European Union Aviation Safety Agency

RESEARCH PROJECT NOISE - SC03

D2.3 NORAH hemisphere database extension

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ANOTEC ENGINEERING SL (ANOTEC)

ANOTEC is a private and independent consultancy company in the field of aircraft noise. Among its main activities are flight tests for noise for both certification and research and noise impact studies of airports. With its participation in relevant working groups and research projects, ANOTEC strives to provide high quality services to its customers (aircraft and engine manufacturers, aircraft engineering companies, airports, civil aviation authorities and policymakers).

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SUMMARY

In the previous project MOVE-C2-2014-269 on rotorcraft noise modelling, noise measurements have been performed for 8 helicopter types. These measurements were used to derive noise hemispheres for the tested helicopter types, for its use in the NORAH model. In the current project this database of helicopter types will be extended to cover relevant additional models, especially in the heavier range.

For the helicopters tested under this Specific Contract a detailed test plan was described in SC03_D2.1. A detailed description of the different flight test campaigns performed is given in SC03_D2.2.

The present document and its annexes, contains a description of the data acquired during the test campaigns, a description of the processing approach and the resulting NORAH 2.0 noise hemispheres generated from this data. This third issue of D2.3 comprises four documents and contains

- A general description of the NORAH hemisphere database structure, file formats, processing approach and other relevant metadata (this document)
- Annex 1: Guimbal Cabri G2 noise measurement database and noise hemispheres (restricted)
- Annex 2: Agusta A109 noise measurement database and noise hemispheres (restricted)
- Annex 3: Sikorsky S-92 noise measurement database and noise hemispheres (restricted)

CONTENTS

1. Introduction

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 very complex and strongly dependent on flight conditions and directivity. Over the last years a new improved helicopter noise footprint modelling methodology, called NORAH, has been developed. NORAH requires a noise database of helicopter types in order to model a noise footprint. In the previous project, MOVE-C2-2014-269, a database was created with 8 different helicopter classes. To increase the usability of NORAH, the database needed to be extended with more helicopters.

To this purpose, in the period of 2022/2023, for three helicopter types, noise measurements were performed that served as input to the NORAH helicopter noise database. Each flight test campaign consisted of a program covering several days. The measurements were performed employing an extensive microphone line array, consisting of multiple microphones on ground plates and three microphones mounted on a tripod at 1.2m height according ICAO Annex 16 specifications. The detailed test plan for the different helicopters tested is given in SC03_D2.1. The noise test campaigns are described in detail in SC03_D2.2.

This document contains in its main part a description of the data processing methodology, which is common for all test campaigns:

Chapter 2 Overview of the selected noise test campaigns
Chapter 3 Description of the data processing methodology
Chapter 4 Description of the methodology to derive the noise hemispheres
Chapter 5 Description of the data set structure

A description of the test results and hemispheres are provided in an Annex for each individual helicopter type. (restricted).

2. Noise test campaigns

In SC03_D2.1 the different helicopter types to be tested under the SC03 contract were identified. Also the tests sites were the flight tests were to be performed were defined. During the course of the project it appeared impossible to do tests with the Cougar helicopter, due to which it was decided to proceed with tests on the Leonardo Helicopters A109 (see Table 1). Due to budget restrictions no further helicopter types could be tested under SC03.

Table 1 Selected helicopter models and test sites for the test campaigns in SC03

HELICOPTER TYPE	Test site	TEST PERIOD
Guimbal Cabri G2	Mollerussa (Spain)	April 2022
Leonardo Helicopters A109	De Peel (Netherlands)	July 2023
Sikorsky S-92	Stavanger (Norway)	September 2022

In SC03_D2.1 a detailed test plan was developed for each helicopter type to be tested. In SC03_D2.2 the noise test campaigns are described in detail. To facilitate the necessary updates and the use by the test teams both Deliverables contain a separate Annex for each helicopter type. For consistency the same structure has been adopted for the present document:

Annex 1: Noise test report Guimbal Cabri G2
Annex 2: Noise test report Leonardo Helicopters A109
Annex 3: Noise test report S92

In this manner each Annex can be used stand-alone for each test campaign.

3. Data processing

The steps below outline the processing of the acquired data:

1. Determine noise measurement intervals from measurement logs generated automatically during the tests (start/stop time logging with GPS time stamp) to allow synchronization with helicopter GPS-position data

2. Calculate average background noise levels (measurement duration at least 60s)

3. Convert microphone GPS coordinates in local coordinate axis system. The local coordinate axis system is aligned with the flight path

4. For each collected test point:

    a. Calculate averaged weather data per test point (wind, temperature, relative humidity and barometric pressure)

    b. Convert measured 1/3 octave band spectra into slow weighted measurements (ICAO annex 16[Error! Bookmark not defined.], App 2, 3.7.5) to calculate EPNL and SEL from which the 10dB down time instances can be determined

    c. Determine noise hemispheres based on the 1/3 octave band spectra acquired every 0.1s (not slow weighted spectra) for noise data acquired in the 10dB down time interval based on EPNL

    d. Derive relevant metadata from the data acquired by the on-board data acquisition system

5. Merge all valid repeat runs for a single test point in one hemisphere.

A schematic outline of the above steps is given below in Figure 1.

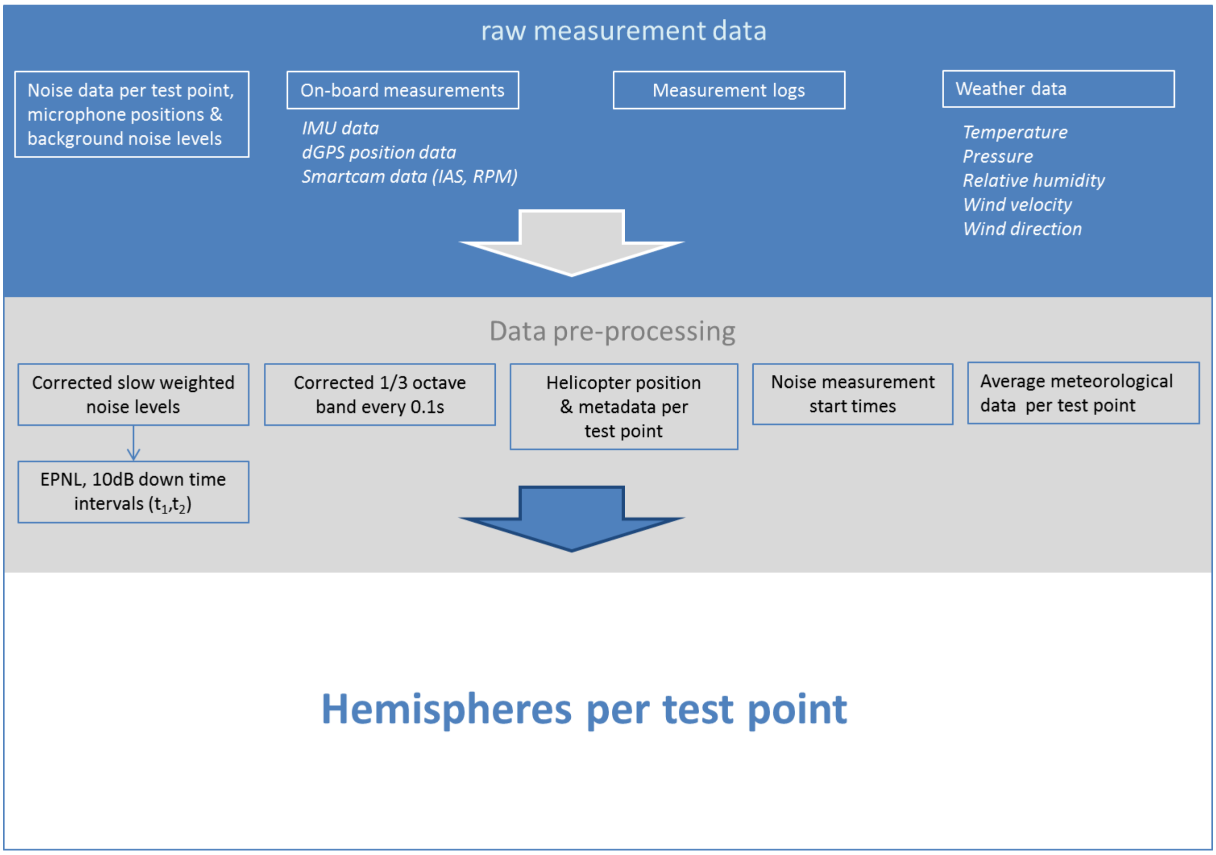

Figure 1: Schematic outline of the data processing steps [Source: NLR]

4. Hemisphere processing

4.1. Axis and parameter definitions

Figure 2 shows the parameters and definitions required for hemisphere processing.

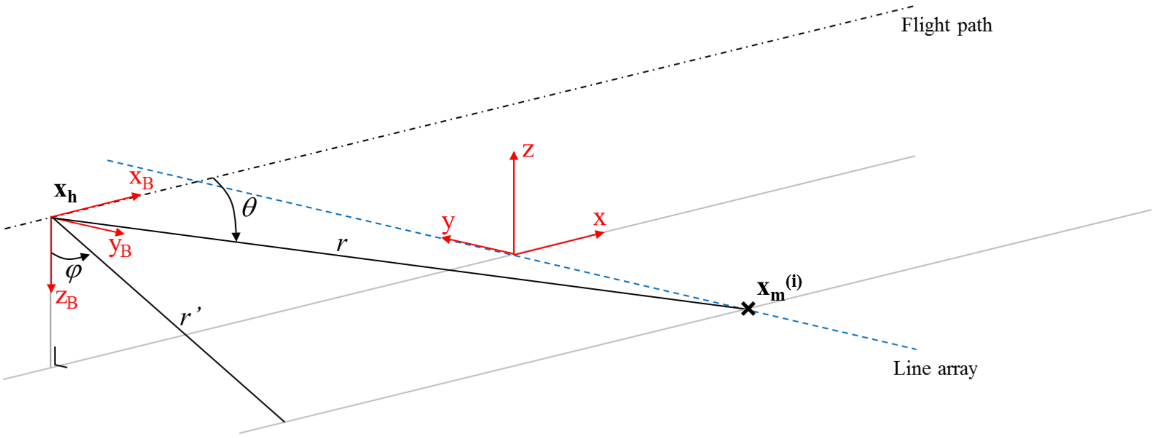

Figure 2: Axis and observer angle definition [Source: NLR]

For a particular time instance, the helicopter is positioned at $\mathbf{x}_h$ (x_h,y_h,z_h), where $\mathbf{x}_h$ is defined in the local coordinate system x-y-z. The x_B-axis of the helicopter body axis system (x_B-y_B-z_B) is assumed to be aligned in local coordinate system x-axis (helicopter attitude is not considered). The positive y_B and z_B-axis are directed to the right of the helicopter and downwards respectively. Note that the positive y-direction in the local axis system and helicopter body axis system are reversed.

The microphone position $\mathbf{x}_m^{(i)}$ is defined in the local axis system and can be converted to the body axis system by

$$\begin{aligned}\hat{x}_m^i &= x_m^i - x_h \\ \hat{y}_m^i &= y_h - y_m^i \\ \hat{z}_m^i &= z_h - z_m^i\end{aligned} \tag{1}$$

The distance R between microphone and helicopter is defined by

$$r = \sqrt{\hat{x}_m^{i\,2} + \hat{y}_m^{i\,2} + \hat{z}_m^{i\,2}} \tag{2}$$

The distance R projected in the y_B-z_B plane is given by

$$r' = \sqrt{\hat{y}_m^{i\,2} + \hat{z}_m^{i\,2}} \tag{3}$$

The polar angle θ can be found by

$$\theta = tan^{-1}\left(\frac{r'}{\hat{x}_m^i}\right) \tag{4}$$

Note to obtain the appropriate quadrant solution, an atan2 function should be used to calculate θ ($0 \le \theta \le 180°$). To obtain the azimuth angle φ the expression

$$\varphi = \tan^{-1}\left(\frac{\hat{y}_m^i}{\hat{z}_m^i}\right) \tag{5}$$

is used ($-90° \le \varphi \le 90°$). This expression shows that for positive φ, the observer is starboard of the helicopter.

For hover test points, θ is set to the angle between the nominal microphone location (0º, 30º, 60º, etc.) and the nominal helicopter orientation (0º, 90º, etc.). In this case φ is set to 0º.

4.2. Processing

Hemispheres require both helicopter position data and noise data as a function of time. 1/3 Octave band spectra are stored every 0.1s and provide the band levels as function of recorded time, frequency and microphone position:

$$L = L\left(t_r, f, \mathbf{x}_m^i\right) \tag{6}$$

The helicopter dGPS measured position is stored every 0.2s and is a function of emission time:

$$\mathbf{x}_h = \mathbf{x}_h\left(t_e\right) \tag{7}$$

Recorded time and emission time are related to each other by the distance between helicopter and microphone and the speed of sound:

$$t_r = t_e + \frac{r}{c} \tag{8}$$

where c is the speed of sound, given by

$$c = \sqrt{\gamma R_s T} \tag{9}$$

In this γ is the ratio of specific heats for a diatomic gas, R_s is the specific gas constant and T is the ambient air temperature. Equations (8) and (9) allow to express the helicopter position as function of recorded time for a given microphone and by linear interpolation the helicopter position can be estimated for a given recorded time.

Prior to the hemisphere generation process, the noise measurement data are corrected and scaled to hemisphere reference conditions at each time instance. This involves the following steps:

1. Apply cable length, microphone frequency response, free field and wind screen corrections.

2. Determine the Last Good Band (LGB), e.a. measured levels are 3dB higher than background noise levels*

* Note that no distinguishment is made between pre- and post detection noise as in the ICAO environmental technical manual, resulting in a moderately more stricter LGB criterion

3. Calculate the scale factor S that scales noise levels to a hemisphere reference distance r_h of 60m, where

$$S(f) = 10^{\frac{\alpha(f)\cdot r - \alpha_h(f)\cdot r_h}{10}} \cdot \left(\frac{r}{r_h}\right)^2 \tag{10}$$

   In which α and α_h are the atmospheric attenuation in dB/m, calculated according to SAE ARP 5534[†], at measurement and reference atmospheric conditions (T=298.15, p=101325Pa, RH=70%) respectively. No Doppler shift or amplification correction is applied[‡].

4. Apply scaling factor to measured noise powers to obtained scaled noise levels

5. For masked bands equal to or higher than 2kHz replace the scaled measured levels with the scaled LGB noise power[§].

6. For $f \geq 8000Hz$, perform an *equal energy check* for unmasked scaled noise levels. If the scaled noise levels increase more than 3dB in the next one-third octave band, mark the band as last good band and replace the following bands with the LGB noise level[**]

Based on the corrected and scaled noise powers the hemispheres are derived. A hemisphere E and W is defined in constant bins of 10 degrees interval in both azimuth and polar angle direction ($\varphi = -90°, -80°, ..., 80°, 90°;\ \theta = 0°, 10°, ..., 170°, 180°$). At the start of processing the bins of both hemispheres E and W are empty, containing respectively zero acoustic energy and weighted number of samples.

To fill the bins with measured source data the following steps are taken for each time instance within the 10dB down interval and microphone position.

1. Determine helicopter position at recorded time t_r. Note that the helicopter positions recorded in emission time and related with recorded time by eq. (8).

2. Calculate the polar angle θ, azimuth angle φ and distance r (see 4.1).

3. An increment in acoustic energy of the affected bins is calculated and added to the hemisphere E. The acoustic energy is assigned to the closest neighbouring bins, by an inversely proportional weighting with the distance from the bin centre. This is schematically shown in Figure 3, in which the closest bins are $(\varphi_n, \theta_m), (\varphi_{n+1}, \theta_m), (\varphi_n, \theta_{m-1}), (\varphi_{n+1}, \theta_{m-1})$. The increment of acoustic energy in for example the bin m,n is then given by:

[†] SAE ARP5534, Application of pure-tone atmospheric absorption losses to one-third octave band data, 2013.

[‡] The helicopter noise generation mechanism can change significantly with velocity. This makes application of Doppler corrections not very useful, since you cannot use the same source data for different velocities

[§] In the ICAO ETM additionally a time extrapolation method is defined for masked bands between 630Hz and 1.6kHz, this was not applied in hemisphere dataprocessing since this condition did not occur

[**] A temporary increase in high frequency background noise levels (causing a failure to detect masking of the band) or non-linear noise propagation can lead to a very strong, but non-physical increase of high frequency noise levels for back-propagated spectra. The equal energy assumption, applied in reconstruction of partly masked spectra, is used as a criterion to detect if the aforementioned situations occur.

$$\Delta E_{m,n} = w_{m,n} \cdot 10^{\frac{L'(\varphi,\theta)}{10}} \tag{11}$$

Where L' is the corrected and scaled noise level as described above and

$$w_{m,n} = \left(1 - \frac{|\varphi - \varphi_m|}{\Delta\varphi}\right)\left(1 - \frac{|\theta - \theta_m|}{\Delta\theta}\right) \tag{12}$$

4. The weighted number of samples per bin in hemisphere W is updated. This allows merging of hemispheres of repeat runs. The increment in the weighted number of samples is given by the weight factor defined in eq. (12).

5. Go to next microphone or time step and return to step 1 until all time steps and microphones within the 10dB down time have been processed.

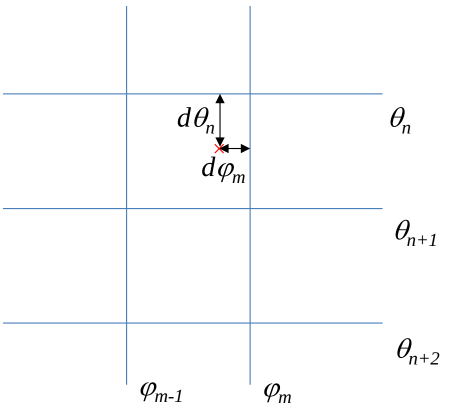

Figure 3 Interpolation stencil, the red cross indicates a measured φ and θ [Source: NLR]

Note that most but not all bins will be filled, e.g. in general azimuth angle around ±90° will remain empty.

After processing all repeat runs, the hemispheres can be merged into a final hemisphere. Prior to merger two checks are performed (see also section **Error! Reference source not found.**):

1. Are more than 90% of the acquired velocity samples within ±5kts of the nominal velocity?

2. Are more than 90% of the acquired position samples located within the airspace contained between γ±γ/12?

When the answer on one of the above questions is no, the hemisphere is rejected for automatic merger. Finally the merged hemisphere, in decibels per one-third octave band is given by:

$$L_h = 10\log_{10}\left[\frac{\sum_{i=1}^{K} E_i}{\sum_{i=1}^{K} W_i}\right] - \Delta G \tag{13}$$

where ΔG is the correction for the pressure doubling that occurs on the surface on the ground plate. The theoretical increase for a pressure doubling is 6dB. Note however, experience has shown that due the limited size of the ground plate a value less than 6dB (~4dB) is often found empirically.

5. Data set structure

This report is accompanied with a digital helicopter noise dataset, which comprises the data given in Table 13.

Table 1: Data set structure

Location	**Filename**	**Description**
.\	ExecutedTestPoints.csv	A list of executed points
.\	metaData.csv	List of metadata per data point
.\Noise\BGNoise	BGNoise_mic**N**.png where N=1..20	A plot of 1/3 octave band spectra of all background noise measurements, for a given microphone
.\Noise\BGNoise	BGNoiseMic**N**.csv where N=1..20	A .csv of 1/3 octave band spectra of all background noise measurements, for a given microphone
.\Noise\BGNoise	[*bgn filename*].csv	A .csv containing background noise levels given in 1/3 octave band spectra for all microphones for a single background noise measurement
.\Noise\DPN**M** where M is a data point number	Mic**N**_DPN**M**.png where N=1..20	A figure of processed slow measured data for a single microphone
.\Noise\DPN**M** where M is a data point number	TimeHistoryMic**N**_DPN**M**.csv where N=1..20	A .csv file with the time history per microphone
.\Noise\DPN**M** where M is a data point number	TimeIntegratedMetrics_DPN**M**.csv	A .csv with an overview of the time integrated metrics of all microphones
.\Noise\DPN**M** where M is a data point number	t01_Mic**N**_DPN**M**.png where N=1..20	Plot of 0.1s interval measured noise data used for hemisphere derivation, quality check file
.\Noise\DPN**M** where M is a data point number	Hemisphere_DPN**M**.csv	Hemisphere data
.\Noise\DPN**M** where M is a data point number	HemisphereOverviewDPN**M**.png	An hemisphere quality check plot

Location	Filename	Description
.\Noise\DPN**M** where M is a data point number	HemispheresPart**J**_DPN**M**.png Where J=1..6	Hemisphere plot per 1/3 octave band
.\Hemispheres	*[helicopter type]_[procedure]_[IAS]_[gamma].hem*	Merged hemispheres
.\Hemispheres	*[helicopter type]_[procedure]_[IAS]_[gamma].sum*	Hemisphere merge report, summarizing the hemisphere used and rejected for merger
.\HemispheresAnx16	*[helicopter type]_[procedure]_[IAS]_[gamma].hem*	Merged hemispheres, applying annex 16 rejection criteria
.\Hemispheres Anx16	*[helicopter type]_[procedure]_[IAS]_[gamma].sum*	Hemisphere merge report, summarizing the hemisphere used and rejected for merger
.\FTR\ DPN**M** where M is a data point number	FTRDataNominal_DPN**M**.png	Figure with helicopter position, RPM and IAS measured data compared to nominal hemisphere reference conditions
.\FTR\ DPN**M** where M is a data point number	FTRGPS_DPN**M**.csv	.csv file with track data, for the PNLT 10dB period of a test point
.\FTR\ DPN**M** where M is a data point number	FTRSC_DPN**M**.csv	.csv file with RPM & IAS data recorded by the SmartCam, for the PNLT 10dB period of a test point
.\Certification	CertificationMerged.csv	Averaged ICAO Annex 16, chapter 8 certification noise levels
.\Certification\DPN**M**\ M is a data point number	CorrectedEPNL_DPN**M**.csv	.csv file with corrected EPNL levels and correction values

5.1. Dataset summary files

The comma separated file *ExecutedTestPoints.csv* gives an overview of the executed test points and the corresponding reference conditions, background noise measurement and microphone configuration (**Error! Reference source not found.**). The data has the following column structure:

- DPNnr: Data point ID
- Procedure: Flown procedure

- Heading: The direction of flight
- Airspeed: Reference air speed
- Overhead: Overhead reference position
- Angle: Reference path angle
- BGNid: ID of the used background noise measurement in processing the data
- MicCFGid: Microphone configuration ID.

The comma separated file *metaData.csv* gives an overview of the metadata for each test point. The data is structured as follows:

- DPNnr: Data point ID
- Day: Day number from the start of the year 2017
- SecondsUTC: Seconds since the start of the day in UTC
- Duration: Duration of the noise measurement in seconds
- TimeSaved: Save time of the noise data file
- TimeInitiated: Start time obtained from synchronization signal
- TotalWind: Total wind speed given in knots
- HeadWind: Headwind given in knots, negative values indicate tail wind
- Crosswind: Crosswind given in knots, positive value indicates wind coming from the right of the helicopter
- Temperature: Average temperature at 10m altitude, in degrees Celsius
- Pressure: Average pressure at 10m altitude in Pa
- Humidity: Average relative humidity at 10m
- SoundSpeed: Sound speed
- Att8Khz: Atmospheric attenuation at 8kHz in dB
- PathAngle: Measured path angle in degrees
- zOk: Fraction of flightpath within airspace margins ($\gamma \pm\gamma/12$)
- ohHeight: Overhead height of nominal flight path in m
- PathOffset: Offset from centre in m, defined in local microphone coordinate system
- IAS: Measured indicated airspeed in kts
- medianIAS: Median measured IAS during 10dB down time

- stdIAS: Standard deviation IAS during 10dB down time
- minIAS: Minimum IAS during 10dB down time
- maxIAS: Maximum IAS during 10dB down time
- IASok: Fraction of IAS measurements within 5kts margin
- RPM: Measured average RPM (in %)
- medianRPM: Median RPM (in %)
- stdRPM: Standard deviation RPM during 10dB down time
- minRPM: Minimum RPM during 10dB down time
- maxRPM: Maximum RPM during 10dB down time
- RPMok: Fraction of RPM measurements within 1% margin
- Pitch: Measured pitch attitude in degrees
- Roll: Measured roll attitude in degrees
- Errorcode: Data collection error code,

    0=complete
    1=FTS data missing
    2=IMU data missing
    3=FTS&IMU data missing
    4=Smartcam data missing
    5=FTS&SC data missing
    6=IMU&SC data missing
    7=FTS&IMU&SC data missing

- Rejected: Hemisphere rejection code,

    0=accepted
    1= Flight path deviation too high zOk<0.9
    2= IAS deviation too high IASok<0.9
    3= Flight path and IAS deviation too high
    4= Data collection error, set incomplete
    5= Data collection error & Flight path deviation
    6= Data collection error & IAS deviation
    7= Data collection error & IAS deviation & Flight path deviation

- Warning:

    1=(cross)-wind conditions exceeding ICAO maximum
    2=IAS variation exceeding ICAO maximum (5kts) IASok <1
    3=Wind and air speed variation exceeding ICAO maximum
    4=RPM variation exceeding ICAO maximum (1%) RPMok <1
    5=Wind and RPM variation exceeding ICAO maximum
    6=RPM & IAS variation exceeding ICAO maximum
    7=Wind conditions, RPM & IAS variation exceeding ICAO maximum
    8=Flight path deviation exceeding limits zOk<1
    9=Wind & flight path deviation exceeding limits

10=Air speed variation & flight path deviation exceeding limits
11=Wind and air speed variation & flight path deviation exceeding limits
12=RPM variation & flight path deviation exceeding limits
13=Wind and RPM variation & flight path deviation exceeding limits
14=Air speed and RPM variation & flight path deviation exceeding limits
15=Wind conditions, RPM & IAS variation and flight path deviation exceeding limits.

5.2. Background noise data

Figure 4 shows an example of BGNoiseMicN.png file for two runs of the S92 (position P1).

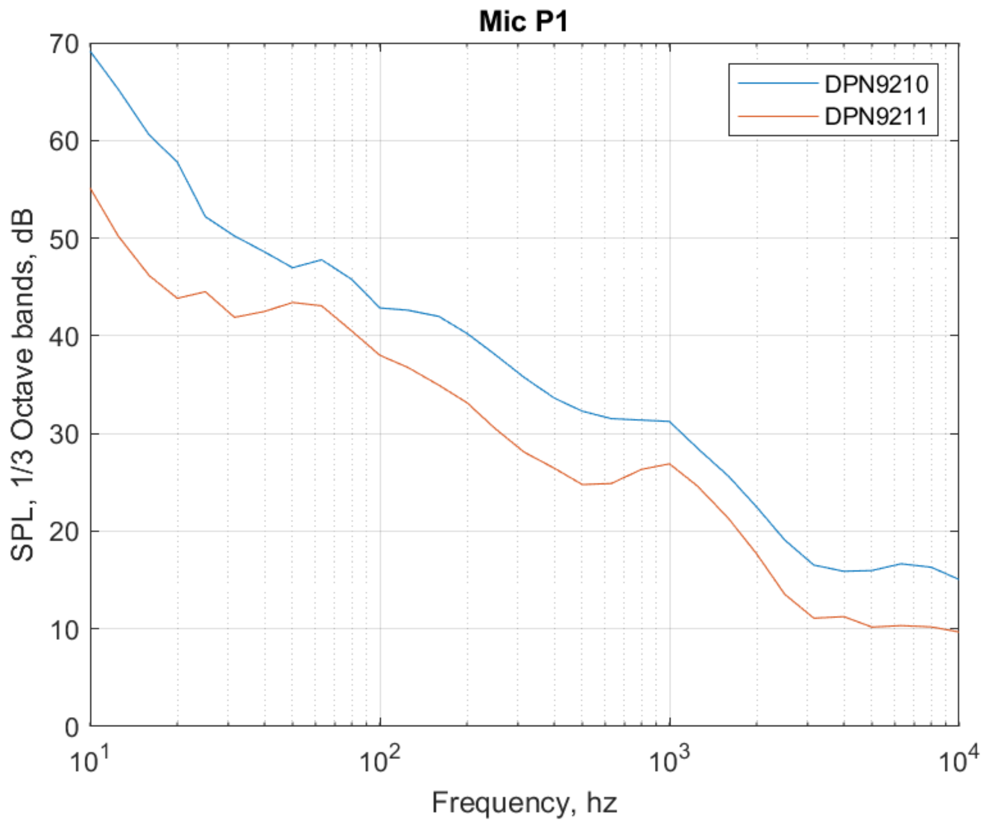

Figure 4: Background noise measurements for S92 (Position P1) [Source: Anotec]

All background noise spectra are given for easy comparisons. This data is also stored in numerical values in the *BGNoiseMic**N**.csv* file, in which the rows correspond to the 1/3 octave band frequencies and the columns to the individual background noise measurements.

The file *[bgn filename].csv* contains average background noise measurements for all microphones for the two background noise measurements made at the start and end of each test day. The rows again correspond to the 1/3 octave band frequencies and the columns to the microphones.

5.3. Slow processed noise data

The figure given in *Mic**N**_DPN**M**.png* gives an overview of the slow measured noise data for a single test point. An example is given in Figure 5.

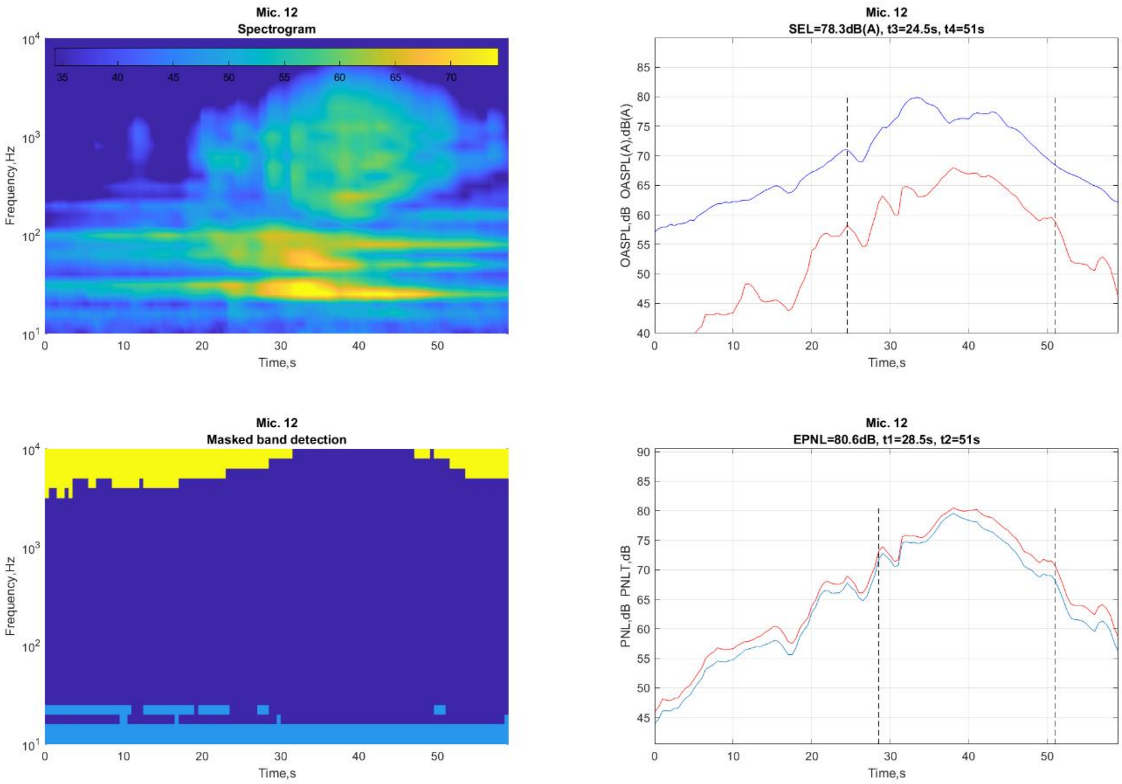

Figure 5: Overview of slow measured noise data, from top left to bottom right, spectrogram, overall sound pressure level (with and without A-weighting), masked band detection and perceived noise levels for the CAbri (Microphone 12 at position C3) [Source: Anotec]

The figure provides in a single overview transient and time integrated noise level information. The figure contains a spectrogram, overall sound pressure level transients (OASPL), masked band detection and perceived noise levels as function of time. In the figure title, when appropriate, time integrated values (Effective perceived noise levels, EPNL and Sound exposure levels, SEL) are given with the 10dB down time instances (t_1 and t_2). Masked band detection is performed according to the algorithm described in DOC9501[††], Appendix 3, section 3.2. EPNL is calculated according to ICAO Annex 16, Appendix 2, section 4. Note that reported EPNL levels are not adjusted to reference conditions.

This data is also stored in table format in the comma separated files *TimeHistoryMicN_DPN**M**.csv* and *TimeIntegratedMetrics_DPN**M**.csv*. *TimeHistoryMicN_DPN**M**.csv* contains the following columns:

- t : Recorded time (slow)

[††] DOC 9501, AN/929, Environmental technical manual on the use of procedures in the noise certification of aircraft, third edition, 2004

- OASPL : Overall sound pressure level
- OASPL_A : A-weighted overall sound pressure level
- PNL : Perceived noise levels
- PNLT : Tonal corrected perceived noise levels
- Ck : Tonal correction
- LGB : Last good band.

The comma separated file *TimeIntegratedMetrics_DPN**M**.csv* contains data:

- Micid : Microphone identification number
- EPNL : Effective perceived noise level
- t1 : 10dB down time instance before maximum PNLT
- t2 : 10dB down time instance after maximum PNLT
- SEL : Sound exposure level
- t3 : 10dB down time instance before maximum A-weighted OASPL
- t4: 10dB down time instance after maximum A-weighted OASPL.

5.4. Certification data

5.4.1. ICAO Annex 16 Chapter 8

For those helicopters certified against ICAO Annex 16, Chapter 8, take-off, level flight and approach procedures were measured and processed to obtain corrected EPNL. The 'simplified' method (App. 2, section 8.3 of ICAO Annex 16**Error! Bookmark not defined.**) has been applied to adjust the data to reference conditions. The obtained levels are compared to those in the EASA noise certification data base to assess the data quality.

For each data point representing a certification procedure, the corrected perceived noise levels and applied corrections are stored in *CorrectedEPNL_DPN**M**.csv.* The columns give the results for the left, centre and right microphone and the rows give:

- EPNL: Effective Perceived Noise Level in EPNdB
- t1: 10dB down time instance before maximum PNLT
- t2: 10dB down time instance after maximum PNLT
- EPNLr: EPNL corrected to reference profile and reference conditions
- Delta1: Adjustment for differences in the PNLTM spectrum under test and reference conditions

- Delta2: Adjustment for the difference in noise duration, taking into account the differences between test and reference aircraft speed and position relative to the microphone

- Deltap: Adjustment for when the PNLT for a secondary peak, identified in the calculation of EPNL from measured data and adjusted to reference conditions, is greater than the PNLT for the adjusted PNLTM spectrum

- SEL: Sound Exposure Level

- t3: 10dB down time instance before maximum A-weighted OASPL

- t4: 10dB down time instance after maximum A-weighted OASPL.

In the file *CertificationMerged.csv* the average over all runs is presented for the level flight, take-off and approach reference procedures on each row. The columns give the EPNLr for the left, centre and right microphone, and the arithmetic average value over these three microphones.

5.4.2. ICAO Annex 16 Chapter 11

For those helicopters certified against ICAO Annex 16, Chapter 11, the level flight procedure was measured and processed to obtain corrected SEL. The method described in Appendix 4 of ICAO Annex 16**Error! Bookmark not defined.** has been applied to a djust the data to reference conditions. The obtained level is compared to that in the EASA noise certification data base to assess the data quality.

For each data point representing a certification procedure, the corrected noise levels and applied corrections are stored in *CorrectedEPNL_DPN**M**.csv.* The columns give the results for the left, centre and right microphone and the rows give:

- EPNL: Effective Perceived Noise Level in EPNdB

- t1: 10dB down time instance before maximum PNLT

- t2: 10dB down time instance after maximum PNLT

- EPNLr: EPNL corrected to reference profile and reference conditions

- Delta1: Adjustment for differences in the PNLTM spectrum under test and reference conditions

- Delta2: Adjustment for the difference in noise duration, taking into account the differences between test and reference aircraft speed and position relative to the microphone

- Deltap: Adjustment for when the PNLT for a secondary peak, identified in the calculation of EPNL from measured data and adjusted to reference conditions, is greater than the PNLT for the adjusted PNLTM spectrum

- SEL: Sound Exposure Level

- t3: 10dB down time instance before maximum A-weighted OASPL

- t4: 10dB down time instance after maximum A-weighted OASPL.

5.5. Hemisphere data

This section provides an overview of the hemisphere data contained in this dataset. For the hemisphere processing details refer to Section 4.

Hemispheres are derived from measured 1/3 octave band spectra, acquired at a sample rate of 0.1s. The plot in *t01_Mic**N**_DPN**M**.png* provides an overview of the hemisphere source data obtained by a single microphone as function of recorded time. The figure contains a spectrogram (noise levels scaled to reference distance and atmosphere), the observer angles and distance with respect to the helicopter, masked band detection indication and a sample of scaled noise levels at the hemisphere reference distance (60m). An example is given in Figure 6.

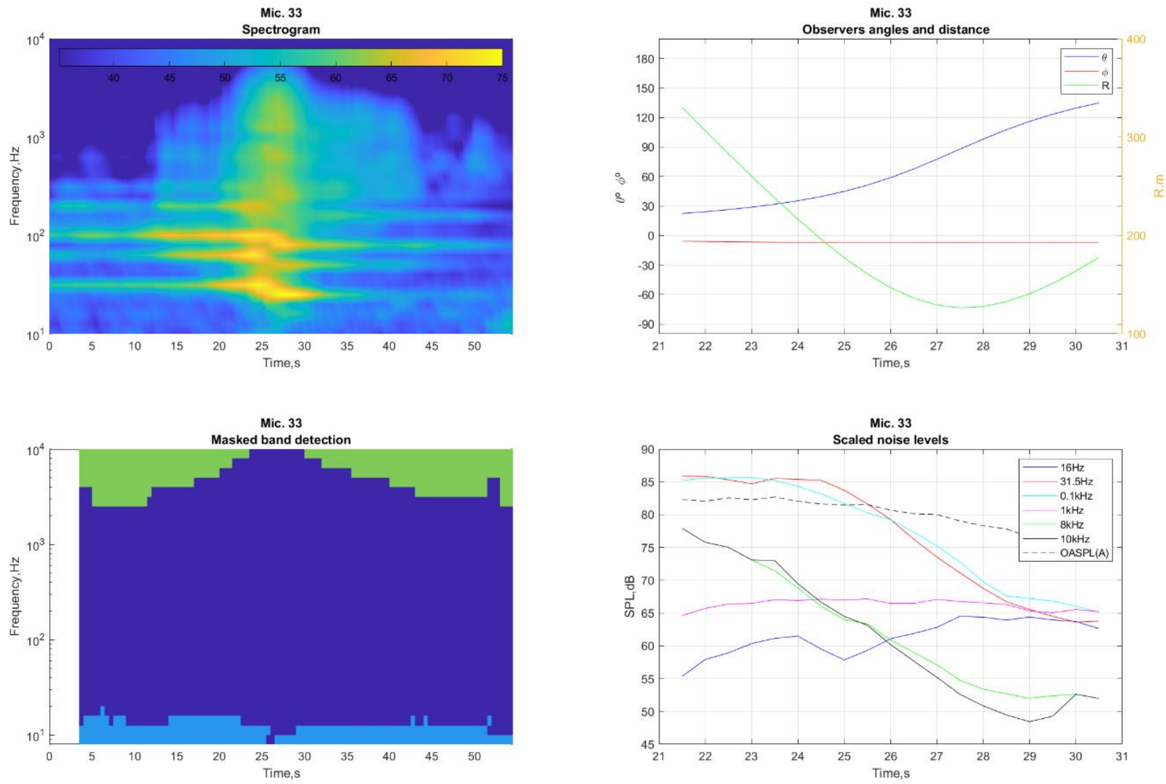

Figure 6: Spectrogram 1/3 octave band spectra every 0.1s [top left]; polar angle (theta), azimuth angle (phi) and distance from helicopter to microphone (R) [top right]; masked band detection, (dark blue = 3dB>background noise, light blue = masked and uncorrected, green = masked and reconstructed, yellow = not masked, equal energy correction) [bottom left]; scaled noise levels for several 1/3 octave band frequencies & A-weighted OASPL [bottom right] (Cabri, Microphone 11 at position P5) [Source: Anotec]

Figure 7 is an example of the hemisphere overview chart given in the file *HemisphereOverviewDPN**M**.png*. The number of averages per hemisphere bin (intervals of 10º), A-weighted overall sound pressure level, the Doppler shifted main blade passage frequency (BPF) and broadband components are plotted to provide a quick overview of the acquired hemisphere data.

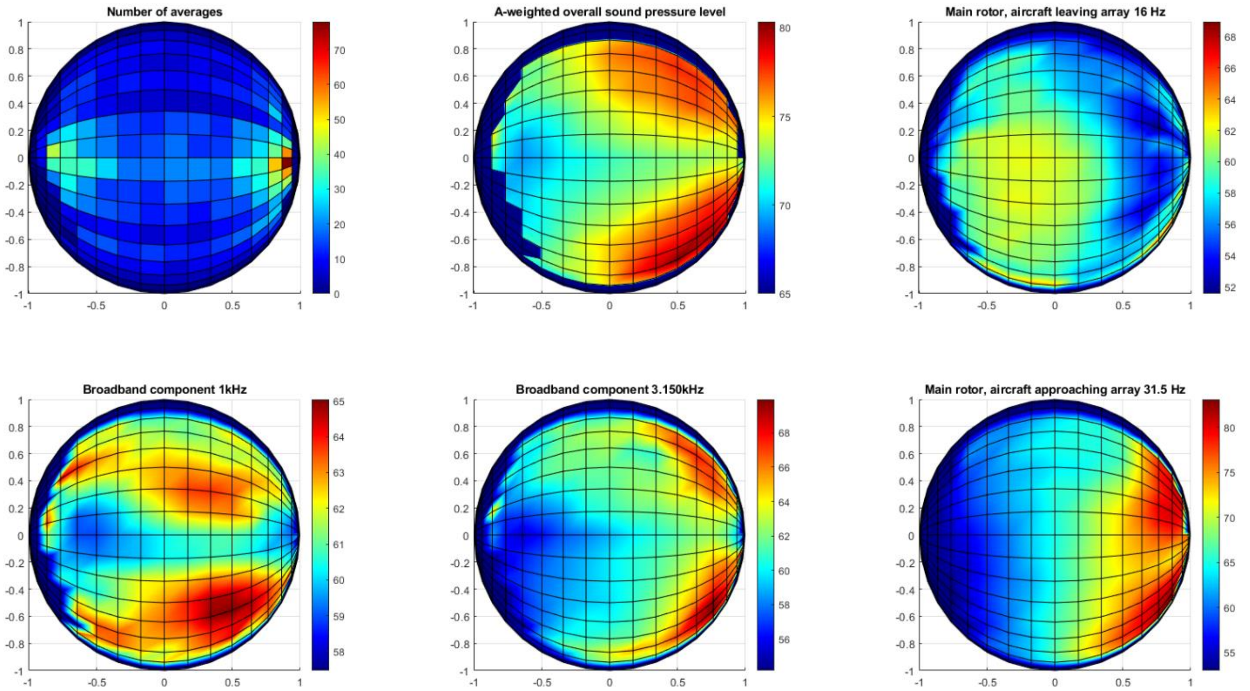

Figure 7: Hemisphere overview chart for the Cabri [Source: Anotec]

In the figures provided by *HemispherePartJ_DPN**M**.png* the hemisphere data for individual 1/3 octave bands are given.

The hemisphere data for a test point is also provided in table format and can be found in the comma separated data file *Hemisphere_DPN**M**.csv*. The file is structured in the following columns:

- Theta : Polar angle
- Phi : Azimuth angle
- TertzBand_1 : 10Hz band
- TertzBand_2 : 12.5Hz band

  . .
  . .
  . .

- TertzBand_n : n+9 1/3 octave band
- OASPL : Overall sound pressure level
- nAvr : The number of averages within the bin.

The polar angle theta varies between 0º and 180º and the azimuth angle phi between -90º and 90º. When no data is acquired for a data bin the sound pressure level (SPL) is given the value *–Inf*. The number of averages is a fractional value (not an integer) due to the applied weighted averaging.

Finally, the merged hemisphere data (weighted average of the repeat runs) is given in the file *[helicopter type]_[procedure]_[IAS]_[gamma].hem*. This is a generic acoustic data (GAD) file compatible with HELENA (HELicopter Environmental Noise Analysis tool). The structure of the file is given below:

```
[TITLE]
17 !   #      Table  constants
POLDIST              60 ! Distance at which hemisphere is defined
FREEFIELD             2 ! Atmospheric absorption included in hemisphere
NOVALUE            -999 ! no value indicator
TAMB               298.1   ! Ambient temperature, deg Kelvin
RELHUM              70.0   ! Relative humidity, %
PAMB            101325.0   ! Ambient pressure, Pa
Tm                  16.5   ! Measurement ambient temperature at 10m, deg Celsius
RHm                 73.2   ! Measurement relative humidity at 10m, %
Pm              101079.2   ! Measurement ambient pressure at 10m, Pa
RmOmega            102.6   ! RotorRPM, rpm
ACSPEED             49.9   ! Indicated airspeed, kts
GAMM                -7.0   ! Path angle, deg
PITCH               -6.8 ! Pitch, deg
ROLL                 3.4   ! Roll, deg
TW                   5.2   ! Total wind, kts
CW                   4.6   ! Cross wind, kts
HW                   2.4   ! Head wind, kts
2 !   Number  of  axis
THETAOBSAC  19   0   3   0
      0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180
PHIOBSAC  19   0   3   0
      -90 -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90
0 !   NPARAD: Additional   point   dependent
parameters
NFREQ        31
    10 12.5 16 20 25 31.5 40 50 63 80 100 125 160 200 250 315 400 500 630 800
1000 1250 1600 2000 2500 3150 4000 5000 6300 8000 10000
PHIOBSAC=   0.000
.... (DATABLOCK)
```

where the data block contains the 1/3 octave band hemisphere data as function of polar angle (THETAOBSAC) for the given PHIOBSAC. When no data was collected for a given data bin, the value -999 is set. The first six table constants define the hemisphere reference distance (POLDIST), the content of the hemisphere (FREEFIELD), the no-value indicator (NOVALUE) and the hemisphere atmospheric conditions (TAMB, RELHUM and PAMB). The other nine parameters record the average conditions (over multiple runs) at which the hemisphere data was acquired. The metadata included in the merged hemisphere file are:

- Tm: Measurement ambient temperature at 10m, deg Celsius
- RHm: Measurement relative humidity at 10m, %
- Pm: Measurement ambient pressure at 10m, Pa
- RmOmega: Rotor RPM, %
- ACSPEED: Indicated airspeed, kts
- GAMM: Path angle, deg
- PITCH: Pitch, deg
- ROLL: Roll, deg
- TW: Total wind, kts

- CW: Cross wind, kts
- HW: Head wind, kts.

In *[helicopter type]_[procedure]_[IAS]_[gamma].sum* a summary is given of the individual hemispheres that were used and those that were rejected in the merger of hemispheres. An example of a summary is given below:

S300_Takeoff_41kts_9deg
merged hemispheres:
Hemisphere_3108 gamma: 10.1 IAS:35.7 RPM:100.0
Hemisphere_3110 gamma: 9.64 IAS:36.8 RPM:100.0
rejected hemispheres:
Hemisphere_3109 gamma: 9.44 IAS:34.1 RPM:100.0

5.6. Helicopter data

The file *FTRDataNominal_DPN**M**.png* present the helicopter position, indicated airspeed (IAS) and main rotor RPM during a test run. The former file shows the margins with respect to the mean, whereas the latter shows the flight track and margin with respect to the reference. An example is given in

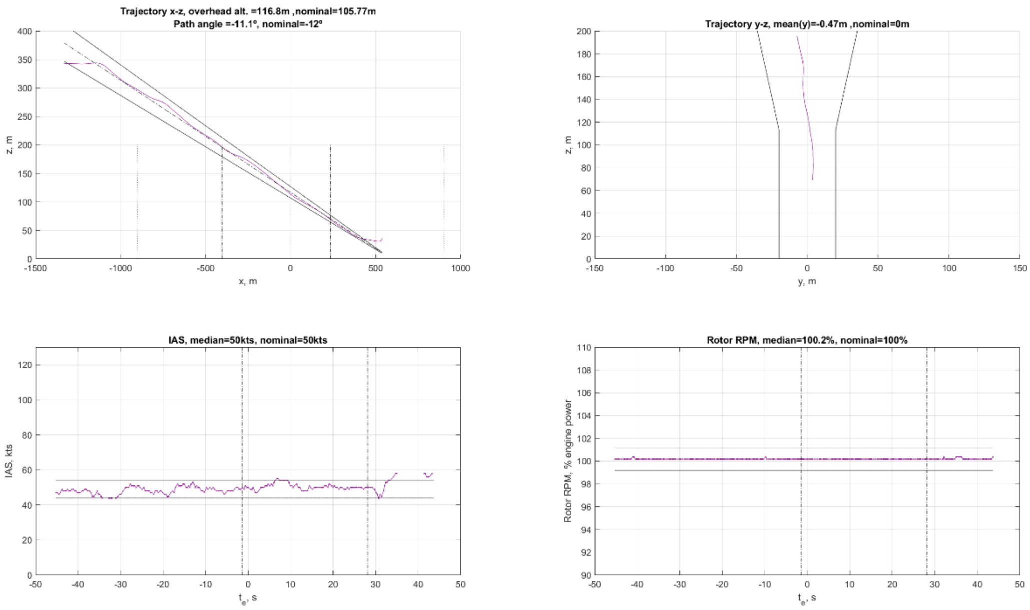

Figure 8. Note that the measured values for IAS and RPM are rounded to an integer value in the digitization process. In addition, the helicopter data for helicopter position and IAS/RPM for the 10dB period are stored in the files *FTRGPS_DPN**M**.csv* and *FTRSC_DPN**M**.csv* respectively.

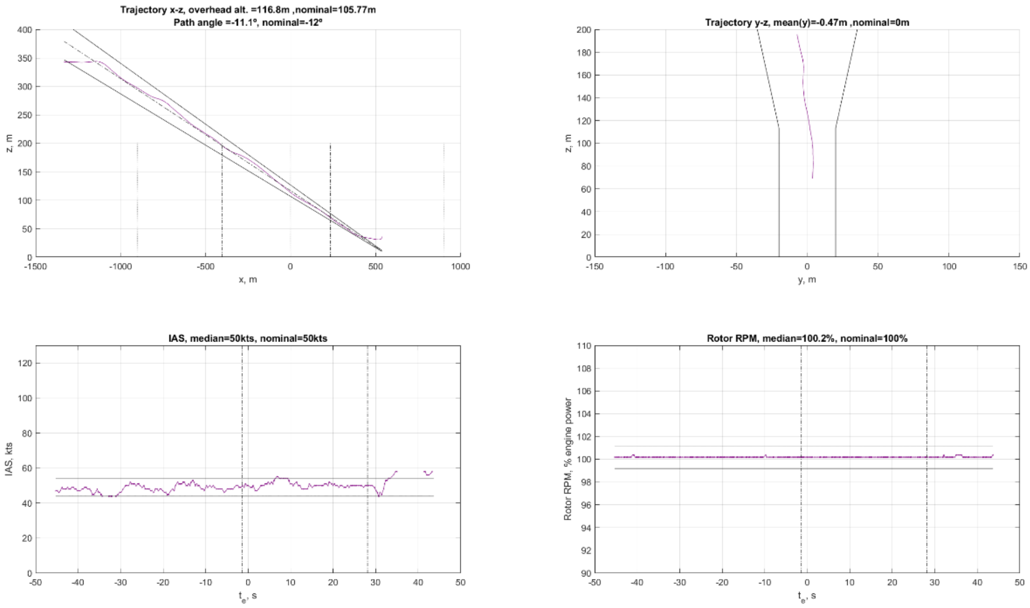

Figure 8: Helicopter position, Indicated Air Speed (IAS) and rotor RPM, 10dB down period is indicated by the dash-dotted vertical lines [Source: Anotec]

6. References

* M. Tuinstra and J. Stevens, Helicopter noise calculation method, D3.2, 2017
* ICAO annex 16, Environmental protection, vol. 1, Aircraft noise, sixth edition, 2011
* DOC 9501, AN/929, Environmental technical manual on the use of procedures in the noise certification of aircraft, third edition, 2004
* SAE ARP5534, Application of pure-tone atmospheric absorption losses to one-third octave band data, 2013.

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