WakeNet3-Europe
A network on Aircraft Wake Turbulence

Wake Vortex Encounter Severity Criteria

WakeNet3-Europe specific workshop
07 FEB 2012

Carsten Schwarz, Dennis Vechtel
DLR Institute of Flight Systems

Wake Vortex Encounter Severity Criteria
Presentation outline

1. Introduction (background, motivation/ focus/ goals, synopsis document, Related activities and documents)
2. Severity Assessment/ Criteria general considerations (Application types, Evaluation types, Possible steps, severity boundaries/ limits, Acceptability vs. unacceptability)
3. Severity Assessment state of the art (pilot evaluation rating scales, pilot view, severity analysis/ assessment activities, severity criteria, vortex deformation, FAA activities)
4. Applications/ tools
5. Available data (evaluated piloted wake vortex encounter data, wake vortex aircraft data)

Wake Vortex Encounter Severity Criteria
Presentation outline

1. Introduction (background, motivation/ focus/ goals, synopsis document, Related activities and documents)
2. Severity Assessment/ Criteria general considerations (Application types, Evaluation types, Possible steps, severity boundaries/ limits, Acceptability vs. unacceptability)
3. Severity Assessment state of the art (pilot evaluation rating scales, pilot view, severity analysis/ assessment activities, severity criteria, vortex deformation, FAA activities)
4. Applications/ tools
5. Available data (evaluated piloted wake vortex encounter data, wake vortex aircraft data)

Wake Vortex Encounter Severity Criteria

WakeNet3-Europe specific workshop - background

- WakeNet3-Europe task group 2.2 Safety Assessment (Airbus)
- workshop organised and hosted by DLR, in coordination with Airbus
- very little preparation time
- invitation on very short notice, hence some invitees not available

Wake Vortex Encounter Severity Criteria

WN3E specific workshop - motivation/ focus/ goals

- why this workshop on wake encounter severity criteria?
  - (still) no commonly accepted severity criteria available
  - severity criteria important element of any WVE safety assessment
  - need for agreement on international level
- focus of workshop on severity criteria, not complete safety assessments
  - requirements & target applications
  - classes of severity criteria (a priori vs. a posteriori criteria)
  - associated severity levels
  - flight dynamic evaluation of wake encounters and fundamental parameters
  - criteria design and identification of thresholds
  - validation requirements and means
- goals
  - agreed next steps toward commonly accepted severity criteria, requirements, definitions
  - overview on available data, tools/ methods
  - create short synopsis document (no minutes) with few consolidated agreed statements

Wake Vortex Encounter Severity Criteria

WakeNet3-Europe specific workshop - synopsis document

- presentations
  - main results/ observations
  - main conclusions/ messages
- consolidated agreed statements on next steps toward commonly accepted severity criteria, e.g.
  - The WHAT (“What is needed?”)
    - requirements & target applications
    - classes of severity criteria (a priori vs. a posteriori criteria)
    - associated severity levels, types of boundaries/ limits
  - The HOW (“How to get there?”)
    - flight dynamic evaluation of wake encounters (definitions: “acceptable” encounter, time/ space fixed, relevant encounter scenarios, flight phase, AIM)
    - fundamental wake encounter evaluation criteria/ parameters (subjective/ objective)
    - criteria design and identification of thresholds
    - validation requirements and means

Wake Vortex Encounter Severity Criteria

Related activities and documents

1. previous similar events (including minutes/ documentation)

1.1 10 - 11 MAY 2004 Hamburg (Airbus) WN2E WG5 workshop "WVE in flight and in flight simulation“ (http://wwwe.onecert.fr/projets/WakeNet2-Europe/wg5/agendaWG5May2004.htm)

1.2 19 - 21 APRIL 2006 Berlin (TU Berlin, EADS/ Airbus) "Wake Encounter Criteria Work-Shop"

1.3 19 NOV 2010 WN3E specific workshop "Wake vortex regulation and safety requirements" (NLR, Amsterdam, http://www.wakenet.eu/index.php?id=172)

2. related documents

2.1 Wake vortex pilot policies (IFALPA (July 1998) and Vereinigung Cockpit (Germany)

2.2 FAA wake hazard severity matrix development

2.3 draft document "Wake Vortex Encounter Assessment - Literature Overview and Applications", based on Part II Section 5.1 and 5.2 of the WakeNet2-Europe Research Needs Document

2.4 Evaluated piloted wake vortex encounter data overview: list of existing wake encounter data with pilot evaluations (encounters not intended by pilots, i.e. "unexpected" for pilots), might be helpful to consider before new piloted trials are planned

Wake Vortex Encounter Severity Criteria
Presentation outline

1. Introduction (background, motivation/ focus/ goals, synopsis document, Related activities and documents)
2. Severity Assessment/ Criteria general considerations (Application types, Evaluation types, Possible steps, severity boundaries/ limits, Acceptability vs. unacceptability)
3. Severity Assessment state of the art (pilot evaluation rating scales, pilot view, severity analysis/ assessment activities, severity criteria, vortex deformation, FAA activities)
4. Applications/ tools
5. Available data (evaluated piloted wake vortex encounter data, wake vortex aircraft data)

Wake Vortex Encounter Severity Criteria
Application types

a priori severity assessment

- severity „prediction“
- severity assessment before an encounter takes place
- assessment based on limited data, e.g. estimated vortex strength and position
- application e.g. for
  - warning and avoidance
  - ATM advisory systems
  - risk analysis with limited level of detail, i.e. without 6 DoF aircraft simulation

a posteriori severity assessment

- severity „analysis“
- severity assessment after a (simulated) encounter takes place
- assessment based on detailed data including time histories of aircraft parameters
- application e.g. for
  - piloted simulations
  - offline simulations
  - flight tests
  - FDR/ incident analysis

Wake Vortex Encounter Severity Criteria
Evaluation types

subjective assessment

- based on pilot ratings/ opinions
- severity critieria, i.e. parameter limits correlated with subjective pilot assessment

objective assessment

- based on data/ parameters
- based on limits applicable for passenger air transport, e.g.
  - max 1000 ft/min sink rate for landing approach
  - bank angle limitations
  - flight path (e.g. ILS) deviations

Is objective assessment possible?

- assessment independent of direct human opinions (pilots, cabin crew, passengers, engineers)
- additional/ complementary assessment (in addition to subjective assessment by humans)

Wake Vortex Encounter Severity Criteria
Possible steps

1. Survey of quantitative limits applicable for passenger air transport, (flight phase dependent) e.g.
   - max 1000 ft/min sink rate for landing approach
   - bank angle limitations
   - flight path (e.g. ILS) deviations
2. Selection of limit values relevant for wake vortex encounters, e.g. for bank angle select a sensible value
   - recommended max 25° [airline flight operations manual]
   - shall not exceed 30° [airline flight operations manual]
   - >30° “cat. A/ serious incident” [CAA Critchley/ Foot UK Database 1991]
   - 45° (autopilot disengage) [aircraft FCOM]
3. Development of severity criteria
   - one or more variables
   - containing the relevant limits from step 2
   - i.e. not violating the severity criteria ensures not to violate any of the relevant limits from step 2

Wake encounter severity boundaries/ limits

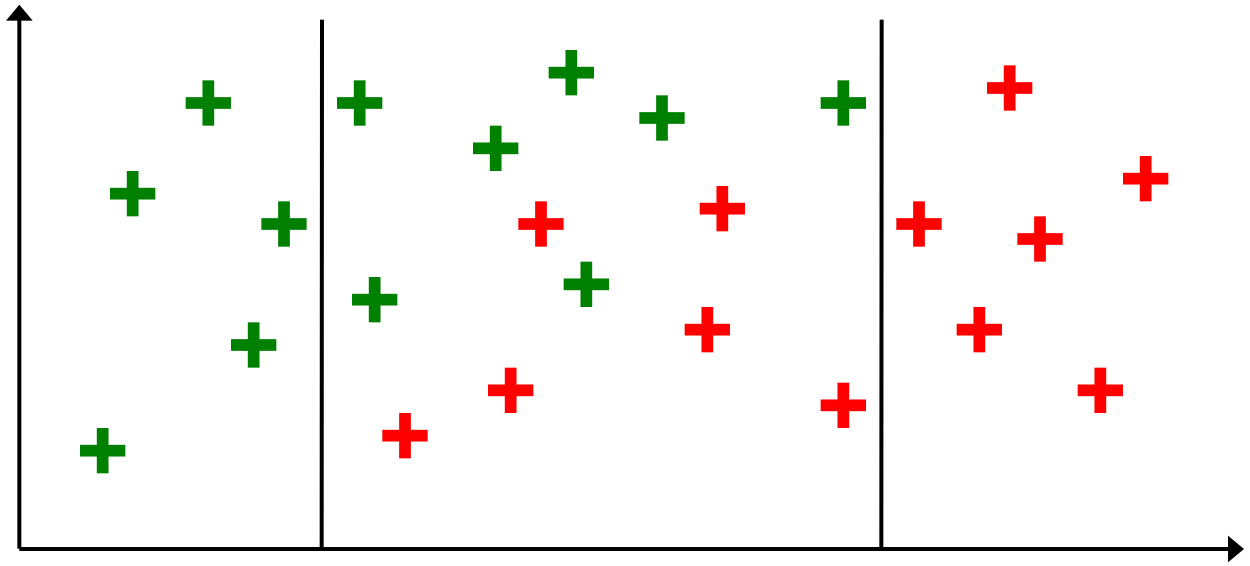
Wake encounter pilot assessment

legend:
+ acceptable encounter
+ unacceptable encounter

encounter definition parameter, e.g. altitude

probabilities:
P_acceptable <1
P_unacceptable = 1

probabilities:
P_acceptable =1
P_unacceptable < 1



severity assessment parameter

Wake encounter severity boundaries/ limits

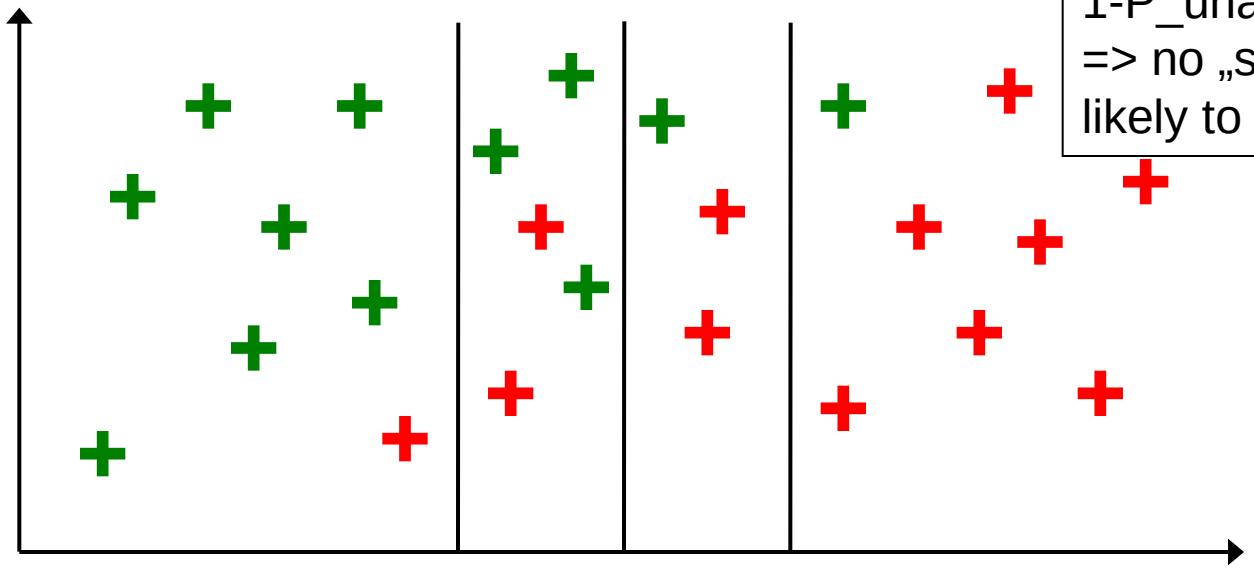
Wake encounter pilot assessment

legend:
+ acceptable encounter
+ unacceptable encounter

encounter definition parameter, e.g. altitude

probabilities:
P_acceptable <1
P_unacceptable < 1

0.73<P<0.97 [S-Wake]
hypothesis:
1-P_acceptable >> 0
1-P_unacceptable >> 0
=> no „single“ boundary likely to be found

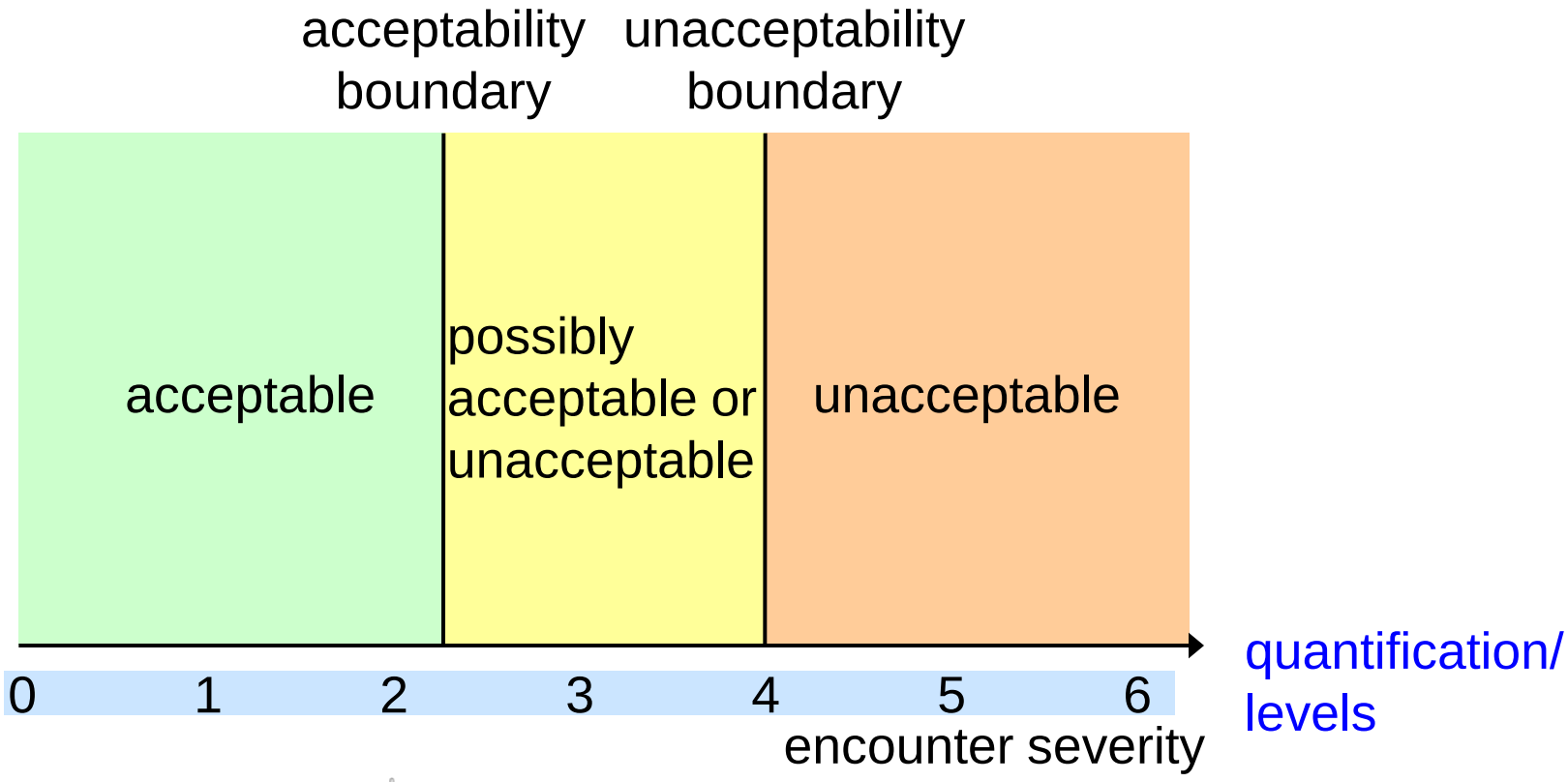


severity assessment parameter

Wake encounter severity boundaries/ limits

Acceptability vs. unacceptability

depending on application:
severity limit/ boundary or quantification/ severity levels



Wake Vortex Encounter Severity Criteria
Presentation outline

1. Introduction (background, motivation/ focus/ goals, synopsis document, Related activities and documents)
2. Severity Assessment/ Criteria general considerations (Application types, Evaluation types, Possible steps, severity boundaries/ limits, Acceptability vs. unacceptability)
3. Severity Assessment state of the art (pilot evaluation rating scales, pilot view, severity analysis/ assessment activities, severity criteria, vortex deformation, FAA activities)
4. Applications/ tools
5. Available data (evaluated piloted wake vortex encounter data, wake vortex aircraft data)

Wake encounter severity criteria

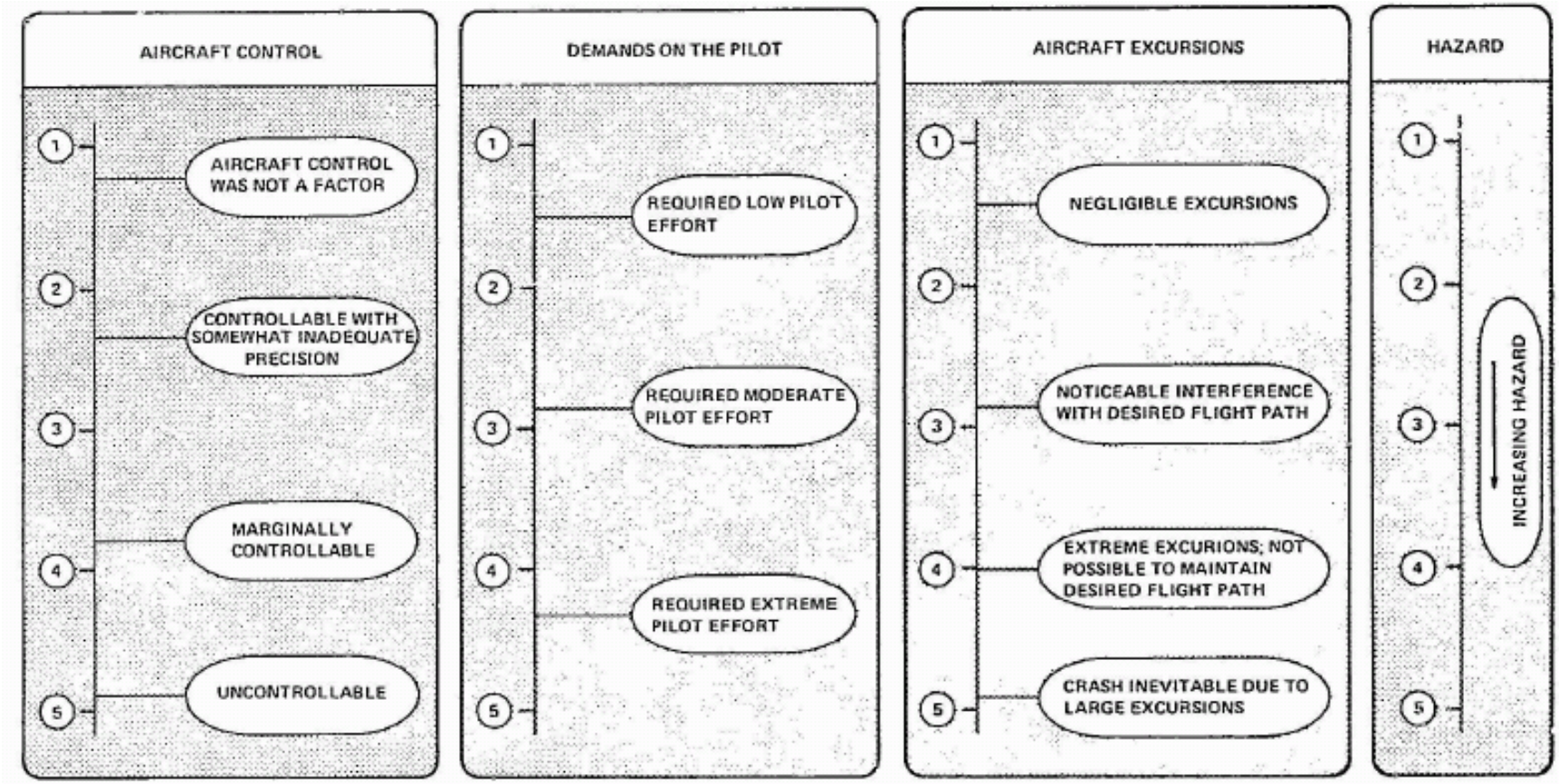
Pilot evaluation rating scale development

- subjective evaluation methodology:
  wake vortex encounters/ possibly atmospheric disturbances in general
- state of the art:
  - vortex hazard rating scale
    [Sammonds & Stinnet, NASA-TM-X-62473, 1975]
  - disturbance rating scale [Stewart, AIAA paper 98-4339, AFM 1998]
  - S-Wake [Airbus/ TU Berlin/ NLR]
  - TU Berlin PhD thesis [Kloidt 2007]
  - CREDOS (all flight phases)
    [Amelsberg & Kauertz, CREDOS D3-4, 2008]
  - Pilot work load: Modified Cooper-Harper Workload Rating Scale
  - NASA task load index (TLX) multi-dimensional work load rating

[DLR internal report IB 111-2011/46 Subjective wake vortex encounter evaluation, C. Schwarz and K.-U. Hahn]

Pilot evaluation rating scale development: state of the art

Sammonds & Stinnet, NASA-TM-X-62473, 1975



Pilot evaluation rating scale development: state of the art

Stewart, AIAA paper 98-4339, AFM 1998

1. GLASSY (2% smaller*): Flight conditions are glassy smooth. There is no detectable turbulence and winds are completely still to very light. It is a still, clear morning when the airplane seems to fly itself.
2. SMOOTH (10% smaller*): There may be an almost imperceptible disturbance and winds are light and steady. Only slight control inputs are required to maintain flight path. Conditions are representative of a nighttime stable atmosphere.
3. CALM (20% smaller*): Pilot may be aware of very small disturbances, but effects require little if any compensation. Conditions are typical of fair weather flying.
4. PERCEPTIBLE (40% smaller*): Small pilot control inputs may be required to compensate for disturbances. Thermal activity has become recognizable.
5. SLIGHT (70% smaller*): Conscious pilot control inputs are occasionally required to compensate for disturbances. Conditions are only slightly less favorable than average weather conditions, but it is still a “good day to fly.”
6. SMALL (95% smaller*): Definite pilot control inputs are required for most of the maneuver to compensate for disturbances. Conditions are typical of mid afternoon summer-time conditions.
7. MODERATE (99% smaller*): Moderate control inputs are frequently required to maintain flight path and attitude. Crew and passengers are aware of conditions. Conditions are representative of approaches conducted in the vicinity of frontal activity.
8. LARGE (99.5% smaller*): Large control inputs are continually required to maintain flight path and attitude. Some passengers may become ill. Conditions are unusual, even for approaches conducted in the vicinity of frontal activity.
9. SAFE LIMIT (99.9% smaller*): Aggressive control inputs are required to maintain flight path. Crew is alert for wind shear conditions. Some passengers will probably become ill and some will complain about the approach. Flight Attendants will discuss conditions after landing. Conditions are representative of approaches conducted in the vicinity of thunderstorms.
10. UNSAFE (99.99% smaller*): Airplane response to control input is insufficient to contain effects of disturbance. Good judgment dictates a missed approach. If the approach is continued, the subsequent landing may be hard, or displaced from the centerline of the runway or from the touchdown zone. Airplane damage may be incurred.

*Numbers are estimated percentages of normal flight operations with smaller disturbances.

Pilot evaluation rating scale development: state of the art

S-Wake [Airbus/ TU Berlin/ NLR]

Limits	Description	Rating
Approach limits not exceeded	No disturbance experienced, no pilot reaction required	1
	Slight disturbance, moderate pilot reaction required	2
	Moderate disturbance, considerable pilot reaction required	3
Approach limits exceeded, Go-around performed	Go-around manoeuvre performed without exceptional pilot skills	4
	Go-around manoeuvre performed with considerable corrective actions for aircraft recovery, critical flight state (attitude, rate, accelerations)	5
	Temporarily or total loss of control (crash if close to ground)	6

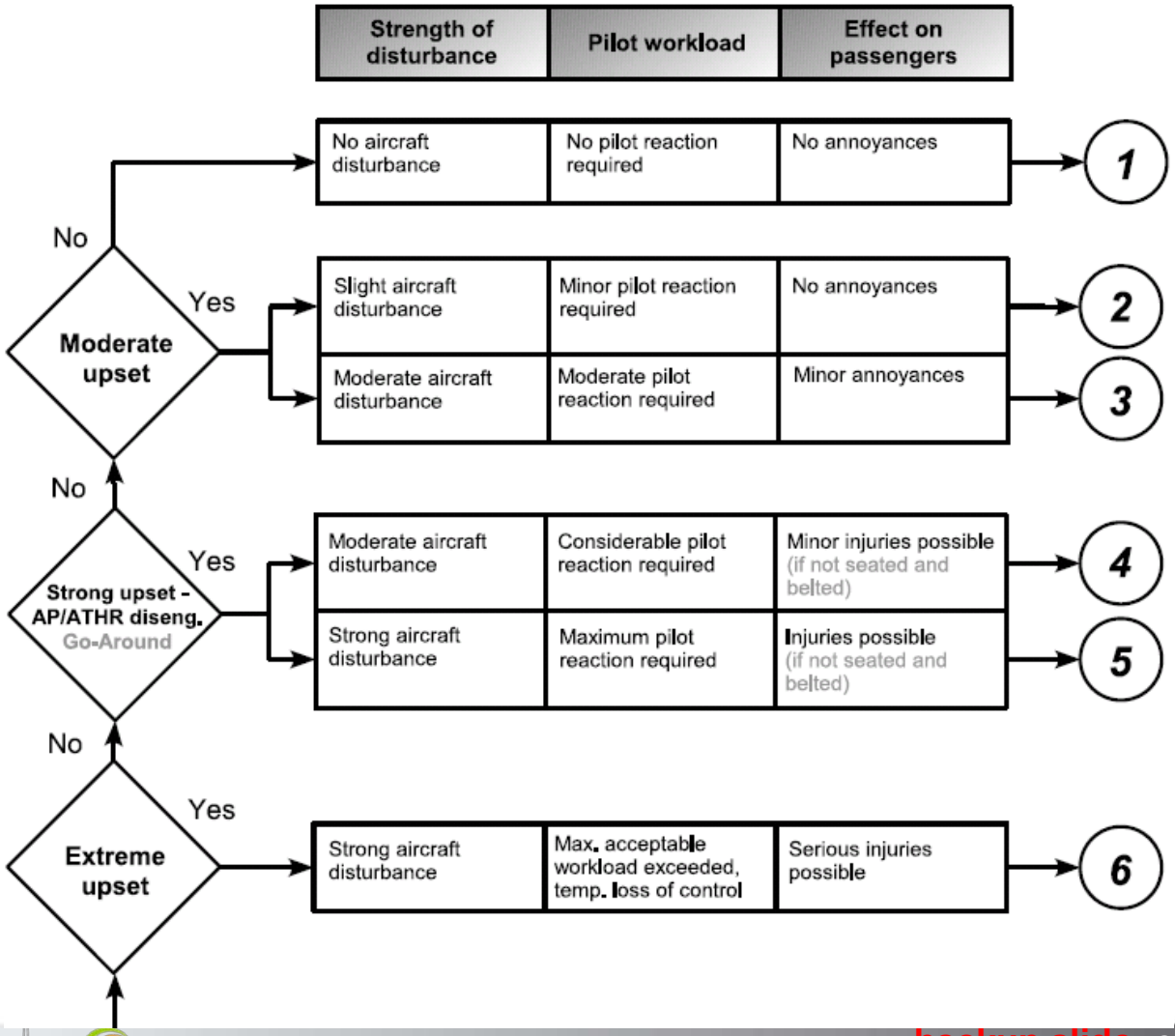
Pilot evaluation rating scale development: state of the art

TU Berlin PhD thesis [Kloidt 2007]

Safety	Description	Hazard Rating
Task can be accomplished safely	No influence of Wake Vortex noticed	1
	WV influence noticeable, Compensation with minor pilot reaction	2
	WV influence noticeable, Compensation with moderate pilot reaction	3
	WV influence strongly noticeable, Compensation with high pilot reaction	4
Task cannot be accomplished safely	Maximum pilot reaction is insufficient for compensation, Safe limits slightly exceeded	5
	Maximum pilot reaction is insufficient for compensation, Safe limits far exceeded	6
Total Loss of Control	Maximum effort insufficient, Total loss of control	7

Pilot evaluation rating scale development: state of the art

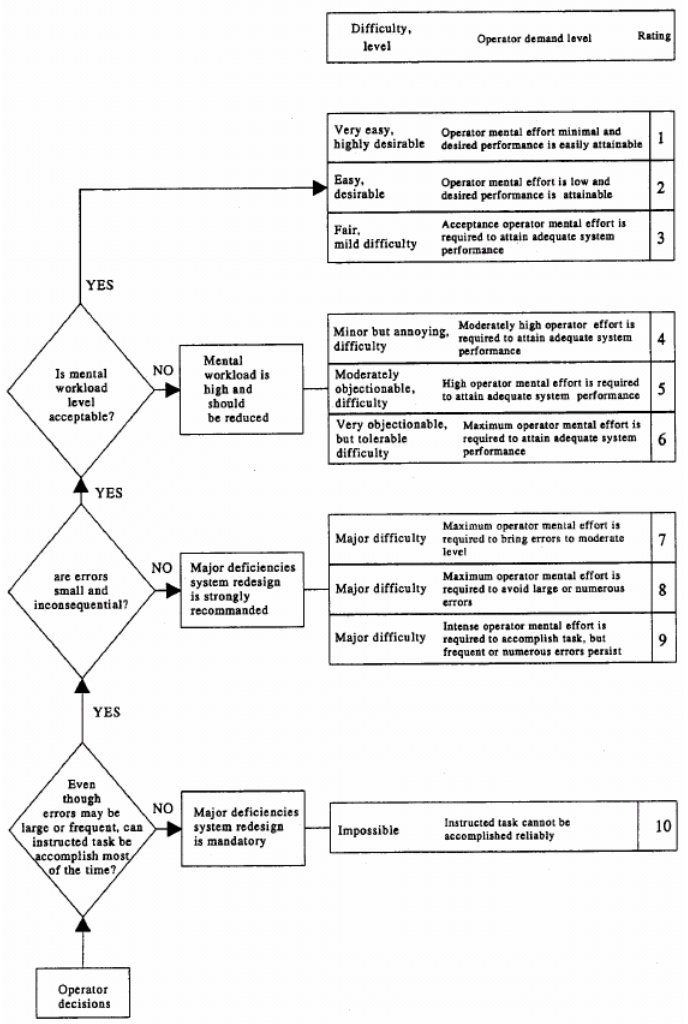
CREDOS (all flight phases)

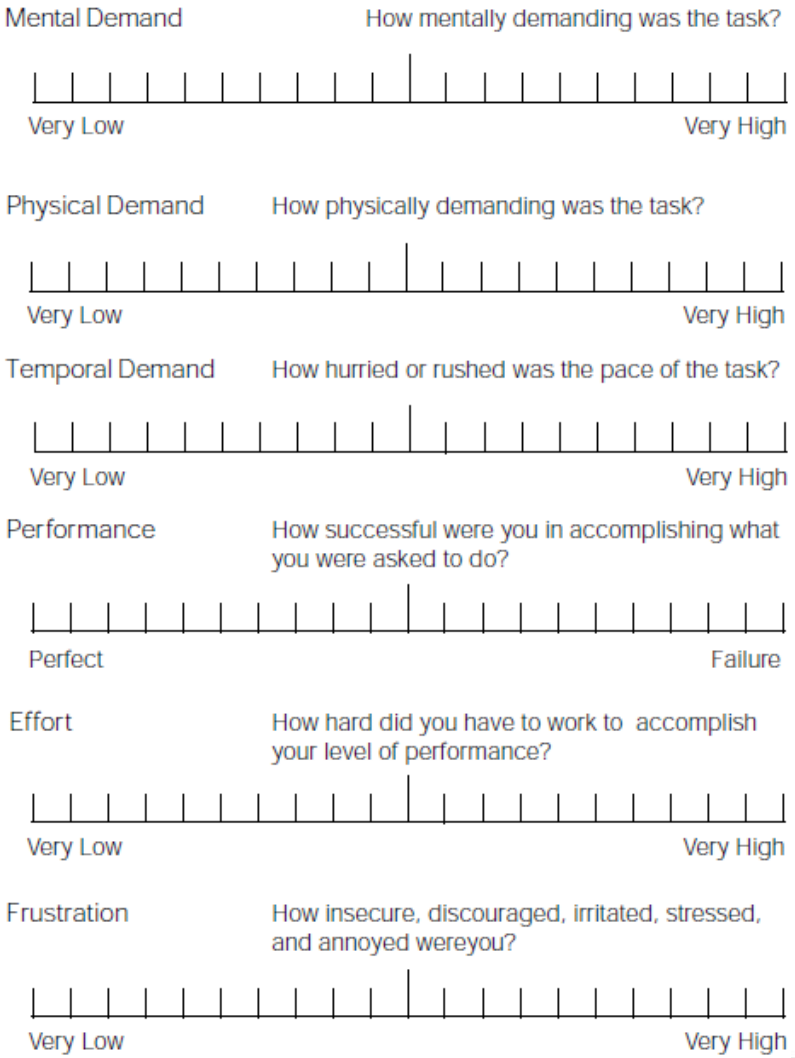


[Amelsberg & Kauertz, CREDOS D3-4, 2008]

Pilot work load rating

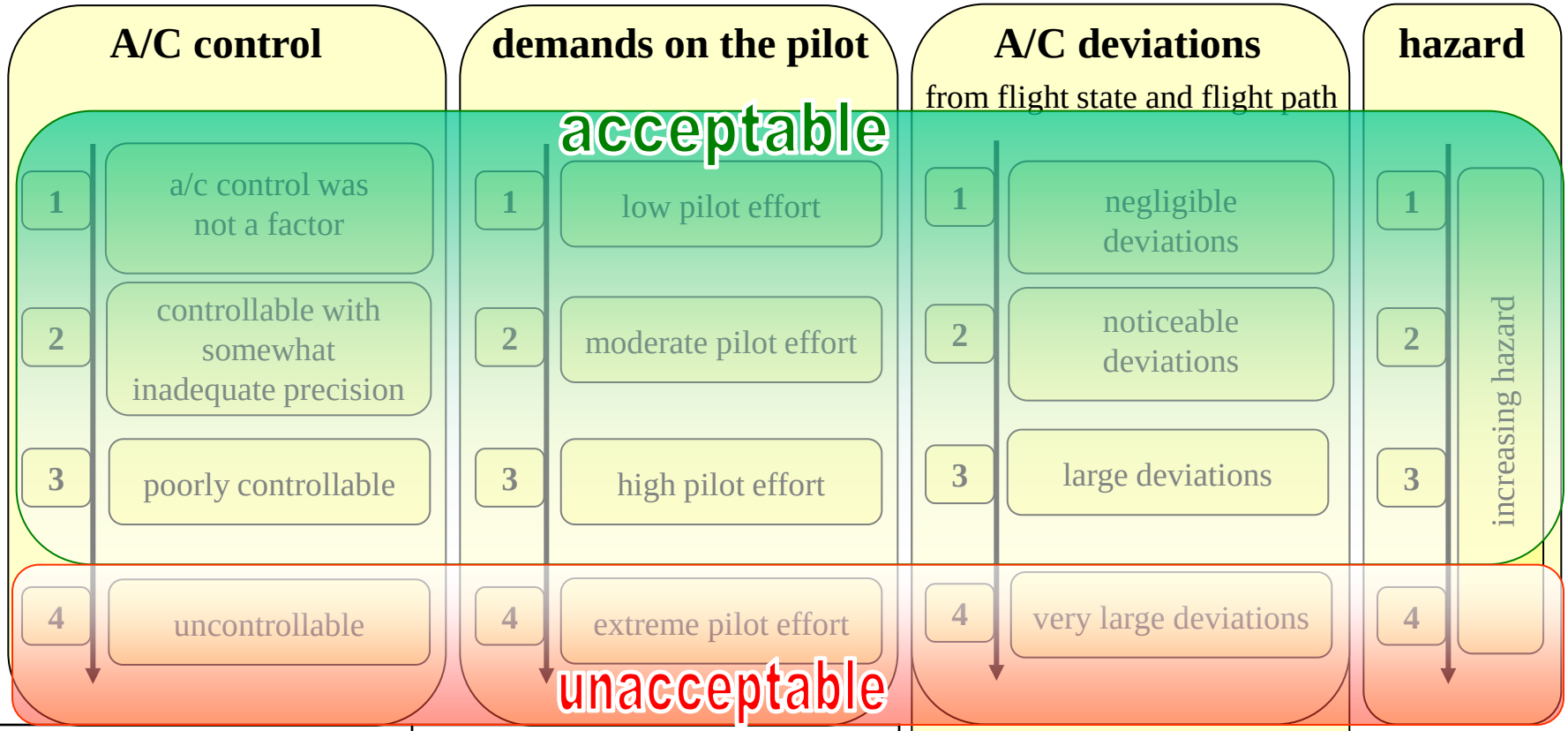
Modified Cooper-Harper/ NASA task load index (TLX)





Wake encounter severity criteria

Pilot evaluation rating scale [DLR IB 111-2011/46 Schwarz & Hahn]



how to use the rating scale:
- Subjective evaluation!
- Ratings after each test sequence
- 4 categories of rating (ratings 1-4, 4 unacceptable)
- A/C excursions: specify main factors of rating (no quantitative values of maximums necessary), GA requires rating of 4

- Hazard: to be treated independently from other rating, i.e. although the demands on the pilot might be high and considerable A/C excursions occur, the pilot might not feel unsafe and therefore corresponding subjective feeling of the threat is low (e.g. a safe GA is not hazardous!)

main factors for rating

bank angle
pitch
vertical speed
load factor/accelerations
airspeed
flight path deviations

Wake encounter severity criteria
Pilot view

IFALPA wake vortex policy 1998

- “1.3. IFALPA supports the 1997 US FAA Flight Standards position that no planned penetration of wake vortices of any intensity is permitted.” (1998)

IFALPA TECHNICAL MANUAL

PANS ATM

PROCEDURES FOR AIR NAVIGATION SERVICES AIR TRAFFIC MANAGEMENT

April 2011

- „1.2 Wake turbulence separation standards should ensure that aircraft are not exposed to known wake turbulence caused by preceding aircraft (= “No Encounter” Policy).” (2004)
- “1.4 IFALPA supports the 1997 US FAA Flight Standards position that no planned penetration of wake vortices of any intensity is permitted.” (1998)

Wake encounter severity analysis/ assessment

State of the art

[draft document "Wake Vortex Encounter Assessment - Literature Overview and Applications“, DLR internal report IB 111-2011/xx, C. Schwarz]

- Analytical Studies
  - qualitative analyses using simplified approaches
- Offline Simulations
  - qualitative and quantitative encounter analyses using models of various complexity
- Pilot-in-the-loop Simulations
  - quantitative encounter analyses using high fidelity real time models
    => development of encounter criteria
- Wind Tunnels Studies
  - using fixed and free flight models

  => validation of WV flow fields & aerodynamic interaction models (AIM)
- Flight Tests
  - data collection for incident/accident investigation
  - investigation of w/v attenuation devices
  - generation of w/v flow field and w/v encounter data bases

  => validation of w/v flow fields and aerodynamic interaction models (AIM)

  => validation of encounter criteria

Wake encounter severity criteria

State of the art

$RCR < 0.5 + 0.006 \cdot H_{RCRmax}$

GA prediction
[2002, Höhne,G., Reinke, A., Verbeek, M.]

RCR < 0.5

acceptable WVE
[1988, Rossow V. J., Tinling, B. E.]

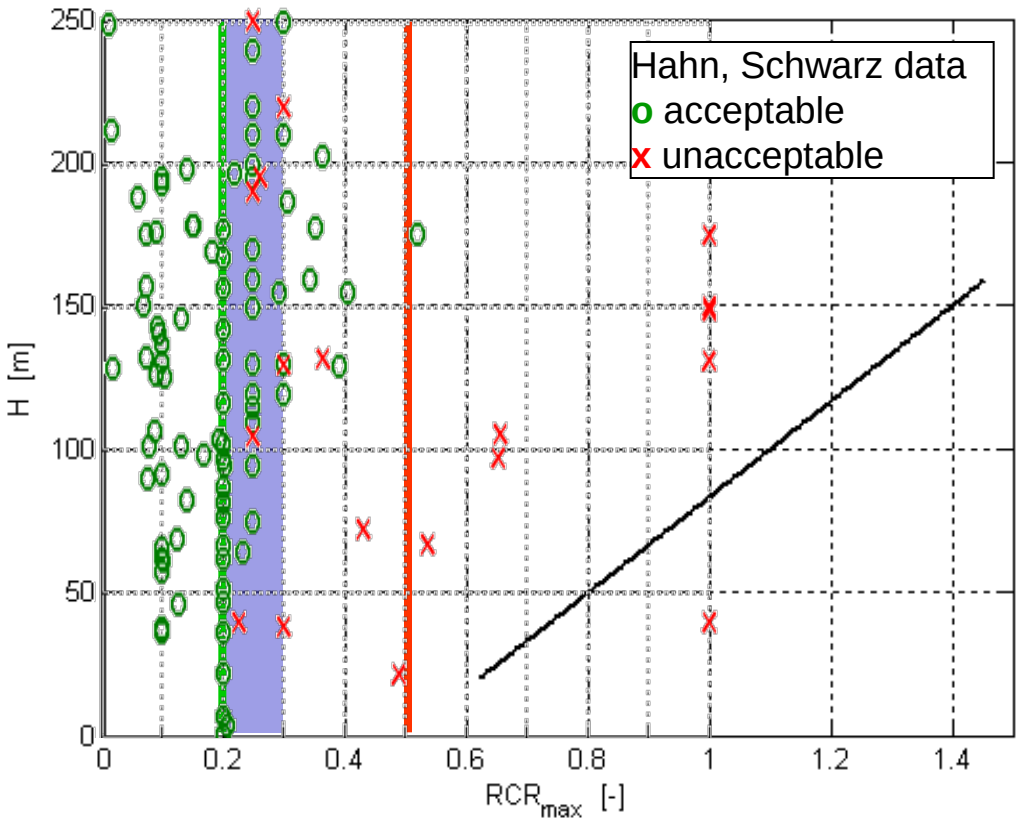
RCR < 0.2-0.3

appropriate limit for acceptable WVE
[1998, Stewart E. C.]

RCR < 0.2

operationally safe WVE
[2006, Hahn, K.-U., Schwarz, C.]

- CREDOS (EU FP 6) multiple severity criteria
- RECAT/ SESAR JU
- FAA risk matrix activity
- WakeNet3-Europe (EU FP 7) task group “safety assessment”



no commonly accepted severity criteria available

Wake encounter severity criteria

State of the art

$RCR < 0.5 + 0.006 \cdot H_{RCRmax}$

GA prediction
[2002, Höhne,G., Reinke, A., Verbeek, M.]

RCR < 0.5

acceptable WVE
[1988, Rossow V. J., Tinling, B. E.]

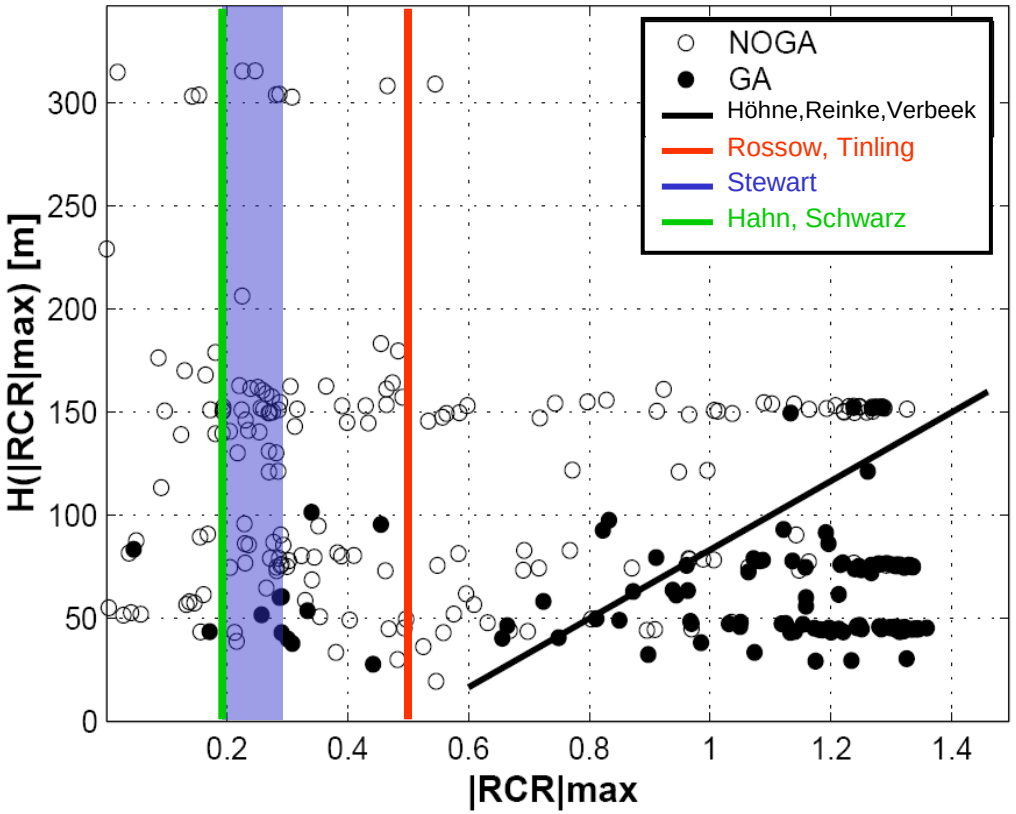
RCR < 0.2-0.3

appropriate limit for acceptable WVE
[1998, Stewart E. C.]

RCR < 0.2

operationally safe WVE
[2006, Hahn, K.-U., Schwarz, C.]

- CREDOS (EU FP 6) multiple severity criteria
- RECAT/ SESAR JU
- FAA risk matrix activity
- WakeNet3-Europe (EU FP 7) task group “safety assessment”

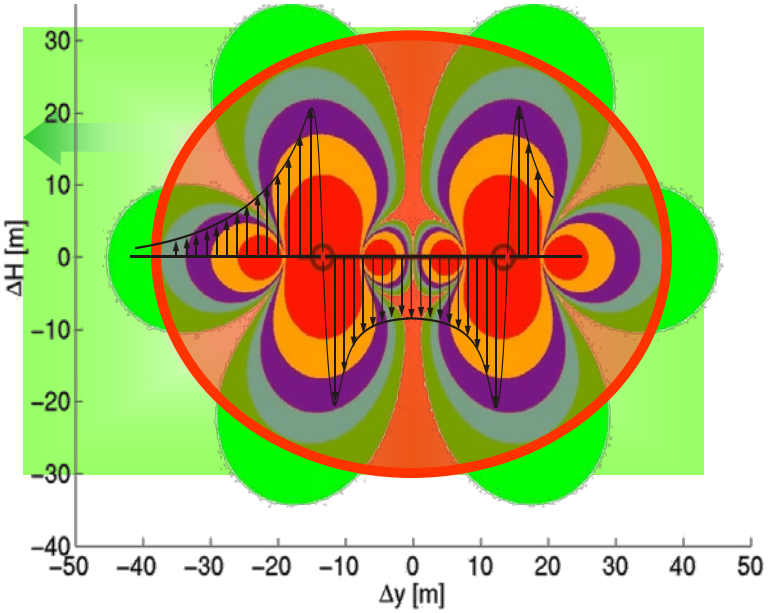


no commonly accepted severity criteria available

Wake encounter severity assessment

Simplified Hazard Area (SHA)/
Simplified Hazard Area Prediction (SHAPe)

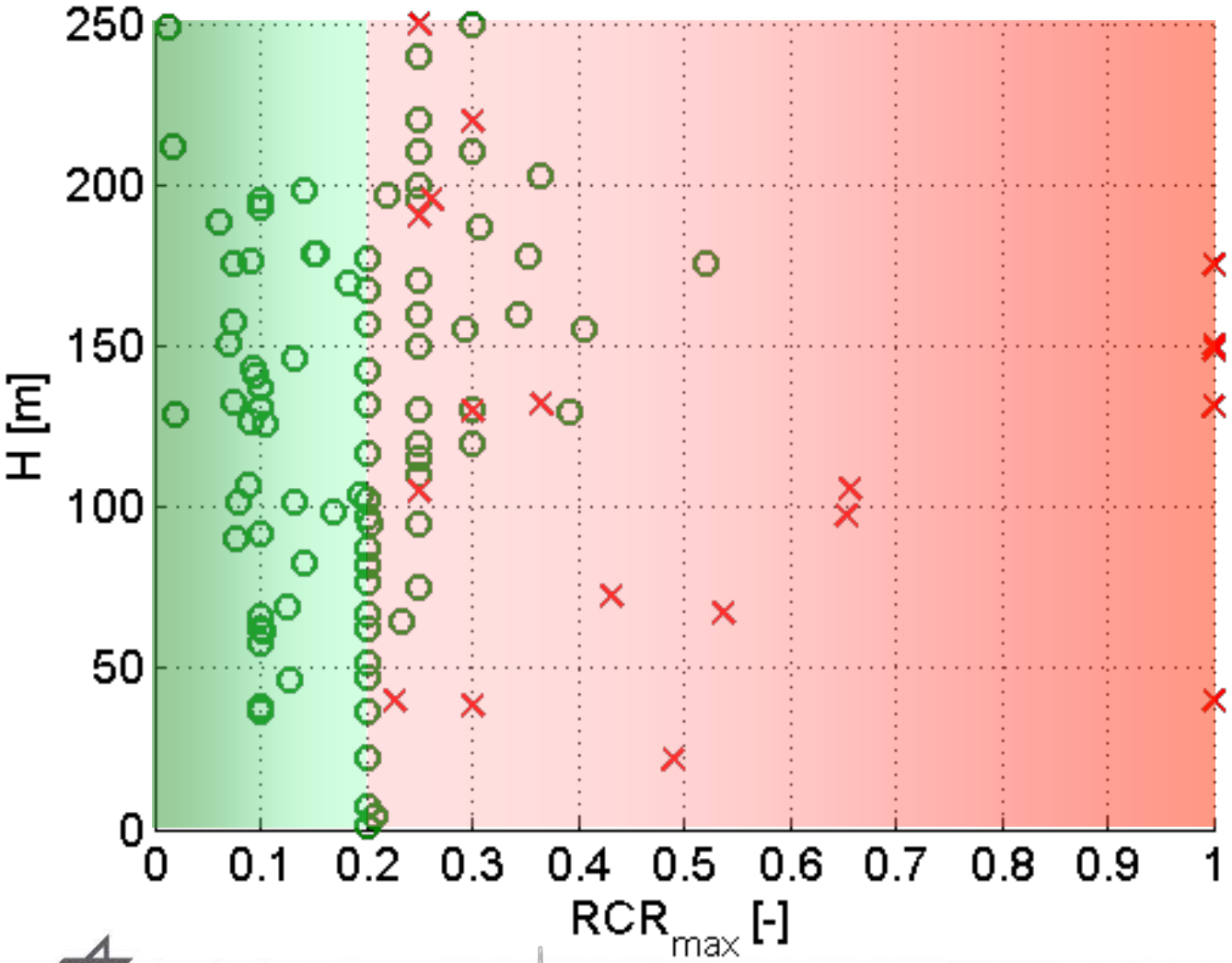
Roll control ratio RCR



- „How close can an aircraft fly safely to a wake vortex?“
- DLR concept: Simplified Hazard Area (SHA)
  - conservative/ non-hazard approach, safe and undisturbed operations possible outside the hazard area, no go-arounds
  - simple, robust severity criterion
  - roll control ratio: one parameter to cover complete A/C reaction
  - validated with pilot-in-the loop simulator & flight tests
  - dynamic (vortex decay, weather)
  - A/C categories and individual/ pairwise
- Simplified Hazard Area Prediction (SHAPe) based on MTOW

Wake encounter hazard area limit results

Manually flown (non controller augmented) ILS approach



o acceptable (95)

x unacceptable (19)

(4 pilots - DLR experimental pilots)

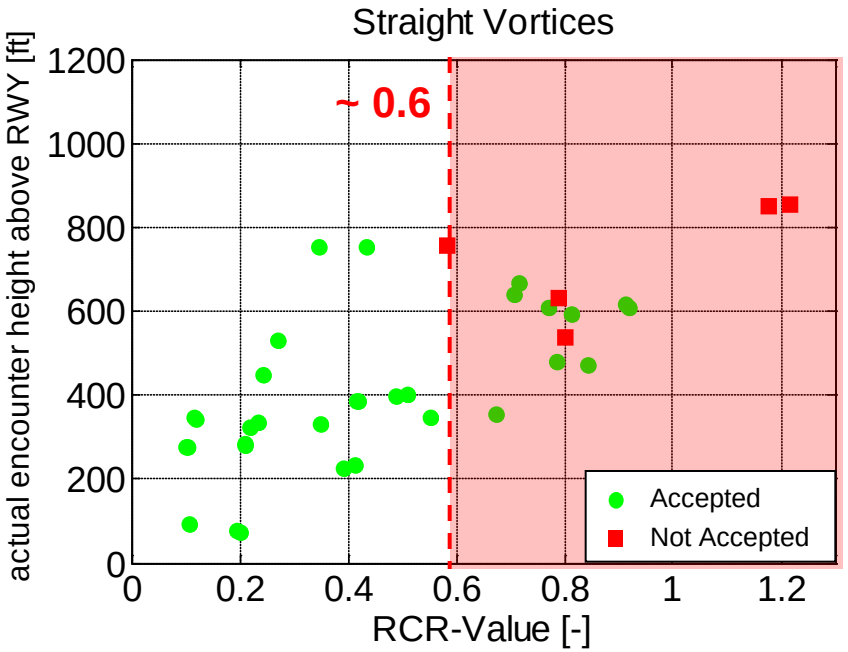
Piloted Studies at DLR on the Influence of Vortex Deformation on Encounter Hazard/ Severity

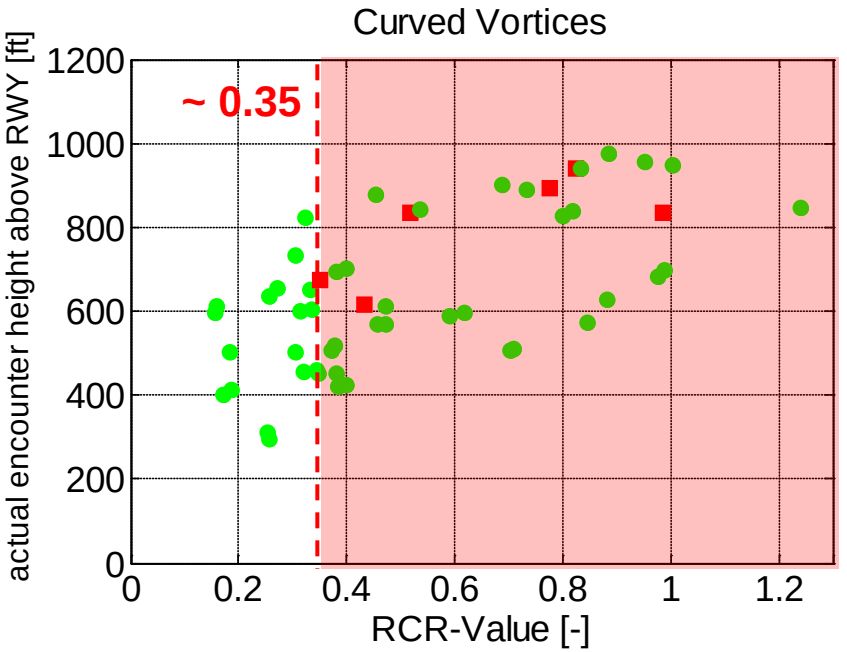
- comprehensive simulator campaign and several in-flight simulation flight tests
- A330 Simulator Campaign
  - 110 encounters
  - curved (wavy) and straight vortices
  - motion-based full-flight-simulator
  - encounters under manual control and with autopilot engaged
- ATTAS In-Flight Simulation
  - 31 encounters
  - wavy vortices and ring vortices
  - vortex flow fields derived from LES for different vortex ages
- time-fixed encounters
- dedicated encounter rating scale for pilot ratings
- correlation between pilot rating and maximum RCR as severity metric

Vortex Deformation Influence on Encounter Hazard/ Severity

A330 Simulator Campaign

- Only 11.6% (11 of 95) unaccepted encounter

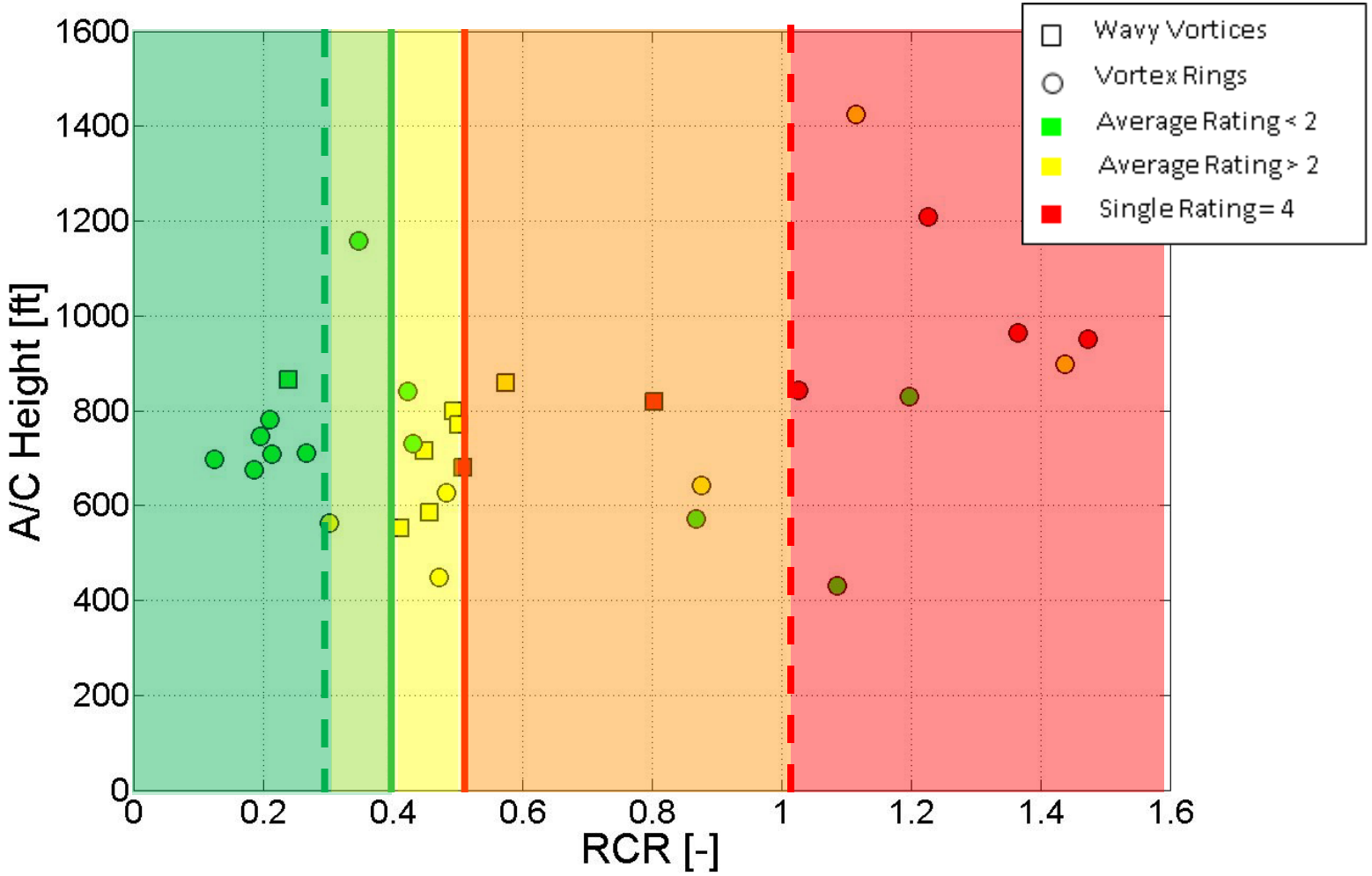




- Relatively high acceptance threshold may come from controller-augmented flight control system (compared to previously investigated threshold of RCR = 0.2)

Vortex Deformation Influence on Encounter Hazard/ Severity

ATTAS In-Flight Simulation



Piloted Studies at DLR on the Influence of Vortex Deformation on Encounter Hazard - Outcomes

- Vortex deformation seem to increase encounter severity
  - Encounters with higher dynamics
  - More unforeseeable for pilots
  - In spite of shorter duration aircraft response in the same magnitude
- With controller-augmented flight control systems vortex deformation seem to increase risk of pilot-induced/involved-oscillations (PIO)
  - Dynamic interaction between pilot control commands and FCS control commands
  - Training effect could be observed → possibly WVE training for pilots useful
- For weak encounters vortex deformation seem to be a negligible factor
- Investigation supports “harmlessness”-boundary of RCR = 0.2 found by DLR in previous analysis (straight vortices)
- Actual unacceptance-threshold varies widely with degree of vortex deformation
- Less roll dominant encounter seem to be rated better by pilots
- The more deformed vortices are the wider is the “yellow” region of acceptance
- “Harmlessness”-boundary not influenced significantly by vortex deformation

Wake encounter severity analysis/ assessment
FAA activities

FAA activity “Characterizing wake vortex encounters for hazard analysis” for Safety Management System (SMS) purposes

- purpose
  - develop wake hazard severity matrix
  - develop standards for determining acceptability of wake vortex encounters from a pilot’s perspective
  - develop metrics to evaluate wake vortex encounters in terms of hazard severity and acceptability
- piloted simulations in full motion flight simulators (B737 and A330)

wake encounter rate & intensity 'baseline'

- developing models/ analysis tools to determine today's wake vortex encounter frequency/ intensity (NAS - US National Airspace System)

Wake Vortex Encounter Severity Criteria
Presentation outline

1. Introduction (background, motivation/ focus/ goals, synopsis document, Related activities and documents)
2. Severity Assessment/ Criteria general considerations (Application types, Evaluation types, Possible steps, severity boundaries/ limits, Acceptability vs. unacceptability)
3. Severity Assessment state of the art (pilot evaluation rating scales, pilot view, severity analysis/ assessment activities, severity criteria, vortex deformation, FAA activities)
4. Applications/ tools
5. Available data (evaluated piloted wake vortex encounter data, wake vortex aircraft data)

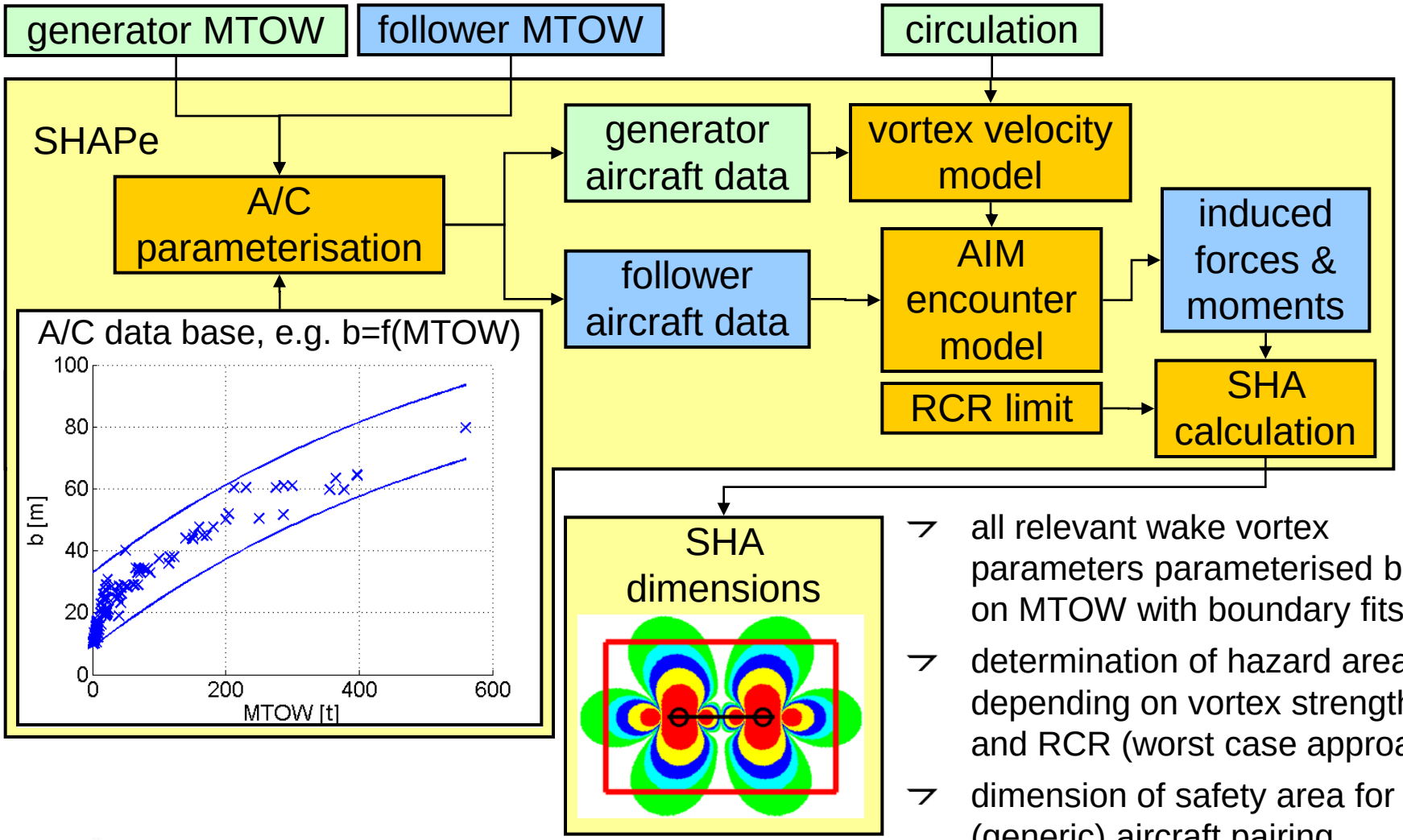
Applications/ tools

- Airspace Simulation
  - ASAT: Airspace Simulation and Analysis for TERPS (Terminal Procedures)
  - WakeScene: Wake Vortex Scenarios Simulation
- Encounter Assessment
  - VESA: Vortex Encounter Severity Assessment
    - severity assessment based on a/c response computed by simulation
    - different criteria available
  - WAVIR: WAke Vortex Induced Risk assessment
    - severity assessment based on a/c response computed by simulation
    - criterion: bank angle = f (altitude)
  - SHAPe: Simplified Hazard Area Prediction
    - boundaries for operationally acceptable situations
    - criterion: RCR using a/c parameters

Applications/ tools

- ATM Advisory systems
  - AVOSS: Aircraft VOrtex Sacing System
    - demonstrated at Dallas/Fort Worth
    - considered to increase airport capacity
    - criterion: circulation strength
  - WakeVAS: Wake Vortex Advisory System
    - based on AVOSS experience
    - designed to minimize the impact of w/v on a/c operations
  - VFS: Vortex Forecast System
    - developed for ATC and pilots in order to reduce separations
    - criterion: admissible rolling moment as a function of speed
  - WVWS: Wake Vortex Warning System
    - designed to increase airport capacity
    - technically completed and applied at Frankfurt Airport
    - operational use gives not enough benefit
    - criterion: crosswind
  - SMP: Separation Mode Planner
    - developed to identify time windows with possible separation reduction
    - criterion: WAVIR, bank angle = f (altitude)
  - WSVBS: engl.: Wake Vortex Prediction and Observation System
    - under development to reduce separations
    - criterion: SHAPe, flight operations not affected by w/v, RCR limit

Simplified Hazard Area Prediction (SHAPe)



- all relevant wake vortex parameters parameterised based on MTOW with boundary fits
- determination of hazard area depending on vortex strength and RCR (worst case approach)
- dimension of safety area for any (generic) aircraft pairing

Wake Vortex Encounter Severity Criteria
Presentation outline

1. Introduction (background, motivation/ focus/ goals, synopsis document, Related activities and documents)
2. Severity Assessment/ Criteria general considerations (Application types, Evaluation types, Possible steps, severity boundaries/ limits, Acceptability vs. unacceptability)
3. Severity Assessment state of the art (pilot evaluation rating scales, pilot view, severity analysis/ assessment activities, severity criteria, vortex deformation, FAA activities)
4. Applications/ tools
5. Available data (evaluated piloted wake vortex encounter data, wake vortex aircraft data)

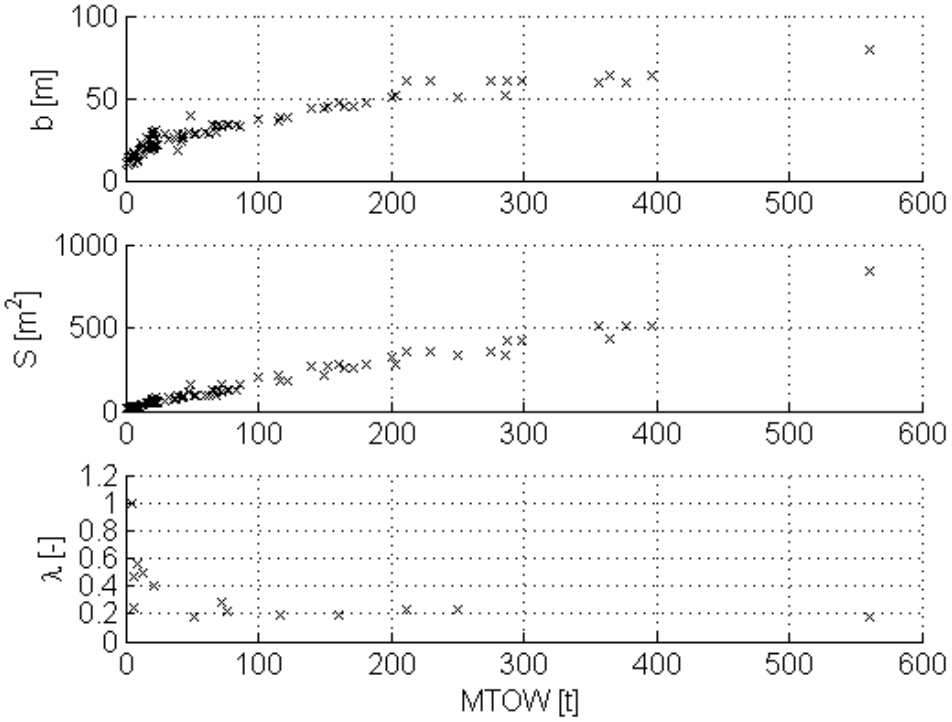
Evaluated piloted wake vortex encounter data
Overview

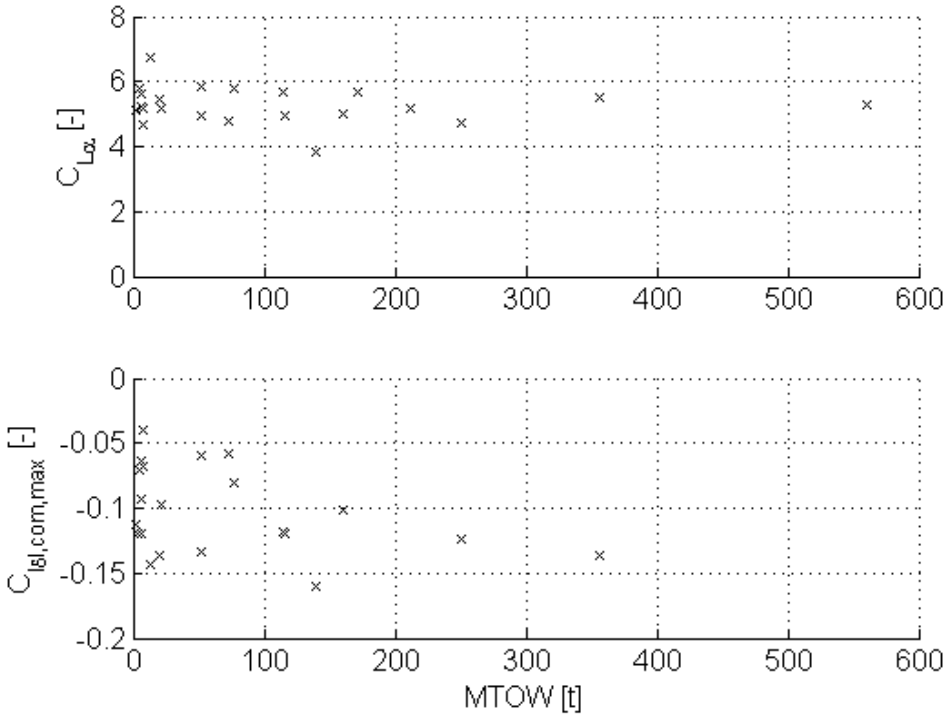
project/ activity	status/ time frame	no of encounters	flight phase	point of contact
DLR project Wirbelschleppe II (wake vortex II)	completed NOV 2003 - JUN 2006	114 (+8 as ref. for FCTL experiments)	landing approach	DLR (Carsten Schwarz)
S-Wake	completed JAN 2000 - MAR 2002	502	landing approach	Airbus
S-Wake	completed JAN 2000 - MAR 2002	163 (F100), 153 (Cessna Citation)	landing approach	NLR
S-Wake	completed JAN 2000 - MAR 2002	308 (Do 228), 497 (A330)	landing approach	TU Berlin (Robert Luckner)
CREDOS (EU FP 6)	completed 2008	576	takeoff and departure	Airbus
CREDOS (EU FP 6)	completed 2008	691	takeoff and departure	TU Berlin (Robert Luckner)
DLR project Weather & Flying (Wetter & Fliegen)	completed DEC 2007 - SEP 2009	47	takeoff and departure	DLR (Carsten Schwarz)
DLR project Weather & Flying (Wetter & Fliegen)	completed 2008 – 2011	110	landing approach	DLR (Dennis Vechtel)
DLR project Weather & Flying (Wetter & Fliegen)	completed 2008 – 2011	31	landing approach	DLR (Dennis Vechtel)
DLR project Weather & Flying (Wetter & Fliegen)	completed 2008 – 2011	26	landing approach	DLR (Christian Horn)
DLR project WOLV (weather optimised air traffic)	2012 - ongoing			DLR
[1988, Rossow & Tinling]				
[1998, Stewart]				

Wake vortex aircraft data
Database

- data sources
- main source: Eurocontrol Base of Aircraft Data (BADA)
- another primary source: type certificate data sheets (TCDS) by EASA, FAA, CAA
- additionally aircraft manufacturers, textbooks/ publications like Jane's All The World's Aircraft, AW&ST Aerospace Source Book, Jenkinson - Civil Jet Aircraft Design
- encounter aircraft data like lift curve slope and maximum roll control power are mainly obtained from NASA/ FAA/ journal publications

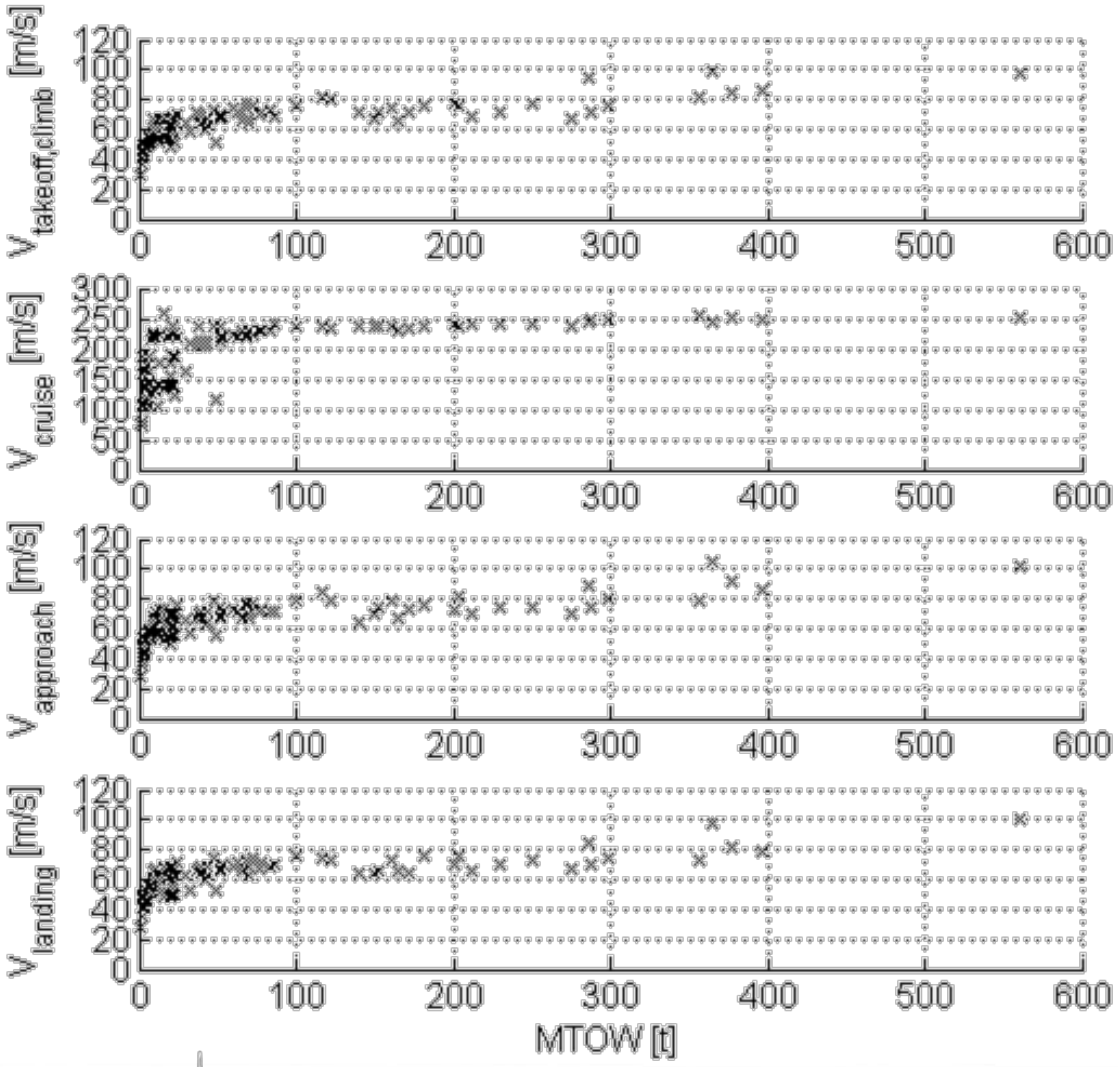
Wake vortex aircraft data
Database





Wake vortex aircraft data

Database



Wake Vortex Encounter Severity Criteria
Conclusions

- Motivation/ goals
  - no commonly accepted severity criteria available
  - agreed next steps toward commonly accepted severity criteria, requirements, definitions
  - overview on available data, tools/ methods
- Severity Assessment/ Criteria general considerations (Application types, Evaluation types, Possible steps, severity boundaries/ limits, acceptability vs. unacceptability)
- Severity Assessment state of the art (pilot evaluation rating scales, pilot view, severity analysis/ assessment activities, severity criteria, vortex deformation, FAA activities)
- Applications/ tools
- Available data (evaluated piloted wake vortex encounter data, wake vortex aircraft data)