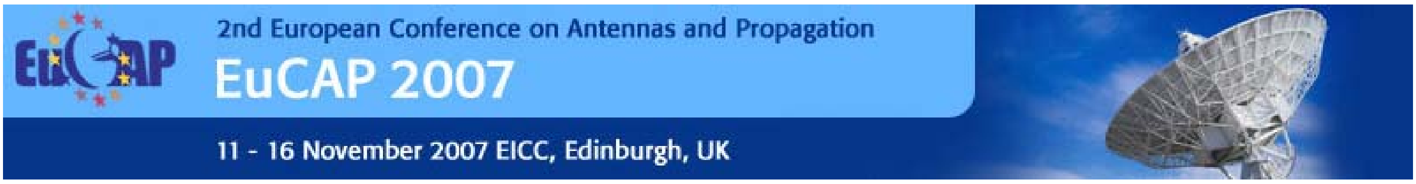

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SYSTEM SIMULATIONS BASED ON ANTENNA AND SCATTERING ANALYSIS - CAPABILITIES AND LIMITATIONS

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Abstract

The scattering analysis of distorting objects is an integral part of the discussed system simulations for navigation, landing and radar systems. The modeling of the antennas, the environment, the distorting objects and of the system itself are important steps of the system simulation process. The selection and adapted application of the suitable numerical method for the developed models are important assumptions for useful simulation results.

Two scattering cases are described and evaluated by numerical results, namely the widest body aircraft A380 with regard to the ILS Instrument landing system and the wind turbines with regard to the C-band radar. It has been shown that the simple models for the A380 fail for the grazing angle incidence even if the best available numerical methods are used. These models do not describe the physical features of the aircraft or the tail fin correctly. By that the modeling and the applied numerical methods are a critical issue for approximate models for complex objects having in mind all the possible and relevant geometrical scenarios.

It has been shown also that the calculation of the field distortions by scattering at the wind turbines cannot be interpreted by two fixed points in space, namely a distant source and a radar location.

1 Introduction

Numerical system simulations are carried out today for the analysis of distortions on navigation or radar systems by scattering objects. The systems are quite different in terms of application, frequency and distortion mechanism

- Navigation and Landing systems (e.g. NDB, ILS, VOR, GPS, MLS) ranging in frequency from about 300kHz to 6GHz,
- ATC Air Traffic Control radar system; i.e. the secondary surveillance radar at about 1GHz and the primary radar at about 3GHz,
- Military Radar covering a wide range of system types and frequency range,
- Weather radar operating mostly in the 3GHz and 6GHz frequency range.

The systems consist as a rule of thumb of several parts

- a transmitter and its associated antenna
- an environmental part and wave propagation section
- a receiver and its associated antenna.
- a signal processing part.

The objects to be analyzed (e.g. Fig. 1) are very much different in its geometrical size and by the much different frequencies also very much different in the electrical sizes.

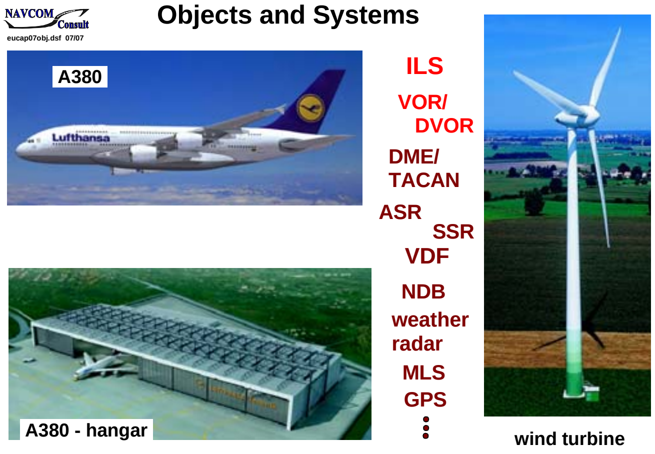

Fig. 1: Scattering objects and navigation, landing and radar systems

Some examples will be studied showing problems in the

- modeling,
- numerical method,
- system modeling and its interpretation of the scattering results.

2 System Modeling and Numerical Methods

The discussed system simulations consist of 4 major modeling tasks

- modeling of the antenna and signal source,
- modeling of the environment and of the wave propagation,
- modeling of the scattering object,
- modeling of the system and the required signal processing. This includes in case the receiver.

In each of the modeling steps of the simulations serious errors can be made. The most important rule for the modeling in all steps is to model as accurate as possible and as required or needed. The modeling in all the steps must include the factors and parameters which have significant impacts on the final results. The numerical system simulations must reflect and model the most important parameter or quantity of interest, i.e. the so-called system parameter. This system parameter has to be simulated in its full operational range and coverage.

It does not make sense to have unbalanced accuracies and depth of details in the different modeling steps. Relevant errors in one step cannot be compensated by a better modeling in the other step. E.g., a two-dimensional model of the scattering object cannot be compensated by a finer discretization in the subsequent numerical methods. If the scattering object is determined in its characteristics by a three-dimensional shape the model has to be three-dimensional. On the other hand the full three-dimensional approach and its rigorous numerical solution promise the most accurate results, but is for sure also that it is the solution which needs the largest modeling effort and computer time. Often this approach cannot be handled by far due to lack of computer power and storage. This is true also despite the increasing speed and capabilities of the commonly available PCs or cluster of PCs.

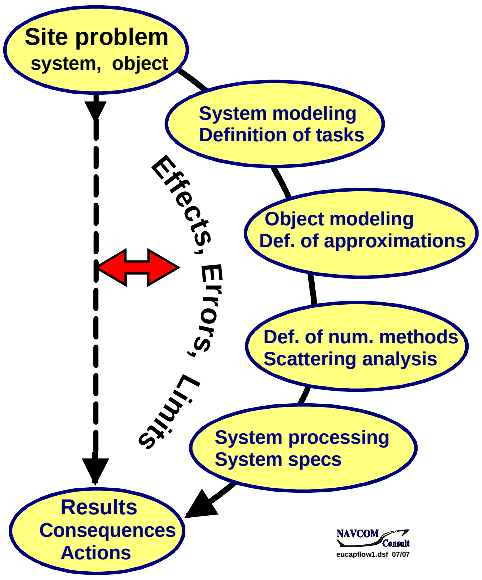

Fig. 2: General flow of the system simulations

Quite a number of numerical methods are available to solve the scattering characteristics of the scattering object. The selection criteria are

- The electrical size and structure of the objects to be modelled,
- The electrical size and structure of the integrated antennas.
- The distances between the sources points (antennas) and the field points (e.g. locations of the aircraft in space).
- The characteristics of the ground which have to be taken into account.
- The frequency and the materials to be taken into account.

Typically, the electrical distances to be taken into account are very large compared to the wavelength. Also, the objects are typically large compared to the wavelength.

In this situation the wide powerful range of discretization methods (finite element, finite differences, finite integration) cannot be used, except for the analysis of details in case of a hybrid application. In order to reduce the computation time, asymptotic and high frequency numerical methods are used wherever possible.
The following methods [5] are used for the scattering analysis

- IPO ***I***mproved ***P***hysical ***O***ptics (i.e. an extended PTD version)
- GTD/UTD (***G***eometrical or ***U***niform ***T***heory of ***D***iffraction)
- MoM and MLFMM (***M***ethod ***o***f ***M***oments; ***M***ulti ***L***evel ***F***ast ***M***ultipole ***M***ethod) as rigorous methods
- PE (***P***arabolic ***E***quation).

These and other methods are used in a hybrid manner in the so-called IHSS-scheme (***I***ntegrated ***H***ybrid ***S***ystem ***S***imulations; Fig. 3).

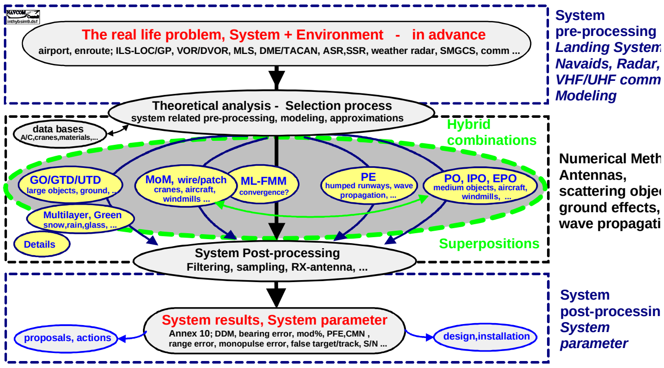

Fig. 3: Detailed signal flow of the system simulations IHSS

Two examples shall be discussed in the following chapters

- Efficient systematic numerical analysis of the A380 on airports with regard to the Instrument Landing System ILS,
- Methodological analysis of the effects of wind turbines WT on primary radar by interpretation of field distortions by scattering at the WT.

2 Scattering Analysis of the A380 on Airports

One of the recent particular interests is the effect of the widest body aircraft A380 on the worldwide used Instrument Landing System ILS. The discussed ILS-subsystem, i.e. the so-called “localizer”, is operating at about 110MHz and is horizontally polarized where the antenna arrays are installed typically about 2m above ground. The A380 is a big metallic object having a long and wide body and a large vertical metallic tailfin rising up to a height of 24.1m (Fig. 1, 4) is to be analyzed for horizontal polarization above ground. By that the exciting fields are weaker for lower heights and small close to the ground. Vice versa, the large tail has a major contribution to the scattering of the A380 if the A380 is taxiing and rolling on the ground.

The tailfin is relatively thin and metallic. This suggests modelling the tailfin by a flat metallic plate. It is suggested elsewhere to model the total aircraft by a square metallic plate which has the cross-section area of the tailfin. This assumption is governed by the availability of the simple PO (Kirchhoff approximation) yielding to the well known sinc-scattering pattern.

Fig. 5 shows 3 different models of the tailfin itself

- Flat metallic rectangular plate having the correct area,
- Flat metallic plate having the correct shape and area,
- Full metallic 3D-tail .

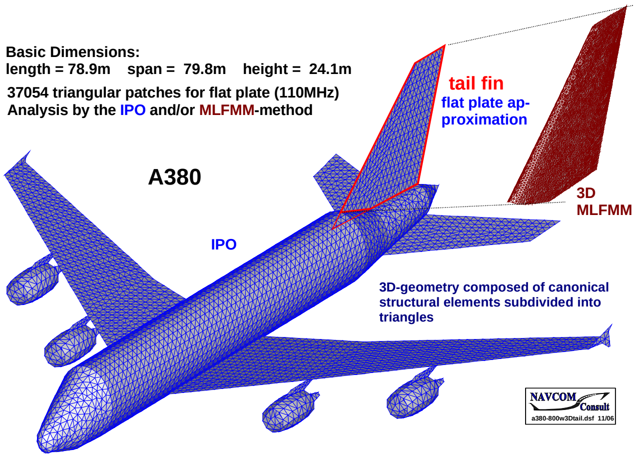

Fig. 4: 3D-model of the aircraft A380; flat and 3D tailfin

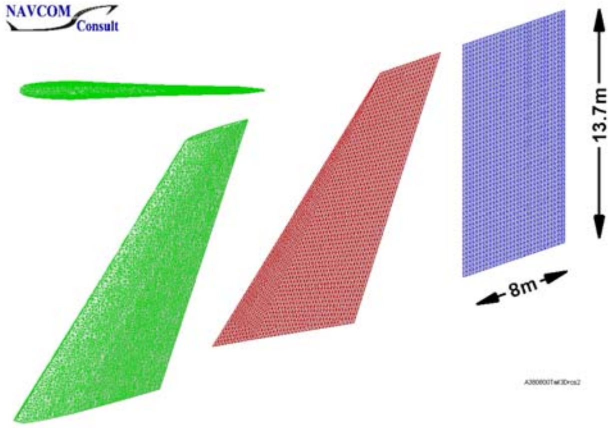

Fig. 5: Three different models of the tailfin of an A380

Fig. 6 shows the scattering for a grazing angle of incidence of 3.6°. Such scenario is typical on an airport when the aircraft is on the parallel taxiway close to the threshold when rolling for takeoff.

It can be seen clearly for this grazing angle case that

- The scattering response by the simple PO is much too large for the rectangular plate.
- The scattering response for the correct shape and area is too small for the IPO as well as for the MoM. The two solutions agree however quite well.
- The maximum of the scattering response by the thin 3D-tail is about 4dB larger than for correct solutions for the flat tail.

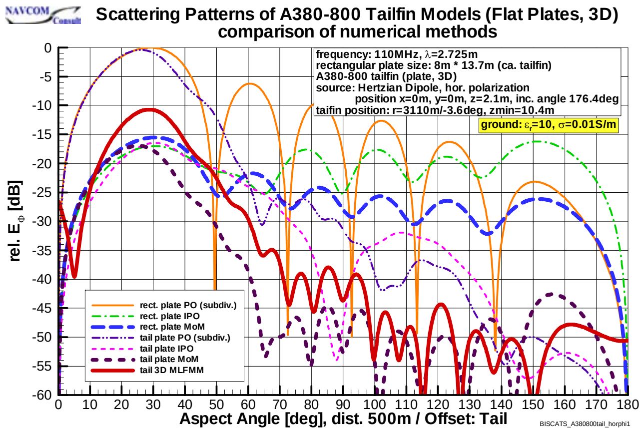

Fig. 6: Scattering pattern of the tail models acc. Fig. 5 using different numerical methods

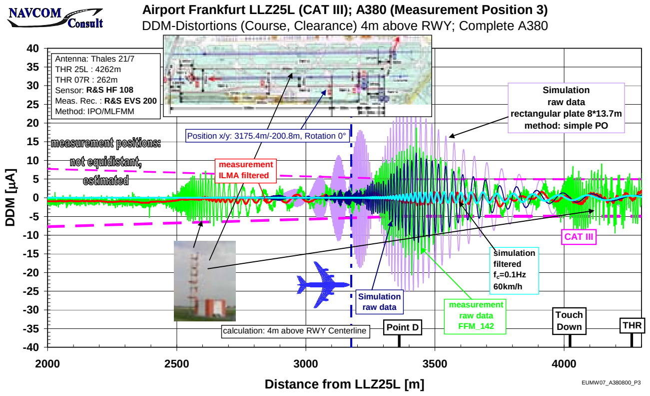

Fig. 7: ILS-system results using different models and different numerical methods for the scattering analysis

The system response for the ILS-guidance parameter DDM (***D***ifference of ***D***epth of ***M***odulation) agrees quite well with the field measurements (Fig. 7) using the full 3D-model of the A380. The surprising result finally is that the scattering response of the thin tail is significantly different from the really flat tail although well adapted numerical methods are used for the solution. As expected from Fig. 6 the system response for the rectangular plate is much different from the correct solution for the isolated tail as well as for the total aircraft. Detailed explanations will be given on the conference.

3 Scattering of Wind Turbines and Radar

Wind turbines WT are constructed in large numbers as a regenerative substitute for the production of electrical energy. However by that, the wind WT are often in some distance to navigation and radar systems. It is of vital interest to predict and analyze in advance the distorting effects to be expected.

The author has published already several technical publications on that topic [1,2,3]. This paper focuses on the scattering effects and its interpretation with regard to the shadowing, range coverage and potential countermeasures derived from scattering and field analysis.

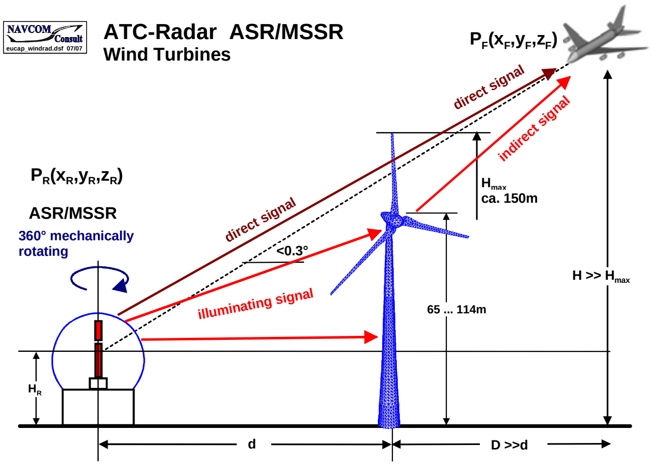

Fig. 8: General scheme of an ATC-radar, WT and an aircraft

Fig. 8 shows the geometrical relationship of the radar, the WT and the aircraft schematically and un-scaled. Also, it is visualized that the radar signal at the aircraft is composed of the direct signal and of the indirect multipath signal if the WT is illuminated significantly. The 3D-model of the WT (Fig. 9) is composed of a large number of metallic triangles treating that model as the worst case for the scattering effects.

It is obvious on first hand that the metallic loss-less WT cannot have any real loss and absorption effect and by that may not have range reduction effects. The scheme in Fig. 8 suggests, however, that some interference will take place between the direct and the indirect scattered signal and certain effects have to be expected. It is often tried to apply the RCS-scheme (***R***adar ***C***ross ***S***ection, [2,3,4,5]) for the analysis of the scattering of wind turbines. Unfortunately the RCS as defined in the literature is not applicable to the WT due to the presence of the ground. The fundamental definition of the RCS requires a plane wave excitation which is not existent in the presence of the ground, i.e. in case if the radar illuminates the ground significantly.

The scattering effects of an object can be made visual by the distortion of the electric fields.

The following series of graphics shall illustrate the attempt to describe and interpret the scattering effects of wind turbines by the "field distortions" measured between 2 fixed points P_R (radar) and the field point P_F. (see Fig. 8). The WT is in some distance d to the radar, i.e. 12.5km in all the following graphics. The source is far behind the wind turbine in a distance D of 30km, meeting the condition D>>d. The considered 2D plane in all the following graphics is inclined by 0.2° through the radar and through the mast some below the nacelle of the WT towards the source in 30km. The nacelle is at 0.394° relative to the radar.

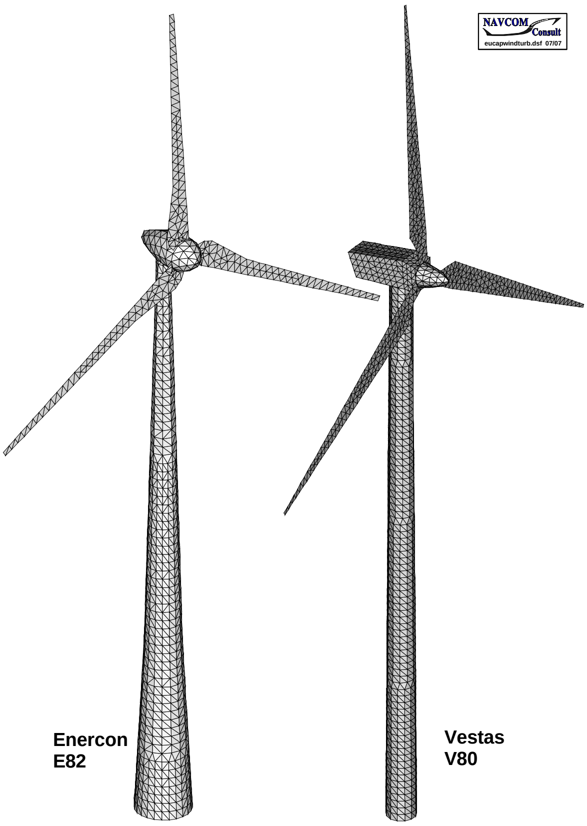

Fig. 9: Numerical 3D-models of 2 types of WT

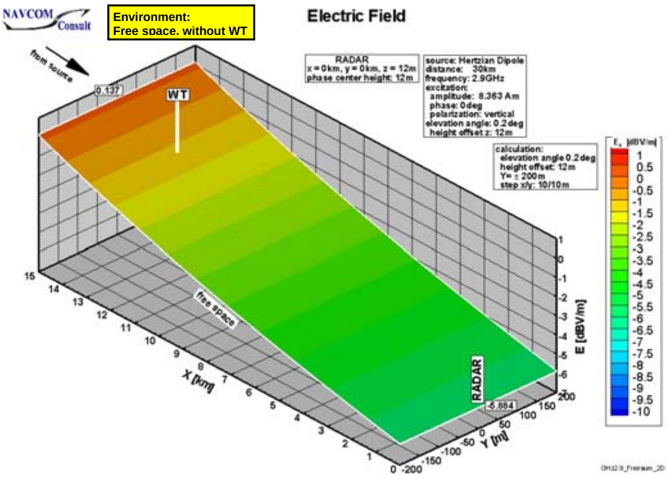

Fig. 10: 2D-display of the electric field in the region between 15km and 0km (location of radar); free space condition; without WT

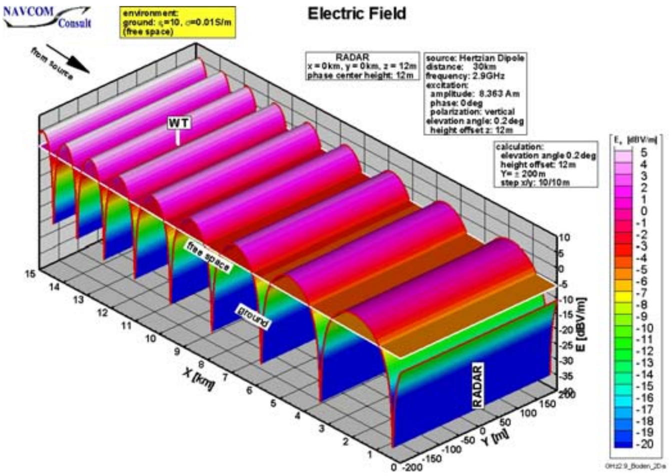

Fig. 11: 2D-display of the electric field in the same region; only ground taken into account

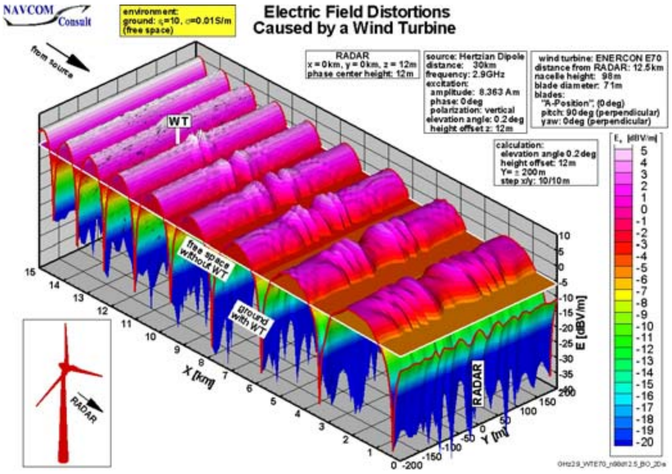

Fig. 12: 2D-display of the electric field in the same region including ground; field distortions by the wind turbine

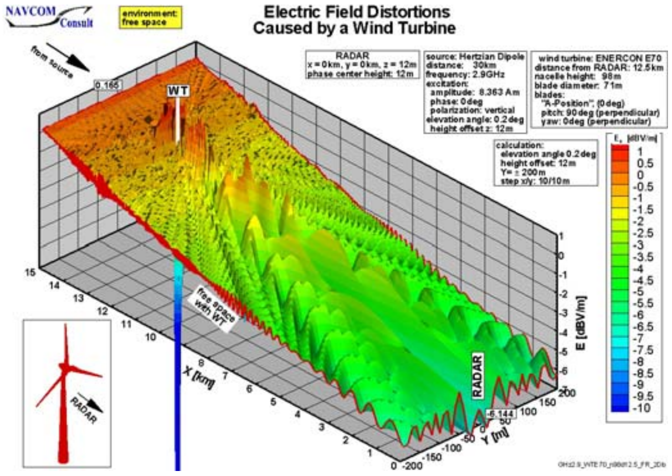

Fig. 13: 2D-display of the electric field in the same region without ground; field distortions by the wind turbine

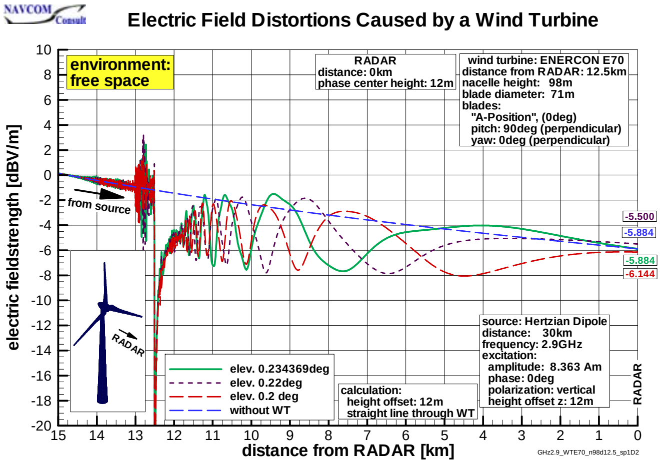

Fig. 14: 1D-display of the electric field on the symmetry line through the radar and the nacelle towards the source in 30km; slight variation of the elevation angle from 0.2° to 0.22° and 0.234369°.

The following results for an S-Band radar have been found by this series of field calculations carried out by IHSS/IPO :

1. The field behaves smooth in the absence of the ground (Fig. 10) and of the WT and is decaying as expected.
2. The ground has decisive and large effects by the interference of the direct signal and the ground reflected signal (Fig. 11) on top of the decaying effect (Fig. 10).
3. The additional distortions by the WT are small compared to the ground effects (Fig. 12).
4. The isolated effects in free space without ground are visible in Fig. 13. At the location of the radar the field drops from -5.884dB (Fig. 10) to -6.144dB. This is a drop of 0.26dB by the interference effects of the WT.
5. This “drop” or “increase” at the exact location of the radar depends on the location of the source which was varied slightly in Fig. 14. In the given scenario, the “drop” varies between
   - * -0.26dB for 0.2° elevation angle.
   - * **+0.384dB for 0.22°**
   - * 0.000dB for 0.234369° .
6. Almost arbitrary figures of “drop” or increase” can be found for different relative geometrical figures (variation of distance (Fig. 15), elevation angle (Fig. 16), azimuth angle (not shown))
7. By the variation of the position and the height of the single WT or additional WTs, this point to point “drop”/”increase”-figure caused by interference can be manipulated while fixing the position of the source and of the radar in space.
8. This arbitrary “drop”/”increase”-figure cannot be interpreted as a shadowing effect or a range reduction effect or at the end as a measure for the probability of detection. There is almost no physically valuable interpretation in the operation of radar.
9. If the distance of the source is increased the difference between the free space propagation and the distorted field disappears very fast (Fig. 15). This is in contrast to the case including the ground.

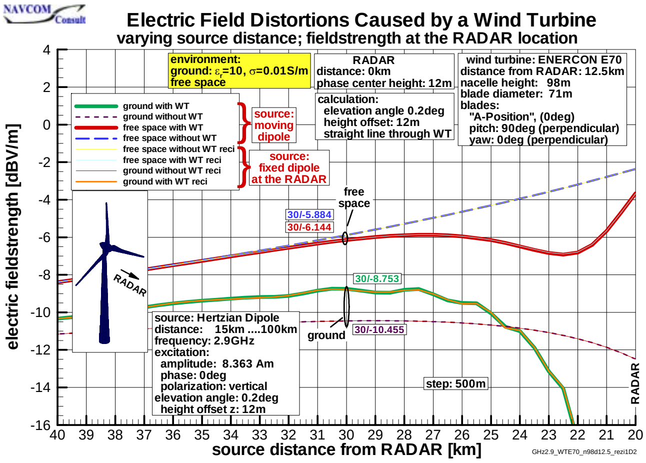

Fig. 15: Electric field amplitude at the location of the radar versus the distance variation of the source between 20km and 40km.

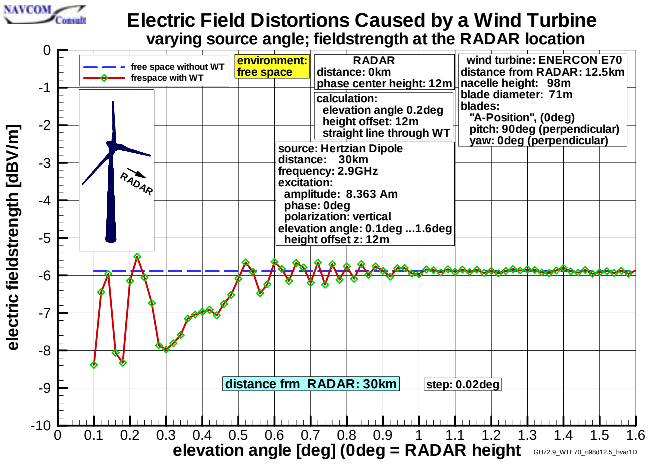

Fig. 16: Electrical field distortions on a vertical elevation angle trace at a distance of 30km to the radar; free space without WT for comparison

All these field calculations can be interpreted as the distortion effects of the WT on the reflected signal at the radar target. As can be seen the effects of the WT are larger at certain regions in space when the ground is present compared to the free space case. However, the ground effects are much larger in general in practical scenarios if the WT are not too close.

The summarizing result is that the two-point approach does not enable unique conclusions for the evaluation of the distortions of a WT or of a wind park on the performance of radar. Such kinds of field calculations are correct in itself but the intended interpretation for the system is not possible and will lead to wrong conclusions. The system consequence can be that the effects of (close) WT on the radar can be virtually and artificially minimized between the considered two points in the modelled scenario. But this two point approach is idealized and remote from reality. The geometrical scenario of the radar, the turning and rotating WTs and the distance and spatial position of the source cannot be treated as being fixed in the analysis. The field point or by reciprocity the radar target is moving. It is obvious that countermeasures or mitigations and improvements for wind parks by repositioning and height optimizations cannot be based on such kind of fixed two-point-approaches. A general 3D-analysis has to be exercised instead.

4 Summary and Conclusions

The role of the scattering analysis in the context of system simulations for two actual objects has been described and evaluated, namely for the widest body aircraft A380 with regard to the ILS Instrument Landing System and for a WT with regard to primary radar. The scattered field by the WT interferes with the direct field of the source.

The summarizing results of this paper are that the voluminous 3D-tail has to be modelled and used for the thin tail fin of the A380 and, hence for other aircraft too, in the grazing angle incidence case. This is operationally the case when the A380 is taxiing on the parallel taxiway. Simple rectangular models and the related applied simple PO-methods yield are clearly not adequate for the numerical analysis.

It has been shown that the distortion interference effects by the scattering WT between two fixed points cannot be interpreted for the system operation and the consequences for the radar system, e.g. between the source in a larger distance behind the WT and the radar. The results depend on many parameters and are by that arbitrary and not unique and practically almost useless. The interference effects are not an absorption process, but a redistribution of the field by the scattering in the region of the WT and in the back by the forward scattering.

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