Feature Stories

JAXA Aeronautics at the heart of "all-Japan" R&D landscape

D-SEND#2 Successful flight

Flight system technology for making aircraft safer and more familiar
**FLIGHT PATH**

2015 No. 9 / 10

This issue introduces JAXA’s commitment and everyday efforts in supporting Japanese aviation industry, together with updates on recent projects. Two topics from a new serial ‘Aeronautics in depth’ are introduced as well.

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**Feature Story**

JAXA Aeronautics at the heart of “all-Japan” R&D landscape

Supporting the aircraft industry to grow into one of Japan’s major economic forces

In April 2015, JAXA embarked on its new journey as the National Research and Development Agency. By further enhancing its research and development capabilities in the aerospace field and incorporating input from diverse areas of study, JAXA will aim to fulfill its new role as the National Research and Development Agency, the core objective of which is to “optimize its research and development results as an all-Japan force.” The organizational transition has also reshaped the JAXA Institute of Aeronautical Technology into the Aeronautical Technology Directorate, which will foster research initiatives within a new framework in hopes of making even more valuable contributions to the Japanese aircraft industry. We spoke with Kazuhiro Nakahashi, Vice President and Director General of the Aeronautical Technology Directorate, about the primary goals of the new setup and the projects that the organization will be pursuing.

JAXA’s approach to help stimulate the growth of Japanese aircraft industry

How has JAXA’s transition into the National Research and Development Agency changed the structure of the Aeronautical Technology Directorate?

JAXA has always focused its efforts on “projects,” a framework that involves commitment at the management level in all aspects of the project process, from defining the technological goals and planning to monitoring progress to delivery. That approach has helped to develop and operate satellites and explorers, including GPM-2 (the Advanced Land-Observing Satellite-2) and the HAYABUSA 2 asteroid explorer. In the field of aeronautics, ALF (Advanced Fan Jet Research) and POHR (Flight demonstration of Quiet technology to Reduce noise from High-lift configurations) has been operated under this type of project framework in hopes of transferring developed technologies to industry. Although the organization will continue to pursue this project framework, we will also alter our basic research structure so that we can also create new innovations. Building on these two foundations, we are committed to generating as much output as we can.

With experts predicting that aviation demand will more than double over the next two decades, the Japanese aircraft industry has started to exhibit substantial growth in the last few years. Japan’s share of the global aviation market may only account for 4% as it currently stands, and this amount is expected to grow further to around 10% within the next 15 years. In the “Strategic Vision for Researching and Developing Next-Generation Aircraft,” which the Ministry of Education, Culture, Sports, Science and Technology released in 2014, the ultimate goal is to bring that share all the way up to 20% and develop the aircraft industry to the point where it can stand shoulder to shoulder with the auto industry as one of Japan’s key industrial forces. It’s our role at JAXA to make that happen—and to do so, we need to spark breakthroughs that put Japan at the head of the pack. The new organizational framework puts JAXA on the front lines of that effort.

What does that entail, specifically?

We have to forge close bonds with the aircraft industry to create new technologies, always making sure that what we develop finds applications for use by industrial partners in their operational settings. The new projects that we’ve launched this year are a part of that effort.

For the past two years, the JAXA Aeronautical Technology Directorate has been initiating a program with three main pillars: the Environment-Conscious Aircraft Technology...
**Feature Story**

**JAXA Aeronautics at the heart of “all-Japan” R&D landscape**

Innovation Hub Center

The “Next Generation Aeronautical disposal—it also demands knowledge of new fields. In addition to utilizing our assets in aerodynamics, thermodynamics, structural dynamics, composite materials, control, and other areas that we’re traditionally praised ourselves on, we’ll also be needing human resources in less familiar fields like electrical engineering and chemistry. The Innovation Hub exists to provide an environment where JAXA can collaborate with people from universities, other research institutions, and manufacturers on creating new technologies through an all-Japan framework. With the Innovation Hub, I’m expecting that all the different parties involved will be benefiting from this flexibility in forming groups by topic and taking multidisciplinary approaches across organizations and areas of expertise.

—Whether it’s a project or an innovation hub, there needs to be an industrial element to the initiative for JAXA to contribute to the aircraft industry. What do you envision along those lines?

The research initiatives at the Innovation Hub need to conform to industrial needs and needs. Otherwise, we won’t be able to attract human resources or industrial technologies. Building on the many steps that JAXA has taken to make its intellectual property as accessible as possible to partnering researchers, we’re now committing ourselves to giving manufacturing partners more freedom to use the intellectual assets that come out of the Innovation Hub as they wish. That way, we’ll be able to ensure that manufacturers will be able to participate strategically with a view to industrialization.

I hope that the Innovation Hub can get university professors and students involved, too. If we want to attract students then outside the metropolitan area, we’ll need to be able to provide support for longer-term projects. That’s one area that I want to focus on. Students will be able to flourish at the Innovation Hub. I think, and put themselves in position to lead the aircraft industry into the future. The Innovation Hub has the potential to be a liberating platform for young JAXA researchers, as well—by sharing goals with manufacturers and academia, our up-and-coming generation of JAXA scientists will have the opportunity to take on increasingly important roles in areas like operations development.

—The IT field is another important area, right?

I think it’s important to install the Innovation Hub to provide opportunities even when faced with weather like last year. In 2014, we were forced to suspend the flight experiment because appropriate weather conditions did not exist during the ascent. During the actual flight experiment, it looked like the airplane was separated upon reaching an altitude of 30 km to balloon trajectory (Pattern B) in which the experiment airplane was separated. For this year’s flight experiment, we added an option: an altitude of 33 km first, then come down to an altitude of 30 km. After this, the experiment airplane could drift up to 3 km away from the experiment balloon, and then descend down to an altitude of 30 km for level flight for the separation of the experimental airplane. For this year’s flight experiment, we added an option to balloon trajectory (Pattern B) in which the experiment airplane was separated upon reaching an altitude of 30 km during the ascent.

During the actual flight experiment, it looked like the
—and the balloon would pass through the donut-shaped separation zone at an altitude of 30.5 km. While following the path of the meteorological briefing, the “go-sign” was given. Upon hearing this news, our team started a movement to wear something green to meetings. As another diverse team for team members, the site manager purchased a green t-shirt at the space center (looking back, I now wonder why the center was selling green t-shirts...), and other members wore green sweaters and shoes. In sum, it was just a coincidence, but we got the go-sign in about a week after starting the “green movement.”

Preparation to completion

—How did you arrive at the decision to conduct the experiment?

First, every day at about 11:00 am local time, our JAXA team held a pre-briefing session to forecast the weather for two days later and to make a decision on whether or not to carry out the experiment. JAXA conducted preliminary review based on weather conditions such as temperature, humidity, wind speed and wind direction, and by considering factors such as the predicted flight trajectory of the balloon and measuring conditions for the sonic boom. Then, from 2:00 pm, we attended a meteorological briefing held by the Swedish Space Corporation (SSC), who operates and maintains the Esrange Space Center. At this meeting, the SSC confirmed factors including weather conditions, balloon trajectory, and the status of preparations by JAXA, and then issued a final decision regarding the weather experiment. The process was repeated every day, once Saturdays and Sundays, until we finally got the go-sign.

Unlike in 2011, when we aimed for the slight chance of conducting the experiment amidst poor weather conditions; the end of this year’s experiment period gave us several consecutive days of appropriate weather conditions. When making a decision, we classified the weather conditions into the categories of red, yellow, and green. Remember how I mentioned the green t-shirt? The green category meant that the conditions were good. Even better, several of those “green days” continued in a row. It really seemed like our prayers via the green movement had been answered. In fact, there were so many green-days that we had our choice of when to release the balloon. It was so fortuitous that we started worrying that something had been overlooked!

—How was the team’s mood on the day of the experiment?

For the majority of airplane team members, it was their third time. They had rehearsed the operation procedures countless times. Accordingly, everyone was confident that they could follow all the necessary procedure correctly without any problems. The experiment site of the Esrange Space Center is extremely expansive, measuring about 100 km from north to south and 70 km from east to west. The central site and the BMS sites were located separately. As a result, in order to prepare for the experiment, team members in charge of the BMS had to travel to the BMS sites via helicopter about 30 minutes before the start of the experiment. The BMS site was located directly south of the central site.

The experiment started at 20:30, ten hours prior to the balloon release. Each BMS group consisted of two members, and there was a total of three BMS sites. Four of those members were new to the project. Although they had undergone regular preliminary training at an airport site, training at the actual BMS site had only been held once. I imagine that those members were quite nervous at the time of the actual experiment.

Even after the go-sign was given for the experiment and preparations were started, it was still necessary to make a go or no-go decision at certain points such as deploying the balloon and filling the balloon with gas. During that process, it started raining lightly prior to transportation of the experimental airplane from the hangar. Consequently, the experiment coordinator was put on hold and there was a delay in preparations by the SSC technicians who were responsible for releasing the balloon. Even at the time required until releasing the balloon was longer than when we released the balloon in Japan. Since the experiment coordinator was only based in Japan, there was no detailed information on local conditions, so I can say that they were filled with anxiety.

What was the situation after releasing the balloon?

The experiment team was divided into an Operations Center where the SSC operated the balloon and JAXA confirmed flight safety for the experimental airplane, and a Science Center where the status of the flight airplane and BMS sites was monitored. I watched over the release of the balloon from the Balloon Operation Center at 4:43 am. I had heard from our experiment airplane would be the heaviest payload that SSC had ever tested with, so I was holding my breath at the moment that the balloon was released. I stood at the display for a day or after the balloon was released, worrying that it would burst and fall down. After seeing that the balloon was rising steadily, I entered the Science Center and began working with other team members to check wind conditions and the balloon flight trajectory.

Initially, we had planned to use Pattern B and separate the airplane three hours after the balloon release. During that three-hour period, there was some heated debate regarding the separation timing. In the end, the timing was right for Pattern B separators, so we gave up and switched to Pattern A. Afterwards, when the team arrived at the balloon, we guided the balloon in an attempt to locate the best possible conditions (to the outside of the dome where the experimental airplane was to pass over BMS sites).

We were able to perform separation under outstanding conditions about two hours later, at 10:00 am. After overseeing the separation procedure and the separation was completed, we confirmed the flight data and planned to give the go-sign. The actual flight didn’t go as exactly according to plan. As I watched the control monitor, each single light indicating a deviation from the scheduled flight path became my nemesis. Members in charge of autodynamics and flight control also remembered the flight deviation which had occurred in 2011, so everyone was extremely nervous.

The BMS sites were being monitored in real-time, so we gave up on flying away. The fact that we had succeeded in measuring the sonic boom was exchanged. However, I didn’t truly feel like we had succeeded until I collected measurement devices which had been attached to the BMS and then played back the data. Thanks to the efforts of the team, we were able to check the data the day after the experiment.

Leading the world in sonic boom reduction technology

—Please tell us what is known about experiment results at the current time.*

Flight control for the supersonic airplane must consider not only the flight procedure according to place. For the BMS, all recorders, both airborne and on the ground, operated correctly. We recorded many sonic booms. From among the three BMS sites, we succeeded in measuring low sonic boom waveforms at Site N. Microphones at the other two sites (Site C and Site S) measured several sonic booms. When combining all of these recordings, we succeeded in measuring a total of 196 sonic booms signatures. This is the first time that such a large amount of valuable sonic boom data was acquired through a single flight experiment.

From the acquired sonic boom data, we confirmed a sonic boom reduction effect. However, since the flight environment and other factors differed slightly from our original forecast, we are currently taking a more detailed look through CFD (Computational Fluid Dynamic) analysis and sonic boom propagation analysis. We still need a little more time before we can validate the “low sonic boom design concept” which is the objective of the project.

What will detailed analysis results be released?

I hope to report on detailed analysis results at the SSTs (Supersonic Task Group), a meeting of the IACO (International Civil Aviation Organization), which will be held in Canada at the end of October. I would also like to present the experiment results at a general meeting of the CAEP (Commission on Aviation Environmental Protection) of the IACO, which will be held in February 2016. At the meeting, discussion will be held regarding the formulation of international sonic boom standards in preparation for the operation of supersonic transport aircraft in the future.

What aspect of the D-SEND Project has been the most difficult?

The experimental supersonic airplane doesn’t have an engine or wing for running on the ground. Therefore, it wasn’t possible to conduct testing in the stages of ground test, subsonic flight, and supersonic flight. Instead, prior to the actual flight, we were only able to test functions on the ground. For that respect, this project may have had more in common with the launch of a rocket than the flight test for an airplane. It’s truly an all-or-nothing experiment.

While being conscious of our budget and schedule, we had to think creatively, consider all possible happenings, and conduct development to ensure the success of our flight experiment. On a different note, the SSC staff working at the test site in Sweden was conducting close communication with the SSC. In order to facilitate an environment for smooth implementation of the flight experiment, I had to overcome various obstacles and troubles.

In closing, please tell us your future plans and aspirations.

In the recent experiment we conducted supersonic flight for an experimental airplane which was designed with a low sonic boom and tested. We succeeded in acquiring a large amount of sonic boom data which includes low sonic booms signatures, and we are conducting detailed analysis and evaluation of this data. In doing so, I can say with confidence that Japan is one step ahead of the rest of the world in the future. In addition to summarizing the results of the D-SEND Project, I hope to use these results as a base for pursuing new research themes in supersonic airplane technology.
Flight system technology for making aircraft safer and more familiar

It is important for aircraft to be structurally strong and environmentally friendly. However, if aircraft built to possess such characteristics cannot be controlled, safe flight is not possible and passengers will lack peace of mind during flight. Aircraft are sometimes operated by pilots and sometimes flown via control by a program. In order to realize safe flight, it is necessary to formulate measures by assuming a variety of conditions including human error by the pilot and loss of control due to equipment failure. An extremely broad range of technology is needed to resolve such issues. What kind of technology is being researched at JAXA?

JAXA flight testing facilities are unlike any other in the world

The efficiency of research and development for flight technology has increased dramatically due to the use of wind tunnel experiments which have been utilized since long ago and to remarkable advancements in computational fluid dynamics (CFD) in recent years. However, as the final step for realizing actual operation, it is necessary to guarantee performance by conducting flight demonstrations in the actual operation environment. Aircraft manufacturers, onboard equipment manufacturers, airline companies and research institutions all have a wide range of varied needs which include evaluation of new sensors, actuators, avionics and control programs through flight demonstration, establishment of flight demonstration technology required for aircraft development, and flight evaluation for safe and efficient operation technology. In order to respond to these needs, JAXA operates three research aircraft (helicopter, propeller aircraft and jet aircraft) which possess different flight envelope (altitudes and speeds), as well as two flight simulators for fixed-wing aircraft and rotorcraft, whose control characteristics are completely different (see page 11 for details). In addition to responding to various demonstration needs, we are working to establish efficient testing technology, and to improve the level of testing technology and measuring technology.

The twin-engine turboprop aircraft MuPAL-α is equipped with an experimental Fly-By-Wire (FBW) control system in addition to the original mechanical system. This enables MuPAL-α to simulate the motion of various other aircraft. Aircraft with this functionality are rare and unique even on a worldwide level. These functions make it possible to conduct simulated flights by replicating the control of aircraft under development and the conditions of aircraft involved in accidents. As part of joint research with the University of Tokyo, MuPAL-α is being used in experiments for control technology which enables malfunctioning or damaged aircraft to continue safe flight and to land safely.

The research jet plane Hisho was unveiled in 2012 in order to enable flight testing at high speed and higher altitude. Hisho was used to conduct noise source measurements during JAXA’s FQRGH (Flight demonstration of Quieter Technology to Reduce nOise from High-lift configurations) project. Furthermore, Hisho is scheduled for use in future flight demonstrations of technology for reducing noise. Hisho will also be used to conduct performance testing of evaluation instruments for flight testing of Japanese commercial aircraft, as well as confirmation for operation in flight testing.

Currently, while enhancing the functions as a research aircraft, the BK117C-2 is being used in demonstrations of the Situational Awareness and Visual Enhancer for Rescue Helicopter (SAVERH) system which utilizes Helmet Mounted Display (HMD), and in measurements of wake turbulence.

As ground facilities, JAXA possesses two types of flight simulators which provide pilots with the same controllability and sensation as actual aircraft. The flight simulator has the same cockpit display program, which are used in the FBW system of the MuPAL-α. This makes it possible to perform preliminary confirmation using the flight simulator before actual flight demonstrations.

`SAVERH display`

One advantage of JAXA is that we do much more than simply fly aircraft,” explains Kenji Fujii, Director of the Flight Research Unit. “We possess technology and know-how related to measurement technology and flight testing. We will continue to contribute to the growth of the aeronautical industry through joint research with private sector companies, universities, and other public organizations by using our flight testing facilities.”

Preventing human error by pilots

As one type of technology for preventing human error, Crew Resource Management (CRM) training is widely conducted by airline companies, the Japan Self-Defense Forces, the Japan Coast Guard, and organizations which train pilots. JAXA has also contributed to the implementation of CRM, which is a concept in which safe and efficient flight operations are realized through the effective utilization of all resources; specifically, people (pilots, air traffic controllers, mechanics, etc.), objects (manual, airports, etc.), and information.

JAXA is currently developing a tool to evaluate the effectiveness of CRM education. Furthermore, from the viewpoint of human elements, JAXA plans to establish a system which comprehensively evaluates various human factors which include pilot emotions, mental state, ability, skill and fatigue.

One JAXA technology which has already been put into practical use at several airline companies is the Data Review and Analysis Program (DRAP), which replicates actual flight conditions as three-dimensional visual information. By using DRAP to reconfirm their own flight conditions and maneuvers, pilots can reduce future errors and improve their skills.

Another technology which has already been put into practical use is Tunnel-in-the-Sky. Tunnel-in-the-Sky is a flight support system which displays a tunnel-shaped flight path on the cockpit display. By flying inside of the displayed range, pilots can realize smooth flight and landing. By explaining this technology as drawing an imaginary tunnel in the sky and flying inside the tunnel, the technology might be easily understood. In addition to use in JAXA flight demonstrations which require precise flight trajectories, Tunnel-in-the-Sky is also being use at private helicopter companies for airborne laser surveying which also demands precise flight trajectories.

JAXA is also focusing on research and development for the aforementioned SAVERH as a human interface for supporting control of helicopters for which only visual flight is possible. This system combines infrared
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**Flight system technology for making aircraft safer and more familiar**

In Japan, a country which has little flat ground and is filled with mountains and islands, helicopters (rotorcraft) account for roughly 30% of all registered aircraft. This is an inordinately high ratio when compared to other countries. Helicopters are used in a variety of situations including search and rescue, emergency transport, and shipping of goods. However, the further expansion of helicopters is hampered by threats to safe flight due to poor visibility as well as by noise control issues in urban areas. In order to improve these conditions and expand the usage of helicopters, it is necessary to develop safer flight support technology.

“Through advancement of such technology, we hope to realize aircraft which can be controlled easily by anyone,” says Fujii. “Accordingly, our goal is to develop a safe flight system which can be controlled easily and which responds under any conditions.” The establishment and spread of this technology will make aircraft a more familiar tool of our lives.

*Toward expanding the use of helicopters*

In Japan, a country which has little flat ground and is filled with mountains and islands, cameras and topographic data to reduce workloads on pilots and increase flight safety even in poor weather conditions without sufficient visibility.

Topographic information, flight path information, infrared camera images and other required information are displayed on the HMD, and the system automatically measures the distance to specified obstacles. Also, flight control systems are important to enable safe control for broad flight envelope such as from takeoff, landing, to high-speed flight at high altitudes, as well as supersonic flight for the future theme. In addition, flight control systems should be able to handle emergencies and sudden changes in weather conditions such as turbulence. JAXA is conducting research to develop tools which enable efficient design and evaluation of such flight control systems.

“A sensor which uses a laser to irradiate airborne particles and then measures wind speed based on the scattered light. 

*Kenji Fujii*

**Director, Flight Research Unit**
JAXA’s Chofu Aerospace Center not only features wind tunnels but also boasts a wide variety of aircraft engine testing facilities. This section takes a closer look at how these facilities have driven aircraft engine research and development and how the testing equipment will open up the skies to new possibilities in the future.

Jet engine structures that facilitate component research and development

A jet engine has a “modular configuration” that comprises several components in series: the fan (which feeds in air), the compressor (which compresses the air), the combustor (which mixes the compressed air with fuel and burns the mixture), and the turbine (which uses the high-temperature gas that comes from the combustor to rotate the engine). Unlike the structures of piston engines and other engine types, the modular configuration of a jet engine has an independent, four-step cycle—intake, compression, combustion, and expansion—that makes it possible to develop and test each component separately and thereby create an optimal engine by combining the components that ensure proper performance. The modular configuration of a jet engine is also why the aFJR project, which began in 2015, can concentrate specifically on developing technologies for environmentally friendly fans and low-pressure turbines. Taking advantage of the unique benefits that modular configurations offer, the Chofu Aerospace Center features facilities for developing and demonstrating components on an individual basis and jet engines in complete packages.

Jet engine test cell

Users can assess the operations of jet engines at subsonic speeds, and semi-free-jet testing, which measures performance under supersonic flight conditions with the air intake on the engine. To provide researchers with information on shrouds that occur inside the air intake, the design of the facility also enables schlieren*1 measurements.

Most of the aircraft engine testing facilities at the Chofu Aerospace Center went into use after the research and development project for the F8F7 (during the 1970s and 1980s), the high-bypass-ratio turbofan engine that represented a first for the domestic Japanese market and laid the foundation for the country’s aircraft engine industry. The jet engine test cell—one of the post-F8F7 installations—allows researchers to test engines ranging from ultra-small engines with 2.5 kN of thrust to regional jet-class engines with up to 100 kN of thrust. Since the turn of the century, the Center has revamped the facility for testing various engine control technologies by enabling partial engine operation functionality during testing (variable turbine nozzles, etc.) and supporting controls of fuel flow volume and other parameters.

The altitude test facility recreates airborne flight environments in a sealed chamber and features engine testing equipment that allows researchers to simulate conditions at speeds of up to Mach 2 and air altitudes of 15 km. The facility provides an optimal setting for two main test types: direct-connect testing, which involves feeding air directly into the engine and measuring the performance levels of the engine itself at subsonic speeds, and semi-free-jet testing, which measures performance under supersonic flight conditions with the air intake on the engine. To provide researchers with information on shrouds that occur inside the air intake, the design of the facility also enables schlieren*1 measurements.

From the late 1970s through to the 1980s, the “Moonlight Project”—a Japanese governmental initiative to create energy-saving technologies—used JAXA’s engine testing facilities to research and develop electricity-generating gas turbines. As jet engines and gas turbines have essentially the same basic structure, the JAXA testing facilities offered that kind of versatility. In the late 1990s, JAXA, the National Institute of Advanced Industrial Science and Technology, aircraft engine manufacturers from Japan and around the world, and other organizations used the engine testing facilities as part of the ESPR project for the development of next-generation supersonic engines.

“Since there might be bigger facilities abroad,” says Hisao Futamura, Director of the Propulsion Research Unit, “but the

Facilities that have evolved together with aircraft engine research in Japan

*1 An optical method that involves passing a parallel light beam through a flow and observing the variations in the resulting light to measure changes in (the gradient of) gas density.
facilities we have in place right now can make valuable contributions to regional jet-class engines.” The ongoing affR project (see FLIGHT PATH No. 1/2 for details) is assessing fans made of carbon fiber reinforced plastic (CFRP) at the fan and compressor test facility and planning to test low-pressure turbines made of ceramic matrix composite (CMC) at the materials test facilities. In the effort to research engine noise reduction technologies, researchers have placed microphone arrays at the noise test facilities, the jet engine test cell, and other facilities to determine noise sources, evaluate the effects of noise-reduction devices, investigate noise propagation conditions, and more.

Like JAXA’s wind tunnels and other facilities, several of the testing facilities at the Center are open to outside organizations like companies and universities. In high-pressure and high-temperature combustion test facilities, for example, all jet engine fuel is just one of many materials that users can test—the facility also enables testing of natural gas and hydrogen gas, helping companies research and develop industrial use gas turbines that use non-fuel.

Creating environment-friendly aircraft engines

Responsible for mixing and burning compressed air and noise-reduction devices, investigate noise propagation (CFRP) at the fan and compressor test facility and materials that users can test—the facility also enables pressure and high-temperature combustion test facility, friendly aircraft engines researchers have placed microphone arrays at the noise matrix composite (CMC) at the materials test facilities. In conditions, and more.

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JAXA’s electric aircraft! For Harmonized Ecological Revolution project has demonstrated

During FEATHER (Flight demonstration of Electric Aircraft Technology for Harmonized Ecological Revolution) project has demonstrated

Advances in battery technology have opened up new possibilities for electric aircraft

For about ten years now,” says Atsuo Hori, FEATHER Team Leader, “electric propulsion technologies for aircraft have been making rapid progress all around the world. One of the catalysts behind that accelerated development activity was the arrival of the lithium-ion rechargeable battery. Lead and nickel-metal hydride batteries, which had been the main power sources before the lithium-ion battery came along, were too heavy to use in transport aircraft and often failed to ensure sufficient endurance and cruising distance. A lithium-ion battery—even one light enough to install onboard an aircraft—has enough energy density to guarantee the power it takes for an aircraft to fly. The introduction of lithium-ion batteries has opened up a world of new possibilities in electric propulsion technologies for aircraft. Unlike recirculating engines, which run on aviation fuel, battery-driven motors produce no carbon dioxide (CO2), nitric oxide (NOx), or any other exhaust gases and also deliver amazing energy conversion efficiency levels of 90% or higher. The structures and mechanisms of a battery-powered motor are simple, too; they eliminate the need for elements like oil piping, thereby reducing the overall engine weight and cutting maintenance costs. However, batteries lack the energy capacity per unit of weight (weight energy density) of traditional fossil fuels. Even a lithium-ion battery, a battery type with a relatively high weight energy density, needs to be heavy in order to enable the same duration of flight as a reciprocating engine; that added weight can prevent an aircraft from taking off. That does not mean that electric aircraft are totally impractical, though. Around 10 years ago, the United States created a “Light Sport Aircraft” (LSA) sub-category of small, sports-oriented aircraft that fall into the broader “small propeller aircraft” classification. As LSAs only have to be able to fly for short periods of time, electric aircraft can meet user expectations. The results showed that the remaining motor components were enough to allow the aircraft to climb, maintain the minimum necessary thrust, and remain safe in flight. Some companies and organizations outside Japan are also working on ways of driving the tail rotors of helicopters using redundant electric motors with two motor components. If the current efforts are any indication, redundant motors might represent a key piece in the development of electric propulsion technologies. JAXA’s “regenerative air brake,” another unique technology, uses the rotation of a propeller—which acts as an air brake—to supply the aircraft with power. Hybrid and electric can have regenerative systems that regenerate kinetic energy into electric energy during deceleration and use that new electric energy to charge the vehicle’s battery. With the regenerative air brake system that came out of the FEATHER project, as aircraft can recover power as the wind turns the propeller during descent procedures and other situations where the electric motor is not powered. At the same time, propellers that are not using any motor drive also serve as aerodynamic resistance (air brakes). As gliders usually have only lift (L/D) ratios, they deploy air brakes on their main wings during landing procedures to expedite the descent process. Regenerative air Brake systems not only help save energy but also eliminate the need for those types of main wing air brake devices, a benefit that brings the overall weight of the aircraft down and improves maintainability. Although pilots normally have to use both the throttle lever and air brake controls, regenerative air brake systems reduce the overall workload for electric aircraft pilots—all a pilot needs to do is switch the power lever for adjusting thrust from the drive side to the regeneration side. The propellers of reciprocating engines and electric aircraft produce the same acoustic noise, but electric aircraft engines generate less vibration and noise. When a pilot who flew JAXA’s electric aircraft experimental flights in February went back to flying the same aircraft models with reciprocating engines, he was apparently surprised at just how much shaking and noise they experienced. Electric aircraft engines also save pilots the trouble of having to check hydraulic pressures and engine temperatures, which are two of the many things that they have to keep an eye on with reciprocating engines. With fewer items to monitor, pilots have an easier job of flying their aircraft.

JAXA’s unique “redundant motor” and “regenerative air brake” technologies

Small, single-propeller planes that use reciprocating engines are prone to accidents caused by engine failure and the resulting loss of thrust. To help remedy that problem, the FEATHER project developed a “redundant motor system” that uses four serially linked electric motors to drive the propeller. Even if some of the motors fail, the redundant configuration makes it possible to maintain flight and complete a safe landing with the remaining motor. Overall, a redundant motor system makes electric aircraft operations safer and more reliable than a traditional reciprocating engine can. In February, researchers tested the motor by setting the output of one of the motor components to zero. The results showed that the remaining motor components were enough to allow the aircraft to climb, maintain the minimum necessary thrust, and remain safe in flight. Some companies and organizations outside Japan are also working on ways of driving the tail rotors of helicopters using redundant electric motors with two motor components. If the current efforts are any indication, redundant motors might represent a key piece in the development of electric propulsion technologies. JAXA’s “regenerative air brake,” another unique technology, uses the rotation of a propeller—which acts as an air brake—to supply the aircraft with power. Hybrid and electric can have regenerative systems that regenerate kinetic energy into electric energy during deceleration

Setting precedents in the skies with revolutionary new aircraft!

To secure flight clearance for revolutionary, brand new aircraft, JAXA started implementing its electric propulsion system in aircraft in 2014, conducted sufficient ground-based static tests (where researchers rotate the motor with the motor fixed to the ground), and performed the necessary ground-based runway tests (before the aircraft travels on the ground until it reaches a speed that it would obtain just before takeoff). The Civil Aviation Bureau finally grants flight clearance once these tests are complete. Immediately after receiving flight clearance, JAXA conducted jump flight tests—assessments where aircraft “jump” several meters off the ground. For the final testing procedures in February 2015, JAXA performed demonstration flights by sending aircraft into traffic patterns at an altitude of 60m. Rangeing from flight clearance protocol and wind tunnel testing to load testing, discharge testing, full-aircraft ground-based testing, and flight testing, the breadth of the experience and expertise that JAXA has gained through the FEATHER flight demonstration process will be useful resources for electric aircraft tests at Japanese companies and universities.

Could electric aircraft technology be a Japanese specialty?

For the experiments, JAXA took a glider that had originally had a reciprocating engine and modified the configuration so that the aircraft would run on an electric motor and battery. Researchers also made sure that the modifications would not alter the glider’s airframe weight or center of gravity—conditions that made it impossible to install a heavy battery. During the February flight demonstration tests, researchers successfully flew the aircraft for up to around 17 minutes using a battery that had about 30% to 35% of its power left. Had they been using an unmodified electric aircraft, however, they would have been able to load a heavier battery and achieve longer flight duration.

Looking back on the process, Nishizawa says, “The time and effort that Japan has gone to in order to develop electric aircraft and develop demonstrations. It’s really encouraging to know that we have achieved something that has never been done in Japan before—maneuvering flight in an electric aircraft!” The FEATHER project’s efforts to demonstrate an electric propulsion system may have come to an end in March 2015, but the drive to demonstrate aircraft electrification technologies is still pushing forward across the globe. Just as electric and hybrid cars have given non-automotive companies new avenues into the automotive sector, electric aircraft technologies have the potential to bring other industries into the aircraft market. That opportunity for involvement is sure to increase as the electrification of aircraft, which requires technologies for high performance electric motors, high-energy batteries, fast charging and systems that enable longer cruising distances, and systems for controlling those various components. There are all fields where Japan boasts some of the best technologies available. If the country can unite all of its cutting-edge technologies in these areas, Japan will be able to establish electric aircraft technologies that stand a head above the international competition.

Specification of the experimental motor-driven glider system

Original glider

Diamond Aircraft Industries GmbH

Type

LSA

Max takeoff weight

120kg

Max. output

160kW

Cruise speed

100m/s
In response to demand for more fuel-efficient aircraft, research and development are being conducted to improve jet engine performance. For example, the bottom of the fuselage of the retired NASA space shuttle was made from host-resistant tiles which protect the airframe from high temperatures caused by aerodynamic heating when re-entering the Earth's atmosphere. Made mainly from silica glass, these tiles are extremely lightweight and provide superior heat resistance, but are as fragile as pumice.

As a result, much attention has been given to ceramic matrix composites (CMCs) in recent years. Since the 1990s, JAXA has conducted research on the application of CMCs to high-temperature structural materials of space planes. Made mainly from ceramics, CMCs weigh less than metal, and are highly resistant to heat and oxidation. Furthermore, the use of ceramic fibers in CMCs resists cracking. CMC materials are difficult from silica glass, these tiles are extremely lightweight and provide superior heat resistance, but are as fragile as pumice. For example, the bottom of the fuselage of the retired NASA space shuttle was made from host-resistant tiles which protect the airframe from high temperatures caused by aerodynamic heating when re-entering the Earth's atmosphere. Made mainly from silica glass, these tiles are extremely lightweight and provide superior heat resistance, but are as fragile as pumice.

CMCs are still have a low level of technological maturity when compared to metal materials. CMCs are not currently used in high-performance jet engines, CMCs are conducting research on CMCs which are inexpensive and can withstand even higher temperatures. There are several manufacturing methods for CMCs. The most prominent of these methods is the polymer infiltration and pyrolysis (PIP) method. In this method, polymers which convert SiC through heat treatments are injected into the gaps among SiC fibers and then baked to form SiC fibers. Another prevalent method is the chemical vapor infiltration (CVI) method, which consists of infiltrating source gases to react with the matrix to form SiC fibers, and then with SiC fibers to form SiC fibers.

CMCs are being developed and demonstrated on engines that have already been built. JAXA started research on CMCs for use in jet engines from around 2003.

**What are Ceramic Matrix Composites (CMCs)?**

CMCs are composite materials which withstand high temperatures. They are used in the structural components of aircraft and spacecraft, and are a composite material in which carbon fibers woven into a flat surface or three-dimensional shape are infiltrated with a resin (plastic). CMCs are made by using silica carbide (SiC) or other ceramic fibers with a diameter of 7 μm to 20 μm into a flat surface or three-dimensional shape. Next, raw materials such as silane gases or organic silicon polymers is infiltrated into the gaps among fibers, and the raw materials are then converted into ceramics. This hardened portion is called the “matrix.” The matrix will crack easily if the bond between the fibers and matrix is too strong. Therefore, it is necessary to weaken the adhesive strength between the fibers and matrix. Compared to ceramic-caps on other metallic matrices which do not use fiber, CMCs manufactured in this way are much more resistant to cracking.

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**Viable CMC attitude control technology**

Once the initial four-year R&D phase is completed at the end of fiscal year 2016, the core players involved in the committee will shift to advising manufacturers and turbine makers for commercialization. Focusing on commercialization, the committee has already started discussion on how to make use of the detected turbulence information for making safer flight. Firstly, regarding conditions in the passenger cabin of a passenger aircraft, a standard model for 5-minute intervals was proposed for SafeAvio for independent turbulence accidents. The SafeAvio Research Committee is also working to achieve commercialization in a shorter period of time. SafeAvio is JAXA’s R&D initiative that seeks practical solutions to prevent turbulence induced aircraft accidents. The uniqueness of the SafeAvio initiative is its R&D framework that accommodates diverse opinions and expertise through the SafeAvio Research Committee, a collaborative community consisting of universities and the aviation industry including avionics and airframe manufacturers and airlines. Let’s look into what makes the SafeAvio initiative different from conventional R&D.

**SafeAvio**

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**Aeronautics in depth**

This section goes deeper into the research going on at the JAXA Aeronautical Technology Directorate. Although the details are a bit technical, the content will give you a glimpse of how JAXA technologies are making the skies a better place.

The first technology in the “Aeronautics in depth” series is Doppler LIDAR, which detects clear-air turbulence.

### Requirements for onboard Doppler LIDAR systems

JAXA is currently researching and developing an onboard Doppler LIDAR system to detect clear-air turbulence, a cause of aircraft incidents. Compared to radar, lidar, and other remote-sensing technologies, Doppler LIDAR makes it possible to conduct aircraft measurements in clear-air conditions at longer distances.

A Doppler LIDAR system emits laser light into the space in front of the aircraft, receives the light scattered by aerosol particles in the atmosphere, and measures the difference in wavelength between the transmitted laser light and the received scattered light to detect aerosol particle movements. “Aerosol particles,” which refer to tiny airborne particles with radii ranging from 1 nm to 100 μm, are found in the atmosphere around aircrafts. To identify clear-air turbulence, then, one could measure aerosol particle movements and look for significant “shifts.”

There are some challenging elements to installing a Doppler LIDAR system on an aircraft and using it to measure clear-air turbulence. However, one of the issues is that the amount (density) of aerosol particles in the air—the key measure for measuring aerosol conditions—extremely low at aircraft cruising altitudes. When an aircraft is flying at a cruising altitude of 10,000 m, for example, there might only be one aerosol particle with a grain diameter of less than 0.1 μm per cubic centimeter of air. Detecting these rare aerosol particles requires better detection efficiency, which comes from higher levels of laser output.

### How JAXA technologies achieve higher output levels in smaller packages

However, higher laser output causes the equipment to generate more heat and thereby creates the need for large cooling devices. In other words, you need to achieve two different, generally incommensurate objectives to install a system on an aircraft: higher output and smaller size. JAXA thus optimized the detection process by integrating fast signals 10 times to isolate the actual signals from the background noise. To do that, researchers defined the following figures of merit (FOM) to serve as indicators:

\[
FOM = \frac{E_{\text{signal}}}{P_{\text{background}}}
\]

\[E_{\text{signal}} \times P_{\text{background}} \]

*F* represents the peak energy of the laser.

In 2011, after going through several prototypes, JAXA developed a high-altitude model of a Doppler LIDAR system capable of detecting aerosol particles at cruising altitudes. Table 1 shows a comparison of the corresponding performance characteristics. As aircraft fly at high speeds (covering approximately 10 km every 40 seconds at cruising altitude), pilots need to detect conditions from far out in order to avoid turbulence. The high-altitude model of a Doppler LIDAR system with a grain size of at least 0.3 μm per cubic centimeter of air was used. By using fast laser output, it is now possible to measure extremely fast pressure changes which are caused by turbulence.

### Effective use of PSP

Pressure sensors have been used to measure the surface pressure distribution acting as aerodynamic models during wind tunnel experiments. Although pressure sensors are capable of high-precision measurement, they conduct measurement at a point known as a “pressure tap.” Accordingly, the pressure at areas other than pressure taps cannot be ascertained, and only a limited number of pressure taps can be installed. Conversely, pressure-sensitive paint (PSP) measurement can ascertain the pressure distribution over the entire surface (Figure 1). Using PSP makes it possible to reduce the number of pressure taps. This helps support the cost associated with previous methods by reducing the number of expensive pressure sensors and pressure taps, as well as the layout of sensor cables.

When PSP containing a mixture of polymers and pressure-sensitive dyes such as platinum porphyrin (PtTFPP) is exposed to excitation light, the dye emits phosphorescence (Figure 2). The amount of emitted light is decreased (darkened) when the oxygen concentration is high (i.e., when pressure is high) (see Figure 3). PSP measurement utilizes this property to calculate pressure from the intensity acquired by cameras. However, the PSP property in which intensity changes in response to pressure (pressure sensitivity) changes slightly for each PSP or model. Moreover, the intensity of pressure changes according to the temperature (temperature dependence).

Therefore, prior to each test using PSP measurement, the automated calibration system developed by JAXA is used to obtain characteristic data for the intensity of light emitted by test PSP in response to pressure and temperature (see Figure 4). In the case of wind tunnel tests, temperature-sensitive paint (TSP) is used together with PSP in order to measure the temperature distribution for the model. Pressure is derived from the temperature distribution data and the amount of light emitted by the measured PSP. This pressure data is inserted into even more accurate data through combination with the results of simultaneous pressure measurement performed using pressure taps.

### Compensating for the flaws of PSP measurement

In the case of normal PSP measurement, model surfaces are painted with pressure-sensitive dye mixed into polymers. It takes several seconds for pressure changes to reach the pressure-sensitive dye and a response to be issued. This made it difficult to conduct pressure measurement for ultra-short time periods and for irregular pressure changes caused by aerodynamic pressure. In response, JAXA has developed advanced-aluminum alloy (AA-PSP) coating technology which eliminates polymers and causes pressure-sensitive dyes such as transition metal complexes to be absorbed directly onto uncoated aluminum surfaces. This makes it possible to cause changes in the intensity of emitted light during an extremely short period of time (see Figure 5). By using this technology, JAXA has conducted the world’s first successful measurement of pressure distribution during the ultra-short time period of 20 milliseconds. JAXA has further advanced this technology to realize actuality PSP measurement in which a high-speed camera is used to measure the emitted light. As a result, it now possible to measure extremely fast pressure changes which are affected by noise. This makes it difficult to calculate the pressure distribution with high precision. The current accuracy of PSP measurement was usually lower than 1%, but it is now necessary to develop pressure measurement technology with a higher level of accuracy, to develop PSP from which a large amount of emitted light can be obtained even in a low-speed flow, and to use a high-speed camera with superior sensitivity.
JAXA has been working on the FLIGHT PATH (Flight Demonstration of Electric Aircraft Technology) project to realize practical aircraft. The University of Tokyo and the Tokyo Metropolitan Government have been working on developing an all-electric aircraft system for aircraft, which uses an electric motor-glider system for aircraf 

"ALWIN" is a joint development project between the JAXA and the Japan Meteorological Agency, and is being carried out to practical use.

"Development of Reuse Technology for Recycled Carbon Fiber" wins SMAPe JAPAN Product & Technology Award

In July 2011, the Japan Aerospace Agency (JAXA) launched the Test Flight for the Verification of Reuse Technology for Recycled Carbon Fiber Program (CfRecycle Project). The CfRecycle Project is a joint project carried out by JAXA, the Japan Aerospace Exploration Agency (JAXA), the Ministry of Economy, Trade and Industry (METI), and the Japan Society for the Promotion of Science (JSPS).

The CfRecycle Project aims to develop and verify the technology for the reuse of carbon fiber materials, which are used in the manufacturing of aircraft and other high-performance products. The project seeks to verify the technical feasibility of the reuse technology, and to verify the performance of the newly developed materials.

Overhaul and upgrade of pyramidal six-component balance system for JAXA's 6.5 m 5.5 m low-speed wind tunnel

From October 2014 to October 2015, JAXA performed overhaul and upgrade of the Japan's first six-component balance system (pyramid balance) for the JAXA 6.5 m 5.5 m low-speed wind tunnel. The balance system is a key component for the wind tunnel, enabling it to be used for a variety of tests in aeroelastic analysis.

Ceramics matrix composites (CMC) testing method proposed by JAXA is adopted as JIS standard

The JAXA proposed a new testing method for ceramics matrix composites (CMCs) that is based on the International Standard (ISO) 15669-1. The testing method is based on the evaluation of the mechanical properties of CMCs, which is essential for ensuring the safety and reliability of aircraft structures.

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