Goals of the "Next-Generation Aircraft Development" Projects and Details of Their R&D

Total budget: Maximum of 21.08 billion yen

- As elements necessary for creating a hydrogen aircraft, conduct technical development related to (1) an engine combustor that can achieve both stable combustion of hydrogen and low NOx emissions; (2) a small, lightweight liquid hydrogen storage tank that can withstand extremely low temperatures (-253°C); and (3) airframe design, which will require significant changes (Goal (1)). In addition, aim to dramatically reduce the weight of the aircraft structure, with a view toward post-next-generation aircraft (post 2035) (Goal (2)). The following goals and research and development details have been set in order to achieve these:

R&D goals and the thinking behind them, etc.

- Goal (1): **By 2030, among other things, establish the core technologies (TRL6+*) essential to establishing hydrogen aircraft**, including liquid hydrogen fuel storage tanks, engine combustors, and airframe designs

  Note: Technology level set by NASA. Equivalent to the IEA's TRL6+

  → The unique demands for aircraft to be made dramatically lighter, safe, and reliable will need to be addressed, so the hurdles are high.
- Goal (2): With regard to the main wings and other important structural components, achieve **TRL6+ and a weight reduction of approximately 30%** compared to the materials used for existing parts (aluminum alloys), with the aim of fitting **aircraft introduced from 2035 onward** with the technology.

  → This will be essential for decarbonization of the aerospace sector in terms of, e.g., major design changes due to low fuel consumption and changes to the propulsion systems.

Goal (1)
- Detail (1): Development of engine combustor technology for hydrogen aircraft
- Detail (2): Development of liquid hydrogen fuel storage tank technology
- Detail (3): Considering the structure of hydrogen aircraft airframes

Goal (2)
- Detail (1): Development of technology to dramatically reduce the weight of aircraft's major structural components

Main Technologies Necessary to Achieve Hydrogen Aircraft

- Compared to ground-based equipment, **aircraft face strict demands to be lightweight, space-saving, and low-Nox emitting, while at the same time they must ensure extremely high levels of safety and reliability under low pressure conditions.**
- Technology for hydrogen aircraft will be developed progressively while utilizing technologies cultivated in the space and energy sectors.

Fuel control (Backfiring, production of NOx)

Hydrogen fuel is prone to backfiring, and the combustion temperature is higher than that of existing jet fuel. Consequently, NOx is more likely to be produced.
→ **An engine combustor** needs to be developed that solves these problems.

Hydrogen fuel storage

It is said that replacing existing jet fuel with hydrogen fuel will require four times the volume of conventional fuel.
→ **A tank** needs to be developed **that is lightweight and capable of storing cryogenic liquid hydrogen appropriately**.
→ Together with this, **airframe design** needs to be **appropriately reviewed.**

Ensuring safety

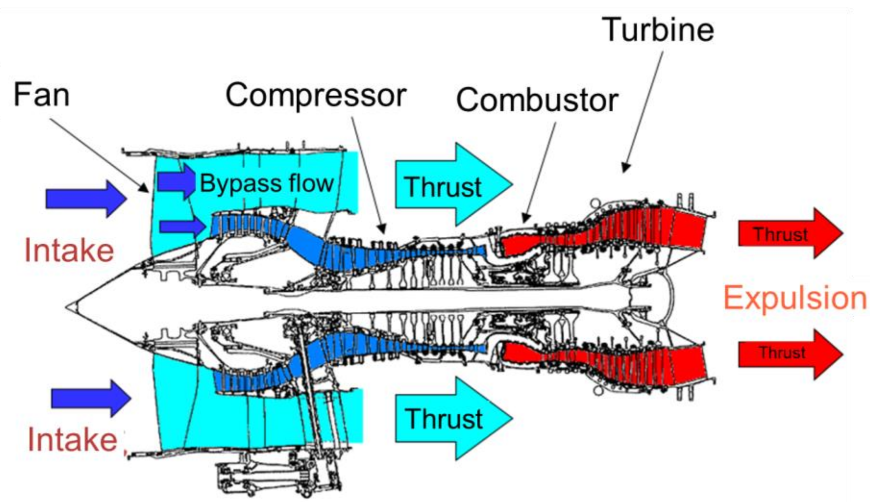
The components that make up an aircraft require a high level of safety. This is especially true of ones that have an important impact on flight (for which the acceptable failure rate is just one in a billion).
→ **A series of highly safe storage and supply systems covering everything from the storage tank to the engine** needs to be developed.

Development of an Engine Combustor for Hydrogen Combustion

- **Backfiring, NOx emissions, and other issues** unique to hydrogen need to be addressed. In particular, for aircraft engines, the combustor inlet temperature gets higher than when combusting existing jet fuel and higher than ground-based hydrogen gas turbines, so reducing NOx emissions is important.

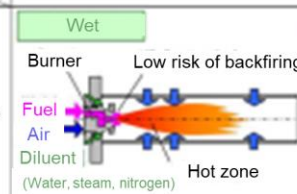
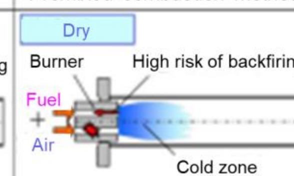
Structure of an aircraft engine

- Air drawn in by the fan is compressed by the compressor, then mixed with fuel and burned in the combustor, and rapidly expelled after passing through the turbine. At the same time, remain of the air drawn in from the fan is also blew off as is. The whole process provides efficient thrust.
- For hydrogen aircraft, the structure of the engine is the same as with existing aircraft, but the combustor's surroundings need to be improved to accommodate hydrogen combustion.



Technical issue: Hydrogen combustion system

- The faster the combustion, the more prone it will be to backfiring. This will lead to combustor damage. In addition, the higher the temperature, the higher the NOx emissions will be.
- Knowledge gained from development in the field of ground-based gas turbines is expected to also be utilized in hydrogen aircraft in order to address the above challenges.

		Diffusion combustion method	Premixed combustion method
Structure			
Features	Advantage	Low risk of backfiring	Low-NOx, highly efficient
	Disadvantages	Reduced plant efficiency (because diluent is fed in to reduce NOx)	High risk of backfiring
NOx reduction		Wet (Diluent must be fed in)	Dry (Diluent does not need to be fed in)
Compatible fuels		Natural gas, hydrogen-rich gas, low-calorie gas	Natural gas

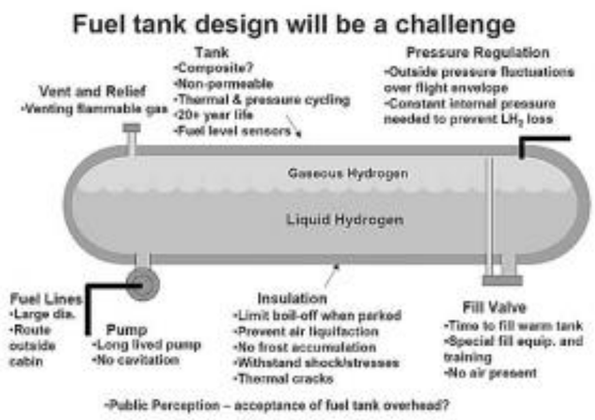
Source: Society of Automotive Engineers of Japan, Inc., "JSAE Engine Review SOCIETY OF AUTOMOTIVE ENGINEERS OF JAPAN Vol. 8 No. 5 2018"

Considering Hydrogen Fuel Storage Tanks and the Airframe Structure

- From the perspective of reducing weight, a practical approach to using hydrogen fuel in aircraft is to store it onboard as a liquid, in which state it will be high in density and low in pressure. Storing liquid hydrogen onboard will require **about four times the volume as for existing fuel**, so the structure of the whole airframe needs to be considered.
- The tanks also need to be made **lightweight, safe, and able to withstand cryogenic temperatures**. In addition, **a fuel supply system** needs to be developed **to supply hydrogen fuel stably from the storage tank to the engine**.

Hydrogen fuel storage tank

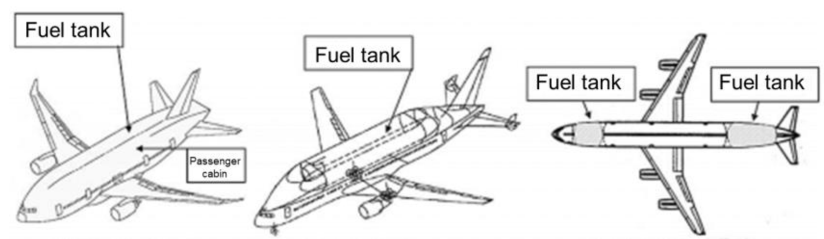
- While liquid hydrogen tanks have been commercialized for rockets, the different requirement characteristics mean that none have been commercialized for aircraft yet.
- For aircraft, they will need to be simultaneously made sufficiently lightweight, durable, and airtight.
- Suitable technologies for fitting in aircraft also need to be developed for the vent pipes, relief valves, pumps, supply valves, etc.



Fuel supply system

- While jet fuel is stored in the main wings, liquid hydrogen occupies about four times the volume. This means the tank placement, etc. needs to undergo a radical review.
- In addition, a supply system needs to be developed to transport the cryogenic hydrogen fuel from the storage tank to the engine.

Example: Considering fuel tank placement



Source: Japan Aerospace Exploration Agency (JAXA), "Current status of R & D on hydrogen fueled aircraft: A review"

Addressing Significant Changes in Aircraft Structure

- Developing hydrogen aircraft for introduction from 2035 onward and airframes that aim to further improve fuel efficiency may require significant changes to the structure of the aircraft. Accommodating these structures will require **significantly increasing the strength of the structural materials**.

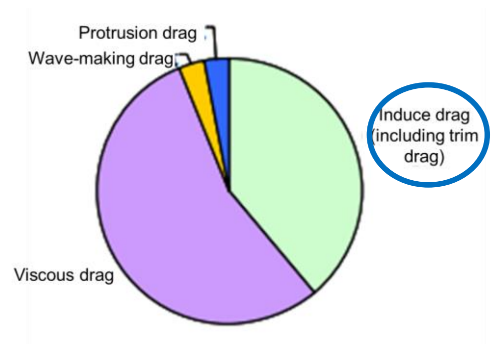
Blended Wing Body released by Airbus

Transonic Truss-Braced Wing released by Boeing

- Although there are issues regarding the feasibility of the airframe form and many other matters, research on the Blended Wing Body (BWB) as a hydrogen fuel airframe is being conducted in various countries.

- Viscous drag (surface friction drag, etc.) and induced drag (drag that arises when lift is generated) make up 90% of a passenger aircraft's aerodynamic drag during cruising, so reducing both of these is an effective approach.

Example: Increasing the aspect ratio of the B787's wings has given it lower aerodynamic drag than conventional aircraft.



Source: International Aircraft Development Fund, "Aerodynamic Technology for Achieving Eco-Friendly Aircraft"

Technological Development to Improve Strength and Reduce Weight

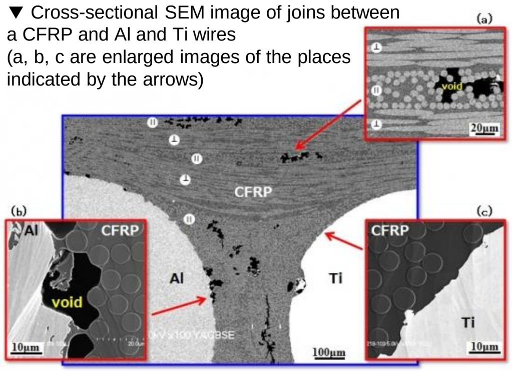
- Accommodating significant changes in the aircraft structure will require **the strength to be improved**. Technology needs to be established to **reduce voids and wrinkles** in composite materials. In addition, **significantly reducing the weight** will require the number of fasteners in joints to be reduced, while maintaining reliability. An important challenge is to reconcile this technological development with achieving production rates and costs that meet demand.

- The difficulty of predicting the failure of carbon fiber composites is a technical challenge. An important task is to proceed with technological development while also recognizing the importance of guaranteeing the safety of carbon fiber composites, establishing methods for evaluating weight savings, and establishing non-destructive inspections with a view toward when the aircraft are in operation.

No voids

- Factors such as air and moisture in the resin can cause voids.
- Voids reduce the strength characteristics of CFRPs, so molding technology needs to be established that will reduce them as much as possible.

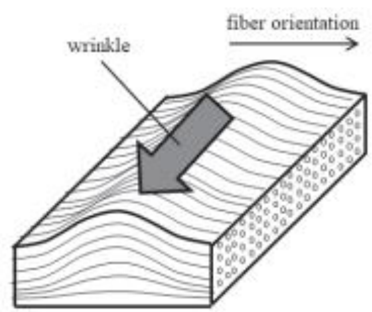
▼ Cross-sectional SEM image of joins between a CFRP and Al and Ti wires
(a, b, c are enlarged images of the places indicated by the arrows)



Source: Nitto Analytical Techno-Center Co., Ltd.'s website

No wrinkles

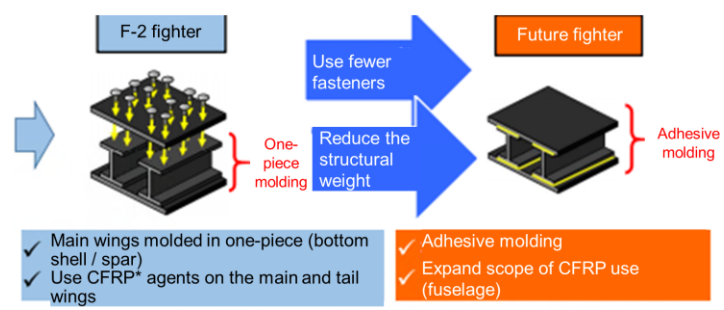
- Wrinkles can occur especially during the process of molding thick CFRPs.
- Wrinkles lead to insufficient rigidity and strength, so molding technology needs to be established that will reduce them as much as possible.



Source: Osaka University, ShinMaywa Industries, Ltd.,
"A Criterion of Wrinkle Generation under Molding of Carbon Fiber Reinforced Plastics"

No fasteners

- Every fastener (nut or bolt) used in a joint adds to the weight and cost.
- Reducing the weight will require establishing joint technology that does not use fasteners, while maintaining the reliability of the joints.



Source: Acquisition, Technology & Logistics Agency, "Study on technology for lightweight airframe structures: External evaluation report"