Assessment of a Fuel Cell Powered Air Taxi in Urban Flight Conditions

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Challenges of today's mobility concepts

Modern technologies enable new transportation possibilities

Alternative Options

I Use of the “third dimension”

- **Diversified** mobility options
- Opportunity of **individualized mobility** (on-demand)
- Travel distance corresponds to approx. **linear distance**, which is why **travel duration is shorter** than with conventional mobility concepts
- **Bypassing areas at risk of congestion**

II Different application cases

- **Regional air transport**
for ranges between $50\text{km} < s < 500\text{km}$
- **Suburban air transport**
for commuting purposes & feeder services
- **Urban air transport**
daily transportation (leisure and commuting)

Design Concepts

Single phase

MULTIROTOR
lift

Dual phase

LIFT AND CRUISE
combination

Transition phase

TILT-X
tilt-wing, tilt-rotor, tilt-duct

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Energy

Batteries

- Rechargeable
- No local emissions (noise and pollution)

- Long charging times
- Limited capacity (ranges)
- Possible overheating risks
- Limited lifetimes (capacity < 80%)

Fuel Cells

- Short refueling times
- High power density
- High energy conversion efficiency
- “No” local emissions (noise & pollution)

- Complex design
- Thermo management
- Missing infrastructure

Does the application of fuel cells in air transportation offer operational benefits?

Considerations are based on the initial battery powered Vahana concept

A simplified version of the original design tool is available to the public

Approach

Reference vehicle

A

- Characteristics
- Vahana concepts

Principles of fuel cells

B

- Energy storage
- Equivalent specific energy

Parameter Studies

A

Assumptions and highlighting of **affected parameters**

B

Definition of **study mission**
(mission profile)

C

Parameter studies: range and payload

D

Effects on **cost structure**

E

Conclusions

Considerations are based on the initial battery powered Vahana concept

A simplified version of the original design tool is available to the public

A simple design tool provided by A³ is used to conduct parameter studies

Vahana is a **self-piloted vertical take-off and landing (VTOL)** all electric personal vehicle primary for urban mobility options

Vehicle characteristics

Characteristic	Value
PAX capacity	1
Fuselage length	5.70 m
Overall height	2.81 m
Wingspan	6.25 m
Empty weight	475 kg
MTOW	815 kg
Payload	250 lbs

Vahana Alpha One

➤ Size of the dots represents the respective **take-off mass**

➤ First results show a **cost advantage of the tilt-wing configuration especially on longer distances** (fixed-wings are used to generate lift during cruise flight)

Fuel cells contain higher energy densities than batteries

Storage

Low volumetric density calls for special storage technologies

- ➡ Hydrogen is stored under pressure, liquid or in hybrids
- ➡ High pressure storage is considered most viable for small aerial vehicles (350-700 bar, volumetric energy density improved)

Equivalent

A fuel cell system requires several components such as fuel tank, hydrogen and fuel cell

- ➡ Transformation of different parameters into one equivalent specific energy is necessary for proper comparison

Considerations are based on the initial battery powered Vahana concept

A simplified version of the original design tool is available to the public

Initial assumptions are retained for comparability purposes

General assumptions are based on a forecast predicting values in 2021 when Vahana is supposed to enter production

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Performance and dimensions

Performance and efficiencies of electric powertrain unit and dimensions of the vehicle

Parameter	Value	Unit
Battery specific energy	230	Wh/kg
Motor specific power	5	kW/kg
Depth of discharge	95	%
Fuselage width	1	m
Fuselage length	5	m
Fuselage height	1.6	m
Gearbox efficiency	98	%
Motor efficiency	85	%

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Manufacturing costs

Material and production expenditures

Cost design	Value	Unit
Material	220	\$/kg
Battery	161	\$/kg
Motor	150	\$/kg
Servo	800	\$/pcs
Avionics	30,000	\$
Insurance	6.5	% aq. cost
Facility rental	2	\$/ft ² /month
Electricity	0.12	\$/kWh

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Operating costs

Costs due to daily flight operations such as replacement of individual wearing parts and personnel costs

Maintenance	Value	Unit
Battery replacement	2000	Cycles
Motor replacement	6000	FH
Servo replacement	6000	FH
Personnel costs	60	\$/hrs
Periodic maintenance	0.05	MHR/FH

Which parameters are affected by a propulsion modification?

Two main design parameters must be adapted for the application of a fuel cell

Affected Parameters

The implementation of an equivalent fuel cell is carried out by **adjusting the performance values** of the previous battery.

Battery specific energy

Available energy provided for propulsion (hydrogen instead of electricity)

Depth of discharge

Unlike a battery, a fuel cell system can use 100% of its available energy (empty tank)

- ➔ **Engine, servo components and efficiencies** remain unchanged (associated data can be adopted). **Avionics, insurances, leasing and personnel costs** are not affected by a modification
- ➔ **Battery costs per mass unit (kg) and replacement cycle** will change as the price of the fuel cell system will be different.

Mission study

Parameter Studies: Effects on the range capacity

Range

Payload is kept constant and all default parameters are applied

- ➔ Range increases nearly linearly with increasing energy density
- ➔ Strong correlation between both parameters since there are no real weight effects due to empty and lighter tanks

Payload

Increasing range capacity is used to increase payload capacity

- ➔ Buffer time increased from 20 min to 40 min due to heavier weights
- ➔ Higher energy density results in a higher max. payload capacity
- ➔ Higher energy density for a certain range apparent for certain payload if a longer range is assumed for study mission

Direct operating costs vary considerably due to different assumptions

**Lifetime of both power systems
(30 min duration of flight)**

Range	Max. power	Energy	Flight time
100 km	~200 kW	112.4 kWh	1843.2 s

Battery Costs

$$\text{battery costs} = \text{energy density} * \text{energy price} * \text{battery weight}$$

Scenario	Energy density	Energy price	Battery weight	Total battery costs
High-price	230 Wh/kg	700 \$/kWh	752.11 kg	121,250 \$
Low-price	400 Wh/kg	350 \$/kWh	225.77 kg	31,607 \$

Fuel Cell Costs

$$\text{FC costs} = \text{price p. power} * \text{max power} + \text{hydrogen storage costs} * \text{energy demand}$$

Scenario	Price per power	Max power	Hydrogen storage costs	Energy demand	Total FC costs
High-price	230 \$/kW	200 kW	33 \$/kWh	112.4 kWh	49,709 \$
Low-price	40 \$/kW	200 kW	10 \$/kWh	112.4 kWh	9,124 \$

Insights

Total costs **fluctuate significantly** due to deviating technological maturity and uncertainty about future price developments of energy sources. **More detailed investigations** necessary, which emphasize the costs

Key takeaways and future work

Today's fuel cell technologies provide a higher energy density compared to batteries, which is why longer ranges can be achieved.

The advantage of higher range capacities can be used for larger number of missions without having to refuel in between, which facilitates faster, smoother flight operations

A higher range capacity can also be used to increase the max. payload capacity (up to six times the payload compared with standard configuration)

Studies are based on a simplified design tool, which is why further investigations will be necessary to validate recent findings:

- Required components for the application of fuel cells must be considered and included in future studies to optimize component weights
- More detailed economic data in terms of acquisition and operating costs are necessary
- External factors such as the distribution of hydrogen (i.e. infrastructure) must be included

Thank you.

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