Antenna Pattern Measurements of Full-Size Air Vehicles with an Airborne Near-field Test Facility (ANTF)*

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Abstract: The paper starts with an overview on types of state-of-the-art antenna test facilities suitable to accurately measure the performance of installed antennas. In comparison to in-flight and on-ground antenna measurements of full-size aircrafts a new and innovative, extremely mobile and flexible concept of an Airborne Near-field Test Facility (ANTF) will be introduced. Near-field probing of electromagnetic fields will be realized by a small remotely controlled helicopter measuring the entire radiated near-field of large objects outdoors, allowing one to generate any far-field Antenna Radiation Pattern (ARP) with an unprecedented high spatial resolution and accuracy.

Keywords: Antenna measurements of full-size aircrafts, installed performance of antennas, on-ground antenna measurements, antenna test facilities, system verification.

1. Introduction

The demand on wireless communication explosively increased for numerous applications in the sectors of telecommunication, navigation and science during the last years. Newest developments in CNS/ATM and C4I systems pushing up massively the demand in reliable radio frequency links between space-borne, air-borne and ground-borne systems & networks. To optimise frequency bandwidths signal structures are becoming increasingly more complex, however by that they become also more sensitive to interferences or signal fading, which needs carefully to be considered for reliability aspects. In this scenario also the predictions of the radiated performances of antennas play a crucial role, since the parameters determining the propagation characteristics can be quite complex compared to other link components required to calculate a radio link budget. The increasing use of non-metallic materials in the construction of air vehicles and sophisticated antenna designs in terms of conformal and reconfigurable active antenna systems additionally hamper accurate predictions of ARPs.
To get access to reliable information about ARPs of security relevant and complex antenna installations antenna measurements are mandatory, even they can be time consuming and costly.

*) International Patent Pending

2. Types of Antenna Test Facilities

In this chapter a brief overview is given on the capabilities of the three classical types of antenna measurement methods in view of ARP measurements of air vehicles and shall serve as a reference to the complementary capabilities of the ANTF introduced in the next chapter. Furthermore for each range type one example of an European state-of-the-art antenna test range is given.

2.1 Far-field Ranges

For ARP measurements of full-size aircrafts far-field ranges are very often used mostly due to cost reasons. A further advantage is the fact that no down scaling of the aircraft is necessary, no constraints due to model laws have to be considered and no up-translation of frequency is necessary. However special measures need to be undertaken to minimise ground reflectors, which is a major challenge with this type of facility. Please refer to [1] for more information about system considerations of far-field ranges.

Figure 1 shows the 'RaSigma' far-field range allowing ARP measurements of full-size aircrafts. Due to its focusing illumination subsystem ground reflections are kept minimal. Further, the sophisticated positioner subsystem (Figure 2) allows a wide range of RF measurements over large angular ranges. Far-field conditions are achieved by moving the mobile illuminator subsystem to the required distance. For more information please refer to [2].

Figure 1: 'RaSigma' Far-field Range for Antenna & RCS Measurements; Set-Up for In-Service Aircrafts

Figure 2: 'RaSigma' Positioner Set-Up for ARP Measurements of Full-size Aircraft Mock-Ups

2.2 Compact Ranges

By the use of one or two large collimating precision reflectors an electromagnetic field is generated which ensures parallel and time coherent RF-radiation representing far-field conditions over a short distance nearly independent of frequency and DUT size.

Typical test zone sizes are in the order of 5 to 6 meters and are predestined for ARP measurements of UAVs or scaled aircraft models. Figure 3 shows a so-called Compensated Compact Range, which is, due to the reflector geometries, free of any crosspolar radiation and therefore very well suited for antenna measurements and also for polarimetric RCS measurements. For more information please refer to [3,4].

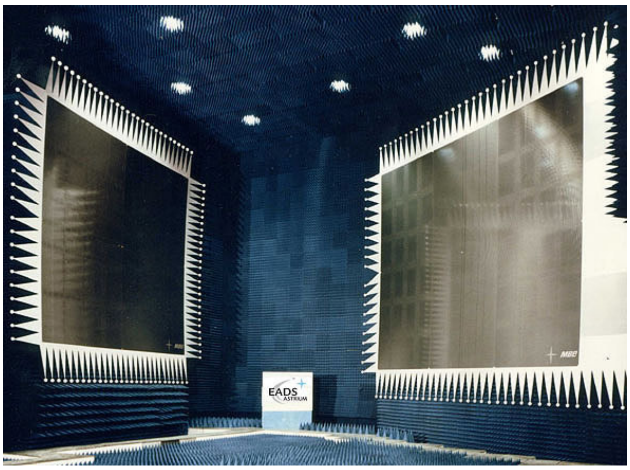

Figure 3: Reflector System of a Compensated Compact Range

2.3 Near-field Test Ranges

Near-field Test Ranges consciously are probing the near-field of DUTs and transform these data into far-field ARPs by well known Fast Fourier Algorithms. Thanks to the immense increase of processing power these complex transformations can be done within a few minutes. Another critical item in near-field measurements is the very precise scanning of the electromagnetic field on a predefined contour, which could either be planar, cylindrical or spherical. But also in this concern modern laser measurement technology and advanced transformation algorithms ease the realisation of cost efficient near-field scanner systems. The relaxation of near-field scanner accuracy has reached to such an extend, that remote controlled airborne platforms can be used, opening up untouched application fields in near-field testing. In the next chapter a concept for such an Airborne Near-field Test Facility (ANTF) is introduced.

Figure 4 shows an outdoor Cylindrical Near-field Test Facility (CNTF), which was designed for production testing of ATM and sophisticated defence radar antennas. Due to its 30m vertical probe travel and due to the maximum diameter of the measurement cylinder of 20m this type of CNTF could also be used for scanning the near-field of full-size fighter aircraft mock-ups with high and medium gain antennas as well as for UAVs. For further information about the CNTF please refer to [5,6].

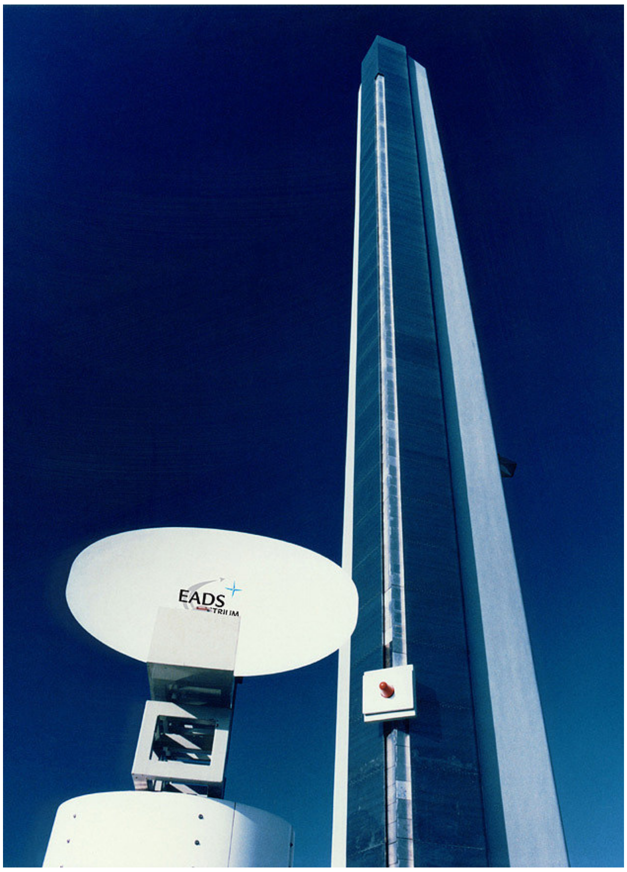

Figure 4: CNTF with 30m Scanning Tower and a Reference Antenna installed as DUT on top of an Azimuth Positioner

3. Airborne Near-field Test Facility (ANTF)

3.1 Introduction of the ANTF

The major distinction of the ANTF to the types of antenna test facilities mentioned in the previous chapter is the method how the RF-Field Probe is scanned or positioned. Instead of using complex mechanisms for probe positioning and scanning, a remote controlled airborne platform will perform this task.

This approach implies four major breakthroughs at once in the antenna near-field measurement technology:

- Flexibility in size. The ANTF covers large scan surfaces without the burden in erecting costly scanning mechanisms in sizes of a multi floor house. For the airborne platform it does not make a big difference to fly 50m high or only 8m; for mechanical scanner constructions it does.
- Mobility. Independent of the size of the scanning contour the ANTF remains a mobile system. Through this property the radiation of large outdoor antenna installations can be completely characterized, which only could be performed in a very rudimentary way in the past. It can be stated that most of the large antenna installations worldwide have never ever seen an antenna test facility in their life due to the lack of a proper measurement method.
- Outdoor capability. 99% of the near-field test ranges are installed indoors, since more or less laboratory environment is required for mechanisms, sensors and absorber material. The ANTF will be operated outdoors, however when it is not in use it can be stored indoors – a feature which stationary outdoor test facilities cannot provide. The CNTF mentioned in previous the chapter is already a novelty due to its outdoor use, but also due to its comparable large cylindrical scanning contour.
- Multi-contour scanning capability. The ANTF is able to scan all needed contours required for near-field probing, which are:
  - Vertical Planar
  - Horizontal Planar
  - Cylindrical
  - Spherical,

  but also any other contours like elliptical, conical, etc. can be addressed – even when currently not requested. The change of the scan contour to be flown is just a matter of software parameters.

3.2 ANTF System Description

In order to perform near-field measurements with a remote controlled airborne platform, which in this case will be an unmanned helicopter, the following technical requirements need to be achieved:

- Availability of a remote controlled helicopter. Although this item is the most spectacular unit of the ANTF, it is not really that hard to fulfil this requirement, since commercial available RC-helicopters already have sufficient payload capacities.

Figure 5 shows an illustration of an ANTF airborne platform for a payload capacity of 30 kg at a flight duration of 1,0 hour.

Figure 5: ANTF RC-Helicopter equipped with RF-Payload and Laser Targets

- Development of a so-called Inverse Method. Traditional data collection for sampling an antenna near-field require highly precise probe positioning in the order of $\lambda/50$ to $\lambda/100$ (e.g. 2,0...1,0mm @ 3,0GHz) at a sample spacing of $<\lambda/2$ in X and Y coordinates for e.g. a planar scan plane. To enable a technical and commercial feasible Airborne Near-field Test Facility (ANTF), an interpolation routine was developed, which allows near-field scanning with a significant lower probe positioning accuracy in the order of 1λ (100mm @ 3,0GHz). Figure 6 shows an ideal cylindrical scan contour and the trajectory of a remote controlled helicopter (*** lines). Due to illustration reasons the density of the required number of data points is reduced.

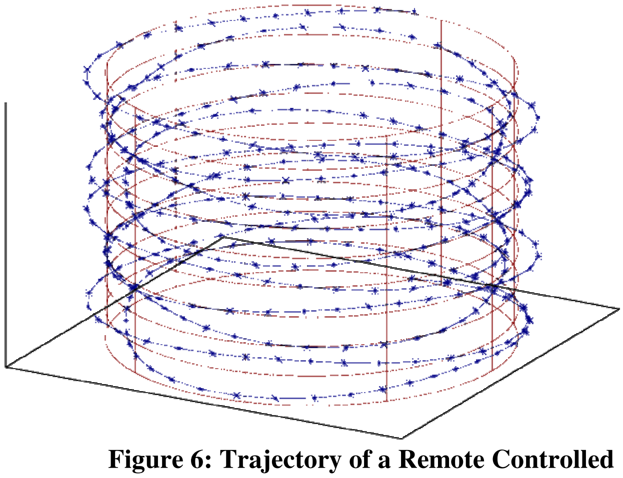

Figure 6: Trajectory of a Remote Controlled Helicopter

In addition a stabilisation unit for the RF probe will support the required probe position accuracy in order to give more freedom to the tolerable envelope of the platform at high frequencies.

- A position measurement system, which needs to precisely measure the positions and orientations of the helicopter at each moment when a RF-measurement is executed. This information is needed in order to perform the interpolation routine mentioned in the previous point. For this task the following methods can be used depending on the required scan contour, contour size and measurement frequency:
    - Laser Trackers / Theodolites
    - Phase Differential GPS / Galileo Signals
    - Terrestrial Local Area Augmentation Systems

- A wireless downlink of the amplitude and phase information of the measured RF-signal. This will be achieved by a transponder unit installed on the airborne platform reflecting back the measurement signal at a slightly different frequency. By this the entire measurement equipment can remain on-ground, which helps to minimise the payload capacity of the airborne platform.

- Optimized dynamical control of the helicopter in order to reach an optimum between trajectory accuracy and flight speed.

Beside these requirements of course healthy system engineering is required in order to ensure proper interfaces and to ensure safe and reliable operations. Please refer to [7] for more information about the ANTF system.

3.3 Antenna Measurements of Full-Size Aircrafts

As already pointed out in the introduction the number of antennas installed at an aircraft is quite high, due to the developments of CNS/ATM applications. Figure 7 shows the antenna layout of a typical commercial aircraft.

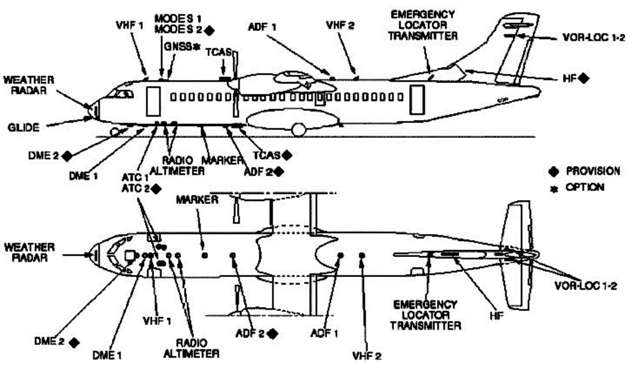

Figure 7: Typical Aircraft Antenna Layout

In the following it will be briefly explained to which degree the ANTF can contribute to improve full-size aircraft ARP in-flight and on-ground measurements.

A. Accuracy of ARPs

During in-flight tests the effect of ground reflections may vary considerably and it is difficult to eliminate these effects [1]. At on-ground tests reflections of the illuminating RF-signals by ground and other obstacles might degrade the measurement accuracy significantly for certain radiation directions. The achievable accuracy by the ANTF is considered much higher, since relative little efforts would be necessary to reduce effects through ground reflections by absorbers or corrective post-processing.

B. Spatial Resolution of ARPs

Flight characteristics of the aircraft limit the choice of aspect angles at which measurements can be made. In-flight and on-ground measurements are performed as far-field measurements, meaning that spatial resolution is directly connected with the number of cuts measured and by that limited by efforts / costs. Once a near-field data collection is taken by the ANTF all kinds of far-field ARPs can be generated at any time.

C. Coverage of ARPs

For in-flight tests the coverage is limited on the manoeuvrability of the aircraft, which e.g. differs significantly between fighters and airliners.

D. Dynamic Range of ARPs

For in-flight tests the dynamic range mostly is limited due to the large measurement distances by free space attenuation and restricted levels of transmission power.

E. Compliance to Far-field Condition

The far-field condition depends linearly on the frequency and in a quadratic way on the aperture size. As a conservative approach the entire size of an aircraft could be considered as aperture size, resulting in a far-field distance of several kilometres, e.g. for airliners. Therefore, it can be assumed, that the far-field conditions for in-flight and on-ground tests are not always a fulfilled.

F. Measurements of In-Service Aircrafts

For on-ground ARP tests mostly special re-enforcements need to be integrated to the airframe in order to ensure a safe installation at the positioner avoiding the use of in-service aircrafts.

G. Aircraft Sizes

For on-ground tests there are limitations in the aircraft size due to technical and commercial reasons. The ANTF addresses measurement objects up to 100m and is by that able to measure also the largest aircrafts.

H. Top Fuselage Antennas

In-Flight ARP measurements of top fuselage antennas is very limited and requires extreme flight manoeuvres like looping or overhead flights, which are more related to fighter aircrafts.

I. Bottom Fuselage Antennas

Measurement of bottom fuselage antennas is not possible with the ANTF due to the use of an airborne platform.

J. Real Flight Conditions
Real flight conditions are only given during in-flight tests. The effect of moving parts, propellers, helicopter rotors and stabilizing rotors can be measured also with the ANTF, but not always during on-ground tests due to the use of partial functional aircraft mock-ups.

K. Efforts / Costs
The high costs of in-flight test compared to traditional on-ground tests are well known. Since for ARP measurements with an ANTF no airplane needs to be moved and no installation of the aircraft on top of a positioner is necessary, the use of an ANTF would additionally save costs.

Pos.	Test Parameters	Full-Size In-Flight	Full-Size On-Ground	Full-Size On-Ground with ANTF
A	Accuracy of ARPs	😐	😐	☺
B	Spatial Resolution of ARPs	☹	😐	☺☺
C	Coverage of ARPs	😐	☺	☺
D	Dynamic Range of ARPs	😐	☺	☺
E	Compliance to FF Conditions	😐	😐	☺
F	Test of In-Service Aircrafts	☺	☹	☺
G	Aircraft Sizes	☺	😐	☺
H	Top Fuselage Antennas	☹	☺	☺
I	Bottom Fuselage Antennas	☺	😐	☹
J	Real Flight Conditions	☺	☹	😐
K	Efforts / Costs	☹☹	😐	☺☺

Table 1: Improvement Potentials of ANTF

3.4 Application Areas of the ANTF

Beside ARP measurements of in-service aircrafts the ANTF is also addressing characterisation of electromagnetic fields for the following categories of measurement objects:

- Airport Navigation Aid Antennas
- Antennas for Electromagnetic Combat
- Antennas for Intelligence Service and Signal Reconnaissance
- ATM Radar Antennas
- Broadcast and Radio Link Antennas
- Cellular Basestation Antennas
- Coastal Radar Antennas
- Combat Radar Antennas
- Large RCS Objects
- Large Scattering Objects
- Outdoor Antenna & RCS Test Ranges
- Radio Telescope Antennas
- Satellite Ground Station Antennas
- Ship Radar Antennas
- Shortwave Antennas
- Spectrum Monitoring and Beacon Antennas
- Weather Radar Antennas

Figures 8, 9, 10 show illustrations of different ARP measurement scenarios for an ANTF.

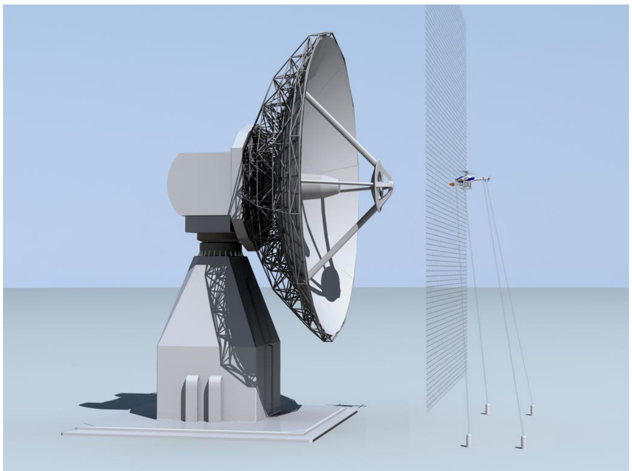

Figure 8: Planar Near-field Measurements of a Satellite Ground Station Antenna

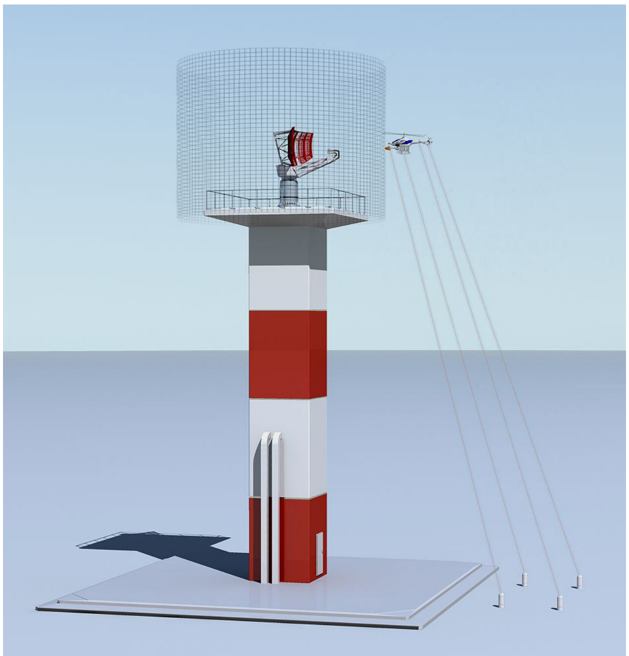

Figure 9: Cylindrical Near-field Measurements of an ATM Radar Antenna

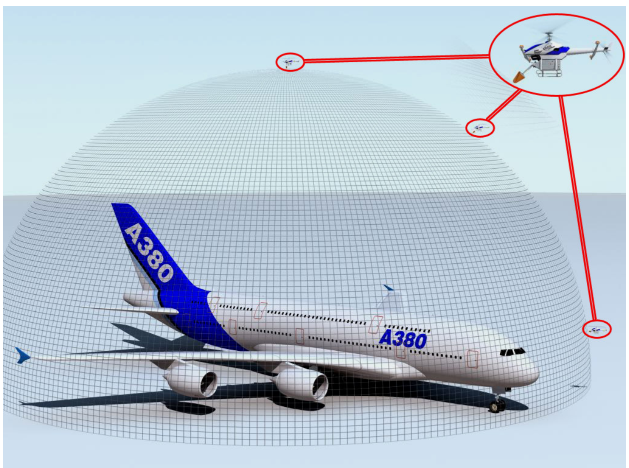

Figure 10: Spherical Near-field Measurements of Top-Fuselage Antennas of an A380

3.5 ANTF Expected System Performances

Max. Size of DUT:	Near-field: 100x100x100m Far-field: several kilometres
Frequency Range:	30 MHz to 50 GHz

Measurement Accuracy @ 1,5 GHz:

- Sidelobes: ±1,0dB @ -30dB SLL
- Gain: ±0,3dB
- Cross Polarity: ±0,3dB @ -25dB
- Beam Pointing: ±0,2°

Max. Wind Speed:	10m/sec
Operational Temperatures:	-10 to 45 °C
Typ. Measurement Time:	3 hours@1,5GHz; 30mx30m planar
Typ. Installation Time:	0,5 day

3.6 ANTF Development Plan

Current developments are focussed on the feasibility of critical subsystems of the ANTF funded through the IPAS project of the 6th Framework Programme of the European Commission. The IPAS project started in November 2003 with duration of 3 years. The IPAS Project is carried out by 10 European consortium partners with the common goal to develop and to validate electromagnetic simulation tools for Installed Performance of Antennas in Aero-Structures (IPAS) [8]. EADS Astrium is task leader of the activities related to the feasibility assessment of the ANTF and is supported by NLR for the development of advanced algorithms for near-field to far-field transformation as well for the developments of flight dynamic and control concepts. Further support within the IPAS Project is given by the EADS Corporate Research Centre in Toulouse for electromagnetic simulation of interactions between helicopter and device under test and in respect to EMC aspects.

A first flight trial is planned for summer 2005 in order to test the laser tracker subsystem in conjunction with the airborne platform and to obtain real world data to optimize dynamical control algorithms.

A second flight trial is planned in summer 2006 with a fully equipped helicopter in order to perform a first near-field data collection of a known reference antenna for verification of the measurement accuracy.

4. Conclusion

The ANTF closes a technological gap in mobile outdoor antenna testing and opens up state-of-the-art antenna measurement technology to application areas, where until now only limited access was possible to precise knowledge about the radiated performances of antenna systems. Due to the mobility of the ANTF a mobile service for antenna measurements would be possible to ease the way in obtaining radiation information about nearly any kind of outdoor antenna system at any time over its lifetime, also enabling periodic checks of radiated performances, which can degrade due to numerous possibilities of environmental and operational impacts.

5. References

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[8] IPAS - Description of Work (Annex I); Specific Targeted Research or Innovation Project of the Sixth Framework Programme – Priority 4 Aeronautics and Space; European Commission

6. Glossary

AGARD:	Advisory Group for Aerospace Research & Development
AMTA:	Antenna Measurement Techniques Association
ANTF:	Airborne Near-field Test Facility
ARP:	Antenna Radiation Pattern
ATM:	Air Traffic Management
C4I :	Command & Control, Communications, Computer & Intelligence
CNS:	Communication, Navigation, Surveillance
CNTF:	Cylindrical Near-field Test Facility
DUT:	Device Under Test
EC:	European Commission
EADS:	European Aeronautic Defence and Space Company
EADS CCR:	EADS Corporate Research Centre
EMC:	Electromagnetic Compatibility
GPS:	Global Positioning System
IPAS:	Installed Performance of Antenna on Aero Structures
NLR:	Dutch National Aerospace Laboratory
RC:	Remote Controlled
RCS:	Radar Cross Section
SLL:	Side Lobe Level
UAV:	Unmanned Aerial Vehicle