Protecting the body from impact force during emergency landings

An airplane in the air cannot make a temporary stop like an automobile, even when trouble occurs. Accidents must be prevented as a matter of course. In the very unlikely event that an accident does occur, an aircraft must be designed to minimize damage. Today's aircrafts incorporate many devices to minimize the force subjected to the bodies of passengers and crew in the case of an impact.

Safety unachievable by chance

In January 2009, an airliner was forced to make an emergency landing on the Hudson River in New York. Just after takeoff, a collision with a flock of birds shut down the engine. Miraculously, the plane was safely landed on the river without a single casualty. With masterful precision, the pilot maneuvered the aircraft like a glider smoothly onto the surface of the river. Yet the skill of the pilot was not the only life-saving factor. This narrow escape from human tragedy could also be credited to the fruits of aeronautical technologies and improved safeguards to protect aircraft from impact force during emergency landings.

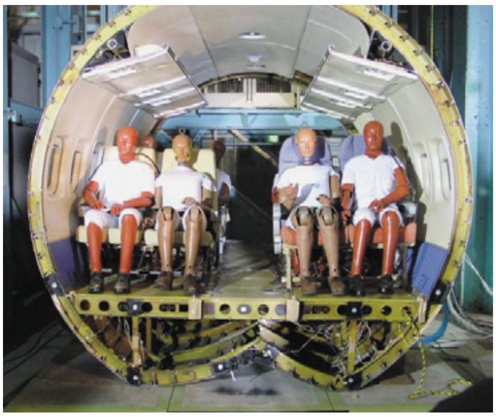
The safety designs of aircraft are partly based on accident experiences. If an accident strikes, the cause is investigated and the results are used to develop safer aircraft for the future. Ultimately, an aircraft is designed and manufactured to ensure the safety of the passengers by allowing the pilot to keep control even when incredibly unlikely anomalies beset the aircraft in flight. Aircrafts are manufactured based on standards commonly adopted in almost all countries.

How can passenger safety be maintained when an aircraft is subject to impact? Here we describe several situations that arise in the event of impact and several of the technologies used to cope.

Contrivances to mitigate impact

Passengers hardly feel the impact at landing because the landing gear absorbs the impact. If, for some reason, the landing gear becomes unusable, the aircraft must land on its fuselage. In this case an immense force is applied to the aircraft and the force of the impact is transmitted to the passengers.

To fly legally, an airliner must obtain Airworthiness Certification (an authorization to fly). To ensure safety

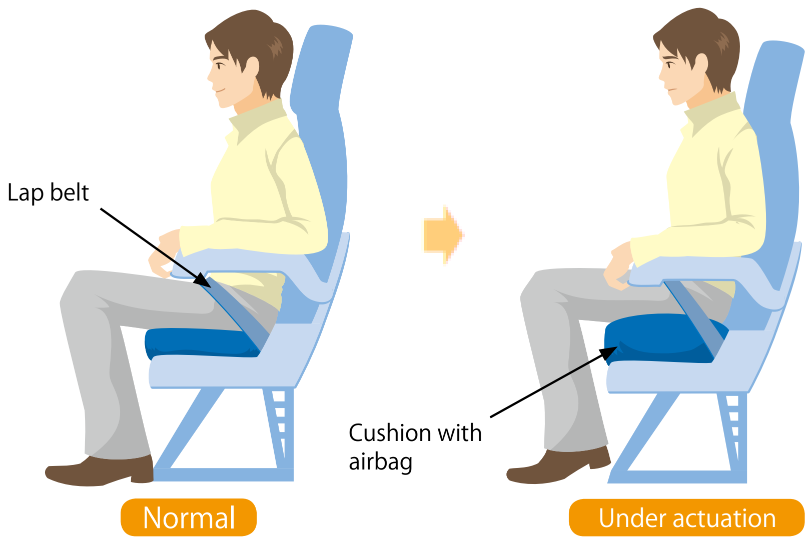


Before Drop

Fig. 1: Fuselage structure after drop test (Using an actual airplane)

Seat with an improved safety structure based on a JAXA concept.

Air bag functions added to the cushion



Same configuration as a normal cushion

Immediately before impact, an electric signal is transmitted from the sensor and gas is filled into the air bag built into the cushion. The impact acceleration applied onto the human body is reduced by control of the internal pressure of the air bag.

Aircraft seat with a cushion equipped with the same type of airbag commonly used for automobiles. The cushion mitigates the impact in the vertical direction specific to the airplane and the impact applied to the lower back of the passenger.

even during a forced landing, the following criteria are established:

○ An airplane taking an emergency landing "should resist impact and not cause a fire."

○ An airplane landing on water "should resist impact and float to allow evacuation."

To satisfy these criteria, an aircraft must meet all of the following conditions:

● The aircraft is structured to prevent fires, particularly the fuel tank inside the main wing.

● Flame-resistant materials are used in the passenger cabin.

● Corridors and doors are designed to enable passenger evacuation from anywhere in the cabin within 90 seconds.

● The airplane can float for a certain period of time after landing on water, to permit passenger evacuation.

The items above are just a few of many design conditions imposed. No airplane is permitted to fly in the sky until all of these items are demonstrated or proved. To cope with the impact during emergency landing, the current airliners are designed with seats that absorb the force at impact to protect passenger bodies from lethal loads.

Protected with being fractured

Rigid, unbreakable airplanes are not necessarily safe for passengers. The crushing of the bottom of the fuselage at impact (Fig. 1) absorbs some of the impact energy, reducing the force applied to the passengers. This demonstrates how an easily breakable structure deliberately incorporated into the design of an aircraft can actually help to ensure safety. Some helicopters have fuselages with lowermost structures designed in consideration of the above.

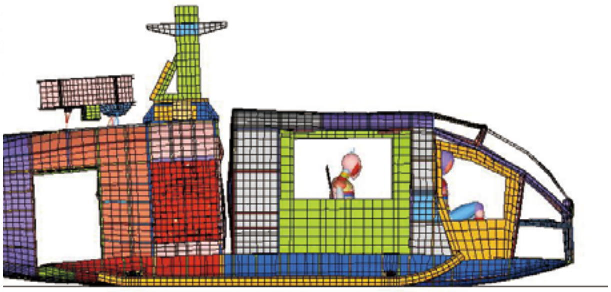
If the lowermost portion of the fuselage is actively used as an impact-absorbing component in airliner design, survival rates can be expected to improve and damages will be reduced during emergency landings. Aircraft producers around the world seek to apply this type of design in the aircrafts of the future.

Crash simulation

What type of structure at the bottom of the fuselage has the optimal impact-absorbing capacity? Several methods are being studied. A rigid foam plastic with tiny cavities can be filled into the area under the floor, or composite materials with better impact absorption can be introduced.

Impact-simulation technology is indispensable for the development and design of new structures for the bottoms of fuselages. Given the prohibitive cost and infeasibility of testing with actual airplanes, the main work of development is to analyze the impact behavior

Appearance at 0.1 seconds after landing



Analysis Diagram

Fig. 2: Drop test with an actual helicopter and analysis diagram

by computer. Airplane crash tests are carried out in virtual space, that is, by computer.

JAXA is researching an analysis technology to precisely simulate what occurs in an aircraft during impact. To understand the phenomena of impact, we are collecting data by carrying out various types of drop tests. Comparisons and verifications with those data help us improve the analytical technologies at our disposal (Fig. 2).

In a collaborative project with Mitsubishi Heavy Industries, Ltd., we recently carried out a water landing test with a scale model (Fig. 3) to quantify and characterize the force received by the airplane fuselage from the water surface. By doing so, we also succeeded in verifying the results from earlier analyses. One of the challenges to carrying out the impact analysis at higher precision is to model the joints of the rivets[*1] more precisely for more exact simulation of fracture events of the structural joints.

(*1) A metal fastener to be used to join the members.

Preparing for collision of foreign objects

An aircraft in flight can also collide with foreign objects such as hail or flying birds. And when running on a runway, an aircraft can collide with pebbles or tire fragments swept up from the ground in strong blasts of air. At the high speed of airplane travel, a collision with even a small foreign object can have tremendous force and reap great

Structure	Projectile	Mass	Requirements
Leading edge of main wing, etc.	Bird	Approx. 1.8 kg	Safe flight and landing under appropriate pilot operation
Leading edge of horizontal tail Leading edge of vertical tail	Bird	Approx. 3.6 kg	Protection of strength of tail unit and attached portion; and important systems
Cockpit wind shield	Bird	Approx. 1.8 kg	Prevention of intrusion through wind shield and attaching structure
Lower surface of main wing	Tire fragments	1 % of tire mass	Protection of landing gear well system Prevention against leakage from fuel tank in wing

Table: Required conditions for airworthiness

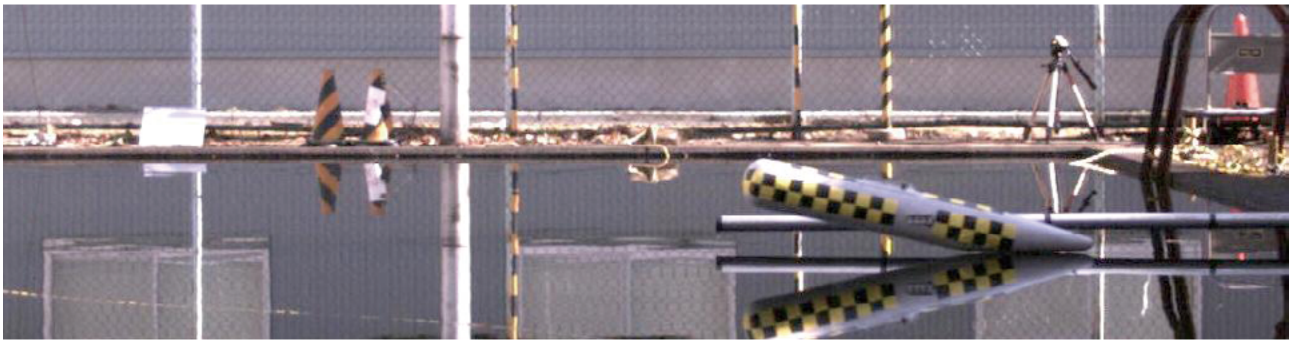


Fig. 3: Water landing test with a scale model
A model simulating the fuselage shape was landed onto a water bath.

damage.

The airliner forced to land on the Hudson River lost its engine power due to a bird strike. This was an anomaly, as airplane designs require the maintenance of safety even when an airplane collides with foreign objects (Table). Foreign objects colliding into the main wing can cause fires due to fuel leaks [(*2)], or foreign objects may penetrate the windshield (the glass covering the cockpit) and knock out the pilot.

In October 2008, JAXA manufactured and installed a test system for the testing of foreign object damage. This system collides foreign objects into specimen at designated speeds and measures the properties of their collisions. In our cooperative research with Mitsubishi Heavy Industries, Ltd. to date, we have measured the speeds of projectiles, the locations of projective collisions, and the load, acceleration, strain, etc. to which specimens are subjected during collisions. We carried out these experiments by colliding gelatin balls (projectiles similar to birds) into specimens such as rigid-body flat plates and the leading-edge components of the main wings of real airplanes. (Fig. 4). While doing so, we also analyzed the above by simulations. Our target is to improve the technology to enable us to analyze loads during highly precise simulations of foreign object collisions and then to use technology as a source for design hints, etc.

(*2) In 2000, a Concorde operated by Air France exploded into flames immediately after takeoff, According to a recent announcement, the catastrophe was caused by the collision of tire fragments with the lower surface of the main wing during taxiing.

Contribution to safety in sky

It has been predicted that many more airplanes will fly in the future. Though the rate of aircraft fatalities has been flattening-out in the recent years, the growing prevalence of aircraft transport has actually increased the number of accidents. To help prevent accidents before they can happen, JAXA is researching ways to improve safety in the sky and improve the crashworthiness of aircraft.

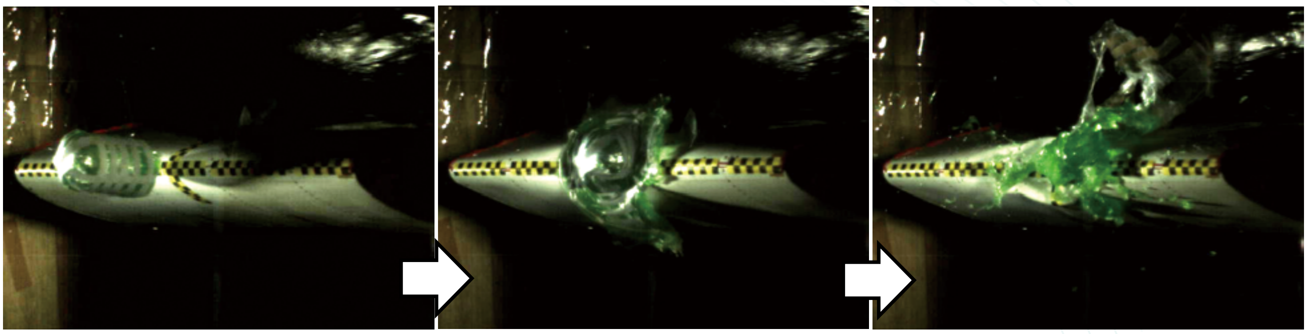


Fig.4: Impact test onto the components of the leading edge of the main wing of an actual airplane

Research Report

From the research field

Indispensable CFD technology for research and development on the jet engine

Clean Engine Team

What is CFD?

An aircraft flies in the sky and changes its flight attitude by the force of air. As it does so, it maintains its flight speed against the force of air drag. The engineering discipline for the handling of these forces is referred to as fluid dynamics. The computer technology for simulating air flow is called Computational Fluid Dynamics (CFD). An air flow can be expressed by mathematical equations, but it is impossible to answer equations expressing airflow over multiple regions all at the same time. Instead, the area of the air flow to be examined is divided into small meshes and the answer is found by repeating calculations to solve the equations in each mesh. Weather forecasts by computer are performed by a similar approach, but much finer meshes are used for CFD in aviation. CFD also plays an important role in clarifying the very complicated flows in jet engines (Figure 1).

Analyzing noise generated from the engine fan

The fan of a jet engine is a major source of thrust. At the same time, the blades rotating at high speed are a source of noise. CFD can directly calculate the generation and propagation of noise, but doing so requires an enormous number of finer meshes and long hours. To simplify the process, a more elaborate CFD is applied exclusively in the region near the noise source, around the fan blades. Meanwhile, the manner in which the generated noise is transmitted from the inside of the engine to the outside is expressed based on acoustic theory (Figure 2). Quieter jet engines can be designed by clarifying the sound propagation and sound intensity by these methods.

Analysis of compressor performance

Air sucked into the engine is compressed to high pressure in the compressor to burn fuel. The compressor has rows of rotating and stationary blades. Engine designs with reduced loss from the blades are important for improved engine performance and reduced CO_2 emissions. Figure 3 shows an example of a CFD analysis of an entire compressor. The distribution of loss near the blades is expressed in color (the largest loss is expressed in red). CFD analysis is a very helpful method for making better designs, as it shows the magnitude of loss from each blade and how air flows down to the neighboring row of blades.

Developing low-pollution combustor

Jet fuel with a composition similar to kerosene is burned with compressed air in a combustor. To reduce the nitrogen oxides (NOx) generated during combustion, the engine must control the fuel mixing ratios in different parts of the combustor. A well designed combustor will maintain a fuel-rich flow from the nozzle to the upstream region of the

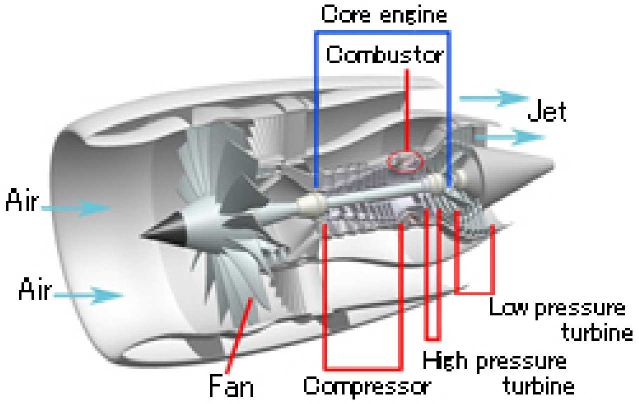


Fig.1: Structure of the Jet Engine

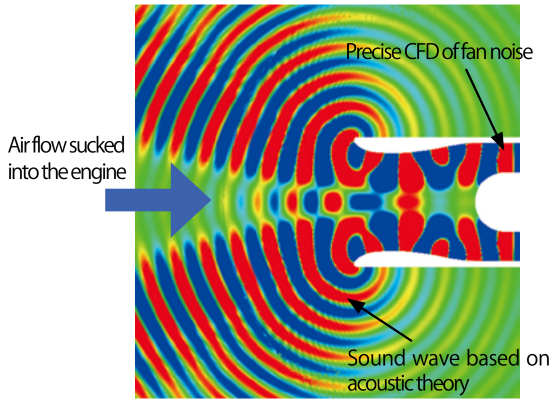


Fig.2: Fan noise near the intake of the jet engine

(Back row, from the left) Takeshi Yamamoto, Junichi Kazawa, Osamu Nozaki
(Front row, from the left) Takashi Yamane, Mitsumasa Makida

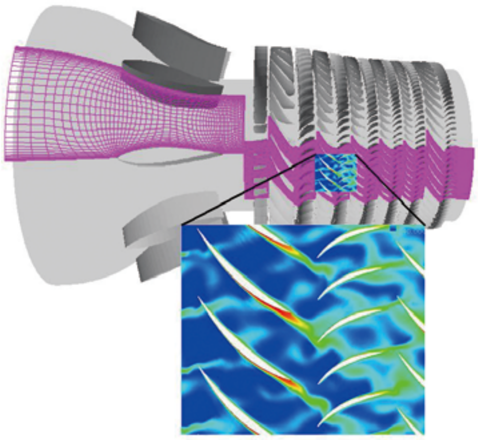
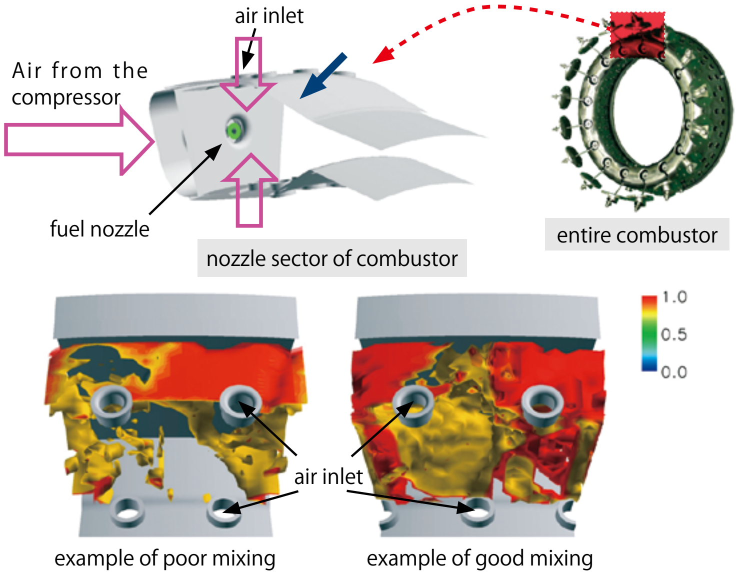


Fig.3: CFD mesh for compressor and loss distribution
(Collaboration with IHI Corporation)



(Seen from the blue arrow in the above figure)

Fig.4: Mixing air in the combustor

combustor. Figure 4 shows how a flow from the fuel nozzle is mixed with that from the side air inlets by CFD analysis for a single fuel nozzle sector region in the entire combustor. CFD helps check how changes in the size and arrangement of the side air inlets affect the mixing of fuel and air. Another of our research targets is to develop a method for predicting the generation of pollutants such as NOx by calculating chemical reactions during combustion.

Predicting turbine temperature distribution

The energy of high-temperature high-pressure gas generated by the combustor is converted into rotating power by the turbine to drive the fan and compressor. The turbine blades exposed to temperatures high enough to melt the blade material, but cooling air from the inside protects against this outcome. The amount of cooling air should be reduced to improve the engine performance. The design of an effective cooling structure with these properties requires accurate temperature prediction. Our team is researching a conjugate heat transfer analysis capable of calculating the flow of high-temperature gas and cooling air concurrently with the heat conduction in the blade material. Figure 5 is an example of a calculated temperature distribution in the cross section of a turbine blade with cooling passages provided inside. This analysis provides accurate details on the temperature distribution, a parameter impossible to measure experimentally. As such, it can be used as an effective tool to develop a high-performance cooling structure and reduce CO_2 emissions.

CFD in development of a clean jet engine

The Clean Engine Team pursues three challenging targets in its work to develop jet engine technology: low noise, low NOx, and low CO_2 emissions. As introduced in this report, CFD technology plays a crucial role in all of three directions. We are pressing onward in our research and development to improve the availability of this tool.

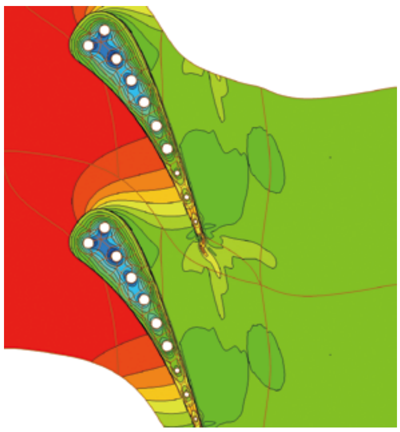


Fig.5: Temperature distribution in the turbine blade

Research Report

From the research field

Research on VaRTM and prepreg hybrid fabrication technology of composite materials

— Aiming to develop a low-cost high-quality CFRP structure

Civil Transport Team

Lower manufacturing costs

Composite materials such as carbon-fiber-reinforced plastics (CFRP) are now being commonly adopted as structural materials for aircraft. Several properties of these materials are ideally suited to the mission requirements of flight safety and extended flight times. The most essential of these properties are corrosion resistance and lighter weights and greater strengths compared to metal. Composite material will be used for about half of the weight of the state-of-the-art passenger plane now under development. Compared to today's planes, the coming plane is expected to fly over longer distances with improved mileage due to reduced airframe weight, and its superior corrosion resistance is expected to endow it with a stronger body and better cabin environment.

Significantly, however, the superb performance of composite material comes at a price. The materials composing it are expensive to begin with, and once procured they are costly to mold into finished parts. The costs are tremendously high in terms of both time and money.

To reduce manufacturing costs, the Civil Transport Team is researching the "VaRTM and Prepreg Hybrid (VPH) fabrication technology," a completely new process for molding composite material.

What is VPH fabrication technology?

According to the dictionary, a "hybrid" is "a thing composed of two or more other things in combination" or "a thing made by combining two different elements." Recently, hybrid cars are seen everywhere on the road. As you know, automakers have achieved better gas mileage by combining conventional gasoline engines and electric motors into hybrid engines.

Hybrid fabrication technology, our research theme, is based on the same concept. A low-cost high-quality CFRP structure can be manufactured by mixing and matching two conventional composite material molding technologies.

A typical CFRP structure molding method for aircraft is the autoclave molding process (Figure 1(a)). A pile of sheets called "prepreg," carbon fibers pre-impregnated with a resin, is placed into an autoclave for curing. When sheets of prepreg are stacked, the adhesive property of the impregnated resin binds them together. Thanks to the uniform impregnation of resin, the application of a uniform heat source will cure even a large prepreg structure composed of multiple sheets all at once. Yet during the stage between adherence and curing, the adhered sheets are difficult to peel away and reshape. Prepreg sheets are far more suitable for fabricating

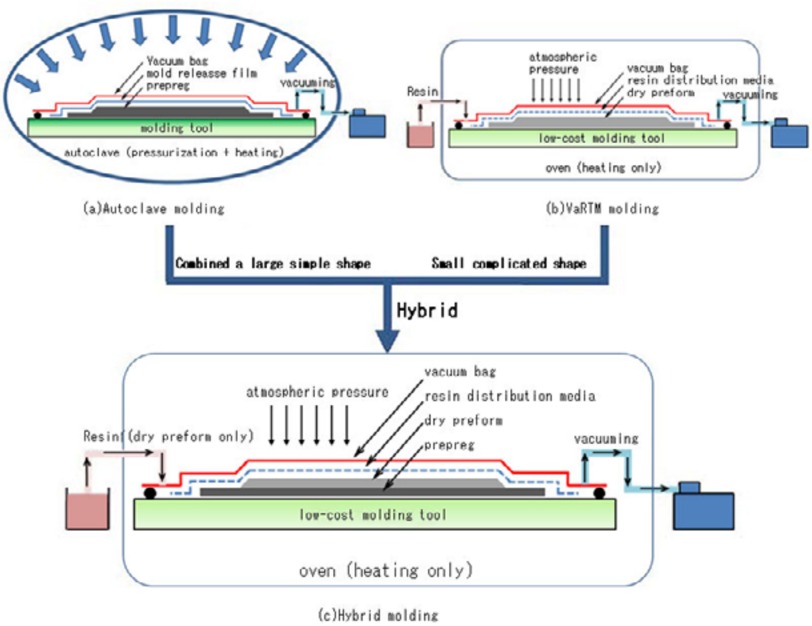
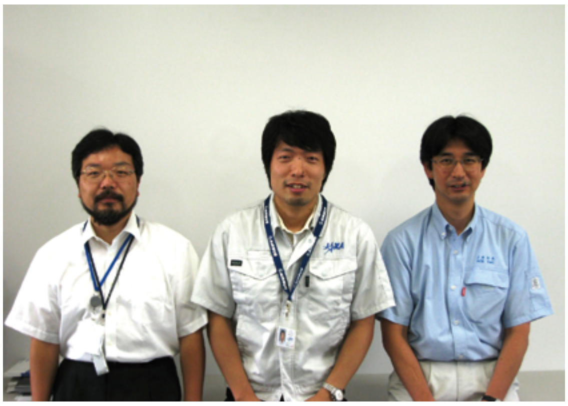


Fig.1: Outline of VPH fabrication technology



Structure Material Engineering Section
(From left) Sunao Sugimoto, Yuichiro Aoki, Yutaka Iwahori

simple shapes (flat and smooth) than complicated ones. This fabrication process requires expensive autoclave equipment, which entails high fabrication costs. Vacuum-assisted Resin Transfer Molding (VaRTM) technology (Figure 1(b)) will solve this problem. In the VaRTM process, dry carbon fiber fabric (dry preform) is placed in a mold of a desired shape, covered by a vacuum bag, and vacuumed. Next, the CFRP structure is obtained by infusing resin into the dry preform and curing it at an elevated temperature. In contrast, the VaRTM process molds and cures the dry preform under atmospheric pressure without the use of autoclave equipment. As the name implies, dry preform is a dry fabric material. Even if dry preform has a slightly complicated shape, it can be reshaped as easily as a piece of paper folded into an origami sculpture. The fabrication is also less costly, as there is no need to apply high pressure with a molding jig. Our research concludes that VaRTM can offer a 25% cost reduction compared to the autoclave fabrication process. Importantly, however, the quality of the fabrication is greatly affected by the method of resin infusion and the size and shape of the structure. This makes it quite challenging to fabricate larger structures by the VaRTM process.

The VPH fabrication technology (Figure 1(c)) combines the advantages of these two molding processes. Prepreg is used for larger, more simply shaped components, while dry preform is used for small, complexly shaped components. Once the components are shaped, they are integrated and covered by a vacuum bag and vacuumed. Next, resin is infused into the dry preform components only, and the temperature is elevated to cure the prepreg resin and dry preform all at once. We seek to improve manufacturing efficiency by this process and develop a low-cost high-quality CFRP structure. Our goal is to reduce costs by 50% compared to the autoclave molding process.

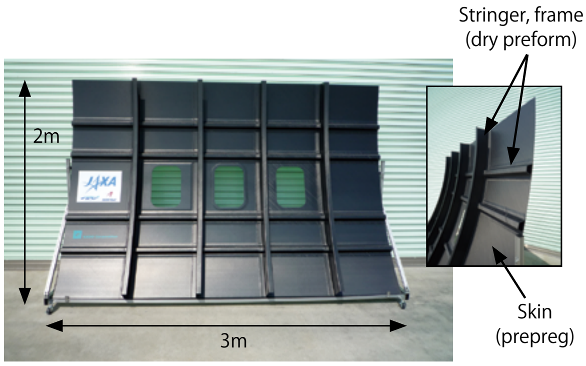


Fig.2: Fuselage structure prototype by VPH fabrication technology

Aiming to apply hybrid molding to aircraft structure

The most suitable part of an aircraft for application of the VPH fabrication technology is the fuselage. Figure 2 shows a fuselage quadrant structure. The large-area skin is made of prepreg, while the complexly shaped reinforcing members are made of dry preform. JAXA has already succeeded in fabricating a prototype with the size of 2 meters x 3 meters. This prototype was well received by experts at the 48th Paris Air show held in June 2009. In coming months we will be further stabilizing the fabrication quality and conducting structural tests to demonstrate the excellent strength. We expect to apply the VPH fabrication technology to the next-generation domestic passenger airplane.

(Yuichiro Aoki)

Interview
People who fly dreams
Vol.13

An easily deployable UAV system to collect information just after a disaster strikes

A UAV (unmanned aerial vehicle) can collect visible information from the sky when a disaster-stricken area is too dangerous for people to approach.

Unmanned and Innovative Aircraft Team
Shouki Togou

This time, we interviewed Shouki Togou, a computer expert invited from a company to work for JAXA. Togou is lending his considerable expertise to a JAXA project to research and develop a disaster-monitoring UAV (unmanned aerial vehicle) system.

Controlling airships

Mr. Togou, can you tell us about the research you are overseeing?

Togou The Unmanned and Innovative Aircraft Team is developing a disaster monitoring UAV system using a small airship and a fixed-wing aircraft. I'm in charge of research and development of an application for wireless data communication between the airship and ground.

This system is designed to promptly collect information using an unmanned aircraft in the event of a disaster. We want to simplify the system so that anybody can easily use it. The unmanned aircraft automatically flies to preset monitoring points. My role in the project is to make sure that the ground station will smoothly send instructions for mission changes, such as additions or cancellations of monitoring points, as the airship flies along its preset course.

Shouki Togou
Lectured at an IT-related vocational college before finding his place at JAXA.
Specialized in program development, network technology, CG, etc.

Can anybody use the system?

Togou We try to develop a system that anyone who has received simple training can use. A user, for example, can set the monitoring points simply by setting on points on a map. It works much like a software application. Surely you are familiar with office use applications. Once you install the software, it's the user who composes the words and sentences. This is our part of the project for the disaster-monitoring UAV system: we create a user interface which works much like word-processing software. We are also developing a system to send commands to the unmanned aircraft by radio communication.

How far have you gone in this development?

Togou We use wireless LAN for radio communication between the airship and ground. In experiments so far, we have demonstrated that a airship about 700 meters away can be controlled in a "line-of-sight" area which radio waves reach directly. This is not enough. Unless radio waves reach farther in actual operation, we will not be able to accomplish the mission. We are now thinking of controlling the airship using the iridium satellite communication system. But this has its challenges, as communications from the satellites are frequently interrupted. We have been working on this problem since last November, but the airship still doesn't navigate as well as we would like. After a process of trial and error, we finally created a program engineered around the communication characteristics of iridium. We have reached the stage where we can produce good results on the ground level. In our next test we plan to demonstrate the program.

What is the most rewarding and challenging part of your job?

Togou I think of my lifework as "making the immovable (software) movable." It takes lots of hard work to create a good program, but I don't consider that a hardship. It's best not to worry too much about failures. Instead, I use failures to improve upon earlier designs.

I think the process of trial and error is fun.

Togou That's true. After a series of trials and errors, you come to understand that when you do this, you get this result. Over time, you collect a lot of knowledge. I wish I could feed back the knowledge I have accumulated, in some form or another.

He used to be a teacher.

We hear that you taught at a

vocational college until last March.

Togou I work for a company that owns a vocational college and system research and development departments. They assigned me to the vocational school as an instructor in multimedia and networks. They told me to study up on leading-edge trends in system development, and then they sent me to JAXA. Before working at JAXA, I worked at another research institute for about two years.

What did you think about the disaster-monitoring UAV system when you heard about it for the first time?

Togou I had no idea about the disaster-monitoring UAV system, so naturally it was intriguing to hear about it for the first time. Then again, I wondered why no one had built such a system before. As I gradually came to understand the system, I felt the urge to produce a better system by extending the existing technologies and thinking up my own ingenious touches.

When did you first take an interest in programming?

Togou I touched a personal computer for the first time back in elementary school. NEC and Fujitsu Limited were just beginning to launch personal computers onto the market. I remember seeing a hoard of kids playing with a PC on display at a nearby do-it-yourself store. It turned out that they were playing computer games. Not long afterwards, I was playing computer games all the time.

We had a computer class in the third year of senior high school. We learned the programming language called Fortran. Each term, we had the chance to work with the computers directly in practical training sessions at a “computer center” outside school. We input program codes into the computers and printed out the processing results. Next, our teacher checked whether the results were output as ordered. Fascinated by the process, I decided programming would be a desirable job

Isn't programming tough?

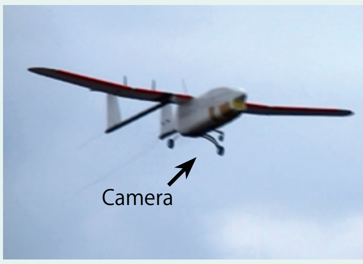
Togou I sit at my desk, concentrating on the code. I try to complete my tasks during normal working hours. That doesn't free me from overtime, of course. But in my experience, it's impossible to do programming outside working hours. When my brain runs dry after a long stretch at the computer, when I can't come up with new ideas no matter how hard I concentrate, I reset my thinking. Basically, I work at the code for about six hours, then put it aside for the next day. I forget about it completely and switch to more routine tasks. But sometimes when I'm doing something completely unrelated to work, a good idea will flash into my mind. When this happens, I take note of it and try it out the next day.

How do you spend your days off?

Togou I like comedy shows and variety programs in TV. I spend my days off watching them on video. Laughing refreshes my spirit and clears my brain of the little scraps of code stuck inside.

What are your ambitions for the future?

Togou First of all, I have to complete my current task. After that, I assume I'll return to my vocational school. But I want to put out my antenna to collect information on what's happening in society, instead of confining myself to the school and teaching. I am trying to become an instructor who can tell what's happening now and what will happen in the future. I hope I can feed back the technologies I have learned in JAXA to my students.



Two small optical apparatuses, one placed onboard a small airship and one placed on a fixed-wing aircraft (on the left), take pictures of a disaster-stricken area from the sky The pictures are extremely useful for relief activities.

The picture below was taken from a fixed-wing aircraft at an altitude of 110 meters