

Whole transonic wind tunnel analysis

If only we could remove the walls and support

"Wind tunnels" are essential for designing new aircraft. A wind tunnel is equipment that generates wind. Airframe models are installed inside the test section, and wind is generated to simulate an aircraft in flight so that we can obtain the forces as well as the surface pressures on the model.

To keep a uniform flow, the test section is surrounded by walls. A support is needed for the model to be suspended in the air. However, the walls and support affect the pressure and surface pressure values obtained in wind tunnel tests. In order to obtain accurate data, the measurements must be corrected.

To study the effects of the walls and support, tests with no walls or supports are desirable. This is difficult with a wind tunnel, but it is possible with computer simulation. JAXA's supercomputer was used to conduct a complete numerical analysis of the test section in JAXA's 2 m × 2 m transonic wind tunnel (fig. 1).

Porous walls

Analyses of aircraft models with a support have been conducted. However, this is the first analysis with a support and "porous walls". In flight, the flow bends and wraps around the airframe. If the walls surrounding the test section of the wind tunnel were not permeable, this air bending could not be realized and the measurement results would be affected. Therefore, we employ walls with a countless number of holes, through which the airflow can come and go freely. The "porous wall" simulates airflow conditions of actual flight. However, there are issues with this porous wall in numerical analyses. In order to resolve these issues, we "modeled" the porous wall.

In order to model the porous wall, it is necessary to model the airflow movement for a single hole.

Waseda University was charged with this modeling, and Nagoya University was charged with wind tunnel tests to verify it. Based on the model of the single hole, movement

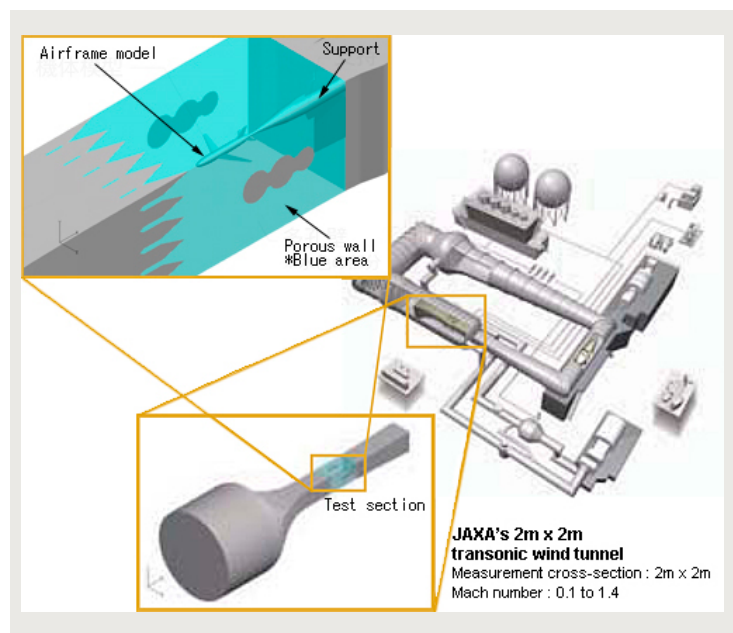


Fig.1 2m x 2m transonic wind tunnel

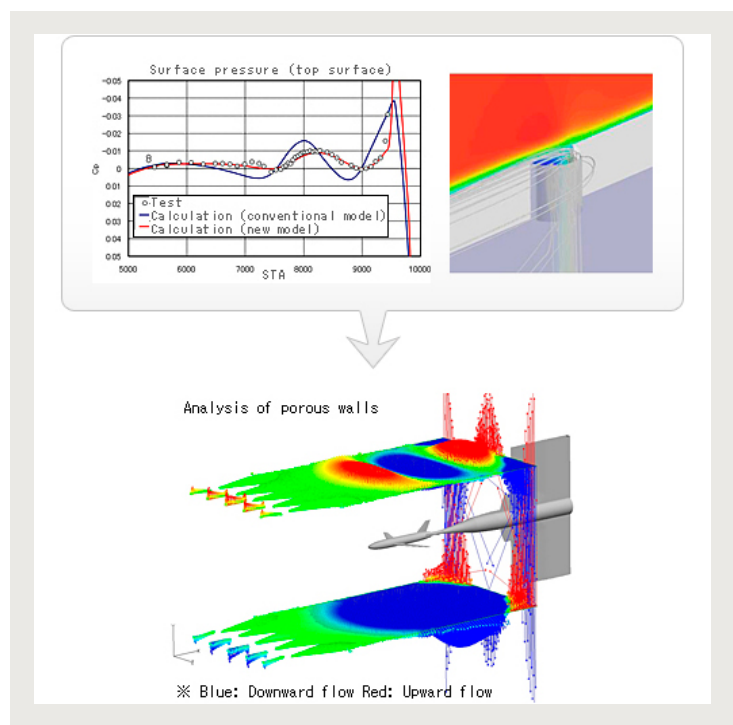


Fig. 2: Modeling the porous walls

Analysis of wall/support interference in JAXA's 2 m × 2 m transonic wind tunnel

of airflow for the porous wall was modeled. The model is then incorporated in the "analysis of the porous walls" of the complete transonic wind tunnel analysis, allowing for complete numerical analysis of the entire wind tunnel (fig. 2).

Revealing the effects of walls and supports

Figure 3 shows surface pressures obtained through analysis of only the model (A), the model and the support (B), and the model, support and walls (C). Deducting (A) from (B) shows the effects of the support (D), and deducting (B) from (C) shows the effects of the walls (E). In addition, deducting (A) from (C) shows the effects of both the support and the walls (F). In this way, numerical analysis is an effective method for understanding the effects of the support and walls.

Through this analysis, we were able to determine not only the individual effects of the support and walls but their mutual interference as well as the amounts of the interferences. The phenomenon that the support and walls interfere with each other was presumed throughout the wind tunnel tests, but this analysis could confirm that for the first time.

In the future, we will use these results to properly remove wall and support effects from wind tunnel test measurements, and we hope to transfer this technology to development of accurate wind tunnel testing.

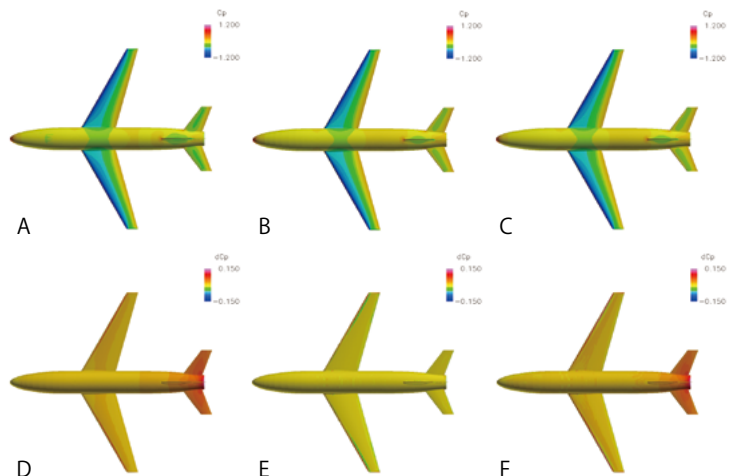
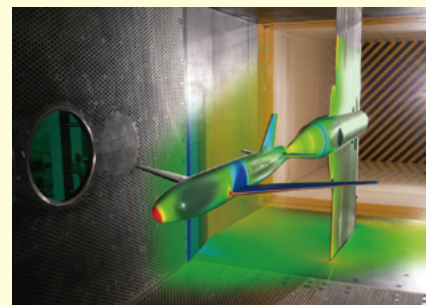
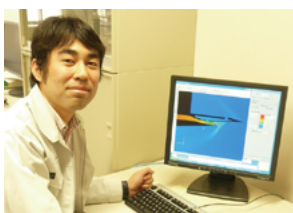


Fig.3 Comparison of surface pressures on models

Best CFD Graphics Award



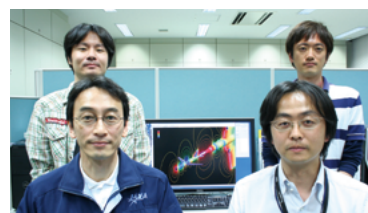
In December 2010, we received the "Best CFD Graphics Award" at CFD 2010, which is held every year by the Japan Society of Fluid Mechanics. It is awarded based on the beauty and technological level of the graphics. We received this award for the originality of the presentation combining the analysis result and photograph as well as the high level of the analysis technology, which included the support and walls of the wind tunnel.



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Method of global surface pressure measurement for an oscillating wing

Method for global measurement of surface pressure

In the past, "pressure transducers" have been used to measure the surface pressure for models in wind tunnel tests. Pressure transducers are limited by the number applied to the model and their method of discrete measuring. Therefore, with the aim of measuring the surface pressure for the entire model, we have researched measurement technology using "pressure-sensitive paint" (PSP).

PSP is a luminescent paint using organic dyes whose luminescence is excited by light such as ultraviolet rays and varies with oxygen. Since about 21% of the air is oxygen, the luminescence decreases as pressure increases (oxygen quenching). PSP measurement uses such intensity to determine the surface pressure on the model (fig. 1). The pressure can be measured by applying PSP to the entire model and acquiring images of its luminescence with a CCD camera. At JAXA, pressure measurement technology using PSP is already applied to practical wind tunnel tests..

Using PSP for flutter research

On a very windy day, blinds covering the windows shake and rattle. This same oscillation phenomenon, called "flutter", occurs with aircraft wings. Fluttering is a dangerous phenomenon for an aircraft, which may eventually lead to damage. Aircraft wings are designed with an adequate margin so that fluttering does not occur no matter how fast the aircraft is flying. By accurately estimating this margin, the weight of the aircraft can be further reduced and its efficiency increased. Therefore, it is important to first measure the pressure behavior on the wing and to understand in detail the phenomenon of flutter.

At JAXA, flutter studies through wind tunnel tests using flutter models, which are actually shaken violently, are being researched. We tried to use PSP to measure the pressure on oscillating models. If the pressure on the entire wing when it is fluttering could be visualized, it would be helpful in establishing the numerical analysis model necessary for a simulation to predict the flutter phenomenon.

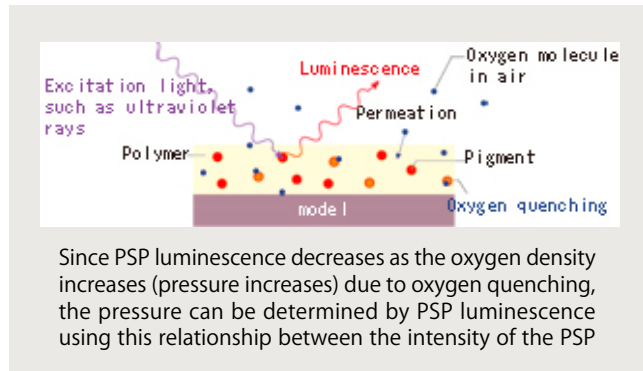


Fig.1 Principle of Pressure-Sensitive Paint

Visualization of the surface pressure on a wing when flutter occurs

The fluttering wing in the wind tunnel test oscillates up and down more than 100 times in one second. In other words, the time required for the wing to oscillate one period is only 1/100 second. In order to study the surface pressure for a wing over one oscillation period, we must measure pressure changes in an even shorter length of time. So, the key is the time response of PSP in reacting to pressure changes.

With conventional PSPs, luminescent dyes were mixed with polymer and applied to models, but this polymer became a barrier so that several seconds were required for a reaction to pressure changes. There is a technique using a chemical treatment to directly coat the model with the luminescent dyes without polymer. This type of PSP can react to pressure changes in an extremely short period of time, specifically less than 1/1000 second. It was used in flutter tests.

A high-speed camera that can take a number of images during one oscillation period of the wing was used as a detector. However, there was the problem that the image became dark because the exposure time for one image was extremely short. Therefore, a high-power laser was used as the excitation light and the PSP luminescence increased more than in the past (fig. 2).

Flutter measurement test using PSP

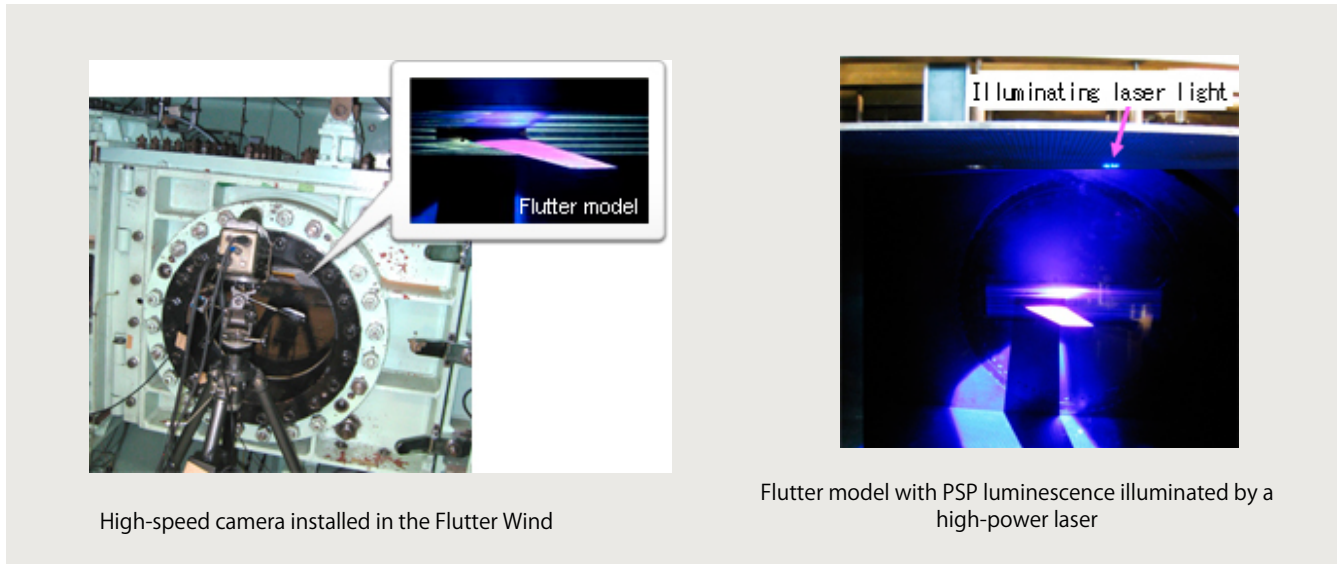
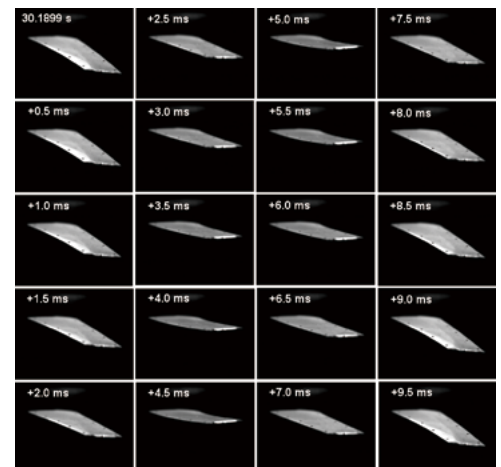


Fig.2 Test conditions

This combination allows continuous imaging in an extremely short period of 1/4000 second and succeeded in capturing the pressure variation of the fluttering wing (fig. 3). "Fast time-response" is not the only difficulty in measuring flutter with PSP. Since the luminescence of PSP also varies depending on temperature and humidity, it is necessary to compensate for such effects. In addition, we must introduce deformations in the model. Currently, we are taking up the challenge of realizing these tasks.

The results obtained in these tests could properly capture the surface pressure variations on the wing when flutter occurs. We will continue research to advance measurement technologies in order to establish the numerical analysis model for predicting flutter.



The white areas indicate low pressure, and the black areas indicate high pressure.

Fig.3 Wing surface pressure variation measured with PSP when flutter occurs



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What is a Mach number?

■ Mach 1 = Speed of sound

What is a "Mach number"? Does the word "number" indicate that something is being counted?

"Mach" is often used to represent the flight speed of aircraft, for example, in "exceeding the Mach 1 barrier" or "a cruising speed of Mach 0.8". The Mach number expresses "speed as a multiple of the speed of sound". Saying "an airplane is flying at Mach 1" indicates that "the airplane is flying at the speed of sound".

A property of sound is that the speed at which it advances slows down as the atmospheric temperature decreases. At an airplane cruising altitude of 10 km, the atmospheric temperature is very low compared to that on the ground, so a speed said to be Mach 1 differs from that near the ground. Mach 1 near the ground is about 1,200 km/h; however, at an altitude of 10 km, it is slower at about 1,070 km/hr.

■ Properties of air related to the speed of sound

Isn't it inconvenient that a speed said to be Mach 1 is different if it is on the ground or in the sky? Why is it represented as a Mach number?

The properties of air are determined by the speed at which an object moves. The air around an object moving at a certain speed is compressed, and the properties of air are influenced by this compression. If the speed at which an object moves is Mach 0.3 or more, compression has an effect. This effect is especially pronounced near the speed of sound. The Mach number, which is based on the speed of sound, is a unit that is extremely easy to understand if the properties of the air are understood.

■ Significance of Mach 1

When an airplane cruises at Mach 0.8, the air facing the direction of travel is compressed (fig. A). If the speed is increased to exceed the speed of sound, a high-pressure air barrier, called a "shock wave", occurs in front of the airplane (fig. B). When this wave reaches the ground, a large booming sound (sonic boom) occurs. The supersonic transport "Concorde", which was in service until 2003, could fly at Mach 2, but sonic booms became an issue and flights over land became limited.

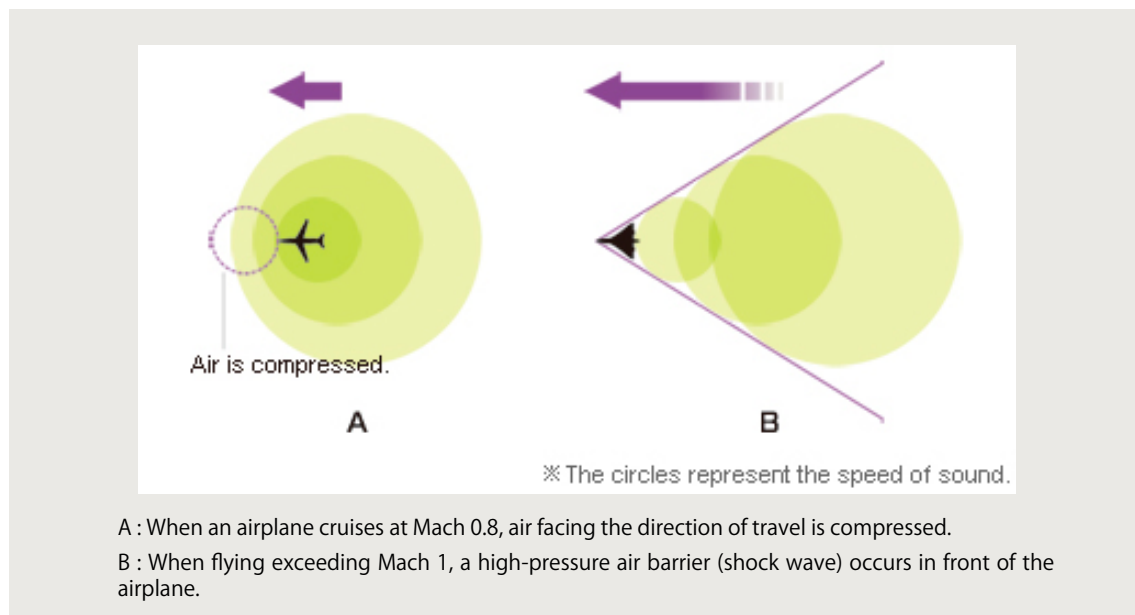


Fig. Relationship between Mach number and air compression