

JAXA Aeronautics Magazine

FLIGHT PATH

Shaping Dreams for Future Skies



Institute of
Aeronautical
Technology

2013

No.1/2

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静粛超音速研究機

- ソニックboom低減技術の確立
- 機体重量軽量化技術の確立

ハ2クラスの静

5時間

Feature story

JAXA's Institute of Aeronautical Technology takes off
ECAT: Program for environment-conscious aircraft technology

FQUROH: Flight demonstrations of noise reduction technology
Measuring aircraft noise in a wind tunnel

aFJR: The Next-Generation Fan/Turbine System Technology Demonstration

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The JAXA Institute of Aeronautical Technology has launched "Flight Path," the organization's public relations magazine.

In April 2013, JAXA integrated the Aviation Program Group with the division in the Aerospace Research and Development Directorate that was once responsible for fundamental research on everything from aviation to space. This combination formed the new Institute of Aeronautical Technology. We would like to thank you for your dedicated readership of "Sora to Sora" and "Aviation Program News," the PR brochures for the Aerospace Research and Development Directorate and the Aviation Program Group, respectively. "Flight Path" will deliver all the latest news on JAXA's aviation-related research and development efforts. We hope you enjoy the new publication!

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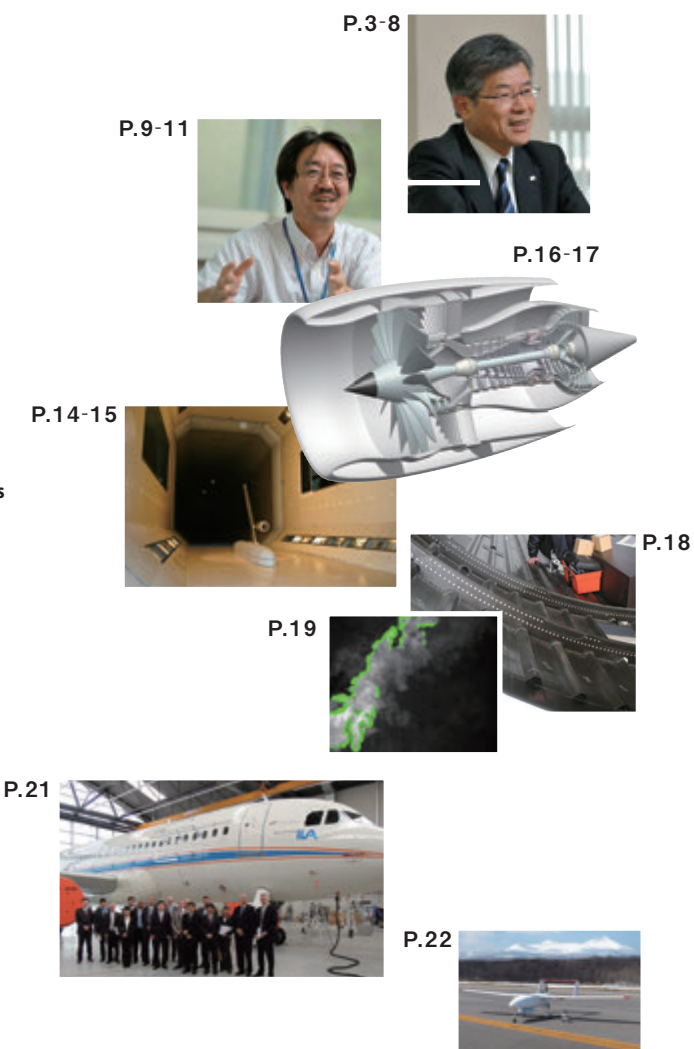
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Feature story >>> An interview with Dr. Nakahashi
Executive Director of the Institute of Aeronautical Technology

"Shaping dreams for future skies"

JAXA's Institute of Aeronautical Technology takes off



Profile

Kazuhiro Nakahashi

Executive Director of the Japan Aerospace Exploration Agency
(Executive Director of the Institute of Aeronautical Technology
and Aerospace Research and Development Directorate)

After obtaining his doctorate in engineering from the University of Tokyo in 1979, Nakahashi joined the National Aerospace Laboratory (NAL; now JAXA) and began analyzing rocket engine nozzle performance at the NAL Kakuda Branch. He later researched computational fluid dynamics (CFD) at NASA from 1983 to 1985 and then returned to Japan to work on jet engine CFD projects in the Power Systems Division. Serving as an assistant professor at Osaka Prefecture University in 1988 and a professor at Tohoku University since 1993, Nakahashi has continued to research and teach aviation-related CFD. He has also contributed to the development of MRJ through the development and application of Tohoku University Aerodynamic Simulation (TAS), a CFD coding that enables efficient calculation of aircraft flows. He has held his current position since April 2012.

Although many people probably associate JAXA with space development projects like the HAYABUSA asteroid explorer and the International Space Station (ISS), the organization's research and development efforts go beyond the realm of space. The aircraft technology field, for example, is another area where JAXA is active on a global scale. With aircraft serving as a vital component of the social infrastructure and playing important roles in people's economic activities and social lives, growing demand in the aircraft industry has sparked intense development competition around the world.

Having led Japanese research in aviation technology, JAXA created its Institute of Aeronautical Technology in April 2013 to forge stronger bonds with society and contribute to further development in Japan's aviation industry. We sat down with Kazuhiro Nakahashi, the Executive Director of the JAXA Institute of Aeronautical Technology, to get his thoughts on the new venture.

The new Institute of Aeronautical Technology: Fortifying further growth in the Japanese aviation industry

– How has JAXA’s aviation technology research contributed to Japan’s aviation industry?

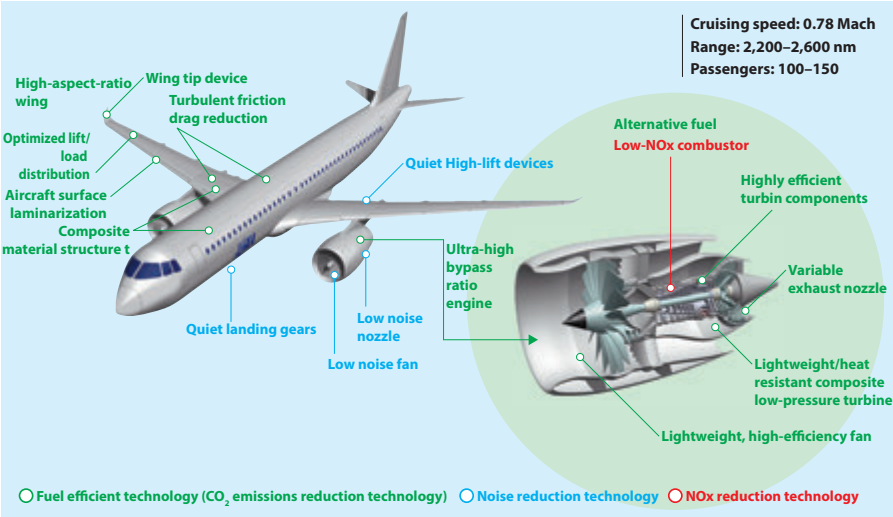
In the late 1970s, JAXA collaborated with industry, academia, and government to develop the FJR710—a Japanese-made aircraft engine that would later power the “Asuka” experimental quiet STOL aircraft developed by JAXA, which made its maiden flight in 1985. The technology behind the FJR710 continues to thrive to this day, providing the basis for the V2500 turbofan engines used for the current A320 series of Airbus aircraft. With a track record of over 7,000 orders from airlines spanning the globe and more than 5,000 total deliveries, the V2500 is now the third-best-selling engine of all time. Japanese manufacturers have accounted for 23% of international joint development on the V2500, making the engine a major source of profit for the Japanese corporations involved.



The FJR710 developed by JAXA through industry-academia-government collaboration

JAXA has also done substantial research on carbon-fiber-reinforced plastics (CFRP). By creating a model of the “Asuka” tail wing section, we designed and evaluated Japan’s first-ever aircraft structure using CFRP. The results of our research have been incorporated into passenger aircraft, spurring the adoption of composites in many cutting-edge passenger planes.

Our research output has also played an important role in MRJ development. From reducing structural weight to simultaneously optimizing



An overview of the TRA2022: JAXA’s vision for competitive next-generation passenger aircraft in 2022

aerodynamic and structural performance, JAXA’s aviation technology helps give MRJ the technological advantage to achieve outstanding levels of fuel efficiency.

– JAXA has been involved in aviation technology research for many years. What does the creation of the Institute of Aeronautical Technology mean for those efforts, and what role does JAXA play in relation to the Japanese aviation industry?

The aviation industry is an advanced technology-intensive industry that epitomizes the very best in manufacturing—a high-value-added industry that fuels the spillover of sophisticated technologies to other industries. As booming economic growth in Asia, the Middle East, and Central and South America opens the doors for massive increases in aircraft demand across the globe, the aviation industry will be poised to drive future growth in Japan—provided that it can use its technological capabilities and sharpen its competitive edge to capture that demand.

As a public institution, we would like to forge

deeper collaborative partnerships with the industrial sector to realize the positive development of our aviation industry. By further strengthening industry-academia-government collaboration and focusing on systematic research, we also hope to contribute in propelling the Japanese aviation industry forward by enabling companies to apply our research in an accurate, timely manner.

At the same time, we will continue to provide JAXA’s research tools to a wide range of universities and companies in order to help develop the next generation of young engineers responsible for carrying the aviation industry into the future.

This fiscal year marks the beginning of JAXA’s third Mid-Term Plan, which will run for five years, and the launch of the Institute of Aeronautical Technology’s research and development program,



which aims to take a more active approach to meet the social needs of industry, government, and other sectors. To coincide with these new programs, JAXA has integrated the division in the Aerospace Research and Development Directorate that was responsible for fundamental research on everything from aviation to space and the Aviation Program Group, which traditionally focused on more aviation industry-oriented, society-minded aviation research, into the Institute of Aeronautical Technology. This new organizational structure allows JAXA to manage all aviation research—from fundamental study to applied research—in an integrated manner, not only making its research and development activities more dynamic but also showcasing JAXA research and its output more easily.

– What are some of the specific activities that you plan to focus on?

In order to make contributions to the development of a safer, more prosperous society, the Institute of Aeronautical Technology focuses on research and development aimed at environment-conscious technology and safety technology in the aviation field. We will also continue our research on future technologies designed to benefit generations 20 and 30 years down the road—an area that industry often struggles to tackle.

Creating safe, environment-conscious aircraft

– What does research on environmentally friendly aviation technology entail?

Air transportation is expected to grow by a factor of 2.6 over the next 20 years. This high rate of expansion has raised concerns about the increase in environmental impact from aircraft emissions of greenhouse gases like nitrogen oxide (NOx) and carbon dioxide (CO₂), as well as noise levels around airports. The market thus needs environmentally friendlier aircraft capable of complying with the stringent regulations being implemented around the world.

The first step in reducing aircraft noise and emission levels is to find ways of making jet engines quieter and more efficient. At the Institute of Aeronautical Technology, we are working on next-generation engines that cut CO₂ emissions by more than 15% compared to today’s passenger aircraft and NOx output by at least 70% relative to the CAEP/6 standard set at the 6th meeting of the International Civil Aviation Organization (ICAO)’s Committee on Aviation Environmental Protection.

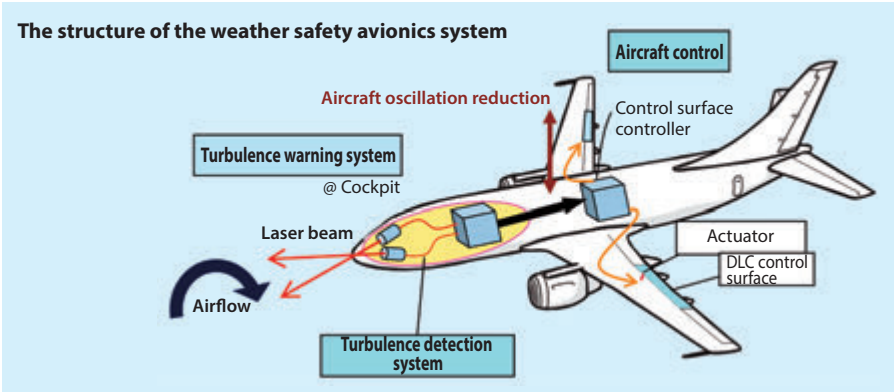
One major noise factor that needs to be addressed is the wind noise created by the wings, high-lift devices, and landing gear of passenger aircraft. We have already conducted supercomputer-based simulations and wind tunnel experiments to determine the optimal approach to limiting noise, and we plan to continue building on that foundation by performing flight verification tests using real aircraft.

– People hear a lot on the news about airport expansion, hub development, and the growing popularity of low-cost carriers (LCC). With more passenger aircraft in the air, there must be a stronger need for appropriate safety measures.

The ICAO is trying to realize a new air navigation system called “Global ATM Operational Concept” by 2025 to manage the world’s air traffic more safely and efficiently as traffic volume is expected to increase dramatically. The NextGen (US), SESAR (Europe), and CARATS (Japan) programs have been launched to make this vision a reality, with JAXA collaborating with CARATS on the DREAMS project. To cope with increased air traffic levels around airports, the DREAMS project is currently researching technologies to efficiently avoid wake turbulence and shorten flight intervals to improve airport capacities and reduce traffic delays, as well as to optimize flight paths to reduce aircraft noise around airports during the landing phase. We are also conducting research on technology that facilitates optimal mission management and collision avoidance systems to improve efficiency during disaster relief activities. We aim to make practical proposals to international standardization agencies or transfer these technologies to industry by 2015.

– What kinds of research are you doing on aircraft accidents?

According to the White Paper on Land, Infrastructure, Transport, and Tourism in Japan, approximately 50% of all aircraft accidents that occurred in Japan from 1999 to 2009 were caused by turbulence. JAXA has world-class laser radar (LIDAR) technology, having conducted R&D on on-board high-output turbulence detection system. The Institute of Aeronautical Technology hopes to further develop this technology to realize a weather safety avionics system that detects clear air turbulence before it has a chance to cause problems and automatically controls the aircraft based on turbulence information. With this undertaking, JAXA hopes to make significant improvements to the safety of air travel.



—The Great East Japan Earthquake is still fresh in our memories. How can aviation technology developed at JAXA contribute to disaster monitoring and response activities?

In the aftermath of the Great East Japan Earthquake, many aircraft were dispatched to the disaster area for rescue and relief activities, but the lack of an integrated aircraft mission management and operational system made it difficult to keep the refueling process moving smoothly and prevented



The D-SEND project
The supersonic aircraft used in second-phase testing (D-SEND#2)

controllers from assigning planes in a timely manner. To fill the need for an effective system, JAXA is developing an optimal mission management and collision avoidance system called “Disaster Relief Aircraft Information Sharing Network (D-NET)” as part of the DREAMS Project to improve efficiency and safety of aircraft operations during disaster relief activities.

Although JAXA was engaged in unmanned aerial vehicle research, the vehicles weren’t ready for practical use when the earthquake and tsunami hit. We were frustrated that we didn’t have the vehicles ready to help out in the wake of the disaster, so we’re now putting a lot of energy behind research in this area. First of all, we’re working with the Japan Atomic Energy Agency on a radiation monitoring system that uses unmanned aerial vehicles to

observe radiation levels of large areas from the sky. The other project we’re working on is the development of High Altitude Long Endurance (HALE) UAVs, which can remain in the air and observe disaster areas from altitudes higher than the cruising altitude of civil passenger aircraft. Satellites can also observe disaster stricken areas, and the contribution made by JAXA’s Earth observation satellite “DAICHI” immediately following the earthquake is still fresh in our memories.

Satellites with on-board radar sensors can capture high-precision images of large areas, regardless of the time of day or the weather, without being impacted by the damage on the ground. However, they’re not suited for monitoring smaller areas for

long continuous periods of time. HALE UAVs can complement the satellite’s capabilities, and they can be equipped with different sensors and devices depending on mission requirements, so it is necessary to utilize the capabilities of both satellites and UAVs in a coordinated manner.

Exploring the future possibilities of air transportation

—You’ve shared a lot about environmental and safety-related technologies that can make contributions to society. What about longer-term, future-oriented research?

In order to open up new markets in the field of aviation, it is important to embrace new possibilities in air transportation and direct our research efforts based on a long-term perspective.

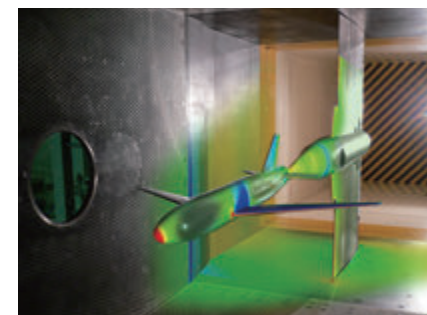
We are engaged in research activities such as

aircraft with entirely new configurations, technology that promises even greater convenience, engines with dramatic improvements in fuel efficiency, motor-powered electric airplanes, and more. I also believe that engaging in future-oriented research is a great way of sparking stronger interest among younger people.

Technologies bridging aviation and space

—How is your research on supersonic and hypersonic aircraft coming?

We need to push ahead with research on future-oriented technologies that the private sector might not be able to engage in on its own—and we’re not just talking about supersonic and



The Digital/Analog-Hybrid Wind Tunnel (DAHWIN)

hypersonic aircraft technologies. These future technologies need to be tested and verified, after all, and if we don’t engage in research and validation of these technologies now, we won’t be ready when the actual need arises. That’s where JAXA and other public research institutions from around the world come in, engaging in long-term research.



The domestically produced MRJ aircraft (© Mitsubishi Regional Jet)

Supersonic flight still has to deal with the problems of sonic booms—the loud “boom” that can be heard on the ground when an aircraft flying at the speed of sound produces shockwaves. The Concorde, retired from service in 2003, was banned from traveling at supersonic speeds over land because of the sonic boom issue. If we manage to get around that problem, airlines might be able to fly supersonic passenger aircraft once again. As we speak, JAXA and other organizations around the world are trying to figure out to what extent sonic booms need to be reduced to allow for proper supersonic aircraft operations over land. At JAXA, in our D-SEND (Drop test for Simplified Evaluation of Non-symmetrically Distributed sonic boom) project, we are working to validate our low boom aircraft configuration, and the second-phase tests of this project, D-SEND2, was conducted in Sweden in late August. In addition to these efforts, we are also contributing to the creation of noise standards for supersonic civil transport at ICAO by offering our technical expertise.

—JAXA naturally does a lot of work on space development. Can the technology created through research at the Institute of Aeronautical Technology make an impact on space development, too?

Technologically speaking, rockets, probes, and aircraft actually face a lot of the same challenges. They all have to have structures that are as lightweight as possible. They also require high levels of reliability. They have a lot in common when it comes to composite and computational simulation

technology, as well. JAXA’s “KOUNOTORI” H-II Transfer Vehicle (HTV), an unmanned resupply spacecraft for the space station, is built for one-time-use. Therefore, we’re working on “HTV-R”—“retrievable” HTV—that can come back to earth after completing their missions. We know that the technologies and

capabilities at the Institute of Aeronautical Technology, such as wind tunnels, will contribute to our HTV-R research. Our composite technologies are also used in some rocket components. Since fundamental research plays a very important role in R&D for both aircraft and space missions, we will need to work closely with relevant directorates within JAXA while playing a role as a specialized technology organization at the same time.

Also, looking at the operational side of things, we are seeing growing links between satellites and aircraft in remote sensing, for example. I believe the linkage between aviation and space will continue to grow stronger.

—How do you think the Digital/Analog-Hybrid Wind Tunnel (DAHWIN), which went into operation this fiscal year, will be used?

With computational fluid dynamics (CFD), we can use computers to change the shape of the aircraft to determine aerodynamically ideal configurations. But since these calculations are computer-based simulations, the results could be different from actual airflow conditions.

Wind tunnel experiments, on the other hand, use real-life airflow that allows us to accurately grasp air behavior, but it takes a lot of time and money to construct the necessary models. The Digital/Analog-Hybrid Wind Tunnel (DAHWIN), therefore, aims to strike the best possible balance between computer simulations (CFD) and wind tunnel experimentation, enabling us to accelerate R&D operations and produce dramatic improvements in precision at the same time. DARWIN makes it possible to do what would



The IFAR Summit, held at Yagoto Kosho-ji temple in Nagoya (October 2012)

normally take a month under the conventional setup in a matter of just a few hours. It also lets us look at the experimental data and the result of simulation analyses from remote settings practically in real time.

When flying aircraft under flight test conditions, we can encounter unexpected behaviors and defects. Even in these situations, DAHWIN gives us the ability to optimize aircraft configuration and perform wind tunnel experiments simultaneously, thereby making it possible to apply our findings to aircraft design quickly.

Shaping dreams
for future skies



Feature story ▶ ▶ ▶ An interview with Dr. Nakahashi

Executive Director of the Institute of Aeronautical Technology

Developing domestically produced aircraft to invigorate the aviation industry and train skilled human resources

– We're closing in on the MRJ's maiden flight, the first passenger aircraft designed and produced in Japan since the YS-11.

At a value of over 1 trillion yen, the Japanese aircraft industry currently represents just 0.3% of the country's total GDP. However, the industry is a knowledge-intensive one that demands sophisticated manufacturing technology, requires enormous amount of parts and components, and involves a broad range of other industries. Therefore, we think the MRJ will help invigorate Japanese industry across the board.

The development of domestically produced aircraft like the MRJ also figures to serve as a compelling goal for students and young engineers in aviation-related academic disciplines. By taking the lead in development, Japan will have to work on research and development for a massive array of technologies. In addition to manufacturing components as suppliers according to specifications established by overseas OEMs, Japan will also need to assume responsibility for operational performance after delivering the MRJ to airlines. Given the scope of these efforts, I think that Japan-led development efforts will really motivate young engineers and students to do profoundly challenging, worthwhile work.

We also hope that the MRJ succeeds and Japanese aircraft development efforts pick up momentum going forward.

– What do you think is needed to develop human resources for the aviation field of the future?

I think we need to provide younger people with a robust vision for the aircraft industry. More often than not, things like aviation and space tend to inspire people to dream big dreams. That's fine in itself, but those visions can lack concrete definitions.

We need to take another step forward to show people a more realistic image of the industry, emphasizing the practical necessity of aviation and the real, tangible appeal of cutting-edge technologies.

Universities are the driving force behind educating human resources, with JAXA providing the necessary technologies and equipment. Few universities have the ability to furnish large-scale testing facilities, so we think we can play a helpful role in supporting student research. JAXA has already launched an "Aviation Education Support Forum" in collaboration with the Japan Society for Aeronautical and Space Sciences, for example. The project provides universities with JAXA's CFD research results as research tools to be used at classrooms, gives students opportunities to experience real-life testing equipment, and brings Japanese students together with students and researchers from around the world through an international network of public aeronautical institutions. We will continue to do our best to contribute to the development of future human resources in the aviation field.

Working with companies is another important ingredient in developing human resources. For example, a manufacturer employee that spent two years at JAXA studying wind tunnel-based measurement technology went back to his employer and became a leader in aircraft development. Young JAXA researchers have also been involved in aircraft development at a manufacturer and brought their experience back to JAXA, incorporating their findings into their research activities.

We'd be severely limiting ourselves if we were to adopt a closed-door policy and focus solely on projects within the confines of the Institute of Aeronautical Technology. That's why we need to promote lively interaction with companies and universities to train the human resources responsible for the future of Japan's aircraft industry. Therefore, we are actively seeking out technology-related ideas from the business and academic spheres to promote joint research projects.

– How does the Institute of Aeronautical Technology work with organizations abroad?

JAXA is a member of a global organization called the International Forum for Aviation Research (IFAR). Created in 2010, it is the world's only public aviation research establishment network and currently has 24 participating institutions from around the world. The mission of IFAR is to promote collaboration among the world's aviation research institutions and formulate frameworks shared by participating institutions for research on noise, emissions, high-efficiency operations, safety, and other environmental issues. JAXA played host in 2012 to the first-ever IFAR summit (annual meeting) held in Asia and is now acting as the Vice Chair of IFAR and working in close partnership with the Chair organization, NASA, to ensure the growth of this unique and valuable venue for multilateral cooperation in aviation research.

JAXA is also engaged in a wide range of joint research with public aeronautics research organizations around the world, such as NASA (the United States), DLR (Germany), ONERA (France), KARI (S. Korea), as well as private companies like Boeing and Airbus, and universities to promote strategic collaboration of mutual benefit.

Through this strategic international collaboration in pre-competitive research that complements the respective strengths of the parties involved, we hope to enhance Japan's aviation technology and bolster its presence on the global stage.

The future of JAXA Institute of Aeronautical Technology

– What does the JAXA Institute of Aeronautical Technology aim to be?

We want to embody our slogan, "Shaping Dreams for Future Skies," to provide the state-of-the-art aviation technology that will make the skies of tomorrow cleaner, safer, and more comfortable for everyone. As Japan's central R&D institution for aviation, we will do our very best in supporting the Japanese aviation industry so that it can rise to even greater heights in the world arena.



Feature story: An interview with Dr. Akira Murakami, Advisor and Chief Engineer of the Institute of Aeronautical Technology, JAXA

Working with an eye toward needs 10 years down the road ECAT: A research and development program for environment-conscious aircraft technology

Estimates suggest that air traffic volume is going to increase 2.6* fold over the next 20 years. With climbing air traffic levels come concerns about increases in noise, emissions, and the other environmental effects of aviation. In the realm of aircraft development, eco-friendly aviation technology is thus becoming a key indicator of market competitiveness—and that is exactly why the JAXA Institute of Aeronautical Technology has positioned its new “Environment-Conscious Aircraft Technology Program” (ECAT) at the center of its research and development activities. We spoke with Dr. Akira Murakami, Advisor and Chief Engineer of the Institute of Aeronautical Technology, about what ECAT is designed to accomplish.

*JADC “Worldwide Market Forecast For Commercial Air Transport 2012-2031” (2012)

– Could you tell us about the current state of environmental technology in the aviation industry?

As environmental restrictions on cars got stiffer over the years, we saw incredible evolution in environment-related automobile technologies. With air traffic volume expected to grow by a factor of approximately 2.6 over the next 20 years, the environmental impact of aviation has become a global issue, and the International Civil Aviation Organization (ICAO), the UN’s regulatory body that sets standards and regulations concerning aviation, is introducing increasingly stricter standards on aircraft noise and exhaust gases. Airlines thus need aircraft that meet these requirements, which means

that the manufacturers that supply aircraft need to ensure that their aircraft satisfy the applicable environmental standards. In hopes of enhancing the global competitiveness of the Japanese aviation industry, the JAXA Institute of Aeronautical Technology focusing R&D on “environment-conscious aircraft technology”—high-value-added technologies that can help Japan establish an innovative edge in international competition.

– What kinds of environmental technologies is the Institute of Aeronautical Technology researching at the moment?

Looking at the environmental performance of small-scale aircraft (with a capacity of 100-150

passengers), we think that we’ll be able to make a lot of improvements in that area; ten years from now, for example, aircraft will be at least 30% more fuel efficient than they are now. JAXA will not be directly responsible for the actual manufacturing of these aircraft, but in ECAT we will take advantage of our strengths and mainly focus on conducting R&D for advanced technologies airframe noise and resistance reduction, composite structures, ultra-high bypass engine technologies that can live up to demands for higher efficiency, less noise, and reduced emissions.

–Noise, fuel consumption, and gas emissions are major issues for jet engines. What are the trends surrounding jet engine development?

Manufacturers around the world are adopting ultra-high bypass engines with large fans to improve the environmental performance of their jet engines. Best-selling aircraft like the Airbus A320 and Boeing 737 have engines with a bypass ratio of about 5, while the latest large-scale engines in the Boeing 787 and other planes have bypass ratios of over 10—but even higher ratios lie ahead: the Boeing 737MAX and Airbus A320neo, expected to hit the market in the next few years, have engines that boast bypass ratios of around 12.

Higher bypass ratios mean much bigger fans, which add considerably to overall engine weight. When an engine gets heavier, the aircraft as a whole runs the risk of consuming more fuel. Thus, we want to make engines as lightweight as possible.

–What about other areas besides the fan?

As turbines reach extremely high temperatures that sometimes exceed the levels carbon fiber reinforced plastics (CFRP) can withstand, heat-resistant ceramic matrix composites (CMC) are gathering attention as a possible solution. There are still plenty of issues with CMC, though, so CMC-related work at engine manufacturers around the world is still in the developmental stages.

To contribute to this development, JAXA Institute of Aeronautical Technology has launched the “Next-Generation Fan/Turbine System Technology Demonstration Mission” (aFJR) to validate fans and low-pressure turbines that will be compatible with the ultra-high bypass engines of the future.

– Why are you concentrating on low-pressure systems?

High-pressure systems are an appealing area, indeed. They require frequent part

replacement, which makes them quite profitable, and there is a lot of room for improvements in environmental performance. The big problem is the market—manufacturers in Europe and the United States have a firm hold on the competition, making it hard for Japanese companies to get into the mix.

Given the obstacles in the high-pressure field, we want to focus on expanding the role Japan plays in international joint-development projects for low-pressure systems—an area where Japan already has a strong background. Japan has plenty of experience in the composite field. CFRP has been used in aircraft since before Boeing 787 aircraft went into operation, after all, and JAXA boasts excellent composite testing and evaluation technologies. We think that these composite technologies can serve as a powerful tool for Japan to use in next-generation fan/turbine system development.

Japanese manufacturers currently develop and produce the low-pressure systems for the V2500 engines in A320 aircraft. Moving forward, we want to help Japanese manufacturers not only make and provide high-quality parts but also show engine manufacturers in Europe and the United States that they can make

even better engines using component technologies from Japan.

– What is the goal of aFJR?

The core goal is to reduce total engine weight by around 10% by boosting the fan aerodynamic efficiency of existing engines by at least one point and using composites to make fans and low-pressure turbines lighter.

To do that, we are working to develop and demonstrate component technologies for the laminar flow fan aerodynamic designs of fan modules, shock-resistant FRP blade design manufacturing, lightweight metal disks, and lightweight, sound-absorbing liners. For low-pressure turbines, we are also developing lightweight, low-pressure turbines that incorporate CMC.

These efforts will help us develop and demonstrate the kinds of high-efficiency, lightweight technologies that will give Japanese companies an edge over foreign manufacturers, compete more effectively in international joint-development projects on next-generation jet engines, and thereby secure larger shares of the design and manufacturing responsibilities in collaborative efforts.

– Is the ultimate goal to make entire engines completely in Japan?

The JAXA Institute of Aeronautical Technology has started research and development on “green engine technologies” for high-pressure systems and core engine technologies. As part of this initiative, we want to enhance the lean-premixed combustors and other advanced technologies that we have been working on and eventually establish them in a feasible system package. For our first step, however, we are planning on driving the aFJR effort, which focuses on low-pressure systems—an area where we already have

experience and are confident about securing a larger market share.

Today, jet engines are developed through international collaboration, so we rarely see instances where a single manufacturer makes an entire engine by itself. Currently, Japanese engine manufacturers account for about 6% of the global share, and we would like to see it go up to about 10 % by expanding their roles in international joint-development projects. Somewhere down the road, I’m confident that Japanese manufacturers will be able to break into the private-sector engine market with domestically produced engines.

– What kinds of research are you doing on noise issues?

As for engine noise, noise levels have decreased by substantial margins thanks to the introduction of high bypass ratio engines. Now that engines are quieter, people are paying closer attention to noise generated by airframe during takeoff and landing at airports. JAXA has launched the “FQUROH” (meaning owl in Japanese) mission, which aims to demonstrate noise reduction technology. The core objectives of the FQUROH mission are to develop noise reduction technology for high-lift devices such as flaps and slats as well as landing gear, which generate significant noise, and to perform flight tests for technology validation.

– What other objectives does ECAT have?

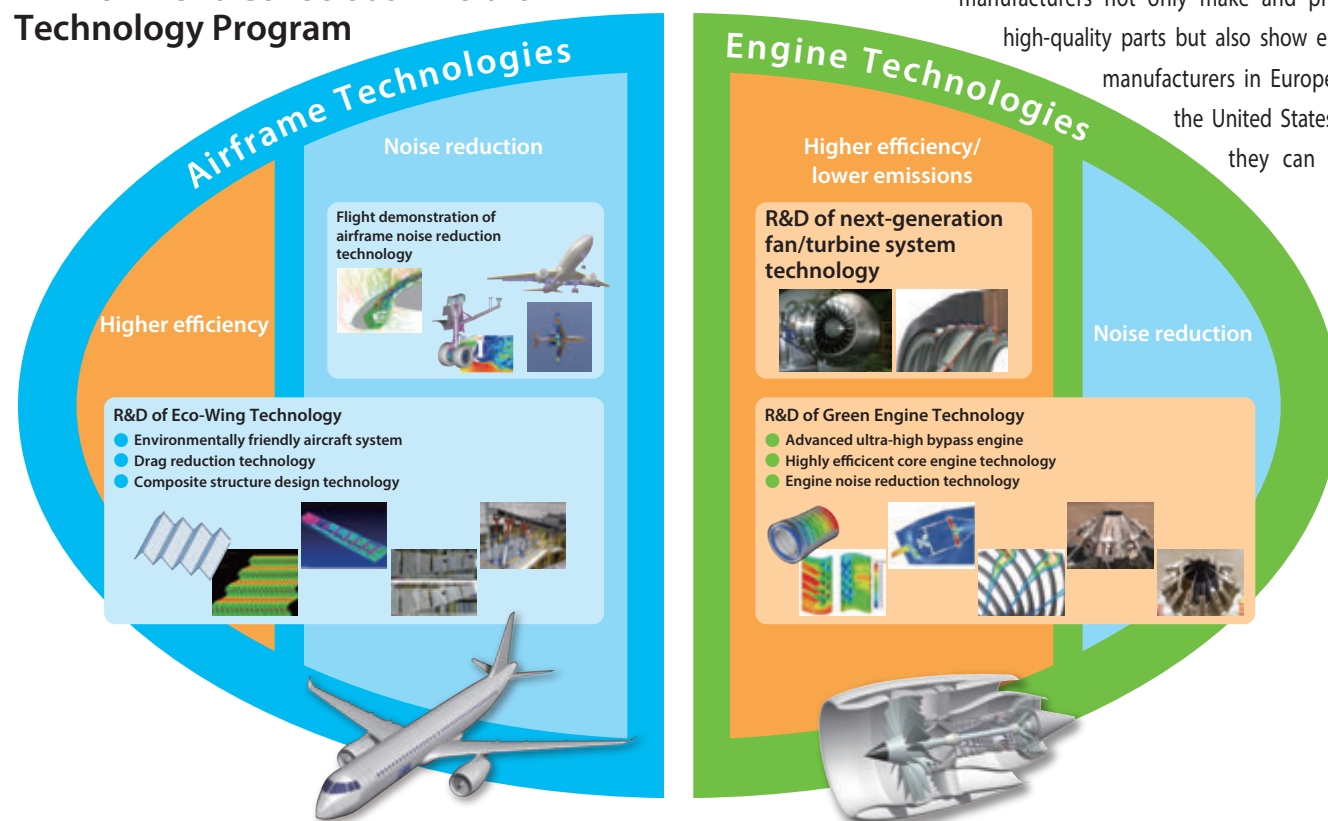
We are advancing our work on composite materials and aerodynamic design in our Eco-Wing Technology R&D initiative, a project that focuses on reducing aircraft weight and improving lift-to-drag ratio. Through this effort, we hope to cut aircraft structural weight by 20% and boost cruising lift-to-drag ratio by 7% over the next 10 years.

– Finally, how do you want to see ECAT contribute to society?

In order for society to make full use of the fruits of science and technology R&D, strong cooperative ties between industry, universities, and research institutions like JAXA are vital.

As a driving force in research and development, JAXA wants to play a central role in pushing advanced technologies forward with a sense of urgency and uniting various parties in fruitful collaboration. Doing that will contribute to making the Japanese aircraft industry more competitive internationally, which will also solidify JAXA’s presence and value within Japan. It takes a considerable amount of time—often at least 10 to 20 years—for aircraft-related businesses to make good on their investments. Unlike companies in other industries, manufacturers in this sector cannot just put aircraft on the market, sit back, and watch the sales roll in. Releasing aircraft is just one point on a protracted path. To stand a chance in international competition, aircraft manufacturers have to keep developing the next versions of aircraft and have their sights set on several steps ahead. Although JAXA’s Mid-Term Plan outlines the desired results for a five-year period, the process of making these technologies commercially viable stretches well beyond that scope. We need to bolster our support structure and keep our eyes locked on the next innovations to be made. Two or three decades from now, I hope we will have made it to the point where we can improve fuel consumption by over 50%, achieve noise reduction levels that rank among the best in the world, and boast unrivaled emission-reducing technologies.

Environment-Conscious Aircraft Technology Program



FQUROH: Flight demonstration of airframe noise reduction technology

Owls hunt their prey without making a sound. Taking its name from the Japanese word for these silently flying birds (“fukuroh”), the FQUROH project was created as a mission to conduct flight demonstration of technology to reduce airframe noise. The research work on noise-reducing technologies cultivated at JAXA is now preparing for full-fledged technology demonstration using real aircraft. Here’s a little more about what the FQUROH mission entails.

Why is noise reduction necessary?

When passenger jets started flying in the 1960s, the aircraft tended to be extremely noisy. As conventional turbojet engines were gradually replaced with high-bypass turbofan engines, however, the noise levels began to drop. A turbofan engine adds a fan to the front of the jet engine and generates most of its propulsion from the large amounts of jet thrust that the fan produces. By using fans that are larger in diameter, the latest turbofan engines can generate the same propulsion levels at lower jet velocities. As the noise of a jet engine is proportional to the eighth power of the jet velocity, slower speed means less noise. These developments have helped achieve substantial noise reductions compared to early-generation jet engines, reducing overall airport noise levels by a considerable margin. Still, takeoff and landing approach zones are exposed to noise levels of around 90 dB. With air traffic volumes expected to keep increasing in the future, the abatement of airport noise impact on airport communities requires even quieter aircraft. Efforts to reduce aircraft noise levels will need to devote further attention to aerodynamic noise emitted from airframes (airframe noise), which begins to exceed engine noise due to lower power during landing approach procedures. Environmental concerns for airport communities are not the only factors behind the need for noise reduction, though—for airlines that provide regular service to airports that offer landing fee discounts for low-noise aircraft, noise reduction also has an impact on profits. Moreover, noise reduction technologies are important for aircraft industries from the perspective of their products’ international competitiveness.

Using the fruits of research initiatives that began in earnest around 2004, JAXA has now launched its “FQUROH” (Flight demonstration of QUIet technology to Reduce nOise from High-lift configurations) mission to verify developed noise reduction technologies by implementing them in actual aircraft and evaluating the results through a series of flight tests.

JAXA's noise reduction technologies

JAXA has focused its research on reducing the amount of aerodynamic noise from the airframe, a large amount of which comes from the flap on the trailing edges of the main wings, the slat on the leading edge, and landing gears.

The flap extends downward from the trailing edge during landing, increasing the size of the main wing camber and expanding the total wing area to generate

sufficient lift as the aircraft flies slowly. The same principles apply to the slat: it protrudes downward out of the leading edge of the main wing in accordance with the extension of the flap. This creates space between the slat and the leading edge of the main wing; from this space, air flows over the surface of the main wing to prevent the separation of smooth airflow and delay stalling. Lift is generated by the airflow passing smoothly over the surface of the main wing. “Stalling” refers to the condition where this smooth airflow comes off (“flow separation”) the surface of the main wing, preventing the aircraft from maintaining the lift required to keep the

around the aircraft’s high-lift devices. JAXA has thus performed many wind tunnel experiments and numerical analyses to develop technologies that will reduce airframe noise.

In its efforts to develop flap noise reduction technology, JAXA has cooperated with an aircraft company to draw up a configuration and structure that will make the bottom surface of the flap edge bulge slightly. Extending the flap lets airflow curl up from the lower surface to the upper surface at the flap edge, which creates a strong vortex at the flap edge. On aircraft with normal flap edge surfaces, this resulting

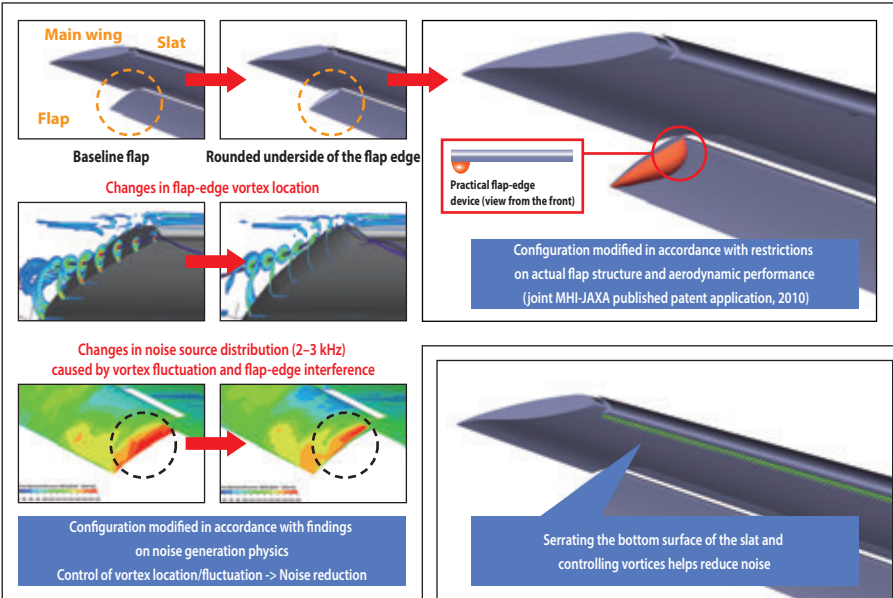
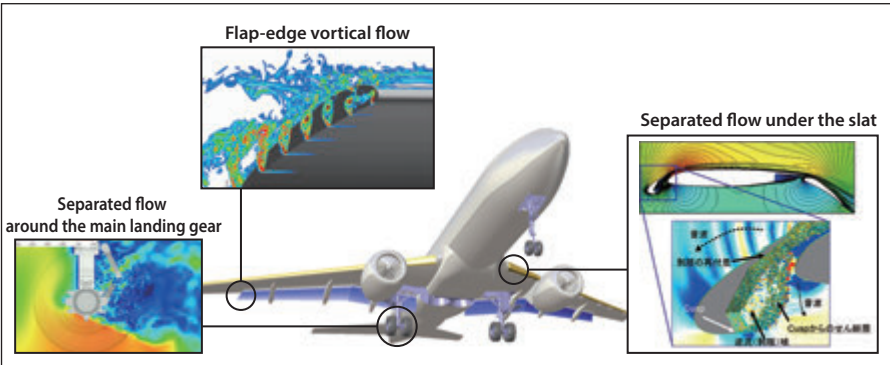
FQUROH: Flight demonstration of airframe noise reduction technology

aircraft aloft against the force of gravity. Although high-lift devices like flaps and slats delay stalling by boosting lift and preventing major flow separation on the wing surface, local flow separations that occur inside the slat and at the flap edge form turbulent vortices and pressure fluctuations. Those are the causes behind the rasping aerodynamic noise we hear during flight.

The most effective way of abating this noise is to control and restrict the local flow separations that occur

vortex becomes an extremely turbulent airflow and leads to lift fluctuation around the flap edge. That’s what causes the noise. By suppressing the amount of vortex turbulence and changing the location where the vortices occur on the flap edge, we can suppress pressure fluctuation and, consequently, reduce the amount of associated noise.

JAXA’s wind tunnel experimentation has demonstrated that the method can achieve a 2 to 3-dB reduction in



Unique features of owl wings
Owl wings have unique features, such as a comb-like (serrated) leading edge, fluffy feathers, and trailing fringe, that allow the birds to fly silently at night. They reduce flow disturbance on wings, thereby keeping aerodynamic noise to a bare minimum. Thanks to these features, owls can catch their prey without being noticed.

Development of noise reduction technology shifts to full-scale flight demonstration. The story behind FQUROH: JAXA’s mission to perform flight demonstrations of airframe noise reduction technology

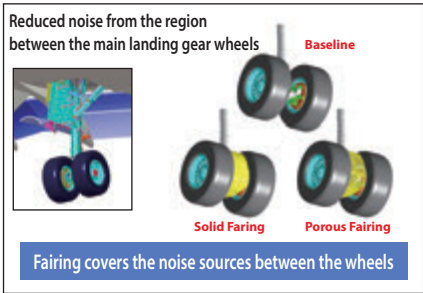
noise.

The next source of noise is the inside of the slat, where airflow separates and creates turbulent vortices. By modifying the configuration of the inside of the lower surface to eliminate the vortices, JAXA has successfully reduced noise by about 10 dB. However, this approach, in practice, prevents slat from being stowed in the main wing. That’s why JAXA is now looking into reducing noise by serrating the cusp at the bottom of the slat for application in actual aircraft. Most slat noise comes from near the slat trailing edge (the side near the leading edge of the main wing), but the turbulent flow vortices that cause the noise originate at the slat cusp. If JAXA serrates this portion to break larger vortices into smaller pieces, it will be possible to decrease the large-scale turbulent flow that generates substantial noise inside the slat.

The landing gear is another key area to look at. Most landing gear noise originates from fluctuating flow around the main structural elements such as the tires and a support structure called the “side brace.” The

region between the tires is full of various parts—wheels, brakes, shock-absorbing structures, hydraulic piping, and electric cables—arranged in an elaborate configuration. When airflow gets into this area, it creates noise. The idea that JAXA is exploring involves putting perforated fairings (covers) over this region to both reduce noise and allow cooling flow to reach the brakes. Wind tunnel experiments have shown that these fairings can cut noise by approximately 2 dB.

How much of an effect will these technologies have once they are installed in actual aircraft? That’s what FQUROH’s flight demonstration is designed to find out.



FQUROH: An overview

In 2013, FQUROH (Flight demonstration of QUIet technology to Reduce nOise from High-lift configurations) will get things started by performing a flight test for JAXA’s “Hisho” experimental aircraft to establish source noise measurement technology in preparation for the flight demonstration of noise reduction technology.

JAXA has conducted noise source measurement experiments using a business jet in the past. At the JAXA Taiki Aerospace Research Field in Taiki, Hokkaido, JAXA flew a business jet at low altitude directly over a measurement system of approximately 200 microphones in a 50 m-diameter array to localize the noise sources on the aircraft. Using the noise source measurement from the Taiki experiment, JAXA has been able to determine where on the plane various frequencies of noise come from.

For instance, low-frequency sounds of around 200 Hz appear to emerge from the left and right main landing gear and nose gear, while 500-Hz sounds come from flap edges, as well.

This year, the FQUROH project plans to fly “Hisho” at Noto Airport in an attempt to drive further developments in noise source localization technology and improve measurement resolution of measurement to obtain more accurate results.

The purpose of the FQUROH project is to demonstrate noise reduction technologies developed with aircraft industries by applying them to high-lift devices and landing gears and performing flight tests on the aircraft. The objective of the initiative is to collaborate with domestic aircraft manufacturers in maturing the technology.





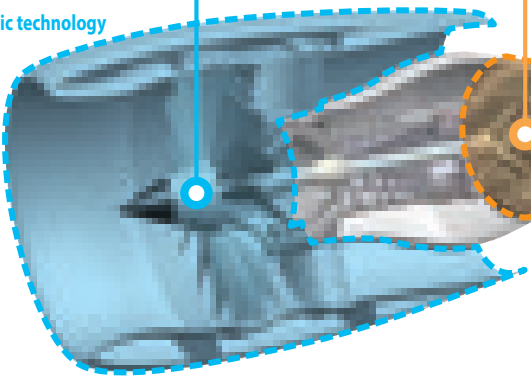
For its next steps, FQUROH will conduct optimal design and structural design for installing noise-reducing devices on actual aircraft and establish noise measurement technologies. Once the technology is fully prepared, the project plans to obtain permission from the Civil Aviation Bureau to perform flight tests using aircraft with on-board noise reduction devices and finally go through with the actual testing procedures.

“In Japan, owls are believed to bring happiness and good luck,” says Mission Leader Kazuomi Yamamoto. “I hope that good fortune carries over to the FQUROH project, too, as JAXA does everything in its power to bring the goals to fruition and offer valuable support to the Japanese aircraft industry.”

aFJR: The Next-Generation Fan/Turbine System Technology Demonstration Mission

High-efficiency, lightweight fan technology




- High-efficiency laminar flow fan aerodynamic technology
- FRP hollow blade technology
- Lightweight metal disk technology
- Lightweight, sound-absorbing liner technology
- High-reliability evaluation



Demonstrating structural properties of fan aerodynamic performance

Lightweight, low-pressure turbine technology

- CMC turbine blade overspeed protection design technology
- High-reliability evaluation



Demonstrating structural properties of the heat-resistant composite blade

The FJR710, Japan's first high-bypass jet engine ^{(*)1}, formed the basis of the JAXA Institute of Aeronautical Technology's engine research with its development 40 years ago and has now earned a spot on the Mechanical Engineering Heritage list ^{(*)2}. Like the FJR710, the aFJR (advanced Fan Jet Research) mission aims to make a positive impact on the Japanese aviation industry. Here, we take a closer look at the next-generation jet engine that aFJR is determined to create.

Having impressed British engine manufacturer Rolls-Royce with its performance in demonstration tests, the FJR710 left its technological mark on the V2500 series—the global best-seller that provides the engines for Airbus A320 aircraft and has over 7,000 total orders to its name. Japanese companies provide the fans for the engine's low-pressure system components, giving Japan a 23% share of the total manufacturing effort

The jet engine aFJR is after

The environmental standards on the noise, NOx (nitrogen oxide), and other negative products generated by aircraft continue to get increasingly stringent year after year. Due to sharp increases and general instability in fuel prices, the market is also showing a demand for aircraft with reduced fuel consumption. Lower fuel consumption levels make

it possible to cut down on emissions of gases like CO₂ that exacerbate global warming.

One way that manufacturers are currently attempting to solve these problems is by increasing their engine bypass ratios, which represent the proportion of the airflow that passes only through the large fan at the front relative to the airflow that passes through the core engine. Early-generation jet engines were fanless "turbojet" engines, ideal for supersonic jet warplanes because they could emit gas from the jet at extremely high speeds. However, fanless turbojet engines are not effective means of propulsion in jet passenger aircraft that cruise at subsonic velocities. For these aircraft, a jet engine exhaust velocity that exceeds flight speed by just a narrow margin produces the best propulsion efficiency.

Higher bypass ratios lower the overall exhaust velocity, including the speed of the emissions

coming from the high-temperature, high-speed core engine, and thus make the emission jet noise quieter.

Turbofan engines thus represent the predominant engine type for subsonic passenger planes, and manufacturers the world over are trying to find ways to boost their bypass ratios. Engines in the V2500 series, mentioned above, have bypass ratios of around 5; meanwhile, the RR Trent 1000 engines used in the latest Boeing 787 models boast bypass ratios of 11. By using a system of gears to transform the high-speed rotations of the low-pressure turbine into lower-speed fan rotations, the PW1000G series—a lineup of "geared turbofan engines" for use in the Japan-made MRJ aircraft currently in development and so on—is on the verge of reaching a bypass ratio of 7 to 12.

As these trends continue to solidify the course of current progress, aFJR aims to develop an engine

that achieves an ultra-high bypass ratio of over 13, improve on the fan aerodynamic efficiency of existing engines by at least 1 point, and lower fan weight (by 0.9%) and turbine weight (by 9.1%) to reduce overall engine weight by approximately 10%.

Thanks to their central roles in developing fan and other low-pressure system components, Japanese manufacturers have a wealth of technical expertise. We want to leverage those advantages into securing a leadership role for Japanese manufacturers in the collaborative, international effort to develop next-generation engines.

Technology for creating ultra-high bypass engines

What sorts of component technologies go into creating an ultra-high bypass engine with a bypass ratio of over 13, then? A higher bypass ratio requires a bigger fan, which in turn creates a heavier engine. Bigger means heavier; heavier means worse fuel efficiency. That is why creating lighter engines is the most pressing issue at the moment.

Manufacturers have thus started using carbon fiber reinforced plastics (CFRP) to help make large-scale engines lighter. aFJR's goal is to reduce overall engine weight further by redesigning the CFRP structure and making the materials hollow—

something that no one has ever done before. The organization will also tweak the configuration of the fan blade, applying its "laminar flow fan aerodynamic design technology" to move the point where the laminar airflow on the surface turns into turbulence further back and thereby reduce resistance.

For the disk in the center of the fan, aFJR will develop new processing technologies that will make it possible to reduce the weight of the traditional metal materials without sacrificing any strength.

Another way to make engines lighter is by developing technologies that, for example, use different materials for the liner of the honeycomb structure inside the fan nacelle, which serves to cut down on noise.

aFJR is also working on using ceramic matrix composites (CMC) for the low-pressure turbine blades. Lighter and more resistant to heat than metal, CMC has a temperature limit of approximately 1,200°C—around 100°C higher than that of the conventional metals. Although that may not seem like a big difference on paper, introducing CMC makes it possible to achieve reductions in weight while still maintaining the necessary heat resistance performance.

The project is also designed to develop flutter and overspeed protection design technology for improving the safety and reliability attributes

unique to aircraft engines.

Cultivating human resources for the aviation industry of the future

"The development of next-generation engines is expected to begin sometime around 2020," says mission leader Toshio Nishizawa, who is also a group leader. "No matter what, we need to have the right base technologies in place before development starts." By that time, the domestically produced MRJ passenger aircraft will likely be in service, prompting overseas manufacturers to introduce their own new models into the market. Japan will need to be able to withstand that pressure and weather the competitive storm.

"Aircraft projects are long-term efforts," Nishizawa continues. "Cultivating capable human resources is going to be a crucial piece of ensuring that we continue to thrive in the market. I hope to see more and more young people get interested and involved in the aviation field."

The JAXA Institute of Aeronautical Technology is ready to be a powerful driving force for the future of Japanese aviation, infusing the industry with the boundless energy of youth.

Target engine performance comparison

Engine	V2500 (V2524-A5) Installed in A319 aircraft	GENx (GENx-1B70) Installed in B787 aircraft	PW1000G Used on the A320neo, MRJ, and CS100/300	The project's target engine proposal
Takeoff thrust	24,800lbs	69,800lbs	15,000-33,000lbs	20,000-lb class
Fuel consumption reduction rate (cruise SFC)	(0.575lb/h/lb)	15% reduction compared to the CF6-80C2	12-15% reduction compared to existing engines	16% reduction compared to the V2500 (1% of the overall target reduction)
Bypass ratio (fan outside diameter)	4.9(63.5 in)	8.6-9.6(111 in)	7-12(56-81 in)	13 + (66 in. [estimate])
Weight	5,200lb	12,400lb		Approx. 22% reduction compared to the V2500 (10% of the overall target reduction)
Technology	Hollow titanium fan blade Nickel superalloy low-pressure turbine blade	Solid FRP fan blade Lightweight, low-pressure turbine blade	Advanced aluminum alloy fan blade Lightweight, low-pressure turbine blade	High-efficiency laminar flow fan/FRP blade design/ CMC turbine blade design
	Aluminum alloy sound-absorbing liner/titanium alloy fan disk			Lightweight, noise-absorbing liner/lightweight, high-strength metal disk

Image source: The JAEC website

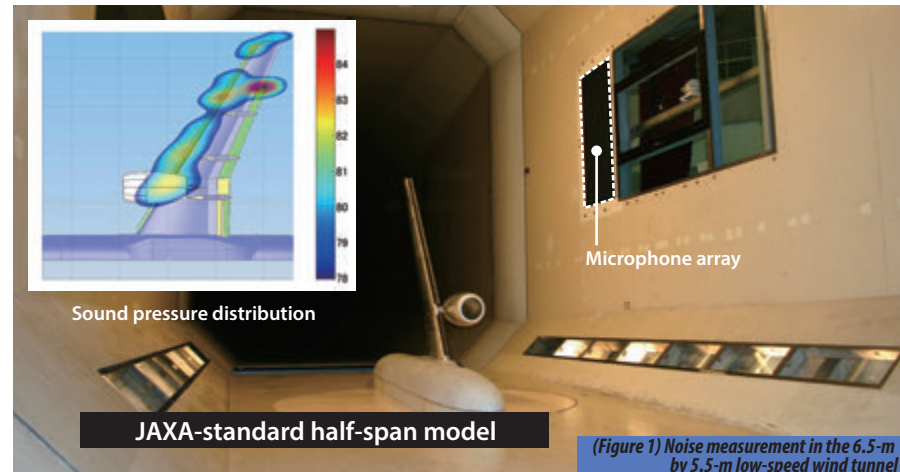
*1: The Mechanical Engineering Heritage-certified FJR710 is stored at the Chofu Aerospace Center. A model of the FJR710 is on permanent display for public viewing at the Chofu Aerospace Center exhibition area.

*2: The "Mechanical Engineering Heritage" is a list of unique, culturally valuable mechanical engineering-related items that made significant contributions to the history of mechanical engineering. Items in the list are certified by the Japan Society of Mechanical Engineers in order to signify their cultural value to future generations.

Advanced noise source measurement technology

Measuring aircraft noise in a wind tunnel

To reduce aircraft noise, we need to determine exactly where on the aircraft the noise comes from. Flight tests to measure noise from actual aircraft represent one important step in pinpointing the sources of noise, but wind tunnel testing not only makes the measurement process less expensive but also lets researchers perform their experiments repeatedly. However, the electric motor-driven fans at the general wind tunnel facility used by JAXA and the majority of research institutions produce a substantial amount of noise, which severely complicates noise measurements. To get around this problem, most research organizations do their measurements in special low-noise wind tunnels with anechoic measurement areas. JAXA, on the other hand, is developing technology that will enable advanced noise source measurement in general wind tunnel environments.



Why measure noise in a wind tunnel?

With the International Civil Aviation Organization (ICAO) tightening its restrictions on aircraft noise and airports setting landing fees based on noise volume, airlines are clamoring for quieter aircraft. Noise reduction technology will also play an integral role in the development of aircraft that thrive in the world market. JAXA is thus conducting research and development on noise reduction, using simulations and wind tunnel testing to evaluate aircraft noise sources and corresponding levels. Through these efforts, JAXA is working to create noise reduction technology. Using its deep reservoir of technological resources, JAXA has launched the FQUROH Mission

(see Flight Path No. 1) to demonstrate promising noise reduction technology through flight tests on actual aircraft.

In most cases, developing noise reduction technology based on wind tunnel testing involves using models (element models) that simulate various aircraft parts. First, researchers understand noise generation phenomena by analyzing the measurement noise data in detail. Then, they work out noise reduction technology concepts on a trial-and-error basis. These noise reduction technologies can be precisely evaluated to under various testing conditions, making noise measurement in wind tunnels an important piece of the development effort.

What is noise source identification technology in a wind tunnel all about?

Although useful, noise measurement in a traditional wind tunnel poses a significant challenge. Wind tunnels were originally built for the purpose of generating high-speed airflow that would allow researchers to measure the force pressure, flow field, and other aerodynamic characteristics of the model inside the tunnel. Therefore, they lack noise-suppressing features and thus produce a considerable amount of operating noise. A loud wind tunnel can mask the sound coming from the model, making it hard to detect the target noise.

Why are wind tunnels so noisy? The answer lies in the devices that the tunnels require and the configuration of the tunnels themselves. To generate high-speed wind, a wind tunnel uses a giant fan powered by an electric motor. The noise from these devices reflects off the wind tunnel walls, generally made of metal and concrete, and travels the length of the tunnel. Generally, sound tends to decay as the corresponding propagation distance grows. In a closed circuit type wind tunnel, however, sound continues to bounce off the walls and maintains an essentially constant level.

JAXA has developed measurement technology that can identify noise sources under noisy conditions, pinpointed where sounds come from,

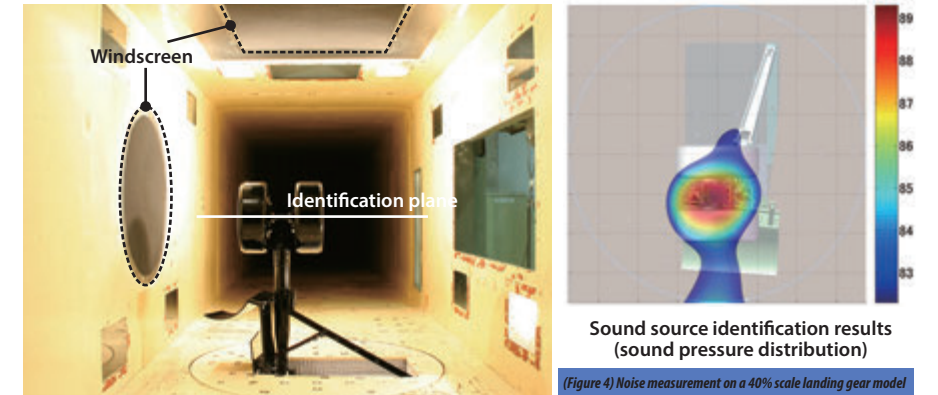
and evaluated the effects of noise reduction technology (Figure 1). The organization has also performed noise measurements using low-noise wind tunnels provided by outside institutions. However, JAXA is planning to add a low noise feature to the 2-m by 2-m low-speed wind tunnel by covering the interior surface of with sound-absorbing materials to prevent the fan noise from reflecting off the walls.

When measuring noise in a wind tunnel, researchers generally remove the walls of the test section to keep the test noise produced by the model itself from reflecting throughout the tunnel interior. They then place the microphones outside the airflow for measurement purposes. Although this method does limit the noise generated by reflection, it leaves a portion of the wind tunnel open; this can interfere with airflow quality by creating turbulence in the air around the model or causing spillover, thereby making it more difficult to assess the noise coming from the model.

JAXA thus developed an anechoic test section that uses high-acoustic-transmission sheets as wall surfaces, allowing researchers to conduct measurements without opening the wind tunnel. To minimize the effects of sound reflections, the wall surfaces are replaced with Kevlar sheets, and the sound from the model is picked up through the sheets by a microphone array in an adjoining anechoic chamber (Figure 2). By shutting out wind but allowing sound to pass through, Kevlar sheets make it possible to capture sound without disrupting the airflow.

How can microphones be used to identify noise sources?

Researchers usually use a radial array of around 100 microphones to pinpoint the sources of noise coming from a model inside a wind tunnel. Arrays currently in development are about 1.5 m in diameter and have thirteen radial arms, seven microphones on each arm, and five other microphones in other locations. The sound from a single source reaches the different microphones in the array at slightly different times; a microphone closer to the source, for example, will pick up the sound a split second before a microphone farther away. Using these small time difference values, researchers can back calculate the propagation time to determine where the sound is coming from (Figure 3). The microphones are omnidirectional, but you can also create a directional setup by arranging them in certain ways.



From a purely technology standpoint, that is how most noise source identification systems work. When it comes to actual usage inside wind tunnels, however, you have to deal with the potentially problematic effects of strong winds. JAXA's system minimizes that impact. Noise source resolution varies according to frequency and processing method, but the JAXA array has a resolution (*1) of around 30 cm at 1 kHz.

Using this noise source identification technology, we performed noise measurements on a 40% scale model of the landing gear for a regional jet with a seating capacity of around 100. The results showed that a significant amount of noise (2 kHz) was coming from the structure between the landing gear wheels (Figure 4). As the model was less than half the size of the real-life landing gear, we used the reciprocal of the scale value to determine that the amount of noise coming from the actual landing gear was equivalent to 800 Hz (*2).

With just a few calculations, tests on scale models thus make it possible to identify the characteristics of noise coming from actual, full-size equipment: the sources and approximate wavelengths of the sounds. That means that we can figure out which locations, levels, and frequency bands of noise sources need to be targeted in order to minimize noise most effectively.

Human ears have an audio-frequency range of 20 Hz to 20 kHz. Noise source identification on the lowest end of the range requires a microphone array with a larger diameter (*3), which would make the array simply too big for wind tunnel equipment to hold. Given these limitations, there is currently no way to measure noise at these low frequency levels in wind tunnels.

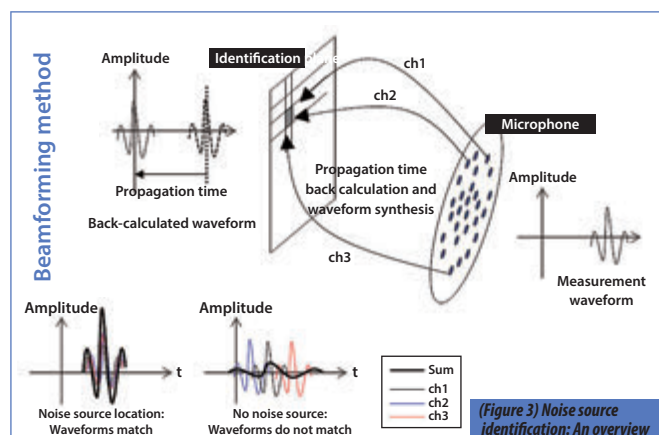
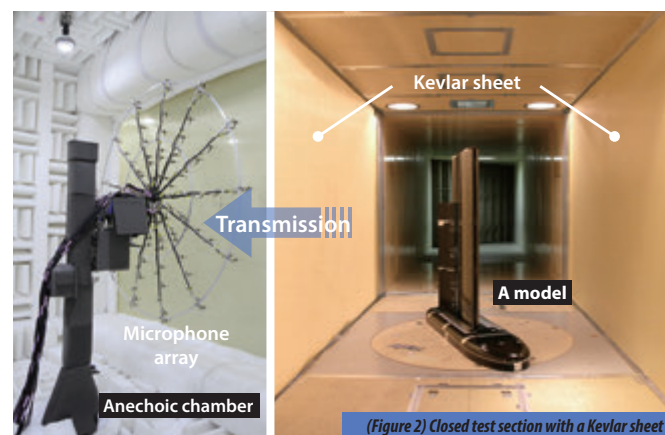
However, research on ultrasonic sound—sound that exceeds the audio-frequency range—is booming at JAXA. As scaled models are used in wind tunnel testing, the surrounding flow conditions differ from those around actual aircraft. If the model is one-tenth the size of the actual aircraft, for

example, you would divide the frequency of the sound coming from the model by 10 to find the frequency of the sound coming from the full-size device (*2). When researchers try to assess noise of up to 10 kHz—the standard range for aircraft noise regulations—they need noise source identification technology capable of measuring ultrasonic sound, which sits above the audio-frequency range. Having already confirmed that its technology enables measurements of up to 80 kHz, JAXA is now working on research that will boost measurement precision to even higher levels.

Linking noise sources and fluid phenomena

JAXA's 2-m by 2-m low-speed wind tunnel was originally built to investigate aerodynamic characteristics. If the tunnel successfully makes it possible to perform noise measurement with higher quantitative accuracy, researchers will be able to conduct noise measurement and assess aerodynamic characteristics at the same time. By simultaneously observing changes in aerodynamic characteristics, aeroacoustic characteristics, and noise source distribution over time, investigations into noise attributes will reflect actual conditions much more faithfully. JAXA is also working to develop its image processing technology to prevent noise interference from obscuring sound sources.

What lies ahead, then? "JAXA is also developing measurement technologies for unsteady velocities and pressure fluctuations," Wind Tunnel Technology Center researcher Hiroki Ura says. "Right now, researchers are analyzing the measurement results from these technologies and the results of noise source identification projects separately. We'll be able to get a better idea of the mechanisms behind noise generation if we can establish a direct link between noise sources and fluid phenomena and develop analysis technology accordingly. I'm looking forward to making noise reduction more accurate."



(*1) Using a microphone array with a diameter of 1 m at a measurement distance of 1 m (*2) When the wind speed is the same, assuming a constant Strouhal number (*3) Generally, noise source resolution is proportional to measurement distance and inversely proportional to microphone array diameter.

Supporting the world's aeronautical technology through advanced composite materials testing standards

Working toward international standardization for advanced composite material testing methods

Ever since its days as the National Aerospace Laboratory of Japan, JAXA has worked hard to promote the practical use of composite materials through research into composite curing technology development and performance evaluation techniques for advanced composite materials. In hopes of sharing the fruits of our research on composite material evaluation techniques, the **JAXA Advanced Composite Research Center (ACRC)** provides a comprehensive database on the mechanical characteristics of advanced composite materials and contributes to the standardization of mechanical performance of composite material evaluation techniques.

International standardization (ISO) represents a significant investment in the Japanese aviation industry

Over half of the structural weight of the Boeing 787, an aircraft that ANA put into service before any other carrier, is made of carbon fiber reinforced plastic (CFRP). Light, strong, and durable, CFRP generates dramatic improvements in aircraft fuel efficiency and represents a vital element in enhancing aircraft performance. However, new materials have to clear certain hurdles. An aluminum alloy database has already been prepared for public specification use in the development of aircraft designs due to the long history that metal materials have as aviation structural elements. However, one of the problems with CFRP is the lack of a sufficient public database rooted in identical testing methods.

These issues do not have a direct effect on aircraft safety, of course. Aircraft made of CFRP have been cleared to fly by the Federal Aviation Administration (FAA) in the United States, so there are no doubts about the safety of the composite material itself. Without standardized identical composite evaluation methods, however, it takes a considerable amount of time to test and evaluate new materials—and this lack impedes effective material development and aircraft development among the world's aircraft manufacturers and related industries.

Seeing the pressing need for composite material testing method standardization, the JAXA ACRC is currently researching and developing Japanese original composite testing methods for initial use as a JIS (domestic) standard. If the international standards (ISO) are identical to the Japanese standards (JIS), Japanese aircraft part manufacturers and the other related industries will be able to use the same testing methods as international standards and, as a result, their development and manufacturing processes will be more efficient.



An example (demonstration) of an aircraft composite fuselage structure

Trends in the aircraft world: Reductions in weight and fuel consumption

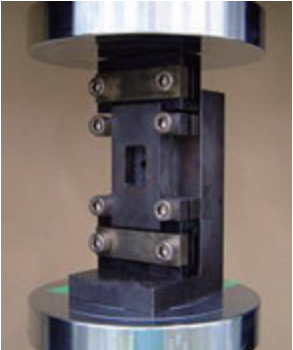
Why are people clamoring to establish an ISO standard for composite materials as aviation technologies? Because there is mounting pressure to make the world's aircraft lighter and more fuel-efficient, as described above. The Boeing 787 is a perfect example. Planes across the globe, including the MRJ currently in development by Mitsubishi Aircraft Corporation, need to be light and save on fuel consumption if they want to be successful.

Manufacturers are now trying to satisfy these demands by exploring the potential of new materials like CFRP and another new material called ceramic matrix composite (CMC). CMC development has sparked competition among countries trying to use it for future-generation jet engine turbine blades. CMC is very light and strong in extreme high temperature environments, so it can help bring down the weights of turbine blades and related parts, as well. Once CMC turbine blade development has succeeded, engine cooling systems designed to maintain engine performance will be unnecessary. The development will be directly linked to engine weight reduction and fuel efficiency improvement.

JAXA is working to achieve ISO standardization for its CFRP and CMC evaluation testing methods. CMC is still in relatively limited use, so it will be necessary to establish testing

standards quickly. France is currently leading the way in proposing CMC testing standards thanks to the considerable CMC-focused work being done by Snecma, a French engine manufacturer. The United States is also interested in this matter, of course, trying to establish its own standards for adoption in other countries.

JAXA wants to be an active part of this CMC proposal competition, help establish international standards, and do whatever it can to support the development of the world's aviation technology without bowing to the interests of a single country. That will contribute to the Japanese aircraft industry's ability to maintain an edge in the global market and give Japan favorable import/export conditions when dealing with aircraft parts and component manufacturing. In all, JAXA's proactive involvement in CMC-related efforts will represent an important contribution to the growth of the Japanese aircraft industry.



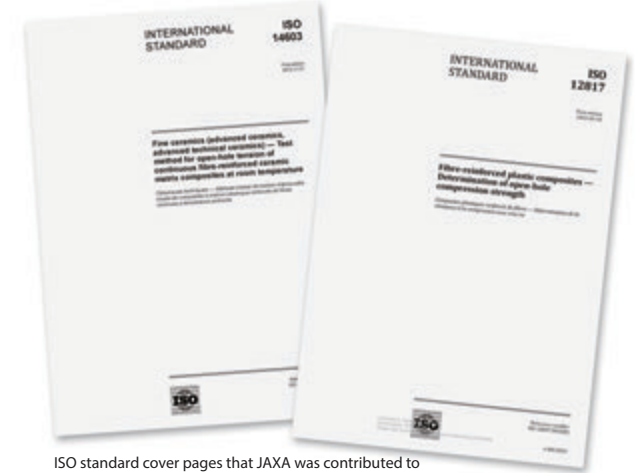
Loading fixture of open hole compression test method for ISO standard (ISO12827)

JAXA has already achieved four ISO standardizations

- JAXA has already made three testing methods for CFRP and CMC into ISO standards.
- CFRP: Compression after impact properties
 - CFRP: Determination of plain-pin bearing strength
 - CFRP: Determination of open-hole compressive strength
 - CMC: Test method for open-hole tension testing for CMC

It takes at least five years to establish new ISO standard. While the long, arduous work involved in the process might not always produce immediate results, it has many positive long-term effects on the aircraft industry in Japan.

By cooperating with related institutions and companies to play a central role in the effort to standardize advanced composite testing methods, the JAXA Institute of Aeronautical Technology's Advanced Composite Research Center (ACRC) makes substantial contributions to aircraft industries both in Japan and overseas.



ISO standard cover pages that JAXA was contributed to

Solving combustion instability problems that arise during jet engine development

One of the critical problems that jet engine developers face is a phenomenon called combustion instability. Combustion chambers in jet engines have an annular shape. Depending on the operating conditions, heat released via combustion can interact strongly with acoustics (and acoustically driven velocity fluctuations) in the chamber and eventually excite natural acoustic oscillation modes of the system. Intense pressure fluctuations caused by this thermo-acoustic interaction may cause catastrophic failures of engine components.

JAXA is now conducting research and development on low-NOx combustors for jet engines by implementing lean-premixed combustion technology. Lean premixed combustors have the advantages of reducing pollutant emissions such as NOx and soot. However, this type of combustor is also prone to combustion instability. The JAXA Propulsion Systems Research Group is working on the technology development for solving this problem.

Understanding the mechanism behind combustion instability

To suppress combustion instability, we need to understand why and how the instability occurs. Right now, JAXA is developing laser diagnostic tools to investigate the dynamic behavior of flame leading edges. One example is the diagnostic process utilizing high-speed OH-PLIF (Planar Laser-Induced Fluorescence) measurement. This technology is designed to illuminate the flame with a very thin laser sheet, thereby capturing sliced images of high-temperature regions of the burning flame. This is analogous to medical diagnostics, such as MRI and CT scans, used to capture images of the interior of a patient's body to assess affected areas.

Typically, problematic combustion instability in jet engine combustors occurs at frequencies in the range from 10^2 to 10^3 Hz. Detailed investigations can be conducted if one can capture the flame images at a sampling rate of more than 10,000 frames per second.

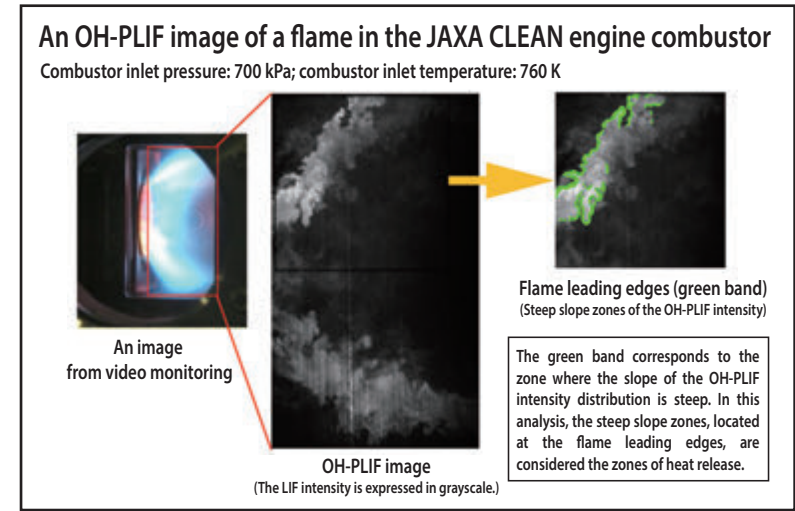
JAXA is thus developing high-speed OH-PLIF-based combustion diagnostic technologies that can be applied to combustion instability under high-temperature and high-pressure combustions.

Preventing combustion instability from occurring

Dynamic pressure data show very quick transitions to large amplitude oscillations when combustion instability is excited. Something needs to be done before the transition happens to counteract the sudden event. JAXA is working with Ritsumeikan University to develop a technology that detects instability as quickly as possible. This joint research project is designed to create a detection system that displays dynamic pressure data in the so-called "phase space" and calculates the non-linear characteristics of the trajectory within the phase space. The non-linear characteristics are expected to be sensitive to changes in the combustion state as operations approach unstable conditions. The goal is to predict instability around 1 second in advance. If the research team manages to achieve this objective, it will be possible to prevent instability by modifying the fuel injection rate and distribution or other control parameters.

It is also known that combustor stability is sensitive to the flame structure, which is determined by factors such as flow field and fuel distribution. Therefore, JAXA is also working on optimizing fuel injector design and combustor geometry to create an insensitive flame structure.

As observed above, the Propulsion Systems Research Group is taking a wide variety of approaches to realizing stable low-NOx combustion. A clearer understanding of the combustion instability phenomenon is useful not only to suppress instability but also to enhance the thermo-acoustic interaction, which may lead to spin-off technologies such as thermo-acoustic engine devices and so on.



* What is lean-premixed combustion?

Burning fuel at a ratio that leaves no oxygen or fuel in the air after combustion (called the "stoichiometric ratio") results in high flame temperatures. NOx emissions increase exponentially as flame temperature increases after a critical point. In lean-premixed combustion, fuel is mixed with an excess amount of air (a fuel lean condition) to keep flame temperatures down across the board and cut NOx emissions by a sizable margin. JAXA researchers have developed a staged fuel nozzle that places the lean-premixed main fuel injector around the pilot fuel injector. Experiments using a multi-sector combustor equipped with the staged fuel nozzles have shown that the technology reduces NOx emissions by 82% relative to the International Civil Aviation Organization (ICAO) standards (CAEP/4), making it the most effective solution of its kind in the world.

RESEARCH INTRODUCTION

“DAHWIN”, a wind tunnel in the near future

Integrating analog technology and digital technology for higher efficiency and accuracy

From the aircraft research and development field

20XX, the digital/analog-hybrid wind tunnel—Research and development of an aircraft is in progress using the system named Digital/Analog-Hybrid Wind Tunnel (DAHWIN). Figure 1 shows the wind tunnel measurement room. This is the place where wind tunnel data are collected. In the wind tunnel, a 1:50 scale model of an aircraft under development is kept at an angle of attack of 1° and a Mach number of 0.8. The status of the test can be checked on the screens in the room. Numerical results computed by a supercomputer are also monitored on screens nearby. Based on these results, real-time wind tunnel data corrections can be applied. The aircraft designer checking the data via the Internet is sending an instruction: “Let’s try changing the angle of attack to 2°.” Then the model’s angle of attack is rapidly changed. As the model position is changed, corresponding numerical data are immediately displayed on the screens.

This is a view of the aircraft design field in the not-so-distant future. Completed in 2012, DAHWIN became our new wind tunnel system that realizes improving both efficiency and accuracy of the aircraft research and development process.

Taking full advantage of numerical analysis

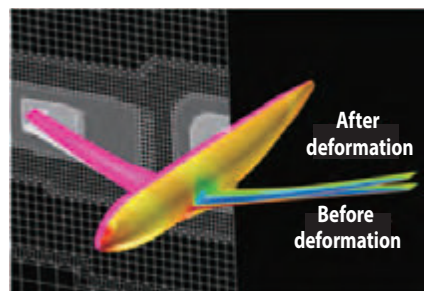
A wind tunnel is a facility that artificially creates the flow field around flying vehicles in order to

predict their aerodynamic properties. Since the measurement data are affected by the model support system and the wind tunnel wall, it is necessary to eliminate these effects to estimate the free-flight condition. This is effectively conducted by numerical simulations. Computations of the model configuration with the support system and computations including wind tunnel components (wall, strut, etc.) are used to correct for the effects of wall/support interference in wind tunnel tests.

In addition, if a model is designed and the test is planned by utilizing pre-test computational data, it is possible to shorten the schedule of the test campaign. To realize this, in DAHWIN, new computational tools are developed that can efficiently perform the numerical analyses before and after the wind tunnel test.

Future of DAHWIN—from shape determination to real-flight predictions

In the numerical analysis, complicated flow physics are modeled and solved. However, the results show different trends depending on the choice of the model. Furthermore, in wind tunnel tests, the wing of the model is deformed and these effects are usually not taken into account. Therefore, an approach was developed where wind tunnel data are fed back into the numerical tool and computations are conducted again using these data (fig. 2). This step improves the precision with which wind tunnel data and computational data can be compared.

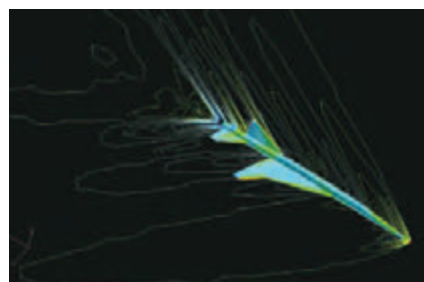
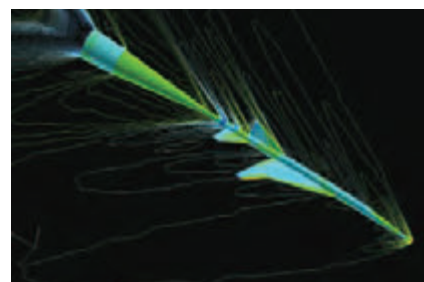


Wind tunnel data are fed back into the digital wind tunnel and the numerical analysis is conducted again using these data. This step improves the precision with which wind tunnel data and computational data can be compared.

Figure 2: High-fidelity numerical analysis using model deformation measurement data

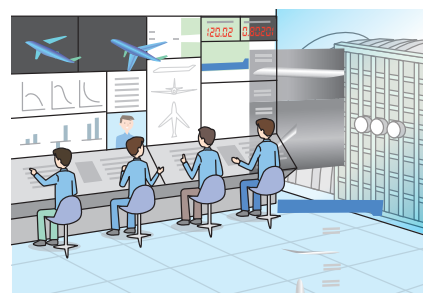
The system is presently constructed for use in the JAXA 2 m × 2 m Transonic Wind Tunnel and will be routinely operated from the spring of 2013. DAHWIN has already been applied to a number of test campaigns, including the low-sonic boom design concept validation of a supersonic transportation system (D-SEND project, fig. 3) and the recoverable H-II transfer vehicle (HTV-R).

DAHWIN will be extended to other JAXA industrial facilities, including low-speed and supersonic wind tunnels, in the near future. Furthermore, the system will be utilized to determine the optimal shape of aircraft and to predict real-flight performance by combining flight data with EFD/CFD data.



Numerical analysis is conducted considering the model configuration with support systems (left) as well as without (right). These results are used to correct for the support interference in wind tunnel data.

Figure 3: Numerical analysis results for silent supersonic aircraft model



In parallel with wind tunnel tests, numerical analyses are conducted by a supercomputer, and the results are rapidly fused with the wind tunnel data. Since the test can be monitored in real time via Internet, designers can quickly check the data and rearrange the test schedule.

Figure 1: Aircraft design research and development field in the near future

Promoting international cooperation to boost the global competitiveness of the Japanese aviation industry

Research and development activity at the JAXA Institute of Aeronautical Technology is guided by a mission of forging stronger relationships with industry and academic organizations to help the Japanese aviation industry attain stronger international competitiveness. Russia, China, and other countries have entered the market to compete with countries like the United States, Europe, Brazil, and Canada. This has intensified competition in aircraft development. Japan will need to continuously create globally competitive technologies to carve out a solid foothold in the global arena. It will also have to continue working with collaborators abroad on system development for aircraft, engines, and more. By fostering strategic international collaboration, the JAXA Institute of Aeronautical Technology hopes to fortify its technological offerings and return the fruits of its research to industry, universities, and society as a whole. In doing so, JAXA does more than just work with official research institutions such as NASA (the United States), DLR/ONERA (Europe) and KARI (South Korea); it also promotes collaboration and joint research with Boeing, Airbus, and other manufacturers and universities in the interests of mutual benefit, and cooperates with initiatives led by a United Nations agency. Let’s take a closer look at the major international collaboration efforts JAXA is involved in.

IFAR

JAXA belongs to the International Forum for Aviation Research (IFAR), the world’s only public aviation research establishment network founded in 2010. With 24 member nations, IFAR bases its activities around promoting collaboration among the world’s aviation research institutions and formulating frameworks shared by participating institutions for research on noise, emissions, high-efficiency operations, safety, and other environmental issues. Member institutions gather every year for the IFAR Summit (the organization’s annual meeting) to exchange ideas on various issues. In October 2012, JAXA hosted the Summit at a 300 year old Yagoto Kosho-ji temple in Nagoya, drawing 36 participants from 17 countries to IFAR’s first-ever Summit in Asia. Using the input culled from the discussions in Nagoya and from this year’s Summit held in Moscow in August, IFAR is now at work on initiatives to drive multinational joint research and human resource development. For instance, JAXA is currently participating in a NASA-led discussion in conducting a multinational project involving research institutions, industry, and universities from 6 nations in alternative aviation fuel research. JAXA also recognizes the great potential in what IFAR can offer in educating future aviation researchers and engineers. IFAR’s initiative on student networking is a perfect way for doctoral students in training at JAXA to network with their counterparts at IFAR member institutions. These opportunities in networking will be instrumental in helping the future leaders of Japan’s aviation industry forge meaningful and lasting relationships with their colleagues from around the world. As a newly selected Vice-Chair of IFAR, JAXA hopes to demonstrate its leadership working closely with the Chair organization NASA, and contribute to IFAR so that it can achieve its full potential in global research collaboration and training the next generation of leaders in aviation research.

<<International collaboration at the JAXA Institute of Aeronautical Technology>>



DLR, ONERA, and other Japan-Europe collaboration

Since 1997, JAXA had been engaged in bilateral collaborative researches with DLR (the German Aerospace Center) and ONERA (the French Aerospace Lab). In 2001, a trilateral joint research framework was established by JAXA, DLR and ONERA, since the three organizations have been accumulating fruitful collaborative researches under this valuable framework.

Each organization also take turns hosting annual trilateral meetings, where aviation research leaders from the respective organizations discuss research progress and strategic directions for future collaborations. In all, this trilateral partnership continues to form close, mutually beneficial bonds.

Japan and the European Union (EU) also signed “The EU-Japan Science and Technology Agreement” in November 2009, which entered into force in March 2011, paving the way for ongoing collaboration in aeronautics research projects uniting Japan and Europe.

NASA

The NASA Aeronautics Research Mission Directorate is JAXA’s one of the closest and most important partners. Since 2008, JAXA and NASA have conducted joint research on noise reduction for aircraft and helicopters, as well as several collaborative works on supersonic flight. The two organizations have agreed to continue working together on joint projects in the environmental and safety-related fields in the coming years. JAXA researchers engaging in joint research benefit enormously from the relationship with NASA: many have taken advantage of opportunities to spend up to a year at NASA facilities as visiting researchers and hone their skills through direct, on-site collaboration with NASA scientists. The leaders of the aviation divisions at JAXA and NASA also meet annually to continue building a strong, trusting relationship that offers mutual benefits and enables fruitful strategic collaboration.

BOEING/AIRBUS

Since 2000, JAXA has been researching and developing an on-board Doppler LIDAR capable of detecting turbulence in-flight and preventing accidents before they can occur. In 2010, JAXA began working with Boeing to enhance performance, reliability, durability, and compactness based on actual device specifications and installation requirements. Through this on-going collaborative partnership with Boeing, JAXA hopes that this technology will have a significant impact in the not too far future in making the world’s skies safer places to travel. In its collaborative partnership with Airbus, JAXA has been working on joint research in composite materials since 2009. Researchers from the JAXA Advanced Composite Research Center had the opportunity to conduct research at Airbus Headquarters in Toulouse, France, in 2011 and 2012, and an Airbus engineer spent a summer at JAXA working with JAXA composite researchers in 2013, just another of the many valuable experiences the relationship has created.

Contributions to international organizations

JAXA serves as the Japanese government’s official adviser (for the Civil Aviation Bureau) on the Committee on Aviation Environmental Protection (CAEP), which oversees the development of global regulations on aircraft emissions and noise for the International Civil Aviation Organization (ICAO)—a UN agency that establishes standards for global air transportation. JAXA sends six researchers to act as

technology specialists at CAEP’s technical working groups.

JAXA also contributes in the development of ISO standards for composite material testing methods by utilizing its world-class composite material testing equipment and simulation technology.

Flight Path Topics

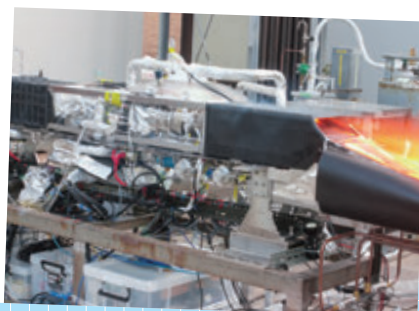
JAXA completes flight demonstration tests on its small unmanned aerial system for radiation monitoring

On March 7, JAXA conducted flight demonstration tests for its unmanned aircraft, equipped with radiation spectrometer technology developed by the Japan Atomic Energy Agency (JAEA), at Shikabe Airport in Hokkaido. The tests were designed to confirm and fine-tune the flight functionality of the small unmanned aircraft and validate the performance of the on-board radiation spectrometers. JAXA and JAEA have been working together since 2012 to create a radiation monitoring system using unmanned aircraft, which can fly at lower altitudes than manned aircraft and make close, detailed observations of the ground surface. JAXA's unmanned aircraft can also fly faster, longer, and farther than unmanned helicopters, thereby enabling monitoring of broader areas. The unmanned aircraft used for the March tests had a length of 2.7 m, a span of 4.2 m, a total height of 1.3 m, and a takeoff weight of 50 kg. Flying with a reciprocated engine and an auto-flight (program flight) system (disabled during takeoff and landing), the aircraft successfully met the intended basic functionality requirements. JAXA plans to improve the safety, reliability, and flight functionality of the aircraft to make unmanned aircraft-based radiation monitoring systems feasible for practical use.



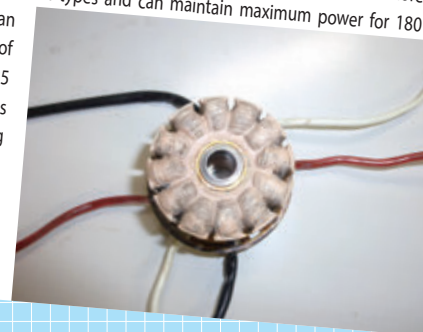
Combustion experiments at Mach 4 prove successful for JAXA's hypersonic turbojet

Combustion experiments were performed at the Noshiro Rocket Testing Center on March 5 to evaluate the performance of JAXA's hypersonic jet at simulated Mach 4 flight conditions. As the turbojet's engine uses ultra-low-temperature liquid hydrogen for its fuel source, it can cool the compressed, high-temperature air that flows into the engine during hypersonic flight. In front of the engine is a heat exchanger with an array of thin metallic tubes through which the liquid hydrogen flows, cooling the air. The heat exchanger also restricts temperature increases inside the engine, which makes the engine operable at up to Mach 5. Driven by the aim of one day making its hypersonic turbojets part of hypersonic passenger aircraft, JAXA has already developed an engine for technological verification purposes and used it to conduct static firing experiments under takeoff conditions and flight experiments at Mach 2. With the successful results of the recent combustion experiments at Mach 4, JAXA has now established the world's fastest turbojet technology.



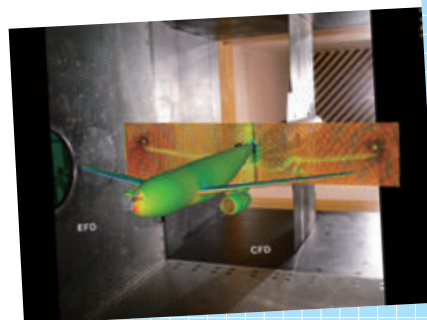
JAXA develops a motor coil for use in electric aircraft that can maintain its maximum power more than two times longer than conventional models

JAXA has been researching electric aircraft as a promising solution for achieving substantial reductions in aircraft fuel consumption and maintenance costs. At takeoff, electric aircraft need to maintain maximum power for around two to five minutes. Traditional electric aircraft motors faced serious problems: when running at full power for an extended period, temperatures would climb rapidly, thus increasing electrical resistance and impeding the current. This not only produced a drop in the motor's maximum power but also created the possibility of burnout. As a result, electric aircraft needed either to use bigger motor systems that could generate the necessary power without maxing out or to have cooling systems for reducing motor temperature. JAXA and Nippon Kayaku Co., Ltd. have successfully developed a motor coil that can maintain its maximum power more than two times longer than conventional models. Featuring a strong, reactive polyamide resin base coating that ensures high thermal conductivity, excellent insulation performance, and the ability to withstand temperatures of up to 250°C, the new coil rises in temperature more gradually than conventional types and can maintain maximum power for 180 seconds—more than double the duration of traditional models (85 seconds). JAXA looks forward to pushing motor output to even higher levels and expanding its focus to larger electric aircraft.



The DAHWIN hybrid wind tunnel goes into full-scale operation

After five years of development, the DAHWIN hybrid wind tunnel is now complete and in full-scale operation as of this April. DAHWIN combines a conventional wind tunnel (an "analog" wind tunnel) with supercomputer-driven airflow simulation technology (a "digital" wind tunnel) to create a "digital/analog hybrid wind tunnel." Although analog wind tunnels boast high levels of data reliability due to their use of real-life airflow, the models require a considerable amount of time and money to produce. The support equipment under the models also has an impact on the experimental data outcomes. Meanwhile, computer simulations alone are not enough to guarantee reliability—the different physical models used in the simulations all produce different results. JAXA thus decided to combine supercomputer-driven simulation data with analog wind tunnel data to compensate for the two tunnel types' respective shortcomings, improve design precision for aircraft and spacecraft, and shorten development periods.



JAXA appointed as IFAR* Vice-Chair

For four days in August, 37 participants from 22 countries gathered in Moscow for the 4th IFAR Summit. At the event, JAXA was nominated by the Russian Central Aerohydrodynamic Institute (TsAGI) and unanimously selected to become the next IFAR Vice-Chair. In selecting JAXA for this leadership role, voters recognized the success of last year's 3rd IFAR Summit in Nagoya, hosted by JAXA, and the many active contributions JAXA has made to IFAR. Executive Director Nakahashi will serve in an official capacity at IFAR as vice-chair for two years and then automatically accede to the chair position for another two years.

Nakahashi expressed his commitment to helping IFAR fulfill its great potential as the world's only public aviation research establishment network. He also wants to take a leadership role in promoting multinational research collaboration and human resources development in partnership with NASA, the current IFAR Chair.

* IFAR: The International Forum for Aviation Research (www.ifar.aero/)



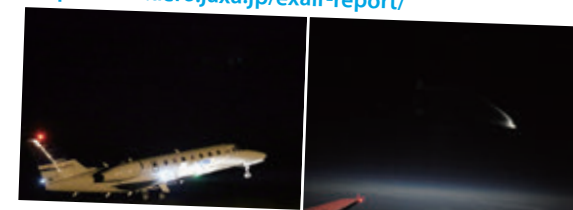
The 4th IFAR Summit (Moscow, Russia)

Hisho monitors an observation rocket experiment from high altitude

"Hisho," JAXA's experimental aircraft, completed its lithium light photo-shooting mission during the demonstration tests for the S-310-42 (launched at 11:00 p.m.) and S-520-27 (launched at 11:57 p.m.) observation rockets at the Uchinoura Space Center on July 20.

Flying above the clouds with special optical equipment on board, Hisho's mission was to capture the light generated by the reaction of the trimethylaluminum (TMA) and lithium emitted by the two observation rockets. The nature of the mission required special adjustments. Due to the faintness of the target light, for example, the perimeter of the window where the camera was installed had to be sealed. As lithium generates red light, the camera to capture lithium also had to be installed on the right-side window so that the red navigation lights on the tip of the left wing would not interfere with the objective. Hisho took off from Tanegashima Airport at night to reach its observation location by the time of the rocket launch and, after the observation rockets splashed down, successfully observed the luminescent cloud.

<http://www.aero.jaxa.jp/exair-report/>



Hisho takes off from Tanegashima Airport

The recently photographed luminescent cloud