RESEARCH INTRODUCTION

Enhancing domestic wind tunnel technology to heighten Japan's competitiveness in international markets

JAXA owns and operates seven basic wind tunnels designed for the development of aircraft and spacecraft. Over the last year, the Wind Tunnel Technology Center (WINTEC) has drawn up the "JAXA Wind Tunnel Vision 2025," a guiding principle for managing and planning out research and development for these wind tunnels in the future. To learn more about this vision, we spoke with Masashi Shigemi,director of the WINTEC, and Shigeya Watanabe, one of the leading creators of the vision.

A shared and clearly defined objective will promote "willingness" and a sense of "unity."

Why did you draw up the JAXA Wind Tunnel Vision 2025?

Shigemi: We were convinced that the motivation of the entire Wind Tunnel Technology Center would grow if we had commoQn challenges and dreams. Another important factor was the enforcement of the "Space Basic Law," a legislation laying down the policy for Japan's space exploration, from August of last year. Aware that this law would serve as an encouragement to JAXA, we realized that much could be gained from coming out with an orientation for wind tunnel facility management and wind tunnel technology development.

Watanabe: In March 2005, JAXA painted an ideal future for the field of aerospace over the next 20 years by drawing up the Long-Term Vision (JAXA2025). While this vision looked forward to a new generation of wonderful technologies, it offered little direction on how to develop the fundamental technologies required for realization. To respond, we decided that it would be necessary to create a set of hierarchical visions for each technical item to be pursued. This is how we came to develop our vision for wind tunnels, as leaders in that area.

How did you work out the vision ?

Watanabe: First, we set up a committee of knowledgeable persons from outside the agency, to discuss how the Aerospace Research and Development Directorate should carry out its R&D in wind tunnel engineering. Then, based on the opinions from this committee, the director of the WINTEC brought together section leaders and equivalent persons for discussions on a more concrete plan. Through these discussions, we came up with three pillars for the vision. Then we listened to opinions more extensively, including those of the young people who will actually be forging the future of wind tunnels. Finally, we drew up a vision which reflected all of the opinions we had sounded out. In listening to the opinions of young people, I have had a growing desire to pursue truly great objectives. By pursuing great objectives, we can take pride in our purposes not only as a nation, but as humankind the world over.

Concrete activities to achieve the vision

We hear that it will be necessary to obtain wind tunnel users from abroad to achieve the first vision.

Watanabe: Users from all over the world have their own diverse technologies. At JAXA, we hope to absorb outstanding technologies by bringing in users with high engineering capabilities from the United States and Europe. By having such users work with our wind tunnels, we will also be able to publicize our technologies widely to other parts of the world. In this way, we think we can improve and enhance wind tunnel technologies and management know-how through hard work in friendly international competition. This, we think, will lead to the achievement of the first vision. But we must remember that JAXA's wind tunnels are positioned as "test facilities standard in our country." In light of this, we have to seriously consider the balance between testing by domestic users and testing by overseas users.

As the second vision, we've heard that you are considering the development of the world's No. 1 wind tunnel.

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Shigemi: The aerodynamic performance of almost all aircraft and spacecraft developed domestically are confirmed in JAXA's wind tunnels. Indeed, JAXA's wind tunnels have a long history of achievement and value. But the tunnels were constructed many years ago. Now they are quite old, and their designs disregard the new and very important requirements for environmental measurement, such as measurement of noise. The same holds true for many of the large wind tunnels used for aircraft development in other parts of the world. If we can develop a low-speed wind tunnel, the first candidate, equipped with environmental (noise) measurement capabilities together with the ability to simulate the flight conditions of actual aircraft and spacecraft," the tunnel will be the only of its type in the world. This would be a boon for Japan's international competitiveness in aerospace.

JAXA Wind Tunnel Vision 2025

Through the achievement of the vision, contribute to advance toward the realization of the JAXA Long-Term Vision and to improve the international competitiveness of domestically produced passenger aircraft.

1. Through the development of wind tunnel technology, create the world's most advanced wind tunnels and position them as the Asian standard wind tunnels.
   Invite 10% or more of the JAXA wind tunnel users from abroad.
2. Develop a world-class wind tunnel which outstrips the testing abilities of wind tunnels in the United States and Europe.
   One promising candidate for development is "the world's only low-speed wind tunnel capable of measuring environmental (noise) properties and simulating flight conditions of actual aircraft and spacecraft." We will be conducting studies to investigate the potential for this candidate in the future, including studies on "low-cost transonic wind tunnels with world-class performance and efficiency."
3. Obtain the world's top technology for predicting and evaluating the aerodynamic characteristics of actual aircraft and rockets based on wind tunnel technology.
   Realize this vision through the fusion of wind tunnel technology and CFD technology, the use of flight test data, and so on.

Watanabe: Environmental problems associated with aircraft, problems such as carbon dioxide emission, air pollution, and noise, have come to be discussed more and more seriously in recent years. Aircraft cannot be sold in international markets unless they have both high aerodynamic performance and high environmental performance. This is why we need wind tunnels capable of testing such performance. Some of today's young people hope to engage in the construction of new facilities which can compete in the world. I think that the construction of wind tunnels will be a good objective for them.

Will the achievement of the third vision require CFD (computational fluid dynamics) and other technologies besides wind tunnel testing?

Watanabe: One of the keys is a "mutual understanding" of various technologies. The wind technology and CFD technology, for example, have their own strengths and weaknesses. If they can be skillfully combined to complement their respective advantages, I think it will become possible to do things unachievable by individual technologies alone. Specifically, we hope to find accurate and efficient ways to collect the aerodynamic data required for aircraft design. If we succeed in this, we will be able to develop high-performance aircraft capable of winning out in international competition.

Achieving visions with a comprehensive perspective

What, in your opinion, are the most important requirements for realizing the Wind Tunnel Vision 2025?

Shigemi: We have always wanted to do the things that are clearly stated in this vision. Now, we have a target year for realizing them: 2025. To succeed, we will have to pass on and entrust the spirit of this vision to the young people who will be taking control in the coming years. The most import ingredient to success is the desire to realize the technologies envisioned.

Watanabe: By drawing up the visions and publicizing them inside and outside, we are showing a real determination to realize the visions. Once an objective is set out, I hope that the persons concerned will strive and cooperate together as a team and stay the course towards realization by 2025. When we mention a "wind tunnel vision," people may think we are only talking about wind tunnels. In fact, we have set up a vision which will require the use of other technologies in coordination with wind tunnels, such as CFD technology and flight measurement technology. If the concept isn't extensive enough to include these technologies, the significance of the vision will be weakened. By the same token, the JAXA Long-Term Vision includes activities not under JAXA's direct control.

Shigemi: This vision cannot be realized solely by our people working on wind tunnels. We will be relying on the understanding and cooperation of not only people inside JAXA, but also people from universities, manufacturers, and elsewhere.

[Wind Tunnel Technology Center]

(from left) Shigeya Watanabe, Masashi Shigemi

RESEARCH INTRODUCTION

Measuring drag with a drag count of 1

The performance of an aircraft is determined by aerodynamic force

One of the characteristics of a high-performance aircraft is the extremely small drag relative to the force required to float the aircraft body (the lift). These aerodynamic forces working on an aircraft can be ascertained by a "wind tunnel," a testing facility which blows a high-stream flow of air against a model fashioned in the shape of an actual aircraft body (Fig. 1).

Our team managed to work out the problems with measurement accuracy, but …

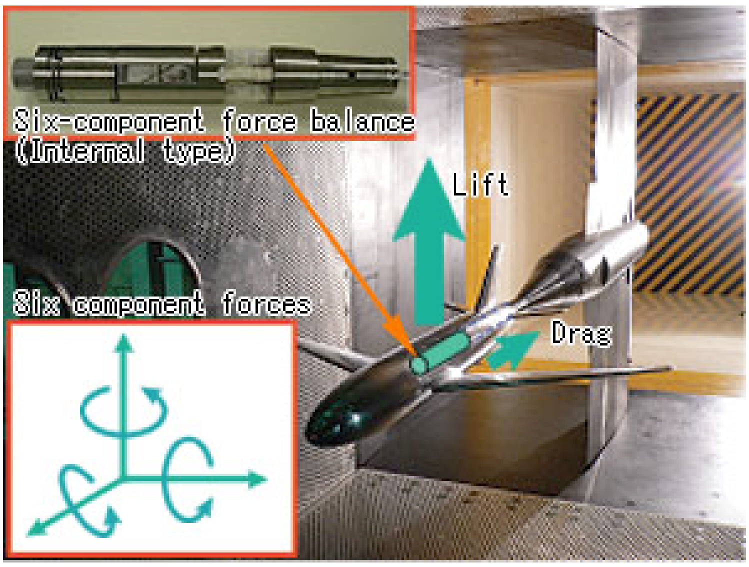
The drag of an aircraft is expressed in "counts[*1]". If the drag can be reduced by 1 count, the number of passengers can be increased by several persons without changing the amount of fuel on board. Thus, the economic efficiency of the aircraft increases as the drag count is reduced. This makes it important, in wind tunnel testing, to take the measurements with 1-count accuracy.

JAXA's 2m x 2m Transonic Wind Tunnel (front page), one of the largest transonic wind tunnels in our country, can run tests for many hours continuously at high airflow velocities ranging from Mach 0.1 to Mach 1.4 (0.1 to 1.4 times the speed of sound). This high capacity in terms of testing duration makes the tunnel one of the most productive sources of testing data in the country. But long-duration testing also poses a problem, as the airflow temperature rises considerably over time. Even when cooling devices are applied during testing, factors such as the energy added from the air blower and the heat from the friction between the air and wall push the temperature up to close to 50 ℃ . The high temperature also compromises the measurement accuracy of the balance in the testing model, as the heat has strong effects on the strain gauges used to measure the deformation of the balance (Fig. 2). To cope with this problem, we worked out a "preheating method" that enables us to obtain high-accuracy aerodynamic data by waiting for the balance temperature to reach a nearly constant value. Furthermore, we develop a method to make fine adjustments of the airflow temperature to keep the balance temperature at constant levels at all stages of a test, even with abrupt changes in the Mach number. We also have methods to collect reference data[*2] in the middle of testing and enhance measurement accuracy in the data-processing stage. Through these efforts, we have been able to obtain satisfactory test results from the system overall.

Fig. 3 shows an example of test results from an ONERA-M5 standard model. Six series of tests were carried out under different seasonal conditions. The results from these tests were all more or less the same (good repeatability).

Towards more accurate measurement

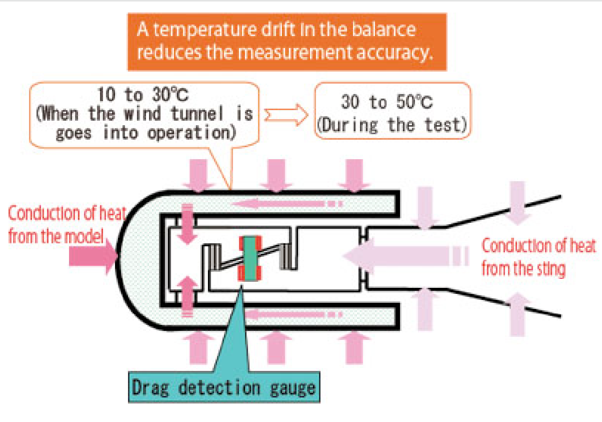
The present method has a disadvantage, however, as we need to preheat the testing apparatus until the balance temperature reaches a constant level. This takes at least one hour under normal conditions, and often more. As a consequence, we cannot take full advantage of the high productivity we have gone to the trouble to obtain. To overcome this limitation, we have decided to develop a high-accuracy balance which will not be affected by



The photo shows the ONERA-M5, a standard model used throughout the world to examine the basic characteristics of wind tunnels. Aerodynamic forces are applied to the model in six directions: back and forth, from side to side, up and down, and moment (the forces working around each axis). Therefore, a six-component force balance is inserted into the model. Aerodynamic forces applied to the model deforms the six-component force-detection portion of the balance. Aerodynamic forces can be determined by measuring the deformation of a strain gauge[◆] attached to this detection portion.

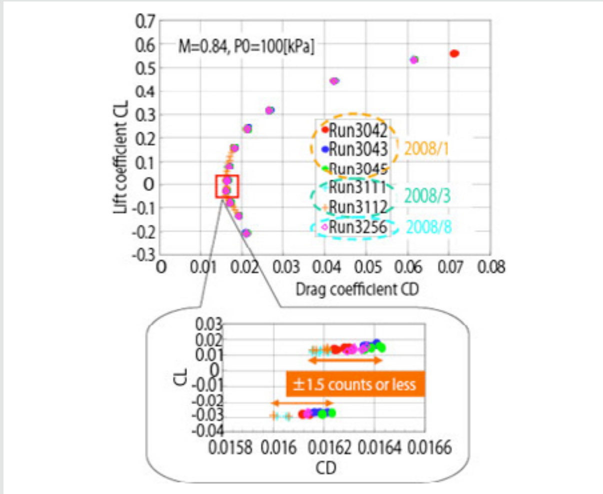
(◆) Strain gauge : Strain is the value obtained by dividing the elongated length (the original length extended by the action of an external force) by the original length. The strain gauge is a measuring device for determining this strain. Six-component force balance (Internal type) Six component forces

Fig. 1 Measurement by a six-component force balance in the 2m x 2m Transonic Wind Tunnel



In a continuous-type transonic wind tunnel, the heat from the air and friction pushes up the airflow temperature. The heat enters the balance through the model, and the supporting portion (sting), and creates a temperature difference in the drag-detection portion. This temperature difference produces an apparent output in the strain gauge (temperature drift). This is one of the main factors compromising the measurement accuracy.

Fig. 2 Temperature drift in the balance during a wind tunnel test



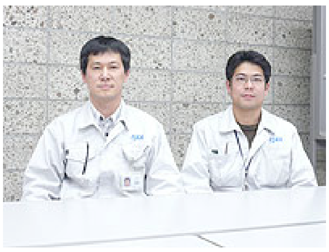
Differences in the outside air temperatures during the tests changed the airflow temperatures. By the end of the last test, we had confirmed the accuracy of about 30 sets of data. The accuracy in areas where the drag was minimum was ± 1.5 counts or less. Thus, we achieved an accuracy comparable to that obtained in major wind tunnels overseas

Fig. 3 Improved accuracy of force measurement data We carried out six series of tests in three seasons.

changes in the airflow temperature. In this new balance, we hope to incorporate a method of strain gauge application and strategies to cancel the heat deformation of the shapes and materials. As of this writing, we are going ahead with the thermal-structural analysis of the balance.

Once we have developed the high-accuracy balance, we will be able to take far more accurate measurements. But to achieve this accuracy, we first must carry out high-accuracy balance calibration. In the wind tunnel test, a simulation of an aircraft in actual flight, forces in all directions (combined loads) are applied to the test model (balance) at the same time. To work within the parameters of this condition, we have also started to design a "combined-load-type automatic balance calibration machine." If we can get this machine to calibrate a balance with combined loads automatically, we will be able to maximize the accuracy of wind tunnel testing data (to obtain values as close as possible to those obtained during actual flight).

(*1) 1count: The magnitude of drag (the number of drag counts) of an aircraft is represented by the "drag coefficient," a value determined by the aircraft shape, flight speed, and other factors. When the drag coefficient is 0.0001, the number of counts is 1 (one). When expressed as a percentage of the total drag of a passenger aircraft during a cruise, 1 count is in the order to 0.3 to 0.5%.
(*2) Reference data: Measurement data on a balance obtained when the airflow condition and model attitude are taken as reference values. If the airflow condition and model attitude are the same, the measurement data on the balance should also be the same at all times. Thus, we can ascertain the state of the temperature drift in the balance by obtaining reference data during a test.



[Wind Tunnel Technology Center]

(from left) Norikazu Sudani, Masataka Kohzai

R E S E A R C H
INTRODUCTION

Serving as a national standard wind tunnel

What is uncertainty?

Every experimental result has error. To discuss results in a meaningful fashion, the quantitative error of the results must therefore be presented. Fig. 1 and Fig. 2 below show examples of comparisons between experimental values and theoretical ones. Most people would probably judge that the two values have better agreement in Fig. 1 than in Fig. 2. Yet these two figures are actually plotting the same data. The only

This is why researchers conducting experiments estimate and use "uncertainty" scientifically. The limit of error in experimental results is expressed as a confidence level (usually 95%). Fig. 3 plots the same data shown Fig. 1 and 2, with uncertainties indicated as error bars (I). By presenting the results in this way, we can objectively discuss the differences between experimental and theoretical values. In addition, one of the data points in the center of Fig. 3 can be regarded as an outlier according to the statistical identification criteria(*).

International standards on the methodology for uncertainty assessment (uncertainty analysis) have been issued. And academic societies issue their own standard guides according to the international standards. These societies recommend that uncertainty be defined in their papers, and in many cases they even demand it. Sometimes, an experiment must be cancelled if the estimated uncertainty prevents the purpose of the experiment from being achieved. Uncertainty analysis can even be used to identify the contribution of each source of elemental error before an experiment is carried out. In this way, uncertainty analysis can improve an experiment efficiently.

National standard wind tunnels comparable to others in the world

JAXA's large wind tunnels provide the wind tunnel test data adopted as national standards. In this regard, they play a role similar to that of the prototype meter adopted as a standard of length, or the standard clock used to set the standard time. Wind tunnel tests (experiments) are superior in absolute accuracy to CFD, which requires flow modeling. Yet because of their model sizes, the medium- and small-sized wind tunnels operated by industries are

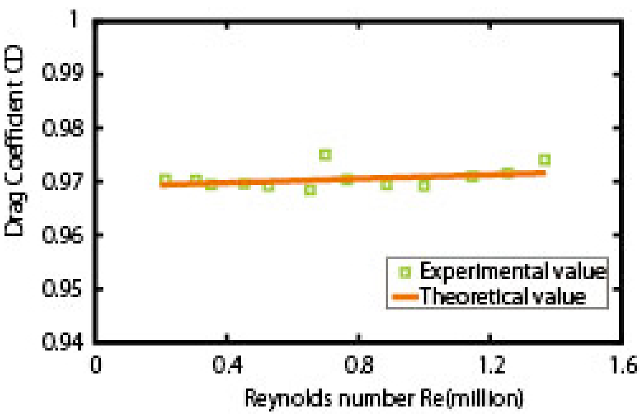


Fig. 1

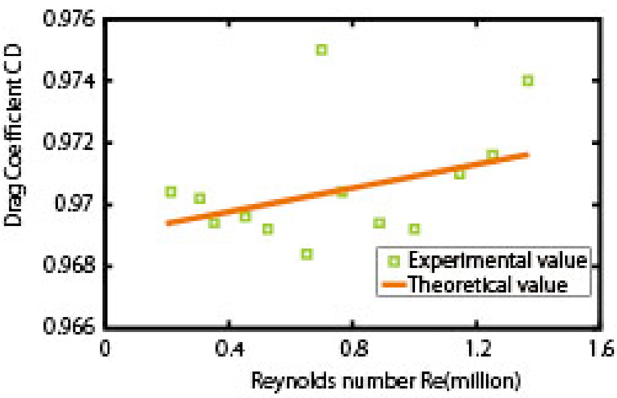


Fig. 2

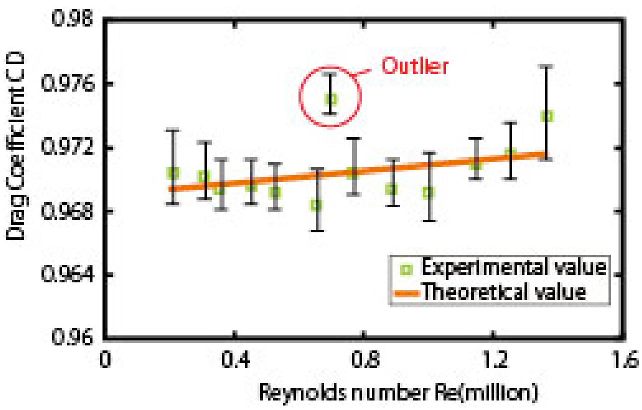


Fig. 3

often difficult to use for detailed tests. For this reason, the national agencies of many countries put large national-standard wind tunnels into service. The engineers running these wind tunnels estimate the uncertainty of their results by determining uncertainty with regard to wind tunnel flow, instrumentation, and other factors.

Crucial in wind tunnels are the components of "flow quality," such as the uniformity and disturbance rate of the flow. A fundamental problem with wind tunnel testing is the method for simulating an aircraft's flying state in still air using an artificial flow around a supported model. The performance of actual aircraft has to be predicted using similarity rules from test results obtained with scaled models. It thus becomes necessary to estimate the uncertainty of performance predictions not only in wind tunnel testing, but also in the prediction methodology for the actual aircraft. As things stand , this can only be estimated based on experience.

From JAXA to Japanese aircraft industries

The Wind Tunnel Technology Center (WINTEC) is building a database of test data obtained from different wind tunnels in Japan. With this database, we can compare test data on common configurations. Then, with regard to the standard model configuration shown in Fig. 4, we can clearly ascertain the bias error of a wind tunnel and variations in a whole wind tunnel test (that is, the uncertainty of wind tunnel testing).

WINTEC has also published a Japanese translation of the standard guide on uncertainty, AIAA-S071A-1999 of the American Institute of Aeronautics and Astronautics (AIAA), for distribution to wind tunnel users, and has started services for uncertainty indication/estimation in hypersonic/supersonic wind tunnels.

Fig.4 AGARD-B standard model installed in the JAXA supersonic wind tunnel

Wind tunnel testing consists of various procedures carried out by wind tunnel workers of different kinds. Wind tunnel workers must cope with problems related to uncertainty, as it depends on their testing procedures. In conjunction with these activities, we carry out research on the uncertainty assessment methodology. In coming years, I expect our current work on uncertainty to spread from JAXA's wind tunnels to wind tunnel users in Japanese aircraft industries.

(Shinji Nagai, Wind Tunnel Technology Center)

(*) Statistical identification criteria: With the engineering application of statistics, we can determine the criteria for identifying outliers.

[Reference] Kasagi and Nagano, "Basics and application of uncertainty analysis in measurement (First)" 'Turbomachinery', Vol. 17, No. 4, 1989

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