Dedicated to innovation in aerospace

NLR-CR-2016-089 | July 2016

Verification of Heathrow Noise and Track Keeping Systems

CUSTOMER: Community Noise Forum commissioned by Heathrow Airport Limited

NLR – Netherlands Aerospace Centre

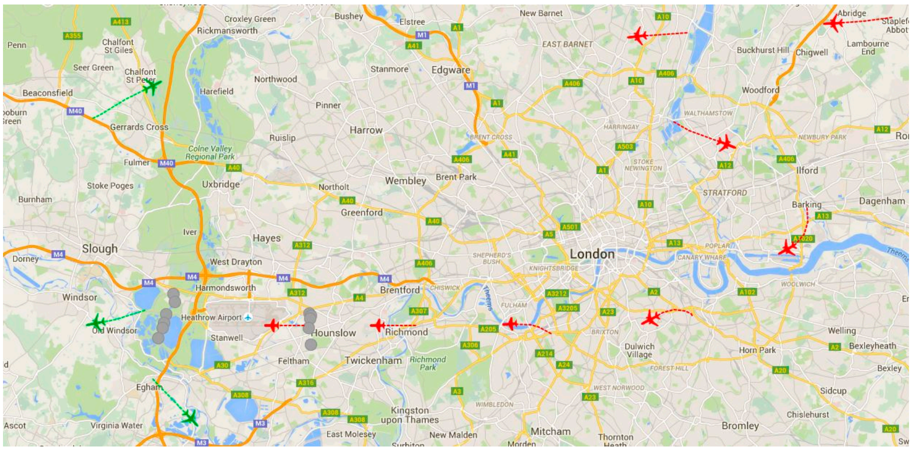
Netherlands Aerospace Centre

NLR is a leading international research centre for aerospace. Bolstered by its multidisciplinary expertise and unrivalled research facilities, NLR provides innovative and integral solutions for the complex challenges in the aerospace sector.

NLR's activities span the full spectrum of Research Development Test & Evaluation (RDT & E). Given NLR's specialist knowledge and facilities, companies turn to NLR for validation, verification, qualification, simulation and evaluation. NLR thereby bridges the gap between research and practical applications, while working for both government and industry at home and abroad.
NLR stands for practical and innovative solutions, technical expertise and a long-term design vision. This allows NLR's cutting edge technology to find its way into successful aerospace programs of OEMs, including Airbus, Embraer and Pilatus. NLR contributes to (military) programs, such as ESA's IXV re-entry vehicle, the F-35, the Apache helicopter, and European programs, including SESAR and Clean Sky 2.
Founded in 1919, and employing some 650 people, NLR achieved a turnover of 73 million euros in 2014, of which three-quarters derived from contract research, and the remaining from government funds.

For more information visit: **www.nlr.nl**

Verification of Heathrow Noise and Track Keeping Systems



REPORT NUMBER
NLR-CR-2016-089

AUTHOR(S)
H.W. Veerbeek
D.H.T. Bergmans

REPORT CLASSIFICATION
UNCLASSIFIED

DATE
July 2016

KNOWLEDGE AREA(S)
Environmental aircraft noise

DESCRIPTOR(S)
Aircraft Noise
Environmental Monitoring
System Verification
Modelling
Noise Measurement

Problem area

In 2014 trials were conducted to test concepts and techniques to examine how Heathrow's airspace can be better managed in the future. These trials are related to the Government's plans to update and modernise UK's airspace.

During the trials the number of complaints increased and remained relatively high afterwards. In addition to this increase, residents questioned the accuracy and reliability of the data provided through the airport's Noise and Track Keeping system (ANOMS) and the publicly accessible WebTrak system.

Description of work

In response to the above mentioned concerns, the Heathrow Community Noise Forum was established. One of the first objectives stated by the Community Noise Forum is to get more confidence in the information Heathrow provides to local communities. An independent verification is therefore conducted by the Netherlands Aerospace Centre (NLR). Hereby, tracks are held against tracks collected through other means than Heathrow's systems and calculated noise results are held against noise measurements to see if the publicly provided information is plausible. The scope of this work is developed and agreed with members of the Community Noise Forum and funded by Heathrow Airport Limited.

Results and conclusions

The overall conclusion of the verification study is that there is no indication which reduces the trustworthiness of the information presented. The information available via Heathrow's Noise and Track Keeping system as well as via the publicly accessible WebTrak system is based on correct input, is processed in a correct way and is complete.

The noise models ANCON2 and INM are internationally accepted models and considered to be the best practice. Based on the findings Heathrow's noise climate is assessed adequately, both by the UK-CAA and Anderson Acoustics. Thus from NLR's perspective the models are used in a good manner and the results of these models are trustworthy.

Applicability

The results of the study answer the questions of the Community Noise Forum. The positive outcome of the study gives confidence in the correctness of the information presented to the community, either through ANOMS, WebTrak or the used models ANCON2 and INM.

NLR
Anthony Fokkerweg 2
1059 CM Amsterdam
p) +31 88 511 3113 f) +31 88 511 3210
e) info@nlr.nl i) www.nlr.nl

Dedicated to innovation in aerospace

NLR-CR-2016-089 | July 2016

Verification of Heathrow Noise and Track Keeping Systems

CUSTOMER: Community Noise Forum commissioned by Heathrow Airport Limited

AUTHOR(S):

H.W. Veerbeek NLR
D.H.T. Bergmans NLR

NLR - Netherlands Aerospace Centre

CUSTOMER	Community Noise Forum commissioned by Heathrow Airport Limited
CONTRACT NUMBER	103769549
OWNER	Heathrow Airport Limited
DIVISION NLR	Aerospace Operations
DISTRIBUTION	Limited
CLASSIFICATION OF TITLE	UNCLASSIFIED

APPROVED BY :		
AUTHOR	REVIEWER	MANAGING DEPARTMENT
H.W. Veerbeek D.H.T. Bergmans	R.H. Hogenhuis	P.L.J. Eijssen
DATE 05 07 16	DATE 05 07 16	DATE 05 07 16

Contents

Abbreviations

ACRONYM	DESCRIPTION
ADSB	Automatic Dependent Surveillance – Broadcast
AIP	Aeronautical Information Publication
ANCON	Airport Noise CONtour model
ANOMS	Airport Noise and Operations Management System
BA	British Airways
B&K	Bruel & Kjaer
CAA	Civil Aviation Authority
DfT	Department for Transport
ECAC	European Civil Aviation Conference
FAA	American Federal Aviation Authority
Ft	Feet
FL	Flight Level
ICAO	International Civil Aviation Organization
INM	Integrated Noise Model
LA_{max}	Peak level (noise metric)
mbar	Millibar; bar is a metric unit of pressure
NATS	National Air Traffic Services
NLR	Netherlands Aerospace Centre
NMT	Noise Monitoring Terminal
NTK	Noise and Track Keeping system
QNH	Air pressure at mean sea level
SEL	Sound Exposure Level (noise metric)
SI	International System of units
WebTrak	Online system that allows a view how aircraft operate in the area

1 Introduction

In 2014 trials were conducted to test concepts and techniques to examine how Heathrow's airspace can be better managed in the future. These trials are related to the Government's plans to update and modernise UK's airspace.

During the trials the numbers of complaints increased and remained relatively high afterwards. In addition to this increase residents have questioned the accuracy and reliability of the data provide through the airport's Noise and Track Keeping system and the publicly accessible WebTrak system.

In response to the above mentioned concerns, the Heathrow Community Noise Forum was established. This forum brings together community representatives, local councillors and representatives from NATS, CAA, DfT and BA, along with Heathrow employees. The aim of the Forum is to keep residents and stakeholders informed on airspace plans and improve the understanding on the associated issues.

One of the first objectives stated by the Community Noise Forum is to get more confidence in the information Heathrow provides to local communities. An independent verification is therefore conducted by the Netherlands Aerospace Centre (NLR). The scope of the work is developed and agreed with members of the Community Noise Forum and funded by Heathrow Airport Limited. Hereby, tracks are held against tracks collected through other means than Heathrow's systems and calculated noise results are held against noise measurements to see if the public provided information is plausible.

1.1 Main actions required to reach the objectives

To meet the objectives of the study the following detailed actions were defined:

1. Verification of the ANOMS and WebTrak systems information in regard of the following aspects:
   - The lateral accuracy of the mapping and presentation of flight tracks over the ground
   - The vertical accuracy of the flight tracks in relation to height/altitude over the ground
   - The capture rate of the data, i.e. are all the flights operating from Heathrow accounted for in the system.

2. Assessment of individual flights to demonstrate the level of accuracy displayed by the ANOMS and WebTrak systems.

3. Assess whether there has been any historical change in the past 5 years to the ANOMS or WebTrak systems which may have altered the accuracy of the information.

4. Verification whether the noise models used by Heathrow are compliant with international standards and provide an accurate assessment of the calculated noise climate.

1.2 Heathrow Noise and Track Keeping Systems

For monitoring purposes of the Heathrow operations, airport-wide systems including ANOMS and WebTrak are used.

ANOMS

Airport Noise and Operations Management System (ANOMS) is the main Noise and Track Keeping (NTK) system at Heathrow. ANOMS receives radar data from National Air Traffic Services (NATS) Air Traffic Control radars, which provides information about the height of an aircraft above airport elevation, the track it has flown, its ground speed at any particular point and the aircraft's call-sign. ANOMS also provides noise measurement results for several measurement locations in the vicinity of Heathrow.

WebTrak

WebTrak is an online system that allows those affected by aircraft operations at Heathrow to locate their residence and view how aircraft operate in their area. It has been in operation at Heathrow since 2008. Currently the system shows information on the last 12 months of operations, with a 20-minute delay.

1.3 Noise Models used to compute noise around Heathrow

To get an understanding of the total noise impact in the vicinity of Heathrow, noise calculations are executed using noise models.

ANCON2

The official model used by the UK Government and Heathrow Airport to monitor long term trends and compliance with regulatory requirements is ANCON2. This model is under management of United Kingdom's Civil Aviation Authority (UK-CAA). Their model is compliant with the international standards ECAC.doc29 and ICAO.doc.9911. Recently, in the context of a European Civil Aviation Conference (ECAC), ANCON2 is verified with other European models like STAPES by EUROCONTROL, NORTIM by SINTEF and NLR's doc.29 model. The verification results show a very good match, which makes ANCON2 results trustworthy from NLR's perspective.

INM

For Heathrow's trend analysis – executed by Anderson Acoustics – the Integrated Noise Model (INM) by the American Federal Aviation Authority (FAA) is used. This model is complaint with ICAO.doc.9911, however has currently minor differences with the ECAC.doc29 methodology. INM was also included in the ECAC model verification study mentioned above. Absolute results may have small differences between ANCON2 and INM, but if the same input is used the same trend is to be observed.

Section 2.4 elaborates further on the use of the mentioned noise models.

1.4 Reading guidelines

Headlines are enclosed is a textboxes like this one. These boxes can typically be found at the beginning of paragraphs and give brief overviews.

In Chapter 2 an overview of the approach is given of all the elements examined during this verification study. Subsequently the chapters onwards present the results for each element. At the end – in chapter 7 - conclusions are drawn.

Appendices are provided to describe more detailed results of explain relevant aspects of the study in more detail.

For readability purposes information textboxes are added to the report. Those boxes typically provide more detailed information relevant in the context of the report. These textboxes do not contain essential information to follow the storylines.

2 Overview of the verification study

The initial approach of this study was discussed and agreed upon with members of a working group of the Community Noise Forum, all being community representatives. Together with the forum independent data resources were selected as trustworthy for verifying purposes.

On the basis of the underlying questions, this chapter gives a brief overview of the different parts of the verification study. For each part the task and approach are described. In the subsequent chapters the results are presented and explained.

2.1 Flight track data

Task: To enable community stakeholders to be confident that the aircraft are at the heights and locations that the Heathrow systems indicate.

ANOMS uses radar data from National Air Traffic Services (NATS) Air Traffic Control radars. The quality of these data is not questioned as it is continuously monitored and used to guarantee safe operation. For this reason original NATS radar data are used as a reference set for NLR's verification. To obtain this data the connection between NATS and Heathrow Airport was tapped and processed by NLR.

On request of the working group if was decided to include East and West operations (where this distinction is relevant) and to verify flight data up to 10.000ft.

The verification process followed the main processing steps in ANOMS and WebTrak:

1. Capture the incoming data
2. Reconstruct the flight tracks
3. Present the flight tracks; i.e. show them on a topographic background.

To gain extra insight the input to ANOMS (step 1) is also verified using ADS/B (Automatic Dependent Surveillance – Broadcast) data.

The results of the verification activities with respect to track data are shown in chapter 3.

2.2 Flight data completeness

Task: To enable community stakeholders to be confident that all operations from Heathrow are accounted for in the system and have correct flight attributes.

Separately from the radar data, ANOMS receives flight plan data, describing amongst others the aircraft type and the departure route. To verify the completeness of ANOMS data a flight plan data set from Heathrow's charging system is used as reference. The airport uses this data to collect landing fees. It is therefore assumed this data are highly reliable and complete.

To cover a representative sample period, four periods were taken each covering one week. The samples included periods for which working group members had reported data is missing in WebTrak.

Task: Verify flight characteristics with respect to flight type, runway and aircraft type

On request of the Community Noise Forum the verification was extended in order to check the most relevant flight characteristics, like flight type (i.e. arrival or departure), runway and aircraft type. For future analysis the forum mentioned it is utmost important these characteristics are complete and correct.

Chapter 4 shows the results of this verification.

2.3 System changes

Task: Assess whether there has been any change in the past 5 years, to the ANOMS or WebTrak systems, which may have altered the accuracy of the systems.

The assessment of historical changes is based on input provided by Heathrow Airport and Bruel & Kjaer (B&K), the supplier of the systems. The feedback is judged by NLR with respect to relevancy for impact on system accuracy (see chapter 5).

2.4 Noise modelling

Task: Verify that the Noise Models used to compute the noise load around Heathrow are compliant with international standards and provide an accurate assessment of the noise climate.

As mentioned in section 1.3, the models used are compliant with the international standards. This makes the (predefined) calculation core - see Figure 1 - and thus the models trustworthy from NLR's perspective.

The word **validation** is used when overall outcomes of models are held against the reality (measurements). The word **verification** is used when elements of the models are examined.

To provide an accurate assessment of the noise climate the models have to be fed by its user. While connecting a scenario (e.g. from a track monitoring system) and model settings to get input for the calculation core, assumptions are to be made which affect the outcome. For example aircraft settings -

like engine power - have to be defined by its user for flown (or to fly) operations. Guidance for users is given by the ECAC.doc.29 and ICAO.doc.9911 documents.

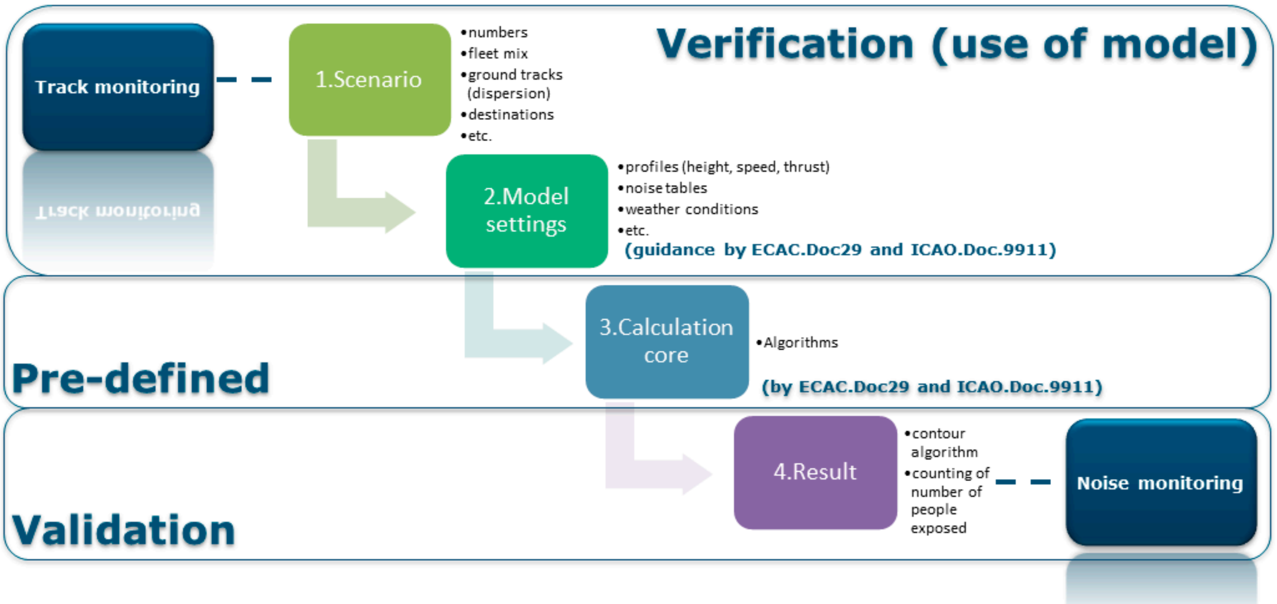


Figure 1: Schematic flow chart of environmental aircraft noise modelling

Aircraft typical used for intercontinental flights:
- Boeing 777 (B77W)
- Boeing 747 (B744)
- Airbus 380 (A388)

Aircraft typical used for European flights:
- Airbus 320 (A320)

To see if the UK-CAA and Anderson Acoustics experts made good assumptions in their calculation, the results of many individual flights are validated with noise measurements derived by ANOMS (noise monitoring). The four aircraft types in the textbox are commonly operating at Heathrow and are selected for the validation of the noise models. Flight operations of these types were input in ANCON2 and INM to get the calculation results.

At a meeting with representatives of Heathrow's community noise forum on August 2015 the preferred measurement locations and operations to be examined in the research were discussed. NLR recommended to examine departures and approaches for both East and Westley operation and to use measurement locations near and far from the airport. Reference was made to the trials in 2014 as during that time mobile measurement positions were installed further away from the airport. The forums recommendations are taken into account while conducting the validation.

For delimitation of the investigation: the NLR task does not include verifying the model settings itself as it does not match with the depth of the study. Results of the noise validation are depicted and elaborated in chapter 6.

3 Verification of flight track data

Findings:
- ANOMS uses correct input data
- ANOMS produces correct flight tracks based on the data it receives
- No incorrect flight track presentation is found.

ANOMS receives radar data from National Air Traffic Services (NATS) Air Traffic Control radars. These radars provide information on the position of an individual aircraft every 4 seconds (e.g. the typical rotation time of a radar unit). The information of all aircraft movements is transferred to ANOMS as a continuous stream of information.

ANOMS captures all the data (1) and reconstructs the aircraft flight track (2). The result is stored in ANOMS and becomes available for analyses and/or presentation on a topographic background (3). This process is illustrated in Figure 2.

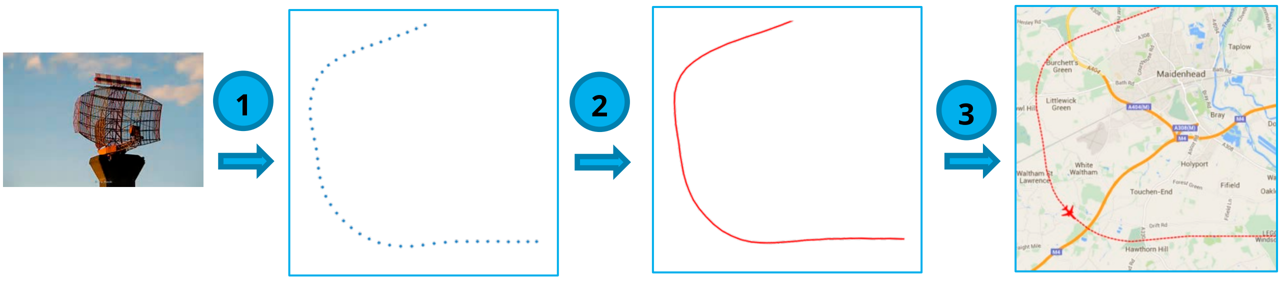


Figure 2: Processing chain from radar data to presentation

The verification of flight track data addresses each of these three steps individually, to check whether the process is done in an accurate way.

3.1 Input data processing

The first step of the chain for radar data processing is the handling of the incoming raw data. To verify this, the raw data stored in ANOMS are compared to the data sent to ANOMS. For this a copy of these data was obtained by tapping the data-connection.

3.1.1 Verification using radar data (step 1)

For this verification a reference set of radar data was collected on December the 8th of 2015. The data cover all flights in the period between 00:00 and 23:59 hours. Only the flights during this day were extracted and examined for which both data are available in the ADS/B set and in NATS radar data set (see 3.1.2).

Flight route from radar data

Figure 3 shows all the aircraft positions points, up to 10.000ft, whom are included in the verification. Figure 3 shows over 120.000 points spread over the area. Each flight consists out of multiple points (due to the rotation period of a radar unit) and the total dataset contains multiple flights.

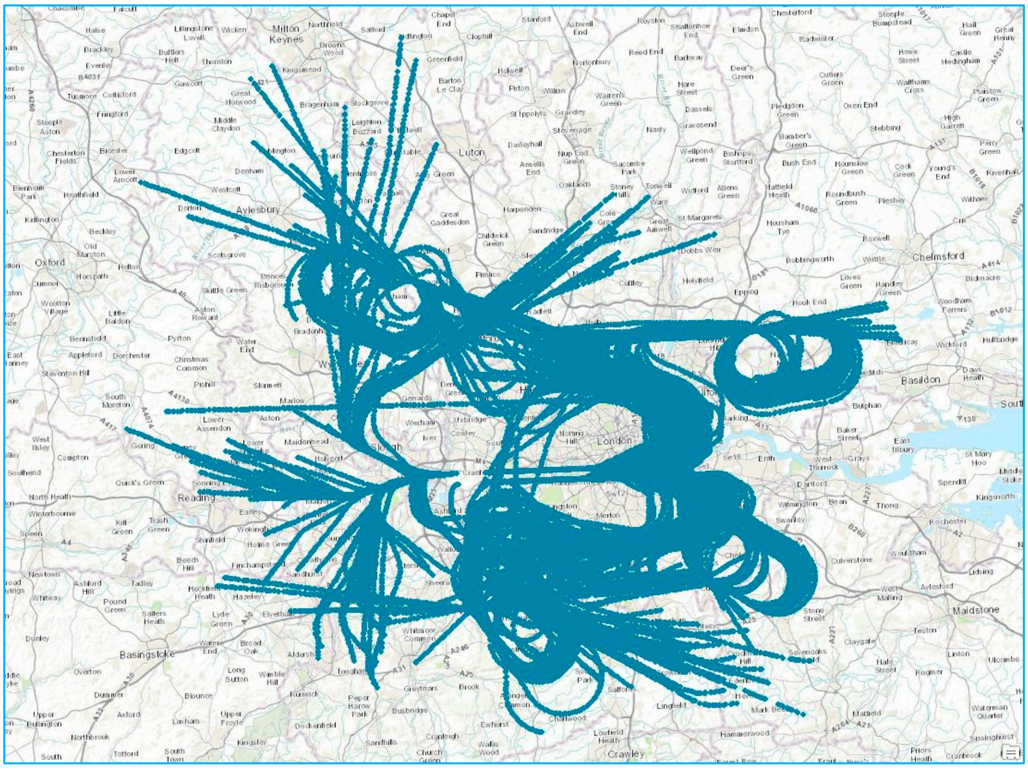


Figure 3: Graphical representation of radar data reference set

Height in radar data

The reference data contains altitudes relative to the pressure level of 1013 mbar. As ANOMS works with heights relative to the airport elevation, NATS heights are translated to the same elevation in order to make the radar reference set comparable with ANOMS (see Appendix A for further information).

Verification results

NLR noticed the raw NATS position points are not equal to the extracted data from ANOMS. This does not mean ANOMS data is incorrect. ANOMS might for instance conduct a processing step to increase computing speed before the use of the data in its software.

The aircraft position points in the raw data are compared with the NLR constructed ground tracks out of the ANOMS points. For each raw NATS point the closest distance is determined. Ultimately, the results show whether the aircraft positions in the raw NATS data are near the ANOMS ground track. The differences found are averaged over the flights and the results are given in Table 1 in the ground distance column.

For the height a similar exercise is undertaken, whereby the positions are aligned in time. This alignment makes sure that the aircraft is in the same ground position above the ground in time while NLR verifies the height differences. The differences found are again averaged over the flights and the results are given in Table 1 in the height distance column.

Table 1: Closest distances - Raw input data compared to radar reference data

	Ground distance	Height distance
Average (per flight)	5 to 20m	-30 to 90ft
Maximum (per flight)	5 to 250m	-15 to 180ft

Besides the summary of average values a distribution is generated of all the differences found in Figure 4 and Figure 5.

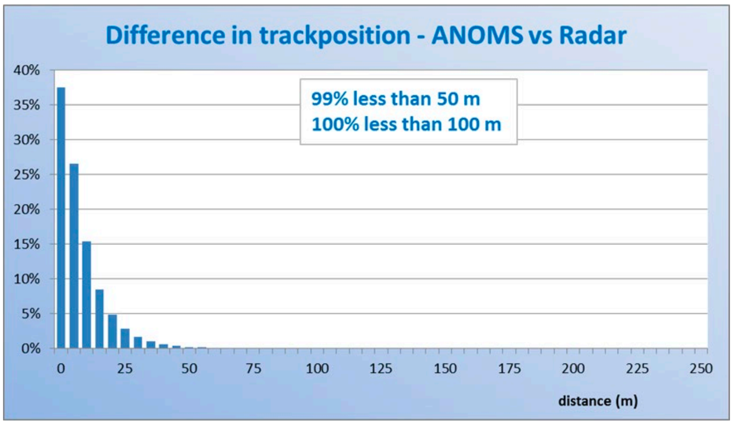


Figure 4: Distribution of differences in track position (radar data reference set)

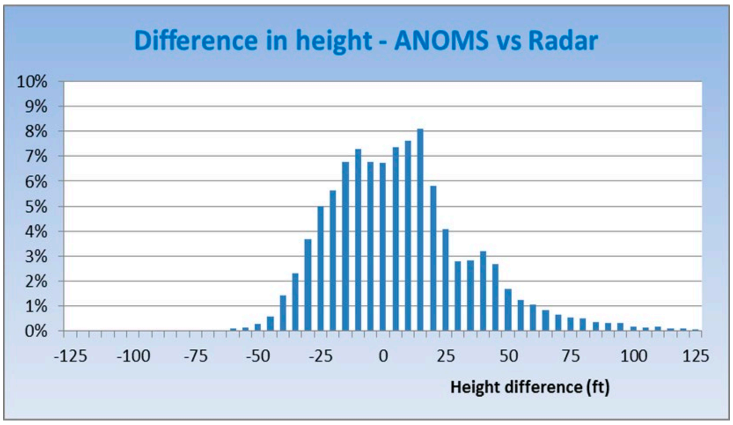


Figure 5: Distribution of differences in height (radar data reference set)

From the figures it can be concluded that ANOMS extracted data show a good match with the raw NATS data which is sent to ANOMS. In other words, if ANOMS reports the position of the aircraft, it has flown there. Ultimately, the input data processing by ANOMS gives no unwanted effects. ANOMS uses correct data as input for the second step in the processing chain.

3.1.2 Verification with ADS/B data

On top of the verification with radar data as a reference it was decided to also make a verification using data from an ADS/B source.

ADS/B (Automatic Dependent Surveillance – Broadcast) is a standard technology which broadcasts the position of the aircraft periodically. The information can be received by receivers on the ground. It is "automatic" and requires no pilot or external input. The broadcasted data is "dependent" on data from the aircraft's navigation system [Ref. 1].

Reference set description

The reference ADS/B data set covers flights at Heathrow airport on December the 8th of 2015. The set was captured via an ADS/B receiver positioned in the office block of Heathrow Airport. It covers flights in the period between 07:30 and 10:30 hours.

Figure 6 shows the aircraft positions which are included in the verification. The number of positions points is over 75.000, which is a smaller sample compared to the radar data reference. Figure 6 shows a poor coverage to the North of Heathrow; this is typically due to the antenna position. Despite the reduced number of data points it is still a more than sufficient amount of points to give insight in the difference between the use of ADS/B and ANOMS data.

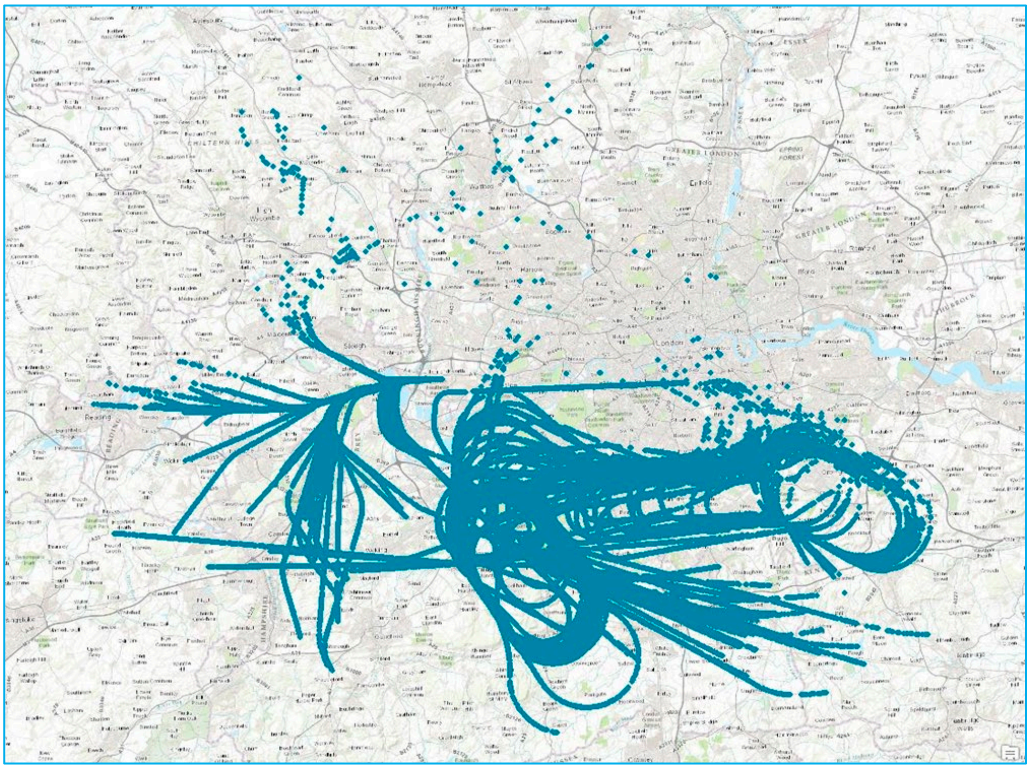


Figure 6: Graphical representation of ADS/B reference set

Removal of incorrect ADS/B data

The ADS/B data depends on data from the aircraft's navigation system. Some aircraft fly without a GPS transmitter, which means the ADS/B is based on the inertial reference system of the aircraft. This system is less accurate, whereby relatively large inaccuracies arise typically at the end of the flight. These aircraft (without a GPS transmitter) transmit ADS/B data, but flag the data as “no integrity”. Because the receiver does not filter these data, NLR removed these flights as they probably contain inaccurate flight positions.

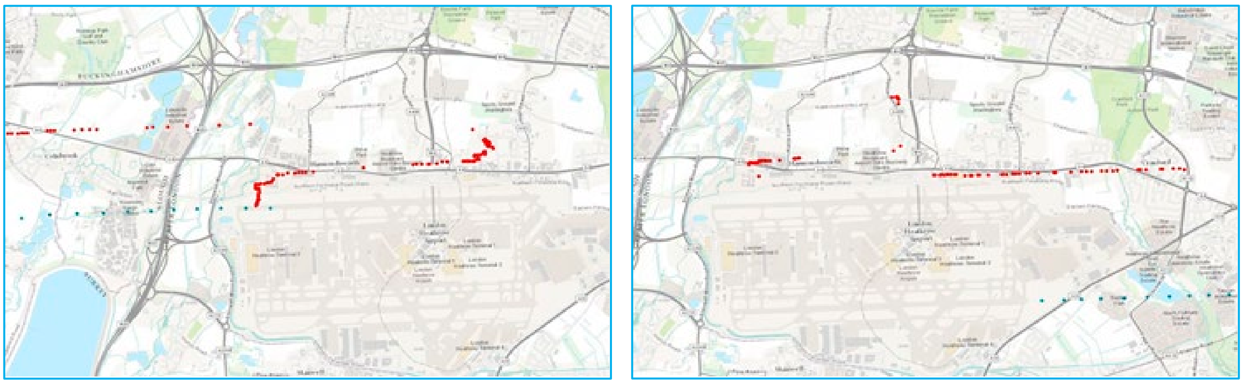


Figure 7: Examples of incorrect ADS/B flight representations

Two examples of the inaccurate flight position data are shown in Figure 7, where the aircraft lands besides the runway according to the ADS/B data. The red dotted lines show the ADS/B data whereas the blue dots represent the ANOMS raw data. For both examples it is clearly shown that the ADS/B tracks are not aligned with the (correct) runway and taxiing goes outside the airport perimeter.

<u>Height in ADS/B data</u>

The reference data of points contain altitudes relative to the pressure level of 1013 mbar. As ANOMS works with heights relative to the airport elevation, the ADS/B data is translated to this height a in order to make the radar reference set comparable with ANOMS (see Appendix A for further information).

<u>Verification results</u>

The aircraft position points in the raw data are compared with the NLR constructed ground tracks out of the ANOMS points. For each raw ADS/B point the closed distance is determined. Ultimately the results show whether the aircraft positions in the ADS/B data are near the ANOMS ground track. The differences are averaged over the flights and the results are given in Table 2 in the ground distance column.

For the height a similar exercise is undertaken, whereby the positions are aligned in time. This alignment makes sure that the aircraft is in the same ground position above the ground in time while NLR verifies the height differences. The differences found are averaged over the flights and the results are given in Table 2 in the height distance column.

Table 2: Closest distances - Raw input data compared to ADS/B reference data

	Ground distance	Height distance
Average (per flight)	5 to 150m	-55 to 40ft
Maximum (per flight)	15 to 250m	-35 to 120ft

When comparing the above results, with the earlier figures in Table 1, it is noticed the average distances show higher values. The distribution in Figure 8 also indicates this distance increase. The aircraft positions in ANOMS are therefore more in line with the raw NATS radar data. However, this does not mean the ADS/B data is wrong. ADS/B data is derived through other systems having different purposes and different measurement accuracies.

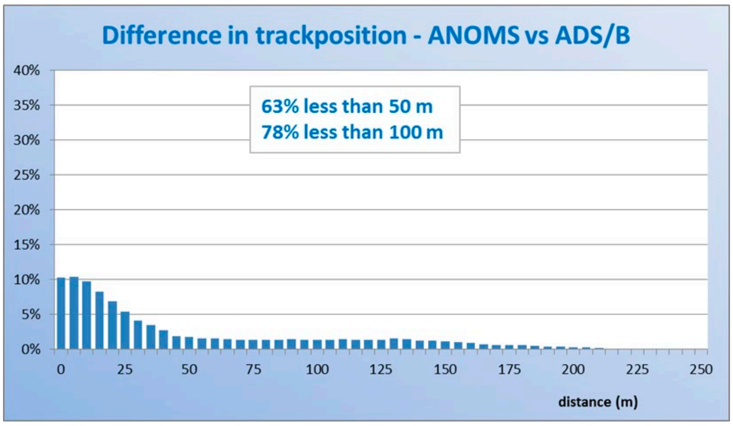


Figure 8: Distribution of differences in track position (ADS/B reference set)

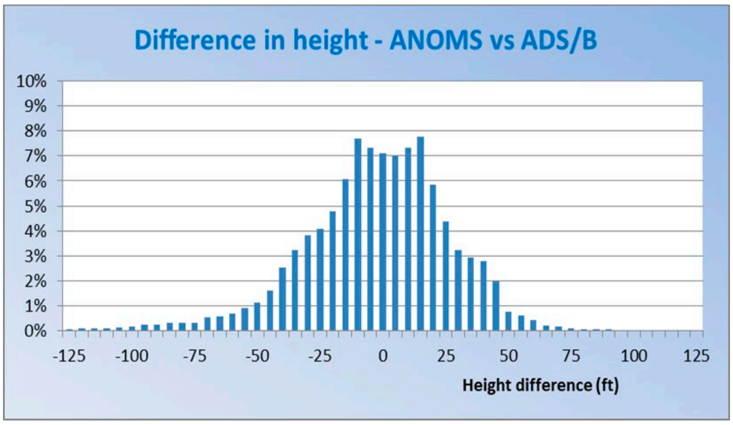


Figure 9: Distribution of differences in height (ADS/B reference set)

3.2 Ground track verification - smoothing

The second step of the radar data processing is the flight track reconstruction and smoothing. The aim of this process is to join the individual aircraft positions to one flight track (the reconstruction step). The smoothing compensates for small defects caused by the lower resolution of the input data. Figure 10 illustrates this. The figure shows the individual aircraft positions recorded by radar are not aligned for 100%. The resulting flight track is shown as the straight red line.

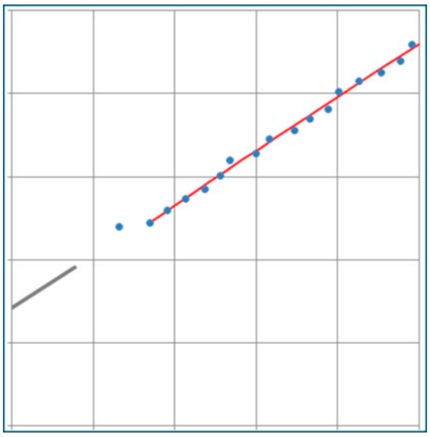


Figure 10: Example of smoothing process

Reference set description
This smoothing process can be sensitive to flight patterns (e.g. curved parts of the flight). It is therefore decided to use a larger reference set for this verification. The set includes all flights between August the 11th of 2015, 00:00 hours and August the 16th of 2015, 23:59 hours. In total 8.076 flights are included, equally divided between departures and arrivals. The figure below shows a graphical representation of the aircraft positions up to 10.000ft included in the verification (over 1.300.000 positions in total).

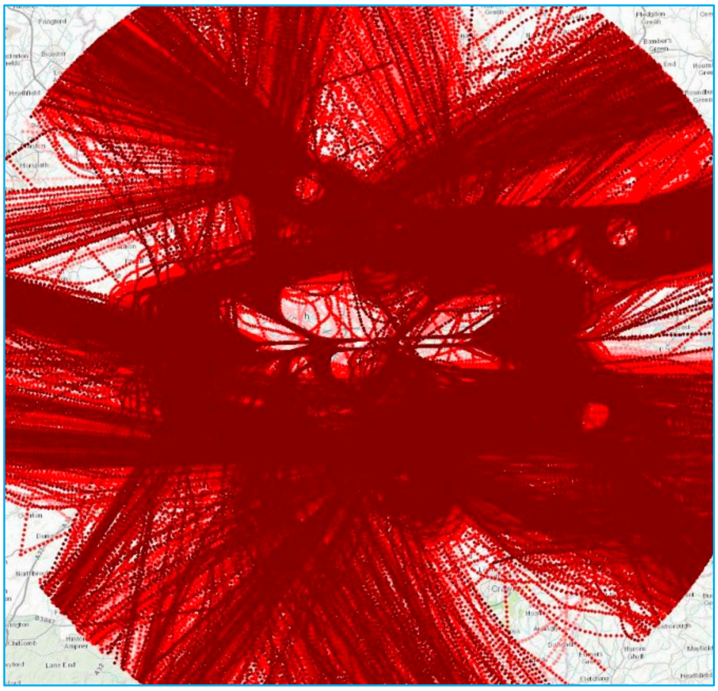


Figure 11: Test set for verification of smoothing process

As arrivals do show longer flight trajectories below 10.000ft, about 75% of the points belong to arrivals.

Verification results
The verification is conducted by determining the closest distance between an individual aircraft position and the reconstructed flight track. The differences in the horizontal plan are summarised over the flights. The average per flight and the maximum is given in Table 3 in the ground distance column. These results are classified as "good" and do match expectations based on experience with similar Dutch and German [Ref. 2] radar systems.

For the height a similar exercise is undertaken, whereby the positions are aligned in time. This alignment makes sure that the aircraft is in the same ground position above the ground in time while NLR verifies the height differences. The differences are again averaged over the flights and the results are given in Table 3 in the height distance column.

Table 3: Closest distances - Distances of point (input) to smoothed line (result)

	Ground distance	Height distance
Average (per flight)	5 to 45 m	5 to 50ft
Maximum (per flight)	10 to 150 m	20 to 150ft

Higher distances between the aircraft positions and the resulting flight track are typically found in the curved parts of a flight rather than on the straight parts. Also the maximum deviations are likely to be found in the curved parts.

The distribution of the three dimensional average and maximum distances (thus resultant of height and ground distance) per flight is depicted in Figure 12 and Figure 13. When compared to departures, the arrivals show lower average distances. This is related to the longer straight flight path of arrivals and lower ground speed close to the airport. At the same time, arrivals have more complex curved parts, like holding patterns, which result in greater maximum distances.

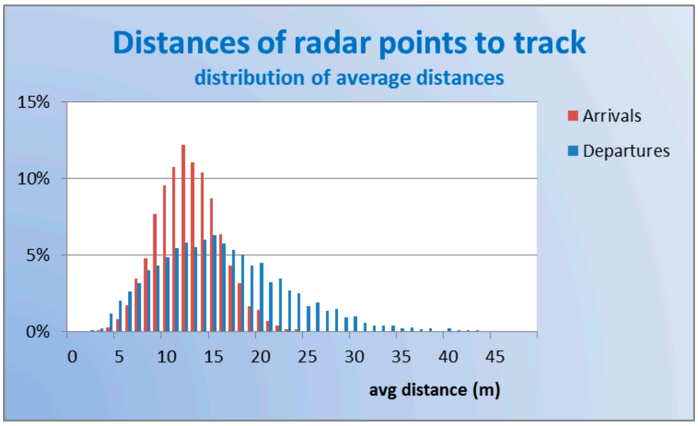


Figure 12: Distribution of average differences in track position due to flight track reconstruction

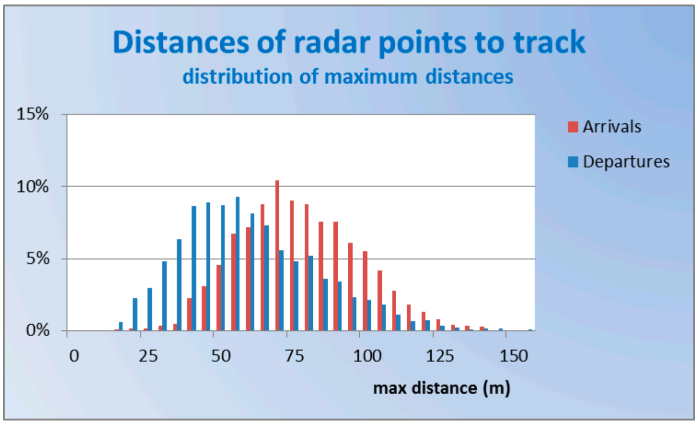


Figure 13: Distribution of maximum differences in track position due to flight track reconstruction

Overall it can be concluded that no evidence is found for undesirable deviations being introduced during the flight track reconstruction process in ANOMS.

3.3 Height profile verification - QNH

In the processing of raw data, the translation to the actual air pressure is an important step (see Appendix A). The aircraft height is derived from a reference air pressure. Flight levels in the raw data (being relative to a reference pressure level of 1013 mbar) need to be translated to actual height, thus relative to local air pressure at airfield elevation to make a safe landing.

A separate test is conducted to check whether the dependency on actual air pressure is handled correctly by ANOMS or not. To include different air pressure levels, the test was based on a longer period: August the 11th of 2015, 00:00 hours until August the 16th of 2015, 23:59 hours. The air pressure values during this period are shown in Figure 14 and vary between 1002 and 1021 mbar.

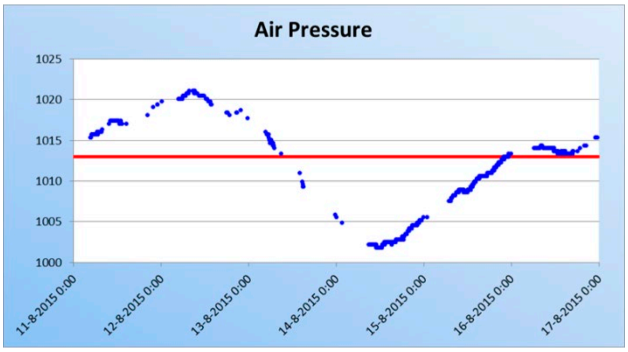


Figure 14: Air Pressure at mean sea level (QNH) during test period

For the test period the daily average height profiles (the average height at a certain distance from the runway threshold of all arrivals during a day) are plotted. Despite the variation in air pressure (20 mbar reflects a height range of 540ft) the profiles stay very well aligned (see Figure 15). Therefore it is concluded the QNH correction is applied correctly making the height values presented by ANOMS trustworthy.

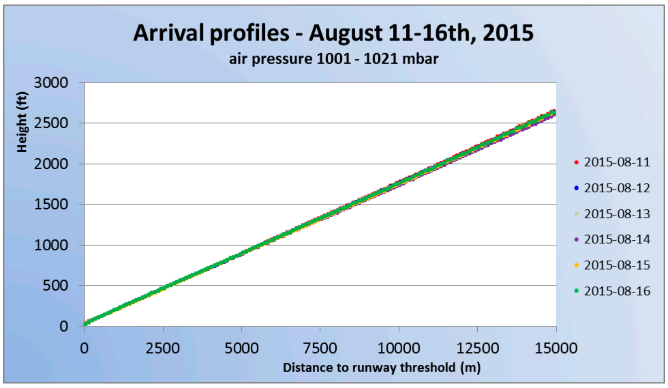


Figure 15: Daily average height profiles of arrivals between August the 11th and August the 16th, in 2015

3.4 Flight track mapping

The final step in flight track processing is the presentation of tracks on a topographical background, either in ANOMS or in WebTrak.

<u>Verification reference</u>
In the verification a visual inspection is conducted of WebTrak presentations to check whether tracks are positioned correctly on the map. In this check two references are used:

1. For arrivals the alignment with the runway center lines is checked.
2. For en-route traffic the flight paths are checked for flying over known positions (e.g. flying over beacons).

<u>Verification results</u>

In WebTrak many samples are verified. An example is shown in Figure 16, including an overlay of the runway centerline. All arrivals are correctly lined-up on the centerline of the arrival runway. No incorrect track presentation is found.

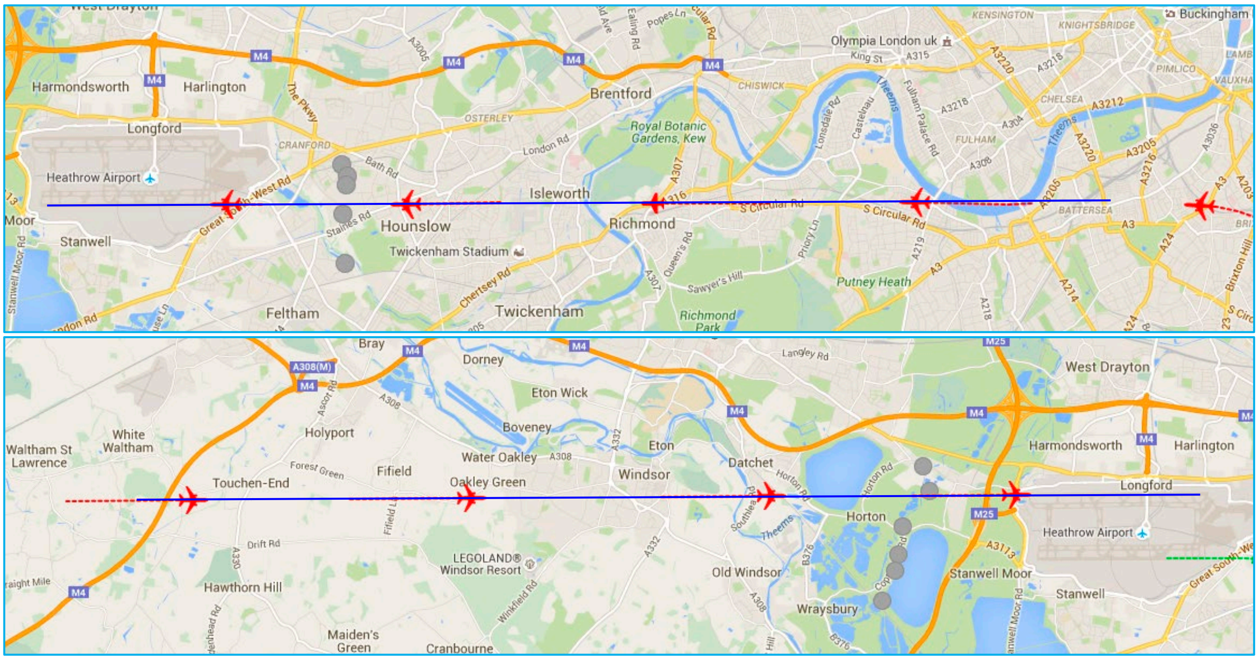


Figure 16: Flight track visualisations on WebTrak background map

The tracks at greater distances from the airport are verified via the positioning of tracks over beacons. Such beacons are used as navigational aids and can be found on charts published in an Aeronautical Information Publication (AIP). As an example, a chart showing the beacon located at Biggin Hill Airport is shown in Figure 17.

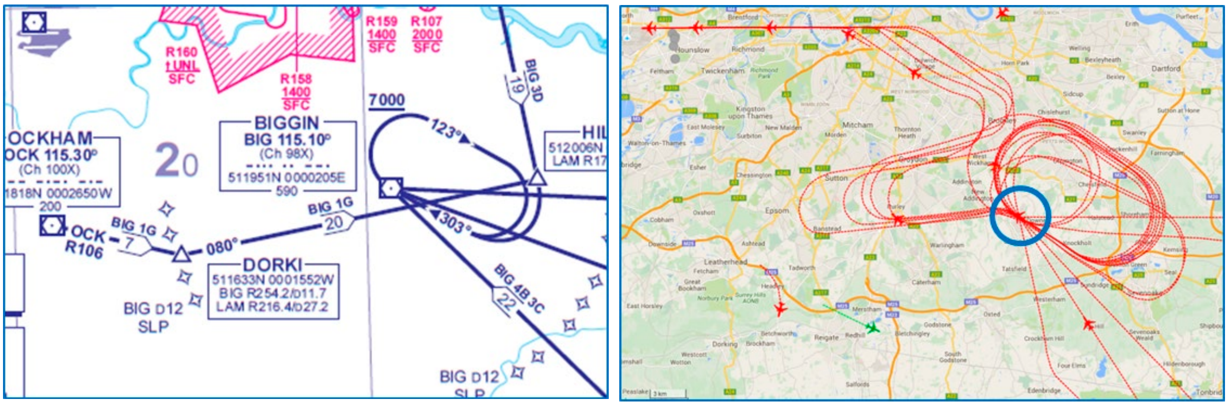


Figure 17: Part of an AIP chart and WebTrak presentation showing the standard arrivals via BIGGIN

WebTrak presentation of arrivals clearly shows the flight routes to the BIGGIN beacon, including the holding pattern, as shown on the AIP chart. Figure 18 shows an aerial chart in WebTrak, zooming in on the beacon. The beacon itself can be spotted on the map and is underneath the flightpaths as expected. Similar results are found for other beacons around Heathrow.

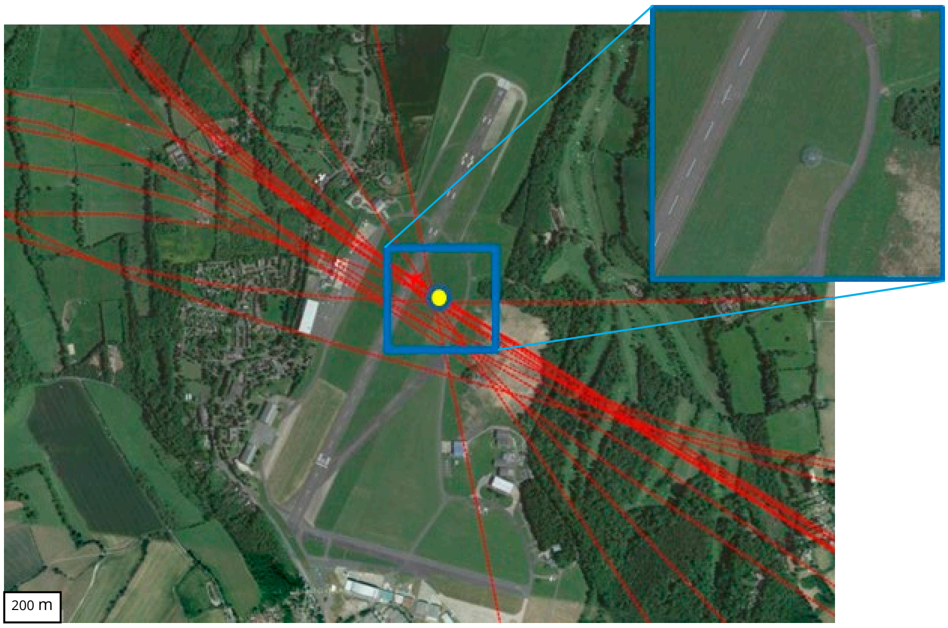


Figure 18: Aerial chart presentation in WebTrak showing flights over the BIGGIN beacon

4 Verification of flight data

Findings:
- 100% of the flights are available in ANOMS
- Not all (but 99.8%) operations were shown in WebTrak. Since the verification was conducted, system changes have been made to improve this
- Flight data show correct attributes

For the verification of the flight data, a reference set is made available from the airport charging system. In total this reference set covers 36.000 flights, which are spread over four periods of one week each.
- January the 1st until January the 7th of 2015
- March the 1st until March the 7th of 2015
- May the 1st until May the 7th of 2015
- June the 21st until June the 27th of 2015.

All flights in this reference set are verified for the ANOMS database (completeness and correctness) and partially for information shown in WebTrak.

4.1 Completeness of flights

The verification of the flight data completeness in ANOMS matches individual flights of the reference set to ANOMS flights. The completeness verification for WebTrak is conducted via manual inspection of WebTrak results and is limited to the week in January.

Verification results on completeness

It is found that all flights which are available in the reference set can be matched in the ANOMS set of flights. In WebTrak however, missing flights are found:
- 31 Flights are missing due to a missing flight track in ANOMS; these occurrences are spread over time.
- The missing flights included those flights that had been reported by community members.
- 34 additional flights are missing on January the 4th of 2015.

Follow up on the verification

On July the 4th of 2015 a system upgrade was installed (see chapter 5). After this upgrade ANOMS track building should no longer show missing flight tracks. This improvement should also have a positive effect on availability of flights in WebTrak. Both improvements are not verified within this project.

The missing WebTrak data on January the 4th were caused by a known issue related to data transfer from ANOMS to WebTrak. After this issue was identified, a process was put in place to stop this issue reoccurring.

4.2 Correctness of flight data

At the request of the Community Noise Forum the flight characteristics are verified. In other words are flight type, runway and aircraft type correct?

To verify the correctness of flight data items the ANOMS values are compared with the values in the reference set. This verification involves all 36.000 flights.

<u>Verification results on correctness</u>

1. Flight types (departure or arrival) are correct.
2. Five incorrect runway identifications are found; for these flights the runway heading is correct, but the identification of left/right runway is not.
3. For aircraft types that show differences, two names are used for the same type: e.g. 738 as well as 73H can be used to identify a Boeing 737-800, and 76E and 76B which both represent a Boeing 767-300. It was concluded that although the aircraft types show differences, the aircraft types in both sets are classified as correct as it concerns a different naming for the same aircraft type.

5 Verification of system changes

Findings:
- Several changes, all improvements, are applied to system functionality as well as input data.

A list of changes applied to the ANOMS monitoring system and to WebTrak is drawn up. This list is limited to the last five years and contains those changes that (might have) affected the flight track reconstruction or presentation. It is based on input provided by staff of Heathrow Airport as well as information provided by Bruel & Kjaer, the system provider.

The list is divided in two categories:
1. changes to system functionality
2. changes to the input data.

5.1 Changes is system functionality

The following list of system changes is provided for this assessment:
- (2011 *****) Increased accuracy of WebTrak target point speed calculation
- (2012 *****) WebTrak 4.0 upgrade:
  - The mapping of flights was improved
- (2012 *****) ANOMS-to-WebTrak configuration correction:
  - Affected the completeness of data shown in WebTrak
- (2012) Upgrade to ANOMS version 8.9.6
- (2013) Upgrade to ANOMS version 8.13.7
- (2013) The track point filtering was turned off:
  - Aiming at a performance improvement
- (2014) Enable WebTrak Sync service to send radar data to message store
- (2015) ANOMS 8 to 9.1 upgrade
- (2015 *****) Migration to Earth track builder system:
  - Data for WebTrak are now provided by the Earth system rather than by ANOMS
- (2015) The real-time radar is enabled:
  - Smaller time delay in WebTrak data.

From interviews no clear evidence is found that any of the above mentioned changes in functionality affected the output of the ANOMS and/or WebTrak systems. Based on NLR expert judgement, the updates marked with ***** might have caused a change of results.

5.2 Changes is input data

Apart from changes in system functionality, the system is modified following changes in the data stream from external data sources. Such changes require modifications in data processing or in configuration parameters.

- (2011) The so-called H23 radar was decommissioned; therefore a new primary (radar H10) and backup (Bovingdon) radar feed was configured:
  - Radars H23 and H10 displayed the data with minor differences; track alignment to the runway shows differences.
  - During use of the Bovingdon backup radar no track data are available for the parts of the Bovingdon holding area which is directly above the radar.
- (2015) A new multi-radar feed is introduced and an antiquated interface box is now bypassed:
  - This offers a better resolution in altitude (25ft instead of 100ft).
  - Flight tracks show a better alignment to the runway.
  - Less gaps in the radar data due to use of *multi*-radar data; i.e. the cone of silence problems are solved by using data from other radar.
  - No more missing flight tracks, due to by-passing of the interface box.

Cone of silence – Radar is not designed to detect aircraft directly above the radar antenna. This gap is known as the cone of silence.

The above mentioned changes in data feeds do have their effect on the results of the ANOMS and/or WebTrak systems. The changes are classified as *improvements* to the results, with respect to both the quality of the data as well as the completeness.

6 Validation of noise models

Findings: the results between measured and calculated aircraft noise in the vicinity of Heathrow show a good match. Based on these finding and since the noise modelling is within the boundaries of 'best practice' (i.e. use of the models), the assessment of the noise climate of Heathrow by UK-CAA and Anderson Acoustics is considered to be done adequately.

To see if the UK-CAA and Anderson Acoustics experts use their internationally accepted models in an appropriate way, results of many individual flights are validated with noise measurements derived by ANOMS. For delimitation of the investigation: the NLR task does not include verifying the models input itself as it does not match with the depth of the research conducted.

The purpose of models like ANCON2 and INM is to calculate the noise impact in the vicinity of airport for a longer period, typically one year. The purpose is not to estimate the exact noise level as measured on the ground for each individual flight. The models are a simplification of reality and average model settings apply to each individual flight to sum the contribution of each flight to determine the overall noise load during a year. For example, at a certain time an aircraft may be exposed to more headwind in reality then the average headwind throughout a year. This leads to a higher climb rate during take-off than assumed in the calculation, thus a higher altitude in reality and thus less noise measured on the ground. A distribution for measured results is therefore expected and considered to be normal. Nevertheless, the found distribution should be in the right order of magnitude to ensure the chosen model settings are adequate to calculate the yearly noise impact.

6.1 Noise

6.1.1 Metrics

Noise levels are the sum of energy of air vibrations at the audible frequencies over a certain time. Low frequencies include the bass sounds, high frequencies include treble sounds. There are several standard ways to sum the noise energy in time and several standard weightings of the sound energy in order to give sound results more meaning. Different metrics can be used containing different summations and different weightings. The sum of noise energy is typically expressed in the unity decibels.

The relevant metrics in the context of this reports are the peak levels (L_{Amax}) and the sound exposure levels (SEL). The 'A' annotation in the metric refers to the standardised A-weighting (see text box).

The unit of the above mentioned metrics is A-weighted decibels (dB(A)) and is the amount of noise (loudness) expressed on a logarithmic scale. The dB-values can therefore not be added directly to each other (two sources of 60 dB do not collectively expose 120dB). Here are some calculation examples of how the logarithmic scale works:

- 60 dB + 60 dB = 63,0 dB
- 5 dB x 60 dB = 67,0 dB
- 10 x dB 60 dB = 70,0 dB
- 70 dB - 60 dB = 69,5 dB

Please note that roughly speaking, the loudness difference of 1 A-weighted decibel (for instance L_{Amax}) of a noise event cannot or hardly be distinguished by the human ear. From 3 decibels onwards a human is able distinguish a difference properly.

A-weighting – The sound weighting of energy in the frequency domain to include the sensitivity of the human ear for specific frequencies. A-weighted sound is represented by dB (A).

Peak level - The maximum sound level produced during the passage of an aircraft at a specific location. The peak level (L_{Amax}) is expressed in dB (A).

SEL - All sound energy produced by an aircraft during one overflight at a specific location. The normalised SEL refers to a period of one second. One can say the SEL represents all the noise energy of the aircraft passage scaled to one second. Therefore the SEL contains the same amount of sound energy as the entire considered air passage.

6.1.2 Noise measurements

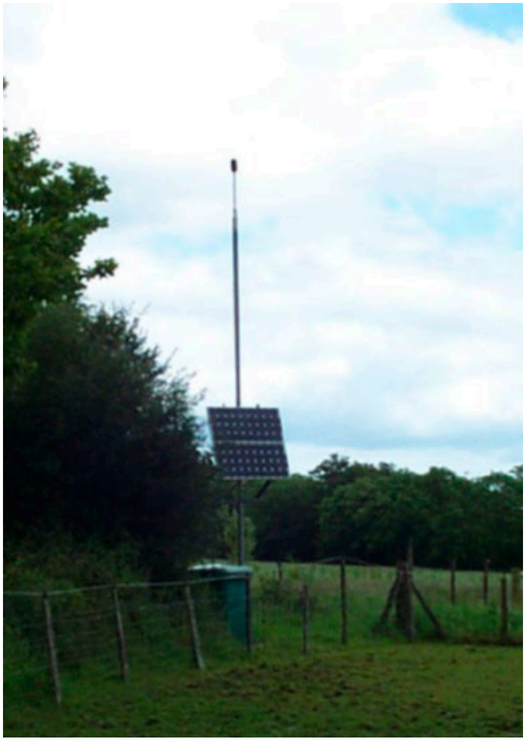


Figure 19: Noise monitoring terminal

With the current measuring system ANOMS, it is possible to record the noise of passing flights unmanned at different locations. However, noise measurements can be disrupted, for example when the noise exposure due to the passing aircraft does not sufficiently rise above the ambient background noise i.e. other non-aircraft sources interfere. In addition, measurements can become unreliable under certain conditions - according to international measurement standards -, for example when it rains. These matters are to be taken into account when using, judging and processing noise measurements. It is for these reasons that the model validation conducted is done with a large set of individual flight measurements.

For the selection of the measurement positions, the recommendations of Heathrow's community noise forum are adopted. It was recommended to examine departures and approaches for both Easterly and Westley operations. Preferably measurement locations near and far from the airport should be used. Herewith reference was made to the trails in 2014, as during that time mobile measurement terminals were installed further away from the airport.

The trail period August to December 2014 is therefore selected as measurement period and the following measurement positions are used:

- B (18 at Poyle)
- K (21 Hounslow Heath)
- 119 (NPL)
- 123 (Ascot)
- 108 (Barnes)

The above measurement positions are depicted in Figure 20

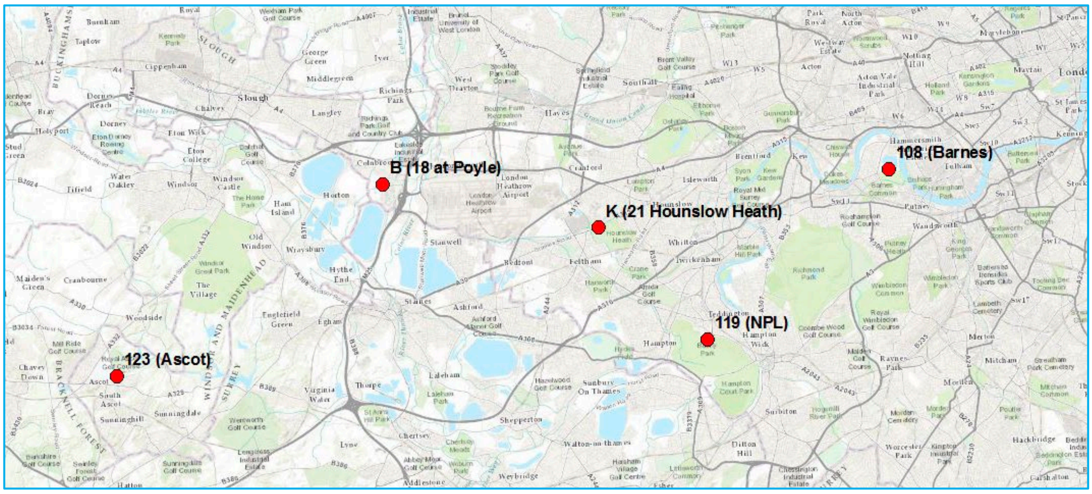


Figure 20: Noise measurement positions

For building confidence purposes the measurement results are scanned, to be sure the ANOMS results are plausible. In general, whilst the aircraft is further away from the measurement location, it is expected that noise levels will drop. In Figure 21 the measured peak levels for the individual aircraft are depicted against the distance between the measurement position and aircraft when the peak level occurred. As expected, clouds of dots (distribution) of measurement results are visible including the trend that noise levels drop while distances increase. Except in the position Ascot (123) where the levels hardly drop while the distance increases. Therefore, and as these measured levels are just above ANOMS threshold level to start recording, it is likely that disturbances occurred whilst an aircraft flew in the catchment area of the measurement position, especially for aircraft that pass the location at high distance (i.e. 2 km or more).

All collected ANOMS measurement data for the B77W aircraft are depicted in Figure 21. The clouds of points represent different operations and are typically noticeable in the upper left, upper right and lower left figures. These measurement positions are relatively close to the runway and depending on which runway the aircraft operates a cloud enfolds.

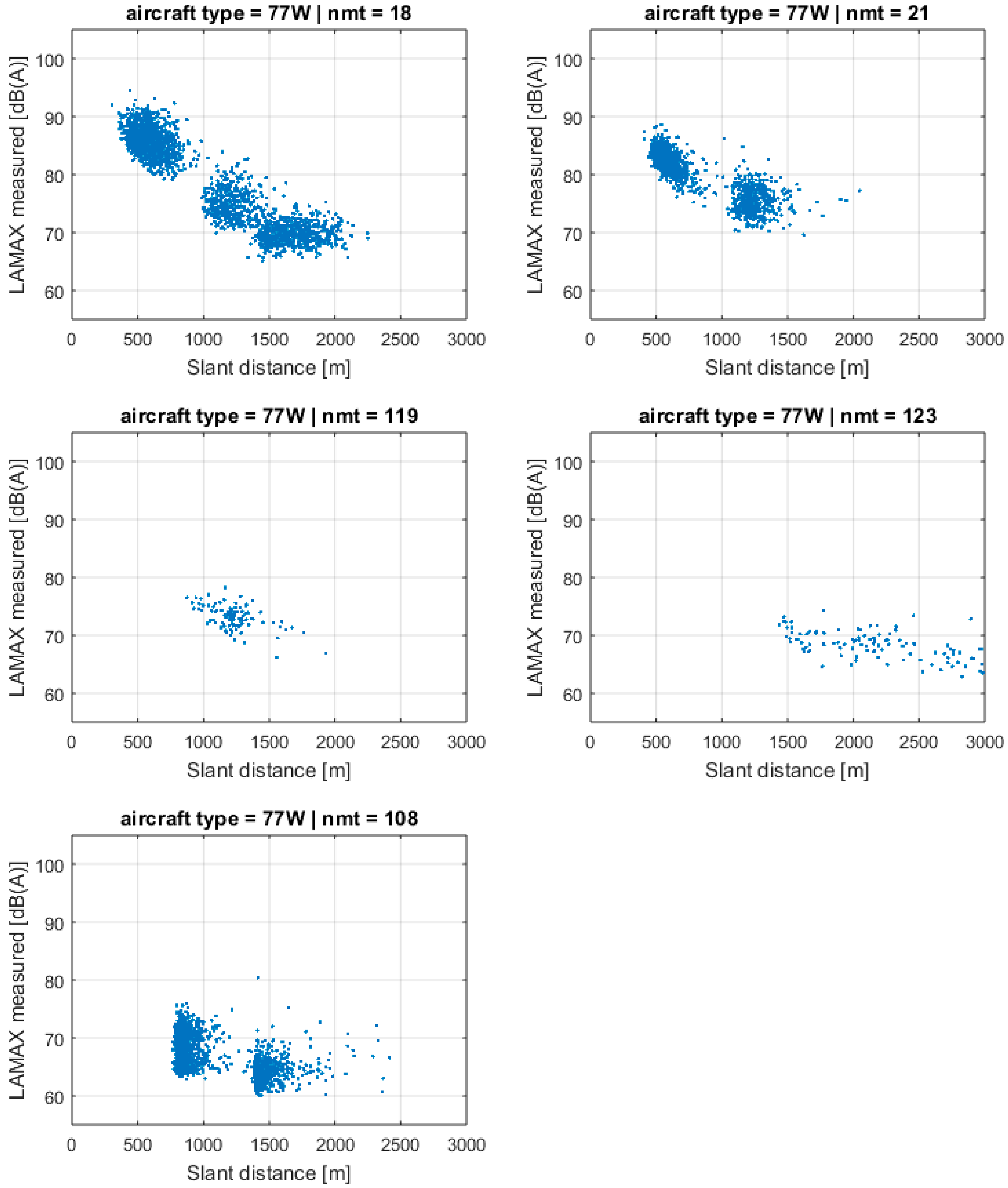


Figure 21: Noise measurement results of the B77W – peak level versus distance

6.2 INM noise modelling

Originally only an ANCON2 validation was foreseen. As this model is the legal model to be used at Heathrow. NLR understood that the Integrated Noise Model (INM) by the American Federal Aviation Authority (FAA) is used for Heathrow's trend analysis executed by Anderson Acoustics. Results of INM may therefore become part of public discussions and should also be trustworthy. Based on the already available INM results out of the 2014 trail, it was decided - together with the Community Noise Forum – also to hold INM calculation results against measurements.

The trail only contained departures, which did not fly close to Barns (108) measurement position. Thus, due to the availability of trial data, only departures are included and the Barns position (108) is left out in the INM validation.

For the four remaining measurement positions the figures below compare the calculated INM peak and sound exposure levels for the B77W with the measured peak and sound exposure levels. The red line indicates an exact match. Figures for other examined aircraft types are included in the Appendix B.

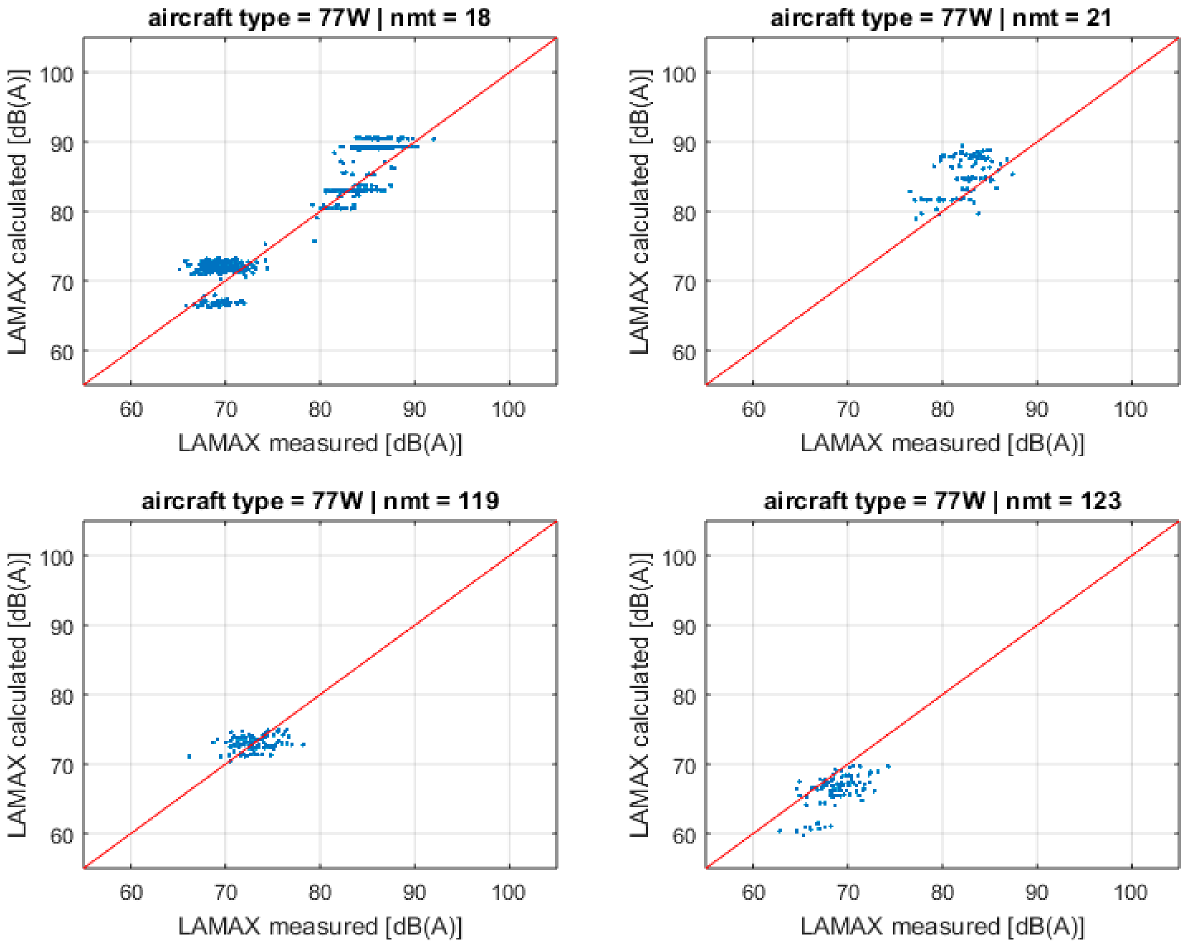


Figure 22: Peak levels of the B77W - measured versus calculated INM results

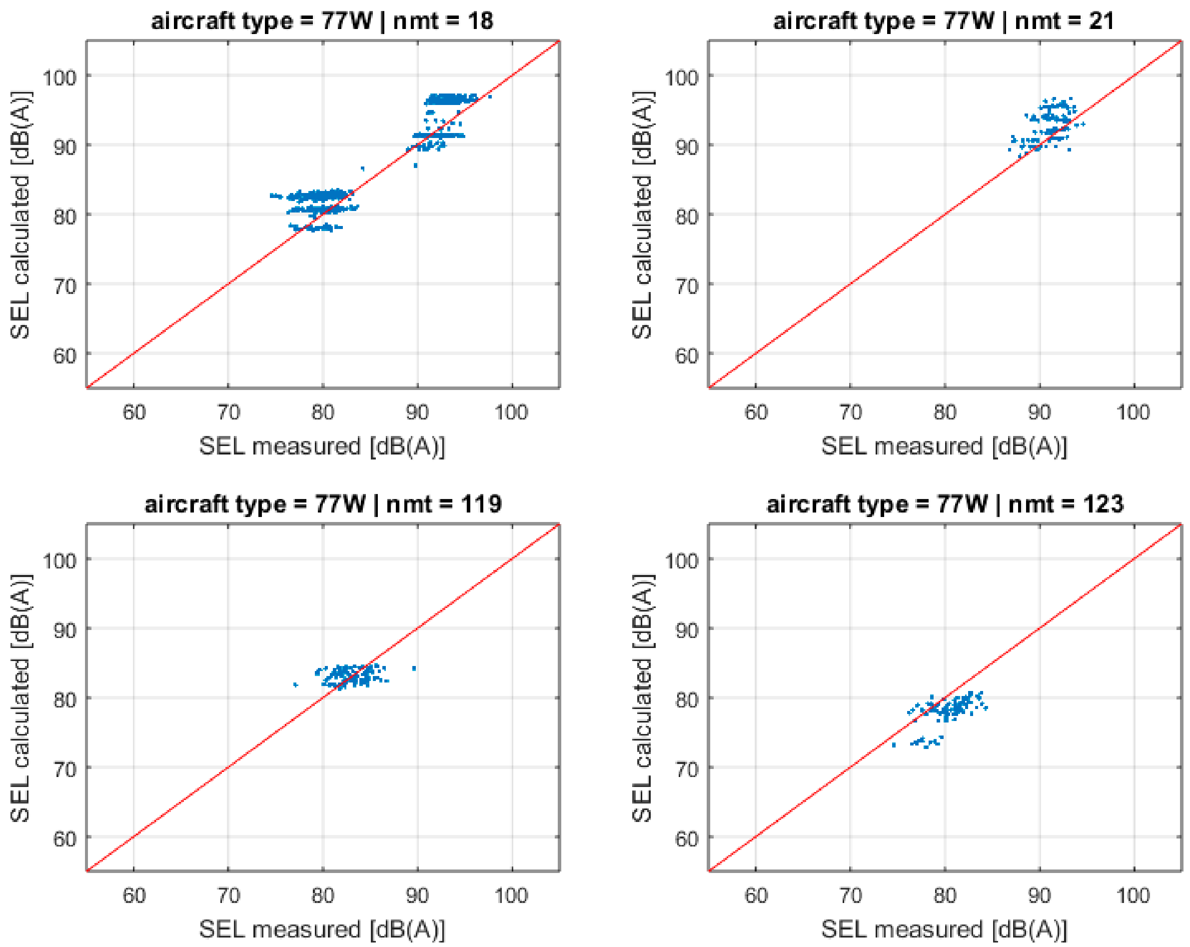


Figure 23: Sound exposure level of the B77W - measured versus calculated INM results

In above figures the clouds of dots are visible. Around the red line a distribution is seen. In the upper left figures horizontal lines become visible. At these lines calculated levels are more or less fixed due to the assumptions made in the calculation. All distributions are in the right order of magnitude and all red lines cross the clouds, which show that the chosen model settings are adequate to calculate a representative noise climate. Similar trends are determined for INM computations for the other examined aircraft (see Appendix B).

Figure 21 showed that noise levels hardly decreased with increasing distance between aircraft and measurement position at the Ascot position (123). Figure 22 and Figure 23 however, do not show a disturbance effect. It should be noted that Figure 22 and Figure 23 only depict results for which both measured and calculated results are available. Whereas, Figure 21 shows all available measurement results. This might lead to a better correlation between measured and computed noise levels in Figure 22 and Figure 23.

Nevertheless there still might be a potential unwanted influence in the cloud for the Ascot position (123), but it does not influence the trend depicted in the picture above. The measurement threshold still might play a role in the trend that was found in Figure 21. Thereby due to the relative large distance between aircraft and the noise measurement location, weather conditions will have more influence on the noise propagation from the aircraft to the microphone, which leads to a larger dispersion in the measurement results.

In the figures of the other examined aircraft in Appendix B, it is also expected that for Ascots most noise levels produced by aircraft are below the measurement threshold. Therefore the full trend (cloud) for Ascot will not be visible in the available data.

6.3 ANCON noise modelling

In the previous paragraph the INM calculation results of a B77W are held against measurements. In this paragraph the same is done with ANCON2 calculation results of a B77W. Figure 24 shows measured versus calculated peak levels. Figure 25 shows the sound exposure levels.

Findings:

- The clouds of dots – as discussed in the previous paragraph – are also visible including horizontal lines. These horizontal lines represent that the calculated levels are more or less fixed due to the assumptions made in the calculation.
- For the lower levels – Ascot (123) and Barns (108) - disturbances potentially influence a shift towards higher measured noise levels than calculated. At the same times it must also be taken into account that the larger the distance between the aircraft and the measurement position, the harder the predictions become.
- All the found distributions are in the right order of magnitude - all red lines cross the clouds - to ensure the chosen model settings are adequate to calculate a representative noise climate.

Similar ANCON2 figures are determined for the other examined aircraft (see Appendix C).

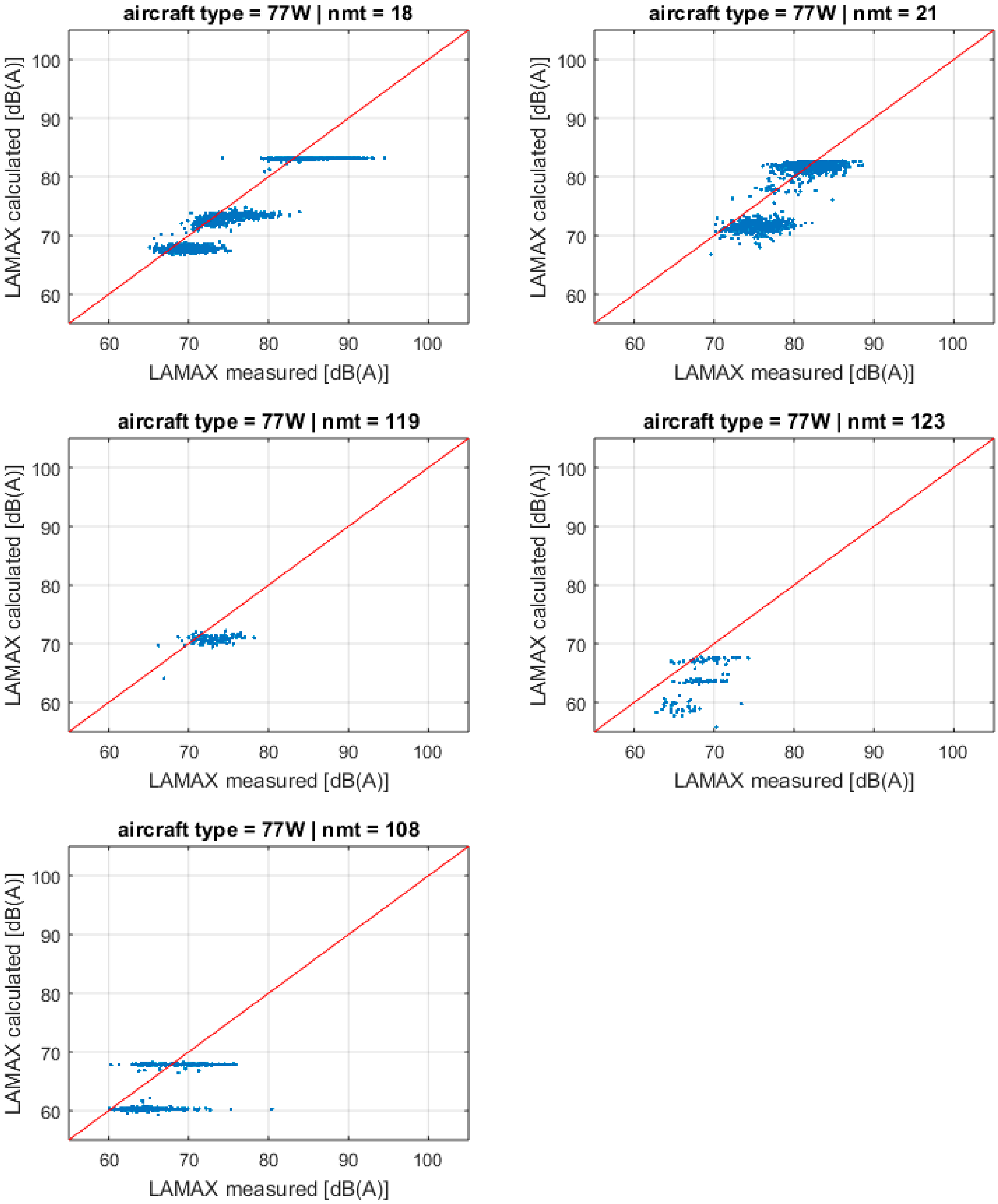


Figure 24: Peak levels of the B77W - measured versus calculated ANCON2 results

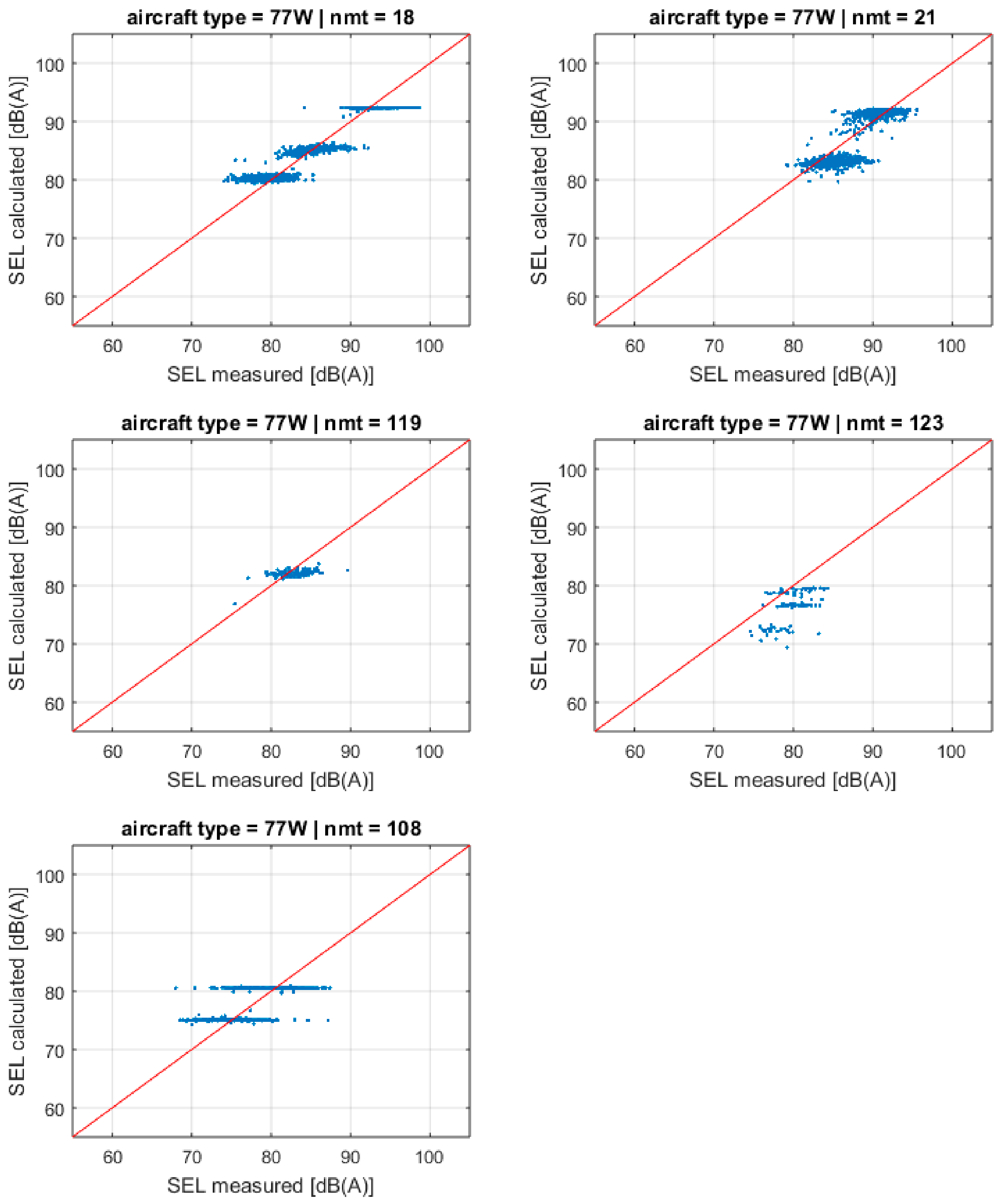


Figure 25: Sound exposure level of the B77W - measured versus calculated ANCON2 results

7 Conclusions

The overall conclusion of the verification study is that no indication has been found which reduces the trustworthiness of the information presented. The information available via Heathrow's Noise and Track Keeping system as well as via the publicly accessible WebTrak system is based on correct input, is processed in a correct way and is complete.

The noise models ANCON2 and INM are internationally accepted models and considered to be best practice. Based on the findings it is concluded that Heathrow's noise climate is assessed adequately, both by the UK-CAA and Anderson Acoustics. Thus from NLR's perspective the models are used in a good manner and the results of these models are trustworthy.

The verification study answers the questions of the Heathrow Community Noise Forum. The main conclusions, per task are elaborated below.

1. *Enable community stakeholders to be confident that the aircraft are at the heights and locations that the Heathrow systems indicate:*
   - ANOMS uses correct input data
   - ANOMS produces correct flight tracks based on the data it receives
   - No incorrect flight track presentation is found.

2. *Enable community stakeholders to be confident that all operations from Heathrow are accounted for in the system and have correct flight attributes.*
   - 100% of the flights are available in ANOMS
   - Not all (but 99.8%) operations were shown in WebTrak. Since the verification was conducted, system changes have been made to improve this.

3. *Verify flight characteristics with respect to correct flight type, runway and aircraft type*
   - Flight data show correct attributes.

4. *Assess whether there has been any historical change in the past 5 years, to the ANOMS or WebTrak systems, which may have altered the accuracy of the systems.*
   - Several changes are applied to system functionality as well as input data
   - Although all changes are improvements, some of them led to changes in the results.

5. *Verify that the noise models used by Heathrow are compliant with international standards and provide an accurate assessment of the noise climate.*
   - The comparison of measured and calculated aircraft noise in the vicinity of Heathrow shows a good match.
   - Based on this finding and since the noise modelling is within the boundaries of 'best practice' (i.e. use of the models), the assessment of the noise climate of Heathrow by UK-CAA and Anderson Acoustics is considered to be done adequately.

Please be aware, a flight track monitoring system, like any other complex system, can incidentally not work as intended. Heathrow airport staff and the supplier of the system continuously monitor the function of the systems. NLR concludes, based also on the findings above, that they are dedicated to make sure the systems work properly in order to provide the correct information.

8 References

1. "How ADS-B works"; Airservices Australia; 28 November 2012. Retrieved January 2015.
2. Website Deutsche Flugsicherung (DFS - http://www.dfs.de/dfs_homepage/de); sub-page Flugsicherung/Umwelt/Flugverläufe online/Frankfurt/FAQs STANLY_Track.

Appendix A Information on altitude and height

When it is expressed how high an aircraft flies or when height results from different systems are compared, it is important to know what reference is used. Figure 24 shows the references in a graphical way.

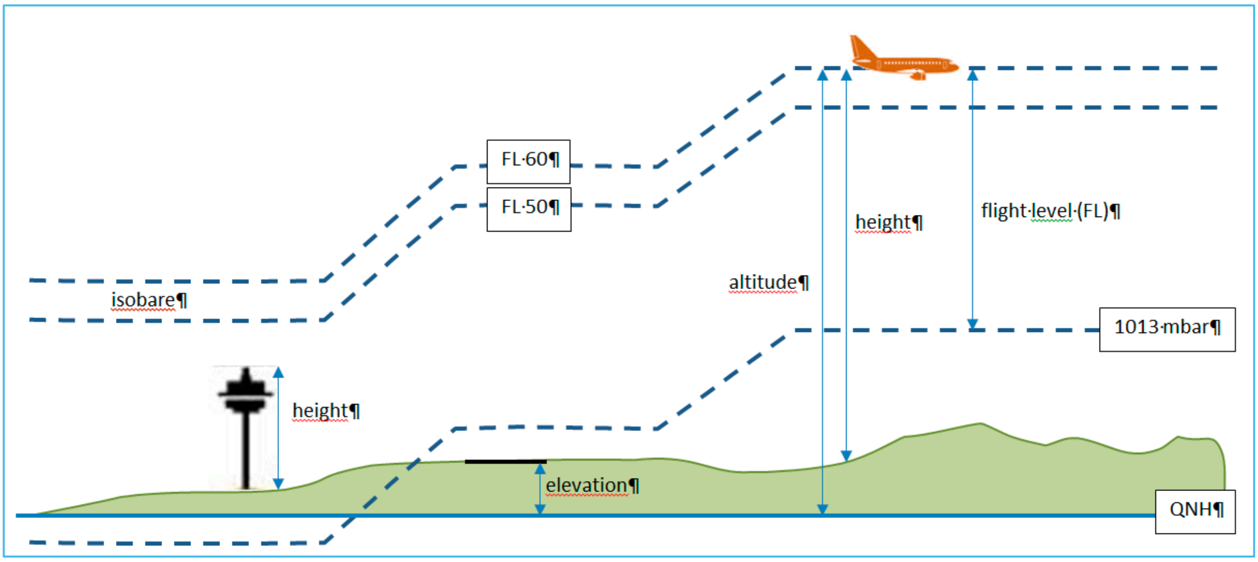


Figure 26: Height values

Aircraft transponders report the height in **flight levels**. A flight level (FL) is a specific barometric pressure, expressed as a nominal altitude in hundreds of feet. The pressure is computed assuming an international standard sea-level pressure of 1013 mbar, and therefore is not necessarily it is the same as the aircraft's true altitude either above mean sea level or above ground level.

A correction for atmospheric pressure variations is applied on the ground. Using the actual pressure at mean sea level, known as **QNH**, the **altitude** of the aircraft can be calculated: for every 1 mbar pressure difference between the QNH and standard pressure, a correction of 27.3ft is applied.

ANOMS presents **height** values relative to the airport level. For this, the airport **elevation** is subtracted from the altitude: 83ft for Heathrow. It is important to note that the actual terrain elevation underneath the aircraft is not taken into account.

Appendix B Results of INM validation

This appendix provides similar formatted figures for INM computations as in chapter 6. In that chapter, the B77W aircraft results are explained. In addition and for understanding purposes the following extra comments are made:

- A cut-off is visible in the upper left graph of Figure 27. This is explained by the fact that some of the A320 procedures do not exceed the threshold of 65 dB(A) of this measurement location. The cloud will be incomplete therefore.
- For the lower right figures (Ascot) a clear cut-off is not visible. As the levels are close to the threshold level the cloud might also be incomplete for this location.

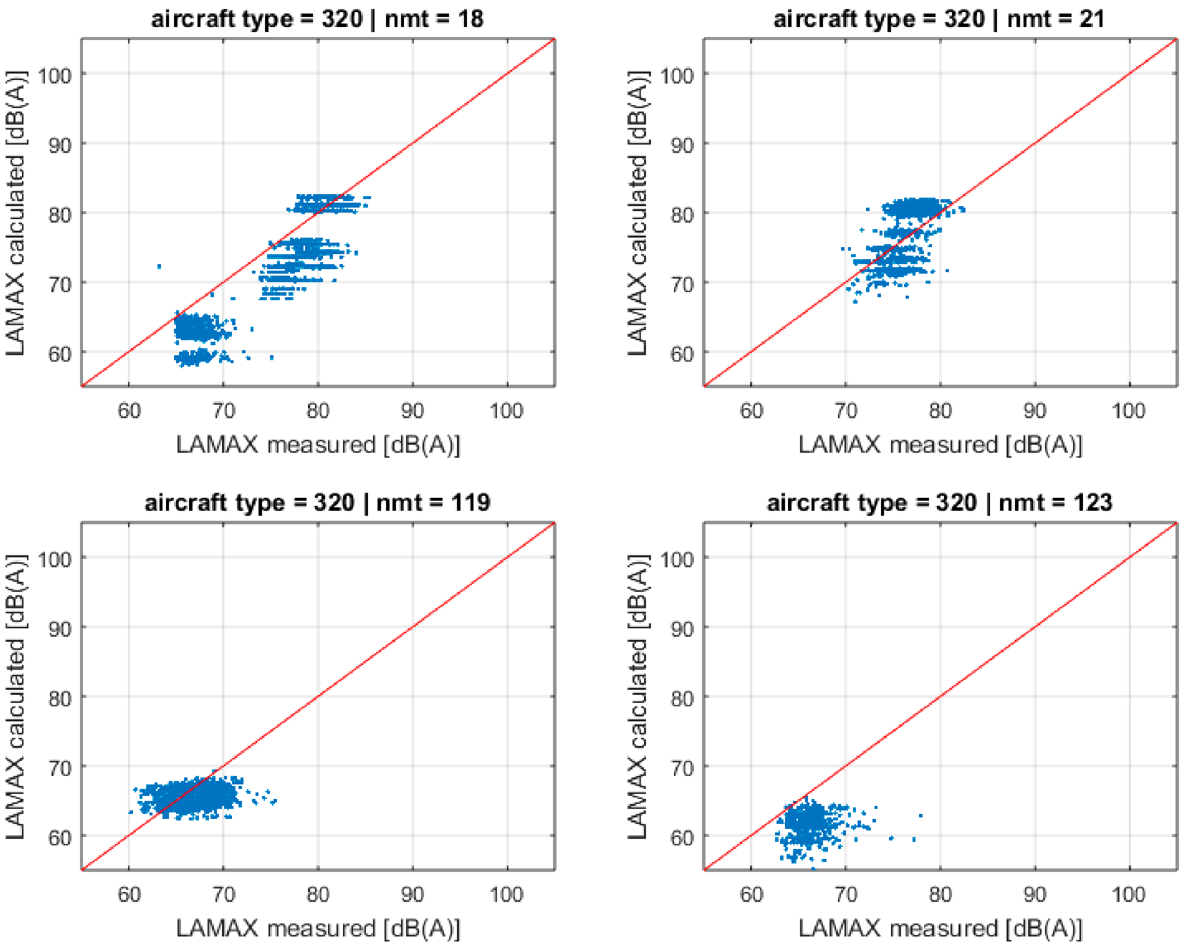


Figure 27: Noise results of the A320 – L_{AMAX} measured versus calculated INM results

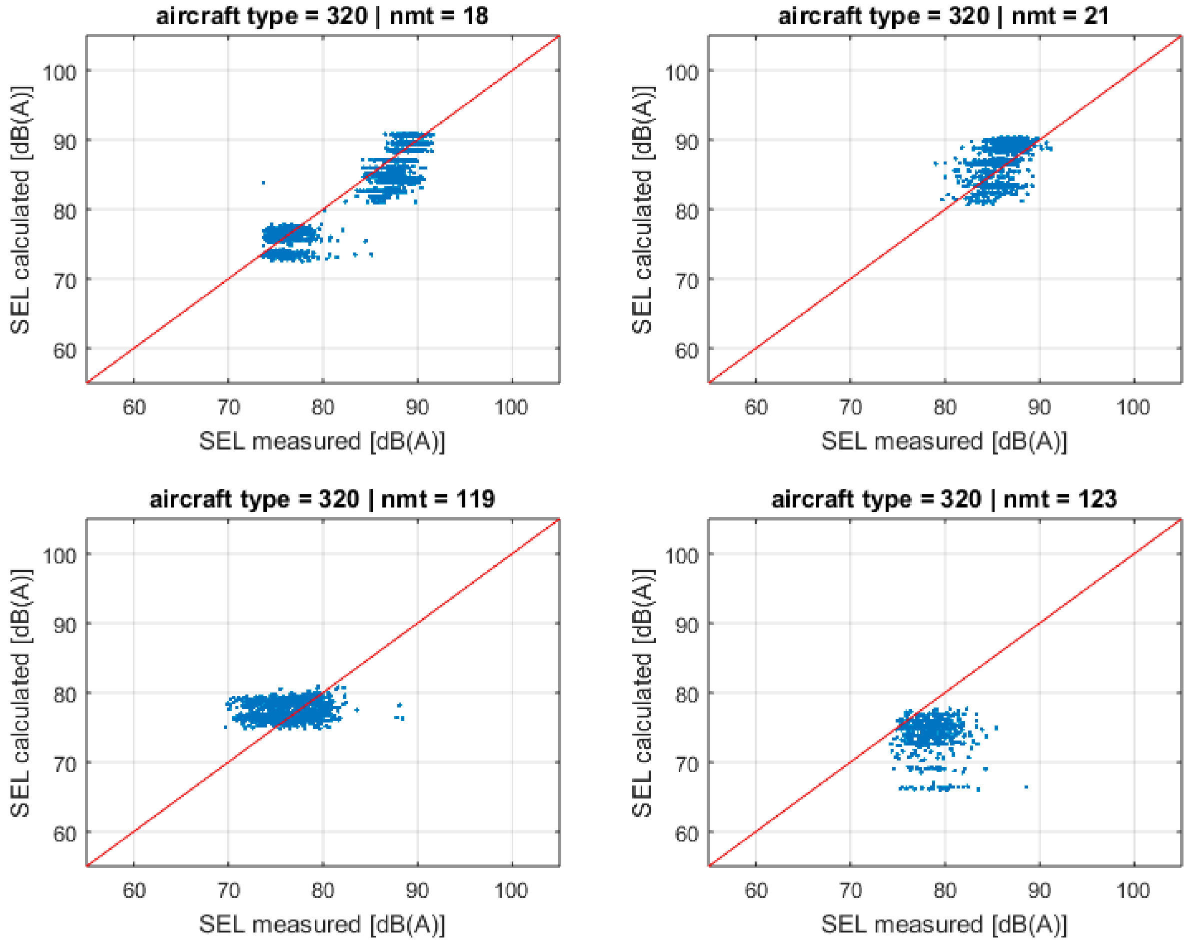


Figure 28: Noise results of the A320 – SEL measured versus calculated INM results

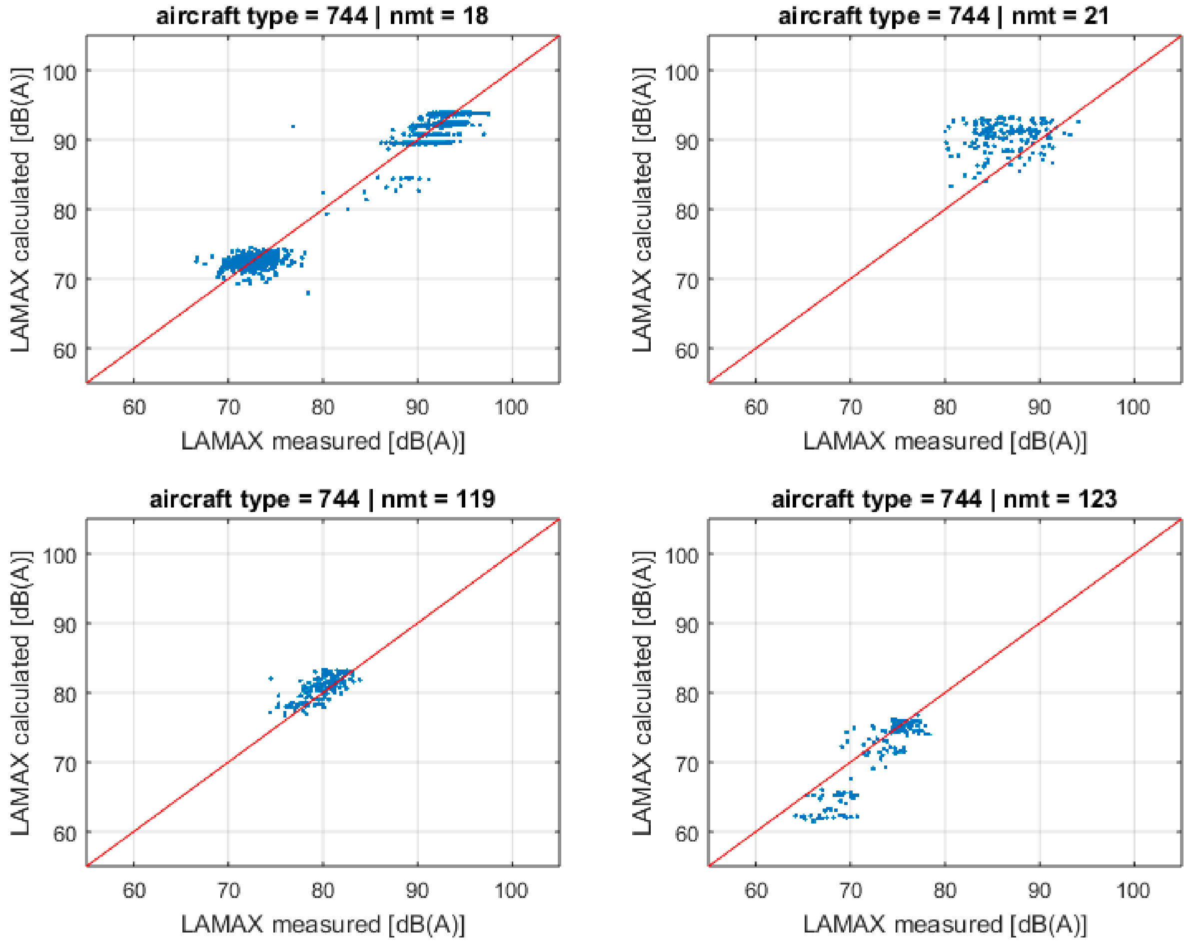


Figure 29: Noise results of the B744 – L_{AMAX} measured versus calculated INM results

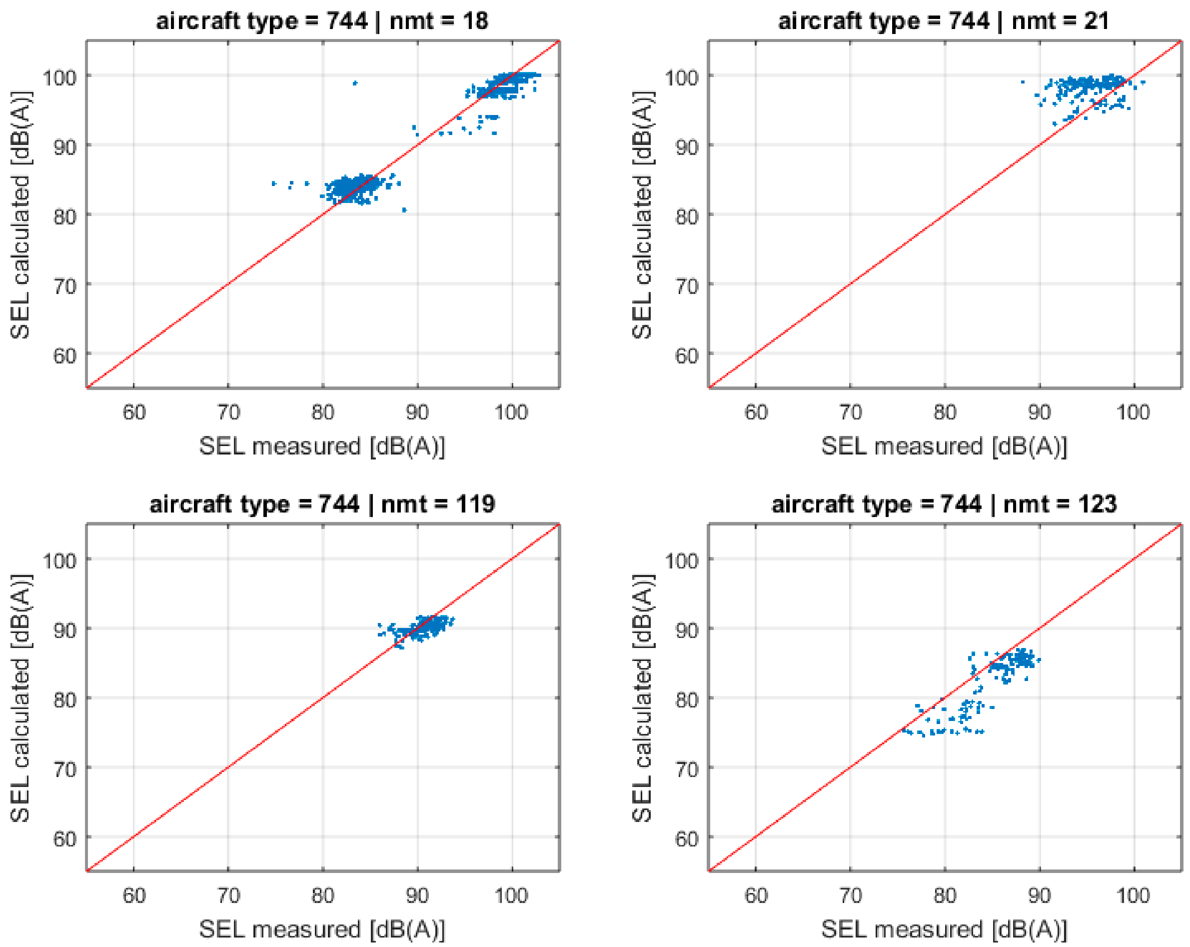


Figure 30: Noise results of the B744 – SEL measured versus calculated INM results

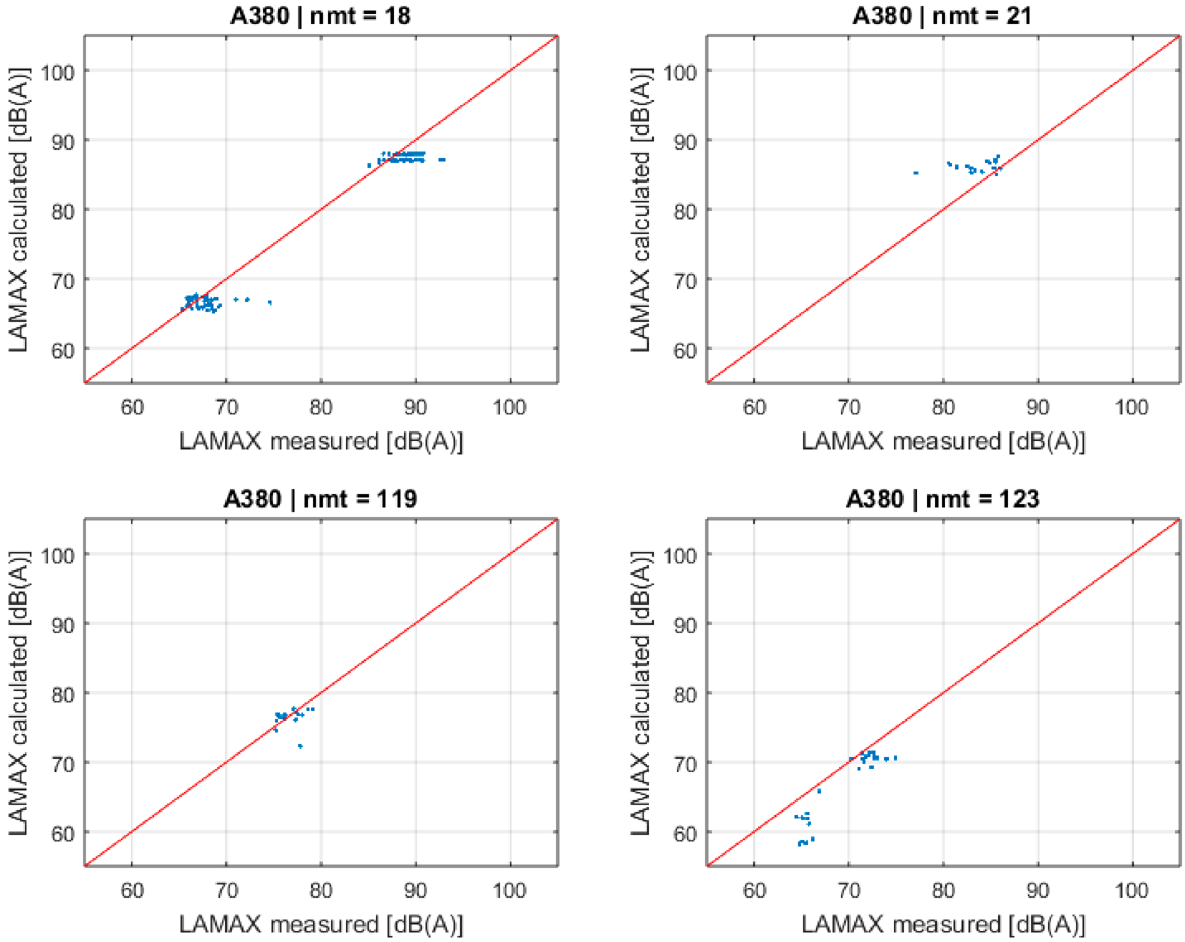


Figure 31: Noise results of the A380 – L_{AMAX} measured versus calculated INM results

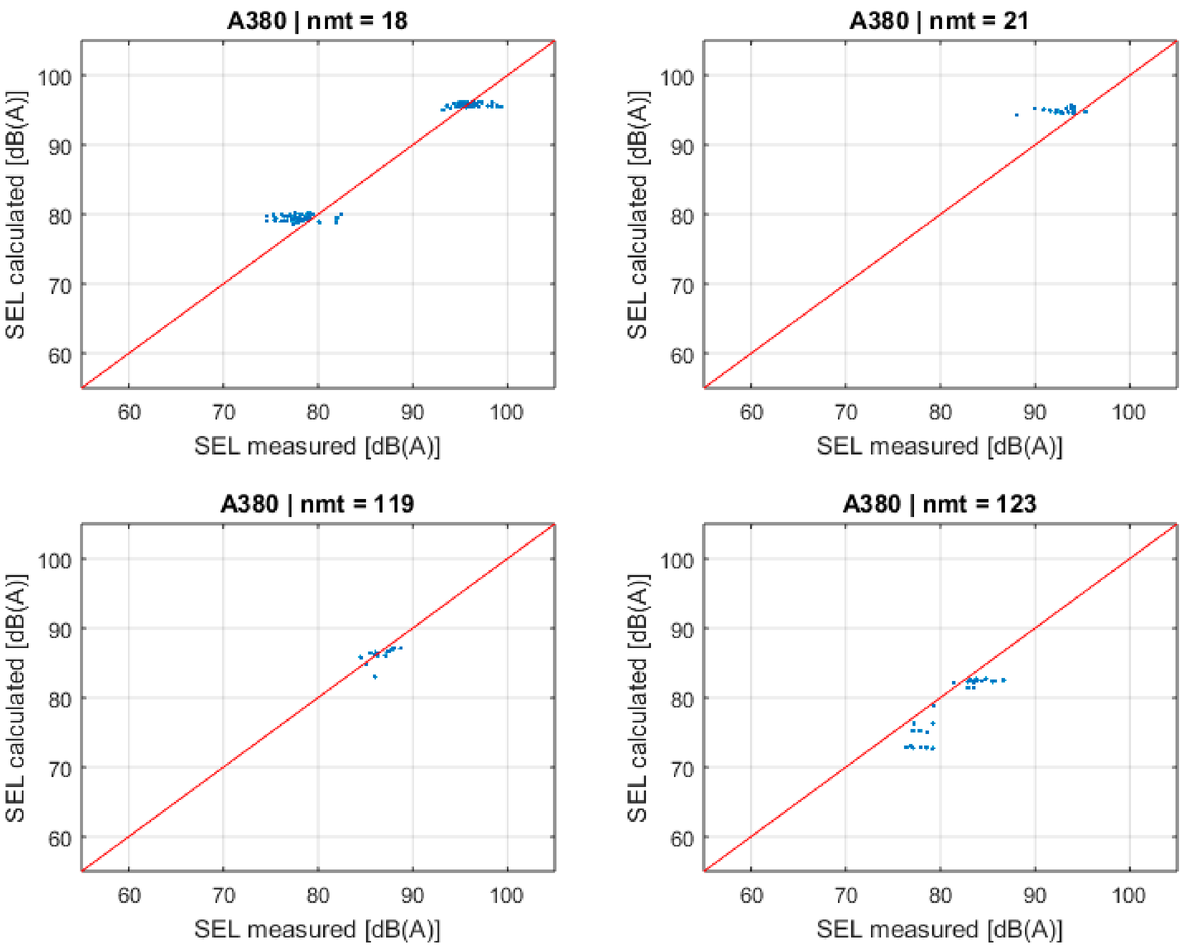


Figure 32: Noise results of the A380 – SEL measured versus calculated INM results

Appendix C Results of ANCON2 validation

This appendix provides similar formatted figures for ANCON2 computations as in chapter 6. In that chapter, the B77W aircraft results are explained. In addition and for understanding purposes the following extra comment is made:

- In the A320 figures the lower peak levels (L_{Amax}) at Ascot (123) and Barns (108) show a higher offset from the red line (measured = calculated) than the sound exposure level results (SEL). This offset will not influence the yearly impact results as these results are based on SEL.

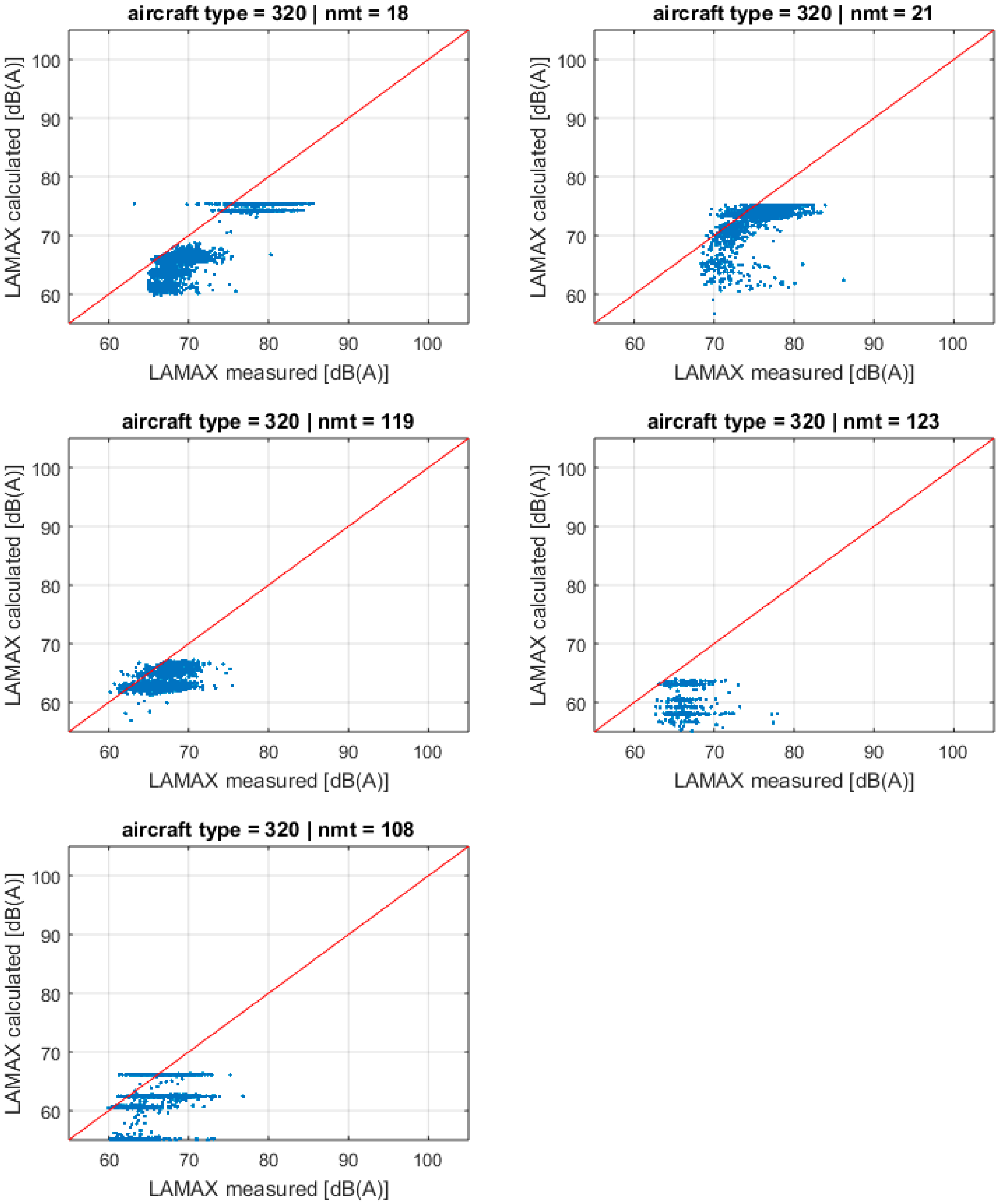


Figure 33: Noise results of the A320 – L_{AMAX} measured versus calculated ANCON2 results

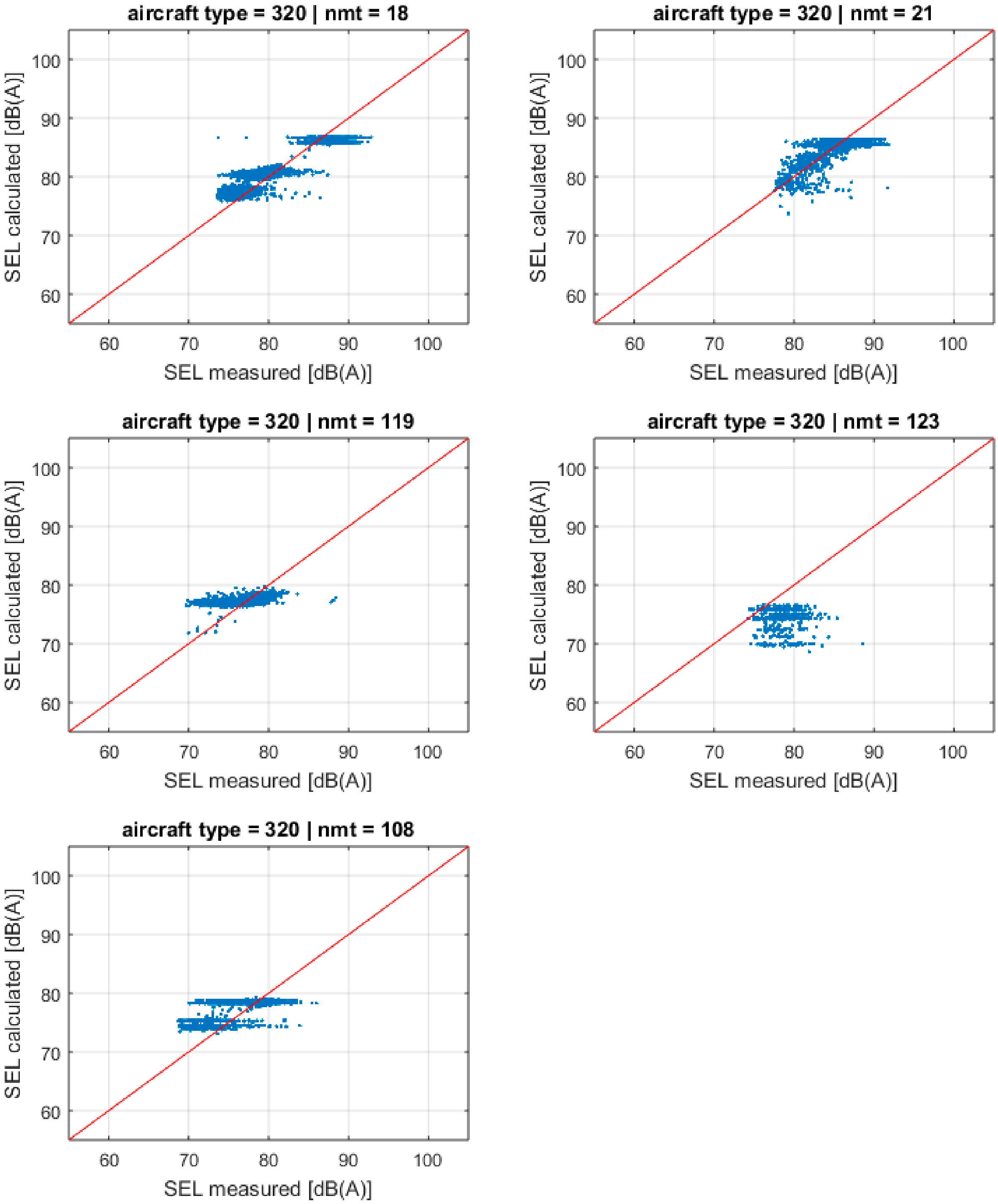


Figure 34: Noise results of the A320 – SEL measured versus calculated ANCON2 results

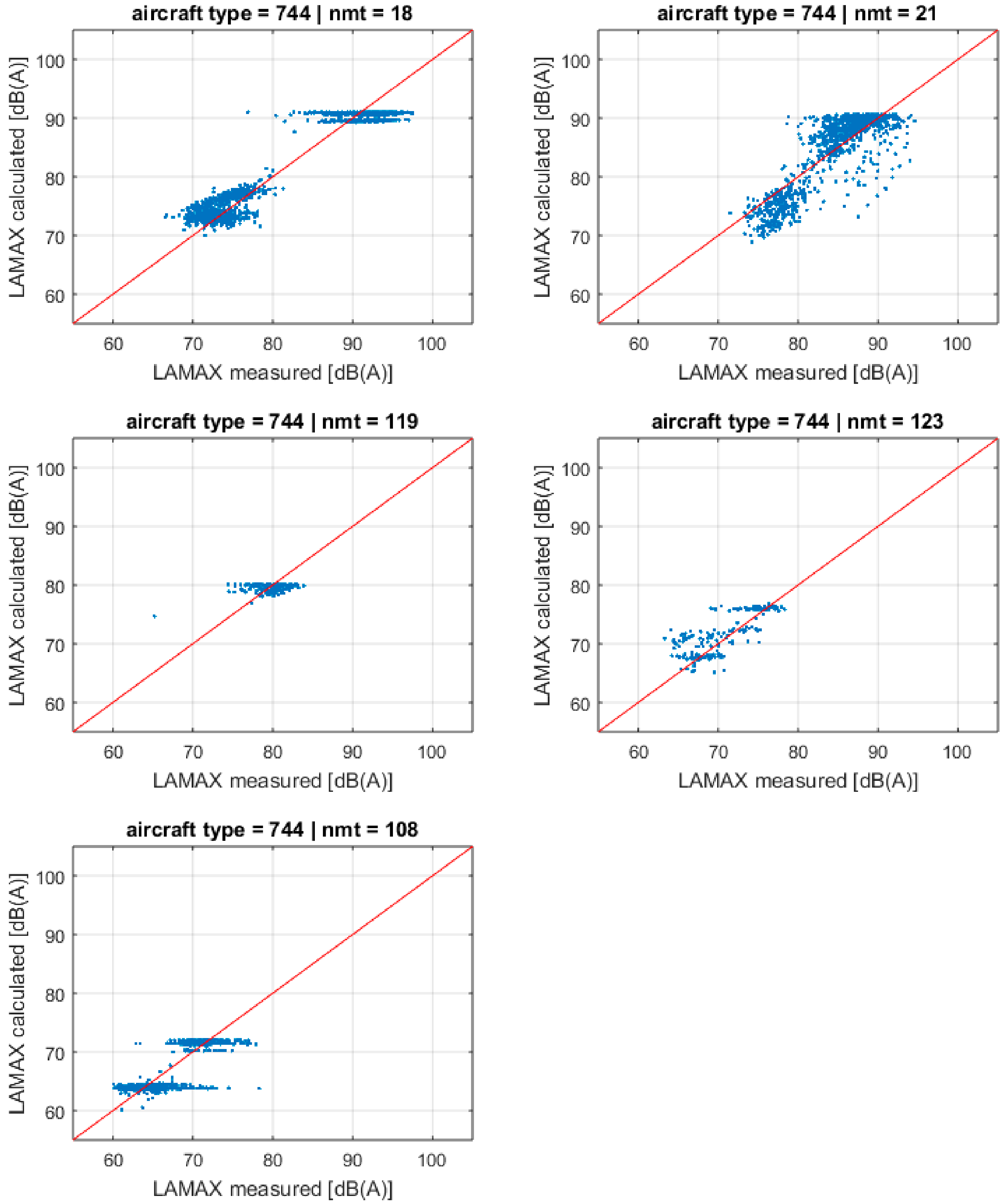


Figure 35: Noise results of the B744 – L_{AMAX} measured versus calculated ANCON2 results

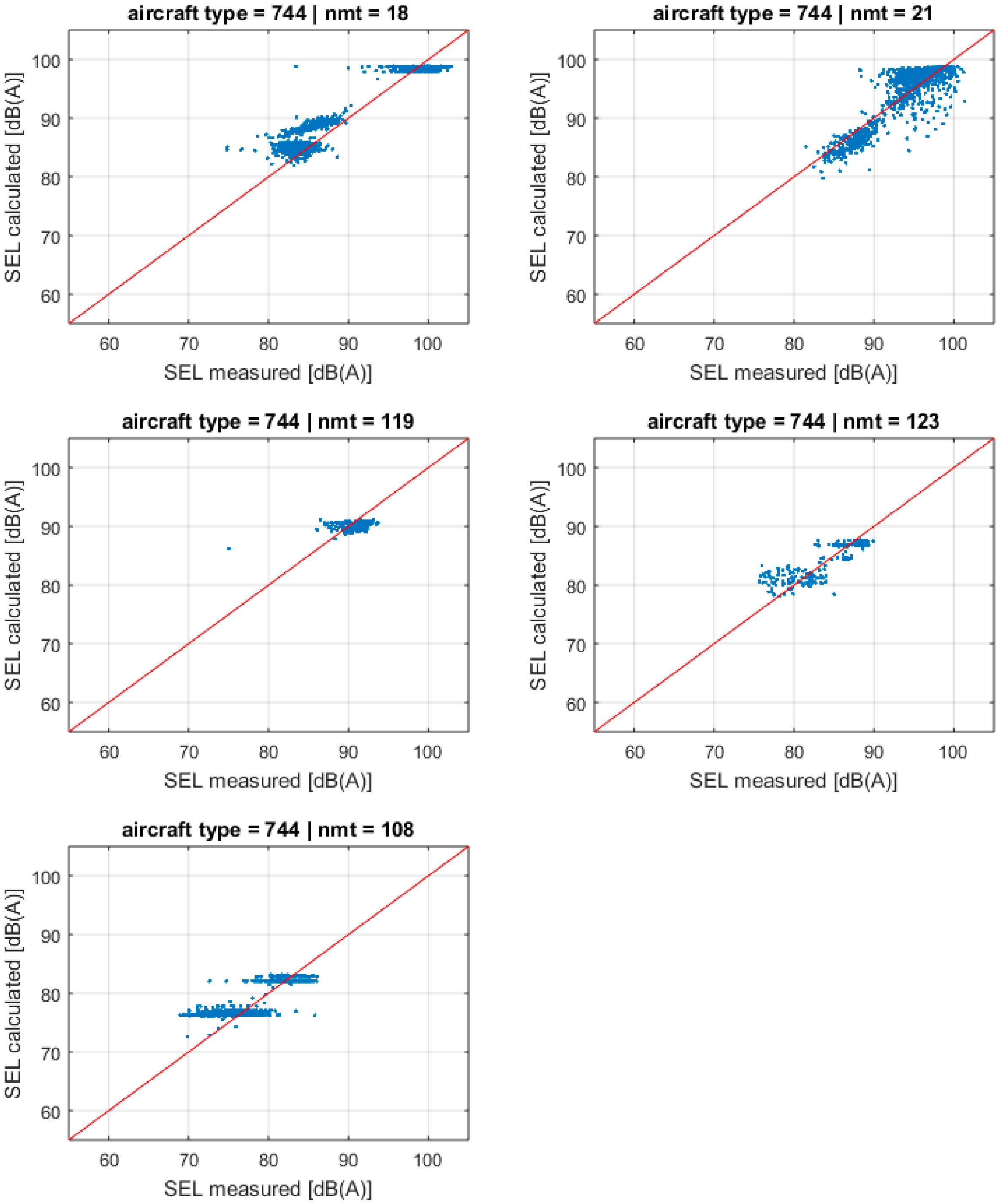


Figure 36: Noise results of the B744 – SEL measured versus calculated ANCON2 results

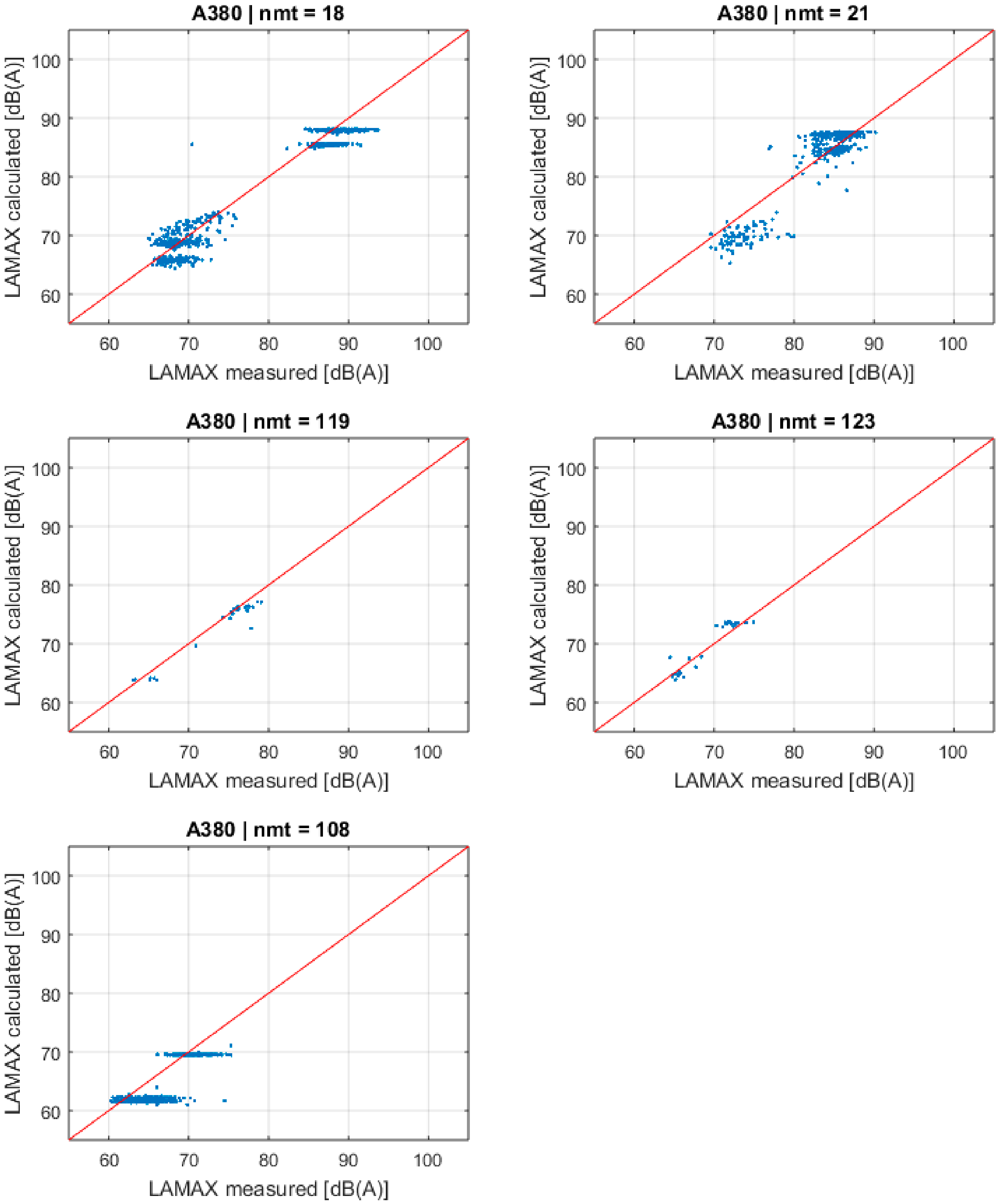


Figure 37: Noise results of the A380 – L_{AMAX} measured versus calculated ANCON2 results

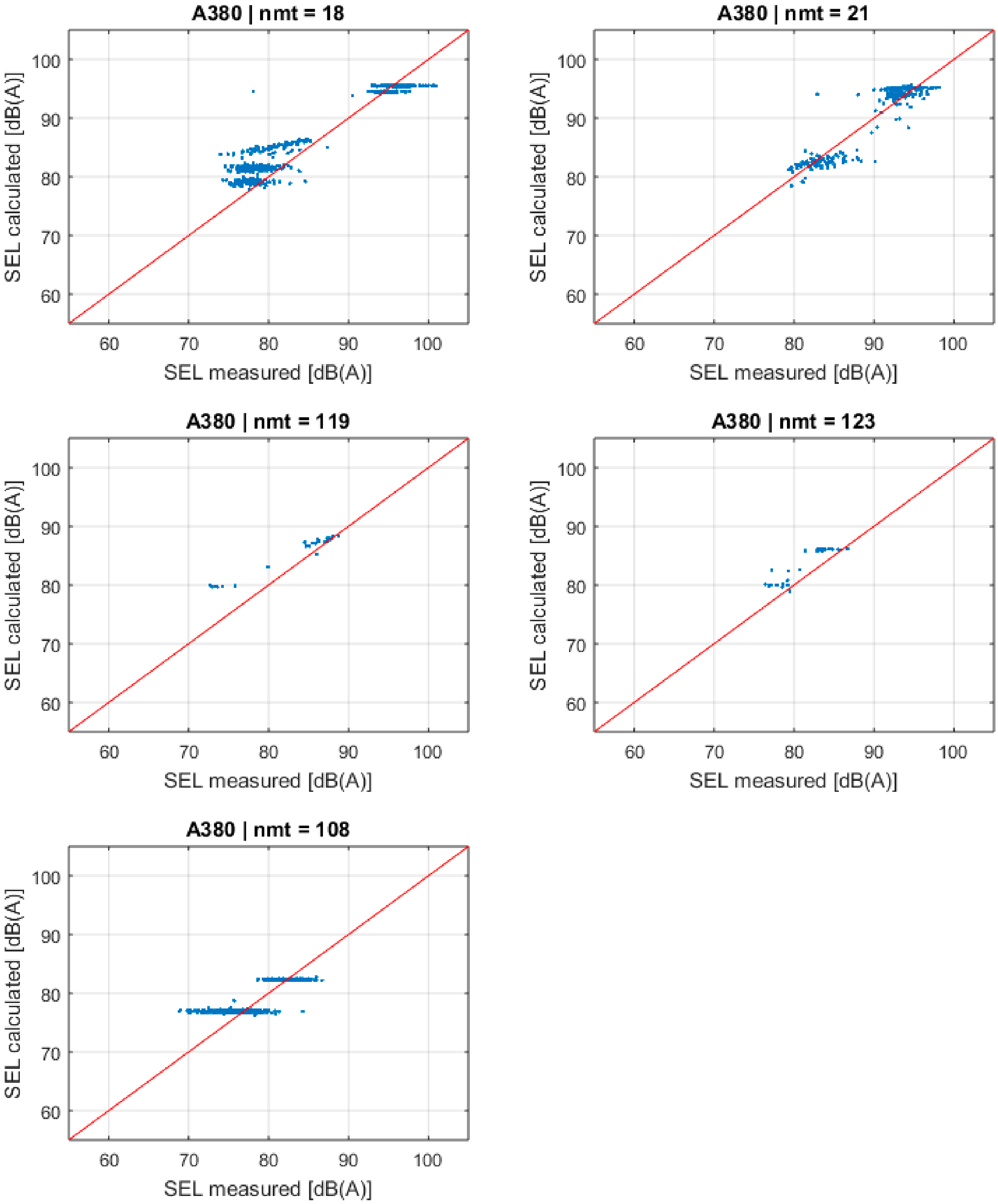


Figure 38: Noise results of the A380 – SEL measured versus calculated ANCON2 results

NLR

Anthony Fokkerweg 2
1059 CM Amsterdam, The Netherlands
p) +31 88 511 3113 f) +31 88 511 3210
e) info@nlr.nl i) www.nlr.nl