Knowing operational loads in flight!

—Research in identification technology for operational loads

Civil Transport Team

What is the purpose of operational load identification?

Focus has recently been given to technology called structural health monitoring. This is technology for preventing fatal damage to structures by deploying sensors on the structure to detect the actual load applied, stress (a sort of force field distributed within a material) or the damage itself. Load is what is most fundamental in assessing structural design and structural integrity. However, a wide variety of loads are generated by sudden gusts and steering while taxiing, taking off and landing, or maneuvering, making it nearly impossible to fully predict all of those loads in the design phase. Therefore, if there was some method of identifying the loads applied to the structure of the aircraft while it is being operated, fatigue assessment (the phenomenon where damage is caused by the repeated action of a small load) would be possible based on the actual load history. This would be useful in maintaining and improving structural integrity and reliability as well as creating more suitable maintenance plans. In addition to providing feedback to the designer about whether the assumed load during designing was appropriate, we are considering it for future applications in wing-morphing technology, which is expected to improve flight efficiency drastically.

Inverse analysis-Estimating load from structural deformation

The technology for obtaining such operational loads is not new and can be traced back to before World War II. Usually, stress is estimated through empirical methods, for example, by using data obtained from accelerometers and strain gauges (sensors that measure local material deformations); however, an overall stress distribution over a wide area of the structure cannot be obtained because of problems with extrapolation.

Contrary to normal analysis (direct analysis), inverse analysis searches for the cause (load) from the result (strain). Based on inverse analysis using a computer and a finite number of measured strain data, we are developing a technology for identifying operational load and stress distribution. The biggest characteristic of our method is that it can reconstruct continuously distributed loads such as aerodynamic forces (pressure).Figure 1 shows an example where validity of the method was confirmed through numerical work, and we can see that the pressure distribution was identified quite accurately. By using identified loads as the boundary condition of the direct finite element method, we are able to investigate the operational stress distribution. While taking into account the uncertainty of the model and the error of measurement from fragmentary data, the appeal of this research is how to reconstruct the overall image of the actual load and stress distribution.

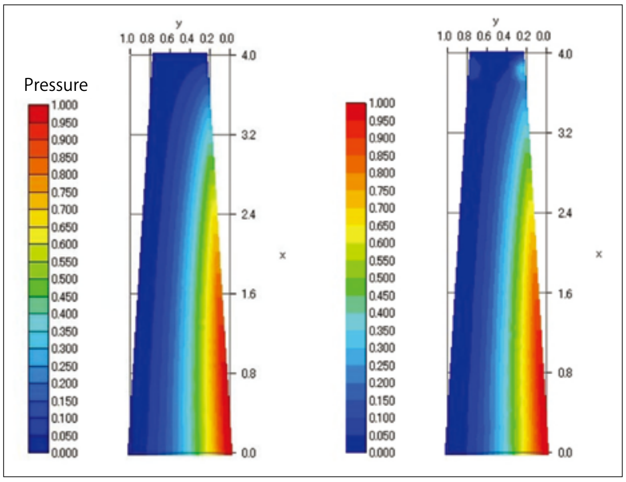
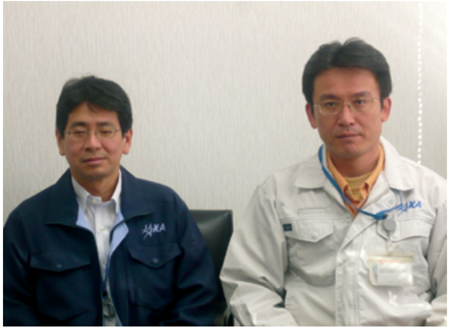


Fig.1: Assumed pressure distribution (left) and its inverse analysis results (right)

Applications of fiber-optic strain measurement technology

In recent years, strain measurement technology using fiber optics has grown remarkably. An optical frequency domain reflectometry (OFDR) system has been developed by the Airframes and Structures Group of the Aerospace Research and Development Directorate. We are conducting the present study in collaboration with that group and Tokyo University. Quite many data are required for inverse analysis; however, with OFDR technology, a large amount of data can be obtained far more easily than by using conventional strain gauges. Actually, one motivation for conducting this research is that we would like to develop an application technology which would use the potential of this advanced sensing technology to its fullest. Figure 2 shows an experiment



Structures and Materials Technology Section
(From left) Toshiya Nakamura, Hirotaka Igawa

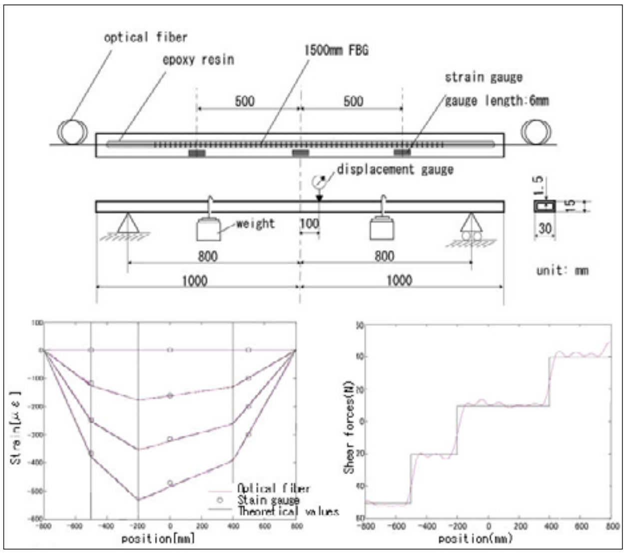


Fig. 2: Application to beam bend testing
(Top) Experimental setup
(Lower left) Strain measurements (Blue: Theoretical values, Red: Measured values)
(Lower right) Shear forces (Blue: Theoretical values, Red: Results identified from measured strain)

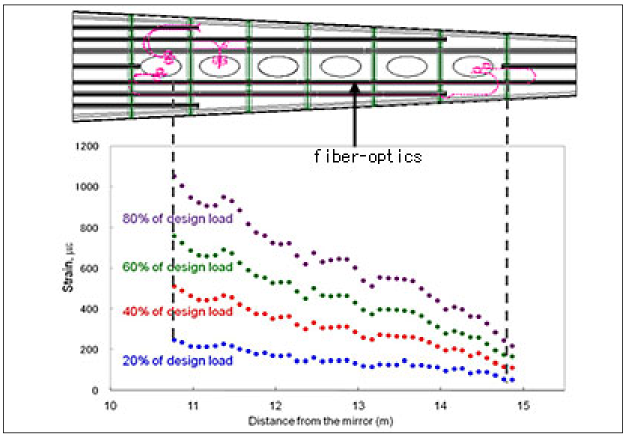


Fig. 3: Example of fiber-optic strain measurements in the structural test of a full-size wing model manufactured with a composite material

where concentrated loads were applied to three locations on a beam, and the generated strain was measured with OFDR strain sensors. As shown in the diagram, the shearing force distribution produced in the beam could be accurately identified with the method from this research.

Figure 3 shows an example of strain measured in strength testing of a composite material wing model performed in collaboration with the Airframes and Structures Group and the Advanced Composite Group of the Aerospace Research and Development Directorate. In addition, figure 4 shows wing deformations measured in wind tunnel tests where fiber-optic sensors were attached to the wind tunnel model in tests conducted with cooperation from the Aerodynamics and Airframe Noise Technology Section of the Civil Transport Team. We have started reconstructing the aerodynamic load using the obtained data. In the future, we plan to develop technology for identifying various loads, such as dynamic loads and thermal loads, in more realistic structures.

(Toshiya Nakamura)

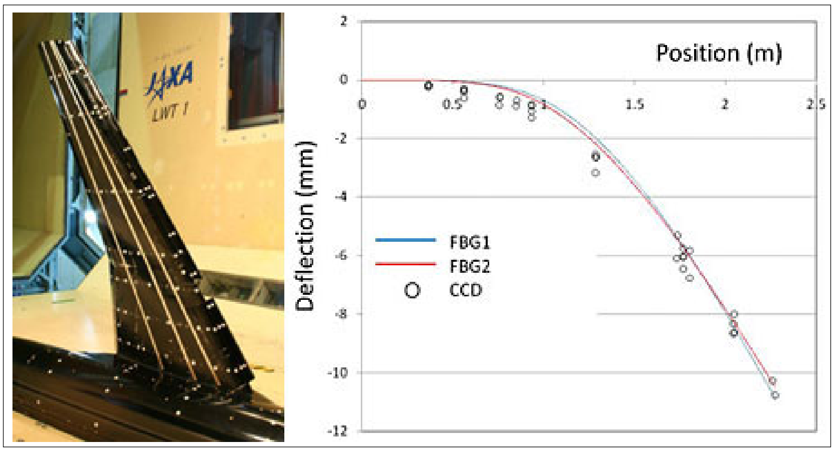


Fig. 4: Wind tunnel model deformation measurement using fiber optics
(Left) Wind tunnel model: Fiber-optic sensors have been attached along the three white lines on the skin of the wing. The sensors themselves are thinner than a single hair and, therefore, are not visible.
(Right) Wing deflections estimated from measured strain. These are consistent with the three-dimensional measured results obtained separately using two CCD cameras.

Research Report

From the research field

Flight testing of compact electric fixed-wing unmanned aerial vehicles for disaster monitoring

Unmanned and Innovative Aircraft Team

JAXA is continuing research of the unmanned aerial vehicle system "SAFE" (Smart Autonomous Flying Eyes), which immediately rushes into areas where a disaster has occurred in order to take aerial photographs. These compact electric fixed-wing aircraft and airships are eyes in the sky and obtain information effective in the deployment of rescue operations. We heard about how this technology is advancing from section leader Kazutoshi Ishikawa, who is currently performing test flights of compact electric fixed-wing unmanned aerial vehicles in places such as Taiki, Hokkaido.

What can the electric fixed-wing unmanned vehicle be used for?

The advantage of compact unmanned aerial vehicles, compared to manned vehicles, is that they can be launched almost immediately in addition to being able to take detailed photos while flying at a low altitude. In order to maximize this advantage, we are aiming at making them easily operable by anyone. Specifically, the airframe would be placed in municipalities and be programmed to launch with a simple operation, for example, the press of a button, when a disaster occurs, take photos of the previously specified destination, then return to its original location. In order to establish the technology necessary for unmanned aerial vehicles like this to be realized, we are collecting and assessing data through flight testing and analyses.

Fig.1: Test vehicle set on catapult launcher

Past achievements and future issues

[Photographing]
Previous flight tests have confirmed that, when photographing level ground during the day, the image quality allows a 30 cm square object to be recognized from an altitude of about 100 m. We believe this is a level that allows information necessary to the development of rescue operations to be adequately obtained.

This time, the aircraft flew over roads through the forest and along the coast and took photographs. Since it is necessary for the aircraft to make decisions automatically according to the various geographical features in order to photograph the specified location, the photographic conditions were changed and various data was obtained.

[Automating take-off and landing]
The disaster-monitoring unmanned aerial vehicle will be launched from and land in narrow locations, for example, from an open space or the top of a building. We have been confirming if a catapult method (fig. 1) for launch is plausible and if stable flight is possible during steep glide path approach at a low speed. Currently, the future issues are still automating launch and landing by remote control, not only taking pictures.

[Avoiding obstacles/impact force in a collision]
The flight path to the location to be photographed can be specified beforehand; however, we must consider that, during actual operation, the aircraft may encounter unforeseen obstacles, such as towers not yet drawn on maps or helicopters making an emergency landing. Technology for detecting obstacles and avoiding them is essential in order to prevent these types of collisions. In a flight test conducted in 2009, we confirmed that the test airplane could detect and avoid a weather probe simulating an obstacle, in order to continue its flight. (Fig. 2)

We are also studying what impact force would injure people or damage objects in the case that the small unmanned aerial vehicle collides with a pedestrian or a house. In order to assess the airframe shape, material, weight, speed and descent angle, etc. that maintain safety, we are collecting basic data from computer analyses and collision tests (fig. 3) using dummies.

Unmanned Airplane Technology Section
Kazutoshi Ishikawa

Experimental aircraft
Red: For confirming automatic flight technology; Yellow: For confirming short-distance launch/landing equipment

Compact electric fixed-wing unmanned vehicle

Technological objectives

- Wing span: 2.5 m or less; Weight: 5 kg or less; Payload: 0.3 kg or more
- Flight at 30 to 90 km at an altitude of 150 m or less
- Arrives at the location within 30 min. after a disaster; performs its mission before manned aircraft are deployed
- Fully automatic launch→photographing (specified location)→return/landing
- Enable identification of a 30 cm square object on the ground
- Also flight-capable at night or in adverse weather

[Mission changes during flight]
The current location of a flying unmanned aerial vehicle is monitored from the ground station. The mission from launch to landing is automated, but it should be possible to send additional commands from the ground station. These are functions needed to change the photographed location after launch or to interrupt the flight mission, for example, due to an aircraft malfunction, and perform a Return To Base (RTB) operation. A flight demonstration of the simple RTB function has been conducted; however, the future issue is the additional photographing function when a path change is required.

With past flight tests, we have reached the level where the necessary functions have been divided into the various technologies that are being confirmed. Now, it is necessary for a series of duties, from launch to landing, to be conducted automatically. In addition, with radio stations that do not require a special license, a flight range of a few tens of kilometers is possible, corresponding to expected operations, compared with radio waves that only reach an unobstructed distance of a few kilometers. In this regard, we are considering a method that would allow the aircraft to safely fly long distances via radio relay stations. We are focused on resolving these technical issues and conducting local demonstration flights next year.

Fig. 2: Obstacle avoidance flight test

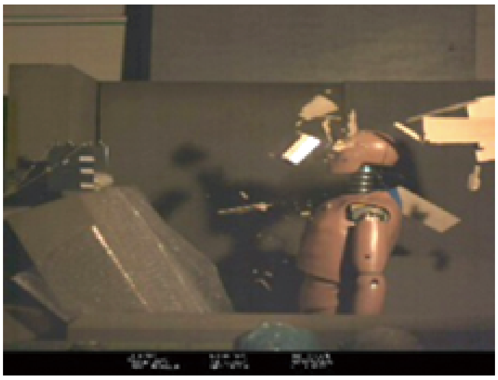


Fig. 3: Collision test with test dummy

Overseas Researcher's Report

From Stuttgart, Germany

On September 1, 2010, I came to Stuttgart, Germany as an overseas researcher. Although, at the time that I am writing this, it has only been one and a half months into my one year stay, I would like to describe my daily life and the research that I am conducting here.

■ Research

I am in the Electrochemical Energy Technology department of the Institute for Technical Thermodynamics at the German Aerospace Center (DLR). Here, we are conducting research in the aircraft application of a fuel cell system. The electric power consumption of the newest passenger aircraft has increased dramatically, compared to that of older aircraft. In order to promote electrically powered systems and replace the engine starter and cabin air-conditioning system, which depends on conventional engine bleed air, with electrical systems, we are considering replacing the auxiliary power unit, among others, in future passenger aircraft with a fuel cell. The main reasons for promoting electric power are improved energy efficiency of the aircraft as well as reduced fuel consumption. With fuel cells regarded as one prevailing key technology in this effort, DLR, in cooperation with the aircraft industry, is conducting research and actively performing flight assessment tests of aircraft installed with fuel cell systems.

Beautiful Stuttgart streetscape

The team that I belong to consists of four people, including me. The team supervisor is extremely busy, and about the only time I see him is at the team meetings, held once every two weeks; however, these rare opportunities are quite productive. The meetings are held, not in a conference room, but in the supervisor's office, and not at a conference table, but instead in an arrangement of chairs. At the meeting, we sit in chairs arranged in a circle in a quite open space of a small room, and conduct the discussion. Not at all like mere business reporting, it starts with a question-and-answer session, with us peppered by a rapid succession of straight-to-the-point questions from the supervisor. The meeting was held in English, specifically for me, but everyone spoke so quickly. When the meeting was over, the supervisor smiled and gave me the illustrated notes written down about each point during the meeting as if they were a treat.

There has also been one meeting of the entire department. The entire department consists of 50 members; however, since a good many are doctoral students, more than half of the participants were students. I was surprised that, even for 50 people, the meeting was held with chairs arranged in a circle inside a large conference room with no table. Whether the chairs are arranged in a circle or in a U shape, which seems normal to me, felt a little like a cultural difference.

In terms of specific research details, we are currently concentrating every day on obtaining fundamental data on fuel cells. In the meantime, I am discussing with teammates the quality of the data, and talking about the construction of the next device and future plans. Perhaps because of the strong relationships with companies, there are many confidential matters concerning the research details, and I am not allowed to take photographs on the premises.

Recent photo of the writer

From Germany

Unfortunately, I am not able to show a photo of my workplace.

■ Stuttgart

Some corporations that are also well known in Japan, such as Mercedes-Benz, Porsche and Bosch, have their headquarters in Stuttgart, and the city seems to be enjoying a very rich economy. As a result, it is positioned at the top of a ranking of German cities that are desirable to live in, with its safe streets and low crime. Actually, it is a comfortable place to live, and I have nearly no feelings of inconvenience with daily life. The other day, a yearly international fuel cell conference was held at the industrial convention center. Many German corporations, beginning with Mercedes-Benz, participated, and I was happy to see a fuel cell car being exhibited by Toyota of Japan.

Although Stuttgart also has an industrial-town aspect, the streetscapes are beautiful, and the main street, KonigstraBe, is crowded with people walking around and shopping on weekends. Near there, a morning market is held every week, and I am surprised at how inexpensively I can buy vegetables, fruits and flowers, compared with Japan. Although the building of the Stuttgart Central Station has the feel of a historical building, its deconstruction has recently begun. Major plans for rebuilding it and modernizing the station operation seem to be advancing, and almost every week, there are large-scale demonstrations and assemblies of people against this project. It must be unique to Germany that there is no pessimism at these demonstrations, where parades of smiling people seem to be having fun, almost like at a festival.

■ Daily life

Overall, German people are obviously self-assertive and will argue with store employees at the cash register until they are satisfied, even if a line is forming behind them. The other customers in the line wait patiently as if this is normal.

The other day, the lipstick that my wife bought from the supermarket fell out when she opened the lid. Since this was clearly a defective product, we went to the supermarket to request that it be exchanged. There, the female employee forcibly screwed in the lipstick that had fallen out and said “There, nothing serious.” She seemed to have a so-what attitude to the point where she almost seemed like wanting to say “Well done!” This was quite a culture shock. However, when my wife did not back down and said “Since this is defective and fell out, it touched the ground and is unhygienic. So I would like to exchange it,” a male employee came out and said “Since we are busy, we don’t have time to give attention to things like this.” Nevertheless, when she did not give up and continued her appeal that “this defective product should be replaced,” finally the store manager emerged. He said, “I would like to replace it, but too much time has passed since the purchase. Would you accept 2 euros from my pocket?” After having already

Morning market

wasted a considerable amount of time and energy for a mere 3.50-euro product, we took the 2 euros and returned the defective product to the store manager while saying “It's all yours,” then left the store. We wondered whether we had won or lost this match. Although we tried to imitate the German character of valuing self-assertion and simply not giving up, it still seems like a high hurdle for us.

Stuttgart is still a less familiar city to the Japanese, but there are a number of sights, including the Christmas Market, beer festivals, music, ballet and architecture. If anyone has the chance, they should be sure to try and visit Stuttgart.

(Akira Nishizawa)

Station where reconstruction has begun

Demonstrators and the police (on horseback for some reason) watching them

Source of the aviation knowledge base of tomorrow

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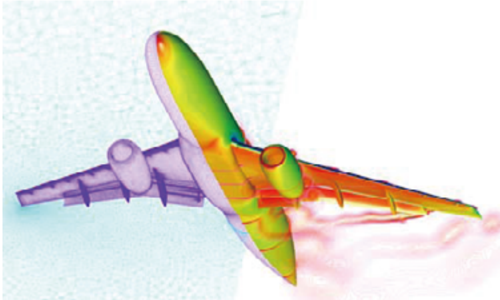
What is the supercomputer used for?



Pressure distribution: Computational grid (left) and airframe surface (right). The calculation results can be visualized in this way.

Q Supercomputers have become the topic of the year. Since there is a supercomputer here at the Chofu Aerospace Center and it is being used in the research of aviation technology, we are somewhat aware of them. What is the supercomputer being used to do?

A First, do you know how the supercomputer is used in the aviation field? When making airplanes, it calculates what performance an airplane would have from an airframe that has been designed. For example, when we are pursuing calculations as to what extent aerodynamic forces are acting on an airplane, we study various patterns while slightly changing flight conditions or the airframe shape. Long ago, studies could only be conducted through actual experiments; however, now, there are many parts that are calculated using supercomputers. Since the amount of calculations is so extensive, people would not be able to do them, no matter how much time they would have. Therefore, a supercomputer, which can perform a large number of calculations as quickly as possible, is necessary.

Q I see. But, is it good if only the supercomputer can perform calculations so quickly? I thought, no matter how good the tools are, aren't they only as good as the people using them?

A Both are needed. What we are researching is not the technology for making excellent computers, but calculation methods for studying fluid phenomena using a calculator, or computer. This is called computational fluid dynamics (CFD). We make programs that describe the steps and commands that allow what we wish to know to be calculated by the computer. This part is equivalent to software. In order to know how air flows around an airframe when an airplane flies, we are studying methods for representing the movement of the fluid (air) as a numerical formula and methods for calculating that efficiently with the computer. Additionally, we are trying to use that to calculate the actual flow of air around an airplane. A more easily understood way of saying it would be that we are simulating flight conditions with the computer. At present, properly modeling the actual physics of air flow and coming up with a result in a short time is difficult. A lot depends on how the program is made or what calculation method is used.

Q So, about how much time does it take until the calculation results appear?

A It differs depending on what you want to know, but there are some things that we know within one hour, and there are some things that take one to a few months. Devising the program or calculation method is very important, but if the processing speed of the computer is faster, this time period can be shortened. You may ask what are the advantages to that, but being able to make a large amount of calculations would allow us, from now on, to extensively study the relationship between airplane shape and flight performance, and design a comfortable airplane with better fuel efficiency. Or, to create an environmentally friendly airplane, we could extensively study internal engine combustion or airplane noise, which currently cannot be calculated in a short time. We are also putting in technical requests to computer manufacturers so that computers can be more efficient.

Q So, there is a close relationship between software development and hardware development, right?

A Actually, the introduction of the first domestically manufactured supercomputer was at the National Aerospace Laboratory of Japan (NAL), a predecessor of JAXA. Ever since, we have been contributing knowledge, together with aircraft manufacturers and universities, in the development of Japanese CFD technology. It was NAL that succeeded in creating the world's first three-dimensional analysis around an airplane, which had been impossible until then. The efficiency of supercomputers is gradually improving, and NAL's supercomputer, the "Numerical Wind Tunnel", was no. 1 in the world in 1993. Currently, in addition to tackling research on analysis technology necessary for improved accuracy as well as methods for obtaining calculation results more efficiently, we are taking on challenges in the aviation field.

Q Impressive! It's the result of everyone who is sharing the facilities working together. By the way, I wonder if this is useful not only on the research side but also in the actual manufacturing of objects.

A Of course. Aircraft manufacturers are using JAXA's supercomputer and CFD technology to obtain information necessary in design, and the results of past collaborative research should be useful even for the CFD technology of aircraft manufacturers. Consequently, it can be said that it is an essential tool for the manufacturing field and the development of CFD technology.

Essential to CFD technology development and manufacturing

A tight relationship with the aviation field