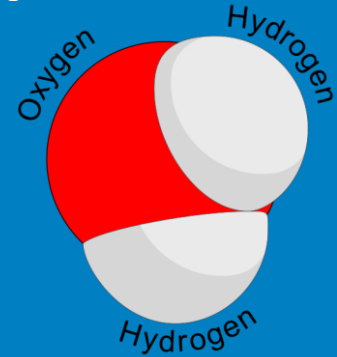


Hydrogen Fire & Explosion

Report from the Task Groups

E. Canari
(representing the H2 Task Groups co-chairs)
Atlantic City, 25 September 2024



Introduction

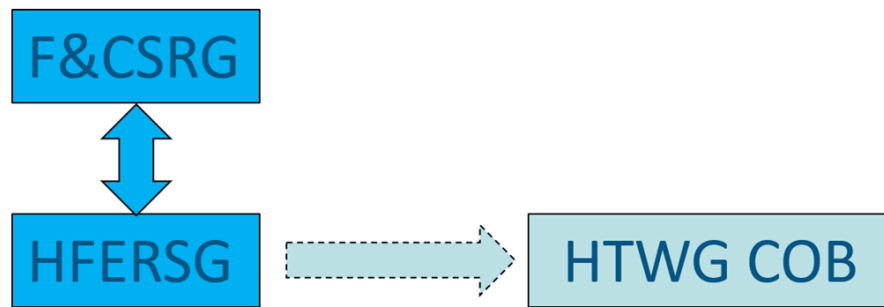
➤ Apr 2024 meetings (Regulator only, Regulator / Industry)

➤ Topics For Discussion

- ToR For Hydrogen Fire & Explosion Research Steering Group (HFERSG)
- Work Plan/Task Groups
- List of Topics and Prioritization

Introduction

- ToR for Hydrogen Fire & Explosion Research Steering Group (HFERSG)
 - Subset of Fire and Cabin Safety Research Group, F&CSRG
 - Contributor to Hydrogen Technologies Working Group (HTWG) COB

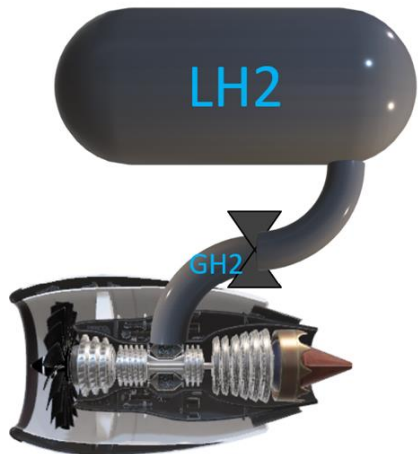


Introduction

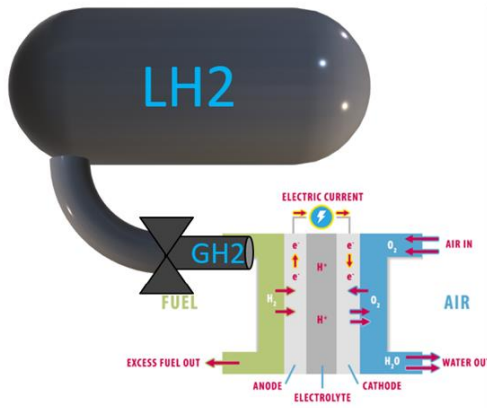
► Work Plan

► CS-25 Amdt 28 as reference

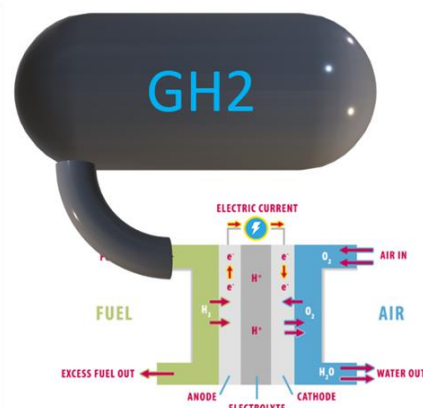
► Make some high level assumptions of architecture



Option 1
H2 burn



Option 2
LH2 FC



Option 3
GH2 FC

Safety Objectives

- Example for assessing (CS-25) regulatory impacts:
 - Maintain the same level of safety achieved by circa 70 years of fire/explosion regulatory evolutions for large airplane commercial transport: H2 presence shall not degrade this achieved level.
 - Keep the spirit of current CS-25 Fire & Explosion Safety requirements

Task Groups

<u>Preliminary list of issues</u>	Post Crash	In-flight
Cabin Safety	FAA (S. Rehn) 1) Characterization of a fire resulting from a crash landing 2) Impact on materials flammability 3) Stay-out zones 4) ...	EASA (E. Canari) 1) H2 Accumulation in pressurized areas (cargo, cabin, hidden areas) 2) Impact on materials flammability 3) Need for leakage detection 4) Impact of H2 accumulation on fire-fighting / fire suppression 5)
Powerplant	FAA (?) 1) Powerplant fire 2) Fuel tank/systems crashworthiness 3) Fuel tank/systems explosion 4) ...	EASA (R. Deletain) 1) Powerplant fire 2) Leakage detection 3) Fuel tank/systems explosion 4) Fire suppression 5) ...
Other problematics	1) Evacuation Strategy 2) Refueling 3) Impact on MPS for cargo compartment / engine fire suppression 4) Freightier aircraft	

Cabin Safety/ In-Flight Fire Task Group

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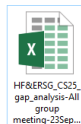
What has been done

→ Powerplant In-flight / Ground/Postcrash Task Group:

→ From the beginning, single task group

→ 14+ meetings

→ Excel file with gap analysis



→ Spreadsheet from ARC Fuel Cell report

→ EASA SEPIAC as file sharing site

- CS-25 subpart E and corresponding FAR25 rules analysis completed.
Subparts D, C, J, F, CS/FAR definitions, CS-E/FAR33 analysis on-going
- Fire and Other Research subjects identified (consolidation on-going)

Research Topic Title	Research Topic Description	FEDR threat	CS or FAR rule concerned	A/C Concept	Priority	Existing material
Research quantity of leakage	Determination of hazardous quantities of leakage. The quantity might differ for a GND or a LIR application.	F2.1	(25.9034 - 25.9636 - 25.9796) (25.998 - 25.1091 - 25.1121) (25.1180 - 25.1191 - 25.1196) (25.1187 - 25.1195 - 25.1121)	concerned	Short term	Lesson to provide a summary
H2 fire/leak detection	Hydrogen leak detection and localization Hydrogen fire detection Technology capable to detect and withstand H2 fire requires research need (including qualification and potential adaptations). Deliverable should performance requirements that provide safe operation Hydrogen fire threat timeline (to determine appropriate detection of "spark arcing")	F2.4	F2.4	concerned	Short term	Review Tail - Naval - Fuel based industry
H2 concentration criteria	Criteria in terms of zone H2 concentration below which the machine is considered safe and ventilation is adequate or fixed ACPM Accumulated quantities (based on the zone average value) considered not hazardous from an explosion point of view.	F2.4	(25.9835 - 25.1181)	concerned	Short term	Flammability limits Lesson to provide data to existing literature
H2 (G) (solid or ambient) or L2 Dispersion in open air and/or in compartments	H2 mixing/dispersion and release characteristics to define non-dimensional relationships for constraining peak outlet state to ensure safe release with inherently buoyant momentum jet or to define forced ventilation requirement or positions of leak detection probes. H2 gaseous buoyant drainage including with natural/forced ventilation Dispersion of water under external (or wind or wind conditions) etc.	F2.4	(25.9034 - 25.975 - 25.1003 - 25.1187 - 25.1121)	concerned	Short term	

What has been done

→ Cabin Safety/Post Crash Task Group:

→ Initial review of background of requirements related to post crash fire

→ Change of co-chair in June (from N. Gerasimov to T. Krause)

→ Change of approach: spreadsheet based on hydrogen phenomenology

→ Merge with In-Flight Task Group (from September 2024)

#	Physical property of hydrogen or hydrogen system	Aircraft scenario influenced by this property	Related hazard vert cabin safety (theoretical, could be excluded by design)	Effect on cabin safety				Measurable parameters that could help quantifying the hazard	Possible mitigations / counteractions vert the hazard
				effect on in-flight cabin safety	related current in-flight cabin safety requirement	effect on post-crash cabin safety	related current post-crash cabin safety requirement		
1	difficult detectability of H2 flames in VTS through human eye	internal / external fire	fire undetected by crew/pass	flame spread is only detected when fire moves to organic matter	25.853(a) 25.855(c)+(d) 25.856(a)	evaluation of safe exit conditions difficult when no assessment of distance to fire or existence of a fire is possible	25.809(a) 25.853(c)+(d) 25.856(b)	quantify radiation of H2 flames in VTS (depending on type of flame, mixture...), assess effect of interior/exterior lighting conditions	IR cameras, temperature sensors
2	wide flammability range (-75%), low ignition energy (0.02mJ)	cloud formation, mixture with oxygen/air	low energy ignition, different concentrations (flammable to inflammable) in one cloud, cloud being visible/invisible does not mean it is flammable/not flammable	Capacity of existing extinguishing agent to extinguish the fire (Cargo / cabin). Ignition due to electrical or other failure	25.851 (a)(6) to (b),(c),(2), (c) 25.853(a) 25.858 (a)(b) 25.173(c)	H2 cloud ignition can lead to spread through the cloud depending on local H2 concentration		quantification of flammability range in respect to cabin atmosphere as well as ground/potable conditions (pavement/air temperature, pressure, pavement type, pavement dry/wet/snow, atmosphere sunshine/rain/snow)	fire fighting or letting the fire burn off by itself, depending on assessment of the fire
3	No smell to H2	cloud formation	Detection difficult that may lead to occupant hypoxia if concentration increases					quantification through sensors	internal/external sensors
4a	Volatility / buoyancy	Leaking liquid hydrogen fuel	Detection of hydrogen is different than for kerosene leak detection	existing detection means are not appropriate to detect H2 presence or H2 fire in the cabin	25.854 25.857			Dispersion/movement of gas, Heat Flux, temperature	IR cameras, temperature sensors
4b			Leakage in open space			Rapid ignition (jet fire) damage to the fuselage	25.856(b)		
4c			leakage in confined space - general	cloud risk of asphyxiation or hypothermia					
4d			leakage in confined space - continuous leak	may change ignition of materials with hydrogen present, may lead to jet fire and may change possibility of a flashover			25.853(d)		
5a	Cryogenic H2 storage / distribution on aircraft level	Leaking liquid hydrogen fuel	Formation of a pool of LH2 w/ ignition Evaporation / H2 cloud w/ignition	hydrogen ingress through air conditioning	25.853(a) 25.855(c)+(d) 25.856(a)	Pool fire: Cloud fire: External fire in the upper part of the fuselage (contrary to kerosene pool fire) Flames can be directly contacting fuselage area Heat and flames hitting fuel tank Possibility for originated H2 to enter cabin Cloud risk of asphyxiation or hypothermia	25.803 25.807 25.809 25.810 25.813 25.853(c)+(d) 25.856(b)	Pool formation: leak dimensions (does the leak widen?), spillage rate Pool fire: stability/evaporation, continuous spillage, temperature, heat flux depending on pavement/air temperature, pavement type, dry/wet/snow, wind conditions, freezing of air Cloud: x-y-z movement, temperature Cloud fire: x-y-z movement, temperature, heat flux	

Future Steps

- Consolidate accumulated material:
- Finalize the content of the working files
- Develop a research subjects list
- Define ranking of priority between the research subjects

Future Steps

- Review of existing research data:
 - Identify existing research studies that may be related to the research subjects
 - Establish links, if possible, between existing research and the identified research subjects
 - For each research subject: determine if new research is necessary

Future Steps

→ Release the draft research plan in **December 2024**:

→ Introduction and explanation on the work methodology

→ Research subjects list

→ Recommendations for high priority research subjects

→ Working files as appendices

Future Steps

- Structure of the report:
 - Introduction
 - HF&ERSG structure
 - Assumptions (GH2 ; LH2 ; FC and H2burn)
 - Powerplant
 - analysis method
 - Research subject list
 - Cabin Safety
 - analysis method
 - Research subject list
 - Research recommendations
 - Conclusion
 - Appendices (working files)

Top level priority subjects for research

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

Top level priority subjects for research

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

Any Questions?