

Constructing an aerial sonic boom measurement system

Having tackled research and development of a silent supersonic civil transport, JAXA has begun the D-SEND project. D-SEND (the abbreviation for the "Drop test for Simplified Evaluation of Non-symmetrically Distributed sonic boom") refers to the drop tests for simple assessment of non-axisymmetric sonic booms. The aim is to demonstrate, through drop tests, the validity of JAXA's original design concepts, which reduce sonic booms by half. With this project, we aim to lead the world by promoting JAXA technology and to establish a foothold in the realization of civil supersonic aircraft.

The drop tests will be conducted in two stages during the project term, which continues until 2013. The mission of the first stage (D-SEND#1) is to demonstrate aerial sonic boom measurement technology. With the second stage (D-SEND#2), we will demonstrate low-boom design concepts. These tests will be carried out in Sweden. In both drop tests, test bodies carried on a balloon to an altitude of 30 km are released and fall to reach supersonic speeds. The mission of each stage can be confirmed by measuring the sonic boom generated at that time. #1 is planned for April/May of this year. For details about the test that is to begin soon, we talked with project manager Kenji Yoshida.

Aerial measurements essential for verifying design effects

— How is #1 progressing?

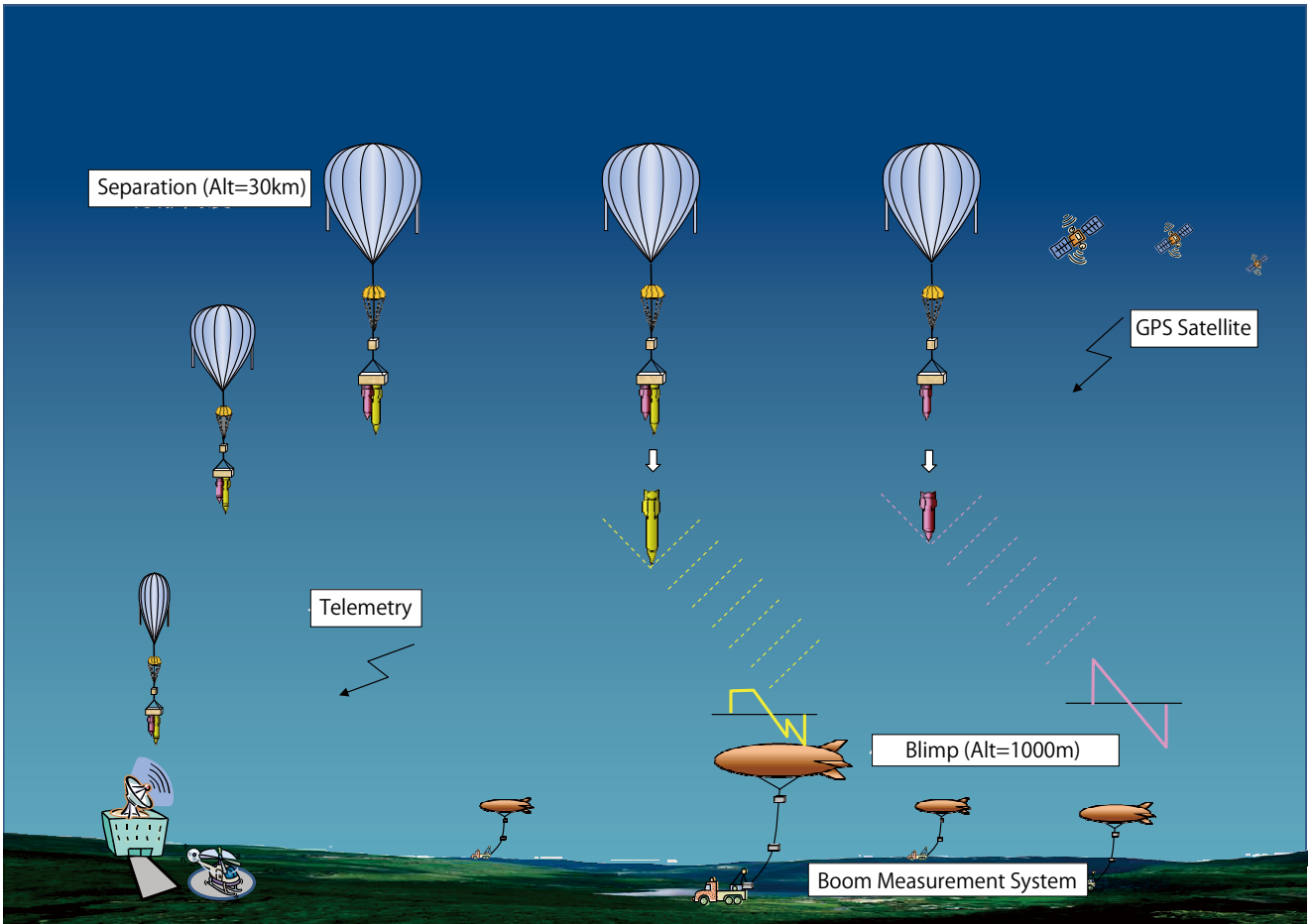
Yoshida With #1, which will be conducted between April 19 and May 16, we aim to establish the aerial sonic boom measurement technology that we have devised. Two simple test bodies (axisymmetric models) will be taken to

an altitude of 30 km by a balloon, and the sonic booms generated when each is dropped will be measured. One of the test bodies will generate the same large sonic boom as in the past, and the other test body should theoretically produce a smaller sonic boom. A total of two drop tests will be conducted with two types of test bodies dropped in each test. The mission of #1 is to be able to accurately measure, in air, the sonic boom signature generated by different test bodies. The measurement data obtained from the first drop test will be thoroughly scrutinized before the second drop test is performed.

Since the balloon with the test body hanging from it drifts in the wind, we will set up a boom measurement system at four locations so that we can take measurements anywhere the test body would be within a test range extending nearly 100 km by 60 km. Each measurement system will be tethered to a blimp positioned at an altitude



Kenji Yoshida
D-SEND Project Team
Project manager



D-SEND#1

of about 1,000 m, and the measurement instruments will be located at several points along the tether to the ground. Since access into the test range is prohibited for safety reasons, we will control and monitor the measurement instruments from a control center near the launch site.

— Why is it so important to be able to take measurements in the air?

Yoshida Accurately measuring sonic booms in the air is necessary in order to verify the validity of low-boom design concepts, which will be performed with #2. Therefore, we will use the data of the measurements between the ground and an altitude of 1,000 m to verify whether or not the results are as predicted.

In order to design an airframe configuration that produces a reduced sonic boom, the shock wave produced near the airframe as well as how that shock wave is transmitted to the ground as a sonic boom are being analyzed in detail. In other words, without this analysis technology, we would not be able to create a low-boom design. This is called sonic boom propagation analysis technology, and the data that will be obtained in these tests will also be used to verify this analysis technology.

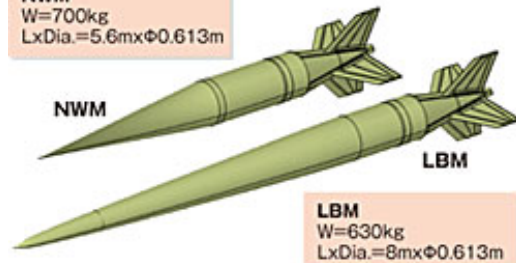
The changing behavior of air between the ground and an altitude of 500 m

— People hear sonic booms on the ground, though.

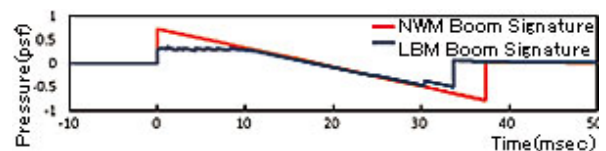
Yoshida You may think that because there is a low boom

D-SEND#1 test models

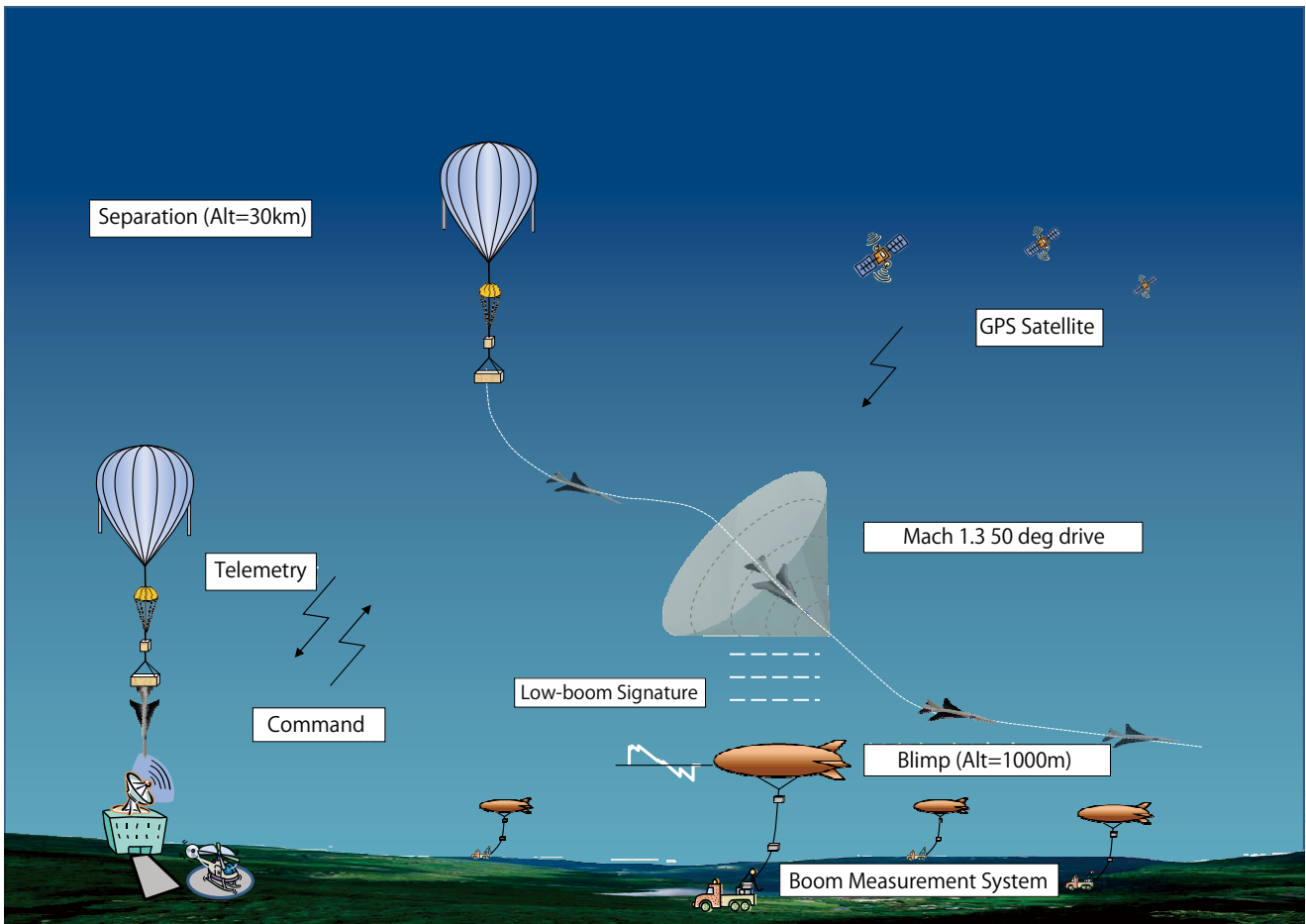
NWM
W=700kg
LxDia.=5.6m×Φ0.613m



LBM
W=630kg
LxDia.=8m×Φ0.613m



Measured Sonic Boom Signature



D-SEND#2

in the air, it will be the same on the ground. The reason why this is done at an altitude of 1,000 m is because there is a high possibility of data obtained on the ground being influenced by atmospheric fluctuations. Therefore, we believe that we must verify design effects with data from an altitude without these influences.

The atmospheric conditions are not uniform, but this changes at an altitude of 500 m from the ground. Below 500 m, there are complex fluctuations, commonly called atmospheric turbulence (📎). In fact, how a shock wave propagates through the space with this atmospheric turbulence and reaches the ground is still not fully clear. Currently, we are striving to understand this mechanism, which is a hot research issue globally. Therefore, in order to reliably avoid the effects of atmospheric turbulence when conducting #2, we have selected 1,000 m, a height double the altitude of 500 m. Since aerial sonic boom measurement technology is necessary to demonstrate this low-boom design concept, we plan to establish that technology with #1.

Of course, we also must ultimately take into account to

what extent atmospheric turbulence affects sonic booms in order for supersonic aircraft to be realized. This data from measurements taken on the ground and at multiple locations in the air is valuable with regards to atmospheric turbulence analysis technology.

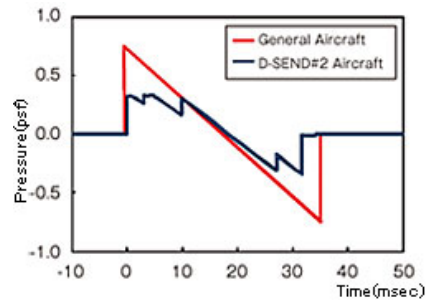
Our technology as the global standard

— So, original technology and know-how are necessary for measuring, right?

Yoshida Acoustically speaking, sonic booms are special noises, so an original system was invented for it. Currently, there is a move to review the rules presently in force to prohibit over-land supersonic flight, and a study is underway to establish new standards for sonic booms at ICAO in 2016. Since the researchers of this project team are participating in the technical study for setting these standards, establishing measurement technology with the success of #1 will allow us to suggest that sonic booms can be measured with high accuracy by using our measurement system and methods while providing measurement data and their analysis results as well as to



D-SEND#2 test model



Measured Sonic Boom Signature

contribute to the study for setting the standards. It would be great if our measurement system and methods could become the global standard.

— When do you plan to conduct #2?

Yoshida We are considering conducting it between July and August 2013. With #2, we will drop a test body with an aircraft shape designed based on JAXA's original low-boom design concept, and demonstrate that the sonic boom can be reduced by half, compared with conventional technology. By promptly demonstrating the effects of this design concept, we aim to establish it as internationally superior technology, transfer the technology to the industrial world, and contribute to the development of the aviation industry in Japan.

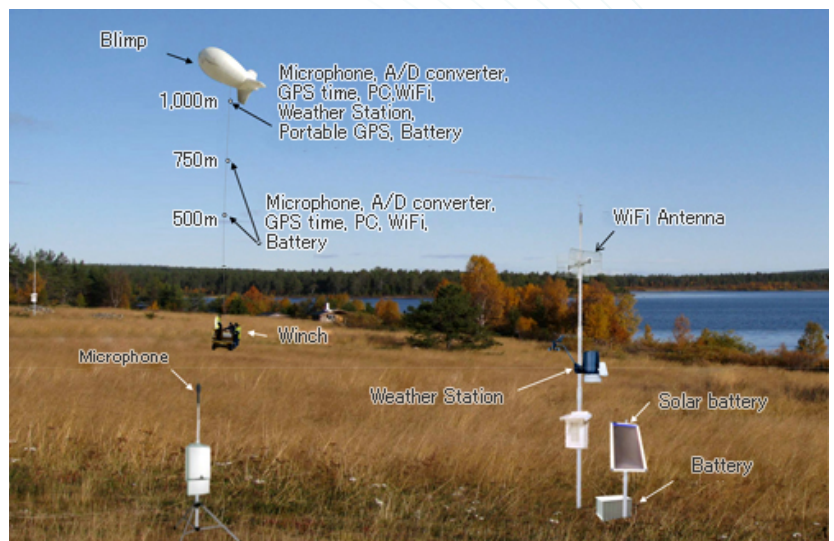
— What are your current feelings about conducting #1?

Yoshida Sonic boom abatement technology is an inevitable challenge in the development of the next generation of supersonic civil transport. JAXA has already developed original design technology and obtained the patent. We believe that this flight demonstration is essential to promote this technology globally and to ensure its application possibilities in future equipment development. #2 aims for exactly that, but #1 is the important first step to its success. Currently, the preparations for #1 are progressing smoothly, and we have great confidence in accomplishing its mission. You should look forward to the results.

Atmospheric turbulence

Fluctuations in atmospheric density, temperature and humidity over time and space. The time and space variations occur on an extremely small scale in the atmosphere from Earth's surface to an altitude of 500 m.

According to test data for the Concorde, it was confirmed that the sonic boom signature measured on the ground differed from day to day, even when the measurement methods, measurement time, flight altitude and weather were the same. This is called the atmospheric turbulence effect.



Boom Measurement System

How to realize a low emission jet engine?

With the recent addition of electric cars to the hybrid vehicles that are available, "eco-cars", which use electric technology, are attracting attention. This is superior technology that reduces CO₂, which is related to global warming, and nitrogen oxides (NO_x), which are a cause of photochemical smog and acid rain, as well as the trails of black smoke that were familiar a decade ago in addition to particulate matter (PM), which has come under close scrutiny as being carcinogenic. But what about aircraft? Although advanced research is being conducted by research institutes including JAXA, the battery to supply the power to propel such a bulk through the air would be extremely heavy using conventional technology. Therefore, an engine that does not greatly differ from the current system, but does not pollute the air around airports or the sky through which airplanes fly is anticipated at least in the near future.

Jet engines produce energy by injecting a spray of jet fuel, which has properties similar to kerosene, from the fuel nozzle, mixing it with air, then burning it. How could we reduce the emissions in the combustion exhaust gas? Wouldn't your instinct be that it would be better for the fuel and air to be well mixed? That is somewhat coarse, but, by and large, the answer is yes. However, there are also cases in which too perfect mixing causes problems: For example,

at low-power operating conditions in which only a small amount of fuel is injected, the fuel distribution should be adequately concentrated in a specific volume of the combustor to avoid incomplete combustion or flame blow-out. Consequently, the key is development of a fuel nozzle that produces an optimal mixture according to the engine operating conditions.

Analyzing fuel spray with light

In order to comprehend the mixing of fuel and air, it is necessary to know where the fuel droplets in the spray are located in the airflow of the combustor (spatial distribution). Additionally, in order to understand why the droplets are carried in that way, we must know their velocity. Furthermore, the fineness of the spray mist, in other words, the droplet size, is an important property of a spray. If we can generate a fine spray, the fuel evaporates quickly and can burn in a well-mixed state at the molecular level. However, with a coarse mist, it begins to burn before evaporating and being completely mixed, causing NO_x and soot to form easily, and at low-power conditions, an incomplete combustion takes place.

So, how can we investigate the size, velocity and spatial distribution of the droplets in the spray? For example, to measure their size, a microphotographic technique was previously

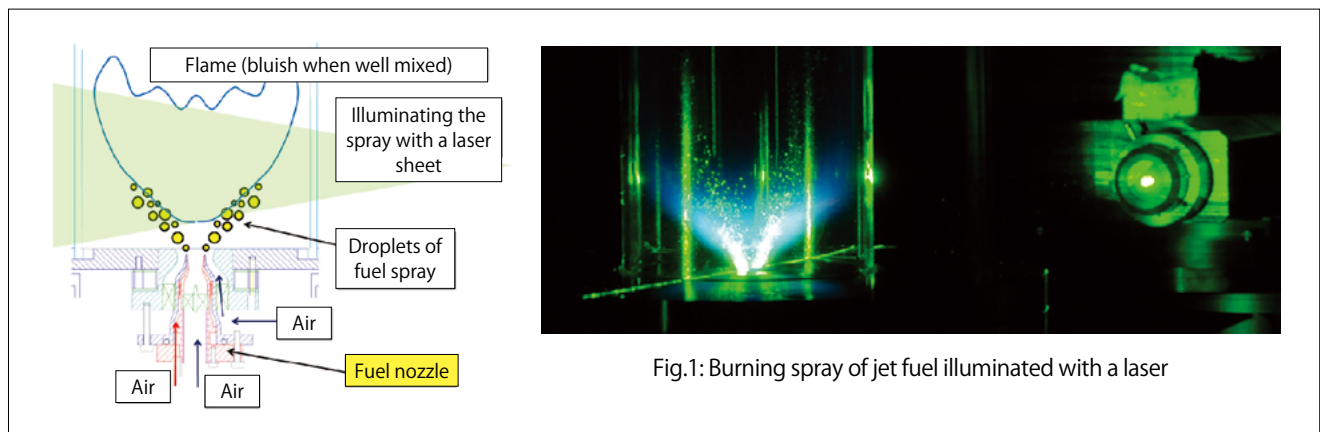


Fig.1: Burning spray of jet fuel illuminated with a laser

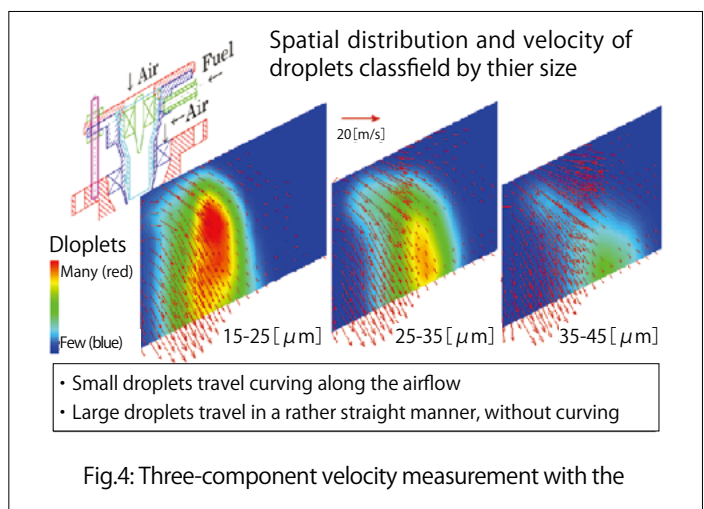
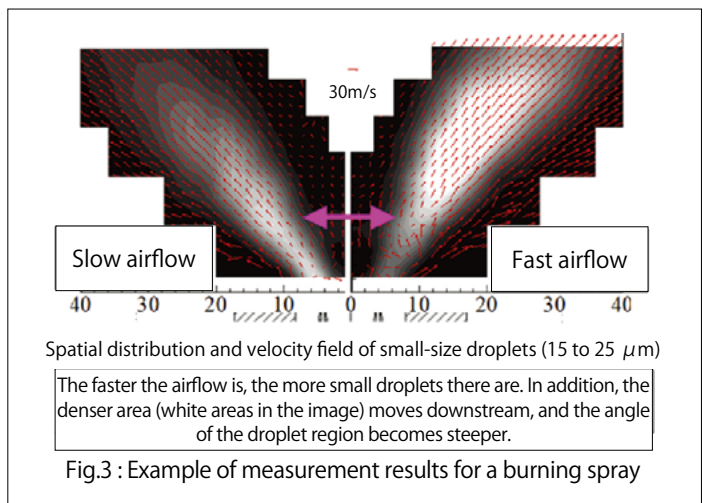
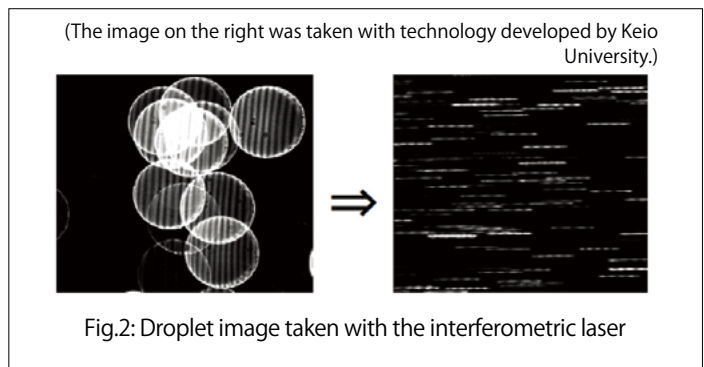


Members of the team in charge of measuring fuel nozzle sprays of jet engines
 (* indicating technical trainees)
 (Front row, from left) Kurosawa, Matsuura, Yamada, Suzuki*
 (Back row, from left) Yoshiura*, Goto*, Fujita* Yoshida*, Ishikawa*

used for droplets collected from the spray. However, currently, measuring by means of light such as laser diagnostic techniques has become mainstream. By using light, we can measure the properties of droplets in their actual ongoing flow without disturbing it. As one example, we will introduce the "interferometric laser imaging technique", which, at one time, can measure the size and velocity of individual droplets in a plane. The spray is illuminated by a planar laser sheet (fig. 1); by purposely taking a defocused photo from an intentionally selected angle, a droplet in the spray appears as "a circle filled with streaks of lines (fringes)" (fig. 2). The size of the droplets can be determined not by the size of the droplet image (circle size), but by the number of fringes. If two photos are taken in a short time interval, the velocity appears through the amount of movement. If the spray is dense and droplet images are overlapping, making it difficult to distinguish them, then we use a special lens system that converts the "fringes in a circle" into "dashed lines", which can be counted to know the droplet size. At JAXA, we are utilizing our abundant know-how of this technique for research of the fuel nozzle spray of jet engines. With this technique as one of the powerful tools, we are investigating the relationship of spray properties with flame structures and emission characteristics, and accumulating design data for nozzle improvement (fig. 3). In addition, we have, in collaboration with universities, further improved the technique to measure the third velocity component of depth in addition to the horizontal and vertical ones. Currently, we are studying how droplets move through a complex airflow depending on their size, and we are striving to understand the phenomenon in the flow field. (Fig. 4)

A great deal of effort is required to accumulate data with these detailed measurements. This research is supported by the activities of the young, determined and energetic students studying as technical trainees with us at JAXA.

(Kazuaki Matsuura)



Research in aerial firefighting technology for firefighting amphibians

— Flight simulation tests with pilots —

Civil Transport Team / Flight Research Center

JAXA, together with ShinMaywa Industries, Ltd. and the Japan Aircraft Development Corporation, are advancing research on the technology necessary to realize a domestically manufactured firefighting amphibian. Based on the short water take-off/landing amphibian technology domestically developed by the ShinMaywa Industries, Ltd., we are focusing on developing a firefighting amphibian with firefighting effectiveness and safety higher than existing machines by providing the firefighting function of aerial water-dropping. (Fig. 1) As part of the examination of technologies necessary for firefighting, we have conducted water-drop tests using aircraft models in an existing JAXA wind tunnel and examined the behavior of dropped water. In order to study a pilot interface suitable for firefighting tasks, we began assessment testing with pilots using JAXA flight simulators in 2009. (Fig. 2) In this article, we will introduce the conditions and implications of the tests conducted by the members of Civil Transport Team and Flight Research Center in December 2010.

Making dangerous aerial firefighting safe

Firefighting amphibians are amphibious aircraft that can be



Fig. : Illustration of a firefighting amphibian

The low flight speed and 12-ton water capacity, about 2.5 times that of existing airplanes, ensures that the fire is extinguished. Since this plane can take off from and land on water, it can take up a large amount of water in a short time. The illustration was provided by ShinMaywa Industries, Ltd.

used for combating fires from the air. There are no fixed-wing aircraft doing this work in Japan, but they are used overseas to fight large-scale fires, such as forest fires. Compared to firefighting with a helicopter, these have many advantages like the ability to carry a large amount of water and take it up in a short time. However, there is a high degree of difficulty in visually fighting fires while flying, and accidents frequently occur since it is necessary to aim at the fire and dive close to it, then quickly fly away after dropping the water. Therefore, we are focused on developing an aircraft capable of extinguishing fires both accurately and safely.

Pilot assessment through flight simulations

As a solution to this, we are examining the installation of a system that provides pilots with visual support information so that they can safely and accurately perform their firefighting tasks. A computer calculates and generates support information, such as the guidpath to the fire and the timing for dropping water, then shows it in the display. If pilots operated the aircraft according to this information, they could safely drop the water at the proper location. (Fig. 3)

In order to assess firefighting tasks using this system and determine issues, we have conducted simulation flight tests with multiple pilots using JAXA's flight simulator. By inputting characteristic data on firefighting amphibians and data on water-drop behavior previously obtained from wind tunnel testing into the flight simulator, we are able to simulate actual flights affected by, for example, flight altitude and speed as well as terrain and wind direction.

We set up various flight scenarios from water scoop to water drop and, by flying according to each of them, we were able to obtain such data as "which flight method is safe", "how water should be dropped to fully extinguish the fire", "which information display is easy to understand" and "how it was perceived".

Research members in the flight simulation tests for a firefighting amphibian
 (From left) Koji Muraoka, Kohei Funabiki, Ryoji Yamamoto,
 Hiroka Tsuda, Kaoru Wakairo, Hiromi Takaoka, Takeshi Ito

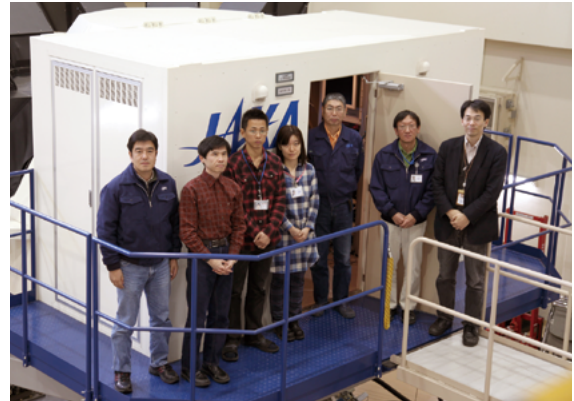


Fig.2: Flight simulator testing

Mountain fires are simulated in the flight simulator, and water-dropping flight is assessed. We are assessing research of more effective operation support technologies in addition to displaying information on the fire and water-drop position in the instruments as well as in a helmet-mounted display (HMD), described later.

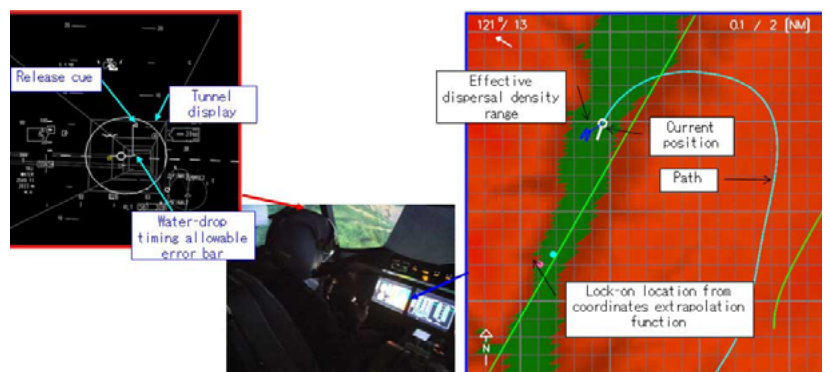


Fig.3: Sample of information displayed in the HMD

Pilot wearing an HMD. Support information appears in the visor in front of the face. By flying according to the tunnel display, the pilot can safely arrive at the water-drop location. As the plane approaches the target, the release cue is gradually lowered, and the water for extinguishing the fire is dropped when the allowable error bar is reached.

World's first application of visual information support technology to firefighting amphibians

Some devices that show support information to pilots include displays installed in the instrument panel and displays attached to the pilot's head. Based on the results of simulator tests conducted in 2009, where pilots watched displays in the instrument panel, we have carried out research and development of more effective operation support technology using helmet-mounted displays (HMD), developed through collaborative research performed separately with Shimadzu Corporation.

For example, by locking onto the fire using an HMD and the generated tunnel display, shown in figure 3, the pilot can fly toward the water-drop location according to the operation support display. We are aiming at realizing technology that, in addition to allowing the aircraft to arrive at the fire safely as described, will automatically drop the water at the ideal

location to ensure that the fire is extinguished.

If aircraft equipped with this type of pilot visual information support device could be realized, it would be the first firefighting amphibian of its kind in the world.

* * *

The data that we have obtained is currently being analyzed. Additionally, we are measuring wind conditions during actual flights and assessing gusts near fires as well as establishing water-drop flight methods that take these into consideration. Moreover, there are many issues such as the effects on engines from smoke and increased temperatures near fires as well as the effects on the structure due to sudden changes in the load when water is dropped. Therefore, we are studying the implementation of tests, and continuing collaborative research with the aim of contributing, through JAXA's large equipment and advanced technology, to the realization of superior aircraft with unparalleled performance.



Interview

People who fly dreams

Vol.18

Developing a high-accuracy airplane navigation system

Operation and Safety Technology Team
Yoshimitsu Suganuma

✈ In this interview, we will talk with Yoshimitsu Suganuma of Tamagawa Seiki Co., Ltd., who is tackling research together with JAXA. Four years after joining the company, he was transferred to JAXA. He is involved with research of navigation systems, and this year will be his second year here. Let's find out what Mr. Suganuma, who remarked that he became associated with the aviation field for the first time after coming here, is working on every day.

In an emergency, airplanes cannot stop in the air.

✈ What is the Navigation Technology Section researching?

Suganuma We are researching the technology necessary to create a navigation system, which you could say is the airplane version of a car navigation system. The technology for accurately knowing the location and attitude of airplanes has become essential.

✈ So, airplane navigation is about to

change now?

Suganuma Currently, aircraft fly relying on radio waves sent from radio base stations on the ground. However, in the future, this will be replaced by a method of flying relying on radio waves from artificial satellites such as GPS. Today, aircraft have to take circuitous routes to fly over the base stations to their destination, which is not very efficient, but satellite navigation allows them to travel in a straight line to their destination.

With GPS satellites, there is some error since they were not originally developed for airplane navigation. Therefore, it is necessary for high accuracy and reliability to send to the aircraft correction values calculated with the GPS signal received on the ground. GBAS (ground-based augmentation system) and SBAS (satellite-based augmentation system) are being considered as augmentation systems. At present, these systems are being implemented globally in trial installations and the technologies are being confirmed.

We are researching high-accuracy navigation systems that integrate GPS and INS (inertial navigation system) in order to increase the reliability of satellite navigation. External signals are not necessary with INS, which allows continuously highly accurate navigation when combined with GPS. Since the GPS signal may temporarily not be received when the airplane attitude changes or an absurd location may be outputted when the GPS satellite fails, we must focus on eliminating such errors. On the

ground, we can make decisions based on information from our surroundings if errors occur, but in the sky that is difficult, requiring a highly reliable navigation system.

✈ Has the GPS/INS integrated navigation system already been commercialized?

Suganuma Micro-GAIA was developed through a collaboration between JAXA and Tamagawa Seiki. Currently, we are tackling research to further improve the reliability of this technology and apply it to manned aircraft.

✈ What was your role at your previous employer?

Suganuma I suggested the hardware to be produced, installed the prototype on aircraft and measured navigation data in flight.

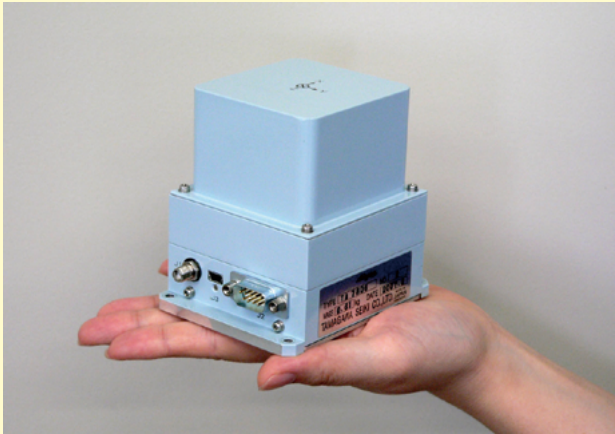
✈ What other issues are there?

Suganuma There are many causes of errors in the results received from GPS, but one is the effects of the ionosphere. The ionosphere is a shell of electrons and electrically charged atoms and molecules in the upper layer of the atmosphere. Its density is not uniform and varies by location and day. Therefore, the error in the GPS signal that passes through it will differ.

We know that, in addition to this, a phenomenon occurs in Asia where the electron depletion density in the ionosphere has a bubbly appearance, like a foam, which is called plasma bubbles. The error further changes according to differences in the density of this foam, whether or not this foam is at the location, or whether the foam is slightly grazed. Since this



Yoshimitsu Suganuma
Navigation Technology Section
Specialized in electromagnetic compatibility in graduate school



Micro GPS/INS integrated navigation system "Micro-GAIA"
 This navigation system combines a small GPS receiver for portable electronic devices with only 1 to 2 cm² micro gyros and accelerometers. The system has a mass of about 600 g.

phenomenon is specific to regions at low latitudes near the equator, such as Southeast Asia, and Japan receives GPS signals that graze it, we must study how much of an error occurs due to it. JAXA has set up a gauging station in Thailand to obtain data from there, and we are studying how raw data received simply from GPS satellites fluctuates before the position is calculated.

✈️ What are the difficulties of your job?

Suganuma It is definitely the flight tests. In order to verify the performance of devices during flight, I am flying in a way that is not experienced when I fly the airplane normally. I sway and am jerked like on a roller coaster. It is difficult even if your body is accustomed to it. When it is especially difficult, I take motion-sickness medicine before flying.

Declaration of an actively involved father!

✈️ What was your childhood like?

Suganuma I liked soccer, and I played from second grade in primary school until I graduated high school. Now, I occasionally participate in games with the JAXA team since I was invited to join the team.

✈️ What are your hobbies other than soccer?

Suganuma Since I worked at a video rental shop when I was a university student, I took in a lot of information and watched a random variety of movies that seemed interesting. The bulk of the rentals were movies that were not shown in

movie theaters, so I saw many of these types. These movies are shown on TV late at night, and I still find myself watching them now.

✈️ What was your motivation for choosing this career?

Suganuma Originally, I wanted to go into architecture. When I was little, our house was being rebuilt, so I watched the carpenters steadily build our house. I thought designing was interesting, and I considered continuing with something related to that at university. However, when I was taking entrance exams and deciding my career, it was the time when the construction industry was just beginning to have difficulties and my family was strongly opposed to it, so I went into information communication. But, after entering the field, it became interesting since it is similar in that we are designing something.

✈️ What do you enjoy doing in your free time?

S u g a n u m a

Recently, we had twins, and there is not much time on weekdays, so I give the babies milk and change their diapers to help my wife. Raising children is difficult, but I enjoy being involved in parenting since I can savor them growing a little day by day.

✈️ What are your future goals?

Suganuma At my company, I was primarily responsible for hardware development. After coming to JAXA, I have participated in software development, and I feel that it has broadened my view. After returning to my company, I will have less time to devote to research, so I would like to increase my knowledge as much as possible during the few remaining months that I am here. I don't know whether I will be able to immediately apply what I have learned over the past nearly two years, but, since even more advanced technology will become accessible a few years from now, I think it would be great if I could apply it to something in the future.



Conducting flight tests
 Checking the next flight pattern

