NLR Air Transport Safety Institute

Research & Consultancy

Wake vortex severity criteria
towards a unified approach for atmospheric disturbances?

Peter van der Geest

June 2, 2010

Observations and Questions

NLR Air Transport Safety Institute
Research & Consultancy

- **For applications in the area of wake vortices a standard wake vortex severity assessment criterion is strongly needed.**
- **Is there currently a widely accepted wake vortex severity criterion?**

Wakenet3-Europe Jan 2008

- **Why is this problem not solved?**

- CREDOS (EU FP 6) severity criteria under development
- WakeNet3-Europe (EU FP 7) task group “safety assessment”
- RECAT/ SESAR JU

- **What direction to go?**

no commonly accepted severity criteria available

Many have been proposed, ...but characteristics for a successful criterion are unclear

Experience from windshear

In the 70's and early 80's several windshear accidents occurred

Initiatives were taken to solve this problem

- windshear training aid
- reactive windshear detection and guidance systems
- predictive windshear detection systems

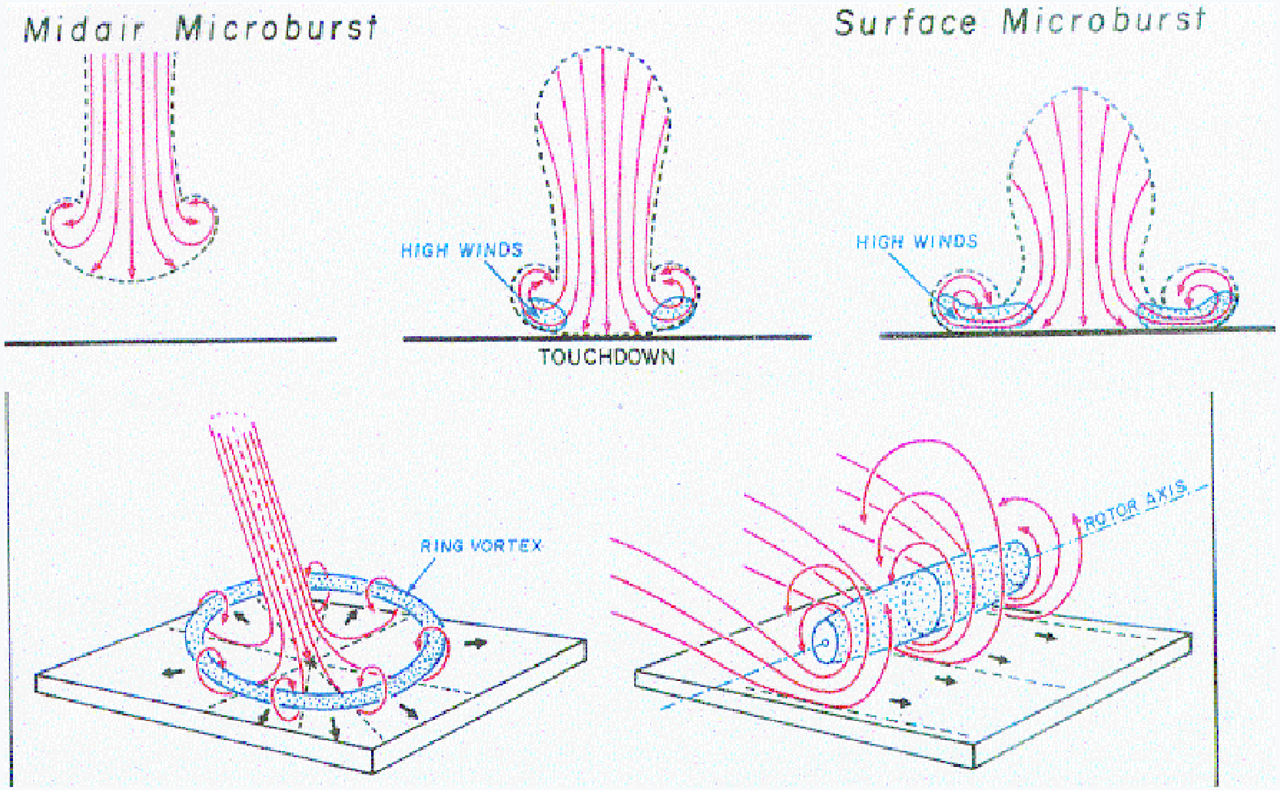
Question how to define the severity of a windshear encounter?

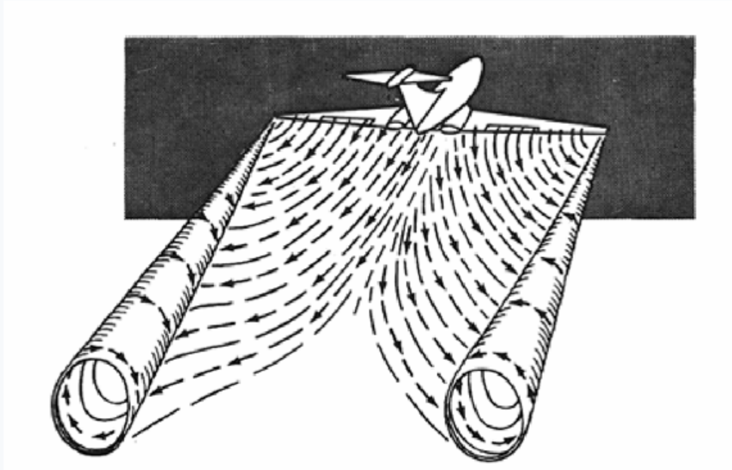
- Warning should be early enough for successful escape
- Warning should be robust against nuisance alerts
- Generally applicable (Advisory Circulars)

Many proposals

- Energy criteria
- Performance ratio criteria
- Pilot in the loop models, optimal control models, etc

Windshear vs. Wake Vortex





Early initiatives at Fokker

Difficulty to clearly discriminate between various forms of atmospheric disturbances, such as: Windshear, Microburst, Mountain waves, Turbulence, Gusts & Wake vortex

All can be characterized by summation of vortices of different scales, strength and form (ring vortices, line vortices, free form vortices)

⇒Windshear & Wake vortex are just special forms of atmospheric disturbance

Criterion should address performance and handling

$C = k_1$ (Energy rate) + k_2 (induced moments)

C would be a distinct fingerprint characterizing different disturbances

Severity factor

Criterion

$$C = \frac{\dot{W}_x}{g} - \frac{W_h}{V} + \left| k_1 \frac{p_{eq} b}{2V} + k_2 N_{eq} \right|$$

where

$\dot{W}_x$ = Horizontal component of the wind rate of change expressed in g units (positive for decreasing headwind).

W_h = Vertical component of the wind vector w (m/sec) (positive for updraft).

V = True airspeed (m/sec).

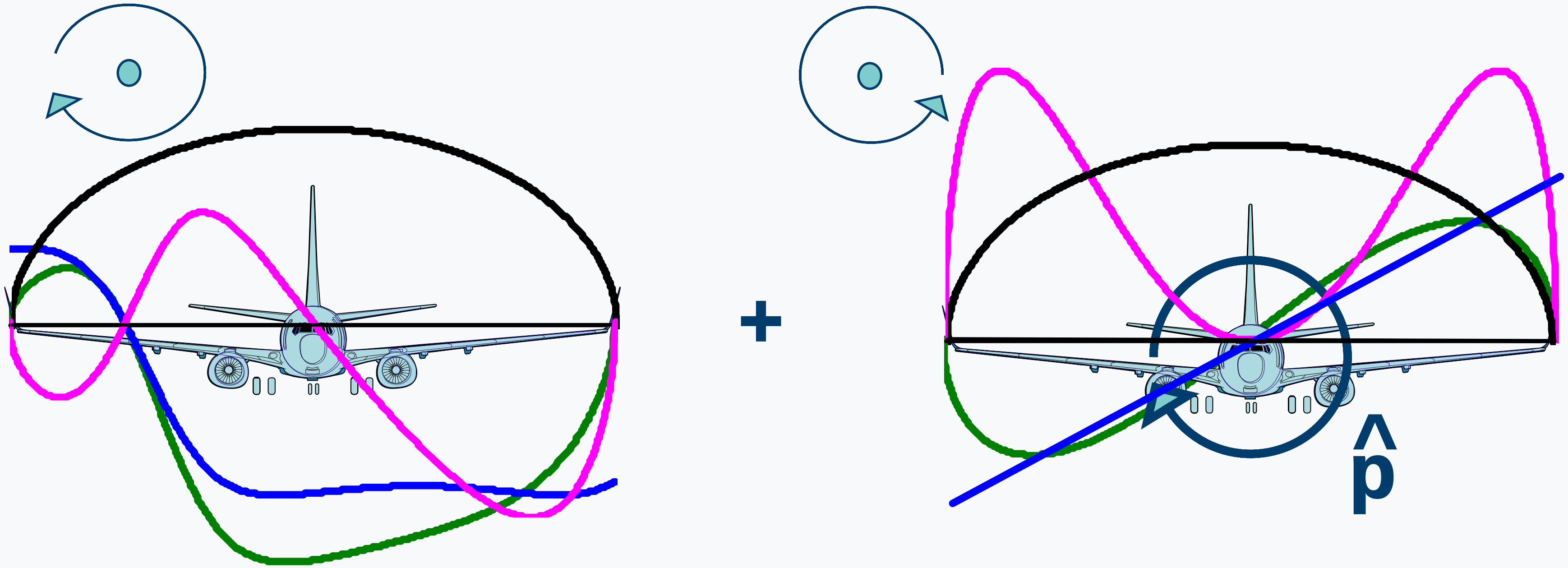
g = Gravitational acceleration (m/sec^2).

p_{eq} = equivalent roll rate

N_{eq} = equivalent load factor

k1, k2 = tuning factor

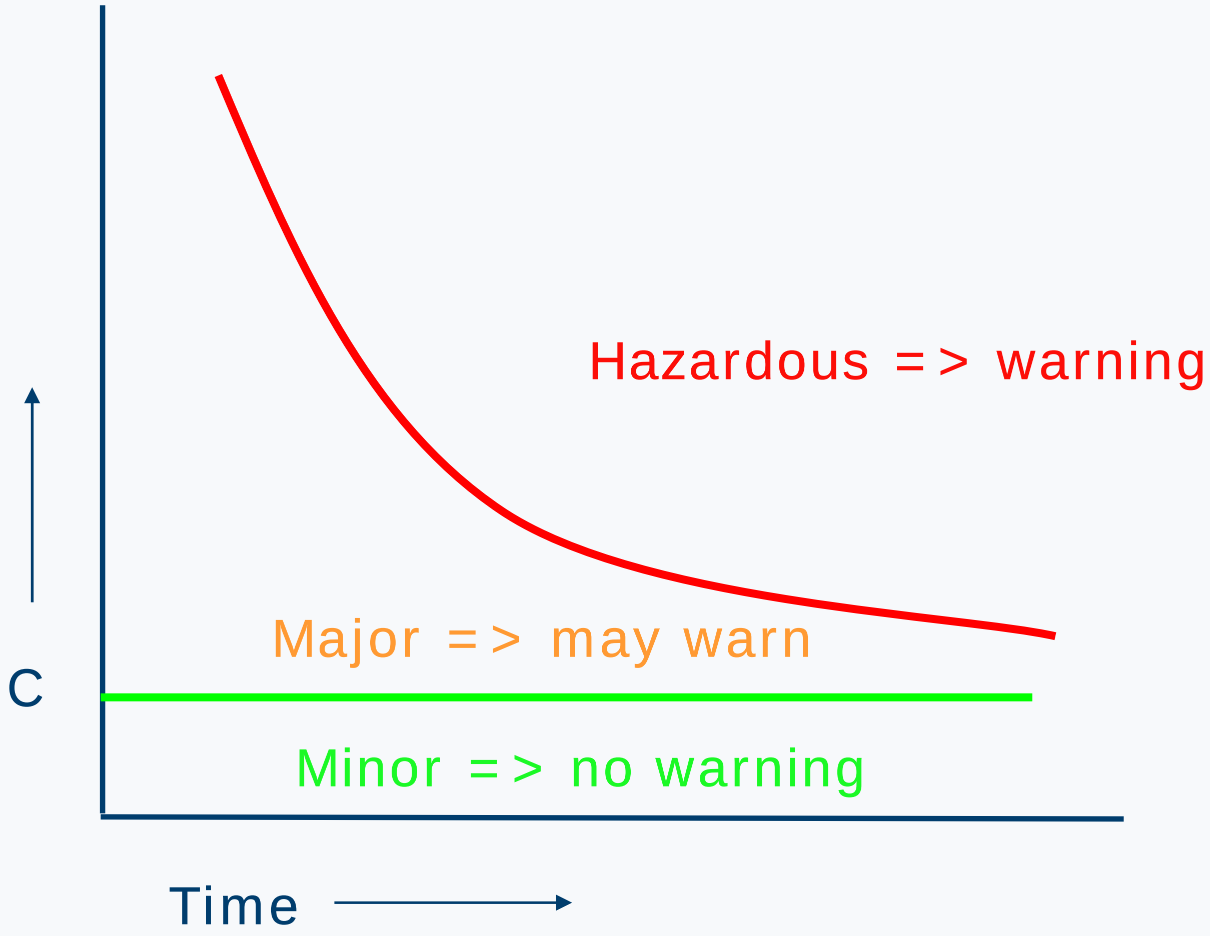
Equivalent roll rate



$$= 0 \Rightarrow P_{equivalent} = \hat{p}\, b / 2V$$

- angle of attack distribution
- nominal lift distribution
- induced lift distribution
- rolling moment distribution distribution

Severity criterion



How did it work out?

Fokker Criterion was only partially successful:

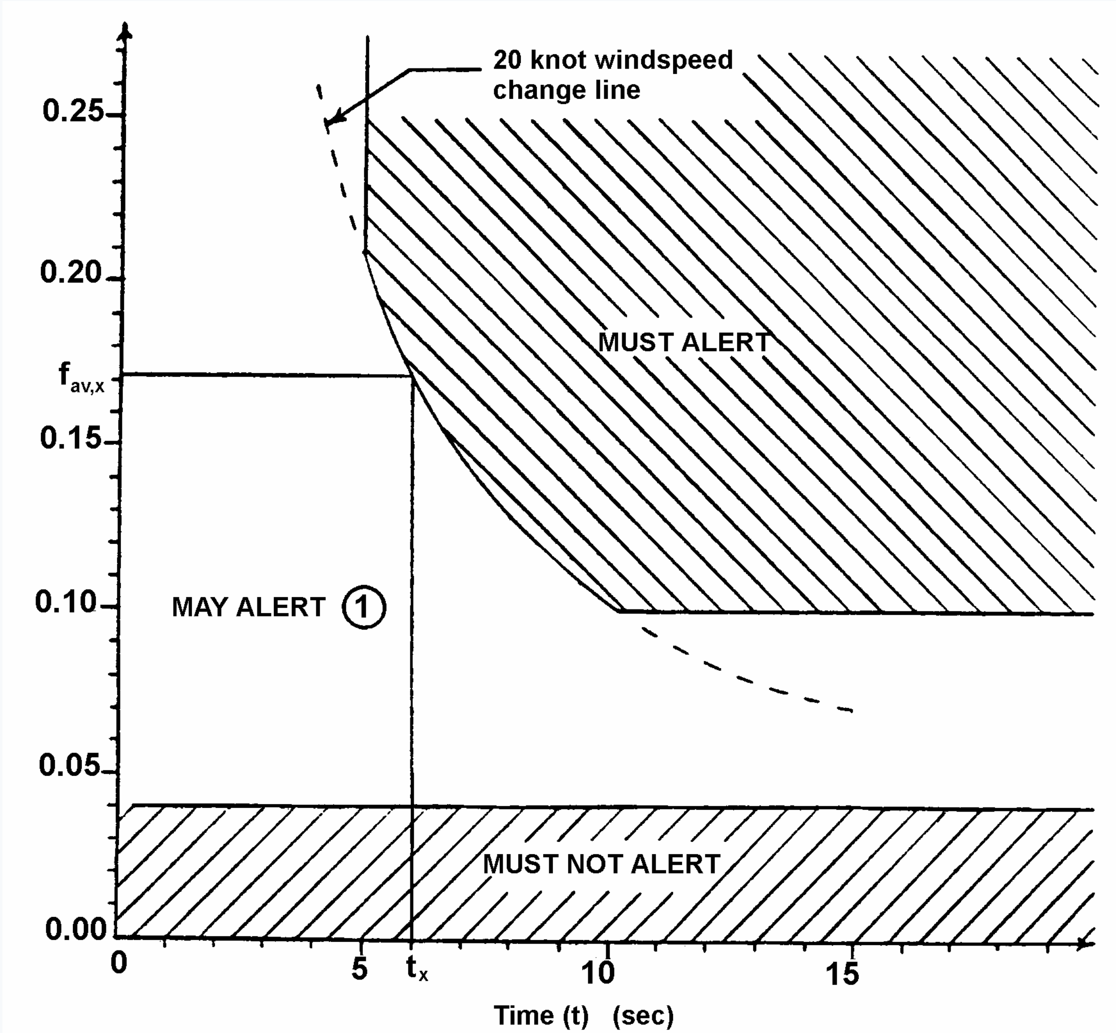
- **equivalent roll rate became irrelevant for windshear detection system due to the prescribed (AC120-41) windfields (did not contain vorticity)**

- **equivalent loadfactor showed promise by advancing windshear warnings and in heavy turbulence, but was later abandoned due to perceived increase in nuisance alerts**

Eventual windshear severity criterion

TSO-C117

$$F = \frac{\dot{W}_x}{g} - \frac{W_h}{V}$$



Severity criterion requirements

A severity criterion should:

- be independent of aircraft parameters as much as possible
- be as simple as possible, but sufficiently discriminative
- Ideally be able to assess any atmospheric disturbance.
- be able to address performance and handling aspects.
- be useable for in-flight severity measurements and for off-line safety assessments

Wake vortex severity criteria

Currently there is no widely accepted wake vortex severity criterion, despite availability of various methods available.

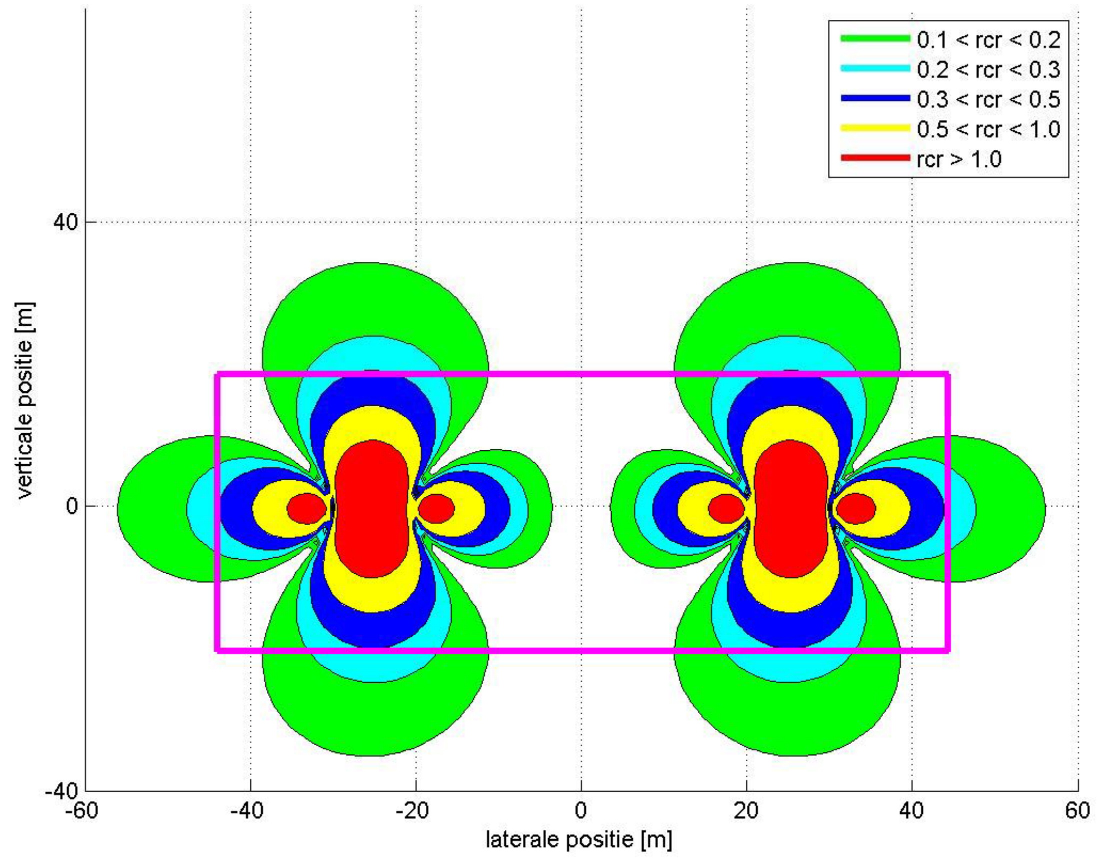
To name a few:

- Tatnall
- Roll control ratio
- SHAPE
- ....

Consequence: difficult to assess (or agree upon) safety of wake vortex related issues, and to assess in-flight severity of potential encounters.

Roll control ratio criterion

- **'Simplified Hazard Area Prediction' (SHAPe)**
- **RCR > 0.3**



Drawbacks of RCR

RCR probably most accepted WV criterion available at the moment, but...

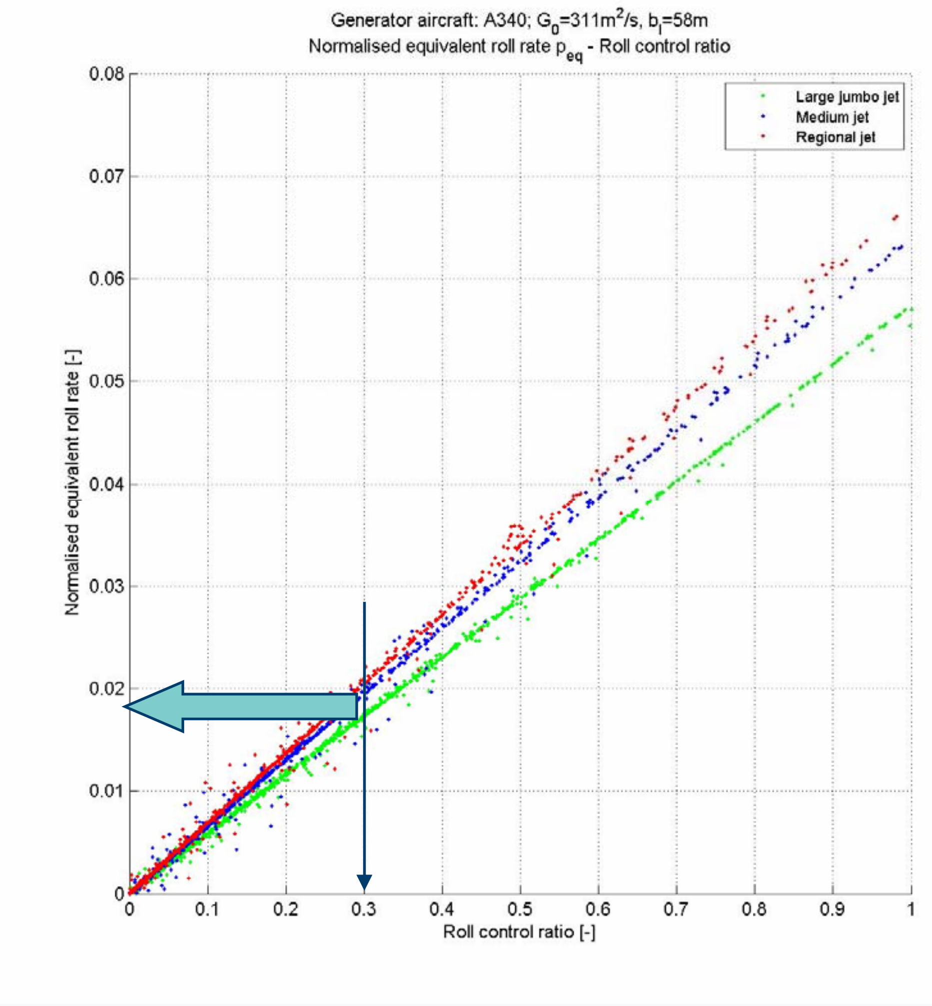
- **only assesses the roll axis**

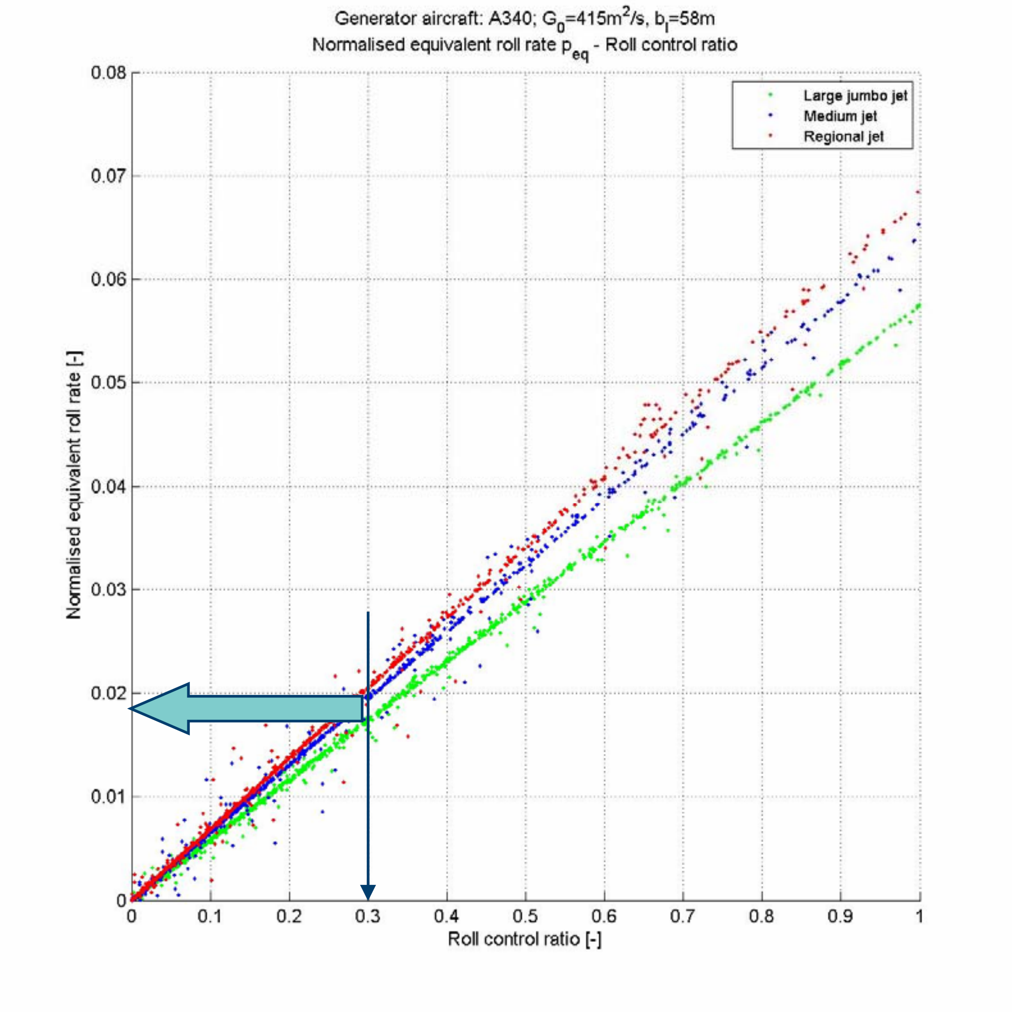
- **strongly dependent on accuracy with which maximum roll control power can be determined:**
  - difficult to acquire this data for a large variety of aircraft in practice
  - max. roll control power can be strongly dependent on flight condition
  - roll control systems can be complex due to combinations of inner & outer ailerons and flight spoilers
  - application to FBW systems

Revival of the C-criterion?

- Application of equivalent roll rate does not require aircraft characteristics other than spanwidth
- Allows severity assessment of intersection with wake vortices at any interception angle
- Could integrate potentially windshear and wake vortex severity assessment

Correlation RCR & Eq. roll rate





Conclusions

- NLR has used C-criterion alongside RCR in several WV projects, resulting in comparable severity assessment results
- Any severity criterion should be as simple, but effective, as possible to become an accepted standard
- Without an accepted standard, any WV safety assessment is vulnerable to endless discussion and reluctant decision making
- Based on it's simple and integrated concept the C-criterion is a possible candidate for extending the accepted F-factor criterion to applications in the WV domain
- but.... further research into the viability of the C-criterion is required.