Dedicated to innovation in aerospace

Safety aspects of electric flight operations

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SAFETY FORUM
SAFE SUSTAINABILITY
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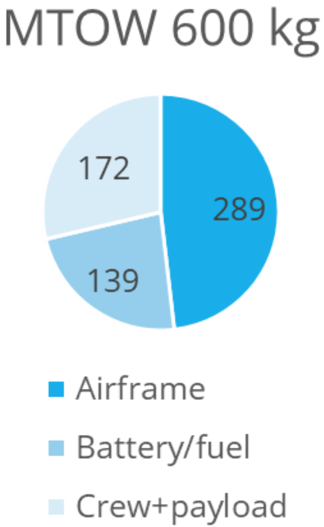
Royal Netherlands Aerospace Centre (NLR)

Mission

Royal NLR makes aerospace more sustainable, safer, more efficient and more effective. The innovative solutions and practical advice strengthen the competitiveness of the business community and contribute to solutions for social issues.

NLR PH-NLX – Pipistrel VELIS Electro (PIVE) Electric Research Aircraft, in operation since July 2021



- EASA-certified all electric Aircraft (CS-LSA)
- MTOW 600 kg
- Built in Slovenia
- Two seater
- Full battery charge 1:00 hr

The pilot-in-command shall only commence a visual flight rules (VFR) flight if the aeroplane carries sufficient electrical energy used for propulsion for the following:

(1) by day, taking-off and landing at the same aerodrome/landing site and always remaining in sight of that aerodrome/landing site, to fly the intended route and thereafter for at least **10 minutes** at normal cruising altitude;

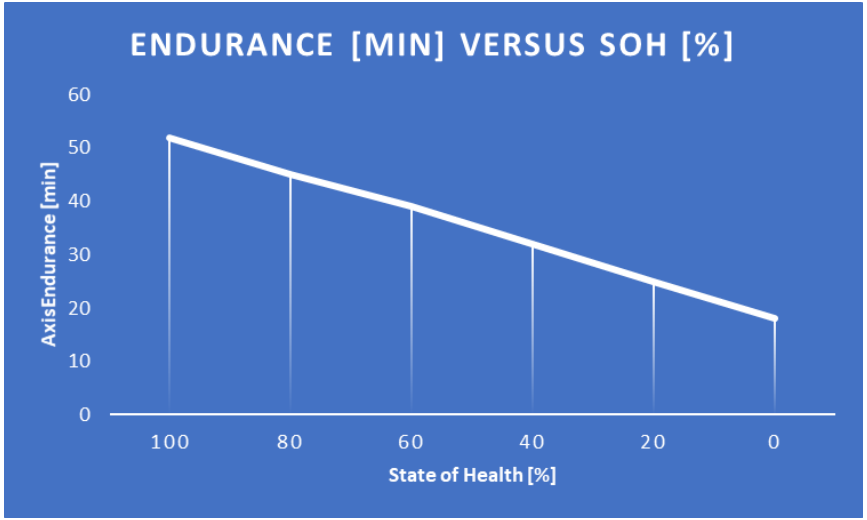
(2) by day, to fly to the aerodrome of intended landing and thereafter to fly for at least **30 minutes** at normal cruising altitude

(CAA-NL ref NCO.OP.125)

Aspects of all electric flight – Battery

Battery use

- SOH and SOC – monitoring needed
- The charging and discharging process (BMS) - performance versus preservation
- High Amperage at high and low SOC
- Temperature effects
  - Battery performance
  - Battery temperature management



Storage

- SOC
- Physical loads
- Temperatures

Efficiency

- Efficiency all electric drive train is high (well-to-wheel 70-80%)

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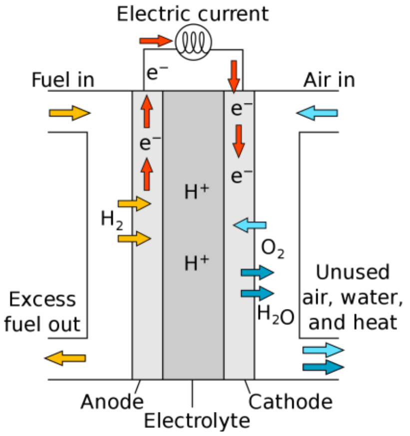
Aspects of electric flight - H2 PEMFC Fuel Cell

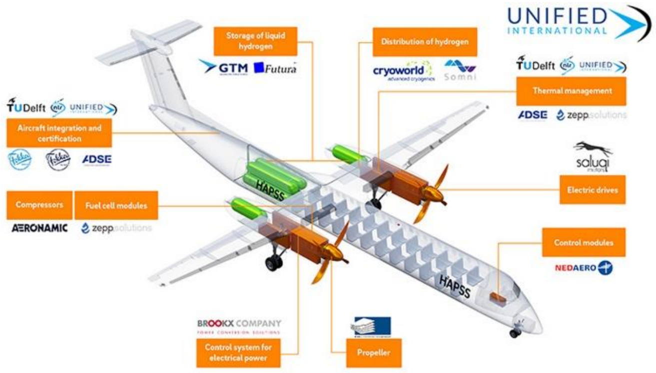
Components

- Fuel cell
- Hydrogen storage
  - Pressure tank (350-700 bar)
  - Cryogenic (liquid H2 at -260C)
- Tubing
- Cabling
- Cooling



Efficiency

- Well to wheel 30-35 %, but ..
- H2 has much a higher energy density than batteries



Safety study, objective and criteria

Triggered by the introduction of the PH-NLX to NLR fleet

Create a high-level knowledge base on the safety aspects related to the operation of electric aircraft.

Focused on the **safety aspects** of **manned, electric flight** based on the emerging technologies that are developed in near future (2020-2030)

Three concepts of operations. Scenario-based

Concept 1	Concept 2	Concept 3
		
2020-	2025-	2030-
50-250 kW	250-2,000 kW	50-1,000 kW
CS-VLA/LSA/23 (L1-2)	CS-23 (L3-4)	TBD
Fully electric	Fully electric	Fully electric
Li-Ion	Li-Ion	Hydrogen fuel cell
30 NM	300 NM	300 NM
One or two motors	One or two motors	One or more motors
Training, GA (NCO)	Air taxi (CAT)	GA, Air taxi (NCO, CAT)

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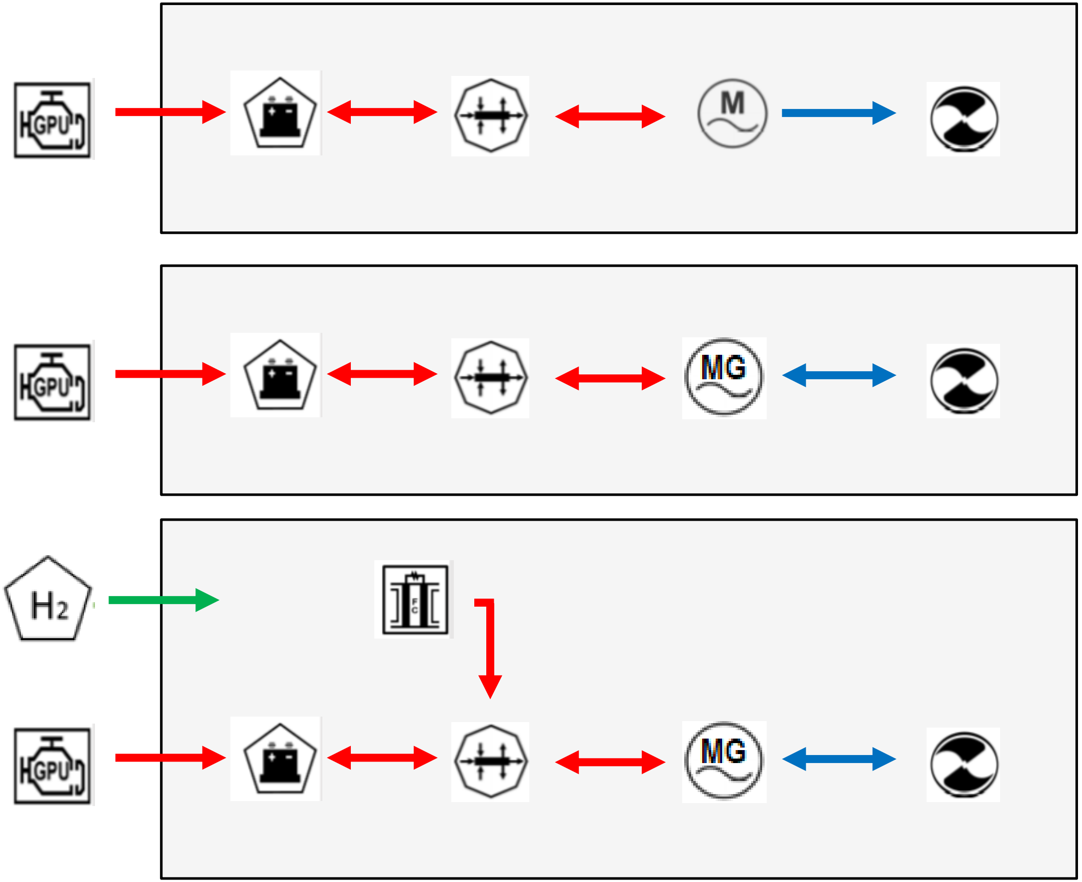
All-electric concepts (drive-train)

CONOPS 1 (2020-)
Energy stored in Li-Ion batteries
No regeneration

CONOPS 2 (2025-)
Energy stored in Li-Ion batteries
Power regeneration

CONOPS 3 (2030-)
Energy stored in hydrogen fuel cells
Power regeneration



Safety assessment methodology

For the safety assessment in this study it is assumed that aircraft certification and operator- and maintenance approvals have been completed.

Literature review
- NTSB
- AIAA
- NASA
- EUROCAE
- …

NLR SME brainstorm sessions
- Battery
- Certification
- Regulatory developments
- Flight test operations
- Hydrogen safety
- Electric and hybrid propulsion

46 hazards identified

5 scenarios and 2 attention areas

- Battery charging
- Energy reserves
- Temp sensitivity
- Electric effects
- Maintenance
- Post-crash fire
- Hydrogen

Risk assessment per scenario

		Severity		
		HIGH	MEDIUM	LOW
Probability	HIGH	(1)	(2)	(3)
	MEDIUM	(2)	(3)	(4)
	LOW	(3)	(4)	(5)

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Examples of included and excluded hazards

All electric (Concepts 1+2)	H2 fuel cells (Concept 3)	Excluded Hazards normally addressed during certification such as
• Battery fire/thermal runaway • Motor failure • Toxic fumes • Personnel exposed to high voltage/current • Battery energy uncertainty • Battery charging safety • Energy regeneration hazards • Common mode failures • Battery aging • Battery performance change with temperature • …	• Fuel contamination • Fuel cell overheat • Unintentional release of H2 or H2O • Liquid H2 low temperatures • Fuel cell fire • Fuel cell explosion • Asphyxiation • …	• EMI • Arcing • BMS design • Lightning strike protection • …

Safety Card – Electric Flight Risk/Attention areas

All Users
Pilots
Certifying Staff
Airport

Charging

Be aware of limitations and procedures related to battery charging!

When guidelines are not followed, batteries may damage or catch fire during a charging cycle!

Reserve

Always be vigilant about remaining battery capacity and how that translates into range/endurance!

Indicated remaining capacity may be less reliable.

Hot or cold?

Be aware of temperature limitations!

Battery performance, and therefore aircraft performance, depends on temperature. This is relevant both in hot and cold weather conditions.

High V/A systems

Know your emergency procedures!

Failure conditions of high amperage electrical systems may have unexpected consequences in other aircraft systems.

Maintenance

Apply caution when working on electric power train components!

Arcing, short circuit, damage and fire are hazards when working on electrical systems and batteries.

Fighting an electrical fire

Know the fire fighting procedures for Li-Ion fires!

A Li-Ion fire cannot be extuinguished, it needs to be contained and cooled, When using liquids for cooling, be aware of electroshock hazard.

Hydrogen powered aircraft

In the future aircraft will use hydrogen propulsion and fuel cells to store energy. These new technologies will also introduce new procedures and limitations.

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In-service operational experience gained

- Tour of The Netherlands
- Battery SOH degradation
- Certification issues
- Range/endurance issues
- Fire hazard
- Commercial viability of electric flight

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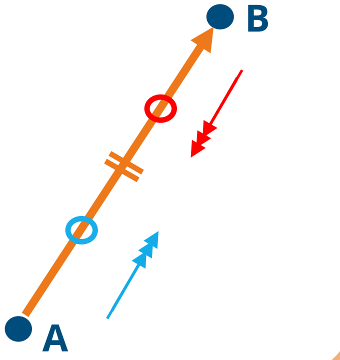
Tour of The Netherlands

- EHRD-EHGG and EHRD-EHBK, August 2021
- 11 airfields visited in 4 days
- Supervised charging
- Simulated commercial turn-arounds

PNR flightplanning



Tour of The Netherlands, lessons learned

- A LOT of interest in electric flight !
- 380V charging points mostly limited to 16A (6 kW)
- Proprietary charger, supervised charging requires qualified ground crew
- Flight planning (range, weight) is critically dependent on wind, and SOH
- Difficult to keep to a schedule due to many variables
- High pilot workload during turn-around

Evolution of regulations

Commission Regulation (EU) 965/2012

5 October 2012

- Consolidation of Air Operations Regulatory framework

Commision Regulation (EU) 2021/1296

4 Augustus 2021

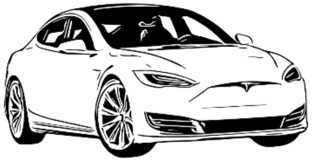
- Amending and correcting Regulation (EU) No 965/2012 as regards the requirements for fuel/energy planning and management.
- *The new fuel/energy planning and management requirements should support innovation and allow for the smooth integration of new technologies into the air operations domain. Therefore, the term **'fuel/energy'** should be used instead of the term 'fuel', wherever appropriate, to accommodate operations with aircraft that use other energy sources than conventional hydrocarbon-based fuel.*

ED Decision 2022/005/R

25 March 2022, effective 30 October 2022

- Proposes that air operators be allowed to reduce the amount of fuel carried during operations, thereby reducing the CO2 emissions of the overall flight and environmental impact of the flight.
- 3 million tons CO2 reduction per year (baseline 2015 flights).
- Fuel schemes detailed in new AM/GM.

Charging times



	Concept 1 Part NCO	EV	Concept 2 Part CAT
Capacity	25 kWh	100 kWh	> 500 kWh ?
Max power	58 kW	500 kW	250-1,000 kW
Cruise power	30 kW	25 kW	> 200 kW
Charging power	12 kW AC (380V/32A)	12 kW AC 150 kW DC	250 kW DC ?
Time to charge	2 hrs	8 hrs (AC) 30 min (80% DC)	2 hrs ?
Ratio charge : use	4:1	2:1 (AC) / 1:8 (DC)	2:1 ?

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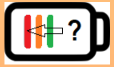
Reserve energy, in-service experience

Reserve

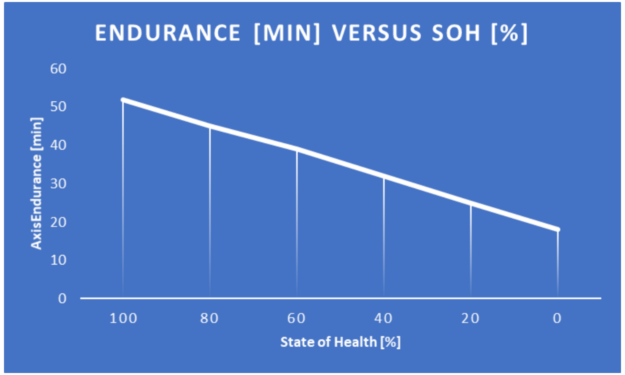


Always be vigilant about remaining battery capacity and how that translates into range/endurance!

Indicated remaining capacity may be less reliable.

Recent EHRD runway blockages for 30 minutes or more:

- 15 May 2019
- 31 October 2020
- 17 April 2021
- 23 February 2022 (*)
- 7 March 2022 (*)

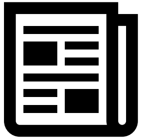


RFF category based on aircraft dimensions

Fighting an electrical fire

Know the fire fighting procedures for Li-Ion fires!

A Li-Ion fire cannot be extuinguished, it needs to be contained and cooled, When using liquids for cooling, be aware of electroshock hazard.



Firefighters tackling an EV blaze said they had to use 40 times more water than for a regular vehicle fire because of the car's lithium battery cells.
"Normally a car fire you can put out with 500 to 1,000 gallons of water," Fire Department Division Chief Thayer Smith said, "but with an EV it may take up to 30,000-40,000 gallons of water, maybe even more, to extinguish the battery pack once it starts burning and that was the case here."

Aircraft Category for Fire Fighting	Aircraft Overall Length	Aircraft Maximum Fuselage Width
1	< 9 m	2 m
2	9 m ≤ length < 12 m	2 m
3	12 m ≤ length < 18 m	3 m
4	18 m ≤ length < 24 m	4 m
5	24 m ≤ length < 28 m	4 m
6	28 m ≤ length < 39 m	5 m
7	39 m ≤ length < 49 m	5 m
8	49 m ≤ length < 61 m	7 m
9	61 m ≤ length < 76 m	7 m
10	≥ 76 m	8 m

Source: skybrary.aero

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Electric aircraft: RFF category based on battery capacity?

Critical Category for Fire Fighting	Quantity of Water	Quantity of Complementary Extinguishing Agents	Minimum Number of Aircraft Fire-fighting Vehicles	Total Discharge Capacity
1	230 l	45 kg	1	230 l/min
2	670 l	90 kg	1	550 l/min
3	1200 l	135 kg	1	900 l/min
4	2400 l	135 kg	1	1800 l/min
5	5400 l	180 kg	1	3000 l/min
6	7900 l	225 kg	2	4000 l/min
7	12100 l	225 kg	2	5300 l/min
8	18200 l	450 kg	3	7200 l/min
9	24300 l	450 kg	3	9000 l/min
10	32300 l	450 kg	3	11200 l/min

Aircraft Category for Fire Fighting	Electric aircraft battery capacity (example…)
1	-
2	-
3	50 kWh
4	100 kWh
5	200 kWh
6	400 kWh
7	800 kWh
8	1 MWh
9	1,5 MWh
10	> 1,5 MWh

Source: skybrary.aero

RFF
1→3

RFF
2/3→6/7

Commercial operations with electric aircraft ?

- Selection of aerodromes
  - Charging facilities
  - RFF requirements
- Energy reserves
  - Taxi + Trip + Cont + Alternate + FRF
  - SOH degradation
- Charging time versus hot-swapping of batteries

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Fully engaged

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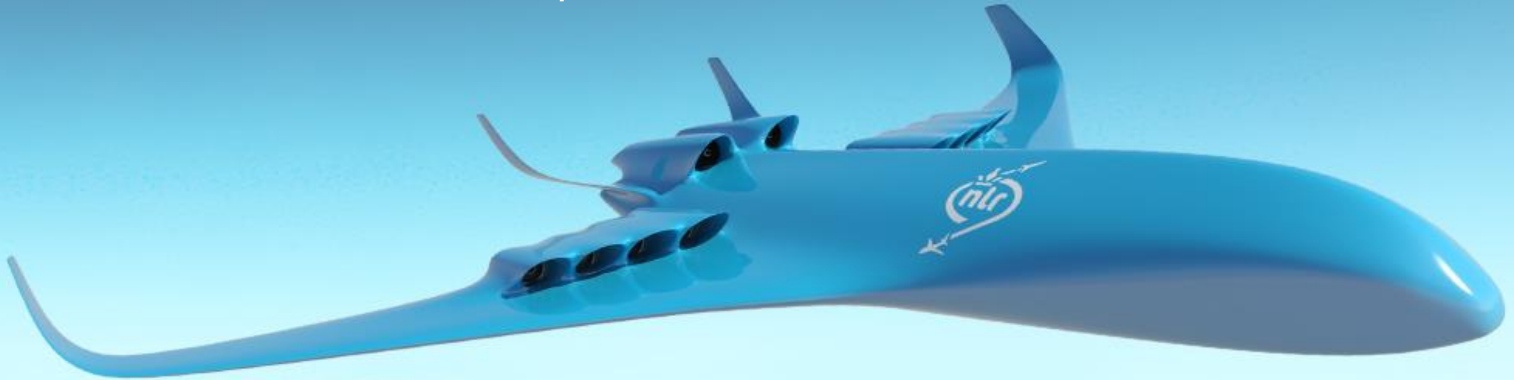

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