Towards a Wake Encounter Advisory & Avoidance System – Recent work at DLR

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Content

- **Background:**
  DLR Internal Project “Wetter und Fliegen”

- **Motivation and Objectives:**
  Wake Encounter Advisory & Avoidance (WEAA) System

- **WEAA System Architecture**

- **Existing System Components**

- **Recent Work**
  - Trajectory Generation
  - (E)GPWS Alert Avoidance
  - Human Machine Interface

- **Future Work**

[Photo: Hahn]
Objective: Increased safety and efficiency of air traffic with weather information in the TMA and optimised aircraft behaviour

Time frame: 2008 - 2011

DLR & partners: DWD, HYDS, EADS

SP W: airport weather
integrated airport weather systems for wake vortex, thunderstorms and winter weather

SP F: aircraft behaviour
systems for control, monitoring and information for improved aircraft behaviour in gusts, wake vortices and thunderstorms
Motivation: Wake Encounter Advisory & Avoidance (WEAA)

- system for **tactical small-scale evasion** from wake vortices to avoid possibly hazardous wake encounters
- **pure safety net** function (no means of defining separation)
  - however, supports reduction of separation distances by providing mitigation measures
- pilots’ **situational awareness** is key issue
- evasion **without ATC request** (similar to TCAS)
  - stay within navigation limits
- **DLR objectives:**
  - system proof-of-concept, in-depth investigation of selected components
WEAA Objectives and Constraints

- **System Design Objectives**
  - increase the pilots’ situational awareness in case of a predicted, imminent or even current encounter
  - define, guide and monitor evasive manoeuvres (where possible)
  - NB: wake alleviation is not part of WEAA but can be integrated

- **Manoeuvre Design Constraints**
  - evasion without ATC request (similar to TCAS), i.e. within navigation limits
  - generally 4-D manoeuvre (adjustment of speed, track, flight path angle) possible but
    - ATC compatibility of speed changes
    - manoeuvre should be kept as simple as possible
  - no conflict with TCAS and/or (E)GPWS/TAWS generated
  - aircraft performance
  - passenger comfort (accelerations)
System Architecture: Functions

- **predict wake vortices** from performance data and planned trajectories of surrounding aircraft using meteorological data
- perform a **conflict detection**, using prediction of own trajectory, in connection with **hazard assessment** where required
- **generate evasion trajectory**, taking into account terrain data and surrounding traffic

- **define and display** required **evasive manoeuvres** to the pilots on PFD (and VSI)
- **generate overview display** on ND (and VSD) to increase pilots’ situational awareness
WEAA System Architecture

- **Modular architecture** gives possibility to
  - adapt single components without changing the whole system
  - combine components for different system architectures

- **Two design options**
  - evasion purely based on *wake prediction*
    - vortex habitation volumes grow significantly with vortex age
  - evasion based on combined *wake prediction and detection*
    - detection likely by LIDAR
    - most LIDARs deliver only line-of-sight measurements
      - vortex characterisation necessary
    - long-term perspective (sensor availability critical)
WEAA Functional System Breakdown (WV Prediction Only)

**Sensors**
- traffic data
  - type
  - configuration
  - traffic intent
  - flight path vector
  - weather/wind?

**Data Preparation**
- ADS-B
- TIS-B
- Decoding
- Range Filter

**Detection/Prediction**
- 4-D Trajectory Prediction (surrounding traffic)

**Conflict Detection and Evaluation**
- Safety Zone Traffic (for definition of evasion trajectory)

**Conflict Resolution**
- Information / Warning (Wake Vortex Advisory)
- Definition and Generation of Evasion Trajectory (type of manoeuvre, generation of trajectory)

**WEAA System Boundary**
- audio
- display
- ND
- VSI
- PFD
- FMA

**Flight Performance Data (BADA ?)**

**4-D Prediction of own Trajectory**
- flight plan
- A/P mode
- configuration
- mass

**Flight Performance** (flight phase dependent; passenger comfort)

**Flight Phase Dependent Restraints** (width of corridor; ground proximity)

**Command generation**
- implementation of evasive manoeuvres
- controller target values

**Range Filter**
- wind vector
- further meteo data?

**ADIRU (WIMS ?)**
- wind vector
- own flight state

**FMS**
- RNP
- XTK error

**Terrain Data**
- (data base; ground proximity)

**EGPWS / TAWS**
- G/S, LOC where necessary

**FMGS**
- flight plan
- A/P mode
- configuration
- mass

**FMGC**
- RNP
- XTK error

**Terrain Data**
- (data base; ground proximity)

**Flight Phase Dependent Restraints**
- (width of corridor; ground proximity)

**Safety Zone Terrain**
- (for definition of evasion trajectory)

**Alerting**
- wake vortex and traffic situation
- increased situational awareness

**Command generation**
- implementation of evasive manoeuvres
- controller target values

**Conflict Resolution**
- definition and generation of evasion trajectory

**Command generation**
- implementation of evasive manoeuvres
- controller target values

**Conflicting Data**
- traffic data
- type
- configuration
- traffic intent
- flight path vector
- weather/wind?

**Conflict Detection and Evaluation**
- wake vortex and traffic situation
- increased situational awareness

**Command generation**
- implementation of evasive manoeuvres
- controller target values

**Conflicting Data**
- traffic data
- type
- configuration
- traffic intent
- flight path vector
- weather/wind?
WEAA FBS: Existing Functions

**4-D Wake Vortex Evolution Prediction**

**Wake Vortex Detection and Characterisation (PEst / Observer)**

**Hazard Assessment** (e.g. hazard area, SHAPe)

**Data Preparation**

**Detection/Prediction**

**Conflict Detection and Evaluation**

**Conflict Resolution**

- 4-D Trajectory Prediction (surrounding traffic)
- 4-D Wake Vortex Evolution Prediction
- Wake Vortex Detection and Characterisation (PEst / Observer)
- 4-D Prediction of own Trajectory
- Flight Performance (flight phase dependent passenger comfort)
- Safety Zone Traffic (for definition of evasion trajectory)
- Flight Phase Dependent Rudder (roll of center of gravity)
- Safety Zone Terrain (for definition of evasion trajectory)
- Information / Warning (Wake Vortex Advisory)
- Conflict Detection (Wake Vortex)
- Hazard Assessment (e.g. hazard area, SHAPe)
- Command generation (implementation of evasive manoeuvres)
- HW (Information)
- Hazard Assessment (e.g. hazard area, SHAPe)
- HW (Information)
- Wake vortex and traffic situation
- Increased situational awareness
- Command generation
- Implementation of evasive manoeuvres
- Controller target values
- Ground Data (ground proximity)
- EGPWS / TAWS
- FMCS
- FMGS
- ADIRU (MIMU?)
- Monocular camera (ADIRU)
- LIDAR
- Signal Conditioning
- velocity field (possibly LIDAR)
- RNP
- XTK error
- QNS, LOC where necessary
WEAA: Exploitation of Existing DLR Knowledge

- **Vortex Prediction Model: P2P** *(HOLZÄPFEL)*
  - probabilistic two phase model
  - effects of a/c configuration, wind, wind shear, turbulence, stratification and ground proximity
  - real-time capability
  - extensively validated on LIDAR measurements and LES

- **Severity Assessment: SHAPe** *(HAHN, SCHWARZ)*
  - simplified hazard areas (rectangular or elliptical)
  - hazard rating by means of roll control ratio RCR

- **Wake Parameter Estimation: Online-ID** *(FISCHENBERG)*

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T. Bauer & D. Vechtel, DLR, Wake Encounter Avoidance & Advisory System
WEAA FBS: Recent Work

Definition and Generation of Evasion Trajectory
(type of manoeuvre, generation of trajectory)

HMI (Information)
- wake vortex and traffic situation
- increased situational awareness

Conflict Detection
- Wake Vortex

Safety Zone Traffic
- Identification of evasion trajectory

Information / Warning (Wake Vortex Advisory)
- Wake Vortex

Hazard Assessment
- Wake vortex and traffic situation
- Increased situational awareness

Command generation
- Implementation of evasion manoeuvres
- Control of target values

System Boundary
- Audio
- Display
- ND
- VSI
- PFD
- FMA

Detection and Generation of Evasion Trajectory
(type of manoeuvre, generation of trajectory)

Flight Performance
- Flight phase dependent
- Passenger comfort

Flight Phase
- Dependent Constraints
- Wake vortex avoidance

Safety Zone Terrain
- Identification of evasion trajectory

Terrain Data
- Data fusion
- Ground proximity

GPS/ILS
- Data fusion
- Ground proximity

FMS
- RNP
- XTK error

FMS
- FMS Data
- Configuration
- Mass

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Recent Work

Trajectory Generation

- trajectory generation using **potential field approach** (from robotics)
  - obstacles, boundaries surrounded by potential field modelled by super-quadratic ellipses
  - intended flight path as attracting potential
    ⇒ “automatic” return to cleared flight path
- trajectory smoothing
- lateral or vertical evasion
  ⇒ decision algorithm using encounter geometry
- status:
  - tested offline with A/P in cruise
  - simulator implementation in progress
- next step: (E)GPWS interoperability (inverted alerting boundary as limit)
Recent Work
Display Concepts

- simulator study conducted with **display concept similar to FLYSAFE** project (Airbus development, PFD + ND)
  - simplified evasion algorithm
  - visual and aural warnings
- wake **visualisation extended to vertical situation display** (VSD)
  - enhanced situational awareness
Summary: Objectives, Work So Far

- DLR is developing a Wake Encounter Advisory and Avoidance System (WEAA)
  - **tactical small-scale evasion** to avoid possibly hazardous wake encounters
  - **pure safety net** function
  - **interoperability with TCAS and (E)GPWS / TWAS** assured

- two design options
  - pure wake prediction
  - prediction + wake detection/characterisation (long term)

- existing DLR knowledge exploited:
  - WV prediction model
  - wake characterisation from forward-looking measurements
  - severity assessment

- on-going development of new system functions:
  - evasion trajectory generation using potential field approach
  - ground and traffic collision avoidance interoperability
  - pilot displays for **situational awareness**
Future Work: Where Do We Want to Go?

- **Component Function Development**
  - conflict detection concept and algorithms
  - refinement of conflict resolution algorithms taking into account
    - (E)GPWS & TCAS interoperability
    - passenger comfort
    - aircraft performance
  - ConOps for additional flight phases
  - analysis of different concepts for pilot assistance w.r.t. work load and situational awareness
  - enhanced severity assessment
  - enhanced wake characterisation with (LiDAR) measurement

- **System Proof of Concept**
  - implementation in engineering flight simulator
  - perspective: motion based simulator and flight test

- **Benefit Analysis**
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