SAFETY, QUALITY AND EFFICIENCY IN FLIGHT DATA GATHERING

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Abstract
Safety, quality and efficiency are basic requirements on flight data gathering campaigns. The challenges of meeting all three of them in flight test campaigns planned for the purpose of simulator development are the main subject of the present paper. Specific processes for preparation and conduction of flight test campaigns are discussed according to the challenges of campaigns for simulation compared to those for aircraft certification. A newly developed flight test instrumentation that can be easily adapted for integration in a wide range of helicopter types and fixed-wing aircraft is described. The use of the flight test instrumentation and defined processes lead to convincing results with high safety standards. Thus, the flight test team optimises the process flow allowing the best possible result in terms of quality and completeness of the collected data, with acceptable investment costs for chartering the helicopters. During the data acquisition campaign, the Netherlands Aerospace Centre NLR carried out a substantiation of the data acquisition process through an independent assessment. The goal of this substantiation is to evaluate whether the data acquisition process is capable of delivering accurate data of good quality and is representative of the helicopter type to be modelled.

ABBREVIATIONS

CS	Certification Standard
DOF	Direction of Flight
EASA	European Aviation Safety Agency
FAA	Federal Aviation Administration
FFS	Full Flight Simulator
FSTD	Flight Simulation Training Device
FTC	Flight Test Cards
FTE	Flight Test Engineer
FTI	Flight Test Instrumentation
FTP	Flight Test Plan
ICAO	International Civil Aviation Organisation
NLR	Netherlands Aerospace Centre
NR	Rotor Speed
OEM	Original Equipment Manufacturer
QTG	Qualification Test Guide
ST	Simulation and Training
SIMD	Specifications for Simulator Data

1. INTRODUCTION

For the development and qualification of simulators, data acquisition on the ground and in flight is required. Simulator certification standards from EASA [1], FAA [4] and ICAO [3] contain detailed requirements on how to qualify a FSTD. From those, requirements on the flight data can be derived. In addition, the EASA evaluates the suitability of gathered data for the qualification of a simulator based on the Certification Specifications for Simulator Data (CS-SIMD), which is a new regulation applicable to air vehicles certified after 2014 [2]. Common practice in simulation industry is the procurement of data models from the OEM of the air vehicle. Reiser Simulation and Training (Reiser ST) decided to perform the data acquisition themselves. The processes leading to a positive result in flight data gathering are described below.

2. FLIGHT TEST INSTRUMENTATION

The most demanding topics in the context of flight test instrumentation are quality and safety. The quality is highly influenced by the selection of sensors and the system architecture, while safety is the most important topic in the context of mechanical installations. The following subchapters contain a description of the flight test instrumentation.

2.1. FTI Components

The Flight Test Instrumentation (FTI) has a modular CAN-based system architecture that can be easily adapted to different aircraft types and purposes of flight test. The components for flight data gathering for helicopter simulation purpose are the following:

1. Video recording
2. Sound recording
3. Vibration recording

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4. Inertial measurement unit
5. Control deflection measurements
6. Independent air data

Figure 1 shows an example of a basic system architecture of the flight test instrumentation and Figure 2 is a picture of the installation of the core unit inside the cabin.

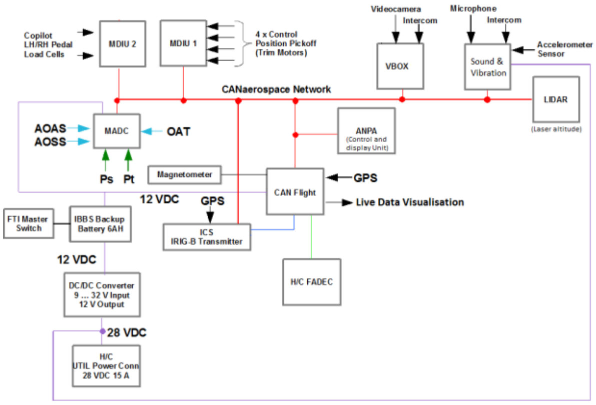

Figure 1 FTI System Architecture

Figure 2 FTI Core Unit and ballast in a helicopter

2.2. FTI Installation

The installation of sensors and recording units aims to be secure and as little invasive as possible. For fully certified aircrafts, a Part 21 organisation issues a permit to fly for test flights with the installed equipment. Typically, only temporarily installed equipment and no minor change characterises the design guideline. This implies that the installations do not leave any traces after their removal. Instead of drilling holes into the aircraft structure to install single components of the FTI, the following options are available:

1. Replace the original structure. i.e. replace a single cover with a new one including the required - permanent - modifications. See Figure 3 and Figure 4 for an example.

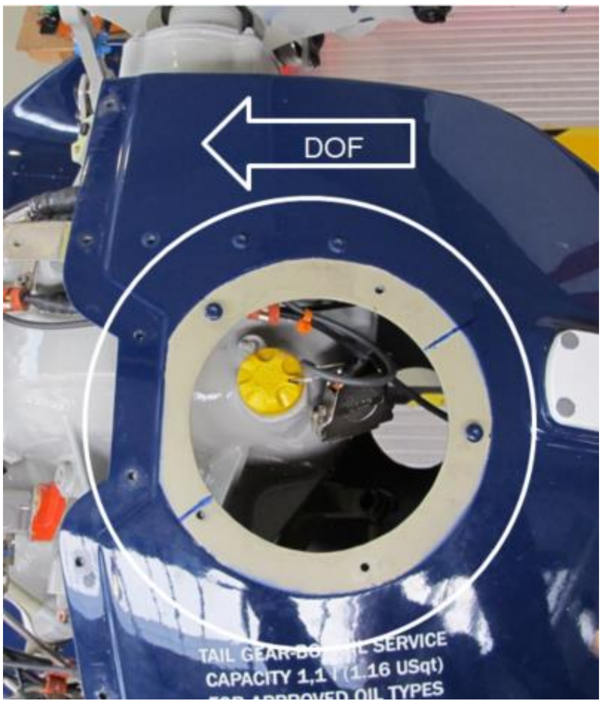

Figure 3 Tail Cover Position on a AW169

Figure 4 Replacing Tail Cover with installed FTI-unit and drill holes as permanent change.

2. Use original fixing points and replace bolts by longer ones to add the item. See Figure 5 for an example of the installation of a laser sensor in the trim motor bay.

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Figure 5 Original bolts replaced by longer bolts for the purpose of installation of a laser sensor

3. Use existing store and fixation opportunities designed for flexible use like seat rails or the baggage compartment. Figure 7 and Figure 6 explain the principle of the installation of parts on seat rails.

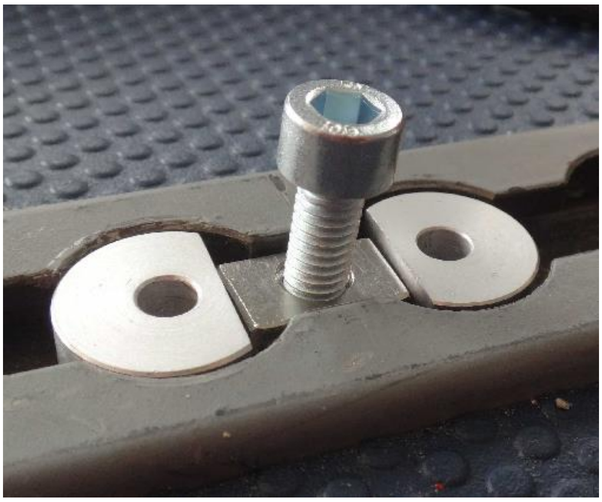

Figure 6 Seat rail mounting device

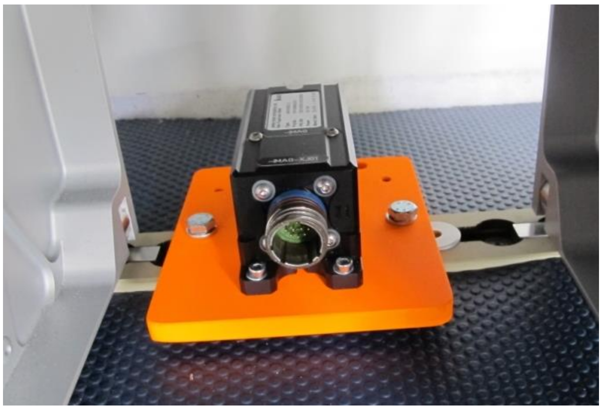

Figure 7 Magnetometer installation on seat rails

The pilots have to be comfortable with all installations. Especially cockpit installations are a possible point of discussion as they are most likely to disturb the pilot or lead to hazardous situations. Cameras that are installed to record avionic systems need to allow the pilot and co-pilot free view on them. A typical installation example of cameras at the glare shield is shown in Figure 8.

Figure 8 Camera installation at the glare shield

2.3. FTI Approval

After the agreement of operator and pilot regarding the planned installations, usually a Part 21 organisation and a Part 145 organisation are involved in the approval process. With positive evaluation, Part 21 issues a Permit to Fly for the duration of the flight test campaign.

3. INTERACTION BETWEEN PILOT AND TEST ENGINEER

The workshare between the pilot and the test engineer includes the communication before, during and after the flight as well as teamwork

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during the flight. Prior to a flight, all parties are briefed on the planned program for the upcoming tests. Nevertheless, typically the test engineer is the lead of the program, which might be different in other organisations. In the following, the normal workshare, the way of communication and the work with so-called “control fixtures” are described as the most critical example in terms of safety in pilot-engineer coordination.

3.1. Workshare and communication between test engineer and pilot during flight

During the flight, at least one test engineer is on board to announce upcoming test points to the pilot and to fill in flight test cards. A second engineer might monitor the data in real-time in order to provide direct and constructive feedback on flown manoeuvres. For proper test crew coordination, it is very important to agree on a standardized communication between all people on board. For performance tests, the engineer would announce a test in detail i.e. “Next test point is a level flight at 80 kt in 1000 ft. Air condition and all unnecessary consumers off”.
The pilot would repeat and confirm similar to a checklist procedure:
“Level flight at 80 kt in 1000 ft. Air condition off”.
At the time the pilot achieves the desired flight state, the pilot would announce this by saying “on condition” as information.
The end of a test can be announced by a test engineer “test complete” or by anybody on board by “recover” when a possibly hazardous situation like traffic in sight occurs.
The exact wording is adapted according to normal operations procedures the crew is used to. Thus, the pilot does not focus unnecessarily on specific formulations that are different from his normal communication procedures.

3.2. Communication with pilots

According to different studies, human factors are the most often cause of accidents in aviation [5]. A critical example is a NASA statistic concerning incorrect or incomplete communication between the flight crew and controllers as a direct or circumstantial factor in 80 % of all accidents [6].
Communication between the test engineers and pilots is usually on board communication except when telemetry is used. Misunderstandings are less likely when both communication partners are participating in the flight. Nevertheless, these statistics are a warning and a call for action. As a consequence, communication within the crew has to be adapted to the specific team and should be critically scrutinised to avoid misunderstandings.

Especially when flying with commercial pilots, care has to be taken on how to communicate during the flight test campaign. Usually, it is a flight test engineer who plans the test flights. This workshare hosts the risk that the pilot is not asked for his feedback. Actively involving the pilot in planning leads to improvements in term of safety.

One example is the question for the amount of fuel and desired take-off weight during a test that shows rearwards-flight at low altitude along the runway. The question to the pilot could either be “Can we fully refuel for the next flight?” or “With how much fuel would you like to fly the upcoming tests?”. Even if the pilot has with the first question the chance to regard the request for full fuel, he will most likely not do so. Using the second version of the same question the pilot is forced to think about the amount of fuel he is comfortable with.

Another example would be the very frequent question about the Take-off time for the next flight: “Can we go flying again within one hour?” against “When would you like to do the next flight?”.

The planning role of a flight test engineer has the advantage that the pilot is relieved from this work, but care has to be taken in order not to ask suggestive questions. Active revising of the formulation of questions that address the pilot and other team members improves a comfortable feeling of the flight test crew, avoids errors and leads to safer operation.

3.3. Defined control inputs

The use of control fixtures for defined inputs with its challenges is the topic of the upcoming paragraphs.

3.3.1. Principle of control fixtures

To realize defined, repeatable and high-quality control inputs for determination of handling qualities, the so-called “control fixtures” can be used. They can be used by a co-pilot or test engineer on a co-pilots seat for cockpits with dual controls.
The co-pilot holds a mechanical limiter against the controls when the pilot is applying an input.
Figure 9 illustrates an example of the position of the control fixture ready for a cyclic control input to the right. The cabin wall on the left works as mechanical stop for the fixture in that case. A rubber band indicates the initial position prior to input. An aluminium bar functions as a mechanical stop for the pilot's input, that is only active when the handbrake of the fixture is pressed with the right hand of the co-pilot (or test engineer). When the test has to be aborted for whatever reason,

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the co-pilot (or test engineer) has to release the brake as quickly as possible and get the control fixtures out of the way. Then, the pilot regains full movement of the controls.

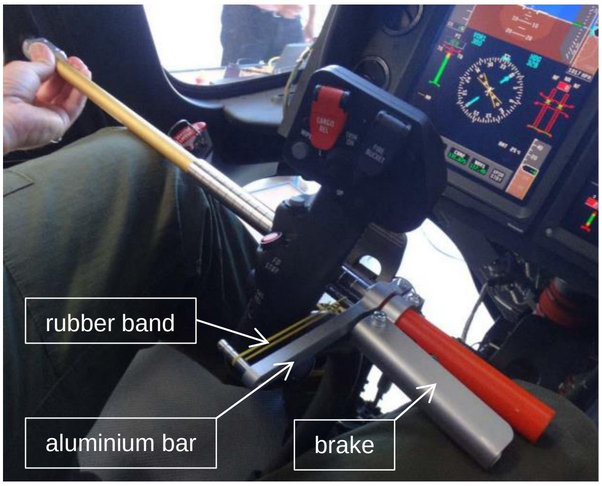

Figure 9 Control fixture in position for right cyclic input

3.3.2. Crew training control fixtures

As the control fixture severely interferes with normal controls, this interference has to be thought through and trained in detail prior to flight. A planned reaction to abort a test at any time has to be agreed upon.
The training for the pilot and co-pilot could be structured like the following:

1. Explanation of the principle on the ground at the real helicopter.
2. Training of procedures with moving controls (hydraulics on) on the ground.
3. Training of principle and procedures in a simulator.
4. Training in a flight prior to the flight that is declared to have the purpose to record the control step inputs.

The training needs to be adapted to the experience of the pilot. When working with qualified test pilots, it is more likely that they are able to estimate the effort of training they require. Commercial pilots with no experience in flight testing might need repeating loops to achieve an adequate training.

3.3.3. Communication in flights with control fixtures

With three people on board involved in control input actions, the formulation of communication between test engineers and pilot follows a defined process. The wording is agreed in detail during the training and could be as follows:

FTE: "Next test point is a hover 1 cm right cyclic step input"
Pilot: *when ready on initial condition* "On condition"
Co-Pilot: *when fixture in place* "fixture ready"
FTE: *when data stable enough for initial condition* "Ready for input right"
Pilot: "Ready right"
Co-Pilot: "Ready right"
FTE: "Input coming, 3-2-1-now"
Pilot: *giving required input up to mechanical stop*
FTE: *when satisfied with data* "Test complete"
Co-Pilot: *when fixture out of the way* "Fixture clear"

If the pilot feels to abort the test for safety reasons at any time, he shall say: "Recovery". The Co-Pilot has to release the brake and get the fixture out of the way as soon as possible.

The communication example shows that the test engineer has a leading role in communication, while the pilot has a veto and chance for interruption on every action. The control input tests have to be conducted as fast as possible to profit from stable air and to reduce the time of concentration of the pilot and co-pilot to a minimum. Therefore, only the most important phrases are confirmed by the pilot and co-pilot: "Ready right".

With a well-trained crew, the use of control fixtures becomes a reliable factor during handling quality tests that improve the data quality significantly. Results are compared in the following chapter.

4. REQUIREMENTS ON DATA

The requirements on data are drawn mainly from the simulator qualification standard and address the scope of the flight test program as well as the data quality of individual test points.

4.1. Scope of the flight test program

If a required test is not or only partially compliant with the helicopter type, alternative tests can be defined in collaboration with the responsible authority. For example, if autorotational landing is prohibited by the flight manual, a decrease of airspeed up to hover out of ground effect with adjusted power settings could be used as an option for the required QTG test case.

Modellers have the interest to get a wide range of different test points throughout the flight envelope. It is helpful to have the same test point at two distinctly different weight configurations, while all

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other parameters remain the same. Hereby little extrapolation is needed in modelling. Other tests are characterised by a challenging model development and need more variations than those requested by the standard. Hover is such an example. The EASA standard asks for a minimum of four different hover heights [1] while a physical model needs at least ten as input.

4.2. Resolution and accuracy of data

The tolerances from the standard lead to the minimum required resolution of the parameters that are recorded. Those vary with the nonlinear change that is expected for each parameter, i.e. for the heading it would be the agility of the helicopter that needs to be fully captured.

With the use of modern sensors, the resolution and accuracy are usually not a demanding topic. Quality can be an issue if data is drawn from the pilot's instruments. The purpose of sensors that provide instrument data is often significantly different from that for validation data. Rotor speed is an important indication for the pilot. He needs to be able to read a possible loss of rotor speed when it occurs in normal flight with an accuracy of about 1%. For the start-up process on the ground, the pilot only needs to know when the NR correlates to IDLE or FLIGHT setting. The modeller instead requires an exact graph of NR increase during engine start, because it is not linear as shown in Figure 10. For QTG testing of the simulator NR during engine start-up is a tested parameter with a tolerance of 3% [1].

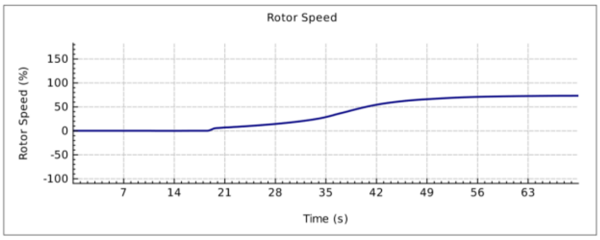

Figure 10 NR increase during engine start-up

4.3. Data quality for modelling purpose

Requirements from modellers often address the set of parameters, that is much more than what is required for single QTG tests. For engine modelling N1 and N2 need to be known for almost all performance test cases while they are not always parameters that are presented in QTG testing

Further, for some type of tests, there can be a requirement for the length or the repeatability. The example of repeatability refers to handling quality tests like control step inputs. The reaction of the helicopter needs to be proven in its repeatability as it can be influenced significantly by environmental influences. Control step inputs are extremely small for helicopters in order to stay within the safe limits and get the required five seconds of response before recovery. As an example, a longitudinal step input from a hover is given in Figure 11. While the control input is only about 6 % of total travel the pitch angle changes by 5 °/s. The rapid change in pitch angle is acceptable in this case because it is not divergent. If it would be, the test would need to be stopped already after a total difference of 15° depending on absolute angles.

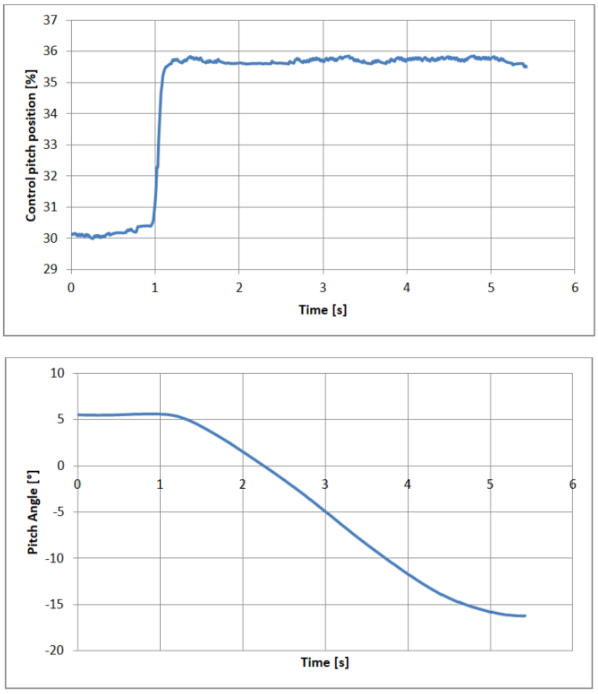

Figure 11 Longitudinal control step input in hover

The data quality improves a lot with the use of control fixtures. Their principle is described in chapter 3.3. Figure 12 compares two examples of a pitch step input. When the fixture is not used, an overshoot can be seen prior and after input. Towards the end of the test, the control position drifts slightly which is another typical error that reduces data quality. With the use of control fixtures, results with a quality that helps the modeller can be achieved much more quickly and reliably. Less cross-coupling effects in the data improve the model quality. In this case, it is the shape of the control input together with a steady flight state that approves the quality.

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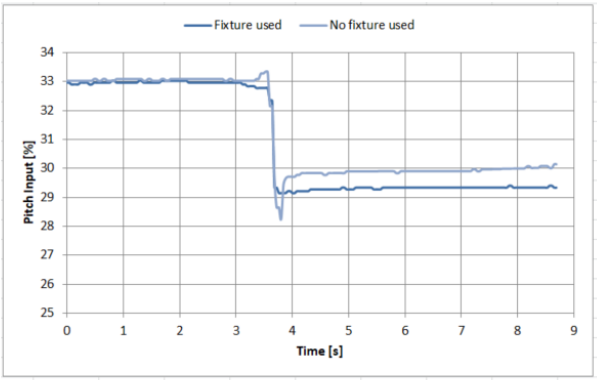

Figure 12 Control step input data quality

4.4. Data quality for validation purpose

The main source of requirements for data quality is the standard for simulator qualification by EASA [1], ICAO [3] and/or FAA [4]. The standard provides a list of Qualification Test Guide tests that have to be presented in the simulator during qualification. Specific simulator parameters have to fit the flight test results within a defined tolerance. With that information, the standard provides an implicit requirement on data quality. Environmental influence has to be reduced to a minimum. The smaller the tolerance for a parameter is, the smoother the flight data has to be.

For steady state test points as for performance tests, the goal is a sequence of at least five seconds length in undisturbed air with no or only linear change in airspeed or altitude and steady flight without the need to give corrective control inputs. Figure 13 provides an example of a heading during a steady climb. The flight data varies between 33° and 39° and the acceptable tolerance is 5°. The same tolerance is applied in flight on that parameter in order to reach an acceptable result.

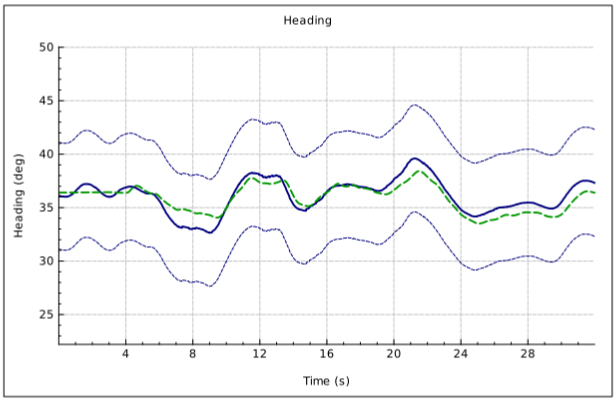

Figure 13 Heading during a steady climb (bold blue: flight data, blue dotted: tolerance, green dotted: simulator)

5. EFFICIENCY DURING FLIGHT TEST CAMPAIGN

Since the helicopter charter cost can take easily 10 % of the total project budget for the development of a full flight simulator, the pressure of saving money is not negligible. On first sight, efficient work might seem to stay in conflict with safety and quality. This should not be the understanding. Efficiency reduces workload for the entire team and supports quality by lean processes instead.

5.1. Efficiency supporting quality

Dedicated tools and processes increase efficiency and quality at the same time. Optimization is possible when setting up a database that includes information written down in flight test cards.

An approach for a process that assures quality could be the following:

- After the flight, the flight test engineer reviews the handwritten flight test cards.
- The information on the flight test cards is digitalized by manually entering the information into an electronic table that lists all test.
- A second person checks if the information is complete and reflects what is written in the flight test cards.

A different approach would be:

- Flight test cards are compiled in a standardized electronic format during flight or alternatively digitalized during review after the flight in the same standardized format.
- Tools using simple logic can import this information into a database.
- After completing, a review of the contents is done.

This approach replaces the most labour intensive step with an automatic toll-based process. Apart from saving time, other positive effects can be observed:

- The review of the database happens shortly after the debriefing of the flight and is still very present.
- Typing errors in term of numbers are avoided.
- Especially on helicopters, it can be easier to fill in flight test cards using a device like a laptop or a tablet instead of filling them in by hand.

A second example is the use of the previously described control fixtures. They increase the

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quality of the data and since it is more likely that the results are satisfactory after a few trials, the flights are also more efficient and less exhausting for the pilot.

5.2. Efficiency supporting safety

Safety is mainly improved by the reduction of workload resulting from efficient processes. A quick sense of achievement takes away the pressure on the team and has, therefore, a positive effect.

6. SUBSTANTIATION OF DATA ACQUISITION PROCESS

6.1. Background

As part of a simulator certification process, a substantiation of the data acquisition process needs to be carried out through an independent assessment. The goal of this substantiation is to establish whether the data acquisition process is capable of delivering accurate data of good quality that are representative of the helicopter type to be modelled. This not only includes the way in which data are collected during flight tests, but also the flight test instrumentation and the flight test program, reflected in the test plans and the test cards. Finally, whenever possible, some test flights will need to be witnessed on board by the independent organization.

The Netherlands Aerospace Centre (NLR) carries out the independent substantiation of the data acquisition process of Reiser ST. The substantiation work includes the following individual aspects:

- The Flight Test Plan (FTP);
- The Flight Test Cards (FTCs);
- The Flight Test Instrumentation (FTI);
- The flight testing process;
- The data handling process;
- Witnessing of several test flights (whenever possible).

Comments, mainly being aspects that need correction or clarification, are provided to Reiser ST. It is verified that the comments are satisfactorily answered and, as far as applicable, taken into account.

Further details for each of the substantiation aspects are described in the following sections.

6.2. Flight Test Plan

The FTP document outlines the tests and methodologies required for gathering the relevant helicopter data. It covers technical and organizational planning aspects, like flight test points, helicopter configuration, test locations and operating environments, etc. The FTP contains a detailed listing of all of the individual tests that are required to provide data for the development, testing and qualifying the simulator.

NLR evaluates the FTP, thereby checking:

- The completeness of the tests against the relevant EASA [1], ICAO [3] and/or FAA [4] requirements for an FFS at Level D;
- The way in which the tests are carried out, taking into account the specific helicopter configuration and its operating limitations.

During previous campaigns, it was concluded that the FTP is well-structured, complete and compliant with relevant EASA, ICAO and/or FAA requirements.

6.3. Flight Test Cards

The FTCs reflect all of the tests that are described in the FTP. Each single FTC contains a reference to the relevant EASA, ICAO and/or FAA requirement(s) and all details required for the individual test points to be flown, including possible limitations and potential hazards.

NLR evaluates the FTCs against the FTP to assure that the combined set of the FTCs covers all aspects mentioned in the FTP. It was concluded during previous campaigns that the FTCs are a good reflection of the FTP. They are sufficiently detailed with all information for the individual tests, including the test conditions, the set-up of the specific test, the limitations to be adhered to, and the hazard level.

6.4. Flight Test Instrumentation

The FTI is a proven system, based on a networked assembly of small computer systems, installed in suitable places in the cabin of the helicopter and elsewhere. Figure 14 shows the nose boom with the FlightLog as an example for an external installation. See Chapter 2 for a detailed description of the FTI.

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Figure 14 Boom with air pressure, angle of sideslip and angle of attack sensors

NLR reviews the FTI installation on the helicopter and the relevant documentation to assess its suitability to measure all data that is required for FFS Level D. It was concluded for all previous campaigns that the FTI is capable of measuring the required data with sufficient accuracy.

6.5. Flight testing process

The flight testing process contains a number of steps. All steps were detailed to NLR and witnessed by NLR during the visit.

- *Test flight preparation.* Based on the expected weather conditions and the need for certain tests, one or more flights are prepared. Relevant FTCs for the intended flight(s) are prepared and/or selected.
- *Pre-flight briefing.* Before each flight, a pre-flight briefing is carried out by the flight test team and everyone else involved. For the briefing, a briefing checklist is used. The decision to authorize the test flight itself is taken unanimously by those flight test team members who will perform the flight.
- *Pre-flight FTI checks at the helicopter.* The FTI pre-flight checks are carried out using a checklist, after which the FTI is started up.
- *Test flights.* The test flights are normally executed by an on-board flight test team of four persons, consisting of two pilots and two Flight Test Engineers (FTEs). The on-board team is supplemented by a ground team taking care of various tasks, like progress tracking, data handling, data processing, data extraction and handing over the data to the flight dynamic modellers.
- *After landing FTI checks at the helicopter.* After landing, FTI checks are carried out using the checklist, before shutting down the system. All acquired data is handed over to the data analysts for further processing.
- *After flight de-briefing.* After each flight, a de-briefing is carried out by the flight test team and everyone else involved. For the briefing, use is made of a de-briefing checklist.

NLR has carried out various evaluations of the flight testing process for its suitability to generate accurate data that reflects the actual helicopter. It was concluded then that the flight testing process is fully in line with good engineering practice and is fully suited to generate correct and accurate data. The process steps are clear, the flight test team members have well-defined tasks with comparable levels of workload, and sufficient checks are built in to reduce errors and increase the flight safety level.

6.6. Data handling process

After each flight, the acquired data is stored redundantly on hard drives, together with the completed FTCs and other flight information. All data sets are clearly labelled and are easily accessible. Next, the data set is automatically cut-up in relevant sections for individual test points based on the information contained on the FTCs. The data is checked for completeness and quality by the modelling team.

During several occasions, NLR assessed the complete data handling process, from the FTI up to the handover to the flight model makers. It was concluded that the data handling process after the test flights is a sound and strict process. The data processing is largely automated and therefore less prone to errors. Checks are performed to guarantee the completeness and quality of the data.

6.7. Test flight witnessing

During the flight test campaign NLR, as an independent entity, witnesses the test flights by being on-board the helicopter during the flight.

Figure 15 On-board test flight witnessing

The goal is to assess the flight test methodologies used and to confirm the validity of the test points and quality of the acquired data. The test flight witnessing includes the complete process, from the preparations of the test up to and including the post-flight de-briefing.

During previous campaigns NLR made the following observations for the flight test activities before and after the flights:

- The flight tests are performed in a professional manner;
- On-board there is a clear division of tasks between the flight test team members;
- The team members are involved, dedicated and highly motivated, and the team spirit is admirable;
- The on-board communication for the individual test points is concise and clear;
- Relevant data parameters are observed during the execution of the test; a test point can be stopped by the test flight leader when sufficient data have been acquired or by the pilot(s) in case an early recovery is required.

6.8. Results of substantiation work

NLR concludes that the data acquisition process is capable of delivering accurate data that are representative of the specific helicopter type. The current set-up of the data acquisition process is a solid basis for acquiring data with good quality for the purpose of creating a Level D simulator.

7. SUMMARY

For the development and qualification of helicopter flight simulators, sufficient and accurate data are required. Instead of procuring the data from the manufacturer, Reiser ST decided to perform the data acquisition themselves. For that purpose, they have developed an efficient flight data acquisition instrumentation that can be easily adapted for integration in a wide range of helicopter types and fixed wing aircraft. Safety, quality and efficiency are basic requirements during the flight test campaigns and the processes that are used are fully in line with those requirements. Reiser ST is constantly improving the instrumentation and processes. Some aspects are generally applicable, but under different circumstances, processes might need to be adapted. That is made possible by the inherent flexibility of the company, the flight data acquisition system and the adopted processes.

8. CONCLUSION AND OUTLOOK

General processes provide a reliable basis for successful data gathering. They define the structure of the day, workshare and roles of team members. Processes are adapted to the circumstances prior to a campaign and critically reviewed on their suitability especially at the beginning.

The crew communication is very sensitive for errors especially when being on the ground, as no check-lists are available apart from briefing and de-briefing. Every team member is asked to revise formulations critically.

A study that gives proof to the different aspects that are observed and presented in this paper is planned. The amount of benefit with different actions to improve safety and quality in flight data gathering as well as cross-coupling positive effects resulting from efficient processes can be compared with the results.

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BIOGRAPHIES

As a M.Sc. aeronautic engineer and a glider pilot Regine Pattermann is head of flight test at Reiser ST GmbH and RS Flight Systems GmbH. With participating and leading flight test campaigns for different types and purpose i.e. on a H145, she contributes a wide range of experience in data gathering especially for simulation purpose.

Jos Stevens holds an M.Sc. in aerospace engineering from Delft University and joined the Netherlands Aerospace Centre NLR in 1985 as research scientist in the areas of rotorcraft flight performance and operational support. He participated in various large European research projects and played an active role in various flight test campaigns.
