RESEARCH INTRODUCTION

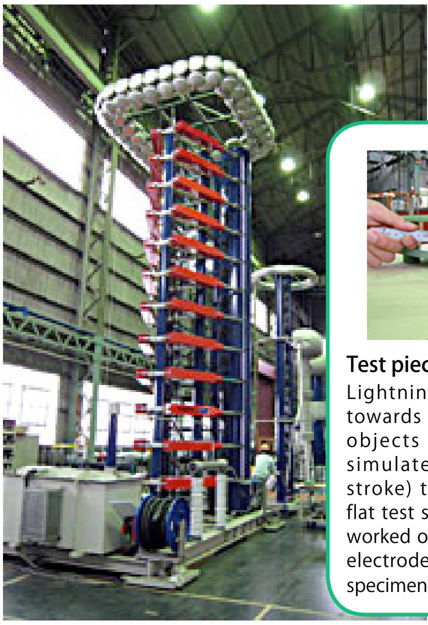
Aiming for CFRP highly resistant to lightning strokes

Well-developed protection systems protect aircrafts from many of the problems associated with lightning strokes

The friction between an aircraft body in flight and the atmosphere generates static electricity around the aircraft. To discharge this static electricity, a discharge device called a "static discharger" is installed at the wing's trailing edge and empennage section. The same device discharges electricity when an aircraft is hit by a lightning stroke.

The airframe of a traditional commercial aircraft is made from an aluminum-alloy called "duralumin." More recently, "carbon-fiber-reinforced composite material (CFRP)[*1]" and other types of advanced, lightweight materials with remarkable strength have been attracting the attention of aeronautical engineers. Some of these materials are already used to fabricate several sections of aircraft, including empennages, ailerons, and flaps. CFRP is used in the fuselage, main wing, and many other structural parts of the Airbus A380 (entered service in October 2007) and Boeing 787 (scheduled to go into service in the near future).

A composite airframe will not readily conduct lightning away in the manner of a traditional metal airframe. A strong electrical impulse current from a lightning stroke can therefore damage a composite airframe severely. Engineers are responding by devising various ingenious solutions for lightning protection, such as metal meshes applied to the surfaces.



Test piece installation portion

Lightning strokes tend to head towards pointed portions of the objects they strike. To induce simulated lightning (lightning stroke) to strike the center of a flat test specimen, we ingeniously worked out the shape of discharge electrode, the distance to the test specimen, and so on.

Fig.1 Impulse current generator (Owned by Nissin Electric Co., Ltd.)

Results from artificial lightning tests

Well-developed lightning protection systems are already designed into the composite parts in service today. Even so, it is important to understand the responses when CFRP is hit by lightning strokes. Partly as a consequence of its newness, CFRP has yet to be well characterized by systematic experimental data. JAXA has begun to collect data on CFRP by conducting tests on the "basic behavior of lightning stroke damage" and the "relationship between the size of the damaged area and lightning energy variation."

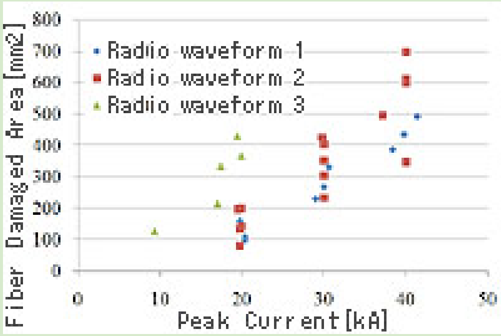
The "Impulse Current Generator (ICG)" is a device used to generate artificial lightning strokes for testing (Fig. 1). Fig. 2 shows the typical test result of the specimen after impulse current discharge. The test results demonstrated that an increase of the peak current of the simulated lightning stroke increased the size and depth of the carbon fiber damage. As the amount of specific energy of the whole current applied increased, the damage of the composite material increased in parallel. In addition to testing the levels of the lightning strikes, we also varied the plate thicknesses of the test specimens. By doing so we found that the laminate thickness had only a limited influence on the size of the damaged area.

Developing CFRP with high conductivity

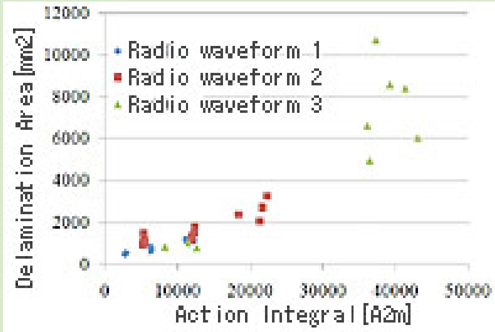
Our researchers are now considering proposals for new lightning protection systems for CFRP in the future.

One candidate method is to use carbon nanofiber[*2] to increase the electrical and thermal conductivity. We can ensure the flow path of electrical current and thermal flow by mixing epoxy resin with carbon nanofiber (Fig. 3). An increase in the electrical and thermal conductivity of CFRP, if achievable, would give us more leeway to reduce or eliminate the amount of metal to be applied to the composite surface, and thereby make further reductions of the airframe weight.

Specimen after the test

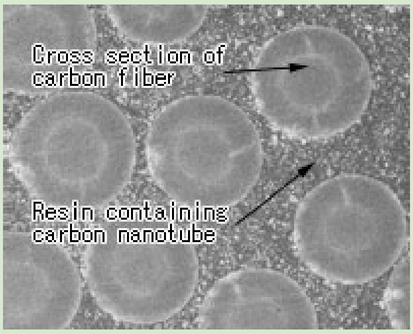


Relationship between the maximum current and the area of fiber damage



Relationship between specific energy (Action Integral) and the dimensions of the internal damage

Fig.2 Test result

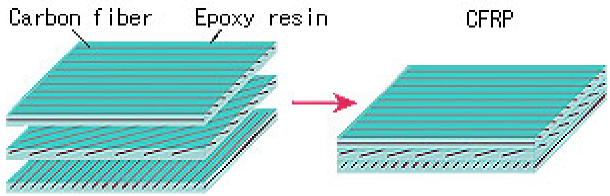


An electrical current path is secured by mixing microscopic carbon structures such as carbon nanofibers or carbon nanotubes in resin portions where electrical current doesn't flow.

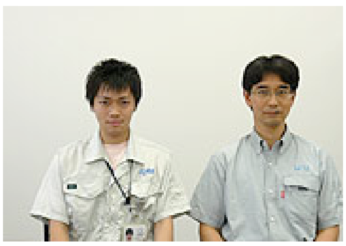
Fig. 3 CFRP consisting of carbon nanotube[*3] mixed into resin portions(Presented by GSI Creos Corporation)

In addition to the above, we are also researching a lightning protection system with a structural surface made from a composite material more conductive than the composite materials now in common use in aircraft.

(*1) Carbon-fiber-reinforced composite material (CFRP): Carbon-fiber-reinforced composite material is made up of two or more raw materials. A composite material retains the properties of the materials of which it is composed, while offering improvements through the composite design. The CFRP is made up of a lightweight and strong (high specific-strength and high specific-rigidity) carbon fiber hardened by a plastic called epoxy resin. Engineers often describe it as "stronger than iron and lighter than aluminum." The strength of CFRP is greatest in the direction of the fiber. Engineers can therefore design materials with outstanding strength in a required direction by angling and overlapping (laminating) the fibers.



(*2) Carbon nanofiber: Very minute fibrous carbon on the order of 10 to 1000 nm in diameter and a few micrometers in length. As in the case of carbon fiber, carbon nanofiber is lightweight, strong, and efficient in conducting electricity and heat.
(*3) Carbon nanotube: Carbon crystal more microscopic than carbon nanofiber



[Advanced Composite Research Center]

(from left) Yoshiyasu Hirano, Yutaka Iwahori

RESEARCH INTRODUCTION

Flying safely behind an aircraft

An aircraft in flight creates a phenomenon in the atmosphere called wake turbulence

As the aircraft moves through the air, it leaves a pair of vortex flows in its wake (wake turbulence). These flows are caused chiefly by disturbances of the air flow at the tips of the two main wings. (Fig. 1).

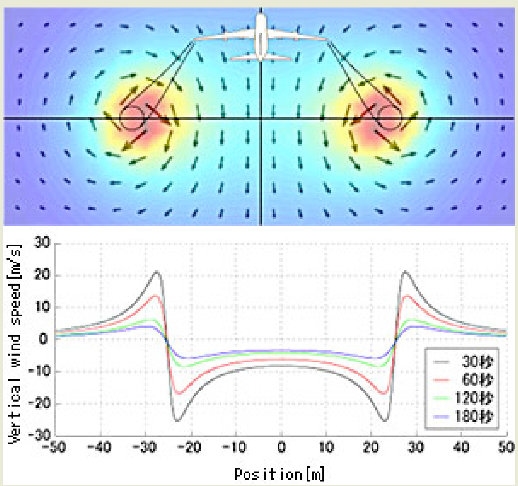
The intensity of wake turbulence is proportional to the aircraft weight and stronger at lower speeds. The turbulence is therefore strongest during takeoff. An aircraft flying behind another can be affected by this turbulence, and smaller aircraft are affected most severely. One effect, a loss of balance, can even lead to accidents. This is why air traffic authorities require a safe separation distance (or time) between aircraft during takeoff and landing. The separation required is determined solely by the aircraft weight. Though the type of aircraft is wholly neglected in this decision, helicopters are said to be more robust against wake turbulence than fixed-wing aircraft.

JAXA's research on wake turbulence

If we can prove that helicopters are insusceptible to wake turbulence, it will be possible to create opportunities for more frequent helicopter takeoffs and landings even during busier conditions, with shorter separations in time and distance. The gains in operational efficiency at airports would be significant. In pursuit of this target, we carried out experiments using the flight simulator owned by JAXA (refer to page 5).

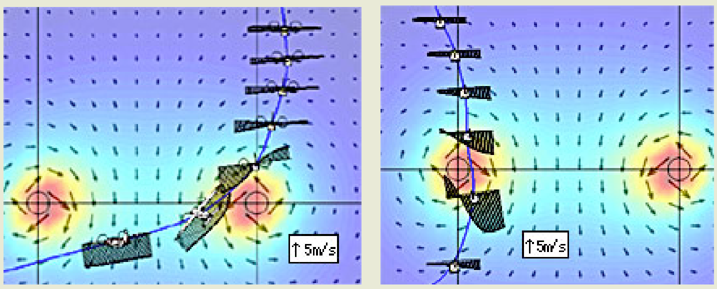
We simulated the landing approach of a small airplane and helicopter flying behind a Boeing 747-400, a large passenger jetliner, with wake turbulence at an altitude of about 300 feet (90 meters). Fig. 2 shows an example of the results. Fig. 3 shows the results of the evaluations by pilots who flew the simulations. With this experiment, we proved that helicopters are less susceptible to wake turbulence than fixed-wing aircraft.

The results also helped us recognize the dangers of wake turbulence anew. The chances of getting caught in wake turbulence in real flight are actually quite slim. But even so, aviators in Japan have experienced three accidents involving wake turbulence in the last five years alone. If an aircraft gets caught in wake turbulence, the pilot must take proper counter actions (judgment and steering) to return things as normal immediately. In our last round of experiments, we realized that simulations can help a pilot learn to judge the situation and steer an aircraft back into stable flight. We plan to continue to provide pilots outside



Even after an elapse of 60 seconds from the initial turbulence, upward and downward flows in excess of 10 m/s are still blowing.

Fig. 1 Results of a calculation of wake turbulence after takeoff of the Boeing 747-400, a large passenger aircraft



Dornier Do228 airplane　　Mitsubishi MH2000A helicopter

The figures on the left and right are examples of an airplane (Dornier Do228) and helicopter (Mitsubishi MH2000A), respectively. The figures show airframe movements and distributions of vertical winds received by the main wing of the airplane and main rotor of the helicopter. The airplane responds to the wake turbulence by heavily rolling to the left. The helicopter responds with a far less pronounced airframe roll, even though the craft receives stronger vertical winds while passing through the center of the vortex.

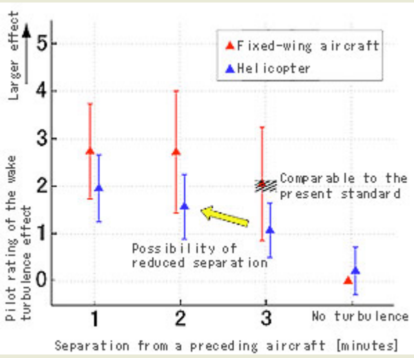
Fig. 2 Results of experiments by a flight simulator

JAXA with opportunities to experience simulated wake turbulence in the future, as well.

Providing safety information to pilots

Some airports are equipped with a LIDAR (Light Detection and Ranging), a laser device capable of observing the direction and speed of wind up in the air. JAXA is working in collaboration with the Electronic Navigation Research Institute and Tohoku University to develop a system to predict the behavior of wake turbulence based on LIDAR data and CFD (Computational Fluid Dynamics) analysis (Fig. 4).

Once the system makes its predictions, it will send the data to pilots and air traffic controllers. JAXA has already developed a technology to transmit data on wake turbulence to aircraft for display in the cockpit for the pilot (Fig. 5). In the future we target the development of a system to integrate these achievements and realize safer and more efficient operation by maintaining optimal separation times and distances between aircraft.



Sixteen pilots from operators/manufacturers were invited to participate in about 200 simulation runs. The longitudinal axis of the figure shows the pilot rating, which becomes larger as the wake turbulence effect increases. A rating of over 2 rules out a safe landing. Under the current standard, the separation from a preceding aircraft is set at 3 minutes for both of the aircraft types used in the simulation trial. In the case of the helicopter, however, the evaluation result indicates that safe landing is possible even with a separation of only 2 minutes (the ratings are less than 2).

Fig. 3 Results of evaluations by pilots

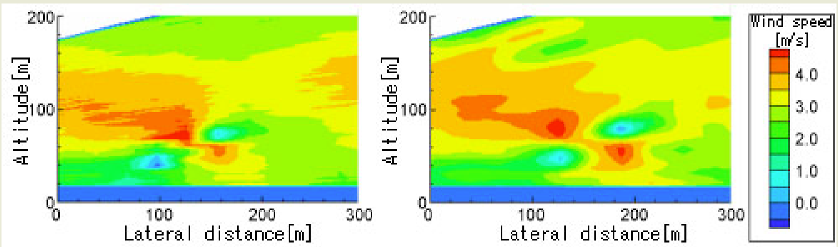


Fig.4 Enhancing the accuracy of the LIDAR observation data with CFD (Provided by Tohoku University)

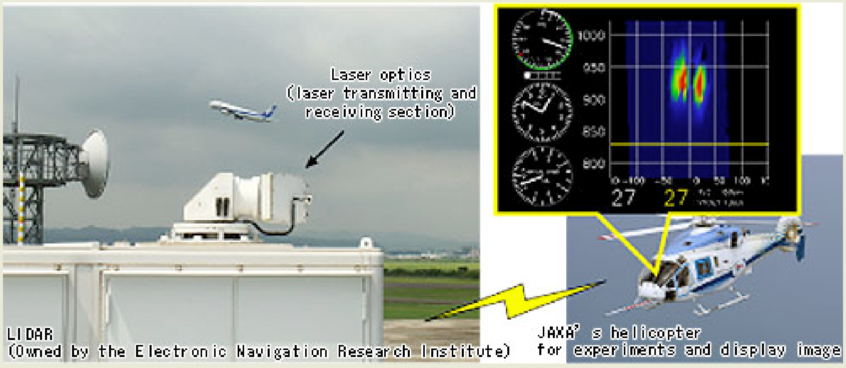
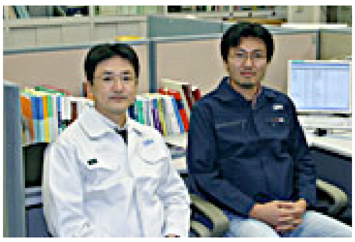


Fig. 5 System with cockpit displays to show pilots the wake turbulence observed by LIDAR on the ground



[Flight Research Center]

(from left) Yoshinori Okuno, Naoki Matayoshi

Intermission Break

Aircraft and meteorological conditions

A plane on a runway on rainy or snowy days is susceptible to hydroplaning, the trapping of a water film in the space between the tire and runway surfaces. The phenomenon takes place when the rotational speed of the tires exceeds a certain level, causing the wheels to run idle. An aircraft is difficult to control when this film is allowed to form. To reduce the risk of hydroplaning, runways are ingeniously designed with improved mechanisms for water drainage. The accretion of ice on an airplane wing on a snowy day subtly warps the shape of the wing, compromising its ability to provide "lift," the force that floats the plane. Airplanes are therefore designed to prevent the accretion of ice by directing hot air from the engine to the leading edge of the wing, etc.

As a country subject to frequent lightning strokes, Japan must take thorough measures to deal with lightning. We generally think of lightning as a common phenomenon in the summer. But the coast of the Sea of Japan is susceptible to "winter lightning," a phenomenon very rare in other parts of the world. Winter lightning strokes have the potential to tremendously impact aircraft, as they tend to deliver far more energy than summer lightning strokes. Fortunately, lightning is rarely severe enough to endanger flight, though we may expect it to char whatever it strikes. The damage of the stroke is minimized by a "discharge device," a piece of equipment designed to discharge the electricity that accumulates on the body of the aircraft under normal conditions. When lightning strikes, the device efficiently discharges the energy (electricity) instantly delivered (Fig. 1). There is great concern, however, that measuring instruments may be affected by flows of electricity on the surface of the aircraft body. To cope with this risk, the aircraft body is ingeniously designed with redundant measuring instruments configured to start up when the main instruments fail. More of the aircraft bodies now being produced are made with a new material called carbon-fiber-reinforced composite material (CFRP). It has become important to understand the characteristics of CFRP for lightning strikes (refer to page 1).

One of the crucial meteorological conditions to understand in operating aircraft is wind movement. About half of the aviation accidents involving passenger aircraft in our country are said to be caused mainly by "turbulence." It is therefore important to have information on turbulence well in advance. Almost all airports throughout Japan have facilities to forecast aviation weather several hours in advance. Major airports such as Tokyo International Airport and Narita International Airport also monitor weather over vast areas, including parts of the ocean where air routes pass. Large passenger aircraft are equipped with weather radars capable of predicting turbulence ahead by observing the conditions of raindrops, etc. and confirming the conditions of air currents even after takeoff. Yet weather radars are incapable of detecting 'clear air turbulence,' a turbulence generated in the absence of clouds over certain terrains and under certain wind conditions. JAXA is researching and developing a device to measure wind conditions ahead, including air currents unaccompanied by clouds.

Various kinds of turbulence present problems during take-off and landing, as shown in Fig. 2. If an aircraft flying behind another in the same path gets caught in the "wake turbulence" generated by the wing tip, etc. of the aircraft before it, catastrophic accidents may result (refer to page 2). The danger is greatest for small aircraft. This is why air traffic controllers require a proper separation, in time or distance, between two planes flying along the same path.

To release static electricity accumulated over the aircraft body due to air friction, etc., a discharge device is attached to the landing gear or trailing edge of the wing. The photo shows a 'static discharger,' a discharge device attached to the trailing edge of the main wing.

Fig. 1 Static discharger

Aircraft may be subject to the effects of various kinds of turbulence during take-off or landing. *Low-level wind shear: A rapid change in the speed or direction of the wind near the surface of the ground at an altitude of several hundred meters or less.

Fig.2 Types of turbulence that present problems during take-off and landing