JAXA Aeronautics Magazine

# FLIGHT PATH

*Shaping Dreams for Future Skies*

JAXA
Institute of Aeronautical Technology

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**Feature Stories**

## Aeronautical Science and Basic Technology Research
## Cultivating and growing Japan's aerospace technology

## Round Table Discussion
## "The Future Opened Up by Unmanned Aircraft"

# FLIGHT PATH

## 2014 No.5/6

***This issue features "Aeronautical Science and Basic Technology Research" which creates new technologies for the future; and Unmanned Aircraft, a topic that has been attracting attention in recent years.***

**The cover depicts a wind tunnel experiment aimed at improving aerodynamic design technology of high-lift devices on aircraft, such as flaps and slats. By coating the surface of a model with oil mixed with fluorescent material then blowing air through the tunnel while exposing the model to an ultraviolet light, the flow pattern of the airframe surface can be visualized.**
**This makes it possible to understand the aeroacoustic noise generation as well as physics of lift and drag forces of the aircraft. The resulting information from these experiments is being applied when designing real aircraft.**

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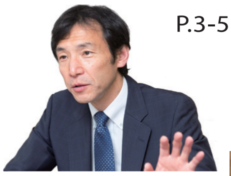
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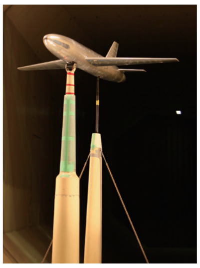
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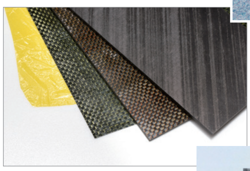
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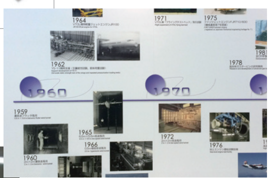
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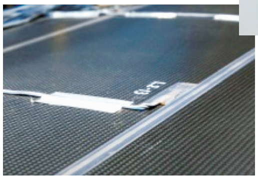
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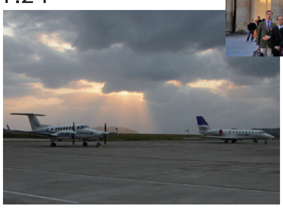
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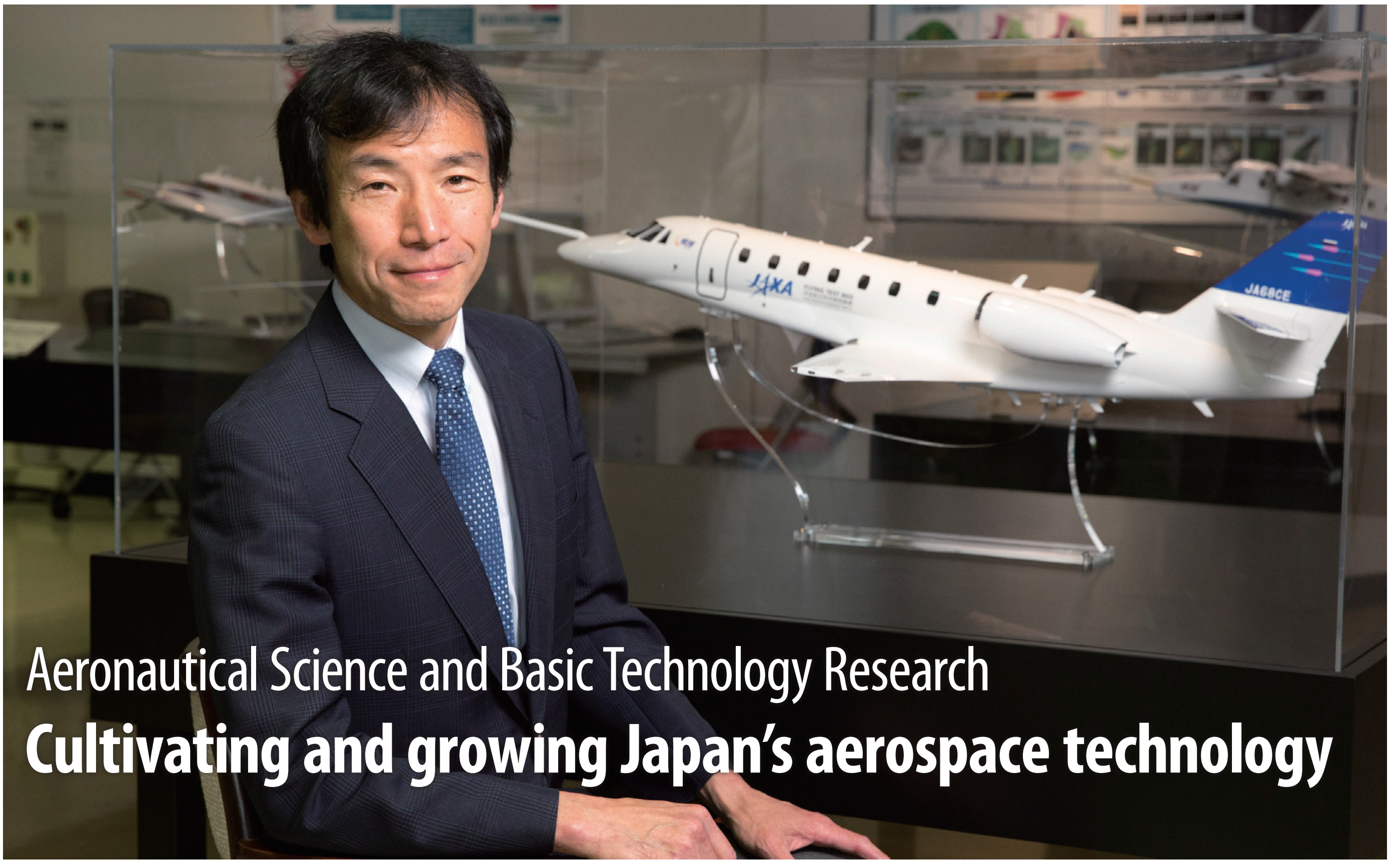


# Aeronautical Science and Basic Technology Research

# Cultivating and growing Japan's aerospace technology

**In order for new technologies with future potential to be invented, basic research that provides a foundation and research that improves common foundation technologies for testing and analysis are indispensable. We asked Masaaki Yanagihara, Senior Chief Officer of Fundamental Aeronautics Research, for an overview of research into basic and fundamental technology that the JAXA Institute of Aeronautical Technology is undertaking with its "Aeronautical Science and Basic Technology Research" program, and what role this research has in Japan's aerospace industry.**

**—Please tell us what the terms "basic technology" and "fundamental technology" mean.**

Basic technology refers to technology that will connect to a variety of projects – for example if we were talking about plants, basic technology would be like the buds that will grow into big trees. Fundamental technology is the soil for cultivating that basic technology. Technologies related to facilities and testing are considered to be fundamental technologies. The concept is that basic technology grows as a result of fundamental technology, and will eventually develop into a large project.

Basic and fundamental technology research are the unsung heroes – it is because basic technology and fundamental technology are in place that large projects can develop. That is the motivation for our work.

**—What technologies are included in basic and fundamental technologies at the JAXA Institute of Aeronautical Technology?**

Research into basic and fundamental technologies is centered on the four fields of "aerodynamics", "structure and materials", "aircraft engines", and "flight technology" at the Institute of Aeronautical Technology.

"Aerodynamics" is part of fluid dynamics and is the basis of aviation. There are more than 10 wind tunnels at the Institute of Aeronautical Technology and these are the devices used for aerodynamic experiments. Our greatest selling point is our ability to perform experiments that correspond to a variety of speeds from low speeds to transonic, supersonic, and hypersonic speeds. For example, the 6.5 m × 5.5 m low-speed wind tunnel has a test section that is the largest aircraft wind tunnel in Japan. The transonic wind tunnel, which can produce wind speeds of around Mach 1, is used by JAXA (also by the private sector and other external parties) and has the highest operating ratio of any wind tunnel in Japan. The supersonic and hypersonic wind tunnels are used for aircraft and also for rocket and other experiments in the field of space.

In addition to this variety of wind tunnels, in recent years we are at the forefront in computational fluid dynamics (CFD), used to investigate air flow using computers.

**—The JAXA Institute of Aeronautical Technology also has the Digital Analog Hybrid Wind Tunnel (DAHWIN), which combines wind tunnels and CFD, right?**

Yes. CFD calculated by computer does not involve experiments and therefore enables effective aerodynamic design. But being based on calculations, CFD can differ from actual reality. DAHWIN is a hybrid wind tunnel system that combines the best of both efficient CFD and realistic wind tunnel experiments, and provides high-precision results with greater efficiency.

Wind tunnels attempt to be as realistic as possible but are affected by the surrounding walls and the supporting devices for the models, so ultimately wind tunnels differ from actual flight. As the next step forward from hybrid wind tunnels, we are investigating technology that includes flight tests. In concrete terms, we are considering comparing data measured using JAXA research aircraft to data from wind tunnel experiments and CFD, thereby improving accuracy in all three fields.

## Feature story: Aeronautical Science and Basic Technology Research

**—The JAXA Institute of Aeronautical Technology has the full range of facilities to enable all aspects of aircraft aerodynamic research, from theory through to demonstration, doesn't it?**

That is correct. There are many universities that have small wind tunnels and CFD capabilities. The advantage of the JAXA Institute of Aeronautical Technology is that under one roof we have a variety of wind tunnels, as well as CFD capabilities using super computers. Flight experiments with research aircraft are also available at JAXA.

**—Please tell us about the second pillar – "structure and materials".**

In structural and materials technology, JAXA excels in the field of composite materials such as carbon fiber reinforced plastics (CFRP). Approximately 35% of the state-of-the-art Boeing 787 passenger planes are manufactured in Japan and that is because Japan has a high level of composite materials technology. I believe that JAXA has made a major contribution to the areas that form the basis for that technology. Currently, we are researching technologies for making CFRP more lightweight and more easily manufactured.

We are also conducting research that aims to establish mass production techniques for, and improve reliability of, composite materials that utilize carbon nanotubes, as new materials for the future. We are also engaged in research into multifunctional composite materials that have new properties, by not only using carbon nanotubes and graphene, etc., as used in the composite materials, but also by combining these with metal, etc.

By engaging in this research, JAXA plays a major role in contributing to the development of Japan's aeronautical industry on the global stage and increasing its share.

**—What kind of research is being conducted into the third pillar, "aircraft engines"?**

The engine of an aircraft is a system on its own and the Institute of Aeronautical Technology has many experimental facilities relating to engines. We are also researching basic technology for next-generation engines.

Nowadays there is a demand for environmentally-friendly engine design so we are particularly targeting reduced fuel consumption and noise.

The FJR710 engine is a turbo fan engine created under a public-private partnership and JAXA was involved in its development. It was installed in the STOL experimental aircraft "Asuka." The technology obtained as a result of the development of the FJR710 engine led to Japan's participation in the international joint development of the V2500 turbo fan engine.

We want to use environmentally-friendly next-generation engine technology developed at the Institute of Aeronautical Technology to improve Japan's standing in international joint developments in the aeronautical industry.

**—What research is being conducted under the fourth pillar "flight technology"?**

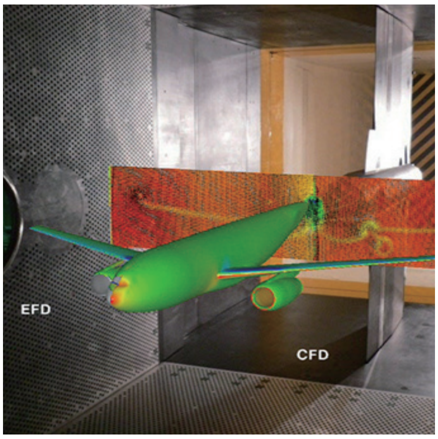
The aerodynamic and materials research that I have mentioned ultimately all need to be demonstrated by flight test, and flight technology is that area of research. For example, the inflight simulator mounted in the MuPAL-α research aircraft is a technology that enables simulated flight of an aircraft for which characteristics data has been input. Flight of a large passenger plane can be simulated by entering data for that kind of aircraft. A simulation of the flight of a new aircraft being developed can be experienced beforehand if data for that aircraft is input, and, even if problems occur, feedback on the design can be obtained prior to manufacture.

Inflight simulation is also effective in evaluating newly developed flight technologies. We are researching and developing "Fault Tolerant Flight Control technology" whereby a pilot can still safely fly an aircraft even if there are problems such as breakage of the control surface (the helm where the attitude of the aircraft is controlled). With the inflight simulator function, the pilot can actually disable the control surface during a test flight, and if a dangerous situation arises the pilot can stop the inflight simulation mode immediately and return to normal flight, thereby ensuring safety of the test flight.

**—How are research aircraft used?**

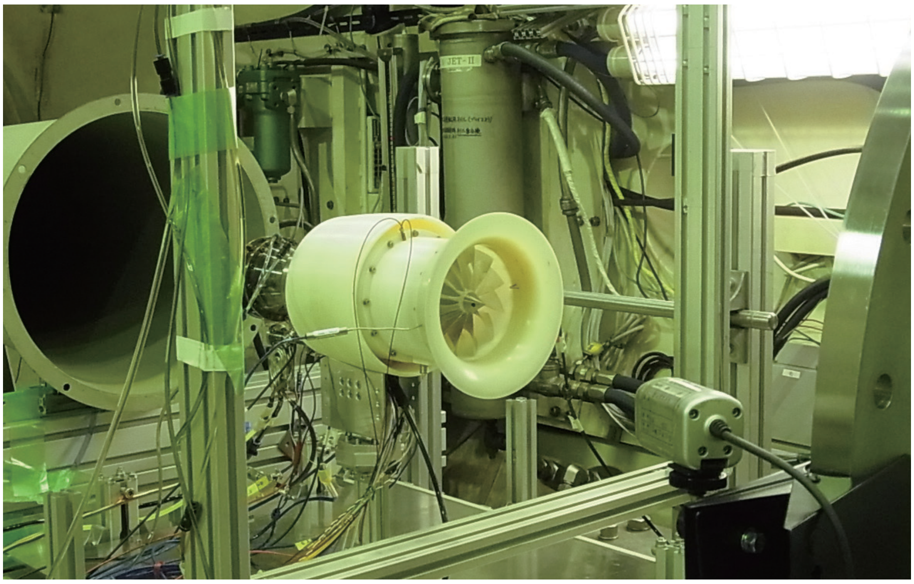
Until now we only had a turboprop plane and a helicopter so even if we created a new technology for a jet plane that flies at high speed at high altitudes, we could not sufficiently demonstrate that technology. In 2012 we introduced the jet plane "Hisho" and now we can, for example, mount devices in Hisho that are for jet planes manufactured by private-sector companies, and confirm whether or not the devices operate properly in the actual operational environment of a jet plane.


*The 6.5 × 5.5 m low-speed wind tunnel has Japan's largest test section for aircraft and is capable of measuring large models.*




*The Digital/Analogue Hybrid Wind Tunnel (DAHWIN) can combine and complement the results of experimental fluid dynamics (EFD) from wind tunnels and computational fluid dynamics (CFD) with the supercomputer.*

*CFRP test piece of VaRTM Prepreg Hybrid (VPH) fabrication technology, which combines the advantages of autoclave molding that uses a prepreg (a sheet-shaped member comprising carbon fiber impregnated by resin) and VaRTM molding whereby costs are reduced and molding occurs under atmospheric pressure.*



*Operation test of small turbo fan at Altitude Test Facility.*

As a result, Hisho is now being extensively utilized.

**—Could these technologies be used in space?**

Fundamental technologies can be used in the aeronautical field and in a variety of other fields, including space. For example, we use CFD technology to analyze acoustic vibration of rockets and investigate the effect on satellites to which they are mounted; we use wind tunnel technology to investigate the aerodynamic characteristics in the atmosphere of a reentry capsule returning to earth; and we perform experiments on landing radar mounted to lunar and planetary probes, by using experimental aircraft. CFRP and other composite materials are used in satellites. We are cooperating in the development of an aircraft for probing Mars, which is currently being researched by the JAXA Institute of Space and Aeronautical Science, and I believe that our technology can be utilized in that project.



*Research aircraft: jet "Hisho" (top) and turboprop "MuPAL-α" with in-flight simulator (bottom).*

**—What are the differences between basic research being conducted by universities and research by JAXA?**

There is an international index called the Technology Readiness Level (TRL) which indicates, in levels from 1 to 9, the practicality of a technology. Universities undertake basic research at levels 1 to 3, aircraft manufacturers, etc., research in fields close to practical application at levels 6 to 9, and JAXA researches technology in between, corresponding to levels 3 to 6.

The difference lies in our respective roles – JAXA takes the research conducted in university laboratories, demonstrates those technologies using wind tunnel tests or flight experiments or puts those technologies together as a system, raises the TRL, and passes those technologies on to the manufacturers.

**—What technologies do you have that are leading the world?**

Our CFD and composite materials technologies are ahead of the rest of the world. We also have a globally top-level technology whereby pressure-sensitive paint (PSP) is used in measurement technology for wind tunnel tests and pressure distribution is optically measured. Although we have some test facilities which are inferior in size, we make up for it in advanced technology such as CFD which raises the overall level and puts us in the international league.

In addition, overseas researchers are collaborating with us through international organizations such as the International Forum for Aviation Research (IFAR) which is a network of public aviation research and development institutions from around the world.

**—How would you like to see the basic and fundamental research conducted by the Institute of Aeronautical Technology playing a role in society?**

On the tenth anniversary of JAXA, under the corporate slogan of "Explore to Realize", we announced a broad policy of conducting research that serves a practical purpose in the real world. We will continue to conduct research into testing technologies, facilities, and other fundamental technologies that will, of course, contribute to the aerospace field and also to the global community in a way that provides support from behind the scenes. Basic technology needs to be researched with a clear vision in mind as to how that research is going to benefit society in 10 or 20 years' time. We also need to be proactive about providing information so that people can understand the research that we are undertaking.

***Masaaki Yanagihara***
*Senior Chief Officer of Fundamental Aeronautics Research*

Feature story: Unmanned Aircraft

Round Table Discussion

# JAXA Researchers Explain “The Future Opened Up by Unmanned Aircraft”

**Aircraft with no people aboard – unmanned aircraft – are used in a variety of applications such as crop spraying and aerial photography and new demand and potential have emerged in the areas of crime prevention, monitoring, and home delivery services. In the round-table discussion, researchers at the JAXA Institute of Aeronautical Technology discussed today’s unmanned vehicles, the issues faced, and the type of vehicles JAXA is striving for.**

## WHAT IS AN UNMANNED VEHICLE?

**The term “unmanned vehicles” is often heard these days, but what are they?**

**Ishikawa**: One of the main characteristics of unmanned vehicles is the ability to perform work without a pilot on board, by being operated remotely or automatically.

**Kubo**: “Unmanned vehicle” is a general term for all unmanned vehicles and some space probes and artificial satellites might be included in that category. “Flying” unmanned vehicles are called “Unmanned Aerial Vehicles” or “Unmanned Air Vehicles,” abbreviated to “UAV.” Other terms used in recent years include “Unmanned Aircraft System” (UAS) indicating not only the aircraft itself but the overall system including on-ground facilities, and “Remotely Piloted Aircraft System” (RPAS) emphasizing the remote operation. In the United States the media favors the term “drone.”

**Kohno**: There are a variety of unmanned vehicles and they tend to be largely grouped into two categories. One is the

ATTENDEES (Interviewer: Mizuno, Editorial Dept.)

**Kazutoshi Ishikawa**, Director, Operation Systems and Safety Technology Research Group

**Takashi Kohno**, Section Leader, Unmanned Aircraft Systems Safety Technology Section, Operation Systems and Safety Technology Research Group

**Daisuke Kubo**, Unmanned Aircraft Systems Technology Section, Operation Systems and Safety Technology Research Group

**Koji Muraoka**, Team Leader, UARMS Team, Technology Demonstration Research Office "large" category, which have similar performance and size as piloted aircraft and often fly together with piloted aircraft. The other main category is "small" such as those derived from model planes, they cannot carry the same equipment as manned aircraft but can be inexpensively and readily produced.

**What technology is required to fly unmanned aircraft and what issues are faced when trying to create that technology?**

**Ishikawa**: One of the advantages of unmanned vehicles is their ability to perform work without being piloted, so they are useful for dangerous, dirty, and dull work – known as "3D" work. This might be long-term observation of the same location or route or flying in to observe places too dangerous for people, such as typhoons. So the applications vary and a technology needs to be developed for each.

Another advantage of unmanned aircraft is they can be made smaller and lighter because no space is required for people.

*A conceptual image of the high-altitude long-endurance unmanned aircraft system that enables continuous observation for 72 hours.*

**Kohno**: Given that there is no pilot on board, technology to replace the functions of the pilot is needed. This technology needs to cover three stages of tasks performed by pilots – observation, determination, and operation. Example technologies include sensors that measure position using GPS and measure speed, to cover the "observation" stage, flight control computers that make "determinations" based on the information from those sensors, and actuators that perform the "operation" function by controlling the aircraft in accordance with the determination results.

One more element not required in piloted aircraft is a communications system for sending information to the ground about the aircraft and its surrounds as measured by the sensors and to send instructions from the ground to the unmanned aircraft.

**Muraoka**: Technologies for safe flight are also the key issues. There are, for example, some redundant on-board automatic flight termination systems (to prevent fatal impact on people or objects on the ground), and so on.

**With regard to pilot-replacement technology, what is happening with autonomous flight technology where the unmanned aircraft can think for itself and fly?**

**Muraoka**: We are jointly researching and developing an "Unmanned Airplane for Radiation Monitoring System (UARMS)" together with the Japan Atomic Energy Agency (JAEA), for radiation measurement over a wide range. The UARMS flies automatically on the predetermined flight route. It is quite a conventional automatic function. In the future, the use of automatic technologies will make flight more intelligent by utilizing on-line rerouting, swarming and so on.

## UNMANNED AIRCRAFT RESEARCHED AND DEVELOPED BY JAXA

**What kind of unmanned aircraft is the focus of your R&D at the JAXA Institute of Aeronautical Technology?**

**Ishikawa**: There are two main types of R&D. One is research into using unmanned aircraft as a tool for flight experiments of aeronautical technologies. An example of this is the experimental supersonic airplane used in the D-SEND project.

The other is R&D to enable unmanned aircraft to be used for social infrastructure. We conducted R&D into a disaster-monitoring unmanned aerial vehicle system, up to 2012, whereby unmanned aircraft could be deployed by local government personnel when disasters occur, to ascertain the scale of the disaster and the damage caused. We are also researching a system whereby multiple small unmanned aircraft called Micro Aerial Vehicles (MAV) can be operated cooperatively and flown inside collapsed

**Kazutoshi Ishikawa**
Director, Operation Systems and Safety Technology Research Group

**Koji Muraoka**
Team Leader, UARMS Team, Technology Demonstration Development Office

buildings after a disaster such as a tunnel collapse or earthquake, and search for survivors and check for fires and toxic gases. (See report on page 15)

The other focus of our R&D is the "Unmanned Airplane for Radiation Monitoring System (UARMS)" already mentioned.

**Muraoka**: We had already worked on an unmanned fixed-wing aircraft capable of 21 hours continuous flight and thought we could develop an unmanned aircraft based on this technology that would be optimal for radiation monitoring, so we started R&D on the UARMS, jointly with JAEA after the Fukushima Nuclear Power Plant accident. We are currently conducting flight tests and expect to complete the project this year. Once completed, the unmanned aircraft will be capable of radiation monitoring during long continuous flight over a 20 to 40 kilometer range.

Current aerial radiation monitoring uses both manned and unmanned helicopters. The UARMS has been developed to compliment their operations by adding fixed-wing UAV. Operations by manned helicopter is quite reliable but the costs are higher and they cannot fly at lower altitudes – which is desirable for radiation monitoring because of minimum safety altitude restrictions under the Civil Aeronautics Act. Unmanned helicopters can fly lower and slower but long and wide range flight performance is not so good. The advantages of the UARMS are they can fly at higher speed, at lower altitude, and for longer distances.

**Ishikawa**: We are also considering a high-altitude long-endurance unmanned aircraft system capable of flying continuously at high altitudes for 72 hours. The concept is to have 24-hour monitoring throughout the year by rotating between unmanned vehicles capable of 72-hour flight shifts, which could be used to monitor Japan's extensive territorial waters and to provide continuous monitoring of and information about changing conditions at disaster sites.

## LEGAL ISSUES WITH UNMANNED AIRCRAFT

**How are unmanned aircraft handled in law?**

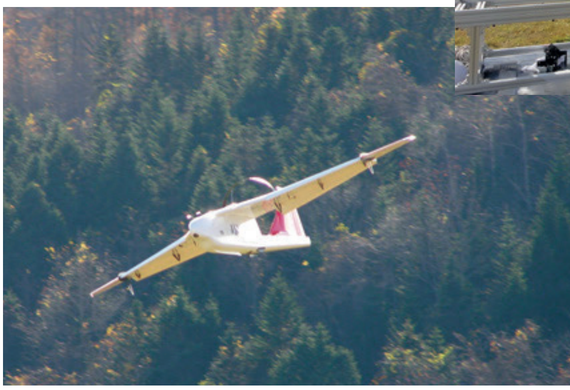
**Kohno**: In the law relating to aircraft, the Civil Aeronautics Act, aircraft are defined as a device that can be used for air navigation with a person on board (Article 2). The Act doesn't

*Unmanned Airplane for Radiation Monitoring System (UARMS) experiment).*

cover unmanned aircraft although it does provide for a piloted aircraft modified such that the pilot can disembark, called "pilotless aircraft" (Article 87). The Act does not consider a machine fundamentally designed to be without a pilot to be an aircraft. So, under the current Civil Aeronautics Act, unmanned aircraft are not specified as aircraft.

**Ishikawa**: The other relevant law is the "Aircraft Manufacturing Industry Act" which stipulates that a license must be obtained and required equipment in place when manufacturing aircraft having a total weight of over 150 kg. This means that large unmanned aircraft of that size require the same level of reliability, safety and airworthiness as piloted aircraft.

**It seems that relevant legislations are being developed in the US and other countries. What about in Japan?**



*ABOVE: Disaster-monitoring unmanned aerial vehicle launch from a catapult mounted on a truck tray.*
*LEFT: Flight testing of the disaster-monitoring unmanned aerial vehicle system using cameras to capture images from above a disaster site.*

**Kohno**: Unmanned helicopters for crop spraying are used widely in Japan – so much so that we are often called a UAV Superpower – but operators follow voluntary operation rules provided by the Japan Agricultural Aviation Association and the Japan UAV Association, which is the industry body.

Our unmanned aircraft experiments are conducted under JAXA's strict safety standards and we make suggestions for improving Japan's legislation, on the basis of our experiment results, to the Ministry of Land, Infrastructure, Transport and Tourism.

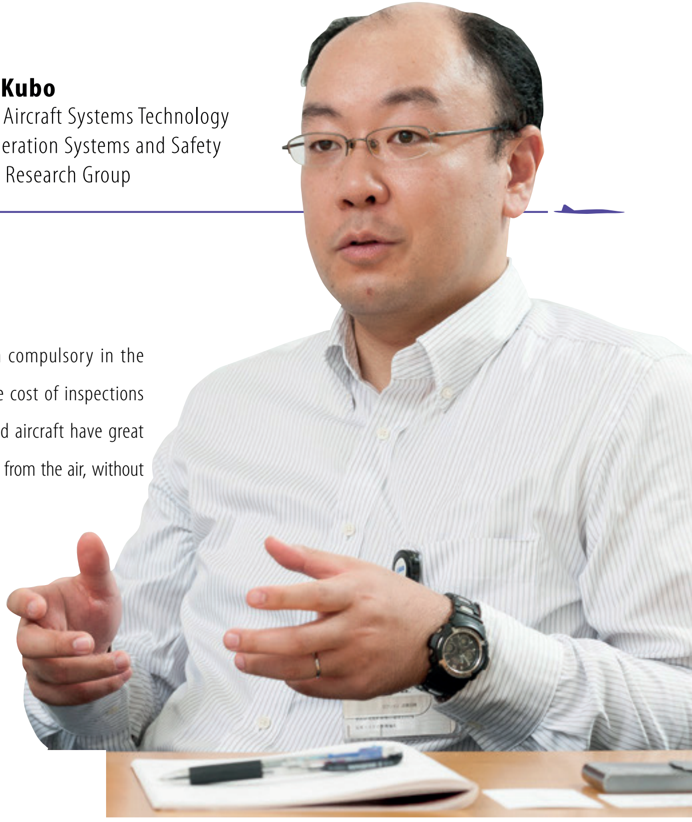
**Ishikawa**: Although not strictly relevant to legislature, there are also complicated procedures in place for conducting flight experiments using unmanned aircraft. We have to apply for aviation authority and airport permits as well as notify local government authorities and residents when we conduct wide-ranging flights. We have to liaise with the Coast Guard and the fishing industry when flying over the ocean and we also have to warn the fire brigade and the police. These procedures are necessary in the experimental stage, of course, but will need reviewing when unmanned aircraft come to be used in everyday applications.

## ■ INCREASINGLY WIDESPREAD USE OF UNMANNED AIRCRAFT

**How are unmanned aircraft used now and what**

*Yamaha Motor's unmanned helicopter for industrial use "FAZER." Yamaha has a long track record in the use of unmanned industrial-use helicopters.*
*Images: Yamaha Motor Co., Ltd*

**Takashi Kohno**
Section Leader, Unmanned Aircraft Systems Safety Technology Section, Operation Systems and Safety Technology Research Group



**Daisuke Kubo**
Unmanned Aircraft Systems Technology Section, Operation Systems and Safety Technology Research Group

**might they be used for in the future?**

**Kohno**: An increasing number of companies in Europe are using small unmanned multi-propeller aircraft, called "multicopters," to provide a variety of services. Aerial photography is the most common but other applications include using infrared cameras to observe crops from the air and creating 3D maps from aerial surveying.

America hasn't developed commercial use as much as Europe but government bodies use comparatively large unmanned aircraft to patrol borders and monitor for bush fires, etc.

**Ishikawa**: As already mentioned, unmanned helicopters are widely used in Japan for crop spraying. They suit Japanese conditions where the agricultural land is close to housing and the cultivated area is relatively small.

**Kubo**: One area that unmanned aircraft have great potential, not only in Japan, is for infrastructure inspections, e.g., for bridges and tunnels.

Regular inspections have not been compulsory in the past but are likely to become so and the cost of inspections using scaffolding is enormous. Unmanned aircraft have great potential because of their ability to inspect from the air, without requiring scaffolding.

**Are passenger jets and other large aircraft likely to be unpiloted in the future?**

**Ishikawa**: Research into unmanned automobiles (Unmanned Grand Vehicle, UGV) is underway now and the day is approaching when unmanned work vehicles will be used in the civil engineering/construction sector and unmanned tractors will be used in agriculture. Technologically speaking, it is conceivable that eventually an unpiloted passenger jet could be flying the skies but, as with unmanned automobiles, there are many social rules and ethical issues that would need to be overcome first.

*Micro Aerial Vehicle (MAV). Aiming to perform complicated tasks with multiple cooperative operation.*

These days we hear a lot about the use of unmanned aircraft to provide a variety of services. There are many potential applications and they will no doubt become an increasingly familiar technology into the future.

However, technological and legislative issues need to be overcome before expanding the use of these aircraft. The Institute of Aeronautical Technology has challenges ahead in order to achieve its goal of utilizing unmanned aircraft technology to contribute to a safe and secure society.

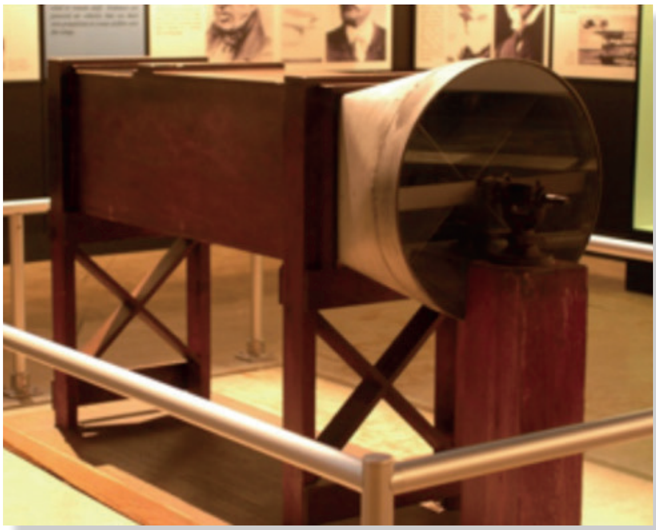
# JAXA's globally-competitive advanced wind tunnel technology

**Wind tunnels are experimental facilities for artificially creating airflow and investigating characteristics of the airflow around a model placed inside it. There is a long history behind wind tunnels. The Wright brothers, who successfully conducted the first ever powered flight, repeatedly conducted tests in a wind tunnel before their flight tests. Wind tunnels, with their extensive history, are indispensable to modern day aircraft and spacecraft development and are evolving as a result of constantly updated technology. The JAXA Chofu Aerospace Center began its history with the introduction of wind tunnels. Here we look at JAXA wind tunnel technology that supports aircraft and spacecraft development.**

***Shigeru Hamamoto***
*Director of the Wind Tunnel Technology Center*

### What do wind tunnel tests reveal?

"Aerodynamic design is the most important element in determining the shape of an aircraft body" – so says Shigeru Hamamoto, Director of the Wind Tunnel Technology Center, which conducts research and development of wind tunnel technology. Aerodynamic design involves investigating what impact (aerodynamic characteristics) airflow has on a body. By repeatedly reflecting this data in the process of designing, the final body shape is determined in line with the purpose of the aircraft, e.g., the need to be faster or more efficient. Since the time of the Wright brothers, models of bodies have been placed in wind tunnels to establish how the force of air acts on the model during simulation of flight in a state that is close to actual flight. These wind tunnel experiments have been indispensable to aircraft design



*Replica wind tunnel device used by the Wright brothers. Image: U.S. Air Force.*

Aerodynamic force has a variety of elements, such as the force that lifts up an aircraft (lift), the force that tries to push back the aircraft (drag), the force that tries to rotate the aircraft around the center of gravity (moment), and the pressure applied to the body surface. The properties of air change with temperature, so temperature data is also required.

In wind tunnel tests, firstly the model is arranged in the test section inside the tunnel and sensors that measure the data are wired up. Then, with air being blown through the wind tunnel, the angle of attack for the model (the vertical angle of the model relative to the air flow) and the lateral sliding angle (yaw angle) are changed and measurements taken. Depending on the scale of the experiment, the series of steps, from installation of the model to ventilation, measurement, and removal takes approximately one to two weeks.

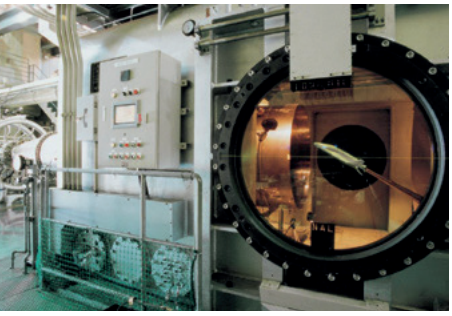
### Diverse wind tunnels covering a wide range of speeds

Aircraft flight speed varies, from the comparatively low speed of helicopters to the high speed of jet aircraft, and the even faster supersonic aircraft. The Institute of Aeronautical Technology owns many wind tunnels that cover a wide range of speeds, from low-speed wind tunnels capable of creating a state in take off and landing, to transonic wind tunnels that simulate a cruising state, to the even faster supersonic and hypersonic wind tunnels. There is also an arc-heated wind tunnel and an inductively-coupled plasma

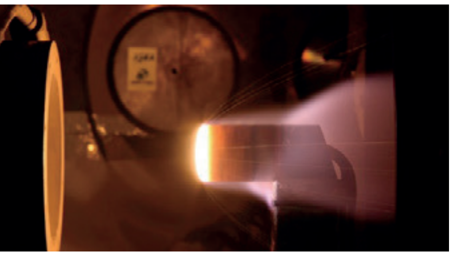
## RANGE OF WIND TUNNELS

*1 m × 1 m supersonic wind tunnel. Used for research and development of aircraft, projectiles, rockets, and reusable space transportation/re-entry vehicles, etc.*

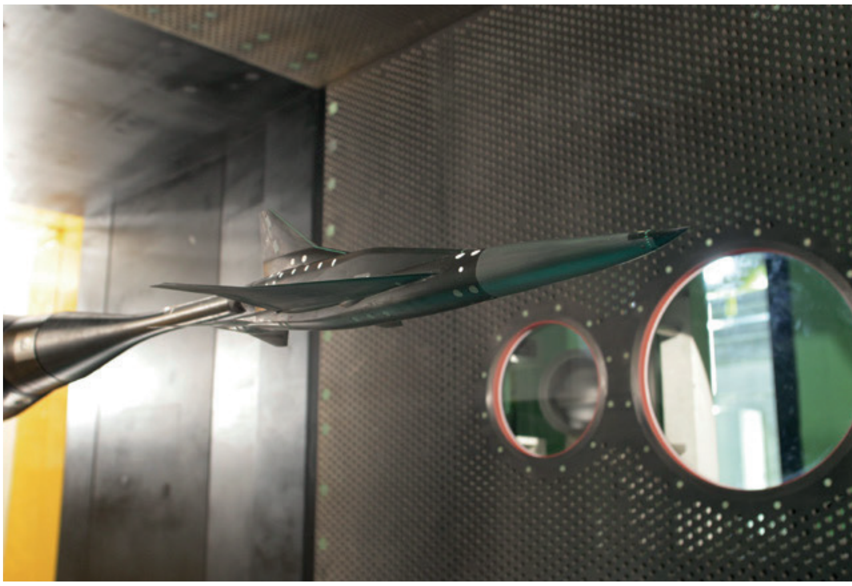
*6.5 m × 5.5 m low-speed wind tunnel with aircraft model. The wind tunnel has the largest test section in Japan and is used for investigating aircraft characteristics during landing and takeoff, and during low-speed flight.*

*1.27 m hypersonic wind tunnel. Capable of producing Mach 10 wind speeds. Used for the design of future hypersonic aircraft and reusable space transportation, etc.*



*750 kW arc-heated wind tunnel, capable of creating a high energy air flow and of facilitating experiments simulating re-entry to the atmosphere. The image shows a heating experiment on low-density ablators.*



*2 m × 2 m transonic wind tunnel. Used for investigating characteristics of aircraft that fly at transonic speeds.*

wind tunnel that applies high energy to the airflow to simulate the state of a re-entry capsule returning to Earth from space.

### ■ Contributing to Japan's aerospace industry for more than 50 years

It is more than 50 years since the 2 m × 2 m transonic wind tunnel started operation in 1960 and this wind tunnel has been used in nearly all aircraft development that has taken place in Japan during that time. In recent years, it was used during the development of the Mitsubishi Regional Jet (MRJ). Experiments were also conducted in this wind tunnel during the development of rockets such as the N-series and the H-series. People may think that aerodynamics have little to do with rockets that fly into space, however the period from when the rocket leaves the atmospheric layer until it reaches space is extremely important, and we need to measure the effect of safety devices (stabilizers) on making the rocket fly straight. We also need to measure the effect of the vibration phenomena that occur when exceeding the speed of sound. For example, experiments were conducted for the H-II rocket and the H-II B rocket, using the wind tunnel to find how aerodynamic characteristics changed depending on the attachment position of boosters.

Many of the wind tunnels at the JAXA Chofu Aerospace Center were completed years ago but they are still active and operating. It is not easy to rebuild an aged wind tunnel but improvements and modifications are continually occurring, such as updating electronic devices and replacing the drive motors with more efficient fans, etc.

Measurement technology for wind tunnels is rapidly advancing. Fifty years ago the force applied to models was ascertained using instrumentation that measured mechanical balance. This balance was read by the human eye and calculated by hand, but these days we have changed from mechanical measurement to electronic measurement using strain gauge sensors and from human calculation to computer processing.

The technology for measuring air pressure on models has also progressed. In the past, a manometer that derived differences in air pressure from the height difference of a liquid surface was used and people visually measured the values. That has now changed to more precise measurement made possible by a pressure sensor that outputs, as electric signals, very small deformation amounts of diaphragm caused by pressure. Furthermore, a pressure scanner has been developed that is capable of measuring pressure at many points in a short amount of time – by rapidly switching between inputs from multiple pressure sensors. The pressure scanner can measure more than 500 points in one second.

*Pressure-sensitive paint (PSP) is light-emitting paint that changes brightness according to pressure. Pressure distribution is measured as an image, by measuring luminescent intensity from the PSP, using CCD cameras, etc. By coating PSP on a model, the pressure distribution for the entire surface can be measured. The redder the color, the higher the pressure - see below.*

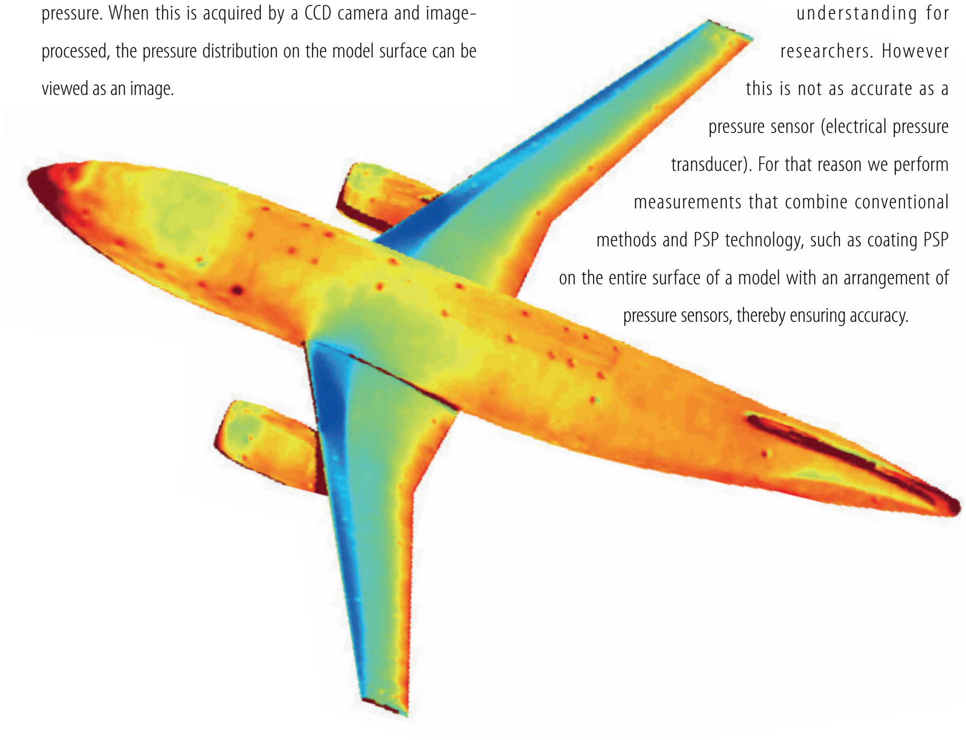
## Pressure-sensitive paint measurement to visualize pressure images on a model surface

Measurement methods continued to evolve, but there was still an issue – the sensors could only measure the pressure at the points where they were located. There is a limit to the number of sensors that can be arranged on a surface, and there will be gaps between the pressure sensors. The pressure in the area between the sensors can only be inferred from the values measured by adjacent sensors. If an unusual phenomenon occurs, errors cannot be detected if there is no pressure sensor at that location.

This issue had been identified for a long time and many researchers wanted to be able to measure the pressure not of a point but of a plane. Pressure image measurement was realized by technology using pressure-sensitive paint (PSP), which changes the amount of luminescence intensity on the basis of the amount of oxygen (partial pressure). When a model coated in pressure-sensitive paint is placed inside the wind tunnel and wind and ultraviolet light are applied to the model, the degree of red light emitted by the paint changes depending on the difference in pressure. When this is acquired by a CCD camera and image-processed, the pressure distribution on the model surface can be viewed as an image.

America and Russia started research into PSP in the latter half of the 1980s and Germany and France have also developed. JAXA has successfully implemented PSP technology in a large-scale wind tunnel. Kazunori Mitsuo, Chief Manager for Planning at the Wind Tunnel Technology Center states "JAXA's PSP technology is internationally competitive at the top level."

Pressure images measured using PSP aid intuitive understanding for researchers. However this is not as accurate as a pressure sensor (electrical pressure transducer). For that reason we perform measurements that combine conventional methods and PSP technology, such as coating PSP on the entire surface of a model with an arrangement of pressure sensors, thereby ensuring accuracy.

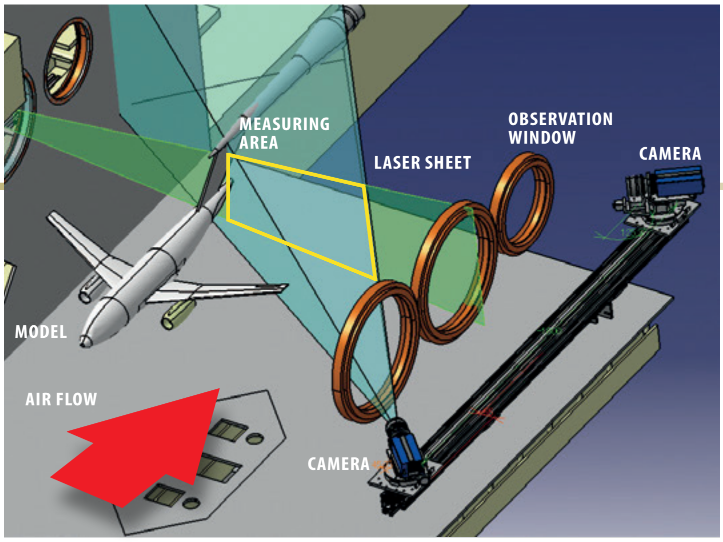


## Particle Image Velocimetry making air flow in space visible

In order to understand aerodynamic force, it is important to understand airflow around the model. There are methods that use smoke, such as in smoke wind tunnels, in order to examine slow flows, but Particle Image Velocimetry (PIV) is a technology that is one step further advanced. With this technology the speed distribution, direction, and behavior of airflow around wings can be observed.

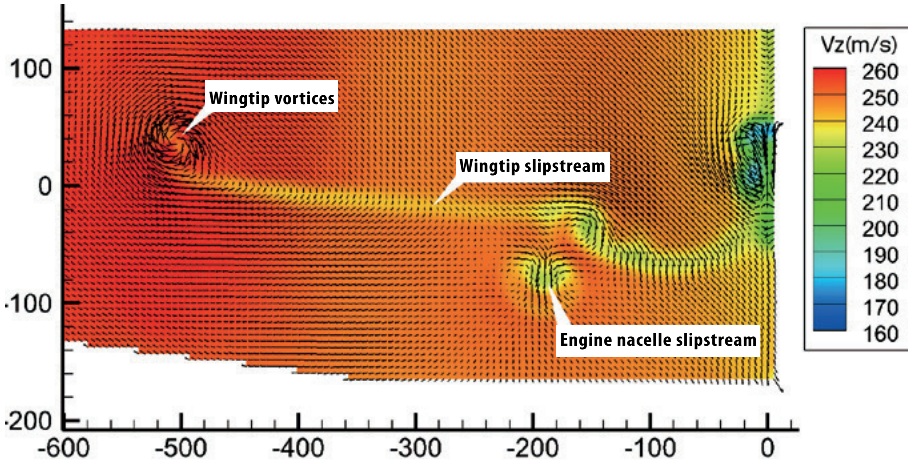
When PIV is used, vortex movement induced near wing tip can be captured. The aircraft in flight is pulled along by the vortices and unforeseen force is applied when a vortex collapses. PIV is very useful in researching this phenomenon.

The principle of PIV is simple – small particles called tracers are mixed into air and caused to flow, and tracers that pass through a laser light irradiated in a sheet pattern (a laser sheet) are captured by camera. After a certain interval another image is taken and the two images are compared. If the distance traveled by the same particles is known, their velocity can be calculated, and, therefore, the velocity distribution on the imaged plane can be found. The principle is simple, but given that many tens of thousands of particles are captured in one image, identification of the particles by the human eye is not possible.




*LEFT: PIV measurement concept diagram. Tracers released in air are captured, by camera, when they come in contact with a laser and emit light.*

*BELOW: PIV measurement results. Vortices created at wing tips (wingtip vortices), turbulence generated behind the wings (wing slipstream), and turbulence created by engine section (engine nacelle slipstream) can be visualized .*




For that reason, the images are processed by computer, the particle travel amount is calculated using a method called cross-correlation analysis, and the velocity distribution calculated. A measurement system using PIV was customized for use in JAXA wind tunnels and has been implemented. By using the customized JAXA PIV, three-dimensional velocity vectors can be measured, by using two cameras and imaging the same sheet area. Furthermore, the airflow for large models can be observed by changing the position of the laser sheet and the camera.

## Evolution that meets user needs

Transonic wind tunnels of ten years ago showed slight variations in the obtained data because the temperature of airflow and measurement devices changes with the time of day and the seasons. Competition is fierce in the modern aviation industry, particularly in relation to environmental performance and fuel consumption, so even slight variations can have a large impact on design.

We are constantly modifying the test environment and measurement methods so as to respond to user needs and get closer to consistently obtaining the same measurement data. Although this kind of work is painstaking, we have been able to achieve globally competitive, high-precision wind tunnels as a result of revealing, in detail, the issues involved and accumulating technological developments in this way. In addition, attention has recently been focused on one of the environmental efficiencies – noise reduction – and, as a result, there is demand for wind tunnel measurement of noise generated by the body. Accurate measurement is not possible if the noise generated by the wind tunnel itself is larger than the body noise being measured. We have been able to make improvements to facilitate more accurate measurement of the sound emitted by a model, by making modifications such as coating the internal walls of the wind path with sound-absorbing material, which reduces the fan noise, and by employing an anechoic measurement chamber in which sound does not reverberate.

We are also currently engaged in even more innovative technology – the development of measurement technology for skin friction (surface friction) using light-emitting oil. This technology has not been successfully implemented anywhere in the world yet, so it should become a predominant technology once it is achieved.

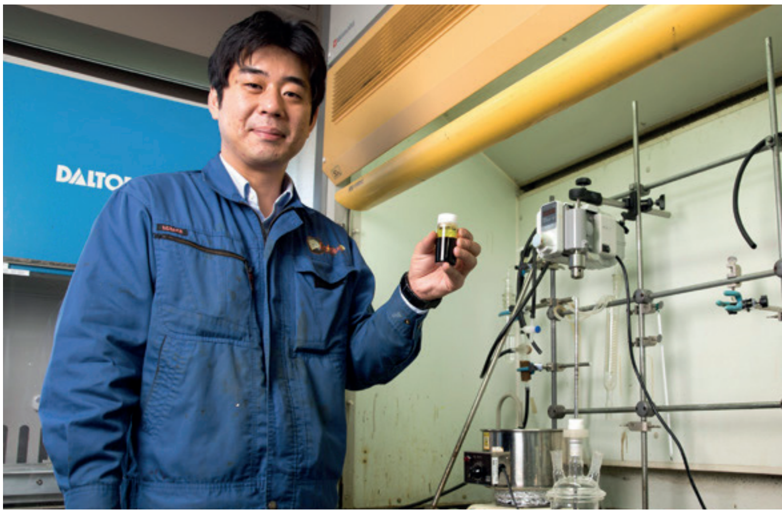
## Aiming for internationally first class wind tunnel technology

The JAXA wind tunnels are available for use by organizations outside of JAXA, through the collaborative use system. The transonic wind tunnels are used, for example, by companies developing aircraft and spacecraft. The low-speed wind tunnels are used for windmills, wind power generation, and antenna for maritime radar. In addition, this technology is used in the sporting field, for example luge and ski jump competition.

The JAXA Wind Tunnel Vision 2025 has been adopted at the Wind Tunnel Technology Center as a guiding principle for research, development and management of future wind tunnel technology. One of the targets of the Vision is the research and development of world-class wind tunnel technology. The director of the Wind Tunnel Technology Center, Shigeru Hamamoto, spoke of his aspirations: "We are aiming for JAXA to have good wind tunnels, excellent wind tunnel testing/measuring technology, and the ability to repond to the diverse demands of the global community. This will prove that we are world class."

***Kazunori Mitsuo***
*Chief Manager for Planning and Section Leader, Supersonic and Flutter Wind Tunnel, Wind Tunnel Technology Center*

# Creating a next-gen composite material and opening up possibilities for Japan's aerospace industry




## KANEKA CORPORATION's Advanced Materials Research Laboratory
## Interview with Masahiko Miyauchi, Senior Researcher

**Here at the JAXA's Institute of Aeronautical Technology, we are working on research into polyimide/carbon-fiber composite materials used in the aerospace field. Through collaborative research with KANEKA, we have developed a polyimide resin with excellent heat resistance and toughness (strength against tension and impact) and are making progress toward creating composite materials that use this new resin. We asked Masahiko Miyauchi, senior researcher at KANEKA's Advanced Materials Research Laboratory, about the results of teaming up with JAXA.**

**—What sort of joint research with JAXA have you been making progress on?**

At KANEKA, we are producing polyimide film, a synthetic resin. Polyimide resins have outstanding heat-resisting properties and are used primarily in the wiring of electronic devices and in multilayer heat-insulating materials used to protect spacecraft from heat. These polyimide resins are often used in the form of a thin film, but we are attempting to use them together with carbon fiber to make a composite that can be utilized in aircraft structural materials.

The structural material of aircraft is primarily aluminum and titanium alloys, although lately CFRP (carbon fiber–reinforced plastic) made from an epoxy resin has entered wide usage. However, epoxy-resin CFRP can only endure continuous-usage temperatures of about 120 ℃, so highly heat-resistant titanium is used in locations that can reach temperatures of 200 ℃, such as those near engines. We aim to replace this titanium with a polyimide-resin composite material, making the airframe of an aircraft even more lightweight and reducing fuel consumption.

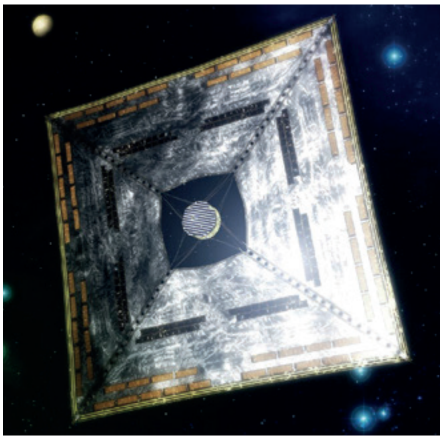
**— Please tell us about the background of your research.**

Research into composite materials that use polyimide resins began at NASA over 50 years ago. They were unable to manage both heat-resisting properties and moldability, though, and the concept was never truly realized. Meanwhile, research led by Rikio Yokota (then with the Institute of Space and Astronautical Science (ISAS)) into polyimide resins continued to progress at JAXA, and through fundamental technological research—supported by NEDO (New Energy and Industrial Technology Development Organization) and carried out for a five-year period starting in 2002—a new technique for developing polyimide resin with excellent moldability and heat resistance was developed. When this research ended in 2007, as a resin manufacturer we entered into collaborative research with JAXA.

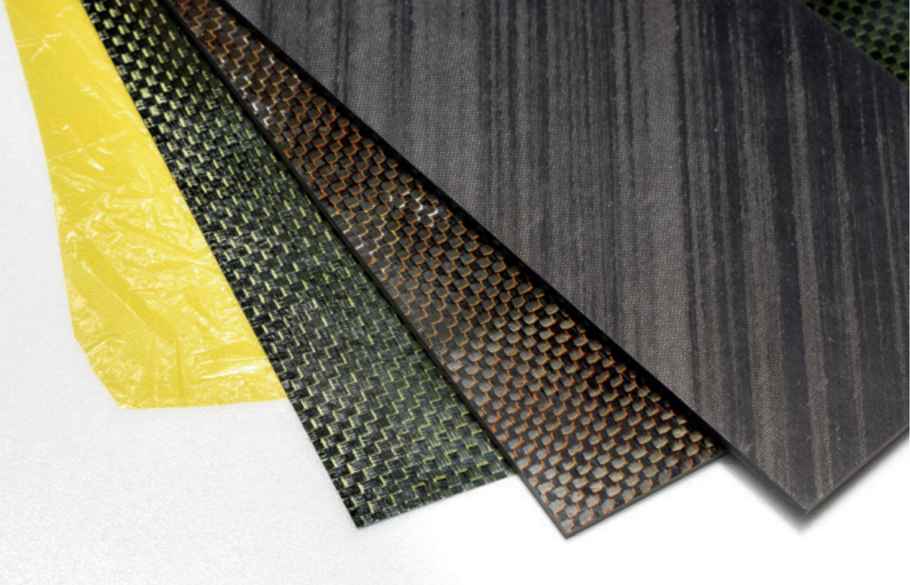
**— At the time, what was Yokota thinking about using the polyimide-resin composite material on?.**

On ultra-high-speed aircraft with cruising speeds surpassing Mach 2. To make this a reality, the weight of the airframe must be reduced. Because wing surface temperatures exceed 200 ℃ when flying above Mach 2, it was necessary to develop a new heat-resistant composite material to replace the epoxy resin.

**— Tell us about the results of the joint research.**



*Polyimide resin material is used for the sail component of the Small Solar Power Sail Demonstrator "IKAROS" (image: CG), and also as thermal insulation material for other satellites.*



*Carbon-fiber composite material formed by laminating layers of sheets coated with oligomeric imide resin (the top plate in the picture).*

First, the production method for the polyimide-resin composite material developed by NEDO was as follows. Start by creating a sheet of carbon fiber impregnated (pre-preg) with an oligomeric amide resin solution, which is a precursor for polyimide. Then laminate this with many layers, and cure it thermally (giving it a high molecular weight) while applying pressure in a type of furnace called an autoclave. However, there is a problem with this method: the process of oligomeric amide converting to oligomeric imide during molding generates water molecules, which make it easy for cracks to form in the materials. During the joint research with our company into solving this problem, Yokota and his team discovered that the issue could be solved by utilizing an oligomeric imide having ingredients with particular chemical structures. Applying this method, we worked together with JAXA to develop a polyimide-resin composite material called TriA-X, which we announced in 2008. TriA-X is a very tough material able to resist temperatures of over 370 °C. Following that, in 2011 we developed a new polyimide-resin composite material with an even higher moldability.

**— What is involved in that method?**

Although the composite that can be obtained from pre-preg molding is high quality, it is also expensive. For manufacturing large numbers of components with identical shapes or those with complex shapes, a better process is resin transfer molding (RTM), which involves directly impregnating pre-laminated carbon fiber with a liquid resin. As the RTM technique can only be applied using a resin with an extremely low viscosity, we have developed a polyimide resin with a low melt viscosity based on TriA-X.

**— If you replace titanium with this material, about how much would you be able to reduce the weight?**

Aircraft titanium alloy has a density of around 4.4. Polyimide-resin composite material is about 1.5, so a sheet of the same surface area and thickness would be about one-third of the weight.

**— Where specifically on an aircraft are you looking to use this material?**

We are aiming to replace titanium alloy in the components of jet-engine fan blades with polyimide-resin composite material. We would also like to use it in places such as around the engine nacelles and the pylons attaching engines to wings.

**— What are some of the challenges moving forward?**

We are now able to manufacture the material in sheets, but when we consider using it in practice we realize that we have to be able to produce three-dimensional shapes. Therefore, we need to produce some I-shaped and C-shaped components as well as some large-scale pieces then investigate their strength. To evaluate whether or not this material can be used in practice, we need to accumulate reliable strength data and consider its ability to be mass-produced.

**— What is the next objective in your joint research with JAXA?**

We are trying even more ways to make new polyimide-resin composite materials. The jointly-developed oligomeric imide we spoke of a bit ago has a high solubility, but because it has a high affinity to the solvent, as the mold sheet gets thicker there is a chance the solvent will be difficult to remove from the laminated pre-preg portion within the mold. So, we are thinking about boldly changing the process by dissolving the polyimide resin ingredients in a solvent with a low boiling point then casting the composite. This would mean that the process of creating the imide from oligomeric amide, hardening it and molding into a sheet could be done all in single process.

**— What originally prompted the collaborative research with JAXA to take off?**

When we were considering expanding the business of our resin division, the aviation and space field seemed extremely attractive. We estimated that these markets will definitely continue to grow in the future. We had already developed an epoxy-resin strengthening agent for composite materials in these fields, which has since been commercialized as an additive (masterbatch). From that point, we were thinking to expand our composite material business by using polyimide resins.

**—Still, the development of composite materials for aircraft takes a long time. It doesn't create new business immediately. It's impressive that you made that decision as a company. What are some of the good points about collaborating with JAXA on research?**

Since the 1980s, we've continued our research into creating polyimide-resin film while trying out various molecular structures. However, since about the year 2000 we have primarily conducted applied research, developing in a short time a great number of resins in accordance with the request of our customers—resins which are intended for use in cellular and smartphone components. So when we think back to our company's polyimide resin technology, we see the need now more than ever to expand our techniques for evaluating and designing the molecules of resins, as they will become the basis for the development of new products.

This means that there is significant meaning to consistently conducting fundamental research from designing polyimide high polymers to evaluating the properties of the resulting resins, together with developing highly heat-resistant composite materials as applied research. And not just with this collaborative research—we have expanded the range of our research into creating polyimides within our own laboratories, as well. Our joint research with JAXA has had a ripple effect, stimulating fundamental research within our company.

Looking forward, we are greatly anticipating JAXA's Institute of Aeronautical Technology working toward full-fledged implementations of heat-resistant composite materials; creating a foundation for further applied development systems along with a cooperative framework for manufacturers in all sectors; and serving as the nucleus that carries the aviation industry of Japan.

RESEARCH INTO "COOPERATIVE OPERATION OF MULTIPLE MICRO AERIAL VEHICLES FOR COMPLEX MISSION CAPABILITIES"

# Multiple Small Unmanned Aircraft performing cooperatively

**These days, the performance of small unmanned aircraft is very high and they are being increasingly utilized in commercial applications. At JAXA we are researching a system for indoor rescue support, such as in collapsed tunnels or buildings in the aftermath of a disaster, using multiple small unmanned aircraft operating cooperatively.**

## SYSTEM FOR MULTIPLE COOPERATING MAV PERFORMING VARIOUS TASKS

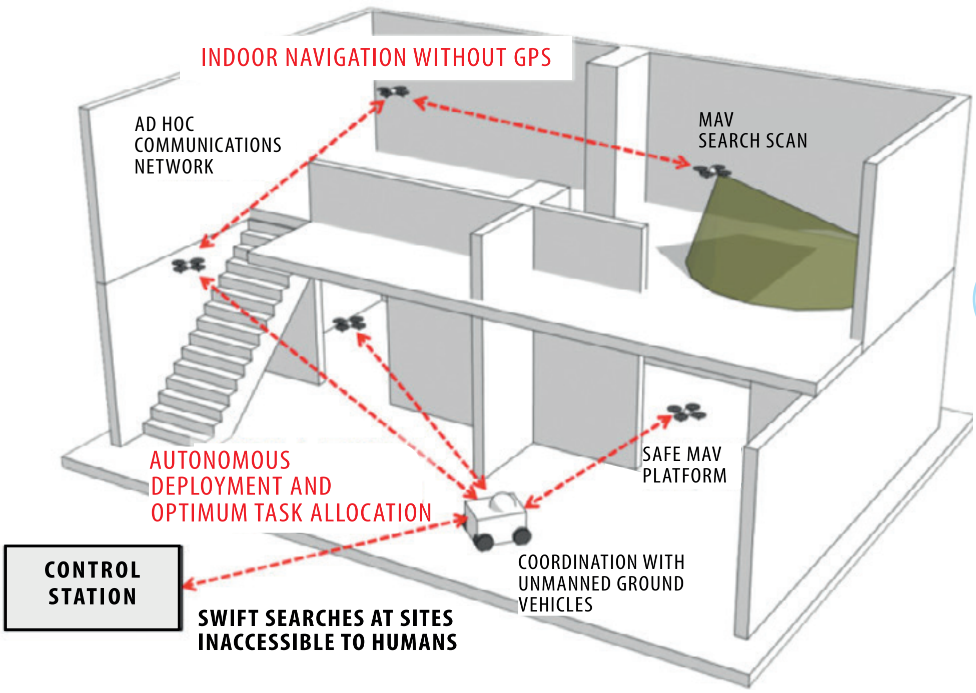
MAV stands for "Micro Aerial Vehicle" – ultra-small unmanned aircraft that, at most, are only tens of centimeters in size. The multi-rotor vehicle used as a platform in this research uses a system without complicated mechanisms, that simply combines electric motor driven propellers and a control system. Simple MAV are available in the hobby market and advanced-function MAV are being increasingly used for aerial photography and disaster damage evaluation

The research into "Cooperative Operation of Multiple Micro Aerial Vehicles for Complex Mission Capabilities," being conducted by the JAXA Institute of Aeronautical Technology aims to provide a system capable of independent response to complicated tasks by cooperative operation of multiple MAVs, indoors where GPS cannot reach. Daisuke Kubo, researcher with the Operation Systems and Safety Technology Research Group conducting this research, gives the example application of "disaster sites inaccessible to rescue workers, such as indoor fires and collapsed tunnels." If small flying robots can first check the situation inside inaccessible sites that pose risks to people, then rescue can proceed swiftly and safely.

What are the merits of using multiple MAVs for such tasks? Radio waves may not penetrate some disaster sites due to collapsed walls and ceilings, but that issue is resolved and all areas can be searched if multiple MAVs are used to relay the radio waves. If there are several MAV operating, the task of an accidentally damaged MAV – which is always possible at a disaster site – can be taken over by another.

Greater efficiency is achieved because each MAV is performing a different task.

"It is the same as when one person is searching for something inside a building – it takes a lot of effort and time. But many people, working together and communicating effectively by radio can find things so much faster." (Kubo)




*Concept drawing. Several MAV communicating and exchanging information to perform tasks. MAV can penetrate sites out of radio range, by relaying radio waves. One MAV can take over if another is damaged.*

## DIFFICULTY OF ACHIEVING STABLE INDOOR FLIGHT

One essential technology in this research is the technology for stable indoor flight. At first glance, indoor flight may seem easy due to the absence of wind and other outdoor factors. But in confined spaces MAV generate their own air currents which reflect off the walls and destabilize the MAV and affect the flight of other MAV.

Also, absolute position can be easily obtained during outside flight by using GPS, but position cannot be determined

*Coordinated flying of multiple MAVs.*

indoors because there is no GPS signal. Knowing where you are is extremely important for safe flight. It is relatively easy to ascertain position, even indoors, if building plans can be entered into a program beforehand – but this doesn't work in a disaster, where conditions inside the building will most likely have changed.

There are several methods for a MAV to determine its surroundings, one method uses images and another uses the LIDAR method that utilizes a laser light sensor. The LIDAR measurement method measures distance from walls and obstacles and creates a map of the surrounds to ascertain position. Kubo explains "The research has progressed to a point where the shape of the room and position of the vehicle can be ascertained to a certain degree." However, onboard LIDAR can only measure planar (two dimensional) data, so MAV attitude (laser direction) and altitude need to be changed to be able to measure the entire indoor space. Another problem is the comparatively heavy weight of the LIDAR itself, which increases the size of the overall vehicle.

## HOW ARE MULTIPLE MAVS COORDINATED?

One more important issue is "task generation and planning" – technology whereby a computer allocates the optimum task to each MAV and plans efficiency during operation of multiple MAVs. This involves a series of decisions and instructions, such as determining which MAV is closest to the target, which MAV will arrive first, and the issuing of instructions to that MAV. An experienced operator can make decisions for each situation and operate one or two MAV accordingly, but management of a fleet of MAVs is difficult no matter how experienced the operator.

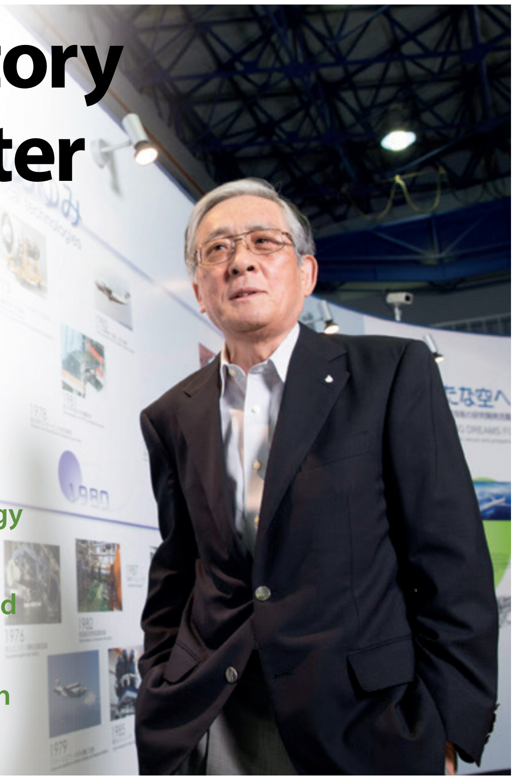
To achieve a system that anyone can easily use, "we are aiming at an optimum and efficient method whereby an operator only need give basic instructions and the rest is handled by the overall system." (Kubo).

Although still at the initial research stage," we hope to be able to test several units by 2015," Kubo explains enthusiastically. However many technical issues must be resolved first.

Unmanned aircraft technology has a wide range of applications. If we can achieve stable indoor flight of MAV, the day may come where MAV can be used in our everyday lives and not just in disaster situations as foreseen by the current research.

**Daisuke Kubo**
Unmanned Aircraft Systems Technology Section, Operation Systems and Safety Technology Research Group

# Looking back on the history of Chofu Aerospace Center



Susumu Toda
Former Head, National Aerospace Laboratory
Former Executive Director JAXA

**The forerunner to the JAXA Institute of Aeronautical Technology, the National Aeronautical Laboratory of Japan [later the National Aerospace Laboratory (NAL)] was founded in 1955. Since that time, a variety of test facilities that support aeronautical and space technology research have been created at the Chofu Aerospace Center and the genes of that research and development have continued to be handed down in an unbroken line. Let's look at part of that history, from the perspective of Susumu Toda (former Head of NAL) who is familiar with the period when Chofu Aerospace Center was established.**

### Reclaiming 7 blank years – to make aeronautical technology world class

Susumu Toda recalls "I joined the National Aerospace Laboratory (NAL) about 10 years after it was founded. At that time it was surrounded by fallow fields and there wasn't the density of buildings that there is today." It is no exaggeration to say that Japan's aeronautical technology prior to the end of the war was world class, with the Aeronautical Research Institute at the Tokyo Imperial University (present day University of Tokyo) setting the world record in long distance non-stop flight and, in the year the war ended, the jet plane "Kikka" completing its maiden flight. However, after the end of the Second World War, Japan was prohibited by General Headquarters (office of the Supreme Commander of the Allied Powers) from conducting any aeronautical research or manufacture.

*2 m × 2 m transonic wind tunnel circa 1962.*
*The surrounding agricultural fields can be seen.*

It was in 1952 that aeronautical projects were allowed to recommence. In order to fill in those seven blank years, a system for aeronautical technological research had to be quickly established. With the recommencement of research into aeronautical technology, the Ministry of International Trade and Industry (now the Ministry of Economy, Trade and Industry), the Ministry of Transport (now the Ministry of Land, Infrastructure, Transport, and Tourism), and the Defense Agency (now the Ministry of Defense), etc., each asked for a research budget, but much of the research and the facilities required were being duplicated. Each wind tunnel requires a colossal amount of funds and it was inefficient for such facilities to be provided at each organization. In 1953 an Aeronautical Research Council was established in the Scientific Technical Administration Committee in the Prime Minister's Office (now the Cabinet Office) and collaboration between the various ministries began on a future aeronautical technology and research system.

As a result of the findings of the Aeronautical Technology Council established in 1954, the National Aeronautical Laboratory (which became the National Aerospace Laboratory of Japan in 1963) was set up as an auxiliary body of the Prime Minister's Office. Later, the Laboratory became an auxiliary body of the Science and Technology Agency (now the Ministry of Education, Culture, Sports, Science, and Technology) when that Agency was established. From its inception, the Laboratory was charged with the mission of accumulating the test facilities necessary for aeronautical research and of offering the use of these to related government organizations, universities, and the private sector, etc. The Chofu Aerospace Center has developed and modified those test facilities in accordance with, and sometimes ahead of, the needs of the time.

### Chofu Aerospace Center – started with wind tunnels

In the seven years that research was not conducted in Japan, the global aviation industry had moved from propeller-driven aircraft to jet aircraft. For this reason, the facility first planned at Chofu was the transonic wind tunnel in which experiments on the cruising state of jet aircraft could be conducted. Construction started in 1956 and was completed four years later, in 1960.

One year after construction began on the transonic wind tunnel, work started on a flutter wind tunnel as a structural testing facility. Being smaller in scale than the transonic wind tunnel, the

*First commercial passenger aircraft in Japan, the "YS-11". (Image: Japan Airlines Co., Ltd.)*


*STOL experimental aircraft "Asuka" during flight testing, it is currently displayed at Kakamigahara Aerospace Science Museum (left). The "Queen Air" was in service as a research aircraft for half a century until it was decommissioned in 2011 (right).*

flutter wind tunnel was completed in 1959, one year earlier than the transonic wind tunnel. The Council found that research into supersonic aircraft was also required, as a future technology, so a supersonic wind tunnel was built. "These days you can't hear any sound or feel any vibration during wind tunnel tests, but in those days there were junior staff members who jumped up and cried out 'It's an earthquake!' during research presentations – that is how much the glass doors shook.", recalled Toda.

The wind tunnels with their wide range of possible speeds, from low to supersonic and hypersonic speeds, have contributed greatly to the development of aircraft in Japan. In particular, the transonic wind tunnel has had a high level of operation and even today it is a struggle to allocate time to all the private sector, university, and other users who apply.

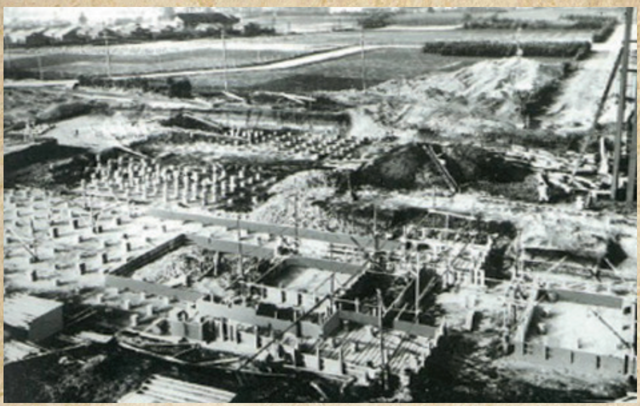
Development of the first Japanese passenger aircraft, the YS-11, began in earnest. An Aerodrome Branch was established on part of the Chofu Airport in 1961 and development support for the YS-11 was provided by conducting load tests, fatigue tests, etc. The first research aircraft "Queen Air" was also bought around the same period.

Between the latter half of the 1960s and through the 1970s, aeroengine test facilities and flight simulators, etc., such as a ground aeroengine test facility and an annular combustor test facility, were built for the development of Japan's first high-bypass-ratio turbofan engine "FJR710", and the short takeoff and landing (STOL) experimental aircraft "Asuka". In addition, the Queen Air was modified to an inflight simulator*, flight of the Asuka was simulated, and its flight test technology learned. NASA pilots participated in the flight tests of the Asuka and, as former Head Toda reminisces "Perhaps we were able to show them that Japan had reached the stage where our aviation industry could be useful to them". It was also around this time that development of a half scale model of a tail wing section using carbon fiber reinforced plastics (CFRP) started, as underlying technology research for Asuka, and experimental facilities for evaluating composite materials were introduced.

Toda says "It may sound like self-aggrandizement, but I believe that the test facilities at the Chofu Aerospace Center and the research that was conducted there contributed to the development of aeronautical technology in Japan". Even now as part of JAXA, some of the test facilities at the Chofu Aerospace Center are widely used by corporations and universities and contribute to Japan's increased industrial competitiveness as well as to improving aerospace technology.

* Inflight simulator: A system whereby characteristics of a variety of aircraft can be simulated, by flying via computer.

## The Chofu Aerospace Center Premises



*LEFT: Transonic wind tunnel during foundation works, photographed in 1958. The general shape of the closed circuit wind tunnel is visible.*

*RIGHT: Panoramic view of the Aerodrome Branch, Chofu Aerospace Center in 1975. The Chofu Airfield is top right.*

A variety of testing and other facilities are built on two large sites that includes the Chofu Aerospace Center, which occupies approximately 120,000 m$^2$, and its Aerodrome Branch, which occupies approximately 50,000 m$^2$. However, these sites weren't always this large.

The site where the Chofu Aerospace Center is located was the Central Aeronautical Laboratories prior to the war, then came under the jurisdiction of the former Ministry of Finance after the war and was temporarily used as a transportation technology laboratory. The site was selected because the availability of power was good (the steel pylons for receiving electricity that were still there), and also because electricity could be supplied relatively easily from the substation, the site was sufficiently large, and Chofu Airport was nearby. Approximately 60,000 m$^2$ of the approximately 250,000 m$^2$ of the former Central Aeronautical Laboratories was acquired (by transfer from the former Ministry of Finance in October 1957) and construction of the transonic wind tunnel, etc., began. The surrounding agricultural fields were subsequently bought, to ultimately create the current site.

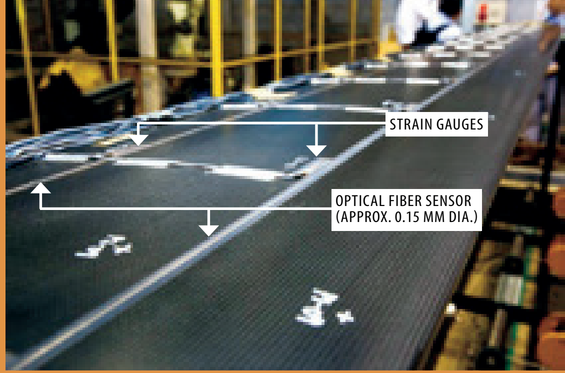
In February 1961, the use of approximately 36,000 m$^2$ of Chofu Airport, under the management of the American armed forces at the time, was permitted and the current Aerodrome Branch of the Chofu Aerospace Center was created.

DETECTING STRAIN WITH A WITH A SINGLE OPTICAL FIBER

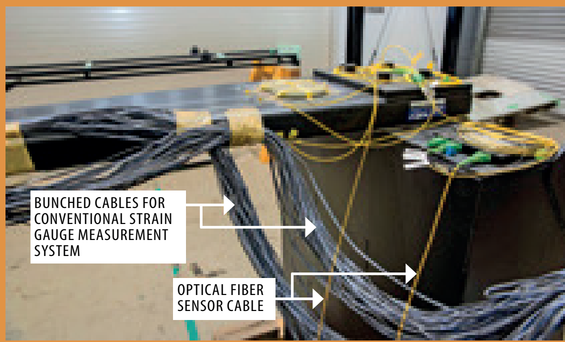
# Optical Fiber Sensor Research

**Understanding strain and the location of damage is important and necessary in aeronautical and spacecraft technology and a variety of other fields. In conventional strain measurement, many gauges need to be attached to the target and these gauges can only measure the local strains where they are attached .**

**At JAXA we are conducting research into optical fiber sensors that will enable strain measurement using only a single optical fiber.**




*Optical fiber sensor is linearly attached to the test wing surface and protected by tape (not always necessary). Conventional strain gauges are shown extending to the left.*




*Cables and optical fiber sensor for strain gauge measurment. Optical fiber sensor can measure strain distribution with a single optical fiber.*

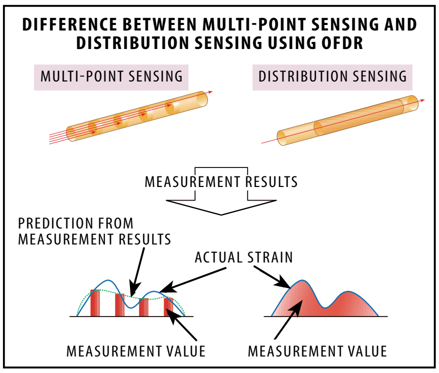
## Optical Fibers As Sensors

Optical fibers were originally developed for the communications field, but a lot of research has been conducted since the 1970s into the possible use of optical fiber properties in sensors. A technology for writing the locations of periodic variation in the refractive index, called Fiber Bragg gratings (FBG), was developed in the late 1980s and is now used in one type of optical fiber sensor..

When light passes through an optical fiber that has an FBG, the FBG functions as a filter whereby light of a specific wavelength is reflected where the FBG is located and all other light is transmitted. The fiber expands and contracts with the application of force and the wavelength of the reflected light changes. Strain and temperature change relative to the longitudinal direction of the optical fiber can be found by finding the wavelength of the reflected light. Furthermore, strain can be measured at multiple points on the optical fiber if FBG are arranged at multiple locations therein.

Strain gauge sensors used in conventional strain measurement can measure strain only at the points where the gauges are attached. Furthermore, a data transmission cable is needed for each gauge which makes wiring extremely complicated. If the number of strain measurement points is to be increased, the same number of cables need to be added. But with optical fiber sensors, strain can be measured at many points in a line, by wiring only one optical fiber.

Optical fiber sensors are already used in the civil engineering, construction and energy sectors – for example, to measure the temperature inside an oil field well, during drilling. They are also arranged along pipelines to detect damage or ruptures.




*Even with one optical fiber sensor, an entire detection area can be measured in detail using distribution sensing thereby enabling precise measurement.*

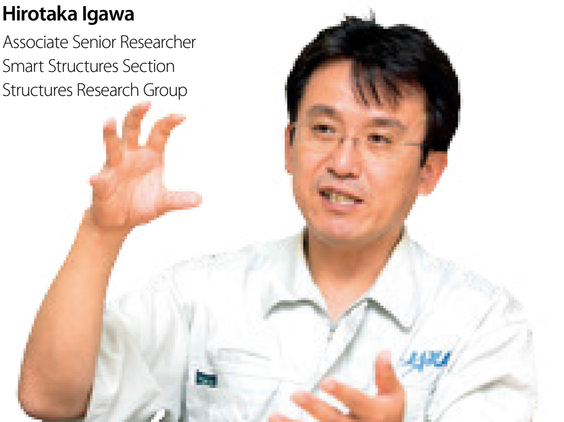
## One Optical Fiber to Ascertain Aircraft Conditions

JAXA is researching the distributed strain measurement system based on Optical Frequency Domain Reflectometry (OFDR) technology, whereby periodic change in the intensity of light generated by the interference between reflected light from a position reference mirror and reflected light from an FBG sensor are examined and relative measurement positions are identified. The concept of OFDR was already known, but at JAXA we have achieved spatial resolution of no more than 1 mm, by using our own data processing algorithm and, although still at the laboratory stage, we can measure overall deformation of an entire wing structure with high precision. We have also successfully detected strain and temperature simultaneously using one optical fiber sensor.

Optical fiber sensors have the capacity to measure model deformation with greater precision if used in wind tunnel tests. In the near future these sensors might be used in static load testing during aircraft manufacture and are being considered for space applications such as the detection of leaks in liquid hydrogen fuel tanks.

Hirotaka Igawa, Associate Senior Researcher in the Structures Research Group, explains the dream: "Our research aims at finding, in real time, strains and damage to the wings and fuselage of aircraft, by using optical fiber sensors. This is for more effective "structural health monitoring." If we can do that, we will reduce accidents and dramatically reduce the amount of maintenance required. If we add actuator technology and improve structural functionality, we can provide the capacity to further improve aircraft performance during flight, beyond the limits of the physical properties of the materials and structural characteristics."


**Hirotaka Igawa**
Associate Senior Researcher
Smart Structures Section
Structures Research Group

# Meeting with IFAR Members in Berlin

## The Latest Report on International Collaboration by JAXA Institute of Aeronautical Technology

**Atsuko Nakasone**
Program Management and Integration Department
Institute of Aeronautical Technology

JAXA actively engages in international collaborative activities to further hone the technologies at JAXA and to eventually contribute back to society. For this purpose, JAXA participates in joint research with international partners, such as overseas public research institutions, universities, and corporations. To maintain and foster cooperative relationships with overseas aeronautical agencies, a series of meetings were held that coincided with the 2014 Berlin Air Show (20-25 May) to which many of members from the International Forum for Aviation Research (IFAR), including JAXA as Vice Chair, were in attendance. Top-level meetings with NASA and the German Aerospace Centre (DLR), who are important cooperative partners for JAXA among the IFAR members, were also held. Here is a summary the successful outcomes of those meetings as the latest highlight of international collaboration undertaken by JAXA's Institute of Aeronautical Technology.

### Cooperation in ATM Field under IFAR

The International Forum for Aviation Research (IFAR) is the world's only aviation research establishment network comprising public aeronautical research and development agencies on a voluntary, non-binding basis. IFAR aims to connect research organizations worldwide, to enable the exchange of information and communication on aviation research activities, and to develop among its members a shared understanding of the challenges faced by the global aviation research community.

Eleven of the 24 member agencies attended the Berlin Air Show and they were appreciative of the warm hospitality extended by the DLR. IFAR members held meetings to discuss collaboration progress and IFAR's operational policies. One of the major achievements was an undertaking to begin collaborating in the field of air traffic management (ATM). This is IFAR's second scientific and technical initiative, following its first joint research initiative to study the impact of alternative aviation fuels on the environment. The first meeting by agencies involved in the ATM Working Group was held in Berlin with the participation of JAXA ATM researchers, and each agency expressed an anticipation of positive results from IFAR's involvement. Air transport is facing the challenges raised from an expected increase in global air traffic volumes, especially in the Asia-Pacific region. A lot of research and development has already been conducted, and IFAR hopes to leverage these efforts through their global network and to contribute to a faster, more efficient resolution of global air traffic problems.

*Attendees of the meeting pose in front of the Brandenburg Gate. JAXA was appointed Vice Chair of IFAR in 2013 and has been playing a leading role in IFAR, together with the Chair, NASA.*

### Agreement with NASA on Mutual Cooperation in the field of ATM

An agreement was signed at a meeting with NASA for research collaboration in the ATM field. NASA's Aeronautics Research Mission Directorate is the most important and closest research partner of the Institute of Aeronautical Technology at JAXA. Based on past discussions which pointed out the needs of promoting more strategic research collaboration in the environment and safety fields, an agreement was reached to begin cooperation in the ATM field. Over the next five years, NASA and JAXA will mutually benefit from this cooperation based on JAXA's noise reduction operation technology, NASA's airport schedule management technology, and JAXA/NASA technology for aircraft operation during disasters.

With the start of this new collaboration, NASA-JAXA can count four joint research initiatives in the field of aeronautics. NASA and JAXA confirmed their mutual cooperation in these collaborative works and also in relation to the operation of IFAR, given that NASA is the Chair and JAXA is the Vice Chair.

*Senior management in the aeronautical field from DLR and JAXA.*

### Deepening Ties with DLR

JAXA's Institute of Aeronautical Technology has built a long-term cooperative relationship with DLR in Germany, one of our important overseas partners. A variety of joint research projects have been conducted with DLR, including those under a tri-lateral joint research framework established in 2001, including the French aerospace research agency ONERA. The senior management of the respective aeronautical departments within JAXA and DLR met in Berlin and resolved to strategically deepen their cooperative relationship.

Whilst in Germany, JAXA's delegation members paid a courtesy visit to DLR Stuttgart, where a JAXA researcher is undertaking overseas training (from 2013 to 2014) and conducting research into composite materials. In the past, DLR Stuttgart has hosted other researchers from JAXA in the field of fuel cells and electric motors. These visiting researchers successfully established close working relationships with their DLR counterparts, which also helps both DLR and JAXA to foster unique and deeper ties at the organizational level.

Personnel exchanges such as this promotes a basis for mutual understanding and trust between research laboratories at both an organizational and personal level. JAXA believes that in the future this will add to an already favorable environment for mutually beneficial R&D collaboration with DLR.

*DLR electric-powered demonstration aircraft (DLR-H2 Antares)*

**There is severe international competition in the field of aircraft technology development. However, this also requires international cooperation if we are to raise the level of technology in non competitive areas, address environmental and safety issues and establish global standards. The JAXA Institute of Aeronautical Research will continue to promote its trustful relationships with overseas partners and promote strategic international cooperation.**

# Flight Path Topics

## Progress Continues in Development of D-NET
## FDMA started using "Centralized Management System for Fire-fighting and Disaster-relief Helicopter Operation" applying D-NET

In April 2014, the Fire and Disaster Management Agency of the Ministry of Internal Affairs and Communications began operation of their "Centralized Management System for Fire-fighting and Disaster-relief Helicopter Operation," a new system which is applied with the Disaster Relief Aircraft Information Sharing Network (D-NET) developed by JAXA.

In the aftermath of the Great East Japan Earthquake and Tsunami, a large number of aircraft participated in rescue operations in disaster areas; however, it became clear that there were problems with making the most efficient use of those aircraft.

D-NET is a technology which makes safer and more efficient operations possible through the sharing of disaster information such as flooding and landslide reports—as well as aircraft location data and operational information such as "in transit" and "mission assigned/completed"—among all aircraft equipped with the system and ground-based disaster-relief headquarters.

On top of real-time tracking of position information of all helicopters, the new operation management system allows FDMA centers to share and monitor detailed information about disaster-stricken areas as well as operational status and progress of tasks assigned to each helicopters. In addition, the new system is expected to facilitate the smooth sharing of information in the event of large-scale disasters in which multiple disaster support groups other than the FDMA also perform rescue operations, because it is built based on the D-NET data standards which summarizes all necessary information that should be shared with aircraft and relevant centers on the ground for safe and efficient disaster relief operation and therefore compatible with other aircraft operation management system currently in use by other organizations. It is anticipated to create a safer and more efficient operational environment for aircraft.

JAXA has worked hard to promote the use of products based on the D-NET data standard in an effort to increase the number of aircraft capable of sharing information via D-NET. In 2013, NAVICOM AVIATION CORPORATION began marketing their helicopter operation management system "Latitude Web Sentinel," newly adopted with D-NET data standards—and one-quarter the weight of existing D-NET devices. With this system, in addition to location data, simple operational data can be transmitted through this system via a numeric keypad to ground terminals, allowing the information to be shared.

*Display screen of the new system (image provided by the FDMA).*

*Courtesy visit by Toshio Oishi, FDMA Commissioner (right) to Naoki Okumura, JAXA President(left).*

## Testing a Next-Generation Landing Guidance System with ENRI at New Ishigaki Airport

From March 19 through March 30, 2014, JAXA and the Electronic Navigation Research Institute (ENRI) conducted an assessment test of the next-generation landing guidance system "GAST-D," for which international standards are being determined.

Currently, instrument landing systems (ILS) are used at many airports to enable aircraft to land safely even in low-visibility conditions due to bad weather. By transmitting GPS correction messages to supplement onboard satellite navigation, ground-based augmentation systems (GBAS) provide the same function as ILS with equivalent or higher precision. GBAS is also expected to allow for curved and flexible approaches that cannot be realized with ILS.

ENRI developed a prototype for a Category-III GBAS (GAST-D) ground facility capable of safely guiding an aircraft even in more severe weather conditions and installed it at New Ishigaki Airport. Flight experiments were performed by JAXA with the research aircraft "Hisho" to investigate the effects of ionospheric plasma bubbles* on satellite navigation, as well as by ENRI with the research aircraft "Yotsuba" to evaluate the performance of the installed GAST-D system.

*Plasma bubble: an ionospheric disturbance where the plasma density is depleted; occurs at low latitudes around the magnetic equator in the night in equinox seasons in the Asian sector. GPS signals that pass through plasma bubbles experience rapid fluctuations in amplitude and phase, which may result in malfunction of GPS-based navigation systems.

*"Hisho" (right) and "Yotsuba" (left) waiting for the start of a flight test at New Ishigaki Airport*

## Assessing the Turbulence Information System "ALWIN" at Narita Airport

During the period of March 3 to May 9, 2014, JAXA and the Japan Meteorological Agency (JMA) conducted an evaluation of the new turbulence information system ALWIN (Airport Low-level Windshear InformatioN) at Narita International Airport with the cooperation of airline companies JAL and ANA.

ALWIN is a system that uses airport weather Doppler lidar already installed by the JMA to implement part of the technology of the "Low-Level Turbulence Advisory System" (LOTAS)*1 that JAXA has been developing. In order to allow aircraft to safely land at an airport, ALWIN provides real-time information to onboard pilots and dispatchers at the airport on the status of winds (direction, speed, wind shear, turbulence, etc.) in the landing paths of their aircraft. For this evaluation, the prototype ALWIN system was used to provide information on winds around the airport and in landing paths to dispatchers via internet and to pilots via a text-based datalink system known as ACARS installed in the cockpits.

Moving forward, the utility of the system will be improved by reflecting evaluation comments collected through questionnaires and meetings with pilots and dispatchers who used ALWIN. In addition, flight data from the aircraft that actually landed will be used to assess the effectiveness of ALWIN by comparing that wind data recorded on the aircraft to the wind information provided by ALWIN.

*1 LOTAS: a system which uses weather observation sensors (radar/lidar) installed at an airport to detect the low-altitude turbulences regardless of weather and provide pilots and airport flight dispatchers with information on turbulences, current and ten minutes in the future.

*2 Airport weather Doppler lidar: a device that measures the wind at low altitudes under non-precipitation conditions by using laser beams to detect the movement of aerosols (fine particles) in the atmosphere; currently installed at Japanese major airports such as Narita International Airport.


*ALWIN wind information displayed on aircraft cockpit instruments (image provided by Japan Airlines Co., Ltd.)*

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## PIV measurement data aids device arrangement design
## Wind tunnel tests to develop optimization technology

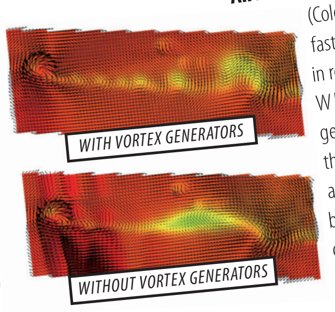
The arrangement of devices such as a vortex generator*1 on the wing of an aircraft usually requires repeated wind tunnel tests in the design stage to determine the optimal arrangement to yield the best aerodynamic characteristics.

By making use of high-density, precise measurement data obtained by particle image velocimetry (PIV)*2, JAXA has been able to conduct research and development on methods to determine arrangements that enable such devices to have good aerodynamic characteristics and to do so in a shorter period of time and with better reliability than ever before.

In PIV measurement tests conducted using the JAXA 2m × 2m transonic wind tunnel in June 2014, we observed clear differences in the airflows generated with and without vortex generators, as well as the airflow variations due to the arrangement of the generators. Using this data, we plan to proceed with R&D to derive a highly effective arrangement of these devices.

*1 A vortex generator is a projecting vane attached to the wing of an aircraft to cause a vortex in the airstream and to control the flow of the airfoil surface.

*2 PIV is a technique for measuring the velocity of fluid flow by seeding tracer particles into the flow and analyzing images of their motion as recorded with illumination from a light source such as a laser. (See page 15)




**Airflow velocity measurement results**
(Color coded in sequence from the fastest speed down to the slowest in red, yellow, and yellow-green.) When there are no vortex generators, the slow airflow area that can be seen colored in yellow and yellow-green (bottom image) becomes smaller when a vortex generator is used (top image).

## Noise measurements taken around Narita Airport

With the cooperation of Narita Airport and the surrounding communities, we measured aircraft noise there from 1 to 11 July 2014. Measurements were first taken in November 2013, then again in January 2014 and March 2014, and so this was the fourth time that measurements were performed. The resulting noise data obtained therefore reflected the weather conditions in each of the four seasons.

As air traffic is expected to increase in the future, noise mitigation is a critical factor that we should address. In order to limit the range of noise impact, irrespective of how much air traffic volume increases, JAXA has been researching low noise operation technology to predict how weather conditions affect the spread of noise – to optimize aircraft approach paths with the aim of containing ground level noise to current levels. This research is part of the Distributed and Revolutionarily Efficient Air-traffic Management System (DREAMS) project. JAXA will continue to use the measurement results taken to date to further its research utilizing noise prediction models that take into account the influence of weather conditions in the propagation of noise.


*Noise measurements being taken during landing*

## Second test of D-SEND#2 suspended

Due to bad weather conditions during the test period, the second test planned for the second phase of the Drop test for Simplified Evaluation of Non-symmetrically Distributed sonic boom project (D-SEND#2) at Sweden's Esrange Space Center has been suspended .

In the first test that was performed on August 16, 2013, after separating from the balloon, the test airplane deviated from the planned flight path at about 12 km short of the measurement point, making it not possible to measure the sonic boom with the flight conditions that had been assumed. JAXA has established an investigation/countermeasure team which has been working to clarify the cause and to study countermeasures.

Preparatory work for the second test began at the site in mid-June 2014. We had been waiting for favorable test conditions to come together since the beginning of the test period. Factors included the ground weather, surface winds, and the predicted trajectory of the stratospheric balloon. When conditions were finally ready on August 23 and 26, preparations began for performing the test but weather conditions worsened midway on each day so reluctantly a decision was made to abort the test.

In light of this current situation, JAXA is re-examining the test plan for D-SEND#2.


*Inspection of the test airplane*


*D-SEND#2 test rehearsal*