R E S E A R C H
INTRODUCTION

Measuring Global Pressure on a Model Surface

Making Pressure Measurement More Understandable

A key stage in the development of an aircraft is wind tunnel testing with scale models. Wind tunnel experiments help designers ascertain the best shapes to improve fuel economy, the flight performance of design configurations, and other points. The "pressure measurement test" in the wind tunnel is used to determine the shape and strength of the aircraft.

In a conventional pressure measurement test, the local pressure is measured by small holes of about 0.5 mm in diameter on the model surface, that is, 'pressure taps,' together with pressure transducers. Though the method is highly accurate, the number of measuring points is limited to several hundred, at maximum.

Another way to measure pressure is to use Pressure-Sensitive Paint (PSP). A model aircraft is sprayed with a special glowing paint whose luminescence varies in response to pressure levels, then the variation in luminescence is measured by a camera during air flow testing. The PSP method can measure pressure values on large model surfaces in high detail. It can also be used to clearly understand the flow over the model surface by visualizing the pressure distribution.

The Wind Tunnel Technology Center operates a PSP measurement system for testing in the large wind tunnels at Japan Aerospace Exploration Agency (JAXA) for the development of the aircrafts and rockets. This system makes the airflow understandable by measuring the pressure distributions on the surfaces of wind tunnel models in detail.

Applying PSP to Various Flows

PSP is made with an oxygen-permeable polymer mixed with probe molecules that change in brightness in response to variations in pressure. Fig. 1 shows a PSP in a luminescent state. The drawing of an aircraft painted with the PSP is placed in a pressure chamber. As the pressure rises, the PSP luminescence decreases. This change in brightness is a result of oxygen quenching, a phenomenon caused by the energy transfer between oxygen molecules and the PSP probe molecules. In PSP measurement, the pressure distribution is determined using images recorded during the wind tunnel experiment, and the relationship between the pressure and luminescent intensity.

Fig. 2 shows a model painted with PSP, installed in the JAXA 6.5m x 5.5m Low-speed Wind Tunnel. The pink PSP is painted on the main wing, the slat of the front edge of the wing, the flap of the trailing edge, and the engine nacelle. Fig. 3 shows the pressure distributions when the angle of attack of the model is changed to 5°, 10°, and 15° at a flow velocity of 60 m/s. Lower pressure portions appear in blue and higher pressure portions appear in red. At first glance we can observe two patterns in the configuration of the flow: a larger angle of attack widens the pressure variation, and the blue deepens in the gap between the slat of the front edge of the wing and the main wing, indicating a very low pressure.

JAXA has already established the PSP technology on a practical level at the transonic speed region of Mach 0.7

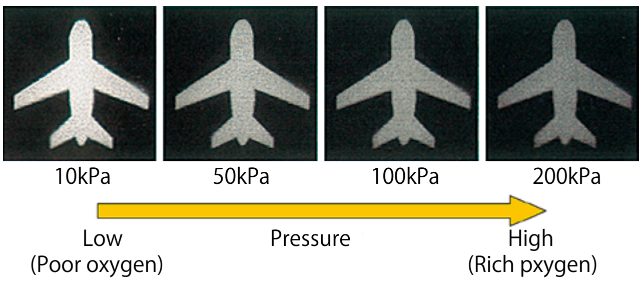
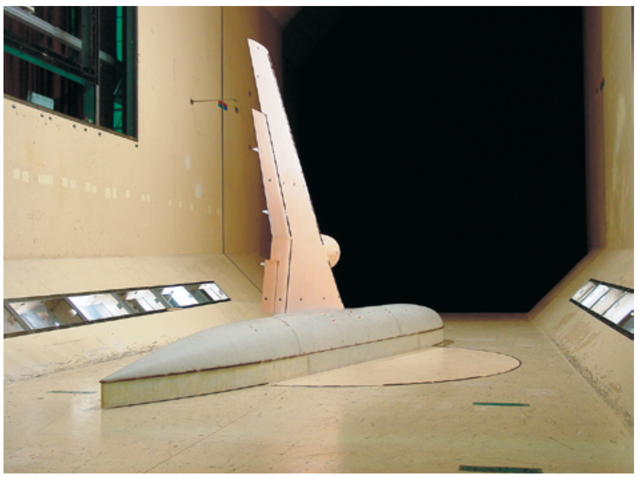
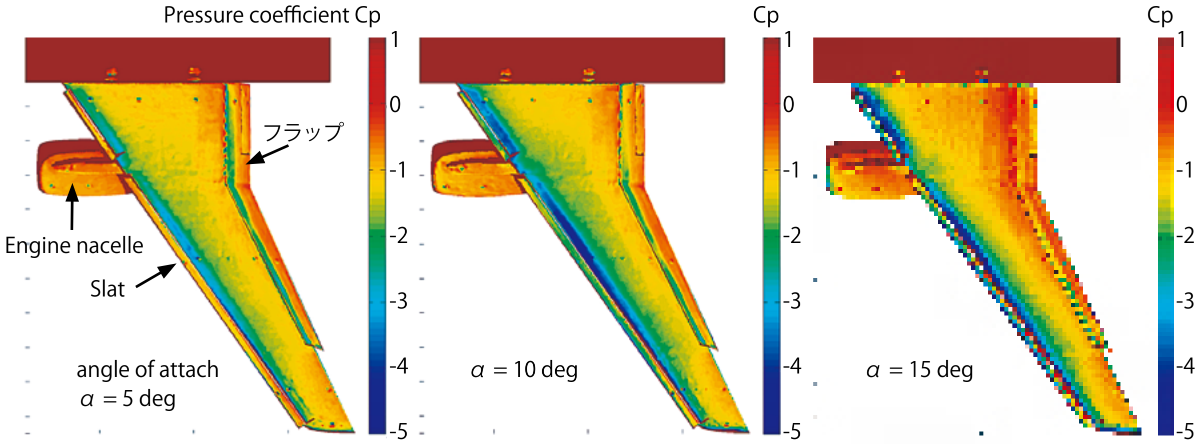


Fig.1 Relation between Pressure and PSP Luminescence Intensity



Model dimensions: fuselage length of 4.9 m and distance between floor surface and wing tip of 2.3 m

Fig. 2 JAXA High-Lift Configuration Standard Model installed in the JAXA 6.5mX5.5m Low-speed Wind Tunnel



Parts unpainted with PSP or invisible to the camera appear in dark red.

Fig.3 Pressure Distribution of Upper Surface of Main Wing of JAXA High-Lift Configuration Standard Model in JAXA 6.5mX5.5m Low-speed Wind Tunnel (Flow velocity: 60 m/s; angle of attack a=5° , 10° and 15°)

and 0.8, the cruising speed of aircraft. The PSP technology can help to improve the performance of the Japanese domestic jet now being developed. JAXA is also developing a PSP for use in low-speed conditions with smaller pressure variations-variations difficult to identify with the conventional PSP technology. The results of this effort have already been reached the PSP in low-speed condition enough for the development of aircrafts, as shown in Fig. 3..

PSP in the Future — Grasp the pressure accurately and dynamically

There are two directions for the PSP to further proceed in the future.

The first is towards the development of a more accurate PSP. The PSP now used responds not only to pressure, but also to temperature. The key to improved accuracy for PSP measurement will be the removal of the temperature effect. JAXA is trying to develop a "binary PSP" capable of measuring both temperature and pressure at the same time, and also a "reduced-temperature-sensitivity PSP" that will resist the effects of temperature. The data-processing methods for these PSPs are also being improved.

The second direction for PSP will be towards dynamic pressure measurement moment by moment. JAXA is also developing an "unsteady PSP technology" for investigating the mechanism by which an aircraft is damaged by the vibration called flutter, and for reducing the noise generated due to pressure changes of airflow.

The PSP technology can be used not only for aircrafts and rockets, but also for automobile, trains, and any other vehicle or artifact subject to air flow. JAXA hopes to expand its PSP into a technology widely used throughout the world.

(Kazuyuki Nakakita)

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RESEARCH INTRODUCTION

Grasping the Flow Structure Precisely!

What's PIV? — A technology to measure the velocity of a flowfield

To develop a high-performance aircraft and rocket, it is important to precisely investigate the flow velocity distribution around the airframe and the surface pressure distribution measured by PSP (Pressure-Sensitive Paint; see refer to page 1).

JAXA has introduced Particle Image Velocimetry (PIV), an optical measurement technique for the investigation of flow velocities. With PIV, researchers can investigate the velocity field on a laser light sheet without disturbing the flow. PIV works by mixing small particles called seeds into an air flow, then identifying how the seeds move in the flow by illuminating the seeds with a laser light sheet and recording the particle image with a camera. The Wind Tunnel Technology Center has developed a stereoscopic PIV system (Fig. 1) for the large-scale low-speed to transonic wind tunnels operated by JAXA. The new system analyzes three components of the flow velocity (velocities in three directions) simultaneously using two CCD cameras.

Observing and Measuring a Complex Air Flow Quantitatively at the Same Time

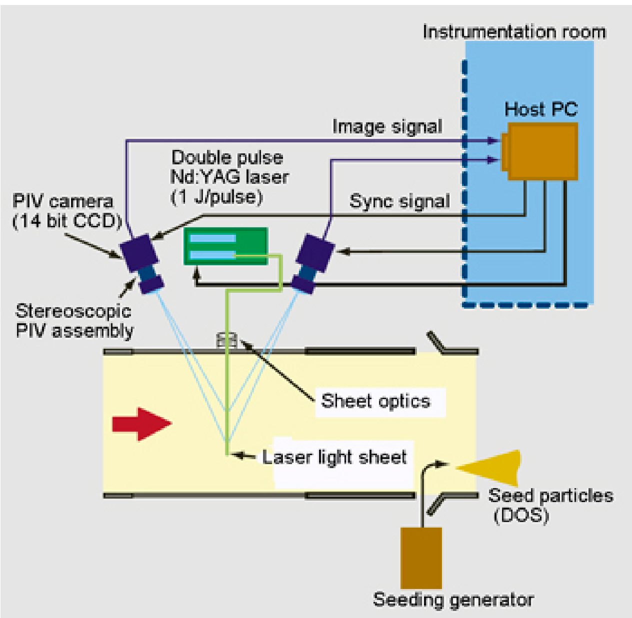


Fig.1 Schematic of Stereoscopic PIV System

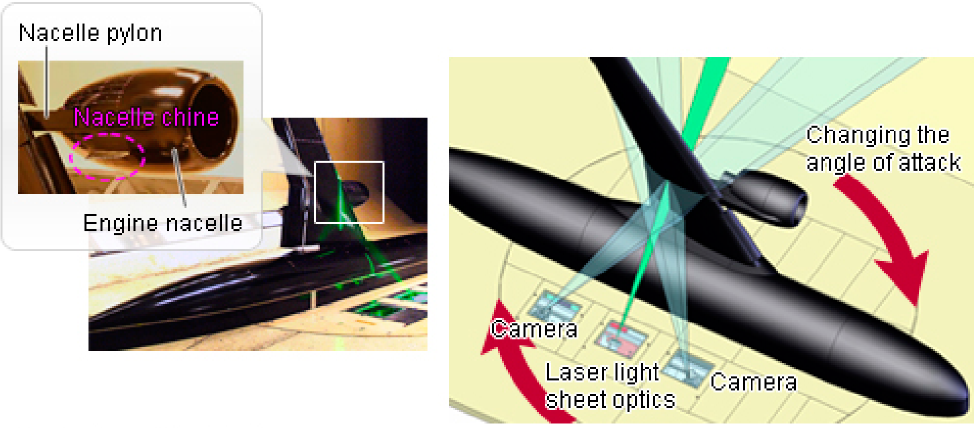
The engines of an aircraft installed in the engine covers (engine nacelles) are attached to the main wings with nacelle pylons. During takeoff and landing, a vortex is generated from the nacelle and pylon. This vortex interacts with the flow along the upper surface of the wing. This, in turn, generates a flow separation that ultimately reduces the lift force. Small plates called nacelle chines are installed on the nacelles to suppress this flow separation. The points of installation for the nacelle chines have an important bearing on aircraft performance. Fig. 2 outlines the features and results of a test to evaluate the performance of the nacelle chines. With PIV measurement, we could quantitatively identify where the flow separation is suppressed by the nacelle chines and how the suppression effect is changed when the nacelle chines were installed at different locations.

In addition to the above-mentioned, PIV is also used to measure air flows around high lift devices. The results from these measurements can help to reduce the aerodynamic noise generated from high lift devices (slats and flaps) during takeoff and landing.

Towards the Development of More Accurate and Useful Technologies

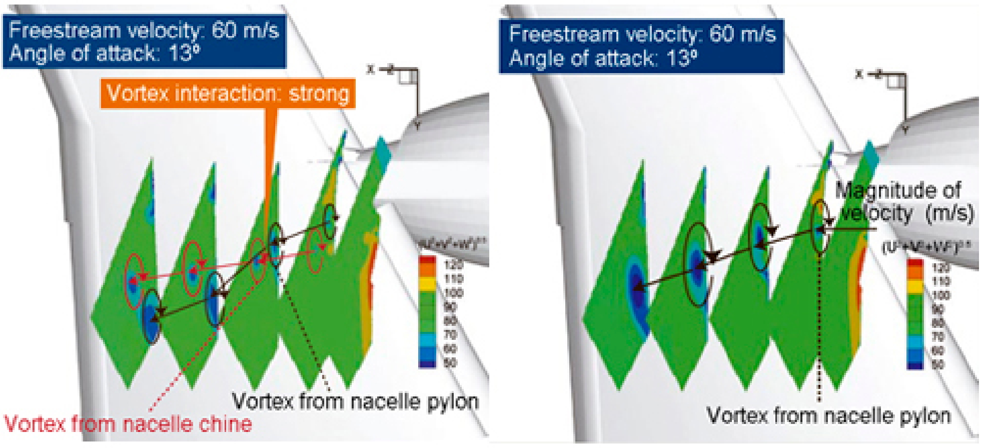
The PSP technology previously presented and the PIV technology presented here have been introduced to precisely measure the surface pressures of aircrafts and rockets, as well as the velocity fields around them. The surface pressures and velocity fields are two- and three-dimensional flow characteristics that cannot be measured with conventional measurement techniques. Our group has been researching these advanced measurement technologies in order to further improve their accuracy and efficiency.

With PSP and PIV, we can collect large amounts of information on the flow in a single test. In conducting tests of this sort, we also need to be able to extract the essential information required for aircraft development, and to visualize it in easy-to-use graphical forms. We will be focusing on these capabilities by developing better data-utilization technologies for these tests in the future.



A : Picture of the Test

The test was conducted using the JAXA high-lift configuration standard model in the JAXA 6.5 m x 5.5 m low-speed wind tunnel. By integrating the equipment required for the PIV measurement with the model, we omitted the step formerly required for the relocation of the equipment when changing the angle of attack.



Without nacelle chine　　　　With nacelle chine

B : Test Results

We can clearly observe the suppression of the flow separation by interaction of the vortex generated from the nacelle chine with the vortex generated from the nacelle and pylon.

Fig.2 Performance Evaluation Test of the Nacelle Chine

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RESEARCH INTRODUCTION

Observing Noises with Multiple Ears

What kind of noises causes problems around airports?

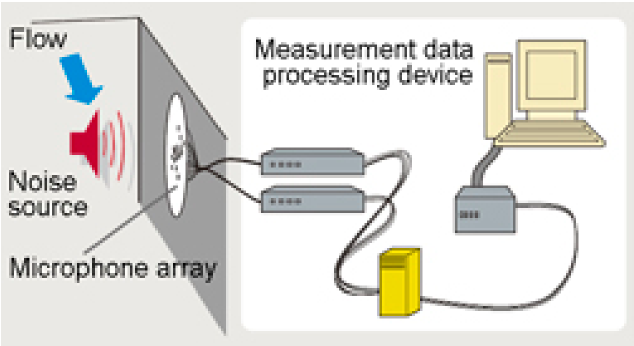
To design a high performance aircraft, it is crucial to measure lift and drag, pressure, the flow field, and other aerodynamic forces acting on the airframe. The data obtained from these measurements can be used to plan out the shape of an airframe. But even a superbly shaped airframe will be unusable if it produces noise.

Japan is a densely populated country with residential areas even around the airports. The aircraft flying in and out of the airports must therefore have quiet airframes. Most important of all, the airframes must suppress noise during taking off and landing. The engine, of course, is a major source of aircraft noise: the maximum engine thrust required at takeoff is the strongest source of noise by far. In contrast, the main source of noise at landing is the interference between the airframe and airflow. Experts in the industry describe this wind roar as "aerodynamic noise."

Searching Buried Sounds

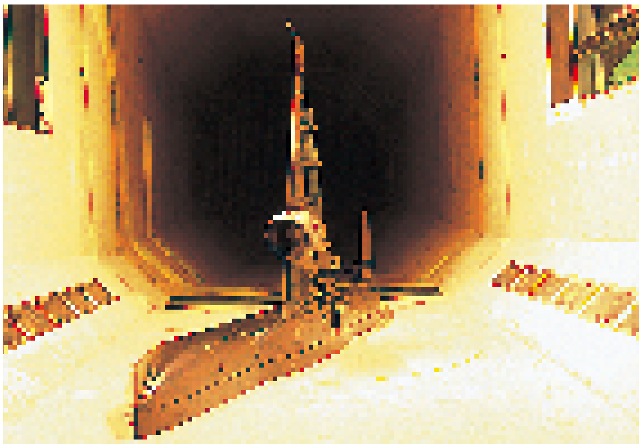
A wind tunnel test is a noisy event, with strong background noise generated by the interference between the uniform flow and airframe wall. This naturally makes a conventional wind tunnel unsuitable for noise measurement. There are special types of wind tunnels arranged for measuring noise. However, if noise can be measured under the same conditions prevailing in normal wind tunnel tests and other experiments, researchers can more easily make comparisons with the data obtained from the other experiments. They also can use the wind tunnel experiments to further clarify phenomena.

unconquered with using one or several independent measuring instruments (microphones) until now, has been to identify the locations from which noise is generated. Noise components are difficult to analyze independently, though the total amount of noise can be studied quite accurately. To address this challenge, we have begun developing a "noise source identification technology" to identify noise locations. The technology relies on multiple measuring instruments (microphone array) flush-mounted on the wall surface of the closed test section of the wind tunnel, in a configuration with little to no impact on the airflow. With this method, it will be possible to

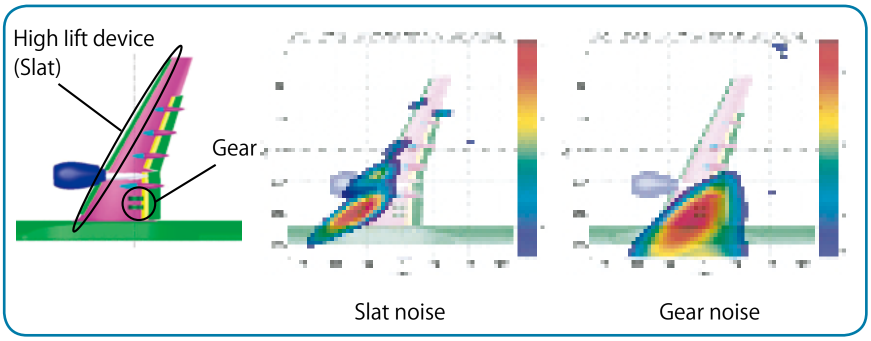


The noise source locations and their levels can be measured by flush-mounting an array of 48 microphones on the wall of the test section in a spiral shape.

Fig.1 Conceptual Diagram of Noise Source Identification Measurement in the JAXA 2 m x 2 m Low-speed Wind Tunnel.



Half-span model of Mitsubishi Regional Jet (MRJ) installed in the JAXA 6.5 m × 5.5 m Low-speed Wind Tunnel (Photograph provided by Mitsubishi Heavy industries, Ltd.)



The noise source generated from the model is visualized in the picture, and the noise source location can be identified.

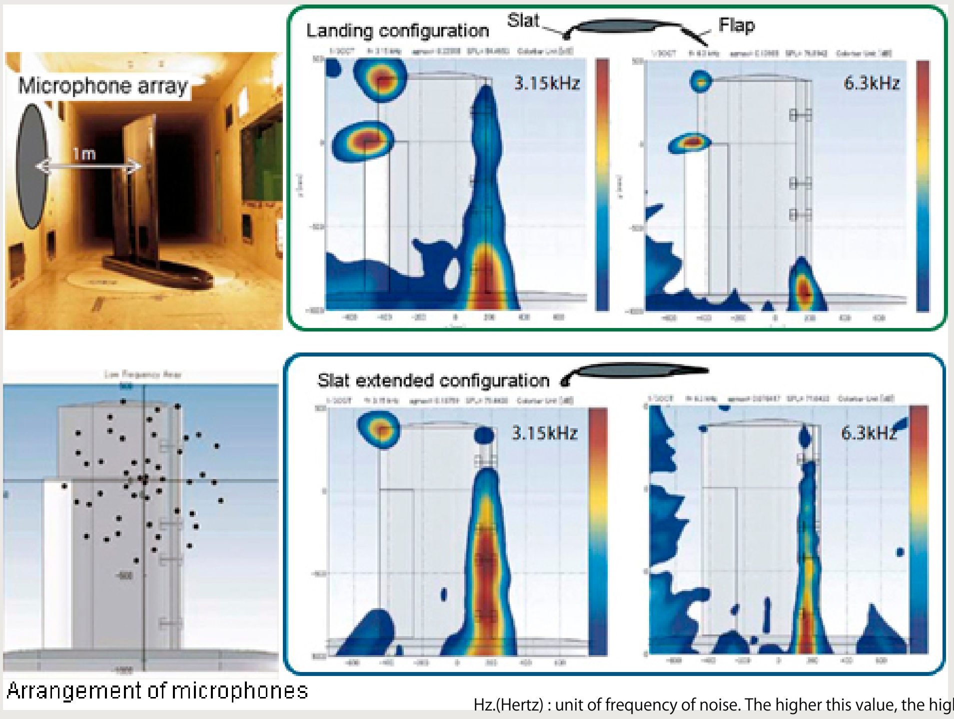
Fig.2 Results of Noise Source Identification with the Half-Span Model of the Mitsubishi Regional Jet (MRJ) identify hidden background noises and their locations.

Fig. 2 shows the measurement results of the noise source identification using a half-span model of the MRJ civil transport aircraft being developed by Mitsubishi Heavy Industries, Ltd. The results identify the noises are generated from high lift devices and landing gear. The data obtained from these tests are used for the development of the MRJ airplane.

Towards a More Advanced CFD Analysis Technology

During the design of the aircraft, the design performance is also evaluated by analyzing the flow around the airframe, the noise, and other phenomena not only in the wind tunnel, but also using computational fluid dynamics (CFD). CFD has limitations, however, as it performs poorly in the analysis of flows around complicated shapes, such as the flows around high lift devices. Current research and development efforts will hopefully improve this. We are now gathering the data required for more complicated forms of CFD analysis (Fig. 3).

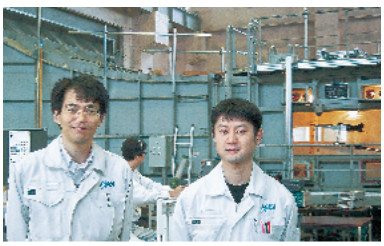
The Wind Tunnel Technology Center has developed technologies for measuring and identifying pressure fields, space velocity fields, noise sources, and so on in JAXA wind tunnels. The data collected are integral to the development of actual aircraft.



Hz.(Hertz) : unit of frequency of noise. The higher this value, the higher the pitch.

First, we take measurements to determine the levels and frequencies of noise generated by various model configurations, such as the landing configuration in which the slats and flaps are extended, a configuration in which only the slats are extended, and other configurations. Once this data is collected, it will be used to establish the CFD analysis technology for aircraft design.

Fig.3 Validation Data for the CFD Analysis in the JAXA 2 m x 2 m Low-speed Wind Tunnel



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