Development of SH-60K Patrol Helicopter

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SH-60K is a new patrol helicopter developed as a successor to the SH-60J anti submarine helicopter currently in operation. SH-60K is carried onboard a destroyer and in cooperation with the vessel fulfills versatile missions, such as anti submarine warfare, anti surface warfare, surveillance, transport, and rescue operations. For this purpose, Mitsubishi Heavy Industries (MHI) has put state-of-the-art technology to full use to develop the main rotor blade, avionics system, Ship Landing Assist System, and other systems of this specialized aircraft with the most advanced functions and levels of performance in the world. After the development phase from 1997 through 2002, technical and operational validation test were carried out by the Japanese government, after which MHI delivered the first production aircraft to the Maritime Self-Defense Forces on 10 August 2005.

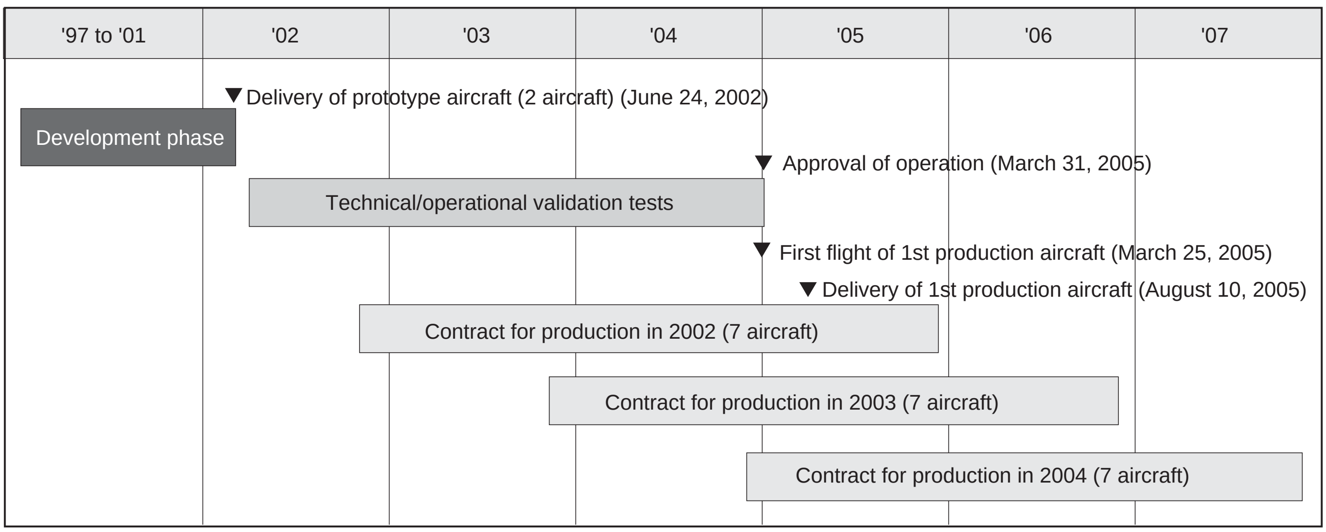
1. Introduction

As global conditions become ever more complex and needs of safety become greater than ever, Mitsubishi Heavy Industries, Ltd. (MHI) has developed the new patrol helicopter SH-60K in accordance with the overall schedule shown in **Table 1**. Based on the SH-60J anti-submarine helicopter currently in operation, SH-60K has been developed to fulfill the needs for greater versatility and enhanced performance for helicopter missions of the Maritime Self-Defense Forces. The development phase began in 1997 and two prototype helicopters were delivered to the Defense Agency in June 2002. Subsequently, necessary technical and operational validation test by the government were carried out, after which the approval for operation of the Director General of the Defense Agency was obtained in March 2005. MHI received production orders for a cumulative total of 21 aircraft during the period from 2002 to 2004, and delivered the first production aircraft on 10 August 2005.

2. Characteristics of SH-60K

Many improvements have been made in SH-60K over SH-60J. Characteristics of these are a new type of main rotor blade, avionics system, and Ship Landing Assist System (SLAS). The new type of main rotor blade is made of all-composite material, and has a unique shape with dihedral and anhedral angle at the blade tip, thereby improving hovering performance. The avionics system is integrally controlled by Advanced Helicopter Combat Direction System (AHCDS). With the adoption of an expert system, AHCDS can also provide the pilot with an optimum tactical plan. In addition, AHCDS has the function of exchanging tactical information among two or more escort helicopters. SLAS provides automatic guidance to and automatic landing on the base ship so as to reduce the pilot load, especially during nighttime operations when the field of vision is narrow. All of these improvements incorporate the world's most-advanced functions and performance.

Table 1 Schedule of Development Phase and Production



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Other improvements include the enlargement of the cabin (enlarged by 30 cm in length and 15 cm in height compared with SH-60J), as well as the installation of additional equipments such as a multifunction FDR (flight data recorder) and video transmission system.

The following sections present an outline of the main rotor blade, avionics system, and SLAS as characteristic systems of SH-60K. In addition, aspects of the company test are also introduced.

3. Main rotor blade

SH-60K's main rotor blade has a unique blade tip shape with dihedral and anhedral angle and swept back angles which provides excellent aerodynamic characteristics during hovering flight. This design makes it possible to increase the maximum gross weight from 21 884 lbs for SH-60J to 24 000 lbs without increasing the rotor diameter over that of SH-60J, the base aircraft of the SH-60K. The tip shape of the main rotor blade is shown in **Fig. 1**.

Composite materials are extensively used in the structure of the main rotor blade in order to realize the complex tip shape described above, as well as to achieve an optimum rigidity/ weight distribution for a low vibration design, and to reduce weight and manufacturing costs. The main rotor blade structure is shown in **Fig. 2**. The wrap-around structure has been adopted for the blade attachments, in which a spar cap is wrapped around the lug hole to reduce the weight, facilitate the manufacturing process, and simplify blade installation and removal (blade installation by two sleeves). The spar cap is a member that mainly bears centrifugal force and bending loads. Aramid fiber reinforced plastic (AFRP) has been used for this member, which has superior strain fatigue strength.

The torsion wrap is a member that mainly bears torsional loads. High-strength carbon fiber reinforced plastic (CFRP) having a high shear modulus is used for this member in order to ensure high torsional rigidity. The skin consists of inexpensive glass fiber reinforced plastic (GFRP) which has a relatively low elastic modulus and which is used to reduce the load of the skin. Although a lightweight Nomex core is mainly used for the honeycomb core, a high-strength aluminum core is used for part of the blade tip portion, which has dihedral and anhedral angles and is kinked, because local high flatwise tensile stresses occur here.

Development and strength (static/fatigue strength) certification process for the main rotor blade were based on the building block approach in which development and strength certification were stepped up while various kinds of tests such as the coupon test, structural element test, sub-component test, and component test (full scale test) were carried out. It was confirmed that the main rotor blade had the specified durability, performance and functions through demonstration tests which include lightning test, ballistic resistance test, and whirl test using full-scale test components.

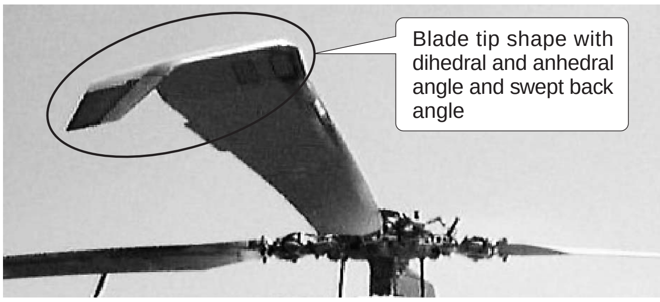

Fig. 1 Tip shape of main rotor blade

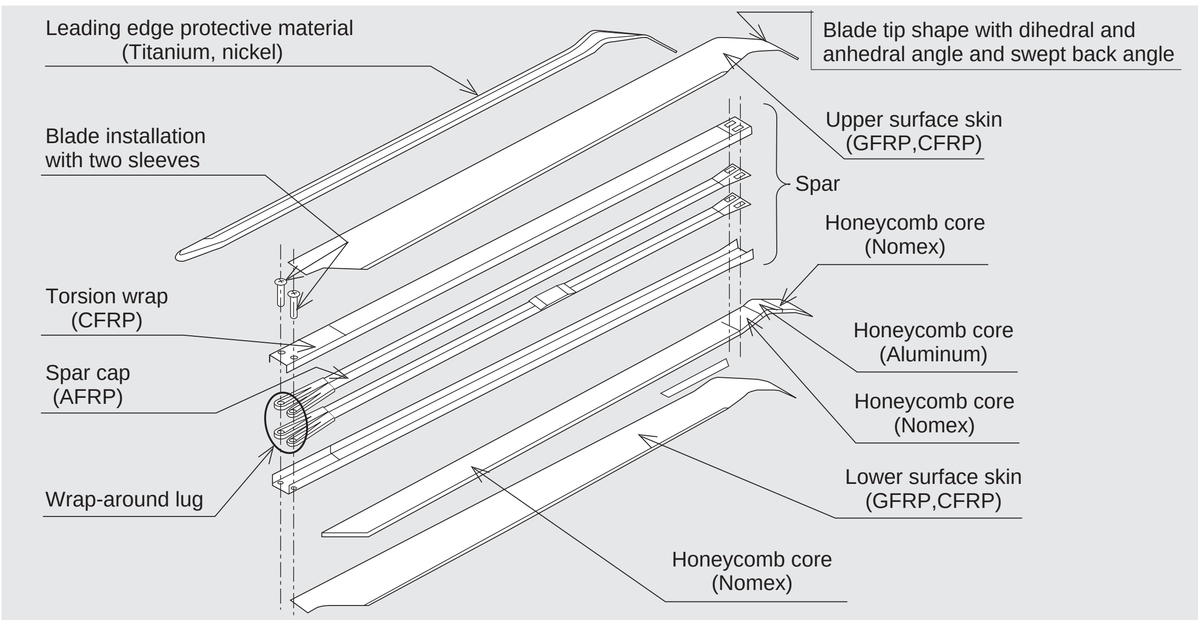

Fig. 2 Main rotor blade structure

4. Avionics system

(1) Principle of system organization

The avionics system consists of three stages: the instrument group, flight control group, and AHCDS, based on the following stepped stage policy.

(a) Instrument group

Devices required for the instrument display are made with dual redundancy, thereby ensuring the acquisition of aircraft condition signals and the redundancy of the display group.

(b) Flight control group

Flight control is done based on aircraft condition signals obtained using duplex avionics. Moreover, it is also possible to control communications and the navigation group by only this group.

(c) AHCDS

AHCDS integrates mission equipment under the above-mentioned basic functions required for flight, and is designed in such a way that it is also connected to each of the above groups.

(2) Data bus method

The amount of required data transferred among the various kinds of avionics equipments connected to AHCDS was estimated to be on the order of 1.2 Mbps. On the other hand, these equipments consist of existing or partially modified equipments. Thus, the MIL-STD-1553B interface with an established track record in military aircraft was adopted as a general-purpose interface.

(3) Data bus topology (Topology of various kinds of avionics equipments)

A comparative study was conducted on the various forms of topology that could be used to connect the various kinds of avionics equipments to the system bus. As a result of this study, a hierarchical structure type was adopted in which the whole is divided into two groups and mutually connected groups are made independent from the system bus, as shown in **Fig. 3**. This approach was adopted because of its superior system reliability in case a failure occurs, and data transfer load.

In addition, the concrete bus arrangement for the various kinds of avionics equipments is set based on the following concepts:

- avionics important for flight safety: distributed arrangement or connection to both buses;
- avionics in which data is mutually exchanged: arranged on a bus of the same group;
- avionics in which high-load communication is made only between specific avionics equipments: distributed arrangement on a local bus; and
- avionics which do not fall under any of the above types of equipments: a connection bus is set from the viewpoint of equalizing data transfer loads for two groups of the system bus.

The bus topology for the avionics system that was finally adopted is shown in Fig. 3.

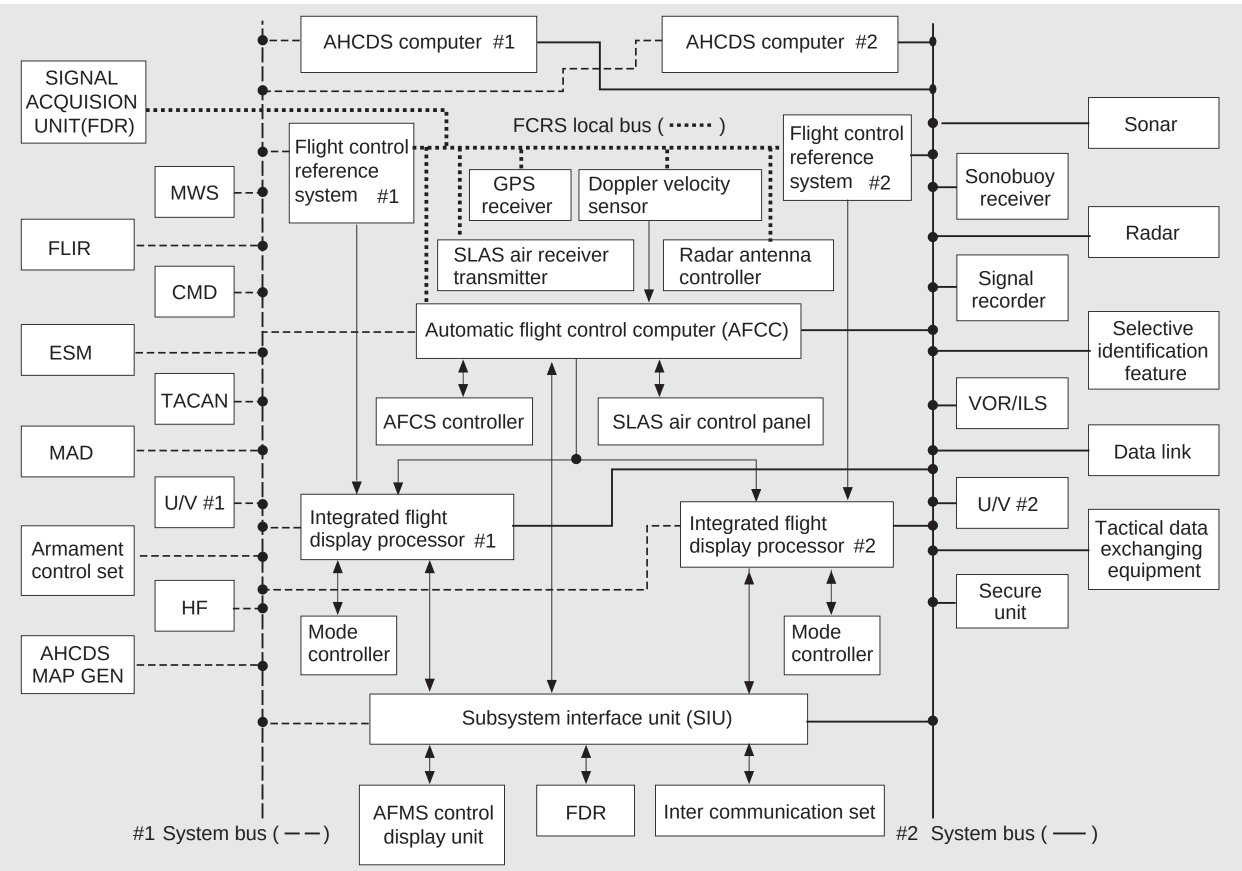

Fig. 3 Connection diagram of the avionics system

5. Ship Landing Assist System(SLAS)

Ship Landing Assist System (SLAS) has the function of automatically carrying out operations of the approach of the aircraft to the base ship, automatic entry, and hovering and landing on the flight deck. Major aims of this system are to reduce the pilot workload and to improve a flight safety at nighttime and stormy wether. The function of SLAS is achieved by the dedicated system which is equipped on SH-60K and destroyer. The equipment configuration of SLAS is shown in **Fig. 4**.

(1) Approach to the base ship

In the approach phase to the base ship, the aircraft flies along a flight course calculated in advance based on the relative speed of the aircraft and base ship. Adoption of a differential GPS (DGPS) as a system to measure data on the relative position of the aircraft and base ship for flight control makes it possible to measure the relative position accurately, thereby making approaches safe.

(2) From automatic entry onto flight deck

In the phases subsequent to automatic entry of the aircraft onto the flight deck, a high measurement accuracy is required for the relative position data used for flight control because the aircraft flies near the structure onboard the ship. Therefore, we adopted a SLAS Ship Guidance Sensor (SSGS) using laser and infrared radiation.

SSGS measures the relative distance and azimuth/elevation from the ship to the aircraft, by tracking the marker and reflecting a laser beam emitted from the sensor off the reflector (**Fig. 5**).

In automatic hovering phase, steady hovering not affected by ship motion is realized by controlling a aircraft for "fixed point in a space", which is obtained by subtracting the amount of ship motion measured with the SLAS Ship Motion Sensor (SSMS) from the relative position data. In addition, for disturbances such as turbulent flow due to a structure onboard the ship, hovering accuracy has been improved by using the actuator of the Stability Augmentation System (SAS) to control relative position and relative speed of the airframe. As a result, we succeeded in automatically landing a manned helicopter on a ship for the first time in the world.

6. Company test

During the SH-60K development phase, system integration test, total aircraft ground test, and company flight test were carried out as tests at the total aircraft level.

(1) System integration test

System integration test was carried out to verify the interface between AHCDS, which integrates the avionics system, and other electronic equipments, and between SH-60K and related ship equipments. This test was carried out by setting a test facility simulating the actual aircraft in the Komaki-minami Plant at MHI's Nagoya Aerospace Systems Works. Avionics equipments were set up on the test facility according to the arrangement onboard the actual aircraft, as well as to connecting ship equipments and consort planes (simulation planes) using cables for the data link system.

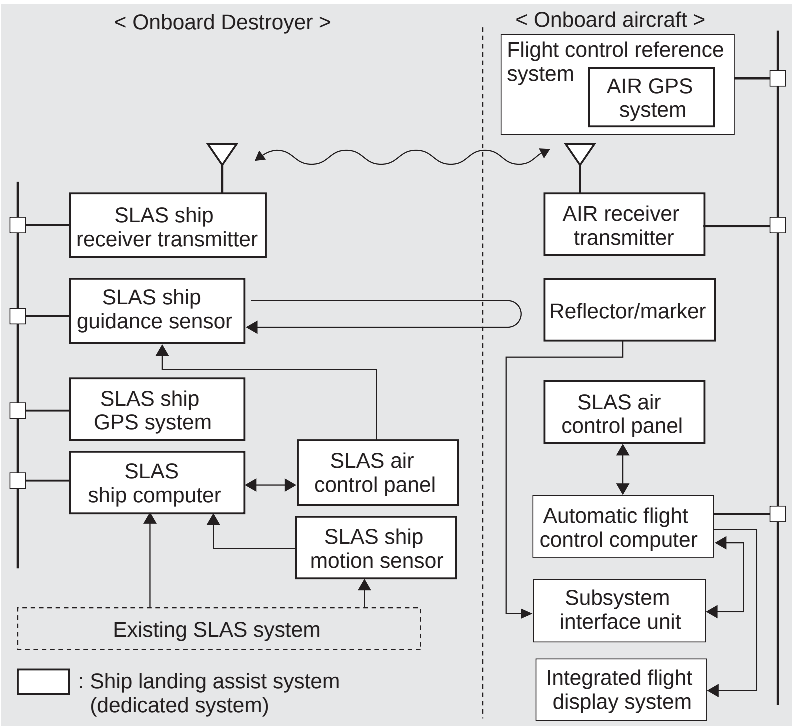

Fig. 4 Schematic of equipment configuration of SLAS

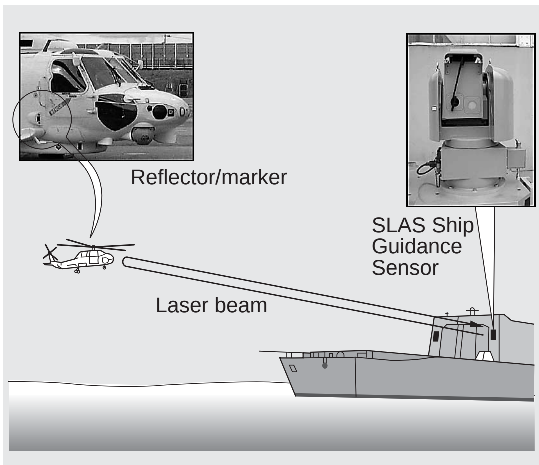

Fig. 5 Relative position measurement by SLAS Ship Guidance Sensor

System integration test made it possible to deal with nonconforming matters and problem areas needing improvement at an early stage before equipment-installation on the actual aircraft. In addition, the test facility was also used to check any nonconformity found in the company flight and related tests and to confirm the effectiveness of countermeasures. Hence, the facility turned proved to be a very effective development tool.

(2) Total aircraft ground test

The total aircraft ground test is a test carried out prior to the company flight test. The total aircraft ground test was carried out mainly in order to confirm the functions, performance and electromagnetic compatibility of the various onboard equipments and systems as they are installed on an actual aircraft. This included a verification of the transmitting and receiveing function of radio equipments, system operability, visibility, and other functional characteristics.

(3) Company flight test

Company flight test was carried out in accordance with the following steps using two prototype aircrafts with the aim of confirming the basic flight performance and characteristics of the aircraft and the basic functions of the equipments installed onboard. This laid the basis for determining the prospects of being able to shift to the technical/operational validation tests conducted by the Defense Agency (conducted during the period from June 2002 through March 2005) after delivery of the prototype aircrafts.

(a) Basic function verification test

The basic airworthiness of the helicopter was verified at the initial stage while the flight envelope was expanded, and it was also verified that it was possible to shift to the detailed function verification test at the next stage.

(b) Detailed function verification test

The flight performance, flight characteristics, flight stress/ vibration, noise, and electromagnetic compatibility were verified. In addition, the functions of the environmental control system, automatic flight control system, and avionics system were also verified.

In the basic function verification test conducted after the first flight on 9 August 2001, the flight envelope, such as the altitude, speed and weight of the aircraft, was expanded on a step-up basis while safety was verified by monitoring the flight parameters, stress/ vibration, and other factors in real time on the ground using a telemeter system. In parallel with the basic function verification test, the function test was also carried out on the automatic flight control system, avionics system, and related systems. The test was conducted within the verified flight envelope.

It was confirmed that the results of the flight test on flight performance and flight characteristics, as well as the flight load of the main rotor blade, flight load of the dynamic components directly affected by the rotor characteristics, and aircraft vibration were almost as designed. In addition, it was also confirmed that the functions of the avionics systems, such as AHCDS, Ship Landing Assist System and dipping sonar had no problem.

The company flight test during the development phase was carried out during the period from August 2001 through May 2002. The test covered a total flight time of about 456 hours with two prototype aircrafts and was completed as planned.

(4) Company test during production phase

During the production phase, the system integration test, total aircraft ground test, and company flight test were carried out, as they had been during the development phase. A focus of these tests was on the systems that were added or modified during the production phase, such as the multifunction flight data recorder (FDR) and video transmission system. In the company flight test, tests covering a total flight time of about 186 hours were carried out using two production aircrafts from the first flight from 25 March 2005 until July 2005 when the test was completed. The test was completed as planned with satisfactory results.

7. Conclusion

First SH-60K production aircraft was delivered just recently to the Maritime Self-Defense Forces on 10 August 2005. Although it took nine years to complete the SH-60K production aircraft from the start of the development phase, it is still a new face in actual operation. Therefore, it is necessary to deal with not only initial problems and failures but also further modifications that arise in the course of operation.

In addition, SH-60K will be used for a few decades to come. Therefore, MHI not only plans to improve the aircraft to make it even more reliable and easy-to-use, but also to put forward new proposals with an eye on global conditions, technological trends, and other factors.


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