Assessment methods suitable for sonic booms

- First step toward new international standards -

Quiet supersonic aircraft have long been a dream; however, we are now seeing the prospects of airframe design technology that would greatly reduce sonic booms, as compared with the Concorde. Therefore, efforts have been initiated to revise the rules prohibiting over-land supersonic flight in order to allow supersonic flight even over land. With the aim of realizing a revision of these rules, establishing the metrics suitable for regulating this particular noise known as a sonic boom has become the issue. In this article, we will introduce sonic boom research at JAXA, other than "low-boom" airframe design technology.

The prospects of quiet supersonic flight design

Do you know the words "sonic boom"? Since these words have appeared several times in past Aviation Program News articles, you may have heard them or may somewhat know what a sonic boom is. In general, however, it is not well known. The reason is that, in our everyday lives, we rarely encounter a sonic boom.

A sonic boom is the change in air pressure observed when the shock wave produced by the sharp compression of air around an aircraft flying at a supersonic speed (speed faster than the propagation speed of sound) propagates and reaches the ground. This pressure change vibrates a person's eardrum and is perceived as a sound. Because a sonic boom is attributed to a shock wave, it has rapid pressure changes and is heard as an explosion-like sound.

This sonic boom phenomenon was identified over half a century ago. In fact, a sonic boom was generated even when Chuck Yeager broke the sound barrier for the first time in human history in 1947. Despite the fact that the sonic boom has been known for that long, why have we never heard it? That is because aircraft do not fly at supersonic speeds over inhabited areas. From 1976 to 2003, the supersonic transport called the Concorde provided regular service, mainly connecting the United States with Europe. Although even the Concorde caused sonic booms during supersonic flights, it flew at supersonic speeds only over the ocean, so there were no people who heard the sonic booms of the Concorde on a daily basis.

The Concorde was a supersonic transport that was not designed with special consideration for reducing the sonic boom. The sonic boom generated by the Concorde was extremely loud, almost like an explosion, and therefore had been clearly determined to interfere with people's daily lives. As a result, supersonic flight of civil passenger aircraft was permitted over the ocean, but over-land supersonic flight generating a sonic boom that has a large effect on people's lives was prohibited as a general rule. This regulation has not changed so far. Thanks to this, we are no longer disturbed by the noise of sonic booms; however, due to the large restrictions imposed on the routes where supersonic flight is possible, the advantages and appeal of operating supersonic passenger aircraft had greatly decreased.

Consequently, for widespread use of the next-generation supersonic transport to succeed the Concorde, it is essential to allow supersonic flight over land. Therefore, we must first reduce the sonic boom that is at the origin of these rules prohibiting supersonic flight over land. In recent years, research on technology to reduce sonic booms has been actively pursued both domestically and overseas. These are primarily the technology for designing the airframe shape of supersonic aircraft in order to reduce the sonic boom on land, based on detailed analyses of how shock waves occur in the vicinity of aircraft and how those shock waves propagate to the ground as a sonic boom. With this low-boom airframe design technology, it has now become possible to design aircraft with a substantially reduced sonic boom in comparison to the Concorde.

Pursuing assessment criteria

Supersonic flight over land cannot be realized, no matter how much sonic booms can be reduced, as long as there are restrictions prohibiting over-land supersonic flight. Therefore, there are moves to formulate new international standards concerning sonic booms and over-land supersonic flight, mainly at the International Civil Aviation Organization (ICAO), a specialized agency of the United Nations that establishes various international standards relating to aircraft. However, with serious discussions having only just begun, the establishment of standards is expected several years from now.

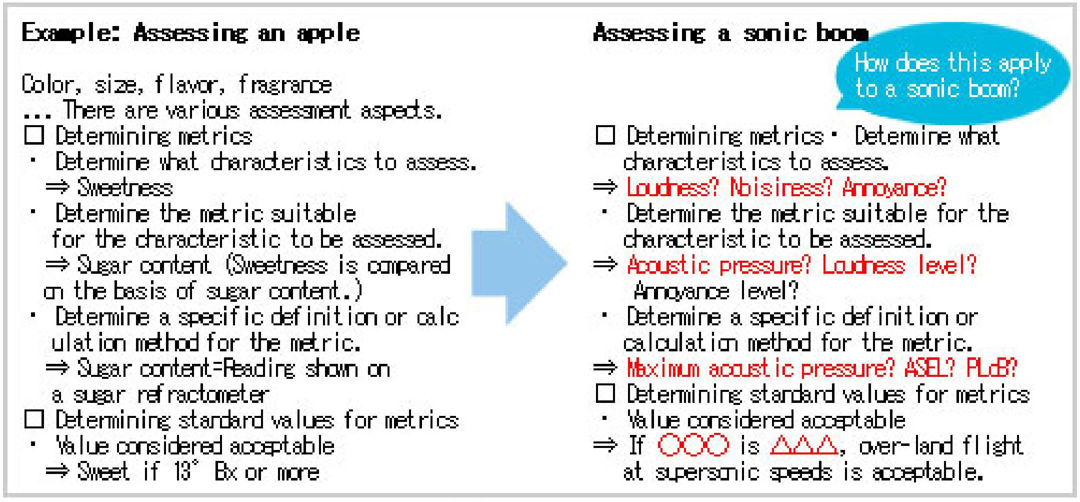
One reason that time is required to create standards is that a method for assessing sonic booms has not been established. Normally, noise standards are determined by "metrics" (the criteria of how noise is assessed) and "standard values", which indicate the permissible level of the metric. To establish sonic boom standards, metrics must first be determined. However, sonic booms possess somewhat special acoustic characteristics, compared with other noises. Specifically, sonic booms have a significantly large level of changes in the sound pressure (acoustic pressure), include many extremely low-frequency sound components (infrasonic components), which cannot be heard by the human ear, and are impulsive, short sounds similar to an explosion due to the rapid acoustic pressure increase originating with the shock wave. At the present phase, research is being conducted on the metrics appropriate for assessing sonic booms, which have these special characteristics.

Start of jury testing

Research on assessing sonic booms is also being conducted at JAXA. Since a sonic boom is an acoustic phenomenon, hearing the actual sound is essential to making an assessment. Although the acoustic characteristics of a sonic boom have been explained above in writing, it may be difficult to understand what type of sound this is-even more so if it has never been heard. One way of assessing a sonic boom is, of course, to listen to one generated from an actual aircraft flying at a supersonic speed. However, since this would be a very large-scale experiment and it would be difficult to control the waveform and the magnitude of the generated sonic boom, this is not necessarily appropriate for the purpose of obtaining a large amount of assessment data with the high reliability required for research. Therefore, equipment for generating a sound simulating a sonic boom, called a sonic boom simulator, is commonly used in sonic boom assessment testing. JAXA has developed a sonic boom simulator (fig. 1), and is performing assessment testing on trial subjects.

In order to review metrics through jury testing, we must consider what characteristics of sonic booms must be assessed. Since a sonic boom is a type of sound, we first consider the general characteristics of sounds. Sound has three attributes: loudness, pitch and timbre. As shown in fig. 2, loudness is related to

Fig 1: JAXA sonic boom simulator



What is sonic boom assessment?

the magnitude of the acoustic pressure, pitch is related to the frequency, which expresses the speed at which the acoustic pressure changes, and timbre is related to the waveform, which expresses temporal changes in acoustic pressure. The horizontal axis of fig. 2 represents time, and the vertical axis represents acoustic pressure. Of these three attributes, "loudness" appears to have the most relevance when creating standards for sonic booms.

Human hearing is sensitive to sound differences of 1/1000 second

In order to assess the magnitude of a sonic boom perceived as sound, we should of course examine the magnitude of its acoustic pressure. In fact, it is not as

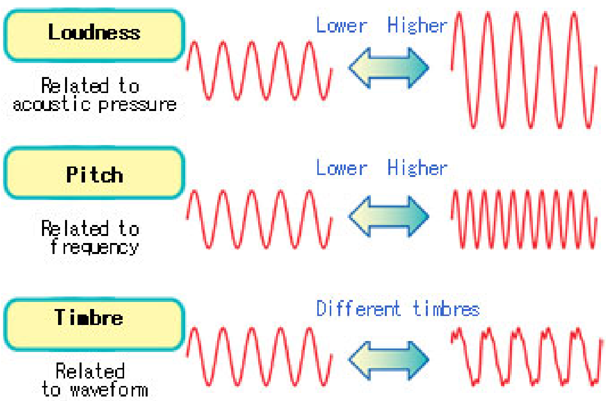


Fig 2: Three attributes of sound

simple as that. For example, look at the three waveforms in fig. 3. As in fig. 2, the horizontal axis represents time, and the vertical axis represents acoustic pressure. Each waveform has a shape resembling the letter "N". This N-shape is a typical acoustic pressure waveform for sonic booms generated by conventional supersonic aircraft like the Concorde. What would be the result of arranging the three waveforms in descending order of the sound's loudness? Considering that the loudness of sound is related to the magnitude of acoustic pressure, as previously described, they would be arranged in descending order as C→A→B. However, from the results of the jury tests, the descending order was assessed to be A→B→C. These are not the same, whether in descending or ascending order of the maximum acoustic pressure. With an N-wave, the sections where the pressure rapidly increases, which correspond to the vertical bars on the left and right sides of the "N", have a large effect on human hearing. By overlapping the three waveforms in fig. 3, we can see that the slope of these sections only differ slightly. (Fig. 4) A is a waveform that has been stretched vertically to twice the size of B, making the slope of the rapid pressure rise twice as steep. By contrast, the amount of the pressure increase is larger for C than for A and B. However, the time duration for the pressure rise in C is longer than those of A and B, resulting in a gentler slope. The difference in time duration necessary for rapid pressure increase is merely 1/1000 second to 1/100 second. It is difficult to understand such a slight difference by visually

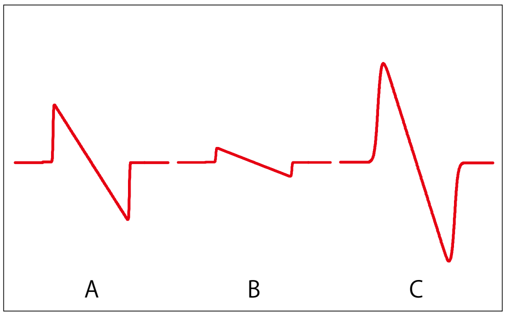


Fig 3: N-shaped sonic boom waveforms

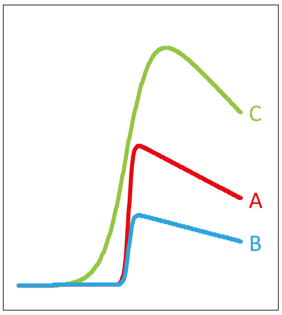


Fig 4: N-shaped sonic boom waveforms (sections of acoustic pressure increase)

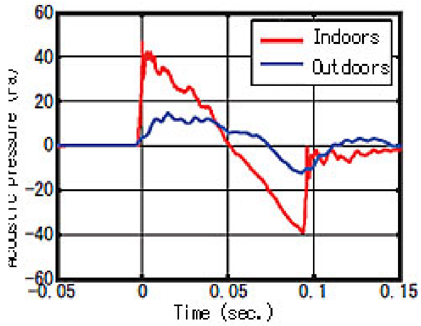


Fig 5: Outdoor and indoor sonic boom waveforms

comparing the graphs arranged as in fig. 3; however, the difference in loudness is distinctive when these sounds are heard. The human ear (auditory system) can perceive even such small changes, and is very complex. In order to examine how people feel a sonic boom with this complex human sense, it is best to perform jury tests so that the actual sound can be heard. Although we have the saying "seeing is believing", when assessing sounds, "hearing is believing".

Previously, we explained that the acoustic pressure waveform of a sonic boom is typically shaped like the letter "N". However, we expect the pressure waveform of sonic booms generated by the next-generation supersonic aircraft not to have this N-shape. With low-boom aircraft design, we are aiming for the sonic boom waveform observed on the ground to have a shape that is less loud to the human ear than the N-wave. Such a low-boom waveform may have a complicated waveform, compared to the N-wave. How will human hearing react to such a complicated waveform? The answer to this question must also be pursued by collecting and analyzing data through future jury tests.

Assessing a sonic boom heard indoors

Another important consideration is the indoor assessment of sonic booms. With over-land supersonic flight, the sonic boom will naturally also be heard indoors. As with normal noises, the sound of a sonic boom inside a building should be less loud than outside. Looking at the results of the sonic boom measurement test performed by JAXA in 2009, the acoustic pressure is significantly reduced indoors as compared to outdoors. Also, the waveform observed indoors has no rapid acoustic pressure increase as seen in the outdoor N-wave, and has a gentle slope. Therefore, the loudness of a sonic boom perceived indoor should be smaller. However, in addition to the direct impact that a sonic boom has on hearing indoors, secondary noises, such as the rattling of windows induced by vibration of the building's walls and windows due to the abrupt acoustic pressure increase and low-frequency component of sonic booms, affect human perception. For this reason, effects other than the loudness of the sound, such as discomfort and annoyance, are greater indoors, and it is said that the psychological effects caused by a sonic boom are larger indoors. Therefore, it is believed that, as metrics to be used in international standards, it is necessary to investigate how to also assess these indoor effects; however, detailed research has only just begun.

As explained, there are still many issues concerning the research of assessing sonic booms. At JAXA, we are proceeding with jury tests for assessing sonic booms in order to tackle these issues as well as contributing to establishing new international standards indispensable in realizing over-land supersonic flight.

Supersonic Transport Team
Yusuke Naka

Research Report

From the research filed

Making aircraft at a lower cost by changing the method of joining materials

— Research on fatigue strength of friction stir welded structures

Civil Tranport Team / Operation and Safety Technology Team

Rivets are predominantly used to join aluminum alloys, which are frequently used in aircraft construction. Friction stir welding (FSW) is being recognized as a different joining method. Some of its advantages are that the aircraft weight is reduced by decreasing the number of parts and that the aircraft is manufactured at lower costs. With the aim of applying FSW to large-scale aircraft, JAXA's Civil Transport Team, Operation and Safety Technology Team and Waseda University are working together for the safety of aircraft construction using the FSW joining process. We talked with researcher Takao Okada.

What is FSW?

Friction stir welding is a solid-state joining process of softening the pieces in the area to be joined with frictional heat in order to combine them. This is a type of welding, but the difference with other conventional welding processes is that the pieces are joined without reaching the melting point. Since conventional welding while exceeding the melting point weakens the material by creating flaws such as voids or cracks in the weld area, joining using rivets is the most commonly used process in the construction of aircraft. In contrast, FSW has the advantages that the weld area has high strength, and a product of consistent quality can be created since the joining operation can be automated.

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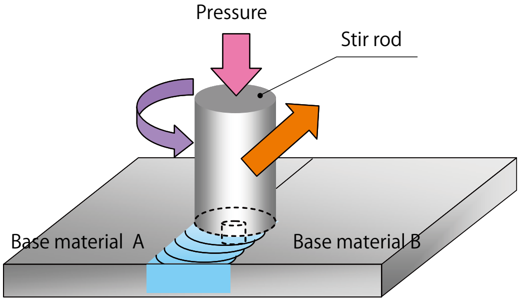
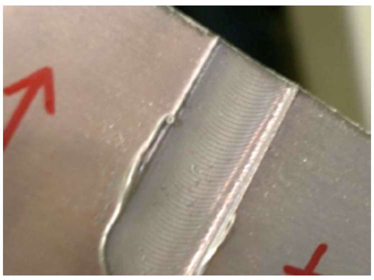
Since its invention in the 1990s, this process has been applied to railroad vehicles, ships, automobiles and so on. In the aerospace field, this process was used on part of the H-IIB launch vehicle, which was launched last year, and it has proven successful when applied to part of the main structure of a six-person small jet. However, can the same safety as with previous processes, such as riveting, be ensured when this new welding process is applied to the construction of even larger aircraft? To that end, we are researching analysis technology while performing various tests to understand the fatigue(*) properties of FSW-joined structures.

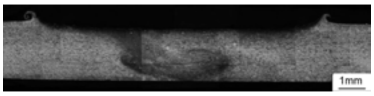


Weld area



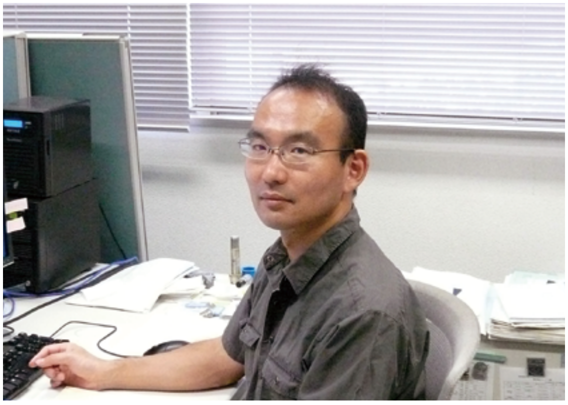
Weld area

This is technology where metal is joined at a temperature below the melting point through frictional heat created by rotating the pin at the end of a stir rod and feeding it between base materials A and B, which are to be joined.

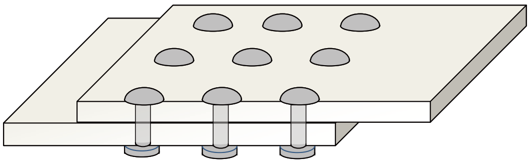


Cross-section of weld area

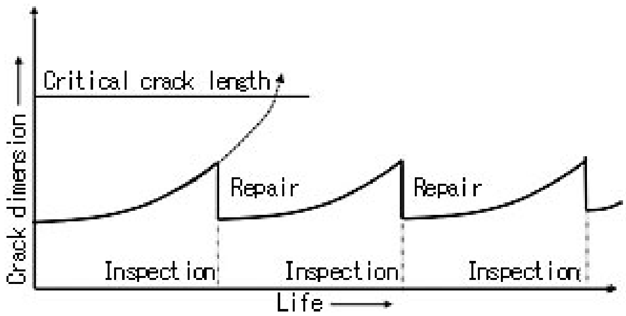
What is friction stir welding?



Operation and Safety Technology Team
Structural Evaluation Section
Takao Okada



Riveted joint



Inspection interval in damage-tolerant design

(*) Process where an object breaks as a result of being subjected to a repeated force; The object fractures when subjected to a repeated force, even if the force is less than what is required to break the object at once.

Damage-tolerant design

The design standard for aircraft structures is based on the concept of damage-tolerant design. Damage-tolerant design enables a structure to withstand the load of a part of the structure functioning during operation, even after a certain level of damage has occurred in the main structure. In other words, aircraft are created to ensure structural safety through detection during inspections and through repairs before reaching the point of failing, even if cracks, for example, arise from any damage that may occur during manufacturing or operation. Therefore, the manufacturer is not only providing a sturdy aircraft but also establishing an inspection and repair program. By guaranteeing structural aircraft safety in this way throughout its entire operation, authorization to manufacture and to operate the aircraft can be obtained from the Aviation Authority (government).

Aircraft applications

How should aircraft structures be designed using FSW so that damage tolerances are met? We must first clarify the progress of fatigue cracks as well as the mechanism in which FSW construction reaches the point of fatigue failure. Therefore, by performing various fatigue tests of FSW-joined aluminum alloys used in aircraft to obtain data, we are conducting the following research. (1) Gaining an understanding of the factors affecting the strength of FSW; (2) Investigating where fatigue cracks occur in structures created using FSW; (3) Revealing the behavior of the fatigue crack from its formation emerging from damage to the point of structural failure.

Furthermore, based on this testing data, we are also tackling the following: (4) Developing technology for calculating and predicting how cracks progress. If we could understand how cracks caused by damage progress, and how they reach the point of failure, we could create a design taking these into consideration and specify suitable inspection intervals.

*

When new construction technologies are developed, we must adequately verify their safety in actual applications, no matter how important a discovery they are. That is why we are continuing with future research.

Brains of the engine Advancing control

Interview
People who fly dreams
Vol.17

Clean Engine Team
Takeshi Tagashira

Sending and compiling commands that integrate components such as turbines, compressors and combustors to exert engine power is called control technology. Controlling constantly varying engine states from take-off to landing is already remarkable, but that is not all there is to it! Engines of the future will be able think for themselves. Let's take a peek at a place where this control technology is being researched.

What can be controlled

What are you researching?

Tagashira　You may think of a jet engine simply as an object, but actually it is a combination of technologies from a wide range of fields. Some people are specialized in aerodynamics, thermal dynamics or heat transfer, and others are specialized in combustion, cooling and mechanics. Of these, I am in charge of control.

With a jet engine, if the fuel is not adequately controlled, you will not get engine acceleration or deceleration. In addition, if the engine speed is not increased or decreased using a fuel injection schedule or some other method, the engine may run away or stall. Since it would be dangerous if this happened during flight, we must make sure that the fuel is controlled accurately. However, this is already being established to some extent.

Until now, the primary goal was control for operating the engine safely, but it is no longer just that. Global research should be directed at control that is performed automatically to run the engine more efficiently, to respond to a malfunction that has occurred, or to make minute adjustments in order to maneuver if a malfunction seems to be occurring. I call this intelligent control. Considering that efficiency falls with repeated use, the goal is to design an engine that performs well by tuning itself while operating.

What are the specific merits?

Tagashira　Extending engine life. Reducing fuel consumption. Improving safety. Reducing direct operating costs such as maintenance. These are possible through control without changing the engine structure or design.

Take, for example, the operating point of an engine. This is determined to be the point where a certain amount of fuel is released at a certain pressure ratio at a certain rotational speed. However, when the efficiency of the engine drops, it may just not be that point anymore, and it may be better to operate it differently. Would it be better to reduce or increase the fuel just a little more, slightly constrict or expand the nozzle area, or perform a small tuning operation to extend the life of the engine-these are the types of things that could be done.

Although they are man-made objects, in fact, different engines of the same model do not necessarily display exactly the same efficiency. The slightly different working accuracy of each part that constitutes an engine, such as the compressor, adds to the variability of the efficiency. Yet, we are using something uniform as the controller. If we can individually control the burning of fuel at an optimal level for each engine, should there be variations, we would be able to run a more efficient engine according to its individual performance. For this reason, a control mechanism that incorporates a function for monitoring the engine status is necessary. We are aiming for future engine control to be able to simply feed back monitoring information and perform control operations.

Can this be done by an engine controller during flight?

Tagashira　It is like self-medication, and monitoring is an examination, similar to that given by a doctor. More specifically, it is like exercising with a device attached to measure heart sounds. If your heart rate rises, you would slightly decrease your pace or you would try to rest. If you started to feel really bad, you might

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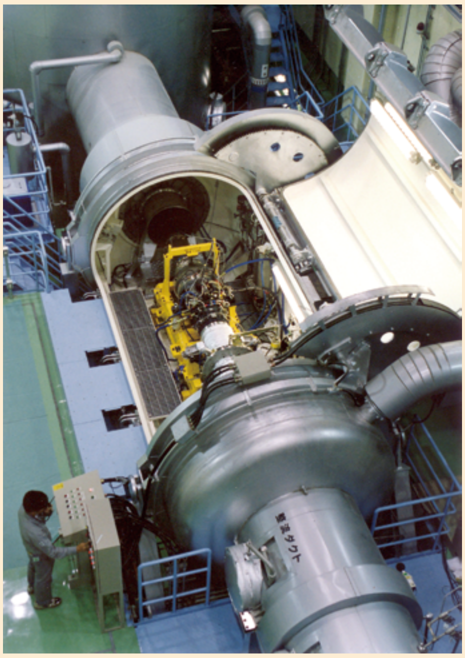
Majored in mechanical engineering as an undergraduate



High-altitude engine test facility-Allows to simulate the actual conditions of aircraft in flight and operate an engine

try to schedule an appointment with a medical professional, and you would try to endure it until then. The controller is doing these types of things.

This monitoring can be done where there are sensors, but they actually cannot be placed in all areas of the engine. There are some places where they do not fit. Currently, efficiency changes, for example, are being detected by means of those limited sensors. In addition, the sensor readings are not 100% accurate. Some readings contain a certain level of noise.

In order to come closer to reality, we are creating, within the control program, a sort of virtual engine based on a physical dynamic model. With that, we are able to use calculations even to obtain temperatures in locations with no sensors. With this model, there is a difference between the simulation results and the measured results, but by feeding back the measured values into the physical model and making calculations, we are able to faithfully reveal the actual engine efficiency. Moreover, the reliability is extremely high, even for values obtained through simulation for places with no sensors.

Does the program you are working on go in the controller?

Tagashira That's right. But, at this point, it is still just PC-based. What I have previously described is called a Kalman filter. Although we know that we are able to make estimates using a Kalman filter and apply feedback control, we are only beginning preparations for the next step of embedding the program that we have created into the controller.

Salesperson for the research laboratory

Have you always done research on engine control?

Tagashira Although it was about control, the topic was slightly different from now. With few results during the first 10 years in addition to fatal flaws, it was very frustrating. Just at that time, I was temporarily transferred to what was then known as the Ministry of International Trade and Industry, so I stopped researching and devoted myself to a new job for about a year. I went to the Ministry of International Trade and Industry to provide technical support based on my experience as a researcher, but it was a good opportunity to dedicate all of my efforts to being a type of salesperson for NAL (National Aerospace Laboratory of Japan; one of the organizations preceding JAXA) by marketing it and collecting information. As a result, I was able to take a break from what I was doing and reset. The current topic is what I have been doing since returning. It was good that I was able to tackle it feeling refreshed. It was tough. (laughing) Now, there is a good environment in engine control research. There are facilities in place. It is unfortunate that there are so few people involved. There are only a handful of control researchers in Japan.

What are your future goals?

Tagashira I would like to develop an engine, from start to finish. I would like to experience being involved in the development and design of an engine system, as a central figure, creating the engine as well as conducting field testing and fatigue testing in addition to flight testing, not just have control technology that I created incorporated into an engine. Long ago, I contributed a great deal to NAL in the development of the FJR engine. It would be great to be able do that sort of thing.

Takeshi (top) preparing for model-engine testing. Checking the monitor outside the test room during the experiment