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Live optical digitisation of flight instruments for flight guidance in helicopter noise measurements

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Live optical digitisation of flight instruments for flight guidance in helicopter noise measurements

Problem area

For the purpose of land-use planning it is of importance to determine noise contours due to flight movements from and to an airport. For fixed-wing airplanes an international consensus exists on the methodology to be applied (ICAO Doc 9911, ECAC Doc 29). For helicopters however, this is less straightforward since the helicopter noise mechanism is complex and strongly dependent on flight conditions and directivity. An intermediate approach is currently recommended in the Environmental Noise Directive (END) to model helicopters in a similar manner as fixed-wing aircraft. A consortium led by NLR has been commissioned to develop a new improved helicopter noise model.

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Description of work

In the second half of 2016 and the first quarter of 2017, NLR in conjunction with Anotec successfully executed a flight test campaign to collect helicopter noise and performance data. This data will form the basis for the development and validation of a numerical model for noise emission in helicopters, to complement the existing set of aircraft noise models. Based on an analysis of the European helicopter fleet, a total of eight different helicopter types have been tested during this campaign. The flight test programme consisted mainly of take-offs, overflights and approaches, based on the noise certification flight procedures described in ICAO Annex 16 Volume I.

In order to capture the helicopter parameters, a carry-on measurement system was developed. This system is non-intrusive and has no parts that need to be fixed to the exterior of the aircraft. The data recorded by the carry-on system is used in the post-flight analyses, but is also fed to a guidance computer in real-time. In addition to a GNSS receiver and an IMU to measure the helicopter position and orientation, the on-board system uses a video camera and imaging software to acquire data from indicators on the instrument panel.

Results and conclusions

The digitised parameters were found to correspond well with the GNSS data of similar parameters. The digitisation process is insensitive to vibrations and the system can be operated under a wide range of lighting conditions for long periods of time without requiring adjustments. The carry-on measurement system can be flexibly adapted for use in a different aircraft.

GENERAL NOTE
This report is based on a presentation held at the European Rotorcraft Forum 2017, Milan, July 13, 2017.

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Abbreviations

ACRONYM	DESCRIPTION
Anotec	Anotec Engineering, S.L.
CAS	Calibrated Airspeed
COFDR	Carry-On Flight Data Recorder
EFIS	Electronic Flight Instrument System
FTE	Flight Test Engineer
FTS	Anotec flight guidance software
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
IAS	Indicated Airspeed
ICAO	International Civil Aviation Organization
IMU	Inertial Measurement Unit
NLR	Netherlands Aerospace Centre
PGU	Pilot Guidance Unit
SBAS	Satellite Based Augmentation System
VSI	Vertical Speed Indicator

Symbols

ACRONYM	DESCRIPTION
a	Hellmann exponent, roughness exponent
h	Height above ground
V_h	Maximum speed in level flight at maximum continuous power
$v_{w,h}$	Wind speed at height h
V_y	Best rate of climb speed

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1 Introduction

As part of the Service Contract for the "Service provision towards the development of a public European environmental model suite for aviation", a numerical model for noise emission in helicopter operations is to be developed and validated, that complements the set of existing aircraft noise models. Since insufficient data is currently available in the public domain to support the model to be developed, a specific task in the project aimed at the collection of helicopter noise and performance data. This data will be used in the framework of subsequent modelling and software development activities.

Ideally the noise model would have a noise data set for each helicopter type and variant. However, since there are too many different makes and models of helicopters to perform measurements on all of them within the framework of this project, a small subset of helicopters was defined. This subset was defined based on an analysis of the European helicopter fleet, through grouping of types and variants with comparable type designator, configuration, weight and noise data. This analysis reduced the European helicopter fleet to 50 separate classes. Out of these, 8 classes of helicopter, together representing roughly 82% of all take-offs and landings in Europe, were selected for testing.
Out of each of these classes one helicopter type was selected for testing. These were the Robinson 22, 44 and 66, the Eurocopter 120 and 135, the Aerospatiale 350, the Bell 412 and the Schweizer 269.

Half of the flight tests were performed by NLR at two sites in the Netherlands, the Marknesse NLR site and the Lt-Gen Best Barracks. The other half of the flight tests were covered by Anotec at Marugán airfield in Spain. This is summarized in table 1. In total over 60 hours of flight testing were performed.

Table 1: Helicopter type, measurement location and date of executed flight tests.

Helicopter	**Location**	**Date**
Robinson 22 Beta II	NLR Marknesse, Netherlands	21-22 June, 2 August 2016
Robinson 66	NLR Marknesse, Netherlands	5, 30 August 2016
Eurocopter 120B	Lt Gen Best Barracks, Netherlands	20-21 September 2016
Eurocopter 135 P2	Lt Gen Best Barracks, Netherlands	26-27 September 2016
Robinson 44 II	Marugán airfield, Spain	26-30 September 2016
Aerospatiale 350B3	Marugán airfield, Spain	3-5 October 2016
Bell 412	Marugán airfield, Spain	20-23 February 2017
Schweizer 269C-1 (300CBi)	Marugán airfield, Spain	1-2 March 2017

The data collection should comprise measurement of trajectories (4D position along with other relevant flight parameters) and correlated noise levels for the set of helicopter types mentioned above. To accommodate the helicopter on-board data collection for different helicopter types, a carry-on measurement system, which can be flexibly adapted for different aircraft, was developed by NLR and Anotec.

2 On-board measurement system

To correctly set up the helicopter noise model, it was necessary to record the helicopter parameters during the manoeuvres, in addition to the noise measurements on the ground. Since the measurements were to be performed for multiple helicopters of different types, but for relatively short measurements per helicopter, it was not feasible to equip each helicopter with a complete custom sensor suite. As such, NLR together with Anotec developed a generic isolated measurement system. This system is easily fitted to an arbitrary aircraft, can be installed quickly and is non-intrusive (i.e. no digital/electronic interface between the sensor suite and the aircraft instruments, no power connection to the aircraft and no required modifications to the aircraft structure). NLR’s main contribution was the further development of their existing Smartcam concept, whilst Anotec provided the flight guidance software, which was adapted to allow communication with the Smartcam system.
These were then integrated into a carry-on flight data recorder (COFDR) and a pilot guidance unit (PGU). The COFDR is installed in the aircraft prior to the flight tests. The PGU is operated by a flight test engineer (FTE) seated in the co-pilot seat during the flight. Using the PGU, he can then guide the pilot through the test procedure via voice commands, so that the aircraft stays within the margins prescribed by the procedure.

2.1 Carry-on Flight Data Recorder

The flight test programme was mainly based on the noise certification flight procedures as described in ICAO Annex 16 Volume I [1]. To indicate to the flight crew whether they were flying within the prescribed margins during the execution of these procedures, it was necessary to record at least the helicopter position, airspeed and rotor rpm. To obtain a more complete data set, the helicopter accelerations and orientation were recorded as well.

The carry-on measurement system consists of the following components:
- SBAS GNSS receiver with a single antenna
- Inertial Measurement Unit
- Optical tachometer
- Smartcam camera
- Laptop computer for data processing and storage
- Notebook pc for flight guidance
- Power supply

2.1.1 GNSS Receiver

The position of the helicopter was recorded by a Septentrio AsteRx3 HDC GNSS receiver, shown in the EC135 in figure 5. This system uses satellite-based augmentation systems (SBAS) to record the position with an accuracy of <1 m horizontally and <2 m vertically as well as velocity and GPS time. The receiver was connected to a single antenna, which was placed underneath the windscreen, above the co-pilot seat, as seen in figure 1. The position of the antenna varied slightly for each helicopter, depending on the SBAS reception. The positioning data was stored on the laptop computer, but was also fed directly to the Anotec flight guidance software (FTS) on the PGU for flight guidance.

Figure 1: GNSS antenna as installed on EC120.

2.1.2 Inertial Measurement Unit

The orientation of the helicopter was recorded by a Crossbow VG400CC-200 IMU, shown in the EC135 in figure 5, using Crossbow's GYRO-VIEW software. This provides the aircraft's roll and pitch attitude with a dynamic accuracy of 2.5°rms. It also measures the roll, pitch and yaw angular rates with an accuracy of 1.0°/sec and acceleration in x-, y- and z-direction with an accuracy of 12 mg. The IMU was strapped down to the baseplate of the measurement system, aligned with the direction of flight.

2.1.3 Optical Tachometer

The rotor rpm was measured with a PROPTACH-3 wireless optical tachometer. This device was mounted on the glare shield overhang above the instrument panel or to the side of the glare shield as in figure 2, depending on the cockpit layout. The device was fitted with an aluminium mirror to observe the rotor overhead instead of a propeller in front. It has a 1 Hz refresh rate and is accurate to 1 rpm. Unfortunately the device has no out-port to directly extract the data from. To record the data, the tachometer was placed inside the field of view of the Smartcam camera. Although this parameter was not digitised in real-time during the flight tests, since the rotor rpm indicator of the helicopter was already being digitised, the images are available for post-processing analysis. During the flight tests the FTE verified that the values of the optical tachometer matched with the values of the rpm-indicator on the instrument panel of the aircraft.

Figure 2: Optical tachometer as installed on EC120.

2.1.4 Smartcam

NLR used its *Smartcam* to record and digitise the airspeed, rpm, altitude and vertical speed indicators on the instrument panel. NLR has previously used the *Smartcam* during a measurement campaign on board of a ship to record the navigation instruments on the bridge and in the control room [2].

Smartcam uses a Basler GigE acA1300-30gm/gc Monochrome camera, with a resolution of 1296 x 966 and a frame rate of 30 fps. The camera's CS-mount holds a 1/3" 5-50mm f1.3 Computar T10Z0513CS varifocal lens with manual focus. The camera was mounted to the window above the co-pilot seat using a suction cup RAM mount, as seen in figure 3, or if available an existing mounting point above and between the front seats. The camera was then directed toward the helicopter instrument panel and zoomed in as far as possible whilst still including all relevant indicators in the image. This small field of view resulted in maximum image resolution of the indicators, as well preventing overexposure due to direct light coming around the instrument panel from outside.

Figure 3: Smartcam as installed on R66.

The camera images were processed by a software routine created in Matrox Imaging Design Assistant V4.0 build 492, tailored to the instrument panel of the specific helicopter. This software routine recognizes needle angles, numeric values and alphabetic characters and converts these to digital values. The values indicated on the dials are recognized in real-time at a frequency of 10 Hz and stored on the laptop computer. The images are also stored, at a frequency of 1 Hz, for possible post-processing analysis of indicators that were not processed in real-time. All variables were recorded in whole numbers. Figure 4 shows the *Smartcam* operator interface with an image of the instrument panel in which the values are digitised for the EC135.

Ref 359.43 deg Scale 1.048 2017-06-16 16:38:49.059 TODS 59929.059

Total pass 353
Total fail 0

Analysis time 91 ms
Frame rate 10.2 fps

IAS 85 kts
VS 0 fpm
ALT 78 ft
R-RPM 101 RPM

Log Data Idle
Image log rate 1 fps
Acceptance 95 %
Certainty 100 %
Image rotate 0 deg
Image source Set: Test
Image-set rate Fastest

Exposure 1/1000 s
GainAuto Continuous
AutoGrayLevel 100
Gain 300

Diagnostics Idle
Image Contrast 1
Image Brightness 0
Search Size 20
Search Scale 1.2

y:\proj\smartcam\projects\ec135\cam\test\20160927_121638_982.bmp

Figure 4: Smartcam operator interface showing the digitisation of the airspeed, altitude and vertical speed indicators.

The digitising process was made insensitive to vibrations of the aircraft. The first step in reducing the vibrations between the camera and the airframe is to rigidly connect the camera to the helicopter. This was achieved by mounting the camera on an as short as possible arm and when necessary using extra padding or tape to press the camera against the airframe. Nevertheless, this does not remove all vibrations. It was found that the instrument panel can also vibrate with respect to the airframe. By setting the camera shutter time to a very short time interval the camera was able to create sharp images regardless of vibrations. Although these images are sharp, they might be slightly differently oriented with respect to the previous images due to the vibrations. To circumvent this problem a reference point on the instrument panel is defined in the image recognition software, e.g. the registration number or the centre of the IAS indicator. Once the software recognises this point, it can infer the orientation and position of the instrument panel in the image. The positions of the other instruments which are to be recorded are defined within this reference frame, allowing the software to easily read these values.

The digitising process was also made largely insensitive to lighting conditions. At the beginning of each test day the camera exposure settings were adjusted to the current lighting conditions, and again before each flight if necessary (e.g. when the weather changed from clear skies to dense clouds). Additionally the flight crew wore plain dark clothes to reduce reflections on the instrument panel. These precautions caused the camera to be mostly insensitive to varying lighting during the flights. The largest issue which hinders successful image recognition is direct incident sunlight on the instrument panel. This can lead to overexposure (blinding the camera), or create uneven lighting on the instrument panel due to cast shadows from e.g. structural parts of the helicopter. To reduce this effect during the tests in the Netherlands, the order of the flight test procedures was adjusted such that the helicopter was always flying facing the sun. Due to restrictions on flight directions for approach and take-off and a North-South orientation of the runway, this solution could not be applied to the tests in Spain. The best performance of the *Smartcam* is expected with overcast skies. An additional solution which was tried on the ship-based camera recordings was to apply a non-reflective coating or sheet on the instruments. This was refrained from in the helicopter trials for fear of reducing instrument visibility to the pilot.

2.1.5 COFDR integration

The GYRO-VIEW, *SmartCam* and Anotec FTS software were running on a Dell LATITUDE ATG E6430 laptop with Windows OS. These programs all used system time for logging the data. The system time was synchronized to GPS time before each flight. The laptop was also placed on the baseplate of the measurement system. Using variable clamps, the baseplate was affixed to the aircraft floor via the seat-rails or by locking the baseplate in place with wedges against the surrounding aircraft structure, see figure 5.

The COFDR system was powered by a Powertraveller PowerGorilla PG001 portable power pack. This power pack and the laptop battery allowed the system to operate independently for several hours. Both batteries were switched with fully charged batteries whenever the helicopter was refuelling to ensure that these would not run out mid-flight.

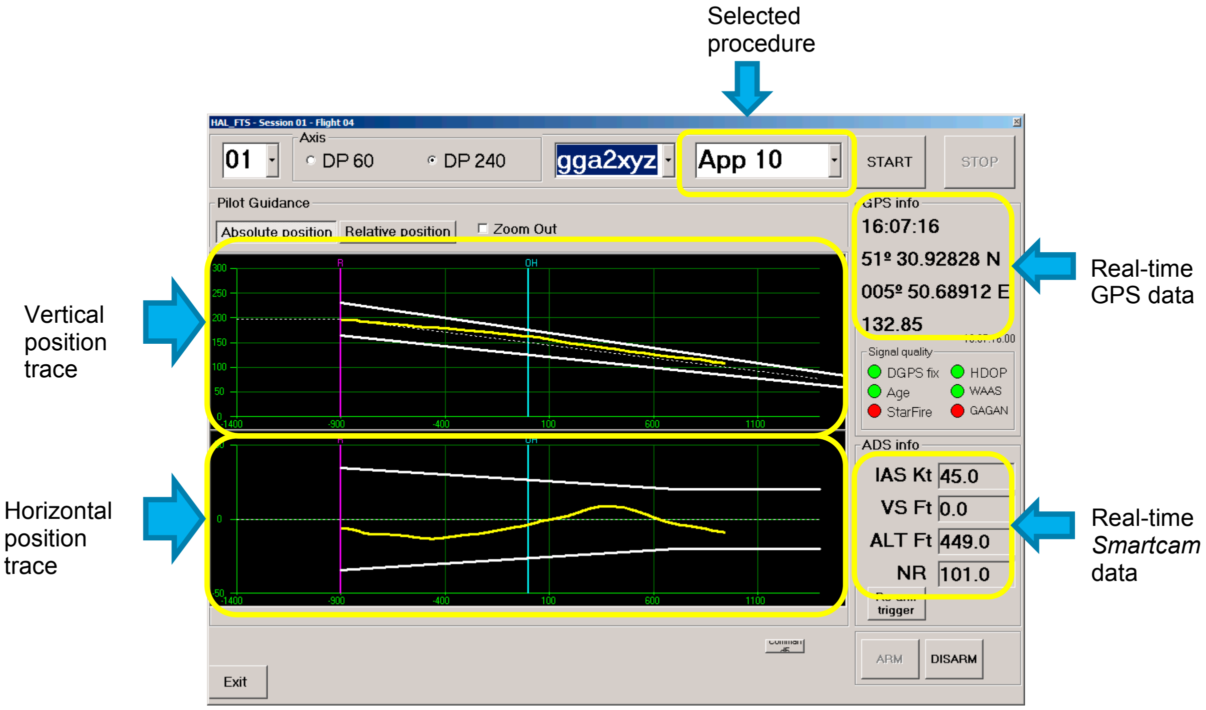
Figure 5: COFDR as installed in the EC135 to the seat rails of a removed seat with 1) GNSS Receiver, 2) IMU and 3) laptop computer.

2.2 Pilot Guidance Unit

During flight the COFDR was operated through a ruggedized notebook pc, GETAC V100, referred to as the PGU. The PGU used TeamViewer 10.0.47484 over Wi-Fi connection to access the laptop. This allowed the FTE to use FTS to guide the pilot through the procedures and observe whether the procedures were executed correctly.

Whilst the laptop computer stores all variables measured by the GNSS receiver, the IMU and the Smartcam, the position data and digitised airspeed, vertical speed, altitude and rotor rpm are fed directly to the PGU in real-time.

The GNSS position data is used to trace the position of the helicopter during the procedure in real-time, as shown in figure 6. This information allows the FTE to guide the pilot to stay within the margins of the ideal flight path through voice commands. The SmartCam data is shown to the FTE in real-time as well. This way the FTE can monitor whether the image recognition is working correctly. At the end of a procedure the average airspeed, average climb angle and average rotor rpm during the procedure, as well as the offset in height and the offset perpendicular to the ideal path at the overhead position, are shown to the FTE. Based on this information the test run can be accepted or rejected.



Selected procedure

Vertical position trace

Horizontal position trace

Real-time GPS data

Real-time *Smartcam* data

HAL_FTS - Session 01 - Flight 04

01

Axis ○ DP 60 ● DP 240

gga2xyz

App 10

Pilot Guidance

☐ Zoom Out

GPS info
16:07:16
51º 30.92828 N
005º 50.68912 E
132.85

Signal quality
● DGPS fix ● HDOP
● Age ● WAAS
● StarFire ● GAGAN

ADS info
IAS Kt 45.0
VS Ft 0.0
ALT Ft 449.0
NR 101.0

Figure 6: Anotec FTS software on Pilot Guidance Unit.

3 Measurements

3.1 Ground setup

The ground set up consisted of a microphone array and a ground station. The microphone array comprised 17 microphones on ground plates and 3 microphones mounted on a tripod, together spanning a line of 420m. The noise measurements performed with this setup allow a noise hemisphere to be defined with an angular resolution of at least 10°. The tripod mounted microphones were located at ICAO Annex 16 certification positions at a height of 1.2m and placed at grazing incidence. The clock of the noise recording computer was synchronized with GPS-time. In order to synchronize the noise measurements with the helicopter position data, an IRIG-B signal was recorded simultaneously with the noise measurements.

The ground station, see figure 7, consisted of a mobile office on which a 10m mast is mounted with a Reinhardt MWS 5MV weather station. The weather station measures temperature, relative humidity, barometric pressure, wind speed and direction. The measurements are automatically stored on a PC. The microphone measurements are also stored at the ground station.

Communication between the helicopter and the ground station was achieved with a portable radio at the ground station. The ground station had no telemetry connection to the helicopter, since the helicopter data is all measured and stored on-board on the COFDR.

Figure 7: Ground station with weather measurement mast.

3.2 Flight procedures

The flight procedures executed during the noise measurements were selected to represent the most common operational procedures performed in daily operations whilst also covering most of the aircraft's flight envelope.

The basic procedures were the ICAO Annex 16 noise certification reference procedures: take-off (maximum take-off power climb at V_y), overflight (0.9 V_h, 150m height overhead) and approach (6° descent at V_y, 120m height overhead). These measurements were also used to perform a cross-check with the ICAO certification noise levels of the helicopters being tested as a quality check. Further procedures were derived from the noise certification reference procedures.

Additional overflight procedures were defined at V_y, V_h-30kts, V_h-15kts and V_h+10kts. Additional take-off procedures were defined for slopes at 3° intervals below the maximum take-off power climb angle for the speeds defined for overflight where the helicopter performance is sufficient for steady climb. Additional approach procedures were defined for slopes at 3° intervals up to 12° for $0.66V_y$ and $1.33V_y$ where the pilot was still able to perform a steady descent. The exact test points for these additional procedures varied slightly between helicopters, due to performance limitations, safety or to get a better distribution of test points in the flight envelope. A typical test point distribution is shown in figure 8. To improve the noise hemisphere resolution, all procedures were performed once such that the height overhead of the microphone array was 120m and once such that it was 150m. All procedures were flown at least twice per overhead height to ensure the data are statistically reliable.

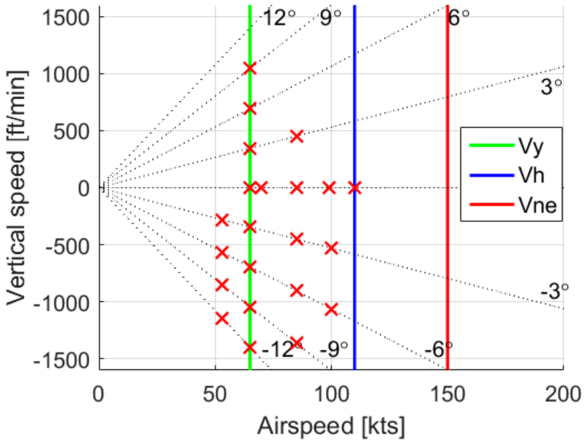


Figure 8: Executed test points for the EC120.

The certification reference procedures were flown with the helicopter at 100% of maximum take-off weight. During the other procedures the weight was kept to at least 90% of maximum take-off weight.

Although not represented in the ICAO-Annex 16 noise certification, a turn and a hover procedure were defined to address the common operational procedures. The turn procedure starts out as the overflight procedure. Once the helicopter is overhead of the microphone array it initiates a steady banked turn and flies two complete circles before resuming forward flight over the track. This ensures that the aircraft is in a steady turn during the second pass over the intersection of the track with the microphone array. If significant wind is present the helicopter will drift off from the centre of the microphone array. To ensure the helicopter still passes overhead of the centre of the microphone array during the steady turn, the procedure is initiated with forward flight upwind of and parallel to the track. The test points were performed for bank angles of 15° and 30° for both left and right turns.
In the hover procedure the helicopter is brought into a hover at 1m above the ground at a distance of 3 rotor diameters away from the centre microphone in the direction perpendicular to the microphone array. To obtain a noise measurement for all orientations of the helicopter, the helicopter slowly rotates around its axis at a rate of 1°/s until a full circle hover turn has been completed.

3.3 Modification/installation process for a new helicopter

Although the initial development of the COFDR for the first helicopter took quite some time, the modification of the system to suit a different helicopter and to install the system is fairly quick.
Once a new helicopter has been selected for the next test, it is first visited by an instrumentation engineer. During this visit the possible locations for the camera and baseplate are analysed as well as the possible mounting options. Additionally, pictures of the instrument panel are taken from the possible camera positions.
After the initial visit to the helicopter the image recognition software routine is modified to recognize and read off the new indicators. These will be similar dials, but will have different positions, sizes and indicator scales. The mounting clamps of the baseplate will also be adjusted or replaced to fit the baseplate to the new helicopter.
Once the software routine and the baseplate had been adjusted to fit the new helicopter a test flight would be made to verify the correct working of the Smartcam. This verification flight was dropped after the first two helicopters, since the image recognition routine was shown to be reliable enough that no additional modifications were required after the ground-based software changes.
Effectively this means that the COFDR can be modified to a different helicopter in roughly two weeks, assuming the dials to be recorded are similar.

Installation of the configured COFDR in the helicopter can be achieved in half a day. Once the system is installed, the exposure settings of the camera need to be set at the beginning of each test day. In case large changes in lighting conditions occur, e.g. when the weather changes from clear skies to dense clouds, these settings might need to be adjusted.

4 Comparison of data acquired from different sources

Figure 9 shows the values for height above ground level, velocity and vertical speed recorded during a take-off procedure executed with the EC120. Shown in red are the values which have been digitised from the instrument panel by the *Smartcam*. In blue are the values as derived from the GPS data.

The top graph of figure 9 shows the instantaneous GPS altitude corrected for local ground level and the digitised altimeter indication. Before each flight the barometric altimeter was nulled at ground level to indicate height above ground during flight testing. Digitised altitude was measured in whole feet. The trend of the digitised values shows a good correspondence with the GPS height. An obvious difference is the delay of 4-5 seconds of the digitised altimeter with respect to the GPS height. This delay is also apparent in the vertical speed measurement. This can be explained by the lag induced by the pitot-static system in registering a pressure change. The tubing and gauges require a finite time to respond to changes in static and dynamic pressure [3].

The middle graph of figure 9 shows the digitised indicated airspeed (IAS) versus the derived GPS speed. A 3rd order polynomial fit has been applied to the vector components of the GPS position with respect to time. The vector components of the GPS velocity are then taken as the 1st power coefficient of the fit. The instantaneous GPS speed is then the vector sum of the GPS velocity components. Shown in green is the indicated airspeed, digitised in whole knots, converted to calibrated airspeed (CAS).

The large gap between CAS and GPS speed can be mostly accounted for by wind. The headwind component of the wind at 10m height, as measured by the ground station, averaged over the measurement period has been used to approximate the headwind at the height of the helicopter as [4]:

$$v_{w,h} = v_{w,10}\left(\frac{h}{h_{10}}\right)^{a}$$

$v_{w,h}$ is the wind speed at altitude h, $v_{w,10}$ is the wind speed at altitude h_{10}=10m and a is the Hellmann exponent, here defined as 0.16 for flat, open coast. The actual instantaneous wind at the height of the helicopter will be slightly different from the approximated wind, both in size and direction, but the approximated wind shows that it can account for most of the difference between CAS and GPS speed. The CAS value corrected with the approximated headwind (in this case tailwind) is shown in magenta.

The bottom graph in figure 9 shows the vertical component of the GPS speed and the digitised values of the vertical speed indicator (VSI), measured in whole feet/min.
The small and fast variations in the GPS speed, both total and vertical, might be caused by small variations in wind, small variations on the control inputs by the pilot or artefacts due to the speed being derived from the position with the given accuracy. Due to the pitot-static system lag, these disturbances are not captured by the VSI. However, the general trend of the larger changes in vertical speed is captured well.

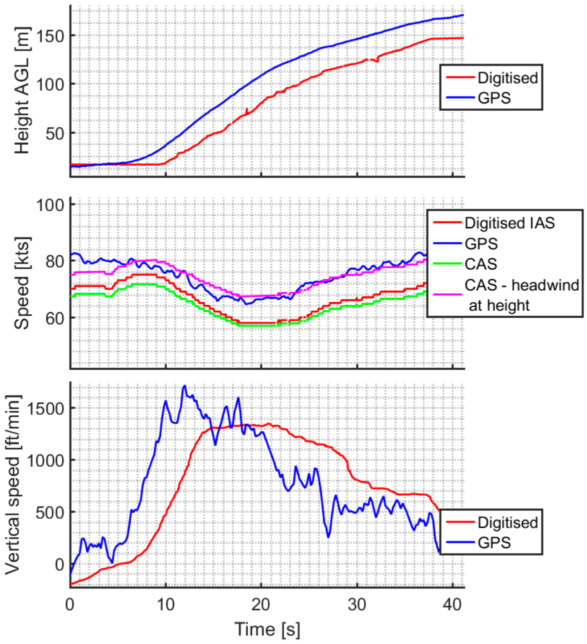


Figure 9: Digitised Smartcam data compared to GPS data during a climb procedure with the EC120.

Overall, the digitised parameters show a good correspondence with the values obtained from the GPS receiver.

5 Conclusions

The current Smartcam system is capable of digitising analogue dial indicators, seven segment digital numerals and a backlit bar graph. This was sufficient to measure the required data in the helicopters used during the flight tests. A next development step would be to upgrade the image recognition algorithm to be able to digitise elements commonly found on EFIS displays, such as e.g. scrolling altitude tape.

The Smartcam digitisation process is made insensitive to vibrations of the helicopter by attaching the camera to the airframe with a short rigid connection and using a short shutter time.

After adjusting the exposure settings of the camera to the current lighting conditions at the start of the test day the Smartcam can handle varying lighting conditions. Drastic changes in lighting, e.g. going from full cloud cover to clear skies, requires retuning of these parameters. Reflections and uneven lighting on the instrument panel can hamper the image recognition of the Smartcam. During testing in the Netherlands, this was largely circumvented by ordering the test points such that the sun was never directly behind the helicopter. The best Smartcam performance is expected with overcast skies.

The COFDR is a non-intrusive system. It requires no digital or electronic connections to the helicopter systems. All components of the COFDR are fitted inside the cabin of the helicopter, there are no external components. All COFDR components are connected to existing attachment points (seat rails, mounting points) or by non-intrusive means without requiring modifications to the airframe (suction mounts, wedges, clamps).

The COFDR can be easily adapted to a different helicopter type by adjusting the Smartcam software to recognize the dials in the new aircraft and changing the connection points on the COFDR baseplate.

6 References

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