

Modern Threats to Precision Approach and Landing - The A380 and Windgenerators and their Adequate Numerical Analysis

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ABSTRACT

Classical and modern navigation, landing and radar systems rely on the radio transmission and reception. Relevant objects in the radiation field can harm the intended characteristics of these systems. Modern state-of-the-art simulation can predict in an increasing number of complicated cases the electrical performance in the presence of these objects. Countermeasures can be designed from this knowledge.

This paper deals with the "threat" (potentially un-acceptable distortions) on these systems by the forthcoming new large aircraft A380 and by the windgenerators which are constructed in an increasing number sometimes close to the systems. The mathematical and numerical analyses are outlined and some results are presented. It is in particular emphasized to apply three-dimensional and sophisticated state-of-the-art methods which are adapted to the three-dimensional characteristics of the objects in contrast to inadequately simple methods.

3D-modeling examples for the A380 and windgenerators and some principle results are presented.

INTRODUCTION

Almost all classic and modern navigation landing and radar systems rely on radio transmission and reception. In a clean environment these systems may work pretty well, but the real life is different. More and more complex distortion and interference problems for nav aids, landing and radar systems are encountered today (Fig. 1). These so-called "problems" are caused by major objects around and in the vicinity of these systems, creating additional reflections and scattering signals ("multipath signals") by the principally unavoidable illumination of

these objects by the systems themselves. These objects can be terminals, hangars, large buildings, windgenerators and power lines as well as the aircraft itself.

A reliable prediction of the potential "threat", i.e. the unacceptable effects on the systems in question is required in advance before the objects are built or before the objects appear. This task can be solved today by system simulations using state of the art numerical methods. Quite a number of publications have been released by the author in the past /2-12/ on the subject of numerical system simulations. This paper highlights two types of objects somewhat more fully, namely the A380 and the windgenerators (Fig. 2). This paper is not intended to present rules and definitions for dimensions of safeguarding areas or safety distances.

MODELING AND SYSTEM SIMULATION

The modeling and simulation process (Fig. 3 and 4) must accomplish the following basic tasks

- Sufficiently realistic modeling of the object having in mind that the subsequent simulation is treating the model and not the reality. The form, the shape and the materials of the object as well as the exciting field above ground have to be modeled sufficiently. The basic way of modeling depends also on the numerical method used in the next steps.
- Detailed modeling of the system in question which is generating the undistorted signal.
- Simulations of the reflection and scattering process by the application of adequately state-of-the-art numerical methods. The most accurate method should be generally used; approximations may be used only if the results are sufficiently accurate.

- Evaluation of the decisive system parameter which the aircraft uses for navigation or landing.

The two objects of this paper (Fig. 2; A380, windgenerator) are highly three-dimensional and therefore a two-dimensional approach and model is neither sufficient nor "state-of-the-art". It is obvious that a three-dimensional approach is not only necessary to apply, but also requires a lot more modeling and computation work. No trade-off is acceptable between the accuracy and the effort to be invested due to the safety issue involved. A simple 2D-treatment which reduces a 3D-A380-aircraft to one rectangular plate in the most extreme simplification, or several composed rectangular flat plates, can be up to many orders of magnitude faster, but can also yield wrong and unpredictable results /12/. Such kind of simple approaches cannot be cured by "some measurements" at a few points under some conditions.

The simulation of the system must take into account all relevant details which affects the so-called "system-parameter" of that particular system, i.e. the DDM (Difference of Depth of Modulation) for the ILS (Instrument Landing System) or the "bearing error" for the VOR/DVOR (Very high frequency Omnidirectional Range; Doppler-VOR). These details comprise as an example (see for more details Fig. 3)

- the correct geometrical and electrical setting and numerical installation of the actual system in the pre-processing section
- the signal processing, the filtering, the sampling, and the receiving antennas in the post-processing section.

Other field quantities (e.g. "field distortions") cannot describe in general sufficiently the system effects. "Field distortions" are necessary effects for system distortions, but are not a sufficient parameter to quantify the system distortions.

The verification of the correctness and the reliability of the system results is a particular challenging task as discussed in /12/. A single or "some measurements" are not sufficient. Each result has to be verified in principle.

Fig. 4 shows the overall flow-chart of the applied IHSS (Integrated Hybrid System Simulation). The best suited numerical method is taken for the particular problem, i.e. the A380 and the windgenerators. In

certain cases cross checks can be made for approval by comparing the results of the preferred approximative IPO-method (improved physical optics) with the results from the rigorous MoM- or ML-FMM-methods (method of moments, multi-level fast multipole method). The latter family cannot be applied efficiently for large aircraft and windgenerators due to the "exploding" storage requirements and/or the excessive computer time for systematic simulations. Moreover, the ML-FMM has the general problem of a questionable convergence of the iterative solution of the integral equation. Cases have been experienced where the defined convergence criterion, e.g. 10^{-3} , has not been achieved after 500 iterations for an aircraft.

The GTD/UTD method is not the preferred numerical method for the discussed applications and three-dimensional curved objects due to the general caustic problem and the generally unavoidable discontinuities of the solution, which results in problematic discontinuities in the DDM-results for ILS.

For both cases (A380, windgenerator) the structure is subdivided into a large number of metallic triangles (Fig. 7 and 10) where the real exciting field is applied.

Worst case principles may be applied as an example for the dielectric blades by assuming the metal material.

Great care and knowhow has to be applied when carrying out these sophisticated methods and interpreting the results in each case, because each of the methods can fail in certain situations /12/. Conclusions on the basis of incorrect results can yield a waste of money or can be the reason for hardly acceptable, in fact unnecessary consequences, such as the closure of a taxiway for A380 taxiing /12/.

PRACTICAL PROBLEMS

The A380 on Airports and ILS

The future A380 is currently the largest civilian aircraft (Fig. 5,7) which will appear in some years on the airports. Compared to the other large aircraft, this aircraft has a maximum height of the tail-fin of 24.1m. Due to the horizontal polarization of the ILS-fields the higher parts of the aircraft may have stronger effects compared to the lower parts. However that does not mean that the tail-fin

can describe the total aircraft sufficiently. Generally speaking, the larger and higher the aircraft, the larger the distortions for the ILS-subsystems. Therefore, the largest currently existing (military) aircraft (AN225; Fig. 5) will not have necessarily the largest DDM-distortions.

The A380 will be by nature on an airport in several operational phases and by that in quite a number of relevant positions and orientations (Fig. 6), such as :

- landing, rolling out, taxiing, parking, starting
- on parallel or sometimes inclined taxiways in relation to the Localizer and/or to the glidepath
- rolling off after landing
- rolling on for starting
- crossing the runway on taxiways in different angles
- taxiing behind the Localizer and/or behind the glidepath
- starting and flying over the Localizer while not precisely above the runway centerline

The international specification ICAO Annex 10 defines the DDM-tolerance limits for each operational category. The signal in space must meet these specifications when a landing aircraft is using ILS. The provider has to guarantee the compliance with these specifications and has to take measures for that.

As a matter of practical handling this basic task is met by the following safeguarding zones and lines

- critical areas (forbidden to enter for all vehicles and aircraft; technically speaking small objects may enter in certain areas except the nearfield monitor area. A verification is recommended by adequate methods.)
- sensitive areas (controlled access possible; e.g. for not too large vehicles and small aircraft; verification recommended)
- holding lines .

These zones and lines have to be redefined for the A380 aircraft. The sizes of these zones or the distances of the holding lines to centerline or on the taxiways depend on a number of factors which have to be taken into account, such as

- type of system (single/dual frequency; installation of out-of-phase clearance (/1/)

- type and characteristics of antennas (medium, wide aperture, capture ratio, pattern shape, sidelobe suppression etc.)
- existing distortions by stationary objects (hangars etc.)
- structural details of the layout of the airport (e.g. length of the runway)
- topological details of the runway or airport, such as humped runways
- operational category CATI-III
- type of the aircraft
- single or groups of aircraft (e.g. when queuing for takeoff)
- type of receiving antenna in the aircraft or used for ground measurements.

The setting and installation of the ILS-antennas as well as the receiving antennas do have a great impact on the results. Simple unrealistic dipoles, adapted antennas (e.g. R&S HE108) or 3 element Yagis will show very much different DDM-results /1,6,9/ and would result in quite different safeguarding areas or holding lines. It is problematic to compare measurements results for verification purposes and also to compare different results of simulations when the boundary conditions and the underlying numerical methods are not sufficiently known.

The minimum separation between successive landing aircraft is also a function of the preceding rolling-off aircraft or of the starting aircraft. It is a well-known effect that large DDM-oscillations occur when an aircraft is lifting off and flying over the ILS-Localizer which serves the signal for the next aircraft in the landing sequence. Unlocks or disconnects of the autopilot may occur.

It is obvious that only a large number of tedious simulations for the particular case and at a given airport for a certain ILS can yield the required results. The providers and in particular the airports are highly interested to have the minimum size of the safeguarding areas without increasing the risk for unspecified ILS-signals and reducing the safety.

The Figures 8 and 9 show two examples of simulations from a methodological point of view

- A380 on a parallel taxiway for a medium aperture Localizer antenna. The nose of the A380 is assumed to be in the xy-coordinates, the axis is parallel to centerline. Filtered DDM-data are presented. DDM-isolines are marked. From such results the lateral extension of the safeguarding

areas can be defined taking into account the locus of the maximum DDM and the related maximum tolerance limits at this point.

Holding points result from similar simulations where the aircraft is inclined according to the angle of the rollon taxiways.

It is noted that the safeguarding areas ("critical, sensitive areas") cannot be defined on the basis of the maximum DDM-limits. Some margin for existing distortions, stationary objects and superposing aircraft has to be provided. Also, the DDM-distortions increase drastically when the aircraft is positioned in an inclined orientation to the centerline. This is operationally the case when the aircraft is turning towards the runway on the rollon taxiway.

- A380 rolling off on a high speed taxiway. Time dependant DDM-data are presented. From these results the longitudinal extension of the critical area can be defined.

In both cases large DDM-distortions are encountered under the given circumstances.

The windgenerator and nav aids systems

Windgenerators (WG, "windmills", "windturbines") are constructed more and more in major quantities as a single installation or in large arrays ("windparks"). Often these objects are close to navigation stations or in the coverage volume of radars of various types.

The advanced analysis of the effects of these WG on the navigation and radar systems is of increasing interest. The different nature and function of the navigation systems and radar suggest that the simulation also must be quite different. However, the introduced IHSS (Figure 4) and its implemented features allow the adapted analysis. Extensions in the pre-processing part and in the final post-processing part had to be integrated. This is especially true for the analysis of the Doppler-shift characteristics of a turning windgenerator (Fig. 10 and 13). The Doppler shifted scattered fields may have adverse effects on the VOR/DVOR-system because these systems evaluate 30Hz amplitude and 30Hz frequency modulations. This frequency can easily be produced by the fast turning blades (Fig. 10 right) even at the VHF ILS/VOR-carrier frequency of about 110MHz.

The WG are highly 3D-structures and need an equivalent modeling (Figure 13). Typically the shaft is a shaped metal tube or strongly reinforced concrete. The cover of the generator house and the rotor blades are usually made of glass-fibre material. The blades have an integrated metallic lightning protection system. However, the total structure has been modeled for the "worst case" to be fully metallic, i.e. by a large number of metallic triangles. This takes into account environmental conditions. In principle the modeling strategy is identical for the A380 and the windgenerators.

For the VOR/DVOR systems the scattered field components are superposed and processed appropriately, yielding the decisive system parameter, i.e. the bearing error. The field distortions of the VOR/DVOR-field in itself are not a measure for the bearing errors and system distortions. Fig. 11 shows such kind of field distortions on a horizontal plane in 3D-representation. The largest field distortions are behind or beyond the windgenerator, but the bearing errors are minimum in this region. Potential "shadowing effects" are negligible for realistic distances of the windgenerators to the VOR/DVOR-station. The acceptable bearing errors are defined in ICAO Annex 10 and in the flight inspection manual DOC 8071. The bearing errors have to be simulated at the lowest height of the coverage volume defined for each VOR/DVOR. Figure 12 shows an example where the VOR/DVOR bearing errors have been calculated on a horizontal plane (100km*100km) at a height of 3300ft MSL for a large windgenerator.

In this 2D-result for a defined height, all radials in that height are contained up to about 50km. It can be clearly seen that the maximum bearing errors of the DVOR are much smaller compared to the VOR.

Doppler spectrum

The scattered Doppler-frequencies depend on the radial velocity of the scattering objects (Fig. 10 right). This fact has been used to define a method for the calculation of the Doppler-spectrum of the reflected/scattered field.

In a side study it has been evaluated that the bearing error of a 30Hz Doppler-shifted component is larger by factors compared to a non-shifted component. By that, the superposed amplitude of the 30Hz shifted

component at some field point yields the potential bearing error.

It can be easily understood that for the turning blades, the Doppler spectrum must be symmetrical in principle around the unshifted zero line caused by the stationary subparts of the windgenerator, i.e. the shaft and the machine house.

Fig. 13 shows such an example of the Doppler amplitude spectrum of a windgenerator in some geometrical configuration. The spectrum is calculated and plotted for several angular positions of the blades. It can be seen and understood that the spectral amplitudes for a certain frequency are time periodic and time dependant. The amplitudes are small compared to the static zero-line. The results so far indicate that this Doppler-spectrum does not seem to be a problem for the VOR/DVOR .

CONCLUSION

Large objects close to navigation, landing and radar systems can distort the electrical characteristics of these systems. The new large aircraft A380 will appear relatively soon on the airports. An increasing number of windgenerators are constructed often close to these systems.

The numerical 3D-treatment using "state-of-the-art-principles" of these objects has been outlined and contrasted to simplified 2D-approaches.

A380 aircraft will be present in many different positions, in many orientations and operational phases on the airports. Safeguarding areas ("critical and sensitive areas", holding lines) have to be defined and installed to protect the ILS. The case of the "parallel taxiway" is a relatively simple case in terms of the amplitudes of the DDM-distortions. Some principle results for the A380 have been presented, one for a parallel taxiway and one for the dynamic rolloff case. As expected, these results and further results show that the ILS-distortions by the A380 are remarkably larger than for the B747. By systematic simulations for the individual situation on a given airport the adapted and minimized safeguarding areas can be determined.

The numerical treatment of the windgenerator with respect to a VOR/DVOR navigation system has been outlined. Some principle results have been presented, showing the bearing errors for a large windgenerator on a

horizontal plane in some minimum coverage height. The Doppler spectrum of the windgenerator has been discussed with respect to the VOR/DVOR. A numerical result has been presented showing the time variant spectrum of small amplitudes for several blade positions.

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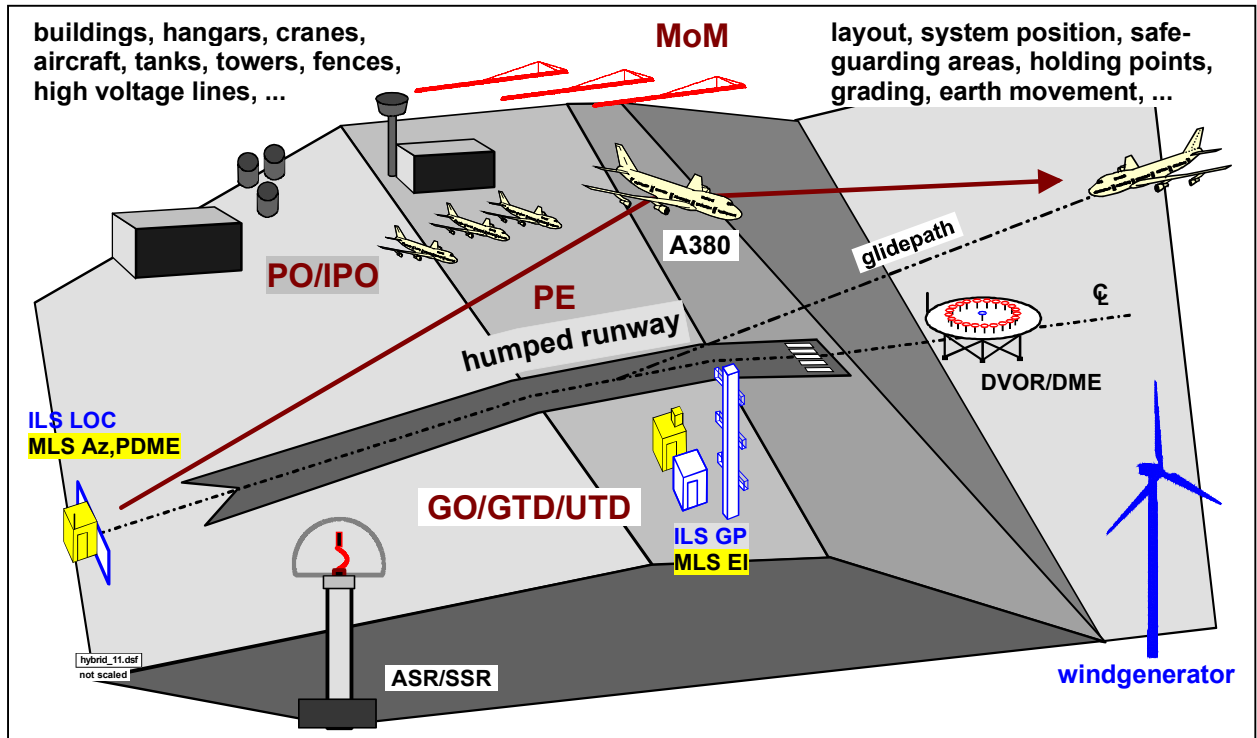


Fig. 1: Sketch of an airport, humped runway, the subsystems of an ILS and MLS, some distorting objects and a landing aircraft

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A380 / Windgenerators - Systems



NLA A3X A380



ILS
VOR/
DVOR

DME/
TACAN

ASR/SSR

VDF
NDB
weather
radar

MLS
GPS
⋮



windturbine / windgenerator

Fig. 2: The large A380 aircraft and windgenerators pose a potential threat to all introduced classic and modern navigation, landing and radar systems

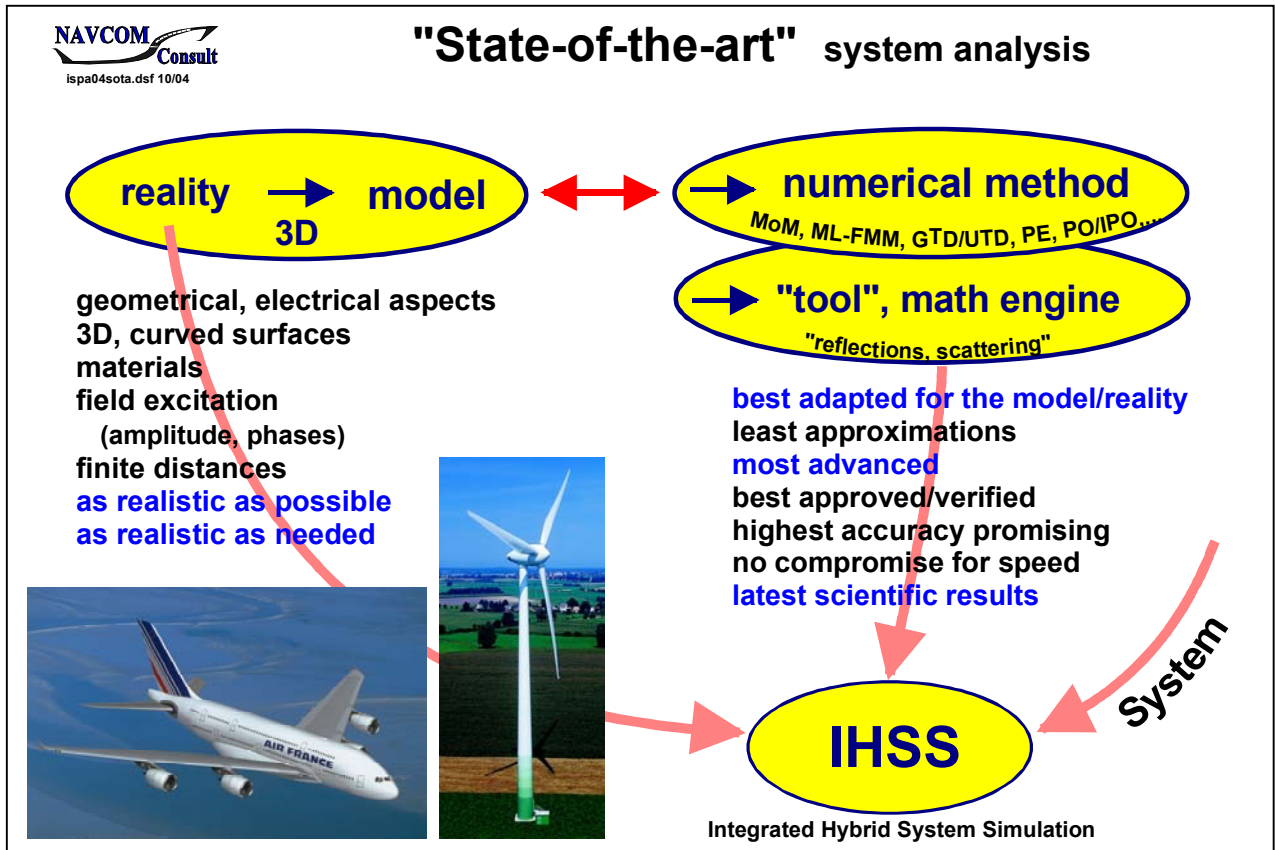


Fig. 3: General process flow and aspects for the modeling and the numerical treatment of the A380 and the windgenerator

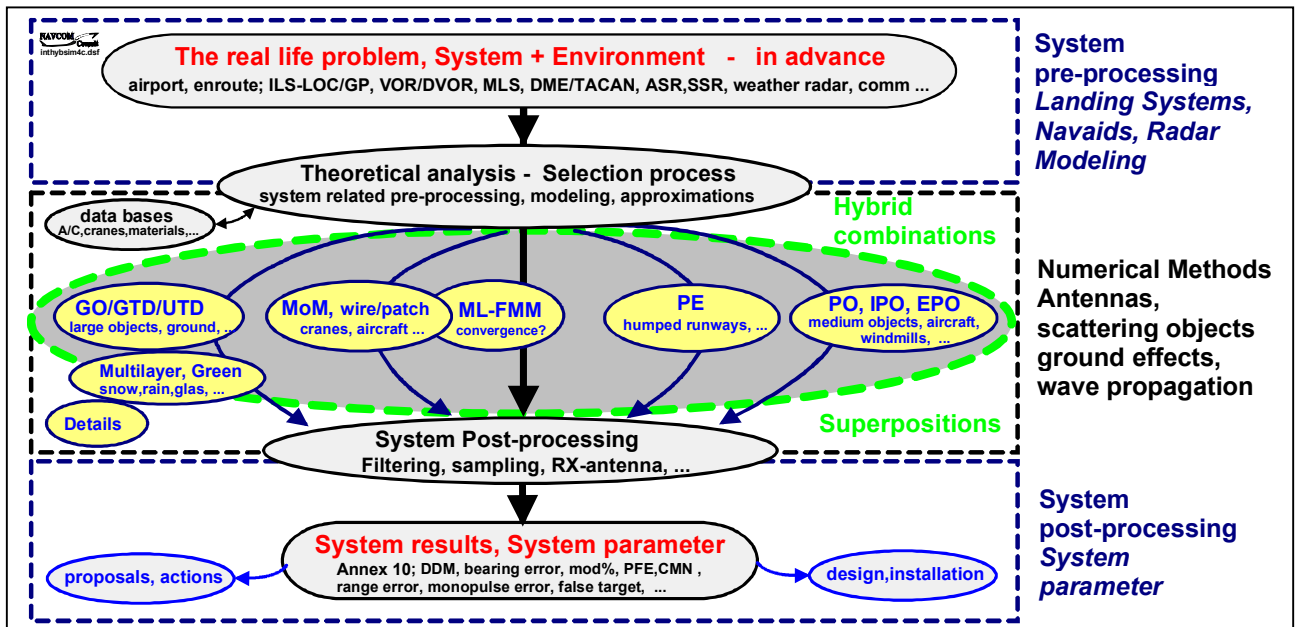


Fig. 4: Process flow of the IHSS (Integrated Hybrid System Simulation)

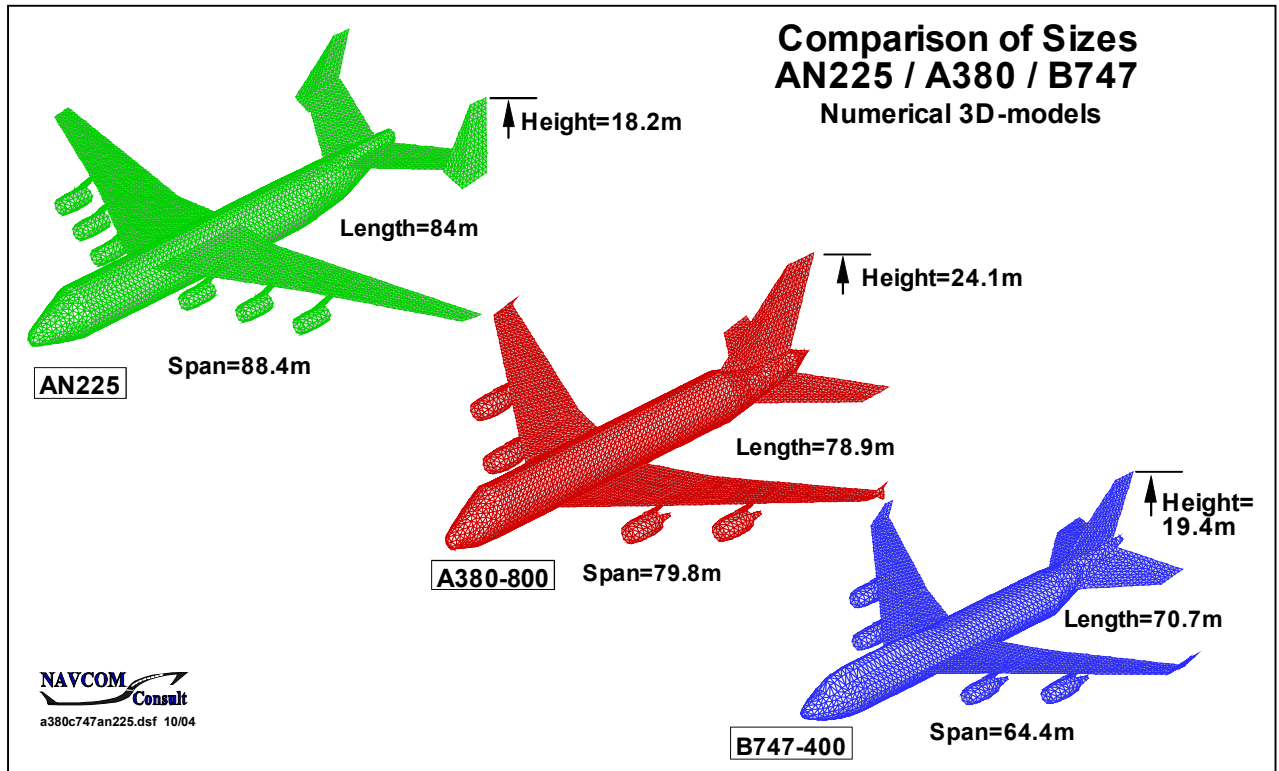


Fig. 5: Numerical 3D-models of 3 large aircraft AN225, A380-800, B747-400; size comparison

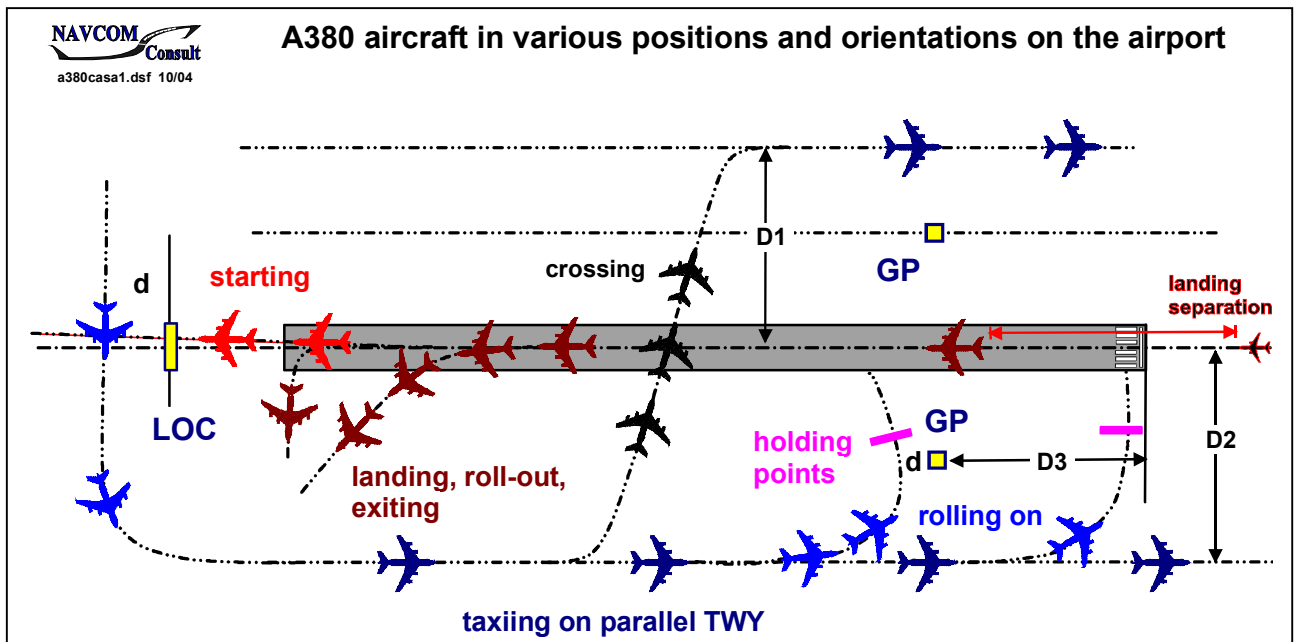


Fig. 6: The A380 aircraft on airports (runways, taxiways, landing, starting) with regard to ILS (Localizer LOC, glidepath GP)

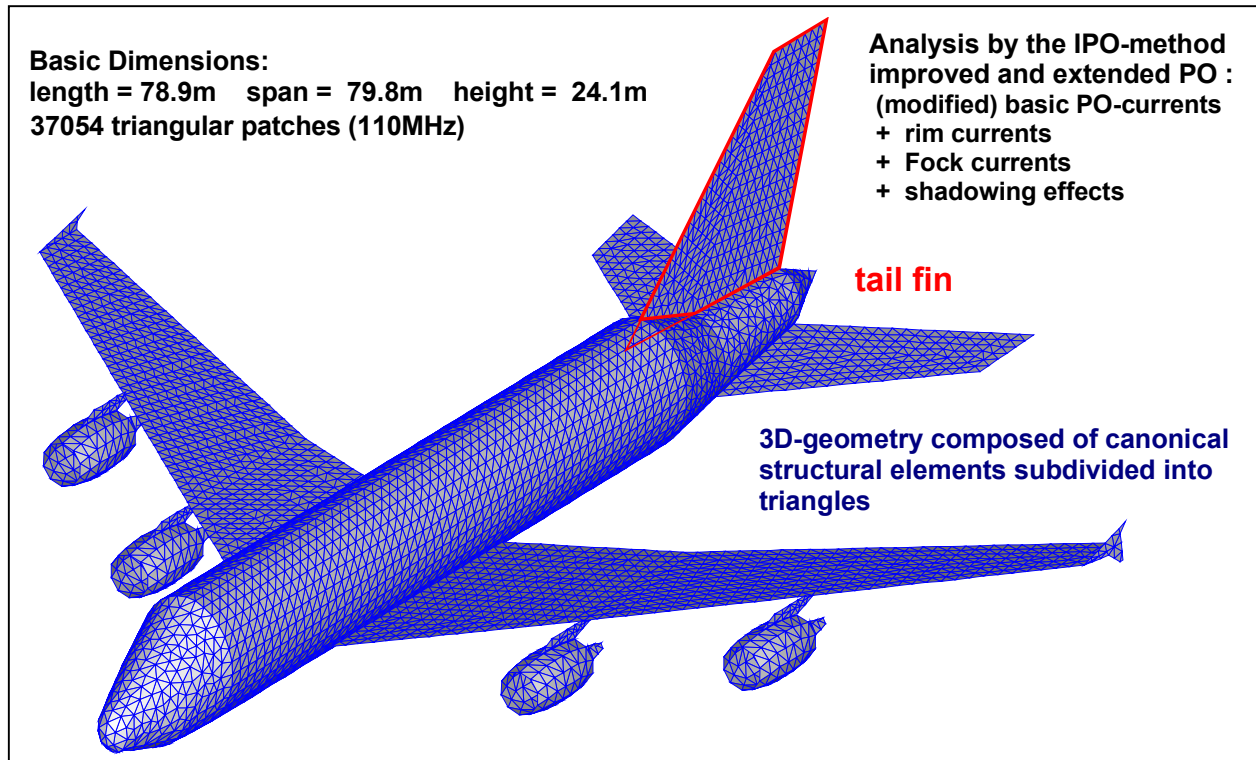


Fig. 7: Numerical 3D-model of the aircraft A380-800 consisting of 37054 triangular metallic patches at 110MHz (ILS Localizer). A reduced number of triangles is displayed.

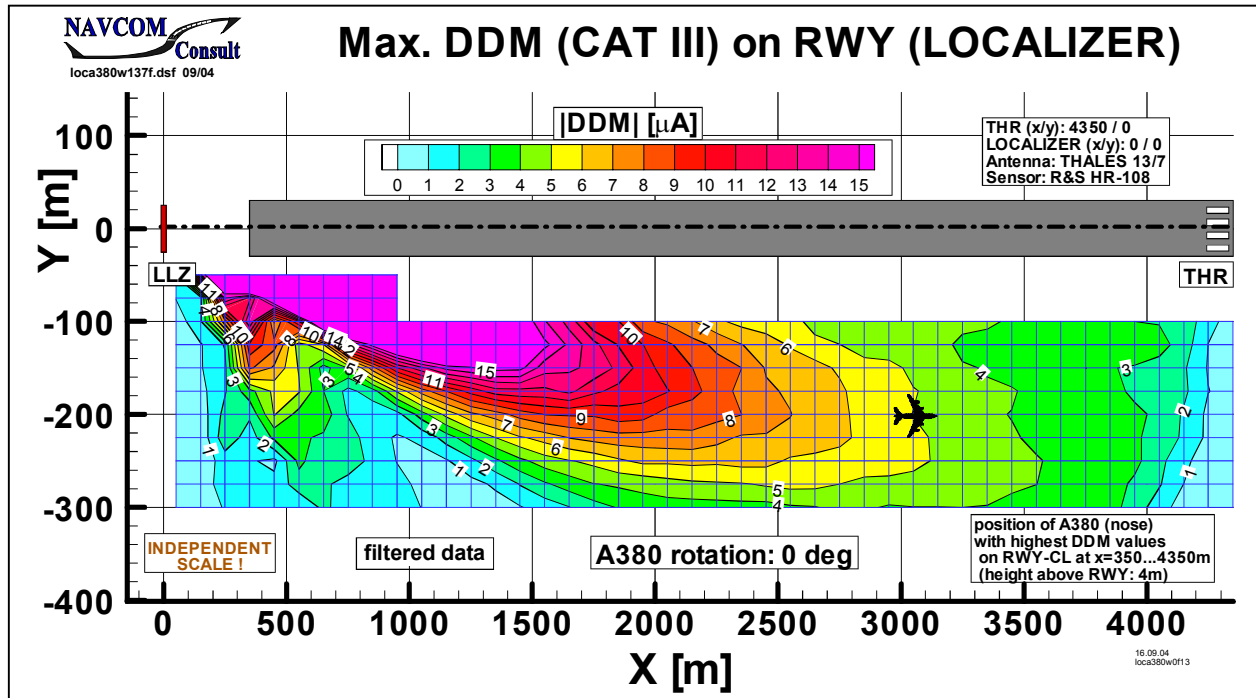


Fig. 8: DDM-distortions on the runway for CATIII applications of an A380 on parallel taxiway; medium aperture dual frequency Localizer; Filtered data; R&S HE108 RX antenna

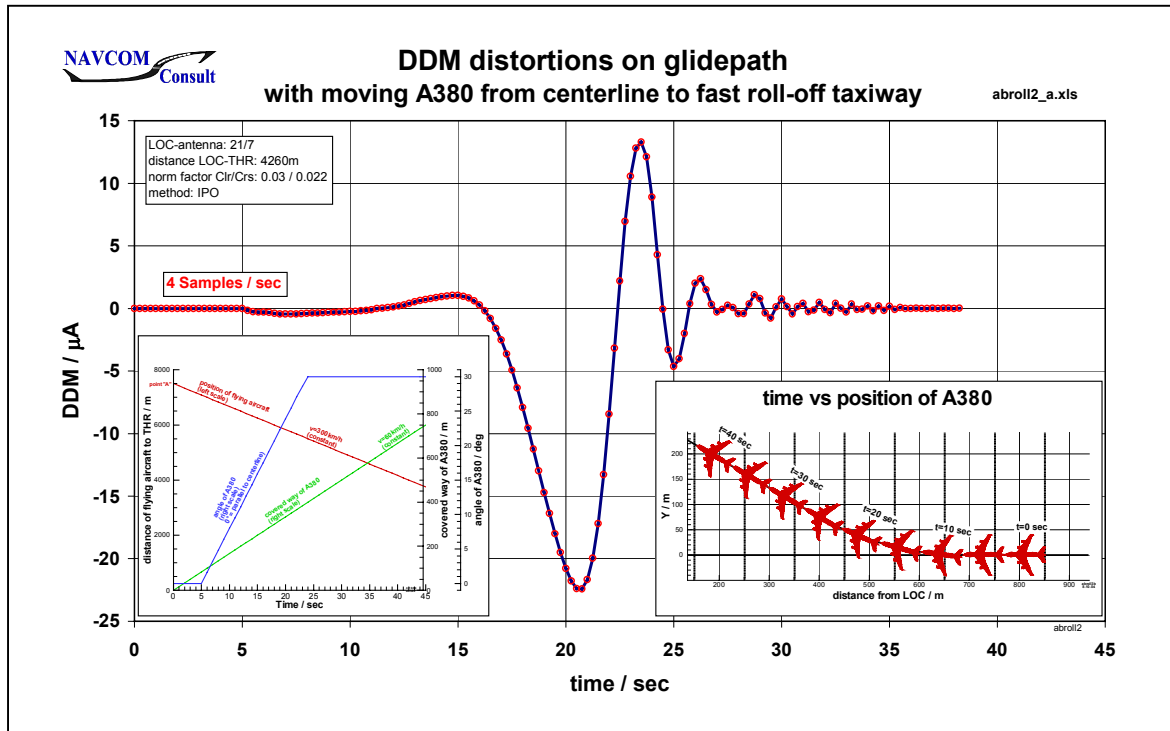


Fig. 9: Time dependant dynamic DDM-distortions by an A380 when rolling on a fast-roll-off taxiway; The landing aircraft is on the glidepath and moving also.

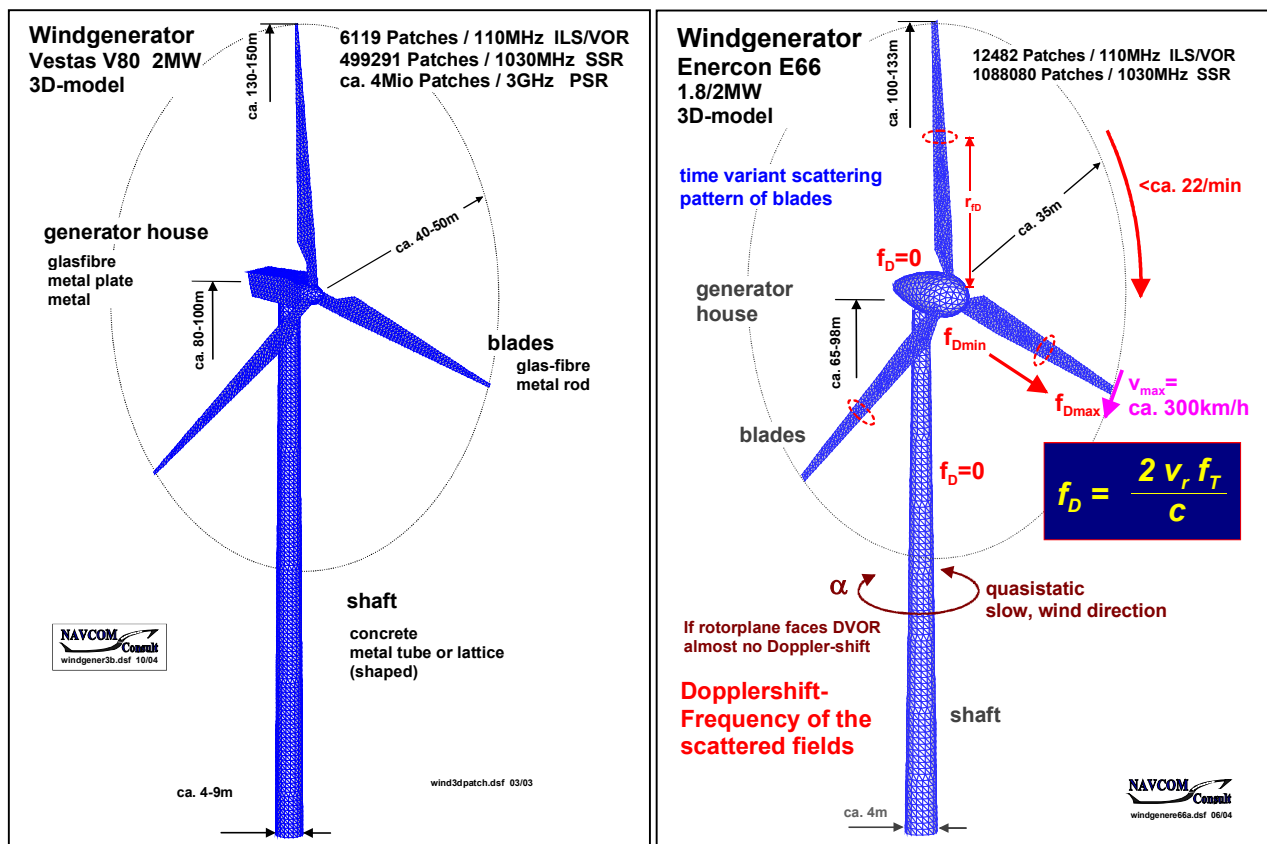


Fig. 10: Windgenerators of the type Vestas V80 (left) and Enercon E66; 3D-models for the numerical evaluation consisting of a very large number of triangular patches; some details of the Doppler-shift problem (right)

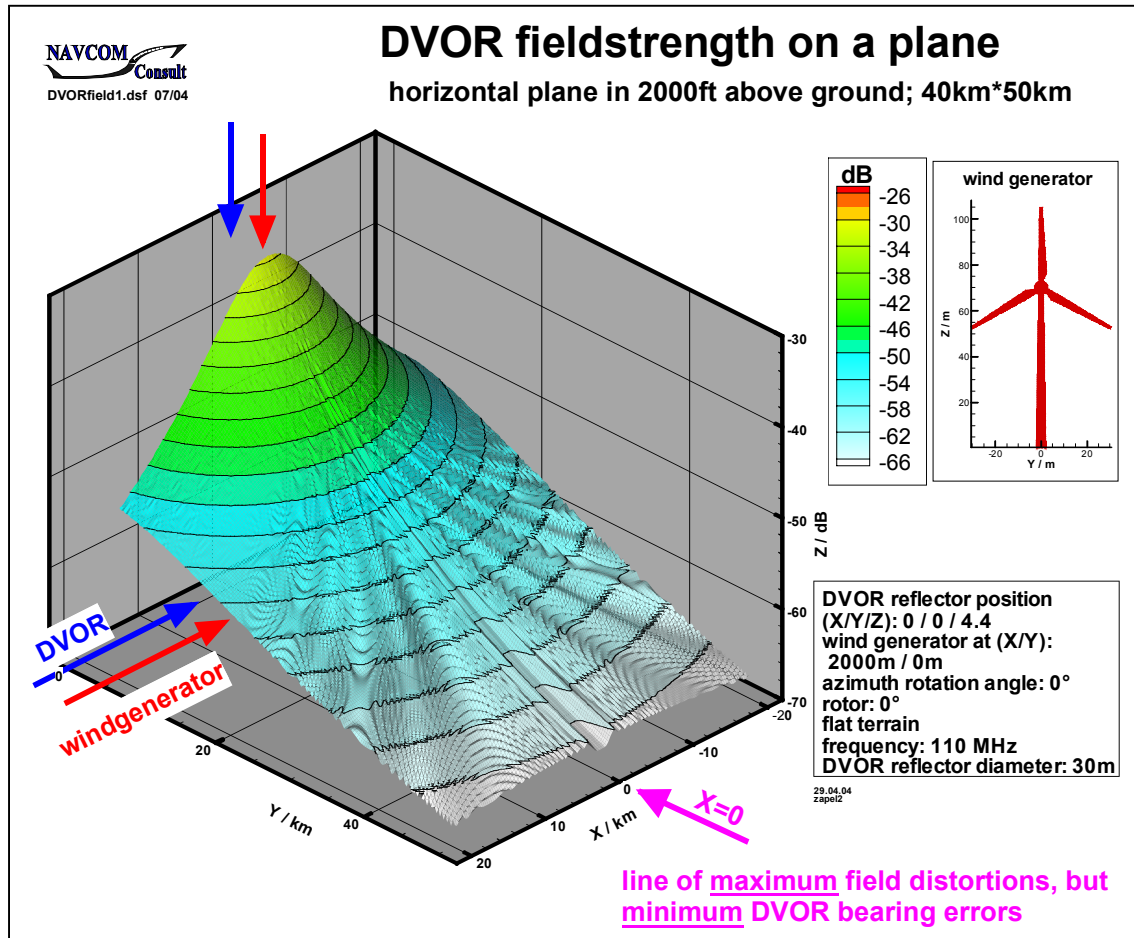


Fig. 11: Distorted field of a DVOR on a horizontal plane caused by a nearby windgenerator

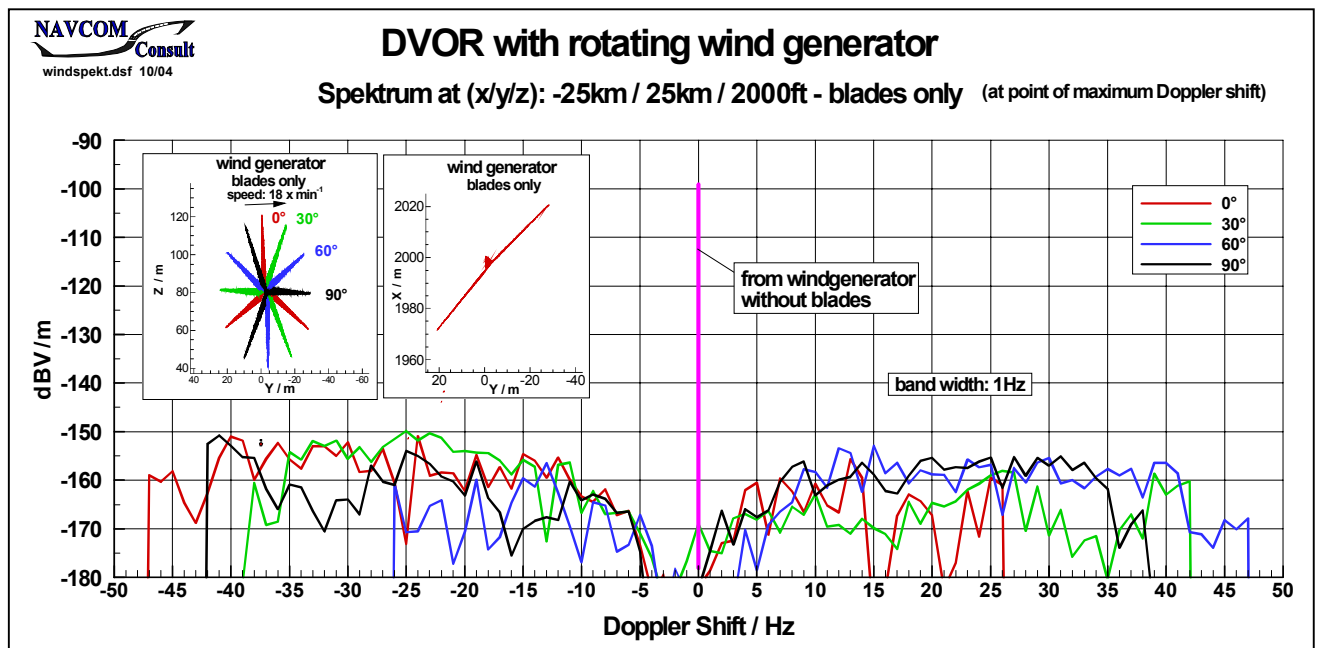


Fig. 13: Simulated Dopplerspectrum for VOR/DVOR-frequency of the rotating blades in different angular positions

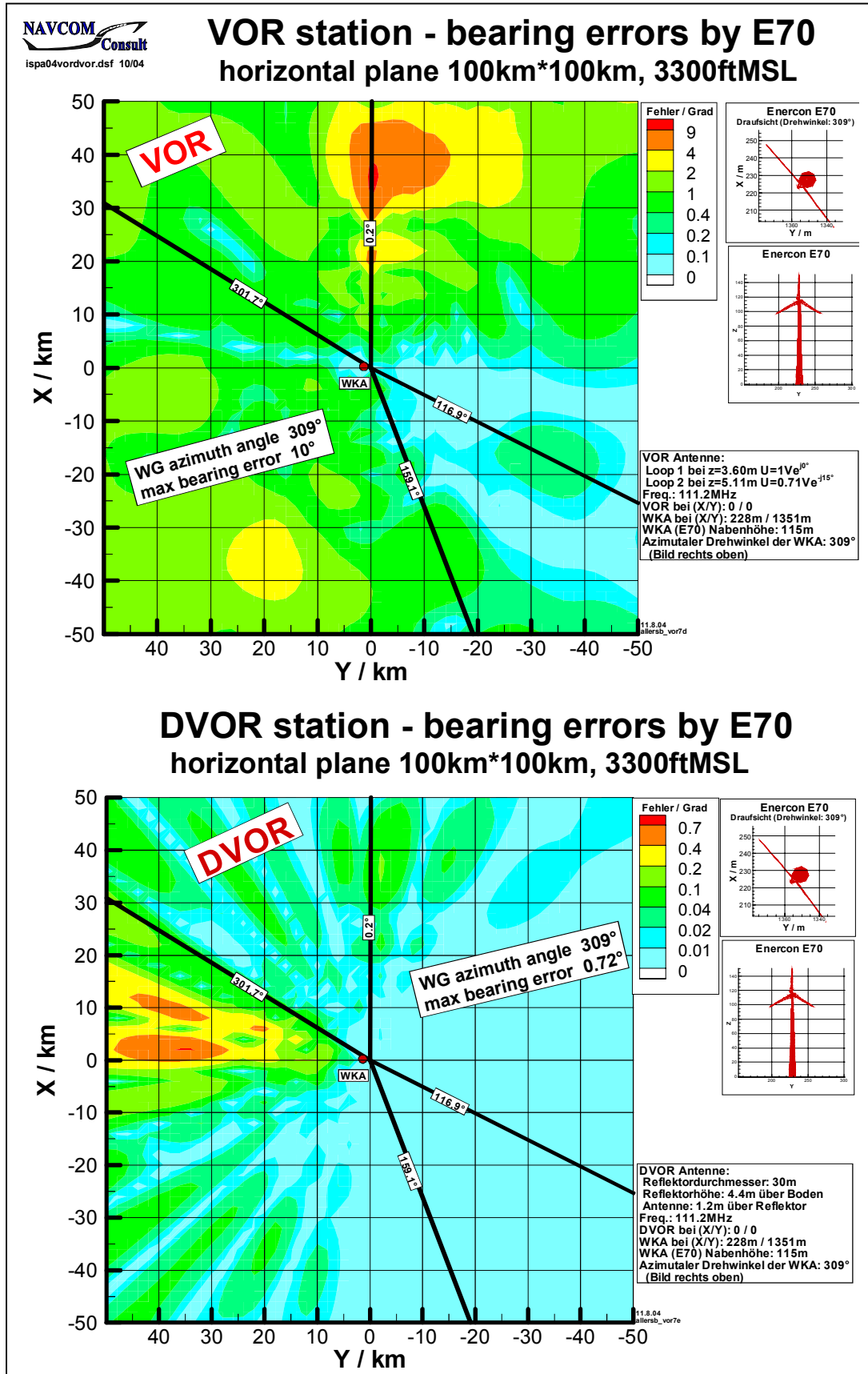


Fig. 12: VOR/DVOR bearing errors caused by a windgenerator type Enercon E70; identical geometrical configuration. Some used radials are marked. Note the different color coding of the bearing errors