ADS-B over Satellite
Global Air Traffic Surveillance from Space

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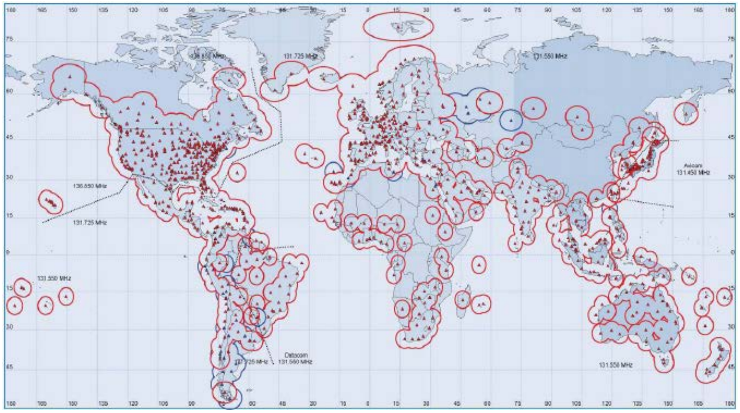
Air Traffic Surveillance today …

- Continental Airspace with Surveillance Infrastructure

  Ground based Surveillance:
  - Radar: PSR, SSR, Mode S
  - ADS-B 1090ES
  - MLAT (Gnd), WAM (en-route)
  - Multiple Coverage
  - Radar Data Networks



- **Extensive and continuous Air Traffic Surveillance**

- Transoceanic Routes, underdeveloped Regions:
  - Non-Radar Airspace (NRA)
  - Procedural: Pilot’s Position Reports via Voice Radio (1~2 hours)
  - ADS-C: Automatic position reporting via data link (~15min)
  - ATN or FANS1/A (“ACARS”), Satcom / Inmarsat or HFDL

- **No continuous Air Traffic Surveillance available**

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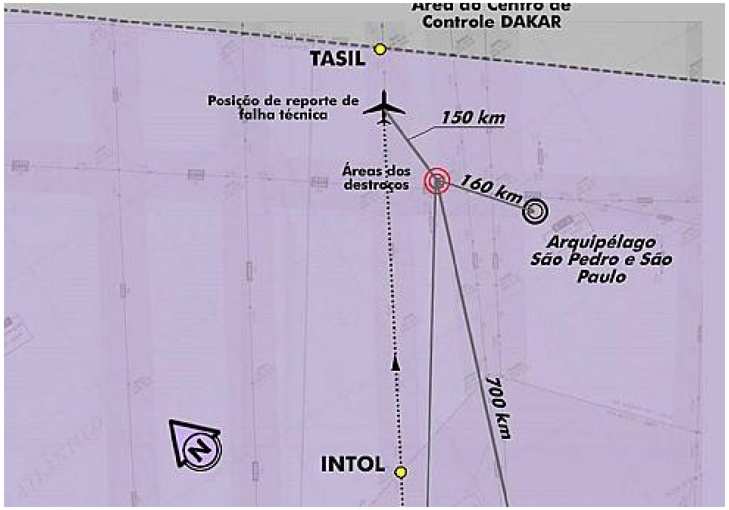
… and the Consequences for transatlantic Routes:

- Ample Separation Distances, non-efficient Use of Airspace
- Expensive and time-consuming SAR Measures
- Example: Crash of AF447 on 1.06.2009 at Flight from Rio de Janeiro to Paris
  - 700 km from Brazilian Coast, 170 km after last voice contact
  - Discovery of crash debris on 6.06.2009
  - Discovery of Black Box after ~ 2 Years
  - Costs of search and recovery of black box: 100 Mio € (Bloomberg, 15.03.2014)



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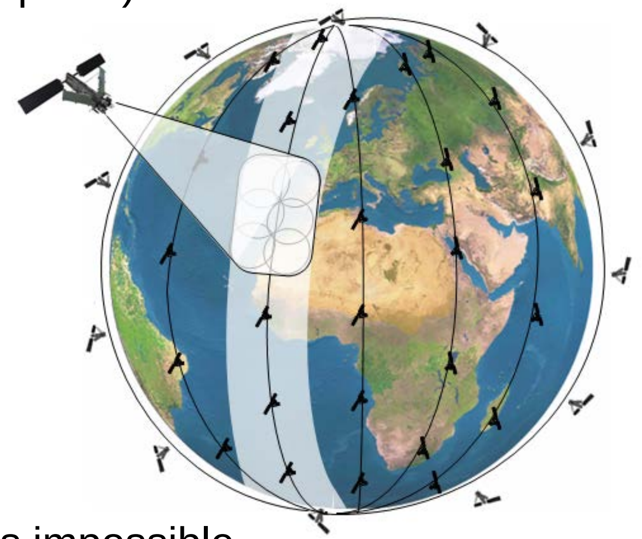
Remedy: Satellite based Reception of 1090ES ADS-B

- Worldwide Reception of 1090ES (1090 MHz Extended Squitter)
  - Mode S Data Format DF17



- Technical Solution:
  - ADS-B Receivers on a Fleet of LEO Satellites
  - Satellite Network for world-wide Coverage
  - Communication Network

- Benefits:
  - Global and seamless Air Traffic Surveillance
    also in Regions, where ground based surveillance is impossible
  - Improved Safety
  - Increased Efficiency:
    - Optimized Separation => Increase of Air space Capacity in todays NRA
    - Optimized and more flexible flight routes
  - Increased efficiency of search and rescue activities
  - No Changes required for Aircraft Equipment
    (European ADS-B-Mandate: Forward Fit until 2015, Retrofit until 2018, Operational 2020
    FAA's NextGen ADS-B Final Implementation Rule: All Airliners equipped from 2020 on)

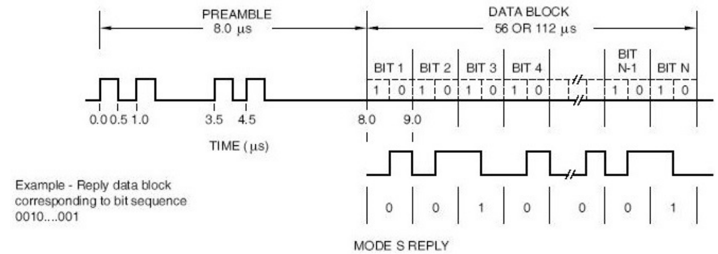
Overview on ADS-B

Automatic	Self-triggered Transmission of Position, without Interrogation
Dependent	Surveillance (on Ground) depends on Data derived from Onboard
Surveillance	Provision of Surveillance Service
Broadcast	Broadcasted Information can be picked up by any Receiver

- Concurrent Technologies:
  - 1090ES (Extended Squitter), DF17 Format on 1090 MHz Mode S Downlink most common (European ADS-B-Mandate, FAA's ADS-B Final Implementation Rule)
  - UAT
  - VDL Mode 4
- Information transmitted:
  - Airborne Position (CPR encoded Latitude, Longitude)
  - Heading and Speed
  - Identity and Category
  - Airborne Velocity
  - Barometric Altitude
  - Call Sign, …

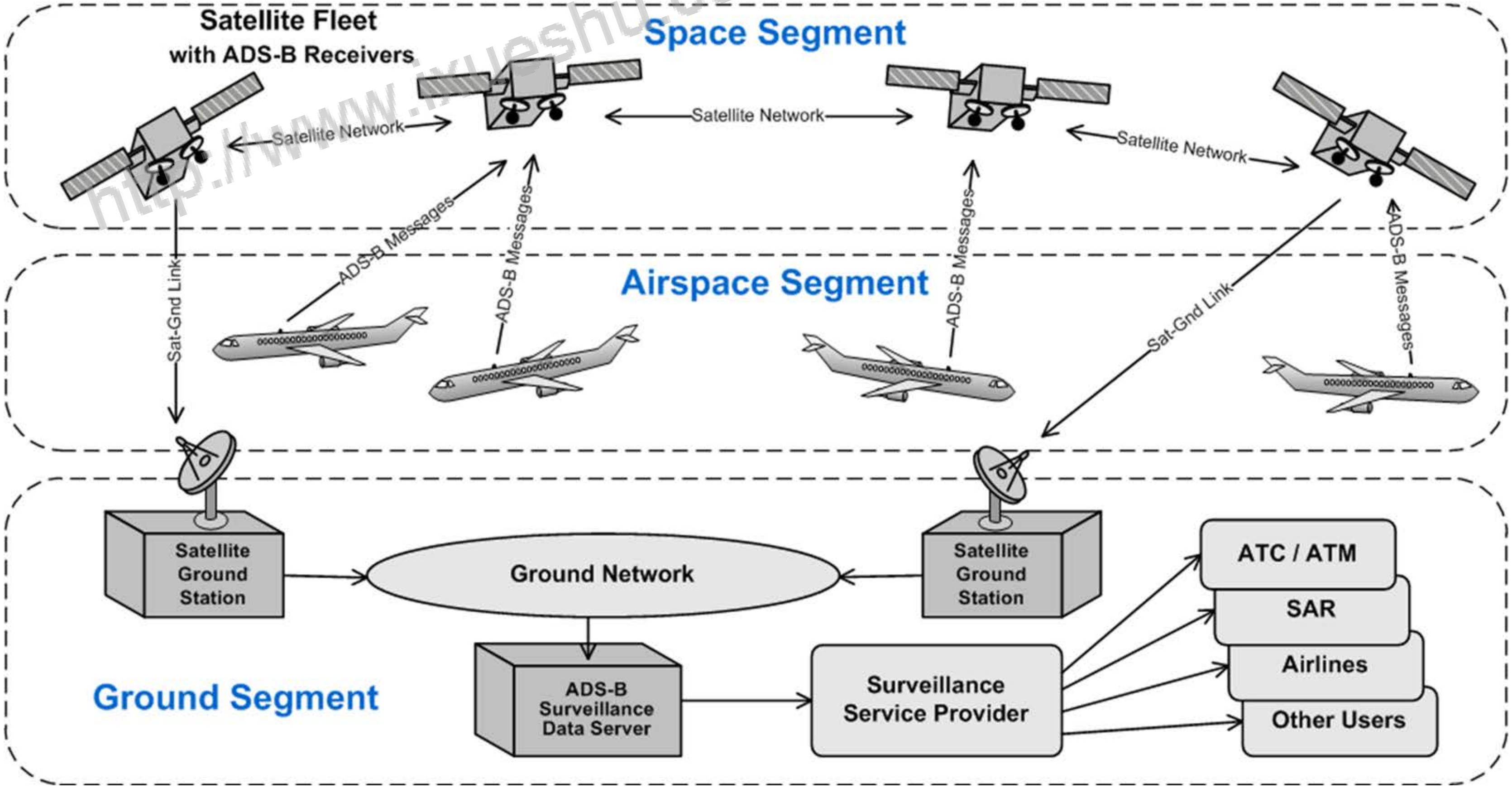
Challenges with Satellite based ADS-B Surveillance:

- **Coverage**
  - 1090MHz Mode S formats not intended for reception of weak signals (<-90dBm) due to poor signal correlation properties
  - Distance between aircraft and LEO satellite ≈ 800 km (≈ 444 NM)
  - „Normal“ coverage of 1090ES ADS-B: 50 NM A/A, 150 NM A/G
- **Modulation Scheme**
  - Pulse Position Modulation not suitable for decoding of signals near to noise level



- **Garbling**
  - Huge coverage because of high receiver position
  - plus stochastic channel access
    => overlap of ADS-B reports
  - Remedy through use of beam antennas: Spatial selectivity + antenna gain
- **Cone of Silence**
  - Recess in vertical antenna diagram of aircraft transponder antennas

System Architecture of Satellite based ADS-B Surveillance



Project “ADS-B over Satellite” by German Aerospace Center (DLR)

- **Objectives:** Proof of Concept: Feasibility of satellite-based ADS-B Surveillance
  In-Orbit Demonstration on ESA-Satellite PROBA-V
  Identification of Key parameters like Probability of Target Acquisition, Probability of Detection and Prob. of Identification

- **Project Duration:** 1st Q. 2011 until End of 2nd Q. 2014

- **Cooperation:** Institute of Space Systems (RY) in Bremen, Germany
  Institute for Flight Guidance (FL) in Braunschweig, Germany

- **Contributions:**

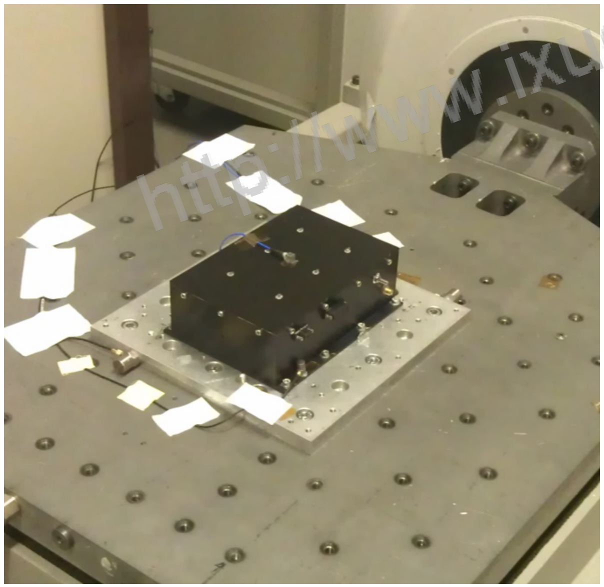
Institute RY:	Development and Assembly of a space-qualified ADS-B Receiver and Antennas
Flight Calibration Services: Institute FL:	Development of ADS-B receiver Verification Concept and Evaluation of ADS-B Data

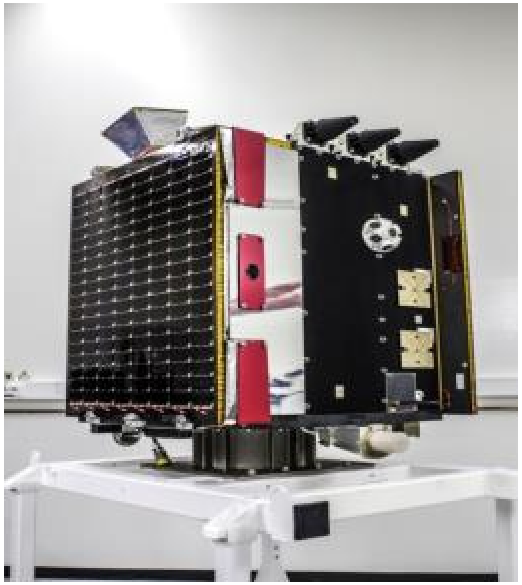
- **Further Cooperation:** RY with SES-ASTRA / ESA: Provision of Data Server

ESA PROBA-V-Mission

- ESA Small Satellite Mission PROBA-V
- Prime Contractor QinetiQ Space nv
- Launch Mass: ~140 kg
- Launcher: VEGA Rocket
- Launch Date: 7 May 2013 from French Guiana
- Orbit: Sun-synchronous Polar Orbit, 820 km Altitude, 98.73° Inclination
- Satellite Control and Communication via Ground Station Redu in Belgium.
- Main Mission: Vegetation Scanner
- Hosted Payloads: ADS-B, Energetic Particle Sensor, Gallium Nitride X-band Power Amplifier

ADS-B Payload Test and Integration on PROBA-V





PROBA-V on VESPA Adapter, on VEGA in Launch Tower and in Space

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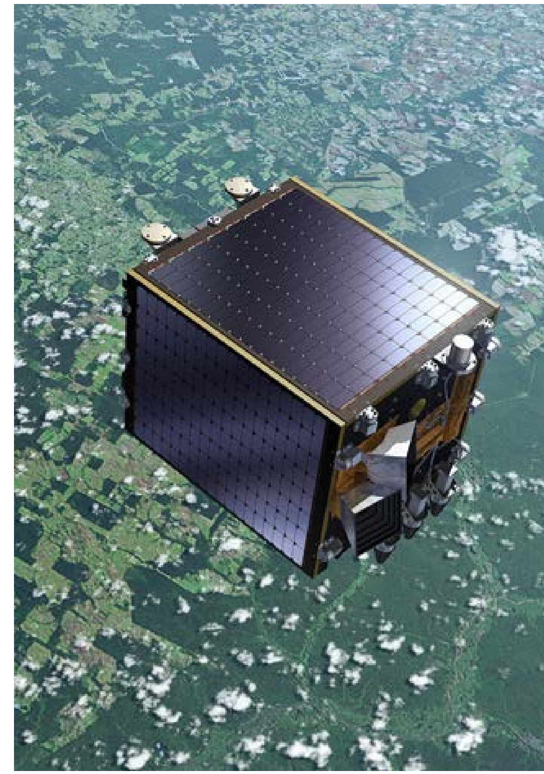
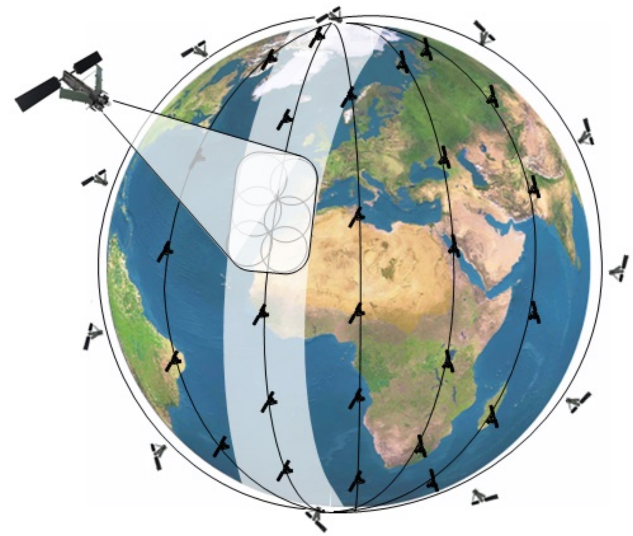


ADS-B over Satellite: Technology Demonstrator vs. future Operational System



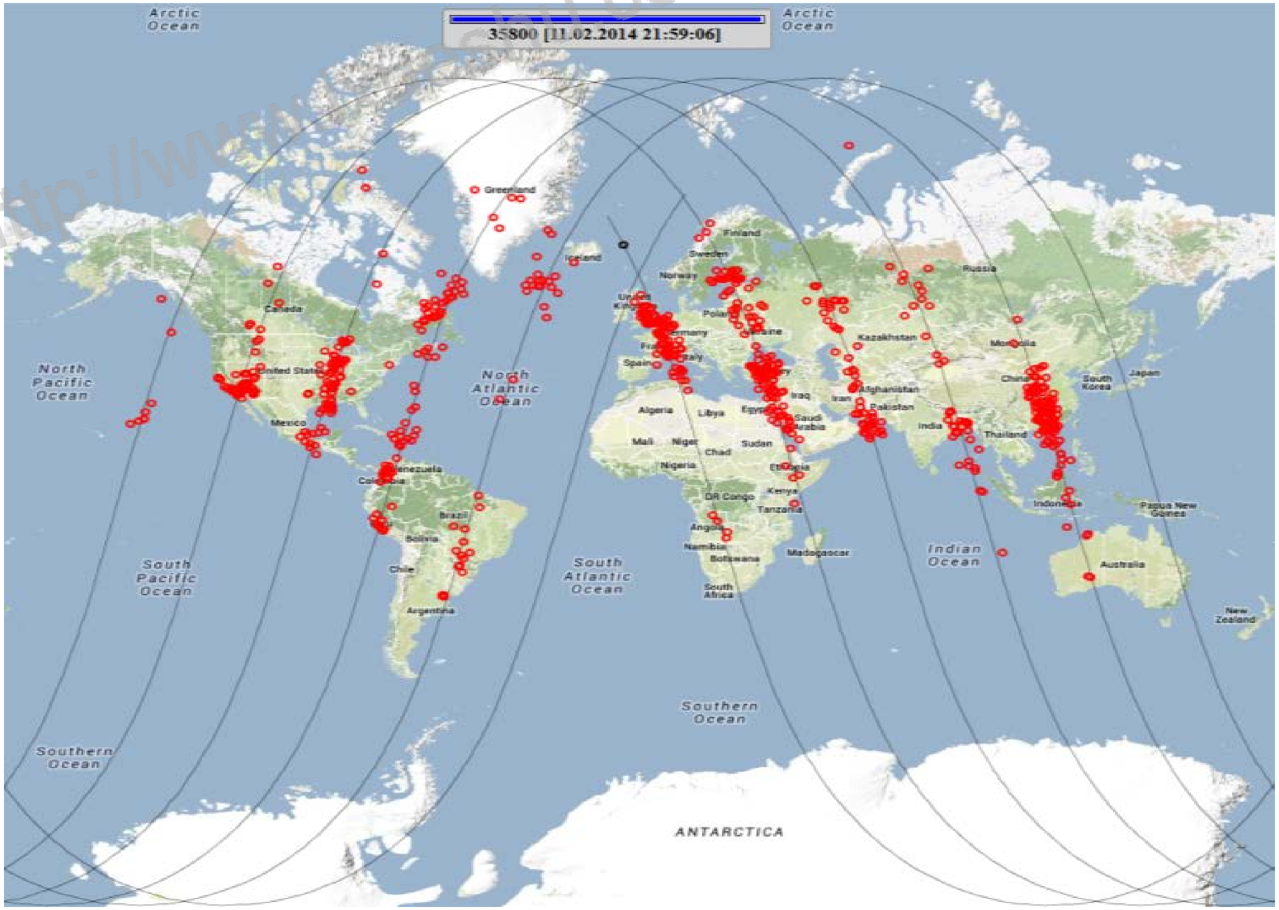
PROBA-V In-Orbit Demonstration:

Constellation:	Single Satellite
Main Mission:	Vegetation Scanner
Hosted Payload:	ADS-B-Receiver of DLR Project „ADS-B over Satellite“

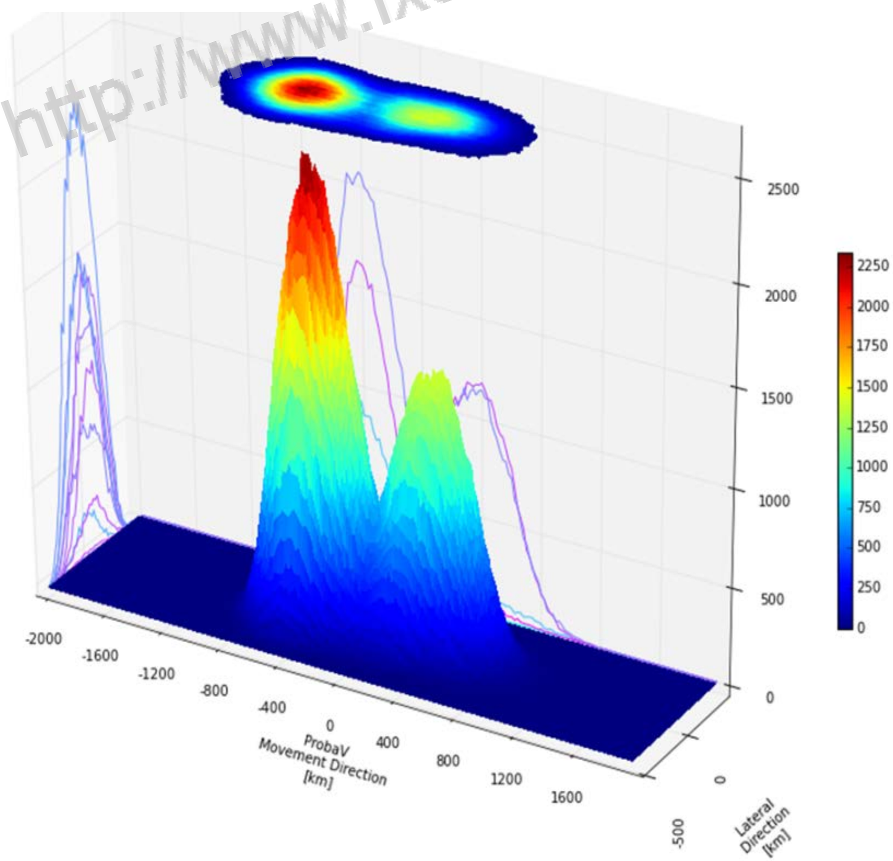
Operational System:

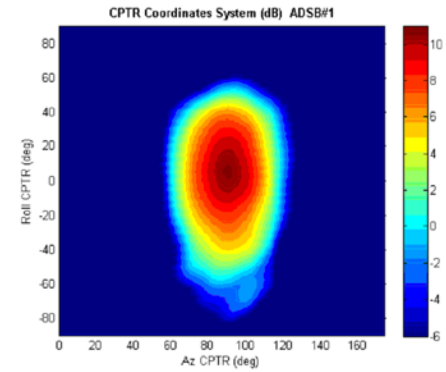
Constellation:	Satellite Network
Main Mission:	Multichannel ADS-B-Receivers and Multiple Antennas
Hosted Payload(s):	Other

Aircraft Tracks detected during a Satellite Pass

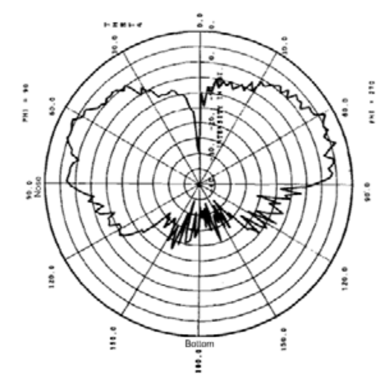


3D Histogram of all received Messages in Footprint: The Effect of the *Cone of Silence*





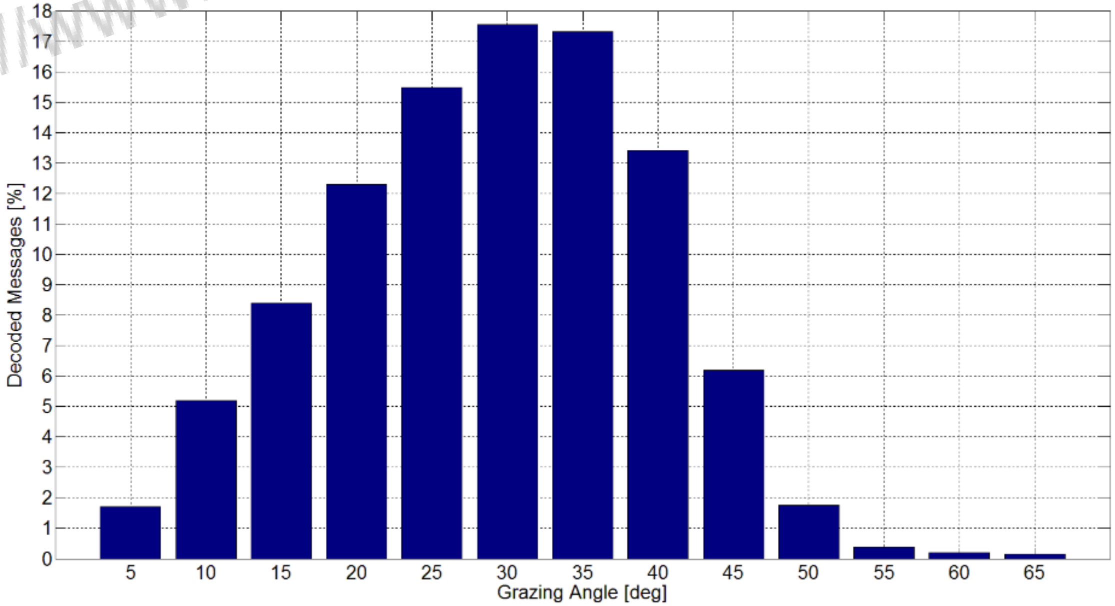
Radiation Pattern of Satellite Antenna



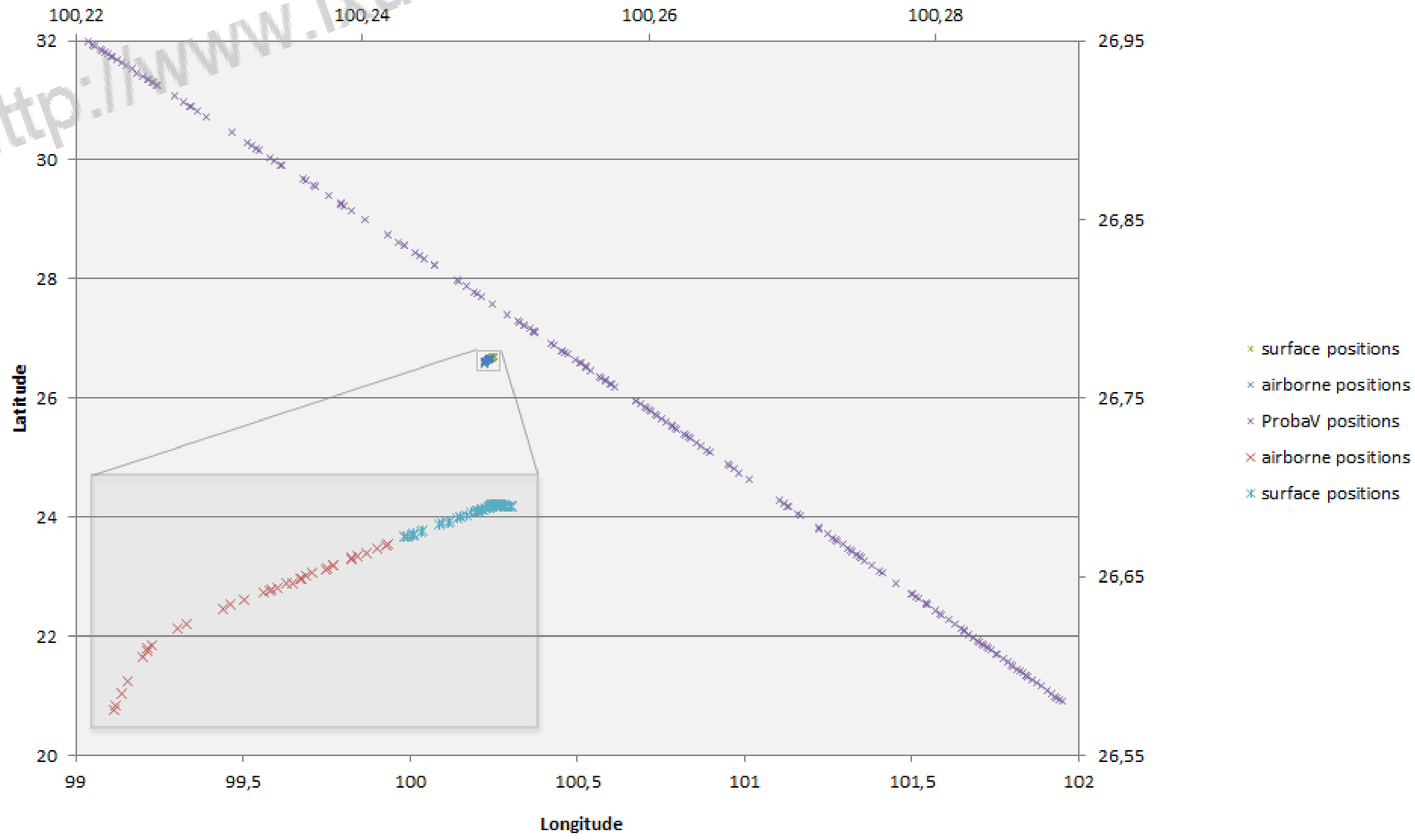
Radiation Pattern of Aircraft Antenna

K. J. Keeping, J.C. Sureau: Scale model Pattern Measurements of Aircraft L-Band Beacon Antennas, Project Report ATC-74, Lincoln Laboratory, MIT, April 1975

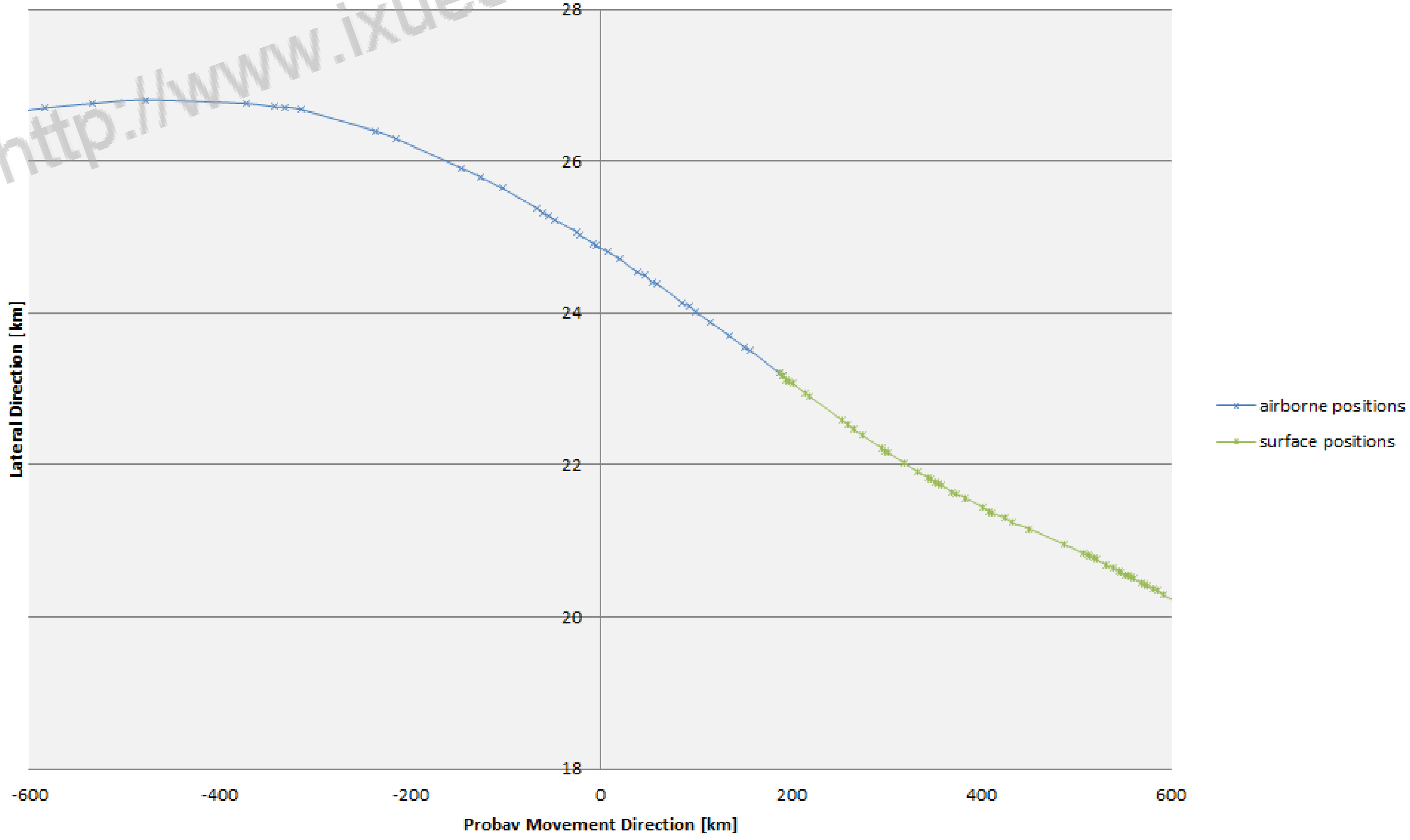
Distribution of decoded Position Messages vs. Grazing Angle



Example Trajectory of Aircraft taking off from Lijiang Airport, South China



Trajectory of the Aircraft taking off in Lijiang in the Footprint



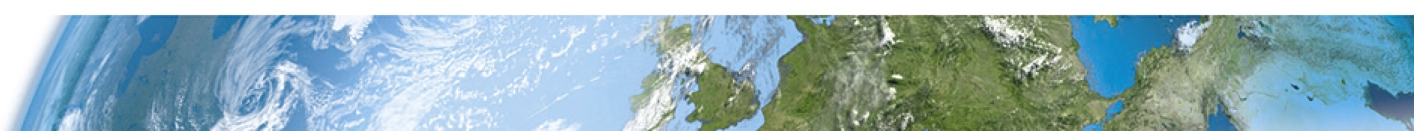
Performance Parameters of ADS-B over Satellite

PTA: Probability of Target Acquisition
POD: Probability of Detection

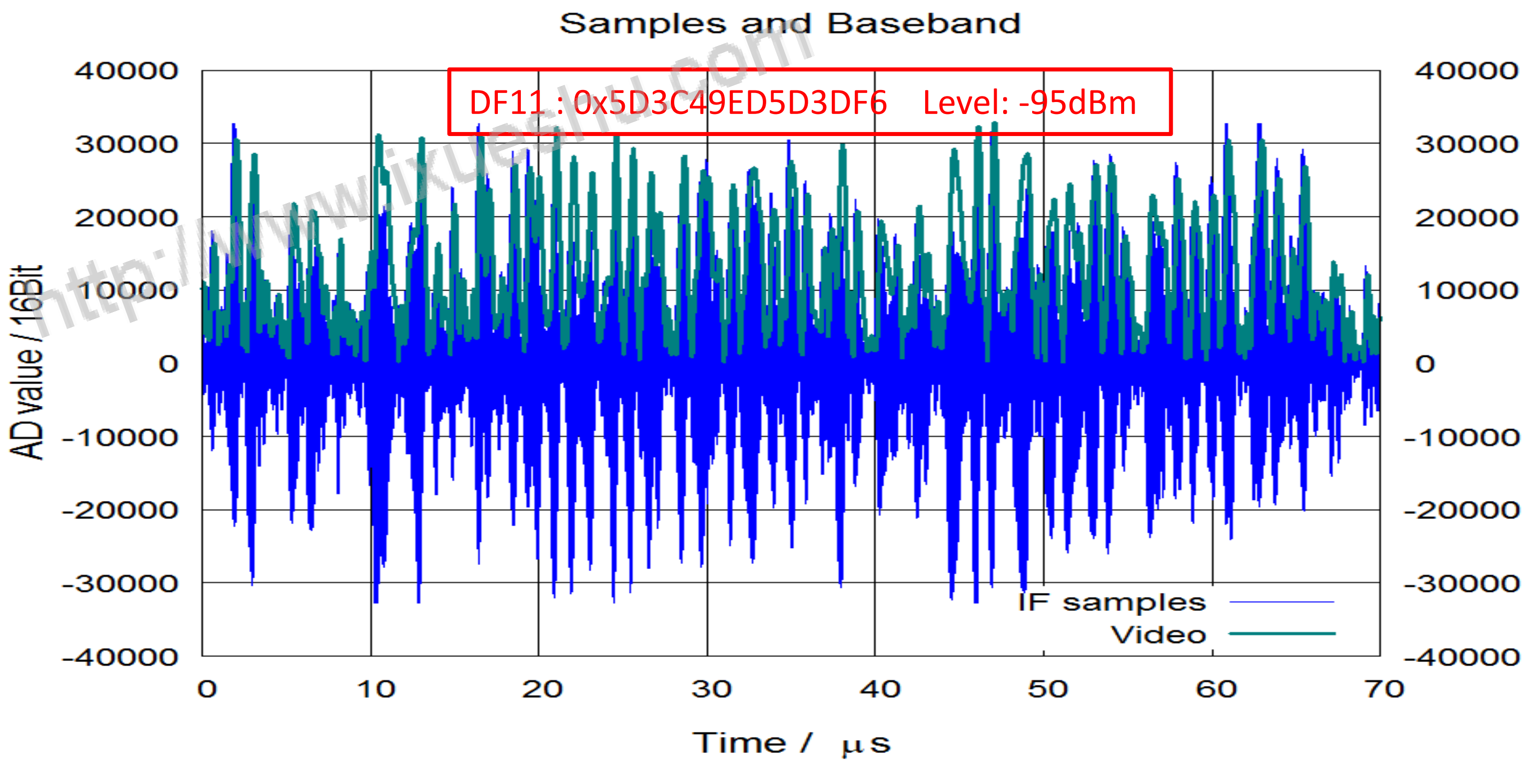
PTI: Probability of Target Identification
PID: Probability of Identification

Zone Filter	Aircraft detected	Aircraft expected	PTA [%]	Aircraft identified	PTI [%]	Average Correlation Gain
All	61798	64652	95,6	44665	69,1	78,3
Australia	2426	2559	94,8	1790	69,9	77
Default	23943	30719	77,9	16578	54	75,7
East Asia	12743	13859	91,9	9142	66	79,2
Europe	15106	17235	87,6	9538	55,3	80,9
North Atlantic	5039	6201	81,3	3480	56,1	72,2
Pacific	997	1301	76,6	734	56,4	70,7

Zone Filter	Positions detected	Positions expected	POD [%]	Ident Messages detected	Ident Messages expected	POI [%]
All	1464447	10878627	13,5	149568	1087863	13,7
Australia	95203	425298	22,4	7240	42530	17,0
Default	520709	3376666	15,4	50641	337667	15,0
East Asia	270910	2102401	12,9	29439	210240	14,0
Europe	244345	2290756	10,7	24863	229076	10,9
North Atlantic	92458	780939	11,8	8887	78094	11,4
Pacific	20508	156205	13,1	2131	15621	13,6



Receiver Technology: SSR Bandpass Raw Data from IF (1)



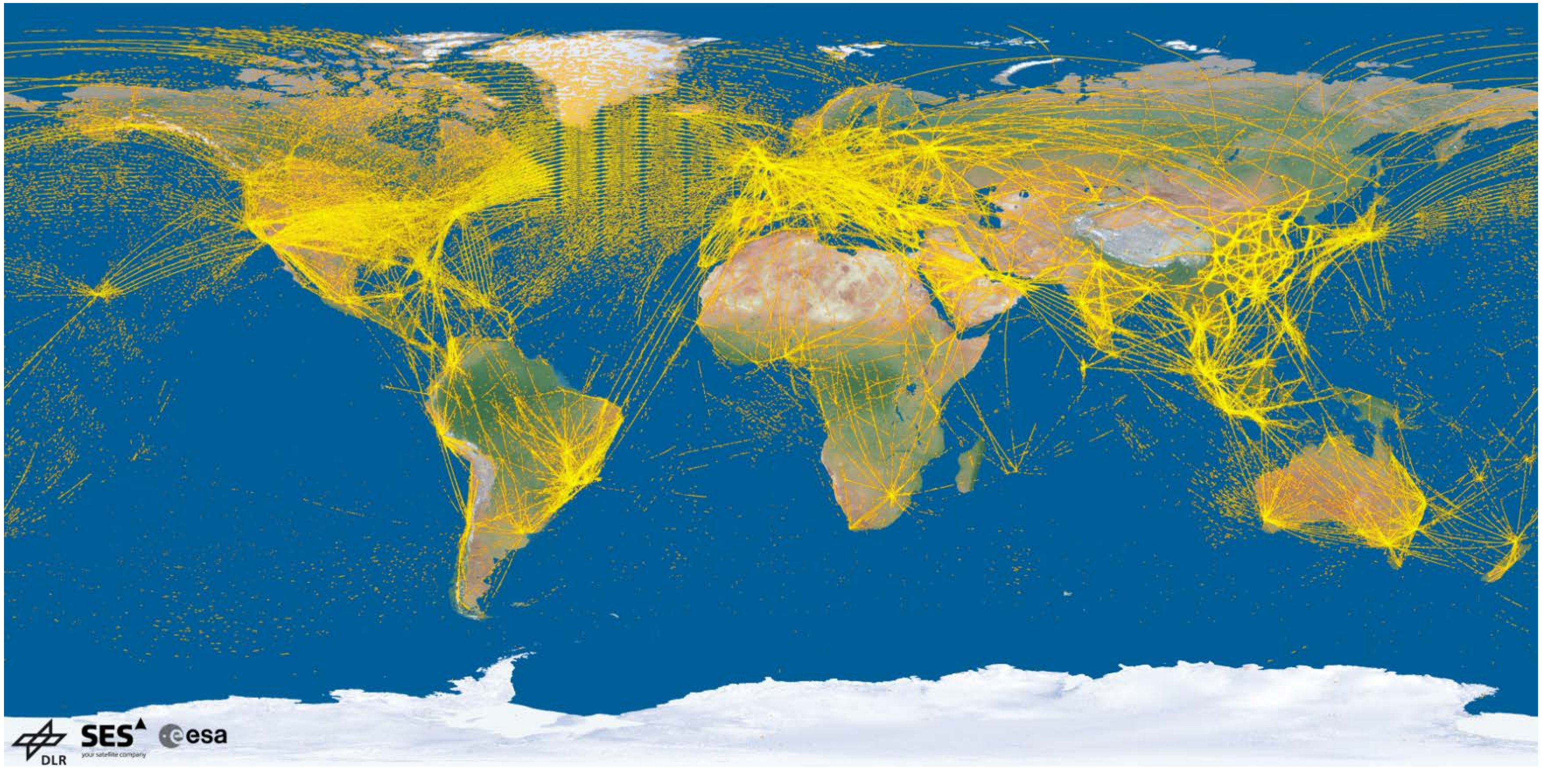
- Receiver Dynamic Range between -90dBm and -104dBm
- The ADS-B receiver can downlink raw data samples of full Mode S telegram length at 105MSPS/s / 16 Bit
- Raw data samples are beneficial for feeding new receivers and correlators during development phase

Summary

The technical Feasibility of

Satellite based Air Traffic Surveillance with 1090ES ADS-B

was proven by the PROBA-V In-Orbit Demonstration.



Thank you for your Attention!

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