



Executive summary

Kamov KA32T Helicopter Flight Testing for Training Simulator Development



Problem area

In 2007, flight trials were performed with a Kamov KA32T helicopter of the Korean Forest Aviation Office (FAO). These trials were part of the KA-32 Helicopter Training Simulator Development Program, managed by the Korea Aerospace Research Institute (KARI).

Description of work

Within this program, the Netherlands' National Aerospace Laboratory (NLR) developed the flight model and executed the flight tests in close co-operation with KARI and the helicopter operator. In this paper, a description is given of the instrumentation system, of the dedicated tools for preparation

and monitoring the test program, generating test cards and for quick post-processing and analysis of the flight test results.

Results and conclusions

A very successful flight test campaign has been executed from 1 to 31 August 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 22 flights have been performed, in about 30 hours of flight time, providing good quality data for the AC120-63 tuning process, thanks to good cooperation between Korean and Dutch engineers and the Korean helicopter operator.

Report no.

NLR-TP-2009-544

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Report classification

UNCLASSIFIED

Date

October 2010

Knowledge area(s)

Helikoptertechnologie

Descriptor(s)

Helicopters, Simulation, Flight tests



NLR-TP-2009-544

Kamov KA32T Helicopter Flight Testing for Training Simulator Development

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This report is based on a presentation held at the American Helicopter Society 65th Annual Forum, Grapevine (TX), U.S.A., 27-29 May, 2009.

The contents of this report may be cited on condition that full credit is given to NLR and the authors.

This publication has been refereed by the Advisory Committee AEROSPACE VEHICLES.

Customer NLR
Contract number ----
Owner NLR
Division NLR Aerospace Vehicles
Distribution Unlimited
Classification of title Unclassified
October 2010
Approved by:

Author 	Reviewer 	Managing department 
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Summary

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A very successful flight test campaign has been executed from 1 to 31 August 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 22 flights have been performed, in about 30 hours of flight time.

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1 Project background

The objective of the KA-32 Helicopter Training Simulator Development Program is to acquire a helicopter simulator which meets level C requirements in accordance with the 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, an 11-tonne twin engine helicopter with a co-axial rotor system (see Figure 1), operated by the Korean Forest Aviation Office (FAO), mainly for the fighting of 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, due to its experience with flight simulation development and flight testing for a competitive price.

The result is 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 paper presents the preparations and execution of the flight test program, and discusses some of its results.



Figure 1: The Kamov KA32T test helicopter

2 Helicopter configuration

The Kamov KA32T is an 11-tonne twin engine helicopter with a co-axial rotor system (see Figure 1). It is operated by the Korean Forest Aviation Office, mainly for the fighting of forest fires.

All flights have been performed with a crew of 2 pilots and 1 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 without a 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 the 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. Since the water tank limits the maximum speed to 150 km/h, as opposed to the normal maximum speed of 230 km/h, it has been decided to perform the flight tests without the water tank to enable testing in a larger speed envelope.

Both engine inlets are equipped with a “Dust Protection Device” and an Anti-Icing System.

It has been decided by KARI to vary the helicopter weight with fuel quantity only. Since the external fuel tanks are not available at FAO, only the internal tanks were used. Using this configuration, weights between about 7300 and 8700 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
- 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/attitude hold. During many of the flight tests the autopilot had to be on. However, some tests specified in the simulator qualification requirements (ref. 1) require maneuvers to be performed without autopilot. The required configuration (autopilot on or off) was indicated on the test cards. 'Autopilot' was referring 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 analogue signals, discrete signals, digital signals, synchro signals and manual data entry (i.e. 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 reasons and safety the system had to be 'non-intrusive'. 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 Flight Data Recorder remained in operation. A second major part in the instrumentation system was a dedicated test Inertial Reference System (IRS), providing ring laser based attitudes, rates and accelerations.

To complement the parameters from the FDR and the NLR IRS, several additional sensors have been installed:

- On the landing light bracket a probe for outside air temperature has been installed.
- To satisfy concerns about flight safety, non-intrusive optical (laser) sensors have been used for longitudinal and lateral cyclic position, with reflectors installed on the longitudinal and lateral push-pull rods below the cockpit floor (see Figure 2):



Figure 2: Non-intrusive laser sensor (on orange bracket) and reflector (on yellow push-pull rod) below cockpit floor to measure stick position

- To measure engine temperature, a break-out connector was installed in the signal from the engine thermocouples. Because it was not possible to measure the cold junction temperature, the measurement will vary with cold junction temperature. This deficiency has been 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 shut down.
- The engine pressure ratio, an indication of engine power, has been measured by installing a breakout connector in the signal to the cockpit instrument.

In order to create the breakout connectors for Flight Data Recorder, engine pressure and temperature, several Russian connectors had to be purchased, 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 was recorded on a Solid State data recorder, and was processed direct 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 Generic Instrumentation System is shown in Figure 3, the system as installed in the helicopter is shown in Figure 4. The parameter list can be found in Table 1. The instrumentation design was 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.

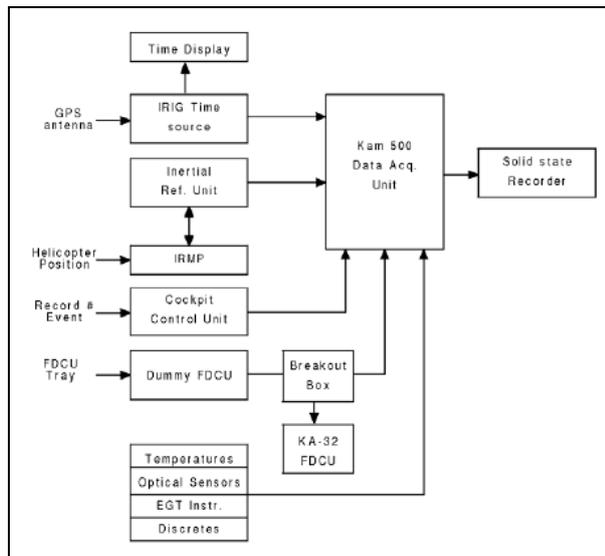


Figure 3: Generic Instrumentation System block diagram



Figure 4: The ring laser gyro and measurement system in the KA32T

Instrumentation systems on ground

A ground station was located at the FAO 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 server-client network environment. The server 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 programmes. A shared hard disk unit is used for securely archiving the acquired data. The specialists were provided with client laptop computers, enabling them to analyse the distributed data on- or offline as necessary. The network is completed with a network printer.

Weather data was gathered with a mobile 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 is 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 (see Figure 10).

4 Installation and calibration activities

The flight test campaign in the summer of 2007 was started with the installation and calibration of the instrumentation system. Because most of the design 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 was started. 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 were calibrated during a ground run, like the engine temperatures, gas generator speeds and rotor speed. 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 EMI/EMC test, a first test flight took place for instrumentation check and final calibration. Several runs have been included to determine the error in the pitot-static system.

The activities described above were performed in a 2-week period, ending on 31st of July 2007.

5 Data processing and analysis

Data from the instrumentation system is 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 (see 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.

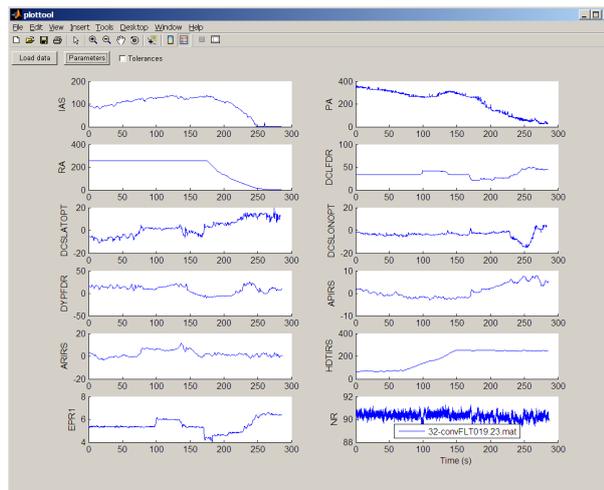


Figure 5: Flight test data plotting tool

- A Matlab[®]-based graphical user-interface (see 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.

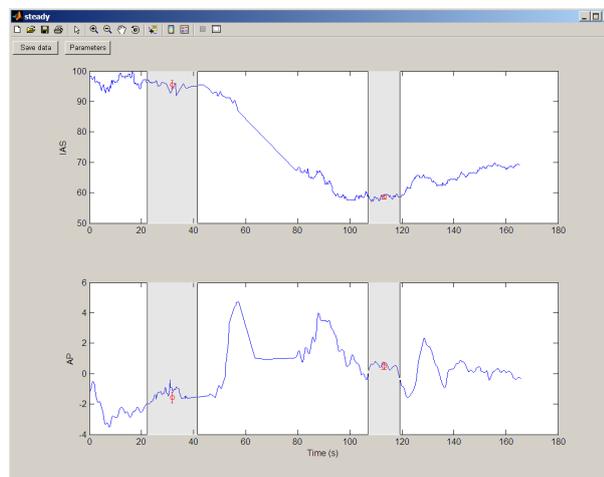


Figure 6: Steady state data selection tool

- Flight test replay tool: HeliX is a 3-D representation of flight path and helicopter motion (see Figure 7, both from 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 the post-flight data analysis.

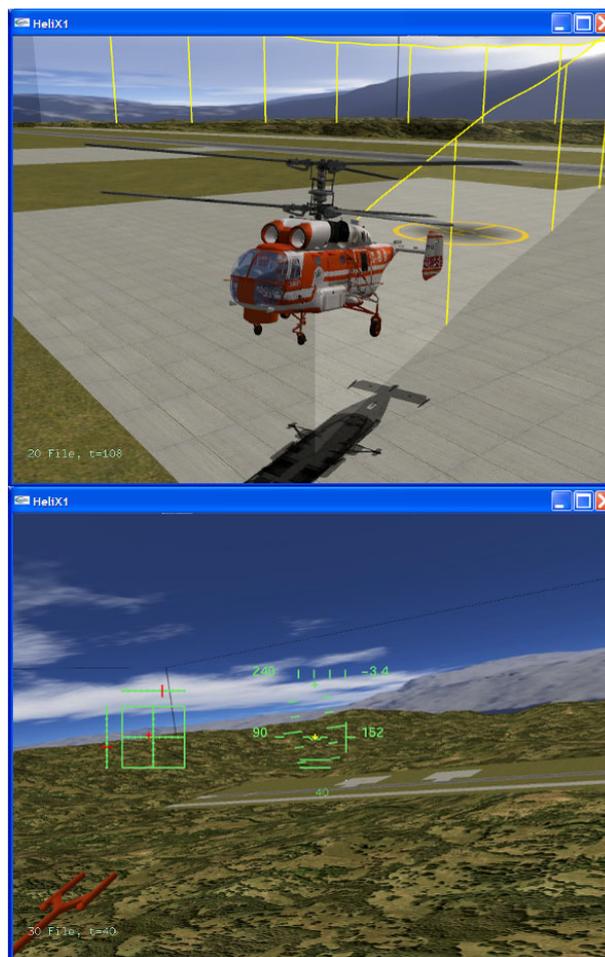


Figure 7: HeliX flight test replay tool

6 Flight test plan

The KARI flight test engineer was responsible for the onboard flight test managing, briefing and debriefing, while NLR engineers were responsible for the test planning, data processing and analysis. FAO pilots and mechanics were in charge of the safety for the flight and instrumentation.

In preparation of 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. Due to 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. 2). 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

Figure 8: Excel sheet for flight test planning



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 of the flight test engineer (see Figure 9).

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 1 August 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 cards were selected for each flight, based on:

- Weather conditions
- Progress of the test program based on analyzed test results
- An efficient combination of maneuvers with respect to helicopter mass, required altitude and airspeed, pilot's workload etc.

21	Level flight performance	KARI - KA-32 Flight Tests FP 619																										
<table border="1"> <thead> <tr> <th colspan="2">Configuration</th> </tr> </thead> <tbody> <tr> <td>Autopilot</td> <td>OFF</td> </tr> <tr> <td>AIS</td> <td>OFF</td> </tr> <tr> <td>DPD</td> <td>OFF</td> </tr> <tr> <td>FE</td> <td>seat 15</td> </tr> <tr> <td>Fuel</td> <td>1800 to 2200 l</td> </tr> </tbody> </table>		Configuration		Autopilot	OFF	AIS	OFF	DPD	OFF	FE	seat 15	Fuel	1800 to 2200 l	<table border="1"> <thead> <tr> <th colspan="2">Condition</th> </tr> </thead> <tbody> <tr> <td>Date</td> <td>20070525</td> </tr> <tr> <td>Time</td> <td></td> </tr> <tr> <td>Flight condition</td> <td>cruise</td> </tr> <tr> <td>Target altitude</td> <td>500 m</td> </tr> <tr> <td>Initial IAS</td> <td>80 km/h</td> </tr> <tr> <td>Wind</td> <td></td> </tr> </tbody> </table>	Condition		Date	20070525	Time		Flight condition	cruise	Target altitude	500 m	Initial IAS	80 km/h	Wind	
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Figure 9: Example of a test card

The test program of the flight consisted of the sequence of the selected test cards. The resulting test 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 flights were executed by the helicopter test crew. During the test flight, previously acquired data was 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 was processed by the NLR instrumentation engineer while the other NLR engineers were debriefed by the KARI flight test engineer.

Low speed flight tests

Since 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 FAO 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 (see Figure 10). This team operated from a car with 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 1 to 31 August 2007, the flight trials at the Iksan airbase of the Forest Aviation Office yielded the following results:

- A total of 22 flights have been performed, in about 30 hours of flight time.
- 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 shows



that it has been executed satisfactorily and provides sufficient data for model tuning, it was approved.

- 99% of the test program has been executed. Of the planned tests only the engine start/shutdown at altitude was not performed (low priority).

With the Matlab[®]-based analysis tools, described earlier, the acquired test data was analyzed. The analysis consisted of verifications of:

- data quality
- steady initial conditions
- steady data i.e. correct performed maneuver
- control inputs applied conform the definition required for tuning.

In Figure 11 an example is given of a graphical presentation of a take-off. To save space on the screen, only the acronyms without engineering units are listed at the vertical axes. Presented in Figure 11 are:

IAS: Indicated airspeed (km/h)

RA: Radio altitude (m)

PA: Barometric altitude (m)

EPR1: Engine Pressure Ratio 1 (-)

EPR2: Engine Pressure Ratio 2 (-)

NR: Rotor speed (%)

APIRS: Pitch angle (deg)

ARIRS: Roll angle (deg)

HDTIRS: Heading (deg)

DCSLONOPT: Longitudinal cyclic stick pos. (%)

DCSLATOPT: Lateral cyclic stick pos. (%)

DYPFDR: Pedal position (%)

DCLFDR: Collective stick position (%)

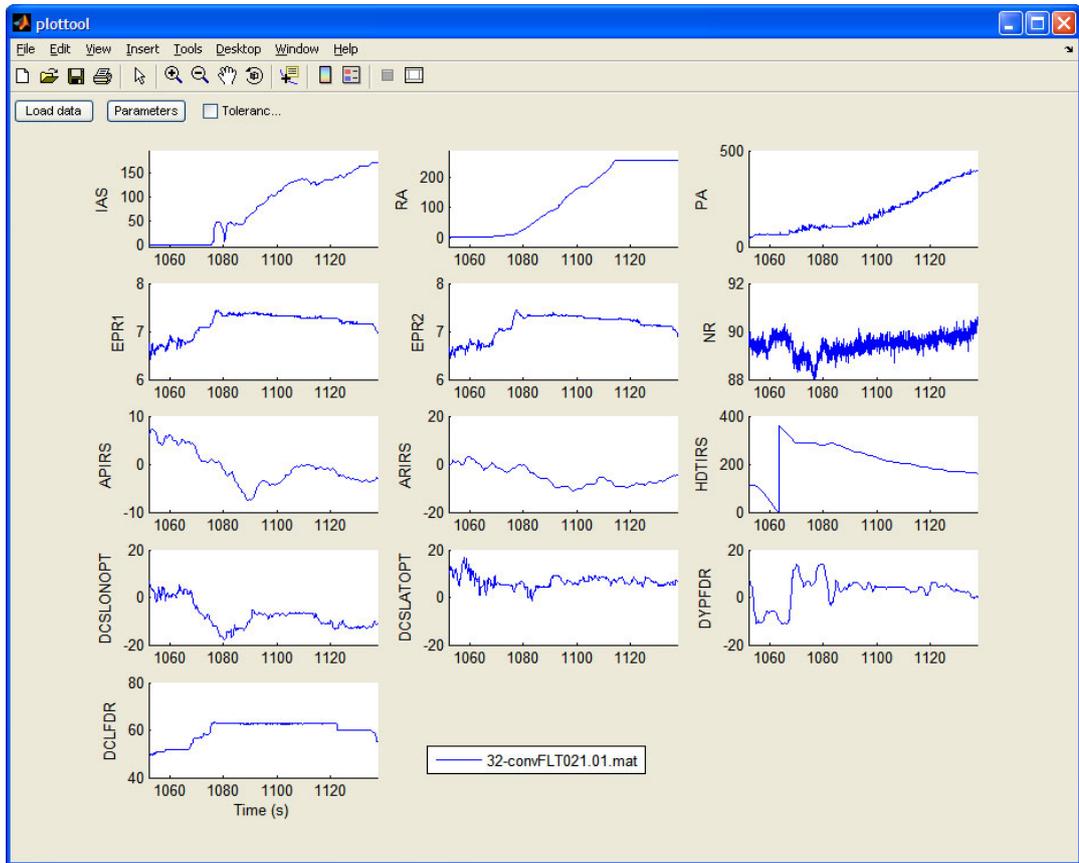


Figure 11: Example of parameter plots used during analysis of the acquired test data

Despite the limitations in instrumentation and allowable flight test maneuvers (no single engine or autorotation), sufficient data has been gathered to follow the full Level-C qualification process (model development, flight test, tuning based on the flight test data).

9 Conclusions

A very successful flight test campaign has been executed from 1 to 31 August 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 22 flights have been performed, in about 30 hours of flight time.

The efficient and flexible set-up 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 a good co-operation between Korean and Dutch engineers and the Korean helicopter operator.

Table 1: Parameter list

ATA	Description
General	
0 Eve	nt Marker
0 R	ecord number
0 C	old Junction Temperature
	Calibration Tool Arms & legs
0 Tim	e
Air Data	
1 Indicated	Airspeed
1	Outside Air Temp at heli
1 Altitu	de (baralt)
1	Altitude (radalt); upto 300 m
Meteo	
15 W	ind Direction
15	Wind Speed
15	Air Pressure Groundstation
15 OAT	Groundstation
Flight Controls	
27	Cyclic Lateral Position_FDR
27	Cyclic Longitudinal Position_FDR
27 Co	llective Position
27	Cyclic Lateral Position NLR



ATA	Description
27	Cyclic Longitudinal Position_FDR
27 Co	llective Position
27	Cyclic Lateral Position_NLR
27	Cyclic Longitudinal Position_NLR
27 Differen	tial Pitch
Ped	al Position
Co	llective Pitch
	Trim button on pilot Cyclic Stick
Landing Gear	
32 Wei	ght-on-wheel signal
Navigation	
34 Lateral	Acceleration
34 Longitudinal	Acceleration
34 Pitch	Attitude_FDR
34 Ro	ll Attitude_FDR
34 Norm	al Acceleration
34 Headi	ng_FDR
34	Lateral Velocity Doppler
34 Lo	ngitudinal Velocity Doppler
34	Vertical Velocity Doppler
34-28 Pi	tch Angle
34-28	Roll Angle
34-28	Ground Track True
34-28	Body Longitudinal Accel.
34-28 Body	Lateral Accel.
34-28 Body	Normal Accel.
34-28	Vertical Acceleration
34-28 Gr	ound Speed
34-28 M	agnetic Heading
34-28 True	Heading
34-28	Present Position Latitude
34-28	Present Position Longitude
34-28	Body Pitch Rate
34-28	Body Roll Rate
34-28	Body Yaw Rate
34-28	Velocity N S IRS



ATA	Description
34-28	Velocity E W IRS
Engine	
72	Engine Pressure Ratio 1
72	Engine Pressure Ratio 2
72	Gas Generator Speed Engine 1
72	Gas Generator Speed Engine 2
72 R	otor Speed
72 To	tal fuel quantity
72	Separate Throttle Control Lever position
72	Turbine Gas Temperature Engine 1
72	Turbine Gas Temperature Engine 2

References

- 1) Federal Aviation Administration Advisory Circular, "Helicopter Simulator Qualification," FAA AC 120-63, October 1994.
- 2) Longo, "Data Standards For Helicopter Simulators Using A Blade Element Rotor Model", AIAA-95-3423-CP, American Institute of Aeronautics and Astronautics, 1995.

