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On the Advanced Simulation of Distortions for Navigation, Landing and Radar Systems - Modern Methods, Cases and Results

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BIOGRAPHY (Presenter Gerhard Greving)

The author was born in Ahaus/Germany. He studied electrical engineering at the Technical University of Aachen and made his PhD in 1978 there too. From 1980 to 1997 he was R&D head for antennas and propagation in SEL, then Alcatel in Germany, developing quite a number of antennas and system components in the fields of navaids, landing, comm and radar systems. In 1997, he founded NAVCOM Consult, an independent consultancy company for services in the same fields. The specialties of NAVCOM Consult are the 3D simulations of the system distortions by almost arbitrary objects on the classical and modern systems in the mentioned fields.

ABSTRACT

This paper is defined as an overview paper on the currently most advanced simulation techniques for the evaluation of distortions by scattering objects on navaids, landing and radar systems.
The methodology of the system simulations is outlined which includes the modelling, the selection and application of the most advanced applicable numerical techniques and the related system related signal processing. Examples and results are presented for a number of systems under methodological and application aspects. Some principles of mitigation measures and validation methods are discussed. It is pointed out that these mitigation measures must really be necessary and must really work as intended. If not, these measures are a waste of money and resources and are called pseudo measures.

1. INTRODUCTION

Many systems in the fields of navigation, landing, radar and communications rely on the transmission and reception of radio signals. In reality these systems are never operating in free space without distorting objects. Fig. 1 shows a schematic of systems and distorting objects on and around an airport. The classical and modern systems operate typically in the frequency range between 500kHz and 6Ghz. A typical variety of distorting objects, such as hangars, control towers, cranes, wind turbines, fences, aircraft can be seen and also the ground itself in the wave propagation.

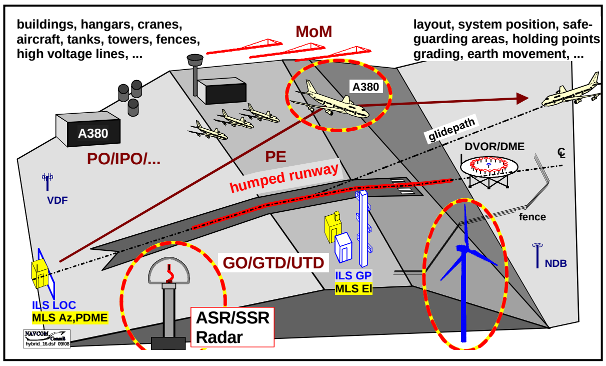

Fig. 1: Schematic airport Scenario with common systems and associated antennas and distorting scattering objects

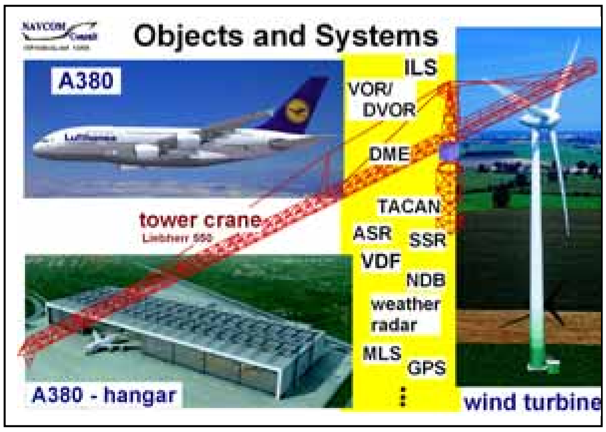

Fig. 2: Actual examples of 3D objects threatening systems on airports and en-route

The increasing air traffic and the related appearance of large aircraft and large buildings and also the of wind turbines (Fig. 2) require the reliable and accurate simulations of the system performance ***in advance*** if construction activities are planned on the airports or in some distance to en-route systems such as wind parks or high voltage lines close to navigation and radar systems (Fig. 2). In particular also the conflict between the increasing number of large objects requires the reliable determination of the distortions to be expected in order

to avoid over-conservative unjustified safeguarding distances or not justified mitigation measures.
A typical system in the context of this paper consists of a ground and an airborne segment (Fig. 3). The wanted direct and the unwanted scattered signals at the distorting objects superpose and create the system distortions.

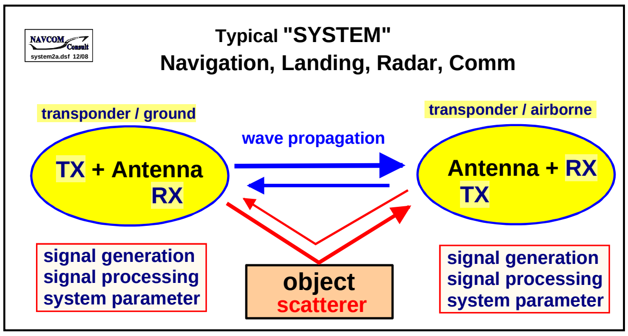

Fig. 3: Typical system configurations consisting of a ground, an airborne and a wave propagation part

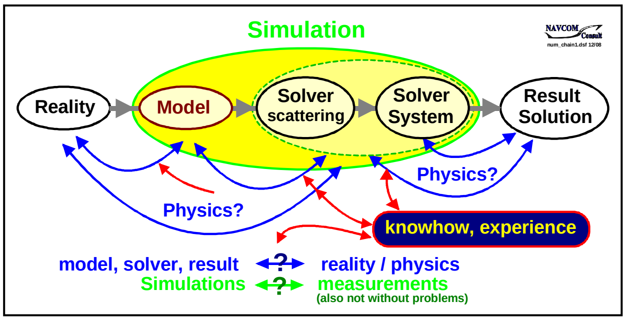

Fig. 4: Typical signal flow of a system simulation and its relevant modules

2. SYSTEM SIMULATIONS AND MODELING

A system simulation process for navaids, landing and radar systems consists typically of a number of consecutive steps (Fig. 4). In each of the steps errors can be made and inconsistencies with the physics may occur. By that, a high level of knowhow and experience has to be applied.
The modeling of the antennas, the environment, the distorting objects and the signal processing of the system itself are the basic steps of the simulation process

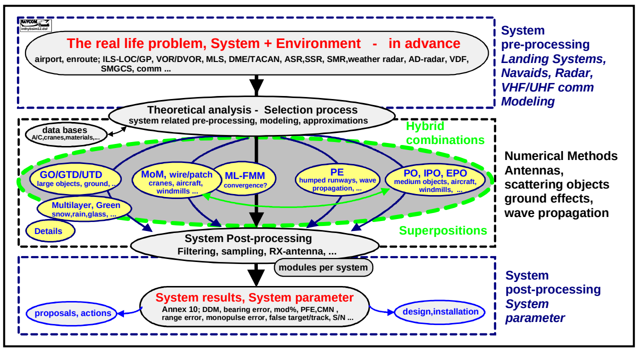

Fig. 5: Detailed IHSS schematic of the steps and the integrated numerical methods for the numerical system analysis of antennas and wave propagation

Three main steps can be defined (Fig. 5) within the detailed simulations process:

1. System pre-processing
2. Simulation process; modeling of the object and of the scenario and application of the numerical methods
3. System dependant post-processing; system (parameter) evaluation and application of specs and interpretation of the results in the required operational coverage volume; transfer to consequences.

It should be anticipated that state-of-the-art-methods and knowhow should be applied for all these safety critical applications discussed here (Fig. 4). Other estimation methods for the scattering analysis, e.g., determination of just the scattering amplitudes by comparison of areas (e.g. RCS), are not discussed here due to their poor qualities and their non- state-of-the-art-characteristics.

The state-of-the-art-methods include the application of the best available and most adequate numerical methods and system evaluation procedures. A further technical commercial strong argument for the use of most modern simulation procedures is the cost of measures and potential constraints to be imposed on the basis of basically potentially unreliable and inaccurate results.

A state-of-the-art system simulation includes all relevant factors in the system simulation process, such as

- 3D transmitting and/or receiving antenna-patterns
- Relevant tolerances
- Ground effects
- Receiver features, such as filtering and sampling
- Correct description of the signal processing (e.g. capture and Doppler effect of the dual frequency ILS-Localizer), see below.

The so-called “system parameter” has to be evaluated as a result of the state-of-the-art system simulations, i.e.,

- DDM for ILS
- Angle error for MLS
- Range error for DME
- Bearing error for VOR/DVOR, TACAN
- Interrogation field strength and monopulse angle error for MSSR Radar
- Shadowing, range, probability of detection (PoD) for the primary radar
- etc.

These system parameters have to be deduced from the scattering process of the object (of the model). The scattering process in itself is characterized by the scattering properties, i.e. the 3D scattering pattern in terms of amplitude and phase. Other sub-parameters like “field-fluctuations” or “field-distortions” have to be justified with regard to the relevance for the considered system. In most cases the system parameters are not directly linked to the "field fluctuations" and therefore these sub-parameters are more or less irrelevant. Two good examples are the DDM for the ILS and the monopulse error for monopulse radar. These system parameters depend on the ratio of 2 field quantities in some field point. If both sub-field-components undergo the same variations, the ratio may be practically constant.

In the simulation process, several general error sources are inherent in:

- the modeling process (e.g. data input errors).
- the selection and application of the numerical methods. Even the best and highly proven numerical methods can have problems in certain situations.
- both, interaction between modeling and numerical analysis
- the system evaluation.

Detailed error sources include the following:

- The object is geometrically and electrically 3D (Fig. 6 to Fig. 9), but the model is 2D. The results and consequences are case dependent and unpredictable.
- All the electrically effective and relevant details of the object are not described in the model.
- The model is not adequate for the numerical method which is integrated into the tool (e.g. open wire structures and the application of physical optics based methods; asymptotic methods for small structures or open wire structures like cranes or high power line masts) and vice versa.
  Fig. 10 shows the 3D-model of widely used tower cranes, which are well suited for the analysis by the so-called "Method of Moments" due to their metallic wire structure. The approximate metal strip approximation is a very crude model for the application of the simple "physical optics" method. The quality of the achieved results by the latter inappropriate method is unpredictable.
- The numerical method itself is fast, but over-simple and not state of the art. Some tools use crudely simple versions of the physical optics method by modeling constant amplitudes and (linear) phases over the modeled often mostly rectangular plates. This is unrealistic due to several reasons: the source antenna, the ground and near field effects.
- The rules for the numerical method are not processed, and limitations are not known or consequently applied. The asymptotic methods (GTD/UTD, PO) require electrically large objects or plates. Also other methods fail under grazing angle incidence, e.g. the basic simple Physical Optics PO (Fig. 13).
- The approximations are not justified (e.g. neglecting the humped runway for ILS-Localizers if present; material characteristics by simple factors).
- The worst case concept may be often technically justified, but it is not generally applicable. It is not guaranteed that the anticipated worst case in 3D-situations is really the worst case. Instead, it is a potential risk and often results in exaggerated safeguarding distances.

Due to the large variability of the system components and of the scattering objects, it is very obvious that the system simulations must take into account this variability due to adequately different modeling and hybrid analysis schemes (IHSS ***I***ntegrated ***H***ybrid ***S***ystem ***S***imulations; Fig. 5). The crucial point in all the steps is that the physics must be modeled, described and evaluated correctly or "sufficiently correct". However also, the physics reality must be adequate in each step and all levels of the simulation. A crude model of the scattering object cannot be compensated by a better numerical analysis method and vice versa. Far field approximations can be very wrong in close distances. Errors may occur on all levels, also on the level of the scattering analysis by choosing wrong methods or suffering artifacts by the used numerical method.

2.1 3D MODELLING OF OBJECTS

The difficult task of the modeling is to find and define a model of the object and of the environment which is describing the physical reality accurately enough, but should be simple enough as well for systematic simulations. A rough and crude model cannot describe the physics sufficiently (Fig. 4) in all required scenarios. In some scenarios the forward scatter may prevail, e.g. in the case of aircraft crossing the runway for the ILS Localizer. The forward scatter is relatively insensitive to details of the objects. In other scenarios the reflective and diffractive scattering prevails and the result can be very sensitive to details of the object. This is in particular in grazing angle incidence cases (Fig. 13), e.g. aircraft on the parallel taxiway.

A typical case of 3D-objects are the control towers of very much different design. These have to be checked and designed according electrical requirements for the installed systems, such as the ILS and the ATC-radar.
Fig. 6 shows 4 different 3D-models of control towers on European airports.

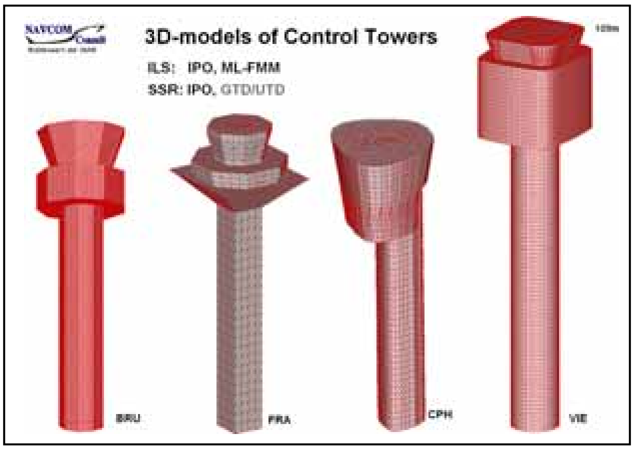

Fig. 6: 3D-models of four control towers used in 3D system simulations

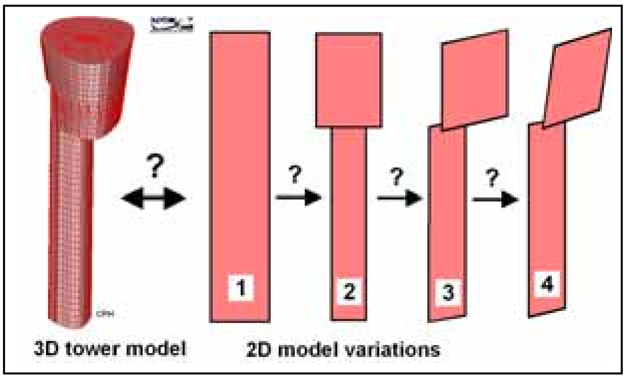

Fig. 7: 3D-model of control tower CPH and various 2D-model approaches

Fig. 7 shows a highly 3D-control tower which was planned to be constructed close to a CATIII runway. This tower cannot be modeled very obvious by non-unique 2D approaches. The scattering results are quite different for each of the 2D models and in any case much larger than for the curved dispersive 3D-model. In the 3D case, the CATIII-specifications are easily met (Fig. 8). This has been verified by ground measurements with excellent agreement. In the 2D case, the CATIII-spec is seriously violated (Fig. 9) and the tower would not be acceptable.

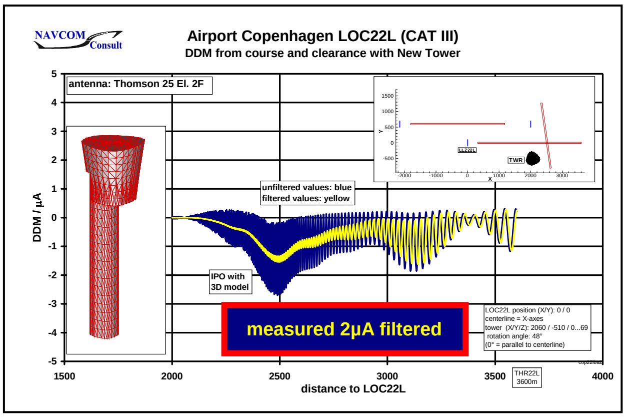

Fig. 8: Simulated DDM-results; 3D-model of tower CPH

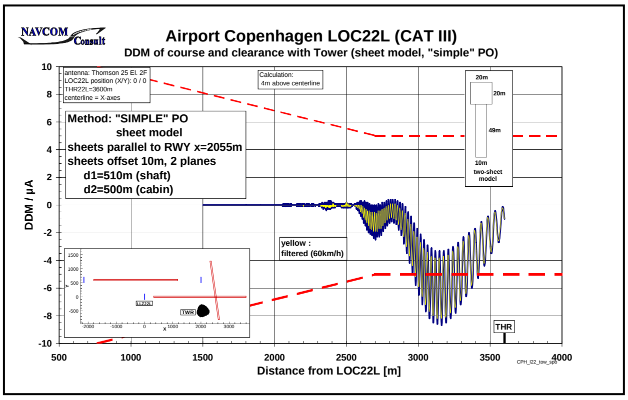

Fig. 9: Simulated DDM-results of a 2D-model of tower CPH

Fig. 10 shows a typical tower crane example. It is obvious that the simple plane metal strip is not an adequate model for the highly structured 3D crane.

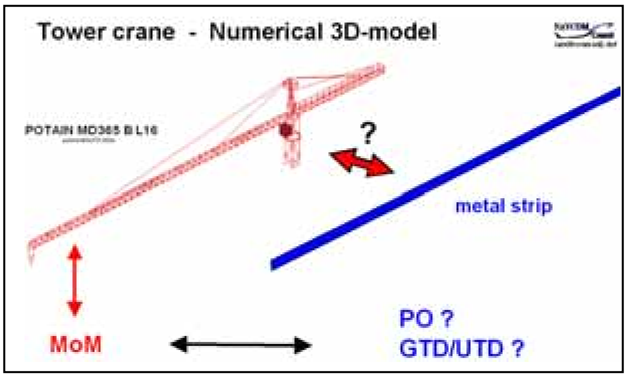

Fig. 10: 3D-model of a tower crane and a 2D-strip model approach

If one tries to model the tower by composed 2D-plates, it is widely open and arbitrary how to do that. Each of the 2D-models has quite different scattering results for this risky application and hence quite different DDM-results. A "worst case" assumption of a strip model is first not verified to be the worst case, second if so, it would penalize the applicant unjustified.

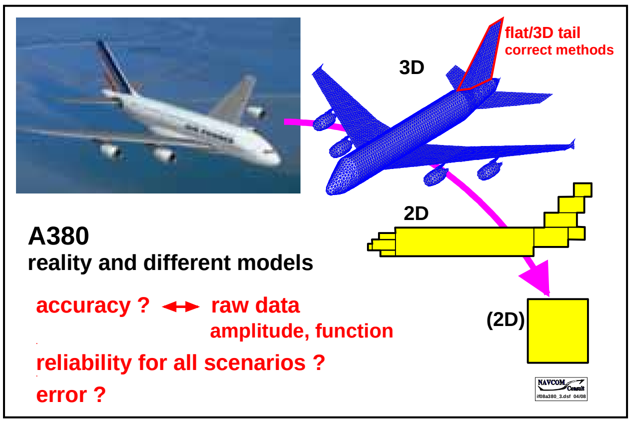

Fig. 11: A380 and 3D-model and various 2D-model approaches

Fig. 11 shows different modeling schemes for the A380. A 2D rectangular plate or a flat multi-plate for an aircraft (Fig. 11) cannot describe the curved 3D surface features of the aircraft in all scenarios possible on airports having different illuminating angles (Fig. 13).

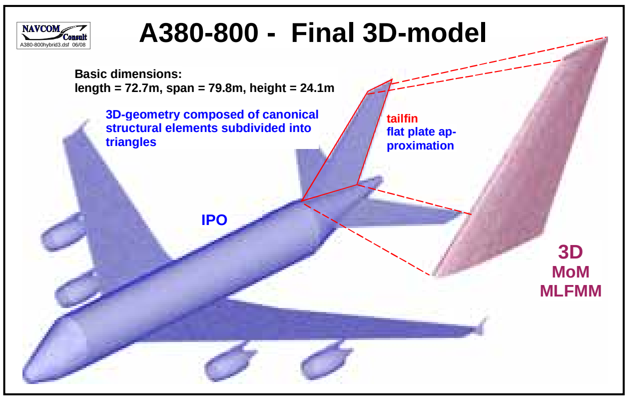

Fig. 12: A380 and 3D-model; tail-fin and rest 3D-model approaches evaluated by different numerical methods

A bad approximate quality of the model of the object cannot be improved or balanced by a sophisticated scattering analysis and a sophisticated signal processing.
The type and details of the model depend on many factors, e.g. on the electrical size and the geometrical electrical properties, on the materials and also on the distance between the source antennas and the scattering objects. In close mutual distances near field principles have to be applied. Often also, different types of objects are encountered in the scenario to be solved. They need an adequate hybrid modeling and scattering analysis.

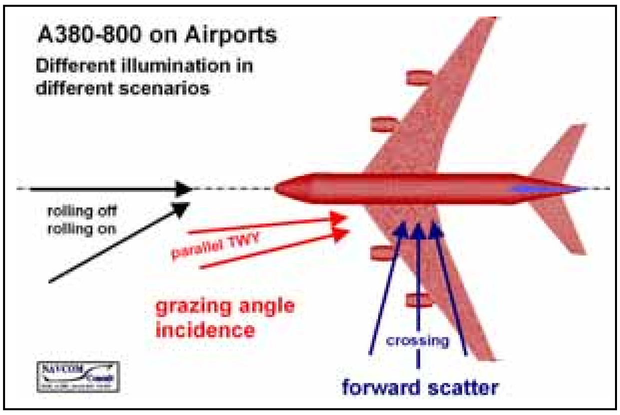

Fig. 13: Numerical 3D-model of an A380; different illumination angles; model consisting of a large number of metallic triangular patches

2.2 NUMERICAL SCATTERING ANALYSIS

As can be seen in Fig. 5, quite a number of different modern applicable numerical methods are integrated and can be assigned to the actual simulation process for a given problem in a hybrid manner. This means, the application of the most adequate advanced methods for the different objects and superposition of the contributions.
Other modern methods, such as the finite element, finite difference and finite integration are not applicable in almost all cases due to the electrically large objects and the electrically very large distances between the sources, the objects and the field points.
The features of modern computers (high speed CPU, large RAM, multicore) extend the applicability of the rigorous methods (e.g. MoM, MLFMM) to increasingly larger objects, such as complete aircraft.
The crucial aspect is that the limitations and application rules of each of the methods have to be carefully followed. Otherwise wrong results can be obtained from each numerical method.

2.3 SIGNAL PROCESSING

The adequate modular system dependant signal processing has to be applied which models the system sufficiently.
The signal processing must reflect the system setup and system function and, also, must reflect the system dependant receiver principles. Often approximations are applied by simple formulas which are valid only under certain constraints, e.g. in the far-field of the source and of the objects.
If the objects are in the near-field, a generalized signal processing must be applied in these cases, such as large and extended objects close to the VOR/DVOR navigations systems (see below).

In case of monopulse radar, the monopulse angle error has to be evaluated by the processed scattering of the difference and the sum-pattern (see chapter 3.3).

2.4 VALIDATION AND VERIFICATION

The validation and verification process of the simulation tools are a crucial task.
One single “validation” in a given scenario is not sufficient and bares a high risk for future applications.

Often the common procedure of system simulations is:

- development of a new numerical method or selection of a method.
- development of the related “new” tool where the numerical method is integrated.
- calculation of one known example, in particular of canonical elements, such as plates, spheres.
- verification of that single example or possibly several examples for all following examples by certain measurements or other reliable methods (if available).
- further use of the tool with almost no further validation procedures.

However, fundamental basics and experiences require a continuous and permanent verification process. A reasonable skepticism is appropriate for every simulated result. It is also clear that an initial detailed and intensive verification process is required in order to exclude programming and coding errors. Continuous improvements of the physical and mathematical core engine of a tool must also be realized, and these improvements and extensions must themselves be verified.

The verification and validation is mostly executed by comparison with measurements. This procedure assumes that the measurements are "correct" and useful as a reference. This assumption has to be carefully proven, because the measurements may have their own problems too as has been in many cases experienced. A missing agreement between measurements and simulations may be also traced to a different system model which is different from the measurements, e.g. by using different sensor antennas. A particular problem is a seriously different sampling rate which may cause serious under-sampling effects and result in non-reproducible measurements.

On the other hand, some of the measurement features are not a proof of the correctness of the numerical method. A good example for that is the DDM-scallop-structure of the ILS. The scallop structure depends solely on the relative geometry between the ILS-antenna, the scatterer and the field points on the track (e.g. glide path or the centerline). The scattering characteristic determines "only" the spatial amplitude and the spatial envelope of the DDM-distortions.

The continuous verification and validation process can be performed by:

- plausibility and experience, minimizing the probability of wrong/erroneous results.
- use only of proven and generally applicable numerical methods
- crosscheck with other methods and other tools if available and possible.
- carefully and consequently following the rules and limitations of the applied method.
- Continuous comparison with available (reliable) measurements.

Each simulation result has to be checked, and should not be accepted automatically. It is obvious that this process is critical and needs a lot of knowhow and experience with the system to be treated. In case of "unexpected" results, a thorough verification procedure must be initiated. Even the best generally proven numerical methods can yield wrong results in certain situations.

Often borderline problems are analyzed where the rules and limitations are violated. Mostly, the users do not have other tools and tend to believe in computer results (numbers, tables and graphics).

2.5 DISCUSSION OF MITIGATION MEASURES

The underlying specifications and requirements must be available, must be well defined and applicable. It is sometimes not clear and not uniquely defined what a "distortion" for that particular system is. The term "distortion" is used often unspecific in a qualitative sense, e.g. for radar systems.
Each proposed mitigation measure, such as

- Absorbing materials
- Relocation of the objects
- Changing the architecture of the objects (form, structure, size)

must be seriously proven and justified in the cases that the defined and published specifications are violated (e.g. ICAO Annex 10) or if the mission of that particular systems cannot be met.
No general requirements by a body or an authority are appropriate without a case dependant qualified justification. Each requested mitigation measure is site adapted and quantitatively site justified. If that is not strictly processed, the requested measures are treated as costly pseudo measures or "placebo" measures, because a lack of distortions after the realization of the object and measures is not a proof of the necessity of the measures.
If the mitigation is not required by applying adequate knowhow and adequate 3D-analysis, no system distortions will be seen as well – just because the measures are not necessary and a waste of resources.

Typical mitigation measures for ILS are the determination of safeguarding dimensions or distances, i.e. the definition of critical and sensitive areas and holding lines

3. SIMULATION RESULTS; COMPARISONS

Some practical cases and associated numerical simulation results for different system types shall be presented in this section.

3.1 RESULTS FOR NAVAIDS; VOR, DVOR

Two cases are shortly demonstrated and the achieved numerical results are compared with the flight check measurements. Both cases can be analyzed only reasonably by the generalized signal processing.
A conventional test VOR was temporarily installed in the direct neighbourhood of distorting objects, electrically speaking in the mutual near-field (Fig. 14). Fig. 12 shows the 3D-model and Fig. 15 shows the comparison of the simulated and measured bearing error. These results have been achieved by applying the amplitude spectral analysis.

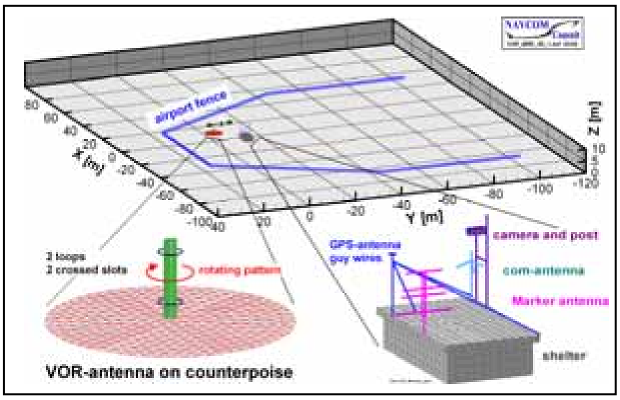

Fig. 14: VOR-navigation-system very close to distorting objects

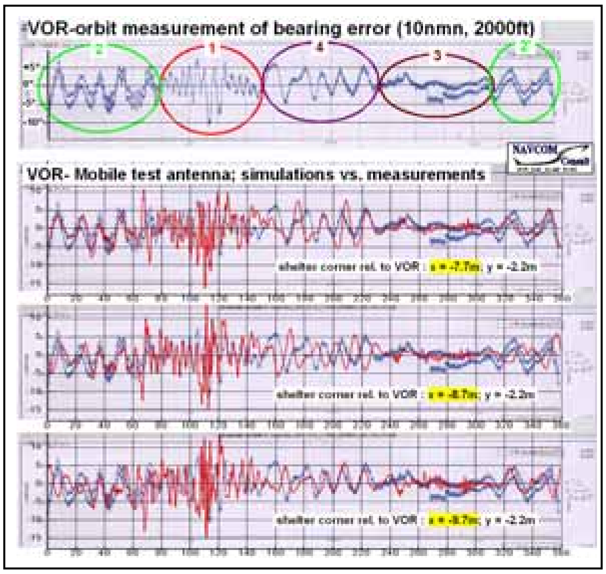

Fig. 15: VOR results; flight check measurements and simulations of near-field objects shown in Fig. 12

Fig. 16 shows a case for the analysis of the distortions by a large silo complex again in a close near-field distance to a DVOR. Fig. 17 shows the comparison of the simulations and of the measurements. An almost perfect agreement has been achieved by the application of the new phase spectral analysis.

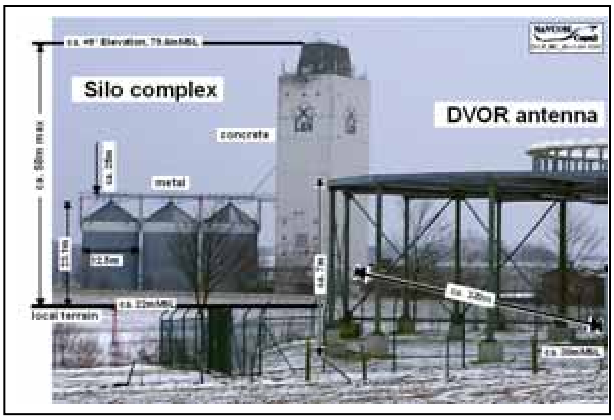

Fig. 16: DVOR-navigation-system very close to very large and azimuthally extended distorting objects

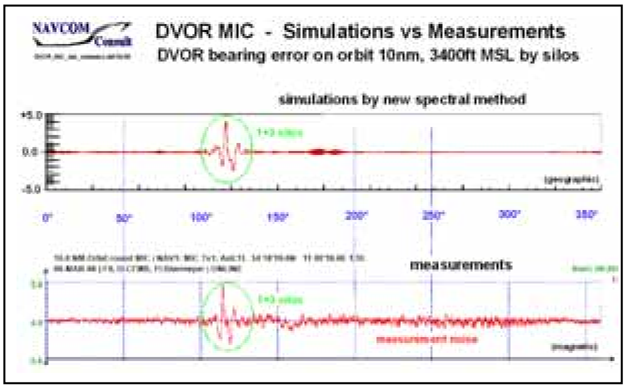

Fig. 17: DVOR results; flight check measurements and simulations of objects shown in Fig. 14

The agreement between measurements and simulations is very good despite the challenging near-field cases. This achievement is due to the newly developed and integrated spectral analysis schemes.

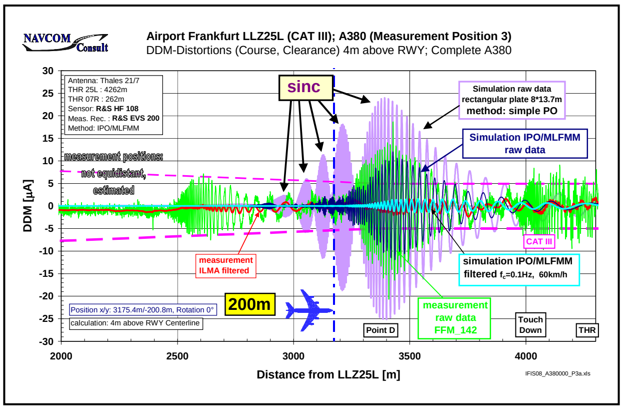

Fig. 18: ILS LOC DDM results for A380 on parallel TWY; flight check measurements and simulations; raw and filtered data; results for simple flat plate and simple PO for comparison

3.2 RESULTS FOR ILS; ILS AND A380

Some results shall be presented for 3 cases of the distortions by the presence of the large new aircraft A380 on the Localizer guidance subsystem of the ILS. These measurements have been carried out on the airport Frankfurt.

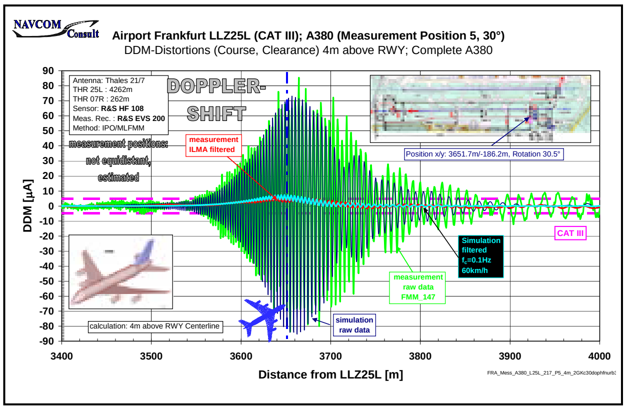

Fig. 19: ILS LOC DDM results for A380 inclined on parallel TWY for roll-on; flight check measurements and simulations; raw and filtered data

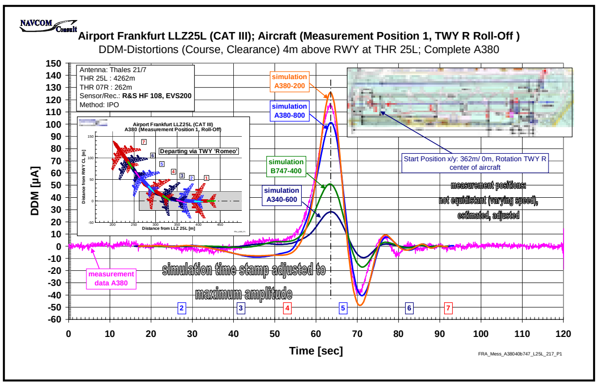

Fig. 20: ILS LOC DDM results for A380 and B747-400 and A340-600 for roll-off; flight check measurements and simulations; raw and filtered data

The good agreement between simulations and measurements can be seen for all scenarios for the most important raw data as well as for the filtered data. The filtering process camouflages often the artifacts in the raw data (e.g. Fig. 18)

3.3 RESULTS FOR RADAR; WINDTURBINES

Wind turbines WT appear in rapidly increasing numbers. Due to the limited space they are often more and more in relatively close distances to navigation or radar and comm-systems. In the approval process the effects of the WT on the systems have to be evaluated by studies and expertises. Rough conservative and oversimplified estimates should not be accepted.

In this chapter 3 aspects shall be shortly discussed:

1. the stated shadowing effects for a S-band primary radar (Fig. 19 to Fig. 23; shown for just the mast). It is proposed that a primary radar would be “blind” in the back of the turbine.
2. monopulse angle errors for MSSR (Monopulse Secondary Surveillance Radar) (Fig. 24)

3. interrogation field strength scattered by the WT yielding potential false targets (Fig. 25).

The first topic applies for an ATC PSR and for an S-band air defence radar as well, while the latter two cases apply generally for SSR and MSSR.

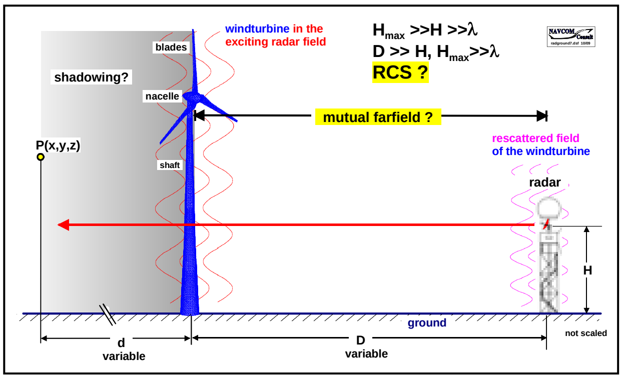

Fig. 21: Wind turbines and Radar; principles of the shadowing

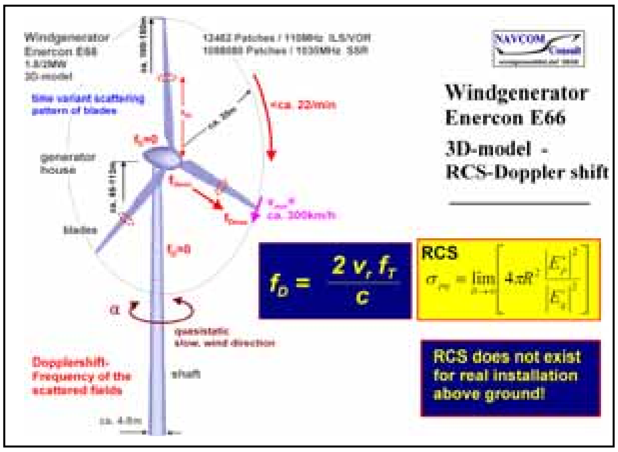

Fig. 22: 3D-model of a WT; Equations for the Doppler shift and the Radar Cross Section RCS

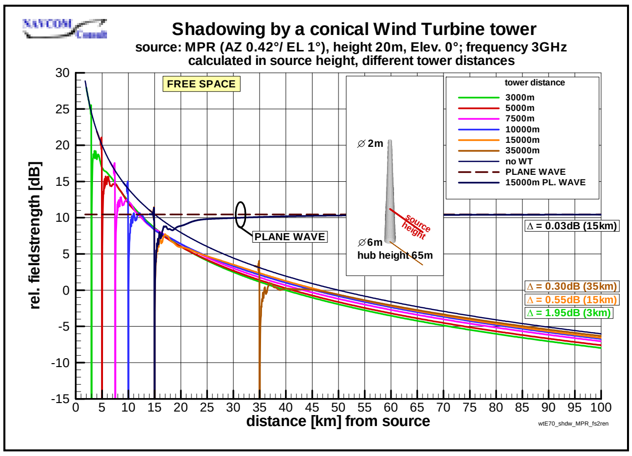

Fig. 23: Field strength in the back of the WT on radial horizontal traces in the height of the radar; different distances of the radar to the WT

Fig. 22 shows a 3D model of a large WT which is used for the evaluation of the general scattering and also for the evaluation of the Doppler shifted scattering components of the rotating blades. The Radar Cross section RCS of the WT can be calculated as well in free space by the excitation of a plane wave. But, the RCS is not defined for a WT above ground and cannot be applied for the analysis of really installed WT.

It can be clearly seen from Fig. 23 that the differences between the undistorted and the “distorted case” become smaller and smaller for larger distances in the back of the WT and also for increasing distances of the WT to the radar. In the limit for very large distances of the radar to the WT, the field of the radar behaves like a plane wave, i.e. constant amplitude. The “shadowing” in the back of the WT vanishes for larger distances, because the scattered field of the WT has its 1/r dependency.

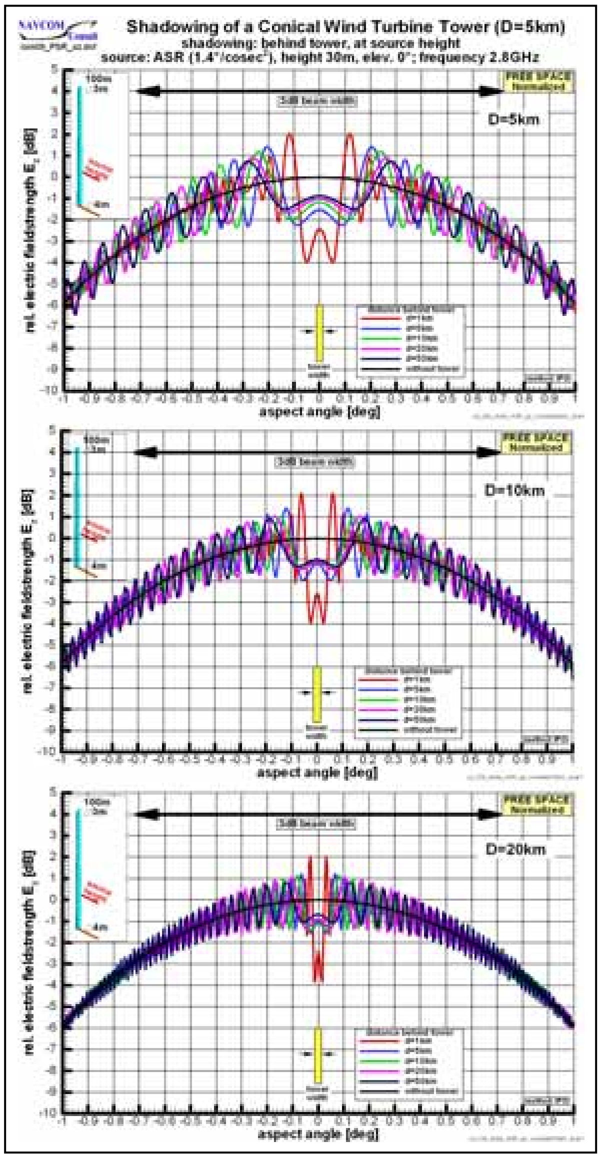

Fig. 24: Field strength in the back of the WT on horizontal azimuthal traces in the height of the radar; different distances of the radar to the WT

It can be clearly seen from Fig. 24 that the distorted azimuthally angular range becomes smaller and smaller for larger distances of the radar to the WT. The amplitudes of the oscillations around the undistorted free space case become smaller as well for larger distances in the back of the WT.

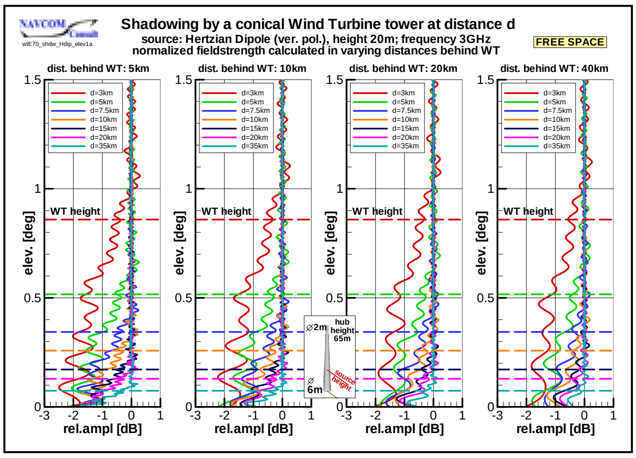

Fig. 25: Field strength in the back of the WT on vertical elevation traces; different distances of the radar to the WT from 3km to 35km; variable distances in the back from 5km to 40km

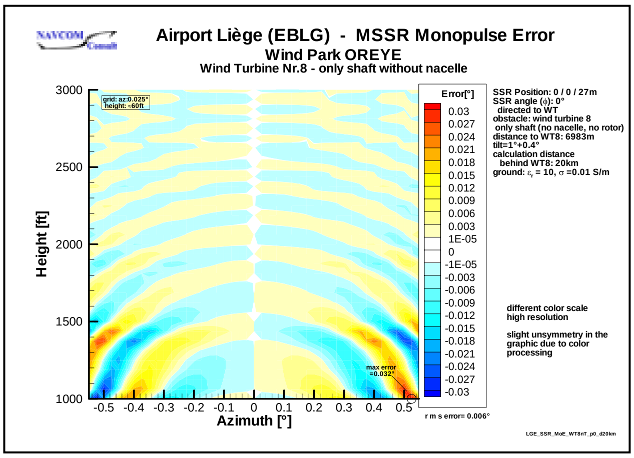

Fig. 26: Monopulse angle error in the back of a WT; distance about 7km to the MSSR.

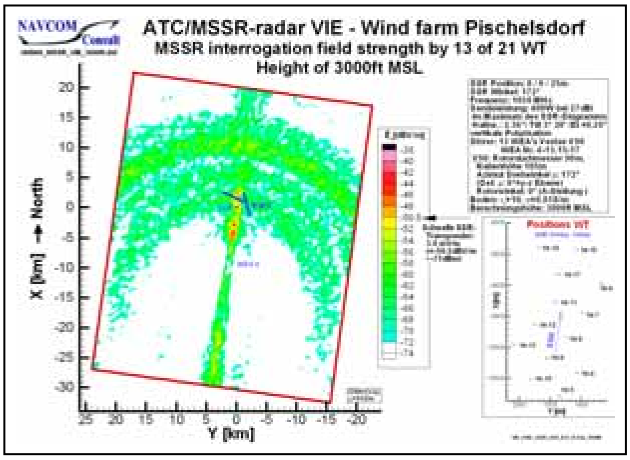

Fig. 27: Interrogation field strength of an MSSR on a horizontal plane in the height of 3000ft caused by 13 illuminated WT in a minimum distance of about 9km

It can clearly seen from Fig. 25 that the distorted "shadowed" volume in the vertical direction becomes smaller and smaller as well for larger distances of the radar to the WT and also smaller and smaller for larger distances in the back of the WT.

These combined three simulation results (Fig. 23 to Fig. 25) show in total clearly that the "shadowed" or "affected" volume is very small and negligible if the distance of the radar to the WT is large enough, i.e. in operationally relevant distances. The maximum range coverage of a radar is not significantly affected in the back of a radar if the WT is sufficiently separated from the radar.

All three results are calculated without ground. In the presence of the ground, the "additional" shadowing effects of the WT would be small compared to the lobbing effects induced by the ground. That is another argument for the in-significance of the shadowing in practical cases. Of course, if the WT is relatively close to the radar, e.g. 3km, then the "shadowing effect" is no more negligible.

Wind turbines may affect the monopulse accuracy of a monopulse radar, such as the ATC MSSR. The monopulse angle is determined by the signal processing of the sum- and difference pattern of the MSSR in the receive mode. The simulated signal processing has to take into account the scattering effects of the WT on both patterns. As an example, Fig. 26 shows the calculated monopulse error of a large WT in a distance of about 7km in the operational heights of 1000ft to 3000ft in the azimuth range of ±0.55°.

Airborne transponders may be interrogated by the scattered signals at the WT. The interrogation threshold is defined in ICAO Annex 10 Vol. IV to be "nominally -71dBm at the input of the transponder". It is assumed that this nominal figure is the transponder setting which should be achieved and has to be applied in these simulations. Fig. 27 shows the scattered interrogation field strength of 13 illuminated large WT in a distance of about minimum 9km in a low height of 3000ft MSL. Some exceeding amplitudes can be observed in small volumes. These are irrelevant in the given low heights due to operational conditions.

4. SUMMARY, CONCLUSION

A state-of-the-art system simulation methodology has been outlined in this paper, namely the so-called IHSS (Integrated Hybrid System Simulation). It contains the scattering analysis of the distorting objects as a central core element. It has been explained that 3D-models of the distorting objects have to be applied and the available adequate numerical methods have to be applied combined with the sufficiently complete signal processing.

Three actual practical examples in three different system fields have been presented by spot results, namely the

- effects of the A380 on the Localizer of the ILS (Instrument Landing System) in 3 relative positions and orientations.
- effects of close and extended objects on the VOR/DVOR navigation system.
- selected effects of WT on the ATC radar or in parts to air defence radar. The shadowing in the back of the WT is discussed and examples for the evaluation of the monopulse bearing errors and of the scattered interrogation field strength are shown.

The modern capabilities and also limitations of these system simulations have been shown by these examples.

5. REFERENCES

The following references are relevant to this paper, but are not explicitly referenced throughout this paper.
In the listed most recent references of the author(s), further references can be found in the references of these papers.

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

[2] BOROVIKOV, 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; Vol. IV Surveillance Radar and Collision Avoidacne Systems http://www.icao.int

[4] 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

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

[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; EUMW 2007, Munich, October 2007.

[7] G. Greving; The Electromagnetic Scattering within System Simulations for Distortions of Navigation, Landing and Radar Systems, URSI GA, Chicago, August 2008

[8] G. GREVING**;** Status and Progress of System Simulations for ATC-systems - Examples, Results and Consequences , 15th IFIS Oklahoma, June 2008

[9] G. GREVING; Status of Advanced Scattering Distortion System Analysis for Navaids and Radar - Examples of A380 and Wind Turbines; MRRS 2008, September Kyiv/Ukraine 2008

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

[11] G. Greving, W.-D. Biermann, R. Mundt; Aspects and Results of Numerical Methods and Wave Propagation Integrated into System Simulations; EUCAP 2009, Berlin March 2009

[12] G. Greving; Hybrid Numerical Scattering Field Analysis Embedded into Simulations of Complex Radio Based Systems - Examples - Capabilities and Limitations; ICEAA 2009, September 2009, Torino/Italy

[13] G. Greving, W.-D. Biermann RCS - Numerical, Methodological and Conceptional Aspects for the Analysis of Radar Distorting Objects; IRS 2009 (International Radar Symposium), Hamburg September 2009

[14] G. Greving, W.-D. Biermann, R. Mundt; Numerical A&P Analysis Integrated into System Simulations for Radar and Navigation, ISAP 2009, Bangkog; October 2009