

# Status and Progress of System Simulations for ATC-systems - Examples, Results and Consequences

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## ABSTRACT

More and more complex distortion and interference problems for navigation, landing and radar systems are encountered today. A reliable prediction of the effects on these systems by complex objects is required in advance according to state of the art procedures and knowhow. This task can be solved today by advanced system simulations using state of the art numerical methods to a large extent wherever possible. Compromises for fast computer time versus accuracy and reliability of the results are unacceptable. It is obvious that the modern numeric is reliable in general if the adequate methods and tools accompanied by the adequate knowhow are applied.

Some latest and actual examples will be outlined and results will be presented in this paper, namely

- The appearance of the A380 aircraft and the associated large hangars and terminals on the major international airports.
- Large extended structures in a close distance to classical navigation systems (VOR/DVOR)
- Single or arrays of wind turbines near to enroute navigation and ATC-radar stations.

These numerical simulations have to be carried out in advance before the aircraft appear on the airport or before the windpark is realized. An "integrated hybrid system simulation" (IHSS) approach has been proposed, where the most suitable numerical methods are applied in a hybrid mode combined with the advanced signal system processing.

The problem of the verification and validation of the numerical results is immanent and has to be solved. It has been done for the A380 by some systematic measurements and widely unknown effects have been encountered. A comparison of flight check results and subse-

quent simulations for a difficult VOR/DVOR-case will be presented as well.

## INTRODUCTION SYSTEM MODELLING

### General Aspects of System Simulations

Numerical system simulations are required and carried out today for the analysis of distortions on navigation or radar systems by scattering objects in advance. This means before the "distorting objects" appear or before the system has been installed on a particular site. The increasing air-traffic has the consequence of larger and larger buildings on airports and also requires more runways and taxiways on a limited space. Moreover, the appearance of large objects in close distances to the systems boosts the need for accurate and reliable system simulations.

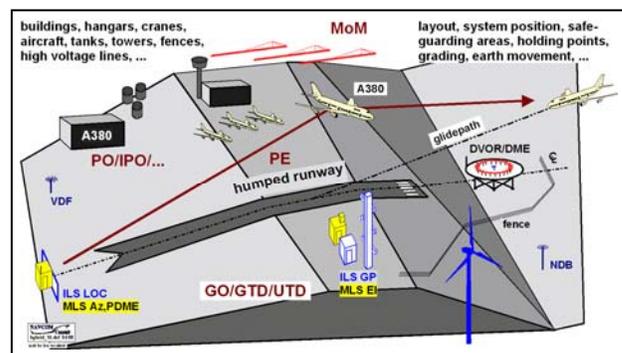


Fig. 1: Assembled sketch of objects, systems and methods

The "distorting objects" can be (Fig. 1, Fig. 2) of a wide variety and combinations, e.g.

- Buildings, hangars, terminals, skyscrapers, tanks;
- High voltage lines, tower cranes, transmitter towers, fences;

- Wind turbines, transmitter towers;
- Aircraft, e.g. A380, B747 etc. or
- Non-flat ground, natural terrain and vegetation.

The real object has to be modeled for the analysis in the simulation procedure. The “computer model” is a “translation” of the reality and must reflect the relevant physical effects of the real model with respect to the considered system.



Fig. 2: Examples of large distorting Objects and related systems

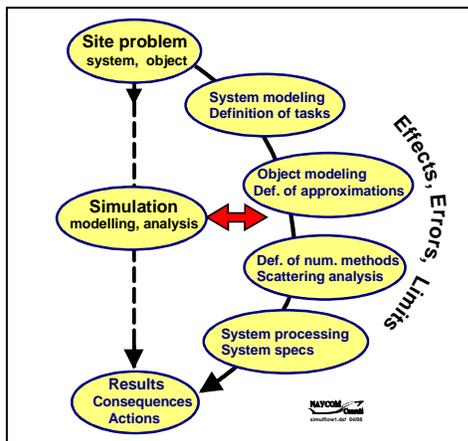


Fig. 3: General flow chart of the simulations; errors, effects

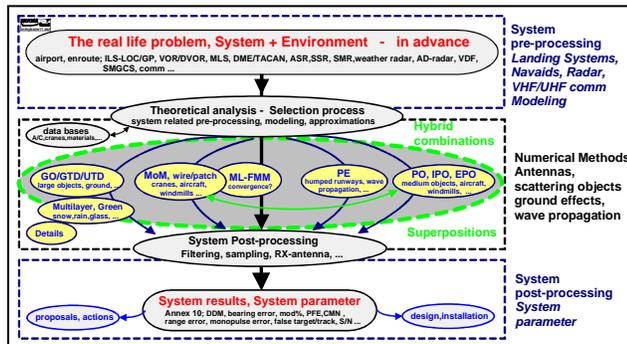


Fig. 4: Detailed flow chart of the system simulations (IHSS Integrated Hybrid System Simulations)

The system itself has to be modeled as well by the

- **Signal generation** (antennas, signal format)
- **Signal processing, signal evaluation** (antennas, receiver, filtering, sampling). The type and concept of the signal processing depends on systems and also on the actual problem as will be shown below for the VOR/DVOR case if the distorting objects are very close to the system.

The result of the simulation process (Fig. 3, Fig. 4) of the distortions has to be at the end the so-called “system parameter”. This is that specified quantity which is the purpose and intention of that considered system, e.g.

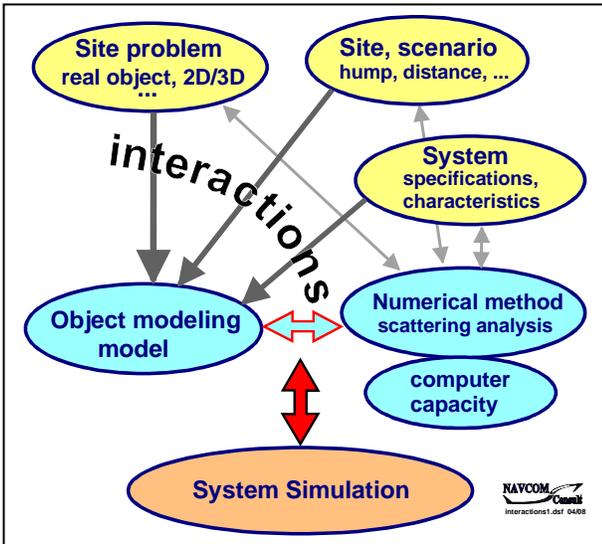
- DDM (Difference of Depth of Modulation) for ILS used for the guidance of the aircraft
- Bearing error for VOR/DVOR, TACAN, NDB
- Range error for the DME etc.

The simulated results are “raw data” in the first step. In certain system-cases a specified filtering is applied, e.g. for ILS the DDM by a low-pass-filtering procedure. However, the “raw data” are the main principle results and must be checked in a verification and validation process. Wrong raw-data cannot be improved and cured by a “camouflaging” filtering process. It seems to be highly questionable to judge a result as being operationally acceptable and within system specifications [3] when the “raw-data” are wrong or show unphysical effects, but the filtered data are within the specifications.

The simulation of other parameters or other quantities rather than this system parameter, such as the calculation of field distortions, is not justified and not useful due to several reasons,. There is no link between these “other parameters” and the system parameter and also no specification available. Approximations in the modeling step as well as in the analysis step have to be introduced to that extent that the system effects are sufficiently correctly reproduced. Computer speed and availability of tools and methods should not be a justification if “state-of-the-art”-methods and procedures are available.

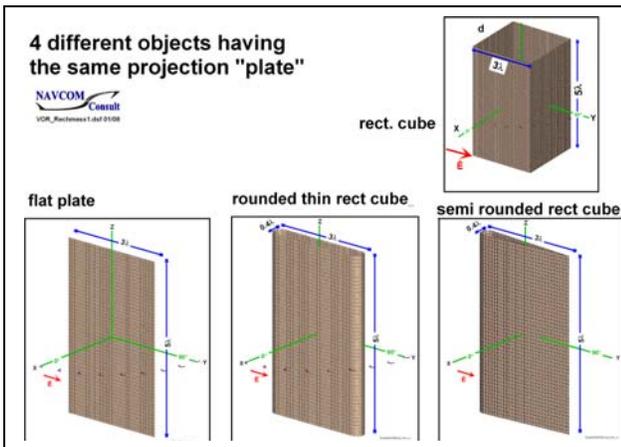
### The model and the numerical method

The definition of the computer model and the selection of the related adequate numerical method for the analysis of the scattering depend in an iterative interaction process on a number of factors and parameters (Fig. 5). By this, it is an important and critical optimization process. It may seem to be straight forward to select the numerical method for the analysis of the scattering according to the characteristics of the object or model and not vice versa. The basic idea of the IHSS approach (Fig. 4) is to take into account all the factors in order to find the best suited model and the related best method.



**Fig. 5:** Interaction between the modeling and the selection of the optimum numerical method for the scattering analysis

However, if one has only available a certain numerical method, such as the simple Physical Optics PO or the GO/GTD/UTD (Geometrical Optics; Geometrical Theory of Diffraction) [1,2], then the model must be tailored to this method in order to meet the conditions of the applicability.



**Fig. 6:** Some objects having the same projection plane

In case of the simple PO and applying the basic Kirchhoff approximation for the resulting assumed current  $\underline{I} = 2n \times \underline{H}$ , the scattering pattern of a rectangular plate can be described approximately by a closed formula, i.e. sinc-function. The sinc-function assumes constant current amplitude and a constant or a linearly progressing phase to be excited on the plate. The calculation of the scattered field is very fast, but the achieved accuracy depends on many factors, e.g.

- Is the plate model a sufficient description of the real object for all scenarios?

- Is the assumed current correct for all scenarios, such as the arbitrary spatial direction of the incoming wave or in the case of close distances?

Both questions can be answered in general with “no”, although the simple PO yields fair results in certain situations, such as the forward scatter and the back scatter for almost perpendicular incidence if the plate model is a sufficient description of the real object.

It is very obvious that a simple projected rectangle can be a model of many different real objects whose scattering characteristics can be very much different [1,4,6], ranging from a finite cylinder or a rectangular box up to a real very thin metallic plate (see also Fig. 6).

The model must meet the restrictions and the constraints associated with this method. But that does not mean that a model, which is generally compatible just with the available method, would yield correct numerical system results for a given object in all scenarios. The limitations and problems of the simple PO are well known and widely discussed in the technical literature [1,2] and in earlier publications of the author [4,6]. A particular critical and important situation is the grazing angle incidence scenario for aircraft on the parallel taxiway. In that situation the scattering response by the simple PO of the very thin rectangular plate is completely wrong in terms of

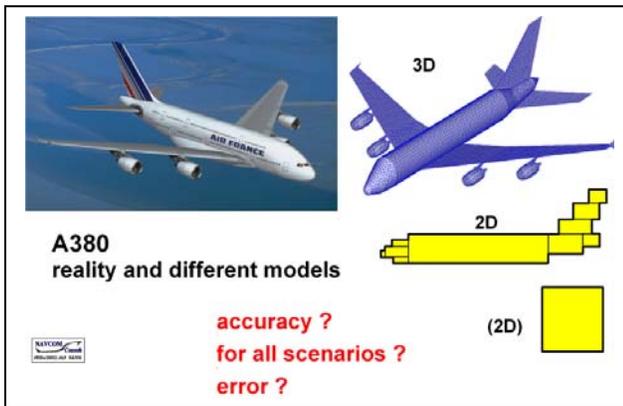
- maximum scattering amplitude which is **much too large** for the simple PO compared to rigorous methods (MoM/MLFMM) and scattering measurements for the same plate.
- Functional scattering pattern, i.e. the sinc-function, which affects the functional characteristic of the system parameter, e.g. the DDM raw data for ILS.

The system consequence is shown in the following for the tail-fin of the A380. Another example for the exaggerated scattering response in case of grazing angle incidence is shown in the VOR/DVOR-chapter below (Fig. 18).

### Modelling of the A380 for ILS System Simulations

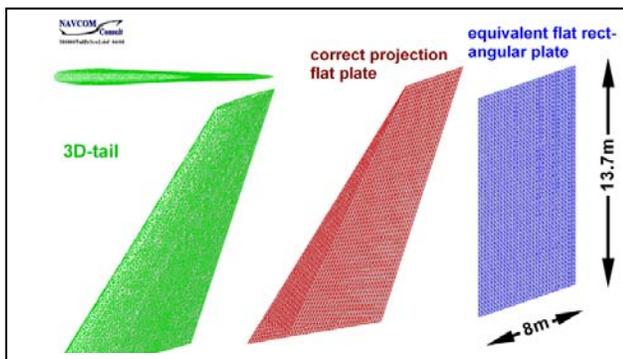
One of the recent particular interests is the effect of wide body aircraft A380 on the worldwide used Instrument Landing System ILS. The discussed ILS-subsystem, i.e. the so-called “localizer”, is operating at about 110MHz and is horizontally polarized where the antenna arrays are installed typically about 2m to 3m above ground. By that the exciting fields are weaker for lower heights and small close to the ground.

The A380 is a very large metallic 3D-object having a long and wide metallic 3D-body and a large vertical metallic tail-fin rising up to a height of 24.1m .

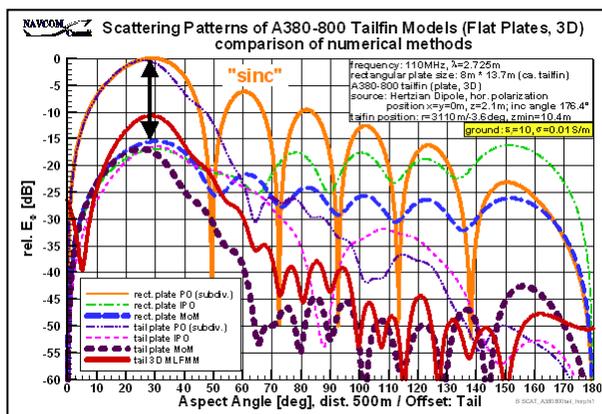


**Fig. 6:** A380 and different numerical models for the ILS-system simulations; reality top left; 3D-model but with flat tail top right; simplified approaches

The real tail-fin is relatively thin, at maximum about half a wave-length and has a curved 3D-form with rounded edges. It seems to be obvious to design a flat (ideally thin) model tail fin which has the same projected area (Fig. 7 top right; Fig. 9 left; [4]).



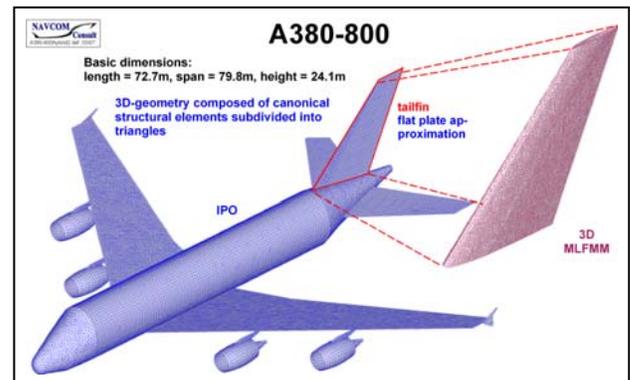
**Fig. 7:** 3 different models of the A380 tail-fin



**Fig. 8:** Scattering pattern of different tail-fin models and different methods of the A380 tail-fin; grazing angle  $3.6^\circ$

A thorough analysis (e.g. Fig. 8) of this flat thin tail fin under grazing angle incidence in comparison to other models shows the following scattering results

- The simple PO-method based on the Kirchhoff approximation calculates a wrong scattering response for the flat tail compared with the rigorous analysis or compared with measurements.
- The advanced IPO-method (Improved Physical Optics) or the rigorous methods (MoM, MLFMM) calculate the real scattering response for the flat tail-fin correctly to be much smaller than the scattering of the simple PO (by about 15dB).
- The real scattering response of the real voluminous 3D-tail calculated by MoM/MLFMM shows a much larger scattering than the approximate flat tail-fin.



**Fig. 9:** Aircraft A380-800; total numerical 3D-model; flat tail approximation and 3D voluminous tail

## ACTUAL EXAMPLES OF SYSTEM SIMULATIONS

System simulations do have the general task and background to analyze and predict the performance of a system in advance under the impact of objects or environmental conditions. Other tasks may deal with the design and positioning of system antennas and with the layout design of airports.

Some actual examples will be analyzed and will be treated under system and method aspects.

### A380 on airports in different scenarios; examples

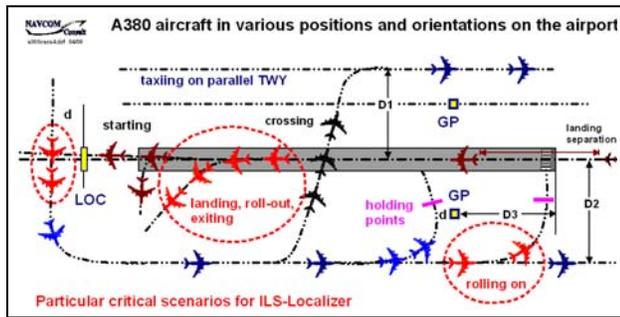
On busy airports the rolling off/on and taxiing aircraft pose a threat to the performance of the ILS-guidance signal for the landing aircraft. Many scenarios for potential distortions are encountered (Fig. 10) and have been analyzed systematically by the 3D-model (Fig. 9).

Several positions and orientations of the A380 have been identified to be a critical situation (Fig. 10) for the ILS-Localizer

1. Parallel taxiway close to threshold taxiing prior to take-off,

- Inclined orientation for the final roll-on resulting in the determination of the holding lines (not shown; showing Doppler effect induced bends),
- Roll-off close to the Localizer-antenna after landing resulting in the determination of the longitudinal length of the critical area,
- Taxiing in the back of the Localizer-antenna. This situation requires in particular a full 3D analysis where the large aircraft is in the nearfield of the LOC-antenna.
- Crossing the runway when the next aircraft is in the final approach.

Some of them are demonstrated in the following by numerical examples which have been verified in parts by field measurements on the ground.



**Fig. 10:** A380 aircraft as a potentially distorting object in different scenarios on the airport; on the runway, on the taxiways, rolling on/off, crossing runways etc.

### A380 on Parallel Taxiway

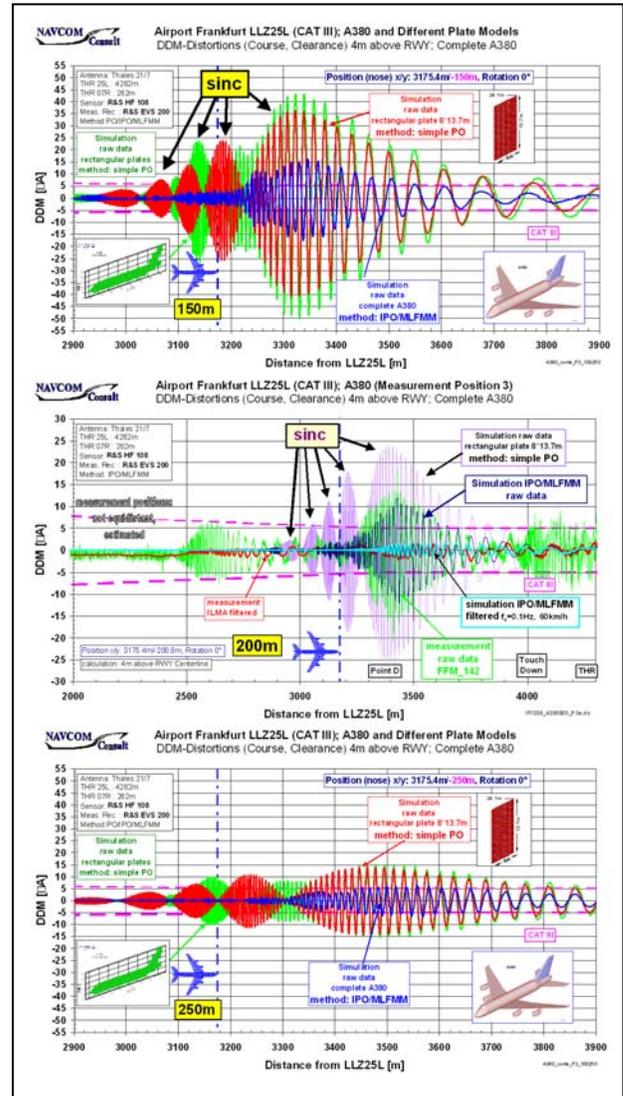
The following first example shows the distortion effects of an A380 in the realistic distance of 200m to centerline (Fig. 11 middle) in a forward distance of 3175m to the localizer antenna (threshold at 4300m). It can be clearly seen that the filtered DDM-distortions (0.1Hz, 60km/h) are well within the CATIII-specifications thanks to the drastic low pass filtering while the raw data exceed the limits by far. In addition DDM raw-data results are shown for the distances of 150m (Fig. 11 top) and 250m (Fig. 11 bottom).

In this situation close to the threshold when taxiing for take-off, the aircraft is illuminated under a grazing angle situation of some degree, typically around 3-4°. The aircraft is located in the course in-beam region even for the standard modern wide aperture dual frequency LOC-antennas. The problematic effects of the approximate flat plate model solved by the simple PO can be clearly seen in comparison to the rigorous approach for the raw data results (Fig. 11).

- Much too large DDM maxima (amplitude) caused by the scattering which is much too large under the grazing angle incidence.

- Artifacts of DDM-lobing in the envelope caused by the sinc scattering function of the flat plate.

These differences correspond with the results achieved above for the scattering of different models and different numerical methods for flat plates.



**Fig. 11** DDM-distortions by A380 on the parallel taxiway; distance to centerline 150m, 200m, 250m; comparison of models and methods; comparison with measurements filtered and unfiltered (200m middle); multiple plate (Fig. 6) also for 150m,250m

A good agreement between the measurements and the numerical simulations carried out by the IHSS (Fig. 4) and the 3D-tail fin can be observed in Fig. 11 (middle). Some measured DDM-effects are not related to the A380, but to the 2 installed glideslope masts.

However, it should be mentioned that the numerical effort for these advanced accurate simulations using the A380-3D-model requires very much more computer time and storage than the simple plate/PO approach.

### A380 rolling-off

The next 2<sup>nd</sup> example (Fig. 12) shows the comparison of the simulated and measured roll-off of an A380 after landing on a high speed taxiway. The roll-off starts at 362m distance from the localizer antenna which is not an unusual current situation on airports. Many systematic sequential positions have been analyzed and combined for this result. It can be clearly seen that the slowly time-varying DDM distortions exceed by far the specifications. These DDM-distortions are almost present over the entire length of the extended centerline or glidepath. By that, this case is an issue for all operational categories.

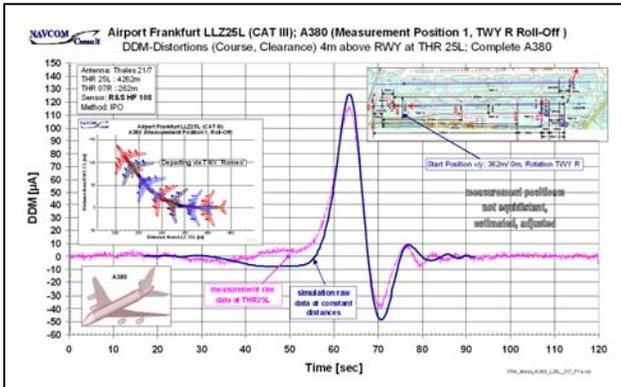


Fig. 12: Measured and simulated DDM-distortions for an A380 rolling-off.

A good agreement between the simulations and the measurements can be clearly seen.

### A380 crossing the runway

The next example (Fig. 13) shows the DDM-effects of the orthogonal runway crossing of an A380 in a distance of 900m to the localizer antenna. The DDM-distortions have been determined at the related threshold in a distance of 4300m.

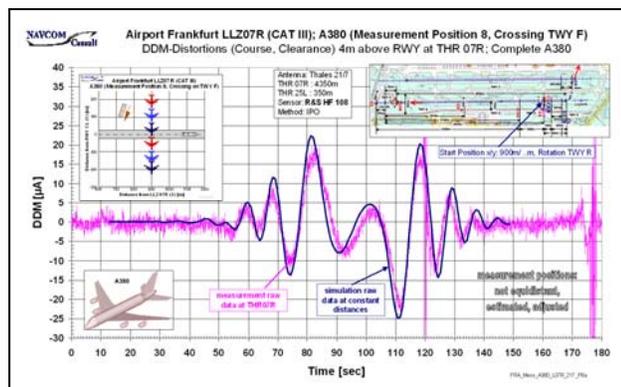


Fig. 13: Measured and simulated DDM-distortions for an A380 crossing the runway

The DDM-distortions can be seen all along the extended centerline or glidepath for the next landing aircraft. By

that this phenomenon is part of the determination of the longitudinal length of the safeguarding areas.

### A380 crossing the centerline in the back of the localizer

In some cases, taxiways are realized or planned in the back of the localizer antenna due to layout constraints on airports. The intention is mostly, that the use of the back taxiway is independent of the landing traffic. The crossing aircraft is in the back nearfield of the antenna. The back radiation of the localizer antennas is at minimum in the order of -20dB depending on the related features of the modern antenna design. The DDM-distortions are caused by the back radiation of the course subsystem and by that are course inbeam distortions. A rigorous 3D-model of the treated antenna has been established which includes the installed reflector in detail. The aircraft (A380 Fig. 14 top; B747 Fig. 14 bottom for comparison purposes) are modeled in 3D as well in this challenging simulation crossing the centerline orthogonal.

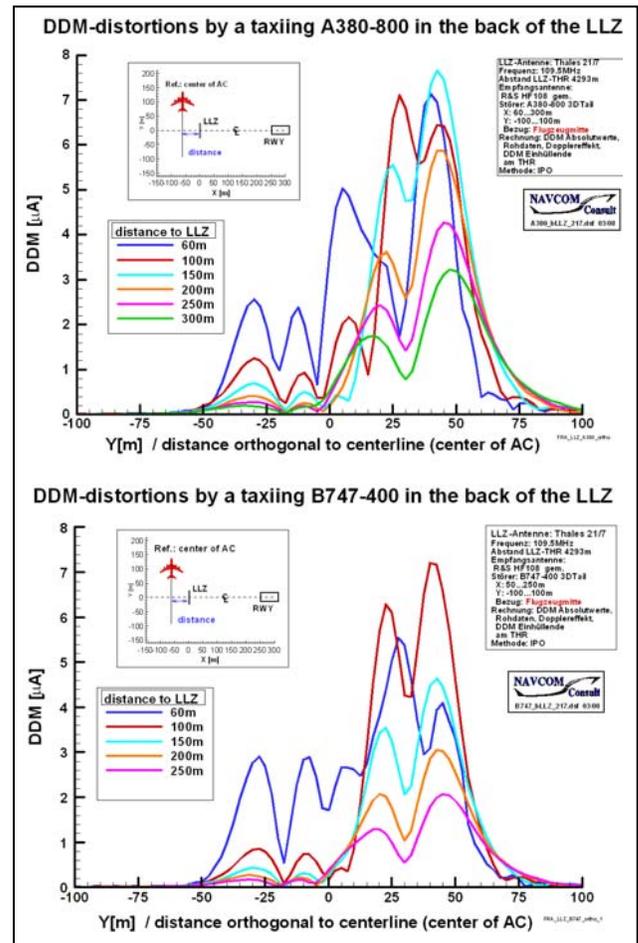


Fig. 14: DDM-distortions by an A380 (top) and B747 crossing the extended centerline in the back of the localizer antenna

The DDM-distortions are simulated at the related threshold in the height of 4m in a distance of about

4300m to the antenna. It can be clearly seen that the DDM-distortions are almost identical for both aircraft in the minimum distance of 100m in the back constituting a problem for CATII/III operation. For larger back distances up to 250/300m, the DDM-distortions by the A380 increase relative to the one for the B747. It can be seen clearly, that for the *orthogonal crossing* a back distance of 200m minimum seems to be required. Improvements can be achieved by a non-orthogonal crossing as has been simulated.

These results for the A380 cannot be transferred to other antennas and cannot be used as well directly for the definition of the safeguarding areas (“critical, sensitive areas”). The results are in principle case and site dependant and require site adapted applications and interpretations.

### VOR/DVOR distortions by objects in the nearfield

The VOR-system is prone to distortions by scattering objects. The classical theory assumes that the distorting objects are in a relatively far distance to the VOR-antenna and, by that, can be treated approximately as a point-scatterer which has a scattering pattern.

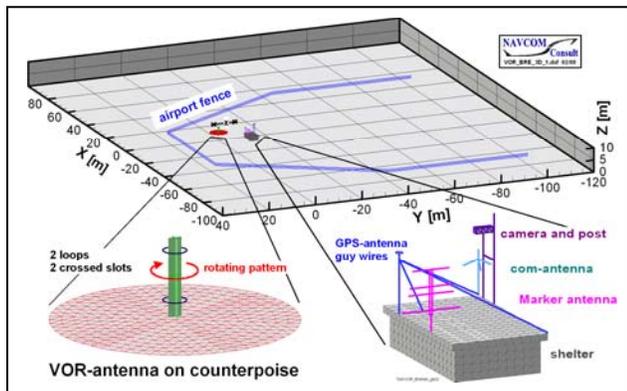


Fig. 15: VOR test installation in a close distance to an airport fence and a ILS-marker shelter and antennas

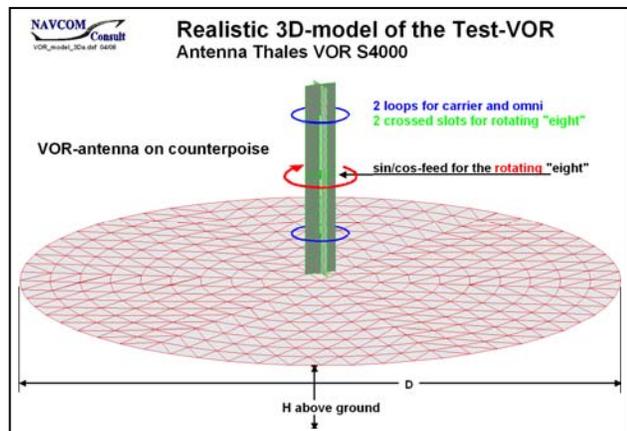


Fig. 16: Realistic 3D-model of the CVOR-antenna (see Fig. 15)

If the objects are extended, the processed difference angle between the radial direction of the scatterer and the aircraft cannot be determined at all in a reasonable way. Moreover, the objects are in the nearfield of the VOR-antenna which should be substituted later by a DVOR-antenna. Back-effects on the VOR/DVOR-antennas have to be taken into account. Fig. 15 shows a recent case where a mobile conventional test-VOR was installed in a close distance to an airport fence and other infrastructure objects.

FI-measurements on orbits (Fig. 17 top) and radials showed unexpected results and an out-of-tolerance performance which should be explained and verified by the numerical system simulations.

The available standard analysis approach is seriously speaking not able to analyze this technical problem. In this situation a generalized new simulation approach is required which has the following target-capabilities

- Analysis of arbitrary multiple objects
- Multiple objects in arbitrary close distances
- Realistic modeling of the rotating VOR antenna(s)
- Realistic signal processing for the fundamentally different VOR- and DVOR systems
- simulation of the bearing error (receiver modeling)
- simulation of the 10kHz modulation degree for DVOR .

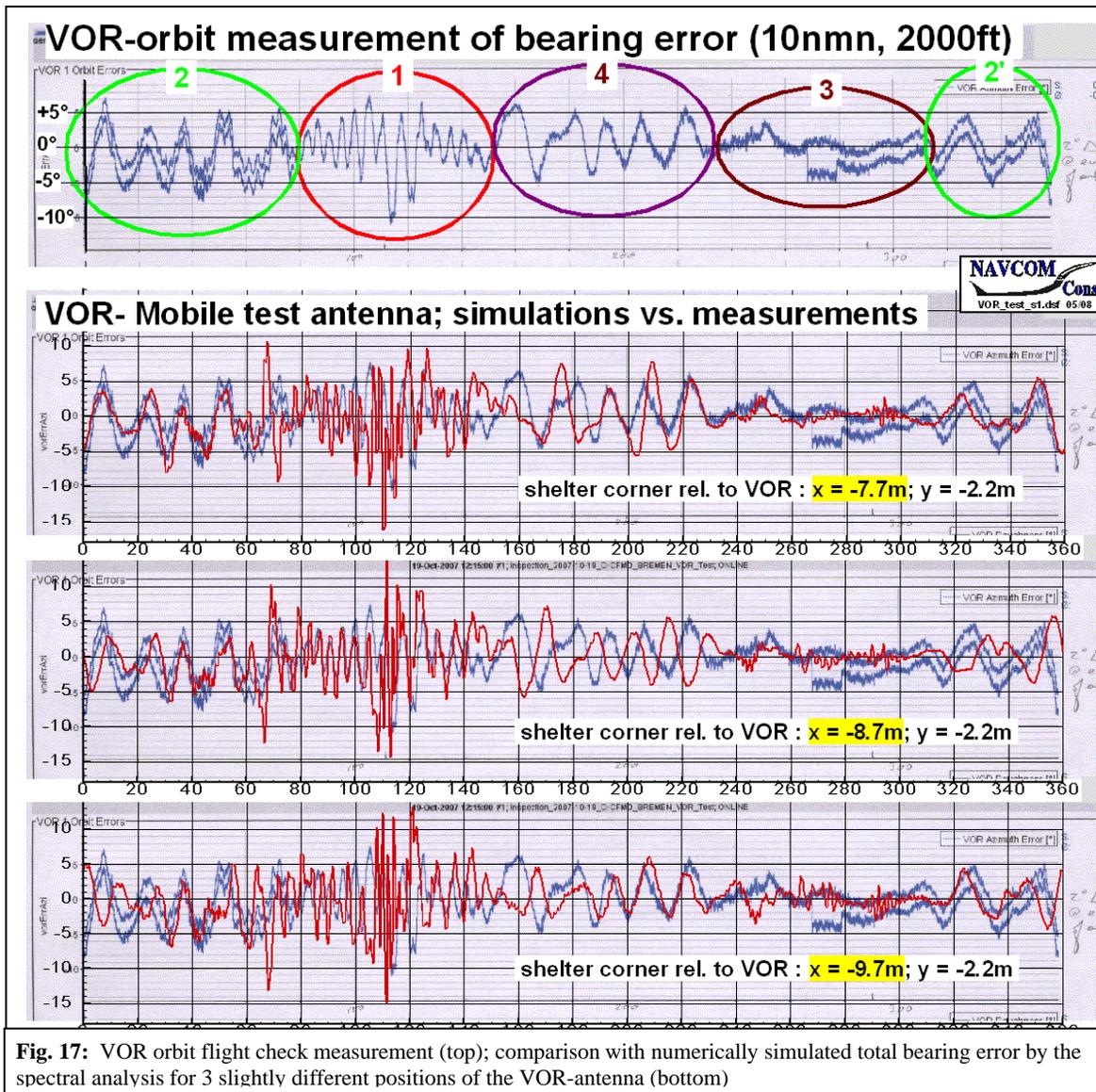
For this challenging requirement, the IHSS (Fig. 4) has been extended by highly specialized modules for the involved time variant analysis and for the advanced spectral analysis adapted to the VOR and in particular for the DVOR systems. In this approach the general and rigorous MoM/MLFMM methods are used for the time variant scattering part taking into account the mutual coupling as well.

The objects to be taken into account are (Fig. 15):

- Airport fence almost all around the VOR which was suspected to create the observed effects.
- Marker Yagi-antenna and marker shelter
- GBAS-antenna having metallic guy wires
- Communication tripod antenna
- Surveying camera and lightning arrester.

Unfortunately, the exact geometry of the VOR-test-antenna (Fig. 15, Fig. 16) relative to the objects was not sufficiently documented. By that the RF-phase dependant bearing scallop characteristics cannot agree in all details.

Fig. 17 shows a small part of the results gained by the systematic study. The top curve shows the flight check measurement results on an orbit (10nm, 2000ft) which are discussed in more depth in a parallel paper [5]. The study was started in order to validate the flight check measurements and explain the effects on the orbit and on the radi-



**Fig. 17:** VOR orbit flight check measurement (top); comparison with numerically simulated total bearing error by the spectral analysis for 3 slightly different positions of the VOR-antenna (bottom)

als. Constant offset bearing errors were measured on certain radials. The offset could be reproduced as well and can be explained by the electrically small distance of the distorting object to the VOR-antenna.

Fig. 17 shows in the lower part the results for 3 slightly shifted positions by 1m of the VOR-antenna relative to the fence and to the other fixed objects. In each sub-curve one can see the comparison between the measured and simulated VOR-bearing error. It can be clearly seen from Fig. 17 that the scallops are sensitive for the relative slight movement of the VOR-antenna due to the phase dependency of the bearing error. However, despite all the uncertainties a good agreement has been achieved. The simulation offers the possibility to study the individual effects of the each of the distorting objects and to study the effect of systematic parameter variations (position,

height and diameter of the counterpoise for the VOR and DVOR). The distortions marked by “1” in Fig. 17 are generated by the fences and the distortions marked by “2” are created mainly by the marker Yagi-antenna. The simulated DVOR has shown only very small bearing errors, but noticeable 10kHz modulation effects by the close objects in the nearfield.

Another practical example of exaggerated DVOR-distortions by the simple PO-analysis of a large building façade (30m\*20m), which may represent a large hangar on an airport, is reported in Fig. 18. The illumination of the façade is again under grazing angle conditions of about 5°. The simulated bearing errors by the simple PO are as expected about twice as high as by the rigorous MoM-solution. The bearing errors have been calculated for both cases by the newly developed signal processing “spectral-scheme”.

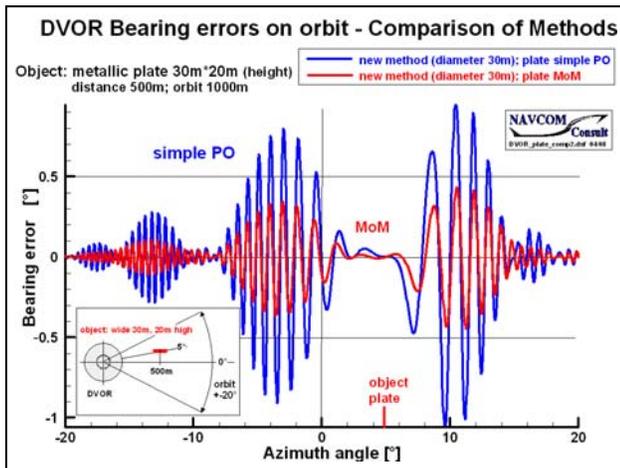


Fig. 18: Comparison of the DVOR bearing errors on the orbit for a large hangar façade under grazing conditions

### Windturbines and navigation and radar systems

Wind turbines WT are constructed in large numbers as a regenerative substitute for the production of electrical energy. However by that, the WT are often in some distance to navigation and radar systems (Fig. 16). 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 [7,8,9], in particular for ATC- and weather radar applications. It has been shown in particular that the Radar-Cross-Section-Scheme (RCS) is not useful and applicable for the analysis as well not for the safeguarding problem. This paper focuses shortly on the scattering effects and its interpretation with regard to the VOR/DVOR-system.

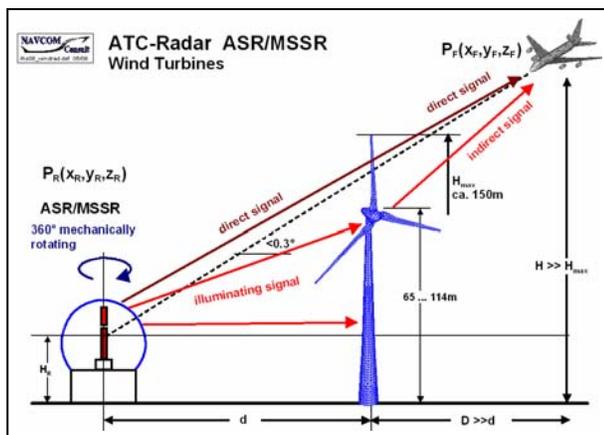


Fig. 19: General scheme of an ATC-radar, WT and an aircraft. The radar may be substituted by a VOR/DVOR.

The WT is modeled (Fig. 20) along the IHSS-principles (Fig. 4) and the system parameter is simulated under the applicable operational conditions.

Fig. 21 shows such a singular example for a VOR-system under the impact of 14 large WT in a distance of around

7km. The bearing error is calculated on horizontal circle planes around the VOR of defined operational heights. It is the worst case “envelope”-error and has borderline characteristics. This result contains all orbits and radials in the given region and range. The DVOR at the same position has shown very small bearing errors as expected.

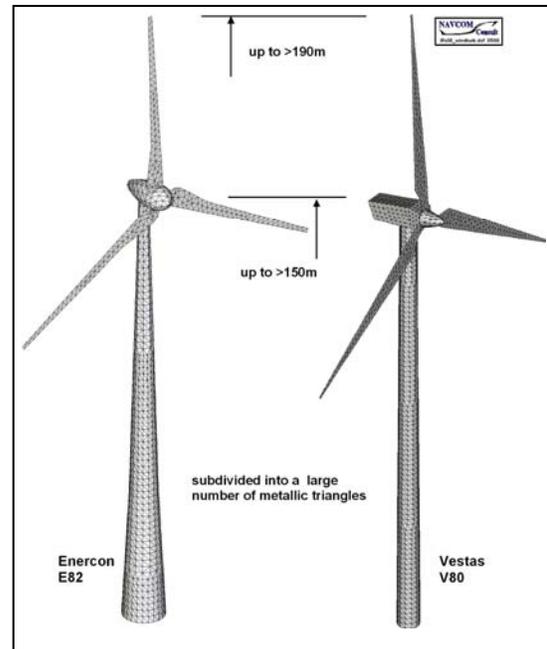
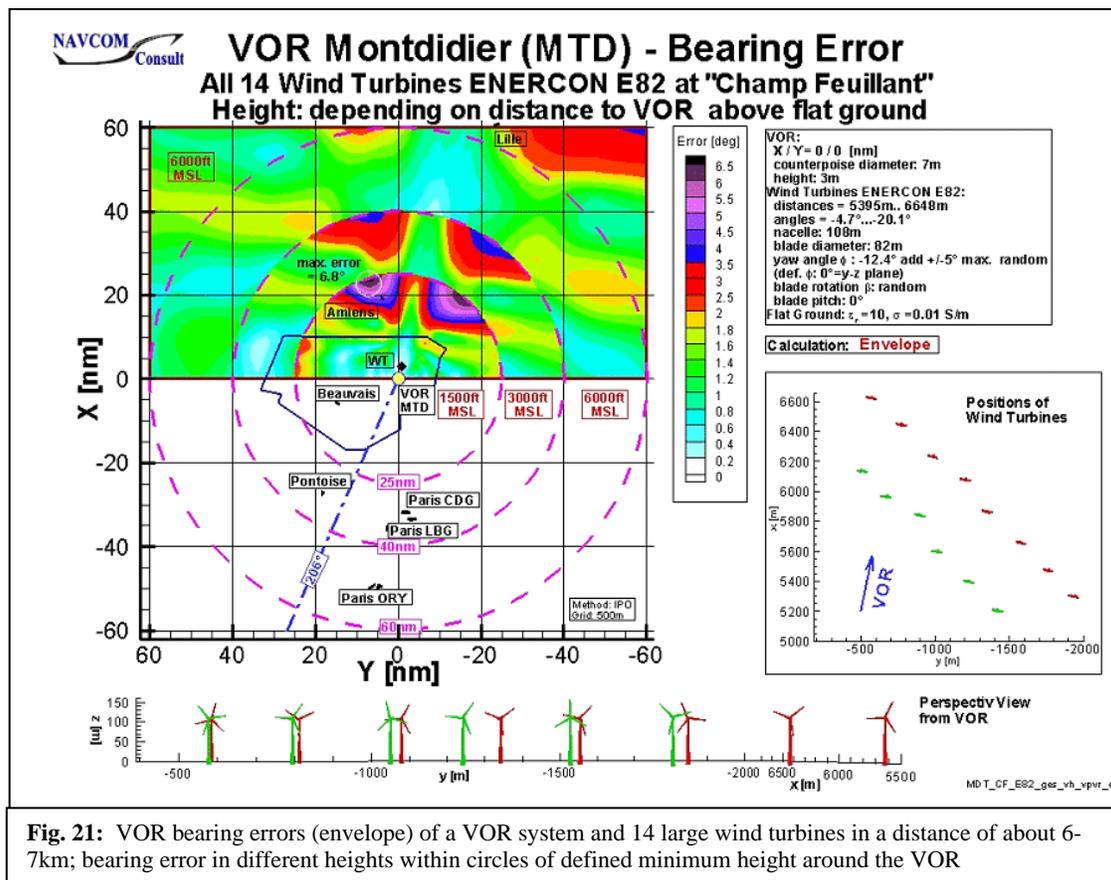


Fig. 20: Numerical 3D-models of 2 types of large WT

### CONCLUSIONS

The presented state-of-the-art system simulations consist of the modeling of the system, the distorting object and the signal processing. It has been shown that by the integration of the applicable most advanced numerical methods even complicated and very complex 3D-cases can be simulated reliably and accurately by the IHSS-scheme. The status and achieved progress have been demonstrated for several challenging system cases, the A380 related to ILS, special VOR/DVOR scenarios and wind turbines. The demonstrated progress made is the general applicability for large 3D objects of curved surfaces or hybrid structures and for small nearfield distances of the objects to ILS and VOR and other systems.

Simulations and measurements show a good agreement to that extent that effects observed in the flight check could be verified and explained. The achieved results by the advanced generally applicable methods also show on one hand their powerful capabilities, on the other hand the shortcomings of rough approximate simulations (flat plates, simple PO). These are much faster in general than the advanced methods, but speed and availability should not be balanced against accuracy and reliability. The demonstrated progress does allow a complementary cooperation with the flight check or may substitute the flight check in certain cases.



**Fig. 21:** VOR bearing errors (envelope) of a VOR system and 14 large wind turbines in a distance of about 6-7km; bearing error in different heights within circles of defined minimum height around the VOR

## RECOMMENDATIONS

State-of-the-art system simulations should be the only basics of any performance predictions and decisions for building permissions and investments such as hangars and windparks.

The availability of tools, which rely on simple models and simple math kernels resulting in high speed processing, should not be used as a tradeoff against general applicability, accuracy and reliability of state-of-the-art simulation techniques.

Apply state of the art simulations for the reliable site dependant determination of minimized safeguarding areas on major international airports serving A380 traffic.

## ACKNOWLEDGMENTS

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## REFERENCES

[1] Y.T: Lo, S. W. Lee, *Antenna Handbook*, Chapman & Hall, New York 1996, Vol. I chapter 4

[2] BOROVNIKOV, KINBER Geometrical Theory of Diffraction, IEE, London 1994; chapter 6: GTD or physical optics?

[3] ICAO, July 1996, International Standards and Recommended Practices, Annex 10 to the Convention on International Civil Aviation, Volume 1, Radio Navigation Aids, 5th Edition, <http://www.icao.int>

[4] G. Greving, Modern Numerical Analysis and Simulations for System Applications - Capabilities and Limitations Exemplified for the A380 Aircraft, in *Proc. ANTEM 2005*, St.Malo/Rennes/France, June 2005, pp. 212-216

[5] G. Greving, N. Spohnheimer, Current Issues in Demanding Flight Measurement Environments; 15<sup>th</sup> IFIS; Oklahoma/USA, June 2008

[6] G. Greving, W.-D. Biermann, Theoretical Aspects and Numerical Solution of Scattering from Objects under Grazing Angle Incidence - The A380 and the Aircraft Tailfin; 37<sup>th</sup> EuMW, Munich October 2007

[7] G. Greving, Numerical Simulations of Environmental Distortions by Scattering of Objects for the Radar - SSR and flat roofs, RCS and windturbines, EURAD 2006, September 2006 Manchester/UK

[8] G. GREVING, W.D. Biermann, System simulations based on antenna and scattering analysis - Capabilities and limitations, EUCAP 2007, Edinburgh/UK; November 2007

[9] G. GREVING, W.D. Biermann, Application of the Radar Cross Section RCS for Objects on the Ground - Example of Wind Turbines, IRS 2008, Wroclaw/Poland, May 2008