Non-Radar Surveillance
ADS-B/MLAT/WAM Products

HOLGER NEUFELDT
Non-Radar Surveillance

New Methods for Air traffic Surveillance

- **Automatic Dependent Surveillance Broadcast (ADS-B)**
  - Transfer of onboard data by an Aircraft

- **Multilateration**
  - Hyperbolic/differential Multilateration – Time Difference of Arrival (TDOA)
  - Elliptical/multi ranging Multilateration – Time Sum of Arrival (TSOA)

Thales Product: MAGS System

**Multilateration and ADS-B Ground Surveillance System**
MAGS Product Line – Multilateration and ADS-B Ground Surveillance

- Based on 1030/1090 MHz SSR ATCRBS and Mode S signals (and UAT)
- Using Multilateration and Automatic Dependent Surveillance Broadcast (ADS-B) technology

MAGS – a product family of co-operative non-radar secondary surveillance sensors
Thales Product Line Non-Radar Surveillance

Automatic Dependent Surveillance Broadcast (ADS-B)
- Standalone ADS-B
- Centralized ADS-B
- Active ADS-B
- ADS-B Server

Multilateration Systems
- Wide Area Multilateration (WAM) Systems
- Precision Approach Monitoring (PAM) Systems
- Airport Multilateration Systems (MLAT)

Monitoring Systems
- 1030/1090 MHz Spectrum Monitoring Equipment
- TCAS Monitoring Equipment and ACAS Server

Key ADS-B Operational References:
- FAA Next Gen SBS
- Airservices Australia
- French DTI
- German DFS
- AirNav Indonesia
- Airways New Zealand

Key Multilateration Operational References:
- UK MoD Marshall Program
- German DFS
- French DTI
- Estonian EATNS#
- South African ATNS

Key Monitoring References:
- DFS Radio Field Monitor – countrywide system
- US NASA, MIT Lincoln Lab
Thales has delivered over 2,000 ADS-B and Multilateration Ground Stations around the World

Last update: October 2016
Thales ADS-B

ADS-B STANDALONE
ADS-B CENTRALIZED
ACTIVE ADS-B
ADS-B SERVER
Automatic Dependant Surveillance Broadcast ADS-B

Global Navigation Satellite System

Aircraft use GNSS and/or inertial navigation sensors to determine their own position.

ADS-B messages contain realtime data, like:
- position,
- altitude,
- velocity vector,
- intent.

Aircraft broadcast ADS-B messages periodically without being interrogated.

ADS-B in
ADS-B out

ADS-B Ground Station

ADS-B Messages

System Output: Aircraft reports

Surveillance Data Processor

Track Reports

ATC Display System

ADS-B acquires Positions via Data Link
Situational Awareness

Surveillance for Radar-like separation

Transfer of Position, Velocity, Identity, Intent

ADS-B out

1090 ES (1090 MHz Extended Squitter)

ADS-B in

ADS-B out

Ground Station

Surface Surveillance

Vehicles

ADS-B out

ADS-B in
ADS-B Extended Squitter

(Short) Squitter extended by 56 Bit data, hence „extended“ Squitter (1090 ES)

Required surveillance data split into different messages:

- Airborne Position Squitter: 2/s („odd“ and „even“)
- Airborne Velocity Squitter: 2/s
- Surface Position Squitter: 2/s („odd“ and „even“),
  1/5s when stationary
- Identification” Squitter: 1/5s (1/15s when stationary)

Further Squitter types:

- Target State and Status Squitter,
- Aircraft Operational Status Squitter, und
- Emergency and Priority Squitter
ADS-B Advantages

- Accuracy like GPS (quality independent of range)
- High update rate (2 positions/s, 2 velocity/s)
- Intent available (level-off altitude, next waypoint, etc.)
- Better surveillance in fringe areas of radar coverage
- Precise report of aircraft position
- Improving the airspace use, particularly in congested areas
- Low ground equipment cost and infrastructure requirements
- Low lifecycle cost
International Standards

- ICAO Annex 10 – Signals in Space

- DO260B / ED102A – MOPS for Avionics
  - data contents
  - encoding rules
  - Guidelines for algorithms/methods

- ED129B – Specifications for ADS-B Ground Systems

- ED 126, 161, 163 – Safety & Performance requirements for
  - Non Radar Airspace (ED126 – ADS-B NRA)
  - Radar Airspace (ED161 – ADS-B RAD)
  - Airports (ED163 – ADS-B APT)

MOPS Versions

- DO260/ED102 – Version 0
- DO260A – Version 1
- DO260B/ED102A – Version 2
Typical Thales ADS-B equipment

AX680

- High Performance Receiver
- AL4/ED109A compliant Software
- Fully DO260B compliant
- Autonomous ADS-B Processing
- Asterix Cat21 Output
- WAM / MLAT Processing

Single/dual channel/link ground station (indoor version)

FAA SBS Radio
Thales MAGS ADS-B System

Based on AX680 ADS-B Ground Station

Without central component – „ADS-B Standalone“
- Airservices Australia – Upper Airspace Program
- DGAC Indonesia – Nationwide ADS-B Deployment Program
- FAA – Surveillance Broadcast Services Program

With central component – „ADS-B Centralised“
- Hong Kong Civil Aviation Department – ADS-B Program
- DFS Germany – PAM FRA, WAM and ADS-B Program
- DTI France – Lyon and Nice Airports, Multilateration and ADS-B Program
ADS-B Standalone

Global Navigation Satellite System

ADS-B out
ADS-B in

ADS-B Messages

Aircraft use GNSS and/or inertial navigation sensors to determine their own position

ADS-B Ground Station

ADS-B messages contain realtime data, like:

- position,
- altitude,
- velocity vector,
- intent.

System Output:
Aircraft reports

Asterix Cat21

Surveillance Data Processor

Track Reports

ATC Display System

Aircraft broadcast ADS-B messages periodically without being interrogated.

ADS-B Ground Station provides Asterix Target Reports
ADS-B Centralized

Global Navigation Satellite System

ADS-B out
ADS-B in

Aircraft use GNSS and/or inertial navigation sensors to determine their own position

ADS-B messages contain realtime data, like:
- position,
- altitude,
- velocity vector,
- intent.

ADS-B out
ADS-B in

ADS-B Out
ADS-B In

Aircraft broadcast ADS-B messages periodically without being interrogated.

ADS-B Ground Station

Asterix or Raw Data

ADS-B Central Processor

System Output: Aircraft reports

Surveillance Data Processor

Asterix Cat 21

ATC Display System

Track Reports

ADS-B Ground Station provides Raw Data or Asterix Target Reports

ADS-B Central Processor provides Asterix Target Reports
Thales MAGS ADS-B System

**ADS-B Server**

- Allows controlled data sharing with adjacent sectors and/or states
- Able to integrate third party ground stations from any vendor
- Converts Asterix versions
- Routes data streams to multiple destinations
- Provides geographical filtering
- Provides ADS-B security screening

**ADS-B Server for well-controlled Data Sharing**
Special Case: Active ADS-B

Issue

➢ ADS-B is fundamentally a passive receive-only mechanism
➢ ADS-B aircraft identification is done via the flight plan number
➢ Target correlation is based on the 24 Bit address.
➢ Some ATM system installations however can still use only SSR Mode A code to correlate tracks to flight plan data.
➢ Older ADS-B MOPS Version Avionics does not deliver Mode A code

Mitigation

➢ Use of passively received replies of ADS-B aircraft to radar interrogations - if within Mode S radar coverage
➢ Additional transmitter, able to interrogate aircraft for their Mode A code – if outside radar coverage
ADS-B Security

AN OVERVIEW
What Type of Security?

1. Physical Security (fences, locks, guards, …)

2. Networks and Software driven Elements (addressed by Cybersecurity)

3. RF Security
ADS-B Security

- Simple protocol and signal structure, vulnerability discussed openly
  - e.g. presentations at DEFCON, BlackHat and others also featured on YouTube*

- Software-Defined Radio (SDR) Technology available at low cost
  - RX, but also TX available
  - Software and Documentation from the internet

- RF hacking is not anymore a challenge for experts and specialists

* Examples:
  - B. Haines, “Hacker + Airplanes = No good can come out of this”, DEFCON20,
  - A. Costin, A. Francillon, “Ghost is in the Air (Traffic)” Black Hat USA 2012
  - B. Seeker, “Hacking the wireless world with SDR – 2.0” Black Hat Europe 2014
ADS-B

![Diagram of ADS-B system with aircraft and processing units labeled DLH123 and AFR143]
ADS-B Spoofing Demonstration

Source: [http://www.youtube.com/watch?v=NSLqRXyiBo](http://www.youtube.com/watch?v=NSLqRXyiBo)

Flight Sim

SDR: ADS-B TX

ADS-B RX

ADS-B Processing

Scenario (cable)

CWP

DLH123

AFR143

SPOOF

ADS-B RX


HN March 2017
**ADS-B Spoofing**

Flight Sim

SDR: ADS-B TX


ADS-B TX

ADS-B RX

ADS-B Processing

Scenario (cable) = Scenario (antenna)

CWP

DLH123

AFR143

SDR: ADS-B TX

Scenario (cable) = Scenario (antenna)
ADS-B Meaconing – Change of Identity

Scenario (cable) = Scenario (antenna)
What can we do? (as Sensor Manufacturers)

ON ADS-B SENSOR LEVEL
ON CENTRAL PROCESSING LEVEL

• DETECT THREAT
• REDUCE OR PREVENT IMPACT ON ATM SYSTEM
• ALERT AUTHORITIES
Sensor level – ADS-B / WAM Ground Station

- Local view, raw data details available
- Target specific behavior
  - Anyone not behaving like a regular aircraft?
- Additional measurements
  - Consistency between measured and transferred data
- Spectrum characterization – not target specific
  - Anything unusual happening?
  - Number of targets, messages, message types…

How to treat “normal” anomalies / malfunctions?

Thales AX680
Integrated Receiver and Signal Processing Board
Digital, Software Defined Radio
High Sensitivity -91 dBm
Mode A/C/S
ADS-B Decoding DO260B
AL4/ED109A (SWAL3/ED153)

Spoofing Detection
Lab Demonstration at DFS
Central Level – ADS-B Server / WAM Central Processor

**Group view, comparing data from several ground stations**

- difficult to attack multiple sites in a consistent way
  - Spectrum characterization – not target specific
  - Target behavior
  - Additional measurements
  - Able to identifying observations as anomalies

**Multilateration position calculation**

- No need for high precision for this purpose
- Checking if movement and position consistent with ADS-B
- Even single TDOA (single hyperbolic line of position) is sufficient

Thales ADS-B Server
Security Screening for Thales and 3rd party ADS-B systems
Asterix Edition conversion
Geographical Filtering
Multiple Output Streams
Data Routing
AL4/ED109A (SWAL3/ED153)
Tracker Level – Multisensor Tracker / ATM System Level

- Global view – various sensor inputs, flight plans, background data
- Filtering, observing, characterizing targets
- Comparing ADS-B data to other sensor feeds – diversity is key!
- Eliminate false positives via flight plans and other sensors
  ➤ SWIM across sector borders
- If threat detected - alert supervisor! (or anyone else to alert?)
  ➤ To do what? ➤ operational Level
Results of R&D Project with DFS and Eurocontrol

- Ground Station prototype proven to detect various threats
  - Spoofing
  - Modification
  - Jamming
  - Detects also anomalies – great for conformance monitoring!

- False Alarm Rate not yet where it should be – continue within SESAR2020

- Central Processing System
  - ADS-B Server: Additional layer to ADS-B Threat Detection
  - WAM configuration rejects threats – difficult to spoof

- Decision to industrialize and integrate first set of functionalities into product
Thales ADS-B Solution

- Easy to implement, best performance, low risk
- Extremely reliable and robust solution
  - Maintenance free
  - Excellent record on low failure rates from the field
- Extremely low lifecycle cost
- Compliant to all international standards – type approved and certified by German Regulator
- Safe and secure implementation
  - on ADS-B level
  - on Network Level – Thales CyberSecurity
- Centralized or standalone architecture – tailored to customer needs
- Growth potential towards full WAM, Airport MLAT, and SBS System

ADS-B Hongkong
ADS-B Example Installations
Radar Surveillance Coverage

FL300 Radar

Procedural ATC in non-Radar Airspace

Many VHF outlets available, i.e. buildings, power, maintenance, links to ATC

Courtesy Airservices Australia
ADS-B + Radar Surveillance Coverage

FL300 Radar & ADS-B

Courtesy Airservices Australia
ADS-B Australia: Installation at Woomera

ADS-B antennas

Old Tower (to be removed)

Solar powered, passively cooled

Satellite Comms Link to ATC centre

Picture Courtesy Airservices Australia
ADS-B Countrywide Coverage in Australia

Picture Courtesy
Airservices Australia

30 Sites / 60 Receivers
The countrywide ADS-B System in Indonesia

Indonesia is a pioneer of countrywide ADS-B!

30 dual redundant ADS-B sites
+ 1 Test Site

ADS-B Coverage

Pictures courtesy ICAO / Airnav
ADS-B Countrywide New Zealand

28 Sites / 39 Receivers

Figure 165 – Airways Lab coverage at 24500 ft ASL
Figure 166 – Cantrona coverage at 24500 ft ASL
Figure 167 – Coronet Peak A coverage at 24500 ft ASL
Figure 168 – Coronet Peak B coverage at 24500 ft ASL

ADS-B Coverage @ FL245
France: ADS-B Outre-Mer
(La Réunion, N. Calédonie, ...)
(operational, complete)

ADS-B La Réunion – DTI Test Flight:
Range of one ADS-B ground station: 300NM

Picture Courtesy DTI
ADS-B La Réunion – DTI Tests
High altitude en-route traffic: range > 300 NM

Picture Courtesy DTI
ADS-B La Réunion – DTI Tests:
Island commuter traffic visible down to ground
NextGen/SBSS USA

SUBCONTRACT TO ITT EXELIS, NOW HARRIS
ADS-B USA
794 Stations

This image depicts complex surveillance coverage in a simplified graphical format. The image does not represent all conditions that will determine the actual coverage.

Picture Courtesy ITT
**ADS-B & Broadcast Services - Principles**

**ADS-B:** Transmission of GNSS-Derived Position & Identity via specialized Aviation Data Links – 1090 ES and UAT (978 MHz)

1090ES ADS-B Out

UAT & 1090 ADS-R: “Cross-Link” Rebroadcast

UAT & 1090 TIS-B: Uplink of Non-ADS-B Targets’ Radar Data

**Ground Station**

1090 TIS-B

1090 ADS-R

Data Fusion

Air Traffic Control Automation Systems

Weather Data

Traditional Radar

1090ES ADS-B Out

1090ES ADS-B In

1090ES ADS-R

1090ES TIS-B

UAT ADS-B Out

UAT TIS-B

UAT FIS-B

UAT ADS-R
Surveillance Broadcast Ground Station - SBGS

- Used in FAA SBS program
- Based on proven AX680 HW components
- 19", 8 HU form factor
- Includes multiple receivers, dual transmitters
- Redundant configuration

**RX-Services 1030, 1090 and UAT**

- Up to 6 channel ADS-B on 1090 ES
- Single channel UAT (978 MHz)
- Optional 1030 MHz receiver for TX blanking

**TX-Services 1090 and UAT**

- ADS-R crosslink
- TIS-B
- FIS-B

**All services locally processed**

FAA SBGS in redundant configuration
Coverage from Radio Stations

More than 300 radio stations are collecting data

Data from September 23, 2010
Status FAA SBS Program 06/2017

- Alaska
- Hawaii
- Guam and Saipan
Multilateration Systems

AIRPORT SURFACE MULTILATERATION (MLAT)
PRECISION APPROACH MONITORING (PAM)
WIDE AREA MULTILATERATION (WAM)
Fundamental Principle of Multilateration

MLAT/WAM CPS calculates surfaces of constant time difference

Transponder Reply or Mode S quitter

Transponder-equipped aircraft
- reply to interrogations from SSR, TCAS or multilateration systems, and
- emit unsolicited squitters

Multilateration Ground Stations (GS)

Signals received and time stamped by Ground Stations

Ground communications network

Multilateration Central Processing Station (CPS)

System Output:
- Aircraft reports
- Surveillance Data Processor
- Track reports
- ATC Display System

Multilateration measures Positions
Recapitulation: Multilateration Principle (TDOA)

A and B are a pair of ground stations receiving both a signal from an aircraft.

The range between aircraft and ground station is

$$ R = c \cdot (\text{TOA} - \text{TOT}) $$

The time difference TOA$_1$-TOA$_2$ thus corresponds to the range difference

$$ R_2 - R_1 = c \cdot (\text{TOA}_2 - \text{TOA}_1) $$

as the Time of Transmission TOT cancels in the difference.

($c =$ wave propagation speed)

At a given time, the aircraft is located somewhere on the line whose points have a constant range difference to the ground stations:

$$ R_2 - R_1 = c \cdot (\text{TOA}_2 - \text{TOA}_1) $$

This line is a hyperbola with the ground stations representing the focal points.

A third ground station in C gives two more differences

$$ R_2 - R_3 = c \cdot (\text{TOA}_2 - \text{TOA}_3) $$
$$ R_1 - R_3 = c \cdot (\text{TOA}_1 - \text{TOA}_3) $$

and thus two more hyperbolas follow.

The aircraft can be located at the intersection of the hyperbolas.
Recapitulation: Multilateration Principle (TSOA)

Ground station A is interrogating at TOI₁ an aircraft eliciting a response at TOT that is received by ground stations A and B.

The range between aircraft and ground station is

\[ R = c \cdot (\text{TOA} - \text{TOT}) \]

with the unknown TOT, i.e.

\[ \text{TOT} = \text{TOI}_1 + \frac{1}{2} \cdot (\text{TOA}_1 - \text{TOI}_1) \]

So that

\[ R_1 = c \cdot \frac{1}{2} \cdot (\text{TOA}_1 - \text{TOI}_1) \]

\((c = \text{wave propagation speed})\)

Typical Accuracy Distribution from Theory

TDOA  TSOA

Hyperbolic  Elliptical

best  best

worst  worst

At a given time, the aircraft is located somewhere on the line whose points have a constant range sum to the ground stations:

\[ R_1 + R_2 = c \cdot (\text{TOA}_1 + \text{TOA}_2 - 2 \cdot \text{TOT}) \]

or

\[ R_1 + R_2 = c \cdot \left[\frac{1}{2} \cdot (\text{TOA}_1 + \text{TOA}_2) - \text{TOI}_1\right] \]

This line is an ellipse with the ground stations representing the focal points.

A third ground station in C gives another range sum:

\[ R_1 + R_2 = c \cdot (\text{TOA}_1 + \text{TOA}_2 - 2 \cdot \text{TOT}) \]

\[ R_2 + R_3 = c \cdot (\text{TOA}_2 + \text{TOA}_3 - 2 \cdot \text{TOT}) \]

and thus another ellipse follows.

The aircraft can be located at the intersection of the ellipses.
Multilateration Characteristics

<table>
<thead>
<tr>
<th>Advantages:</th>
</tr>
</thead>
<tbody>
<tr>
<td>▶ Excellent Performance – depends heavily on system geometry</td>
</tr>
<tr>
<td>▶ High update rate – every received signal used to locate target</td>
</tr>
<tr>
<td>▶ Mode S communication possible (downlink of aircraft parameters)</td>
</tr>
<tr>
<td>▶ Same ground stations as for ADS-B – intrinsic ADS-B capability</td>
</tr>
<tr>
<td>▶ Inherent Integrity/Security Features</td>
</tr>
<tr>
<td>▶ Low ground equipment cost – Low lifecycle cost</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Requirements:</th>
</tr>
</thead>
<tbody>
<tr>
<td>▶ Multiple sites required,</td>
</tr>
<tr>
<td>▶ No of sites strongly depend on vertical coverage limit and terrain</td>
</tr>
<tr>
<td>- Avoid over-specification that may lead to excessive complexity</td>
</tr>
</tbody>
</table>
Real World Constraints

- Quasioptical Propagation @1090 MHz
  - Not much diffraction (good)
  - Obstruction
  - Multipath

- Nutzung des Kanals durch andere Systeme
  - SSR, ACAS/TCAS, IFF, ADS-B
  - Hohe Funkfeldbelastung – Einschränkung der Empfangswahrscheinlichkeit
  - Unkoordinierter Kanalzugriff („Aloha“)
Effects and Anomalies

Transponder Antenna with „omnidirectional“ Pattern?
Main Reasons for good or bad Performance

- Centralized Sensors (Radar, ADS-B, …):
  - Equipment characteristics
  - Algorithms applied
  - Chosen antenna pattern

- Distributed Sensors (WAM, PAM, MLAT, …):
  - Equipment characteristics (Ground Stations)
  - Algorithms applied (Central Processing Station, CPS)
  - Chosen antenna patterns
  - Synchronisation Methods
  - Number and constellation of ground station sites
    - Minimum: 3 Stations for 2D, 4 Stations for 3D Position
## Comparison ADS-B vs Multilateration

<table>
<thead>
<tr>
<th>Criterion</th>
<th>ADS-B</th>
<th>Multilateration</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ground Equipment</strong></td>
<td>Single Ground Station for coverage</td>
<td>Multiple Ground Stations for coverage</td>
</tr>
<tr>
<td><strong>Position Source</strong></td>
<td>Dependent Surveillance: Onboard Navigation Position via Datalink, usually based on GPS</td>
<td>Independent Surveillance: Own Measurement of Position</td>
</tr>
<tr>
<td><strong>Operational Principle</strong></td>
<td>Passive</td>
<td>Passive/Active (e.g. Baro Altitude)</td>
</tr>
<tr>
<td><strong>Equipage</strong></td>
<td>Needs ADS-B – capable Mode S transponder</td>
<td>Needs Mode S or Mode A/C transponder, also supports ADS-B</td>
</tr>
<tr>
<td><strong>Coverage</strong></td>
<td>As defined by ground station antenna and terrain</td>
<td>Tailored by ground station deployment</td>
</tr>
</tbody>
</table>

Ground Communication Network is needed to each Ground Station
Operational Ground Station Equipment Characteristics (1/2)

- **Reception:**
  - High Sensitivity – long detection range
  - Superb de-garbling – good performance even in high density airspace

- **Transmission:**
  - Dual Channel 1030 and 1090 MHz
  - Power Controlled up to 1000W
  - Multirole Transmitter: interrogation, system synchronization backup, test target
Operational Ground Station Equipment Characteristics (2/2)

- **Ground Station Interfacing:**
  - Low bandwidth requirements
  - Dual raw data, dual independent Asterix Cat 21 output per channel

- **Ground Station Maintenance**
  - Maintenance-free equipment
  - Full remote access via network
  - Remote diagnostics via BITE, internal oscilloscope and spectrum analyzer
  - Dual SW, FW, OS, Configuration partitions for easy upload during operation
  - Failsafe remote update
Ground Stations Configurations

- Single or dual Sector
- Local redundant or spacially redundant
- Receive-only (GSR) or Receive-Transmit (GST)

Subrack
Indoor Cabinets
Outdoor Cabinet
Operational System Characteristics

- **System Synchronization for TOA Time Stamping**
  - Distributed Timing (independent time stamping to UTC in each ground station)
  - Dual independent synchronization capability – not depending on GPS alone

- **System Interfacing:**
  - Asterix Cat 19, 20, 21, 23, 25, 247 – and also Cat 34, 48 (radar-like) in pseudo rotation
  - Multiple independent output streams configurable
Redundant Central Site Architecture

Centralised Control and Monitoring System

- Fully redundant Master-Slave Setup
- Any number of remote control positions (RCMS)
- Real time system performance monitoring
- Full data logging and replay
How to build a good WAM System

- Excellent Equipment Performance
- Versatile Algorithms tuned as needed
  - Accuracy, output rate
  - Probability of Detection, interrogations
  - Coverage Volume
- Good Site Selection Process
  - Performance
  - Coverage
  - Operating Cost (number of sites to maintain)
- System has to be managed centrally

Number of Sites

Competitors

TOTAL

New

Thales

A

B

C

D

Managing Large Systems

- Multilateration Systems are fully remote operated / remote controlled
- Maintenance-free
- Larger, more complex systems can be built

Availability becomes an issue – main reasons:
- communication network issues,
- power loss

System Resilience is required

South Africa: Operational WAM Implementation (approx. 100 Ground Stations)
Multilateration System Resilience (1/2)

Classical N-1 System Concept

- **System State: Normal**
  - N-0 Normal
  - Data: Yes
  - Ground Station OK

- **System State: Degraded**
  - N-1 Degraded
  - Data: Yes
  - Ground Station NOK

- **System State: NOGO**
  - N-2 NOGO
  - Data: No
  - Ground Station NOK

- **System State: NOGO**
  - N-2 NOGO
  - Data: No
  - Ground Station NOK
Multilateration System Resilience (2/2)

Solution for improved Availability – Virtual WAM

System State: Normal

System State: Degraded

System State: Degraded

System State: Degraded
WAM Estonia with Virtual WAM Service Volumes

Remote Control Screens

Coverage and Service Volumes (24 Ground Stations)
Virtual WAM also for Airport MLAT?

- **Separate Areas can be identified**
  - Runways systems
  - Aprons
  - Approach areas

- **Even Airport MLAT can benefit from virtual WAM principle**
MAGS

- WAM, TMA, Airport surface, as well as, airport Precision Approach Monitoring
- Great flexibility and scalability to tailor performances to customer needs
- Highly efficient and safe
  (high accuracy, high refresh rate, dual synchronisation, AL4/ED109)
- In operational use e.g. by DFS (sole means of separation in Frankfurt approach) and French DGAC (MLAT Lyon, Nice) in complex operational environments
- Simultaneous Multilateration and ADS-B surveillance
  (includes full ADS-B processing)
- Multiple outputs (including virtual-radar cat 48) to ease interface to ATM system
- MAGS performance exceeds ED129, ED117 & ED142 requirements
WAM, PAM, MLAT
Example Implementations
NICE – Aéroport Côte d’Azur, France

- France’s 3rd largest airport
- Approx. 160,000 movements/year
- Approx. 11 million passengers/year
- Serving both domestic and international destinations
- Significant share on general aviation and helicopter traffic serving Monaco, Cannes, and the entire Côte d’Azur
- DTI contract awarded to Thales to supply MAGS airport multilateration system (plus a WAM option)

MAGS – Multilateration and ADS-B Ground Surveillance System
Ground Station Sites on Airport
Ground Station Sites outside Airport
Some Sites on the NICE MLAT System
WAM Afghanistan

COUNTRYWIDE AND MAZAR-E-SHARIF TMA
Country-wide WAM Implementations

### Afghanistan country-wide WAM

- System operational
- WAM + ADS-B 1090 ES
- Operation via VSAT
- Difficult Environment

![Fortified Ground Station Site](image)

![ADS-B and WAM Coverage in Afghanistan](image)
Local Constraints

- extreme climatic conditions
- earth quake area
- not much infrastructure
- no safe transport routes
- extreme security risk outside ISAF camps
PAM FRA

PRECISION APPROACH MONITOR FRANKFURT
PAM FRA Project

Customer
- DFS
- Main Drivers:
  - High update rate in final approach
  - High accuracy
- Main Task
  - Provide Multilateration Surveillance within 128 x 80 NM coverage region around Frankfurt International Airport
  - Focus on closely parallel approaches
  - Primary means of Surveillance in approach sectors

Source: Fraport AG
Main Parameters

- Output Probability of Detection: PD ≥ 97%
- Up to 500 targets Mode A/C & S in coverage at any one time (plus > 500 targets outside to be detected to discard)
- Reporting interval: 1 second (Radar: 4.8s, 10s…)
- Direct plot output (no coasting, extrapolation or smoothing)
- Horizontal Position Accuracy: HPA ≤ 50m RMS (ED142: 150 m)
- Probability of Code Detection: PCD ≥ 97% (Mode A), ≥ 96% (Mode C)
- Altitude Timeout 1s
- Dual synchronisation required (GPS and RF Time Beacon)
- N-1 redundancy
Siting Model

Also modelled:
- all N-1 cases
- all performances
- Various target altitudes
Siting Concept

- DFS concluded a comprehensive initial site survey presenting a selection of more than 80 sites for tenderers to choose from.
- Thales identified 34 sites (12 of these for airport GND alone) and their respective role:
  - Main driver: low level visibility, rather than power budget.
  - Re-use existing sites as far as practical.
  - Requires system adaptability: antenna types, EMC, communication, packaging, lightning protection, etc.
  - Confirmed findings in final site survey.
Typical PAM FRA Ground Station Sites
Operational WAM Coverage
Physical WAM Coverage
WAM and ADS-B Coverage

Blue = ADS-B
### Accuracy PAM FRA

<table>
<thead>
<tr>
<th>Deviation Type</th>
<th>Mean</th>
<th>SD</th>
<th>RMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Deviation</td>
<td>18.9</td>
<td>27.9</td>
<td>33.7</td>
</tr>
<tr>
<td>Across Track Deviation</td>
<td>2.5</td>
<td>25.5</td>
<td>25.6</td>
</tr>
<tr>
<td>Along Track Deviation</td>
<td>-0.4</td>
<td>21.9</td>
<td>21.9</td>
</tr>
<tr>
<td>Latency</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Calculated by DFS comparing WAM to ADS-B across track error using known good ADS-B aircraft (DLH, BA, RYR).

Across track error eliminates latency effects of ADS-B.

Source: DFS

EDFH low Overflight (100 ft GND)
EDFH Traffic Ccircuit (500-1000 ft GND)
Reference: GPS Tracker
Comparison of Low Altitude Coverage

PAM FRA

MSSR Radar

Source: DFS

PAMFRA Coverage boundary
Comparison of Update Rates PAMFRA – ASR – MSSR

- **PAM FRA WAM (1s)**
- **ASR Radar (4.8s)**
- **MSSR Radar (10s)**

*(Testflight: New Runway North – Frankfurt Airport)*

Source: DFS
Now switching from Radar (4.8s) to WAM (1s)

PAM FRA is operational – sole means of surveillance in Frankfurt Approach

Quelle: DFS
WAM South Africa

World’s largest WAM system

- ~100 Ground stations
- Dual Central Processing
- Implemented in two phases

Coverage Area Phase 1 (yellow) and 2 (red)
WAM in Marshall project

9 WAM Clusters consisting of

- 112 Ground stations
- 9 Central Processing Locations
- Remote Control and Monitoring
- Engineering Services (Design, FAT, Commissioning), Installation Support and Training
- WAM Project Management

Subcontract to AQUILA, a Joint venture of Thales and NATS
Thales Worldwide Non-Radar Surveillance References

Thales has delivered over 2,000 ADS-B and Multilateration Ground Stations around the World

Last update: October 2016


© Thales 2016 All rights reserved.
Thank you very much! Happy to answer Questions

Holger Neufeldt
Product Manager,
ADS – B and MLAT Systems
Phone: + 49 7156 353 28 230
Email: holger.neufeldt@thalesgroup.com