FMRA
Fachgebiet Flugmechanik, Flugregelung und Aeroelastizität

Assessment of Wake Vortex Encounter Severity

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WakeNet3-Europe

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Why are Wake Vortex Encounter (WVE) Severity Criteria necessary?

- It has to be demonstrated that new air traffic regulations and procedures (or proposed revisions of existing ones) are safe (ESARR4, safety case).
- That is also true for minimum wake vortex separation standards.
- Criteria are needed for definition of safe minimum WV separations. They are needed to distinguish between safe and unsafe WVE.

➡ WVE severity criteria are the key for new (or revised) WV separation standards

Criteria development and application

FCOM (Flight Crew Operational Manual)

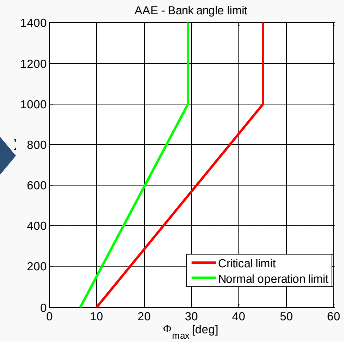
Normal / special procedure

WVE data (sim / flight), pilot ratings
S-Wake, CREDOS
WEHA, CruisEnc

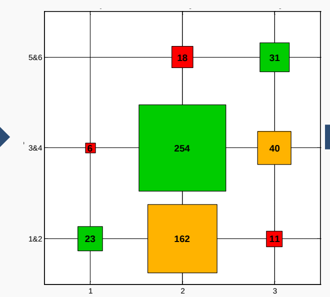
References
R.I. Sammonds
J. Wilborn
A. Reinke

Σ

Selection of metrics, Choice of envelope limits



Criteria validation (Time histories & Questionnaires)



Severity criteria model

SC

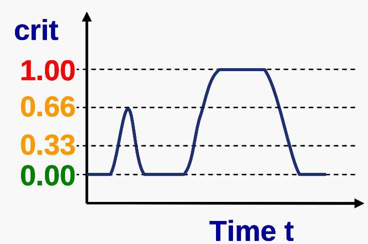
Wake Vortex

Control inputs

Normal / special procedure

Monte Carlo Simulation

SC



WVE risk analysis / hazard rating

General thoughts

Hazards to aircraft are caused by:

- Failures → design (fail safe), redundant system architecture (fail operational)
- Atmospheric phenomena (tropical thunderstorms, crosswind at takeoff and landing, wind shear, icing, volcanic ash) → avoidance, predictions
- Collision with other traffic, terrain → separation rules, systems (TCAS, EGPWS)
- Human capabilities and limitations → training, procedures, rules (e.g. duty times)
- etc.

Hazards are different in nature

Counter measures to contain a hazard depend on the hazard's nature

➡ Are there concepts that can be applied to WVE hazard assessment?

General thoughts

Counter measures against atmospheric hazards (wind) in aircraft design and aircraft operations

- Gust loads for aircraft structural design → stress, fatigue computation
- Control surface design → sizing of rudder for crosswind operations
- Flight control law design → functions for disturbance rejection
- CAT III autoland design → test of robustness against tailwind and crosswind
- Flight planning and during flight → avoidance of severe weather, speed reduction
- ...

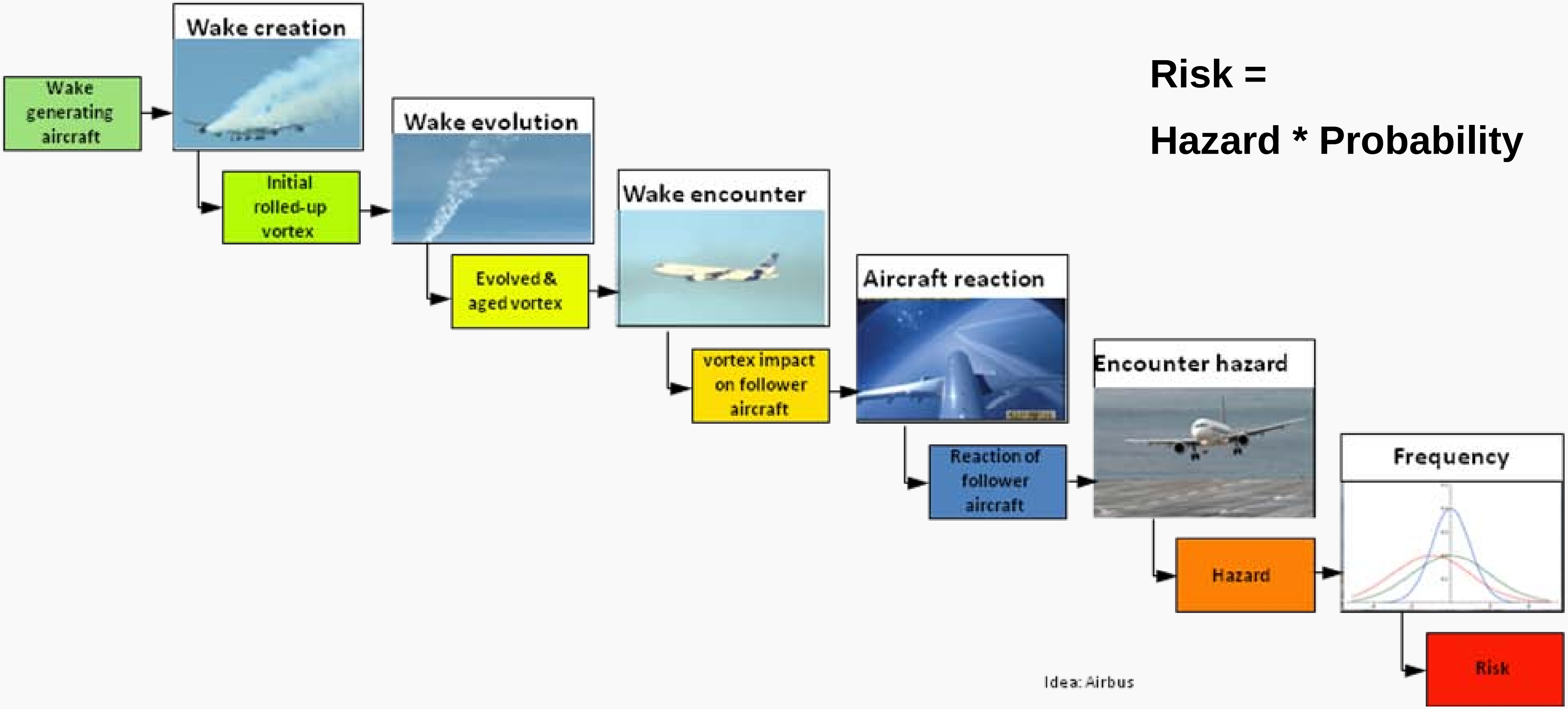
→ Multiple and different counter measures are applied. They require the definition: What is hazardous?

Can this definition be applied to WVE hazard?

From wake vortex generation to encounter risk

Risk =

Hazard * Probability



MTOW, b_g Γ_0 **$\Gamma(t)$** **L_{WV}, l_{WV}, n_{WV}, b_g/b_f** **p, Φ, n_z, …** **Pilot rating, criteria, consequences** **Probability of severe WVE**

ICAO
PANS RAC (Doc. 4444)

RECAT
Phase I

Hazards are assessed by their consequences on

- Aircraft structure
- Pilot workload, cabin crew
- Passengers
- Flight mission

Assessment on pilot workload is done in flight simulations, flight test or during flight operations

- Time consuming (expensive)
- Subjective
- Statistical investigations

→ A model that predicts pilot ratings from objective data is necessary

Where are pilot ratings used for hazard assessment?

	Evaluation by:
• Development of handling quality criteria • Certification requirements (MIL-F 8585C), today guidance (MIL-STD-1797)	➔ Test pilots
• Aircraft design • Definition of a/c configuration • Flight control law development • Definition of system architectures, redundancy • Assessment of failure cases (EASA CS 25.1309) • Aircraft and systems certification	➔ Test / certification pilots

Test pilots (aircraft manufacturer); Certification pilots (authorities); (Technical pilots (airlines))

Assessment of safety critical issues is done by qualified pilots

This method is accepted for aircraft certification

Can we apply this methodology to WVE severity assessment?

1954

- First investigations by Blevis, 1954

  Blevis Z.O.: Theoretical investigation of light plane landing and take-off accidents due to encountering the wakes of large airplanes. Report SM-18647, Douglas Aircraft Company Co. Santa Monica, CA, 1954

1961

- Investigations of vortex effects on encountering aircraft

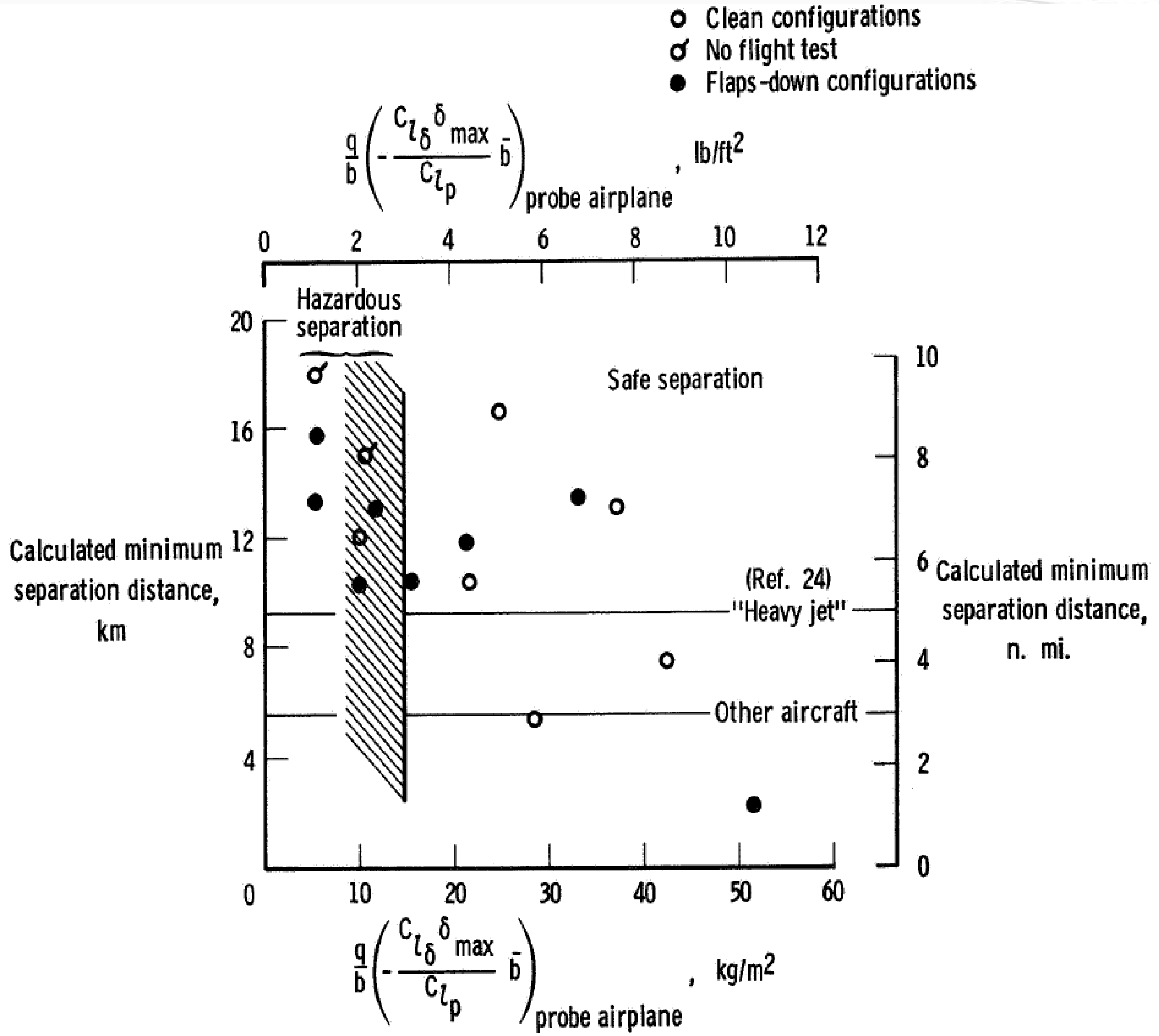
  McGowan WA. Calculated normal load factors on light airplanes traversing the trailing vortices of heavy transport airplanes. NASA TN D-829, May 1961.

  Rose R, Dee FW. Aircraft vortex wakes and their effects on aircraft. Tech. Note No. Aero. 2934, British Royal Aircraft Establishment, December 1963.

- Research for more than 50 years

1972

Limit: RCR = 1



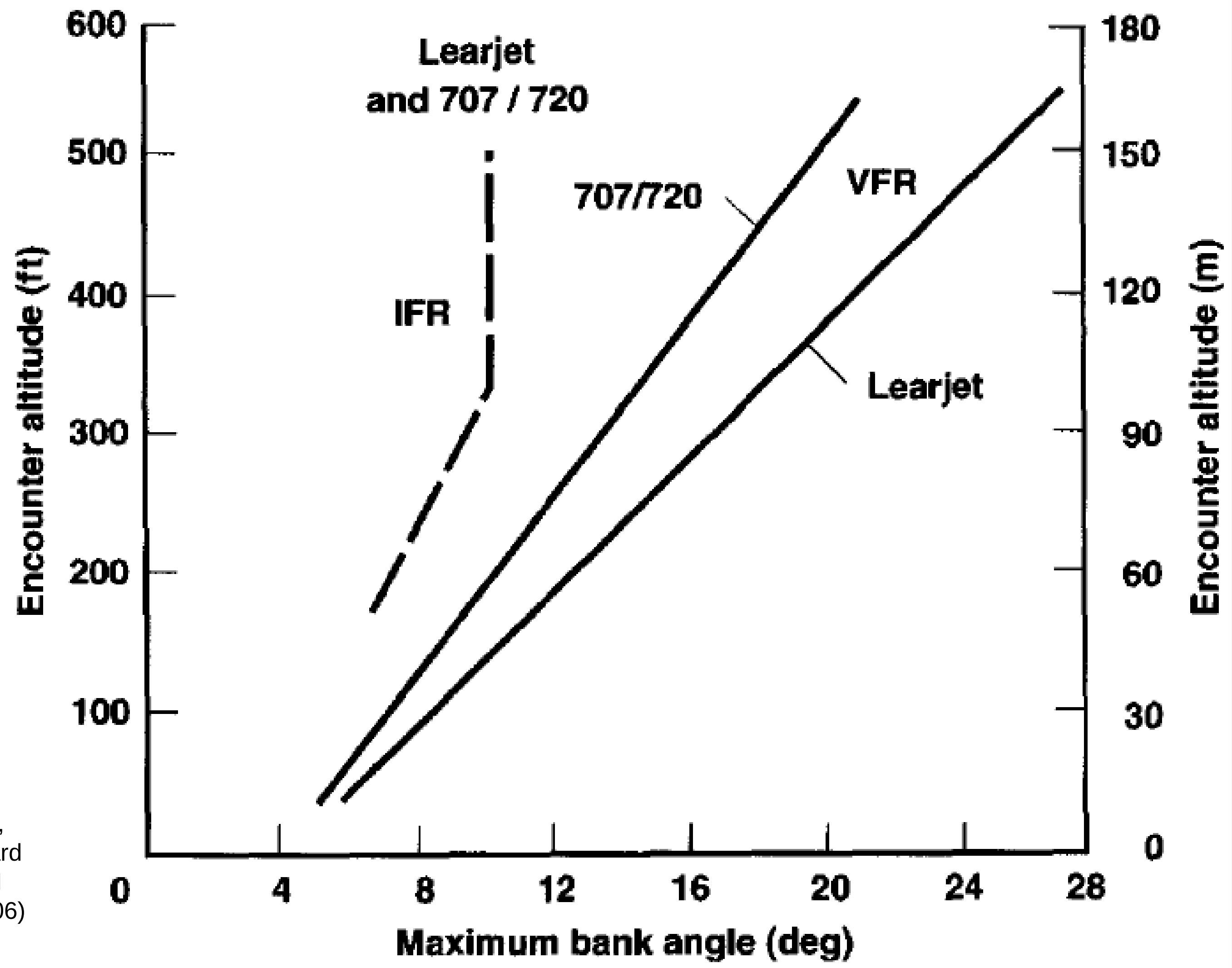
Source: Robinson G.H., Larson R.R.: 'A Flight Evaluation of Methods for Predicting Vortex Wake Effects on Trailing Aircraft'; NASA TN-D-6904, November 1972

1975

Limit: Φ_{max} =f(h)

and $\ddot{\Phi}_{max}$

Vortex hazard boundaries from NASA simulation experiments

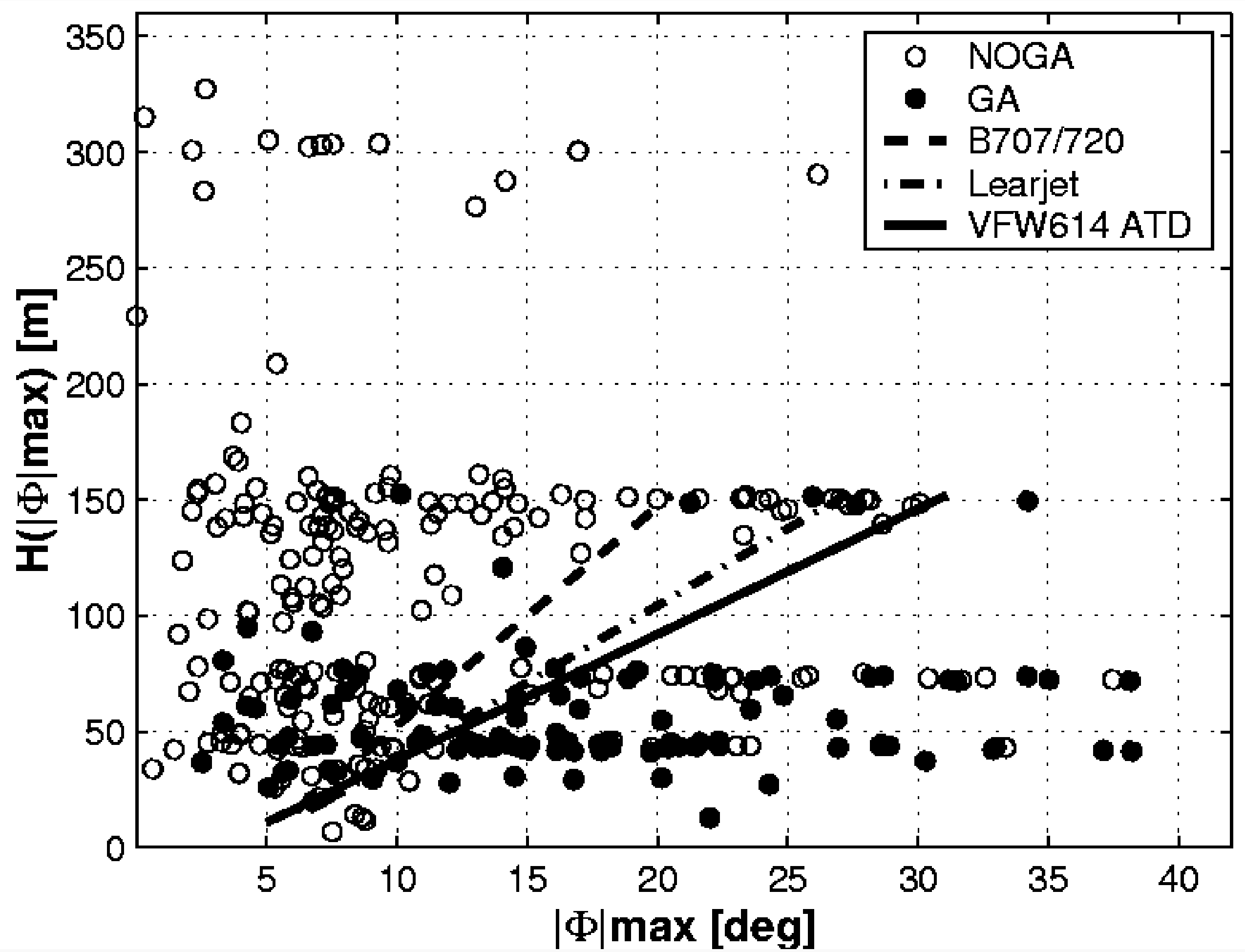


Source: Sammonds R.I., Stinnett Jr G.W., Larsen WE: 'Wake vortex encounter hazard criteria for two aircraft classes'; NASA TM X-73,113, June 1976 (also FAA RD-75-206)

2003

S-WAKE tests

VFW614-ATD



Source: Luckner R.,Höhne G., Fuhrmann, M. 'Hazard Criteria for Wake Vortex Encounters during Approach', Elsevier Aerospace Science and Technology, 8, pp 673-687, 2004

2003

S-WAKE tests

two parameter criterion

Metrics

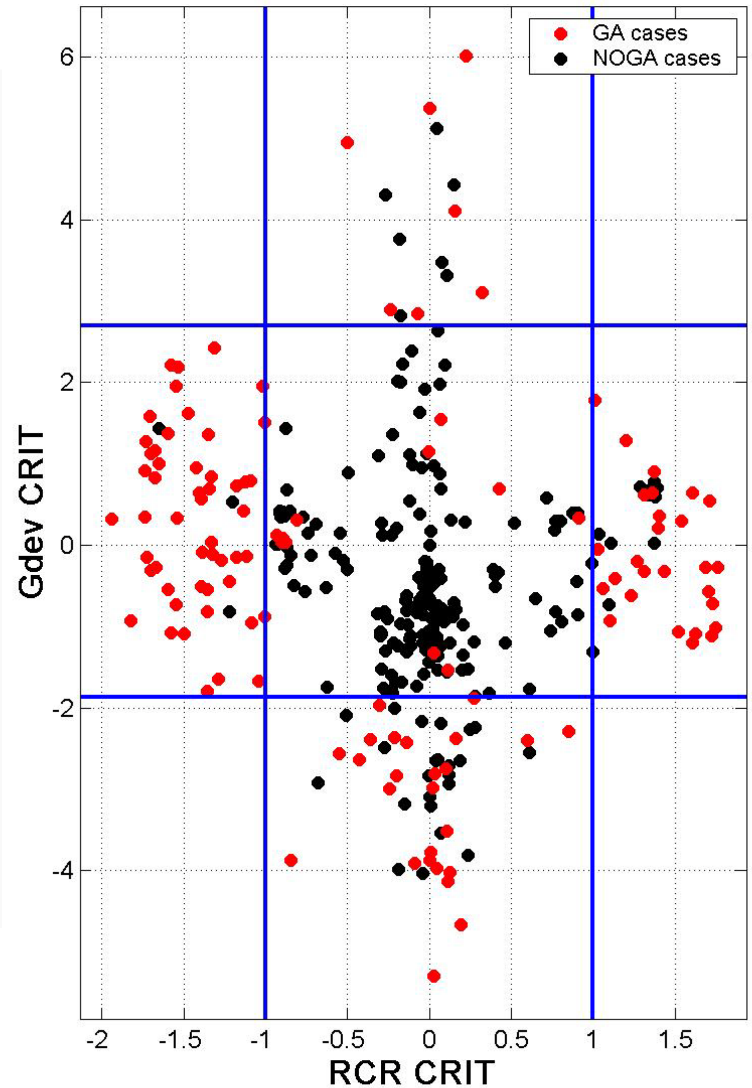
Roll control ratio (RCR)

$$\frac{\dfrac{\ddot{\Phi}_{WV}}{\ddot{\Phi}_{a/c_{max}}}}{0.006H + 0.5}$$

Glide slope parameter (Gdev)

$$\frac{\Delta GS + \dfrac{4 \cdot \dfrac{d\Delta GS}{dt}}{}}{\max(0.12H; 3.6)}$$

337 test cases
Prediction accuracy 85%



Criteria types

- Single parameter criteria
  - Constant
  - Function of H, flight phase, a/c configuration, …

- Two parameter criteria (S-WAKE)

- Multi parameter criteria and models (TU Berlin, CREDOS)
  - Analytical function (Reinke, S-Wake)
  - Multiple two parameter envelopes (Wilburn, Reinke, Kauertz, Amelsberg)
  - Cluster analysis (Amelsberg)

FAA Methodology

- **presented at WakeNet US**
  - **Stephen Barnes: „Characterising Wake Vortex Encounters for Hazard Analysis / Safety Management System Purposes“, WakeNet US, October 20, 2010**
  - **Stephen Barnes: „FAA Process for Establishing Wake Vortex Separations“, WakeNet US, March 2011**
- **A risk matrix (SMS risk matrix) and probability definitions (SMS risk table) are proposed, that are defined in the FAA Safety Management System Manual, Version 1, July 24, 2003**
- **WVE severity definitions are given:**
  - **effects on safety: negligable, minor major, hazardous, catastrophic**
  - **observable results on a/c attitude changes, deviations from approach path, missed approach, a/c control / flight crew reaction, ASRS report or equivalent, effects on occupants**

Conclusions

- Methods and criteria to assess WVE severity have been extensively investigated. They exist and have been demonstrated in research projects.
- Limits that distinguish acceptable and unacceptable encounters have been proposed.
- However, an agreed definition of what is acceptable does not exist
- Therefore, methods and criteria have not yet been applied in safety assessments of ATC procedures and in rule making; instead indirect measures are used (MTOW, circulation, …)
- FAA has proposed an acceptable way ahead for tasks like that:

  Greenhaw, R., Barnes, S., Pate, D., Lankford, D., McCartor, G., Ladecky, S., The New FAA Flight Systems Laboratory's Impact on Flight Procedure Design. Paper AIAA 2005-5880, AIAA Modeling and Simulation Technologies Conference and Exhibit, 15-18 August 2005, San Francisco, California, 2005.
- What has to be done? Who is in lead of that activity? Who are the stakeholders?