Sonic boom measurement met with success!

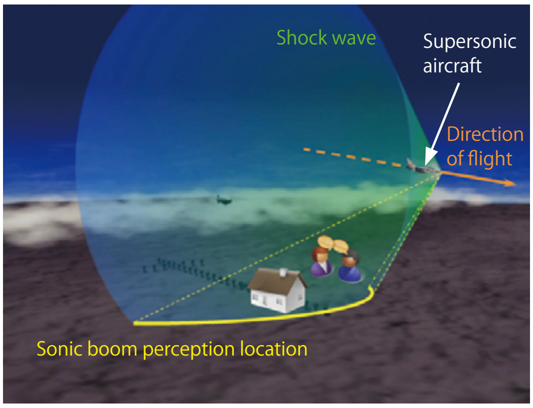
In Sweden in September 2009, JAXA conducted a flight test for measuring sonic booms generated by a supersonic aircraft. The purpose of the test was to validate the prototype of an aerial sonic boom measurement system. Technology for precise measurement of a sonic boom is essential to demonstrate JAXA's concepts of reducing the sonic boom in the planned drop test of a research aircraft. Good sonic boom data were collected by the prototype measurement system. The performance will be further improved before the drop test.

Sonic boom measurement system to demonstrate sonic boom mitigation technology

Mankind has the technology to build aircraft that can fly at supersonic speeds, however, faster speed brings a new problem, a sonic boom, which is caused by unique behavior of the air around supersonic aircraft. The Concorde was not accepted by society in many countries partially due to its loud sonic boom. Now, it is time to reduce sonic booms.

JAXA is actively working on research and development of sonic boom mitigation technology as the most important issue to be resolved toward the realization of civil supersonic aircraft. Sonic booms can be reduced by shaping the aircraft configuration. JAXA has proposed some unique "low-boom" concepts that can reduce the sonic

What is a sonic boom?



When an aircraft flies faster than the speed of sound, a shock wave is produced due to compression of air around the aircraft. When this shock wave propagates and reaches the ground, it sounds like an explosion. This is called a sonic boom. Although usual acoustic waves attenuate with distance, the shock wave generated by a supersonic aircraft is still heard as an extremely loud noise on the ground, even after travelling 10 km or more.

■Three characteristics of a sonic boom

1. Significantly high pressure compared to other noises (The pressure corresponds to loudness of the sound.)
2. Abrupt pressure changes (Unexpected impulsive noise)
3. Strong low-frequency component that cannot be heard by the human ear (The low-frequency component causes buildings to shake and creates a rattling sound.)

The aircraft (JAS39 Gripen) and the house used for indoor boom measurements.

boom by half, compared with the Concorde.

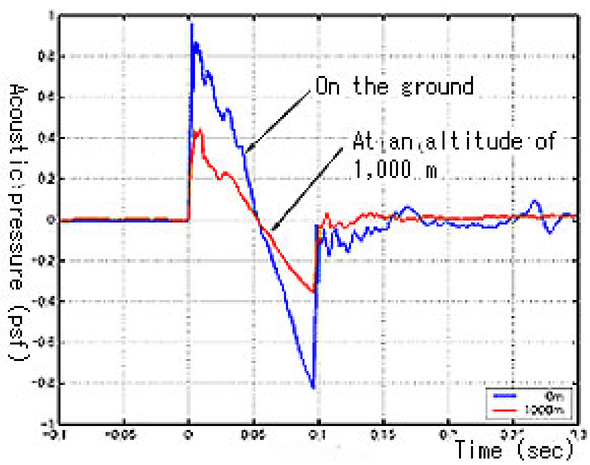
By 2012, we plan to perform drop tests of research aircraft(*) to prove our low-boom concepts. Measured pressure waveforms of sonic booms created by research aircraft should be compared with the analysis. For this purpose, an accurate sonic boom measurement system is essential.

(*) Drop test of research aircraft: Test for validating the sonic boom mitigation concepts by measuring sonic booms generated from a research aircraft designed for low boom, which will be dropped from a balloon at an altitude of about 30 km and accelerated to Mach 1.4

Measuring a sonic boom

Since a sonic boom has unique acoustic characteristics, all features of the sonic boom cannot be accurately captured with general measurement instruments. Therefore, JAXA has developed an aerial measurement system, named the ABBA (Airborne Blimp Boom Acquisition) system, designed for capturing the details of a sonic boom, and has tested its prototype in Sweden in order to check its performance. Military aircraft flew at a supersonic speed in a test range, and sonic boom measurements were made using the ABBA system.

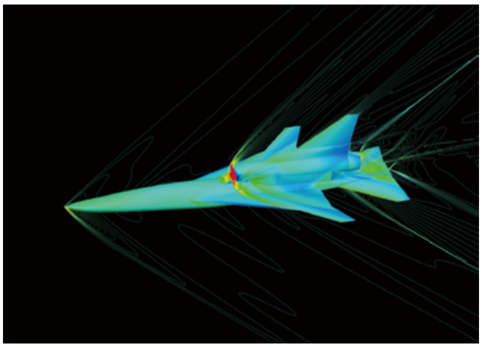
The most important data in assessing the effects of the low-boom design is the sonic boom waveforms. However, these sonic boom waveforms could be distorted by atmospheric turbulence



Sonic boom waveforms

A tethered blimp holds the necessary equipment in place at an altitude of 1,000 m. The system comprises (1) acoustic instrumentation for measuring/recording sonic booms, (2) instrumentation for measuring/recording the atmospheric pressure, temperature, humidity, latitude and longitude of measured points, (3) communication system for monitoring and controlling the data recorder from the ground, and (4) power supply system. The tethered balloon has an overall length of about 15 m, a volume of about 134 m3, and a payload of 25 kg.

ABBA system



▲ CFD analysis of research aircraft

Wind tunnel testing ▼

near the ground. Therefore, the ABBA system was designed to make measurements using a tethered blimp at an altitude of 1,000 m to avoid the effects of atmospheric turbulence.

In addition, in order to understand the mechanism of deformation of sonic booms by atmospheric turbulence, measurements were also conducted on the ground. On the ground, acoustic measurement both outside and inside of a wooden building, and vibration measurement of the windows, walls and ceiling of the building were made for investigating structural responses to sonic booms. These data will be utilized to verify the analysis and design technologies.

How low is low enough?

With supersonic flights over land, a sonic boom is likely to be heard in our daily lives. So, what would be an acceptable level of a sonic boom? There is still no clear answer to that.

In order to clarify the relationship between perception and physical metrics of a sonic boom, JAXA is performing jury tests for evaluating sonic booms reproduced by a simulator. In addition, we are examining indoor booms including secondary noises, such as the rattling noise of windows induced by sonic booms, which play an important role in investigating acceptability of sonic booms. The sonic boom data obtained during the flight test is extremely useful for evaluating sonic boom perception.

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The International Civil Aviation Organization (ICAO) has started discussions to establish environmental standards for civil supersonic transport with a sonic boom. To what extent should a sonic boom be reduced for supersonic overland flight? How should the sonic boom of new supersonic aircraft be measured? With JAXA technology, we aim to contribute to future standards.

We hope to accelerate the development of civil supersonic aircraft by demonstrating the low-boom design technology in our planned drop test.

Testing team goes to Sweden

is characterized by its large acoustic pressure and an extremely powerful low-frequency component. But, how does it actually sound? Since this is not a sound that we hear in our everyday lives, let's talk with the team who performed this test in Sweden.

Makino　In this experiment, we heard a sonic boom of the same level as that produced by the Concorde. It surprised me how loud it was. I have heard sonic booms many times in the past in other countries (including military aircraft and the re-entry of the Space Shuttle), but this was the loudest of them all. I definitely came to realize that this is an unbearable sound that must be reduced.

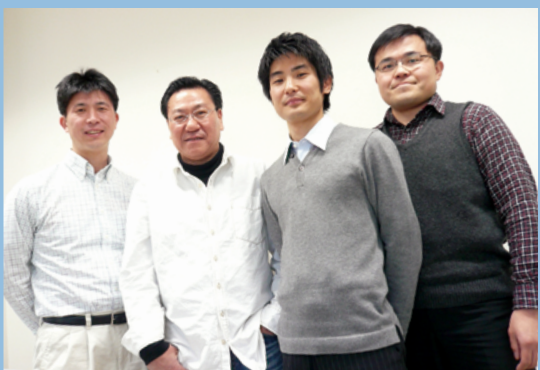
—— Is the recorded sound just as unbearable as the actual one?

Okai　Unfortunately, most of the effect cannot be transmitted by computer speakers.

Shindo　In my opinion, it felt like a cannon striking or fireworks exploding from about 100 m away. Although I think it would have been perceived as normal in the immediate vicinity, it sounded as if it was echoing from a distance. It was a somewhat strange feeling.

—— At what altitude was the aircraft flying?

Makino　For the test, it flew at a maximum of 14 km and a minimum of 6 km. It was not visible from the ground at 14 km and it appeared as a dot at 6 km. Being informed by radio when it passed overhead, we could prepare ourselves for its sonic boom. (Shindo: Because the aircraft is flying at supersonic speed, we hear the sound later.) However, since we could not hear the engine noise or see the aircraft, the sonic boom would have taken us by surprise if we had not received advanced notice.



Supersonic Transport Team
(From left) Yoshikazu Makino, Shigemi Shindo, Yusuke Naka, and Keiichi Okai

Okai　I was recording with a video camera to study the conditions outside of the building, so I was startled each time that I heard it. Later, when watching the video, I could see that the image shook at those moments. An image stabilization function was not useful.

—— It could also be heard inside the building?

Naka　The overpressure of the sonic boom heard inside the building was 1/4 of that heard outside. The sound wasn't so loud as outside, but I felt the whole building vibrating. It was different from the shaking during an earthquake, and it felt as if the entire building was suddenly being compressed. I was so surprised; my heart jumped. There was no radio inside the building, so I didn't know when the sonic boom would come. I was startled when the house and windows suddenly shook.

Recent research shows that the sonic boom heard inside a building causes significant annoyance because of the effects of this rattling noise and the vibration of buildings. I was able to actually experience that, and thus recognize that we must further study the effects of sonic booms, not only outdoors but also indoors.

—— Has this increased your motivation for this research?

Naka　I am studying how people feel when they hear a sonic boom, and I am conducting jury tests using the sonic boom simulator. However, people who have heard a real sonic boom have the opinion that "the simulated sonic booms sound artificial and not realistic". Since I had never heard a sonic boom until then, I was not able to understand what the actual sonic boom sounds like. Now I know that, and I think this will be useful in our future research. It was a very valuable experience.

Research Report

From the research field

In pursuit of reduced fossil-fuel aircraft

Unmanned and Innovative Aircraft Team

Possibilities for and significance of electric aircraft

Against a backdrop of global warming and soaring oil prices, the spotlight is being directed toward hybrid or electric automobiles. The introduction of biofuels as well as hydrogen fueled jet aircraft are being explored, and research and development throughout the world have recently turned to aircraft that can fly on electricity (reduced fossil-fuel aircraft).

Seizing on electrical technology as one of the prevailing candidates for reduced fossil-fuel aircraft technology, the Unmanned and Innovative Aircraft Team is carrying out research and development aimed at contributing to improving the environmental friendliness of future-oriented aircraft and to increasing our international competitiveness by fully applying the advantages of electricity while simultaneously overcoming its shortcomings to create engine systems for highly functional aircraft

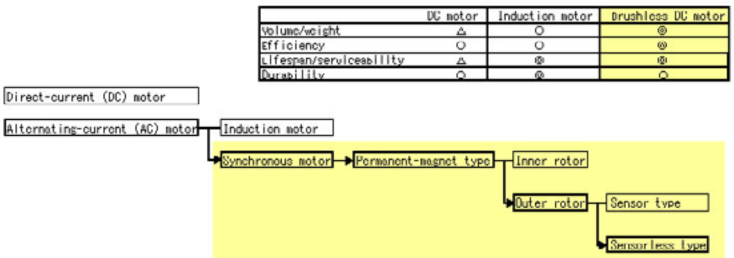
What electric motor system is appropriate for aircraft?

Like electric motors for hybrid and electric cars, an electric motor adaptable to propelling aircraft requires characteristics such as (1) reduced size and weight, (2) high efficiency and (3) high reliability. Figure 1 shows the results of our team's selection for an aircraft motor system. Basically, as in electric automobiles, a brushless DC motor (which emphasizes efficiency and does not use brushes) is employed. However, the few points where it differs from electric car motors are that it uses an outer rotor (the rotor is on the outside, as shown in fig. 2) and is sensorless (no rotor position detection sensor is used).

Compared with the inner rotor type, where the rotor is inside the stator, the external rotor type is suited for a propeller drive (low speed, high torque) since the generating location of the drive force is at a distance from the center of rotation, and the reduction gear can be eliminated. Moreover, Hall-effect sensors, which detect the rotor position and are commonly used in electric car motors, can be eliminated by implementing the sensorless. This type requires only the wiring for the motor drive, as shown in fig. 2, allowing for lower cost and improved serviceability while the sensor type is heat sensitive and requires instrumentation wiring in addition to drive wiring. This sensorless type infers the rotor position from the back electromotive force generated by the coil. However, since rotation control, including startup, is difficult with this type, research and development of the control system is still on-going.

Utilizing the advantages of electric motors

Figure 3 shows the electric motor system that our team is developing for aircraft. This system employs a direct drive system with no reduction gear and strong neodymium



	DC motor	Induction motor	Brushless DC motor
Volume/weight	△	○	◎
Efficiency	○	○	◎
Lifespan/serviceability	△	◎	◎
Durability	○	◎	○

Fig.1: Motor system selection

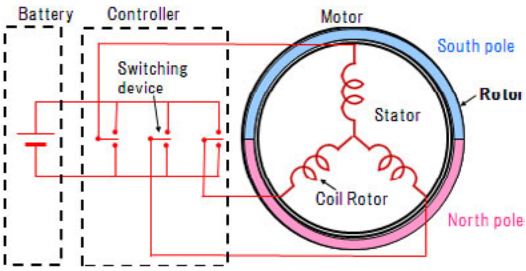


Fig.2: Basic concept of brushless DC motor

Innovative Aircraft Technology Section
(From left) Takao Shimizu, Hiroshi Kobayashi, Akira Nishizawa, Hideaki Hakojima

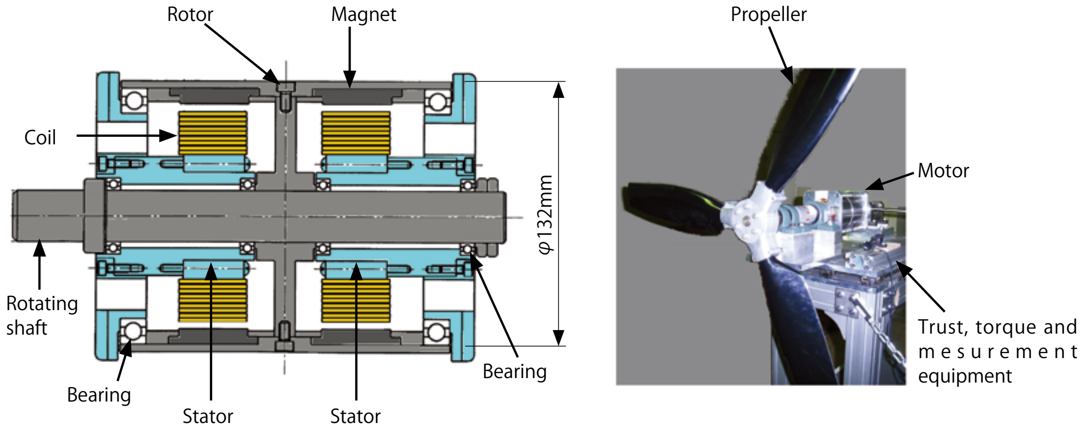


Fig.3: 20 kW electric motor and propeller
The rotor is connected to the rotating shaft, and both rotate as one. The stator wound with the coil is secured to the frame and does not move.

magnets as the permanent magnets. In addition, it is small and lightweight and achieves a high efficiency. This motor is designed for a maximum 20 kW output, which enables only a single-person ultralight plane (gross weight of about 200 kg) to fly. This aircraft-specific motor configuration integrates two stators for one rotor, which is called a redundant motor. A redundant motor allows cruising with output from only one stator in case one fails.

Aircraft reliability is maintained by installing multiple engines, should one fail during flight; however, single-engine planes have become mainstream, due to their small size and low cost. Engine failure, which even now is often linked to fatal accidents of single-engine planes, is one accident-causing factor that must be eliminated. Therefore, by installing a redundant motor, the reliability of aircraft can be improved. Furthermore, the type of maneuvering difficulties related to single-engine flight of a twin-engine plane when an engine fails is not necessarily an issue.

Our team is also measuring motor and propeller characteristics such as thrust, torque, current and voltage. These results will be reflected in the design and performance improvements of the controller and motor. With performance data obtained from independently driving each stator of the redundant motor, we are able to determine the a motor efficiency of about 87% is currently achieved. While devising further future efficiency improvements, we aim to acquire technology for new concepts that incorporate advanced features from the perspectives of safety and low noise, as well as seek new possibilities for electric aircraft.

(Akira Nishizawa)

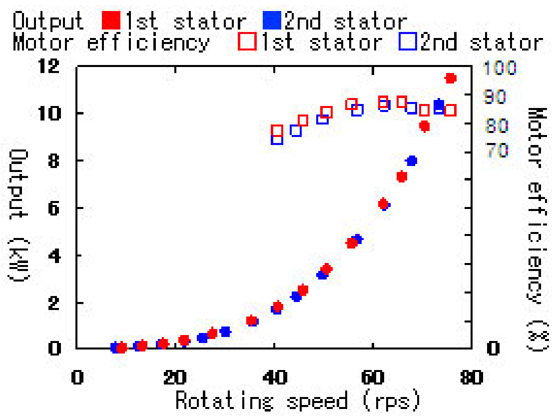


Fig.4: Performance of 20 kW electric motor

Research Report

From the research field

Jet aircraft noise measurement

Civil Transport Team / Clean Engine Team

Toward establishment of noise source localization technique for civil transport aircraft in flight

With the recent increase of environmental concerns and the increased frequency of takeoffs and landings resulting from the further expansion of air traffic volume, we must further reduce the airport community noise level produced by each aircraft. Considering that the lifespan of aircraft is about 20 to 30 years and noise regulations will become increasingly stringent, newly developed aircraft must be quiet enough to provide a margin for projected noise regulations.

In order to develop quieter passenger aircraft, we must know the origin of the noise and understand its generation mechanism. At the design phase of aircraft, we study characteristics and the mechanism of possible noise sources and estimate the entire aircraft noise level, then improve its design when noise reduction is necessary. However, with current technology, the actual aircraft noise is too difficult to predict in advance of flight tests. Actual noise must be studied during flight tests of completed aircraft. Measurement technology called “noise source localization” using a microphone array is a powerful tool in order to accomplish this. Until now, JAXA has demonstrated the noise source localization technique in wind tunnel tests and applied it in various research and development. We have also developed techniques for flight tests using small model airplanes. However, there has been no application and experience in flight tests of actual aircraft in Japan. Therefore, the Civil Transport Team and Clean Engine Team have started to work together to establish the measurement technology by using small jet aircraft.

As a first step, we gathered fundamental data (such as noise characteristics, flight path and flight speed) required to develop the technology for measuring, predicting and evaluating noise from a jet aircraft. Using the business jet MU-300 (total length of 15 m), we performed ground engine-noise measurement testing (fig. 1)-where noise of an aircraft in a static position on the ground is measured-and flight noise measurement testing (fig. 2)-where we repeated approach, low-altitude level flight and climb to simulate takeoff and landing, then measured the aircraft altitude, flight speed and radiated noise on the ground while changing altitude, speed, attitude and configuration.

Measurement of engine noise with microphones surrounding aircraft

The ground engine-noise test was performed in the apron of the Tokachi-Obihiro Airport in Hokkaido early in the morning of October 25, 2009. Microphones were set up at 10° intervals from the nose (0°) to the back on the left and right sides (± 160°) at a radius of 25 m from the center of the aircraft, and the radiated noise was measured at various engine operating conditions. Fig. 3 shows the directivity (radius is the sound pressure level, and angle is the microphone position) of the measured radiated noise level. We can determine that an

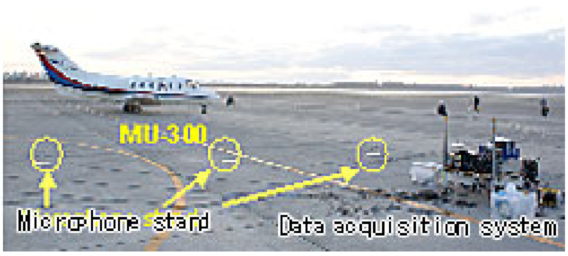


Fig.1: Ground engine-noise measurement test at Tokachi-Obihiro Airport

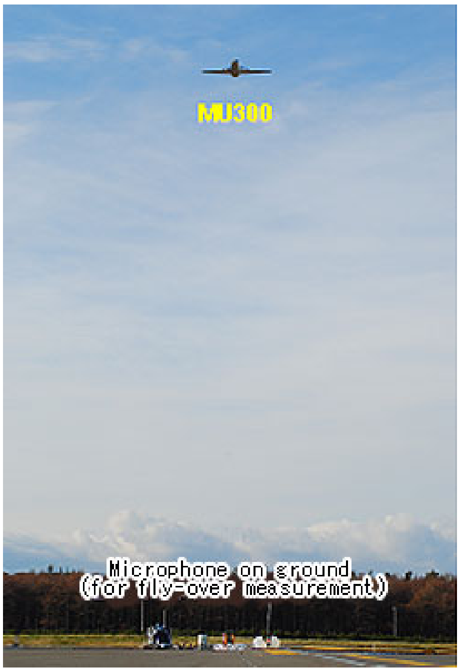


Fig.2: Flight noise measurement test at Taiki-cho airfield

Members who performed tests
(JAXA and Diamond Air Service)

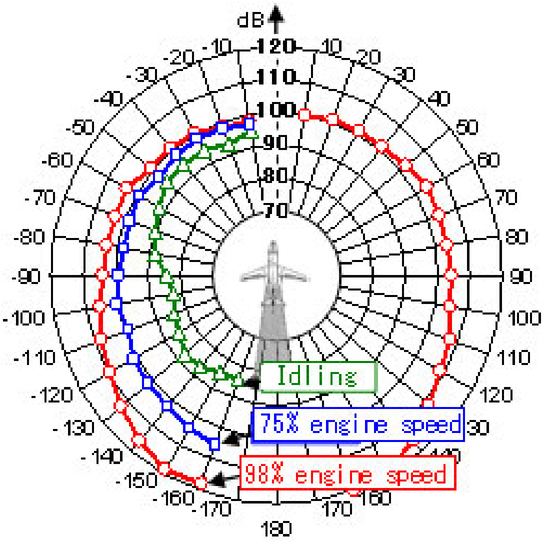


Fig.3: Variations in directivity of engine noise according to engine operating conditions

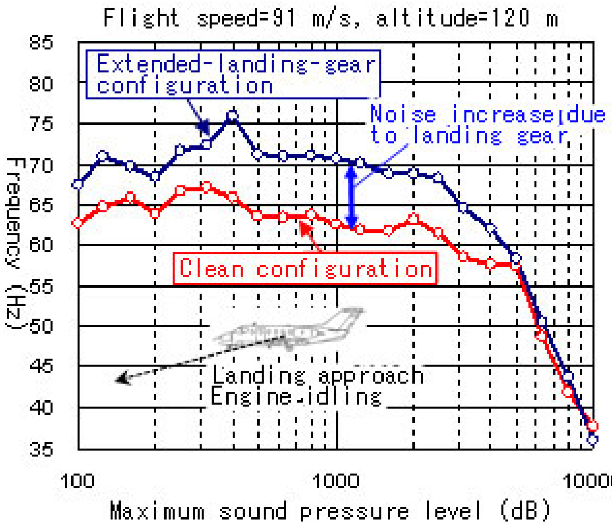


Fig.5 :Variations in noise spectrum according to configuration during landing approach

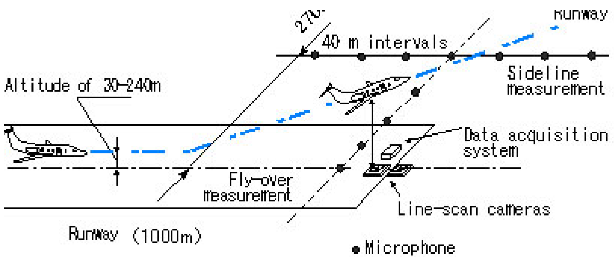


Fig.4: Flight path over runway (for simulating takeoff climb) and location of equipment

increase in engine speed and thrust raises the jet noise level from the engine exhaust.

Toward establishment of noise source localization technique for civil transport aircraft in flight

From November 17 to 19, we performed flight noise measurement tests at Taiki-cho airfield in Hokkaido. Fig. 4 shows equipment locations, such as microphones, and the flight path simulating a takeoff climb. Microphones were arranged to take measurements of fly-over during landing approach and at the sideline during takeoff climb, and then noise was measured during climb/approach/level flight with the takeoff/landing aircraft configurations. Techniques for measuring and processing image data using line-scan cameras were also developed in the flight test for the next phase where the passing velocity, aircraft attitude and aircraft position in relation to the microphone array placed on the runway will be measured for noise source localization. Fig. 5 shows the differences in noise levels according to the aircraft configurations during landing approach. Compared with the clean configuration, where the landing gear is retracted, noise was higher with the configuration where the landing gear is extended, leading us to conclude that noise is generated by the landing gear. Based on the obtained data, we plan to develop a prototype of the noise source localization measurement system and to study flight testing methods in order to establish the technology in coming years.

These tests were performed with assistance from Tokachi-Obihiro Airport, Taiki-cho and Diamond Air Service. We greatly appreciate their cooperation.

(Kazuomi Yamamoto)

Interview
People who fly dreams
Vol.15

Blades are the key to realizing quiet helicopters

Operation and Safety Technology Team
Yasutada Tanabe

Have you ever flown in a helicopter? Helicopters can three-dimensionally fly to any direction and even hover at a point in the sky. This may be the closest counterpart to the car among flying machines!? Unfortunately, we rarely fly by helicopter as a public transport, but it plays an active role in various fields where its unique flying abilities are demanded. However, the truth is that this fantastic flying machine has a few flaws as well.

Controlling air vortices generated by blades

What is the Helicopter Technology Section currently working on?

Tanabe　Our section is engaged in the research and development of new blades that are supposed to reduce helicopter noise. You know helicopters are used in various fields, such as disaster relief, agriculture, news-gathering and broadcasting; however, the noise is indeed a grave problem. One major cause for the noise is the abrupt pressure fluctuation appearing when, as the blades rotate and create air vortices (tip vortices), the following blade encounters (or passes near) the vortex produced by the preceding blade, resulting in strong slapping noise. This type of noise becomes noticeable especially in descent including landing approach.

For reducing this noise, promising methods include active devices, such as an active flap and an active tab, as they can control the degree of the aerodynamic interaction between tip vortices and blades. These devices are basically installed inside a blade and move so as to either increase the spacing between tip vortices and blades or weaken tip vortices in strength. We are currently in the process of developing this active flap.

Yasuhi Tanabe
Helicopter Technology Section
Specialized in aerospace engineering in graduate school

What are you in charge of, Dr. Tanabe?

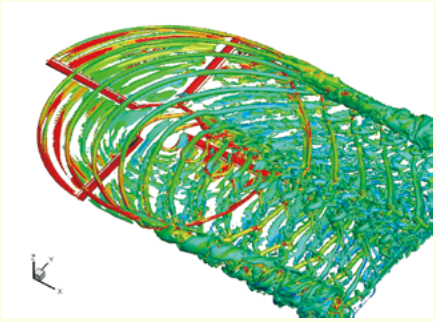
Tanabe　I am in charge of the numerical analyses. I am developing an analysis tool that enables us to numerically scrutinize what occurs around a blade during flight and also the level of noise that is produced as a result of the blade motion. This analysis tool will allow us to fully examine, for example, possible designs of the active flap so that we can determine the optimal control for reducing the noise.

What are the challenges?

Tanabe　The burning issue is how to minimize the discrepancies between what is really happening and what is calculated. If the calculated results are hugely different from the actual physical phenomenon, then we must think the analytic tool is just rubbish. Therefore, we must always compare and validate the numerical results with experimental data. On that basis, we continuously improve the program code and repeat to conduct test calculations. This procedure never ends until we can be convinced that the numerical results have sufficiently simulated actual physical phenomena. I feel my code has reached a reasonable level of usability by now.

What are the plans for the future?

Tanabe　We are obtaining good results in testing of the prototype for the active flap mechanism. Joint research with NASA began last year. On top of an aim to improve mutual analysis technology, the joint team planned that a test program of a full-sized prototype rotor equipped with active flaps would start in five years' time using NASA's enormous wind tunnel. Further in the future, we are now pushing forward a plan to conduct flight tests of helicopters equipped with this blade in cooperation with the Ministry of Defense.



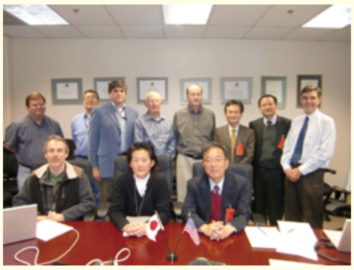
Tip vortices generated by rotating blades (simulation)

You seem to enjoy this work.

Tanabe　I do, indeed. As a matter of fact, we started designing a new blade based on the past research results towards wind tunnel tests that are planned to carry out in five years. Participating in a trend set by my predecessors is now simply accelerating me towards a tangible goal. I am jolly satisfied with my present job. Although our intention was to lay out a path to practical application and pioneer the route, in order to reach a successful progression, I believe it should also be researcher's part to convince the world of the importance and usefulness of this technology.

Is the active flap already used in present helicopters?

Tanabe　Not yet, I'm afraid. It is still in the stage of testing. The good news is that results from wind tunnel tests conducted by US manufacturers showed


After a meeting at NASA

better results than were expected based on initial analyses. Not only was noise reduced but, at the same time, vibration was dramatically reduced and the aerodynamic performance of the blade was improved as well. More advanced flight tests in Europe have begun, and eventual installation in vehicles seems quite likely. Since we are obtaining desirable data from numerical analyses about the blade that we are currently designing, our research has already gained significant attention even in recent international publications. Now, we simply need to corroborate the ability of our blade through testing.

Talking about cutting-edge technologies, the active twist is another possibility. This can reduce noise by allowing the blade to twist so that its shape can be altered. However, this is still a new concept, and a joint international research project that we participated in has only just kicked off recently. Don't you think a blade that can change its shape in this way is a lot like a bird's wing, do you?

Seeking successors

Helicopters are truly indispensable in the field of disaster relief, aren't they?

Tanabe You are absolutely right. They can take off from and land in narrow areas and rescue people from the air; this is the very field where helicopters can exhibit their special abilities. I do believe that helicopters hold great potential for advancing the Japanese aviation industry.

However, I am worrying that there are very few helicopter researchers in Japan. Currently, there are merely an insignificant number of Japanese universities where helicopter studies are available. In fact, Korean, European and American universities that have aerospace departments have quite a few students and research stuff studying helicopter technology. The ratio of rotorcraft students against other aeronautical students is said to be generally about 1/4 in these countries. It is not this way at all in Japan, despite one quarter of industry employees engaged in aviation are asked to participate in research and development of helicopters, as helicopters account for 1/4 of aviation sales even in Japan. As a result of the poor academic backup, those helicopter engineers in industry have no other ways than going abroad to study helicopter dynamics from scratch. I found this present situation seriously problematic.

Are you worried that there are so few Japanese researchers?

Tanabe Yes, ever so much. We are actually working in cooperation with manufacturers and researchers for increasing the number of successors. In our spare time, we are helping to provide some colleges of technology with lectures on rotorcraft dynamics. We helped them write a textbook last year. I am now 48 years old, so I will eventually need successors.

Engineering for commercial use

What in did you specialized at university?

Tanabe Well, I was not specialized in rotorcraft either. I came from China to Japan when I was 18 to study fluid dynamics at a Japanese university and I studied about the aerodynamic heating of objects moving at a high speed, such as the Space Shuttle.

After obtaining your doctorate, you worked for a manufacturer?

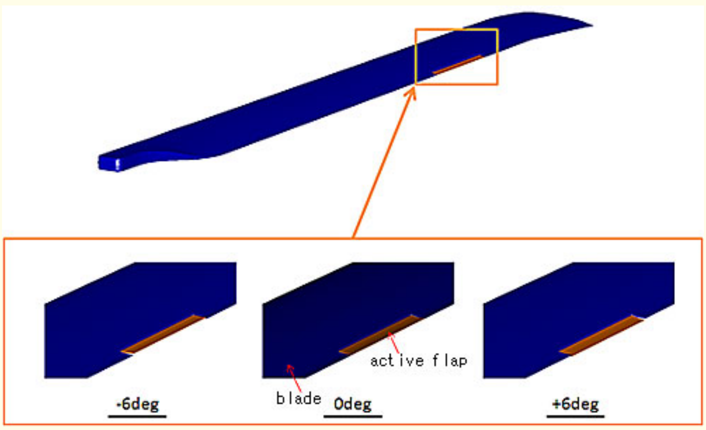
Tanabe Yes, I was involved in helicopter development for about 15 years with a manufacturer. Some ideas that we came up with have been put into practical use. After joining the company, I began studying helicopter technology and was immediately enchanted with it. Since the vehicle moves forward whilst the blade rotates, there are quite a few complex aerodynamic problems. On one hand I thought it would be extremely difficult to sort them out, on the other hand, I felt that there still was a room for coming up with clever ideas to pin down the best solutions. However, the emphasis of research activities in the company was gradually shifting from helicopters to robotics. Just when I was preparing to tackle the new field, though hoping I could concentrate on aeronautics, I found JAXA was recruiting new researchers at the right timing. I had no reason not to apply. I really think I am so lucky that I was employed at that time. It was simply great that I have been given such a great opportunity to work for JAXA.

What do you enjoy doing in your free time?

Tanabe First of all, catching up on sleep. (laughing) Other than that, well, I enjoy cooking, playing Go and fishing. I make my own lunch to bring to work, and I enjoy cooking for my family on weekends. Once a year, I go fishing with all my colleagues, and I prepare a meal with the catch of the day. It is good fun.

What are your future goals and hopes?

Tanabe I hope that my technology will eventually be adopted in industrial products because it would be simply a waste if it just remains at the research stage. Research papers may be important, but engineering would have little meaning if it was not actually useful to industry. I would like to become able to say, "JAXA's technology is here!", with pointing something. This is what I strive for.



Up and down movement of active flap