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Feature Stories

Flight demonstrations: Testing developed technologies in the air

Looking back on the Third Mid-term Plan: Summary and major achievements for FY2013-FY2017

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The cover features six images from the Third Mid-term Plan(FY2013-FY2017): [From left to right] An experimental supersonic airplane flown to validate JAXA's sonic boom reduction concept(D-SEND project); JAXA's jet research aircraft "Hisho" applied with airframe noise reduction designs(marked in red) (FQUROH project); Optical antennas of an onboard clear-air turbulence detection system(SafeAvio project); A low-pressure turbine prototype for flutter testing (aFJR project); [Top] An example of D-NET terminal (fully portable on-board type) that enables real-time information sharing among helicopters and emergency operation centers; [Bottom] Pilots check the latest wind information on approach path using ALWIN (Photo courtesy of Japan Airlines Co., Ltd.)



Flight demonstrations: Testing developed technologies in the air



Flight demonstration plays an important role in the process of developing aeronautical technologies. JAXA has been supporting the Japanese aviation industry to develop its technological capabilities through developing research aircraft and flight demonstration capabilities. This article introduces an in-depth look at what roles those efforts play, why they are so essential, and how they can benefit the aviation industry moving forward. The interviewee is Kenji Fujii, Director of the Flight Research Unit.

Flight demonstrations remain vital despite advances in wind tunnels and CFD

— **Why are flight demonstrations are so essential in the development process of aeronautical technology?**

Aircraft fly in the sky, an environment that's home to innumerable unknowns. To create viable

technologies for aircraft, then, developers have to evaluate and validate their innovations under actual flight conditions—otherwise, it's impossible to assure designers and the public that the technologies will be effective. If you don't go through the flight demonstration process, those technologies won't ever be able to get off the ground and find real aircraft applications. We do a lot of ground-based testing, of course, but we can't replicate all the variables like

speed, air pressure, temperature, weather, wind direction, and wind strength through simulations alone. That's why flight demonstrations are still so vital in the development process, even with all the progress that wind tunnel technologies and computational fluid dynamics (CFD) have made.

— **What do researchers check for during flight demonstrations?**

First, we check to see that the developed technologies are feasible under actual usage conditions. Technologies might perform well in ground-based testing, but they don't always deliver the same results in the air. With flight environments and flight conditions in virtually constant flux, flight demonstrations have to assess performance on a system-wide basis—and that includes pilot maneuvers. For us, "flight systems" not only cover the aircraft themselves but also encompass pilots and, in certain cases, airports and ground-based facilities, as well. Pilots represent a key part of the effort—without them, it'd probably be impossible to achieve the flight and maneuvering conditions that flight tests demand while also ensuring safe flight. They're part of the whole process from the outset, helping us plan and execute the flight tests in the best possible way. We need to evaluate every flight system as an integrated setup that includes pilots, so the JAXA pilots that take part in our flight demonstrations are crucial members of our research teams.

How JAXA's research aircraft has been evolving in response to user needs

— **JAXA's first research aircraft was the Queen Air, a propeller aircraft.**

That was all the way back in 1962, when the age of aircraft development in postwar Japan was dawning. Considering the context, things were kind of on the ground floor—the focus at the time was on researching methods for flight testing. We were doing some work on anti-icing systems and flight load, too. The first thing we did was to equip the Queen Air with a system that'd supply power to the onboard measurement equipment for various testing purposes. After that, we installed flight recorders and other instruments to record flight data such as load, altitude, and speed. The last step was to modify the Queen Air as a VSRA (Variable stability and response airplane) to replicate the flight characteristics of other aircraft during flight for experimental purposes.

With this modification, the Queen Air became able to perform a wide variety of flight tests ranging from evaluations of flight control systems to flight tests under different response conditions, and tests for assessing pilot maneuverability. With the ability to alter flight characteristics, the Queen Air's VSRA function was also used to investigate an aircraft accident through simulated flight and verify the circumstances surrounding the accident.

The VSRA's "in-flight simulation" function was then enhanced and inherited to JAXA's second propeller research aircraft, "MuPAL-α," which was developed based on the Dornier 228-202. "MuPAL-α" is still in use today.

The in-flight simulator function gives pilot a feel of operating other aircraft, allowing researchers to simulate the flight characteristics and maneuverability of aircraft that are still at the planning or design stages. Taking advantage of that functionality, JAXA conducted fault-tolerant flight control testing to simulate what would happen if the aircraft were to experience a fault (a broken control surface, for example) and see how effectively the developed technologies maintain flight under those conditions. Our joint research on fault tolerance with universities has now grown into EU-Japan joint research.

The "MuPAL-α" was also used for testing of GPS-based navigation systems in its early days because GPS technologies had just started to take the world by storm. It was when we first implemented the Dornier as research aircraft, and it did not have a nickname or the in-flight simulation function. The navigation system we tested with the Dornier went on to be part of the ALFLEX automatic landing flight experiment, served in the HSFD high-speed flight demonstration, and eventually made its way into the private sector via technology transfer.

We also used MuPAL-α to help develop the "Tunnel-in-the-Sky"^{*1} technology, which shows three-dimensional visualizations of an aircraft's current

position and target flight paths on the cockpit display to enhance flight safety and efficiency. That technology now plays a valuable role in the FQUROH (Flight demonstration of quiet technology to reduce noise from high-lift configurations) project^{*2} and other flight tests.

—— **MuPAL-α is a turboprop airplane. Are turboprop airplanes still common resources for research in the age of jet aircraft?**

Although they can't simulate high-speed flight, smaller aircraft respond more quickly to pilot maneuvers. That makes them feasible assets for simulating the motion of large jet aircraft flying at low speeds and the motion during the approach and landing phase. The biggest advantage of turboprop airplane, though, is that they're so readily accessible and easy to use. They're also unpressurized, which facilitates modifications and enhances overall user-friendliness, and they don't cost very much to operate. When you look at the industry, it's easy to see that jet aircraft are the mainstream—and that means we'll have to use jet aircraft for plenty of tests down the road. For the time being, however, I think we need to do whatever we can with the turboprop airplane at our disposal.

—— **It's easy to see how JAXA has responded to the needs of the times: implementing research aircraft, developing the necessary technologies for flight testing, and creating a base of technological resources for a variety of testing purposes as demands evolve.**

"Hisho," JAXA's first jet flying test bed (FTB)

—— **What was behind the introduction of Hisho?**

Jet aircraft are the mainstream, as you can see, and you need to demonstrate the feasibility of the latest jet technologies using jet aircraft. The development of the Mitsubishi Regional Jet (MRJ) has also energized the

effort to develop technologies for jet aircraft in Japan. In response to growing needs for high-altitude, high-speed in-flight demonstration capabilities, which go beyond what turboprop airplanes can offer, JAXA has decided to introduce Hisho as its first jet flying test bed with multi-application versatility. Hisho is based on a Cessna (now Textron Aviation) Citation Sovereign (a business jet) and equipped with various measurement devices and instruments required to accommodate diverse experiments. It was quite the process; it wasn't easy to modify a standard business jet to a full-fledged research aircraft.

—— **What kinds of experiments have you done with Hisho?**

One recent example is the FQUROH project to demonstrate airframe noise reduction technologies, which required repetitive flyover noise source measurements to determine the effect of developed noise-reduction devices attached to Hisho's flaps and main landing gear. Our mission was to make Hisho fly precisely on the designated flight path multiple times at specific speeds under various flight conditions. Although it was a tough challenge, we managed to play our role to help get the data the project called for.

—— **Tell us about the results of the FINE project.**

With the FINE (Flight investigation of skin friction-reducing eco-coating) project, we were aiming to improve fuel efficiency by reducing skin friction drag. We coated a part of Hisho's fuselage surface with paint to create "riblets"—ultra-narrow grooves—and measured the airflow over the surfaces. We also put a "pitot rake" (a comb-shaped assembly of pitot tubes) behind the riblets for accurate measurements. It was a meticulous process with modifications in lots of different locations, but we got the results we were looking for; the flight tests demonstrated the effectiveness of the riblet coating.

—— **Did you need to fly an actual aircraft to evaluate reductions in skin friction drag, then?**

Well, aircraft don't fly in the ideal airflow conditions that you can create in a wind tunnel. Air often moves in unexpected ways, exhibiting various types of disturbances. We had to know if our technologies could do their jobs in those types of environments. Flight tests are essential to gathering proper and accurate data at the cruising speeds of a jet aircraft to determine the drag-reduction effects.



Turboprop research aircraft "MuPAL-α"



Jet flying test bed "Hisho"

*1/2: See Flight Path No. 13/14 for details.

Research helicopter



— How is the flight testing for the HOTALW project coming along?

The HOTALW (High performance optical fiber sensor flight tests for airplane wing) project aims to measure in-flight wing deformation using optical fiber sensors. We've done flight tests with Hisho to examine whether the developed distributed strain measurement system using optical fiber sensors (OFDR-FBG system) works properly as designed under actual flight conditions. Due to all the different variables that can affect in-flight conditions, the data from actual flight tests doesn't always match the data from ground-based tests. In other words, you can't get by on simulations alone; you need to do flight demonstrations. When you put the data from different test methods together, the differences that emerge can be really enlightening.

Research aircraft and ground-based flight simulators

— How have JAXA's research aircraft aided in the MRJ development initiative?

In a joint-research project between JAXA and Mitsubishi Heavy Industries, Ltd. to develop a small-sized aircraft technologies, MuPAL-a's in-flight simulation function played an important role. It was well before the MRJ initiative kicked into high gear. In more recent years, we've helped with lots of MRJ flight tests. We worked with Mitsubishi to develop the necessary telemetry system for flight testing, installed the system on Hisho, and flew the aircraft to see if the system would perform as designed. To set the stage for the MRJ—both for the aircraft's maiden flight and during the initial stage of test flights—Hisho did preliminary flights to observe weather conditions and collect data that Mitsubishi used to make go/no-go decisions for the test flights.

— JAXA has flight simulators, as well.

Before you do an actual flight test, it's important to validate the technology with ground-based simulators in advance. Flight simulators are great for situations where a technology might be unfit for flight or the test

conditions might be unsafe. For example, we used a flight simulator to look at what could happen when a helicopter or small-sized aircraft enters the wake turbulence that occurs behind a large-sized passenger aircraft. We try to make the most of both advantages, using both research aircraft and flight simulators as appropriate.

Broadening the scope of helicopter usage

— Why did JAXA start using a research helicopter?

Japan has a sizable fleet of helicopters, which represent about 30% of the country's total number of registered aircraft—a proportion that's much higher than what you'll find in other countries. Helicopters have unique flying capabilities, such as vertical take-off and landing capability and hovering capability, but there are limitations: operating helicopters on search and rescue missions through mountain ranges at night or in adverse weather conditions, for example, can be difficult and dangerous. To enhance the usability of helicopters, we need to develop solutions for such issues. That's why JAXA introduced its research helicopter (BK117 C-2). One of our helicopter-oriented research efforts is the SAVERH (Situational awareness and visual enhancer for rescue helicopter).^{*3} The effort is aiming to develop a system that projects images from infrared cameras, terrain data, and other information onto a pilot's helmet visor to make it easier for the pilot to fly safely in limited-visibility settings. We're researching instrument flight rules for helicopters, too. JAXA's research efforts in the helicopter sphere are really important, in my view.

Contributing to the aviation industry

— JAXA has wind tunnels, supercomputers for CFD, flight simulators, and research aircraft. What are the advantages of being able to use all those different resources on an in-house basis?

There are lots of benefits. For a research institution like JAXA, having the ability to bring researchers, pilots, and other professionals together to do tests and analyses together around a variety of facilities in an organically integrated way is a major asset. The different facilities are complementary, too. When you do flight tests, for example, you can get data from actual flight conditions—but only the specific conditions in effect during the test flight. If you need data on performance under a different set of defined conditions, you can use a wind tunnel; if you need a lot of high-precision calculations, you can use CFD. We keep honing our flight demonstration capability as part of role responsibility.

— How do JAXA's flight demonstration capabilities benefit the Japanese aviation industry?

Testing under actual flight conditions and the resulting data are essential in the process of aircraft development. We'll keep tailoring our flight test facilities to the needs of the times, leveraging our flight test technologies into the development of new, innovative aircraft technologies, and doing what we can to help the aviation industry make meaningful progress.

Visit the JAXA website for details on flight test facilities.

<http://www.aero.jaxa.jp/eng/facilities/flight/>



*3: See Flight Path No. 9/10 for details.

Accurately estimating flight characteristics to enhance aircraft design

When a pilot performs a maneuver—like moving the control surfaces or regulating thrust—the aircraft reacts. Those responses are examples of “flight characteristics.” This page introduces how researchers estimate flight characteristics and utilize the information. The interviewee is Masaru Naruoka, a researcher in the Flight Research Unit.

Masaru Naruoka

Researcher
Flight Research Unit

Measuring aircraft responses to maneuvers

To estimate flight characteristics, you need to start by acquiring various data such as flight conditions (speed, for example), input (the pilot's maneuvers), and response (how the aircraft reacts in response to the input at which timing, to which direction, and to which extent). Then, the relation among the measured data is reduced as the characteristics. JAXA's Flight Research Unit conducts research on flight characteristics estimation with its jet research aircraft “Hisho” and turboprop research aircraft “MuPAL-α.”

One of the important characteristics is maneuver-response lag. To investigate the lag effectively, the pilot moves flight control surfaces in special patterns, e.g., moves elevators upward, downward, upward, and finally downward for 3, 2, 1, and 1 seconds, respectively, as shown in Figure 1. These patterns are important because they reveal the difference of the maneuver-response lag, which varies from aircraft model to model. The flight characteristics represented by the lag relate to the entire aircraft system; therefore, researchers measure not only aircraft motion but also engine conditions and other attributes.

Estimating flight characteristics accurately requires huge amounts of flight data—but performing all the flight tests for gathering all possible cases would be unrealistic. “That’s why we collect all the flight data whenever JAXA’s research aircraft go into the air, even for other experimental purposes,” explains Naruoka. “From that massive database, we identify and accumulate the ideal data for analyzing flight characteristics.”

Making better use of flight characteristics

From the development to operation phases, flight characteristics are estimated and used for various purposes. The most long-established application is in

design verification. In the initial stage of an aircraft design project, developers plan the flight characteristics to be achieved and direct the design process toward those goals. Once the new aircraft is ready, the prototype is checked to see whether the original target characteristics are achieved in real flight tests. That step is particularly important for civil aircraft, which are under legal obligations to undergo that type of testing. If an aircraft fails to demonstrate the target characteristics, the design is revised and tested again. Through that process, an aircraft reaches completion.

Recently, research has focused on a new usage of flight-characteristic data estimated with flight tests. By measuring and analyzing flight data more elaborately, researchers are aiming to make estimations of characteristics more accurate to enable comparisons with results of wind tunnel tests and CFD. If the three sets of data reveal an inconsistency, researchers need to identify the root causes of the difference: it could be the measurement methods, the CFD algorithm, or the testing conditions, for example. This identification process leads to boost the accuracy of wind tunnel testing, CFD analysis, and flight tests alike. “We’re building datasets of wind tunnel, CFD, and flight test results of “Hisho” flight-characteristics,” explains Naruoka.

Embracing that basic approach, JAXA is now developing an “integrated simulation platform” concept that would optimize aircraft design through an integrated system of wind tunnel tests, CFD analysis, and flight tests. The effort to make each of the three components more accurate via interconnected, comparable data integration is a part of that concept activity.

An aircraft is a complex system comprising a wide variety of component technologies. JAXA’s integrated simulation platform continues to take shape not only through wind tunnel tests, CFD analysis, and flight tests but also across even more fields of study—including engine technologies, as well.

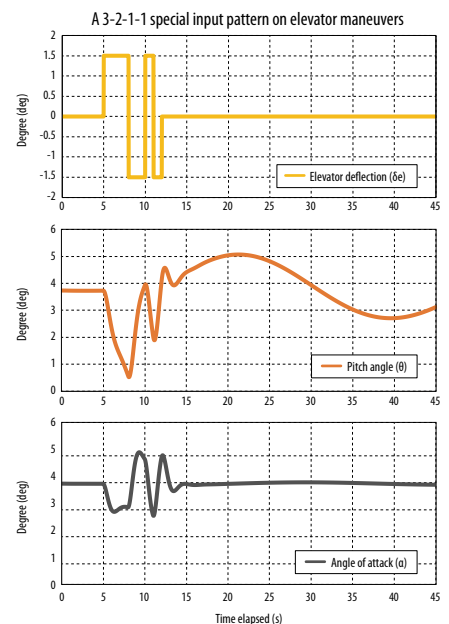


Figure 1: Input/response example for estimating flight characteristics; elevator maneuvers (top) invoke changes in pitch angle (middle) and angle of attack (bottom). The differences in response between pitch angle and angle of attack are important.

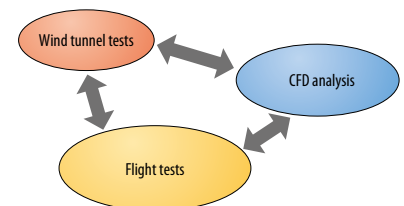


Figure 2: Improving measurement accuracy by interlinking wind tunnel tests, CFD analysis, and flight tests

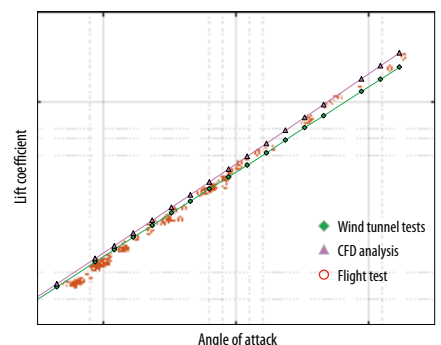


Figure 3: The relation between angle of attack and lift coefficient from wind tunnel tests, CFD analysis, and flight tests; researchers begin the verification process by examining the differences between the three sets of results



Jet flying test bed (FTB) “Hisho”

“Hisho” is a JAXA jet research aircraft introduced to accommodate a wide variety of flight experiments and tests at high speeds and high altitudes. Recent examples of flight demonstrations with Hisho include the FQUROH (Flight demonstration of quiet technology to reduce noise from high-lift configurations) project, FINE (Flight investigation of skin friction-reducing eco-coating) project, and HOTALW (High performance optical fiber sensor flight tests for airplane wing) project.



Flying for research

Responding to a variety of R&D needs





Research helicopter

JAXA's research helicopter is being used to develop technologies that help enhance the safety and efficiency of operations, such as research on wake turbulence separation and the SAVERH (Situational awareness and visual enhancer for rescue helicopter) technology. The helicopter is also used to aid in space-related projects.



Turboprop research aircraft "MuPAL-α"

"MuPAL-α" boasts an in-flight simulation function that can replicate the flight characteristics of other aircraft. Equipped with a fly-by-wire computerized flight control system, data acquisition systems, and more, MuPAL-α offers a multi variety of testing and demonstration environments—as indicated by its full name: "Multi-Purpose Aviation Laboratory." Major R&D using MuPAL-α includes flight demonstrations of trajectory control technology.





Amid growing safety- and environment-related needs and transformative changes in the Japanese aviation industry's business climate, the JAXA Aeronautical Technology Directorate has embodied different roles to meet the demands of the times. In this interview, Shigeru Tachibana, Manager for the Management and Integration Department, takes us back over the last five years for a detailed rundown of JAXA's various efforts under the Third Mid-term Plan set in FY 2013.

Looking back on the Third Mid-term Plan: Summary and major achievements for FY 2013-FY2017

Looking beyond the demonstration stage

— **What goals were set for aeronautical R&D under the JAXA's Third Mid-term Plan?**

JAXA's Third Mid-term Plan was formulated based on mid-term goals set by the government in 2013 with three goals for aeronautical R&D: pursuing research and development with a focus on the environment and safety; promoting the use of aeronautical science technologies; and enhancing technological foundation and contributing to strengthening the competitiveness of Japanese aviation industries. Major difference from the Second Mid-term Plan is in that we put more focus on trying to deliver tangible research outputs that industry and society would use. We didn't want to let R&D projects finish with technological demonstrations—we kept thinking about how our research results could bring about beneficial changes to society at large.

— **For researchers, there's nothing more gratifying than seeing your own research making a difference in the real world.**

Demonstrating the feasibility of advanced technologies is one thing, for sure, but getting those results into people's hands—finding practical applications—is a different kind of payoff. It's a sense of satisfaction that you can't get from presenting research results at academic conferences. Over the last five years, I really feel like we've derived that sense of joy as we pushed forward with our work.

— **Under the Third Mid-term Plan, JAXA has**

been promoting three-pillared R&D programs—the Environment-Conscious Aircraft Technology (ECAT) program, the Safety Technology for Aviation and Disaster-Relief (STAR) program, and the Sky Frontier program—together with fundamental research (Science and Basic Tech.) that supports these programs.

Yes, that is correct. Before the start of the Third Mid-term Plan we looked into what we'd achieved from the Second Mid-term Plan, as well as changes in the social landscape surrounding JAXA, and other such factors. This helped us put together the R&D structure as mentioned above for the Third Mid-term plan.

The ECAT and STAR program are designed specifically to meet the mid-term goals of pursuing R&D with a focus on the environment and safety, and promoting the use of aeronautical technology. In 2011, the Japanese aviation industry was worth around 1 trillion yen—a number that's now risen to 1.7 trillion yen. On top of that, the volume of air traffic is expected to double over the next 15 years. Taking these social trends into consideration, JAXA has pursued R&D with a focus on the environment and safety in order to further bolster growth in the aviation industry and safety improvements.

Sky Frontier program, meanwhile, is designed for R&D with technologies that society will be needing 10 to 20 years from now in consideration. This will also boost industrial competitiveness and safety in longer-term, which is another important role expected for JAXA.

Making the Japanese aircraft industry more competitive internationally

— **Could you introduce some of the achievements from the ECAT program please?**

We've been able to develop and demonstrate engine technologies for low pressure components with our advanced fan jet research (aFJR) project. Development on engines for civil aircrafts is always done through international collaboration, and Japanese aeroengine manufacturers have been securing a certain share for the low-pressure components such as fans, low-pressure compressors, low-pressure turbines, etc. By utilizing composite material technologies and computational fluid dynamics (CFD), two areas where Japan excels, the aFJR project has successfully developed highly-efficient and lighter fans that help improve fuel efficiency.

With the FQUROH (Flight demonstration of quiet technology to reduce noise from high-lift configurations) project, meanwhile, JAXA has been developing airframe noise reduction technologies to make aircraft quieter. By making use of our expertise in CFD and wind tunnel testing, we developed practical noise reduction designs, and applied them to our jet research aircraft Hisho to carry out flight tests. By also then utilizing advanced noise measurement technologies, we successfully demonstrated that our design methodologies could actually deliver the noise reductions we were targeting for.

The outcomes of the aFJR and FQUROH projects will be major selling points for the Japanese aircraft industry, I think, as it works to expand its international

market share. Through collaborative research, these will be put to use by private enterprises for development of new products. JAXA should also be able to apply the highly practical design technology acquired through these projects in the development of even more advanced technologies. That's how we play a major role in putting the Japanese aircraft industry in position to grow and flourish.

—— **In terms of transferring technologies to the manufacturing sector, the STAR program is also producing big results, isn't it?**

That's right. An example is our SafeAvio (R&D of onboard safety avionics technology to prevent turbulence-induced aircraft accidents) project. Turbulence has been reported to cause roughly half of all accidents involving large aircraft. We've successfully developed an onboard clear-air turbulence detection and advisory system based on our Doppler Lidar technology. Clear-air turbulence cannot be detected with conventional radars. Weighing only around 84 kg in an onboard setup, our compact and lightweight SafeAvio system can detect clear-air turbulence at an average range of 17.5 km. That's easily the world's longest range. With that much advance detection provides pilots with 70 extra seconds, helping them to take any safety measures such as turning the seatbelt signs on. We've been working on development of this system in collaboration with Japanese equipment manufacturers who aim to put it to practical use. In Spring of 2018, the US company Boeing will conduct flight tests of a large aircraft equipped with our clear-air turbulence detection system for its ecoDemonstrator program 2018.

Developed technologies make advances toward real-world implementation

—— **Please give us an example of something which had been developed through the Second Mid-term Plan and now producing tangible results during the Third Mid-term Plan.**

ALWIN would be a good example. Together with the Japan Meteorological Agency, JAXA has developed the airport low-level wind information (ALWIN) system, which can provide pilots and operators with the detailed wind profiles on final approach paths in real time. The system went into practical use at Haneda and Narita Airports in April 2017. It's a spin off from the DREAMS project, which established several key technologies for the next-generation air traffic

management system in the previous Mid-term Plan. I think it's worth noting how these results have gone a step further into real-world implementation.

—— **The exit-oriented approach is a key, then. How about the Disaster Relief Aircraft Information Sharing Network (D-NET)?**

The D-NET system enables real-time information sharing among helicopters, emergency operation centers (EOCs) and other related parties involved in response efforts in the immediate aftermath of large-scale disasters. In FY2016, the D-NET team officially received a commendation by the commissioner of the Fire and Disaster Management Agency (FDMA) in recognition of contribution to fire fighting and disaster prevention technology. The team also received a letter of appreciation from the FDMA for supporting the efforts of the emergency fire response team and contributions to lifesaving and damage mitigation efforts during the heavy rains in northern Kyushu in July 2017. We are very grateful that we have ultimately been recognized for our everyday efforts with practical application in mind.

Making the most of Japan's technological prowess

—— **The Sky Frontier program pushed forward with research geared towards the next-generation supersonic airplanes.**

We've been able to establish the sonic boom reduction technology through the D-SEND (Drop test for simplified evaluation of non-symmetrically distributed sonic boom) project. The results of the D-SEND#2 drop test in July 2015, which was carried out in Sweden as part of the second phase of D-SEND project, showed that the experimental aircraft designed with JAXA's original concept successfully reduced sonic booms—one of the biggest hurdles to future supersonic transport. Figuratively speaking, this technology reduces the impact of the sonic boom from a thunderclap level to one comparable to a knock on the door. The success of this flight demonstration put JAXA ahead of the pack internationally in terms of research into sonic boom reduction, for sure. What's more is that JAXA has been actively participating in the technical task group to help formulating sonic boom standards for the International Civil Aviation Organization (ICAO) with the outputs from the D-SEND project. What's demonstrated with the project were not only the cutting-edge technologies for future. We're making

solid contributions to facilitating the use of the developed technology in real-settings.

The flight demonstration of electric aircraft technology for harmonized ecological revolution (FEATHER) in February 2015 was yet another glowing example of a successful system-level flight demonstration highlighting JAXA's unique array of new, world-class technologies.

—— **What can you say about the area of Science & Basic Tech?**

A major achievement would be the FaSTAR (FAST Aerodynamic Routines), a fast flow solver which boasts the world's top-level speed. With FaSTAR, it only takes two minutes to do numerical calculations that used to take a whole day to complete just a few years ago. Numerical computation technologies represent a segment of JAXA's superior technologies, a basic technology that can really give Japanese industry a sharper competitive edge. FaSTAR is already in use at airframe manufacturers (via licensing agreements).

Introduction of the F7-10 engine^{*1}, is also something that has big implications, as engine development is usually done in the international joint efforts. This new engine test bed will allow Japanese engine manufacturers to demonstrate their engine component technologies at system level, which for sure help them to add a lot more persuasiveness to technical proposals that can capture greater market share. To help make Japanese manufacturers even more competitive on the global market, we are steadily enhancing testing capabilities, including preparations to install the F7-10 engine as a new engine test bed.

Forging cross-sector partnerships to overcome challenges

—— **The Third Mid-term Plan also saw the creation of the Next Generation Aeronautical Innovation Hub Center.**

At the Next-Generation Aeronautical Innovation Hub Center, the main goal is to create innovative solutions in the aviation field and beyond by bringing together people with diverse insight and technologies across area of expertise and sectors. An example is the WEATHER-Eye Consortium, in which 18 member organizations are working to develop technologies to protect aircraft from special weather conditions such as snow and ice, lightning, and volcanic ash by making use of each expertise. The consortium is expecting more organizations to join, and we would also like to apply such cross-sectoral and multi-disciplinary

^{*1} Turbofan engine developed by the Acquisition, Technology & Logistics Agency (ALTA) which is 100% made in Japan. It is now available to the private sector, and has been designated for use at JAXA as an engine test bed.

approach for other R&D.

— Tell us more about JAXA's collaborative efforts with external organizations.

JAXA has been forging cooperative ties with overseas organizations in various layers. JAXA had served as the chair for the International Forum for Aviation Research (IFAR), a global network of 26 aviation research institutions, between 2015 and 2017, during which we contributed to help establish a stronger and sustainable operational framework for the IFAR. We've also been expanding our collaboration with the US National Aeronautics and Space Administration (NASA), while also renewing and enhancing the tri-lateral relationship with the German Aerospace Center (DLR) and the French Aerospace Lab (ONERA). We have also been conducting joint research with Boeing. These partnerships are helping us build strong trusting relationships with these organizations, and I am hoping this will help us making the most of our R&D activities in the near future.

Collaborations pertaining to MRJ are a big part of our industry ties. We've been carrying out various joint researches with the Mitsubishi over many years. JAXA technologies are facilitating the MRJ project in a variety of different contexts. Over 3,000 hours of wind tunnel testing has been conducted at our testing facilities and we are also providing technical contributions to the type-certification and the tail-wing strength evaluation. Developing a made-in-Japan aircraft is obviously a big project, and I think we've done our role as public research agency as much as we can.

Looking ahead to the next mid-to-long-term plan

— How would you sum up the last five years?

We were successful in technological demonstrations for the DREAMS and D-SEND projects which carried over from the Second Mid-term Plan, and in subsequent projects we have worked to facilitate actual usage, such as real-world technology implementations and technological supports for establishing standards. We have made steady progress on the new FQUROH, aFJR, and SafeAvio projects in collaboration with industrial partners for technology transfer. We also put the finishing touches on fundamental technologies such as FaSTAR which are now widely used to support numerous projects not only in JAXA but also in industries and academic communities. While we are limited in terms of personnel and financial resources, each and every one of our researchers and staff members have worked hard, giving priorities to focus area in accordance with our overall policies. These five years have seen such efforts bear fruit, and we can also now foresee accelerated success for implementing what we had been working on in society at large. In assessments by the competent authorities, our operations in the field of aeronautical science technology have received "S" ratings—the highest possible marks—in both FY2015 and FY2016. For us, that's a clear reassurance that we're doing things right.

— What does JAXA have to focus on moving forward?

In the Third Mid-term Plan JAXA focused on the

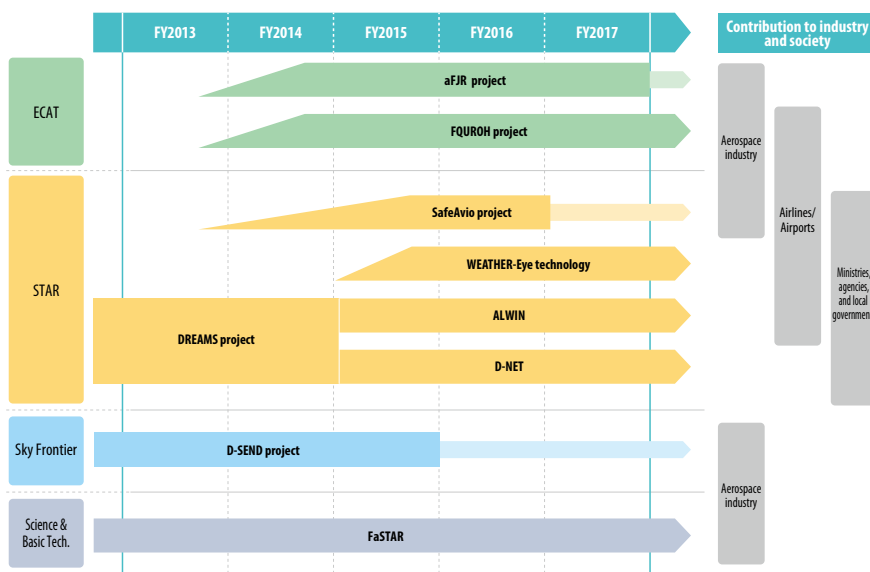
core technologies which we'd been accumulating over the past many years, delivering tangible outputs for practical application for the benefit of society. We are committed in making these R&D fruits back to the society at large. At the same time, we'd also been aware that we need to put a bit more focus on seeds-oriented studies to foster future technological soils. With this awareness in mind, we've launched new initiatives to create the mechanisms in which we can cultivate ideas for brand new research topics. I hope to create an environment where we, both the researchers of JAXA and collaborative partners, can work on things that elicit feelings of excitement.

— What do you see as the main topics for the next mid-to-long-term plan?

The next mid-to-long-term plan is longer than previous ones, as it covers seven years. At least for the first half of it, I'd say we've got three main R&D topics to concentrate on. Engines are one key area: while we've always put focus on low-pressure systems, in the next mid-to-long-term plan we are planning to challenge core engine components which have to withstand the high-temperature and high-pressure conditions requiring higher level technologies. Then there's supersonic transport. We have established sonic boom reduction technologies in the D-SEND project, which gave us a technological advantage globally with successful flight demonstrations. Our next plan is to establish the integrated design technology for the silent supersonic airplane, and mature it through technological demonstrations so manufacturers can make use of it. Third one is to further enhance technological foundation and testing and analysis capabilities, which are the strength of JAXA Aeronautics. Setting ambitious goals and tackling research and development boldly, with excitement, all of these will help enhance our fundamental R&D capabilities, I think. I would also like to make contributions to help improve core aeronautical technology and make industry more competitive, according to the maturity stage of the technology.

Looking ahead, I think that in the next mid-to-long-term plan, the focus will remain the same. We will keep focusing on doing what we need to do in order to help advance the Japanese aviation industry among global competition. That will not change.

<http://www.aero.jaxa.jp/eng/research/>



Major R&D timeline in the Third Mid-term Plan (FY 2013 - FY 2017)

This section features comments from partners and users—airline operators, manufacturers, and government authorities—with whom JAXA has been working over the past five years on the various R&D activities summarized in the Feature Story.

How does JAXA's research make a difference?

Airlines see greater potential in airframe noise-reduction technologies

— All Nippon Airways Co., Ltd. —

Some overseas airports prohibit takeoffs and landings at night. Some airports even restrict takeoffs and landings during the day depending on the aircraft type categorized according to noise level. Furthermore, many airports in



Kiyotaka Honda

Director
Performance Engineering
Flight Operation Standards
All Nippon Airways Co., Ltd.

Europe set annual noise thresholds depending on aircraft type, endorsing the usage of quieter aircraft. For example, each takeoff and landing of quieter aircraft is counted as 0.5 points, while a takeoff and landing of a noisier aircraft is given 1 point. Airlines need to limit the number of flights of noisier aircraft to/from such airports not to exceed the thresholds.

Aircraft noise reduction, therefore, is a major concern for airlines. Although the engine is still the largest noise source during a takeoff climb, airframe noise gets as loud as engine noise during landing approach. For us airline operators, then, finding ways to fly more quietly, including airframe noise reduction, is an important issue.

I'm impressed that the FQUROH project has been taking a well-balanced approach to develop practical solutions for lowering noise levels without impacting wheel and flap performance. I'm sure that airlines would be thrilled with the developed technologies.

I think JAXA is doing a great job with the FQUROH project. There might be some challenges to find the optimal solutions, considering that airframe noise varies by model, but I'm sure JAXA can overcome these hurdles.



Takashi Kondō

Senior Director
Planning & Administration
Flight Operation Standards
All Nippon Airways Co., Ltd.

We're looking forward to operating quieter aircraft with these noise-reducing designs.

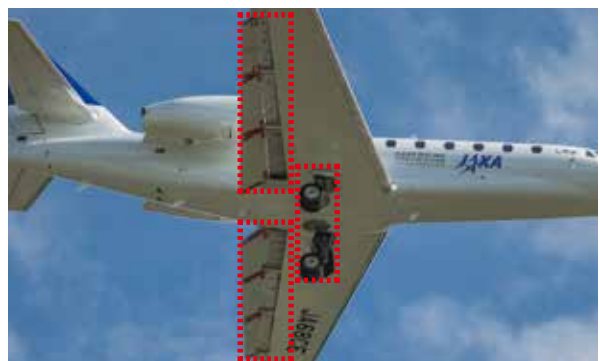
I also want to see JAXA dream big and shoot for more ambitious goals—but also make good on those aims, refusing to let dreams just be dreams. JAXA's ongoing research into silent supersonic passenger aircraft is a perfect example: if that vision turns into a reality, we'd be able to get people to their destinations faster than ever. That would open up a whole world of new possibilities.

FQUROH: A flight demonstration project for airframe noise reduction technology

To make future aircraft quieter, the FQUROH project has been developing airframe noise reduction technologies by taking full advantage of the advanced numerical analysis methods and testing technologies. Through flight tests to demonstrate the developed noise reduction technologies for high-lift devices (flaps and slats) and landing gear, which are the major contributor of airframe noise, the FQUROH project aims to establish design methodology for low-noise aircraft and to contribute to technology upgrade in aviation industry.

JAXA's flight demonstration test for the FQUROH project in 2016 was the world's first demonstration test to show noise-reduction effects on aircraft flaps. In 2017, JAXA achieved further noise reductions according to the improvements in low-noise designs through flight demonstrations.

(FQUROH stands for the flight demonstration of quiet technology to reduce noise from high-lift configurations)



JAXA's jet research aircraft "Hissho" applied with noise-reduction designs (marked in red) for flight demonstration



Masami Ichikawa

Operations Unit, Flight Operations
Japan Airlines Co., Ltd.

Weather-related information accounts for around one-third of the briefing details that pilots need to go through prior to flight. In particular, pilots pay attention to the following two points: whether there's any turbulence on the planned flight path and whether the conditions allow

Airlines welcome weather technologies that enhance flight safety

— Japan Airlines Co., Ltd. —

for takeoff and landing.

Turbulence can trigger severe accidents. Although some types of turbulence can be predicted based on weather information, it's been quite a challenge to predict "clear-air turbulence"—turbulence without any clouds.

The current approach to predicting clear-air turbulence uses weather predictions and reports from pilots on other aircraft. Weather predictions are getting more and more advanced, but the spatial resolution of the predictions is so broad that they only tell you that turbulence might occur somewhere in that vast airspace. I understand that SafeAvio's onboard system uses Doppler Lidar to locate clear-air turbulence and provides practical advisories on approaching disturbances. Just like the earthquake early warning, even a few extra seconds of early warning can make a big difference in taking any appropriate measures. Pilots would be able to turn on the seatbelt signs to warn passengers and crews to prepare for hazardous shaking. The airspace around Japan is a challenging environment, one that has more complicated weather phenomena, including clear-air turbulence, than most places around

the globe. We therefore see great potential in the SafeAvio's clear-air turbulence detection and advisory system. I'm really looking forward to seeing the full implementation of the system soon.

Recent increases in global air traffic have also led to congestion at airports, revealing the importance of safety measures against wake turbulence generated by proceeding aircraft on the same track. In fact, there have been cases where wake turbulence triggered accidents. In this regard, the ALWIN system from the DREAMS project is quite useful for our daily operation. Designed to provide real-time low-level turbulence information near the runway to pilots and dispatcher, ALWIN has been in operation at Tokyo International Airport (Haneda) and Narita International Airport since April 2017, helping us make safer takeoff and landing decisions.

I do hope JAXA keeps carrying out R&D on both fundamental research and cutting-edge research, which will surely help us pilots better handle day-to-day flight operation.

SafeAvio: The R&D of onboard safety avionics technology to prevent turbulence-induced aircraft accidents project

The focus of the SafeAvio project was to demonstrate the capability of onboard clear-air turbulence detection and advisory systems. Developed based on Doppler Lidar (light detection and ranging) technology, the detection system uses laser beams to reveal invisible changes in airflow (clear-air turbulence and wind shear, etc.) ahead of the aircraft. By emitting lasers forward and measuring the frequency shifts of scattered light from aerosol particles, the system detects the movements of fine aerosol particles in the air that moving along airflow. The pilot can receive advisories on approaching turbulence via the cockpit display, as well. In 2017, a compact, high-performance model was mounted on a small jet aircraft for flight demonstration. The detection systems successfully gathered readings of airflow movement at a distance of 17.5 km (an all-flight average)—the world's longest detection distance, prompting an advisory on turbulence ahead roughly 70 seconds in advance to help pilots warn passengers and crews prepare for hazardous shaking. The system's capability on large passenger aircraft is set for testing in the Boeing ecoDemonstrator program in March and April 2018.



The developed turbulence detection system is light and compact enough for mounting on passenger aircraft

ALWIN: Airport low-level wind information

ALWIN provides low-level wind information (wind direction, wind speed, wind shear^{*1}, and turbulence, etc.) around airports. Using data measured by airport-based Doppler Radar and Doppler Lidar, etc., ALWIN automatically detects wind shear and low-level turbulence mainly induced by local terrain and buildings. Both the measured and detected wind information is converted into graphical data and then transmitted to airline operators and pilots in cockpits. Compared to the existing wind shear alerts that use radio voice communications, ALWIN can provide more detailed and precise wind profiles in real-time. This helps pilots and operators monitor sudden changes in winds on final approach paths for safer landing.

ALWIN has been in operation at Tokyo International Airport (Haneda) and Narita International Airport since April 2017.



Pilots in the cockpit check wind information on an approach path using ALWIN (photo courtesy of Japan Airlines)

^{*1}: "Wind shear" refers to sudden changes in wind speed and/or wind direction over a relatively short distance in the atmosphere. Typical types of wind shear include vertical shear and horizontal shear.

We'll work to make snow and ice monitoring sensors into practical solutions

— New Chitose Airport —

In the winter, snow and ice on airport runways can have a big impact on aircraft takeoffs and landings. To minimize that impact, we temporarily suspend takeoffs and landings, and close runways to use special vehicles to monitor snow depths, snow types, snow and ice distribution, calculate friction coefficients, and then clear the snow on runways as necessary. If the measurement results don't meet the airlines' standards, we need to restrict operations.

The snow and ice monitoring sensors that JAXA's currently developing could provide us with the ability

to do real-time monitoring of runway snow and ice conditions without closing runways, which would help us keep takeoff and landing restrictions to a minimum. To ensure safer and more efficient operations in winter seasons, we're happy to provide any assistance to make the snow and ice monitoring sensors a viable, practical solution.

Noritaka Aiso

Deputy chief of air traffic services flight information officer
Air traffic services flight information officer, Air traffic services department, New Chitose Airport Office
East Japan Civil Aviation Bureau, Ministry of Land, Infrastructure, Transport and Tourism

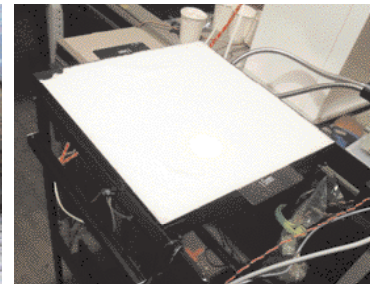


Snow and ice monitoring sensors

JAXA's ground-embedded snow and ice monitoring sensors illuminate the snow that accumulates on transparent glass covering the sensors, measure the light that scatters off the snow, and use those readings to measure the amount and type of the snow accumulation. Embedded in runways and taxiways, the sensors provide users with real-time readings of surface snow and ice conditions. JAXA is currently conducting field experiments on the sensors with Kitami Institute of Technology, Sentencia Corporation, and other collaborators.



Researchers install a snow and ice monitoring sensor



Observing artificial snow with snow and ice monitoring sensors

Making systems and products feasible through collaborative research

— SONIC CORPORATION —

We specialize in ultrasonic measurement products, such as ultrasonic flowmeters, anemometers, and fish finders. Based on our Doppler Sodar (Sound Detection And Ranging) technology, we developed a low-level wind shear monitoring system for airports in 2012. Although our Sodar-based technology could measure wind information above the runway every few minutes, it wasn't good at relaying that information to aircraft dispatchers and pilots. Later on, we came to know about JAXA's low-level turbulence advisory system (LOTAS)*², and we started joint research with JAXA to co-develop "SOLWIN," a Sodar-based low-level wind information advisory system, under JAXA's "Open Lab" scheme*³.

JAXA had apparently been looking for a viable solution for regional airports, as their LOTAS is based on

observations by airport-based Doppler Radar and Doppler Lidar, which are mainly installed at major airports due to their high cost. SOLWIN uses a Sodar sensor, which is compact and easy to install and affordable for regional airports. Thus, the SOLWIN is a perfect and synergized solution for both of us.

We've been conducting trial operations of the SOLWIN system for validation at Oita Airport since March 2017. Once those tests wrap up this March, we'll be running some more trial operations at several regional airports to validate the technology under different conditions and hopefully be ready to launch the new offering full-scale in FY2019. By partnering with JAXA, we were able to develop a practical and viable application of our Doppler Sodar-based technology. We will continue making collaborative



Yoshiki Ito

Director
SONIC CORPORATION

efforts with JAXA to facilitate the full implementation of SOLWIN.

SOLWIN: Sodar-based low-level wind information

The SOLWIN system provides low-level wind advisories to pilots and dispatchers by combining ALWIN's advisory function with SONIC CORPORATION's sonic remote sensing (Doppler Sodar) technology. Not only can Sodar detect low-level wind shear in any weather conditions, but it is also lower in price than Radar and Lidar technologies. Regional airports are the primary target market for the SOLWIN systems.



L: A SOLWIN Sodar (the red box in the middle-foreground area) in a trial setup at Oita Airport



R: A screen shot of SOLWIN. In this example, the visualization (graphs and values) shows the current status of wind direction, wind speed and upstream/ downstream wind (top), and the past records (bottom).

*² : Low-level turbulence advisory system (LOTAS); see Flight Path No. 7/8 for details.

*³ : Designed to propel the creation of new aerospace-related products and services, JAXA's "Open Lab" program solicits ideas from corporations and universities across Japan for joint-research projects.

Technologies enabling safe, efficient operations of firefighting and disaster-relief helicopters

— Fire and Disaster Management Agency —

Since 2014, we at the Fire and Disaster Management Agency (FDMA) have been using the “Centralized Management System for Fire-fighting and Disaster-relief Helicopter Operation (FDMA system),” which is compatible with JAXA’s D-NET. After a gradual rollout with part of our fleet, all of firefighting and disaster-relief helicopters in Japan (75 in total) are now compatible with the system. Although our original plan was to activate the system in the event of an actual disaster situation only, we decided in 2017 to apply the system whenever our helicopters fly to ensure the safety and efficiency of our daily aircraft operations.

Through our FDMA system, we could make use of JAXA’s new D-NET IP System—with an interactive projector function—in our efforts to respond to the torrential rains that hit the northern Kyushu area in July 2017. By distributing the D-NET’s IP addresses to the local and

central disaster-relief headquarters, we and the 22 different organizations involved—from local governments and fire departments to Cabinet Office—were able to share information with remarkable efficiency. For example, the system made it possible to assign optimal tasks to each disaster relief unit from different organizations—local firefighting departments, police departments, and Self-Defense Force etc.—under different operation management systems and visualize the different activities on a map to streamline the overall effort. Having seen how the D-NET IP system functioned in practical applications, we’ve provided JAXA with feedback on possible improvements for future implementation.

We’re hoping that JAXA continues to enhance the D-NET system further. We’re also looking for new technologies for making helicopter operations safer and more efficient, such



Tomihiko Imoto

Specialist for Aerial Fire Service
Mutual Aid Management Office
Fire and Disaster Management Agency (FDMA)

as those that help enhance pilot’s situational awareness via instrumental flight technology and those that enhance poor visibility at night.

D-NET: Disaster relief aircraft information sharing network

The conventional communication during aircraft operation management in immediate disaster relief relies on a variety of communication channels: operational bases and disaster-relief aircraft would normally use aviation radio for voice communication, while operational bases and disaster relief headquarters would exchange information via phone or fax. To share the information that came in, personnel would write points on white boards for others to read.

The concept behind D-NET, therefore, was to create data-communication channels for relaying information more smoothly in the immediate aftermath of a disaster. Based on that concept, JAXA set up D-NET data standardization and developed an integrated aircraft operation management system that enables real-time information sharing among rescue aircraft and disaster relief headquarters on the ground for safer and more efficient operations.

By conducting a battery of evaluations by disaster-related institutions at disaster drills across Japan, JAXA has continuously been enhancing the usability and functionality of D-NET-based technologies, as well. Some have already been commercialized, and a new D-NET IP System product is going to be released in 2018 via technology transfers to the private sector.



A D-NET IP evaluation at a disaster drill



Minoru Yoshimoto

Research Manager
Aerodynamics Laboratory
Fluid Dynamics Research Department
Research & Innovation Center
Mitsubishi Heavy Industries, Ltd.

Simulation technologies with innovative approaches

— Mitsubishi Heavy Industries, Ltd. —

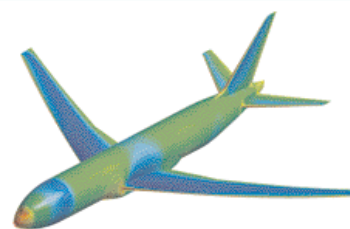
As its name suggests, FaSTAR’s biggest advantage is its faster analysis speed than any other’s. With high-speed capabilities, time on analysis can be saved and, as a result, the design process is streamlined. FaSTAR is an extremely useful CFD tool; in addition to analyzing flows around still objects, it can even perform analyses on flows around objects with relative motion or with structural deformation due to aerodynamic forces. It’s definitely something that we want to use in several adequate researches and business

projects of our products. We hope JAXA keeps responding to user needs with even more functional enhancements.

JAXA possesses wind tunnels, research aircraft and CFD tools such as FaSTAR. We expect JAXA to develop integrated simulation technologies that combine wind tunnel tests, flight tests, and CFD analyses by making use of all of these assets, which will help us study various types of flow phenomena in a way that wasn’t possible with conventional approaches.

FaSTAR: Fast unstructured CFD code

FaSTAR (FAST Aerodynamic Routines) is one of the world’s fastest fluid analysis tools and was developed by JAXA. Featuring a compressible flow solver for unstructured grids, FaSTAR excels at aerodynamic analyses for aircraft and spacecraft and delivers blazing, world-leading speeds with its high-efficiency data structure and computation algorithms. JAXA plans to make FaSTAR even faster, enhance its functionality for analyses in unsteady flows, and continue to mold the technology into an even higher-speed, more sophisticated CFD tool.



Surface pressure distribution simulated by FaSTAR



Kuniyuki Imanari

Deputy Division Director
Research & Engineering Division
Aero Engine, Space & Defense Business Area Operations
IHI Corporation

The private sector expects JAXA to help develop future-oriented technologies with a competitive edge

— IHI Corporation —

We at IHI have been participating in JAXA's aFJR project to enhance our competitive edge in the future market around 2025 to 2030 with low-pressure systems. Our major focus was to develop lighter fan blades with the use of CFRP (carbon fiber reinforced plastic) and integrating aerodynamic, structural, and noise-reduction technologies, and also to develop technologies for the low-pressure turbine by developing better structural designs with the use of CMC (ceramic matrix composites).

Now in its final year, the aFJR project has generated results that can make technologies for fans and turbines of low pressure sub-systems of jet engines more competitive—exactly what we at IHI were hoping for—and put us in position to discuss real approaches to future

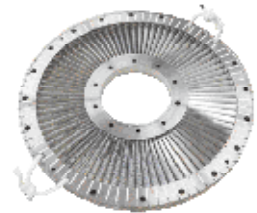
practical applications.

Moving forward, we would also like try a new business model using the F7-10 engine, planned to be installed at JAXA as a new engine test bed, for system level demonstration. If we could demonstrate the feasibility of developed engine components—including the output from the aFJR project, IHI's own technologies, and other manufacturers' technologies—in an entire engine, it would help us take a better approach for proposals to Western engine manufacturers.

We also expect JAXA to address future-oriented R&D and keep enhancing its testing and analysis capabilities and facilities at the same level with Western countries to better support Japanese manufacturers.

aFJR: The advanced fan jet research project

In hopes of reducing our environmental footprint, demands for aircraft engines with better fuel efficiency, less noise, and lower CO₂ and NO_x emissions are growing. JAXA has been conducting the "aFJR (Advanced Fan Jet Research)" project to develop and demonstrate next-generation engine technologies for fans and low-pressure turbines. By enhancing the environmental compatibility of these two components, which Japanese aircraft engine manufacturers have a backed record of developing and supplying, the aFJR project is designed to help raise the profile of Japanese engine manufacturers to play bigger roles in international joint-development projects on next-generation engines.



A low-pressure turbine prototype for flutter testing

The flight demonstration project provided us with greater opportunity to foster our human resources

— Subaru Corporation —

We'd been taking part in the D-SEND project from the start. Our role was to build a silent supersonic concept model (S3CM) demonstrator and integrate everything into a complete system. The challenge for us was to meet the quite demanding design requirements, including the complex wing configuration. We are very proud to have been able to meet all these requirements by making use of our extensive knowledge and experience in manufacturing and processing. Our past experience with JAXA to develop unmanned demonstrators on other projects also helped us, too, I think.

The participation to the D-SEND also helped our staff make huge strides, which, I think, is a great benefit for us. When you're working on R&D in the aviation sector, hands-

on experience is incredibly valuable. A flight demonstration project like D-SEND can provide you with a plenty of tips that you can only learn by actually making and flying a real aircraft and analyzing the resulting data. I think that's where JAXA's strength lies. JAXA boasts both the capabilities and facilities, including the jet research aircraft "Hisho," to conduct flight demonstration. Through getting involved in such flight demonstration project, we manufacturers can also foster our own human resources. I think it's a vital role for JAXA to keep providing us with such opportunities—even if it's on a small scale.

Manufacturers with global competitions often prioritize developing technologies that'll be conducive to immediate results, a stance that can impede investments in more



Hiroshi Wakai

Vice President & General Manager
Engineering Development Center
Aerospace Company
Subaru Corporation

revolutionary, longer-range technologies. Therefore, we also expect JAXA to tackle that R&D, in particular.

D-SEND: The drop test for simplified evaluation of non-symmetrically distributed sonic boom project

Through the D-SEND project, JAXA established sonic boom reduction technologies, which are the key to realizing next-generation supersonic transport. The D-SEND project aimed at validating both the sonic boom-reduction concepts and methods in flight demonstration. The D-SEND#2 drop test in July 2015 was the world's first successful flight test in which an experimental supersonic aircraft applied with a low sonic boom design concept for both the nose and aft fuselage was flown at supersonic flight and had its low boom signatures captured.

Together with aerial sonic boom measurement techniques and associated design and analysis tools, JAXA's low sonic boom design technologies validated through the D-SEND project are now contributing to the International Civil Aviation Organization's (ICAO's) ongoing deliberations on standards for sonic booms for next-generation supersonic aircraft.



The S3CM demonstrator flown in D-SEND# 2 drop test

Kármán line

Benefits of working with the Aeronautical Technology Directorate on the HTV Small Re-entry Capsule (HSRC)

JAXA is currently developing the “HTV Small Re-entry Capsule (HSRC)” for bringing samples from the International Space Station (ISS) back to Earth. How does the Human Spaceflight Technology Directorate, which leads the project, see the benefit of cooperating with the Aeronautical Technology Directorate?

Interviewee: Yasuhide Watanabe, Associate Senior Researcher, HTV Technology Center, Human Spaceflight Technology Directorate

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)

How the Human Spaceflight Technology Directorate and Aeronautical Technology Directorate work together

“Our collaboration history goes back to those days when both departments were still part of the National Aerospace Laboratory of Japan (NAL) and the National Space Development Agency of Japan (NASDA), respectively,” Watanabe explains. “We worked together on the H-II Orbiting Plane (HOPE) project, which aimed at developing reusable space transportation systems, and learned that we could complement each other,” he continues. “Therefore, it was quite natural for us to seek input from the Aeronautical Technology Directorate when we started developing a concept of the H-II Transfer Vehicle-Return (HTV-R). We figured that we could benefit from their expertise, and we got into talks about cooperating on aerodynamics to start with. All of these collaborative efforts for the HTV-R are now paying off in the current HTV Small Re-entry Capsule (HSRC) project.”

Considering the need to bring refrigerated cells, other

delicate samples, and, in the future, humans back from the ISS, recovery efforts will need to minimize high G (gravitational-force) levels using lifting re-entry guidance and control technologies. “To satisfy the requirements for HSRC, we needed to get aeronautical expertise more involved in various R&D aspects,” he explains, “ranging from capsule configuration design, wind tunnel-based measurements of aerodynamic characteristics, and analyses via computational fluid dynamics (CFD) to the study on the thermal properties of composite materials for the “ablaters” that protect payloads from extreme heat during atmospheric re-entry.”

In developing ablaters, JAXA brought together technologies and expertise from three directorates—the Aeronautical Technology Directorate, Research and Development Directorate, and Human Spaceflight Technology Directorate. Research on composite materials for the ablaters was grounded in accumulated data from the Aeronautical Technology Directorate. The combined efforts by the three directorates resulted in shaping the

ablaters in use today—some of the lightest of their kind anywhere in the world.

The work between the Human Spaceflight Technology Directorate and Aeronautical Technology Directorate has also continued into the testing phase. At JAXA's research field in Taiki, Hokkaido Prefecture, researchers from both directorates worked together to conduct ocean-splashdown drop tests of HSRC, using JAXA's research helicopter (BK117 C-2) to demonstrate parachute deployment and recovery functions.

Incorporating aircraft into the recovery process

“Russia and the United States currently do all the recovery work for experimental samples from the ISS,” Watanabe says. “To make sure that Japanese researchers can get their hands on space samples as quickly as possible, Japan needs to develop its own recovery technologies—and ensuring maximum freshness is key, especially for cellular samples. Aircraft could aid in that process by serving as recovery systems.”

The HSRC is slated for installation on the H-II Transfer Vehicle “Kounotori 7” (HTV7), set to launch in FY2018, for atmospheric re-entry and recovery testing. JAXA is currently looking into using its jet research aircraft “Hisho” to handle some of the recovery work. “After the capsule splashes down in the ocean, the plan is to recover the capsule by ship and then have Hisho, standing by on a nearby island, bring the sample to the mainland. If we can do that, we'll have no trouble meeting our goal of getting the sample from ISS storage to Japan within four days,” Watanabe says.

“The development process for the HSRC stands as a model of bringing all the relevant expertise together,” he continues. The Aeronautical Technology Directorate's assets and resources—from its technologies and knowledge in basic and fundamental research to its wide array of test facilities—have enormous potential for applications in both aviation and space. “Both departments are committed to sustaining synergized R&D efforts to bring about better solutions and breakthroughs for both space and aeronautics,” Watanabe concluded.



HTV Small Re-entry Capsule (HSRC)

The HSRC, with a diameter of 84 cm, would be able to fit into the hatches of Kounotori (HTV) and the ISS.

Kármán line

Incorporating plasma flow-analysis methods to investigate the impact of runway water on aircraft

JAXA is developing “Engineering Test Satellite IX,” featuring a “Hall thruster”—an electrical propulsion system. In developing the technology for the Hall thruster, researchers used numerical simulation to conduct various analyses and optimize the design. The analysis methods developed for the Hall thruster also pay a dividend to aeronautical R&D in exploring solutions for needs in the aviation sector. This page looks into one of JAXA’s fundamental efforts into numerical simulation technology, which is widely used in various R&D both in Space and aviation.

Interviewee: Kenichi Kubota, researcher, Numerical Simulation Research Unit, Aeronautical Technology Directorate

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)

Numerical simulation to analyze plasma flow for Hall thruster

One of the artificial satellite projects currently underway at JAXA’s Space Technology Directorate I is Engineering Test Satellite IX (ETS-IX), an all-electric satellite with a high-power Hall thruster. The effort aims to establish a high-capacity satellite communication system with international competitiveness by demonstrating technologies for installing and operating low-cost communications technologies and communications devices. A key goal is to demonstrate a Hall thruster, an electronic propulsion technology.

A Hall thruster is an engine that produces thrust by discharging xenon plasma. Whereas ion engines have high fuel efficiency (high specific impulse), Hall thrusters have an advantage in producing higher thrust rather than specific impulse. JAXA has been relatively quiet in terms of its research efforts on Hall thrusters, while overseas organizations have already done quite a bit of work on the topic. Aiding in that effort is computational fluid dynamics (CFD) technologies that are widely used in aviation sectors. Kenichi Kubota of the JAXA Aeronautical Technology Directorate has been developing a numerical model to analyze the plasma properties for Hall thruster by making use of CFD.

Analyzing complex phenomena with a basis in experimentation

In conducting numerical simulations on Hall thrusters, researchers analyze the movement of plasma particles in high-speed emissions. The basic goal is to determine how plasma erodes the inside of a Hall thruster (the “channel”) and affects other devices over the course of a thruster’s lifespan, estimated to be several thousands of hours. Drawing on those findings, researchers can optimize the strength and direction of the magnetic fields operating on the thruster.

As Kubota explains, however, “There aren’t any numerical models that can simulate the behavior of plasma accurately.” Considering the principles underlying the Hall thruster concept, the charged particles are intricately interrelated inside the magnetic field. To enable precise simulation of plasma behavior, you need to develop a low-cost numerical model which includes a variety of essential physics. Adding more complexity is the vacuum environment of space, which is difficult to reproduce on the ground. Applicability of numerical models for plasma flow simulation, thus, needs to be verified in comparison with experimental data by taking all these complexities into consideration.

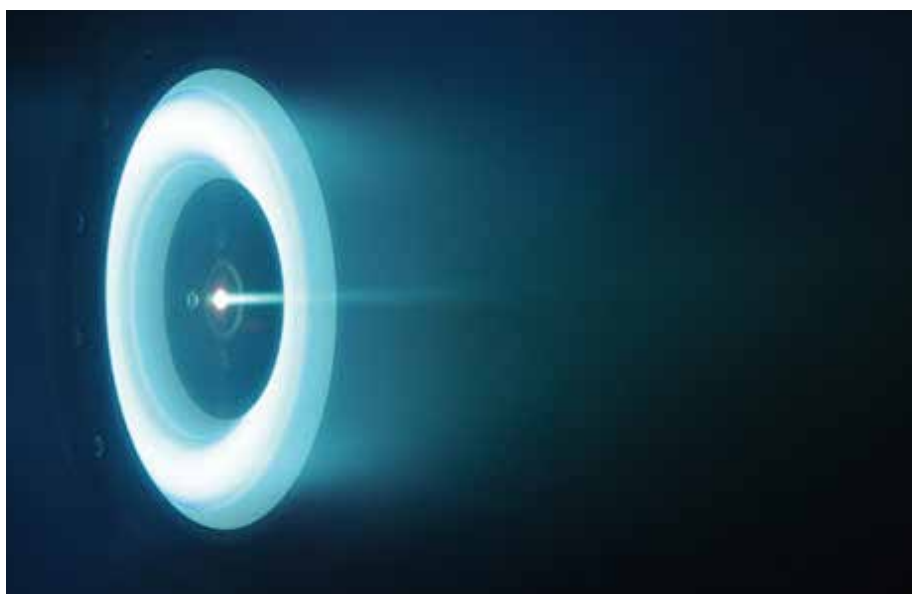
A chamber for conducting experiments on Hall thruster discharge and lifespan is under construction at JAXA’s Institute of Aeronautical Science (ISAS).

Leveraging analysis method for Hall thruster into the aviation sector

Kubota’s current focus is to make use of the numerical techniques developed for the ETS-IX’s Hall thruster for R&D in the aviation field. The numerical simulation for Hall thruster is based on the “particle method,” an approach that tracks and simulates the movement of individual particles rather than looking at rarefied plasma as a continuum. The aviation sector, meanwhile, generally uses numerical simulation that analyzes the continuous flow field around aircraft via a grid-based CFD method. Still, some topics in aviation-related research are compatible with the particle method. One example is the water spray generated by tire operating on wet/flooded runways, which can not only affect an aircraft’s acceleration and deceleration properties during takeoff and landing procedures but also cause engine surge, stall, or even flameout. Kubota is now trying to simulate these effects by using a particle-method based program which originates from the program developed for plasma analysis.

Analyses of interferences between moving objects and puddles had long been common in studies on automobiles, for example, but rarely had they targeted the aviation sector. The need eventually emerged, though—airframe manufacturers wanted to do quantitative evaluations of puddle-induced changes in acceleration and deceleration properties. “Aircraft are much bigger than cars, obviously, so simulating the ways that microscopic water particles interrelate with the relatively giant structures of aircraft is no small feat,” Kubota explains. “That said, the challenges make the effort that much more rewarding.” If JAXA succeeds in establishing these analysis technologies, which have yet to draw much attention overseas, the Japanese aviation industry would have a powerful asset to leverage.

“There aren’t any boundaries in fundamental research,” Kubota says. “Even my research straddles conventional lines—aviation and space.” JAXA will continue pushing ahead with collaborative, boundary-spanning fundamental research, striving to meet social needs across a broad scope.



Plasma-flow ejected from a Hall thruster (courtesy of JAXA/IA)

“Making use optical technologies to benefit the aerospace sector”

Kazuki Hashimoto

Researcher

Next Generation Aeronautical Innovation Hub Center

Born in 1991, Hashimoto graduated from the Department of Chemistry (School of Science) at the University of Tokyo in March 2014. He then went on to obtain a master's degree from the University of Tokyo's Graduate School of Science in March 2016 and later join the Japan Aerospace Exploration Agency (JAXA) that same year. During his time at the University of Tokyo, Hashimoto focused his research on optics, particularly coherent Raman spectroscopy. Now, at the JAXA Aeronautical Technology Directorate, Hashimoto works on snow and ice monitoring sensor technology.



Kazuki Hashimoto explains the mechanisms of snow and ice monitoring sensors using a diagram

Using expertise in optics, Kazuki Hashimoto is taking part in research on snow and ice monitoring sensors technology at the Next Generation Aeronautical Innovation Hub Center. This interview introduces his challenges and aspirations in the field of aeronautics.

— **Could you tell us a bit about your current research?**

As a member of the Next Generation Aeronautical Innovation Hub Center, I'm taking part in research named WEATHER-Eye, which aims to develop technologies to protect aircraft from special weather conditions such as snow, ice, and lightning, for example. My role is to study optical sensors for monitoring systems that provide real-time measurement of snow and ice conditions on runways. That information helps pilots make quick judgments on whether they can complete takeoff and landing procedures safely.

— **Why did you decide to look for a position at JAXA?**

The whole time I was in college, I was studying optics. After graduation, though, I didn't just want to make products for a company that manufactured optical stuff—for me, doing research that would have an impact on an area outside the optics field always seemed more appealing. I decided to apply for a position at JAXA because I figured it'd give me a chance to apply my research in the aviation and aerospace fields, two areas that I didn't really have any strong connections with.

I knew that the space field used some optics technologies, but had no idea how optics might figure into the aviation sector when I was assigned a position in JAXA's Aeronautical Technology Directorate. That's why it's been so exciting to discover those connections. I've now learned that

optics are playing a wider role in the aviation sector, too, such as in the spectroscopic measurement technology used for combustion research and in Doppler LIDAR technology. I never imagined that there'd be so many different applications for what I've been studying over the years. The snow and ice monitoring sensors even uses laser optics to get readings on accumulated snow conditions, giving me yet another way to use my expertise.

— **What makes your research on snow and ice monitoring sensors so rewarding?**

It's a project that relies on insight from so many different areas. To understand the properties of snow, one obvious part of the measurement process, we have to draw on input from snow experts. To process our measurement data through machine learning*, meanwhile, we depend on expertise in areas ranging from machine learning to software engineering and computer science. When I was doing my own personal optics research in college, I could do everything myself—creating the setups for experiments and performing the actual measurements, for example. Now, though, I'm part of a collaborative framework with other researchers, universities, and research institutions. Having more people on board might make coordinating everything a bit of a challenge, sure, but that added diversity of different perspectives and research practices makes for an exciting, eye-opening experience.

— **What kinds of research are you hoping to tackle next?**

I've got my hands full with research on our snow and ice monitoring sensors at the moment, but I'm looking forward to using my background in optics on even more research that could spark technological innovations in the aviation sector.

I'm hoping to network with people doing research in other fields outside aviation, too. When I think about how the Next Generation Aeronautical Innovation Hub Center lets me build those types of horizontal connections, I know I couldn't ask for a better place to be than where I am right now.

— **What advice do you have for people hoping to work at JAXA in the future?**

This is nothing more than my personal opinion, obviously, but I really get the feeling that the people at the Aeronautical Technology Directorate are “researchers” through and through—maybe the most research-oriented people in the whole JAXA organization. I do like research, and I'm happy to be here surrounded by all the researchers. Another thing is that you don't have to be an expert in aerospace to flourish at JAXA; just look at my background. With what we have in the Aeronautical Innovation Hub Center, you can pretty much have any specialization you want. Even if you're from outside the aerospace field, you can really thrive at JAXA. Take my word for it.

*Researchers can mine data to uncover patterns, rules, and criteria for making evaluations.



In front of the high-temperature, high-pressure combustion testing facility

“Make a difference in the world”

Kodai Kato

Researcher
Combustion Technology Section
Propulsion Research Unit

Born in 1988, Kato graduated from the Department of Aeronautics and Astronautics (School of Engineering) at Tokai University in March 2011. Upon completion of a master's program at Tohoku University's School of Engineering in March 2014, he joined Japan Aerospace Exploration Agency (JAXA) in 2017. Over the course of his academic career, Kato focused on combustion engineering, specifically liquid fuel atomization in high-pressure environments and spray combustion. Since joining JAXA, Kato has been researching lean-burn combustion technologies for aircraft engines.

In this interview, Kato introduces what brought him here together with his aspiration towards future.

— Could you tell us a bit about your current research?

At the moment, I'm researching and developing lean-burn combustors for aircraft engines^{*1}. The advantage of the lean-burn is that it can enhance fuel efficiency and reduce environmental pollutant emissions like nitrogen oxide (NO_x) and soot. However, lean-burn often leads to combustion instability with the fluctuations in pressure and flame intensified interactively. Therefore, I'm trying to establish a method for stabilizing lean-burn by visualizing the flame structures in unstable combustion states using laser measurement technics, for example.

— What led you to choose JAXA?

I chose JAXA because I wanted to make positive contributions to Japanese jet engine industries from a wider perspective to drive the development of Japan-made jet engines. As a student, my research topics were engine ignition, fuel spray and combustion for engines of space planes and aircrafts. I wanted to change things so that one day, Japanese companies could lead and cover the whole development of commercial aircraft engines. To develop engines nowadays, several firms from all over the world—including from Japan—need to collaborate under the lead of an overseas company to build one engine. For Japanese companies to win a lead role over the internationally competitive market, we of course need system integration technologies. On top of that, we need stronger competitive edges such as a groundbreaking and cutting-edge technology that is unique to

Japan. At JAXA, I can help create and develop such unique assets that Japanese manufacturers will be needing in the next 10 to 20 years, through which, eventually, I hope I can help open a way to Japan-made engines.

— What have you felt upon joining JAXA, and have there been any changes?

JAXA's testing facilities cover every stage—from components to full engines—and are on a completely different scale compared to those I had at university. To name just a few of the engine-related equipment, we have an annular combustion test facility, high altitude test facility, and the soon-to-be-installed F7-10 engine^{*2} as a new engine test bed. I hope to leverage the strengths of these facilities to create a unique Japanese engine technology.

As for changes, I now approach my work from a different angle. I'm getting more conscious on the research outcomes, not only the outputs, and started to think over how to give back to society with JAXA's role and mission in mind. Now, to set clearer goals on the R&D, I think over various things as well: starting from examining future societal needs to select a research that JAXA should carry out, considering the technologies it will create, and estimating their impact on industry and society once they're fully developed.

— What kinds of research do you want to tackle in the future?

There are many new things that I would like to accomplish, and I'm hoping to help build a groundbreaking aircraft engine of the future,

something that nobody's ever seen before. That'll probably mean coming up with completely new approaches to combustion methods and combustor designs, so I'm looking forward to researching and developing novel concepts that can satisfy the performances, such as fuel-efficiency and environmental-performance requirements, to win a lead role in the new engine market.

The last thing might not be much of a concrete goal, I suppose, but I do hope my research can make the world work better—in whatever capacity that might be. If we could make hypersonic passenger aircraft a reality, for example, people would be able to go anywhere with much less time. Imagine what that would mean for business and tourism. It could maybe even create a new market. So, I really hope to make a difference in the world through my research.

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

The Aeronautical Technology Directorate at JAXA is an incredible place to work. The market growth that is to be expected in the aviation industry calls for technologies and researches that are highly innovative and can overcome international competition. You can pursue what you're interested in if that is really appealing both in terms of competitiveness and innovativeness on an international scale. Also, being able to board actual aircraft and see your research in real action is a big motivator.

If you're thinking you might want to join JAXA, trust that instinct, look into the possibilities, and give it a shot!

*1: See FLIGHT PATH No. 13/14 for details.

*2: See p.10.