ICAO Colloquium on
Aviation and Climate Change

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Application of Liquid Hydrogen as Aviation Fuel – Some Perspectives

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Scope of the presentation

- Introduces study on aero-engine and related aircraft systems being conducted at JAXA in fundamental research and development basis.
- Introduces expectations to acquire a new sustainable, energy-efficient and environmentally compatible alternative aviation fuel.
- Deals with the potential of one of the promising fuels – hydrogen-.

Hydrogen as Aviation fuel

In comparison with the current jet fuels

Merits

+ Higher energy content per weight (3 Times)
+ Zero (CO_2) emission
+ Potential for lower NOx emission
+ Easy handling as combustible gas

Demerits

- Lower energy content per volume (1/4 times)
- Hard handling in storage and supply (cryogenic fuel).
- Material property(brittleness)

Additional Concerns

- Fuel sustainable supply (with environmental compatibility)
- Infrastructure (airport)
- Impact of water vapor emission (>2 times) on atmosphere

Feasibility

- Several feasibility studies show LH2 subsonic transport aircraft is realistic, whereas there are still some ambiguities such as fuel storage and fuel supply systems still exist.
- Small aircraft (from take off to landing) and cruising phase with medium size aircraft were already demonstrated(-1988).
- Fuel cell powered small aircraft with hydrogen fuel has already been demonstrated already(2008, 2009)

- Realization of Large-scale and long-time duration aircraft … still remains a challenge.

Merits of introduction of LH2 to Aviation …

- The aviation industry is ideal to demonstrate a hydrogen fuelled transport society, having experts in restricted areas at airports to supply and manage the fuel.

Aerospace industry is close to hydrogen…

- First demonstrated turbojet-engine used for propulsion was hydrogen fueled (He178).
- Efforts on development of Model 304 hydrogen-fueled engine were redirected to the development of the RL10 hydrogen/oxygen rocket engine. We can utilize tremendous experiences of hydrogen-related technologies for rocket propulsion.

Challenges

Major challenges for LH2 fueled (subsonic) transport are as follows:

(1) Fuel supply management
(2) Tank structure (Fuel Storage system)
(3) Evaluation of effect of water vapor emission on environment

*Sustainable and stable supply of the fuel is of course a precondition.

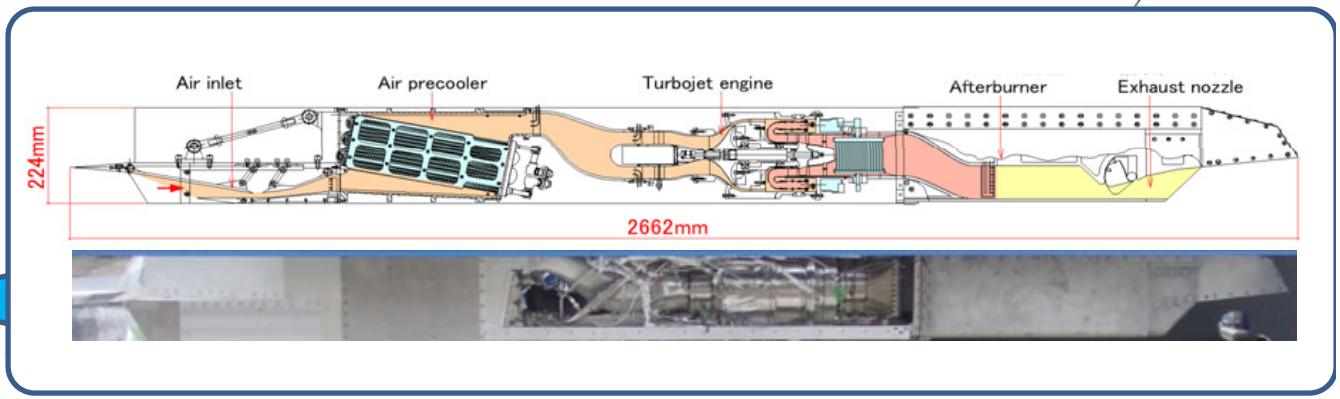
Three examples of JAXA investigation

Case 1: LH2-fuelled Hypersonic Transport (HST) turbojet engine

Case 2: LH2-fuelled Blended Wing Body (BWB) Configuration Supersonic Transport (SST)

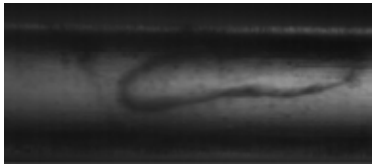
Case 3: Hybrid Aero-Engines

Case 1: LH2 HST turbo-engine

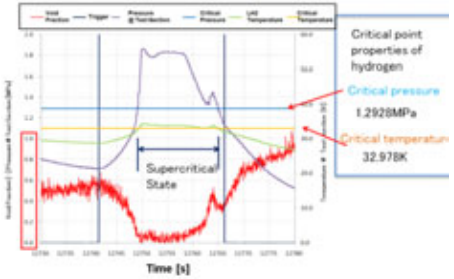


- Scaled (LH2-fueled) Pre-cooled turbojet engine model operable from SLS to Mach 5 in-flight condition (with single flow-path) has been fabricated and tested.
- Experiences obtained in the series of tests on turbojet engine, engine systems, fuel supply system and fuel tank are also applicable to hydrogen fueled supersonic and subsonic transport.
- Investigation includes fuel handling techniques such as fabrication study of cryogenic multiphase flow control and visualization of the flow.

Reference:
-Taguchi, H., Harada, K., Kobayashi, H., Kojima, T., Hongoh, M., Masaki, D., Sawai, S. and Maru, Y., "Firing Test of a Hypersonic Turbojet Engine Installed on a Flight Test Vehicle," 16th AIAA/DLR/DGLR International Space Planes and Hypersonic Systems and Technologies Conference, AIAA 2009-7311, 2009.
-Shirai, Y., Shiotsu, M., Tatsumoto, H., Kobayashi, H., Naruo, Y., Inatani, Y., Preliminary study on heat transfer characteristics of liquid hydrogen for coolant of HTC Superconductors, Cryogenic Engineering Conference and International Cryogenic Materials Conference, Arizona, USA, June 28 - July 2, 2009



Flow visualization



Multiphase flow control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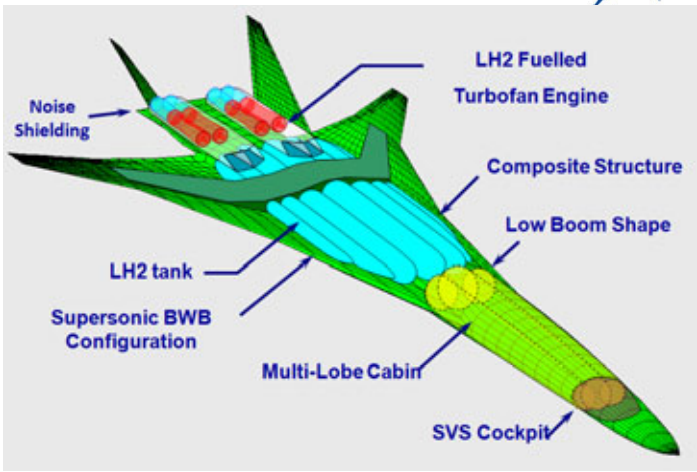
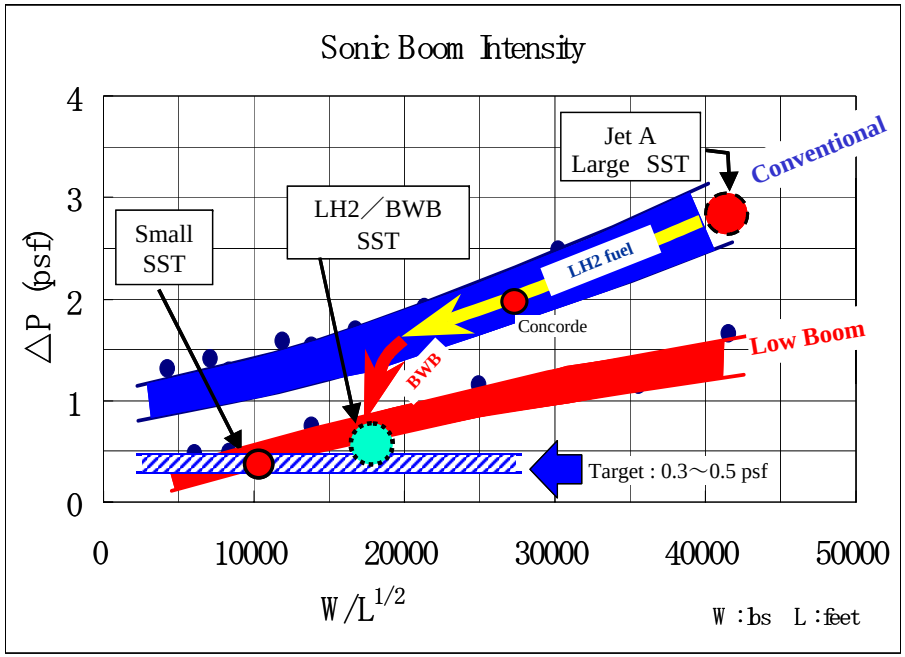
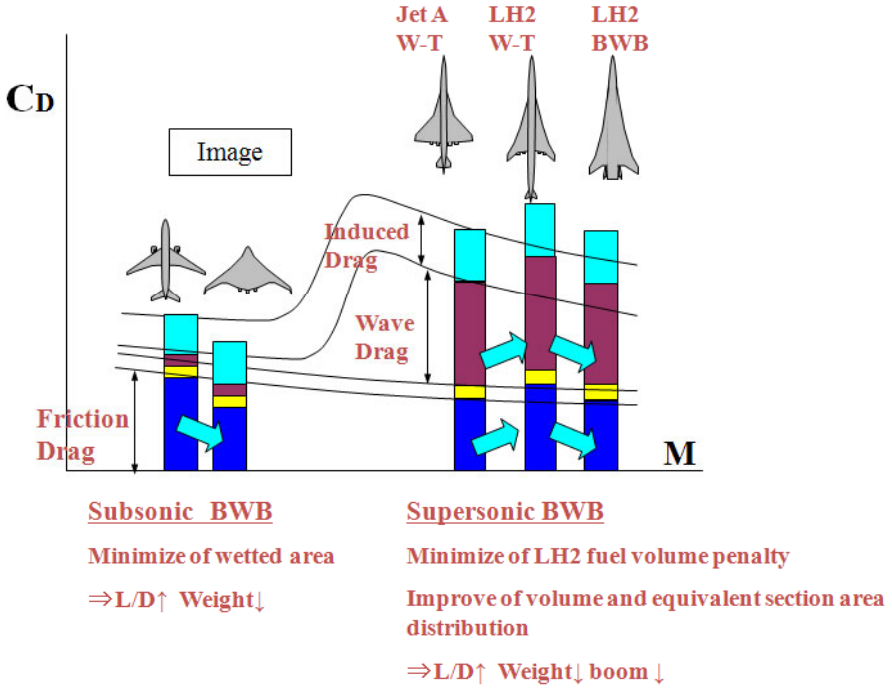
Case 2: LH2-fuelled BWB Configuration SST

-Light weight and BWB configuration may have a merit
=> Energy efficient, Low-emission and Low-boom large-size SST







Subsonic BWB

Minimize of wetted area

⇒L/D↑ Weight↓

Supersonic BWB

Minimize of LH2 fuel volume penalty

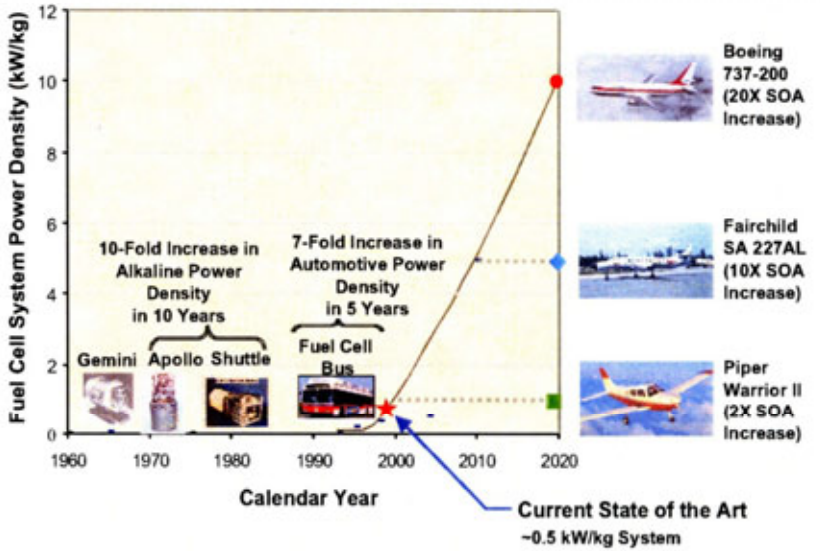
Improve of volume and equivalent section area distribution

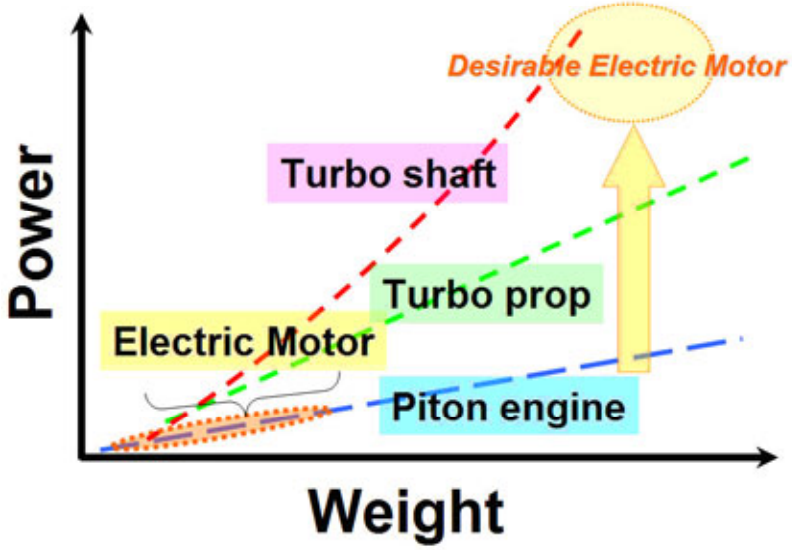
⇒L/D↑ Weight↓ boom↓

Reference: Horinouchi, S., Future Supersonic Transport with Hydrogen Fuel and BWB Configuration, JSASS-2010-1067, presented in the 41th JSASS Annual Meeting, 2010.

Case 3: Hybrid aero-engines (1/2)

Power-weight relationship of electric propulsion system components





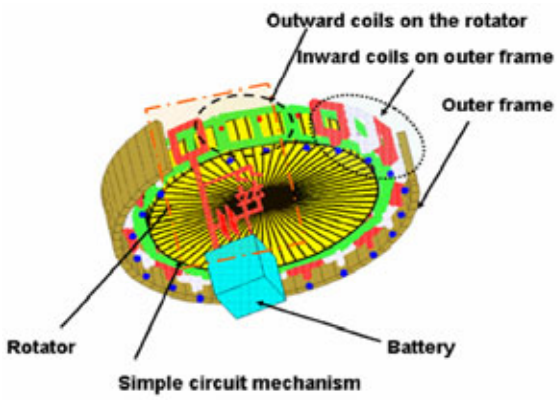
NASA: AIAA2003-2867

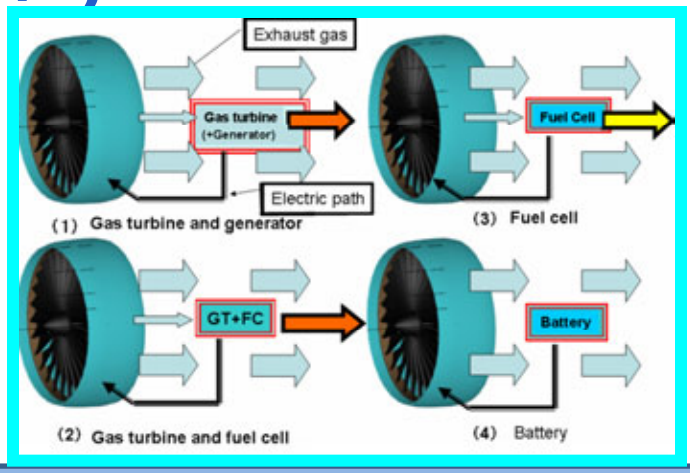
With hydrogen as the fuel, fuel cell or fuel-cell and gas-turbine combination (hybrid) engine would have higher efficiency and higher environmental compatibility than sole gas-turbine engine.

Reducing weight in related devices is one of the key technological challenges.

In addition to introduction of hydrogen fuel, aspects of More Electric Aircraft (MEA) would be key technologies of future aircraft, and hybrid engine technology should be considered as one aspects of MEA.

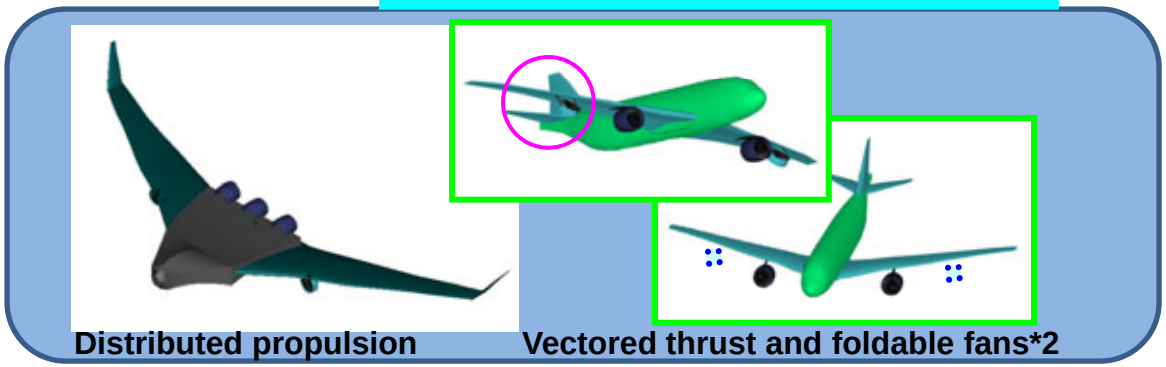
A new light-weight motor concept Case3 (2/2)





A new motor concept *1

1.Driving coils (point of action) on the outer shell
2.No need of iron core
（Large current variation;
Relax physical limits）
-> Small (relative) resistance loss
3.Energy recovery via LC circuit



Distributed propulsion **Vectored thrust and foldable fans*2**

Turbo-fan engine has a limitation in fan-bypass ratio which is an important parameter concerning efficiency and environmental impact (emission and noise).
Electromagnetic fan may potentially release this limitation, because of independent rotation speed from turbine and its (potential) light weight.

*1 K. Okai, H. Nomura, T. Tagashira and R. Yanagi, Electromagnetic Rotating Machine, US-Patent # 7423405 (2008)
*2 K. Okai, H. Nomura, T. Tagashira and R. Yanagi, Aircraft Propulsion System, US-Patent # 7555893 (2009)

AERO ENGINE

Summary

JAXA

- Hydrogen has long been a “new” promising alternative fuel.
- Recent activities for hydrogen society is a good background to accelerate the development of hydrogen fuelled aircraft.
- Research on hydrogen fuelled aircraft has been conducted quite a long time, and we need to add some new aspects on the research field regarding the most recent social needs.
- Systems verification approach would be promising because storage and handlings of the fuel are of great issue.
- Hydrogen fuelled aviation would become a good demonstration for introduction of hydrogen society because handling of aviation fuel is done by trained persons and in restricted areas.
- Introduction of hydrogen as aviation fuel would further encourage the development of fuel cell powered aircraft. Fuel cell or hybrid propulsion should be considered as an activity among the ones for More Electric Aircraft (MEA).