European FP7 UFO (Ultra-Fast wind sensOrs for wake-vortex hazards mitigation)  
14/05/2014  
Wakenet Workshop  
Frédéric Barbaresco, Thales Air Systems
WIND & EDR IMPACT ON WAKE-VORETEX

EDR => WAKE-VORETEX DECAY

WIND => WAKE-VORETEX TRANSPORT

* Wake vortices

A cause of severe incidents and accidents: low altitude, during touchdown
UFO OPERATIONAL GOALS:

- UFO will study dedicated Wind sensors compliant with future Airport Weather operations requirements.
- Safety margin of Wake-Vortex Separations are dependent of Wind/EDR assessment accuracy (Wind for WV transport, EDR for WV decay), UFO will improve the update rate and the accuracy of Wind/EDR assessment:
  - to optimize this Safety Margin
  - to generate Alert in case of abrupt changes of wind /EDR conditions
- UFO will also improve other wind hazards ultra-fast monitoring capabilities
  - Low Level Wind-Shear
Wake-Vortex Rare Hazards Mitigation: with/without sensors

**Without Sensors**

- Model Rare Event of WV outliers (heavy tails of Probability densities)
- Increase Margin of Safe Separations
- Decrease Capacity for same level of Safety

**With Sensors**

- Detect Wake-Vortex In Ground Effect Including Rare WV outliers by Sensors
- Monitor Accurate Wind/EDR by sensors at Ultra-Fast Update Rate
- Decrease Margin of Safe Separations
- Increase Capacity for same level of Safety
- Send Alert for Missed-Approach (SAFETY NET)
- Punctually Decrease Capacity (Go-around)
**EDR sources: Obstacles & Ground Thermal Convection**

- **EDR generated by Obstacles**
  - When strong wind pass over a large obstacle they create turbulence as high as 10 time obstacle height.
  - In PRANDL layer (the Surface Boundary Layer SBL), turbulence is characterized by Roughness Length

- **EDR generated by Ground Thermal Convection**
  - When the earths surface is heated by the sun, it will also heat the air directly above it. Since hot air is less dense than cool air, this heated air will rise from the earths surface to a higher elevation. In the evening, the opposite occurs.
Radar/Lidar 3D Monitoring: WIND, EDR, Wake-Vortex in All Weather

For 100 m < altitude < 500 m (NGE): Wake-Vortex Prediction from Ground Radar/Lidar Wind/EDR measurements (last 10 km in glide)

For 0 m < altitude < 100 m (IGE): Wake-vortex monitoring with Ground Radar/Lidar (close to the runway)
MAIN UFO GOAL: REDUCE WAKE-VORTEX SEPARATION MARGIN

For 100 m < altitude < 500 m (NGE) : Wake-Vortex Prediction with Ground Radar/Lidar Wind/EDR measurements (last 10 km in glide)

- Improve Accuracy/Update Rate of 3D Wind/EDR monitoring
- Better Wind/EDR Data inputs for Nowcast/Forecast HR Models
- Reduced Safety margin on aircraft separations by improving “Wake-Vortex Predictor” performances
- Accelerate Technology Readiness Level of sensors for Weather-Dependent Wake-Vortex Decision Support Systems (RECAT III)

For 0 m < altitude < 100 m (IGE) : Wake-Vortex Monitoring with Ground Radar/Lidar (close to the runway)

- Wake-Vortex Monitoring is requested because of very instable atmosphere at low altitude coupled with IGE
- Wake-Vortex Sensors are used for Safety NET to send alert for Missed-Approach
- Hyper-Safe systems in the most critical phase of the flight
WIND/EDR Monitoring in the glide threshold

Final Approach Fix (FAF)

Runway 3000 m / 60 m

Threshold

Wind

HR Forecast Model

Mode-S Downlink

Radar/Lidar Sensors

WIND/EDR Monitoring in the glide

Final Approach

ILS Glide Slope

ILS Glide Slope: 3° (5.2%) - 4°

Max course deviation: 2°

Horizontal deviation at FAF: +/-800m

Altitude between 2000 and 6000 ft (typically)

ILS Interception Area

2500 m

25 000 m (13.6 NM)

5 500 m (3 NM)

2500 m

400 m

Touch - Down Area

H = 400 ft

14/05/2014

UFO

Ultra Fast Wind Sensors
Scanning strategy: 2D Electronic-Scanning with Fixed Antenna

Final Approach Fix (FAF)

Runway: 3000 m / 60 m (typically)

Wind

Threshold

Final Approach

ILS Glide Slope

Altitude between 2000 and 6000 ft (typically)

ILS Glide Slope: \(3^\circ \) (5.2%) – \(4^\circ\)

Max course deviation: \(2^\circ\)

Horizontal deviation at FAF: +/-800m

5 500 m (3 NM)

25 000 m (13.6 NM)

H = 400 ft

2500 m

400 m

Touch - Down Area
- Studies of new Ultra Fast Lidar/Radar Wind & EDR monitoring sensors, usable for
  - Wake-Vortex Hazards Mitigation
  - severe Cross-Wind, Air Turbulence and Wind-Shear.
- **High update rate and high accuracy Sensors:**
  - 2D electronic scanning antenna based on low cost X-band tile
  - New high power laser source of 1.5 micron Lidar 3D scanner
- **New design tools developed through simulators, able to couple:**
  - Atmosphere models
  - Electromagnetic, Radar and LIDAR models.
- **Advanced Doppler signal processing algorithm developed and tested for 3D wind field and EDR monitoring, including sensors resources management**
- **Comparison with following sensors:**
  - C band meteorological radar
  - Upgraded Weather Channel of S band ATC radar
  - ADS-B Downlink
- **Calibration of the ground sensors and the simulators achieved through a set of experimental trials in Munich and Toulouse**
UFO
ULTRA FAST WIND SENSORS

WP1000
Advanced Sensor Technologies Study
WP1100: E-scanning X-band Radar Technology Study

- To study & develop a test vehicle representative with a compact X-band radar equipment and designed according to a “tile” architecture.

Achievement of last period
- Design of all the antenna parts
- Manufacturing of the first T/R modules
- Start of Tests for these T/R modules
- Cold plate to cool down dissipative components
- Mechanical structure
- Radiating panel: manufacturing in progress
- Command & control board
- Distribution layers
WP1200: High Power Lidar Technology Study

- To study advanced technology for wind Lidar scanner based on compact high power laser sources for a first outdoor demonstration
- To design a robust/Low-Cost Laser in fibered technology

Achievement of last period

- Design, development and validation of the High Power Fiber Amplifier with suppression of non-linear effects
- Adaptation of a Windcube 400S wind lidar to UFO specifications (optics, optronics, scanner, software)
- Mechanical integration of the new laser amplifier, drivers, power control into the lidar casing. Thermal management with new air conditioning unit.
- Software modification to record wind data at fast rate
- Factory and atmospheric tests
UFO Lidar integration

- **UFO transformation**
- Laser diodes
- **Telescope**
- **Door**
- **Scanner rack**
- **Preamplifier** 15µJ
- Onera’s high power amplifier
- **LD controller**
- **PC and optoelec racks**
UFO
processing, modelling and design tools development.
WP2100: E-scanning X-band Radar Model & Design Tool

- To develop Radar Simulator upgrade for wind/EDR monitoring
- To develop, test and validate Radar Wind/EDR retrieval algorithms
- To study 3D scanning strategies for E-scan X-band Radar

ZEPHYROS Radar simulation tool

Large LES Model 2.5 Km x 2.5 km x 1.5 km from ISL (Military French/German Institute)

Large-Eddy Simulation 400 m x 400 m x 400 m of idealized stably stratified atmosphere including humidity (extension to include rain droplets)
Curie radar: Wind and EDR Estimates

**Wind**

**Eddy Dissipation Rate (EDR)**
LATMOS: Wind/EDR Retrieval on Trappes trials

Curie radar: Wind and EDR Estimates

Wind and EDR estimates are shown for the Curie radar on 08/08/2013 from 10h to 14h. The wind data is represented by color gradients, indicating wind speed from light to dark colors. Eddy Dissipation Rate (EDR) is also shown, with blue arrows indicating the direction and magnitude of the EDR.
LATMOS: Wind/EDR Retrieval on Trappes trials

Curie radar vs Leosphere windcube v2 : EDR – 01/08/2013

Comparison of Eddy Dissipation Rate (EDR) measurements from Curie radar and Leosphere windcube v2.

**Curie Radar**
- Time: 01/08/2013, 00h–23h
- Measurement range: 0m–350m
- Displayed values: $m^2 \cdot s^{-3}$

**Leosphere Windcube v2**
- Time: 01/08/2013, 00h–23h
- Measurement range: 0m–350m
- Displayed values: $m^2 \cdot s^{-3}$

**Comparison:**
- Both measurements show similar patterns in EDR values.
- Curie radar (WIND) and Leosphere Windcube (EDR) provide complementary data for wind and turbulence analysis.

**Note:**
- The images illustrate the data visualization techniques used for EDR retrieval from different sensor types.
Processing Chain for Wind & EDR processing

$Z_{\text{meas},b}(r,\theta,\phi)$ → SINUS

$Z_{1}(r,\theta,\phi)$ → DOP.

$|S_{k}(r,\theta,\phi)|^2$ → SPECTRUM

$\sigma_{i}(r,\theta,\phi)$ → EDR

$\nu_{r}(r,\theta,\phi)$ → 3D WIND

$v_{3D}(r,\theta,\phi)$ → Input_DOP

$\langle I_{1}/T_{1} \rangle$ → Spectrum

EDR($r,\theta,\phi$) → Input_EDR
**WP2200: High Power Lidar Model & Design Tool**

- To develop Lidar Simulator upgrade for wind/EDR monitoring
- To develop, test and validate Lidar Wind/EDR retrieval algorithms
- To study 3D scanning strategies for Lidar Scanner

**Achievement of last period**

- **Lidar simulator**
  - LES simulation in the presence of rain
  - Lidar Simulator upgrade for wind/EDR monitoring
  - Simulation of the detection of the radial wind component

- **Lidar Wind/EDR retrieval algorithms**
  - 2D turbulent wind field simulation
  - Implementation of EDR algorithm (structure function)
  - Algorithm testing on simulated Lidar data
  - Algorithm to compute wind barbs along glide path
WP2300 Achievements: ADS-B & PSR Weather channel

**WP2310: “ADS-B Downlink and S band PSR Radar”**

- To define/test/validate Wind/EDR algorithms for S-band PSR Radar Weather Channel
- To study specification of ADS-B Downlink Study for Weather Data

**Achievement of last period**

- First tests of EDR retrieval algorithm based on structure function for PSR radar records (records from STAR2000 in Rouen site)
- Simulation of PSR data from POLDIRAD high resolution measurements
WP2300 Achievements:

**WP2320: “ADS-B Downlink”**
- To study specification of ADS-B Downlink Study for Weather Data

**Achievement of first 18 months study**
- D2320 “ADS-B Downlink Study for Weather Data” delivery at m12

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<th>0.2 - 0.3</th>
<th>0.3 - 0.4</th>
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UFO
Data Fusion and Resource Management

WP3000
WP3100: Radar/Lidar Resources Management

- To study complementarities between Lidar and Radar sensors
- To study Collaborative Lidar/Radar 3D scanning strategies

 Achievement of last period

- Study of Shared awareness: definition of data exchanges between both sensors to have a global weather picture
- Study of Collaborative Decision & Management (Rules and Procedures to assign resources between sensors)
- Exploitation of Toulouse trials to compute sensors range/availability according to weathers conditions
**WP3200: Data Fusion**

- To study interpolation of Wind/EDR data from low speed scanning C-band operational weather radars
- To study Auxiliary Sensors Processing and Data Fusion: X-band Radar/Lidar data (< 10 km), Mode-S EHS, C-band Weather Radar
- To study Data Fusion with weather prediction model (500m res.)

**Achievement of first year study**

- LLWAS X-band radar and lidar wind calculation and fusion
- Comparison with Mode-S EHS wind
- Wind shear detection
- Nesting of airport model COSMO-MUC (2.8 km) in COSMO-DE
- COSMO-MUC test runs
- 3D VAR and 4D VAR (using time dependency)
- Implementation EDR in model HARMONIE (2.5 km)
WP4100: Field tests in Toulouse Airport

- Field Test Plan Definition for trials at Toulouse Airport
- X-band and Lidar trials in Glide slope (until 10 km) for Wind/EDR monitoring (calibration with flight trials and other sources / models)

Achievement of last period

- Deployment of 2 X-band Radars (Thales E-scan Radar, Latmos Profiler)
- Deployment of 3 1.5 micron Fibered Lidar (Windcube UFO, W200S, WL7)
- Deployment of Rain Gauge and spectro-pluviometer
Network communication on Toulouse airport

MODULE 1
- CEV-DGAC Area
- MFR Radar
- MFR Radar cabinet
- Waveguide RF (5m)
- MFR Processing
- TRACKING
- CDE-CTRL Windcube 200S
- W200S Processing
- CDE-CTRL Wincube UFO
- MODULE 2
- WiFi Radio
- Internet Access
- WIFI 5GHz (400m)
- Radio WIFI
- LIDAR Windcube 200S
- GBAS area (Near 32L runway)
- DGAC Hangar
- Internet Access
- WIFI 5GHz (400m)
- Radio WIFI
- LIDAR Windcube 200S
- GBAS area (Near 32L runway)
- DGAC Hangar
THALES WAKE-VOXET/W                                  R, WIND/EDR X-BAND RADAR IN OPERATION

E-lectronic Scanning X-band Radar
600 W Solid-State Transmitter
Pulse Compression: 5 m range resolution
Beamwidth: 1.8 x 1.8
Electronic Scanning Multifunction Radar
Results for Weather mode recordings, **Tuesday, April 29th** (Weather: cloudy / slightly rainy, 3 different elevation beams: {3.5 - 5.0 - 6.5})
Wind field computation results

- **Tuesday, May 6th**
  - Mode: Weather 2
  - Weather: slightly rainy
  - 3 different elevation beams: \{ 3.5 - 5.0 - 6.5 \}

Average velocity: < 10 m/s

- 2 main directions:
  - -45° wrt North
  - 110° wrt North
Spectral width computation results

- **Tuesday, May 6**

High spectral width value ➔ High EDR value?
LEOSPHERE 3D SCANNER WIND/EDR FIBERED LIDAR INSTALLATION
Development of algorithms for computing wind barbs in 3D
Volume and glide paths

- Development of the program to compute wind barbs at several locations at the same time and given one or multiple scans
  - Preliminary results of wind barbs on 6 PPI scan measured at Toulouse airport
  - Preliminary results of wind barbs on Glide path measured at Toulouse airport. Wind shear in direction can be observed at ~250m)
LATMOS WIND/EDR X-BAND RADAR PROFILER (CURIE Radar)
Field Trials in Toulouse Airport: Disdrometer

LATMOS: Disdrometer ("Spectro-pluviometer")

Measures and law size distribution of the raindrops on the basis of cumulative speed on a day 26/08/2006
Dornier 128-6 Technical Features

**General:**
Operation from small airstrips possible
maximum altitude 7500 m
Aircraft is full IFR equipped

**Payload and Endurance:**
400 kg with 4 Persons, 3 hours at 2000 ft
400 kg with 4 Persons, 4 hours at FL 200

**Power Supply:**
28 VDC 200 A
115 VAC (400 Hz) 750 W
220 VAC (50 Hz) 2 kW

**Main characteristics:**
Wingspan : 15.5 m
Length : 13.8 m
Typical Speed : 70 m/s
T/O Weight : 4350 kg

**Meteorological Parameters:**
Temperature
Humidity
Wind
Radiation

**Flightmechanics:**
- Airspeed
- Angle of Attack and Sideslip
- Position
- Control inputs
- Thrust
**Munich Trails Instruments**

- LLWAS (X-band radar and lidar)
- C-band radar (DWD operational) Isen
- C-band radar (DLR research) Oberpfaffenhofen
- MicroRainRadar and Parsivel distometer (DLR) at Munich airport
- Radiosondes at Oberschleißheim
- Mode-S wind and temperature
- DWD Sodar (October – March)
- DLR Cessna Caravan (Aug.-Sept.)
Validation of Wind and EDR by aircraft measurements (DLR)

- Wind and EDR measurements with DLR Cessna Caravan aircraft
- flights at various heights 300 – 1500 m above ground within the 15 km range of the LLWAS lidar
- End of August / beginning of September
  - measurements in cloud free atmosphere
  - convective clouds
  - stratiform precipitation
- **Maastricht Upper Area Control data available for UFO**
  - Munich

- **Thales has received requirements for Mode-S EHS requests by DSNA**
  - Auch (60km west of Toulouse)
  - ASTERIX CAT048 data
  - Exact location of the radar
UFO
ULTRA FAST WIND SENSORS

WP5000
Requirements & Safety Case
WP5000: Requirements & Safety Case

- To define the operational requirements for use of ultrafast wind-sensors
- To define the technical requirements for ultrafast wind sensors
- To develop a Safety Case for Ultrafast wind sensors for wake vortex hazards mitigation

Achievement of first 18 months study

- Operational Service and Environment Definition completed
- First draft of Technical Requirements for X-band Radar & 3D-scanner Lidar
Aim: Easy acceptance of UFO content by SESAR projects
Conference & Workshop

- WAC’14, World ATM Congress, Madrid, March
- AUN’14, Airports in Urban Networks, Paris, April
- WAKENET USA, March 2014
- Conference on Lasers and Electro-Optics (CLEO) 2014, San Jose USA
- 8th European Conference on Radar in Meteorology and Hydrology, September 2014, Germany
- International Radar’14 Conference, Lille, France, October 2014
- Elsevier Optical Fiber Technology (invited paper)
- 11th International Precipitation Conference 2013
- 21st Symposium on Boundary Layers and Turbulence, 2014
Questions

**UFO (Wind/EDR Monitoring)**

- **Website:**
- **Flyer:**

**Wake-Vortex Hazards Mitigation**

- **Video:**
  [https://www.youtube.com/watch?v=zeYP4sn8Tzs](https://www.youtube.com/watch?v=zeYP4sn8Tzs)
- **Flyer:**