



Rijksinstituut voor Volksgezondheid  
en Milieu  
Ministerie van Volksgezondheid,  
Welzijn en Sport

## **Noise Monitor 2010**

*Trend- and validation measurements of  
environmental noise*

RIVM briefrapport 630650001/2011

D.E. Lolkema et al.



National Institute for Public Health  
and the Environment  
*Ministry of Health, Welfare and Sport*

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RIVM Letter report 630650001/2011  
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## Colophon

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## Abstract

### **Noise Monitor 2010**

Trend- and validation measurements of environmental noise

Along the A2, a new noise measurement series started in June 2010 after the reconstruction due to road widening had been completed. Between 2000 and 2008, the noise levels hardly changed at this location; the road consisted of six lanes with a dense asphalt concrete paving. In 2009, no measurements were conducted at this point because of the extensive road works. In the new situation, the A2 has been widened to ten lanes with double-layer porous asphalt. In this new situation, the noise level dropped considerably because the average distance from the measuring point to the lanes has increased and because of the sound reducing properties of the porous asphalt layer. Along the A12 at Voorburg, a slight increase in noise was measured in 2010. This may indicate a slight deterioration of the porous pavement which dates from 2007. Along the A10-West in Amsterdam, as in 2009, the measured noise level remained the same in 2010.

### **Setup and purpose of noise monitoring**

These are the main results of the Noise Monitoring Program of RIVM for road traffic in 2010. The Noise Monitoring Program follows the trends in road traffic noise at four fixed points: the A2 at Breukelen, the A10-West in Amsterdam, the A12 at Voorburg and the N256 at Colijnsplaat (Zeeland). In addition, noise from rail and air traffic is monitored. For rail traffic, data from two noise monitoring sites provided by ProRail were analysed. The measurements are used to identify trends in noise emissions and to validate Statutory Standard Calculation methods for road- and rail traffic at the measurement sites.

### **Railways**

For railways, the measurements are in line with calculations according to the standard statutory calculation method. For road traffic, the measured values at the N256, as in previous years, are higher than the calculated values.

### **Pilot aircraft noise**

Like last year, this report contains a comparison of measurements of aircraft noise at Zegveld (20 km south of Schiphol airport) with noise data sets from the Integrated Noise Model (INM). INM is used in many studies to determine the noise levels around airports. The measurements in Zegveld are in fair agreement with the noise data from INM.

Keywords:

noise, monitoring, decibel, road traffic, railway traffic

## Rapport in het kort

### **Geluidmonitor 2010**

Trend- en validatiemetingen aan omgevingsgeluid

Langs de A2 is medio 2010 een nieuwe meetreeks van de geluidbelasting gestart, nadat de reconstructie van de weg als gevolg van de verbreding is afgerond. Tussen 2000 en 2008 zijn de geluidniveaus op deze locatie nauwelijks veranderd; dit betrof de geluidbelasting van tweemaal drie rijstroken met standaard dicht asfalt beton. In 2009 is op dit punt niet gemeten vanwege de omvangrijke wegwerkzaamheden. In de nieuwe situatie is de A2 verbreed naar twee keer vijf rijstroken en voorzien van dubbellaags poreus asfalt. In deze situatie is de geluidbelasting fors gedaald doordat de gemiddelde afstand van het meetpunt tot de rijstroken is toegenomen (de reconstructie) en door de geluidreductie van het asfalt. Op de A12 bij Voorburg is in 2010 een lichte geluidtoename gemeten. Dit kan wijzen op een lichte veroudering van het poreuze wegdek dat in 2007 is aangelegd. Op de A10-West in Amsterdam is, evenals in 2009, in 2010 het gemeten geluidsniveau gelijk gebleven.

### **Opzet en doel geluidmonitor**

Dit zijn de belangrijkste resultaten van het Geluidmonitorprogramma van het RIVM in 2010 voor het wegverkeer. De monitor volgt de trends in het geluid van wegverkeer op vier vaste meetpunten: de A2 bij Breukelen, de A10-West bij Amsterdam, de A12 bij Voorburg en de N256 bij Colijnsplaat (Zeeland). De geluidmonitor volgt op enkele locaties ook de geluidbelasting van rail- en vliegtuigverkeer; voor railverkeer worden twee meetlocaties van ProRail gebruikt. De metingen worden gebruikt om trends in de geluidsemissies te volgen en te toetsen aan de Wettelijke standaard Nederlandse Reken- en Meetvoorschriften voor wegverkeer en railverkeer.

### **Railverkeer**

Voor railverkeer zijn de metingen in lijn met de berekeningen volgens het standaard Reken- en Meetvoorschrift. Voor wegverkeer zijn de gemeten waarden op de N256, evenals in voorgaande jaren, wat hoger dan de berekende waarden.

### **Pilot metingen luchtvaartgeluid**

Net als vorig jaar bevat deze rapportage een vergelijking van metingen van vliegtuiggeluid bij Zegveld (op 20 kilometer ten zuiden van Schiphol) met geluidgegevens van toestellen uit het Integrated Noise Model (INM). INM wordt in veel studies gebruikt om de geluidbelasting rondom luchthavens te bepalen. De metingen in Zegveld zijn redelijk in overeenstemming met de geluidgegevens uit INM.

Trefwoorden:

geluid, monitoring, decibel, wegverkeer, railverkeer

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## Summary

The Noise Monitor 2010 describes the results of the RIVM Noise Monitoring Program for road traffic and railway noise in 2010. The results are used to monitor trends in noise emission and to validate the standard calculation methods for road traffic noise and railway noise at the measurement sites. In this summary the main findings from the 2010 measurements are presented in short.

### Road traffic noise

The RIVM Noise Monitoring Program contains four permanent monitoring stations: i) the A2 motorway near Breukelen, ii) the A10-West motorway in Amsterdam, iii) the A12 motorway near Voorburg and iv) the N256 in the province of Zeeland.

#### *A2 motorway near Breukelen*

The A2 motorway near Breukelen has undergone a major reconstruction from 2006 till mid-2010. The road has been widened from three to five lanes for both sides of the road and the road surface, which used to be Dense Asphalt Concrete (DAC), has been replaced by Double Layer Porous Asphalt (DLPA). The 2010 measurements showed a considerable decrease in noise level. This is a combined result of road displacement, speed reduction and quieter road surface.

#### *A10-West motorway in Amsterdam*

Noise levels at this location have increased steadily from 2003 up until 2008, only interrupted in 2006 after the introduction of an 80 km/h speed limit. In 2009 however, noise levels at this location decreased. Measurements from 2010 also showed a decrease in noise levels at this location, however, this decrease lies within the measurement uncertainty.

#### *A12 motorway near Voorburg*

In the period 2005-2008 noise levels at this location decreased due to the introduction of a new speed limit and a repaving of the DLPA layer. In 2009, noise levels remained more or less the same, and the 2010 measurements showed an increase of 1 dB. This might be an indication that aging of the DLPA diminishes the sound reducing properties of the DLPA.

#### *N256 motorway near Colijnsplaat (Noord-Beveland, province of Zeeland)*

This location is used to validate the noise emissions calculated according to the Dutch standard calculation method for road traffic noise (RMW, 2006) at this specific site. As for previous years, measured average sound power levels are higher than the levels calculated according to the Dutch standard calculation model RMW2006.

### Railway noise

The measured railway noise emission at normal driving speeds corresponds well with the calculated emission according to the national calculation method. Also, the speed-dependency of the noise emission is in line with the national standard. These results do not differ from the results of previous years.

### **Aircraft noise**

The results of a pilot study on aircraft identification and sound power assessment show reasonable agreement with the source data from the international Integrated Noise Model. The measurement site is at Zegveld, just outside a designated Quiet Area. Noise levels have been measured from various types of aircraft flying to and from Amsterdam Airport Schiphol (17 km away).



# 1 Introduction

The RIVM Noise Monitoring Program aims at monitoring noise emissions from road, railway and aircraft traffic under various meteorological conditions, by use of continuously operating measurement sites. The measurements can be used to analyse trends in noise emissions, and validate the noise propagation models which are used to support the Dutch national noise policies. The results and interpretation of the 2010 measurements are presented in this report.

## 1.1 Monitor locations

Monitoring road traffic noise takes place at the:

- A2 motorway near Breukelen;
- A10-West motorway in Amsterdam;
- A12 motorway near Voorburg;
- N256 provincial road near Colijnsplaat (Noord-Beveland, province of Zeeland).

The latter site aims at monitoring the noise emission of three vehicle categories (passenger cars, medium and heavy trucks) separately. Measurements are used to assess the speed-dependency of the noise emission per vehicle category and to compare the results with the emissions according to the Dutch standard calculation method for road traffic noise (RMW, 2006).

Monitoring railway traffic takes place at:

- Esch (railway line 's-Hertogenbosch – Eindhoven);
- Tilburg (railway line Breda – Tilburg).

These sites are operated and maintained by ProRail, the Dutch rail infrastructure management organization.

A pilot monitoring campaign for aircraft noise takes place at Zegveld, 17 km south of Amsterdam Airport Schiphol.

The geographical locations of these monitoring stations are shown in Appendix 1.

## 2 Road traffic noise

### 2.1 A2 motorway near Breukelen

#### 2.1.1 Description

The permanent monitoring station at the A2 motorway near Breukelen has been operational since the year 2000. The motorway near the monitoring site has undergone a major reconstruction from 2006 till mid-2010. The road has been widened from 3 lanes to 5 lanes in each direction, while the road surface, which used to be Dense Asphalt Concrete (DAC), has been replaced by Double Layer Porous Asphalt (DLPA, Figure 2). In addition, the maximum speed has been reduced from 120 to 100 km/h. From December 2008 until July 2010, all traffic in both directions was directed over the new southbound road, which is further away from the monitoring site, see Figure 1. In the second half of 2010, the new northbound road opened and at the same time, the inner two southbound lanes closed for several months. Anticipating the new situation, in 2009 the microphone has been replaced from a height of +1.5 meters to a height of +4 meters with respect to the road surface.

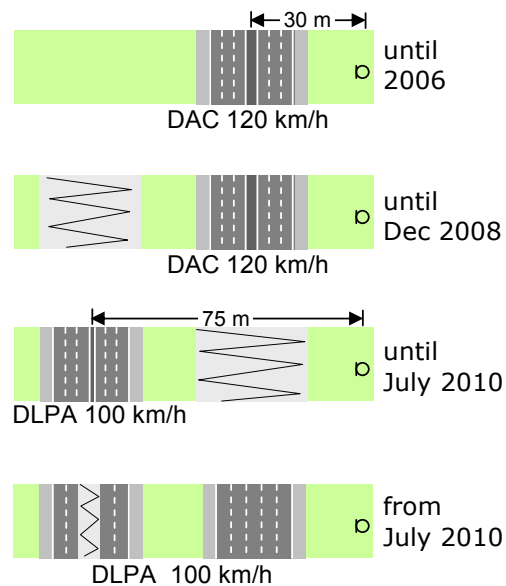


Figure 1 Top-view of A2 motorway near Breukelen during different stages of the reconstruction works.



Figure 2 Double Layer Porous Asphalt (DLPA) at the A2 motorway near Breukelen.

### 2.1.2 Monitor results 2000 – 2010

Figure 3 shows the yearly average 24-hour noise level distributions for the years 2005-2008 and the year 2010. The noise level distributions for previous years can be found in the Noise Monitor 2007 (Schreurs et al., 2008). Note that the noise level in 2010 refers to two distinct traffic situations that existed in that year as described in the previous section.

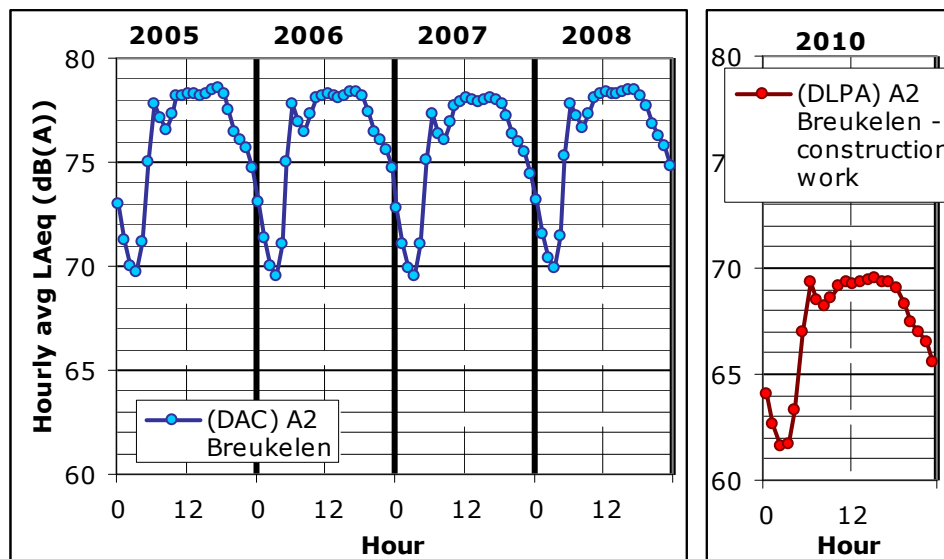


Figure 3 Average 24-hour noise level distributions, measured at the A2 motorway near Breukelen over the years 2005-2008 and for the year 2010.

Table 1 shows the equivalent noise levels for the day, evening and night time periods, as well as the weighted 24-hour average  $L_{den}$  for the years 2002-2008 and the year 2010. Levels for previous years can be found in the Noise Monitor 2007 (Schreurs et al., 2008).

*Table 1 Equivalent noise levels  $L_{Aeq}$  and  $L_{den}$  A2 Breukelen 2002-2008 and 2010.*

	2002	2003	2004	2005	2006	2007	2008	2010
$L_{Aeq}$ 07-19h	77.7	77.9	78.0	78.0	77.9	77.6	78.0	<b>69.1</b>
$L_{Aeq}$ 19-23h	76.2	76.6	76.6	76.5	76.4	76.3	76.7	<b>67.4</b>
$L_{Aeq}$ 23-07h	73.2	73.7	73.7	73.7	73.7	73.5	73.8	<b>65.2</b>
$L_{den}$	80.8	81.2	81.3	81.2	81.2	81.0	81.4	<b>72.6</b>

In the years 2000-2008 the noise levels hardly changed. Only the year 2008 shows a slight increase which is probably due to the construction work. The noise level in 2010 decreased considerably as a combined result of road closure, diversions and a new road surface. For this particular year, it is more interesting to look at the monthly averaged noise level distributions, see Figure 4. Although the northbound road, which is closest to the measurement site, was only taken into use in the second half of 2010, no significant increase in noise levels is observed here.

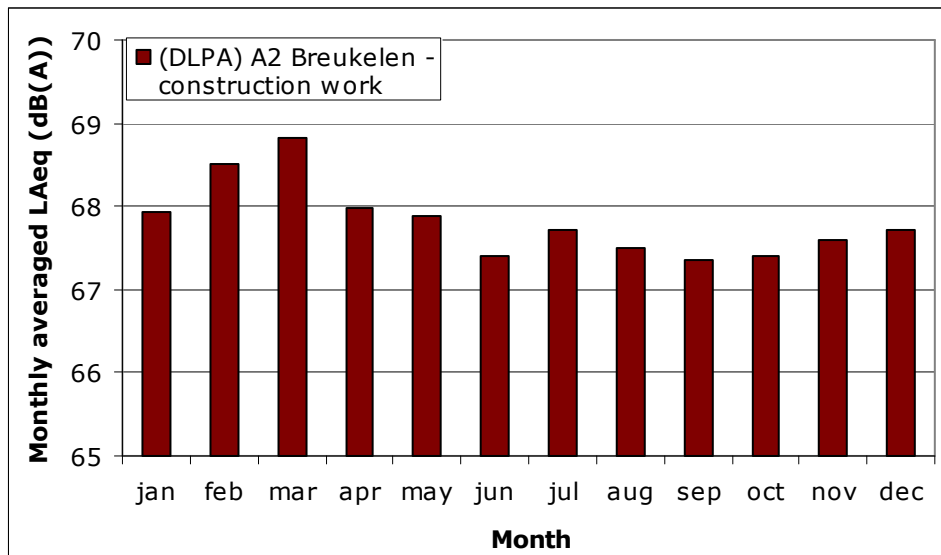


Figure 4 Monthly averaged noise levels at the A2 motorway near Breukelen for the year 2010.

### 2.1.3

#### Evaluation

As the A2 traffic was diverted during 2009 and the first half of 2010, meaningful noise monitoring was not possible in this period. In the second half of 2010 the northbound traffic returned to the original road. The year 2010 should therefore be regarded as a transition year. Its averaged noise emission does not correspond to one single traffic situation.

## 2.2 A10-West motorway in Amsterdam

### 2.2.1 Description

This RIVM noise monitor site is located at the east side of the A10-West in Amsterdam. Monitoring started in 2003. The noise monitor is located between the A10-West motorway and an apartment building (see Figure 5), so the monitor cannot be considered to be in the free field. A correction of 2 dB, subtracted from the measured levels, is applied to the measurements in order to compensate for the façade reflection. The maximum speed is 80 km/h, which is strictly enforced using the average speed check system Trajectcontrole since November 2005.



*Figure 5 The monitor location at the A10-West, indicated by the red circle on the left. On the right, the traffic in the north direction. The three exit lanes are separated from the main road by a low barrier. Source: Google StreetView.*

The motorway is divided in twelve traffic lanes, of which three on each side are exits and weaving lanes. The road surface of the A10-West mostly consists of DLPA, but at some locations the road consists of a Porous Asphalt Concrete (PAC) layer or a Dense Asphalt Concrete (DAC) layer. The PAC layers are mainly situated at bridges and the DAC layers at exit lanes. At the location of the measurement site, the road surface consists of a PAC layer as well as a DAC layer at the exit lanes.

### 2.2.2 Monitor results 2003-2010

Figure 6 shows the yearly average 24-hour noise level distributions for the years 2003-2010.

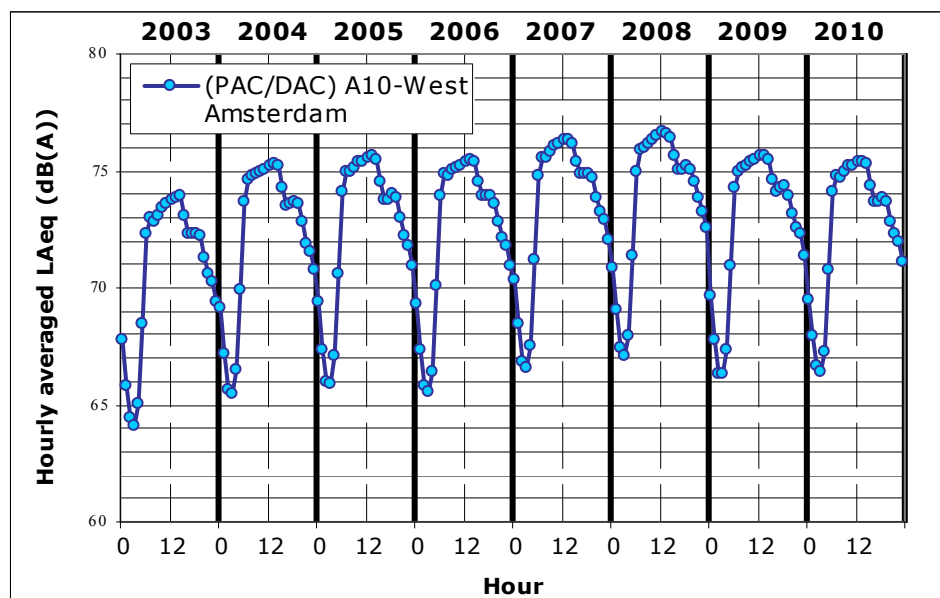


Figure 6 Average 24-hour noise level distributions, measured at the A10-West motorway in Amsterdam over the years 2003-2010.

Table 2 and Figure 7 show the equivalent noise levels for the day, evening and night time periods, as well as the weighted 24-hour average  $L_{den}$ .

Table 2 Equivalent noise levels  $L_{Aeq}$  and  $L_{den}$  A10-West Amsterdam 2003-2010.

	2003	2004	2005	2006	2007	2008	2009	<b>2010</b>
$L_{Aeq}$ 07-19 h	73.0	74.6	74.9	74.8	75.7	76.0	75.1	<b>74.8</b>
$L_{Aeq}$ 19-23 h	71.1	72.6	72.8	72.6	73.7	74.2	73.0	<b>72.7</b>
$L_{Aeq}$ 23-07 h	68.0	69.5	69.8	69.6	70.6	71.0	70.1	<b>70.0</b>
$L_{den}$	75.8	77.3	77.6	77.4	78.4	78.8	77.8	<b>77.6</b>

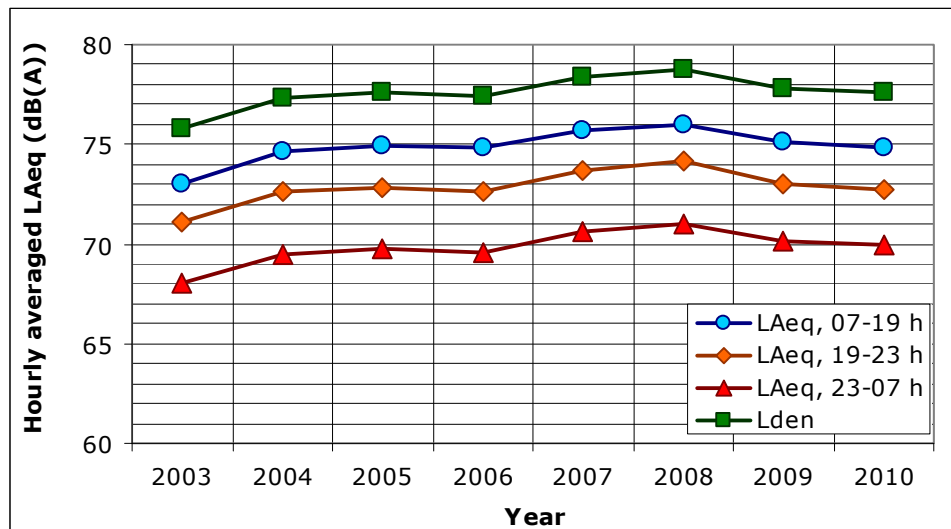


Figure 7 Equivalent noise levels  $L_{Aeq}$  and  $L_{den}$  measured at the A10-West in Amsterdam.

Just like in 2009, the average sound levels in 2010 have decreased compared to the previous year, though less than in 2009. In 2009 the decrease was approximately 1 dB. In 2010 the decrease is approximately 0.3 dB. This decrease however, is not present for all hours, which is shown in Figure 8.

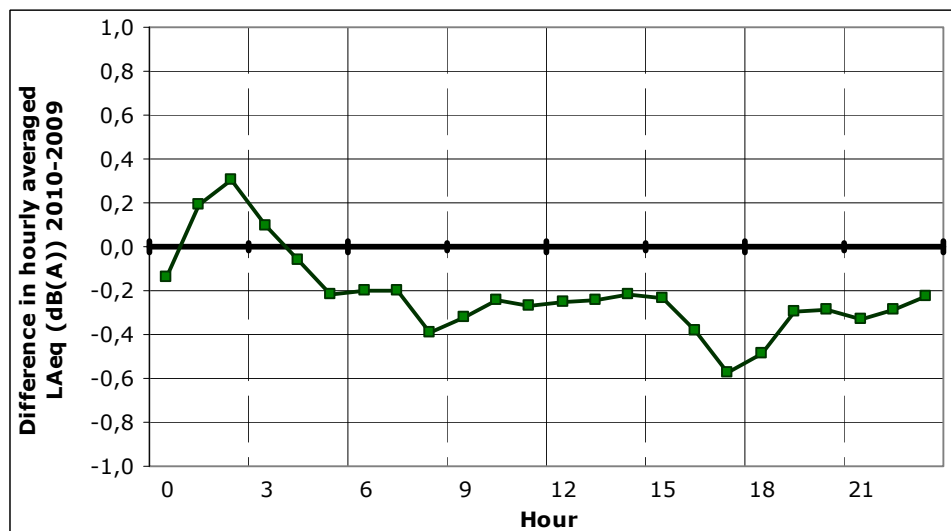


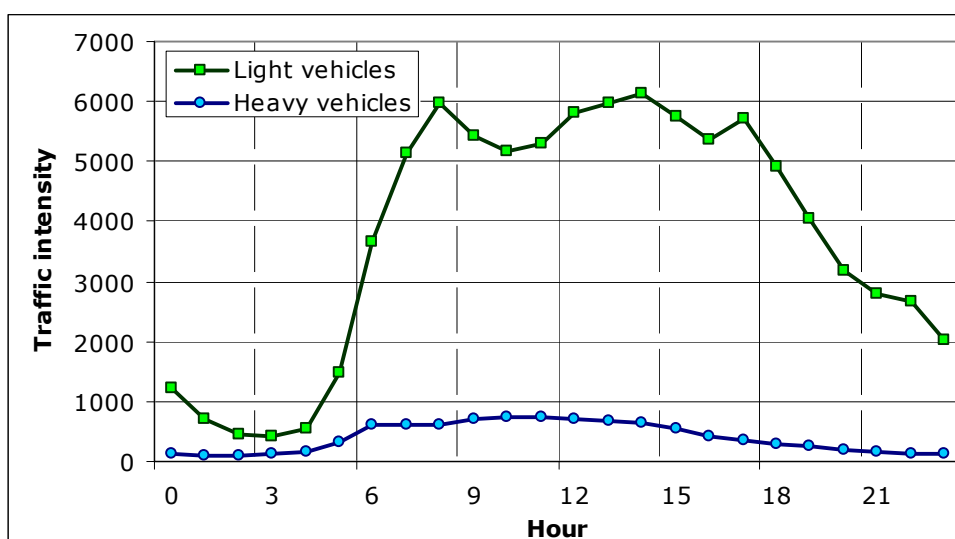
Figure 8 Difference in average 24-hour noise level distribution of the year 2010 compared to 2009. Measurements taken at the A10-West motorway in Amsterdam.

Table 3 shows the number of vehicles and their average speeds measured at the site, using counting data provided by Rijkswaterstaat, the Dutch road authority.

*Table 3 Traffic intensity and speed at the A10-West Amsterdam for the years 2004-2010. Data: Rijkswaterstaat-DVS, counting point 35675 Geuzeveld.*

Period	Daily traffic intensity		Average traffic speed (km/h)	
	Light vehicles	Heavy vehicles	Light vehicles	Heavy vehicles
2004	98734	9554	92	81
2005	102535	9740	86	77
2006	98624	9584	72	77
2007	97280	9880	73	72
2008	97421	10010	72	71
2009	93400	9360	72	72
<b>2010</b>	<b>89943</b>	<b>9480</b>	<b>72</b>	<b>71</b>

In 2010, the traffic intensity of light vehicles has decreased by 3.7% compared to 2009. Opposed to that, the traffic intensity of heavy vehicles has increased by 1.3%. The average 24-hour distribution of both traffic intensities is shown in Figure 9. Average speeds in both categories have hardly changed.



*Figure 9 The average 24-hour traffic intensity distribution for light and heavy vehicles at the A10-West Amsterdam for the year 2010.*

### 2.2.3 Evaluation

The decrease in the observed noise level is in line with the decrease in traffic intensity of light vehicles. Note however that the decrease lies within the measurement uncertainty.



## 2.3 A12 motorway near Voorburg

### 2.3.1 Description

Noise monitoring at the A12 motorway near Voorburg started in July 2005. This is a two 3-lane road and a number of changes, both in speed limitations as in paving, have taken place. Initially, the speed limit was 100 km/h, the northern lanes consisted of Double Layer Porous Asphalt (DLPA) paving and the southern lanes consisted of Porous Asphalt Concrete (PAC). In November 2005, the speed limit was reduced to 80 km/h, which was enforced by *Trajectcontrole*. Then, in September 2007, the pavement in both directions was replaced with DLPA. Finally, in December 2009, another speed limiting measure was taken, called Dynamax. The Dynamax speed control means that at night (from 23:00 h to 05:00 h) and during the evening peak, the speed limit of 80 km/h is increased to 100 km/h. At the A12 motorway near Voorburg, Dynamax is operational at the southern lanes. An analysis of noise levels over the period December 2009 – September 2010 revealed no significant increase in noise levels (Verheijen et al., 2010).

The microphone was initially placed on a traffic portal but due to accessibility and maintenance problems, the microphone was removed in July 2009 and installed alongside the northern traffic lanes in December 2009, see Figure 10. Difference due to this new microphone stand is estimated by model calculations to be +0.6 dB compared to the old situation (Verheijen et al., 2010).



Figure 10 Monitoring site at the A12 motorway near Voorburg, installed 12-12-2009.

### 2.3.2 Monitor results 2005-2010

Figure 11 shows the yearly average 24-hour noise level distributions for the years 2005-2010. Noise level distributions for the years 2005 and 2009 are half-yearly averaged, as monitoring started in July 2005 and ended (by removal of the microphone) in July 2009. The measurements in 2010, with the new microphone stand and the Dynamax speed control system into effect, are indicated with a different color.

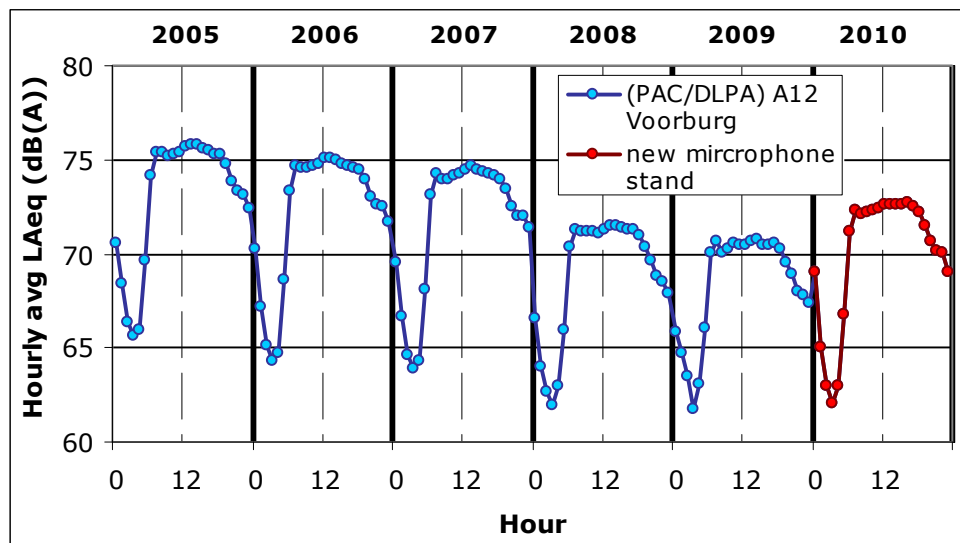


Figure 11 Yearly average 24-hour noise level distributions, measured at the A12 motorway near Voorburg over the years 2005-2010. The measurements with the new microphone stand and Dynamax speed control system into effect are in red.

Table 4 shows the equivalent noise levels for the day, evening and night time periods, as well as the weighted 24-hour average  $L_{den}$  for the years 2005-2010. Noise levels for the years 2005 and 2009 are half-yearly averaged, as monitoring started in July 2005 and ended (by removal of the microphone) in July 2009.

Table 4 Equivalent noise levels  $L_{Aeq}$  and  $L_{den}$  A12 Voorburg 2005-2010.

	2005	2006	2007	2008	2009	2010
$L_{Aeq}$ 07-19 h	75.5	74.7	74.2	71.3	70.2	<b>72.4</b>
$L_{Aeq}$ 19-23 h	73.8	73.0	72.5	69.4	68.5	<b>70.6</b>
$L_{Aeq}$ 23-07 h	70.2	69.3	68.9	66.2	66.1	<b>67.3</b>
$L_{den}$	78.1	77.3	76.9	74.0	73.6	<b>75.1</b>

### 2.3.3 Evaluation

Noise levels for the year 2010 have increased, whereas total traffic intensity has decreased. Part of this increase can be explained by the different microphone stand since December 2009, leaving an increase of  $\sim 1$  dB. This could be an indication of aging of the DLPA surface.

## 2.4 N256 motorway Noord-Beveland

### 2.4.1 Description

Actual noise emission levels for passenger cars and trucks can be measured in remote areas with low traffic intensity. The N256 motorway in Noord-Beveland is such a location. In August 2004 RIVM set up a noise monitor site at the N256 motorway Noord-Beveland near Colijnsplaat in the province of Zeeland, see Figure 12. At the site, not only the noise levels, but also each car pass-by is registered together with the type of vehicle and its speed using an automated counting device. This information allows for determination of the noise emissions per vehicle category (light vehicles, middleweight trucks and heavy weight trucks). The road surface consists of a Dense Asphalt Concrete layer with stone chipping from 0-11 mm (DAC 0-11). The microphone is placed at a distance of 7.5 m from the road centerline at a height of 4 m.



Figure 12 RIVM monitoring site at N256 motorway (Noord-Beveland).

### 2.4.2 Method

To be able to match noise events unambiguously with individual car passes, only data between 02:00 to 04:00 a.m. is taken into account. Between 02:00 and 04:00 a.m. traffic intensity is usually low. Furthermore, only noise events with a separation time of more than 30 seconds (667 m at 80 km/h) are used to minimize the probability of measuring two or more events simultaneously.

From the measured Sound Exposure Levels the  $SEL^*$  values are derived, according to the method described in Appendix 3. The  $SEL^*$  values already include the different correction factors which allows for easy comparison with the sound power level.

### 2.4.3 Monitor results 2004-2010

Table 5 shows the average sound power levels  $L_{WA}$  for the different vehicle categories for the years 2004-2010. The sound power levels were derived from the measured Sound Exposure Levels (SEL), using a reference speed of 80 km/h for light vehicles and 70 km/h for middle and heavy weight vehicles, see Appendix 3. Also the difference with the sound power level calculated according to the Dutch standard calculation model RMW2006 is given.

*Table 5 Sound power levels  $L_{WA}$  as measured at the N256 Noord-Beveland between 02:00 and 04:00 a.m. for the years 2004-2010, together with the difference between the years 2010 and 2009 and between 2010 and the Dutch standard calculation model RMW2006.*

	2004	2005	2006	2007	2008	2009	<b>2010</b>
Lightweight	106.0	105.8	105.6	105.3	105.7	105.9	<b>106.0</b>
Middleweight	109.4	109.1	108.6	108.5	108.9	108.4	<b>108.4</b>
Heavyweight	111.4	111.4	110.8	111.2	112.0	111.6	<b>111.3</b>
	Difference 2010 - 2009				Measured 2010 - RMW2006		
Lightweight	+0.1				+3.6		
Middleweight	0.0				+2.2		
Heavyweight	-0.3				+2.3		

Figure 13 shows the  $SEL^*$  values as function of the relative speed  $V/V_{ref}$  for the different vehicle categories. For each vehicle category the trendline with the according function is given, as well as the calculated value according to the Dutch standard calculation model RMW2006.

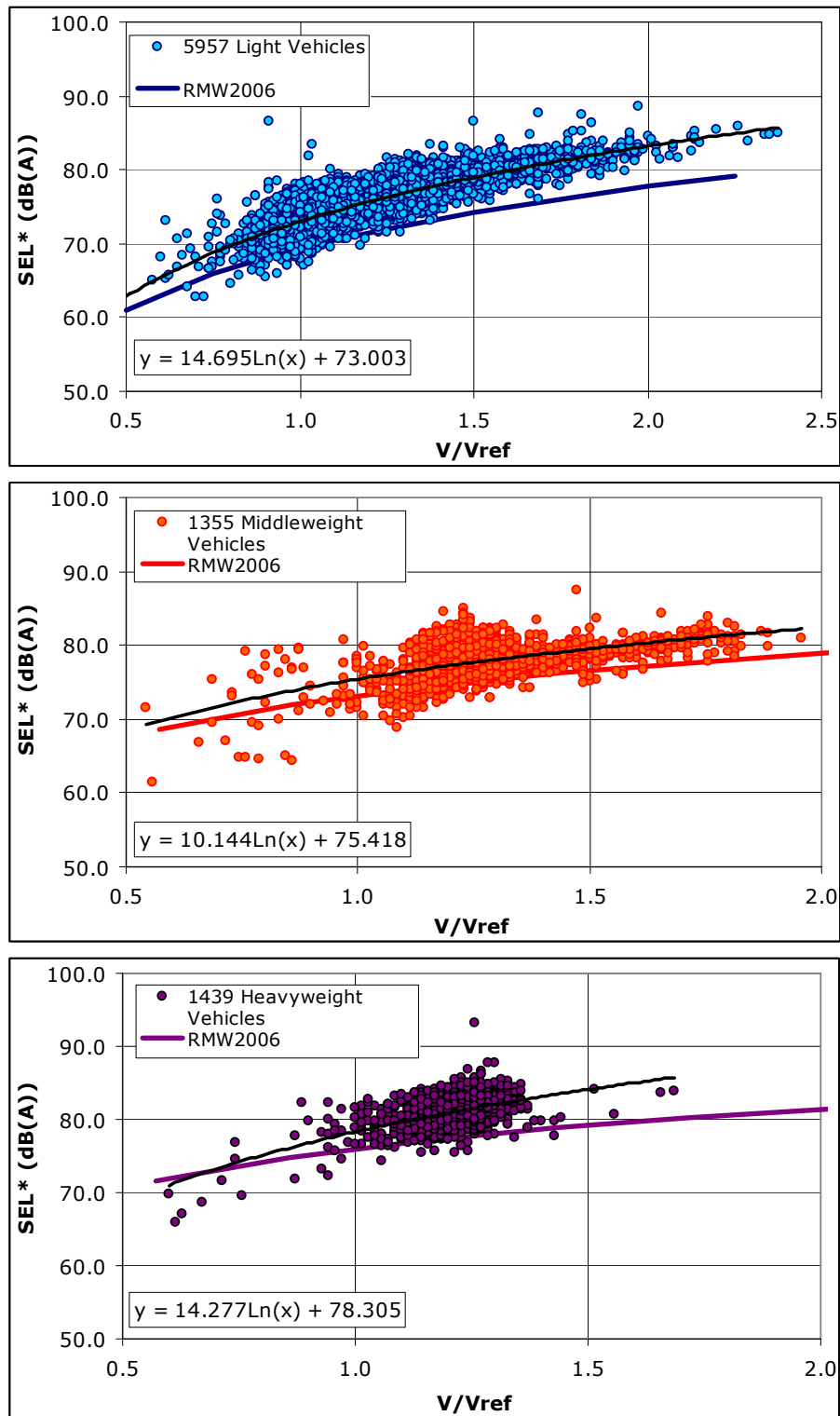


Figure 13  $SEL^*$  values derived from car passages between 02:00 and 04:00 a.m. in the year 2010 as function of the relative speed ( $V/V_{ref}$ ) for light vehicles (upper panel, blue), middle weight vehicles (middle panel, orange) and heavy weight vehicles (lower panel, purple). The black line gives the trendline for the measured values with its function indicated in each panel. The colored lines give the calculated values according to the Dutch standard calculation model RMW2006.

#### 2.4.4 *Evaluation*

Average sound power levels for passenger cars and trucks for the year 2010 stayed almost the same, compared to the previous year 2009. Over the years 2004-2010 no trend can be observed in the sound power levels for passenger cars and trucks. However, a large discrepancy between measured and calculated values is consequently found at this location. On the other hand, sample measurements at the Amsterdamsestraatweg in Utrecht in 2009 do not show this discrepancy (Schreurs et al., 2010), whereas Peeters (Peeters, 2009) does find this discrepancy. At present, a revision of the source parameters in the Dutch calculation method is being prepared by the road authority Rijkswaterstaat.

## 3 Railway noise

### 3.1 Monitoring stations ProRail

In 2005, the Dutch rail infrastructure management organization ProRail installed a small number of noise monitoring stations at specific locations along the railway network. RIVM has been granted access to the internet site containing the measurement data. In this Noise Monitor, pass-by measurements from the Esch and Tilburg stations are analysed, see Figure 14.

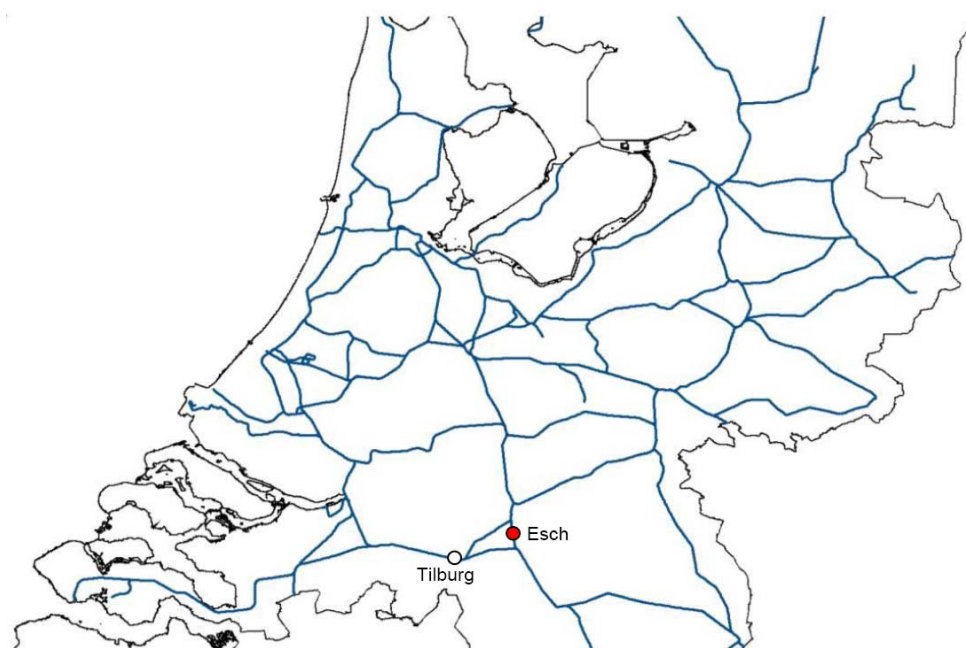


Figure 14 Measurement sites of ProRail. Tilburg (= mobile station) and Esch were operational during 2010.

The monitoring stations have been equipped with a microphone at 7.5 m from the track. Recognition of passenger trains is automated by reading the RFID tags of the vehicles. Freight trains cannot be identified this way, but are sorted out during post-processing by the web application. The noise monitoring stations render the SEL spectrum of the whole train pass-by as well as the SEL spectrum of the separate vehicles. A detailed description of the monitoring stations is given in Verheijen et al. (2008).

### 3.2 Results

The measurement data from the tracks and time periods given in Table 6 were used in the analysis. The selected months are based on periods in which the stations were fully operational. The monitoring stations do not allow for a direct calculation of the  $L_{den}$ . This is because not all pass-by's are measured. Measurements are rejected if trains cross at both tracks just in front of the microphone. Besides this, unfavourable (weather) conditions are avoided. This means that only measurements that fulfill the following requirements are used: dry weather, wind speed below 8 m/s and stable train speed during pass-by.

*Table 6 Measurement period and track.*

site	track	line	period (in 2010)
Esch	A	Eindhoven-Utrecht	Jan. and May-Nov.
Esch	B	Utrecht-Eindhoven	Jan. and May-Oct.
Tilburg	A	Breda-Tilburg	Jan.-Sep.

Instead of evaluating the  $L_{den}$ , the railway noise is evaluated by comparing the measured normalized so-called emission number  $E^*$  with the value that it should have according to the national Computation Method (RMR, 2006) and the Emission Register<sup>1</sup>. The relationship between  $E^*$  and the SEL is shown in Appendix 4.

The measured noise emission is presented with and without correction for the local rail roughness. Applying a rail roughness correction is necessary if the measurement results need to be generalized. The pass-by measurements of each relevant train category (out of the eleven categories distinguished in the national computation method) are averaged and then compared to the value given by the Emission Register for that category. The results for 2010 are summarized in Table 7 and Figure 15.

*Table 7 Normalized emission number  $E^*$  in dB(A) according to the Emission Register (Aswin) and its deviation from measurement (measurement minus computation) in Esch (Es) and Tilburg (Tb).*

Category	Aswin		without roughness correction [dB]		with roughness correction [dB]	
	speed [km/h]	$E^*$	Es	Tb	Es	Tb
1	140	65.5	-0.2	1.4	0.0	1.6
2	140	66.7	-0.4	1.6	-0.3	1.8
4	90	63.4	0.7	0.7	0.8	0.9
8	140	60.3	-1.5	-2.7	-0.6	-0.7

1. Mat64 2. ICR/ DDM1 4. Cargo (freight) 8. DDM2/ICM4/IRM/ICK

<sup>1</sup> The Emission Register is a yearly database published by ProRail under the name of Aswin which contains the traffic parameters and the noise emission number  $E$  along the railway network.



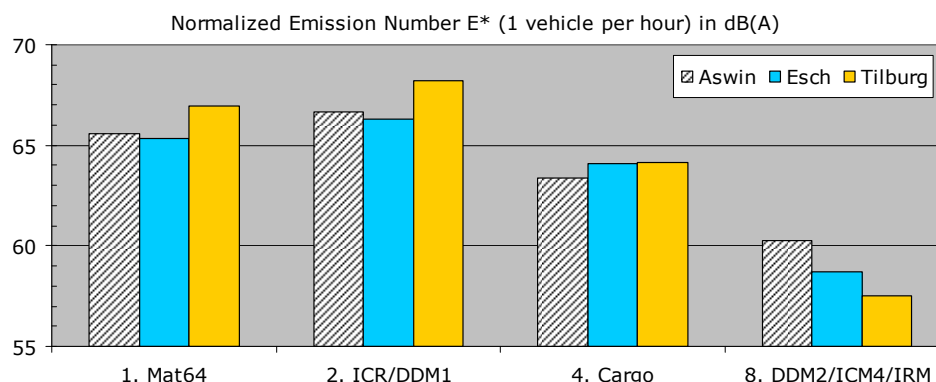


Figure 15 Comparison of the emission number  $E^*$  (normalized at 1 vehicle per hour) according to Aswin and the monitoring stations at Esch and Tilburg (without rail roughness correction).

The differences observed between measurements and calculations are mainly caused by:

- *The local rail roughness.* Rail roughness tends to grow slowly until ProRail commissions the rails to be ground.
- *The actual pass-by speed.* The Emission Register gives only the maximum speed, not the average actual speed. As the actual speeds may differ, the measured emission may deviate somewhat from the calculated emission.
- *Deviations due to features related to the rolling stock.* For instance, the wheel roughness may vary slightly during the seasons. Variations of a few decibels on a seasonal scale are not exceptional (Verheijen et al., 2007a).

The measurement station at Esch is the only station that has been operational every year since 2006. The historical results, as can be found in the Noise Monitors since 2006, have been listed in Table 8. These series show that the normalized emission, corrected for rail roughness, can increase or decrease slightly between subsequent years. There is no clear trend.

Table 8 Deviation between measured and calculated  $E^*$  in Esch with roughness correction (measurement minus computation).

Category	2006	2007	2008	2009	2010
1	0.8	0.4	0.3	0.9	0.0
2	0.4	0.1	-0.7	0.3	-0.3
4	-	-	-	1.9	0.8
8	0.6	0.7	1.6	-0.1	-0.6

### 3.3 Influence of speed

The speed-dependency is assessed for the measurement site Tilburg. The speed-dependency is shown for the four train categories in Figure 16. A rail roughness correction is applied. It is remarked here that at present most of category 8 rolling stock consists of the IRM type, which is known to emit about 2 dB less noise than the category 8 curve (Verheijen, 2007b). The measured speed-dependency of the other trains (black regression line) is in line with the national standard (green line).

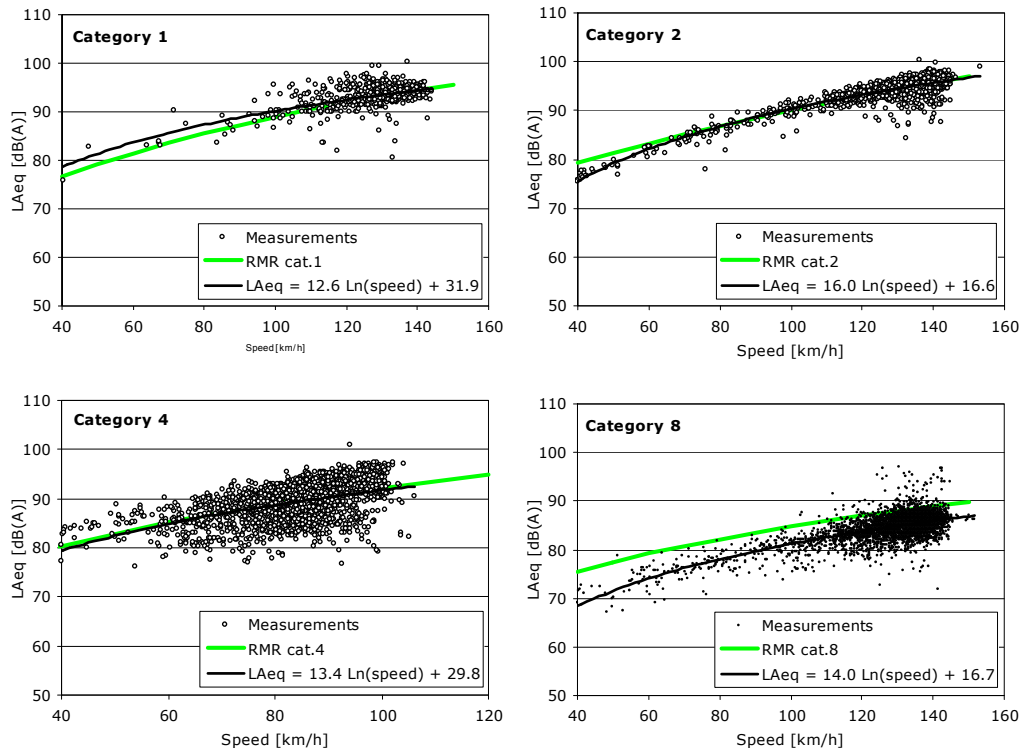


Figure 16 The  $LA_{eq}$  of the pass-by is plotted versus speed (corrected to standard rail roughness). The green curve shows the standard speed-dependency as calculated with the standard calculation method.

### 3.4 Conclusion

The railway noise emission at normal driving speeds, as measured at two monitoring sites in 2010, corresponds within 1 dB with the calculated emission according to the national calculation method. Also, the speed-dependency of the noise emission, as checked at the Tilburg site, is in line with the national standard.

## 4 Airport noise

### 4.1 Introduction

There are several measurement systems for airport noise in the Netherlands that aim to monitor the noise levels as caused by airport noise by means of direct measurement. Amsterdam Airport Schiphol uses its own noise monitoring network, which is called NOMOS (NOise MONitoring System). In addition there are the monitoring networks of 'Geluidsnet' (Geluidsnet, 2012), and 'Geluidconsult' using a 'Luistervink' system (Andringa et al., 2004) that acquire noise data in various municipalities in the neighborhood of airports. Rotterdam Airport uses RANOMOS (Rotterdam Airport NOise MONitoring System) that allows one to relate complaints from inhabitants to specific airplanes.

Although the output of these measurement systems is not used in legislation regarding maximum allowable noise levels (these are evaluated using standard calculation of noise levels), the monitoring sites do provide valuable information as to trend developments and validation of standard models. For an extensive discussion of noise monitoring systems for airport noise see Jabben and Potma (2005) and Jabben et al. (2007).

As to the existing measurement systems, in general they do not provide - by standard - information on the noise levels caused by individual airplanes together with the type of the airplane. Such information can be useful, because in combination with the distance to the receiver the sound power levels (indicating the amount of 'emitted' or produced noise) of airplanes *in situ* can be estimated. By consistently monitoring noise levels, airplane types and nearest distances between plane and receiver over relatively long periods of time, gradually a representative picture of noise emissions characteristics of the airport fleet can be determined. Such an approach is often used in measuring noise emission *in situ* along roadways or railway lines, but both on national and international level it is not practice in airport noise.

### 4.2 Measurement set up

#### 4.2.1 Measurement site

In order to evaluate the possibilities to relate individual noise levels from airplanes to the type of airplane and to assess sound power levels *in situ*, a pilot study was set up at a measurement site near the village of Zegveld, just outside the designated quiet area 'Nieuwkoop and surroundings'. This site is located approximately 17 km south of Schiphol Airport, and when the southernmost runways are in use (the 'Kaagbaan' and the 'Aalsmeerbaan'), the monitor can register planes taking off from or landing at these runways.

#### 4.2.2 Measuring apparatus

For this pilot study noise measurements were carried out using a RION NA-37 (RION, 2012). The NA-37 is capable of determining the sound source position based on sound arrival direction. The directional system allows to separate airplane noise events from other (ground) noise sources. For the analysis given here, all recorded events were checked manually before relating these to airplane passages. For each airplane noise events, the Sound Exposure Level and the maximum noise level were measured and stored.

#### 4.2.3 *Airplane data*

In order to connect the noise events that were identified as flights to specific aircraft data, the time of flight was matched manually with aircraft transponder information through the website *Casper Live Aircraft Tracking* (Casper, 2011). In this way airplane type, speed and height and minimum distance to the Zegveld receiver can be derived. From these data the sound power levels can be assessed for different types of aircraft. As not all aircraft provide transponder information, not all noise events as measured at Zegveld could be matched to a specific airplane. Also the transponder information regarding the position points of the flight tracks is less accurate as compared to the FANOMOS (Flight track and Aircraft NOise MONitoring System) database from air traffic control. The aim of the pilot however is to obtain a sample set of passages for which noise event level and flight data can be matched and not to determine accumulated noise levels of all planes passing by. To this aim the data is considered sufficient.

#### 4.2.4 *Determination of sound power levels*

To first approximation, the airplanes were considered as omnidirectional point sources. Sound power levels ( $L_W$  re  $10^{-12}$  W) were determined according to:

$$L_W \approx SEL + 10\log(4\pi v) + 0.002a \quad (4.1)$$

in which

$L_W$  : Sound Power Level in dB(A) re  $10^{-12}$  Watt

SEL : Measured Sound Exposure Level at the receiver in Zegveld [dB(A)]

$a$  : minimum distance [m] between airplane and receiver during passage

$v$  : speed [m/s]

The last term in equation 4.1 accounts for an average noise attenuation of 2 dB per km due to air absorption.

### 4.3 **Results**

Measurements conducted between March and December 2010 were analyzed according to the method described in the previous section. In that period of time about 1750 events could be linked to specific flights using the Casper website. Of these aircraft, 60% were taking off from Amsterdam Airport Schiphol, while 40% were approaching the airport. Table 9 shows the calculated sound power levels  $L_W$  for these flights, derived from the measured SEL values using Equation 4.1. The columns show the  $L_W$  levels rounded off to the nearest integer, and the rows show the aircraft types that were encountered. Aircraft types with less than 5 recorded events are not shown in this table. The sound power levels reveal a range of about 15 dB for most types. The highest levels were found for the relatively old Airbus types (A330 and A310), although these were only measured once.

The sound power levels have been evaluated in Figure 17. Ascending aircraft clearly emit more noise than descending aircraft. The average of the differences between ascending and descending per aircraft is about 6 dB. The largest and smallest difference in this dataset are found for Fokker F100 (10 dB) and Boeing 767-300 (0.5 dB), respectively.

Table 9 Distribution of the derived sound power levels  $L_W$  for descending and ascending airplanes.  $L_W$  ranges from 120 to 150 dB. Colors emphasize the numbers of event: yellow 10-15, orange 16-25, dark orange 26-35, red 36-50.

$L_W$ [dB] re $10^{-12}$ W	120	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150	Total
<b>Descending/landing (1034 events)</b>																																
a319											2	2	3	3	9	15	16	6	9	7	4	1										77
a320										2		5	2	4	10	20	20	15	8	4	2	1	1									94
a321											1				7	7	5	3		2												27
a330-200										1			1	2	5	2	9	3	2	3	1	1										30
b737-300											2	1	5	6	6	2	4			2	4											32
b737-400										1	1	2	1	2	1	2	2	1			1			1								12
b737-500								1	1			1	2	4	10	3	2	1	1	1			1									28
b737-600								1				1	1	2	2		1	5	2			1										16
b737-700							1	3	2	5	15	25	21	11	10	6	8			1												108
b737-800			1				1	2	9	32	29	37	48	28	21	9	7	2			1			1								228
b737-900							2	1	3	15	9	14	4	5	1	2	1															57
b747-400															1	8	10	15	21	26	16	10	4	4	2	1			1			119
b767-300											1				1	1	1				2	1			1							8
b777-200								1	1	4	4	10	5	5	4	1	3	1			1											40
bae-146-200								2	4	4	2		1	1	1																	15
f100				1	2		4	6	3	5	3	2	2	1																		29
f70	1	2		7	8	8	16	10	12	6	5	10	8	10	4	1	2	3		1												114
<b>Ascending/take off (720 events)</b>																																
a318															1	1	2	3	1													8
a319																5	5	9	13	5	5	3		1								46
a320															1	7	7	20	18	12	8	4	2	2			1		1			84
a321																1	4	5	18	14	11	4	2	1								60
a330-200																					1	3	2	5	5	1					1	18
a340-300																	1				4	1	3	3								12
b737-300																			1	1	1	1	2									6
b737-700												1			2	3	3	12	16	9	6	2	1							1		56
b737-800															3	3	12	21	37	44	43	19	8	1								191
b737-900																	1	1	5	8	4	9	1	1			1					31
b747-400																			1													6
b777-200															1	2	6	11	10	11	17	7	3			1						69
bae-146-200											1	1	6		3	4	1															16
f100															1	2	5	3	8	6	4	3										32
f70															3	8	9	22	17	8	14	3					1					85

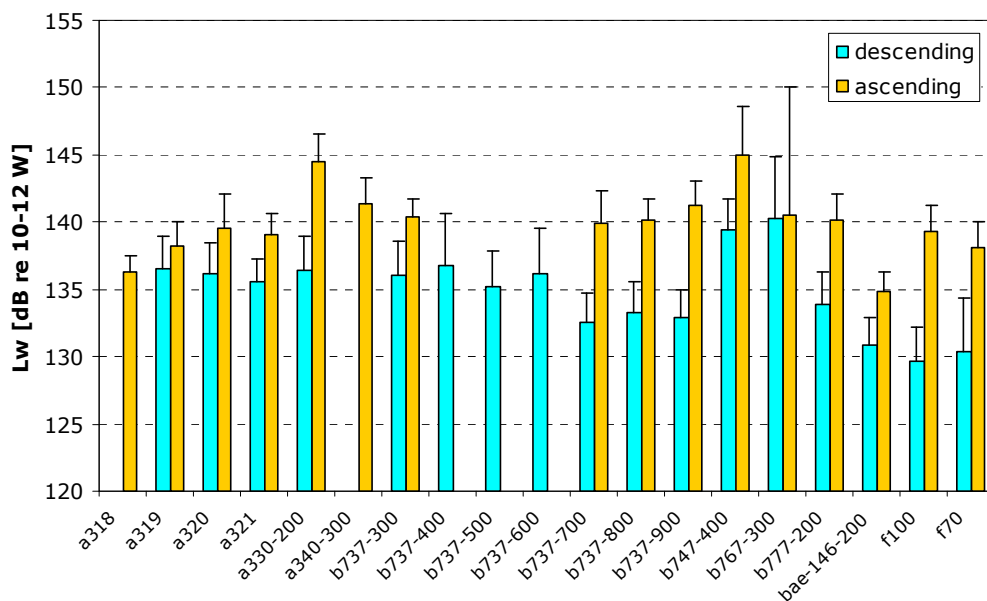


Figure 17 Average sound power levels of ascending and descending flights over Zegveld. Error bars refer to standard deviation.

#### 4.4 Comparison with INM data

These measured results can be compared with the sound power levels that can be derived using the Integrated Noise Model (INM) of the Federal Aviation Association (FAA), which is widely used for evaluating aircraft noise (INM, 2007). From the Integrated Noise Model sound power levels  $L_w$  in dB(A) can be estimated using different thrust settings for the aircraft types. The details are given in Appendix 5. In Figure 18 and Figure 19 the measured and estimated sound power levels are compared for descending and ascending aircrafts, respectively. The agreement for most aircraft types is reasonably well. Fairly large differences are found for descending A319 and ascending F100 and F70. Probably these aircraft apply different (off average) thrust settings than assumed in Appendix 5.

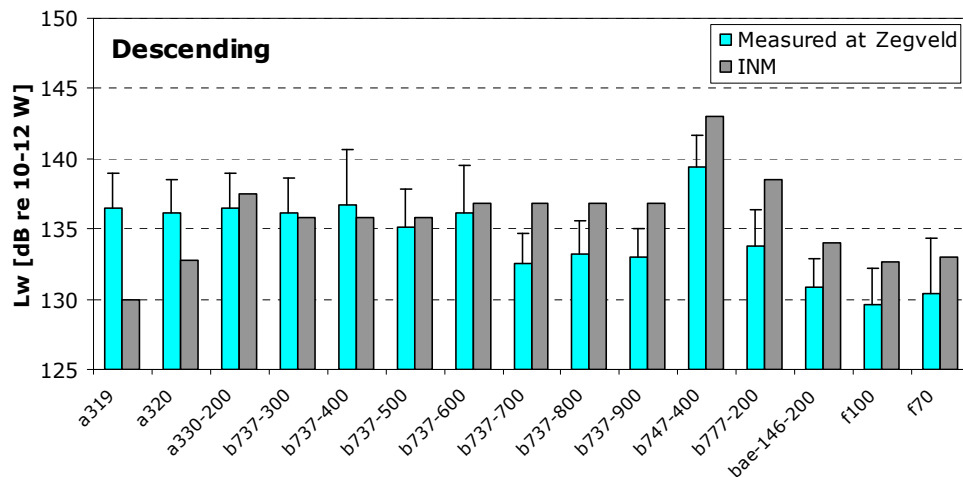


Figure 18 Measured and calculated sound power levels of descending flights near Zegveld.

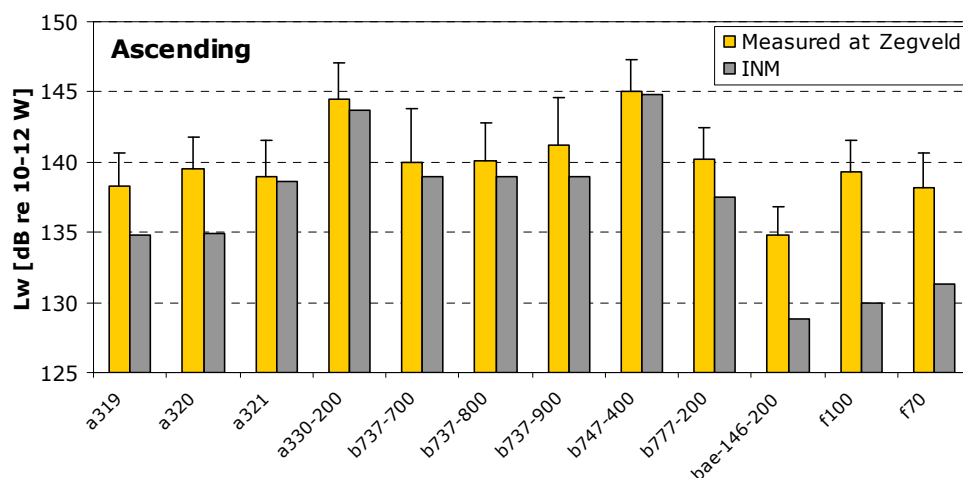


Figure 19 Measured and calculated sound power levels of ascending flights near Zegveld.

## **4.5 Conclusion**

The results demonstrate that the measurement and analysis method described in this chapter in principal allows identifying noisy airplanes from more quiet airplanes. The method can be used to evaluate the fleet composition of an airport and to answer the question to which extent it uses the quietest airplanes available.

## 5 Conclusions

### **Road noise**

The noise levels at the *A2 motorway near Breukelen* for the year 2010 have decreased considerably as a combined result of road displacement, speed reduction and quieter road surface. The year 2011 will probably have a more stable traffic situation.

The noise level at the *A10-West motorway in Amsterdam* has decreased by approximately 0.3 dB. This decrease lies within the measurement uncertainty, but it can also be attributed to the observed decrease in traffic intensity of light vehicles.

Noise levels at the *A12 motorway near Voorburg* have increased by 1 dB. This might be caused by aging of the DLPA surface.

Average sound power levels measured at the *N256 motorway Noord-Beveland* in 2010 are again higher than the levels calculated according to the Dutch standard calculation model RMW2006.

### **Railway noise**

The measured railway noise emission at normal driving speeds corresponds within 1 dB with the calculated emission according to the national calculation method. Also, the speed-dependency of the noise emission is in line with the national standard.

### **Airport noise**

Measurements performed at the Zegveld site demonstrate that it is possible to determine sound power levels of ascending and descending aircraft. The events could be linked to specific aircraft flying to and from Amsterdam Airport Schiphol. On average, descending aircraft appear to be about 6 dB quieter than ascending aircraft at this measurement site (17 km from the runway).

The measured results compare fairly well with the source data of the Integrated Noise Model.



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## Appendix 1 Locations of measurement stations



## Appendix 2 Description of measurement equipment

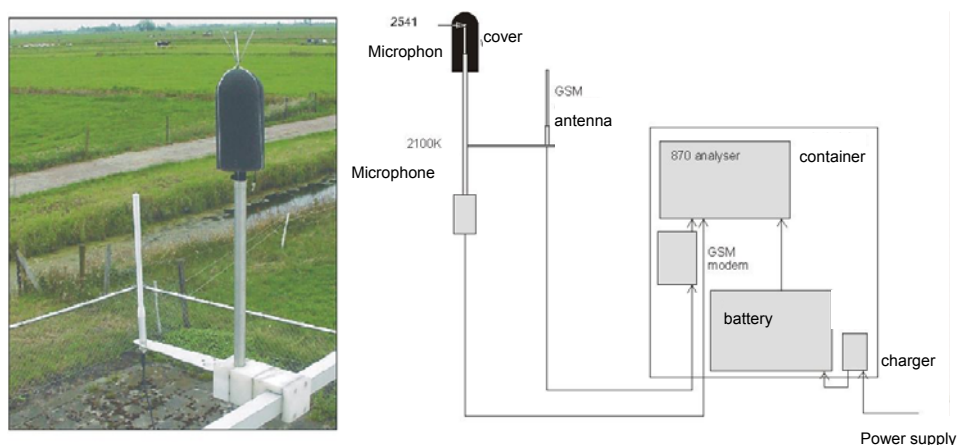


Figure A1 Measurement system on road monitoring locations.

Figure A1 shows how the measurement system is used as monitor for road noise.

One noise monitor consists of:

- microphone stand+pre-amp, manufactory Larson-Davis, type 2100K;
- microphone, manufactory Larson-Davis, type 2541;
- statistical analyser, manufactory Larson-Davis, type 870;
- gsm-modem with antenna;
- battery and charger;
- container.

This type of microphone stand is useful for measurements outside. The microphone itself is equipped with a rain cover and heating. The pre-amp has a heating to prevent the amp from moisture. The microphone is covered with a wind screen. The microphone stand comes with built-in pre-amp to amplify the signal. To prevent the microphone and the pre-amp from moisture, silica gel is used and will be replaced every three months. The statistical analyser measures the signal of the microphone and calculates various statistical parameters like A-weighted level  $L_{Aeq}$ . The analyser has an internal GSM modem with antenna, which is connected to the microphone. A computer attached with a standard modem has to connect to the GSM modem, in order to retrieve the measurement data. On this computer a NMS (Noise Monitoring System) application of Larson-Davis has been installed. The measurements collected from all road locations are stored on a NMS database on a monthly basis.

## Appendix 3 Measured versus calculated noise N256

In order to compare measured Sound Exposure Levels with the calculated values according to the Dutch standard calculation model RMW2006, the  $SEL^*$  has been defined as:

$$SEL_{meas}^* = SEL_{meas} + 10 \cdot \log(V/3600) + 10 \cdot \log(R) + D_{ground} + D_{air} \quad (\text{eq A1})$$

with:

$SEL$	=	Sound Exposure Level (dB(A)) of the measured vehicle pass-by
$V$	=	speed (km/h)
$R$	=	distance lane – receiver (6.7 en 9.2 m for nearest and farthest lane, respectively)
$D_{ground}$	=	ground attenuation according to RMW2006, set at an average value of 1 dB
$D_{air}$	=	air attenuation $\sim 0.1$ dB

According to the RMW2006 the  $SEL^*$  value is given by:

$$SEL_{RMW06}^* = a + b \cdot \log(V/V_{ref}) \quad (\text{eq A2})$$

where:

$V_{ref}$	=	reference speed (80 km/h for light vehicles and 70 km/h for middleweight and heavy vehicles)
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If the measured  $SEL^*$  are plotted against the relative speed  $V/V_{ref}$  a logarithmic regression curve through the measurement points should coincide closely with the calculated  $SEL_{RMW06}^*$  values.



## Appendix 4 Emission of railway vehicles

Table A3 gives an overview of the present acoustical categorization of the rolling stock.

*Table A3 Categorisation scheme of rolling stock according to RMR (2006).*

Category	Description (braking system)	Main train types
1	passenger (cast-iron block)	Mat64
2	passenger (disc + add. cast-iron blocks)	ICR; ICM3; DDM1
3	passenger (disc)	SGM II/III, loco 1700
4	freight (cast-iron block)	Cargo (cast-iron blocks)
5	passenger diesel-electr. (cast-iron block)	DE
6	passenger diesel-hydraulic (disc)	DM90, diesel loco 6400
7	metro (disc)	metro of GVB and RET
8	modern intercity and regional (disc)	ICM4; DDM2/3; IRM; ICK, SLT, GTW
9	high speed (mainly disc)	Thalys; ICE3
10	light rail	A32, Regio Citadis
11	silent freight	Cargo (K-blocks)

The normalized emission number  $E^*$ , that is judged in this research for a number of the above categories, is based on a vehicle flow of 1 vehicle per hour. The relationship between the Sound Exposure Level and the normalized emission number  $E^*$  is:

$$E^* = \text{SEL} - 10 \lg T + 10 \lg a + D_{\text{ground}} + D_{\text{air}} + D_{\text{meteo}} - 10 \lg Q \quad (\text{eq A3})$$

with:

$E^*$	=	normalized emission number in dB(A) based on 1 vehicle per hour
$Q$	=	vehicle flow [#vehicles/hour]
SEL	=	Sound Exposure Level
$T$	=	duration of the pass-by from buffer to buffer [seconds]
$a$	=	distance to heart of track (7.5 m)
$D_{\text{bodem}}$	=	ground attenuation (0.3 dB(A))
$D_{\text{meteo}}$	=	meteocorrection (0 dB(A))
$D_{\text{lucht}}$	=	air attenuation (0.1 dB(A))

The monitoring stations also give the number of vehicles within one pass-by. This number is used to normalize the emission. In this way, the resulting emissions can be compared mutually, independent of the vehicle flow  $Q$ .

## Appendix 5 Aircraft types and INM NPD values

The calculated sound power levels of the recorded aircraft types at Zegveld are compared with the sound power levels as can be derived from the INM NPD tables. For the INM calculation, as average height for descending planes 680 m (2000 ft) was taken, while for ascending planes 1915 m (6300 ft) was used.

<b>DESCENDING</b>	Aircraft type	INM NPD id	Thrust setting (pounds)	L <sub>w</sub> (dB(A))
a319	Airbus A319	V2522A	2700	130
a320	Airbus A320	V2527A	2700	133
a330-200	Airbus A330-200	CF680E	6000	137
b737-300	Boeing 737-300	CFM563	3500	136
b737-400	Boeing 737-400	CFM563	3500	136
b737-500	Boeing 737-500	CFM563	3500	136
b737-600	Boeing 737-600	CF567B	4000	137
b737-700	Boeing 737-700	CF567B	4000	137
b737-800	Boeing 737-800	CF567B	4000	137
b737-900	Boeing 737-900	CF567B	4000	137
b747-400	Boeing 747-400	PW4056	10000	143
b777-200	Boeing 777-200	GE90	17000	138
bae-146-200	BAe 146-200	AL502R	1600	134
f100	Fokker 100	TAY650	3372	133
f70	Fokker 70	TAY620	3372	133

<b>ASCENDING</b>	Aircraft type	INM NPD id	Thrust setting (pounds)	L <sub>w</sub> (dB(A))
a319	Airbus A319	V2522A	14000	135
a320	Airbus A320	V2527A	14000	135
a321	Airbus A321	V2530	18000	138
a330-200	Airbus A330-200	CF680E	42000	144
b737-700	Boeing 737-700	CF567B	13000	139
b737-800	Boeing 737-800	CF567B	13000	139
b737-900	Boeing 737-900	CF567B	13000	139
b747-400	Boeing 747-400	PW4056	32000	145
b767-400	Boeing 767-400	CF680C	25000	137
b777-200	Boeing 777-200	GE90	41000	138
bae-146-200	BAe 146-200	AL502R	1600	129
f100	Fokker 100	TAY650	4496	130
f70	Fokker 70	TAY620	4496	131

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