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TNO report

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Simple Engineering Assessment; The effect of wind turbines at Walcourt on the Florennes STAR 2000 primary radar system without and with Wind Farm Filter

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Contents

1 Introduction

The performance of radar systems can be negatively influenced by wind turbines in the vicinity. EUROCONTROL has issued guidelines, on how to assess the potential impact of wind turbines [1]. Within these guidelines different zones around the radar are defined. A Detailed Engineering Assessment (DEA) for the primary radar is required at distances of the wind turbines from 500 m to 15 km (zone 1). In the zone ranging from 15 km to the instrumented range of the primary radar (zone 2), a so-called Simple Engineering Assessment is required.

The newly planned three wind turbines at Walcourt will be located at distances larger than 15 kilometres from the Primary Surveillance Radars (PSR) at Florennes. Thales France, the manufacturer of STAR 2000 the Primary Surveillance Radars (PSR) at Florennes offers a Constant False Alarm Rate (CFAR) processing enhancement called the Wind Farm Filter (WFF). This enhancement improves the radar performance at the wind turbine positions. In this study we will assess the potential improvement of the WFF by performing a Simple Engineering Assessment (SEA). In this SEA a check will be performed whether there is line of sight between the PSR and the wind turbines. If that is the case the dimensions will be determine of the region of potential impact on the wind turbines on the radar without and with the WFF enhancement.

Note that in a simple engineering assessment the size and position of various regions of impact for the primary radar are determined. However, the extent of the interference within these regions is not assessed.

In Chapter 2 the relevant input parameters of the wind turbines and radar are given. In Chapter 3 we perform the line-of-sight analysis to determine whether the wind turbines are visible to the radar. In Chapter 4 we determine the size and position of the regions of potential impact without and with the WFF processing enhancement. Chapter 5 deals with the potential issues of false target reports and PSR processor overload.

2 Input Parameters

2.1 Wind turbines

The simple engineering assessment is carried out for a total of 60 wind turbines. The three newly planned wind turbines and the 57 existing and authorized wind turbines in a 20 km circle around the newly planned wind turbines, are shown in Figure 2.1 and Figure 2.2. The red dots indicate the existing and authorized turbines, the green dots indicate the three wind turbines under investigation.

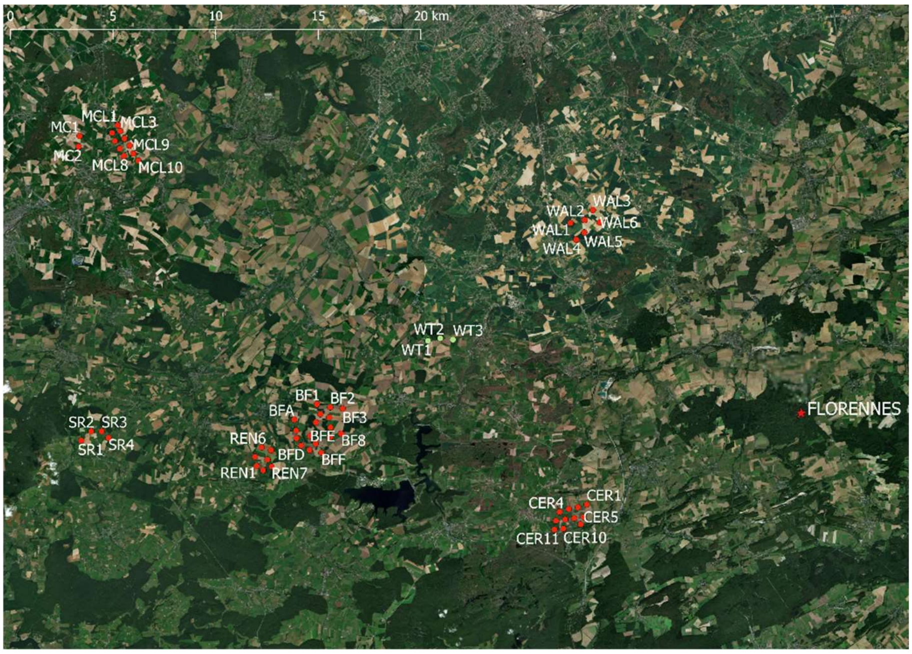

Figure 2.1 The locations of three newly planned wind turbines (green). Background image taken from Bing Aerial.

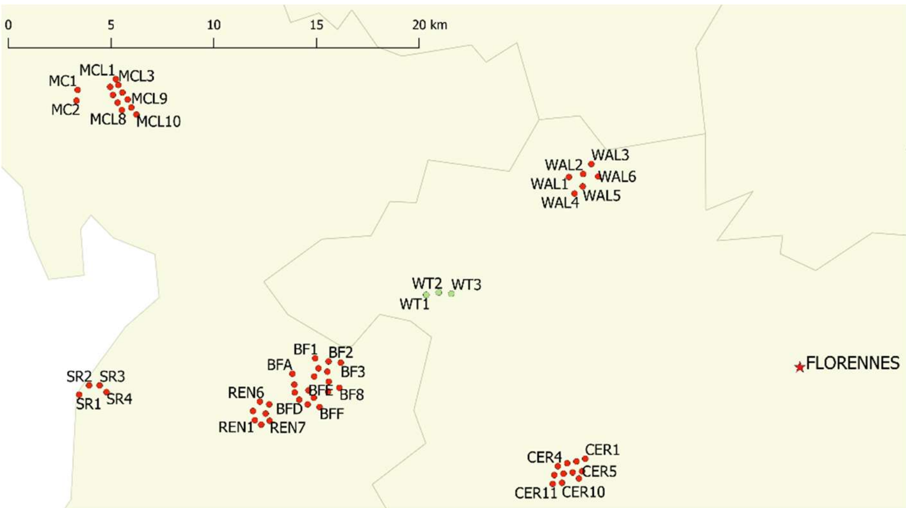

Figure 2.2 The locations the primary surveillance radar at Florennes, the three newly planned wind turbines (green) and the existing and authorized wind turbines (red) in its neighbourhood.

In Table 2.1 an overview is presented of the positions and heights of the 57 existing and authorized turbines as well as the hub and tip heights of these turbines. The coordinates of the wind turbines are given in Lambert72 and have been received from BEE. The WGS84 coordinates have been derived from that. The height of the ground level at the locations is given with respect to the EGM96 geoid and has been derived from the SRTM altitude database. At this stage of the building plan, BEE does not have made a final decision with respect to the final hub height of the turbines. For this reason, an SEA is performed for a hub height of 81 and 111 m, resulting in a maximum tip height of 150 and 180 m respectively. The positions and dimensions of the three planned wind turbines are presented inTable 2.2 for the tip height of 150 m and Table 2.3 for the tip height of 180 m.

Table 2.1 Overview of the positions of the 57 existing or authorized wind turbines in the neighbourhood of the three newly planned wind turbines. The X, Y coordinates have been provided by BEE. The longitude and latitude have been derived from the Lambert72 coordinates. The terrain height has been derived from the SRTM altitude database.

Nr.	ID	Lambert72 Coordinates		Terrain height w.r.t. EGM96	Lon. WGS84	Lat. WGS84	Hub Height	Tip Height
		X [m]	Y [m]	Z [m]	[º]	[º]	[m]	[m]
1	BF1	146598	101490	227	50.22449	4.32107	100	150
2	BF2	147252	101341	229	50.22315	4.33023	100	150
3	BF3	147850	101278	236	50.22259	4.33861	100	150
4	BF4	146767	101004	231	50.22012	4.32344	100	150
5	BF5	147198	100842	243	50.21867	4.32948	100	150
6	BF6	146552	100605	240	50.21653	4.32043	100	150
7	BF7	147262	100356	244	50.21430	4.33038	100	150
8	BF8	147781	100053	254	50.21157	4.33765	100	150
9	BF9	147231	99874	248	50.20996	4.32995	100	150
10	BF10	146534	99573	256	50.20725	4.32019	100	150
11	BFA	145493	100738	235	50.21772	4.30559	104	150
12	BFB	145587	100205	247	50.21293	4.30691	104	150
13	BFC	145606	99830	256	50.20956	4.30719	104	150
14	BFD	145828	99475	256	50.20637	4.31030	104	150
15	BFE	146275	99935	250	50.21051	4.31656	104	150
16	BFF	146817	99123	252	50.20321	4.32416	104	150
17	BEA1	146236	99252	256	50.20437	4.31602	95	150
18	WAL1	158955	110308	239	50.30371	4.49445	85	124
19	WAL2	159651	110456	241	50.30503	4.50422	85	124
20	WAL3	160049	110940	229	50.30937	4.50982	85	124
21	WAL4	159234	109503	231	50.29647	4.49834	85	124
22	WAL5	159629	109849	237	50.29957	4.50390	85	124
23	WAL6	160379	110335	238	50.30393	4.51444	85	124
24	CER1	159751	96609	265	50.18053	4.50527	78	123
25	CER2	159323	96473	258	50.17932	4.49927	78	123
26	CER3	158873	96387	253	50.17855	4.49297	78	123
27	CER4	158421	96243	247	50.17726	4.48664	78	123
28	CER5	159594	95995	264	50.17502	4.50305	78	123

Nr.	ID	Lambert72 Coordinates X [m]	Y [m]	Terrain height w.r.t. EGM96 Z [m]	Lon. WGS84 [º]	Lat. WGS84 [º]	Hub Height [m]	Tip Height [m]
29	CER6	159141	95939	265	50.17452	4.49671	78	123
30	CER7	158696	95877	262	50.17397	4.49048	78	123
31	CER8	158249	95814	261	50.17341	4.48422	78	123
32	CER9	159449	95646	263	50.17188	4.50101	78	123
33	CER10	158616	95435	263	50.17000	4.48935	78	123
34	CER11	158169	95384	264	50.16954	4.48309	78	123
35	SR1	135113	99720	213	50.20840	4.16019	93	150
36	SR2	135594	100170	228	50.21246	4.16691	93	150
37	SR3	136105	100172	226	50.21249	4.17407	93	150
38	SR4	136441	99848	224	50.20958	4.17879	93	150
39	MCL1	136889	115069	175	50.34643	4.18454	100	150
40	MCL2	136617	114692	176	50.34304	4.18073	100	150
41	MCL3	137013	114785	179	50.34388	4.18629	100	150
42	MCL4	136752	114300	169	50.33952	4.18264	100	150
43	MCL5	137217	114418	180	50.34059	4.18917	100	150
44	MCL6	136985	113925	175	50.33615	4.18593	100	150
45	MCL7	137473	114082	185	50.33757	4.19278	100	150
46	MCL8	137188	113565	178	50.33292	4.18879	100	150
47	MCL9	137648	113687	183	50.33403	4.19525	100	150
48	MCL10	137895	113344	173	50.33095	4.19873	100	150
49	MC1	135031	114543	153	50.34166	4.15845	95	150
50	MC2	134980	114028	156	50.33703	4.15776	95	150
51	REN1	143659	98477	241	50.19738	4.27993	89	150
52	REN2	144189	98800	245	50.20029	4.28735	89	150
53	REN3	144362	99254	246	50.20437	4.28977	89	150
54	REN4	143974	98269	236	50.19551	4.28435	89	150
55	REN5	143577	98928	233	50.20143	4.27878	89	150
56	REN6	143903	99385	229	50.20554	4.28333	89	150
57	REN7	144389	98453	235	50.19717	4.29016	89	150

Table 2.2 Overview of the positions of the three newly planned wind turbines for a tip height of 150 m. The X, Y coordinates have been provided by BEE. The longitude and latitude have been derived from the Lambert72 coordinates. The terrain height has been derived from the SRTM altitude database. The hub and tip height of the planned turbines are provided by BEE.

Nr.	ID	Lambert72 Coordinates X [m]	Y [m]	Terrain height w.r.t. EGM96 Z [m]	Lon. WGS84 [º]	Lat. WGS84 [º]	Hub Height [m]	Tip Height [m]
58	WT1	152010	104574	223	50.25222	4.39692	81	150
59	WT2	152617	104696	236	50.25332	4.40543	81	150
60	WT3	153232	104633	220	50.25275	4.41406	81	150

Table 2.3 Overview of the positions of the three newly planned wind turbines for a tip height of 180 m. The X, Y coordinates have been provided by BEE. The longitude and latitude have been derived from the Lambert72 coordinates. The terrain height has been derived from the SRTM altitude database. The hub and tip height of the planned turbines are provided by BEE.

Nr.	ID	Lambert72 Coordinates		Terrain height w.r.t. EGM96	Lon. WGS84	Lat. WGS84	Hub Height	Tip Height
		X [m]	Y [m]	Z [m]	[º]	[º]	[m]	[m]
58	WT1	152010	104574	223	50.25222	4.39692	111	180
59	WT2	152617	104696	236	50.25332	4.40543	111	180
60	WT3	153232	104633	220	50.25275	4.41406	111	180

2.2 Primary Radar System Florennes

2.2.1 PSR Florennes

We investigate the effects of the wind turbines on the Airport Surveillance Radar at the military Airforce Base Florennes (Figure 2.3). This airbase is equipped with a STAR 2000 radar from Thales France and consists of both a PSR and an MSSR. The SEA will be performed for the primary radar only. The coordinates and antenna height have been received from Skeyes [2]. The radar parameters that are relevant for this study are presented in

Table 2.4 and have been received under an NDA [3] with Skeyes and Thales France.

Figure 2.3 The Airport Surveillance Radar at Florennes Military Airbase, still under construction (image: Google Earth).

Table 2.4 Relevant radar parameters of the PSR at Florennes Military Airbase [2] and [3].

PSR STAR 2000 Florennes	
Antenna position	
WGS84	
Latitude [º]	50° 13’ 12.85’’ (50.22024) N
Longitude [º]	4° 39’ 6.72’’ (4.651867) E
Antenna Height	
AGL [m]	33
AMSL [m]	346
Antenna rotation speed	
[RPM]	15
Instrumented range	
[NM]	60
[km]	111
Beam width (horizontal, 3dB, one-way)	
[º]	1.4°
Range cell depth	
[m]	116
CFAR algorithm	
Type	CAGO (Cell Averaging Greatest of)
Number of range cells within the early and late window	8 (per window)
Number of guard cells on both sides of the CUT	2

3 Line of Sight Analysis

Using the information given in Chapter 2, we have carried out a line-of-sight analysis. In Figure 3.1 we show the terrain profile in the area containing the wind turbines and radar. The line in the figure connect the radar to the planned wind turbines WT1-WT3. By studying the terrain profile along this line for each wind turbine, we can determine whether the radar at Florennes will have line-of-sight to the windfarm.

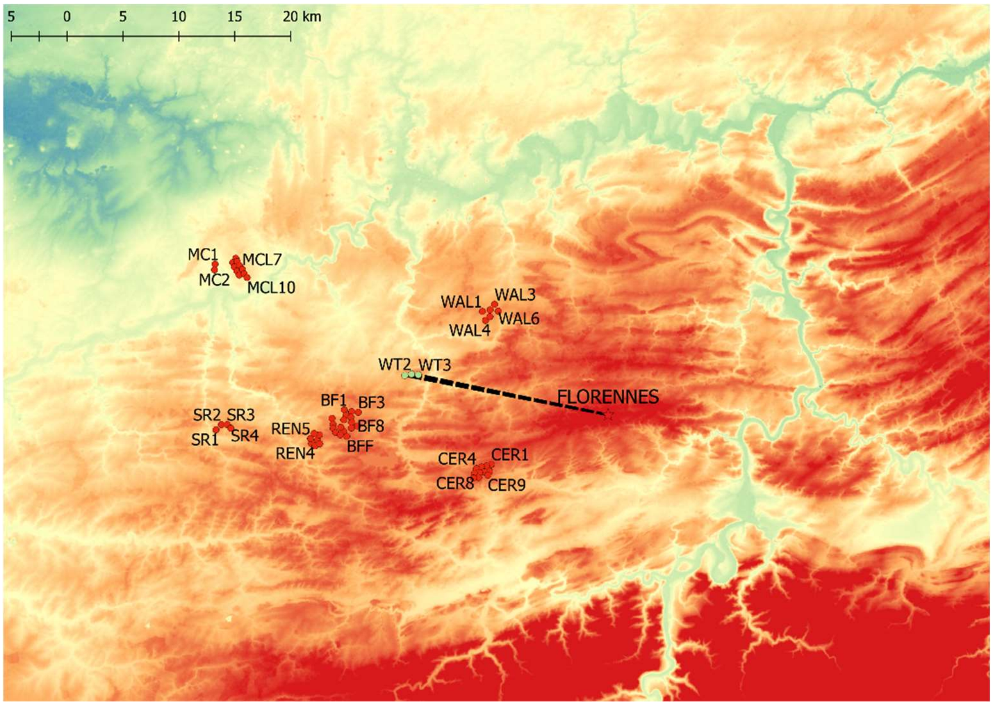

Figure 3.1 The altitude of the terrain between radar and wind turbines taken from the SRTM database. The altitude in this image varies from approximately 0 m (blue) to +300 m (red) ASML. The line-of-sight analysis is performed by studying the terrain profile on the line connecting the radar and each wind turbine.

So-called ‘standard propagation’ is assumed when determining the line-of-sight. This is modelled by multiplying the earth radius by a factor of 4/3 (the “k-factor”).

In the figures on the next pages the red ellipses show the first Fresnel zone from the radar antenna to the tip height of the wind turbine and the blue ellipses show the first Fresnel zones from the radar antenna to the hub height of the wind turbines. These ellipses are referred to as the ¼ λ Fresnel zone, where λ refers to the radar wavelength. Signals travelling between the terminals within the blue and red ellipses are at most 90° out of phase with respect to the signal that takes the shortest path. The black lines show the profile of the ground level between the radar and wind turbine as derived from the SRTM database[1].

[1] For the line-of-sight analysis the data from the Shuttle Radar Topography Mission (SRTM1) is used. This database contains terrain altitude information with respect to the EGM96 geoid. The database was determined by NASA using high-resolution radar carried on the Space Shuttle. The SRTM data has a resolution of 1 arcseconds, which corresponds to a horizontal resolution of about ~20 m at 51 degrees latitude.

3.1 Line of Sight Analysis PSR Florennes

3.1.1 Newly Planned Turbines with a tip height of 150 m

Figure 3.2 to Figure 3.4 show line-of-sight diagrams between the location of the radar system and the newly planned wind turbines locations. The horizontal range is range over ground in kilometres calculated using Vincenty's formulae. The turbines are located approximately 18 km from PSR Florennes.

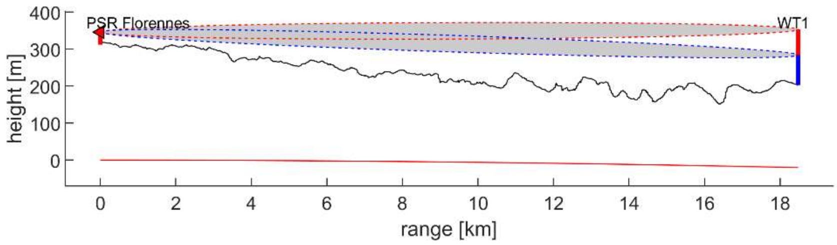

Figure 3.2 Line-of-sight between the PSR of Florennes (antenna height: 34 m, ground level: 312 m) and the first newly planned wind turbine WT1 (tip height: 150 m, hub height: 81 m, ground level: 223 m). The ground range from the PSR to the wind turbine is 17.3 km.

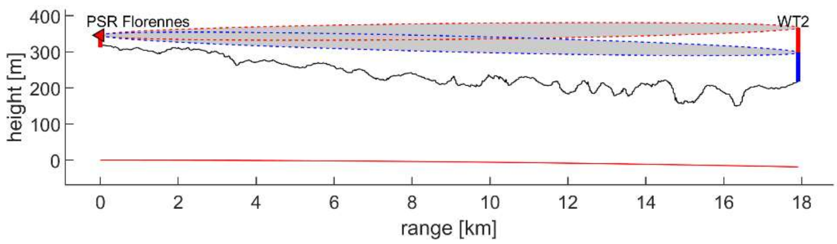

Figure 3.3 Line-of-sight between the PSR of Florennes (antenna height: 34 m, ground level: 312 m) and the first newly planned wind turbine WT2 (tip height: 150 m, hub height: 81 m, ground level: 236 m). The ground range from the PSR to the wind turbine is 17.9 km.

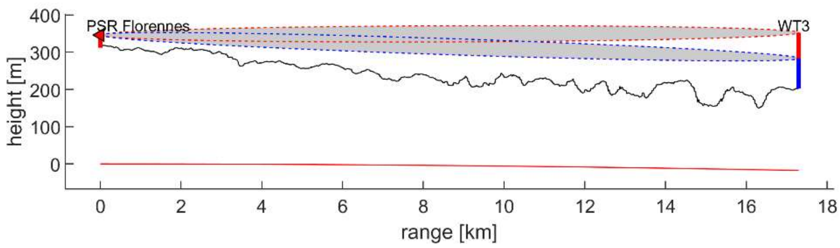

Figure 3.4 Line-of-sight between the PSR of Florennes (antenna height: 34 m, ground level: 312m) and the first newly planned wind turbine WT3 (tip height: 150 m, hub height: 81 m, ground level: 220m). The ground range from the PSR to the wind turbine is 17.3 km.

The Fresnel zones are not obstructed by the terrain profile, meaning that the radar antenna has line-of-sight to the planned wind turbines.

3.1.2 Newly Planned Turbines with a tip height of 180 m

Figure 3.5 to Figure 3.7 show line-of-sight diagrams between the location of the radar system and the newly planned wind turbines locations. The horizontal range is range over ground in kilometres calculated using Vincenty's formulae. The turbines are located approximately 18 km from PSR Florennes.

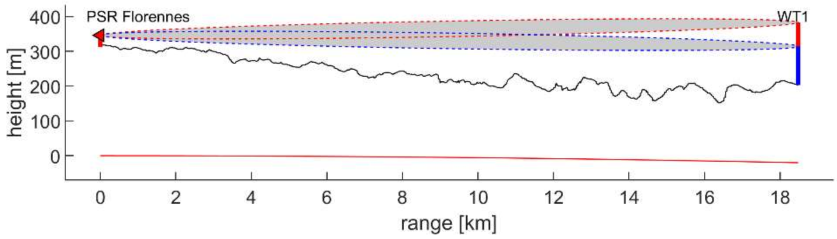

Figure 3.5 Line-of-sight between the PSR of Florennes (antenna height: 34 m, ground level: 312 m) and the first newly planned wind turbine WT1 (tip height: 180 m, hub height: 111 m, ground level: 223 m). The ground range from the PSR to the wind turbine is 17.3 km.

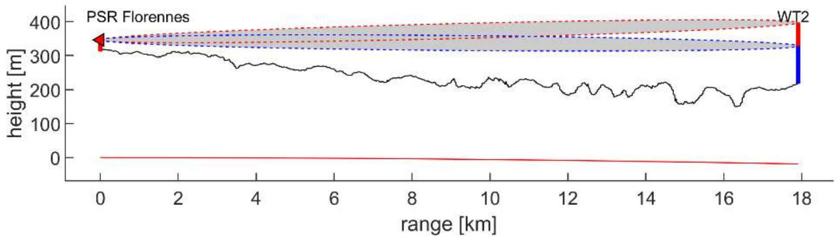

Figure 3.6 Line-of-sight between the PSR of Florennes (antenna height: 34 m, ground level: 312 m) and the first newly planned wind turbine WT2 (tip height: 180 m, hub height: 111 m, ground level: 236 m). The ground range from the PSR to the wind turbine is 17.9 km.

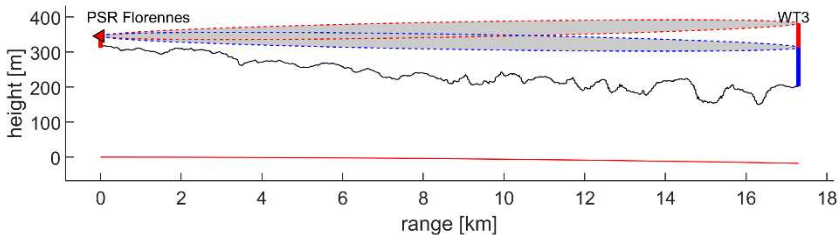

Figure 3.7 Line-of-sight between the PSR of Florennes (antenna height: 34 m, ground level: 312m) and the first newly planned wind turbine WT3 (tip height: 180 m, hub height: 111 m, ground level: 220m). The ground range from the PSR to the wind turbine is 17.3 km.

The Fresnel zones are not obstructed by the terrain profile, meaning that the radar antenna has line-of-sight to the planned wind turbines.

3.1.3 *Existing and authorized Turbines*

There are no exisisting and authorized windturbines considered relevant for this study in the vicinity of the new windturbines. In Figure 3.8 it can be observed that the lines connecting the PSR and the new wind turbine are not close to the lines connecting the PSR and the three newly planned turbines.

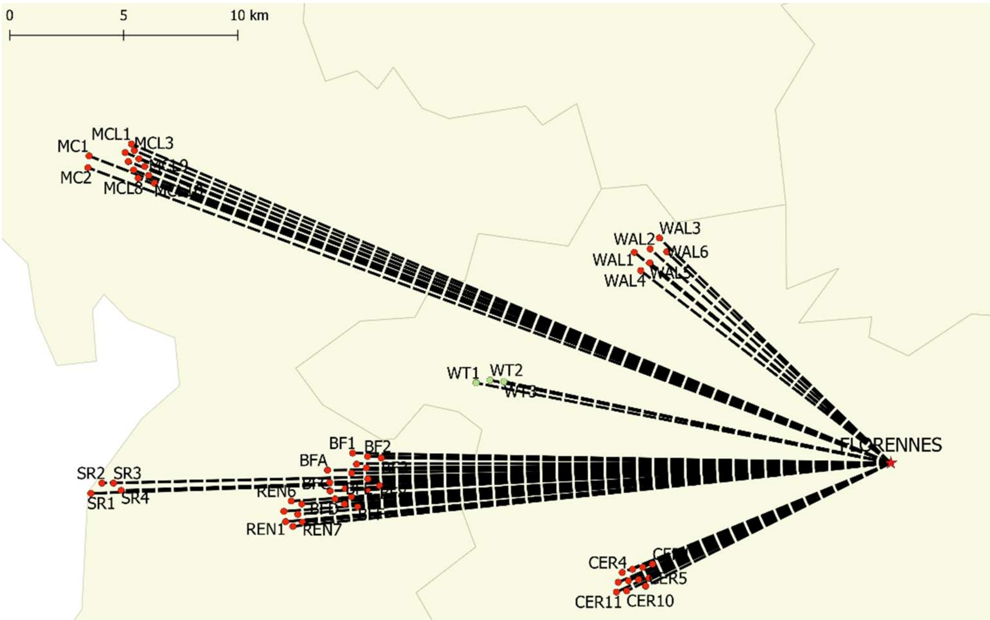

Figure 3.8 Line-of-sight between the PSR of Florennes, the three newly planned wind turbines and the 57 existing and authorized wind turbines in the neighbourhood.

4 Regions of potential Impact

4.1 Introduction

In Chapter 3 we have determined that the radar has line-of-sight to all wind turbines. When this is the case the wind turbines can affect the radar in a number of ways. The EUROCONTROL guidelines [1] prescribe that in the case of a simple engineering assessment, the size of the following two regions must be determined:

1. The shadow region behind the wind turbine, caused by the attenuation due to the wind turbine being an obstacle for the electromagnetic field.
2. The volume located above and around the wind turbine in which the radar detection threshold, generally implemented with CFAR (Constant False Alarm Rate) logic, is affected.

Both regions are shown in Figure 4.1 below. This image was taken from [1], Section 4.3.1. In the next sections the size of the two regions are determined.

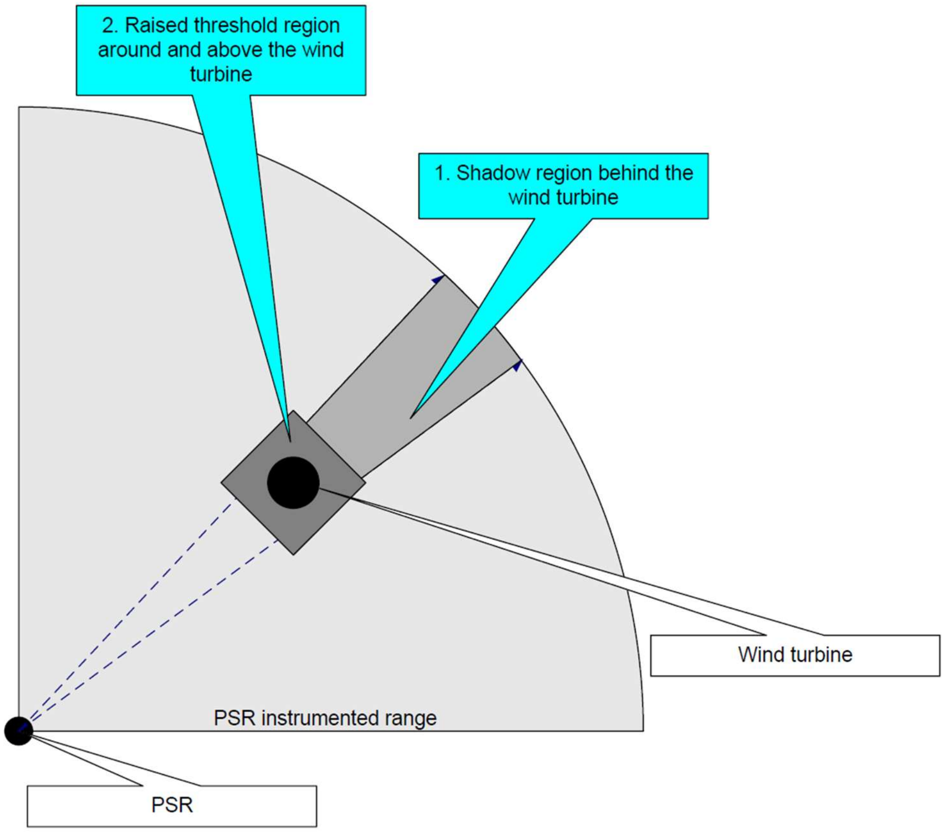

Figure 4.1 Schematic representation of the shadow region behind a wind turbine (1) and the raised threshold region around and above a wind turbine. Image taken from [1].

4.2 Region 1: Shadow region

In this section we determine the size of the shadow regions behind the wind turbine. In Figure 4.2 the shape of the region is shown.
The shadow region extends all the way to the instrumented range of the radar. The length of the shadow region is therefore equal to the instrumented range minus the distance from the radar to the wind turbine.
The width of the shadow region is given by $2\sqrt{(\lambda D)}$, where λ is the radar wavelength and D the distance from the wind turbine. See also Annex A-3 in the EUROCONTROL guidelines [1]. The width is at its maximum at the instrumented range from the radar.

Finally, the height of the shadow region can be calculated according to Equation 1 in Annex A-2 in [1]. Note that this calculation takes the curvature of the earth into account by assuming a spherical earth with radius kR_e, where R_e is the earth radius and k is the standard propagation k-factor equal to 4/3. The calculated height is relative to the EGM96 geoid, which is approximately equal to mean sea level and is accurate within several meters. The height of the shadow region is equal to the tip height at the location of the wind turbine and increases (not taking the ground level into account) to its maximum value at instrumented range from the radar.

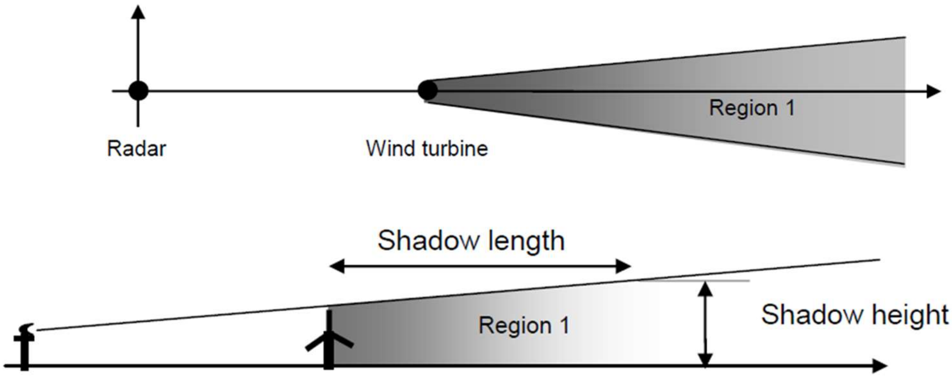

Figure 4.2 Shape of the shadow region. Image taken from Annex A-1 in [1].

In contradiction to an optical shadow, a wind turbine in the line of sight path will affect visibility, but not in all cases will cause the target to be invisible. This principle is illustrated in Figure 4.3. Radio waves diffract around an obstacle, limiting the shadow zone directly behind an obstacle. Due to the fact that energy is reflected back from the wind turbine the presence of a wind turbine will cause a loss in maximum detection range.

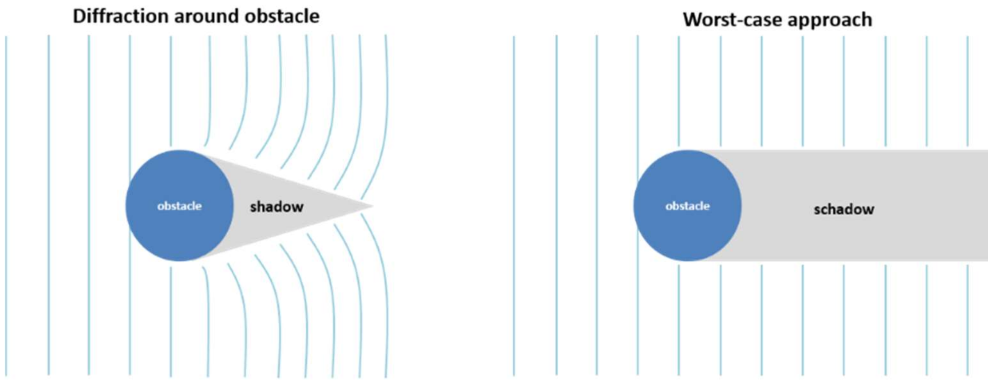

Figure 4.3 Graphical illustration of diffraction effects.

4.2.1 *Shadow Dimensions*

Length, maximum width and maximum height of the shadow regions for the existing and authorised wind turbines are given in Table 4.1

Length, maximum width and maximum height of the shadow regions for the newly planned turbines are provided in

Table 4.2 and

Table 4.3.

Table 4.1 Dimensions of the shadow regions of the existing and authorised wind turbines.

Nr.	ID	Tip Height [m]	Shadow PSR Florennes Length [km]	Max. height w.r.t. sea level [km]	Max. Width [m]
1	BF1	150	87.4	1.063	194.3
2	BF2	150	88.0	1.081	195.1
3	BF3	150	88.6	1.124	195.7
4	BF4	150	87.6	1.084	194.5
5	BF5	150	88.0	1.148	195.0
6	BF6	150	87.3	1.123	194.3
7	BF7	150	88.0	1.153	195.1
8	BF8	150	88.6	1.211	195.6
9	BF9	150	88.0	1.172	195.0
10	BF10	150	87.3	1.197	194.2
11	BFA	150	86.3	1.085	193.1
12	BFB	150	86.4	1.140	193.2
13	BFC	150	86.4	1.181	193.2
14	BFD	150	86.6	1.184	193.4
15	BFE	150	87.0	1.165	193.9
16	BFF	150	87.5	1.183	194.5
17	BEA1	150	87.0	1.191	193.9
18	WAL1	124	96.4	1.106	204.1
19	WAL2	124	96.9	1.128	204.6
20	WAL3	124	96.8	1.033	204.5
21	WAL4	124	97.2	1.053	204.9
22	WAL5	124	97.2	1.102	205.0
23	WAL6	124	97.5	1.114	205.2
24	CER1	123	99.6	1.407	207.5
25	CER2	123	99.2	1.323	207.0
26	CER3	123	98.7	1.263	206.6
27	CER4	123	98.3	1.197	206.1
28	CER5	123	99.2	1.382	207.1
29	CER6	123	98.8	1.374	206.6
30	CER7	123	98.4	1.332	206.2
31	CER8	123	97.9	1.309	205.7
32	CER9	123	99.0	1.361	206.8
33	CER10	123	98.1	1.332	205.9
34	CER11	123	97.7	1.326	205.5
35	SR1	150	75.9	0.896	181.1
36	SR2	150	76.4	0.948	181.7
37	SR3	150	76.9	0.946	182.3
38	SR4	150	77.2	0.942	182.7
39	MCL1	150	74.9	0.771	179.8
40	MCL2	150	74.7	0.773	179.7
41	MCL3	150	75.1	0.784	180.1
42	MCL4	150	75.0	0.753	180.1
43	MCL5	150	75.4	0.789	180.5
44	MCL6	150	75.4	0.773	180.5

45	MCL7	150	75.8	0.806	181.0
46	MCL8	150	75.7	0.784	180.9
47	MCL9	150	76.1	0.802	181.3
48	MCL10	150	76.4	0.772	181.7
49	MC1	150	73.3	0.698	178.0
50	MC2	150	73.5	0.708	178.2
51	REN1	150	84.3	1.084	190.9
52	REN2	150	84.9	1.109	191.5
53	REN3	150	85.1	1.116	191.8
54	REN4	150	84.6	1.067	191.2
55	REN5	150	84.3	1.050	190.8
56	REN6	150	84.6	1.038	191.3
57	REN7	150	85.1	1.069	191.7

Table 4.2 Dimensions of the shadow regions of the three newly planned wind turbines with a tip height of 150 m.

Nr.	ID	Tip Height	Shadow PSR Florennes		
		[m]	Length [km]	Max. height w.r.t. sea level [km]	Max. Width [m]
34	WT1	150	92.5	1.112	199.9
35	WT2	150	93.0	1.201	200.5
36	WT3	150	93.7	1.111	201.2

Table 4.3 Dimensions of the shadow regions of the three newly planned wind turbines with a tip height of 180 m.

Nr.	ID	Tip Height [m]	Shadow PSR Florennes Length [km]	Max. height w.r.t. sea level [km]	Max. Width [m]
34	WT1	180	92.5	1.292	199.9
35	WT2	180	93.0	1.386	200.5
36	WT3	180	93.7	1.303	201.2

4.2.2 Shadow Locations

The relevant shadows of the applicable turbines for PSR Florennes (existing, authorized and newly planned) are presented in Figure 4.5. The geographic locations of the shadows of the planned turbines for PSR Florennes are shown in Figure 4.4. The shadows of the existing and authorized turbines are indicated with black, the shadows of the newly planned turbines are indicated with a red colour.

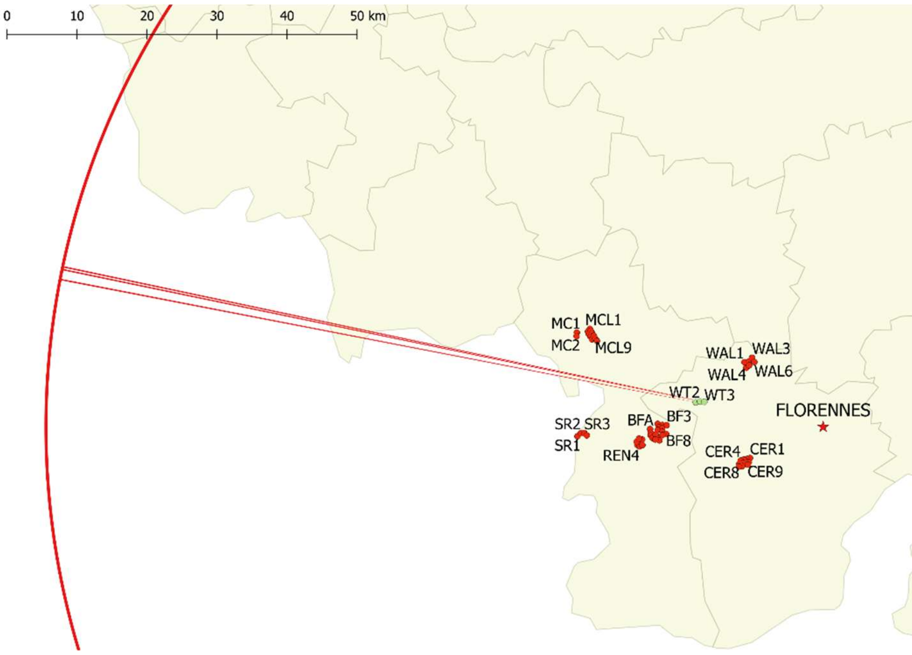

Figure 4.4 The geographic locations of the shadow regions of only the newly planned turbines as seen from the PSR in Florennes. The shadow regions (small red regions) extend from the wind turbine to the instrumented range (60 NM or 111 km) of the radar (indicated with a red circle). The width of the shadow region at instrumented range is approx. 201 m for the new wind turbines. The height of the shadow regions w.r.t. the EGM96 geoid is maximum 1.201 km for a tip height of 150 m and is maximum 1.303 km for a tip height of 180 m.

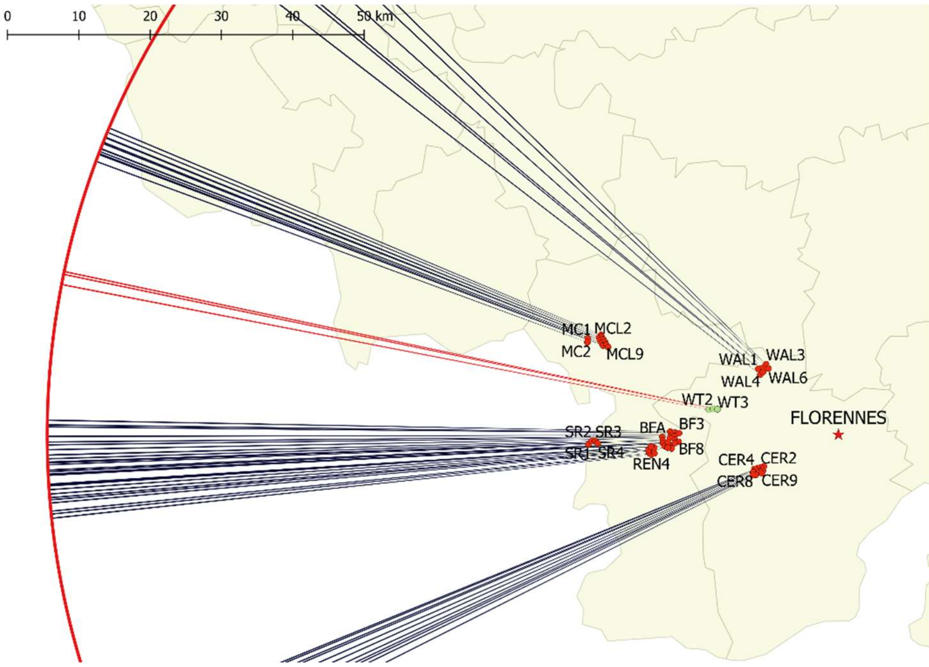

Figure 4.5 The geographic locations of the shadow regions of all turbines at the same sector of the newly planned wind turbines as seen from the PSR in Florennes. The shadow regions of the planned (small red regions) and existing and authorized turbines (small black regions) extend from the wind turbine to the instrumented range (60 NM or 111 km) of the radar (indicated with a red circle). The width of the shadow region at instrumented range is approx. 207 m for the existing and authorized wind turbines and the newly planned wind turbines. The height of the shadow regions w.r.t. the EGM96 geoid is maximum 1.201 km for a tip height of 150 m and is maximum 1.303 km for a tip height of 180 m.

4.3 Region 2: Raised threshold regions

The second region of potential impact is the so-called raised threshold region. In this region the possibly large reflection of the wind turbine raises the detector threshold of the radar, lowering the probability of detection of a target.

The size of the region in range is dependent on the exact implementation of the CFAR detection logic in the radar. In general a radar threshold is determined using a number of range cells around the Cell Under Test (CUT).

In the case of STAR 2000 at Florennes (see

Table 2.4) the number of range cells around the cell under test has been specified to be 20, of which the 2 closest range cells are the so-called guard cells. Given the size of a range cell of 116 m, we calculate that a wind turbine can potentially influence the radar threshold from approximately 1160 m in front until 1160 m behind the wind turbine. The size in azimuth is dependent on the horizontal beam width of the radar. Given the beam width of 1.4°, in

Table 2.4, at a range of 25 km the size in azimuth is approximately 1220 m.

The region in which the wind turbine influences the threshold has been calculated for situation without and width the Wind Farm Filter CFAR processing enhancement. Due to the fact that there is line of sight for both tip heights of 150 and 180 m, the results between both will not differ.

For the WFF enhanced processing, Thales was reluctant to provide detailed information. The assessment therefore has been based on verbal information and should therefore be considered as an approximation. TNO however was able to compare the results from own simulations with the results from Thales simulations for a known off shore wind farm and it was found that the TNO and the Thales results match. Due to proprietary reasons laid down by Thales, TNO is not able to elaborate on the details of the processing. The results in case WFF processing would be applied on the wind turbines around the radar, however, not restricted.:

The results are presented in Figure 4.6 and Figure 4.7.

Figure 4.6 The combined raised threshold regions for all nine newly planned turbines in the range of the STAR 2000 PSR at Florennes without the WFF CFAR processing enhancement.

Figure 4.7 The combined raised threshold regions for all nine newly planned turbines in the range of the STAR 2000 PSR at Florennes with the WFF CFAR processing enhancement.

The affected area due to the new wind turbines without the WFF is 3.60 km^2 and with the WFF 0.61 km^2 for Florennes. The region of raised threshold is now limited to maximum two range cells above the wind turbine position.

The pictures above should be interpreted with care, for two reasons. Firstly, the scattering properties of the moving and the non-moving parts of the wind turbines are not being considered. With respect to the non-moving parts: since wind turbine masts are often shaped like truncated cones, wind turbine mast backscatter is not being sensed by the radar, as illustrated in Figure 4.8, given the distance to the wind farm.

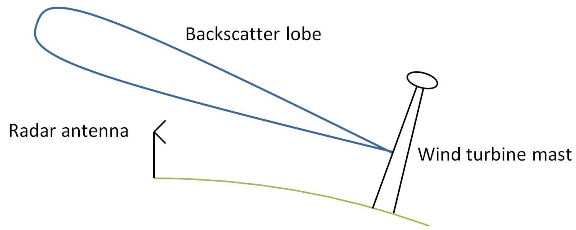

Figure 4.8 Due to the earth curvature as well as the tapering of the wind turbine mast diameter, wind turbine mast backscatter, which is confined in the backscatter lobe, may not be received by the radar. This physical phenomenon is neglected in Figure 4.6 to Figure 4.7.

5 False target reports and processing overload

Modern surveillance radars are equipped with multiple mechanism to obtain detections of flying targets only. To suppress reflections at non-moving objects, adaptive cluttermaps are maintained, potentially within each Doppler filter. Non-moving structures, such as the wind turbine mast and the nacelle will therefore not give rise to false (non-target) plots. A flying target will be detected if its response (echo) also passes the so-called CFAR (constant false alarm rate) circuitry. Radar manufacturers have responded to the detection of wind turbine blade flashes, by adapting the logic of the CFAR process. Rather than the CAGO (cell averaging greatest of) logic, ordered statistics (OS) logic is nowadays often applied, since this processing is better capable to detect aircraft when a wind turbine blade flash occurs. Note that the Belgium Airforce has indicated that the Florennes radar are equipped with CAGO CFAR circuitry (rather than OS or like circuitry).

In case the Florennes radar would be equipped with a modern receiver such as the Next Generation Signal Processor (NGSP) from Intersoft-Electronics, the radar could benefit from the Vertical Clutter Canceller or VCC technology. With this technology the radar will be capable of adapting the elevation antenna pattern on receive, range dependent. Thus, wind turbine backscatter can be ‘nulled’, which improves the detection capability of the radar above wind turbines.

The maximum rotation speed of a wind turbine is assumed to be 30 rpm. Each rotation produces six Doppler flashes, three negative and three positive, when one of the three blades is pointing up- or downwards. This results in a worst case flash frequency of 3 Hz per wind turbine. Given this blade flash frequency of 3 Hz, three additional wind turbines, the azimuth beamwidth and the antenna rotation rate, 0.14 blade flashes per scan are expected from the entire windfarm for the ASR Florennes. A worst case assumption, which neglects the several anti-wind turbine features of these radars described above, is that these flashes will result in PSR-only plots. Since modern surveillance radars are capable to process several hundred plots per s, the extra plots are considered as being insignificant. Processing overload is therefore not expected.

6 Conclusions

In accordance with EUROCONTROL's description of a simple engineering assessment for primary radar systems, three subjects have been analysed: line-of-sight, the volumes of the regions that are impacted, and the occurrence of false target reports.

It is concluded that the wind turbines are not significantly obstructed by altitude level of the terrain between the radar installation and the wind turbines. The sizes of the volumes in which radar degradation without and with the Wind Farm CFAR enhancement occurs have been specified in Section 4 of the document. The newly planned wind turbines will create a volume where the STAR 2000 PSR at Florennes can potentially be desensitised of approximately 3.60 km^2 at a distance of more than 18 km from the radar. Thales France, the manufacturer of the STAR 2000 radar offers a Wind Farm Filter CFAR enhancement. When the radar would be equipped with this enhancement, this area where the radar can potentially be desensitised reduces to 0.61 km^2. Due to the fact that there is line of sight for both tip heights of 150 and 180 m, these results between both will not differ.

Due to the cluttermap processing, it is not expected that static structures of the wind turbines will raise alarms. The probability that an alarm will be induced as a consequence of a wind turbine blade flash has been elaborated in Section 5. The increase of the plot rate due to this phenomenon is expected to be negligible.

7 List of abbreviations

ACP	Azimuth Change Pulse
AGL	Above Ground Level
ASR	Airfield Surveillance Radar
CAGO	Call Averaging Greatest Of
CFAR	Constant False Alarm Rate
CTR	Control
CUT	Cell Under Test
EGM96	Earth Gravitational Model 1996
NASA	National Aeronautics and Space Administration
NGSP	Next Generation Signal Processor
OS	Ordered Statistics
PSR	Primary Surveillance
SSR	Secondary Surveillance Radar
SRTM	Shuttle Radar Topography Mission
TNO	Netherlands Organisation for Applied Scientific Research
VCC	Vertical Clutter Cancellation
WFF	Wind Farm Filter
WGS84	World Geodetic System 1984

8 References

[1] EUROCONTROL guidelines on How to Assess the Potential Impact of Wind Turbines on Surveillance Sensors, Edition 1.2, September 2014, Ref. nr EUROCONTROL-GUID-0130.

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[5] A. Theil, L.J. van Ewijk, Radar Performance Degradation due to the Presence of Wind Turbines, IEEE Radar Conference 2007