# Systematic Approach to Design an Active Hybrid Laminar Flow Control System

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# Agenda

- Motivation
- System Design
  - Preliminary Design
  - Aviation Design Process and MBSE
  - Aircraft Level Requirements
  - Functional Analysis
  - Refined System Architecture
  - Design Solution
- Conclusion

# Motivation

- Hybrid Laminar Flow Control (HLFC) sucks air from airfoil
  - Reduction of drag
  - Decreasing emissions and block fuel
- Technology improved through several research projects
- Major constraints:
  - High cost
  - Suction system too complex and heavy
  - Space constraints on the wing’s leading edge
- Clean Sky 2 investigates Horizontal Tailplane (HTP) and wing
  - Compatibility to industrial processes
  - Enable an economic operation in airline environment
  - Design of a certifiable overall solution
- Goal: Design of a safe and certifiable HLFC system for commercial use

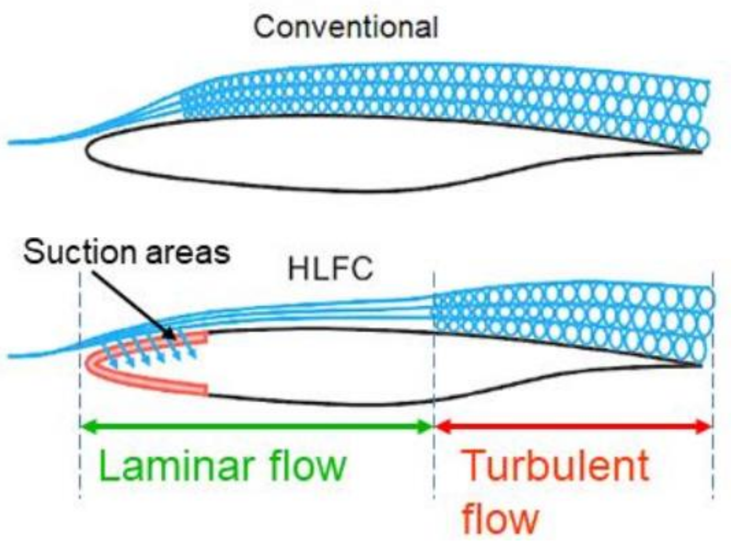



**Image adapted from K.S.G. Krishnan**

# Preliminary Design

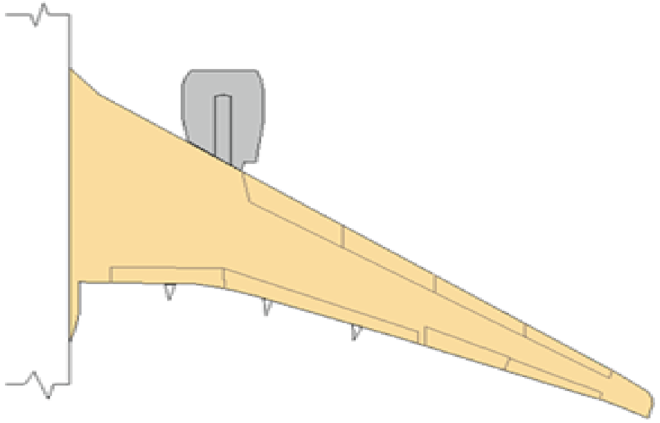
**Aerodynamics**
- Mass flow
- Pressure distribution

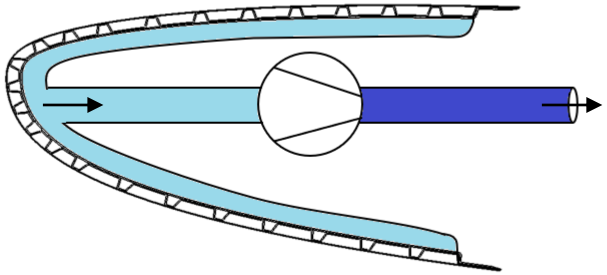
**Structure**
- Preliminary space estimations

**Systems**
- Various system architectures

**Handbook Methods**

**Concept Evaluation**
- Compressor performance
- System weight and size estimate

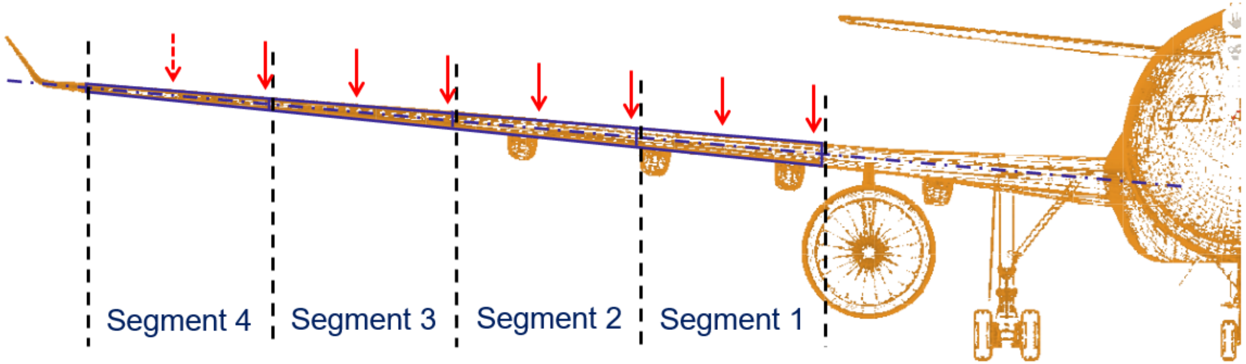




# Preliminary Design

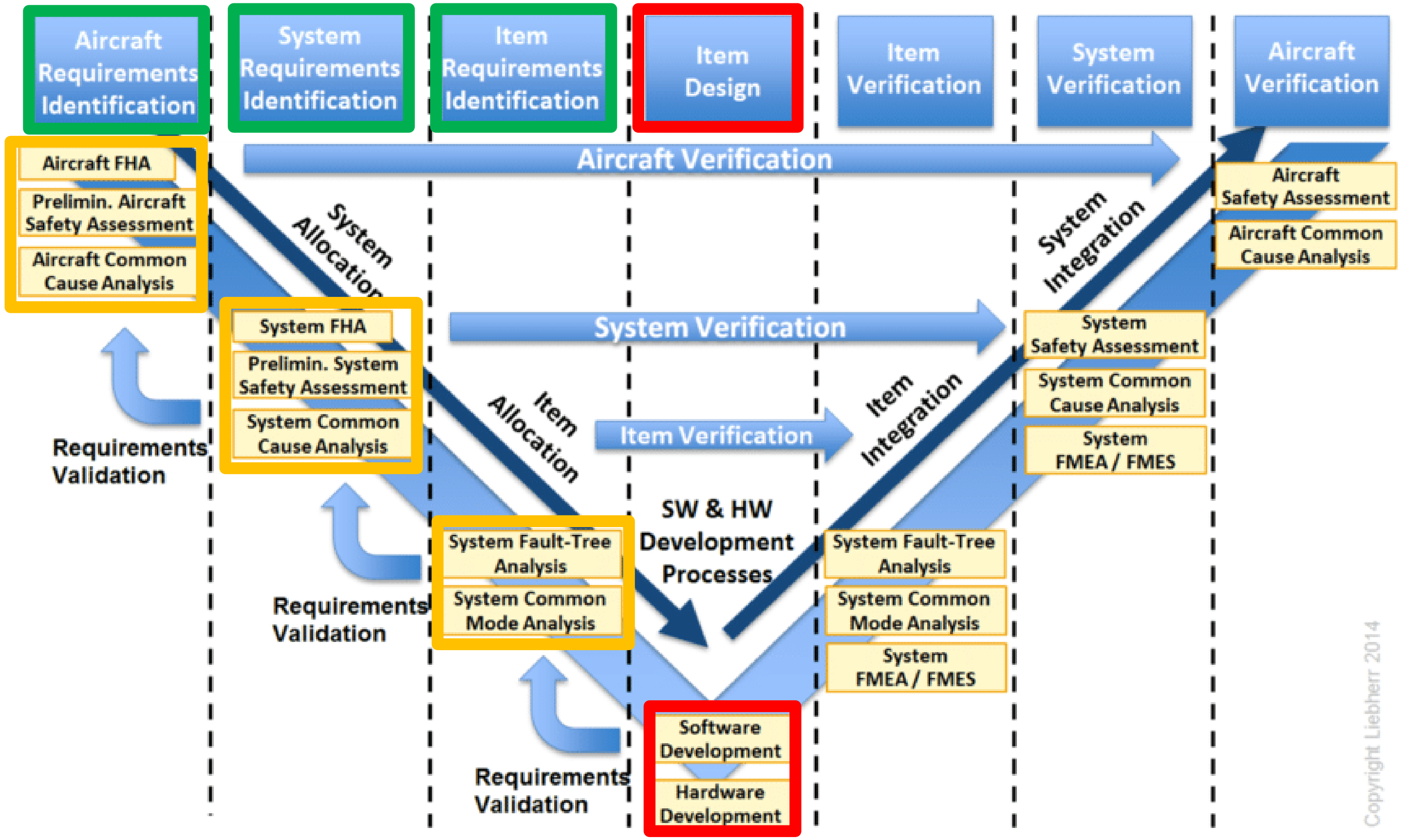
- Winning concept: Separate suction applied on each segment
  - Seven compressors distributed along span, each driven by own inverter
- Open challenges:
  - Transfer preliminary design to real components
  - Ensure system would meet certification process
  - Maintain low system complexity, weight and cost
- Approach: Undergo design process utilizing Model-Based Systems Engineering (MBSE)

| Architectures | Criteria | | |
|---|---|---|---|
| | Mass (kg) | Power Off Takes – POT (kW) | Integration feasibility (Spatial constraints) |
| Concept 1 (Baseline) | 190 | 110 | ☑ |
| Concept 2 | 300 - 360 kg (modular) | 100 | ☑ |
| Concept 3A | 280 | 106 | X |
| Concept 3B | 280 | 106 | ☑ |
| Concept 3C | 240 | 102 | ☑ |
| Concept 4 | 272 | 114 | ☑ |
| Concept 5 | 270 | 108 | Unknown |
| Concept 6 | 310 | 108 | Unknown |



# Aviation Design Process and MBSE

- Increasing use of MBSE for system design in aviation
- Several aspects already covered, though some points under investigation
- Traceable requirement derivation and validation currently largest benefit of MBSE




Already covered
Under investigation
Domain-specific tools

Source: Taibi, D. et al..: Towards a Classification Schema for Development Technologies: an Empirical Study in the Avionic Domain (2015)





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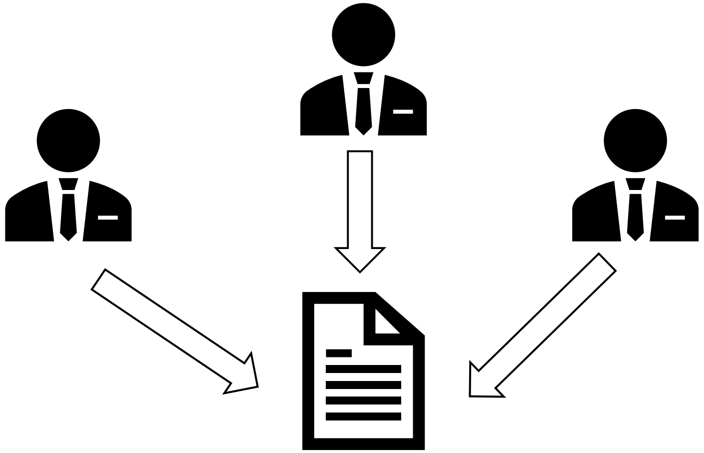
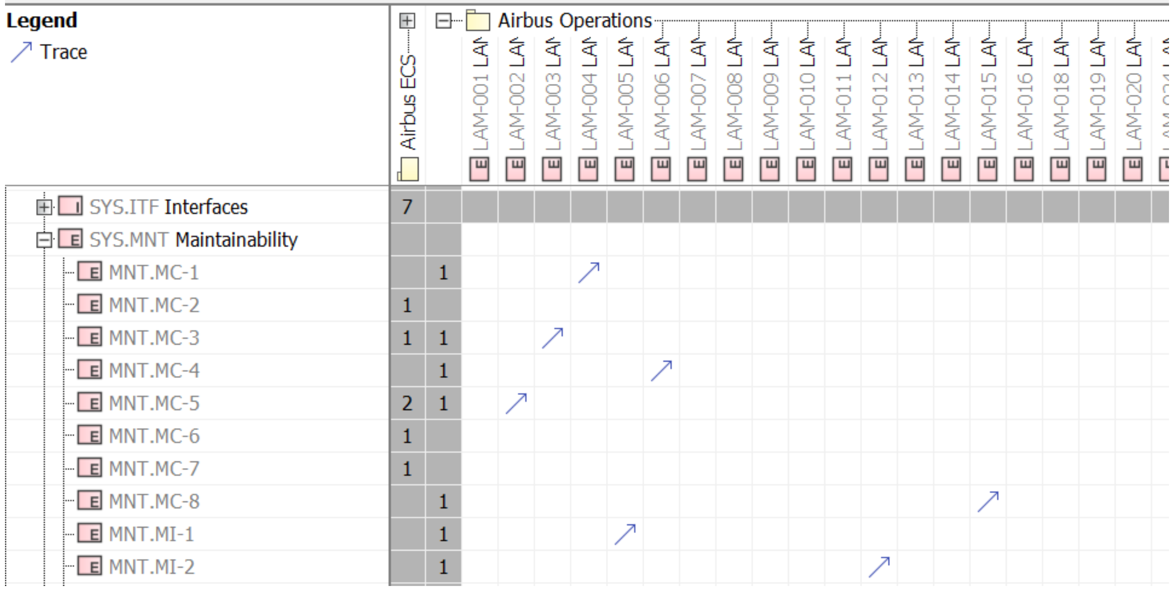
# Aircraft Level Requirements

- Several requirement documents initially created by different stakeholders
- Central reference requirement table created, tracing to original requirement implemented
- Basic requirements:
  - Operation between FL330 and FL410 during cruise
  - Fuel savings through HLFC shall not be considered for fuel planning
  - Modern aviation concepts shall be followed (Integrated Modular Avionics, More Electric Aircraft)



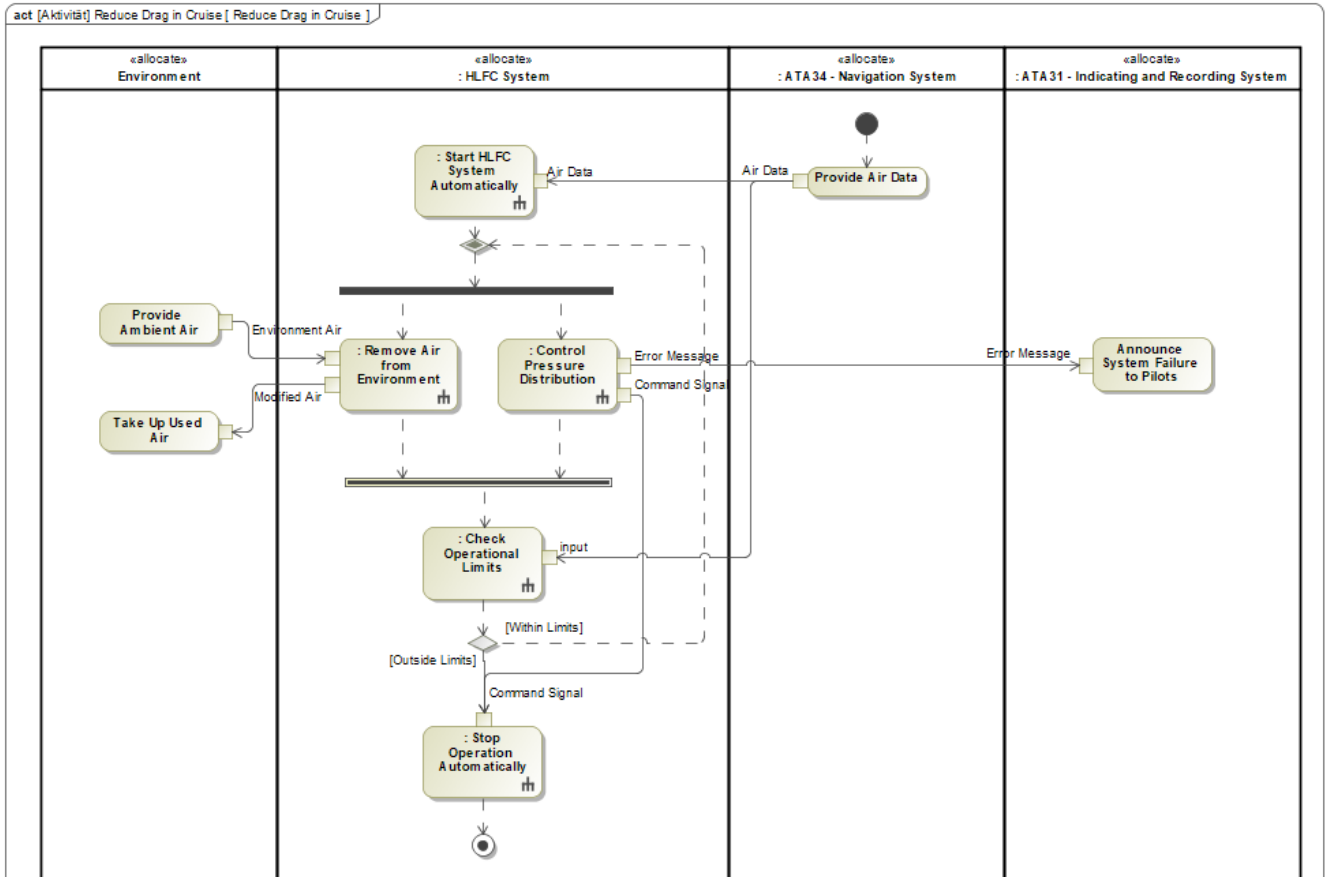


# Functional Analysis

- Breakdown of functions to be performed by the system, either by tree structure or activity diagrams
- Input for safety analysis, namely Functional Hazard Analysis (FHA)
- Initial definition of generic interfaces is applied

Aircraft Level

System Level





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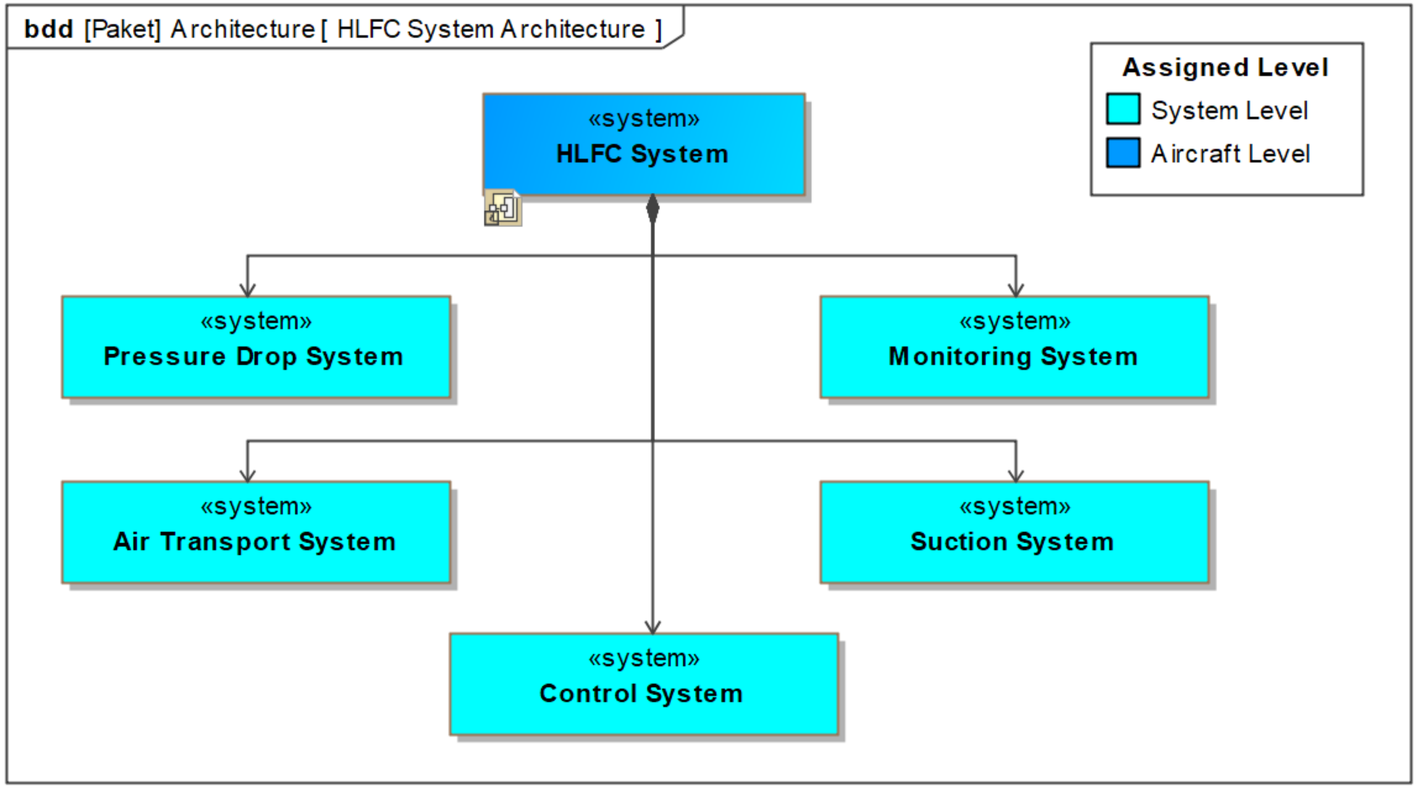
# Safety Analyses

- Previously defined functions classified for their criticality down to system level in case of:
  - Total loss, partial loss (either symmetric or asymmetric) or degradation of function
  - Inadvertent or incorrect operation
  - Unable to stop function
- Critical hazards investigated through Fault Tree Analysis (FTA)
  - Refinement of system architecture
  - Safety requirement development and validation
- Main findings:
  - Compressor malfunction must be identified by redundant sensors
  - Communication with the control computer must be redundant
  - Emergency shut-off must be possible
- Risk Analysis and Assessment Modeling Language (RAAML) provides first implementation of safety analyses

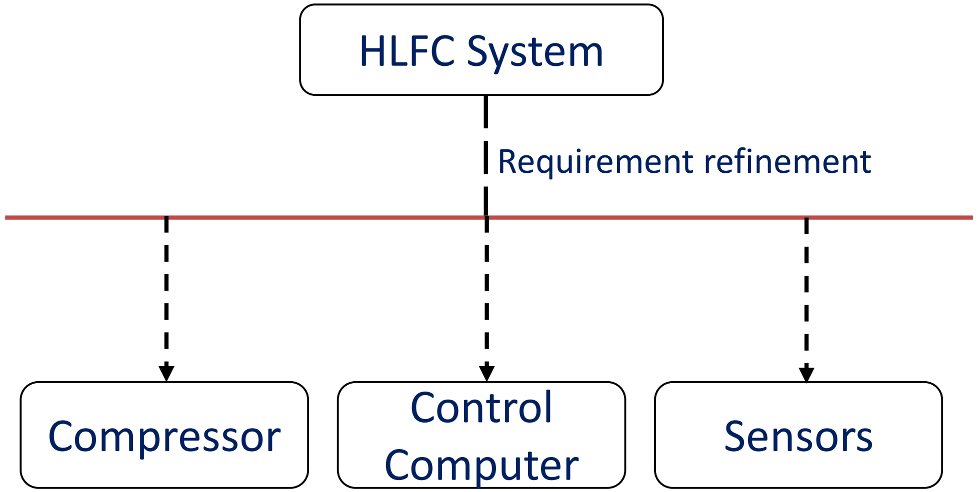
# Refined System Architecture

- Output from previous steps:
  - Generic and safe system architecture including interfaces as well as crucial redundancies
  - Set of requirements down to item level, defined in tables
  - Iterative process until actual design can be started



# Refined System Architecture

- Aircraft Level/Stakeholder Needs:
  - “Applicable certification standards shall be met.”
  - “The drag shall be reduced by means of suction.”
  - “The system shall be compatible to a More Electric Aicraft.”
- Item Level:
  - Wiring separation and design according to standard
  - Equipment classification as per DO-160G
  - Required component Mean Time Between Failure (MTBF)
  - Compressor mass flow and pressure ratio requirements
  - Use of an electric compressor supplied by 28 VDC and 270 VDC
- Requirements can be traced throughout the different levels




| # | Name | Text | Derived From |
|---|---|---|---|
| 1 | SYS HLFC System Requirem | | |
| 2 | SYS.ITF Interfaces | | |
| 3 | ITF.ES-1 | High voltage electric power (270 VDC) shall be supplied for the compressor(s). | ITF.ES Electrical Supply |
| 4 | ITF.ES-2 | 28 VDC electric power shall be supplied for sensors and the outlet actuator. | ITF.ES Electrical Supply |
| 5 | ITF.AC-2 | Air data shall be provided to the controls resources via the data network (AFDX). | ITF.AC Avionics Concept |
| 6 | ITF.AC-3 | System data shall be provided to the controls resources via the data network (AFDX). | ITF.AC Avionics Concept |





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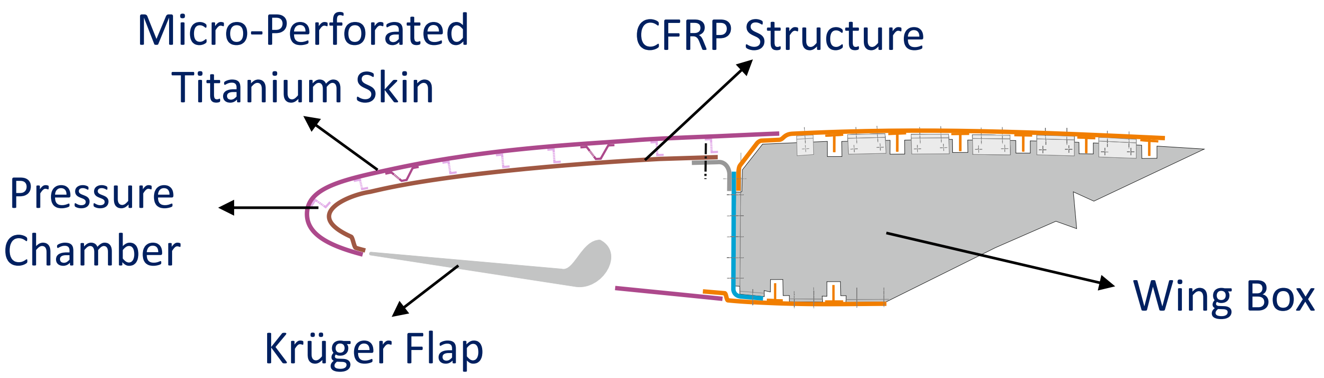
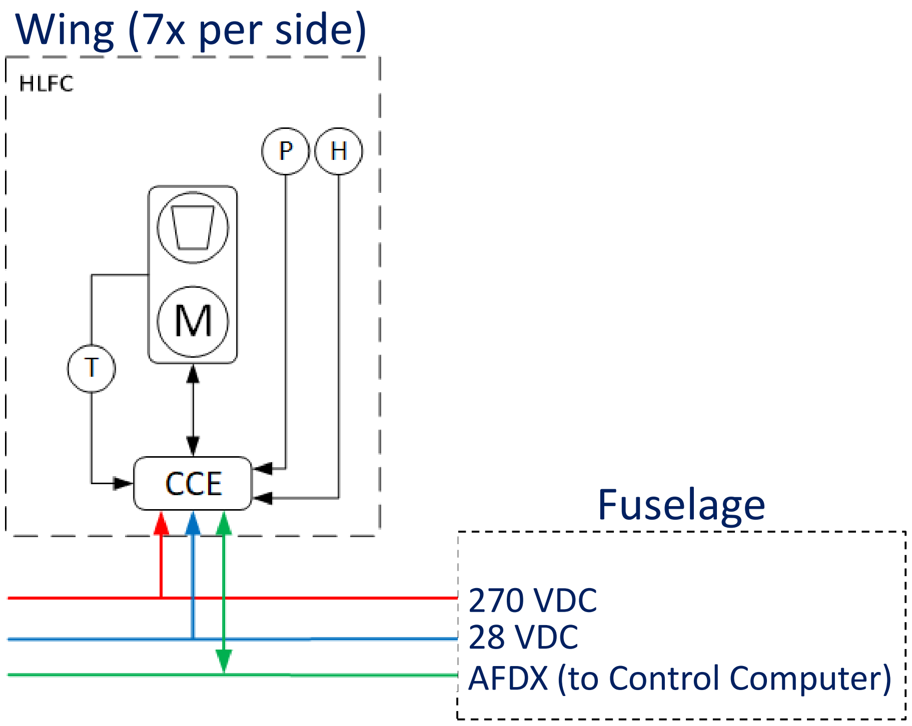
# Refined System Architecture

- Design based on defined requirements
- Specific design challenges:
  - Limited space in the wing's leading edge
  - Spatial conflict with other system (e.g. High Lift, Ice Protection)
  - Avoid use of pipes
  - Ensure easy access and replaceability of components
  - No commercially available components for the compressor
  - → Required power density too high and no liquid cooling feasible

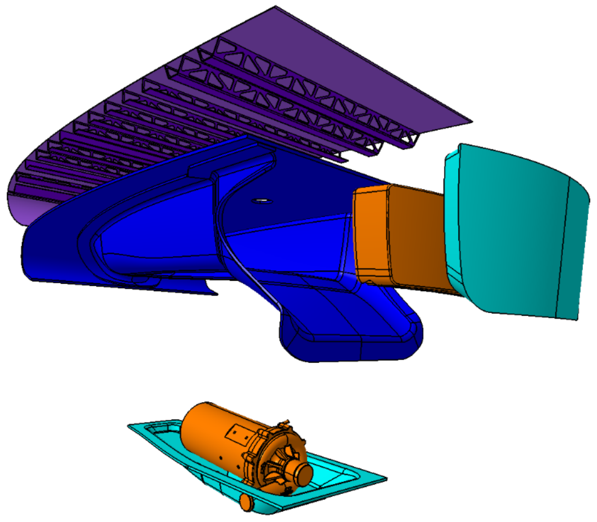


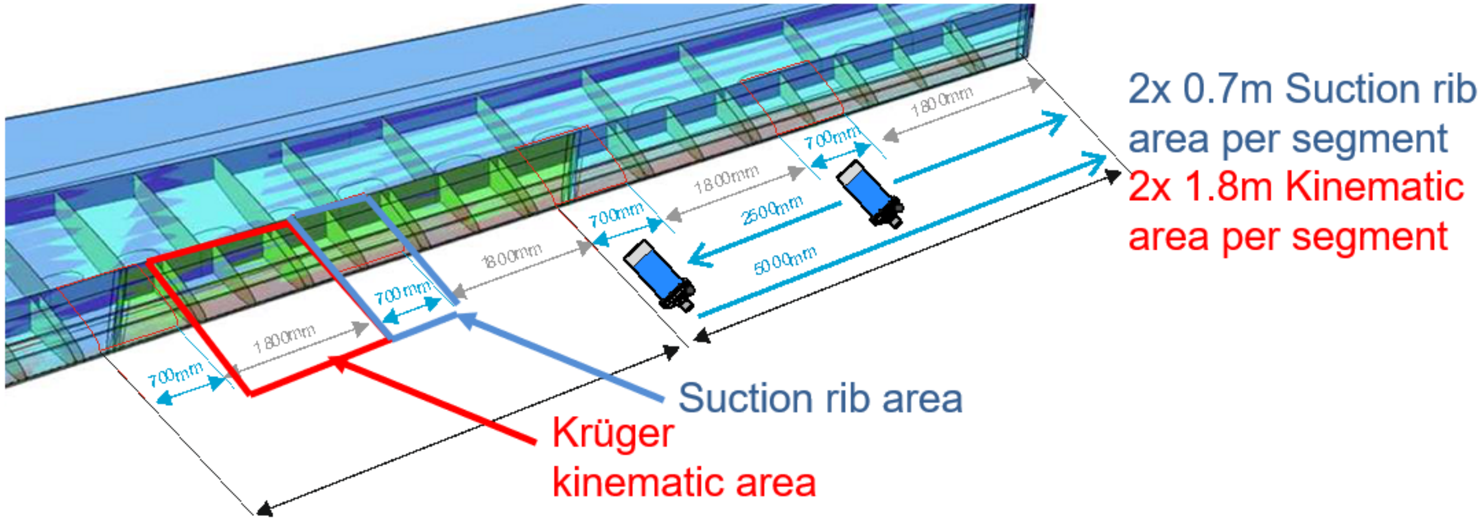



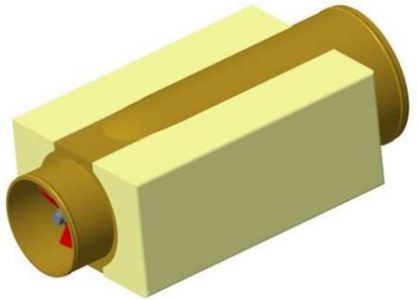

CCE – Compressor Control Electronic
AFDX – Avionics Full DupleX Switched Ethernet

# Design Solution

- Spatial conflict solved by dedicated areas for each system
- Multi-functional rib for as structure and suction element
  - No piping required
  - Easy access to components through maintenance flap
- Exchangeable titanium skin by fasteners
- Preliminary HLFC compressor designed by Safran
  - Compressor, sensors and inverter as one component
  - High efficiency at low mass and size

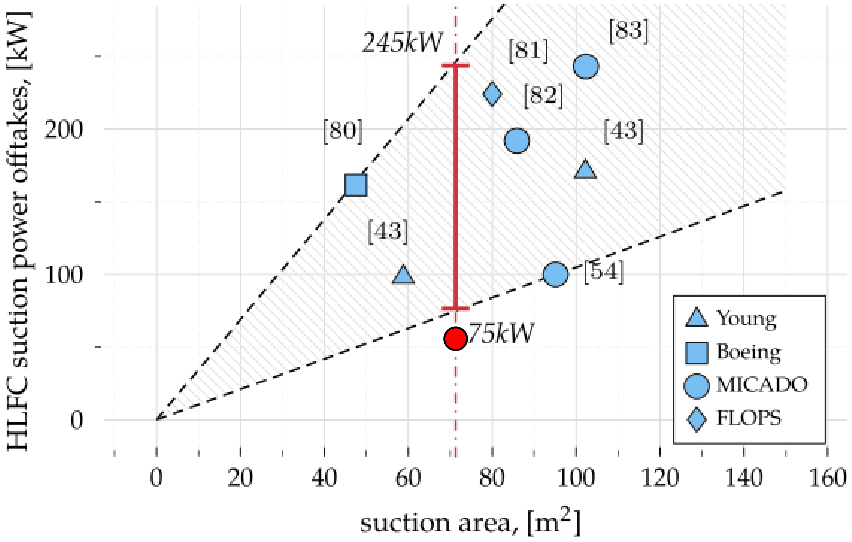


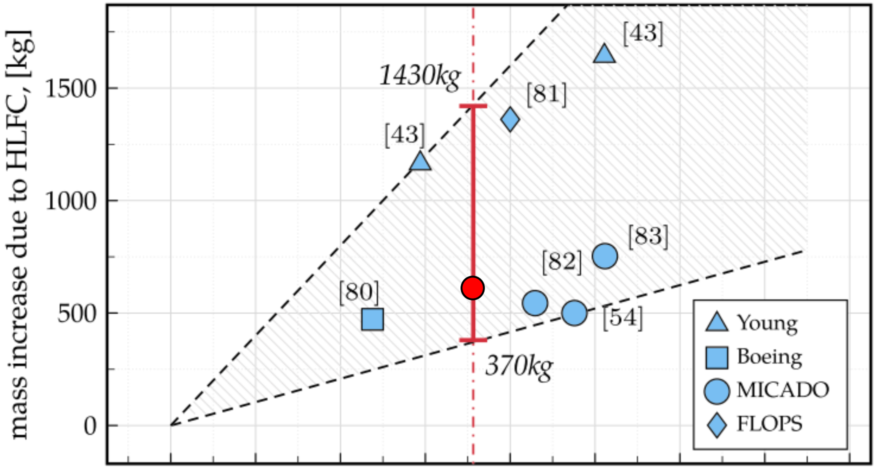


# Design Solution

- HLFC performance:
  - Suction power at design point (FL360): 60 kW (ca. 120 kW electrical power consumption of compressor)
  - Additional mass by HLFC compressor: 160 kg (14 compressors at 11.4 kg each)
  - No additional fluid cooling required
  - Power: 110 g/s at pressure ratio of 2.18




Source: Pohya, A.A.: Introducing variance-based global sensitivity analysis for uncertainty enabled operational and economic aircraft technology assessment (2022)





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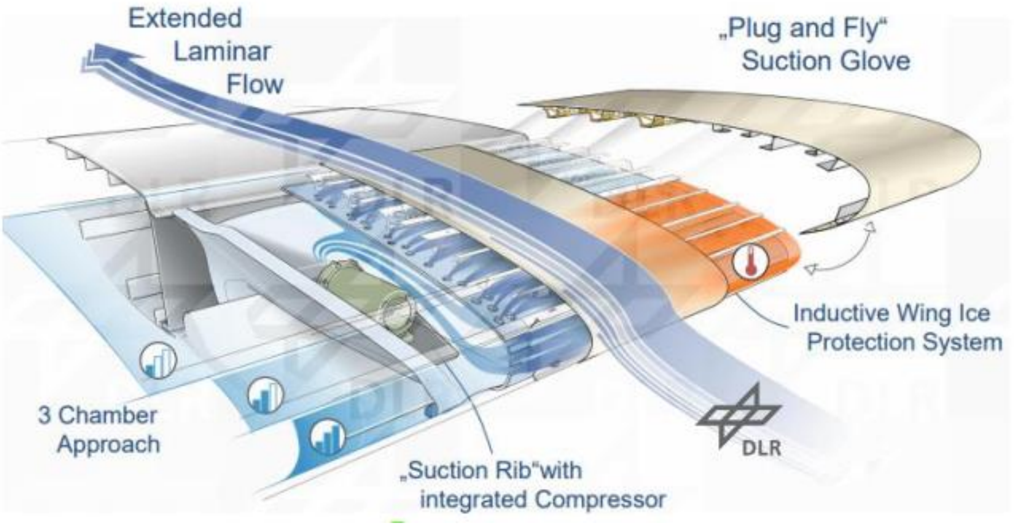
# Conclusion

- HLFC hold potential for reduction of block fuel and emissions
  - Yet, applications too complex and expensive for profitable operations
  - Tests rather focused on feasibility demonstration
- Preliminary architecture was defined, though detailed design missing
- Common design approach in aviation according to ARP4754A was applied supported by MBSE
- First design of HLFC on a wing completed:
  - Low weight increase and power off-take
  - Simple suction system without pipes
  - Components easily accessible and replaceable
  - High MTBF expected
- Next steps:
  - Develop and validate system simulation in MBSE model
  - Integrate overall solution in ground-based demonstrator



# Thank you for your attention!

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