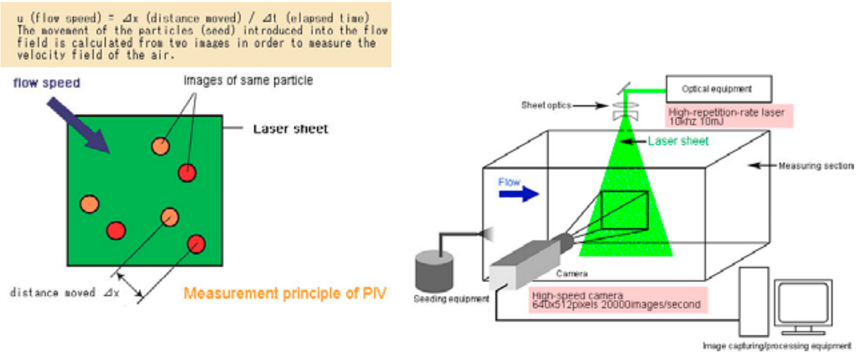
R E S E A R C H INTRODUCTION

“Time-Resolved PIV” - Capturing the Unsteady Flow



The diagram on the left illustrates the principle of PIV measurement. It uses an extremely simple principle of determining the airflow velocity from the displacement of particles (seeds) within a time interval. Compared to almost 10 years ago, we, at the JAXA Wind Tunnel Technology Center, have advanced the practical application of the PIV measurement technique for measuring airflow velocities in wind tunnel tests. This PIV measurement technique has been further developed over the past few years, and we are tackling the practical application of the time-resolved PIV measurement technique in wind tunnel tests, which can also measure the temporal changes of the constantly unsteady flow.

Fig. 1: Time-resolved PIV measurement system

Significance of learning about “flows”

The atmosphere surrounding Earth, the tap water that pours out when the faucet handle is turned, blood circulating through blood vessels...The world is filled with a variety of flows. Learning about flows should help us understand various phenomena of the world.

Even in the aerospace field, “flows” are extremely important. Taking an airplane as an example, “lift” (the force that causes the aircraft to float) is generated by the flow of air (airflow) around the wings, and some of the drag that works in a direction against flight also occurs due to airflow. Airflow around aircraft can be simulated in a “wind tunnel” , which generates airflow around an airframe model. In this way, we are using sensors installed in the model to measure forces, such as lift, that are applied to the model as well as phenomena caused by airflow, such as surface pressure.

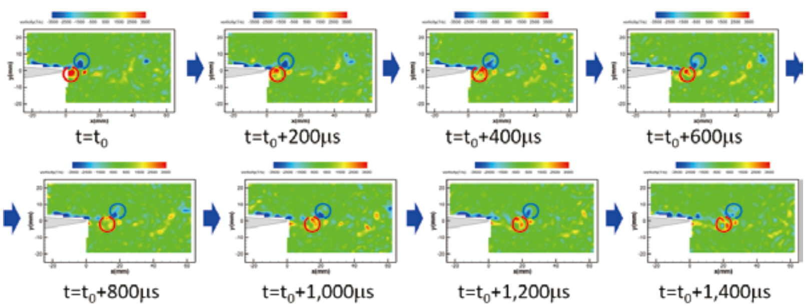
In recent years, “particle image velocimetry” (PIV) has gained attention as a method of measuring the airflow velocities around a model. The principle of PIV is very simple. By introducing minute particles (seeds), which follow the airflow, and measuring their displacement within a time interval, the velocity field of a plane is determined. Optical equipment to illuminate the seeds as well as a camera to record their movement are required for PIV. By importing into a computer the image data recorded by the camera, then analyzing it, the velocity field of a plane can be obtained (fig. 1, left).

Understanding momentary changes

With conventional PIV measurement, images are recorded at an interval of about 10 per second, and then the average of the momentary velocity fields allows us to obtain the velocity field under those conditions. If the photograph interval of PIV could be shortened and images could be recorded at an ultra-high speed, for example, 1000 images per second, we could determine the velocity field at every moment. This is the basis for devising the “time-resolved PIV measurement techunique” (fig. 1).

With conventional PIV measurement, we can capture the flow at the moment when airflow separation at a location on the wing causes vortexes to be created. In contrast, with time-resolved PIV measurement, we can capture not only locations where there is separation of the airflow but also the flow of generated vortexes. (fig. 2)

With time-resolved PIV, the performance requirements of each piece of equipment have risen greatly. In order to pursue an unsteady flow, a high-speed camera for following it as well as a device capable of emitting a light strong enough to reflect into the camera, even at short exposures, are necessary. Time-resolved PIV has become possible due to the progress of equipment in recent years.



The downstream flow of the vortex created at the top surface of the model’s wing (shown by the blue arrow) and the vortex created at the bottom surface (shown by the red arrow) could be captured.

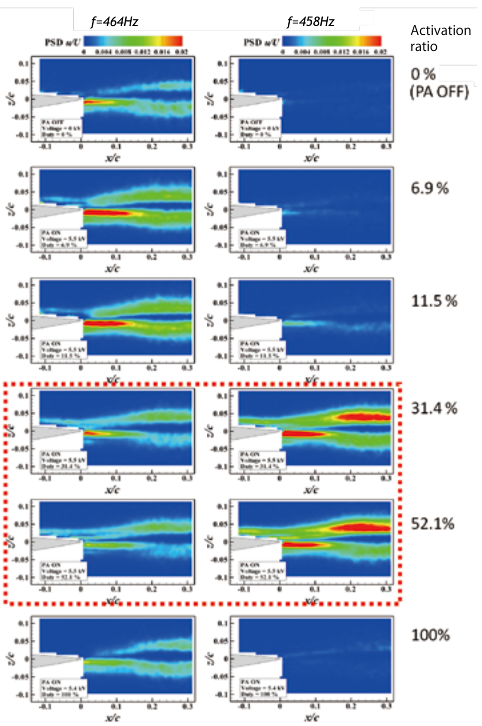
Fig. 2: Velocity field around a rectangular wing measured with time-resolved PIV

We have succeeded in photographing with time-resolved PIV!

At JAXA, we are tackling research to reduce “aerodynamic noise” created by aircraft. In order to reduce the noise, it is essential to accurately determine what noise is being produced from what areas. We believe that this can be accomplished with time-resolved PIV, which can determine the momentary velocity field of a certain space, and are introducing it into research for aerodynamic noise reduction.

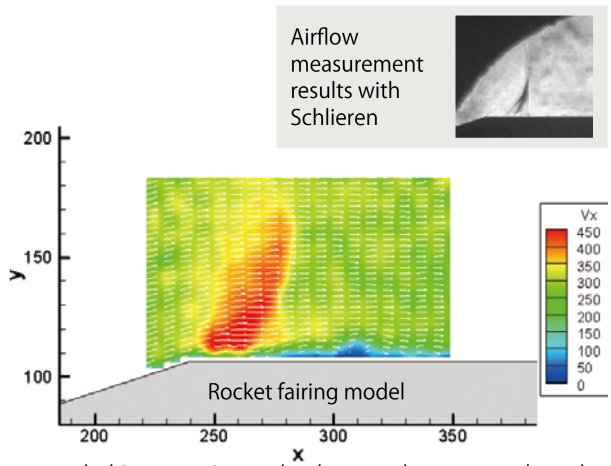
As one method of reducing aerodynamic noise, we are considering attaching plasma actuators to the wings in order to control airflow. Past acoustic measurements have revealed that noise can be reduced by activating plasma actuators and that sounds in other registers become stronger. By analyzing the data of each velocity field measured with time-resolved PIV, we are able to determine the fluctuations in the velocity field for a noise register. These analyses combined with data analysis of actual measured sounds have proven to be effective in determining noise sources as well as evaluating noise reduction devices such as plasma actuators. (Fig. 3) Furthermore, we are conducting research in determining, through time-resolved PIV measurements, the conditions of airflows, such as shock wave vibrations that occur in a rocket nose fairing during launch. (Fig. 4) This phenomenon occurs with the fast flow near the speed of sound, called transonic speed. Time-resolved PIV measurement is still rarely performed in the transonic wind tunnel, but JAXA is leading the way in that measurement technology.

As we have seen, time-resolved PIV is an extremely effective measurement method for “movement” . In the future, we plan to apply it to clarifying the phenomenon of flutter, the vibrations in wings during flight.



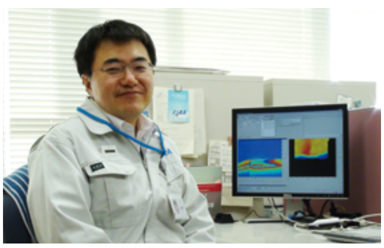
By activating plasma actuators, the change in velocity for a 464 Hz sound is reduced. However, it was revealed that the change in velocity for a 458 Hz sound increased by activating the actuators to 31.4% and 52.1%. This shows a good correlation to the actual occurrence of noise.

Fig. 3: Changes in the velocity field calculated with time-resolved PIV



We succeeded in capturing a shock wave that occurred on the model, similar to that with the Schlieren visualization method performed in the past.

Fig. 4: Time-resolved PIV measurement of a rocket fairing model



[Wind Tunnel Technology Center]

Hiroyuki Kato

"LIPS" -Measurement inside a combustor by using light

Low NOx combustion method

The function of an aircraft engine (jet engine) is to create a force for moving the aircraft forward (thrust). Air is brought in from the front of the engine and compressed. The compressed air is mixed with fuel in the combustor and burned, which generates combustion gases that are exhausted backward, producing thrust. (Fig. 1) The exhaust gas of the jet engine contains a small quantity of materials harmful to humans, such as carbon dioxide (CO_2), soot and nitrogen oxides (NOx). Typically, engines where combustion occurs at high temperatures and high pressure are fuel efficient and it is possible to reduce their CO_2.

However, at high temperatures, there is the problem that a large amount of NOx is produced.

As a combustion method for reducing NOx while preserving the fuel efficiency of the engine, JAXA is focusing on the "lean premix combustion method", which is able to provide fuel-efficient combustion while maintaining a low temperature in the combustor by introducing a large amount of air in proportion to the fuel as well as mixing them before combustion. Through this research, we have determined that lean premix combustion can reduce NOx while retaining the high combustion efficiency. However, we do not yet fully understand the process of combustion inside the combustor.

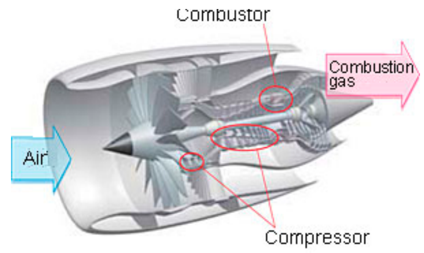


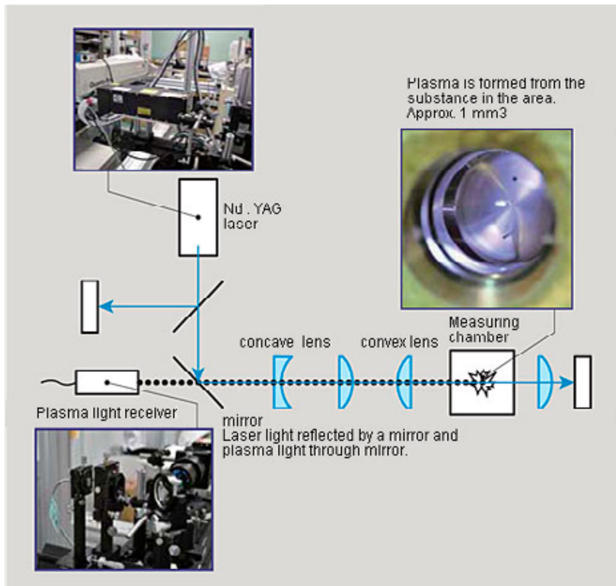
Fig. 1: Principle of thrust generated by a jet engine

Understanding the ratio of fuel and air

With a lean premix combustion, how is fuel distributed in the combustor, at what lean level does combustion occur, and how does that reduce NOx? If we knew the answer to these questions, we could effectively design a low fuel consumption, low NOx engine.

A method of inserting a pipe, called a "probe", into the combustor to collect combustion gases for analysis has long been used to measure the substance distribution quantity (equivalence ratio) in the combustor. This method requires a large hole to be made for inserting the probe well into the combustor, where it is needed in order to measure various locations inside the combustor, making it difficult to maintain the high internal pressure of a regular combustor. How could the equivalence ratio inside the combustor be measured under conditions close to those of the actual environment? "Laser-induced plasma spectroscopy" (LIPS) is being introduced as one such method..

The principle behind LIPS is a simple one of measuring the light emitted when a substance returns from an excited state to the ground state. Laser light is condensed with a lens to form plasma of the substance in the focus area, which becomes excited, and then the light that the atoms emit when they return to the ground state is measured, allowing the equivalence ratio of the substance in that area to be calculated. (Fig. 2)



Laser light travels to reflectors and through lenses, and is condensed at an area in the measuring chamber. Due to the strong energy of the laser, atoms separate from the molecules of the substance in that area, and then atoms and electrons separate to form plasma (excited state). Immediately afterward, the atoms emit light (plasma light), then return to the ground state. The emitted plasma light passes through lenses via the plasma light receiver to be spectroscopically measured.

Fig. 2: Principle of measuring with "laser-induced plasma spectroscopy" (LIPS)

Establishing equivalence ratio calculations using LIPS

Since the plasma light differs depending on the substance, the plasma light spectra are also different when the equivalence ratio is changed. In addition, since the spectra also differ depending on the measuring environment and since the equivalence ratio in the combustor is measured with LIPS, it is necessary to study how spectra are obtained for each equivalence ratio in a high-temperature, high-pressure environment. Therefore, we filled a sealed box-shaped chamber with gases, simulating combustion gas, with known equivalence ratios, then measured their spectra. (Fig. 3) Based on the obtained measurement results, we succeeded in establishing two methods for calculating the equivalence ratio from the spectra. Currently, we are directly flushing high-temperature, high-pressure combustion gas into the same chamber and verifying the test methods and equivalence ratio calculation methods. (Fig. 4) In the future, we plan to create combustor models for LIPS testing and conduct equivalence ratio measurement tests using LIPS.

The fuel of an aircraft jet engine possesses properties similar to kerosene and consists of mostly hydrocarbons (a substance composed only of carbon atoms and hydrogen atoms). Since nitrogen and oxygen are the main components of the atmosphere, most of the substances generated after combustion are composed of carbon atoms (C), hydrogen atoms (H), nitrogen atoms (N) and oxygen atoms (O). Therefore, we flushed gases containing mixtures of C, N and O into the measuring chamber, and

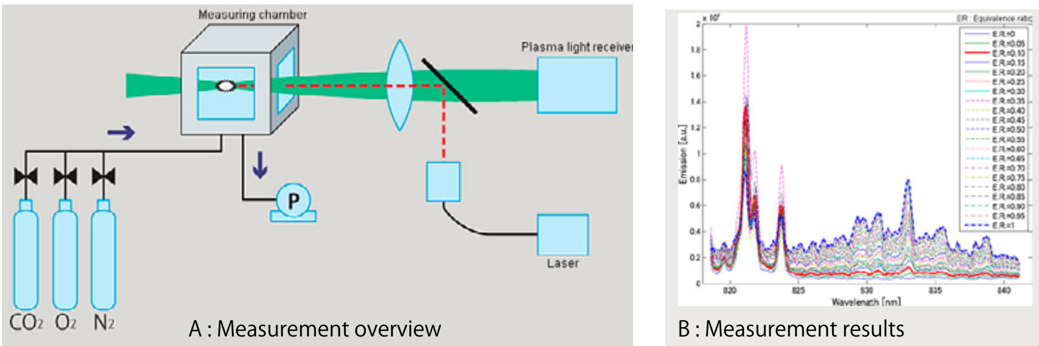


Fig. 3: LIPS test for establishing the equivalence ratio calculation method under high temperature and high pressure

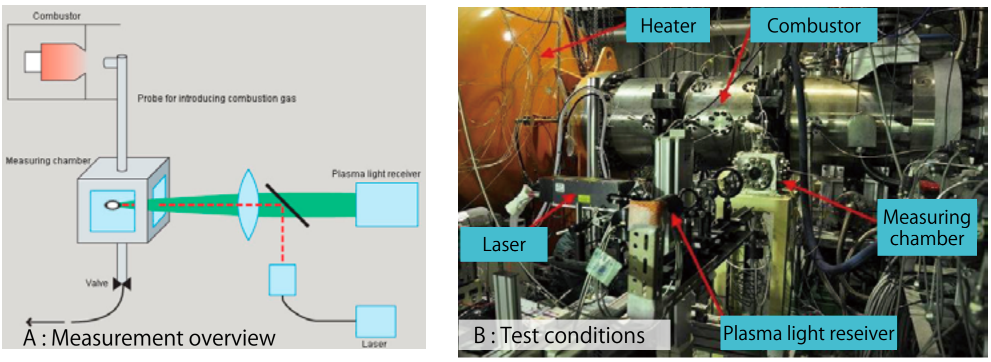
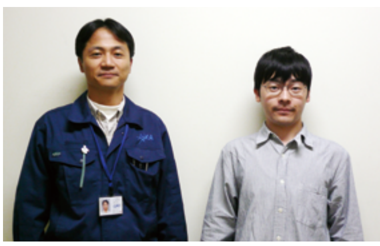


Fig. 4: LIPS test using actual combustion gas



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