Fuel Cells in Aeronautical Applications
Need of dedicated Balance of Plant

Dr F. Boudjemaa

SAFRAN / MICTROTURBO

Workshop on aeronautical applications of fuel cells and hydrogen technologies - 15th & 16th September 2015

AGENDA

- Aircraft requirement for Fuel Cell System certification
- Operational conditions impact Fuel Cell System design
- Fuel Cell and Aircraft Specificities
- Application impacts Fuel Cell System design
- An example : Fuel Cell Emergency Power Unit
- SAFRAN answers
- Fuel Cell System Roadmap

AIRCRAFT REQUIREMENTS FOR FCS CERTIFICATION

V-type development life cycle

EASA CS25 "Certification specification for large airplane"

EUROCAE / RTCA ED14/DO-160G → Environmental Conditions and test Procedures for Airborne Equipment

ARP4754 → Guidelines For Development Of Civil Aircraft and Systems
ARP4761 → Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment

FCS certification

S/S PDR

SS CDR

FCS qualification

DO-178 → Software considerations in airborne systems and equipment certification
DO-254 → Design assurance guidance for airbone electronic hardware

PDR

S/S CDR

FCS component qualification

MIL-STD-704-F → Aircraft Electrical Power Characteristics
AIR-1168 → Aerothermodynamic Systems Engineering and Design
AIR-2000 → Aerospace Fluid System Standards

SAE INTERNATIONAL AIR 6464 / EUROCAE ED-219 "Hydrogen Fuel Cells Aircraft analysis Fuel cell Safety Guidelines"

S/S to be validate:
- **Stack**
- **thermal management S/S**
- **Reactive alimentation S/S**
- **C/C**
- **mechanical, electrical interfaces**

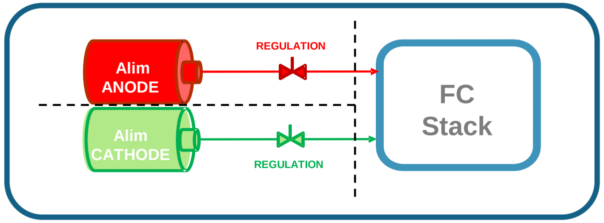
AIRCRAFT REQUIREMENTS FOR FCS CERTIFICATION

➔ Design for safety: "how making a safe O_2/H_2/e- system for aircraft?"

O_2 standard known for aeronautic → CS 25
H_2 standard to be found for H_2 storage sub-system. → SAE AIR 6464
→ EN 12245 (DOT-CFFC) targerted for HP H_2(O_2) bottles (High TRL)

Examples of guidelines
- Robust to single failure + uncontrolled fire on aircraft level is extremely improbable
- HP H_2/O_2 storages shall be treated similarly regarding safety analysis
- Bottle burst to be extremely improbable by combining qualification and design

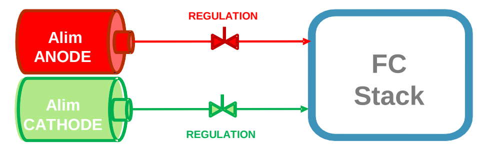
Examples of risk mitigation
- Energetic source segregation, FCS ventilation
- Fire resistance proofness (TPRD + venting line)
- Functions of control and security have to be separated



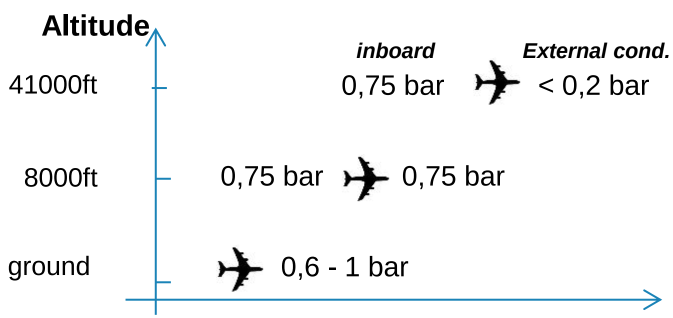
OPERATIONAL CONDITIONS IMPACT FCS DESIGN 1/2

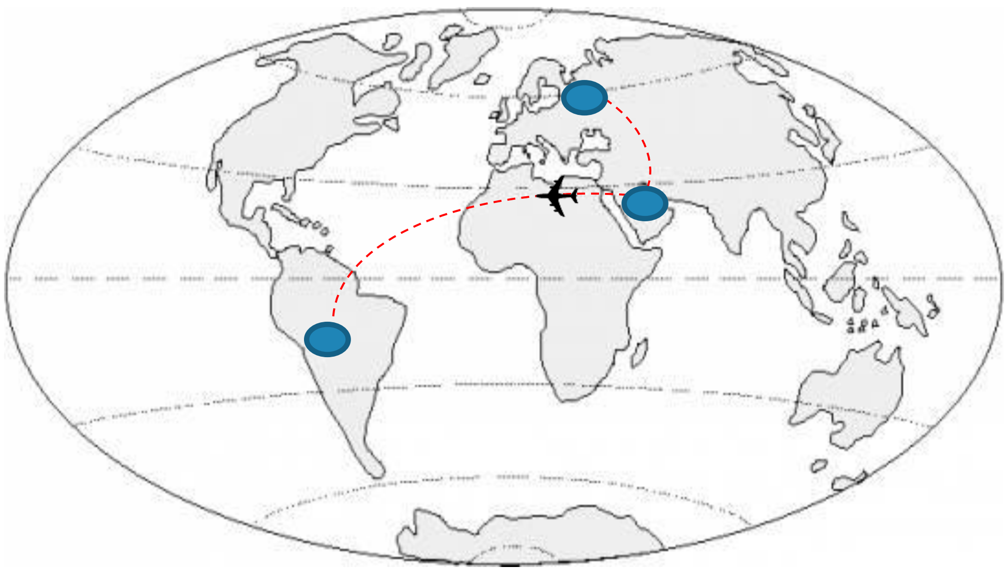
→ Operational conditions (DO-160)

- Mechanical solicitations (vibration, shocks)
  - Shock absorber : mechanical design compliance
- Thermal environment [-55°C ; +85°C]
  - Ground survival conditions
- Pressure [0.1 ; 1.088] bar abs
  - Ground conditions
  - On-board conditions



→ Impact on structure design, alimentation design of FCS and component (gas pressure regulator, air compressor, gasket and coolant)





OPERATIONAL CONDITIONS IMPACT FCS DESIGN 2/2

➔ Operational conditions (DO-160)

- Explosion proofness
  - Define a specific procedure for Hydrogen 
- Fire resistant
  - Define a specific procedure for Hydrogen 

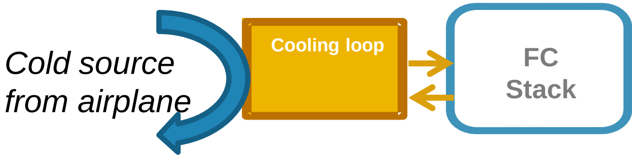
➔ Additional constraints

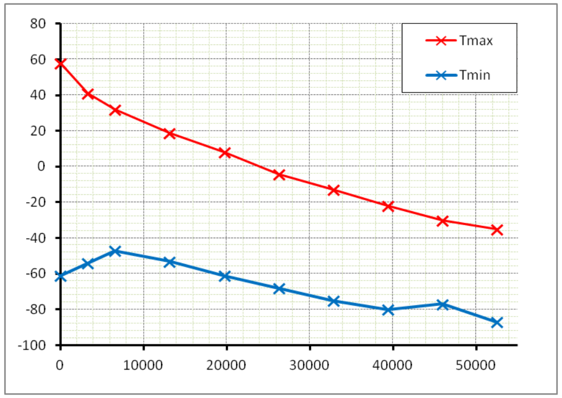
- Confined space
  - Very low leakage allowable
  - Integration of an emergency purge for Hydrogen 

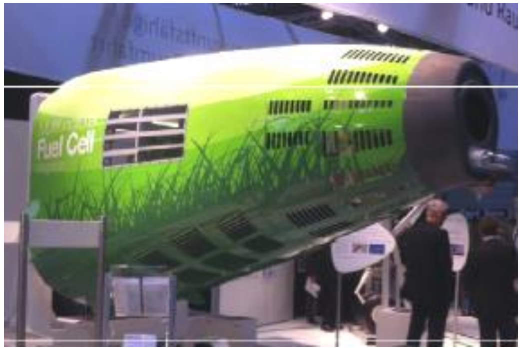
FUEL CELL & AIRCRAFT SPECIFICITIES 1/3

Fuel cell system location onto an aircraft

- Thermal management
  - Waste heat from depleted-air and cooling loop
  - Thermal power to evacuate depends on FCS electric performance (stack design) & operational condition (H2 purity, temperature, pressure)
  - Design of cooling loop
    - Air cabin: limitation by ECS
    - Exterior air: external temperature variation with altitude, no control of air flow rate
    - Specific Equipment: power regulation depends on mission profile
  - Specific exchanger design vs localization
  - /!\ Compatibility coolant vs operational temperature





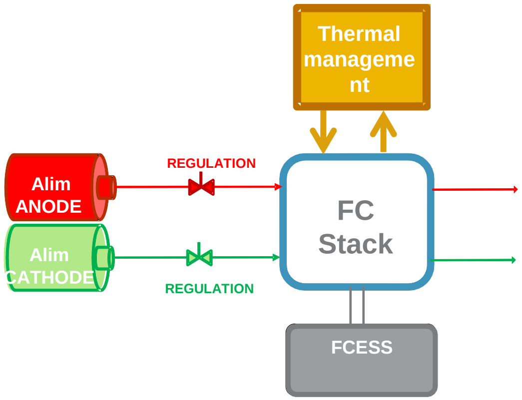


Airbus A320 Fuel Cell-Demonstrator

FUEL CELL & AIRCRAFT SPECIFICITIES 2/3

Fuel cell system location onto an aircraft

- **The localization of FCS on airplane would be mainly influenced by the relative proximity between FC hardware and public**
- **Different options :**
  - FCS near to the load
  - FCS in tail cone
  - FCS in fairing
- **The issues that influence the choice**
  - Availability space
  - Safety
  - Tubing, wire mass & volume
  - Rejection of waste
  - FC waste heat



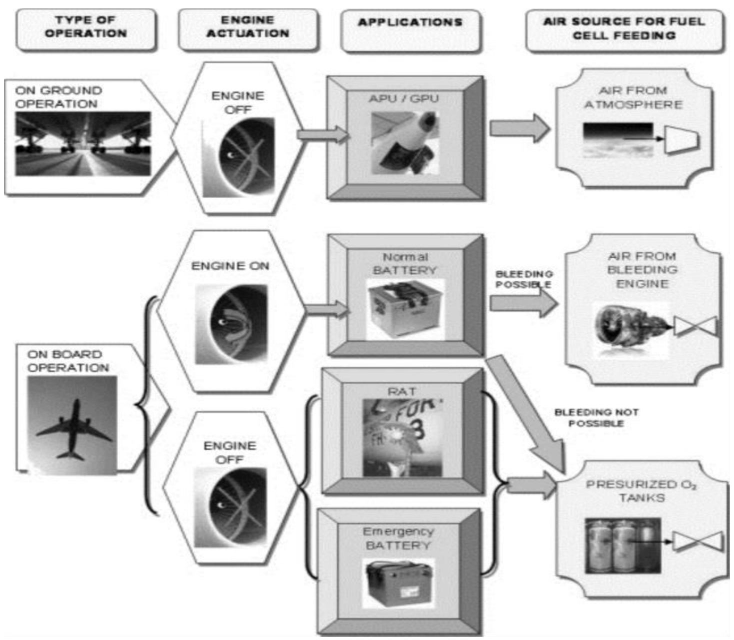
FUEL CELL & AIRCRAFT SPECIFICITIES 3/3

- **Optimizations of FCS design and location vs application**
- **Equipment integration (design) into aircraft = certification specification**
  - Safety assessment early in development phase
  - Operational environment
  - Integration requirements
- **Automotive-based fuel cell system solutions could not be adapted to aeronautical environment**
- **Specific development**
  - Energetic source segregation
  - H_2 fuel cell standards under evolution
  - System and component development needed

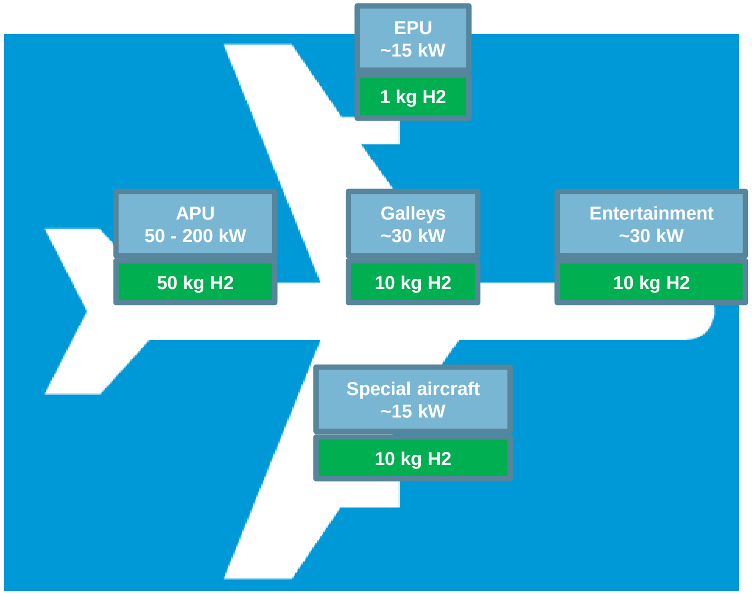
APPLICATION IMPACTS FCS DESIGN

FCS Design criteria

- Mission/cycle : long mission (compressor); short mission (O_2 tank)
- Location : air cabin, atmosphere
- Life time → fuel cell stack size, reactive purity (filtering)



J. Fuel Cell Sci. Technol. 2010;8(1):011014-011014-7. doi:10.1115/1.4002400



EXAMPLE : FUEL CELL EMERGENCY POWER UNIT

➔ Stack - PEM High Temperature

- Accept non pure H_2
- No humidification system
- Facilitate thermal integration

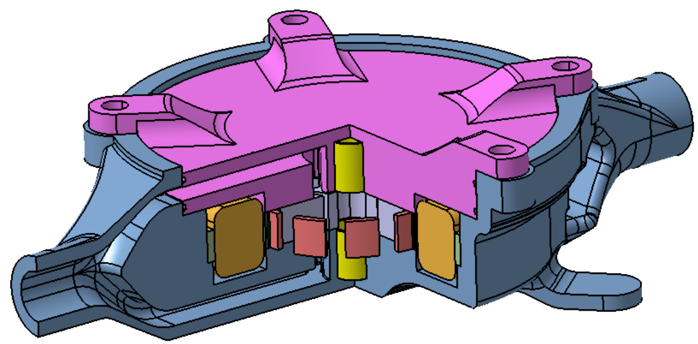
➔ Solid Hydrogen Gas Generator

- Low pressure (20 bar max)
- Long life Storage
- Easier transportation
- Simplify logistic

➔ Air Compressor with Air Bearings

- No air pollution
- High ratio compression

➔ Electrical pump



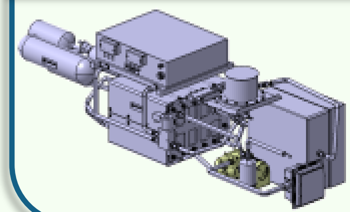
HYDROGEN POWER UNIT: SAFRAN ORGANIZATION

Program Management

SAFRAN Microturbo

Aircraft Integration

SAFRAN Microturbo



- Integration
- Safety
- Certification

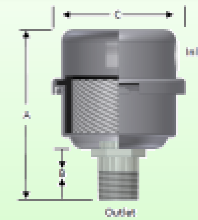
PEMFC stack

SAFRAN Microturbo

Cathode Line

SAFRAN Technofan

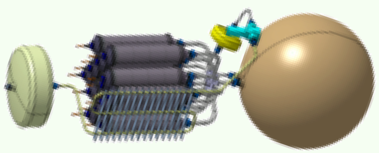
SAFRAN Sofrance



Anode Line

SAFRAN Herakles

CGH2 – 350 bar

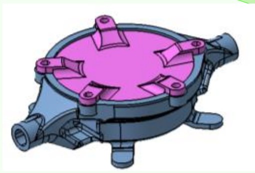


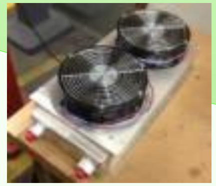
H2 solid P < 20 bar

Thermal Management

SAFRAN Techspace Aero

SAFRAN Microturbo





Conversion / Distribution

SAFRAN Labinal Power Systems

ECU

SAFRAN Microturbo

SAFRAN AEROSPACE · DEFENCE · SECURITY

KEY MISSIONS, KEY TECHNOLOGIES, KEY TALENTS