JAXA Aeronautics Magazine

FLIGHT PATH

Shaping Dreams for Future Skies

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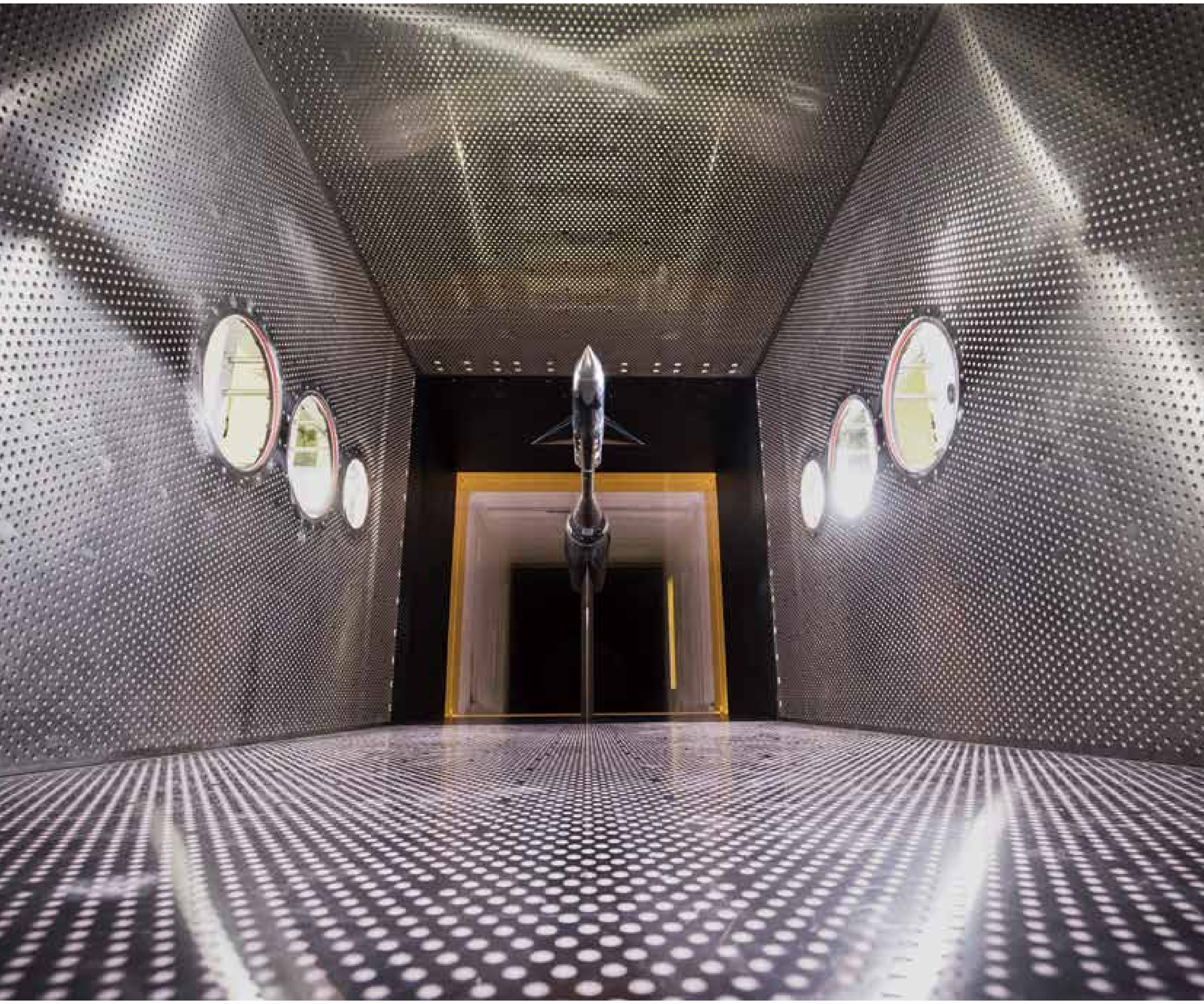

Feature Stories

Future into reality: Inspiring the aircraft of tomorrow with the Sky Frontier program

JAXA's wind tunnel technology – Meeting new needs –

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On the cover: The test section of the 2-m x 2-m transonic wind tunnel from upstream. A wind tunnel model is supported by a sting from behind and located at the center position. The test section has perforated ceiling, floor and side walls, and each side wall have three observation windows.

JAXA Explore to Realize

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Feature Story

Future into reality: Inspiring the aircraft of tomorrow with the Sky Frontier program

The goals of the Sky Frontier program are to create innovative, game-changing concepts for air transportation systems and help further enhance the competitive edge of the Japanese aviation industry. This article introduces JAXA's approach to opening up new potential in future air transportation through an interview with Akira Murakami, Director of the Management and Integration Department.

—— What is the aim of the Sky Frontier program?

The Sky Frontier program is designed to propel R&D efforts that could create new concepts for revolutionizing air transportation systems. This is because creation of game-changing concepts and enabling technologies will help raise the profile of the Japanese aviation industry in longer term.

JAXA's Aeronautical Technology Directorate promotes a three-pillared R&D program underpinned by aeronautical science and fundamental technology research. Sky Frontier forms one of the three pillars, and its targeting time frame makes it distinct from the other two pillars— ECAT (Environment-Conscious Aircraft Technology Program) and STAR (Safety Technology for Aviation and Disaster-Relief Program). The ECAT and STAR initiatives center on R&D for the component technologies and systems required for aircraft and engines in the near future, aiming to deliver results over the next 10 years or so. Sky Frontier, on the other hand, looks further into the future, shaping its R&D activities around what the world might be like in the 2030s to 2050s.

—— Which research field does the Sky Frontier program address?

There are three keywords that explain what we're pursuing through the Sky Frontier program: "high speed," "mobility," and "alternative energy." In other words, we are developing solutions to make air transportation faster, more accessible and usable for passengers and service providers anytime and anywhere, and more environmentally friendly to better serve the needs of society.

—— For starters, could you tell us about the "high speed" initiatives?

JAXA has done a lot of work on quiet supersonic aircraft technology. In 2015, we conducted a flight test to demonstrate the validity of our sonic boom reduction technologies in D-SEND#2, the second phase of the D-SEND project[*1]. We presented the results from the D-SEND#2 project for discussions on sonic boom standards at the International Civil Aviation Organization (ICAO) Committee on Aviation Environmental Protection. That was a big achievement for us, I'd say.

We're also studying hypersonic pre-cooled turbojet engines for Mach 5-class hypersonic aircraft[*2]. In 2016, we successfully completed afterburner combustion experiments for hypersonic turbojets under simulated Mach-4 flight conditions.

—— How about "mobility"?

If you're trying to improve aircraft mobility, one of the keys is enabling aircraft to take off and land vertically—like a helicopter can. That's why we're doing research on a tilt wing vertical take-off and landing (VTOL) aircraft[*3], which combines VTOL ability with the high-speed cruising capabilities of a fixed-wing aircraft. One of the concepts that we're exploring is Quad Tilt Wing VTOL aircraft, which can secure increased stability for take-off and landing. With propellers fixed to each of four wings, the QTW can tilt its wings depending on flight mode—both the wing and propellers face forward in cruise mode but can also be switched to an upward configuration in take-off and landing mode.

We're also working to make helicopters faster. We're exploring the possibilities of compound helicopters that combines standard rotors with a fixed wing and thrust propellers. By adding high-speed capability to mobility, compound designs can further enhance a helicopter's mobility and usability, generating even bigger social value. If an air ambulance could fly twice as fast during rescue missions, it'd be able to expand its coverage from 60% of Japan's land area (the current level) to 90%.

—— JAXA has already done a lot of research on mobility and high-speed technologies for VTOL and supersonic aircraft.

Right. In the 1970s, JAXA carried out several VTOL-related projects, including the development of VTOL engines and attitude control technologies for VTOL aircraft. After that came Asuka[*4], JAXA's short take-off and landing (STOL) aircraft. In 1997, JAXA began the NEXST (National Experimental Supersonic Transport) project to develop drag reduction technologies for supersonic aircraft. The developed NEXST-1 vehicle was successfully flight demonstrated in Australia in 2005. Before all of those projects, though, we'd already been accumulating the fundamental and component technologies integral to each project. All of those efforts become sources for subsequent research, helping us create new key technologies to continue pushing the boundaries forward in pursuit of high-speed and mobility.

—— How about the third keyword, "alternative energy"?

We need to cut down on CO_2 emissions. To do that, we'll have to shift our dependence on fossil fuels to alternative energy sources like electricity and hydrogen. JAXA's Flight demonstration of Electric Aircraft Technology for Harmonized Ecological Revolution (FEATHER), which conducted flight tests in 2015, used a lithium-ion battery for its power source. While we continue our studies on small-sized electric aircraft, we're also starting to look at how we can power aircraft in the future. The key technologies for that effort include hydrogen-fueled superconducting motors and hybrid propulsion systems, which we're now at work on.

—— JAXA works on "Eco-wing technology" with a short time frame as part of the Sky Frontier program.

With Eco-wing technology, we're trying to enhance fuel efficiency by reducing air-resistance and weight. Our target is to develop competitive ideas and key technologies for the next generation mid-sized passenger jet aircraft, which will likely start taking to the skies in the 2020s or 2030s. We've got plenty of projects in the Eco-wing pipeline, like HOTALW (for measuring wing deformations via optical fiber sensors), FINE (for reducing skin friction on airframes), and, looking a bit further into the future, morphing-wing technologies (for reducing air resistance by ensuring smoother flight by deforming wing configurations).

—— What do you think is the key to the success for Sky Frontier?

As a National Research and Development Agency, JAXA has an obligation to benefit industry and contribute to society. While there's definitely a palpable demand for speed, mobility, and new energy sources, those developments are still just "wants"—innovations that'd be nice to make. We want to turn those "wants" into "needs," the kinds of advances that the world depends on. To do that, we have to keep showing society that they're feasible. The way I see it, Sky Frontier embodies the kind of R&D that can validate new concepts and transform "wants" into "needs."

Therefore, it is important for JAXA to foster as much talent as possible. The more researchers we have, the more concepts and ideas we can come up with. We might never have the numbers that organizations in the West do, but we've developed pioneering concepts that go far beyond what our international counterparts are doing—take D-SEND, for instance. To make meaningful progress, the future aviation technologies that we're pursuing through the Sky Frontier program are going to rely on collaboration: institutions and companies from around the world working as partners, not rivals, to lay out ideas and elevate concepts to a higher dimension. As long as we have the key technologies for those concepts, we'll be in position to carve out a stronger foothold in the global arena. It is also important for JAXA to create an environment where researchers can dive deep into new ideas and see where they could lead.

Akira Murakami
Director
Management and Integration
Department

*1: Drop test for Simplified Evaluation of Non-symmetrically Distributed sonic boom; see page 5 for details.
*2: More information on hypersonic passenger aircraft technologies is available online (http://www.aero.jaxa.jp/eng/research/frontier/hst/).
*3: More information on VTOL/STOL aircraft technologies is available online (http://www.aero.jaxa.jp/eng/research/frontier/vtol/).
*4: A short take-off and landing (STOL) experimental aircraft developed based on the C-1 transport aircraft; equipped with four FJR710 engines, the aircraft completed 97 flight tests from 1985 to 1989.

http://www.aero.jaxa.jp/eng/research/frontier/

Feature Story Related technology

The Sky Frontier program pursues "high speed," "mobility," and "alternative energy" to make future air transportation systems faster, flexible and more environmentally friendly. Here, we introduce some key technologies addressed in Sky Frontier program.

Sky Frontier: Creating new key technologies

Supersonic passenger aircraft

Making silent supersonic passenger aircraft a reality

The Concorde, a supersonic passenger jet jointly developed by the United Kingdom and France, made its debut in 1969. Hailed as a "supersonic dream," the Concorde was a significant innovation—but also suffered from two major weaknesses: economic inefficiency, which came from its fuel-hungry design for supersonic flight, and substandard environmental performance, due to its loud noise both during take-off/landing and during supersonic cruise. To create a viable supersonic transport (SST) aircraft, developers need to clear these two challenging hurdles.

JAXA has done substantial research on the various elements of SST development. Looking to improve fuel efficiency, for example, JAXA developed and flight demonstrated drag reduction technology with the NEXST-1 small supersonic experimental plane in 2005. Other efforts focused on noise issues, especially the sonic booms generated by shockwaves from supersonic flight. Through the Drop test for Simplified Evaluation of Non-symmetrically Distributed sonic boom (D-SEND), JAXA flight demonstrated a low-sonic-boom design concept (see the column for details). Reactions to noise levels are largely subjective, but JAXA's D-SEND project has helped make loud booms—equivalent to a lightning strike—sound as soft as a knock at the door.

Yoshikazu Makino
Senior Researcher
Next Generation Aeronautical Innovation Hub Center

"In October 2015, we presented our analysis results from D-SEND#2 at the International Civil Aviation Organization (ICAO) working group meeting in Montreal, Canada," says Yoshikazu Makino, Senior Researcher at the Next Generation Aeronautical Innovation Hub Center. "The reaction was really positive, I think. Our low-sonic-boom design concept and the D-SEND#2 analysis results, especially our insight into atmospheric turbulence effects on sonic booms, generated quite a bit of interest among the regulators and researchers there." The sonic boom-related data from the D-SEND project played a big role in the ICAO's discussions on sonic boom standards.

In the effort to minimize sonic booms, research institutions from around the world are currently bringing their ideas and research results together to devise the optimal approaches. JAXA, for example, is working on joint research with the National Aeronautics and Space Administration (NASA; US) on projects that will likely make use of JAXA's analysis tools for examining the impact of atmospheric turbulence. JAXA has started joint research with other foreign research institutions—the French Aerospace Lab (ONERA) and German Aerospace Center (DLR)—and continues collaborating on airframe designs that can minimize sonic booms.

Developing system integration technologies for SST

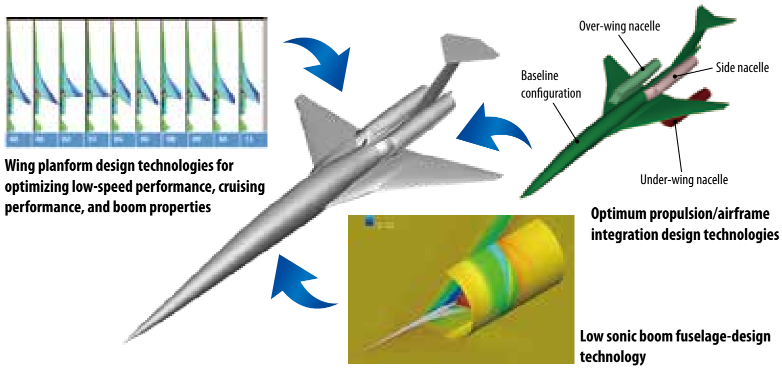
Following the completion of the D-SEND project, JAXA took the next step in FY2016 by launching "R&D for System integration of Silent SuperSonic airplane technologies(S4)." This research explores design technologies for optimum system integration that meets multiple SST requirements—lower noise levels during takeoff and landing procedures and lighter airframes, in addition to low sonic boom and low drag, for example—at the same time.

Low-aspect-ratio*1 wings like delta wings are ideal for supersonic flight, for example, but their aerodynamic characteristics lead to fuel inefficiency at subsonic speeds. JAXA is studying how to create optimized designs for low-aspect-ratio wings with better efficiency at low speeds using computational fluid dynamics (CFD) and other resources. We are working on engine technologies, too. Due to their low bypass ratios, engines capable of supersonic flight are noisier than the engines on normal subsonic passenger aircraft. To get around that drawback, JAXA is also looking at ways to maximize bypass ratios while still maintaining supersonic flight and nozzle configurations that could bring noise levels down. "I want to see those efforts make progress over the next several years," Makino says, "I want to do technical demonstration testing on a test aircraft with a small-scale engine by the early 2020s."

*1: The aspect ratio of a wing, expressed as (Wing span)^2/wing area; in normal passenger aircraft, a higher aspect ratio produces a higher lift-to-drag (L/D) ratio.

The D-SEND project

D-SEND is a two-phase project. For D-SEND#1, the first phase, JAXA researchers dropped two types of axisymmetric bodies from a large atmospheric balloon, measured the resulting sonic booms on the ground and in the air, and gathered basic reference data for comparison purposes. The second phase, D-SEND#2, measured the sonic booms during the flight of an experimental aircraft featuring JAXA's low sonic boom design. The data from D-SEND#2, which JAXA conducted in 2015, demonstrated the technology's ability to reduce sonic booms (see Flight Path No. 9/10).



Using years of accomplishments in component technologies to establish integrated design technologies

JAXA is currently planning to prototype its compound helicopter (here, in a CG rendering) as a scale model. The electric fans on both tips of the main wing (the items circled in red) counteract the torque and generate around 10% of the total required thrust force.

Compound helicopters

Making helicopters faster to unlock new possibilities

Helicopters (rotary-wing aircraft), which do not need a runway for takeoff and landing procedures, play an important role in Japan, where mountainous terrain and numerous islands create considerable constraints. However, rotary-wing aircraft tend to fly more slowly than airplanes (fixed-wing aircraft). Emergency medical service helicopters, for example, can only travel across roughly 60% of Japan's total land area in the 15 minutes—the window with the highest survival rates for emergency response. If helicopters could fly twice as fast as they do now, they could expand their coverage fourfold each to cover approximately 90% of Japan from existing base hospitals.

Yasutada Tanabe
Associate Senior Researcher
Next Generation Aeronautical Innovation Hub Center

JAXA is currently researching compound helicopters that combine both high speeds and excellent mobility. In addition to boasting hovering capabilities and vertical take-off and landing functionality of the helicopters, JAXA's compound helicopter concept enables higher-speed flight than conventional designs by using an aft-mounted propeller to create thrust and a main wing on the sides of the airframe to create lift.

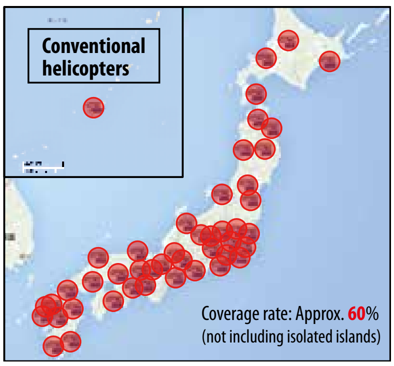
One of the most distinctive components of JAXA's compound helicopter is its electric anti-torque system (see the CG rendering at the top-right corner). "Basically, the system uses electric fans on the tips of the main wing to counteract the torque (rotating force) that the main rotor creates on the airframe," explains Yasutada Tanabe, an Associate Senior Researcher at the Next Generation Aeronautical Innovation Hub Center. The electric fans in the concept have electric motors, which eliminate the need for any complicated mechanisms for transmitting the torque. With no direct link to the main engine, the design thus minimizes the number of moving parts and lowers the risk of accidents when people are in the vicinity of a parked helicopter. The JAXA design would also be the same size as a regular helicopter, making it compatible with existing facilities on the ground.

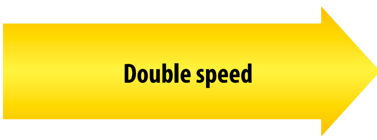
JAXA is now conducting experiments with a modified commercial radio-controlled helicopter. Using its computational fluid dynamics (CFD) tools, JAXA is also performing tests to assess interference between the rotor and the main wing. In FY2018 and beyond, we are planning to turn new designs into sub-scale prototypes and wind-tunnel models for flight tests and wind tunnel tests.

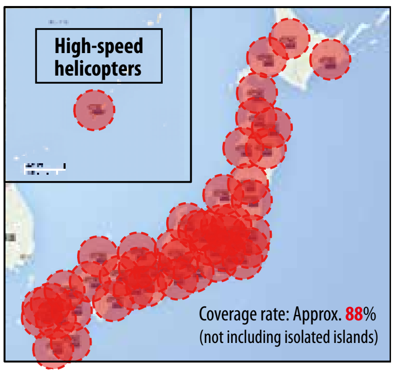
The radio-controlled test helicopter performs a flight experiment

The radio-controlled test helicopter with its outer casing removed

Emergency medical service helicopter coverage in Japan







Notes:
- Assuming that conventional helicopters fly at a speed of 250 km/h
- Assuming that the helicopters use existing base hospitals
- Coverage rate calculated based on mainland area only (not including isolated islands)
- Assuming that the coverage is circular, not accounting for the effects of mountains, etc.

The figures compare the area that helicopters can cover within 15 minutes from existing base hospitals; the figure on the left shows the areas for conventional helicopters, while the figure on the right corresponds to high-speed helicopters flying twice as fast as conventional helicopters (as of August 2015).

A conceptualization of a small electric aircraft in an urban setting (top)
The technology enables aircraft to take off and land quietly at night (bottom)

FEATHER

JAXA successfully flies a manned electric aircraft featuring unique technologies

As aircraft continue to evolve, electrification has emerged into the global spotlight as a viable technology for future developments. By replacing conventional engines with electric motors, the electrification approach limits emissions of CO_2 and other exhaust gases and minimizes noise—changes that make for environmentally friendly results. Electrification has already made its presence felt into the automotive industry, where manufacturers are rolling out electric cars, fuel-cell cars, and more.

JAXA has been studying electrification technologies for aircraft applications. One initiative was "Flight demonstration of Electric Aircraft Technology for Harmonized Ecological Revolution" (FEATHER; see the column for details), which began in 2014. According to Akira Nishizawa, Associate Senior Researcher at the Next Generation Aeronautical Innovation Hub Center, "Companies and other organizations from outside the aviation industry are contacting us about our electrification work. With the interest levels always growing, we're busy exchanging ideas on the next phases of electric aircraft research."

JAXA launches collaborative research with DLR

Akira Nishizawa
Associate Senior Researcher
Next Generation Aeronautical Innovation Hub Center

Following the success of the FEATHER project, JAXA launched a new joint-research project in FY2016 with the German Aerospace Center (DLR), which is also active in promoting electric aircraft research. The purpose of the joint initiative is to flight demonstrate electric propulsion technologies that could enhance aircraft safety performance and to integrate insight from test data analyses to drive progress toward the development of future small electric aircraft. The main objective of FEATHER was to perform flight demonstrations of JAXA's unique electric propulsion system, so the team used an airframe from the commercial market. For the DLR-JAXA joint research, JAXA-developed electric motor will power DLR's four-seater electric aircraft that employs a hydrogen-fuel cell system. The electric motor is a modified version from the FEATHER project. By giving the FEATHER motor a power upgrade and a self-diagnosis function for use in the event of a malfunction, JAXA has created an improved, safer motor system. Over the course of its joint-research arrangement with DLR, set to conclude in 2020, JAXA will work to validate a variety of changes, including how electrification reduces fuel consumption, how fuel-cell batteries extend flight ranges, and how functional improvements to electric motor technology enhance safety performance.

Electric aircraft set a new course for the future

The aviation industries in Europe and the United States, where aircraft represent a part of the basic social infrastructure, are positioning electrification as an ideal for future development. Electric aircraft are going to be hitting the market in the America sky sports sector, for example, and other non-sports markets are formulating certification criteria for electric aircraft. "Air taxi" startups are developing concepts for electric VTOL (vertical takeoff and landing) aircraft, too.

JAXA will continue to push research into electric aircraft. One initiative is an investigation into possible concepts for a hybrid engine combining a gas turbine with a fuel cell. Another project centers on the load change*2 that occurs in a hybrid engine powering an electric aircraft in flight, with researchers examining how the load change affects the engine's cycle characteristics and other attributes. The second effort makes substantial use of data from the FEATHER project.

"We're interested in creating intelligent, optimized setups for electricity usage in electric aircraft," says Nishizawa. Making electricity usage intelligent, or "smart," involves looking at an electric aircraft's power usage and then finding and implementing the ideal distribution of the multiple power sources onboard. By integrating technologies for smart electricity usage with battery technologies, one of Japan's current strong suits, JAXA stands to make an important impact on the future of the country's entire industrial sector.

*2: The amount of output that an engine needs to generate is constantly changing in accordance with wind conditions and other factors.

Flight demonstration of Electric Aircraft Technology for Harmonized Ecological Revolution (FEATHER)

The electric motor-driven glider used for the FEATHER project

The FEATHER project aimed to flight demonstrate the performance of an electric propulsion system. Using a commercial motor glider, the team removed the aircraft's reciprocated engine, replaced it with the developed electric motor powered by a lithium-ion battery, and conducted flight demonstration tests in 2014 and 2015. During testing in February 2015, the FEATHER aircraft became the first of its kind in Japan to perform a full-fledged manned electric flight—including takeoff, landing, and turning—at an altitude of around 600 m.

FEATHER successfully demonstrated the effectiveness of JAXA's unique redundant motor and regenerative air brake technologies. The redundant motor uses four serially linked electric motors to drive the propeller, making it possible to maintain flight with the remaining motors in the event that a motor fails. The regenerative air brake, meanwhile, uses the motor as a generator and the rotation of the propeller to supply an aircraft with power and aerodynamic drag during flight (see Flight Path No. 9/10).

Eco-wing technology

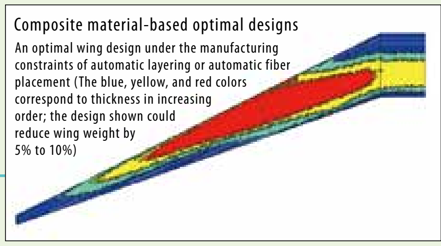
While Sky Frontier has its sights set on researching and developing innovations for several decades into the future, JAXA is also working on technologies that industry will be needing in the next five to ten years. This section goes deeper into one of these initiatives: "Eco-wing technology."

Improving airframe performance to boost fuel efficiency and reduce noise

According to Toshiya Nakamura, Deputy Director of the Next Generation Aeronautical Innovation Hub Center, there are two main focuses of Eco-wing technology: "We want to improve fuel efficiency through enhanced aerodynamic performance and lighter airframe structures, first of all," he explains, "and establish the system evaluation technologies for assessing the corresponding performance." As part of the Eco-wing technology, JAXA is carrying out various research activities such as the Flight Investigation of skiN-friction reducing Eco-coating (FINE), which aims to reduce the aerodynamic drag resulting from turbulent friction on airframe surfaces, and the High performance Optical fiber sensor flight Tests for AirpLane Wing (HOTALW), which serve to demonstrate technologies for measuring airframe strain via optical fiber sensors. The effort also includes research on winglets and boundary layer transition control to reduce aerodynamic drag, for example, and making aircraft lighter by reducing and optimizing the thickness of composite-material layers. The guiding target is to build a range of technologies capable of effecting a 15% reduction in fuel consumption by 2025, but our initiatives are striving to go even further and lay the groundwork for dramatic improvements in the environmental performance of future aircraft.

Measuring strain distribution across entire wings with optical fibers

An example of Eco-wing technology is the strain distribution measurement technology that JAXA is developing in the HOTALW (High performance Optical fiber sensor flight Tests for AirpLane Wing) project*3. An airframe and wings experience deformation during flight due to the effects of aerodynamic forces like lift, drag and gravity. To better understand strain distribution during flight, the HOTALW project team places optical fiber sensors on the structure of "Hisho," JAXA's jet research aircraft (Flying Test Bed), and measures the time-varying strain that wings experience in flight. Unlike a standard strain gauge, a single strand of optical fiber can measure longitudinal strain at thousands points, with spatial pitch of less than 1mm . HOTALW thus takes advantage of that technology by using OFDR-FBG optical fiber sensors*4 with enhanced responsivity and spatial resolution—improvements that came about through JAXA research efforts.

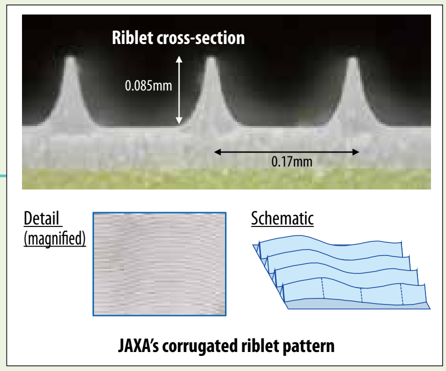

Composite material-based optimal designs
An optimal wing design under the manufacturing constraints of automatic layering or automatic fiber placement (The blue, yellow, and red colors correspond to thickness in increasing order; the design shown could reduce wing weight by 5% to 10%)

The HOTALW flight tests in 2016 confirmed that JAXA's distribution measurement system using optical fiber sensors (OFDR-FBG system), attached to the pressurized parts of the fuselage, could measure in-flight strain changes. The readings agreed well with the motion of the airframe, corroborating the measurements. In the autumn of 2017, JAXA plans to bond optical fiber sensors on the bottom surface of the wing of Hisho to examine wing deformations during flight.

Knowing exactly why and how wings experience deformations during flight would be extremely valuable in designing lighter structures and maintaining structural safety. With that kind of knowledge, it might also be possible to minimize aerodynamic drag through flight control or wing design. The data from the HOTALW project's optical fiber sensors could also be an important asset in shaping controls for morphing wings (discussed later), another research initiative underway at JAXA.

Flight demonstrations of riblets, which reduce turbulent skin-friction drag on airframe surfaces

While HOTALW focuses on reducing structural weight through structural functionalization, FINE seeks to improve lift-to-drag ratios while cruising by reducing skin friction.



JAXA's corrugated riblet pattern

JAXA developed this design, with a groove of 0.1 mm or less deep, through in-house research

For the FINE project, researchers are examining the way to reduce skin friction by coating airframe with a "riblet" pattern of fine grooves. The riblets feature a unique, three-dimensional corrugated design, which JAXA devised through research. By flying the "Hisho" jet research aircraft with the riblet coating, the FINE team is going to verify the effectiveness of the riblet in reducing skin friction. While institutions in Europe and the United States are studying riblets, which have the potential to reduce skin friction levels, the efforts have yet to result in any practical applications. To get a better idea of how riblets reduce drag, JAXA is trying to measure flow velocity distribution within the boundary layers on aircraft in flight using a "pitot rake" (a measurement instrument)—and that initiative could have a significant impact on future endeavors. Flight tests began in May 2017.

Another segment of the Eco-wing effort is research on morphing wings, which will likely start seeing demand more than 10 years down the road. Whereas the flaps, elevators, and other flight-control surfaces on conventional aircraft move via hinges, morphing wings fuse the wings and flight-control surfaces together to create an almost birdlike structure that changes shape in a smooth, gapless fashion. Not only does that type of mechanism reduce the amount of drag that occurs when the aircraft's flight-control surfaces move, but it also enables more flexible control over aerodynamic load than conventional designs do. JAXA is also working on research into other topics, such as tweaking engine layouts and airframe configurations to bring noise levels down.

Eco-wing technology: major research themes

- Improving airframe performance
  - Improving cruising lift-to-drag ratios — Multidisciplinary integrated design technology
    - Reducing induced drag — High-aspect-ratio wings; Advanced wing-tip configurations
    - Reducing skin friction — Natural laminar flow wing design; Turbulent skin friction reduction technology → FINE; Hybrid boundary layer control technologies
  - Reducing structural weight
    - Developing new composite material design technology — Non-linear analysis technology
    - Reducing weight through new materials — Design technologies for composites with thin ply prepregs and optimal structures via automatic fiber placement
    - Reducing weight through structural functionalization — Structural health monitoring → HOTALW; Load-control technology

Toshiya Nakamura
Deputy Director
Next Generation Aeronautical Innovation Hub Center

*3: See Flight Path No. 15/16 for more information.
*4: See Flight Path No. 5/6 for more information.

Feature Story

JAXA's wind tunnel technology – Meeting new needs –

Shigeru Hamamoto
Director
Aerodynamics Research Unit

A "wind tunnel" is a test facility that creates an artificial airflow to measures the forces on and airflow around a wind tunnel model in a test section. The history of wind tunnel technology traces back more than a century; the Wright brothers, who successfully conducted the first manned, powered flight in 1903, used a wind tunnel to conduct countless tests leading up to their actual flight tests. JAXA has the largest cluster of aeronautical wind tunnels in Japan, playing a pivotal role for Japan in advancing aviation-related research. With aircraft always requiring safer, higher-performance designs, wind tunnels need to meet a constantly diversifying array of needs. What does that never-ending evolution entail? Shigeru Hamamoto, Director for the Aerodynamics Research Unit, introduces JAXA's continuous efforts to keep improving wind tunnel technology to meet the needs of society.

Wind tunnels: Aircraft research and fundamental technology

—— The Chofu Aerospace Center is currently home to 14 wind tunnels. When was the first one installed?

After the conclusion of World War II, the GHQ prohibited Japan from conducting any aircraft-related research. When the ban ended in 1952, the Japanese government needed to get its testing facilities up to speed as quickly as possible to fill that seven-year gap. The process of installing and maintaining wind tunnels involved massive costs, however, so the government decided to consolidate all the related equipment at the National Aeronautical Laboratory of Japan (later the National Aerospace Laboratory of Japan and the predecessor of JAXA's current Aeronautical Technology Directorate) and allow relevant administrative organizations, universities, companies, and other entities to use the facilities. Work on the first wind tunnel, a transonic wind tunnel that has a 2-m x 2-m test section, was completed in 1960. Designed to examine the aerodynamic characteristics of aircraft at transonic speeds (speeds around the speed of sound, or Mach 1), the cruising speeds of jet aircraft, the NAL's transonic wind tunnel served as a kind of testing bridge from propeller aircraft to jet aircraft. The institution later completed a 1-m x 1-m supersonic wind tunnel in 1961 and a 6.5-m x 5.5-m low-speed wind tunnel in 1965.

—— Wind tunnels were an essential part of getting Japan's aircraft research back on track, then.

Right. Before you actually fly a designed aircraft, you have to safety-test it in a wind tunnel. At the time, Japan was focused primarily on getting its research back up to speed—but a wind tunnel is a complex array of different technologies. Just making one didn't mean that it'd be able to deliver results right out of the gate. You needed a solid base of fundamental research: insight into how to correct the interferences of the walls and the stings supporting the models inside, for example, and how to gather data that would best approximate the conditions that the aircraft would encounter in actual flight. The researchers at the National Aerospace Laboratory back then were the leading minds in aerodynamics field, and they spent their first 10 years or so concentrating on mastering wind tunnels. When you look at where we are today, you can trace the progress back to the technologies that came out of that process.

—— How do JAXA's wind tunnels play into Japan's aircraft development?

Over the course of our history, I'd say that the research and development on "Asuka"*1—a short takeoff and landing (STOL) experimental aircraft—was the initial beneficiary. Wind tunnels were also used to develop space vehicles such as "HOPE" (H-II Orbiting Plane) and "HYFLEX" (Hypersonic Flight Experiment), too. In recent years, our wind tunnels have provided a variety of aerodynamic data for a Japanese commercial aircraft, the MRJ. Basically, the wind tunnels at our Chofu site have played into virtually all of Japan's aircraft development (see the Figure).

Having the clear, concrete objective of developing an actual aircraft is a big boost to motivation—it fuels progress in technological research. You know exactly what kinds of data you'll need to get the aircraft into the air. With that impetus, we've been able to accelerate our research and development on technologies for wind tunnel testing and measurements—and those new technologies have helped make the flight tests a success. Although I never had a direct hand in those projects, I've gotten some good, practical experience with wind tunnel testing as a wind tunnel engineer. That's helped me get where I am today.

—— What went into the MRJ development effort?

When the people from Mitsubishi Heavy Industries, Ltd. first approached JAXA, they told us that they couldn't do the development with the data quality obtained via the existing 2-m x 2-m transonic wind tunnel; they needed help enhancing the accuracy of the test data. We knew that we had to do whatever we could to meet that need. Our wind tunnels had always been part of Japan's aircraft-development projects, but the MRJ presented new demands for wind tunnel testing: As a commercial aircraft, the design not only had to satisfy safety requirements but also needed to meet economical requirements such as certain fuel-efficiency levels. The wind tunnel testing, then, had to produce results with a

*1 : A short takeoff and landing (STOL) experimental aircraft developed based on the C-1 transport aircraft; equipped with FJR710 engines, the aircraft completed 97 flight tests from 1985 to 1989 higher degree of accuracy. With that objective in place, we got to work on making our test data even more accurate. The effort ended up paying dividends, laying the groundwork for high-reliability data that made a positive impact on the MRJ development initiative. The project used our 2-m x 2-m transonic wind tunnel, mostly, but also incorporated the 6.5-m x 5.5-m low-speed wind tunnel to evaluate takeoff and landing performance. On our side, the initiative hinged on having explicit technical objectives in place. JAXA researchers worked harder than ever to make good on those commitments.

How wind tunnels and CFD complement each other

—— Wind tunnels have more than a century of history. Are they playing different roles in aircraft design today? What kinds of challenges lie ahead for wind tunnel technology?

Wind tunnels are still essential elements in terms of manufacturing safer, higher-performance aircraft. The changes we're seeing now, though, have to do with the fact that aircraft need to reach higher performance and safety levels than ever before—demands that deepen the complexity of the design. The challenges, I think, revolve around the need to produce larger volumes of higher-accuracy data as quickly as possible, all under those kinds of rigorous conditions. When I look at the current trends, with aircraft designs growing increasingly complex, I have a feeling that organizations are going to be spending less and less time on wind tunnel testing but needing more and more wind tunnel test data. To get all the data they need for design purposes, manufacturers can't rely on wind tunnels alone. Computational fluid dynamics (CFD) are what provide the rest of that vital information. The effort to develop the Boeing 767, which made its first flight in the early 1980s, was a wind tunnel-oriented project. That approach shifted in the 1990s with the development of the Boeing 777, however, whose design incorporated CFD. As CFD technologies have continued to make significant progress in both quality and quantity, manufacturers can now use CFD to do most of the aerodynamic performance predictions that they've traditionally used wind tunnel testing for.

—— Do you think CFD is going to be replacing wind tunnels, then?

Eventually, yes, but not for a while yet. CFD is perfectly adequate when it comes to analyzing the aerodynamic characteristics of an aircraft under cruising conditions, but it's not at the level where it can analyze more complicated phenomena—situations where airflow separates from the surface of the wing when the aircraft assumes a high angle of attack during takeoff and landing, for example, or drag-inducing boundary layer transitions. To create the kind of aerodynamic database to design an aircraft with maneuverability, meanwhile, you have to gather a broad range of data on slightly different configurations and attitudes—and wind tunnel testing is still the most effective way to do that. We shouldn't occupy ourselves with weighing the relative merits of wind tunnels and CFD, though: At this stage, we should be focusing on how to combine the unique strengths of wind tunnel testing and CFD technologies to make the design process as efficient as it can be.

Wind tunnels and CFD also share complementary, mutually reciprocal connections. The CFD technologies that we have at our disposal right now are based on mathematical modeling of flow equations. To ensure the reliability of CFD results, you need to validate the calculations in comparison with data from wind tunnel tests. If you can make wind tunnel data reliable, then, you automatically make the CFD data more reliable. CFD complements wind tunnels, as well. Using CFD, you can correct wind tunnel data for the interference of the walls and stings—and thereby improve the overall accuracy levels of wind tunnel data. Those technical links create synergistic effects, making the dual approaches more than just two techniques for dividing up the testing procedures for aircraft design.

The need for actual flight-test data

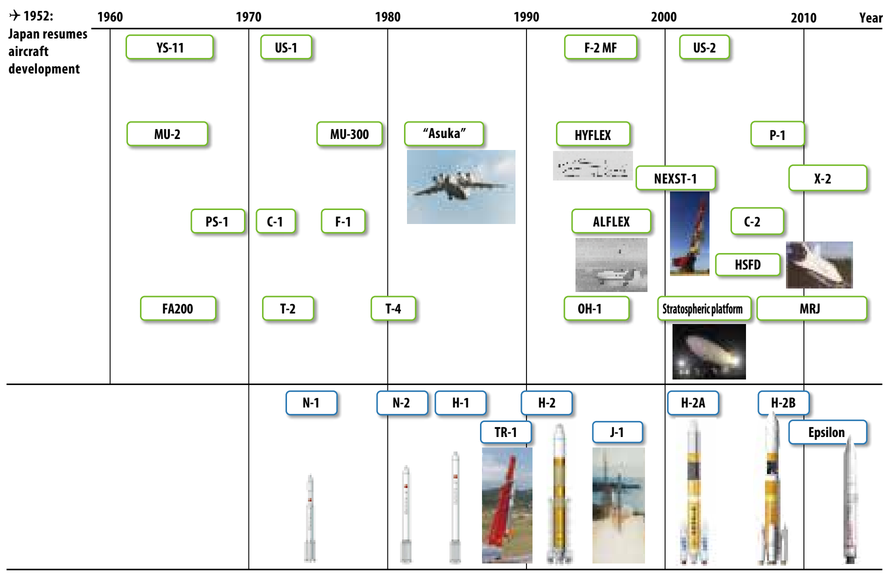
—— What's the current relationship between flight tests using actual aircraft, wind tunnel testing, and CFD?

To design a better aircraft, you need to fuse together all three: wind tunnel testing, CFD, and flight testing. One of the main objectives of wind tunnel testing and CFD is making predictions of how an aircraft is going to behave in actual flight, and you need flight data to make those predictions more accurate. Modern-day wind tunnels have a Reynolds number two orders of magnitude smaller than full scale—which means that the model inside a wind tunnel is at least 1/10 as small as the actual aircraft. Flying the actual aircraft, therefore, is the only way to gather aerodynamic data for the aircraft in a flight environment. The same goes for data on integrated performance components, such as trim, steering, and climbing performance. You can't get adequate information on overall performance from wind tunnel testing or CFD, which both involve accumulating data from multiple simulations—you need to fly the aircraft.

While wind tunnel testing and CFD generate data in rather ideal environments, the challenges that come with obtaining measurements under actual flight conditions make it hard to gather flight test data that you can compare with readings from wind tunnel tests and CFD. There's still quite a gap there. To bring all those measurements into a more compatible framework, we're using the "Hisho," JAXA's jet research aircraft to develop technologies that could facilitate comparisons between wind tunnel data, CFD data, and flight-test readings.

—— What about "hybrid wind tunnels," which combine wind tunnel testing and CFD?

To meet future needs, we've developed a digital/analog hybrid wind tunnel technology named DAHWIN, doing a variety of demonstrations along the way. The DAHWIN technology, which we've only used for internal projects thus far, takes the conventional testing approach a step further to obtain data much more efficiently and generate results that have a real impact on designs. As we move into the future, we're hoping to extend applications of the DAHWIN technology beyond our 2-m x 2-m transonic wind tunnel, too; our plan is to roll the technology out to the 6.5-m x 5.5-m low-speed wind tunnel and 1-m x 1-m supersonic wind tunnel, as well. We also want to offer integrated simulation



The history of aircraft, experimental spacecraft, and rocket development using JAXA's wind tunnels platforms that deliver user-friendly environments for a sweeping range of testing activities—from CFD and wind tunnel testing to engine system testing. It's our job to provide the fundamental technology that the Japanese aircraft industry needs to keep growing. We want to keep delivering on that responsibility in tangible, concrete ways.

Wind tunnel measurement technologies move on to the next phase

—— What can you tell us about the future of wind tunnel measurement technologies?

While meeting an ever-diversifying, increasingly complex set of testing needs, we also have to develop new testing technologies to provide the necessary data for validating CFD results as we work to establish better integration with CFD. Advances in CFD technology come in a constant stream, so validating CFD results at more detailed, meticulous levels means bringing the requisite wind tunnel data to more detailed, meticulous levels, too. We need to be able to measure things we've never been able to measure. Aiming to stay in step with global trends, JAXA has developed advanced technologies such as PIV*2 (particle image velocimetry) and PSP*3 (pressure-sensitive paint). We used to use "probes" to measure pressure and velocity, but that approach only let us gather readings at specific "points." That's what makes PIV and PSP such groundbreaking technologies—they obtain pressure and velocity readings in "planes" instead of points. Over the last two decades, we've seen the technologies find practical applications. PSP, in particular, is a technological field where JAXA is a major forerunner. Using these advanced resources lets users gather plane-form wind tunnel test data for comparisons with CFD, enabling higher-accuracy analyses. PSP also played a part in the development of the MRJ. Before, we only had a tiny amount of information to base our accuracy evaluations on. Now, however, we can do the evaluations using hundreds of times the amount of information that we used to have access to—and that's given us the ability to make substantial reductions in optimal solution error.

Shigeru Hamamoto stands in the test section of JAXA's transonic wind tunnel

—— What are the next steps?

Measurement technologies are shifting from points to planes and, eventually, from planes to "spaces." The last 20 years have represented the establishment phase for planar measurement technologies like PIV and PSP. As we transition into the next phase, I think we're going to be seeing a need for spatial measurements—readings of pressure distributions in three dimensions. A wind tunnel has a test section to set up the model, and we want to know the pressure distribution of the space inside the test section where the air is flowing. We're starting to think up ideas for new measurement technologies along those lines right now. In terms of planar measurements, we're taking on new challenges, too. We're exploring the possibilities of embedding sensors into models to measure deformation, for example, and measuring surface friction .

—— What has JAXA done to boost measurement accuracy?

We've developed technologies to calibrate an internal force balance, which goes between the model and the support structure in the test section and measures the aerodynamic force acting on the model. Basically, the accuracy of the balance-calibration testing process determines the accuracy of the aerodynamic force measurements. Our efforts in balance-calibration technologies used to lag behind the progress that our foreign counterparts were making, but we're taking big strides now, catching up, and making the rest of the world take notice.

Improving calibration accuracy is an extensive process, one that requires its share of big advances and plenty of minor tweaks, too—and if you don't check every last item off the list, you can't reach your goal. When we were working on our automatic calibration system, we originally set it up on a concrete base. The problem we ran into was that the concrete would gradually shrink over time, meaning that the criteria would shift during protracted measurement procedures. To get around that issue, we went back to the drawing board, created new supports for the laser displacement gauge, bolstered the base, and reworked the setup so that the gauge remains independent from the system. That's the kind of attention to detail that goes into achieving world-leading accuracy levels. We've showcased our automatic balance calibration system at international workshops to widespread acclaim, with some potential users already making offers on using JAXA's technology to calibrate their balances.

—— There are probably some social needs for low-noise wind tunnels, too.

The push for quieter aircraft is a global trend. To bring down noise levels around airports and create environmentally friendly aircraft, you need noise reduction technologies—which means you also need ways to get accurate measurements of noise reductions. That's one of the reasons we launched the FQUROH project*4, which involves performing actual flight tests for measurement purposes. You can only do that after a certain phase, however; at the technology development stage, you also need to do on-the-ground evaluations via wind tunnel testing. Using our 2-m x 2-m low-speed wind tunnel, we worked to limit the amount of noise occurring in the wind tunnel itself as a way of evaluating noise output more accurately during takeoff and landing procedures.

Meeting society's needs

—— What does the future hold for wind tunnels, in your view?

When you think of how wind tunnels are integral to gathering data for validating CFD, explaining fluid phenomena, and demonstrating component technologies, it's safe to say that they'll continue to be essential pieces of equipment. JAXA's wind tunnels are now showing signs of aging . We're getting to the point where we'll have to start thinking about new wind tunnels for the coming generations. We're now discussing what kinds of wind tunnels we'll be needing in the future.

—— Industrial companies and universities have wind tunnels, too. What kinds of roles do JAXA's wind tunnels play?

As the numbers of test data points that go into aircraft design continue to climb, it's our mission to implement higher-level testing technologies with the power to enable testing that's both accurate and data-productive. On the horizon, further into the future, is the kind of integrated simulation platform I was talking about earlier. Another way we can make the most of our wind tunnels is keeping the technology levels up. I think I speak for everyone working with JAXA's wind tunnels when I say that our organization is the "center of excellence" of Japan's wind tunnel technologies. While those technologies keep finding their ways into uses at companies and universities, we're committed to leveraging our strengths into keeping those assets as sharp as possible from a technical standpoint. On the operational side, meanwhile, we've been working hard on quality management for decades—we acquired ISO9001 certification as early as 15 years ago. Without that kind of thorough management, our wind tunnels wouldn't be able to keep generating high-accuracy data. In my eyes, JAXA's wind tunnels serve as a benchmark for all the wind tunnels in place at Japanese companies, universities, and research institutions. It's our responsibility, as the central force propelling Japan's wind tunnel technology forward, to keep that standard high.

For more information on JAXA's wide variety of wind tunnels, access the following link.
http://www.aero.jaxa.jp/eng/facilities/windtunnel/

*2 : Particle image velocimetry, a technique that measures the velocity distribution of an airflow by capturing images of small "tracer" particles when they travel through a flat "laser sheet" and then comparing the readings for tracers photographed at different times

*3 : A technique for calculating pressure by illuminating a model coated in pressure-sensitive paint (which fluoresces under certain pressure conditions) and measuring how the red luminescence levels change under ultraviolet light in accordance with differences in pressure

*4 : The Flight Demonstration of Quiet Technology to Reduce Noise from High-lift Configurations project, which aims to reduce airframe noise by placing noise-reduction devices on high-lift systems and landing gear

In this feature story, we examine three new wind tunnel measurement technologies that JAXA is currently working on: automatic balance-calibration technology, which will help enhance measurement accuracy, background noise-reduction technology, which helps create quieter flow, and future measurement technology, which JAXA is aiming to establish as technical assets that go beyond PSP and PIV.

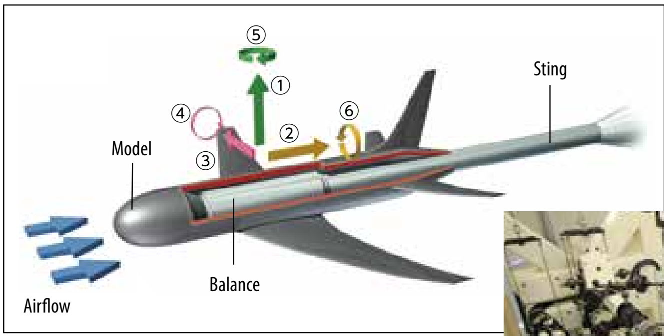
Automatic balance-calibration technology

Making aerodynamic measurements as accurate as can be

A six-component balance (a "balance") is a crucial element of wind tunnel testing, which serves to measure the aerodynamic forces acting on a model. Forming a connection between the sting and the model, an internal balance is a component that normally remains out of sight. In a wind tunnel, air flows subject a model to six types of force:①lift, ②drag, and ③side (horizontal) force, which are three modes of actual force, and ④pitching moment, ⑤yawing moment, and ⑥rolling moment, which are three moments about the center of the balance. The balance experiences deformations in response to the forces and moments, undergoing changes that strain gauges can read and render in terms of voltage. To associate those voltage values with the six types of force, researchers need to "calibrate" the readings—a process that involves applying load to the balance in the six component directions via a variety of patterns and gathering the corresponding voltage readings for each iteration.

Years ago, JAXA used to conduct single-load calibration on an in-house basis. Single-load calibration entails placing a balance under force or moment in one direction only. In actual testing, however, the various forces and moments act on the model simultaneously and create mutual interference—conditions that impact measurement accuracy. Recognizing the need for compound-load calibration, which exposes the balance to combined forces and moments at the same time, JAXA reached out to a balance manufacturer to get the help it needed. "The process was completely manual, with people applying the individual loads by hand," explains Masataka Kohzai. "Sometimes, it'd take a month or two to do the calibration and get everything delivered."

As a mechanical component, a balance is susceptible to the effects of repeated exposure to forces and moments; those external factors gradually bring the measurements out of precise alignment. Different types of wind tunnel testing call for different load ranges, too, depending on which of the six components researchers are looking to evaluate. Given all the variables in play, the ideal approach would be to calibrate balances under optimal load conditions on a test-by-test basis—and performing combined-load calibration in a short time helps boost the accuracy of the balance. JAXA wanted to enhance its balance-calibration capabilities and reap those benefits. In 2010, then, the organization assembled its collective expertise on balances to develop an automatic calibration system that not only accelerates the calibration process but also takes measurement accuracy to a new level.



(Left)
The forces on a six-component balance

(Right)
A balance in JAXA's automatic calibration system; during calibration, the balance is fitted with a cal body. Consolidating the actuator layout helped boost work efficiency.

The mechanisms and technologies behind faster calibration and better measurement accuracy

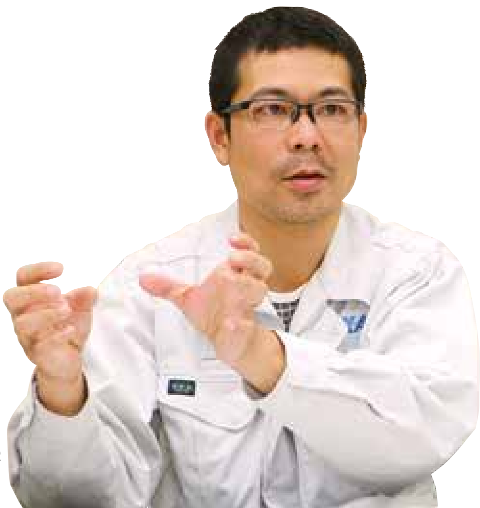
JAXA's automatic balance-calibration system comprises several parts: a support component for holding the balance, a load-application component for applying load to the balance, a high-accuracy laser displacement gauge for measuring the displacement of the balance, a balance temperature-control component, a sting-deflection test support component, and other components.

The calibration process involves placing a "cal body" (the "calibration body," which stands in for the wind tunnel model) on the balance and then placing the setup on the support component. The load-application component, meanwhile, features six electric actuators (one for each of the six force components) that can move forward and backward to apply force to the mounted cal body. Compared to the traditional manual approach, JAXA's automatic system makes it much easier to adjust load levels and directions quickly. With high-accuracy load cells on the actuators detecting load quantities, the system's laser displacement gauge measures the movements and angles of the cal body to determine balance displacement.

One of the most distinctive features of the automatic balance-calibration system is its parallel link mechanism. During calibration, the balance experiences deformation under load conditions—a process that leads to changes in the load direction. Thanks to the parallel link mechanism, a setup with three actuators, the system can return the balance to its original position (reposition the balance) quickly and accurately in accordance with the changes. The repositioning mechanism makes it possible to complete an individual measurement pattern in roughly five minutes, bringing the total calibration period (including setup and takedown) to just three to five days in duration.

In a wind tunnel test, the energy of the air flowing through the tunnel leads to higher flow temperatures. JAXA's automatic calibration system addresses temperature-related issues, as well. By enabling users to control the individual temperatures of the cal body side and the support component side between 10°C and 50°C, the system can calibrate balances under the same temperature conditions as transonic wind tunnel tests. The ability to align temperature conditions across multiple testing procedures makes for better measurement accuracy, first of all, and also helps save time on corrections and other tasks.

JAXA has always been and will continue to be at the center of Japan's wind tunnel technologies. Bringing all of our assets together, including the valuable expertise gained through the development of the automatic balance-calibration system, we want to keep providing companies, universities, and all the other players in Japan's research and development community with effective means of enhancing their measurement accuracy levels.



Masataka Kohzai
Researcher
Aerodynamics Research Unit

Diffuser 1 in the low-speed wind tunnel: Before (Left) and after (Right) the improvements.

Background noise-reduction technology

Obtaining high-precision measurements of airframe noise

Regulations on noise levels around airports have been getting increasingly stringent on a global scale. With the installation of quieter engines, reductions in airframe noise (aerodynamic noise) are becoming a stronger focus in recent years. Airframe noise from high-lift devices and landing gears, deployed for approach and landing procedures, become noticeable as pilots close the engine throttles. How can we reduce airframe noise? And even before that, how can we measure airframe noise precisely in wind tunnels?

Gathering acoustic measurements in a wind tunnel can be a challenging process. One complicating factor is background noise, which comes from the fans, turning vanes, and other components other than the test model when the wind tunnel is in operation. In an effort to reduce the background-noise issue, JAXA made improvements to its 2-m x 2-m low-speed wind tunnel (see Figure 1). "That initiative got started through the FQUROH project, which JAXA launched in 2015 to reduce airframe noise," explains Hiroki Ura, who worked on the actual improvements. The FQUROH project needed a measurement environment with minimal levels of extraneous noise to validate its noise reduction designs.

While recent years have seen the emergence of wind tunnels that have noise-reducing elements in their basic designs, the process of building a new wind tunnel requires substantial investments of both time and money. Aware of the costs that new construction projects entail, JAXA decided to revamp an existing wind tunnel—and the first step of the initiative centered on identifying the sources of background noise.

JAXA researchers thus used the acoustic measurement technologies in its arsenal to gather the background-noise data that they would need to draw up the optimal approach.

Key improvements for reducing noise levels inside wind tunnels

The acoustic measurements showed that the biggest source of noise in the wind tunnel was the fan. Improving or replacing the fan would have been too time- and cost-intensive, however, so the team decided to focus its plans on attenuating the propagation of the sound coming from the fan. Using CFD and acoustic analysis technologies, the researchers performed before-and-after comparisons to evaluate the improvements and eventually formulated an optimal reduction method that would both lower the background noise levels and limit pressure loss*[1]. First, the team installed new walls featuring a noise-reducing design: perforated metal with a 5 cm-thick layer of acoustic absorption material on the inside surface. The improvements also targeted the corners of the wind tunnel, where turning vanes redirect the flow of the wind at 90-degree angles. In addition to installing perforated metal and acoustic absorption material on the corner walls, the team also fitted acoustic absorption materials onto the turning vanes themselves. The turning vanes at corners 2, 3, and 4 were a special focus for the team. "Putting acoustic absorption material on the vanes created a bit of an uneven surface," Ura explains, "so we welded on a flat plate to eliminate that bump and filled the spaces with sealant to keep the flow smooth ."

After completing the initial improvements, the researchers conducted another round of acoustic measurements inside the wind tunnel. The data showed that the adjustments had brought the overall levels of background noise down, but some frequencies still exhibited problematic levels. A closer look revealed that sound was emanating from the breathers — components that help stabilize the airflow downstream from the test section. The airflow separating from the wall surface upstream from the breather opening was apparently hitting the breather downstream, creating sound. By fitting that contact area with pile fabric,

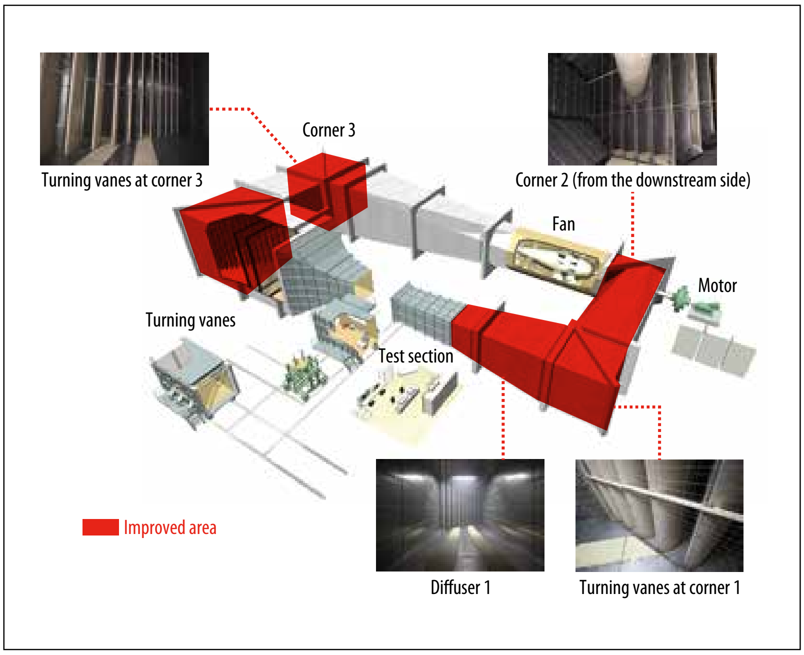


Figure 1: JAXA's 2-m x 2-m low-speed wind tunnel: Structure and main improvements

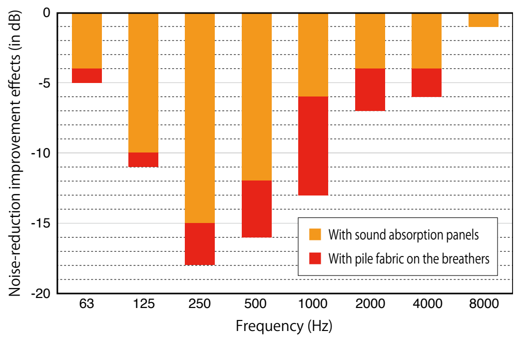


Figure 2: Background noise levels successfully lowered with sound absorption panels (the orange sections of the bars, effects seen in every frequency range), as well as with the improved breathers (the red sections of the bars).

Hiroki Ura
Associate Senior Researcher
Aerodynamics Research Unit

*1: Energy lost due to drag and other factors; large amounts of pressure loss can impair wind tunnel performance, lower the tunnel's maximum wind velocity, disrupt the airflow, increase the airflow temperature, and cause other problems.

The fan in the low-speed wind tunnel

the team successfully reduced the amount of background noise coming from the site (see Figure 2).

"Knowing that we needed to provide high-quality data to the FQUROH project team, we focused on making improvements in the most effective areas," Ura says. "Reducing background noise is something that the entire global community is trying to address, so there's definitely a growing need for acoustic measurements in quiet environments. That's a demand that we can address. We've learned a lot from our efforts to reduce background noise in the 2-m x 2-m low-speed wind tunnel—and that insight is going to propel us toward even better improvements."

Future measurement technology

Essential measurement technologies for the future

Over the last two decades, JAXA has established non-intrusive wind tunnel measurement technologies like PSP*2 and PIV*3. Nowadays, both are used frequently in the wind tunnel testing. What kinds of measurement technologies will be needed in the future, then? "We are having discussions about prospective needs," says Kazunori Mitsuo.

Recent airframe designs call for aircraft with reduced drag (skin friction drag, etc.) to achieve better fuel efficiency. "If you could measure the skin friction drag acting on a model in a wind tunnel testing, you'd be able to create sophisticated designs for lower-drag airframes," Mitsuo explains. "The skin friction drag measurement technologies are still at the laboratory level, but we're making progress on devising ways to enable them in large-scale wind tunnels."

Low-drag airframes also have high-aspect-ratio wings, which gives them higher volumes of deformation—and that creates a stronger need for higher-accuracy deformation measurements. During wind tunnel testing and flight tests using actual aircraft, researchers measure deformation volume by capturing images of how the markers on the aircraft's main wing move in response to wind (see the image in the top right corner). To make these measurements more accurate, JAXA is currently looking at incorporating Moiré fringes (interference patterns) into measurement methods. When you project Moiré fringes on a model, the fringe patterns strain as the model experiences deformation. Based on that strain data, researchers can calculate the corresponding deformation volume. "Moiré fringes would enable accurate, high-resolution deformation measurements," explains Mitsuo. "It used to be little more than an idea for the future—but now, with the higher-performance cameras and advanced image-processing technologies we have access to, it's looking like a real possibility."

The small black spots on the model's wings and fuselage are markers

How to capture complex flow fields in detailed, three-dimensional renderings

Passenger aircraft now need to have quieter airframes, too. To bring noise levels down, you need to understand the mechanisms of how airframes produce aerodynamic noise. Not only does that effort require acoustic measurement technologies for identifying noise sources, but it also creates the need for technologies that measure spatially fluctuating and unsteady flow patterns with high accuracy.

"3D-PIV" and "Tomographic-PIV" (Tomo-PIV), which uses the tomographical techniques common in the medical field (CT scans, etc.), are two such technologies. There are several types of Tomo-PIV technologies, including some that involve creating layers of multiple laser sheets, but JAXA is pursuing an approach that illuminates the entire flow field with laser light and captures images via multiple cameras to track changes in the airflow. As part of an ambitious effort to enable even more meticulous flow-field measurements, JAXA is also researching the "Micro PIV" technique—an approach that aims to visualize boundary layers measuring just 1/1000 of a millimeter on the surface of an aircraft model.

High-precision measurements of complex flow fields via Tomo-PIV or Micro PIV technologies would also benefit the computational fluid dynamics (CFD) field, providing the basis for building numerical models and performing validations.

"We're also looking into the possibility of using technologies like MEMS*4 and PE*5 for measurement purposes," Mitsuo continues. "If you could use MEMS to create micro-size sensors, you'd be able to perform high-sensitivity, high-responsivity sensing with less power—which allows you to increase measurement points to improve measurement accuracy. PE has amazing potential benefits, too . We might be able to print sensors directly onto the models with PE technology, which would make the time-consuming setup time required for embedding sensor in the model much shorter. Another advantage is in that PE based measurement uses electrical signals to generate measurements, eliminating more time-intensive calculations required for image-based measurements. That's not all, either: PE-based approaches would be able to gather measurements from inside engine nacelles, which were impossible with optical measurements due to camera visibility issues."

Kazunori Mitsuo
Chief Manager for Planning
Aerodynamics Research Unit

*2, 3: See p. 4.
*4: Micro Electro Mechanical Systems, which refer to sensors, electronic circuits, and other microdevices fabricated via semiconductor fabrication technologies and other means
*5: Printed Electronics, which refer to technologies for printing electronic circuits and other devices on various surfaces via printing techniques

Message from NASA Aeronautics

The National Aeronautics and Space Administration (NASA) and JAXA have worked together on numerous research and development projects in the aerospace field, forging a strong partnership along the way. Dr. Jaiwon Shin, Associate Administrator for the Aeronautics Research Mission Directorate at NASA, has kindly sent us a message on the occasion of featuring JAXA Aeronautics's Sky Frontier Program in the pages of FLIGHT PATH. In his remarks, Dr. Shin outlines NASA's efforts to develop future aircraft and voices his hopes for JAXA's ongoing work through the Aeronautical Technology Directorate.

Dr. Jaiwon Shin
Associate Administrator for the Aeronautics Research Mission Directorate
National Aeronautics and Space Administration (NASA)

Dear JAXA Aeronautics Friends

My name is Jaiwon Shin and I am NASA's associate administrator for the Aeronautics Research Mission Directorate at NASA Headquarters in Washington, D.C. I began my NASA career at the Glenn Research Center in Cleveland, and have conducted research in a variety of aeronautical fields, including aircraft icing and aviation safety.

Beginning in 1995, I served as the deputy manager for propulsion in the High-Speed Research Program. Our goal was to develop technologies that would enable a next-generation supersonic aircraft capable of carrying 300 passengers. That experience serves me today as NASA develops technologies that could result in even more remarkable opportunities for high-speed air travel.

That is exactly what NASA's aeronautical research is all about. We develop the ideas, tools and technologies required to reduce the financial and technical risk for industry. Then, when industry feels the time is right, it can confidently make investments to further mature those technologies and deploy them into the marketplace.

As we plan our research for this generation, and the generation after that, we strive to ensure our work has a specific purpose, that it will help solve relevant problems resulting from economic and societal changes here in the U.S. and around the world. At the same time, to be successful, we also must embrace transformational technical advances in areas beyond traditional aeronautics disciplines.

During the past few years, NASA has developed a number of aviation technologies and systems that promise to open a new era in global air transportation. We have tested them on the ground using computer simulations and wind tunnel models, and in flight with trials of individual components. Now it is time for the next step, in which we take those technologies into the air with large-scale experimental aircraft, or "X-planes."

We hope to field several subsonic X-planes to showcase the benefits of integrating these technologies by flying them in a real environment using aircraft whose size are of a meaningful scale. With these research aircraft, we intend to verify and validate our research goals of enabling airplanes that burn less fuel, reduce harmful emissions and fly more quietly than the most efficient airliners in the sky today.

With our supersonic X-plane we intend to show how noise from sonic booms can be reduced so it will no longer be a nuisance to the general public. This should allow federal regulators to approve commercial, faster-than-sound overland air travel in the U.S. for the first time in history.

Even as we work toward these goals at NASA, I applaud the work JAXA is doing with your D-SEND program and the creative approach you have demonstrated with the test flights conducted to date. The way JAXA's aeronautical innovators have overcome technical and financial obstacles sets an impressive example that all of us can admire. The data that NASA and JAXA contribute to this area will help bring commercial supersonic flight to the entire planet.

Under the leadership of JAXA Vice-President Fumikazu Itoh, our cooperation in aeronautics research has flourished. We have bilateral agreements in the areas of sonic boom modelling, airframe noise, and air traffic management. This collaboration continues to have tremendous value, helping us solve challenges that will benefit the U.S, Japanese and global aviation communities. In addition, NASA and JAXA continue to work closely within the 26-member International Forum for Aviation Research, of which JAXA is the current Chair.

Each of our nations has a long history of excellence in pioneering research that has benefited people around the world. Let us continue to honor that heritage by working as partners in the sky for many years to come.

Sincerely,

Jaiwon Shin
Associate Administrator for Aeronautics

Concept image of NASA's supersonic X-plane, Quiet Supersonic Transport (QueSST) (Credit: NASA)

Concept image of X-57 Maxwell, NASA's all-electric X-plane (Image Credit: NASA Langley/Advanced Concepts Lab, AMA, Inc.)

D-SEND project (http://www.aero.jaxa.jp/eng/research/frontier/sst/)
International Forum for Aviation Research (IFAR) (http://www.ifar.aero/)

Kármán line

The Kármán line is a theoretical boundary separating the earth's atmosphere from outer space. By forging connections across the divide between aviation and space, JAXA is working to provide society with valuable benefits. This section looks at how technologies from the Aeronautical Technology Directorate are bridging that gap and making a difference in the space field.

How do composite material technologies—vital to JAXA's basic and fundamental research on aviation technologies—relate and contribute to the space sector?

Interviewee: Yutaka Iwahori, Director of the Structures and Advanced Composite Research Unit

(Image Credit: NASA)

How the Aeronautical Technology Directorate's research on composite material technology supports JAXA

"The Aeronautical Technology Directorate's research on composite material technologies is playing an important role in the space field," Iwahori says.

One example is the structural analysis and testing technologies for carbon fiber reinforced plastics (CFRP), which the Structures and Advanced Composite Research Unit has been developing. Considering the promising potential of lightweight, strong CFRP, the Aeronautical Technology Directorate has devoted considerable time and energy toward researching the properties of the materials. Those efforts have paid dividends in the space field , with JAXA using the materials in its rockets and satellites. "As hydrogen-fueled aircraft and space transport systems get closer to practical implementation, we've worked to incorporate CFRP into cryogenic tanks," Iwahori explains. "Our research findings could be a big help in designing structures for space environments."

Future rockets and reusable space transport systems will feature cryogenic liquid propellant tanks, which hold hydrogen fuel. Making the tanks out of CFRP could help reduce overall airframe weight—but a big challenge complicates that process. The inner wall of a CFRP propellant tank is connected to a metal boss, which has a significantly different coefficient of thermal expansion than CFRP materials. Under cryogenic conditions, then, the joint linking the CFRP and the metal boss would break under thermal distortion.

A prototype of a cryogenic tank for holding cryogenic liquid propellant

"We wanted to find a way around that problem, so we did structural analyses on the metal boss and the neighboring area of the CFRP tank wall," Iwahori explains. "Using our findings, we worked with the Research and Development Directorate to identify boss designs and bonding conditions that would alleviate the thermal stress of the difference in the thermal expansion coefficients and help prevent breakage. We then reflected our analysis results in a new design, prototyped the configuration, tested the prototype at cryogenic temperatures, and found that the part was able to withstand the conditions."

Meeting the unique needs of the space field and broadening the scope of application

Before launching a development project in the space sector, project leaders need to orient the technical development effort and establish a basic goal. If a project wants to use composite materials for space equipment or structures, then, it would need to pool together as many resources as possible during the pre-launch discussion phase, conduct a variety of assessment tests and analyses, and work to determine how capable the technologies are. "Composite material-based structural designs for space-related applications operate under a different set of requirements from similar designs in the aviation sector," Iwahori says. "In our Unit, we look beyond aviation and help drive projects in the space field by obtaining the properties that composite materials need for space applications, accumulating technologies, and using assessment facilities."

Working with the space sector is extremely beneficial for the Aeronautical Technology Directorate's basic and fundamental research on composite materials. "The questions and requests that our Unit gets from people in the space field give us an idea of what actual projects and R&D activities need help with—material requirements, measurement and assessment methods, or facilities, for example," Iwahori explains. "That lets us identify and tackle new topics that don't come up in the aviation field. To me, that's going to be one of JAXA's strengths moving forward." By meeting the technological needs of the space sector, the Aeronautical Technology Directorate can keep expanding the possibilities for composite materials into new, space-based applications.

Charging ahead with basic/fundamental research on one side and industrialization-oriented research on the other

Another space application was developed through collaboration with the Space Exploration Innovation Hub Center.

Knowing that humans might one day be building bases on the moon or Mars, the Space Exploration Innovation Hub Center conducts joint research with construction machinery attachment manufacturers to develop construction machinery for applications in space (space construction machinery). The Aeronautical Technology Directorate helped the joint-research efforts from an early stage, and provided support in the design and fabrication of lightweight hydraulic excavator stick and boom* made of light CFRP materials that would deliver the same performance levels on earth and in space. The weight of a conventional hydraulic excavator was successfully reduced by approximately two-thirds. While the lightweight structural parts for space construction machinery are currently all custom-made, pushing further research and development in the field—and finding solutions to cost issues—could very well make the parts feasible for use in machinery and other applications on Earth.

"In the aviation field and collaborations with the space sector alike," Iwahori says, "we need a strong basis in two types of research. Basic and fundamental efforts to drive technological improvements for the future will be vital, on the one hand, and output-oriented research and development for closer-range targets will also be crucial in pushing the commodification and diffusion of technology."

A 1-ton class hydraulic excavator (for ground use) with a lightweight CFRP stick and boom
(Image courtesy of Taguchi Industrial Co., Ltd./JAXA)

* A product of JAXA Space Exploration Innovation Hub joint-research project sponsored by the Japan Science and Technology Agency (JST) Support Program for Starting up Innovation Hubs

Kármán line

The Aeronautical Technology Directorate technologies driving the development of the HTV Small Re-entry Capsule (HSRC)

JAXA is developing the "HTV Small Re-entry Capsule (HSRC)," a capsule-shaped atomospheric re-entry vehicle installed in the H-II Transfer Vehicle (HTV), to safely bring back experiment samples from the International Space Station (ISS) to Earth. This article looks at how the Aeronautical Technology Directorate's expertise on wind tunnel technologies has been supporting the HSRC development project led by the Human Spaceflight Technology Directorate.

Interviewees: Keisuke Fujii and Shinji Nagai, Managers in the Aerodynamics Research Unit .

The Kármán line is a theoretical boundary separating the earth's atmosphere from outer space. By forging connections across the divide between aviation and space, JAXA is working to provide society with valuable benefits. This section looks at how technologies from the Aeronautical Technology Directorate are bridging that gap and making a difference in the space field.

(Image Credit: NASA)

Using JAXA's entire arsenal of wind tunnels to measure the capsule's aerodynamic characteristics

The Aerodynamics Research Unit of JAXA's Aeronautical Technology Directorate is taking part in the development of the HTV Small Re-entry Capsule ("HSRC") led by the Human Spaceflight Technology Directorate. How did the collaboration get started? "I got a chance to meet with some personnel from the HSRC project and talk over some of the issues," Keisuke Fujii explains. "They told me that the team was having difficulties in the aerodynamic evaluation aspect of the development process. As soon as I heard that, I asked them what the issues were and whether our technologies could help find solutions. That was how the collaboration got started." The Aeronautical Technology Directorate has accumulated knowledge and technologies on aerodynamic characteristics together with expertise on wind tunnel testing and numerical analysis. After that initial encounter in the field, our participation in the project has been focused on the three main technical challenges facing the recovery capsule: 1) lifting re-entry guidance and control technologies, 2) lightweight ablative thermal-protection technologies, and 3) national independent recovery capabilities.

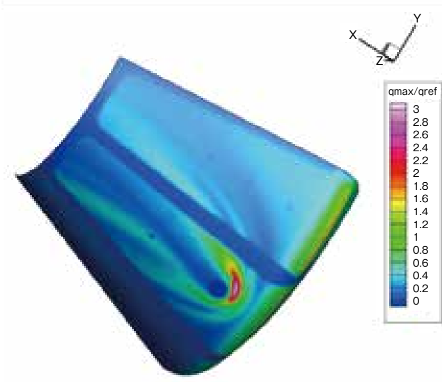
JAXA's approach is to have the HSRC re-enter the atmosphere, open its parachute upon reaching a certain altitude, and then drop into the water at a reduced speed. As it moves all the way from space down to the surface of the water, the capsule will transition from hypersonic speed down to transonic speed and then low speed. To identify the aerodynamic characteristics in each velocity regime, researchers collected measurements from virtually all of JAXA's wind tunnels at the Chofu Aerospace Center, including the hypersonic wind tunnel, low-speed wind tunnel, and arc-heated wind tunnel. The effort goes beyond simply using the facilities for data-acquiring purposes, however. Researchers are also addressing the aerodynamics-related issues affecting the HSRC.

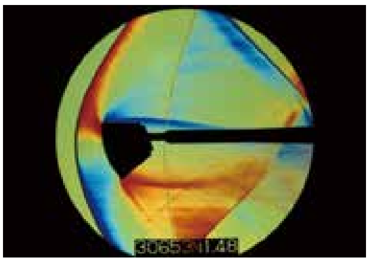
Lifting re-entry flight requires precision-guidance control

A recovery capsule that drops in ballistic flight, like the capsule for the HAYABUSA asteroid explorer, can reach deceleration levels of 50 G*1. As the HSRC from the ISS will be carrying samples of protein crystals and other items, however, it would decelerate too quickly under ballistic-flight conditions. "To reduce the deceleration levels, we shift the center of gravity a bit to tilt the airframe and obtain a small amount of lift," explains Shinji Nagai. Basically, the approach equates to going slowly down a mountain via a gradual series of switchbacks instead of speeding down from the summit in a straight line. Keeping the the capsule-shaped vehicle at the right attitude during lift flight requires precision-guidance controls, and only a handful of national governments and research institutions around the world currently have the ability to enable lift flight via that level of control. For Japan, those requisite technologies will be integral to achieving the eventual goal of manned space flight.

The precision-guidance control for the HSRC uses an RCS*2, which controls the attitude of a spacecraft via thruster firings. "We've been working with project personnel to fine-tune the thruster-firing angles and intensity levels, using the data we've gathered from wind tunnel tests and numerical analysis," says Fujii. The team also initially planned to have the parachute open when the HSRC reached a low altitude in order to keep the splashdown area as small as possible, but the wind tunnel tests indicated that opening the parachute at a low altitude could destabilize the attitude of the vehicle and create unsafe conditions. The team thus altered the plan, opting to go with an approach that would open the parachute slightly earlier. Also, as the adiabatic compression following atmospheric re-entry causes aerodynamic heating that can elevate the vehicle skin temperature to almost 2,000°C, the Aeronautical Technology Directorate also contributed to the development of an ablator that would protect the capsule interior and the vehicle itself as the ablator melted.

The HSRC project brought new insights to the Aeronautical Technology Directorate, which had been involved in various wind tunnel testing on re-entry capsules with blunt bodies. Increasing the angle of attack to simulate lift flight, for example, caused unexpectedly large aerodynamic interference. By employing the latest equipment and cutting-edge measurement methods, however, the effort also helped locate new issues that had never come to light before. All in all, the HSRC project was a fruitful one for the Aeronautical Technology Directorate.





Top left: A conceptualization of a capsule-shaped atmospheric re-entry vehicle, the "HTV Small Re-entry Capsule (HSRC)"
Top right: Hypersonic wind tunnel test results on aerodynamic heating caused by the RCS jet interference
Bottom left: Supersonic dynamic instability testing in progress

*1: "G" is a unit of acceleration; a value of 50 G represents 50 times the acceleration of gravity (1 G, or approximately 9.8 m/s²).
*2: A "Reaction Control System," which fires multiple thrusters to control the attitude of a spacecraft

"There's lots more to explore in aeronautics, which makes work fascinating"

Tatsunori Yuhara

Aircraft Systems Research Team
Next Generation Aeronautical Innovation Hub Center

Born in 1985, Tatsunori Yuhara graduated from the Department of Aeronautics and Astronautics at the University of Tokyo in March 2009. He then went on to obtain a master's degree from the University of Tokyo's Graduate School of Engineering in March 2014 and later joined Japan Aerospace Exploration Agency (JAXA) in 2014. During his time at the University of Tokyo, Yuhara focused his research on conceptual designs of hydrogen-fueled supersonic transport aircraft. Now, at JAXA, Yuhara works on aerodynamic designs for main-wing configurations.

Wind-tunnel models of the wings that came out of the joint-research project, which studied downward-pointing winglets and wing configurations with new underlying concepts

Tatsunori Yuhara tackles challenges in creating an innovative wing concept with better aerodynamic performance for next-generation aircraft. He introduces the story behind his career together with his motivation and aspiration as a researcher.

—— When did you start thinking about joining JAXA as a researcher?

Ever since I was a kid, I've loved racecars and airplanes—anything that looks sleek and moves fast. I ended up majoring in aerospace engineering and then decided to do my postgraduate research on the environmentally friendly aircraft of the future in an aerodynamics laboratory. My main research focus was on conceptual designs for hydrogen-fueled supersonic transport aircraft that wouldn't generate any shockwaves (sonic booms). When I was in the first year of my master's program, I won first prize in a NASA design contest—and that got me even more interested in hydrogen-fueled supersonic aircraft. During the stretch of time between my fourth year in college and my third year as a doctoral student, I had lots of opportunities to come to JAXA as a technical trainee. Seeing how excited the JAXA researchers were about supersonic transport aircraft*1, I couldn't help but feel that I'd found my calling. Someday, I told myself, I'd be at JAXA, researching the new, environmentally friendly aircraft that the world was sure to need in the future.

—— Could you tell us about your current research at JAXA?

As a member of the Aircraft System Research Team, I work on wingtip configurations (winglets) for transonic aircraft. My main focus is to develop design methods that reduce air resistance together with related evaluation methods for the developed designs. In a joint-research project with universities, I'm taking a coordinator role to examine several conceptual configurations. One insight we came up with through the collaboration is a concept of a downward-pointing winglet: Instead of pointing the winglet up, which represents the standard approach, pointing the winglet down has unique advantages. Our analyses have showed that a downward-pointing design not only enhances aerodynamic performance but can also even provide structural benefits. For me, it was really rewarding to help think up an idea that could optimize aircraft systems both aerodynamically and structurally.

Another part of my research deals with aerodynamic wing designs for environmentally friendly supersonic aircraft. In that capacity, I'm trying to find ways of designing supersonic aircraft wings that boost aerodynamic performance during take-off and landing procedures, reduce the amount of air resistance that aircraft experience while cruising, and limit the sonic booms that naturally occur when aircraft fly at supersonic speeds. That kind of research could definitely have a positive impact in lots of areas—making aircraft more environmentally friendly and minimizing noise around airports, for example. Whenever I work, then, I'm always thinking about how society would value the technologies.

I'm also carrying out some research on fundamental technologies for aerodynamic design. One of the factors explaining lift-generating phenomena is the concept of streamline curvature. If we could find a way to tweak streamline curvature levels in design configurations, I figured we could create aircraft with better aerodynamic performance.

My idea for streamline curvature-based aerodynamic design—a concept that people had rarely addressed—was selected as a theme for exploratory research at JAXA. Through this exploratory research, I looked at the aviation sector and a wide variety of different fields to find aerodynamic-design methods using streamline curvature, pieced together clues from what I found, and proposed a new technology for generating curvature-based configurations. I'm now trying to incorporate the outcomes into research on Eco-wing technology*2 and supersonic aircraft. We've applied for a patent on aerodynamic-design methods using the new technology, hoping to make the technology available for use in various scenes. I'm excited about all the possible applications in sectors of all kinds, not just the aviation field.

—— What are your hopes for the future?

Eventually, I want to get to the point where I can call myself a real specialist in aerodynamic wing design. Winglets are one thing—as soon as you've got a good design, you can apply it to aircraft right away and make a viable contribution to current aircraft development. It's an immediate impact. My research on streamline curvature-based aerodynamic designs and supersonic aircraft wing configuration designs, on the other hand, is looking 20 or 30 years into the future. The effort won't be generating substantial, tangible outcomes any time soon; it's a gradual, step-by-step process. That slower pace means I have time to present my day-to-day work in academic papers, get feedback from third parties, and look at things from the different perspectives of my research partners, letting me refine my own work and get in better position to deliver meaningful results. As I stay on that track, using the process to enrich my research, I'm excited about playing a role in making supersonic transport aircraft a reality.

—— What advice do you have for people who want to work for JAXA Aeronautics?

It's important to read as many textbooks and reference books as you can—that gives you a strong base of knowledge. If you ever hit a wall during the research process, the more basic knowledge you have, the better your chances of figuring out a solution are. People tend to think that there's already a complete academic foundation for everything in the aviation field, but there are still holes. Every time I go back to the basics and reassess the research, it doesn't matter how much knowledge is out there—I'm always finding room for more research. It's a really energizing feeling, knowing that there's still so much room for growth in aviation-related research.

*1: See p. 5.
*2: See p. 8.

"It all started with wind tunnels"

Hajime Miki

Researcher
Reentry Aerothermodynamics Section
Aerodynamics Research Unit

Born in 1987, Miki graduated from the Department of Mechanical Systems Engineering in Tokyo University of Agriculture and Technology in March 2010 and then went on to obtain a doctorate from the Graduate School of Engineering from the same institution in March 2015. Upon receiving his doctoral degree, Miki joined the Japan Aerospace Exploration Agency (JAXA). During his time at Tokyo University of Agriculture and Technology, Miki focused his research on aerodynamic design techniques for engine air intakes mounted on supersonic passenger aircraft. Now, at JAXA, he works on aerothermodynamic performance predictions for re-entry capsules.

In front of the operation display board for JAXA's hypersonic wind tunnel. Miki uses it for his research on re-entry capsules

Hajime Miki works on atmospheric re-entry capsules and wind tunnel testing techniques in the Aerodynamic Research Unit. In this article, he talks about the story behind his career at JAXA and the role that he wants to fill over the coming years.

―― What brought you to the JAXA Aeronautical Technology Directorate?

I started getting interested in aerodynamics when I was in high school and saw a wind tunnel experiment on TV; I remember how cool the smoke looked as the air flowed through the facility. Then, the show went deeper into wind tunnels and showed how the configuration of a model shaped the airflow—and how it all had to do with mechanical performance. I felt like I needed to try out wind tunnel experimentation for myself, so I enrolled in the faculty of engineering at my school. When I'd made my way into senior year and had to find a laboratory to do my final research project in, I picked the one on fluid mechanics because it had a wind tunnel I could use.

When I was in college, I got to use JAXA's large-scale wind tunnels and computational fluid simulations to look at aerodynamic designs for supersonic aircraft engine intakes. As I worked on my studies, I eventually figured out that one of the keys to improving aircraft performance was achieving good integration designs between the airframe and propulsion system. Intake design is a key technical element to improve the performance of both the engine itself and the entire airframe. For me, it was so amazing to see how you could create high-quality, integrated designs with that approach.

As I met more and more JAXA researchers through my studies, I got to know a little bit about how their jobs were about more than just research—they also had to manage different areas from technical standpoints. I love research, obviously, but I'd always had hopes of making an impact on Japan's aviation industry from a different angle, too. That's why I decided to aim for a position at JAXA. I knew it'd give me a chance to help forge a better future for aviation through both research and management.

―― What do you find rewarding about your current research?

Ever since I got started at JAXA, I've been working on re-entry capsules that can bring scientific experiment samples from the International Space Station back to Earth. The nature of the capsules means focusing on hypersonic speed, a velocity that tops supersonic speed. The fluid phenomena that I'm dealing with now are different from the things I'd studied through college, creating the kind of new, eye-opening inquiries that we researchers find really rewarding. I also had the opportunity to work a little bit on the HTV Small Re-entry Capsule (HSRC) project (see p. 20), which was another great experience. I'm getting a chance to reacquaint myself with an old area of expertise, too: this year, I'm back at work on supersonic passenger aircraft.

―― Does your current research tie back to what you were studying in college?

For JAXA, the next step after supersonic passenger aircraft is hypersonic passenger aircraft. Researchers will probably be needing technologies to weigh the merits of the propulsion/airframe integration designs in their research and development efforts. So we've started a new development project to formulate testing techniques that'll make it possible to measure aerodynamic performance in a hypersonic wind tunnel simulating engine running conditions. The whole idea goes back to my interests in college, actually, and I took the lead in designing the whole research effort. I'm happy to be a part of JAXA Aeronautical Technology Directorate, where the empowering climate and systems let researchers embark on new topics.

―― What kinds of research are you looking to tackle in the future?

Supersonic passenger aircraft is my first research target, I'd say, but I'm also really excited about having a hand in next-generation aircraft somewhere down the line. I want to help design an aircraft that would turn heads and grab people's attention, presenting the general public—not just aviation insiders—with something they've never laid eyes on before. Another area is integration, which I consider my research specialty. Assuming that the approaches to integrating airframes and engines are bound for change over the coming years, I'm looking forward to using my skills to make a difference in that field. My last goal is a bit broader in scope: working with other researchers from all across the spectrum, not just JAXA, I'm hoping to help create a brand-new take on aircraft that Japan can call its very own.

―― What advice do you have for people who want to work in the aviation field?

The cool thing about aviation is how it fuses so many technical elements—aerodynamics, engines, structures and materials, and flight controls, to name a few—in such tight, complex connections. With all that interrelated diversity comes new discoveries, letting you explore things from multiple perspectives, work with experts in areas that you're not all too familiar with, and make technological improvements through what you learn. It doesn't matter whether you're already an aircraft aficionado or a novice with entirely different interests. Just know that aviation, a field where new possibilities are always forming, gives you a place where you can flourish into the future.