Japan leading the development of aircraft engines

Since 2003, the Clean Engine Team of the JAXA Aviation Program Group has been conducting the "Technology Development for Clean Engine (TechCLEAN)" project to research technology for developing a highly environmentally efficient small engine. Before the final year in 2012, we hope to have achieved our

The clean engine technology being pursued through TechCLEAN aims at realizing a quiet, fuel-efficient engine with greatly reduced harmful emissions. Targeting the 5-ton thrust class of engines mounted on small aircraft with about 50 seats, which is expected to see an increase in future demand, the target values for greatly improving engine environmental indices have been set and technological solutions have been devised. The International Civil Aviation Organization (ICAO), a specialized agency of the United Nations, establishes standards for the emissions and noise produced by aircraft. Considering that those standards will become stricter every few years, the TechCLEAN target values are as follows.

□ CO_2 emissions: Current engines' fuel consumption -15%

□ NOx emissions: ICAO CAEP/4 standard -80%

□ Noise: ICAO Chapter 4 level -23 EPNdB

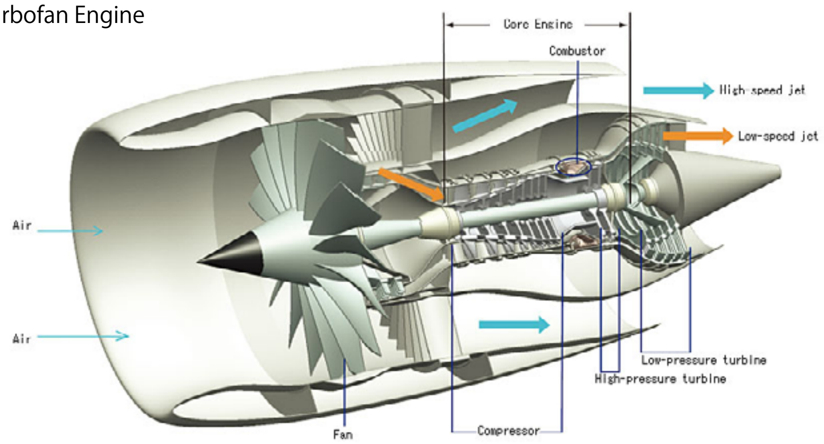
Furthermore, TechCLEAN is contributing to the ECO-Engine Project, which is being tackled by the aviation industry. Currently, Japanese aircraft engine manufacturers, under the leadership of the New Energy and Industrial Technology Development Organization (NEDO), have been working on the ECO-Engine Project with the purpose of acquiring practical technologies for environmentally efficient small engines. Through this collaboration, the advanced environmental technologies addressed with TechCLEAN will be combined with the superior engine manufacturing technologies that manufacturers possess in order to try, by integrating the public and private sectors, to cultivate technologies to develop, under Japan's leadership, passenger aircraft engines that will have the world's highest level of environmental efficiency.

The technology target values are being evaluated using engine simulations, called advanced virtual jet engines (AVJE), in addition to experiments and CFD analyses. AVJE, software that simulates operation of the engine on the computer and performs a system review, is currently being developed by JAXA. With AVJE, it was confirmed that overall integrity can be obtained by combining the component technologies being developed to form a single engine system. We aim to further enhance the technology in the remaining year and meet our objectives. On the following pages, we will introduce the key component technologies.

Environmental standards for aircraft

With the aim of protecting the environment around airports, ICAO establishes standards on the noise and hazardous gaseous substances (NOx, HC and CO) emitted when commercial aircraft take off and land as well as makes recommendations for implementing them. Since these ICAO standards must be met in order to acquire Type Certification for an aircraft fuselage or engine, they are essentially regulatory. CO_2 emissions are currently not regulated; however, establishing standards is being debated in view of the social situation.

Turbofan Engine



Turbofan engines, commonly used on passenger aircraft, gain a lot of thrust by simply propelling backward a large amount of the air taken in by the fan without passing through the core engine (bypass).

Aiming at low fuel consumption

In order to lower the CO_2 emission from engines, fuel consumption must be reduced through better fuel efficiency. For that, the efficiency must be increased by improving the performance of every part of the engine and reducing losses. With the aim of reducing fuel consumption by 15%, compared with that of the 5-ton thrust class of engines currently being used, we are researching the following component technologies.

☐ Technology for increasing turbine cooling efficiency
Turbine blades, which are subjected to combustion gases exceeding 1500 ℃, possess an internal cooling structure to withstand the high temperatures. More specifically, the turbine blade is protected from high temperatures by being cooled internally with part of the compressed air before it is fed into the combustor, then discharged through many holes to wrap the surface of the turbine blade with a thin layer of air. Since there will be a loss of thrust from the use of the compressed air originally created to generate energy by burning fuel, it is necessary to find better internal cooling structures with as little air as possible. By means of CFD and experiments, we are researching internal structures that improve the cooling efficiency.

☐ Evaluating heat-resistant materials
We are collecting data on newly developed heat-resistant materials for turbines through thermal cycle tests (fig.1), which simulate the temperature changes in engines caused by takeoff and landing of jet aircraft. Based on this, we are researching technology for predicting what levels of reduced CO_2 emissions, improved efficiency and extended life can be obtained, compared with turbines made of currently used materials.

☐ Reducing loss in the fan bypass duct
Within the channel that bypass air flows through, the pylons that mount the engine to the fuselage create the biggest obstacle and disturb the airflow. Through CFD, we have confirmed that airflow loss can be reduced by altering the pylon shape and stator mounting angle. (Fig.2)

☐ Lighter weight by using composite materials
If composite materials are used, the engine can be made lighter while retaining its strength and, as a result, fuel efficiency throughout flight operation can be improved. Through experiments, we are evaluating their durability when applied to the compressor casing.

☐ Intelligent control
Conventional engines control the amount of fuel which is necessary for power with some margins. In the future engine, it is important to control this more efficiently. We are researching intelligent control that would allow the fuel to be optimally controlled according to the engine performance requirement using feedback information on various engine operating conditions monitored by the controller itself during flight.

Fig.1: Thermal cycle evaluation test of heat-resistant material

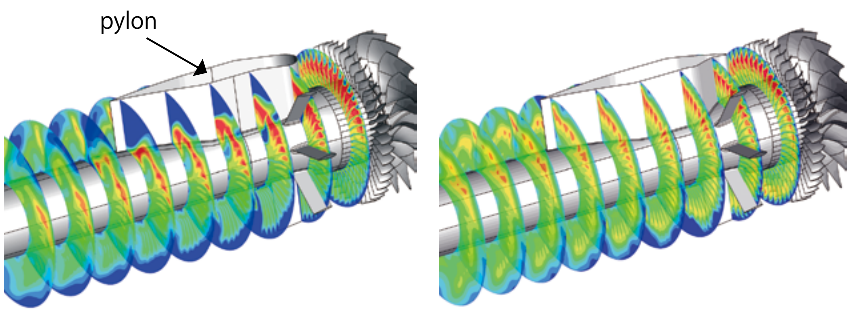


Fig.2: Evaluation of bypass duct loss by varying the pylon shape (collaborative research with IHI)
Comparison of total pressure with rounded pylon (left) and modified pylon (right). The blue areas indicate larger loss.

From the researcher-in-charge

Takashi Yamane
High Temperature Section
Section Leader

Reduced CO_2 emissions are very much a topic of the day; however, it is the same as the improvement of fuel efficiency. It allows for the manufacture of competitive aircraft with benefits of lower fuel cost for airlines and cheaper air travel for passengers like us. In the course of the history of passenger transport, even before talk "about the environment", improved fuel efficiency has always been sought after. Since passenger aircraft continue to fly on petroleum-based fuel for the time being, I believe that our technology will contribute to making air travel more common.

Low-NOx

The core of combustion technology radically reducing NOx emissions

NOx reduction depends on how successful combustion is. At JAXA, we are researching combustion technology that greatly reduces NOx, and we have succeeded in cutting it by 83% of the 2004 ICAO standard in single-sector combustor tests.

☐ Preventing local hot spots

In order to improve fuel efficiency of jet engines, increasing the pressure and raising the combustion gas temperature are effective, but NOx will increase with a higher temperature. What is needed is a combustion method that further suppresses NOx. The key lies with the “fuel nozzle”, which assumes the role of mixing air and fuel, even within the combustor, and injecting it into the combustion area.

In order to avoid a fuel-to-air ratio (mixture ratio) that results in a high combustion temperature and a large production of NOx, the combustion method of conventional engines lowers NOx production with a burn richer than that ratio, a quick mix of air, then a lean burn (RQL combustion).

The newer method prevents local hot spots and lowers NOx production by atomizing fuel, then mixing in a large amount of air, followed by a uniform lean burn of all fuel (lean premix combustion).

With TechCLEAN, we are researching a “staged fuel nozzle” (fig. 1), which consists of two fuel mixers in a single fuel nozzle. By positioning the pilot flame (pilot light) in the center surrounded by the lean premix main flame and separately controlling the pilot and main fuel flow according to the engine output conditions, both a high combustion efficiency and low NOx could be achieved. Fuel supply for only the pilot is adjusted at low engine output, and fuel supply primarily for the main flame is adjusted during high output. For uniform combustion in the combustion area, we successively produced fuel nozzle prototypes and tested them in order to achieve a good mixture of atomized fuel and air.

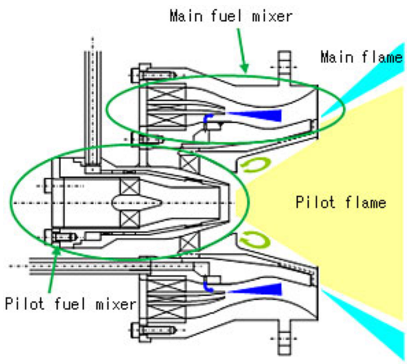


Fig.1 : Cross-sectional diagram of staged fuel nozzle

With the main fuel mixer, air in three layers is swirled in different directions and expelled. In doing so, fuel becomes finer than with a single-directional flow and mixes better with air. As a result, in addition to maintaining a stable flame in the combustion area, combustion is possible at a more uniform temperature

☐ Demonstrated 83% reduction with a single-sector combustor

In 2011, a 79% reduction was demonstrated with a single-sector combustor, and an 83% reduction was demonstrated with a combustor (fig. 2) created by adding another premix fuel nozzle to that combustor. Currently, we are preparing to conduct tests with the goal of achieving an 80% reduction with an annular combustor.

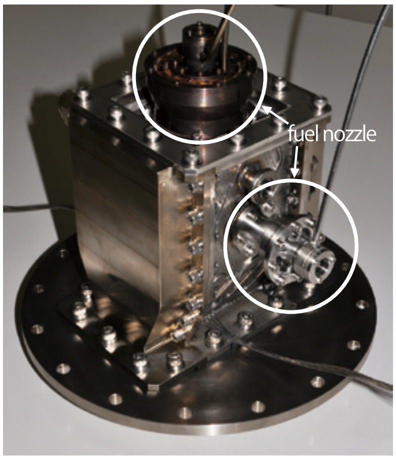
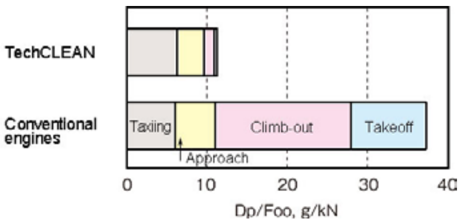


Fig.2 : Single-sector combustor

A sectional combustor model with one staged fuel nozzle for testing



	Engine output	Time
Taxing	7 %	26 min.
Approach	30 %	4 min.
Climb-out	85 %	2.2 min.
Takeoff	100 %	0.7 min.

Engine operating modes that emissions standards apply to

Table 1 : [Results of combustion testing] Comparison of NOx emissions

The amount of emissions differs depending on the engine output. JAXA technology is able to radically reduce emissions at high engine output.

From the researcher-in-charge

Takeshi Yamamoto
Low-Emissions Technology Section
Section Leader

In order to better improve the technological capabilities of the three Japanese jet engine manufacturers, I have been tackling combustor research for the Eco-Engine Project. I have assisted in combustor research at JAXA with the Eco-Engine Project, and I was able to learn various things necessary for the practical application of technology, including ours. I hope the technology that we developed will be incorporated into that of other manufacturers, and that Japanese manufacturers will enter farther into jet engine development.

Persistent efforts

☐ Engine noise and project goals

Jet engines comprise a variety of components that emit noise. In the fan section, the rotating blades and the adjacent stators cause aerodynamic interference that leads to fan tones. The exhaust section of the engine, blowing high-speed flow into the surrounding air, is the cause of jet mixing noise that is dominant during takeoff. Core components such as the combustor and the turbine are also potential noise sources. One component may generate several types of noise, for example, the fan causes broadband noise, buzz-saw noise as well as the tone noise.

Engine noise is a part of aircraft noise. Aircraft noise of commercial jet aircraft has been assessed in terms of airport noise, namely the noise exposure during landing and takeoff. To evaluate aircraft noise, the effective perceived noise level (EPNL) has been used for type certification of aircraft. EPNLs are obtained at three measurement points: approach, lateral, and flyover. Newly type-certified aircraft after January 2006 must comply with ICAO Annex 16 Chapter 4, where the concept of cumulative EPNL of these three points was introduced. This project has set a goal in the form of a cumulative noise margin from the regulation with regard to the target engine and airplane.

☐ Noise reduction research

In developing noise reduction technology, two approaches are employed. One is improving the engine cycle, especially increasing the engine bypass ratio (BPR). This may decrease the average speed of the exhaust jet, which is strongly dependent on the radiated acoustic power. The subsequent noise mitigation increases the noise margin at both lateral and flyover points. In this project, we compare the noise margin of the target BPR engine relative to the baseline BPR engine by taking advantage of engine noise models.

The other approach is to develop noise reduction technology for each engine component. We focus on the lean stator for fan tone reduction and the mixing devices for jet noise reduction. The lean stator, angled in the circumferential direction, is expected to divide the rotor wakes into several pieces and prevent the generation and propagation of acoustic modes. Computational fluid dynamics (CFD) helped understand the mechanism of acoustic sound sources due to the rotor-stator interaction and estimate the sound pressure level on the stator surface. An example of CFD results is shown in figure 1. The sound propagation inside the fan duct and the sound radiation from the nacelle are calculated based upon the sound source information obtained by CFD. This project tries to evaluate the far-field noise response by the lean stator. The mixing device involves the notch and the nail. The notch, revised through the collaboration with IHI Corporation, is a small dent formed at the nozzle lip and plays a role in enhancing the mixing process with little thrust penalty. The retractable nail, having a sharp edge on one side, enhances mixing along the jet surface. These devices are expected to evolve a deformation of shear layer immediately behind the nozzle, enhance mixing of jet with surrounding air, and suppress jet mixing noise. This project tries to experimentally validate the noise reduction performance of these devices. Noise tests with scale models and a jet engine have been performed on these devices. A noise test using a demonstrator engine is shown in figure 2.

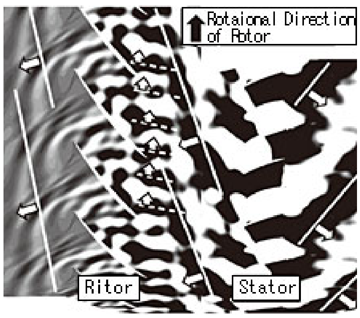


Fig.1: Sample numerical analysis of noise from fan rotor and stator interference

Fig.2: Engine noise test for devices

From the researcher-in-charge

Tatsuya Ishii
Noise Reduction Section
Section Leader

Noise reduction research requires long-term patience. Chevron nozzles, though now common as jet noise suppressors, became practical in aircraft after the intense effort by a great number of researchers and engineers over many years. We cannot expect a drastic advance in a short period of time. However, small steps achieve a certain level after a long time. What we should keep in mind is to continue persistent efforts in the history of noise reduction.

Research Report

From the research field

Control technologies focusing on the practical use of unmanned aircraft

Unmanned Aircraft Technology Section

A small unmanned aircraft (fig. 1) with a length of 1.5 m and weight of around 5 kg has been used in flight demonstration. The aircraft has been designed especially for disaster-monitoring missions. The missions include capturing images of a disaster spot immediately after the disaster occurred and returning quicker than with any other method. Flight control technologies direct the unmanned aircraft to perform these missions without human intervention. As a culmination of almost 5 years of "research and development of disaster-monitoring unmanned aerial vehicles", we are planning to conduct a flight demonstration for a simulated disaster in 2012. We are already in the final preparation stage for the demonstration flight.

* * *

"There have been various design concepts for the principle of robot motion. A controlled robot is just like an obedient child following its parents. It may be an uninteresting robot that follows the way already arranged in detail by the parents. Animals begin to be independent as they grow up. That means "autonomy", and "control" is a completely opposite concept. The characteristics of an unmanned vehicle will change depending on how we blend "autonomy" and "control". A highly autonomous robot will be robust against environmental changes, but may not have enough competence in terms of fidelity to commands. In the case of JAXA disaster-monitoring unmanned aircraft, since the mission priority is assigned to image capturing of the specified spots rather than survivability, an emphasis is placed on control," says senior researcher Midori Maki of the Unmanned Aircraft Technology Section.

In Japan, it seems that unmanned aircraft systems have already been in practical use in several applications such as pesticide spraying, meteorological observation and photographic services. What is the difference between the unmanned systems proposed by JAXA and the existing systems? "One of the important research topics has been control technologies contributing to practical issues such as ease of use and safety. Rather than the aircraft merely being able to fly automatically, how easy is it to use, and can spare people and structures serious damage from system failures and crashes? The aircraft has also been designed with regard to both photographic quality and lower-speed landing and recovery for safety."

In terms of ease of use and safety, the size of the aircraft should be as small as possible. Then again, "how useful can it be with a few hundred grams of mission equipment? In addition, for a lightweight aircraft flying at lower airspeed, the effects of wind disturbance become much more severe compared with a bigger aircraft," says Maki. He says that, in addition to control technology development, the aircraft itself has been modified using feedback through flight experiments. Some of the special features are described below.

■ Operable by a beginner

As hobbyists remotely control model airplanes, remote control of unmanned aircraft requires a high degree of manual dexterity with a radio transmitter, or so-called R/C proportional system. Since it is expected that these unmanned aircraft systems can be operated by general staff at the regional disaster-relief base, the aircraft systems should have easy-to-use operability requiring no special

Fig.1 : Disaster-monitoring unmanned aerial vehicle
(Right) On catapult launcher

Guidance and Control Personnel
(From left)
Shigeichi Takeda, Midori Maki(contact person), Kazutoshi Ishikawa

skill. Therefore, we aim for a simple operation system, which merely requires a 1-week operation course. Usually, the unmanned aircraft is connected to the ground through a wireless data link, and flight status can be monitored from the ground control station. Also, various commands including return to base in an emergency can be sent to the aircraft. Using the easy-to-use controller, the aircraft can be controlled easily even within the visible area. As a result, the system usefulness should increase dramatically compared with before. "A simplified manual flight controller has been developed, which can be handled by a beginner. The operation becomes intuitive as with a gamepad."

■ Obstacle avoidance

As assumed flight paths of a small unmanned aircraft are limited within the near earth environment, see-and-avoid technologies are necessary against terrain uncertainties and structures. (Fig. 2 and Fig. 3) "Using a laser module of less than 100 g due to payload limitations, how can collision avoidance be achieved without complex algorithms? Obstacle detection and collision avoidance technologies have been developed especially for small unmanned aircrafts." (Senior researcher Midori Maki)

■ Fully automated operation

The ultimate unmanned systems would be either fully automatic or fully autonomous. The final form of the proposed disaster-monitoring unmanned systems is a fully automatic system, in which the entire sequence (Detection of the earthquake → Pre-flight check of on-board equipment → Launcher adjustment based on wind speed and direction → Takeoff → Mission execution → Return to base → Landing and recovery) will be executed without any human intervention.

* * *

A camera is mounted on the bottom of the fuselage. The camera may point in various directions depending on the aircraft attitude, making it difficult to focus on the specified spots. To deal with this problem, we have developed a control method of keeping level flight at all times, even when turning, so that the ground can be photographed from overhead (the camera is always directed downward). "The current progress status satisfies almost 70% of the required specifications. One of the challenges to be tackled is low-speed approach and landing within a narrow target recovery area. The problem is expected to be figured out during the earlier part of 2012, which should lead to a success in the subsequent flight demonstration," says senior researcher Maki.

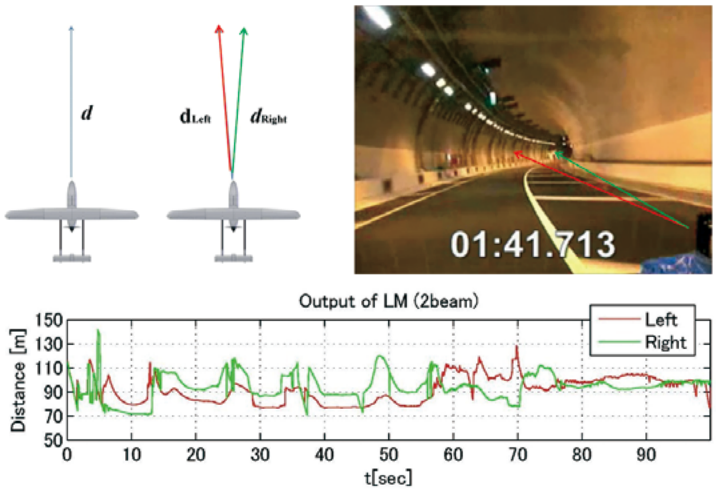


Fig.2 : Feasibility test of obstacle detection using laser modules
We checked the laser modules to see if an actual tunnel curve can be detected at the estimated flight speed.

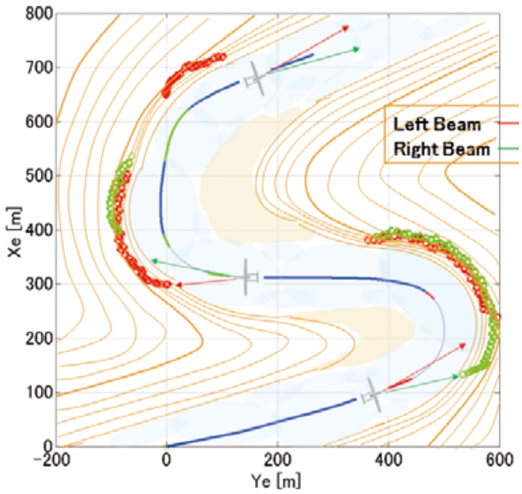


Fig.3 : Simulation example
Flying through narrow mountain corridor

Unmanned Aerial Vehicles (UAV) at a corner of social infrastructure

Interview
People who fly dreams
Vol.20

Unmanned and Innovative Aircraft Team ● Kenya Harada

In an emergency, Unmanned Aerial Vehicles (UAV) will be our eyes in the sky. In the coming year, the disaster-monitoring unmanned aerial vehicles designed by JAXA will enter a phase where they will fly off to a site to demonstrate their usability. Kenya Harada wants the benefits of UAV to be more useful in our daily lives. He passionately explains his thoughts.

What are the possibilities with small UAV?

What type of UAV are you researching?

Harada UAV systems that are useful in assessing the situation during a disaster. Emergency measures must be conducted as efficiently as for a major disaster, and assessing the situation in order to do that is essential. However, assessment becomes difficult since transportation and communication networks break down should a major disaster occur. Therefore, we are conducting research and development of a disaster-monitoring UAV system as a means for local governments at the forefront of disaster response to assess disaster conditions themselves. Simply put, it is a system where a digital camera is mounted on a small aircraft, like a model airplane, and aerial photos are taken. It seems easy, but, in order to use it at a disaster site, it requires operation capabilities that allow it to be reliable even under a variety of constraints, and must be sufficiently safe to be flown over populated areas. With these key technical issues, we are tackling research that draws upon testing/analysis technologies as well as other advanced technologies, such as in flight guidance control, where JAXA excels.

Kenya Harada
UAS Application Section
Specialized in aerospace engineering in graduate school

What are you in charge of, Mr. Harada?

Harada Demonstration and evaluation of the system usability. As I explained earlier, operability and safety of UAV systems are essential conditions for practical application, but those two alone are not enough. As expected, it would be meaningless if it was not useful in some specific missions for disaster monitoring. As a practical matter, the equipment that can be installed as well as the cruising distance and time are limited if small aircraft are used. With those limitations, how can they be used, in what situations, and how useful can they be? What are the merits of using them, even at the operating costs and risks? It is necessary to present those decision criteria. Therefore, we are planning a demonstration test where we will assume a specific disaster-monitoring mission.

What type of test?

Harada We will assume a mission to assess damage caused by a large-scale earthquake to roads and rivers in a mountainous area. Mountainous areas have a great need for aerial monitoring since ground access is limited, compared with plains.

With the demonstration test, we will fly along actual roads and rivers through valleys of the mountainous areas and take photos. Since the UAV can fly at a low altitude of several dozen meters above the ground, detailed images can surely be obtained. Even cloudy conditions are not a problem. However, since only a narrow area can be photographed at one time, many photos must be taken. I think it would not be useful at the disaster site if a bunch of images of such small areas were simply handed over, so the photographed locations and images should be indicated on an electronic map such as Google Maps. (Fig. 1) In addition, an information system (monitoring-image system) is being prepared with functions that visually decipher each image and add disaster site information as well as data management functions for sharing this information.

The demonstration test will show the series of operation processes, from specifying the watch list and area to assessing the damage. Then, we plan to have the usability of the entire system evaluated with the cooperation of local governments and disaster-related research institutes.

Fig.1 : Windows of monitoring-image system
Photographs taken while flying about 120 m above JAXA's Taiki Aerospace Research Field

Expanding situations for UAV activities

Haven't you also worked on the stratospheric platform project (fig. 2)? At that time, what were you in charge of?

Harada I was in charge of simulations for airships that ascend into the stratosphere as well as the development of thermal models for that purpose. Since the buoyancy of airships varies depending on the temperature of the internal gas, thermal models are necessary for predicting this and reflecting it in the design and flight operation.

Fig.2 : Stratospheric platform project
A stratospheric platform is an unmanned airship, installed with communication equipment or monitoring sensors, that remains in the stratosphere, at an altitude of about 20 km, where the atmospheric conditions are comparatively stable, and is intended to be used for communications, broadcasting as well as environmental observation. From 1998 to 2005, JAXA conducted research and development of key technologies of the airship.

What were the struggles?

Harada We conducted two technology demonstration tests for the project. One tested whether a massive airship with a total length of 48 m would ascend to the stratosphere without propulsive power, in other words, only with buoyancy. Through simulation models that I developed, I predicted the buoyancy changes during ascent and determined the optimum helium fill amount. There was a danger of rupture if this was excessive, but there was a danger of the airship stopping if the amount was insufficient. Since this was a one-time-only test with no chance of trying again, there was a tremendous amount of pressure. I was very pleased when it ascended at the estimated speed and reached the target altitude.

What are your future goals?

Harada What I am working on now is research for small UAV, like model airplanes, to assist in disaster monitoring. To put it differently, it is the effort to ascertain the limits of how useful these powerless aircraft can be. In the future, I would like to remove the aircraft limitations and expand their flight capabilities so as to widen the breadth of their use. For example, since there is damage from typhoons every year, the situations for their activities can be expanded if they could fly even in bad weather. In addition, I believe they could be useful in various fields and applications such as disaster monitoring and communication relay as well as environmental research, land management and security, if they could remain in the air for a long period of time, like that needed for use as a stratospheric platform.

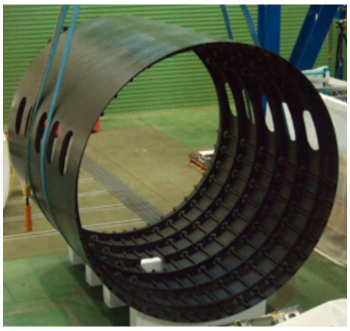
Like an artificial satellite, right?

Harada Yes, like that. The role of watching over our living space from the air is the same. They cannot have the expansive field of view of a satellite, but UAV have the advantage that they can assess a narrow area accurately and continuously. Although satellites are already indispensable in many fields, I am convinced that, by utilizing this advantage, UAV can be used to collaborate with satellites to shoulder one corner of the social infrastructure, ensuring the safety and prosperity of the people. I would like UAV research focused on that future to blossom.

Source of the aviation knowledge base of tomorrow

Aviation Technology Cource - No.2 -

What is so special about Japanese composite materials?



Structure of aircraft fuselage made with CFRP
3 m (diameter) × 3 m (length)

Q Did you see the news that quite a lot of carbon fiber composite materials were used in new models of American-made passenger aircraft put into service last year? It seems to be used even in principal parts such as the main wing, center wing box and fuselage structures. Furthermore, it said that those parts are being constructed by Japanese manufacturers. What about Japanese composite materials is so special?

A Simply put, reliable production controls, such as the high quality and strict on-time delivery, are valued for aircraft parts manufacturing using composite materials.

Q I understand that, but could you explain it more concretely?

A First, composite materials have superior properties, compared with materials made from a single raw material such as metal materials, since it is a material made by combining raw materials with different properties. What we have been discussing is carbon fiber reinforced plastics (CFRP), which are made from carbon fibers and polymeric resin. The reinforcement is made by aligning carbon fibers and weaving them like fabric, and then it is hardened with polymeric resin. It has a big advantage for use in aircraft since it is lighter and stronger than metal materials. So, composite materials make up about 50% of the structural weight of those new models of American-made passenger aircraft.

Q Is Japan so good at making aircraft structures with CFRP?

A It's not only that. Including applications other than aircraft, Japanese fiber manufacturers account for the majority of the world market share in the production of carbon fibers as a raw material of CFRP. There may be some fiber manufacturers that provide just the raw materials to aircraft manufacturers, but many are impregnating the carbon fibers with synthetic resin to form partially hardened sheets (called pre-preg). These pre-pregs are sent to parts manufacturers. Then, the parts manufacturers are heating and pressurizing these in pressure vessels and forming them into the desired shape, such as a main wing, which are finally delivered to aircraft assemblers.

Q So, that is how the roles are shared!

A Some technologies are required for producing the carbon fibers, aligning and weaving them in order for CFRP to have sufficient strength. By further including molding, a product of excellent quality can be reliably created, but the point is that Japanese composite material manufacturing and composite parts manufacturing technologies are highly valued.

Q If it has so many merits, shouldn't the entire aircraft structure be composite materials?

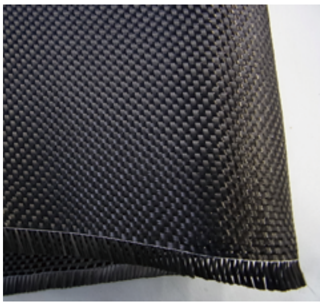
A Research is still necessary to determine whether they can be used for the entire structure, but the proportion of its use should increase. In any case, in order to maximize the merits of using composite materials in aircraft, JAXA is researching VaRTM molding methods for creating stronger composite materials at less cost as well as methods for certifying the safety of structures made with composite materials.

(Provided with cooperation from Yutaka Iwahori, chief of Advanced Composite Group, Aerospace Research and Development Directorate)

Material construction and molding technology
Stable supply of high-quality materials

Making CFRP

Carbon fiber



Woven carbon fibar

Pre-preg (unidirectional)

Single sheet of overlapping pre-preg