R E S E A R C H INTRODUCTION

As if by magic, a model floats by magnetic force

What is the magnetic suspension and balance system?

When building an aircraft, we take into account that it floats as a result of "lift"-the upward force resulting from the pressure difference above and below the wings. Since airflow is required for this pressure difference to occur, "drag" -the opposing force- is also exerted on the fuselage as it advances through the air. Generally speaking, we can create a highly efficient fuselage by increasing lift and decreasing drag.

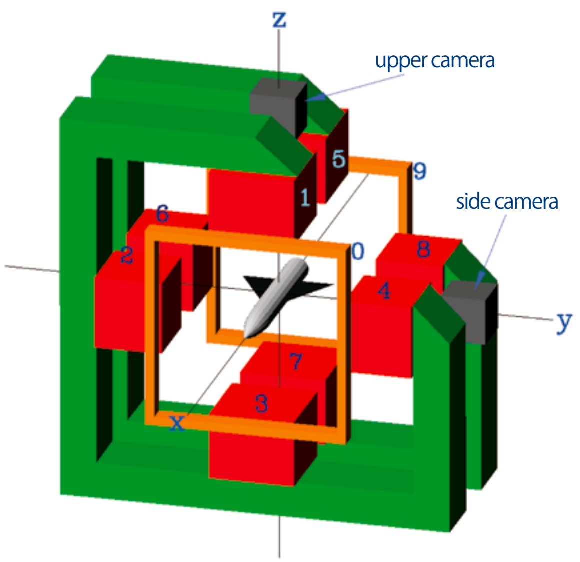
In order to measure these aerodynamic forces, we created "wind tunnels" (refer to here)-facilities for artificially producing airflow in relation to a model of a simulated fuselage shape. In a wind tunnel, some device, such as a support bar, is necessary for holding the model at a fixed position within the measurement section. However, these supports may interfere with airflow or affect the measurements.

A more accurate measurement may be possible if there were no supports. Therefore, we turned our attention to supporting a model by magnetic force using electromagnets. At the same time, research and development was advancing on the "magnetic suspension and balance system", which can also measure aerodynamic forces acting on a model by the change in electricity required to hold the model in place. (Fig. 1) When it is difficult to get accurate measurements because of supports in the airflow, using the magnetic suspension and balance system would make it possible to measure the resistance of airborne objects with very little resistance, such as an airship. In addition, since the model can be moved freely by changing the electrical current, we may also be able to test the flight characteristics of moving objects.

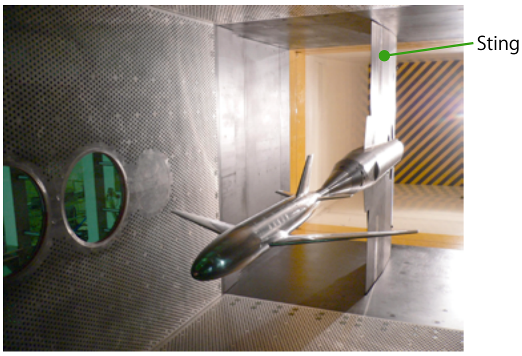
Gradually conveying usefulness

We expect to be able to use the magnetic suspension and balance system in various tests; however, it is not yet widely used since the technology is still on the research level. In order for this system to become more commonly used, we must convey its effectiveness. One way to accomplish this was to perform an experiment on the flight characteristics of a Japanese archery arrow.

Since an archery arrow is a long, thin shaft, the airflow can easily cause deformations such as deflection, making a supporting device necessary. Moreover, the arrow has a complex flight motion described as a "parabolic movement with rotation and sinusoidal oscillation". A wind tunnel experiment simulating the complex motion of an archery arrow was not possible with previous support methods. By supporting the arrow with the magnetic suspension



In order to support a model, ten electromagnets are arranged around the measuring section. The electromagnets are the areas shown in red and orange. In addition, permanent magnets are embedded in the model. The model is held in place inside the wind tunnel through magnetic force.
JAXA's magnetic suspension and balance system is used in low-speed wind tunnels that have a measuring section of 60 cm × 60 cm.



Measurements are possible between 0 and 45 km/s. In a conventional wind tunnel, the model is held in place by a support bar called a sting, and aerodynamic forces applied to the model are measured with a device called a balance, installed in the model.

Fig.1 Magnetic suspension and balance system and a conventional wind tunnel model support and balance system, an experiment could be performed to simulate the movement of the arrow, and basic data on its aerodynamic characteristics could be collected. (Fig. 2)

In addition to the widespread use of the device, our goal is also to establish the magnetic suspension and balance system in technology used in the development of aircraft and spacecraft. Consequently, we are collecting data from experiments performed on the AGARD-B calibration model, which is used for wing shapes in airflow precision testing. (Fig. 3)

Use in research of hypersonic aircraft

At JAXA, research and development continues in technology for hypersonic aircraft, which are capable of flying at five times the speed of sound (Mach 5). If flight at Mach 5 became possible, a transpacific crossing that normally takes about 10 hours could be shortened to 2 hours.

A hypersonic passenger plane can cruise at Mach 5, but it must also provide the low-speed flight characteristics required to take off and land safely at airports. Through numerical analysis, we must thus derive multiple fuselage shapes that can exhibit a good balance of high performance at both hypersonic speeds and low speeds, then select a shape with the best characteristics in wind tunnel experiments. In normal low-speed wind tunnel experiments, since there is a large airflow measurement error caused by interference of supports holding the model, the experiment is performed using various methods of support, and accurate values are obtained by comparing the data. Therefore, an enormous number of wind tunnel experiments would be required in order to evaluate the aerodynamic characteristics necessary for flight control with all models.

With the magnetic suspension and balance system, it is possible to obtain the aerodynamic performance necessary for flight control with just one experiment. As a result, this system enables us to effectively continue the aerodynamic performance assessment of new shapes for hypersonic aircraft, for example. Currently, we are still at the stage where magnetic support methods are being attempted in determining hypersonic aircraft shapes. (Fig. 4) If this method was to become established, we believe that it could become a powerful testing tool in the research and development of hypersonic aircraft.

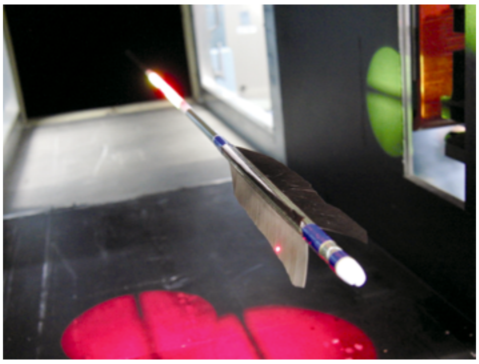


Fig.2: Collecting data on the aerodynamic characteristics of a Japanese archery arrow

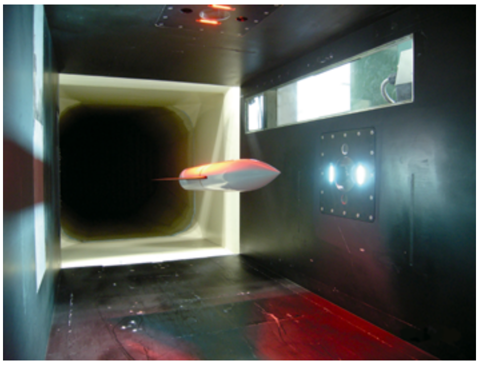


Fig.3: Experiment with AGARD-B calibration model

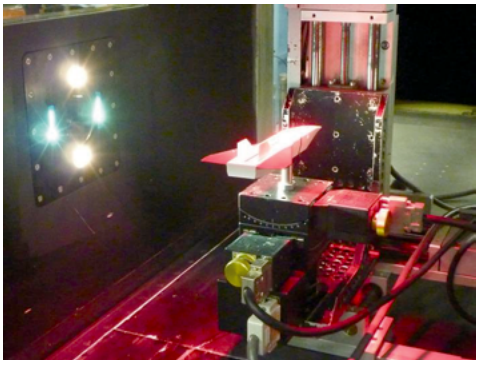
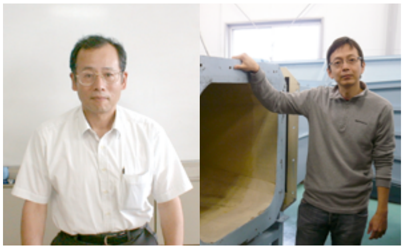


Fig.4 Preliminary conditions of magnetic support wind tunnel experiments for hypersonic aircraft



[Fruid Dynamics Group]

(From left) Hideo Sawada, Hiroki Sugiura

What is the current state of nitrogen?

Wind tunnel facilities simulating re-entry

A spacecraft returns to the blue star that is covered by a thin atmospheric veil. When a spacecraft re-enters the earth's atmosphere, the fuselage is wrapped in air at a high temperature, and its surface is heated to more than 1000 ℃ (aerodynamic heating). Nitrogen and oxygen-components of air-break down, some of which turns to plasma(*1). In order to protect the spacecraft from this harsh environment, carbon thermal protection material is used on the nose cap and wing leading edges of the reusable launch vehicle (Space Shuttle) employed by the National Aeronautics and Space Administration (NASA).

In order to evaluate the performance of heat-resistant materials, a facility that can simulate the re-entry environment is required. The 750 kW arc-heated wind tunnel and 110 kW inductively coupled plasma-heated wind tunnel are such facilities maintained by JAXA.

(*1) Plasma: A fourth state of matter distinct from solids, liquids and gases-This state is one of extremely high energy where negatively charged electrons burst out from molecules and atoms and move around freely; however,

■750 kW arc-heated wind tunnel

In the arc-heated wind tunnel, an electric discharge (arc discharge) occurs between positive and negative electrodes to produce heat, which warms the airflow in the wind tunnel to an extremely high temperature.

A spacecraft in re-entry from the earth's orbit to the atmosphere travels at a speed of about 8 km/s, which, converted to kinematic energy (enthalpy), is about 30 MJ per 1 kg mass. Since the arc-heated wind tunnel can generate a hypersonic flow with a maximum airflow enthalpy of about 20 MJ/kg, performance testing of thermal protection materials can be carried out in a nearly realistic thermal environment. However, there is one problem: as with the major damage caused when lightning-a well-known electrical discharge phenomenon-touches ground, the electrodes are degraded by the arc discharge and seep into the airflow as dust (contaminants).

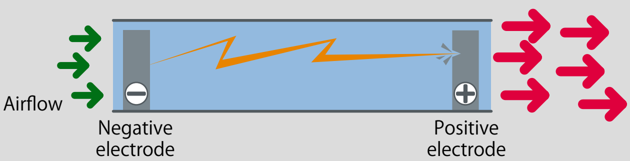


Fig.1 Heating principle of arc-heated wind tunnel

■110 kW inductively coupled plasma-heated wind tunnel

A high-frequency electric current flows through a coil in the plasma generator, creating an induced electromagnetic field within the device, and plasma is generated when the gas is heated by the induced current. The heating rate is relatively low, compared with the arc-heated wind tunnel, and flow speed is limited to subsonic, since the airflow pressure is low, however, there are no contaminants generated since there are no electrodes to erode. Therefore, the behavior of real gases during re-entry can be simulated, and catalysis(*2) of heat-resistant materials can be assessed.

In addition, compared with the arc-heated wind tunnel, maintenance can be simplified, and wind tunnel

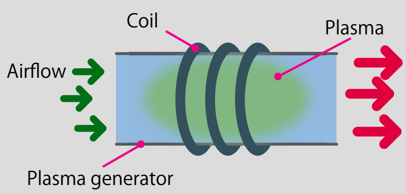


Fig.2 Heating principle of inductively coupled plasma-heated wind tunnel

operation rate and maneuverability can be improved.
(*2) Catalysis : The property that promotes recombination of dissociated atoms-Since reaction heat is generated when molecules are recombined, excess reaction or inhibited reaction may occur if the airflow is impure, preventing catalysis from being correctly evaluated.

overall, it is electrically neutral.

Precisely identifying a gas species

Besides contaminants, there is another problem with the arc-heated wind tunnel. Airflow heated using electrodes suddenly accelerates at the front of the measuring section to become a flow at hypersonic speed. Since it accelerates too suddenly, it becomes difficult to predict the chemical reaction of the airflow.

When the enthalpy of air exceeds 10 MJ/kg, oxygen molecules are nearly 100% dissociated[*3]. However, nitrogen is not fully dissociated even at 30 MJ/kg. (Fig. 3) Moreover, if the airflow rapidly accelerates, nitrogen no longer exists at the value shown in this model. In other words, it is no longer possible to predict the gas species (percentage of dissociation or recombination of nitrogen) in the measuring section.

Accurately identifying a gas species in an arc-heated wind tunnel leads to more accurate analysis. For example, heat-resistant material can be verified either with tests using a wind tunnel or with numerical analysis using models. Once such models for numerical analysis are established with reliable ability to predict gas species, we could increase the accuracy of analyses for verification purposes.

Therefore, we are continuing research on measuring the state of nitrogen with the "laser induced fluorescence (LIF) method"-a measurement method that uses lasers.

(*3) Dissociation: Oxygen and nitrogen molecules are formed when two oxygen or nitrogen atoms, respectively, are combined. Dissociation is the breaking of the bond between these atoms.

Gas species measurement experiments using LIF method

A laser is light with a specific wavelength that radiates from atoms or molecules. Atoms and molecules emit excess energy as light. Incandescent and fluorescent light bulbs illuminate based on this principle, which is called "spontaneous emission". In contrast, with lasers, light of a specific wavelength is directed at atoms or molecules to emit light of a certain wavelength. As opposed to spontaneous emission, a laser works by "stimulated emission". Lasers are used in very familiar applications, such as barcode readers at grocery store registers or laser pointers.

Figure 4 illustrates the basic concept for measuring nitrogen atoms using the LIF method in an arc-heated wind tunnel. Nitrogen atoms absorb a laser with a wavelength of 206.7 nm and emit light between 740 and 746 nm. Therefore, the measuring section is illuminated with a 206.7 nm laser and, in turn, light between 740 and

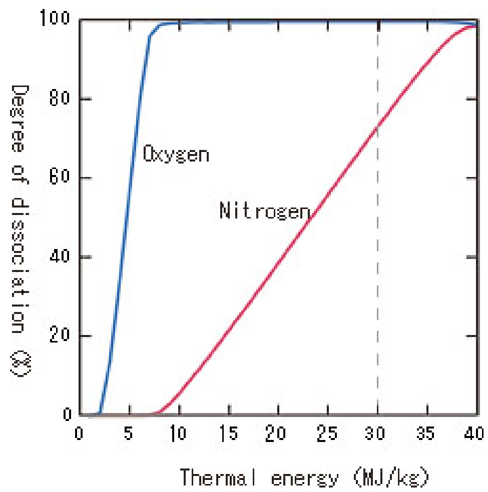


Fig.3 Dissociation rates of oxygen and nitrogen with respect to enthalpy

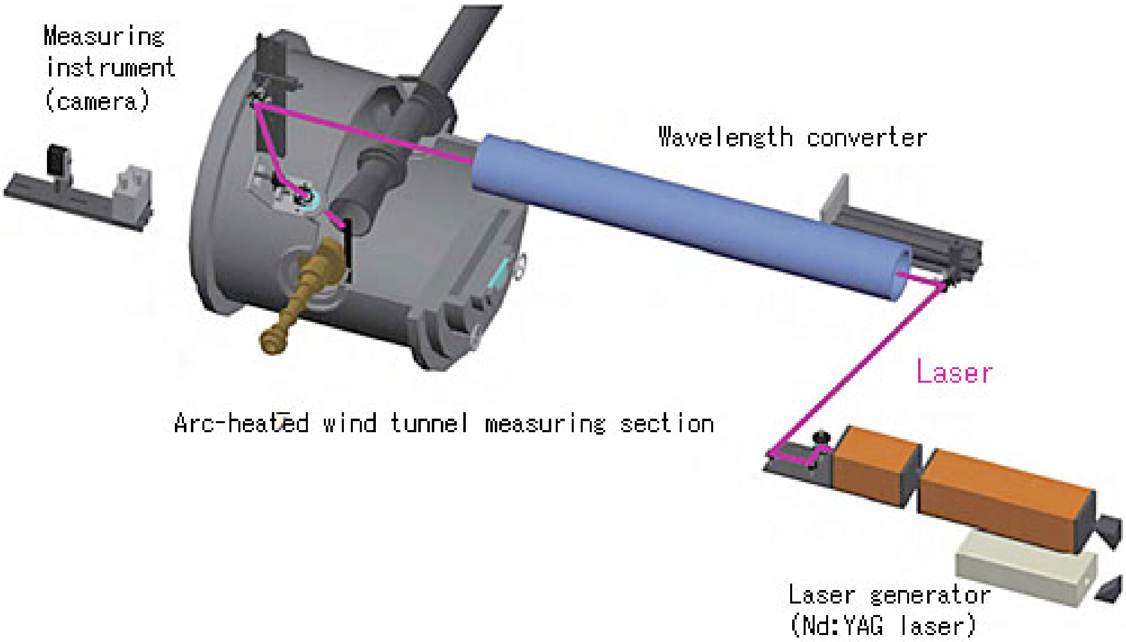


Fig.4 Basic concept for measuring nitrogen with LIF method

746 nm is observed, allowing us to determine the ratio of nitrogen atoms in the airflow and, thus, the gas species for the measuring section. Figure 5 shows the comparison of measured results and analysis results. The values are hardly identical, but since the shapes of the graphs are overall equivalent, we believe that we can obtain accurate values by improving future measurements and numerical analyses.

We are only now beginning to measure nitrogen atoms with the LIF method. In the future, we intend to perform the same measurements in an inductively coupled plasma-heated wind tunnel where a gas model has been established, examine the validity of the measurement method, and achieve more accurate measurements with applications in the arc-heated wind tunnel.

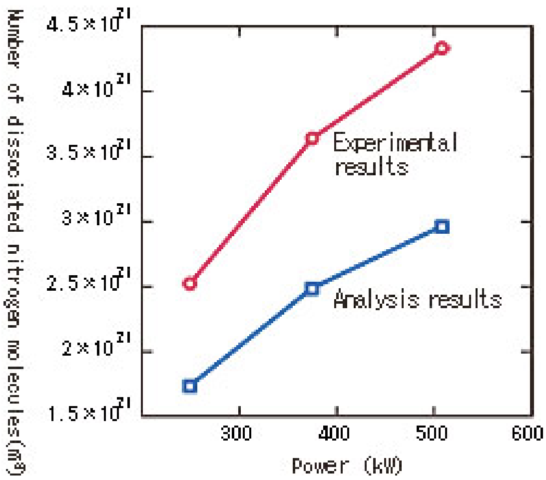


Fig.5 Comparison of experimental results using LIF method and numerical analysis results

[Wind Tunnel Technology Center]

(from left) Kiyomichi Ishida, Keisuke Fujii

(Front row) Hiroki Takayanagi, Tetsuo Yoshida, Masahito Mizuno, Junsei Nagai

Wind tunnels — Achieving the optimal shape

If you were to design a flying vehicle, what form would you use?

Using a facility called a "wind tunnel", we can simulate the conditions of the fuselage flying through the air to determine the shape of aircraft and spacecraft according to the known characteristics of that shape. Normally, an aircraft flies through the air at a high speed. In contrast, when a wind tunnel is used, the fuselage is secured within the measuring section, and an airflow is fed in at the same speed as that of the actual aircraft in flight. This method allows us to simulate various flight speeds, from the low speeds at takeoff and landing to airliner cruising speeds near the speed of sound or speeds exceeding the speed of sound. We can also simulate the environment of flying spacecraft. (refer to page 3)

JAXA maintains wind tunnels for various wind speeds, which are used in the research and development of aircraft and spacecraft. The oldest wind tunnel went into operation in 1960. Ever since, they have been used to perform tests and evaluations of the aerodynamic characteristics of most domestically manufactured aircraft, including those developed in Japan for the Ministry of Defense. In addition, performance assessment testing of various rockets and spaceplanes (Fig. 1) is making significant progress. These facilities will also be used in the study of technologies for the development of aircraft and spacecraft that will be required in the near future, as described in the article "Research and development of technology for the development of hypersonic aircraft" (refer to page 1).

In order to "determine the water-drop aerodynamic phenomenon of a firefighting amphibian", wind tunnels are also contributing to experiments for verifying targeted water drops by allowing us to discharge a water mass from a model simulating a firefighting amphibian so that the behavior can be studied. (Fig. 2)

Wind tunnels are used in determining shapes of various objects other than aircraft and spacecraft, including vehicles such as automobiles and trains, and architecture exposed to airflow such as skyscrapers and bridges. They are also useful in the field of athletics. The quadrennial winter competition of the Winter Olympic Games was held in Vancouver, Canada in February 2010. JAXA's 2m × 2m low-speed wind tunnel was extremely useful in the design to improve the aerodynamic performance of a luge (sled), one of the sporting events.

From bicycles and flying vehicles to various large-scale structures and sports equipment, wind tunnels are highly effective in "determining the shape" of various items in our daily life.

Fig.1: Performance assessment testing of the H-2 launch vehicle fairing

Fig.2 Water-drop testing of a firefighting amphibian