ICAO UNITING AVIATION

Application of Liquid Hydrogen as Aviation Fuels

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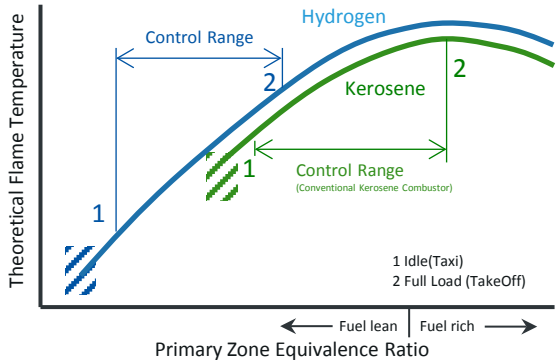
Characteristics of Liquid hydrogen as Aviation Fuels

Hydrogen as Aviation Fuel (1/3)

In comparison with the current jet fuels,

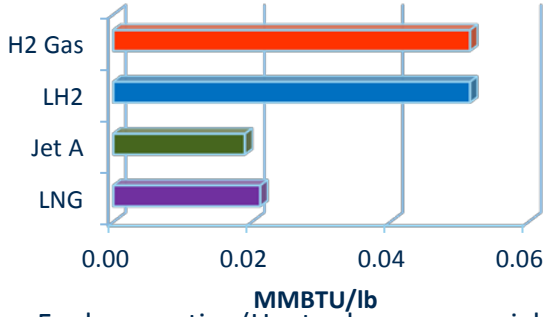
Merits

- ✓ Potentially Zero (CO2) emission
- ✓ Higher energy content per weight(3 times) [Fig. 1]
- ✓ Potential for lower NOx emission [Fig. 2]
- ✓ high performance as a coolant [Fig. 3]

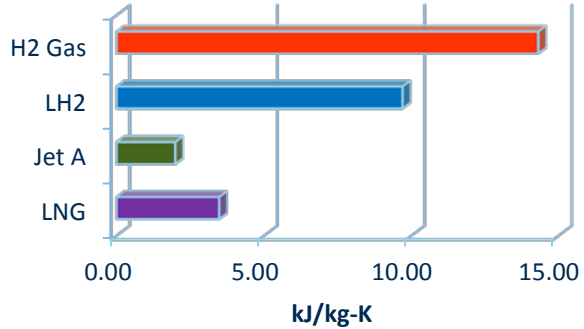


[Fig. 2] Temperature characteristics hydrogen and kerosene

[1] Ziemann J et al, EQHHPP, Phase III. 0-3. Final Report,1992



[Fig. 1] Fuel properties (Heat release per weight)



[Fig. 3] Fuel properties (Specific Heat)

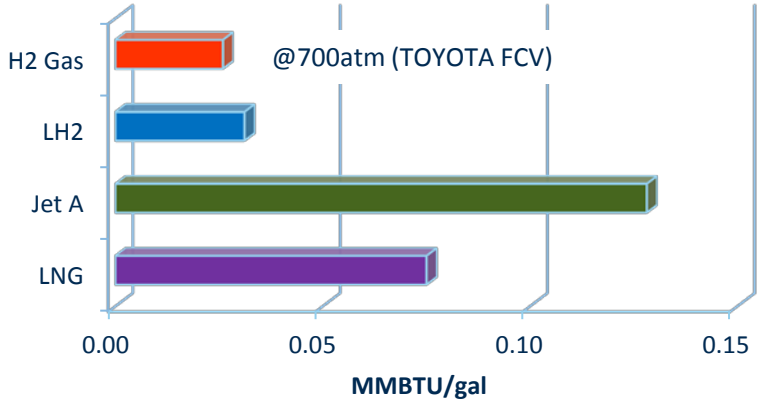
Hydrogen as Aviation Fuel (2/3)

Merits (cont'd)

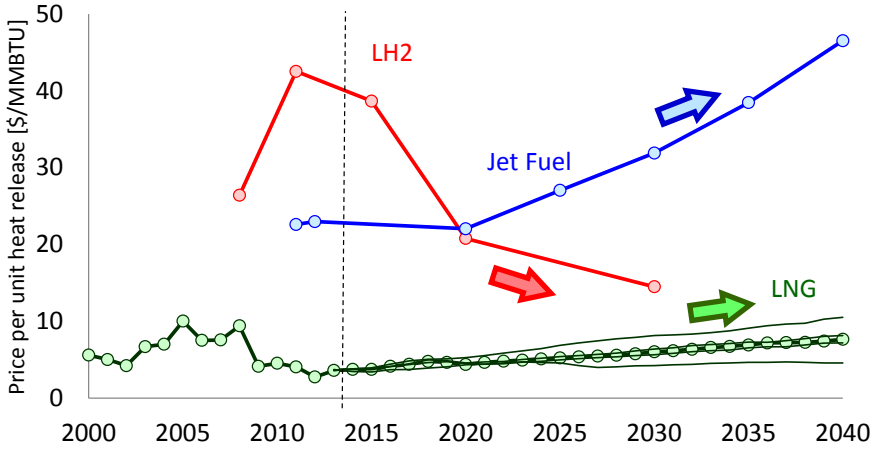
- ✓ declineing production cost [Fig. 4]

Demerits

- ✓ Lower energy content per volume (1/4 times) [Fig. 5]
- ✓ Hard handling in storage and supply
- ✓ Material limitation (hydrogen embrittlement)



[Fig. 5] Fuel properties (Heat release per volume)



[Fig. 4] Production Cost Target

[2] Annual Energy Outlook 2014, U.S. EIA
[3] U.S. DOE hydrogen energy annual report 2013

Hydrogen as Aviation Fuel (3/3)

Additional Concerns

- ✓ Fuel sustainance supply (with environmental compatibility)
- ✓ Infrastracture (airport)
- ✓ Safety [Fig. 6]
  - The aviation industry is ideal to demonstrate a hydrogen fuelled transport society, since experts in restricted areas at airports and aircrafts can supply and manage the fuel.
- ✓ Impact of water vapor emission (> 2 times) on atomosphere [Fig. 7]

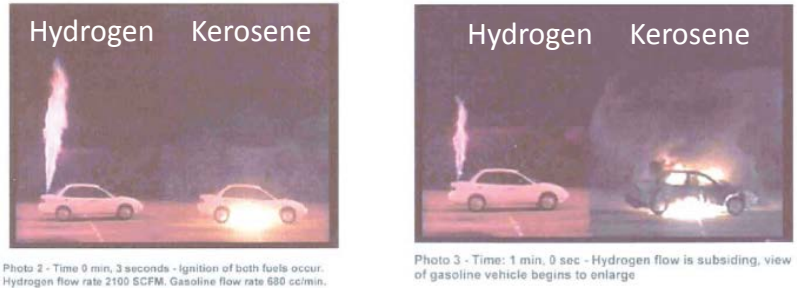
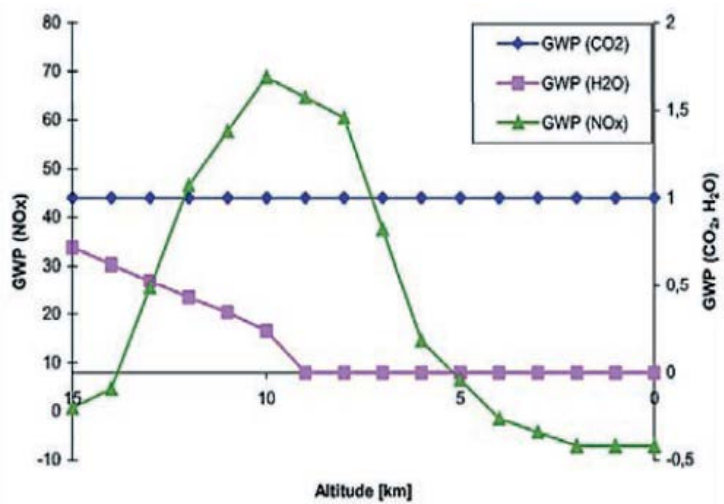


Photo 2 - Time 0 min, 3 seconds - Ignition of both fuels occur. Hydrogen flow rate 2100 SCFM. Gasoline flow rate 680 cc/min.

Photo 3 - Time: 1 min. 0 sec - Hydrogen flow is subsiding, view of gasoline vehicle begins to enlarge

[Fig. 6] Flammability comparison of hydrogen and kerosene

[4] Westenberger A, LH2 as alternative fuel for aeronautics-study on aircraft concepts, 2006.



[Fig. 7] GWP regarding altitude

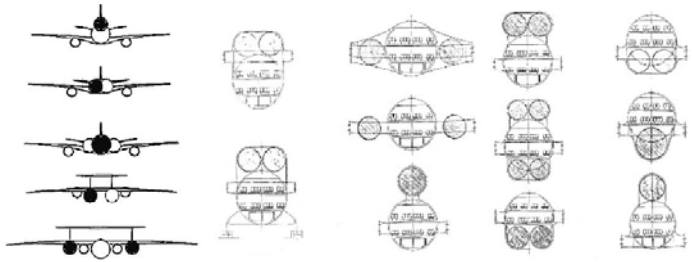
[5] Sevensson F et.al, Aerospace Science and Technology, 2004:8:307-320

Aircraft and Tank configuration

- ✓ Since liquid hydrogen has low density (1/4 of Jet fuel), tank configuration becomes more important.
- ✓ By the progress of composite material technologies, hydrogen aircraft is getting closer to ultimate goal.

BWB concept, CRYOPLANE project

[6] Westenberger , A. et.al, Hydrogen Fueled Aircraft, AIAA2003-2880



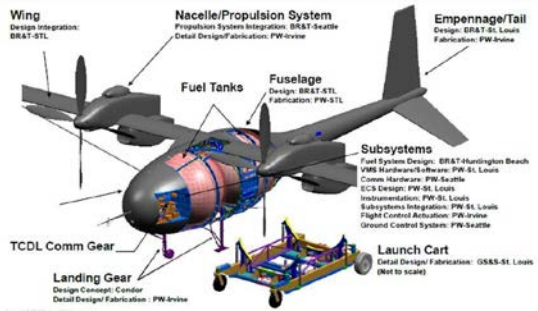
Tank Layout comcepts

[7] Daggett, D. et.al, Commercial Airplanes Hydrogen Fueled Air-planes, 2003.

[Fig. 8] Concepturl Studies of Hydrogen Airplane

ALT: 65,000 feet
Payload: 450 lb

First flight: 2012



[Fig. 9] Boeing Phantom Eye

high altitude, long endurance liquid hydrogen-powered UAS

Examples of JAXA activity

JAXA's Research Initiatives for Aviation

ECAT

Environment Conscious Aircraft Technology Program

STAR

Safety Technology for Aviation and Disaster-Relief Program

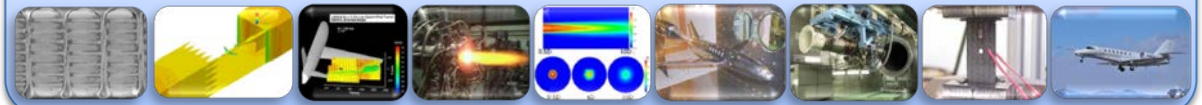
Sky Frontier

Sky Frontier Program

3 major R&D programs and Basic research

Science & Basic Tech.

Aeronautical Science & Basic Technology Research Program



Mid-term plan for 2013-2017

Future Image and Studies of Hypersonic Transpostation

[7] Taguchi, H. et.al, AIAA-2014-2790.

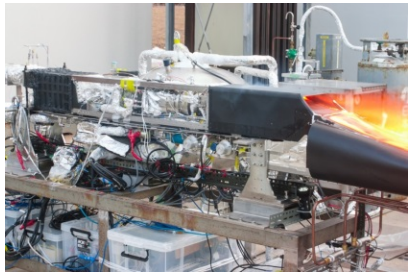
100km altitude
for Space Tourism

Sub-Orbital Plane

Fly Across the Pacific Ocean in 2hours

Hypersonic Transport Aircraft

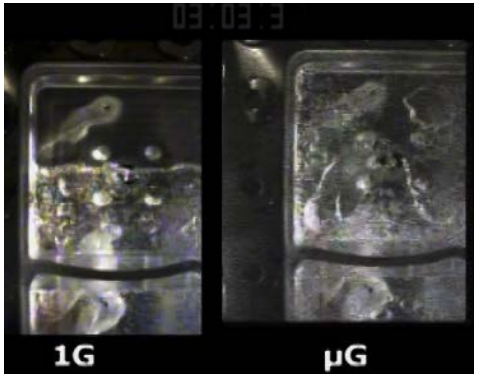
Hypersonic Aircraft Technology



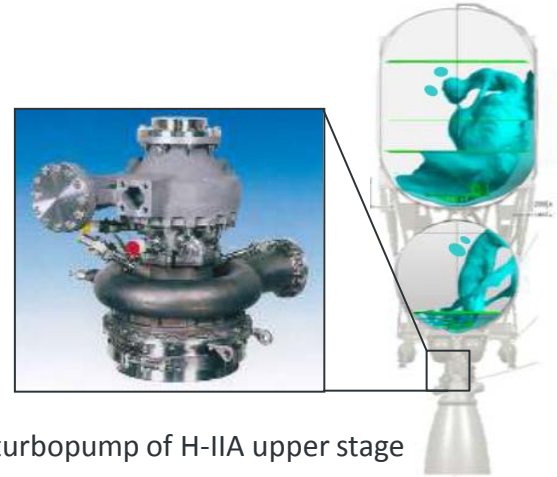
Hypersonic Propulsion Technology

Flight Experiment of cryogenic liquid

JAXA's sounding rocket S-310
[04/Aug/2014, Uchinoura Space Center]



cryogenic liquid flow
under microgravity condition

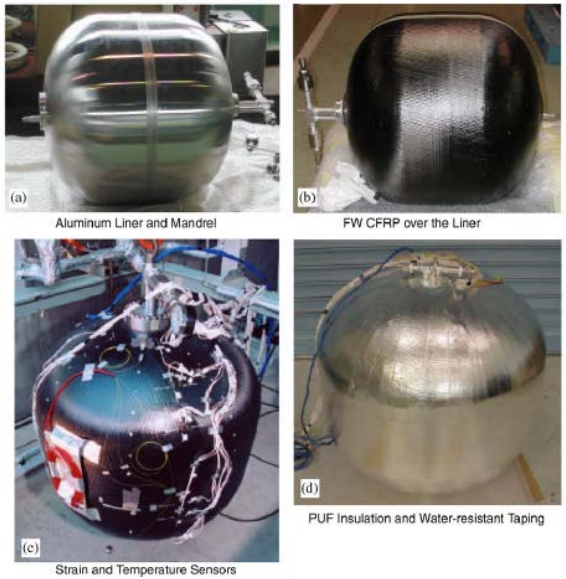


LH2 turbopump of H-IIA upper stage

- JAXA has conducted flight experiment of sounding rocket S-310 to measure behavior and heat transfer properties of cryogenic two phase flow under microgravity condition.
- Results will be applied to improve chill-down operation of second stage for JAXA's main rocket H-IIA.

[7] JAXA Press release, 5/Aug/2014
[8] JAXA brochure, "H-IIA upgrade".

Development of light weight LH2 feed system



Development of metal-lined CFRP cryogenic tank

[9] Higychi, K et.al, Acta Astronautica 57 (2005) 432 – 437.

Test setup

Rotor of Superconducting Motor with MgB2

Superconducting Turbopump experiment

[10] Kyushu university Press release, 10/May/2012 (in-Japanese).

- Light weight CFRP cryogenic tank is a key technology. JAXA have been researching material-lined CFRP tank.
- Superconducting turbopump as one aspect of MEA(more electric aircraft) would be one solution to smplify pressurization system of LH2 aircraft.

Summary

- Hydrogen has been a long-term future solution to environment concerns and energy dependency.
- Research on hydrogen fuelled aircraft has been conducted quite a long time, we are getting closer to ultimate goal.
- Recent activities for hydrogen society is a good background to accelerate the development of hydrogen fueled ground and aircraft sytem.