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H2 Hazards – Overview

- ✓ H2 Fuel Cell
- ✓ Fire & explosion risk
- ✓ Crashworthiness

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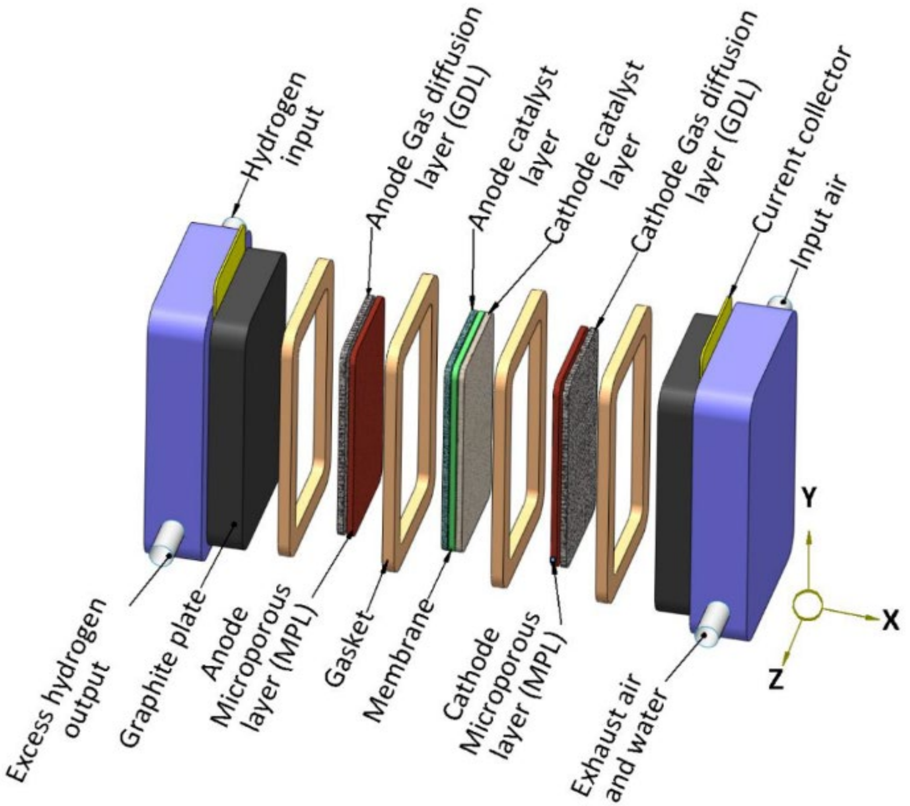
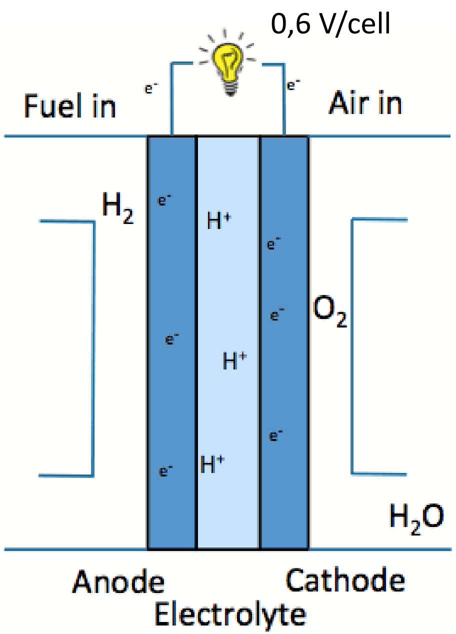
Hydrogen Fuel cell stack

Linda Brussaard

Hydrogen Proton Exchange Membrane Fuel Cell





Failures and effects

- Hazardous fluid/gas leakages. Caused by for example:
  - Above allowable working pressure
  - Gass cross over, due to cell reversal
- Cell reversal. Caused by for example:
  - Loss or inadequate coolant flow
  - Loss or inadequate humidity
  - Loss or inadequate hydrogen or air supply

Example of damage

Abusive Testing of PEM Hydrogen Fuel Cells, DOT/FAA/TC-16/24, October 2016:

- → LT HPEM fuel cell stack with H2 and pure O2 as reactants.
- → Introduced failure conditions were:
  - → Loss of coolant, short circuit test, and cross flow test.
- → Some sparks… fuel cell continued operating for significant amount of time.

Internal damage to the fuel cell stack after the cross-flow condition test; a preconditioned cell was part of the stack bringing H2 and O2 together.

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Hydrogen Installations Crashworthiness

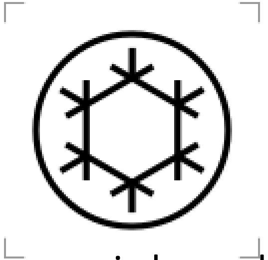
LH2 Tank Crashworthiness

Emily Lewis

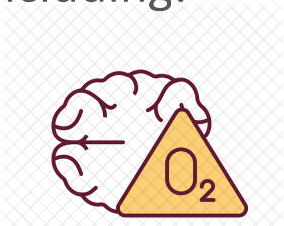
Global Crashworthiness Objective

- OBJECTIVE: **A/C occupants should have every reasonable chance of escaping serious injury and quickly evacuating the aircraft following otherwise survivable crash conditions.**
- All H2 threats should be considered, including:

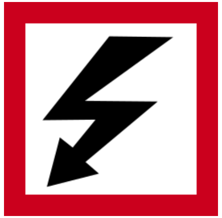
Fire/explosion



Cryogenic hazards



Hypoxia due to H2 leak into occupied areas



High voltage shock

- Passengers should have at least the same level of survivability compared to an equivalent aeroplane with conventional fuel.

LH2 Tank Crashworthiness for Large Aeroplanes

- OBJECTIVE: **Safe behaviour of the LH2 tank should be demonstrated in crash scenarios beyond the condition (referred to as the limit of reasonable survivability, LRS) where occupant protection and survivability becomes affected.**

- 2 different approaches:

OPTION 1: PERFORMANCE BASED

1. Determine impact requirements: rational aircraft level crash scenarios
2. Additional margins:
   i. ‘unknowns of LH2’
   ii. plus a margin between LRS and fire/explosion avoidance

(This approach is only valid if the specific aircraft is identified and rational crash scenarios can be determined, i.e. TC holder)

OPTION 2: PRESCRIPTIVE REQUIREMENT

Conservative vertical impact velocity prescribed to cover:

- generic aircraft types
- location of tank
- margins between LRS and fire/explosion avoidance and to cover ‘unknowns of LH2’

(Valid for tank installations in a generic aeroplane type or if crash behaviour of the aeroplane is not known, i.e. STC holder)

LH2 Tank Crashworthiness Requirement

→ COMPLIANCE DEMONSTRATION: **DROP TEST (for the vertical impact)**

- → Configuration should include any surrounding structure that may contribute to the rupture of the tank
- → Structure representative of the aeroplane may be included → energy absorption
- → System components inside and outside the tank, the failure of which may contribute to hydrogen leakage or that are necessary for safe venting must be included

PASS / FAIL CRITERIA:

- ✓ Fire and explosion should be prevented unless not a hazard to occupants and third parties
- ✓ System components necessary to protect against hazardous fire/explosion remain functional
- ✓ No unintended external leakage of H2

→ The following additional scenarios should also be addressed:

Sliding of the aircraft on the ground after initial impact

(e.g. sufficient separation between the fuel tank and skin)

Fuselage break points should be away from the tank volume

Consequences due to off runway survivable emergency landings minimised as far as practicable

(and/with loss of landing gears and engines due to contact with obstacles)

NOTE: The above criteria cover the installed LH2 tank only. Additional crashworthiness requirements will be necessary for the aircraft H2 system installation.

Conclusion

- A/C occupants should have every reasonable chance of escaping serious injury and quickly evacuating the aircraft following otherwise survivable crash conditions.
- All H2 threats conditions should be considered, i.e. fire/explosion, cryogenic, hypoxia and high voltage.
- Safe behaviour of the LH2 tank should be demonstrated in crash scenarios beyond LRS condition
- Hazardous fire/explosion to be avoided
- 2 options possible for the LH2 tank:
  - Performance based: Rational crashworthiness scenarios
  - Prescriptive: Fixed conservative drop test (no specific aircraft / knowledge)
- Crashworthiness of the full installation should also be addressed

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H2 Fire & Explosion risk

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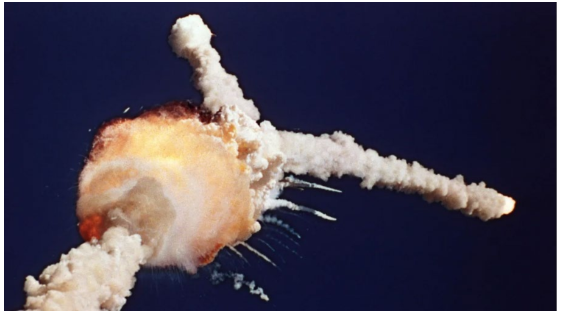
Fire & Explosion Safety Principles

- Fire / Explosion / Smoke / Toxicity risk is commonly addressed in certification specification
- Maintain the same level of safety achieved by circa 70 years of fire/explosion regulatory evolutions : H2 presence shall not degrade this achieved level
- Strategies lay in different degrees of prevention / protection with a mix of prescriptive / non-prescriptive requirements and multi-layers

General
i.e CS 25.1309 CCA with FESRA PRA's, Flammable fluid risk minimization with CS 25.863, …

Specific
Designated Fire Zone, Cargo zone classification, Lavatory, Crashworthiness, Occupant protection from external fire, Oxygen,Fuel tank, PEDs, Cabin material…

Multi-layers
Fuel tank Safety,
Designated fire zones,
2D Nacelle

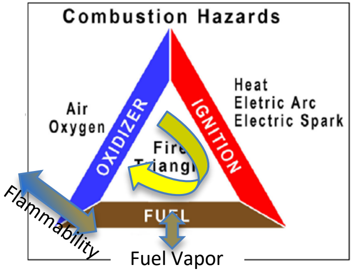


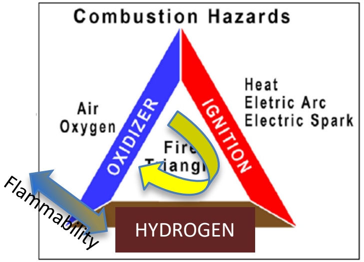
Jan. 28, 1986 file photo, the space shuttle Challenger explodes shortly after lifting off from the Kennedy Space Center in Cape Canaveral, Fla. (AP Photo/Bruce Weaver, File)

January 8, 2007, H2 Powerplant, Muskingum, Ohio. WHA

H2 Fire & Explosion Problematics & Safety Principles

- Fire & Explosion of H2 is generally regarded as a significant safety issue.
- Need to commonly agree on fire & explosion characteristics.
  - Flammability range (air/fuel), detonation range & susceptibility.
  - Minimum ignition energy, Flash point, Autoignition temperature.
  - Intrinsic capability to leak/migrate (surrounding material flammability?)
  - Heat flux, flame temperature, flame speed
- Strategies may differs (in comparison to fuel Jet A) :
  - Prevention of ignition source maybe vain => minimization of ignition .
  - Flammability minimization => Prevention of flammability.





- Fire/Explosion zoning could be used:
  - Specific zone for Fuel Cell installation (Air, H2, Elec power presence).
  - H2 Storage may be treated as same level as H2 distribution.
- No (known) H2 fire extinguishing agent.
  - More dependency on the shut-off / detection (leak and fire) means.
- Venting
  - Prevention of creating an H2&O2 flammable mixture.

International WG and Harmonisation

- HF&ERSG (Hydrogen Fire & Explosion Research Steering Group) initiated mid 2022, formed in 2023, aimed to identify fire & explosion research needs for introduction of H2 onboard aircraft.
  - Joint FAA, EASA, TCCA, ANAC, JCAB ToR
  - Agreed to use the channel of FAA-TC research forums (IASFPF and IAMFTF) and Cabin and Fire Safety research triannual conferences
- Started from original ARC Fuel Cell report (AIR6464).
- 4 task Groups created with Regulator Chair and Industry Co-Chair:
  - Cabin Safety – Post Crash / Cabin Safety – In-flight fire
  - Powerplant - Ground Fire / Powerplant - In-flight fire
- Regulatory Gaps focused on Fire & Explosion → identify needs for **H2 Research**

Need for research: understanding the threats and hazards

- Research on H2 is paramount.
  - Need for testing data to support creation of rule/guidance for H2 introduction
- List of Research topics – Report under drafting
  - Example of topics
    - **Cabin Safety:**
      - Study on hydrogen dispersion resulting from leakage
      - Impact of accumulation of hydrogen on fire severity and fire propagation in hidden areas
      - Use of simulation for the characterization of post crash fire scenarios involving hydrogen (gaseous and/or liquid)
      - Study on methodologies for the assessment of outside conditions before starting an emergency evacuation
      - …
    - **Powerplant:**
      - H2 fire characteristics and components testing protocol
      - Effects on recognized Fireproof and Fire resistant materials/thicknesses
      - H2 concentration thresholds and leak detection
      - Hazardous quantities of accumulated hydrogen in cavities and released hydrogen through compartment boundaries
      - Hydrogen dispersion behavior (cryo versus ambient release)
      - Review of ignition risk due to penetration by impacting debris
      - …

Research Topic Title	Research Topic Description	FESR Threat	CS/FAR rule concerned	P
Air ingress acceptability criteria	H2 tank and cryogenic storage components Pressure collapse phenomena to define requirements that mitigate the risk of air ingress into H2 systems. Refuelling with contaminants or trapped air at connection during refuelling might be condition when air ingress may occur. Research on air ingress acceptability criteria? In which conditions?	F2-O F2-F F2-ED F2-Ed	25.943; 25.963; 25.981	M
Accumulation of liquid oxygen (fire hazard)	During cryogenic or extremely cold Liquid H2/Gaseous H2 release (Jettison; venting; thermal insulation failure…) risk around pipes to condensate leading to potential accumulation of liquid air (cryogenic hazard, explosion hazard in the event of rapid vaporization). Any acceptable amount? Need to tolerate a certain amount?	F2-O F2-E	25.975; 25.1001	M
Hazardous quantity of leakage	Determination of hazardous quantities of leakage. The quantity might differ for a GH2 or a LH2 application.	F2-L	25.963d; 25.963e; 25.979a; 25.994; 25.1091; 25.1121; 25.1189; 25.1191; CS-E130a	S
H2 fire/leak detection	Hydrogen leak detection and localisation. Hydrogen fire detection. Technology capable to detect and withstand H2 fire requires research need (including qualification and protocol adaptation). Deliverable should be a performance requirement that provide safe operation. Hydrogen fire threat timeline (to determine appropriate definition of "quick acting".	F2-F F2-L	25.1187; 25.1203; 25.1121	S
Explosion Proof	Research new methodology for Explosion Proof equipment requirement when considering H2 instead of kerosene. DO-160 should be adapted to other fuels like H2. ' Define acceptable ignition energy threshold below which one would comply with the minimisation effort.	F2-I	25.975; 25.981; 25.994; 25.1001	M L
Surface Temperature limit	Research about new surface temperature limits when …	F2-I	25.975; …	M L

- Recommending further consolidation of topics by aircraft authorities and industries representatives;
- .

Conclusions

- Maintain the same level of safety achieved by circa 70 years of fire/explosion regulatory evolutions : H2 presence shall not degrade this achieved level
- Wide range of fire & explosion problematics
- Technology maturity - for aviation applications - will have to be gained.
- More understanding on fire & Explosion risk/consequences for the aviation domain is necessary.
- Collaborative work from industry, regulators is key.

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