review of literature on hydrogen fuel cells and aircraft design.*
- *Evaluating and plotting the mission profile of the aircraft and the fuel cell power requirements.*
- *Compute the energy needed for the route.*
- *Estimate the flight time to Karlstad.*
- *Compute the weight of the energy system*

Image Credits: ENERGIA

## RESULTS

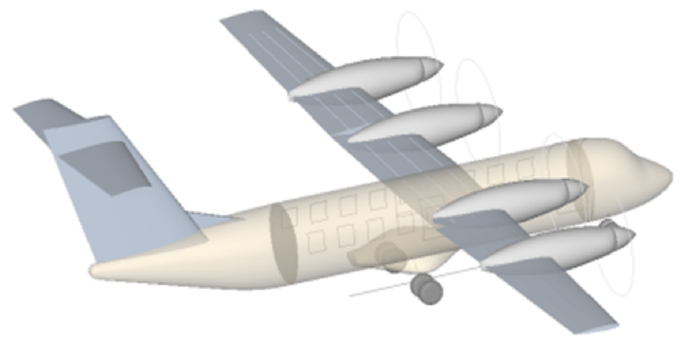


Figure 2: Electric aircraft designed at Chalmers as a part of CARAT Project

*Required power for climb (max power)=1012.92kW*
*Power with efficiencies 1320kW*
*Required power for cruise=485kW*
*Required power for descend: 67.37kW*
*Assuming one would use the POWERCELL MS-100, with a power output of 100kW and a weight of 212 kg. We would need 14 units of 100kW POWERCELL units, which weighs approximately 3000 kg, including the cooling units, power electronics, etc.*
*H2 for climb 13.32 kg (fuel cell efficiency is 51%) (95% of rated power)*
*H2 for cruise 6.84 kg (fuel cell efficiency is 60%)*
*H2 for descend 1.07 kg (fuel cell efficiency is 65%)*
*Total 21kg for total trip. And with safety margin 40% , weight of fuel = 30 kg*
*Weight of a single Type 4 H2 Tank = 100 kg (6 Kg of H2)*
*Total H2 Fuel Tank weight: 500 kg*
*Total weight of the fuel cell system including cooling, electronics, actual fuel and tank is approximately: 3500 kg*

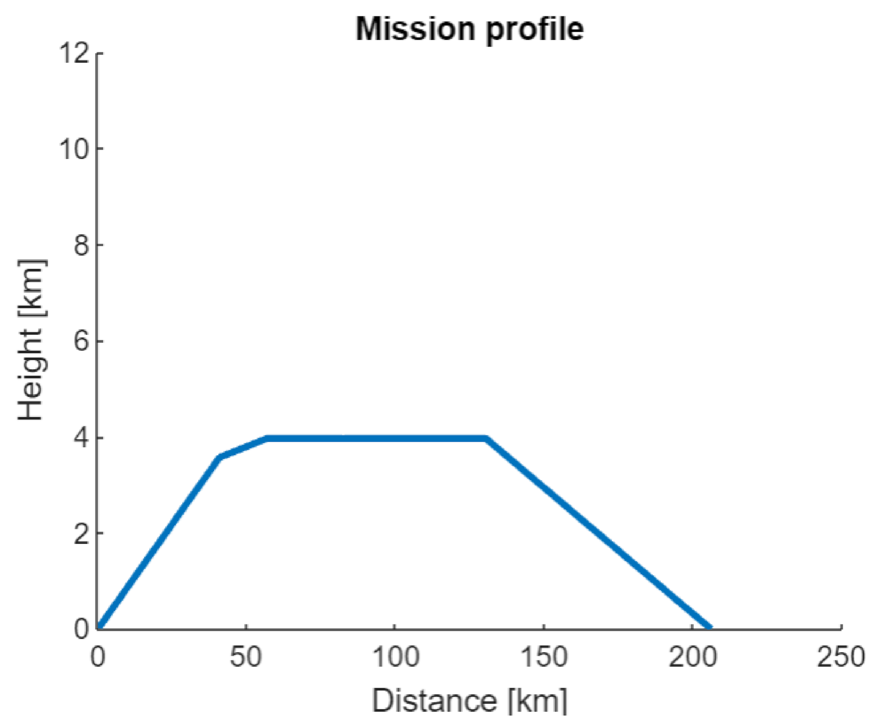


Figure 3: Flight Mission Profile

*Distance to cruising height: 56.6 Km*
*Cruise distance: 73.7 Km*
*Descending distance: 75.6 km*
*Time of climb=10.3 minutes*
*Time of cruise= 13 min;*
*Time of descend= 15.97*
*Total flight time= 39 minutes*

## DISCUSSION

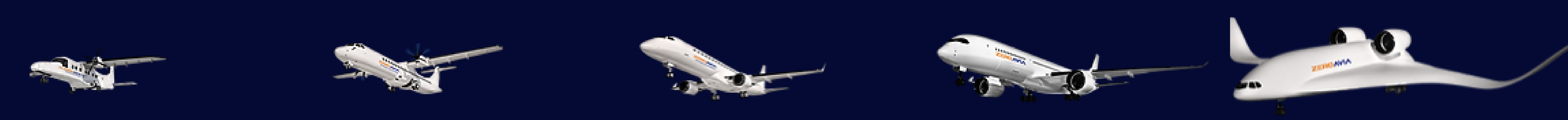
*Currently, there is a lot of investment and development within the fuel cell industry. Companies like PowerCell are working at the fuel cell system at different levels and selling their technology to various OEMs with various applications. One of these OEMs is ZeroAvia, which is an aviation company that is developing fuel cell-powered aircraft. ZeroAvia had its first successful test flight in January 2023 with a small aircraft, and their outlook for the future looks bright for fuel cell-powered aircraft. Their timeline might be optimistic, especially for long-distance flights. But for domestic flights, hydrogen-powered aircrafts might be a good option in the near future.*


Image Source: Credit: DLR

## CONCLUSIONS

- *The limiting factors for a fuel cell aircraft is mainly the power requirement from the fuel cell, which is a function of the power consumption of the aircraft. According to our study we observe that the fuel cell system and cooling are the heaviest components of the entire power train system which leads us to believe that fuel cells may not be a good option for large aircrafts because they require a lot of fuel cell stacks, which in turn adds a lot of weight.*
- *However, for lighter aircraft, such as the one we are considering here, it seems to be a good option because it is possible to easily increase range by carrying more hydrogen without incurring a significant weight penalty. Since the weight of the hydrogen storage is only about 15% of the total weight of the powertrain system. This is an advantage over the battery electric aircrafts where increasing the range inherently increases the weight.*
- *For fuel cell systems to be clean, the hydrogen produced must be in a green way otherwise the gain from a fuel cell powertrain is not significant compared to the already existing fossil fuel powertrains. This means that if the production of green hydrogen increases according the demands in the future then this can be viewed as a beneficial.*
- *It would be advantageous to be able to complement the fuel cell system with a super capacitor or a battery, for contingencies.*

## Powertrain Timeline



**2025**
9–19 seats
300 NM range
First commercial offering

**2027**
40–80 seats
1,000 NM range

**2030**
100–200 seats
2,000 NM range

**2035**
200 seats
3,000 NM range

**2040**
200+ seats
5,000 NM range

Image Credits: ZeroAvia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