JAXA Aeronautics Magazine

FLIGHT PATH

Shaping Dreams for Future Skies

Aeronautical Technology Directorate

2016

No.13/14

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Feature Stories

For safe and comfortable air travel

Challenges of the SafeAvio project

Developing quiet aircraft technologies to reduce airport community noise

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Cover image: JAXA jet research aircraft (JetFTB) "Hisho" applied with noise reduction design for flaps and landing gear (marked in red). Photograph is taken from the ground during flight demonstration campaign in September 2016.

JAXA Explore to Realize

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Message from the Director General

Shaping dreams for future skies

Aircraft are a form of social infrastructure which is essential to our lives. The use of aircraft is expected to further increase in the future. Furthermore, the global aviation industry is expected to approximately double in size during the next 20 years. Amidst such conditions, the Ministry of Education, Culture, Sports, Science and Technology (MEXT) announced its "Strategic Vision for Researching and Developing Next-Generation Aircraft" in August 2014. This vision advocates strengthening the competitiveness of the Japanese aviation industry and technological innovation in air transportation systems. As a National Research and Development Agency which serves as the main implementer of scientific and technological innovation, JAXA has now taken on an even bigger role.

The JAXA Aeronautical Technology Directorate has been promoting the “R&D program with three pillars” respectively named as STAR (for safety technology), ECAT (for environment technology) and Sky Frontier (for frontier technology), while constantly continuing research into “fundamental technology” that underpins them. Under this R&D structure, JAXA has produced results which are highly-acclaimed both in Japan and overseas, e.g. technologies to enable the next-generation air traffic management system via the DREAMS project, sonic boom reduction technology for the future supersonic passenger aircraft through the D-SEND project. Following on the success of these projects, JAXA is working to steadily produce high-level results through various research efforts. Ongoing projects include aFJR, which demonstrates high-efficiency and lightweight fan turbine technology, FQUROH, which demonstrates technology for reducing airframe noise, and SafeAvio, which demonstrates an onboard safety avionics system for preventing turbulence-induced aircraft accidents.

The management policy of the Aeronautical Technology Directorate is based on "open innovation," "result-oriented research and technology incubation," and "designing R&D strategies for the next steps." In terms of open innovation, we would like to facilitate more flexible research structure for further enhancing the aeronautical engineering technology by incorporating knowledge from a variety of other technical fields. The launch of the Next Generation Aeronautical Innovation Hub Center in April 2015 is instrumental in enabling such open research structure.

As a national research and development agency, it is essential for JAXA Aeronautics to pursue both “result-oriented research" and "technology incubation" in parallel. While ensuring greater speed for bringing R&D results back to industry and society with “result-oriented research,” we embrace the challenge of lofty goals for fostering globally competitive technologies with world-class excellence through research for “technology incubation.” Thus, JAXA Aeronautics implements a balanced approach in managing R&D activities in various layers.

For "designing R&D strategies for the next steps," we will examine priority themes and scenarios for Japan to enhance its technological superiority on a global scale, while taking global trends into account in terms of technology, business and society. Collaboration with industry is particularly important. We would like to explore more opportunities to facilitate open innovation from a broader technical perspective with industry players.

Based on this management policy, we have also started reviewing a possible system to aggregate Japan's knowledge in aeronautical technology in fundamental research fields as well. On top of the current open application research system, we’ve introduced the “JAXA Aeronautics Innovation Challenge” to call for research proposals that incorporate innovative ideas and players from a wide range of fields to bring about innovation in air transportation and society. This is another example of open research system.

Moving forward, we will continue making further efforts in creating, maturing and transferring aeronautical technologies with R&D of global values.

"Shaping dreams for future skies"—By providing advanced aeronautical technology needed for future skies in a form which is beneficial to society, JAXA strives to support the global expansion of the Japanese aeronautical industry and to realize a safe, prosperous society.

We look forward to your continued support and cooperation.

Fumikazu Itoh
Vice President
Director General of the Aeronautical Technology Directorate
Japan Aerospace Exploration Agency (JAXA)

SafeAvio operation overview

Feature Story

For safe and comfortable air travel Challenges of the SafeAvio project

With the goal to reduce turbulence-induced in-flight accidents, JAXA is carrying out a project named SafeAvio (R&D of onboard safety avionics technology to prevent turbulence-induced aircraft accidents). This article introduces the current status and future prospects of the SafeAvio project through an interview to Shigeru Machida, SafeAvio Project Manager.

Measures against clear-air turbulence have long been awaited by all airline users, since this type of turbulence is invisible even by radar. JAXA's approach is to use its world-leading airborne Doppler LIDAR system for detection of clear-air turbulence. With the SafeAvio project, JAXA seeks to demonstrate a system which uses a compact lightweight Doppler LIDAR which is mounted in an actual aircraft in order to detect clear-air turbulence and issue warnings to pilots. The turbulence detection and information technology developed with the SafeAvio project will then be transferred to Japanese aviation equipment manufacturers. Thus, in addition to making air travel even safer and more comfortable, the SafeAvio project also aims to support the global expansion of Japanese aviation industry.

Shigeru Machida
Project Manager
Onboard Safety Avionics Technology Project Team

Using lasers to detect invisible turbulence

—— What is the goal of SafeAvio research?

The ultimate goal is to reduce aircraft accidents which are caused by clear-air turbulence. Clear-air turbulence occurs in airspace where there are no clouds. As clear-air turbulence cannot be detected by weather radar installed in passenger aircraft, aircraft enter airspace where clear-air turbulence exists without any forewarning. This may result in injuries to passengers or cabin crews due to violent shaking, and sometimes leads to serious accidents. Accidents caused by clear-air turbulence occur throughout the world. Such accidents occur once a twice a year in Japan as well, in particular, during winter when the jet stream flows directly above Japan. Our goal is to detect this clear-air turbulence and protect the safe operation of passenger aircraft.

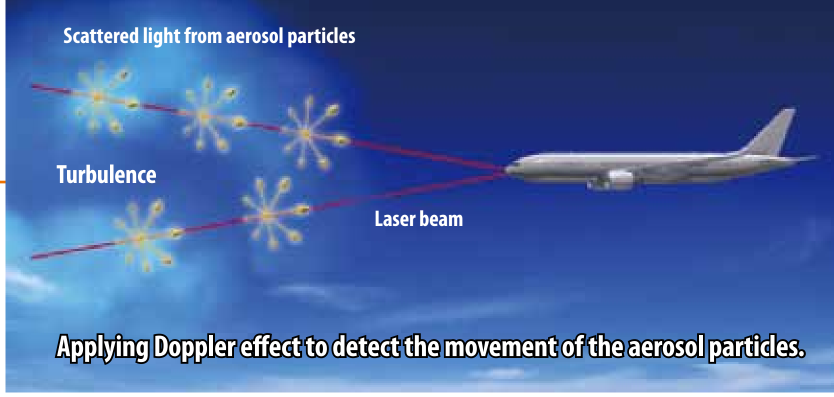
—— How is clear-air turbulence detected?

Clear-air turbulence cannot be detected by normal weather radar, so we use LIDAR, which is a sensor using lasers. The laser beams strike the miniscule amount of aerosol particles (fine particles suspended in the air) which exist in the air, and the reflected signal is detected. If turbulence exists, there will be disruption in the movement of aerosol particles. By analyzing various characteristics of the reflected signals, it is possible to determine the approximate distance of turbulence ahead of the aircraft. Since the movement of aerosol particles is detected using the Doppler effect, this equipment is called a Doppler LIDAR.

—— When did JAXA start research into onboard safety avionics using Doppler LIDAR ?

We started fundamental research in 1998. We continued development in stages, advancing from equipment which can detect turbulence 1 kilometer ahead to equipment which can detect 3 kilometers ahead. The model prior to the current model was actually installed in an aircraft in 2013. We demonstrated that the

Overview of
Doppler LIDAR
installed in aircraft



model can detect clear-air turbulence about 9 kilometers ahead at an altitude of 10 kilometers. The weight of the previous Doppler LIDAR was 150 kilograms. Currently, JAXA researchers are developing a Doppler LIDAR which can be installed in passenger aircraft and working to demonstrate performance through actual flight tests.

The basic technology has already been demonstrated. We are now working to reduce the weight in half while maintaining the same level of performance. While cooperating with manufacturers, we have taken measures such as reducing the number of chassis and reducing equipment size, and we are close to achieving weight goals. Furthermore, we now use a more powerful laser which realizes greater performance, and have also made cooling equipment compact.

Toward installation in passenger aircraft

—— Is similar research being conducted overseas?

Technology which uses lasers to measure particles is not new. It is already used in weather observation and processes such as monitoring flow in industrial processes. However, this conventional technology is only capable of observation at close distances, and the equipment is extremely heavy. It is only JAXA who carries out research into airborne system for aviation use.

—— Does this kind of research attract attention from overseas?

JAXA has conducted joint research with The Boeing Company from fiscal 2010 to 2016. We cooperated with researchers at Boeing to research methods and conditions for installation of Doppler LIDAR.

—— Do you feel expectations from airline companies? Are they welcoming JAXA's clear-air turbulence detection and information technologies?

When speaking with airline officials, it's clear how they view clear-air turbulence as an extremely important issue affecting safety. JAXA researchers also take this issue very seriously. In particular, pilots express their desire for information on clear-air turbulence ahead of the aircraft, no matter how soon before encountering turbulence that information is received. JAXA is highly motivated to provide solutions to these needs.

—— How much time do pilots have to react if clear-air turbulence is detected 9 kilometers ahead of the aircraft?

About 30 to 40 seconds. That's enough time to turn on the Fasten Seatbelt sign, instruct passengers to return to their seats, and have cabin crews stop service. According to a survey by a certain research organization, even in the case of large aircraft such as a jumbo jet, 1 minute is enough for about half of passengers who have left their seats to return to their seats. Therefore, one of JAXA's goals is to equip passenger aircraft with equipment that is capable of reliably detecting clear-air turbulence and providing information to pilots about 1 minute in advance.

—— How is the progress for demonstration testing?

We have already developed an onboard safety avionics system to be installed in aircraft, and are carrying out ground testing which is to be completed in October 2016. We plan to start flight tests in November.

Breakthrough for Japanese aviation industry

—— Accidents caused by clear-air turbulence are a major problem in protecting the safety of air travel. JAXA wants to contribute to society by solving this problem, right?

Exactly. Our role is not only delivering technological outputs, but extends to ensuring a path for manufacturers to make use of them for practical application for the wider use in society. In terms of TRL* (Technology Readiness Level), the goal for the SafeAvio project is TRL 6 which is just one step before commercialization by manufacturers. When commercializing avionics equipment, it is important to create corresponding standards and receive approval for those standards. Although that process is performed by manufacturers, JAXA has also started preparing a path for realizing these goals. As part of these efforts, we've been in touch with a standardizing body in the United States to obtain related information.

In addition to further advancing the results generated by fundamental research, it is important to hand over that technology to industry. We are conducting the SafeAvio project based on clear awareness for both of these aspects. Once the effectiveness of JAXA's turbulence detection and information technology is demonstrated through the

Aircraft accidents caused by clear-air turbulence

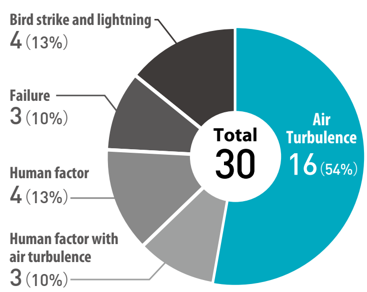
As implied by the name, "clear-air turbulence" refers to turbulence occurring in airspace without any clouds. Although passenger aircraft is equipped with weather radar, the radar cannot detect clear-air turbulence because there are no rainclouds or cumulonimbus clouds. As a result, aircraft encountering clear-air turbulence are suddenly subjected to violent shaking. In some cases, this causes serious harm to passengers or cabin attendants.

The majority of clear-air turbulence occurs in relation with the jet stream which circulates around the earth, causing problems for airline operators and users.

According to the "Aircraft Accident Investigation Report" published by the Japan Transport Safety Board, aircraft accidents caused by clear-air turbulence occur once or twice per year in Japan. In the case of an American Airlines flight in December 2014, a passenger in the restroom and a cabin crew member at the rear aisle of the plane suffered severe injuries when they struck the ceiling.

Moreover, minor injuries are believed to occur more often. If we can reduce in-flight accidents caused by clear-air turbulence, air travel will become even safer and more comfortable.

Aircraft accidents by cause
Large civil aircraft accidents in Japan (2005 to 2014)



54% of aircraft accidents in Japan are caused by turbulence. (based on an analysis of aircraft accident reports published by the Japan Transport Safety Board)

*TRL: Technology Readiness Level. A quantitative measurement scale for assessing the readiness of technology and comparing the readiness of different technologies. A higher level indicates that the technology is close to viable commercialization. In the case of aircraft, TRL6 represents confirmation of technological feasibility via prototypes, TRL7 is flight testing, TRL8 is certification testing, and TRL9 is practical implementation.

Model demonstrated capable of detecting turbulence approx. 9 km ahead of the aircraft. In order to realize installation on aircraft, it is necessary to significantly reduce the weight of 150 kg.

SafeAvio project, I'm sure that they will be used by airline companies and airframe manufacturers. Once technology is actually used in actual operational settings, it will blaze a new path for a variety of Japanese avionic equipment to be used by overseas airframe manufacturers. In this way, JAXA seeks to contribute to the growth of the Japanese aviation industry.

—— You are also working to assist the growth of Japanese equipment manufacturers.

Japanese avionics equipment is still minor in the global market, unfortunately. We hope that our onboard safety avionics system developed through the SafeAvio project will help break through this situation. That has been our intention ever since we started the project. We firmly believe that such a path will be blazed with the SafeAvio project.

—— Cooperation with industry and academia is very important, right?

For that reason, we have established a SafeAvio Research Committee prior to the launch of SafeAvio project. In addition to the University of Tokyo, Tohoku University, and JAXA, members include airframe manufacturers, equipment manufacturers, and the Society of Japanese Aerospace Companies (SJAC). Airline companies also participate in the committee as advisors. All committee members have been exchanging ideas on the optimal system from respective perspectives.

The next step after the SafeAvio project

—— The SafeAvio project is schedule to end in fiscal 2016. What will you do next?

As I said earlier, the ultimate goal of SafeAvio research is to realize significant reductions of in-flight accidents caused by clear-air turbulence. Therefore, in addition to the detection of clear-air turbulence, we want to develop a more integrated safety avionics system that suppresses shaking through automatic control of the flight control surfaces. Further refining existing laser technology would be another way forward.

—— Currently, it is possible to detect clear-air turbulence at a distance of about 9 kilometers ahead. Can this distance be extended even further?

Yes, I believe so. We should be able to extend the distance by heightening the performance of the laser and by improving the signal processing software.

—— How are you conducting research on gust alleviation technology that automatically controls the shaking of the airframe?

Numerous research and development elements are required in developing the gust alleviation technology. Currently, we are examining each element and trying to raise their maturity level under the framework of JAXA's Next Generation Aeronautical Innovation Hub Center. I envision specific steps as follows: First, prior to creating actual equipment, I plan to conduct research using computer simulation. Next, I want to conduct all possible tests using wind tunnels. After that, we will conduct low-speed testing using JAXA's turbo-prop research aircraft MuPAL-α. If this testing is successful, we will then conduct tests using jet aircraft. I believe that making collaborative efforts with the SafeAvio Research Committee members will help advance each of these steps steadily and more effectively.

—— Finally, would you please tell us your aspirations for the SafeAvio project?

The SafeAvio project was established by taking the perspective of manufacturers into account. The establishment of a project team has heightened the sense of solidarity within the team. At the same time, we feel the responsibility of having to respond to expectations. While maintaining an appropriate sense of urgency, JAXA will carry the project through to the point where commercialization by manufacturers is possible.

http://www.aero.jaxa.jp/eng/research/star/safeavio/

JAXA's challenge — Let's see how difficult it is to detect turbulence from the movement of particles 9 kilometers ahead of the plane

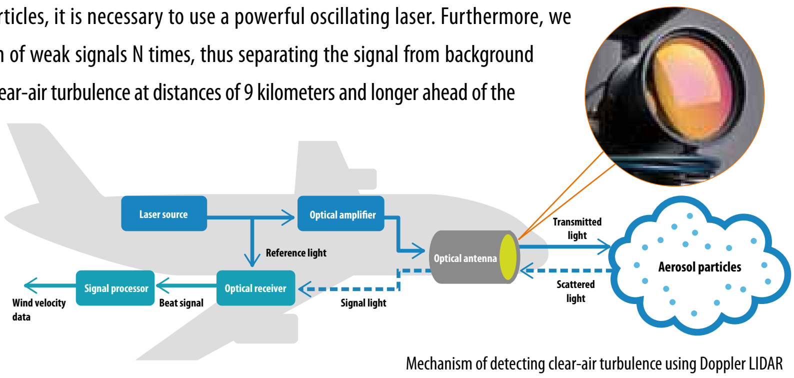
Since clear-air turbulence is not accompanied by clouds, it cannot be detected by radar. JAXA has conducted research on methods for detecting turbulence from the movement of particles (aerosol particles) floating in the atmosphere. However, the diameter of aerosol particles is from about 1 nm to 100 um. Furthermore, the concentration of particles is extremely diluted at the altitude of 10 kilometers, which is the cruising height of passenger aircraft. At most, there is only one aerosol particle per 1 cm3. How is it possible to detect the movement of such a small amount of extremely microscopic aerosol particles from such a long distance?

Equipment called Doppler LIDAR is used for detection. Aerosol particles are irradiated with a laser, and the laser which is reflected back is received by the LIDAR. By analyzing this "Doppler effect," it is possible to determine the movement of aerosol particles. Since aerosol particles move together with air currents, turbulence is judged to exist in areas where aerosol particles are moving violently.

In order to capture the signal reflected back from aerosol particles, it is necessary to use a powerful oscillating laser. Furthermore, we implemented measures to facilitate detection through integration of weak signals N times, thus separating the signal from background noise. As a result, during tests in 2013, we succeeded in detecting clear-air turbulence at distances of 9 kilometers and longer ahead of the aircraft at an altitude of 10 kilometers.

Currently, as part of the SafeAvio project, we are working to realize compact and lightweight Doppler LIDAR equipment which can be installed in aircraft while maintaining the current level of laser performance.

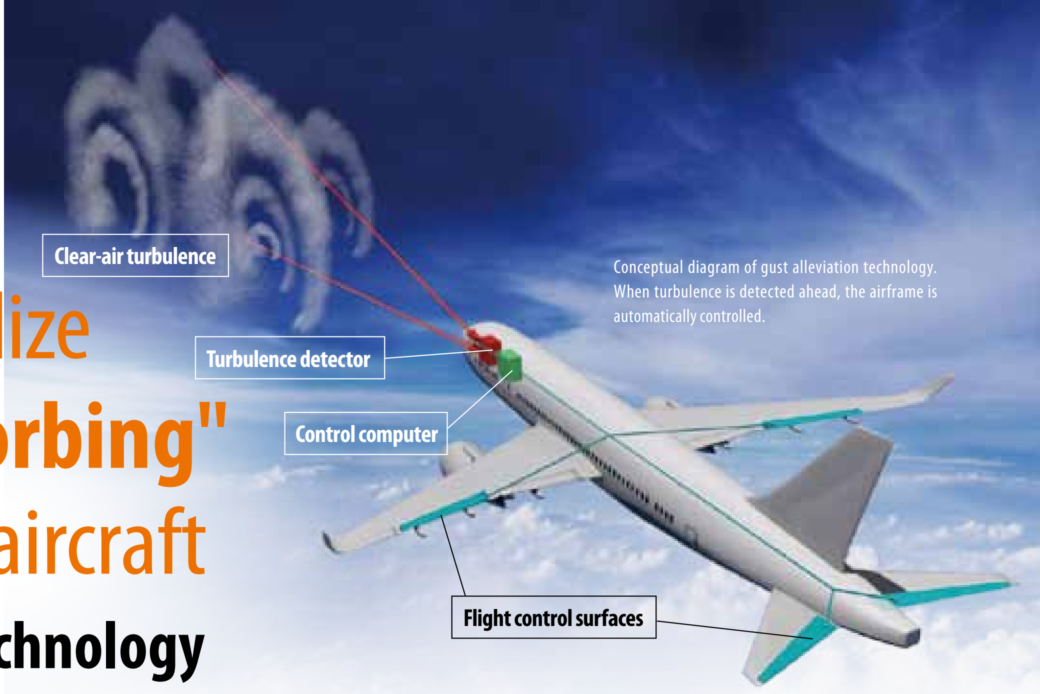
(For details on Doppler LIDAR, please refer to Flight Path No. 9/10.)



Mechanism of detecting clear-air turbulence using Doppler LIDAR

Seeking to realize "shake-absorbing" passenger aircraft

Gust alleviation technology



Conceptual diagram of gust alleviation technology. When turbulence is detected ahead, the airframe is automatically controlled.

Making use of the detected turbulence information for even safer operation is our next plan after the SafeAvio project. This article introduces an outline of the "gust alleviation technology" which automatically suppresses shaking of the airframe in response to the detected turbulence information.

Previewing turbulence and controlling the airframe

While the SafeAvio project addresses a system to detect clear-air turbulence ahead of the aircraft and to send a warning to the pilot, the gust alleviation technology focuses on the next phase: automatically suppressing the shaking of airframe upon the detection of clear-air turbulence — all without the intervention of the pilot.

What method can used to reduce shaking of the airframe caused by turbulence? "We currently envision an algorithm called preview control," explains Yoshiro Hamada, leader of the Gust Alleviation Technology Research. For example, if you see a curve ahead when driving an automobile, you steer your vehicle to turn appropriately according to the size of the curve. Similarly, when an aircraft with an integrated safety avionics system detects turbulence ahead, the aircraft can be steered so that airframe shaking is reduced, even if the turbulence cannot be completely avoided.

In the past, research on gust alleviation technology has been conducted in Europe and the United States. However, since a turbulence detection system like the one we are developing under the SafeAvio project had yet to be realized, the research did not lead to establishment of technology. JAXA is steadily advancing preview control technology which will absolutely be necessary once a turbulence detection system becomes possible.

From simulation to wind tunnel experiment

How does the gust alleviation system function? First, wind direction and wind speed are determined from information on clear-air turbulence detected ahead of the aircraft with an onboard Doppler LIDAR system developed by the SafeAvio project. Then, in order to minimize airframe shaking caused by that turbulence, the gust alleviation system applied with a preview control algorithm changes the attitude of aircraft by automatically adjusting propulsion and moving the controlling surfaces such as elevator. This is similar to noise cancelling technology which cancels external noise by generating vibrations in the opposite phase of that noise. In addition to sending the pilot a warning on clear-air turbulence which lies ahead, the capability to automatically control the airframe will reduce the burden on the pilot.

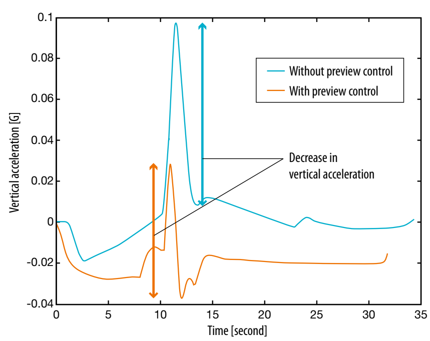
Although the concept of gust alleviation technology seems simple, practical implementation will take a long time. Currently, we are repeating computer simulations to confirm the effects of the algorithms in controlling the attitude. For the next stage, we plan to conduct experiments using a gust wind tunnel in fiscal 2017. We will expose a model aircraft positioned in the wind tunnel to gusts which resemble clear-air turbulence and then use a compact actuator installed in the model to confirm the effect of preview control.

Contributing to the Japanese aviation industry with world-first technology

After wind tunnel experiments, we plan to integrate both the turbulence detection and information technologies, developed under the SafeAvio project, and the gust alleviation technology into a combined system sometime in or after fiscal 2018. We will then conduct demonstration tests using JAXA research aircraft. These demonstration tests are a major hurdle to practical implementation. When entrusting a computer with control of passenger aircraft, there must be absolutely no possibility of an accident occurring. Therefore, demonstrations must be conducted with great care. Certification for installing the system in an actual aircraft will also require a long period of time. Ultimately, the practical implementation of gust alleviation technology may require 20 years or even longer.

Currently, no gust alleviation technology has been established even overseas. It is JAXA's mission to establish such technology ahead of the rest of the world, thereby contributing to the Japanese aviation industry. With this mission in mind, we will continue our research in the future.

Verification/demonstration results for preview control technology



By performing preview control during an experiment in which artificial disturbances are exerted on aircraft, decreased acceleration in the upward and downward directions was observed.

Feature Story

Developing quiet aircraft technologies to reduce airport community noise

FQUROH

Flight Demonstration of **Qu**iet Technology to **R**educe N**o**ise from **H**igh-lift Configurations
(Japanese word for an owl, a silently-flying bird)

Ready for flight demonstration

Ever since the introduction of jet airliners, airport noise reduction has been a major environmental issue for airport communities in the world. While improvements have been made for jet engine noise, there will be strong demand in the future for reduction of "airframe noise" which is generated from airframe components such as flaps and landing gear during approach.

The FQUROH project launched by JAXA aims to demonstrate noise reduction technologies for the airframe noise through flight tests. This article features an interview with Kazuomi Yamamoto, Project Manager of the FQUROH project, on the objective and progress to date just before the first flight demonstration test scheduled in September 2016 using JAXA's jet research aircraft "Hisho." A separate column also shows a preliminary report on the flight demonstration.

Kazuomi Yamamoto
Project Manager, FQUROH Project Team

Airframe noise reduction is a major challenge for the future of air transport

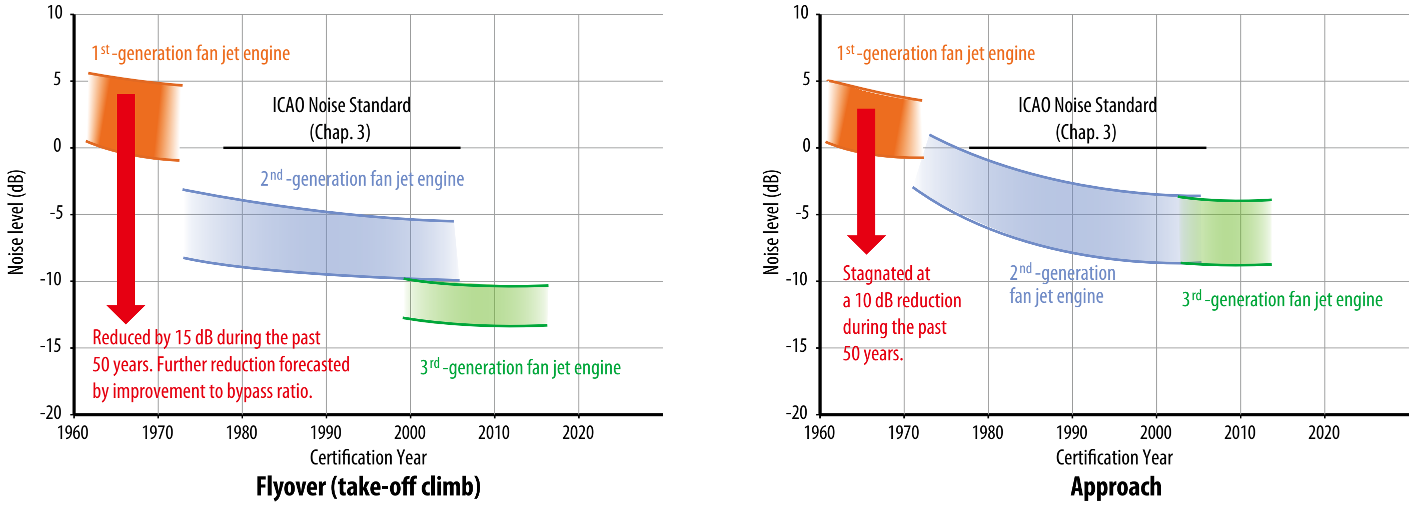
—— Could you start by introducing the objective of FQUROH?

In order to reduce aircraft noise for airport communities, JAXA has been conducting research on the reduction of "airframe noise," which is mainly emitted from high-lift devices (flaps and slats) installed on the main wings and from the landing gear. Through flight demonstrations implementing the airframe noise reduction technologies developed in the research, the FQUROH project aims to mature the technologies to be applicable in future aircraft development. We also intend to contribute to raising the level of noise reduction technologies of Japanese aircraft industries through this project. Now we are just before the first flight demonstration of the project, and focusing all our efforts on the final preparation.

—— Could you explain the background for increasing demand for reducing airframe noise?

The passenger-kilometers of air travel will continue to grow in the future. An increase of 2.6 times the current amount is forecasted during the next 20 years. This trend will be particularly remarkable at airports of major cities where population is concentrated, e.g. airports in the Tokyo metropolitan area (Narita and Haneda) in case of Japan. These airports therefore intend to expand their capacity by handling increasing numbers of take-offs and landings. One bottleneck here is increasing

Change in aircraft noise level relative to ICAO Chapter 3 standards



Noise level during the take-off climb has been reduced by approximately 15 dB over the past 50 years (left) for which engine noise reduction was a major contributor. Engine noise is expected to be even lower with improvements in the bypass ratio. On the other hand, the noise level during approach has stagnated at a decrease of about 10 dB for the same period (right). During approach, engine noise is relatively low, particularly for the latest passenger aircraft, so airframe noise becomes prominent. The noise standard determined by ICAO (International Civil Aviation Organization) as a measure for commercial aircraft noise is stringent step-by-step as the new standards of Chapter 14 to be employed from 2017. For further stringent noise standards in the future, it cannot be accomplished without reduction of airframe noise.

aircraft noise which affects local communities due to the increase in take-offs and landings. Accordingly, there has been demand for reducing the aircraft noise level. Some airports restrict nighttime operation due to noise, and other airports independently enforce stricter noise regulations. Furthermore, the landing fee charged to each airline is determined based on the noise level.

Today, the noise level of aircraft is significantly lower compared to the 1960s when jet passenger aircraft began to operate in the world. The improvement of jet engines is a major contributor to this reduction. However, in order to realize further reductions in aircraft noise, it is now necessary to reduce airframe noise that exceeds engine noise during the approach phase.

Aircraft noise during the take-off climb has been successfully improved over the past 50 years, since measures to reduce engine noise have been highly effective, realizing a decrease of about 15 dB. Engine noise will be lowered further with the development of even quieter engines in future generations. On the other hand, although noise during the landing approach was reduced by about 10 dB by the 1990s, it has remained at essentially the same level ever since. One of the major causes is the airframe noise. It is because aircraft approaching airports reduces power of jet engines and emits relatively lower engine noise. Instead, airframe components such as landing gear become major noise sources.

—— In the first place, how is airframe noise generated?

Airframe noise is "aerodynamic noise" caused by turbulent air flow (a mass of many vortexes) around the airframe components. During approach, the slats attached to the leading edge of the main wings move forward. A large number of air vortexes is generated in the resulting space between the slats and the main wings. Vortexes are also generated at the side edges of flaps which extend from the trailing edge of main wings. The complex shape of the landing gear also generates vortexes. The vortexes around each component are generated by different physical mechanisms, so it is necessary to devise a different noise reduction approach for each one.

JAXA's technology to realize quieter aircraft

—— When did JAXA start research on airframe noise reduction?

It was from around 2004 when there was increasing momentum in Japan to develop a Japanese passenger

Column

Efforts to make airports quieter

Balanced and customized initiatives according to regional circumstances

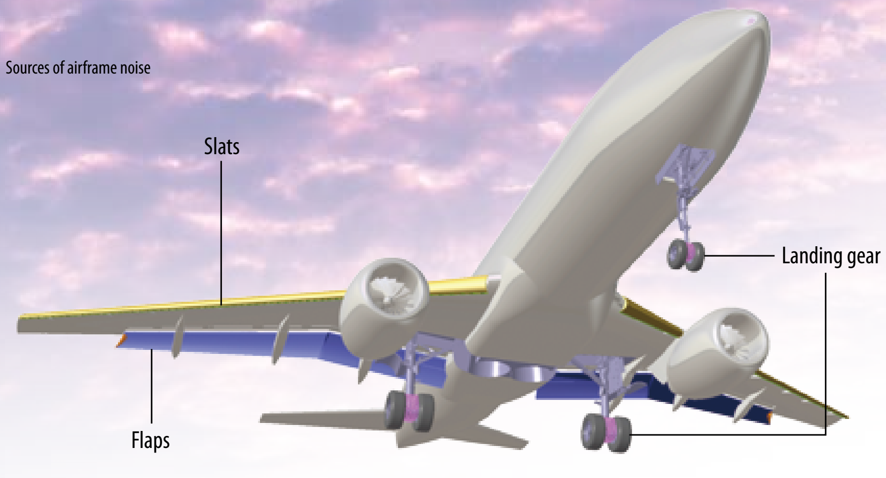
ICAO recommends the adoption of its Balanced Approach to Aircraft Noise Management. This approach includes four measures: 1) Reduction of Noise at Source, 2) Land-use Planning and Management, 3) Noise Abatement Operational Procedures, and 4) Operating Restrictions. These measures are implemented by combining them in a balanced way according to the circumstances of each airport.

Japanese efforts to manage aircraft noise also conform to this concept. An environmental standard for noise management was regulated in the Aircraft Noise Prevention Law, which was enacted in 1967. For areas exceeding this standard, such countermeasures as follows are taken accordingly: establishment of green buffer zones in Class 3 zone (adjoining airports); compensation for relocation and re-development into parking areas, warehouses, or retail facilities in Class 2 zone (around Class 3 zone); and soundproofing work and air conditioner installation at private houses in Class 1 zone (around Class 2 zone). Each airport has different characteristics and nearby areas, so they implement detailed initiatives in line with these factors. Airport landing fees also include an additional amount based on aircraft noise level, which is determined by the national government.

Some overseas airports have set unique noise standards based on their regional circumstances, and many have set landing fees according to aircraft noise level. One example would be London's Heathrow Airport known for its robust noise management efforts. Working together with the community and airlines, Heathrow takes a step-by-step approach to making airport quieter every year. Their efforts include introduction of lower landing fee for quieter aircraft, quarterly publication of ranking of airlines according to their noise performance, both encouraging airlines to adopt quieter aircraft and to fly them in the quietest possible way. Also, to mitigate noise during approach, Heathrow recommends the "continuous descent approach" to alter the conventional "phased approach" which causes noise as it comes down in steps with periods of level flight in between. Introduction of lower landing fees for the quietest type of aircraft, known as "Chapter 14 aircraft," is also underway to make Heathrow the first airport in the world to reflect the ICAO new noise standards to be employed in 2017.

Cover image of "Heathrow's Blueprint for noise reduction" (August 2016)

Sources of airframe noise



aircraft for the first time in 50 years.

Although pioneering research in airframe noise already began in the 1970s in the United States and Europe, the research has actually become active since the late 1990s. It was when modern jet engines had become quieter and the problem of airframe noise had become obvious. Then, around 2000, technology was established for localizing the noise sources of aircraft. This made it possible to pinpoint where noise is emitted from airframes. Around 2004, demonstration flight tests for noise reduction technology were performed by modifying the landing gear of actual passenger aircraft in the US and Europe.

In comparison, JAXA was a late-comer to this field of research. However, even from the start, we actively conducted numerical simulations for airframe noise. The simulation method is based on the Computational Fluid Dynamics which JAXA has studied for a long time as a fundamental technology. It provides us with the detailed airflow at locations where noise is emitted and helps us to better understand noise generation physics. In parallel, we continued to develop wind tunnel testing technology for investigating airframe noise and measurement technology to localize noise sources of flying aircraft. Based on these fundamental technologies, we came to a research step to investigate effective noise reduction methods and verify noise reduction designs in wind tunnel tests.

—— Then, you launched the FQUROH project, didn't you?

That's right. Applying the research outcome to actual aircraft and demonstrating its feasibility in flight tests are important activities to step up the technology to be transferred to actual aircraft development. Accordingly, we started FQUROH in January 2015.

In the first phase of the FQUROH project, we plan two flight demonstration campaigns using Hisho, which is JAXA's research aircraft based on a business jet. The final goal of this project is to demonstrate noise reduction for passenger aircraft. Therefore, after demonstrations with Hisho, as the second phase, we plan a flight demonstration campaign using the MRJ, which is a regional jet currently being developed in Japan.

—— The upcoming flight test will be the first flight demonstration using Hisho in the FQUROH project, right?

Yes. A major objective of the upcoming (September 2016) demonstration is to establish processes for demonstration flight testing as well as verification of preliminary noise reduction design, including modifications to flaps and landing gear and the acquisition of flight permission.

—— What kind of airframe noise reduction technology is being applied to Hisho?

First, in the case of flaps, we found from our previous research that creating a small bulge on the edge of the flap's lower surface is effective at reducing noise. We then decided on a shape by using numerical simulation to test various shapes. After having verified the noise reduction effect of computed design through the wind tunnel experiments, a newly designed attachment for flaps was installed on Hisho. As for landing gear, we applied a concept to cover the noise source, which exists between two wheels, with a porous plate. The cover is attached by a support clamped on the landing gear. Because landing gear is exposed to a great load at the landing, we wanted to avoid making a major change to the original structure such as opening screw holes. We are also working on a noise reduction method for slats as well. But, unfortunately, Hisho has no slats, so we will have to wait until the second phase of flight demonstration using a passenger aircraft.

"Tunnel-in-the-Sky" display and navigation system used for flyover noise measurements

—— How will airframe noise be measured during flight tests at Noto Satoyama Airport?

We use 195 microphones which are radially laid out in a star shape on a 35-meter square flat wooden platform built beside the runway of Noto Satoyama Airport. By making Hisho fly over the platform at a low altitude, noise emitted from flying Hisho is simultaneously measured by all of the microphones. The location of noise sources for each frequency and the noise level are calculated by using the time delay of sound reaching each microphone. Then, by comparing noise data for Hisho before and after modifications intended to reduce airframe noise, we can ascertain the reduction of noise emitted from specific locations. It will be necessary to measure the same flight conditions many times to average data, because variations in measurement will occur due to weather conditions such as wind and temperature, as well as due to the flight path and attitude of the aircraft.

—— In order to measure data many times, it will be necessary to fly Hisho using the same flight conditions. Will any special techniques be used to fly Hisho using the same flight conditions?

In order to reduce the engine noise of Hisho during measurement, we ask pilots to fly with reduced engine thrust for one second each before and after passing over the measurement point (two seconds in total), which is extremely difficult to match the timing. Furthermore, the level of airframe noise changes by the flight speed to the power of six. Therefore, we have to fly Hisho at the same flight speed as much as possible. To meet these challenges, we use a display and navigation system named "Tunnel-in-the-Sky (TIS)," a unique technology developed by JAXA. By following the specified flight path shown on a small display in the cockpit, the pilot can fly along the designated flight path with precision.

World's first flight demonstration for flap noise reduction

—— Have similar flight demonstrations already been performed in other countries?

As I mentioned earlier, pioneering demonstration flights were held in the United States and Europe around 2004. However, there has never been a flight demonstration on noise reduction design applied to flaps similar to the FQUROH project. I have heard that the National Aeronautics and Space Administration (NASA) plans to conduct a flight demonstration in the near future using a larger business jet. However, JAXA has a chance to take a lead in flight demonstration of airframe noise reduction technology for flaps.

—— Why could JAXA lead the flight demonstration?

Some of the research institutions in other countries have top-level research capabilities in one of the fundamental technologies required for flight demonstrations which are

Flaps and landing gear of "Hisho" after modification for noise reduction. Modified locations are shown in red.

"Hisho" flies over the phased microphone array (see page 6) for measuring noise sources.

numerical simulations using large-scale computers, noise measurements in wind tunnel tests and noise source localization techniques in flyover tests. On the other hand, although JAXA may be behind in each technology, our advantage lies in the well-balanced approach in our research activities to develop all of the technologies to be in high-level.

—— What is the worth of using actual aircraft to investigate results which were obtained in numerical simulation and wind tunnel tests?

For example, in the case of flaps, wind tunnel tests are conducted using a model which is 18% of the actual size. However, the air vortexes which cause noise differ for the actual size. Through detailed investigations using numerical simulation, we have confirmed that results will be close to what we expect. Nevertheless, the truth can only be verified by flying an aircraft of actual scale. Furthermore, there are many cases in which ideas that can be realized easily in wind tunnel tests are difficult to realize with actual aircraft. This difference is due to drive mechanism restrictions and safety requirements. Practical application only becomes a real possibility after such issues are cleared.

Quieter aircraft applying FQUROH technology

—— How will results from the upcoming flight demonstration test be used in the second flight demonstration using Hisho?

The upcoming flight test will provide us with information on the extent of the difference between design and actual data. In other words, we will be able to confirm whether the approach we've been taking are correct or not. The improved noise reduction designs that will be applied to Hisho for the second flight demonstration in 2017 have already been almost determined. However, if necessary, we will improve them further after the flight test in this September.

—— And tests using the MRJ will be the next and final phase of the FQUROH project?

Our goal is to advance developed airframe noise reduction technologies to a mature level where it can be applicable to development of passenger aircraft. Therefore, tests using actual passenger aircraft are extremely important for all aspects of the technology, including slats.

FQUROH project is being conducted in a joint research framework with Japanese aircraft and landing gear manufacturers who have needs for airframe noise reduction technologies — Mitsubishi Aircraft Corporation, Aerospace Company of Kawasaki Heavy Industries, Ltd., and Sumitomo Precision Products Co., Ltd.

We hope to achieve the goals of FQUROH by 2020 and then to pass on the technology to these manufacturers. FQUROH technology is essential for building quiet airframes for the next generation of passenger aircraft. I hope that this will also lead to facilitating their development of fundamental technologies for manufacturing such as numerical simulations and measurement techniques not just for noise reduction, then lead to Japanese industries acquiring more international competitive capabilities.

—— Finally, could you tell us your aspiration toward FQUROH project please?

I am hoping that it will be successfully proved that our ideas can be applied to actual aircraft with Hisho and then MRJ, and finally to see that technology developed in FQUROH project will be applied in future quiet aircraft in the world.

http://www.aero.jaxa.jp/eng/research/ecat/fquroh/

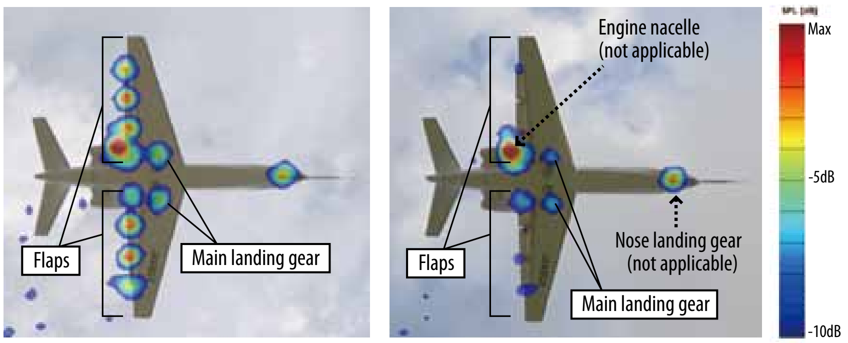
First flight demonstration successfully completed

From September 12 to 30, 2016, the flight demonstration test on airframe noise reduction designs was held at Noto Satoyama Airport using the JAXA jet research aircraft (JetFTB) "Hisho." The purposes of the test are to establish all necessary processes required for flight demonstration, such as aircraft modification and obtaining permission for flight tests, as well as evaluation of preliminary noise reduction designs.

A total of 177 flyover noise source measurements were performed during the test period. Preliminary results showed the noise reduction effect as seen in the figure, confirming the effectiveness of the design for the flaps and main landing gear. In particular, noise from the flaps were successfully lowered as intended at the design phase. It was a world-leading demonstration for noise reduction in high-lift devices such as flaps.

The flight demonstration test was performed with participation by more than 25 people from JAXA (FQUROH project team and Flight Research Unit), industry partners and staff for noise measurement and operation/maintenance of aircraft. It was conducted under support from the Noto Satoyama Airport, the Japan Aviation Academy, the Chubu International Airport Office of the Osaka Regional Civil Aviation Bureau, the Tokyo Aviation Weather Service Center, and Wajima City.

Comparison of noise sources at 1kHz band (preliminary results)



Without noise reduction design (baseline aircraft)

With noise reduction design applied to the flaps and main landing gear (modified aircraft)

Feature Story | Related Technology

Noise measurement technology essential for research on noise reduction

Technology for measuring noise is essential for the FQUROH project and other research aimed at reducing noise. This article explains the noise measurement technology which JAXA has developed over many years.

Microphone (top) and microphone phased array used in noise measurement

Takehisa Takaishi
Function Manager,
FQUROH Project Team

The difficulty of measuring aircraft noise

The issue of noise has attracted wide attention ever since jet airliners began service. There is increasing need for technology which can resolve the issue of noise. Until now, countless researchers and designers have worked to reduce noise emitted from engines and airframes. One example of such efforts is the FQUROH project which is currently being implemented by JAXA. Technology for measuring aircraft noise is essential for research on noise-reduction technology.

There are no global standards for noise measurement. Instead, the optimal method is used depending on the target and objective of measurement. Noise measurement in the FQUROH project incorporates knowledge which has been acquired by JAXA based on measurement methods used in similar noise-measurement tests performed overseas. "Some aspects of noise measurement in the FQUROH project are being conducted as an extension of research," explains Takehisa Takaishi who manages the noise measurement system for the FQUROH Project Team .

Measurement technology in FQUROH

JAXA has conducted research related to noise measurement technology for many years. Measurement methods and analysis technology have been improved by initially performing tests using model aircraft and then moving to measurement using actual small business jets. For example, the size of the platform for mounting the microphones and the selection, positioning and usage method of the microphones are JAXA technologies that were created from knowledge obtained from past tests and reviews.

A series of noise source localization tests were carried out by varying the number and layout of microphones in 2010 and 2011 in Taiki Town, Hokkaido Prefecture. After having gone through various options using a trial-and-error approach, the optimal settings for the noise measurement system in the FQUROH project has been determined via the noise source localization tests in 2013 at Noto Airport with the JAXA jet research aircraft "Hisho".

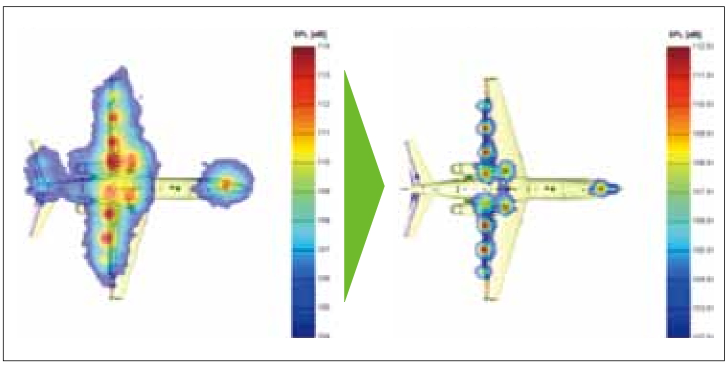
In 2015, flyover tests for noise source localization were performed at Noto Airport to obtain baseline acoustic data from Hisho without applying any airframe noise-reduction devices. This baseline data will be used to confirm the effect of airframe noise-reduction devices developed under the FQUROH project.

The current noise measurement system uses 195 microphones arranged in a radial pattern (phased array of microphones) installed on a square platform (35 meters per side) temporarily installed on the side of the runway. Optical fibers are used to connect each microphone with a measurement site located 200 meters away. Each time after Hisho has flown over the microphone phased array, within a short period of 5- to 6- minutes, high-speed processing is performed for broadband signals and the measured acoustic data is used to output quick analysis results for determining the subsequent flight conditions. There were lots of constraints to be tackled when installing such a large-scaled noise measurement system, including a phased array microphone system with a diameter of 30 meters, on the premises of an airport operating regular flights. This system represents unique technology established by JAXA.

Optimized configuration

Increasing the number of microphones makes it possible to collect more data. However, it also increases the time spent for daily deployment of microphones and analysis processing. The current configuration of 195 microphones has been optimally balanced for the FQUROH project. The method used to position the microphones has also been optimized to enable accurate positioning in a short time while also maintaining the accuracy of analysis. "In the future, if we are able to obtain cooperation from airlines and install microphones at airports such as Haneda or Narita, it may be possible to collect even more sample data," explains Takaishi. "This data will be useful for implementing noise-reduction measures at airports." When installing microphones at airports, the position of microphones and other configuration aspects will be optimized depending on the installation location/conditions and the size of the aircraft being measured.

In addition to the measurement side of technology such as the microphone installation method, the analysis methods are also an important key for improving noise measurement using a microphone phased array. Provisional analysis immediately after measurement can be performed quickly by using the Fixed-Array method which analyzes data from several microphones selected depending on frequencies. However, the Fixed-Array method has the disadvantage of significant fluctuation in resolution and signal-to-noise (S/N) ratio depending on the microphones selected for use. Therefore, detailed analysis after flight tests is performed using the Active-Sub-Array method, which weights each frequency and uses data measured by all microphones. The advantage of the Active-Sub-Array method is to be able to acquire continuous data with the same resolution and S/N ratio for wide frequencies , although it requires a substantial amount of time for analysis. Also, in order to eliminate noise caused by natural wind, supplemental corrections to the Active-Sub-Array method were made based on accumulated noise measurement/analysis techniques developed by JAXA. The combination of the Active-Sub-Array method and customized corrections makes it possible to identify noise sources with greater accuracy when compared to conventional methods. This has enabled evaluation of noise-reduction effects as required for the FQUROH project.



Analysis results using conventional technology (left) and analysis results using methods improved upon by JAXA (right)

"Continued involvement in control technology made it possible for me to participate in a variety of research"

Yoshiro Hamada
Aviation Safety Technology Research Team
Next-Generation Aeronautical Innovation Hub Center

Born in 1972. Graduated from the Department of Mathematical Engineering and Information Physics, School of Engineering at The University of Tokyo in March 1994. In March 1996, earned his Master's degree in Mathematical Engineering and Information Physics, School of Engineering at The University of Tokyo. Afterwards, entered the Doctoral Program and then left the program in March 1998. In April 1998, joined the National Aerospace Laboratory of Japan (currently JAXA). From March 2006 to March 2007, studied at Cambridge University in the UK as a Visiting Scholar. Assumed his current position in April 2015.

Yoshiro Hamada, who now leads research for gust alleviation technology at JAXA Aeronautics, has been involved in a variety of research relating to control. He speaks about his experiences and challenges to date.

—— Would you please explain your current research?

I conduct research on gust alleviation technology, which uses control algorithms to suppress shaking by automatically controlling the attitude of aircraft when encountering turbulence (refer to p. 6 for further details). Specifically, I am in charge of coordinating overall research and overseeing the control component. Although the concept of applying control algorithms for gust alleviation has existed since long ago, no one in the world has ever developed technology for detecting turbulence ahead of aircraft. Accordingly, I believe that our research is the first of its type in the world. However, even though the idea has existed for quite some time now, there are still many issues which must be overcome for practical implementation. For example, is it truly possible to perform control to suppress shaking? Also, what will happen if turbulence is mistakenly detected? These are just some of the issues which we are working to solve.

—— What kind of research have you been involved in in the past?

When I first joined the National Aerospace Laboratory of Japan (NAL) in 1998, I conducted research related to KAGUYA (SELENE). At that time, KAGUYA was in the initial review stage, and NAL conducted joint research with the Institute of Space and Astronautical Science (ISAS) and the National Space Development Agency of Japan (NASDA). NAL employees were in charge of the landing module, and I myself was involved in developing the control algorithm to make it land on the moon. Although the KAGUYA mission itself at that time was changed and the idea for landing on the moon was scrapped, it was my first research as a NAL researcher. I was also involved in Phase 1 of the High Speed Flight Demonstration project, which were a series of flight experiments conducted for the re-usable space vehicle planned at the time as well. After the three institutions merged to form JAXA in 2003, I participated in a team conducting attitude control demonstrations as late-stage utilization experiments of KIKU No. 8 (ETS-VIII). Afterwards, I conducted experiments for Small Scale Research Vehicles (SSRV), which are compact, unmanned aerial vehicles.

Looking back, I have been involved in a variety of research. However, generally speaking, I have always conducted research in control theory.

—— Why did you decide to major in control at university? Also, what led you to join NAL?

In addition to aerospace and aviation, control is also used in automobiles, chemical plants and other industrial fields. I decided to major in control theory because I felt the discipline would enable me to find employment in a variety of industries. Indeed, my classmates from university are now employed in a variety of industries, so it seems that I was not entirely mistaken.

When I was a graduate student, I went to some academic conferences and met several NAL researchers involved in control. I learned that they were conducting experiments on control. I developed an interest in the aerospace and aviation industry as a place to apply what I learned in control theory, and this led me to join NAL.

—— What research or experiment has had the greatest impression on you?

I don't think that there are many researchers who have had experiences in a variety of fields like me. For example, I have been involved in control for small unmanned aircraft, for 4-ton communication satellites in geosynchronous orbit, and now for passenger aircraft. Among this varied research, I still remember control experiments for the large satellite KIKU No. 8. Other than experiments, it was an interesting experience to travel to Christmas Island for Phase I of the High Speed Flight Demonstration project.

—— What do you find fulfilling about your current research?

Our research team has a big goal and my own role is clearly defined. Furthermore, the research matches the skills that I possess. Therefore, I am able to conduct research enjoyably and without stress. If any of these aspects were absent, I would most likely find the research very taxing.

Up until now, I have been involved in a variety of research. The passenger aircraft control which I am currently researching is basically the last field that I have yet to experience. That's why I am committed to carrying my current work through to completion. However, when conducting control for aircraft which are flown by human pilots and carry passengers, my research is directly connected to human life. This creates greater responsibility. No matter what may occur, accidents are completely unacceptable. For this reason, research will be conducted over a long span that will probably continue until my retirement. In the future, I hope to be able to think "I accomplished this" when riding on an aircraft for which shaking is suppressed by gust alleviation technology.

"Improving safety with research into human factors in aviation"

Hiroka Tsuda

Human Factors Section
Flight Research Unit

Upon completion of her studies at the Graduate School of Information Systems, The University of Electro-Communications, she joined JAXA in 2004. Engaged in researches for preventing human errors in aviation, technology to improvement of flight crew's situational awareness, as well as various tests and experiments utilizing flight simulators and research aircraft.

Hiroka Tsuda enthusiastically pursues research on human factors in aviation while involved in various flight tests and experiments, including the FQUROH (Flight Demonstration of Quiet Technology to Reduce Noise from High-lift Configurations) project. In this article, she introduces what inspired her to become involved in aviation and the fulfillment she gains from her research activities.

—— Could you tell us about your current research?

I'm involved in the FQUROH project that uses the JAXA jet research aircraft "Hisho" to perform flyover tests for noise source measurements. In particular, I am in charge of control of the cockpit display and navigation system "Tunnel-in-the-Sky," which guides pilots to fly precisely over a microphone installed on the ground. My role includes in-flight tasks such as providing instruction to cockpit crews and handling air-to-ground communication. Prior to actual flight, I hold a series of orientation trainings for pilots using the JAXA flight simulator on the ground.

—— What is your primary research field?

My main research theme is human factors in aviation. There are two main areas of human factors research: Crew Resource Management (CRM) and pilot interface.

CRM is defined as a management system which effectively utilizes all available resources including hardware, information and human beings to prevent accidents. By practicing CRM, flight crews build a team in which each crew member takes responsibility for safe operation together, instead of simply forming good working relationships. The crew's ability of practicing CRM is called CRM Skills. JAXA has conducted a research about effective training for CRM Skills and methods of measuring the level of crew's CRM Skills with support from airlines and pilot schools.

Pilot interface, on the other hand, addresses display technology which supports and improves the situational awareness and maneuvering of pilots. The Tunnel-in-the-Sky display used in the FQUROH project is one such example. My research aims to provide the pilot with situational awareness equivalent to that of daytime flight conditions even at night or in poor visibility conditions. This situational awareness is achieved by providing pilots with images taken using equipment such as an infrared camera.

Both CRM and pilot interface contribute to safe operation of aircraft, although they approach the issue from different perspectives.

—— What led you to start researching human factors?

Initially, I started simply because I found the field interesting. When I was a university student, I researched control systems for robots and had been interested in the use of robots in outer space. One day, I toured the National Aerospace Laboratory of Japan (NAL; predecessor of JAXA) as part of my job hunting, and it was then that I first encountered research in aviation human factors. Actually, the researcher who guided me on the tour is my current supervisor!

—— During your research career thus far, what has left you with the deepest impression?

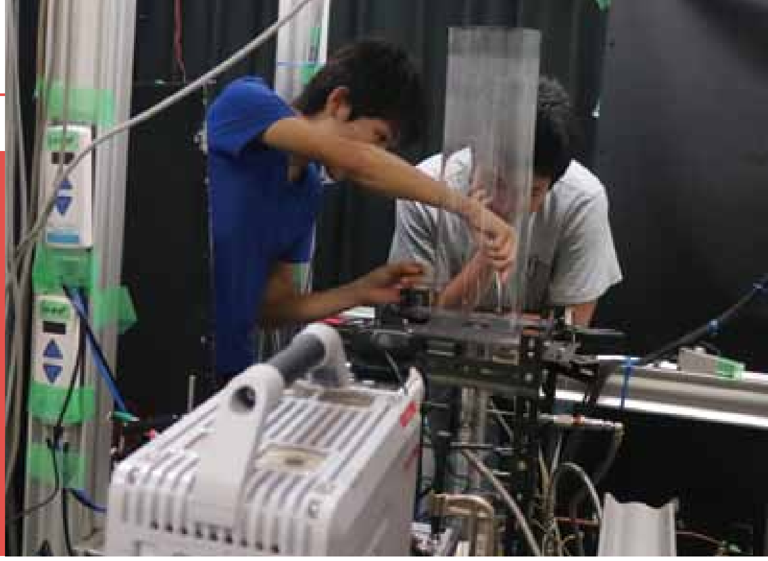
I never imagined that I would be on-board airplanes and helicopters so often. Each flight has left me with a lasting impression, and each is memorable in its own way. During the FQUROH project, I was so proud to see "Hisho" fly over the microphones along the designated flight path with precision repetitively using the Tunnel-in-the-Sky display system to which I made adjustments. Also, I will never forget my involvement in joint research for the MRJ cockpit. The experience taught me the difficulty of evaluating "safety." The flight test in Alaska in 2006, carried out as part of the DREAMS project, was also impressive, especially in that it changed my awareness and perception towards safety. In the severe natural environment of Alaska, small aircraft are used as an alternative to automobiles, and flights are operated incessantly. In such conditions, passengers also help monitor outside of the aircraft, and do not forcibly request flights. In Japan, passengers are treated with great care as customers; however, my experience in Alaska taught me that passengers also have an inherent responsibility for safety. During tightly-scheduled flyover tests for the FQUROH project, I sometimes want to operate flights and collect data under during somewhat bad weather. At such times, I remember the lesson which I learned in Alaska.

—— What aspects of your work do you find fulfilling?

It's very fulfilling to work on issues which are directly linked to actual operation of airplanes and helicopters. At the same time, I am aware of the great responsibility of my work. I would be more than happy if the results of my research on human factors contribute to improved safety of aircraft in the future.

Combustion instability

Combustion instability is one of the critical issues in the lean burn combustor technology which addresses strict gas emissions regulations. JAXA is conducting research and development to suppress the occurrence of combustion instability in lean burn combustors.



Students from universities cooperating with JAXA participate in combustion instability experiments. Photograph showing preparations to conduct experiments.

Combustor technologies which meet future gas emissions regulations

The aviation industry is working to address a variety of environmental issues as global awareness continues to heighten. In particular, carbon dioxide (CO_2), nitrogen oxides (NOx), and other gases emitted from aircraft engines are regulated by the international standards of the International Civil Aviation Organization (ICAO). Regulations for the gas emissions have become stricter every few years. Consequently, when developing aircraft engines, it is necessary to envision regulatory values which will exist in 10 to 20 years in the future, and to suppress the emission of NOx and particulate matter (PM) as much as possible. The ability to create engines which meet future regulatory standards would be an extremely advantageous sales point.

When fuel is burnt at an air-fuel ratio where no oxygen or fuel remains after combustion, the combustion temperature rises and a large amount of NOx is generated. The RQL (Rich Burn/Quick Quench/Lean Burn), which is currently the mainstream combustion method, is not capable of completely eliminating localized high-temperature regions. This limits the extent of NOx reduction. There are also other issues which must be overcome, such as how combustion in a state with a large amount of fuel (rich state) tends to generate soot and PM. On the other hand, when combustion takes place with a premixed ratio where the amount of fuel is small compared to the amount of air (lean state), the combustion temperature is suppressed and NOx is also significantly reduced. As a low-NOx combustion technology which will serve as an alternative to the conventional RQL combustion, JAXA is developing advanced combustors which incorporate the lean burn technology. We are working to develop a lean premixed two-stage combustion method with a pilot fuel mixer that creates a pilot flame at its center. Main combustion mixers are then placed around the pilot burner. The combustors succeeded in reducing the NOx emissions amount by 80% in relation to ICAO standards (CAEP/6), which were enacted in 2008.

Why does combustion instability matter?

However, lean burn technology generally faces the technical issue of being prone to oscillating combustion due to the sensitivities of the flame against the inlet flow disturbances. Combustion instability is a type of resonance phenomenon which occurs inside of annulus combustion chambers when pressure waves and flames interact with each other with a positive feedback. At a certain frequency, this causes pressure oscillations with extremely large amplitudes, thus creating the possibility of damage to engine parts. Internal damage may lead to engine failure and can result in severe accidents and incidents. Consequently, it is necessary to completely resolve this issue in the development phase prior to the production phase. In addition to being related to the safety of aircraft, combustion instability is also an economic issue that affects engine maintenance costs.

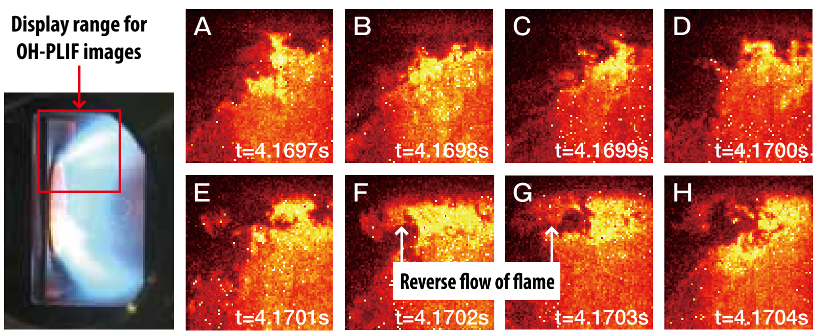
In order to clear this issue of combustion instability, it is of utmost importance to first observe the phenomena and identify the causes. This is similar to medical diagnostic technology in which problems are identified using CT scan tomography that is taken prior to operations for illnesses such as cerebral infarctions.

JAXA reproduces combustion instability by using a combustion chamber with quartz glass windows which provide visual access to the inside of the chamber. This reproduction is a method for developing measurement technology used to diagnose the instability mechanisms. In order to conduct the diagnostic measurement of combustion instability in a high-temperature high-pressure environment, we are advancing application of an OH-PLIF measurement method which operates at 10,000 Hz. The PLIF (Planar Laser-Induced Fluorescence) technique is an optical measurement method which photographs the light emissions from molecules whose electron energy was excited by a laser sheet with a specific wavelength. Flame cross-sectional images are taken at the high repetition rate of 10,000 Hz. The concentration of OH molecules is high in high-temperature regions. We conduct detailed investigation of the fluctuating movements of the flame under combustion instability. This enables us to detect the local causes of combustion instability. Typical frequencies of combustion instability of jet engine combustors are in the range of several hundred to several thousand Hz. Conducting measurements at 10,000 Hz makes it possible to assess the unstable flame behaviors with a sufficient time resolution.

Providing solutions on combustion instability for the benefit of both aviation and non-aviation sectors

We are also cooperating with universities to perform fundamental studies. In addition to experiments with the OH-PLIF measurement, we are working on computational fluid dynamics (CFD) for elucidating instability mechanisms. Furthermore, we have started research on monitoring technology for early detection and prediction of combustion instability occurrence. We will use these research results to develop tools which are capable of predicting the stabilities in the design phase.

This kind of research will make significant contributions to new combustor designs and to existing combustor improvements. Furthermore, technology to measure and prevent combustion instability can be applied not only to aircraft engines but also to a wide range of applications such as gas turbines and boilers for generating energy and rocket combustion systems. This technology is capable of contributing to many industries including the aviation industry.



Combustion instability experiment at the high-temperature and high-pressure combustion test facility (Inlet pressure: 7 bar, Inlet temperature: 760 K). Time-series OH-PLIF images during a transition to combustion instability. The images were measured by the high-speed OH-PLIF at an interval of 1/10,000 of a second.
Reverse flow of flame seen in F-G occurs periodically under the combustion instability.

Composite materials

Activities for international standardization

International standardization is the key to realize future aircrafts that utilize advanced composite materials. But while these materials are promising, their potential as airframe structures has not yet been verified. Therefore, JAXA has been focusing on standardization, in addition to scientific/engineering research for advanced composite materials. Structures and Advanced Composite Research Unit of JAXA's Aeronautical Technology Directorate is the main unit for the international standardization of new testing methods for advanced composite materials.

Samples for present standard (back) and JAXA proposed standard draft (front)

Why is standardization necessary?

Developing practical testing methods for new materials and advanced structures is one of the important subsets of scientific and engineering research. JAXA has been therefore harvesting seeds of international standardization for the aerospace industry. Some have already come to fruition through the standardization activities of Japanese Industrial Standards (JIS) and the International Organization for Standardization (ISO) (refer to Flight Path No. 9/10 for further information), and several new testing methods are on the registration track for the ISO.

Standardization is the process of establishing mutual understanding for procedures ranging from the specimen/product geometries, characteristics, quality, storage/transportation, etc., to the testing operations for confirming each item. JIS is the representative standard in Japan. However, an international standard is essential for the international aerospace engineering industry. ISO is one of the international standardization organizations for a wide range of fields except for telecommunications, which is under the control of the IEC*1 (International Electrotechnical Commission).

International standardization provides people worldwide the benefits of safe and moderately qualified products, in addition to the legal background of the jurisdiction of each country. For the worldwide activities of modern industries, standardization provides the merit of optimized cost of international mass production through the compatibility of parts, tooling, jigs, etc. On the other hand, a promising seed of new technology may lose growth opportunities in international business if the fertile soil of on-time standardization is not provided.

International standardization — why is JAXA active?

JAXA is one of the National Research and Development Agencies in Japan. Why is JAXA active in international standardization? It is active because, JAXA missions range from the 'seed-push' scientific/engineering stages to the 'demand-pull' realization/practical application stages.

There is no border in the sky—bilateral agreements for 'Type Certification (TC)' are required for an aircraft of international operations. What is more, new materials, such as carbon fiber reinforced plastics (CFRPs), require to be type certified through new test standards in the realization steps. Therefore, standardization links to the national strategy of any country, not to mention US-Euros, with an active aerospace industry. For Japan—a newcomer to the worldwide aerospace market, though its technologies of advanced materials and related engineering are competitive—standardization is one of the key strategies, too, to hold an honorable position in the future aerospace market. Standardization is an important mission for JAXA.

*1 International Electrotechnical Commission. An international standardization organization for all electrical, electronic and related technologies. Established some international standards in collaboration with the ISO.

*2 Ceramics matrix composites. Composite material based on ceramics. Lightweight with outstanding thermal resistance.

Milestone discussions — the long ways from a proposal to the issue of an international standard

ISO standardization takes 3 to 5 years through repeated discussions and reviews as follows:

- A plan is proposed at a working group of experts in a field. The working draft is proposed by the project leader to be discussed and reviewed by a sub-committee composed of standardization organizations from various countries.
- Next, the standard is reviewed by a higher level Technical Committee.
- The working draft is released to ISO member groups for further review when the Technical Committee approves the draft.
- The draft is issued after approval by the member groups.

JAXA has proposed the seeds of public test potentials to ISO after the filtration of new testing/evaluation methods developed in Structures and Advanced Composite Research Unit. Four standards have been issued as of October 2016. One draft in review is for the evaluation standard of 'Galvanic corrosion,' a severe corrosion of metal-CFRP assemblies that may potentially compromise the future of CFRP airframes. In addition, proposals have been submitted for: 1) A method of measuring the strength of inter-laminar directions in which the reinforcing fibers of composite materials are less effective; 2) A method of measuring the high-temperature emissivity, and; 3) A creep testing of CMCs.*2

ISO standardization flow

Estimating flight control difficulty with LOTAS (Low-level turbulence advisory system)

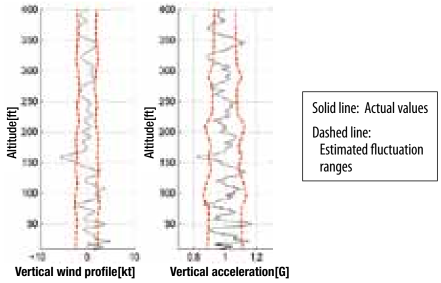


Figure 4 Example of actual flight parameters on landing and estimation results of fluctuation ranges

Why measures against low-level wind disturbances?

There are many Japanese airports which are susceptible to low-level wind disturbances such as wind shear*1 and turbulence. These wind disturbances cause a reduction in the service rate and operating efficiency of aircraft, and may lead to accidents. In fact, approximately 100 go-arounds were reported at Narita International Airport in 2008, 98 percent of which were caused by low-level wind disturbances. Currently, major Japanese airports such as Narita, Haneda, and Kansai are equipped with weather observation systems installed by the Japan Meteorological Agency (JMA). When the system detects low-level wind shears with the airport-based Doppler radar or lidar, the information is conveyed to pilots via the Japan Civil Aviation Bureau (JCAB, the Japanese air traffic control authority).

However, the current system faces several issues. The scale of wind shear which can be detected is in the order of a kilometer, which might fail to identify turbulence with small-scale changes (changes on a scale in the order of 10 to 100 meters) such as those associated with terrain features. Furthermore, the current system uses radio voice transmission for ground-to-air communication. Therefore, the information that pilots can receive is limited to minimum wind shear information that does not include detailed data such as wind speed and wind direction. Also, the current system provides wind shear alerts only when the wind shear is severe enough to present a high risk of accidents. Although the current system is effective at preventing accidents caused by low-level wind disturbances, there is a demand for improved advisory systems from which pilots can obtain more detailed wind data at any time to mitigate air service disruptions due to go-arounds, diverts and so on.

What is LOTAS? – providing additional information to assist approach and landing decisions –

JAXA has developed the LOw-level Turbulence Advisory System (LOTAS), which supports pilots and operators to make more appropriate approach and landing decisions.

Based on observed wind data from weather Doppler radar and lidar, LOTAS detects low-level wind disturbances along the landing approach path. In particular, the system is capable of providing severity information of the detected wind disturbances considering the flight characteristics of specific aircraft types. LOTAS also supports pilots in judging appropriate "landing timing" by providing both the "current" data and "predicted" weather in 10 minutes. This information is provided to aircraft operators on the ground via the internet (Figure 1) and is sent to pilots in the air by using the existing datalink system named ACARS*2 (Figure 2). LOTAS enables pilots to obtain detailed wind information at any time in flight. In addition to preventing accidents, this is also expected to improve operating efficiency by reducing operational disruptions such as go-arounds. One core technology of LOTAS is "technology for estimating the flight control difficulty." The flight control difficulty metric reflects the impact of wind disturbances on flight control difficulty.

How does LOTAS estimate flight control difficulty?

The estimation of flight control difficulty consists of three estimation processes (Figure 3). First, headwind/crosswind components and their vertical shear rate over the approach path are calculated using observed wind data together with runway direction information. Furthermore, the system uses a neural network (NN) to estimate the variations of the headwind, crosswind and vertical wind components which cannot be directly observed by the Doppler radar or lidar. To train this NN, we used the wind data extracted from actual flight data of aircraft landing on the target runway. The flight data resolution was fine enough to extract small-scale wind disturbances which would affect the flight stability.

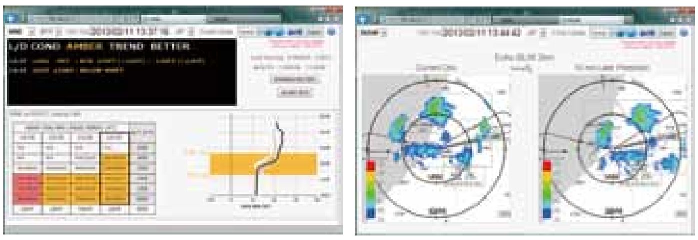


Figure 1 LOTAS Web screen displays

Next, the system estimates the aircraft responses against the estimated wind variations considering flight characteristics of the target aircraft type. The estimated aircraft responses include the fluctuation ranges of airspeed, attitude and vertical/lateral accelerations of the aircraft. Again, the NN trained for the target aircraft type is used for this estimation process (Figure 4).

Finally, based on the estimated aircraft responses and the information of aircraft type, the flight control difficulty metric is estimated using a Bayesian network. The flight control difficulty metric is displayed in the three classifications of "green," "amber," and "red." Green indicates that there is no problem, amber indicates that caution is required, and red indicates a high possibility of a go-around. Note that the actual pilot's decision of flight control difficulty is quite subjective and can be different between pilots even in the same wind conditions. The Bayesian network used in LOTAS can simulate such subjective decision-making processes by introducing probabilistic estimation methods.

The technology developed for LOTAS is also being used in the Airport Low-level Wind INformation (ALWIN) system which was jointly developed by JAXA and the JMA at a later date. The effectiveness of ALWIN has been demonstrated through operational evaluations to date, and the JMA will proceed to implement ALWIN aiming to begin operation in fiscal 2016 at Haneda Airport and Narita International Airport where the Doppler radar and lidar are already installed. If ALWIN begins operation, pilots will be able to easily obtain wind severity information in addition to detailed wind information.

*1 Difference in wind vector between two points in the air. Horizontal shear occurs in the horizontal direction and vertical shear occurs in the vertical direction.

*2 ACARS (Automatic Communications Addressing and Reporting System) is a digital data link system which is used in ground-to-airborne communication. Automatically sends and receives required information such as weather information.

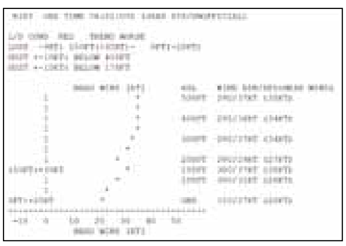


Figure 2 LOTAS ACARS message

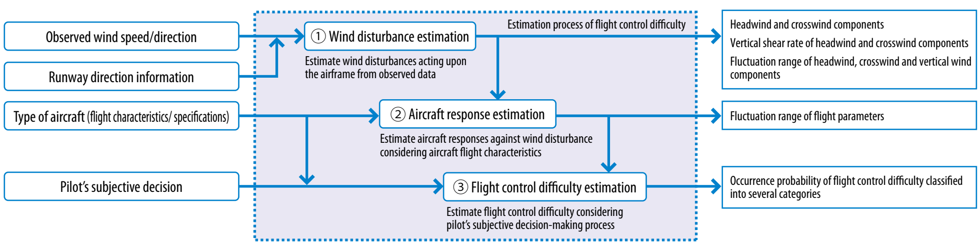


Figure 3 Flow of estimating the flight control difficulty

Enabling precise flight path control with intuitive guidance


Tunnel-in-the-Sky displayed on a monitor


Displayed on the cockpit frontal display

Technology with more than 50 years of research history

Tunnel-in-the-Sky (TIS) is a method of cockpit display to indicate the current and the desired flight path. The name "Tunnel-in-the-Sky" refers to how the continuing rectangles used to represent the flight path resemble a tunnel drawn in the sky. By flying along the tunnel drawn on the display, pilots can proceed on the pre-set flight path. In this way, technology which instructs the pilot regarding the flight path and enables precise flight control is called "flight path control." TIS is technology which has embodied the concept of flight path control into a single flight instrument. The idea of displaying the desired flight path as a tunnel on the display is apparent to anyone seeking to enable precise flight of an aircraft. Actually, similar technology has been researched in countries throughout the world since over 50 years ago. In the late 1960s, the basic characteristics and benefit of TIS were confirmed by flight simulation, conducted at a research organization which was the predecessor to today's German Aerospace Center (DLR). In the 1980s, researchers at the National Aeronautics and Space Administration (NASA) of the United States significantly improved the operability of tunnel technology by adding prediction to a flight path symbol (also known as a flight path marker) that indicated the flight path vector of an aircraft.

JAXA established fundamental technology for TIS around 2005

JAXA has conducted research on perspective flight path display for 40 years. In addition to the tunnel and flight path symbol, the system also uses a ghost aircraft symbol. This symbol moves along the desired flight path while maintaining a fixed distance from the aircraft. During the flight test performed in 1988 for the STOL aircraft Asuka*1, the ghost aircraft symbol and flight path symbol were concurrently displayed on a head-up display (HUD)*2. Around the same time, JAXA (NAL at that time) conducted joint research with NASA regarding STOL aircraft. The ghost aircraft symbol which was used in Asuka's HUD was praised as being "intuitively easy-to-understand" by NASA pilots. Conversely, JAXA learned about the concept of flight path prediction from NASA.

The JAXA-developed TIS was first evaluated in a flight experiment held in 1998. At that time, tunnel display was still in the R&D phase. Afterwards, research continued to improve the dynamics and readability of the symbols until 2005.

TIS enabling precision flight required for various flight tests

TIS provides pilots with intuitive guidance information especially when flying a curved path which is nowadays becoming more common to be segments of approach to runway. However, it is currently common for transport aircraft to use a Flight Management System (FMS) and autopilot when precision flight of such complex approaches is required. In this respect, TIS is not considered absolutely necessary for a modern transport flight deck. On the other hand, during flight tests such as those JAXA is conducting by research aircraft, there is the need to fly with extremely high precision paths which cannot be enabled by using FMS. TIS is a useful tool in such cases. In the case of railways, trains run on the rails, so it is easy to reproduce certain conditions for position and speed. However, because aircraft fly in an open space while being affected by factors such as wind, flying the same route at the same speed is a burden even for highly-experienced pilots. Support from TIS enables such consistent flight by aircraft. TIS has been used in external noise tests for helicopters and in the DREAMS project*3.

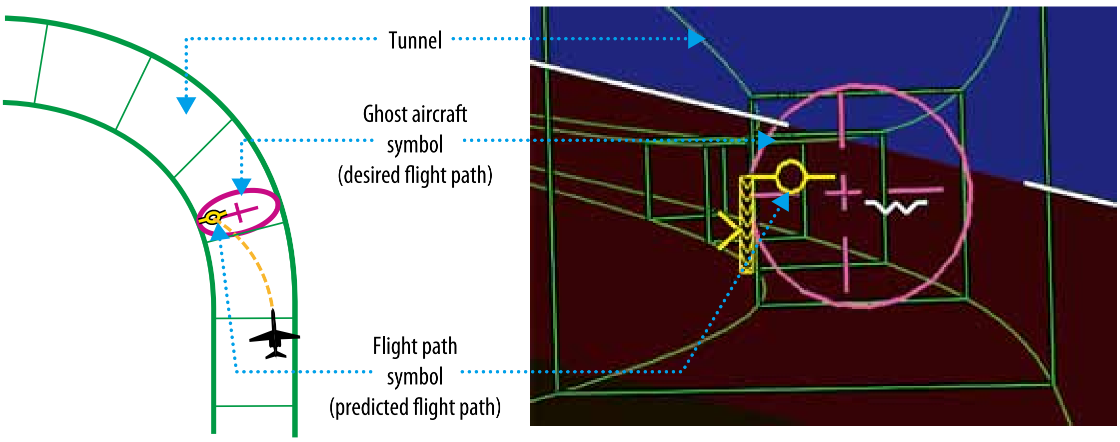
TIS also provides essential support for flyover tests in the FQUROH project. In order to satisfy particularly high requirements for speed accuracy, newly developed thrust command is integrated in TIS and used in the flights in the FQUROH project. The ability to customize TIS in accordance with test requirements and the environment is one advantage of JAXA's flight test capability. In addition to turning of the parameters performed on the ground prior to flight, it is also possible to turn parameters in-flight in order to respond to pilot requests.

TIS is an essential technology for supporting flight tests at JAXA.

*1 A short takeoff and landing (STOL) experimental aircraft with four FJR710 engines. Developed based on a C-1 transport aircraft, the Asuka conducted 97 flight tests between 1985 and 1989.

*2 A device which displays flight information and images on a half-mirror installed in front of the pilot. Reduces the need for the pilot to look away from his/her viewpoint and enables easy acquisition of information.

*3 R&D project to establish key technologies required for next-generation air traffic management systems. See Flight Path No. 7/8 for details.



Conceptual diagram for TIS (left) and example of display (right)