# ELECTRICAL SYSTEM ARCHITECTURES FOR FUTURE ELECTRIC AIRCRAFT

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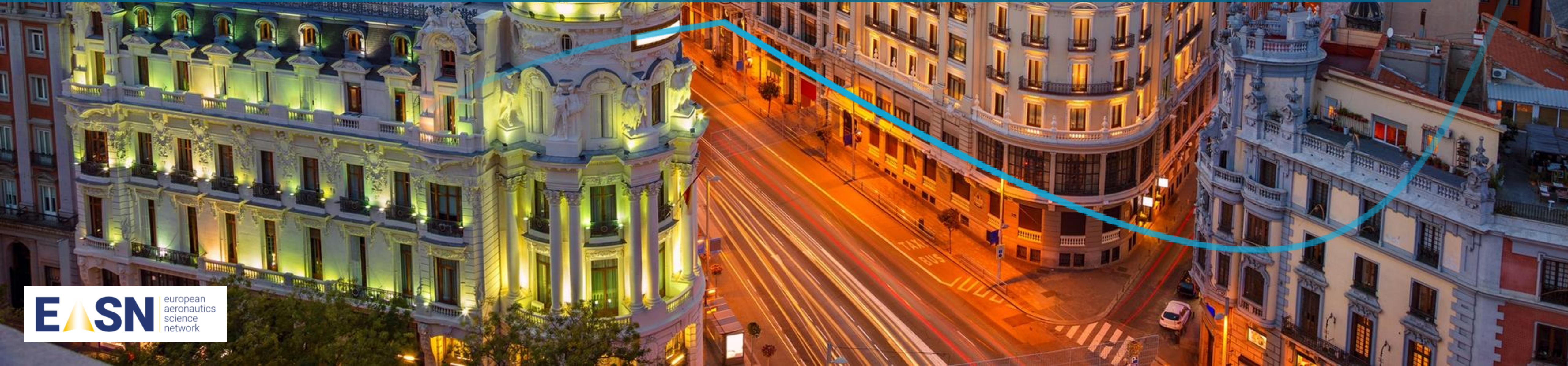


EASN european aeronautics science network

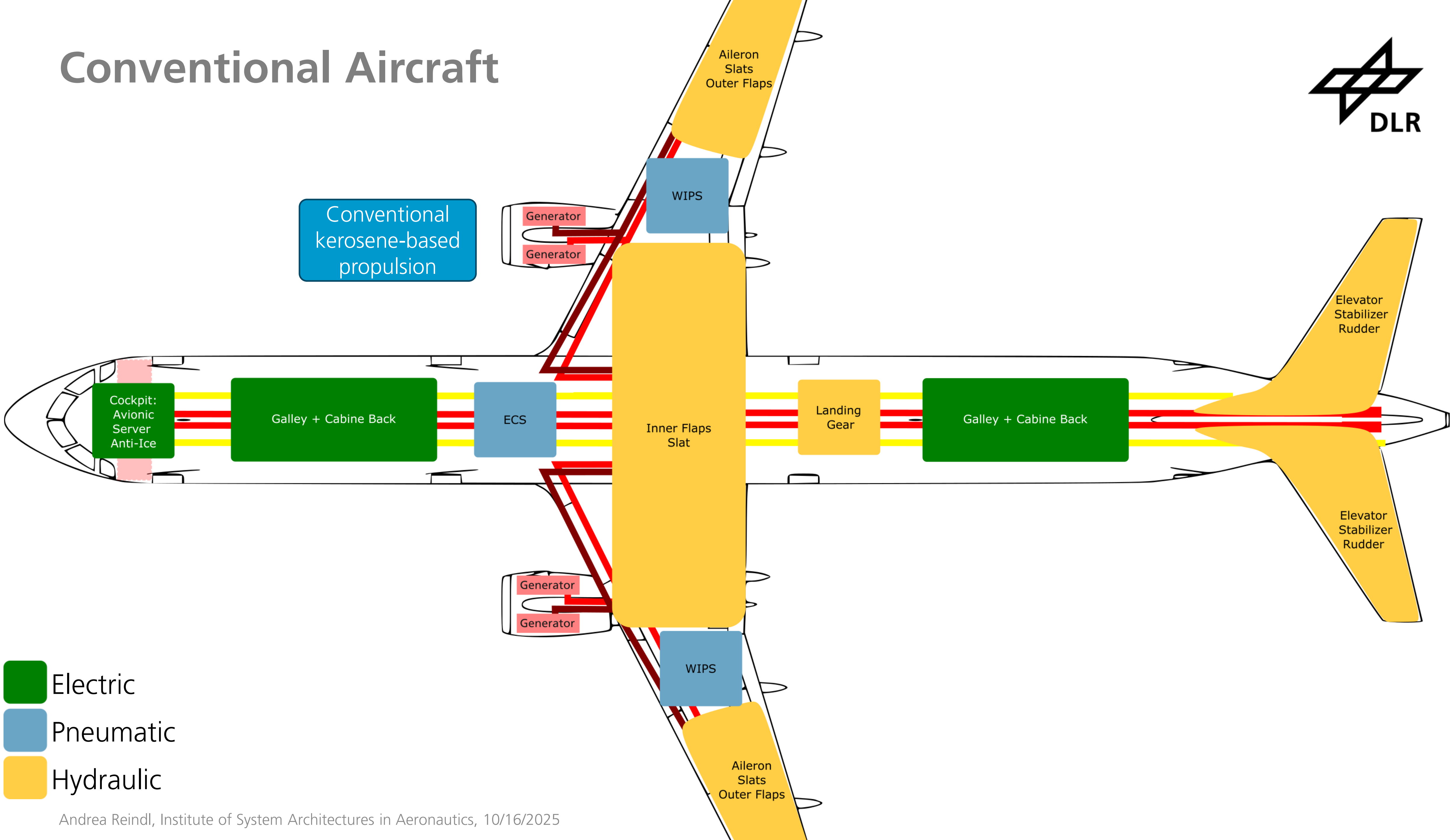
# Acknowledgement

The project is supported by the DLR-internal initiative EXACT.

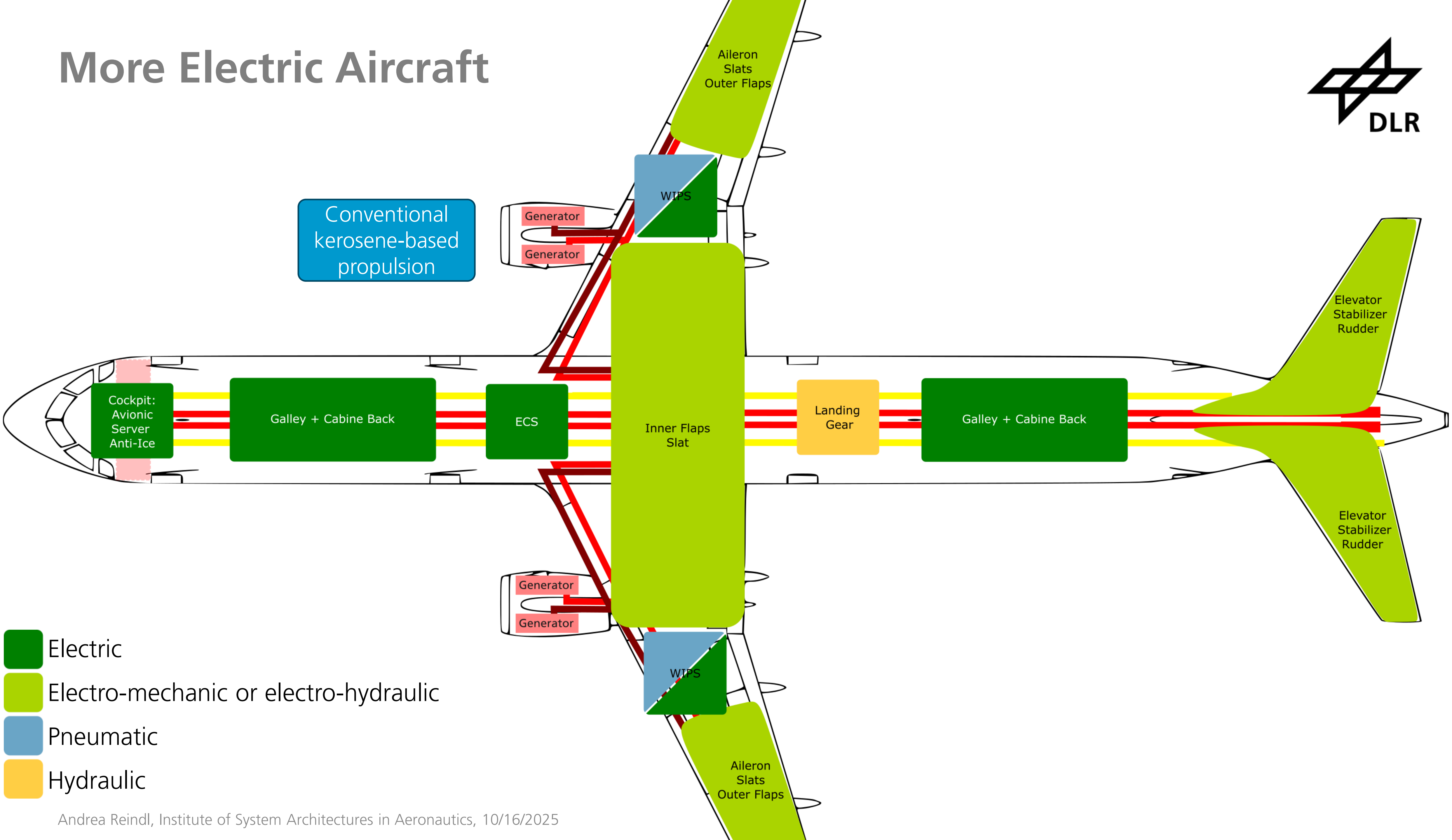
The project is supported by the Clean Aviation Joint Undertaking and its members. Funded by the European Union under Grant Agreement No 101102011. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the Clean Aviation Joint Undertaking. Neither the European Union nor the granting authority can be held responsible for them.

Co-funded by the European Union

# Conventional Aircraft



# More Electric Aircraft



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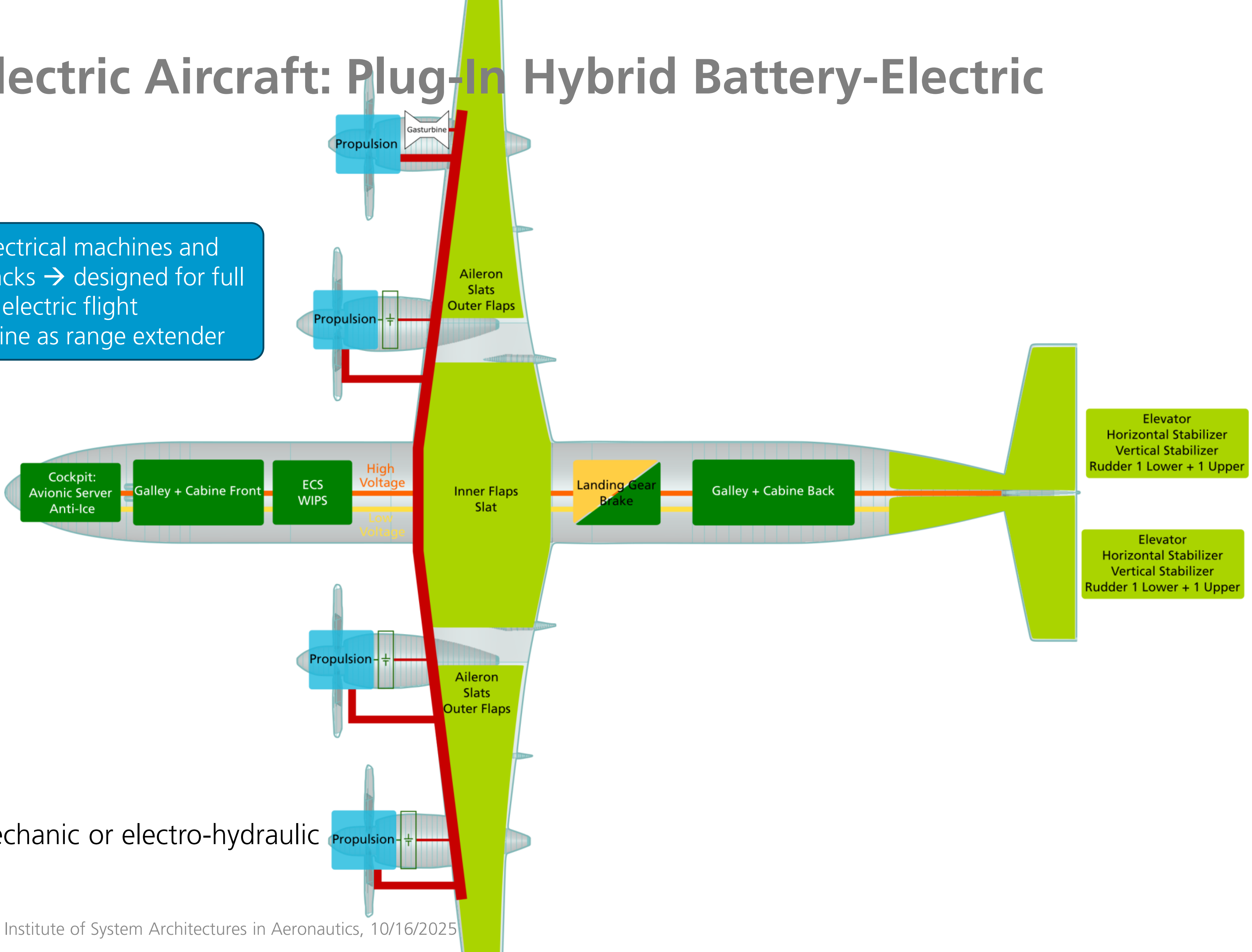
# All Electric Aircraft: Plug-In Hybrid Battery-Electric

Four electrical machines and battery packs → designed for full electric flight
Gasturbine as range extender




Electric
Electro-mechanic or electro-hydraulic
Hydraulic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# POWER RATING ELECTRICAL SYSTEM

## CONVENTIONAL

| | | | |
|---|---|---|---|
| Type | A320 | A321 | A380 |
| Maximum passenger capacity | 180 | 220 | 853 |
| Installed electrical power | ~100 kW | ~150 kW | ~600-800 kW |

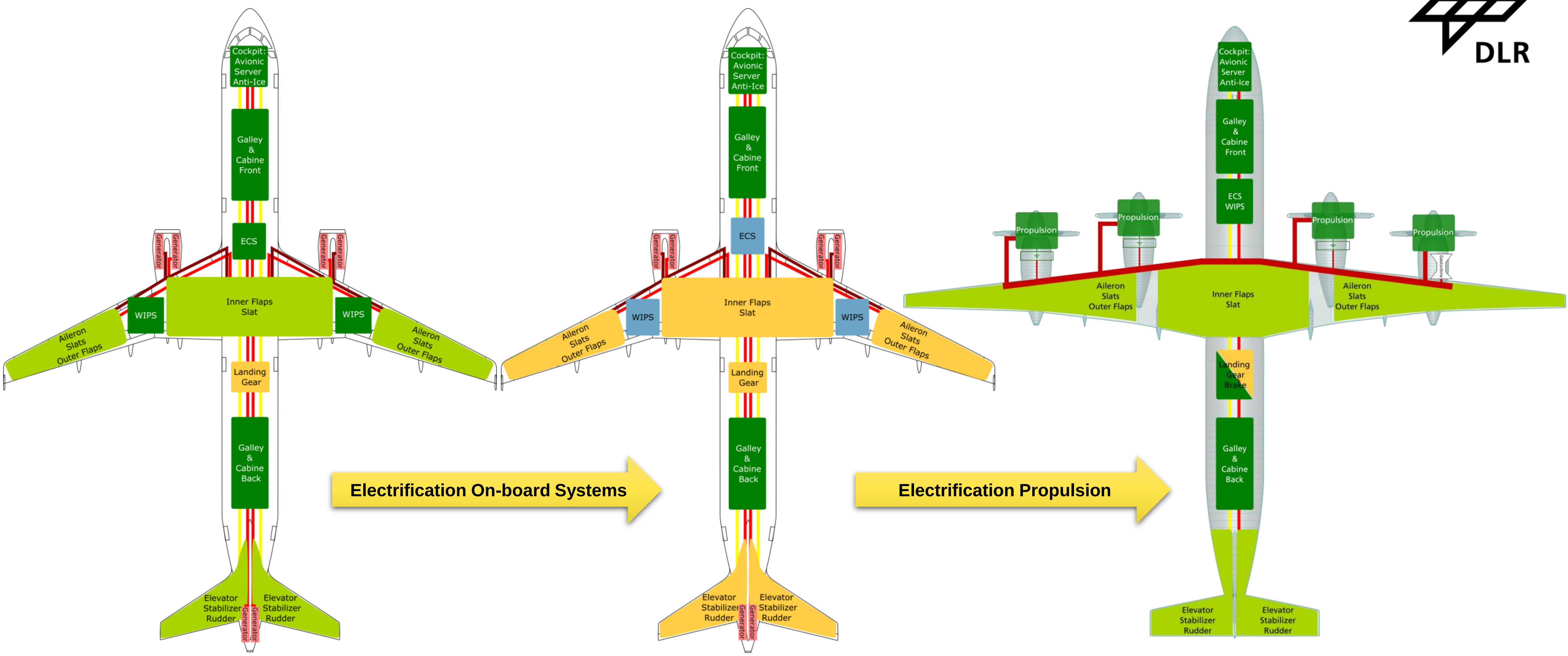
## MORE ELECTRIC AIRCRAFT

| | | | |
|---|---|---|---|
| Type | A350 | A321 (under research) | B787 |
| Maximum passenger capacity | 440 | 220 | 250 |
| Installed electrical power | ~1000-1400 kW | ~800 kW | ~1500 kW |

## ALL ELECTRIC AIRCRAFT

| | |
|---|---|
| Type | EXACT PHEP (under research) |
| Maximum passenger capacity | 250 |
| Installed electrical power | ~17.5 MW = 17500 kW |

## Conventional Aircraft | More Electric Aircraft | All Electric Aircraft




Installed electrical power (A321 like)

~150 kW | ~800 kW | ~17500 kW

Low Voltage (28V up to 48V)
High Voltage (540V up to 800V)
Electric
Electro-mechanic or Electro-hydraulic
Pneumatic
Hydraulic

# Research Questions

1. What is the impact of the electrical system at the Overall Aircraft Design (OAD)?
2. How can system architectures be designed to meet advanced requirements for fail-safety, reliability and availability?
3. Which control strategies are most effective in ensuring control stability while maximizing system availability?

# Research Questions

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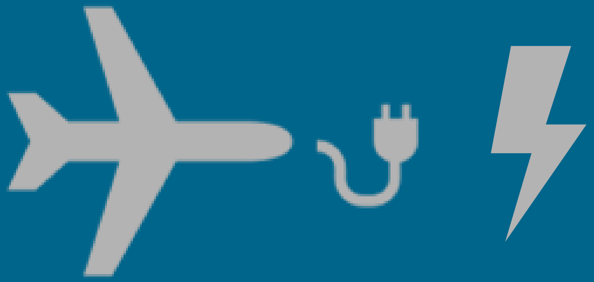
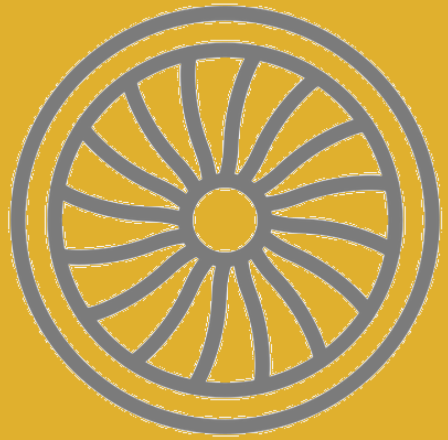
## 1. ALL ELECTRIC AIRCARFT ELECTRICAL SYSTEM



## 2. MORE ELECTRIC AIRCARFT ELECTRICAL SYSTEM

## 3. PROPULSION SYSTEM ARCHITECTURE



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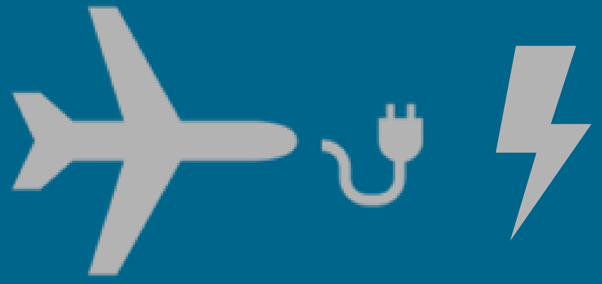

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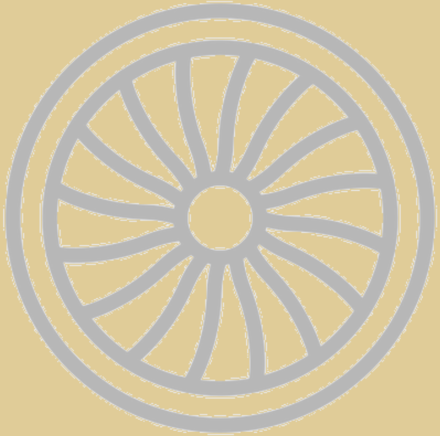


# Method of Procedure

Analyze the **state of the art** and **map** it to the selected aircraft configuration

↓

**Conventional Approach**

Focus on **new** aircraft configuration and the **technical innovations** and associated advantages for the system level

↓

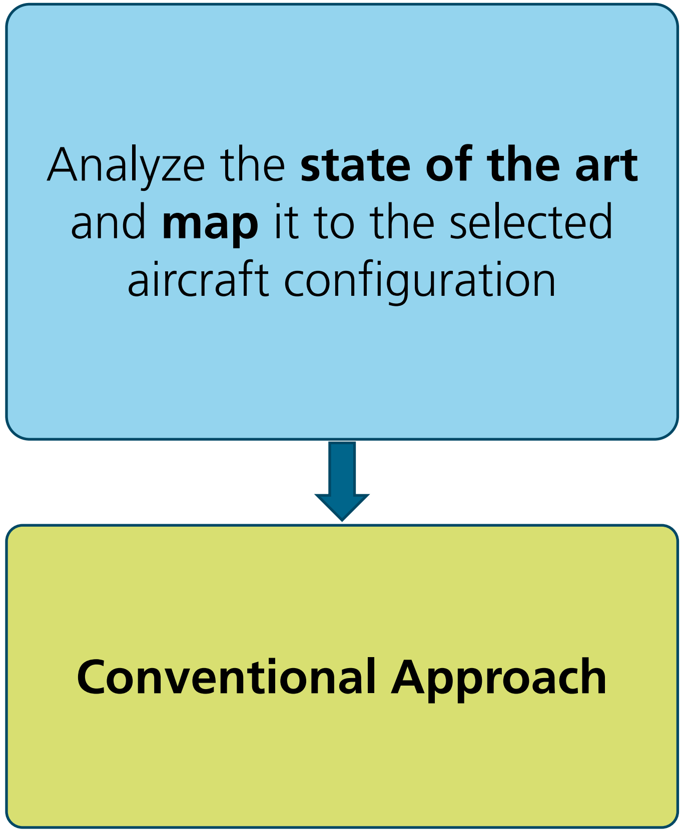
**Disruptive Approach**

Compare the **advantages** of the **conventional approach** with the **disadvantages** of the **disruptive approach** and derive a **hybrid** of both approaches.

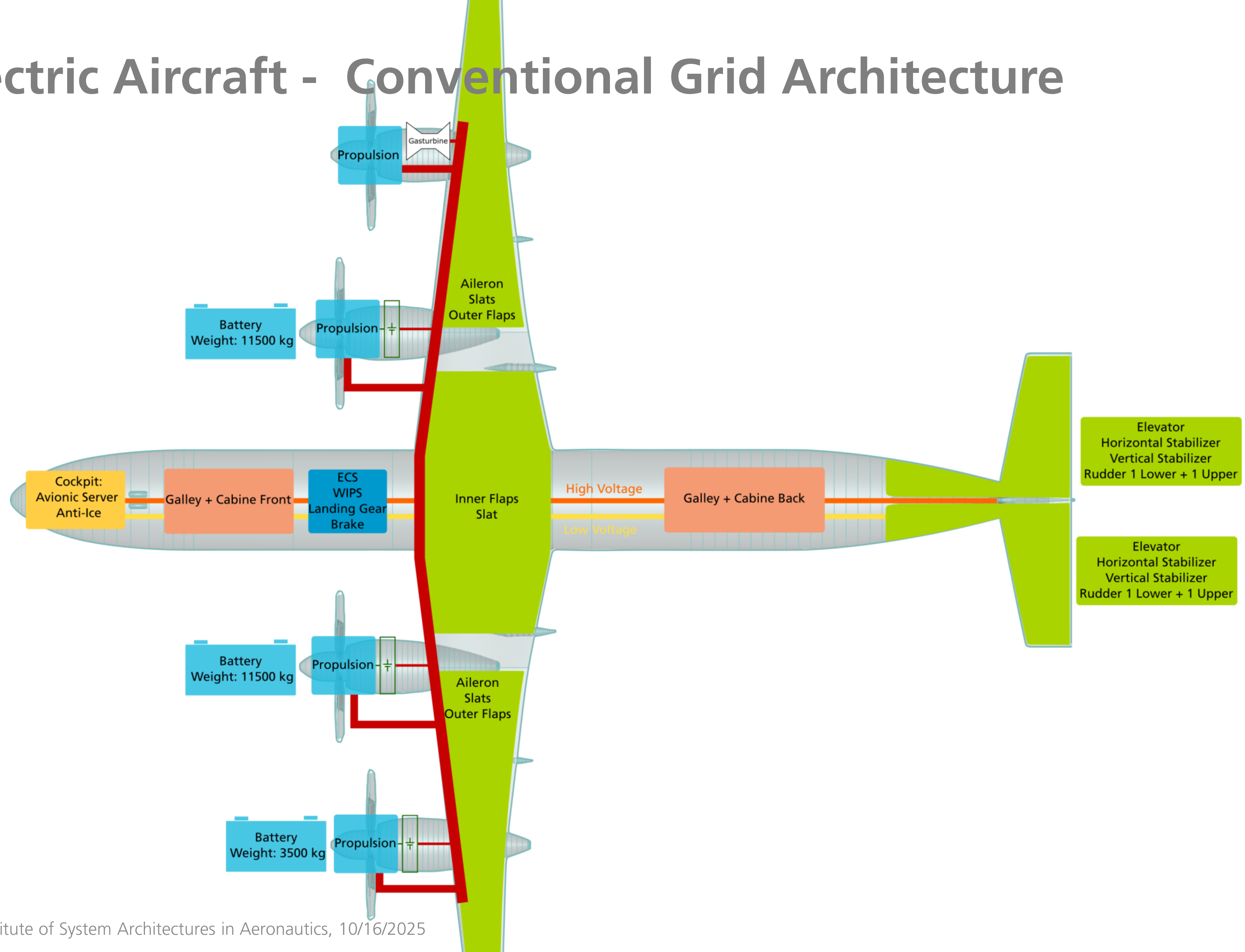
↓

**Hybrid Approach**

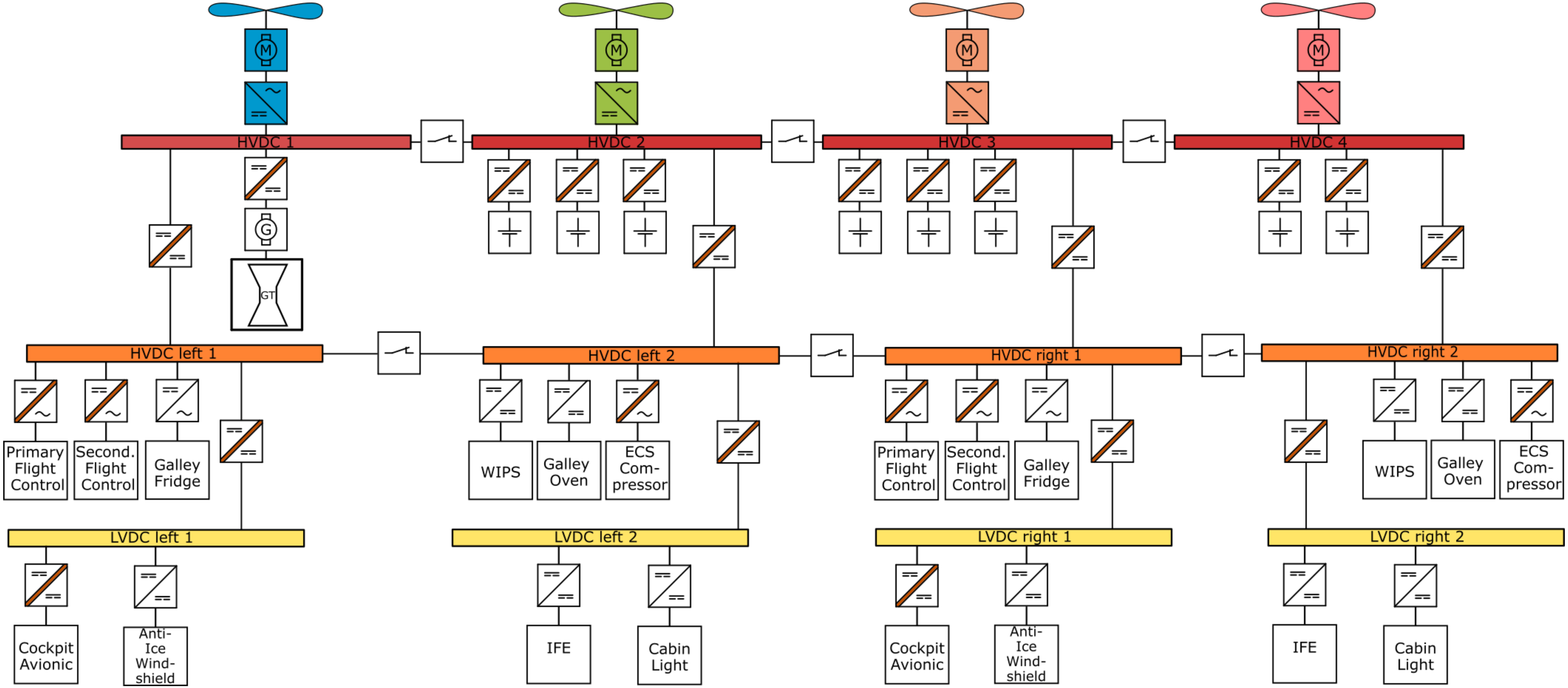
# Method of Procedure



# All Electric Aircraft - Conventional Grid Architecture

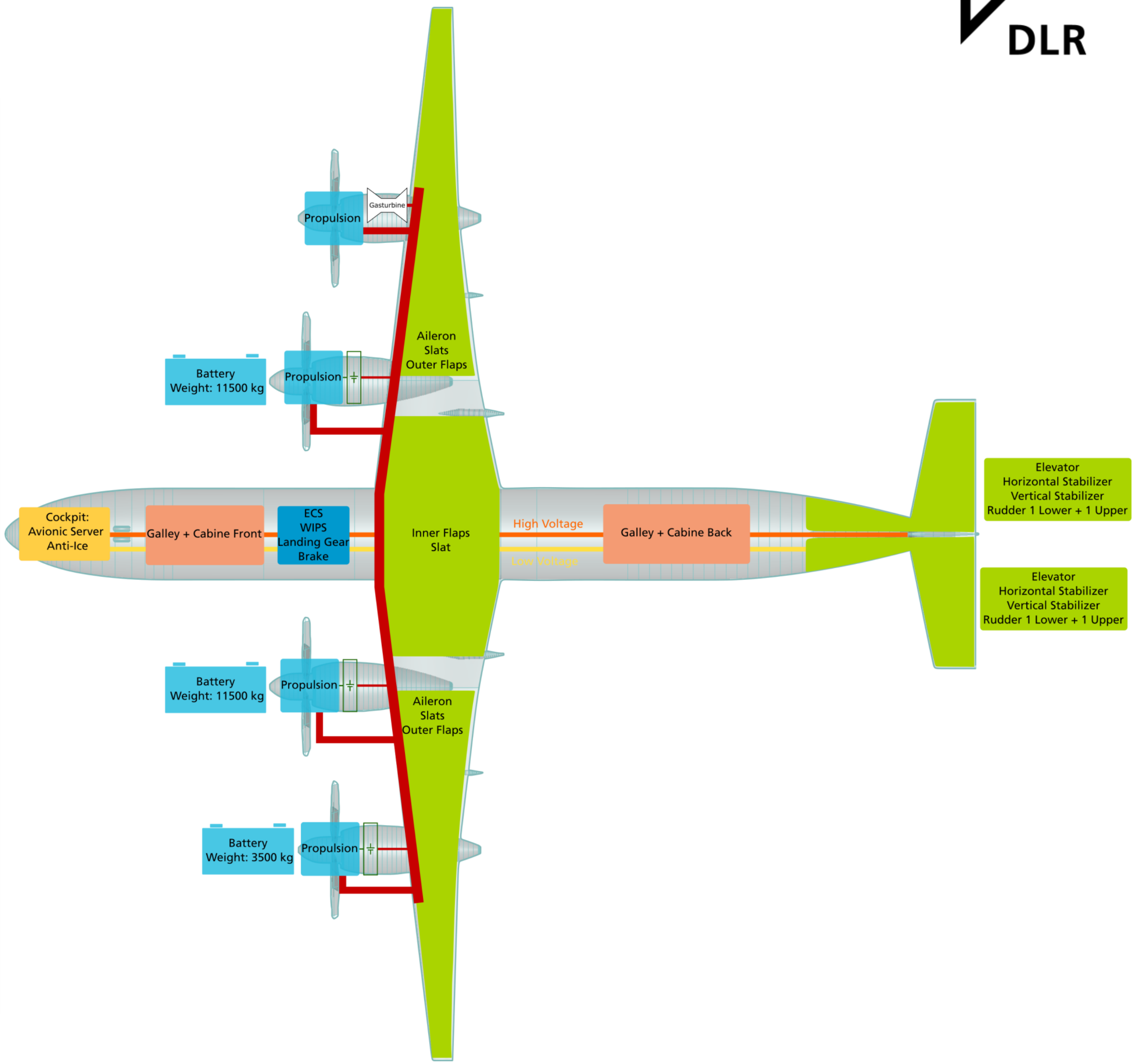


# All Electric Aircraft – Conventional Grid Architecture



# All Electric Aircraft - Conventional Approach: Connected Grid

- \+ Failure of one engine: available battery capacity is used to operate and overpower functional e-machines → availability
- \+ Failure of a single battery pack has little effect on the system
- \+ Batteries are placed in the narcelles: the fire load is separated from the remaining aircraft in case of a thermal runaway
- – Fault currents and line faults affect the entire system to some extent: complex protective mechanisms, bulky circuit breakers
- – Galvanic isolation is required at several points → heavy transformers, less efficiency
- – High voltage DC disconnection: risk of arcs is very high
- – Many components connected in parallel: high fault discharge currents



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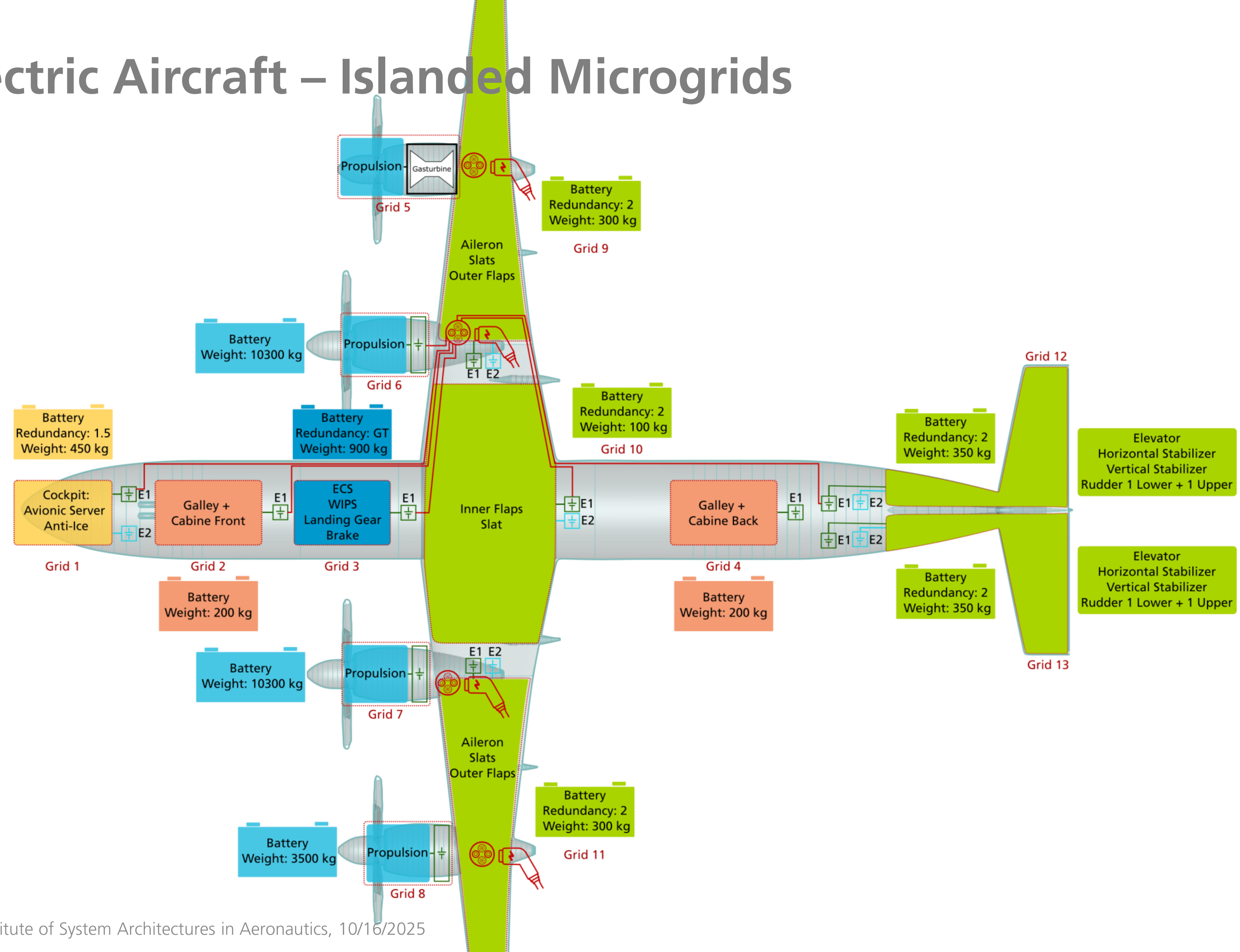
**Disruptive Approach**

# All Electric Aircraft – Islanded Microgrids





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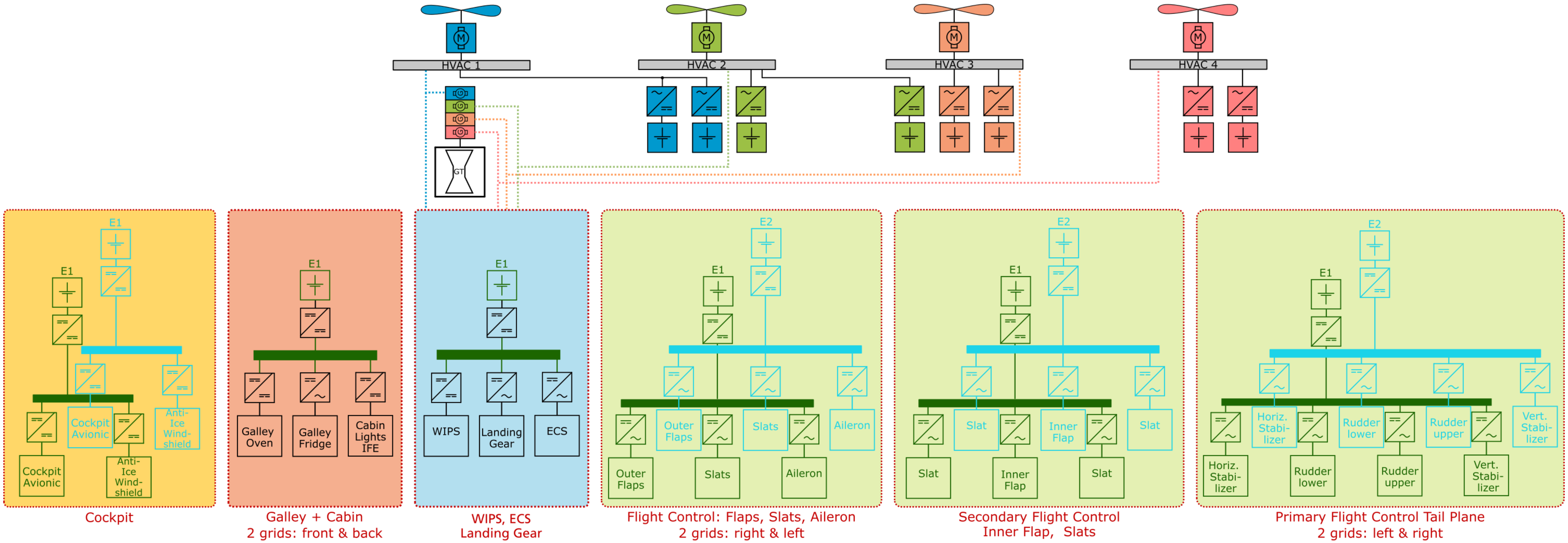
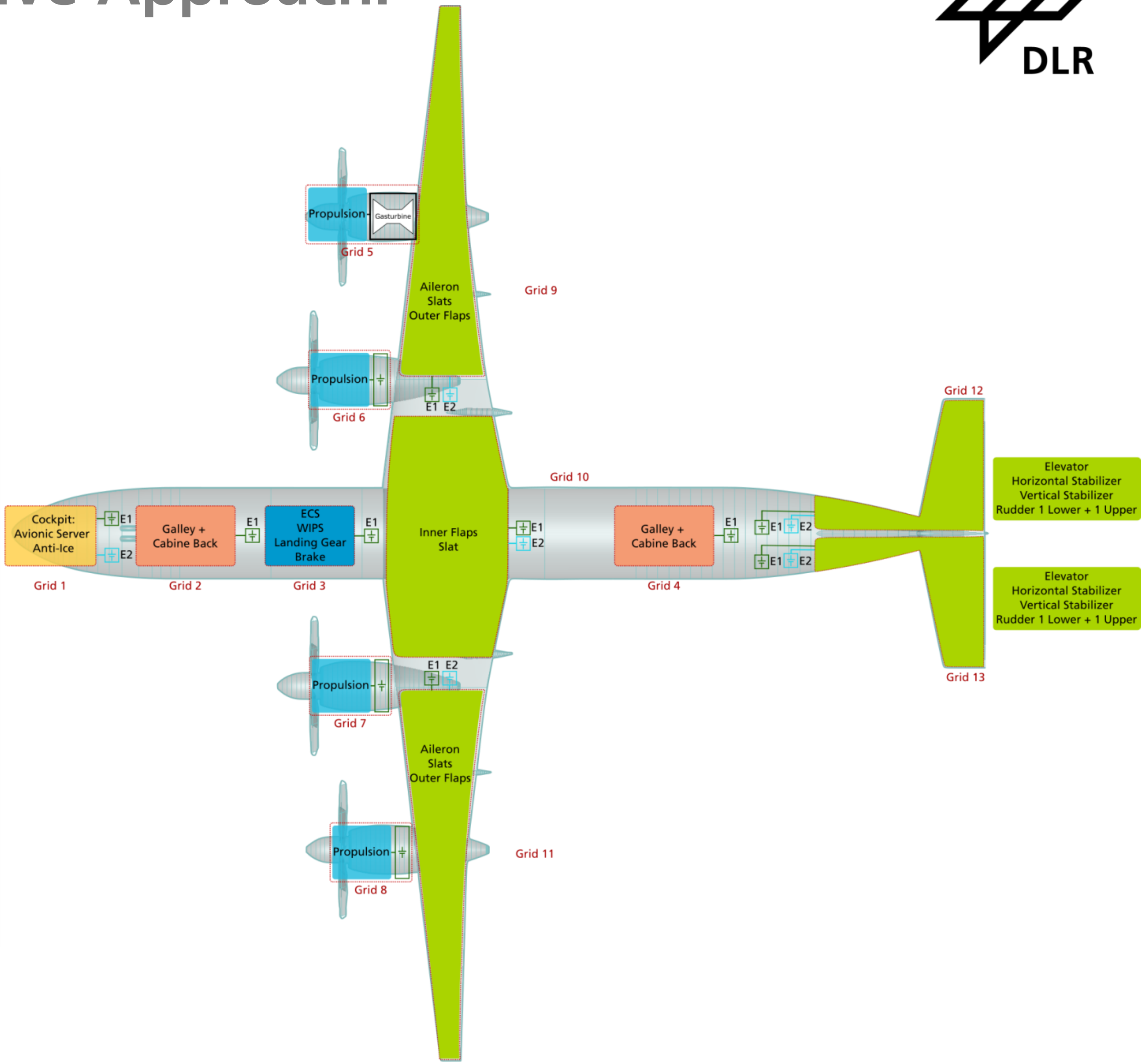
# All Electric Aircraft – Islanded Microgrids



# All Electric Aircraft - Disruptive Approach: Islanded Grid

- \+ Batteries isolated from each other → improved fail-safety
- \+ Fault current amplitude is lower → fewer components connected in parallel
- \+ Less galvanic isolation required
- \+ Shorter cable lengths, improved EMC → less complex filters
- \+ Separation of safety-relevant and non-safety-relevant grids
- \+ Decreased total weight: increased battery weight, but decreased cable weight
- \+ Severity and impact of faults, e.g. single line faults is reduced → increases availability
- – Batteries are distributed throughout the aircraft
- – Failure of one engine → battery capacity can **not** be used → charging lines?



# Method of Procedure

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**Conventional Approach: Connected Grid**

Focus on **new** aircraft configuration and the **technical innovations** and associated advantages for the system level

↓

**Disruptive Approach: Islanded Microgrids**

# Method of Procedure

Analyze the **state of the art** and **map** it to the selected aircraft configuration

**Conventional Approach: Connected Grid**

Focus on **new** aircraft configuration and the **technical innovations** and associated advantages for the system level

**Disruptive Approach: Islanded Microgrids**

Compare the **advantages** of the **conventional approach** with the **disadvantages** of the **disruptive approach** and derive a **hybrid** of both approaches.

**Hybrid Approach**

# Features Hybrid Approach

The objective is a grid architecture that offers these advantages additionally

- \+ Failure of one engine: available battery capacity is used to operate and overpower functional e-machines → availability
- \+ Failure of a single battery pack has little effect on the system
- \+ Batteries are placed in the narcelles: the fire load is separated from the remaining aircraft in case of a thermal runaway

while overcoming the following disadvantages

- – Batteries are distributed throughout the aircraft
- – Failure of one engine → battery capacity can **not** be used


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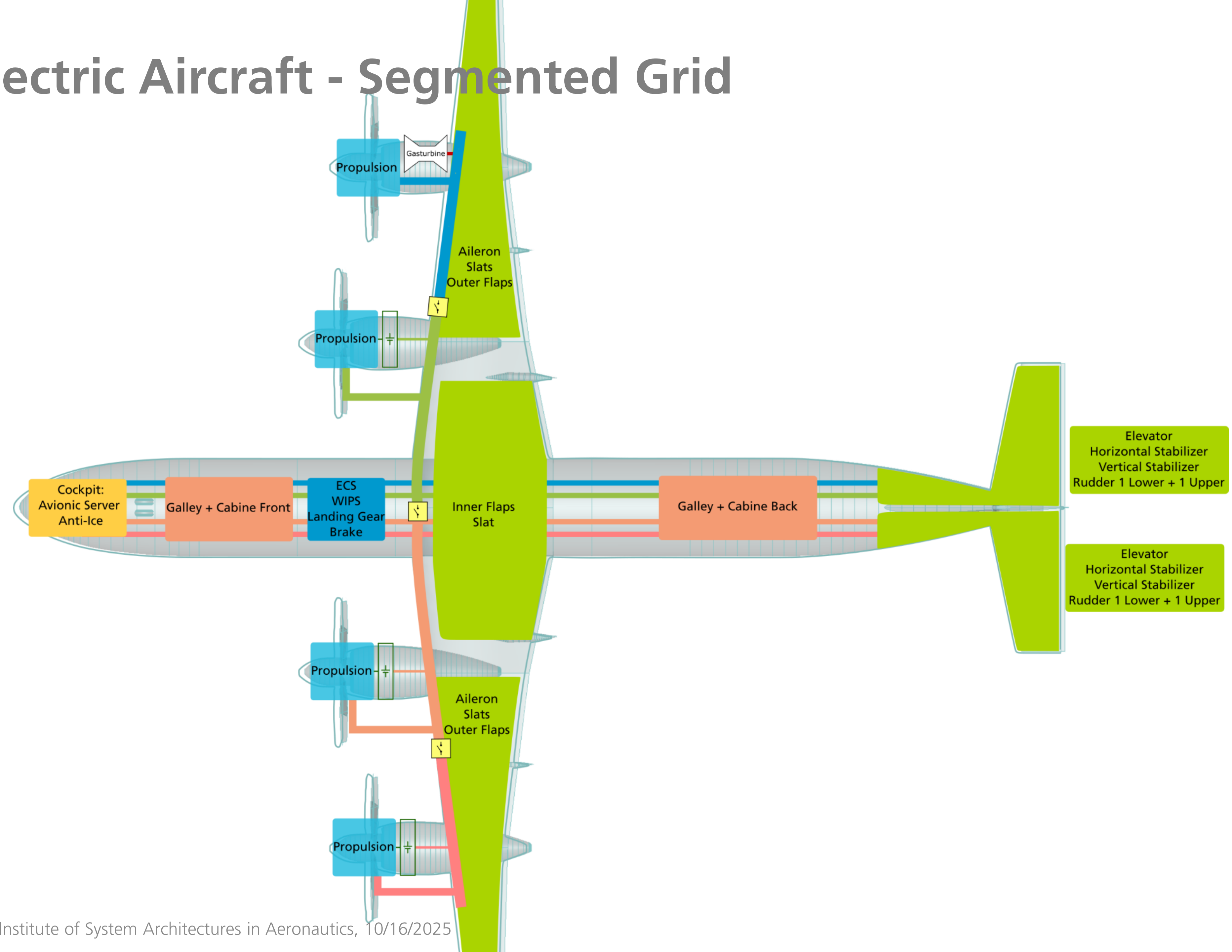
# All Electric Aircraft - Segmented Grid



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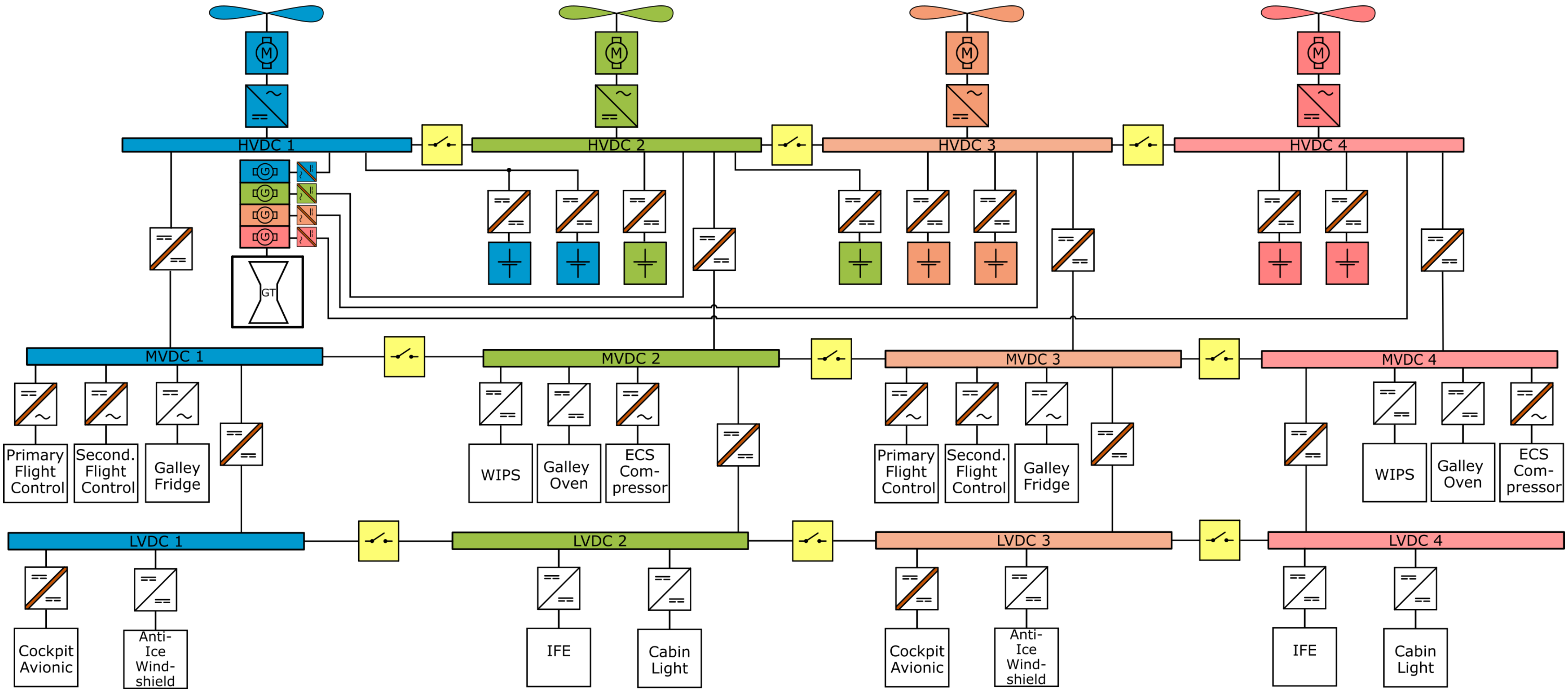
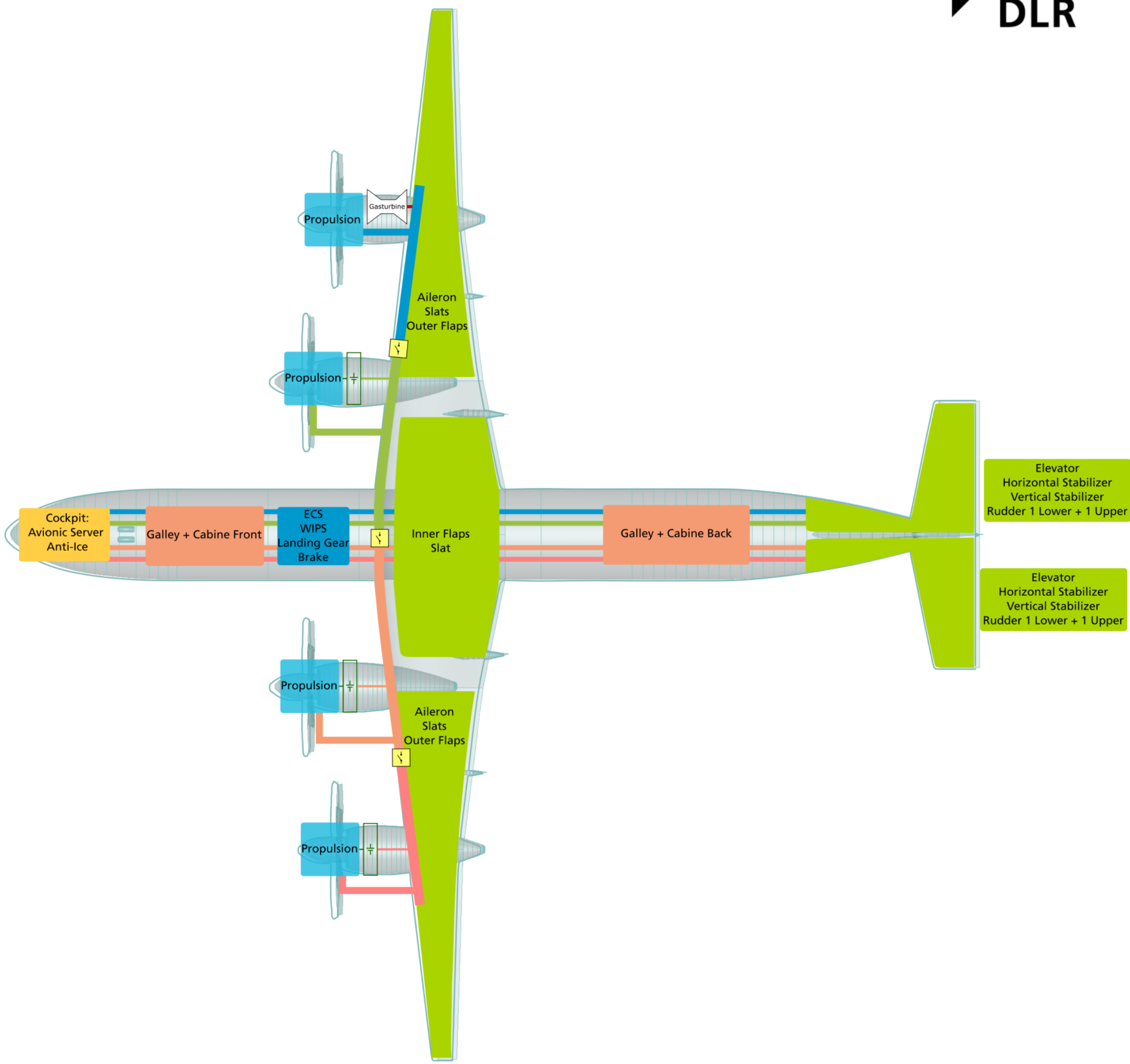


# All Electric Aircraft - Hybrid Approach: Segmented Grid

- \+ Failure of one engine: available battery capacity is used to operate and overpower functional e-machines → availability
- \+ Failure of a single battery pack has little effect on the system
- \+ Batteries are placed in the narcelles: the fire load is separated from the remaining aircraft in case of a thermal runaway
- \+ Batteries isolated from each other → improved fail-safety
- \+ Severity and impact of faults, e.g. single line faults is reduced → increases availability
- \+ High voltage DC connection → minor risk
- \+ Less components connected in parallel: lower fault discharge currents
- \+ Two different energy sources
- – Fault currents and line faults only affect the sub-system
- – Galvanic isolation is required at several points → heavy transformers, less efficiency
- – No separation of critical and non-critical grids



# Conclusion

Analyze the **state of the art** and **map** it to the selected aircraft configuration

→ **Conventional Approach: Connected Grid**

Focus on **new** aircraft configuration and the **technical innovations** and associated advantages for the system level

→ **Disruptive Approach: Islanded Microgrids**

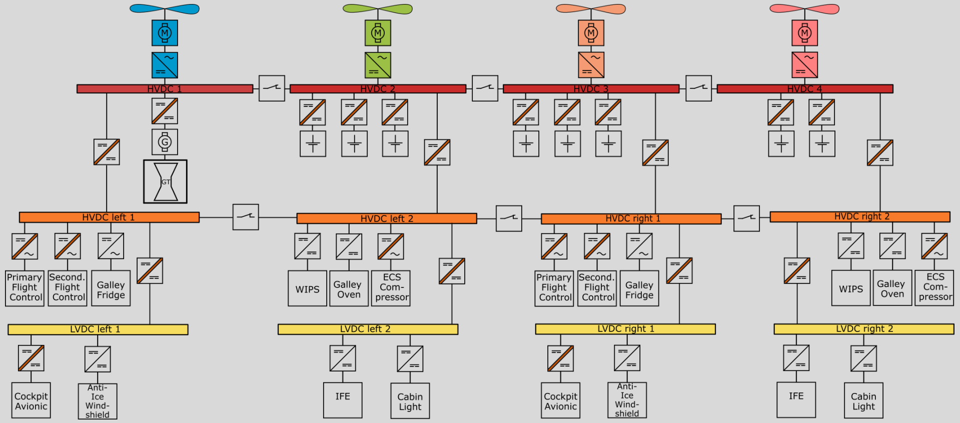
Compare the **advantages** of the **conventional approach** with the **disadvantages** of the **disruptive approach** and derive a **hybrid** of both approaches.

→ **Hybrid Approach: Segmented Grid**

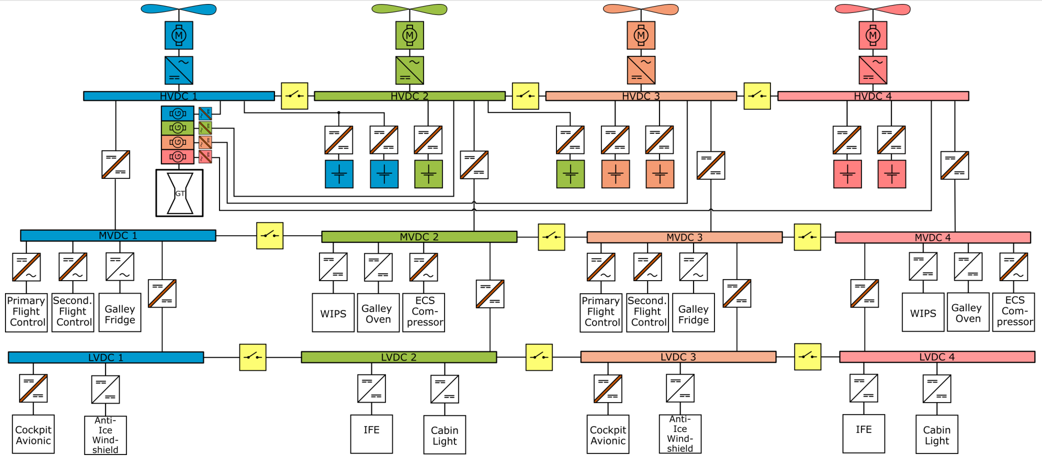
Preliminary design: basic models for weight study following electric simulation

# ALL ELECTRIC AIRCRAFT ELECTRICAL SYSTEM ARCHITECTURES

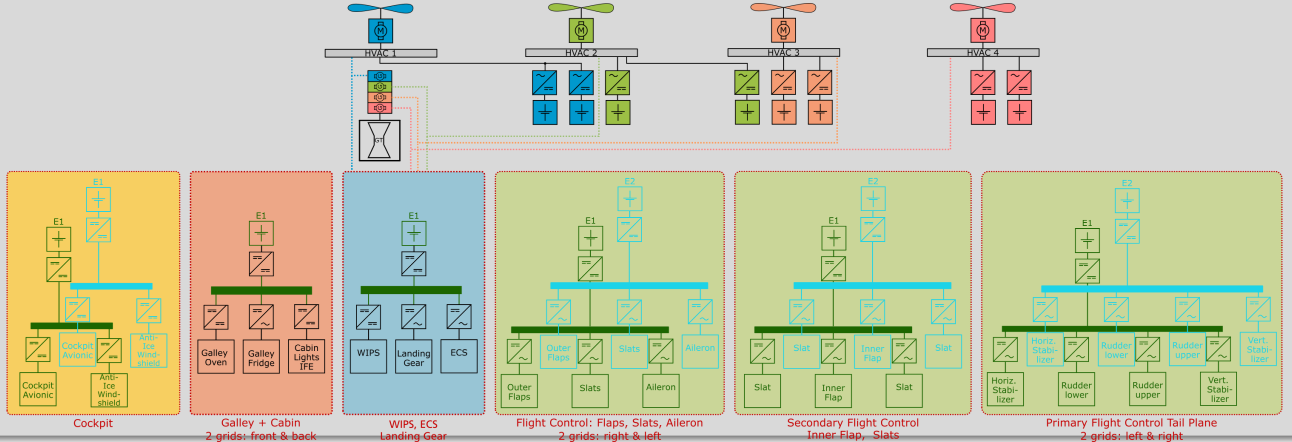
**Conservative Approach: Connected Grid**
The grid is subdivided into a left and a right sub-grid corresponding to the feeding generators. In some configurations, there is also a mandatory grid that is connected to both, the left and the right generators. The sub-grids are connected to each other during normal operation and can be separated in the event of a fault using corresponding circuit breakers.




**Hybrid Approach: Segemented Grids**
The segmented grid is a mixture of the conventional grid approach and the islanded microgrids. In normal operation, the electrical subgrids are divided depending on their supplying battery pack. If a fault occurs, the grids can be reconfigured and individual or all loads of a grid can be connected to another grid.




**Disruptive approach: Islanded Grids**
The electrical system is divided into several subgrids that are electrically isolated from each other. These subgrids are never connected to each other, neither in normal operation nor during charging. Subgrids that contain safety-critical components are designed redundantly. Both the batteries and the electrical lines are implemented multiple times. In the event of a fault, individual subgrids can be connected to each other via the charging lines.



## 1. . ALL ELECTRIC AIRCARFT ELECTRICAL SYSTEM

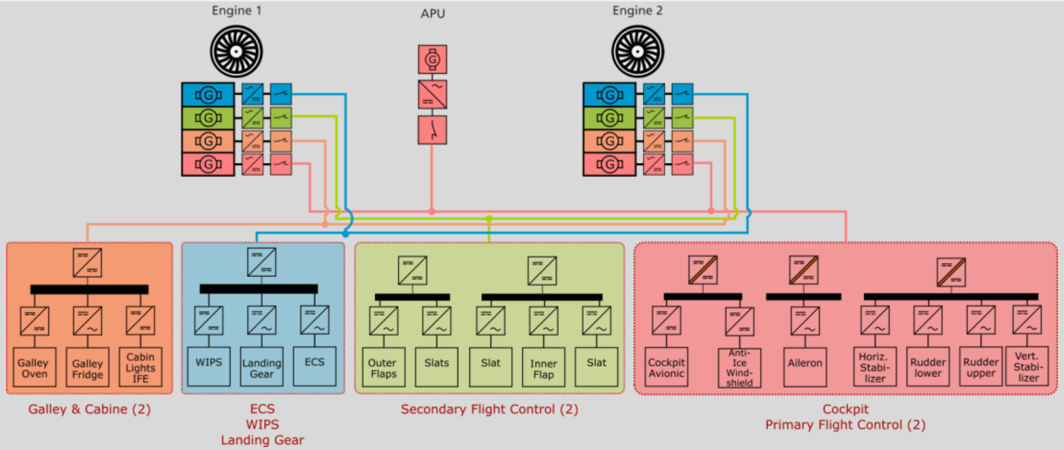
## 2. MORE ELECTRIC AIRCARFT ELECTRICAL SYSTEM

## 3. PROPULSION SYSTEM ARCHITECTURE

# MORE ELECTRIC AIRCRAFT ELECTRICAL SYSTEM ARCHITECTURES

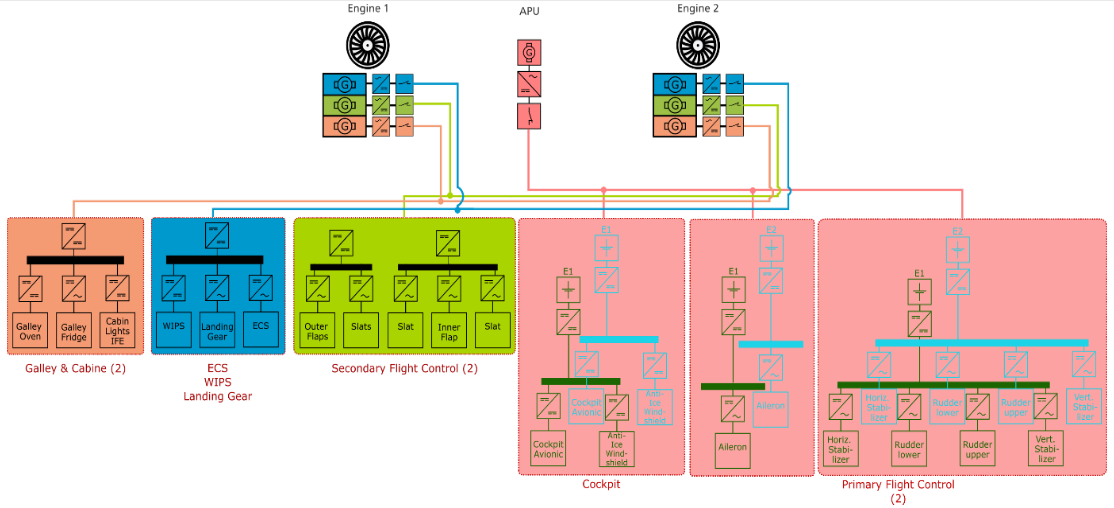
**Conservative Approach: Four Separated Grids**

Four stacked generators with the same power rating are used instead of the previous two generators. The generator for the galley and cabin can be used to supply the more safety-relevant grid if one of the other generators fails. Additionally, the safety-relevant grid (cockpit and primary flight control) can also be supplied by the APU.



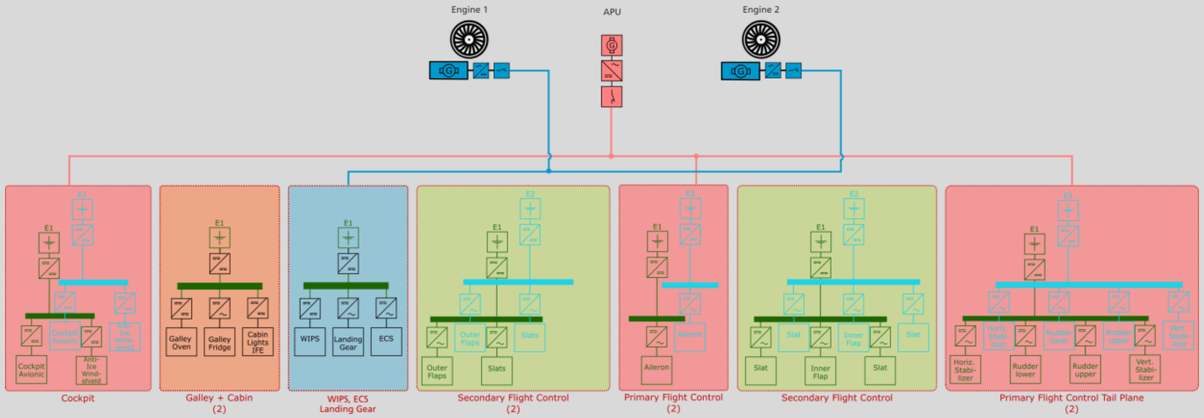

**Hybrid approach: Separation between Safety-critical Systems and Propulsion**

This approach completely separates the safety-critical grid (primary flight control and cockpit avionics) from the propulsion system, whereby batteries are used to ensure the supply of these grids. In order to improve the reliability, the APU is connected to these systems and two separate battery-supplied DC busses are available.




**Disruptive approach: Islanded Grids**

The on-board system is divided into disconnected islanded grids, which in turn have at least one DC bus with a supplying battery pack. In safety-relevant grids, the DC grids with battery packs are designed redundantly. Only the grid with the environmental control system is fed by a comparatively small (lower power rating) generator. The APU can also supply the safety-relevant grids in the event of a fault.



## Key Take-Away-Messages

- In the context of aircraft electrification, **reliability**, **fail-safety**, and **availability** of the electrical system represent essential requirements on top of system **weight** and **volume**.
- **System architecture** influences not only **weight** and **volume**, but also **fault-behavior**, **reliability** and **availability**.

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