The RMAX Helicopter UAV

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Abstract

In Japan, chemical spraying by "manned" helicopter was started in 1958, nowadays it has spread throughout Japan. But residents who live near paddy rice field have began to complain of using 'manned helicopter', because the agricultural chemical drifts to their houses. Looking at the Japanese farming industry, because of the aging of the work force and lack of a younger generation of successors, it has been more and more difficult for farm workers to engage in heavy labor for pest control. In light of this situation, Yamaha Motor Co. LTD began developing industrial-use, unmanned helicopters in the 1980s. In 1990 we delivered the first unmanned helicopter for crop dusting. Among a total of 1,565 unmanned helicopters, 1,220 units of Yamaha unmanned helicopter have been sold and are in use as of October 2001, in Japan. There are two reasons why unmanned helicopters have become popular in Japan. First, the unmanned helicopter has such performance that farmers can control it easily and spray paddy fields effectively. Second, the unmanned helicopters are safely operated in Japan. The Japanese government has made numerous standards and an operator licensing system. In adding to this, Yamaha provides its own training system for operators and servicemen. Based on this unmanned helicopter, we have developed an autonomous flight control system. Because our autonomous, unmanned helicopter has succeeded in observation roles at erupting volcanoes, the Japanese government and other industries have began to be attracted to the operation of unmanned helicopters.

Introduction

Numerous studies about the development of unmanned helicopters and their flight control systems have recently been conducted in the United States and Europe. But most of these are prototype models and practical use of them is mostly seen in military applications.
In Japan in 2001, 1565 unmanned helicopter are used for chemical crop dusting. YAMAHA unmanned helicopters have established an overwhelming 80 % share of this market. The reason for our success is due to emphasis on (1) ease of use, (2) safe operation, (3) reliability. We also wisely concentrated on introducing these unmanned helicopters by promoting an initial application with a well-defined market of agriculture, specifically, paddy field. Agriculture is characterized by a shortage of labor and hence, a need for labor-saving devices.
In April 2000, we had our GPS-based autonomous helicopter play an observation role at an erupting volcano. This is the first time in the history of Japanese disaster management that an unmanned helicopter has been used for observation operation.
In this paper we wish to discuss the reasons why an unmanned helicopter was developed and has become popular in Japan. We will describe the history of our development of the unmanned helicopter and it's control devices. We will explain how unmanned helicopters are used safely in Japan and describe the "Safety and Certification" process. I will also explain about Regulations and Law related to unmanned helicopters.
We also present here our GPS-based autonomous helicopter and our successful observation activity at the volcano on Mt.Usu. Finally we would like to discuss the potential benefits and the problems of an unmanned helicopter in various usages in Japan.

Background of Development of Industrial –Use- unmanned helicopters

In Japan, chemical spraying by 'manned' helicopter was started in 1958, nowadays it has spread throughout Japan. While about 27 % of rice paddy fields were sprayed by manned helicopter in 1992, it posed some problems, too. The construction of houses in farming areas has increased and consequently many paddy fields were surrounded by residential quarters. In such a situation, the residents in these areas began to complain about the use of 'manned' helicopters. Looking at the Japanese farming industry, it has been faced with problems. Because of the aging of the work force and lack of a younger generation of successors, it has been more and more difficult for farm workers to engage in heavy labor for pest control.
To solve these problems, there arose the need for alternatives to 'manned' helicopters that would be able to spray paddy fields near residential quarters efficiently and precisely and reduce necessary labor.

Prototype model of 'RCASS' Counter-revolution Dual-rotor Helicopter

Yamaha developed its first unmanned helicopter in 1983, a counter-revolution dual-rotor helicopter known as the Remote-Controlled Aerial Spraying System (RCASS). The main feature of this helicopter was the incorporation of two main rotors that spun in opposite directions so that the use of a tail rotor (commonly used to absorb the torque generated by a single main rotor) was unnecessary. However, the utilization of dual rotors required that there be a large distance between the rotor positions and the helicopter's center of gravity. This caused the effect of very poor stability as compared to normal helicopters and made human operation impossible. Consequently, a microcomputer and sensor had to be installed to enable an automatic control function.

We had little knowledge about the control systems of unmanned helicopters at the time, so a control system was constructed by requesting the assistance of some university professors. There were also many problems involved in conducting test flights. Without any type of human- controlled backup system, whenever a problem occurred, the helicopter tumbled to a crash landing. The use of a test flight stand that slightly restricted helicopter flight was adopted so that control system parameters could be adjusted. Months passed, but success was finally achieved, and we succeeded in getting the helicopter off the ground and hovering without any restrictions. That moment of success imparted feelings that will never be forgotten.

Fig.1 RCASS – Counter-revolution Dual-rotor Helicopter

There were many more difficulties as testing continued, but finally a helicopter was completed that could be lifted off, flown approximately 30 meters and landed, directed only by simple stick-type control, even with input being given by an individual completely inexperienced in operating a radio-controlled helicopter. **(Fig.1)** Regrettably, however, the stability and controllability of flight were not sufficiently satisfactory to allow the use of the helicopter for actual crop-dusting activities. Nevertheless, considering the technological level at the time, it was truly an epoch-making achievement to fly a helicopter under automatic control, and our efforts were considered a great technological achievement.

Development of first model 'R50'

Recognizing the difficulty of putting the RCASS into practical use, we set out on the development of another unmanned helicopter capable of flight without control devices, the R-50. The year 1990 saw the marketing of the Yamaha Aero Robot “R-50,” the first industrial-use unmanned helicopter with a 20 kg effective load capacity. **(Fig.2)** Yamaha industrial-use unmanned helicopters have become the focus of attention as economical, environment-friendly, next-generation agriculture devices that are now being used primarily for crop dusting. For example, in the case of dusting rice paddies, an unmanned helicopter can do the job in about 1/15th the time it takes the aging, human work force.

Fig.2 Unmanned Helicopter - R50

Attitude Control Device,' YOSS'

In considering ways to enable an operator easy control through the use of a relatively low-priced sensors rather than a high-priced gyro, an altitude control device was consequently developed by adding a laser sensor made for a vehicle collision avoidance device to an altitude sensor. In this system, distance is calculated from the time it takes for transmitted light to be reflected off the ground and return. A piezo-resistant acceleration sensor was

incorporated in order to provide high-speed response on a vertical axis, and a small magnetic sensor coil made of a highly permeable alloy that detects geomagnetic materials was adopted for the direction sensor.
As basic control specifications related to altitude and direction control had already been successfully determined during development of the RCASS, development was not so difficult. Yet many problems surfaced when practical test flights for crop dusting were conducted; the biggest of these being that of body inclination. During the process of crop dusting, the body of the helicopter can reach a maximum inclination of 30 degrees at the time of sudden deceleration. At this time, the altitude and acceleration sensors miss-read the body movement as an increase in altitude. Consequently, the main control system gives the command to reduce altitude and the helicopter descends as a result. The resulting helicopter descent during crop-dusting activities is a dangerous event that could easily cause the helicopter to crash during the flight, and is therefore, very hard on the operator.
If the helicopter was equipped with an attitude sensor, this device would enable immediate compensation for the sudden helicopter movement, but it was decided such a device could not be added. After several studies, we discovered the correlation between the human steering control stick (angle) and attitude angle and, it was decided to employ fuzzy estimating theory to calculate an estimation of attitude angle. The YOSS R-50 **(Fig. 3)** was initially released on the market to wide acclaim in 1992. However, factors like the inherent weakness of an altitude sensor system over uneven terrain, which limited the types of land it could be used on, and the fact that the sensor unit and its batteries added more than 4kg to the weight of the aircraft and thus reduced the dusting payload, Yamaha was eventually forced to withdraw this model from the market.

Fig.3 R50 Equipped with YOSS –Altitude Control Device

YAMAHA Attitude Control System, 'YACS'

Determined to "learn from ones mistakes," the failure of the YOSS spurred us in the development of a new Yamaha Attitude Control System (YACS**, Fig. 4**). At the time, a gyro assembly capable of outputting three axial attitude angles was still quite expensive. However, the price of a more simplified unit, a gyro capable of detecting a single-axis angle speed, had fallen dramatically due the use of such devices in car navigation systems. As a result, it became economically possible to equip an unmanned helicopter with a gyro, and it was decided to construct a gyro assembly in-house.

Fig.4 Yamaha Attitude Control System (YACS)

The gyro assembly built for the YACS was equipped with three acceleration sensors and three fiber-optic gyros combined to form a three-axis, strapped-down-type gyro capable of detecting helicopter attitude angle, attitude angle speed and acceleration. Additionally, an operator-controlled model-tracing device with more faithful response to steering commands was also developed. These developments led to the manufacture of an attitude control device that combined stability and controllability. With this, it became possible to detect and correct vertical acceleration regardless of the attitude angle.

With the introduction of YACS, it became possible to control vertical speed. Furthermore, since the system did not use a ground distance sensor like that installed in the YOSS, the helicopter was able to maintain a stable altitude free of field terrain limitations.
It was also possible to keep the gyro assembly weight to only 2kg owing to the shared use of the helicopter's main electricity source (battery). The YACS was released on the market in April 1995. Due partly to the fact that it was possible to reduce the training-hour requirements to one-third that of previous units, the YACS still has an excellent reputation in the market today.

Latest Model 'RMAX'

Control devices produced up until this point in time were only optional components to be mounted on the R50 unmanned helicopter. This changed with the development of the RMAX **(Fig. 5,Table.1)**, the company's first unmanned helicopter with a control device built into the main body of the helicopter itself. The control device incorporated has basically the same functions as the YACS for the R50. Redundant transmission systems for the control calculation unit and operation signals were utilized to improve reliability. The market debut of the RMAX in October 1997 marked the achievement of a target set nearly 14 years earlier with the development of the dual-rotor RCASS helicopter

Fig.5 Unmanned Helicopter - RMAX

Table 1 Specification of R50 and RMAX

	R50	RMAX
Main Rotor		
Diameter (mm)	3,070	3,115
Tail Rotor		
Diameter (mm)	520	545
Complete helicopter		
Overall Length (mm) (with Rotor)	3580	3630
Overall Height (mm)	1,080	1,080
Overall Width (mm)	700	720
Weight		
Empty (kg) (With Fuel)	47	64
Payload (kg)	20	30
Engine		
Displacement (mm^3)	98	246
Category	Water cooled 2 stroke	
Maximum Output (KW)	8.8	15.4

"RMAX" mounts a specially developed horizontally opposed, liquid-cooled, 2-stroke, 246cc engine rated at 21 hp. This made possible an effective load capacity of 30 kg at an operating weight of 64 kg. A total of 1,220 units of 'R50' and 'RMAX' have been sold so far in Japan.

The area of Japanese agricultural land presently being dusted by these helicopters has increased annually and is expected to reach a total of 270,000 hectares (approximately 1,000 square miles) in the year 2000, including not only flat fields but also orchards and other crops grown on steep slopes. **(Fig.6)** We are engaged not only in the sales of industrial-use unmanned helicopters but also the training of operators and repair service.

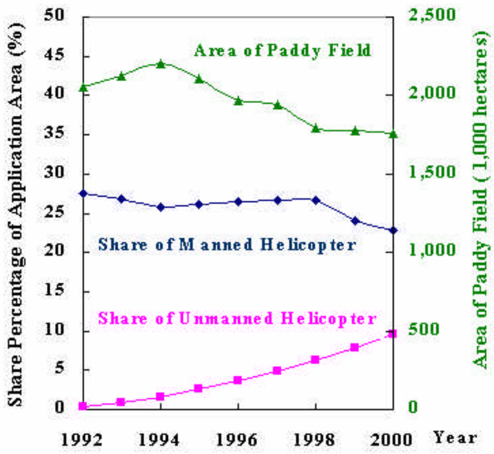

Fig.6 Area of Paddy Field and Share Percentage of Application Area

Safety and Certification Process

The best and the most suitable characteristic of an unmanned helicopter, from a safety viewpoint, is that it is unmanned (no pilot). Therefore, no crewmembers are injured or killed even if the helicopter crashes for some reason. Also, the RMAX is never flown above people. In addition, there is a very low possibility that humans may be injured or property is damaged when the unit is operated properly. The reasons are that it flies at low speed (20km/h), and low altitude (3-5 m), that is its intended use. Besides the safe characteristic of the unmanned helicopter, many safety features and measures are designed into it.

Ministry of Agriculture, Forest and Fisheries of Japan (MAFF) and its affiliated association, Japan Agriculture Aviation Association (JAAA), first promoted the idea of the agricultural unmanned helicopter. JAAA is supported and audited by MAFF and makes safety standards. They include airframe structure, flight performance, inspection and maintenance of the unmanned helicopter for agricultural purpose. Every unmanned helicopter that is used for crop dusting in Japan must meet all safety standards.

JAAA also has an operator flight certification system for unmanned helicopters for agricultural purposes and all operators are required to take flight certification testing before they operate the unmanned helicopter for agricultural purposes in Japan. Furthermore, JAAA assures safe operation and a training system on the unmanned helicopters for the user/operator and has a registration system for the unmanned helicopters and their customers for safe usage.

On the other hand, Yamaha incorporates various safety features into the RMAX unmanned helicopter design. One of the safety features is what we call a "Fail Safe System". This is to avoid a no-control flight of the RMAX if the radio signal between the radio transmitter and the RMAX receiver is interrupted for some reason. This system signals the RMAX to land on the ground immediately if the flight control signal is lost. This is why the helicopter is always flown away from people and buildings.

Yamaha performed various tests on the RMAX for reliability and durability before RMAX production started. During the RMAX production stage, we also conduct various quality control activities.

Also, Yamaha has its own RMAX maintenance procedures and holds training periodically for RMAX dealer's technicians using the RMAX maintenance manual. Periodically, the dealer's servicemen perform maintenance on RMAX's already sold to customers using their maintenance skills obtained through Yamaha maintenance training. Yamaha has trained numerous RMAX flight instructors, and the flight instructors have been training RMAX flight operators periodically or depending on necessity. In doing so, Yamaha is always treating safety as a number one policy. As a result of the training and maintenance provided, the 1500 plus helicopters fly safely, while operating nearly simultaneously, during the spraying season in Japan.

In **Fig.7**, we will show operator rules that we make our operators strictly observe.

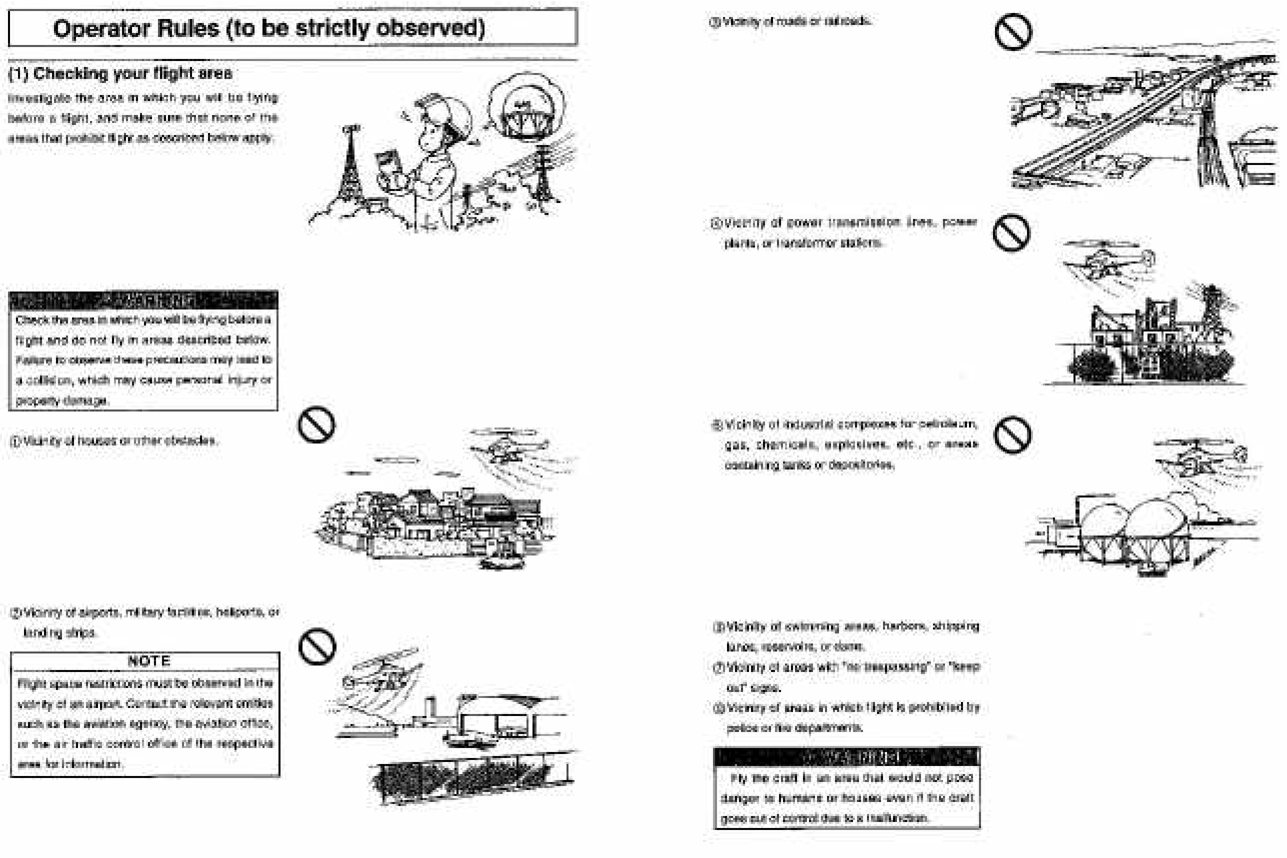

Fig.7 Operator Rules

Japanese Regulations or Laws

Related to the industrial unmanned helicopter such as the RMAX, there are 'Aviation Law', 'Aviation Manufacturing Law', 'Radio Wave Law' and 'Agrochemicals Regulation Law'.

1. Aviation Law

According to Aviation Law regulated by Ministry of Land, Infrastructure and Transport (MLIT), the unmanned helicopter is not regarded as “Aviation”.

The definition of “Aviation” is that the Aviation/Aircraft which a pilot can ride on/in such as an airplane, helicopter, glider and airship. Because the unmanned helicopter is pilot-less, it is not considered “Aviation". Therefore, you do not need a “license” issued by MLIT to fly the unmanned helicopter, but need a “certification” issued by JAAA to fly the unmanned helicopter for agricultural purposes. One can not fly the unmanned helicopter any place where MLIT prohibits flying of any other kind of aerial vehicle based on Aviation Law.

For example, the flight of unmanned helicopters is prohibited or restricted near airports. Aircraft (or any “Aviation”) not under the control of an air traffic controller may not over-fly an active runway or over the approach to the landing area. Nearby an active runway, UAV’s or other “aviation” are restricted to an altitude of 150 meters. Outside the restricted areas of an airport under air traffic control, UAV’s are restricted to a maximum altitude of 250 meters. These restrictions are similar to that of the International Civil Aviation Organization.

2. Aviation Manufacturing Law

The Ministry of Economy, Trade and Industry (METI) issues a “Manufacturing Certification” for all aerial vehicles in excess of 100kg. This applies to both manned and unmanned aircraft.

3. Radio (Electric) Wave Law

The radio/electric wave incorporated into the industrial unmanned helicopter is very weak and is not applied to the Radio/Electric Wave Laws regulated by Ministry of Public Management, Home Affairs, Posts and Telecommunications. Therefore you do not need a “license” for wireless operation to fly the RMAX.

The radio frequency incorporated into the industrial unmanned helicopter is 73.26, 73.28, 73.30 or 73.32 MHz. These four radio frequencies are allowed for use of the industrial unmanned helicopter (not for RC model helicopters) by the Authority.

4. Agrochemicals Regulation Law

The agrochemicals used for aerial spraying by unmanned helicopters have a higher concentration as compared with those for land application. Because of this, greater care must be taken when using pesticides for helicopter operation. Only the agrochemicals registered as those for unmanned helicopter spraying in accordance with the Agrochemicals Regulation Law (regulated by Ministry of Agriculture, Forest and Fisheries) may be used.

Those who desire to apply for this registration are required by Law to present data concerning the effectiveness, chemical injury, crop persistent and environmental effects.

Development of autonomous helicopter

Japan is famous for volcanoes and earthquakes. In 1990 Unzen volcano erupted. In 1995 the Great Hanshin Earthquake took place. Many people were killed by these disasters. 29 volcanoes in Japan are currently being watched, experts say there is a possibility that some of them might erupt anytime. What is more, some experts predict earthquakes.

The most important thing we have to do in these disasters is collecting information, especially images from the sky. Unfortunately ‘manned’ helicopters could not approach active volcanoes to gather precious images because it is too dangerous for their human operators.

We started to develop an autonomous unmanned helicopter that could plays roles in disaster management, by modifying the RMAX. We established an experimental model in 1999. We used it to gather valuable data in areas like the grasslands of Mongolia **(Fig.8)** and the ice flows of the Okhotsk Sea, but they were within the visual range of the operator.

Fig.8 Observation of Vegetation in Mongolia

At the end of March 2000, the 732-meter high, active volcano Mt. Usu, on Japan's northern island of Hokkaido, erupted for the first time in over 22 years. The Japanese Government asked Yamaha's R-Max to perform volcano area surveillance at Mt.Usu in April 2000. It could gather valuable and precise data that would not have been possible using manned helicopter and aircraft. This is the first time in the history of Japanese disaster management that an unmanned helicopter has been used for observation operation. This experience has revealed a lot of information about an autonomous unmanned helicopter and that is possible to be employed in disaster situations.

System Configuration

The autonomous control system configuration is shown in **Fig. 9**. The airframe side has an attitude sensor, a GPS sensor and a communication modem on board.

extending flight time from 60 to 90 minutes. As for observation equipment, a digital video camera and a digital still camera are mounted along with three miniature cameras for navigational purposes. Images from these cameras are sent from the airframe to the ground on a real-time basis, where they are viewed on a four-window split screen monitor.
On the ground a GPS, three personal computers and a communication modem for the base station are set up to send the correction data to the GPS on the airframe.
Three personal computers give three displays for operators to fly the helicopter.
The "Helicopter Status" display gives him information about the behavior during the flight, such as altitude, roll, pitch, speed, and climb rate. Also, some information from the helicopter is presented, like engine speed, engine temperature, battery condition, radio wave condition, etc. Moreover, a 3-dimensional picture of the helicopter is shown in the display.

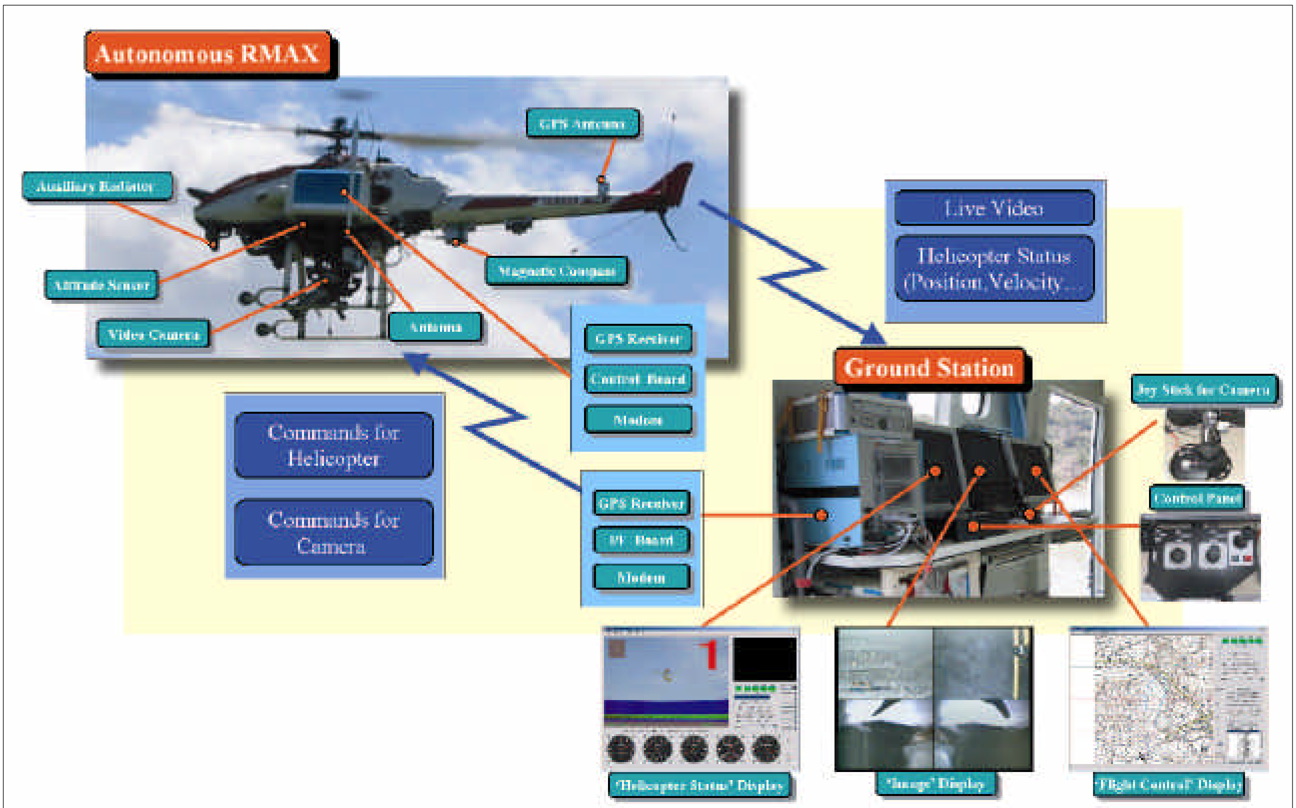

Fig. 9 Autonomous Control System Configuration

A communication modem receives the GPS correction data and control (steering) commands from the ground, and sends the information regarding the position and attitude angles of the airframe to the ground.
To increase flying time, an auxiliary fuel tank is added,

The "Image " display shows images from four cameras on the helicopter, where they are viewed on a four-window split screen monitor.
The position of the helicopter is presented on the map on a "Flight Control " display.

We have a camera transmitter that can move the angle position of the camera on the helicopter. Furthermore, in order to ensure the safety of the system, we made the system so that an operator can also back it up by using a normal radio transmitter and the transmitter of the communication modem.

Observation Flight at Erupting Volcano, Mt. Usu

On April 24 in 2000, our operations staff of eight persons arrived in Hokkaido. The volcanic activity on Mt. Usu had quieted some compared to the initial eruption, but the danger was far from over. What's more, due to constant observational flights by manned helicopters on the perimeter of the no-fly zone that our unmanned helicopter would be entering, our team's observation flights would be limited to the morning hours before 8:30 a.m. to avoid the possibility of accidents in the congested air space around the mountain.

Fig.10 Observation Flight at Mt.Usu

The field headquarters had been set up in tents at a position just 2.5 km from the mouth of the volcano. Tensions were high at the camp, with thunderous explosions being heard up on the volcano from time to time as towering clouds of steam rose into the sky. The tension was palpable at the five police checkpoints the Yamaha team had to pass through on the road from their hotel to the base camp.

Fig.11 Destroyed Houses and a Crater

During the team's three days at the base camp our helicopter made six observation flights, filming the targeted areas and successfully relaying the images back to the headquarters. The result was many clear, live images of changes in topography of the mountain and build-up of volcanic ash that could not be seen by the manned helicopters or the Defense Forces' aerial photographs. Some of the impressive images quickly found their way to the media where they were shown on nationwide TV and in the newspapers. In addition to these sources sending out these images, our unmanned helicopter proved valuable in a number of unexpected ways, such as for dropping scales to actually measure the depth of volcanic ash and gravel build-up, an important indicator for predicting dangerous mudslides.

Another observation flight on Miyake-jima Island

Following the volcanic activity alert on June 26, 2000 and the ensuing eruption of Mt.Oyama on Miyake-jima Island on July 8, volcanic activity continued intermittently. This resulted in the complete evacuation from the island of all its' inhabitants on Sept.1. Since then, the volcanic activity including the release of volcanic gases has continued, limiting access to the island even by disaster prevention specialists.
At the request of the Miyake-jima branch of the Tokyo Metropolitan Government office, we deployed a GPS-based autonomous unmanned helicopter. It was used for a series of observation flights from Feb.13 thru 15, 2001.
Flights were made about 1.5 km. up the mountain to observe the upper ends of the gouges. Footage was taken with the digital video camera mounted on the helicopter. Communications signals from the base camps were employed to drop lance-shaped measuring poles mounted on the helicopter to make estimates of the thickness of the mudslide layers. Also, we used a gas detection meter to measure densities of volcanic gas. The data gathered from these observation flights is expected to play an important role in the future for studies concerning the construction of " landslide dams" designed to limit the spread of land/mudslide damage.
The use of the unmanned helicopter under these conditions has enabled the gathering of previously unavailable data such as, low-flight observation images from the high-danger areas near the volcano that only a helicopter could provide. This valuable data will now contribute to the research and studies of the various related agencies and research institutions.

Potential Ability and Problems

Because of our successful observation role at Mt.Usu, the Japanese government and other industries have been attracted to the operation of unmanned helicopters. For example, Hokkaido Regional Development Bureau already bought our unmanned helicopters for an observation role of volcanoes including Mt.Usu.(**Fig 12**)

Fig.12 Autonomous RMAXs for Hokkaido Regional

The Japan Meteorological Agency also bought unmanned helicopters for gas sampling and putting measuring devices for earthquakes in dangerous sites. The Japan Coast Guard is also contemplating unmanned helicopter use for search and rescue operations. Even electric power plant companies, which have many nuclear power plants all over Japan, are very interested in unmanned helicopters. (There was an unfortunate accident at a nuclear fuel processing plant in Tokai-mura in 1999.).

We believe an unmanned helicopter has a lot of potential because it can go in and perform operations in areas too dangerous for humans. But in order to realize this potential we first have to increase the reliability of the technologies.

Eventually we would like to have a system that is so foolproof that even people who know nothing about helicopters can fly it.

Conclusion

Over ten years have passed since an unmanned helicopter was put to use for aerial crop dusting in Japan. Because it is laborsaving, environment-friendly for next generation agriculture, it is widely used all over Japan. Actually it becomes expected for Japanese agriculture now.

In order to fly safely, the Japan Agriculture Aviation Association has made numerous standards and an operator licensing system. We also put safety features into the design and have our own training system for the dealer's serviceman .

We have successfully flown our autonomous unmanned helicopter out of visual range to play an observation role at erupting volcanoes. Recently we have had many disasters including earthquakes and volcanic eruptions and accidents at a nuclear plant in Japan. The Japanese government is now very interested in using an unmanned helicopter in dangerous situations.

In order to realize this, we must continue to strive to increase the reliability of the autonomous unmanned helicopter, even more than we have achieved with the agricultural unit.