Executive summary

Korean-Dutch Flight Testing for Kamov KA32T Helicopter Training Simulator Development & Validation

Problem area
Together with (and contracted by) the Korea Aerospace Research Institute (KARI), the Dutch National Aerospace Laboratory (NLR) has performed a successful flight test campaign with the Kamov KA32T in South Korea in the summer of 2007. These trials were part of the KA-32 Helicopter Training Simulator Development Program, managed by KARI.

Description of work
Within this program, NLR developed the flight model and executed the flight tests in close cooperation with KARI and the helicopter operator. A very successful flight test campaign has been executed from 1 to 31 August 2007 at the Iksan airbase of the Forest Aviation Office.

Results and conclusions
The installation and calibration of the instrumentation was accomplished within 2 weeks. A total of about 30 hours of flight time has been performed in 22 flights. The very successful flight test campaign provided good quality data for the AC120-63 tuning process, thanks to good cooperation between Korean and Dutch engineers and the Korean helicopter operator.
During the model tuning process, a very good result was achieved, providing a simulation model that has a high (Level C) fidelity in representing the KA32T and an almost 100% fit to the flight test data.

This paper describes an interesting project with an international touch, including some distinctive logistical challenges: Korean and Dutch engineers working on a Russian helicopter.
Korean-Dutch Flight Testing for Kamov KA32T Helicopter Training Simulator Development & Validation

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Summary

Together with (‘and contracted by,) the Korea Aerospace Research Institute (KARI) the Dutch National Aerospace Laboratory performed a successful flight test campaign with the Kamov KA32T in South Korea during the summer of 2007. These trials were part of the KA-32 Helicopter Training Simulator Development Program managed by KARI. Within this program, National Aerospace Laboratory developed the flight model and executed the flight tests in close cooperation with KARI and the helicopter operator. A very successful flight test campaign was executed from August 1 to 31, 2007, at the Iksan airbase of the Forest Aviation Office. The installation and calibration of the instrumentation was accomplished within 2 weeks. A total of about 30 hours of flight time was performed in 22 flights. This article describes an interesting project with an international touch, including some distinctive logistical challenges: Korean and Dutch engineers working on a Russian helicopter.

Key words: Flight test program; helicopter; Iksan airbase; international collaboration; Jeonju airbase; Kamov KA32T; Korea; simulator development; test data; test plan.
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1 Project background

The objective of the KA-32 Helicopter Training Simulator Development Program is to acquire a helicopter simulator that meets level C requirements in accordance with FAA AC 120-63. The Korea Aerospace Research Institute (KARI) managed the development program and was in charge of developing and validating the flight dynamics model based on simulator design data and flight test data. The helicopter chosen for this project was the Kamov KA32T (Figure 1) operated by the Korean Forest Aviation Office (FAO), mainly used for fighting forest fires.

KARI was presented with the challenge of finding sufficient data for the development of the flight dynamics model. The Netherlands’ National Aerospace Laboratory (NLR) was awarded a contract to develop the flight model and gather flight test data because of its experience with flight simulation development and flight testing for a competitive price. The result was an interesting project with an international touch, including some distinctive logistical challenges: Korean and Dutch engineers working on a Russian helicopter. Key innovations for NLR for this project are the non-intrusive measurement system and the setup of a flight test program with restrictions in operation and instrumentation. The project has been successfully finished in a short time and on a tight budget.

The KARI/NLR project consisted of three phases: flight mechanics model development, flight testing, and model tuning. During the flight test phase, the goal was to gather data for flight mechanics model improvement and data for the comparison between model and flight test (qualification test guide). This article presents the preparations and execution of the flight test program and discusses some of its results. At the end of the article, the application of the measured flight test data within the project is discussed briefly.

![Figure 1: The Kamov KA32T test helicopter](image)
2 Helicopter configuration

The Kamov KA32T is an 11-tonne twin engine helicopter with a coaxial rotor system. All flights were performed with a crew of two pilots and one flight test engineer, complemented during several flights with a flight mechanic. The pilots of the test aircraft were senior pilots within the Forest Aviation Office; however, they had no formal test pilot training. The flight test engineer from KARI was in charge of the in-flight organization of the tests, managing the instrumentation system, and recording of events using event marker and flight test cards.

The FAO normally operates the KA32T with a Simplex Model 10900-050 Fire Attack water tank mounted below the fuselage. Because the water tank limits the maximum speed to 150 km/h, as opposed to the normal maximum speed of 230 km/h, it was decided to perform the flight tests without the water tank to enable testing over a larger speed envelope. Both engine inlets are equipped with a dust protection device and an anti-icing system.

It was decided by KARI to vary the helicopter weight using fuel quantity only. Because the external fuel tanks are not available at FAQ, only the internal tanks were used. Using this configuration, weights between about 7,300 and 8,700 kg can be achieved. Additionally, the center of gravity range was varied with the position of a flight mechanic in the cabin. The test helicopter was not equipped with an external hoist or air conditioning. The dust protection device and anti-icing system were off for all tests except for those tests measuring the performance impact of these systems.

During normal operation of the helicopter, the autopilot is on, providing rate stabilization and attitude hold. During many of the flight tests, the autopilot had to be switched on. However, some tests specified in the simulator qualification requirements (FAA, 1994) require maneuvers to be performed without the autopilot. The required configuration (autopilot on or off) was indicated on the test cards. “Autopilot” referred only to the yaw, roll, and pitch channels on the center control panel. Other modes such as altitude hold were not used during the test maneuvers.
3 Instrumentation system

Instrumentation system in helicopter
After several preparatory visits to South Korea, the preliminary design of the instrumentation system was started using NLR’s Generic Instrumentation System (GIS) as a basis. The GIS is an advanced airborne measuring and recording system. It is capable of adequately measuring, conditioning, and recording analog signals, discrete signals, digital signals, synchro signals, and manual data entry, e.g., record number.

A constraint for the instrumentation system design from the operator was to install equipment with as little impact on the helicopter as possible, both mechanically and electrically. For both operational and safety reasons, the system had to be nonintrusive. Therefore, the approach for the design of the instrumentation system was to use as many parameters going to the KA32’s Flight Data Recorder (FDR) as possible. This required the design of a “breakout box,” which enabled recording these parameters by the NLR data acquisition system, while the FDR remained in operation. A second major part in the instrumentation system was a dedicated test inertial reference system, providing ring-laser—based attitudes, rates, and accelerations.

To complement the parameters from the FDR and the NLR inertial reference system, we installed several additional sensors. On the landing light bracket, a probe for outside air temperature was installed. To satisfy concerns about flight safety, we used nonintrusive optical (laser) sensors for longitudinal and lateral cyclic position, with reflectors installed on the longitudinal and lateral push—pull rods below the cockpit floor (Figure 2). To measure engine temperature, we installed a breakout connector in the signal from the engine thermocouples. Because it was not possible to measure the cold junction temperature, the measurement varies with cold junction temperature. This deficiency was solved by correcting the measurement with observations of the cockpit instruments from video (for ground tests) and from the flight test engineer (for flight tests). A temporary transducer, for ground test only, was connected to the engine throttles to measure the deflections during engine start-up, (ground) operation, and shutdown. The engine pressure ratio, an indication of engine power, was measured by installing a breakout connector in the signal to the cockpit instrument.
Figure 2: Non-intrusive laser sensor (on orange bracket) and reflector (on yellow push-pull rod) below cockpit floor to measure stick position

To create the breakout connectors for the flight data recorder, and engine pressure and temperature, we had to purchase several Russian connectors, which proved to be a very critical part of the design. A video camera was used to record engine instruments during ground runs in the engine start procedure.

All flight test data were recorded on a solid state data recorder and were processed directly after the flight in the Omega data processing system to enable analysis of the data before the next day. The Omega system contains all the calibration data of the individual parameters and calculates the engineering units from the raw recorder data. The block diagram of the GIS is shown in Figure 3, and the system as installed in the helicopter is shown in Figure 4. The parameter list can be found in Table .1. The instrumentation design concluded with a safety analysis report, showing that the instrumentation design has a high degree of reliability and damage tolerance and that it has provisions to protect the helicopter signals in the event of a failure.
A ground station was located at the PAO base at Iksan. It consisted of a KARI portable office container in which the NLR ground station was installed. The NLR ground station is based on a WYLE Omega processing system in a sewer—client network environment. The sewer is operated by the instrumentation engineer, and processes and distributes all available data from helicopter and ground instrumentation. The Omega system contains all the calibration data of the individual parameters and calculates the engineering units from the raw recorder data. The system design allows for quick configuration changes for different test programs. A shared hard-disk unit is used for securely archiving the acquired data. The specialists were provided...
with client laptop computers, enabling them to analyze the distributed data on- or offline as necessary. The network is completed with a network printer.

Weather data were gathered with a mobile meteorology (meteo) system, consisting of temperature, pressure, humidity, wind speed, and direction sensors. These transducers are mounted on a transportable 10 meter high meteo mast. The system can be powered by a car. The data are logged onto a PC. The meteo system was used during several hover trials at the FAO base at Iksan and the low speed trials at Jeonju airbase.
Table 1: Parameter list

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<td>Pitch Attitude_FDR</td>
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4 **Installation and calibration activities**

The flight test campaign in the summer of 2007 started with the installation and calibration of the instrumentation system. Because most of the design work was performed in the Netherlands, some minor adjustments had to be made in Korea to the mechanical interface. After the instrumentation installation, the parameter calibration began. As far as possible, parameters were calibrated on the ground. For example: the fuel gauge was calibrated through a weight and balance procedure at several fuel weights; the airspeed and pressure altitude were calibrated with a pitot-static test set, and the flight control rigging was checked through a ground test with hydraulic power. Other parameters, like the engine temperatures, gas generator speeds, and rotor speed, were calibrated during a ground run. The engine pressure parameters (substitute for engine torque) could only be calibrated in flight.

After the first ground runs for a general instrumentation check and electromagnetic interference and electromagnetic compatibility test, a first test flight took place for instrumentation check and final calibration. Several runs were included to determine the error in the pitot-static system. The activities just described were performed in a 2-week period, ending on July 31, 2007.

5 **Data processing and analysis**

Data from the instrumentation system are processed directly after flight and, after calibration in the Omega data processing station, converted to Matlab data files. Several tools have been developed for quick post-processing and analysis of the flight test results.

- A Matlab-based graphical user interface (Figure 5) for fast presentation of flight test data. This tool can represent both steady state data (average values and standard deviations) as well as time history data (parameters as a function of time). The appropriate parameters are displayed, depending on the type of test. Additional parameters can easily be added manually. A provision has been made to show AC120-63 tolerances.

Figure 5 shows data for an approach and landing. Shown are, in the left column of graphs, from top to bottom: airspeed, radio altitude, lateral stick position, pedal position, roll angle, engine 1 power. In the right column of graphs, from top to bottom: pressure altitude, collective stick position, longitudinal stick position, pitch angle, true heading and finally main rotor RPM.
A Matlab—based graphical user interface (Figure 6) for the selection of steady state (trim) data. From time history data, selections can be made manually, automatically showing the average value and standard deviation. Figure 6 shows indicated airspeed in the top graph, and pitch attitude in the lower graph. The two grey bands are manually selected areas. The red dot and lines indicate the average value and standard deviation. The result from this selection would be two test points, with flight parameters like pitch attitude as a function of airspeed.
Flight test replay tool: HeliX is a three-dimensional representation of flight path and helicopter motion (Figure 7) from either an outside view or a cockpit view with head-up display, including stick positions, enabling the replay of test data. This was found to be a highly valued aid in postflight data analysis.

6 Flight Test plan

The KARI flight test engineer was responsible for the onboard flight test management, briefing, and debriefing, while NLR engineers were responsible for test planning, data processing, and analysis. FAO pilots and mechanics were in charge of safety for the flight and instrumentation. In preparation for the flight test campaign, the test plan was drafted as well as a flight test execution guide. The test plan described in detail which configuration and maneuvers were planned, while the flight test execution guide provided guidelines to the pilots on how to perform the maneuvers. Because of FAO operational limitations, no autorotation or (simulated) single engine flights could be performed. Also, no torque measurement was available. Due to the KA32's design philosophy it has no torque indicators in the cockpit. The gearbox is designed to absorb all engine power at all times, also with one engine inoperative. Therefore, a torque indication is not required. To provide the pilot with a measure of engine power, 'Engine Pressure Ratio', is displayed instead of torque. This is a measure of engine power, but cannot be converted to horse power directly.

Sideslip angle has not been measured, due to limitations on flight test instrumentation by the operator. This makes judging the initial condition for cruise flight difficult. For dynamic tests with a tolerance for sideslip angle it was decided to replace it by rate of yaw, with a tolerance of 2°/s (similar to the directional step inputs in cruise).
The majority of the test plan consisted of AC120-63 validation tests (see ref. 1). Additional tests were included in the test plan for validation outside the AC120-63 requirements, like accel-decel maneuvers and hover turns. These maneuvers were based on ref. 3. Other tests, like autopilot and engine performance checks, were performed to provide additional data for the simulation model. A total of 143 test cards were prepared, distributed as follows:

- 14% ground,
- 19% hover,
- 8% low speed,
- 5% climb & descent,
- 54% cruise.

The test plan was summarized in an Excel sheet (Figure 8), which was the main flight test planning tool. It provides a quick overview of progress and includes test priority and pass/fail indication. Also, from this sheet, test cards are generated automatically, including a short description on how to perform the test, required configuration for the test, and room for remarks by the flight test engineer (Figure 9)

![Figure 8: Excel sheet for flight test planning](image-url)
7 Flight Test Execution

After a 2-week instrumentation installation period, the test campaign started at the Iksan airbase of the forest Aviation Office on August 1, 2007. Nearly 5 weeks of flight tests followed. The flight tests were performed in a daily schedule of up to two flights a day. After acquiring the actual meteo information, the test tart Is were selected for each flight based on weather conditions; progress of the test program based on analyzed test results; and an efficient combination of maneuvers with respect to helicopter mass, required altitude and airspeed, pilot’s workload, etc.

The test program consisted of the sequence of the selected test cards. The resulting program was briefed to the KARI flight test engineer by NLR in English. Subsequently, the helicopter crew
was briefed by the flight test engineer in Korean. Next, the test crew executed the test flight. During the test flight, previously acquired data were analyzed by NLR on the ground. The main objective of the analysis was approval or rejection of the data as a source for tuning. The approval of data defined the status and progress of the test program. After landing, the acquired data were processed by the NLR instrumentation engineer while the other NLR engineers were debriefed by the KARI flight test engineer.

**Low speed flight tests**

Because the FAO base at Iksan has only a helicopter platform, the low-speed flight tests requiring a runway were performed at the Jeonju Air Force Base, which is only 4.5 nautical miles from the FAQ base. For these tests a mobile meteo team deployed to Jeonju air force base to set up the 10-m wind measuring mast just outside the base perimeter for security reasons, in close proximity of the runway (Figure 10). This team operated from a car with a power supply, laptop, and data acquisition system connected to the measuring mast.

*Figure 10: Installation site of meteo mast at Jeonju air force base*
8 Flight test results

In the period from August 1 to 31, 2007, the flight trials at the Iksan airbase of the Forest Aviation Office yielded the following results:

- A total of about 30 hours of flight time has been performed in 22 flights;
- A distinction was made between “performed” tests and “approved” tests: A test was performed once it has been executed during a flight. Only when the data of the test show that the test has been executed satisfactorily and provides sufficient data for model tuning, were the data approved;
- Of the test program, 99% was executed. Of the planned tests, only the engine start and shutdown at altitude was not performed (low priority).

The Matlab-based analysis tools, described earlier were used to analyze the acquired test data. The analysis consisted of verifications of data quality; steady initial conditions; and steady data,
i.e., correctly performed maneuver; the analysis also verified that control inputs applied conformed to the definition required for tuning.

In Figure 11 an example is given of a graphical presentation of a takeoff. To save space on the screen, we list only the acronyms without engineering units on the vertical axes.

## 9 Application of the Flight Test results

During the flight test phase as described in the previous section, the goal was to gather data for flight mechanics model improvement and data for the comparison between model and flight test (qualification test guide). This section presents a brief discussion of how the flight test data were used within the project. The complete results of model development and subsequent tuning process are presented in van der Vorst et al. (2009).

Before starting the tuning phase, the flight mechanics model was updated with data measured during the flight test phase. This included airspeed calibration, flight control rigging, engine performance data, and autopilot performance (gains and limits). The tuning process consisted of an iterative loop. Together with postprocessing the flight test data, an appropriate selection of the flight test data was made, for example, selection of the most successful control inputs or best steady data.

These data were input for the creation of scripts that enabled automatic simulation of all test points. The subsequent data analysis led to changes in the model, or changes in data selection, after which another iteration was performed. An example of the result of the tuning phase is shown in Figure 12, the all-engines takeoff. The green and blue lines present the simulation and flight test results, respectively, and the shaded area indicates the tolerance defined in the simulator qualification requirements (FAA, 1994).

During the tuning phase a number of challenges were encountered because of limitations in instrumentation and allowable flight test maneuvers (no single engine or autorotation), lack of wind tunnel data (only computational fluid dynamics), etc. Despite these limitations a very good result was achieved, providing a simulation model that has a high (Level C) fidelity in representing the KA32T and an almost 100% fit to the flight test data.
Figure 12: Comparison between model and flight test data for the take-off maneuver.
10 Conclusions

A very successful flight test campaign was executed from August 1 to 31, 2007 at the Iksan airbase of the Forest Aviation Office in Korea. The installation and calibration of the instrumentation was accomplished within 2 weeks. A total of about 30 hours of flight time was performed in 22 flights. The efficient and flexible setup of the NLR flight testing tools enabled a small test team to quickly analyze the acquired data on-site, resulting in efficient monitoring of the program progress and flexible adaptation of the test program to ambient weather conditions and operational constraints. The flight test campaign provided good quality data for the AC120-63 tuning process, thanks to good cooperation between Korean and Dutch engineers and the Korean helicopter operator.
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HANS BRUGMAN was born August 15, 1956. After obtaining his bachelor degree, he joined NLR in 1980. Since then he has contributed to the development and operation of many flight test instrumentation systems for Fokker aircraft, Royal Netherlands Air Force aircraft, and self-steering parafoils reconnaissance systems. He is also experienced in video techniques, human factors measuring instrumentation, and telemetry systems. E-mail: brugman@nlr.nl

JOOST HAKKAART graduated in 1992 from Delft University of Technology and joined the Dutch National Aerospace Laboratory, NLR, as project manager at the low speed wind tunnel, especially for helicopter development testing. He changed to the Helicopter Department for helicopter testing in general. In 1999 he became the head of Wind Tunnel Projects for the NLR/DNW wind tunnels in Amsterdam. After 5 years, he changed again to the Helicopter and Aeroacoustics department in the position of principal project manager. Currently, he is supervising major (tilt) rotorcraft projects, including flight testing and wind tunnel testing. E-mail: hakkaart@nlr.nl

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