Comparative wake-turbulence assessments and findings for the B747-8

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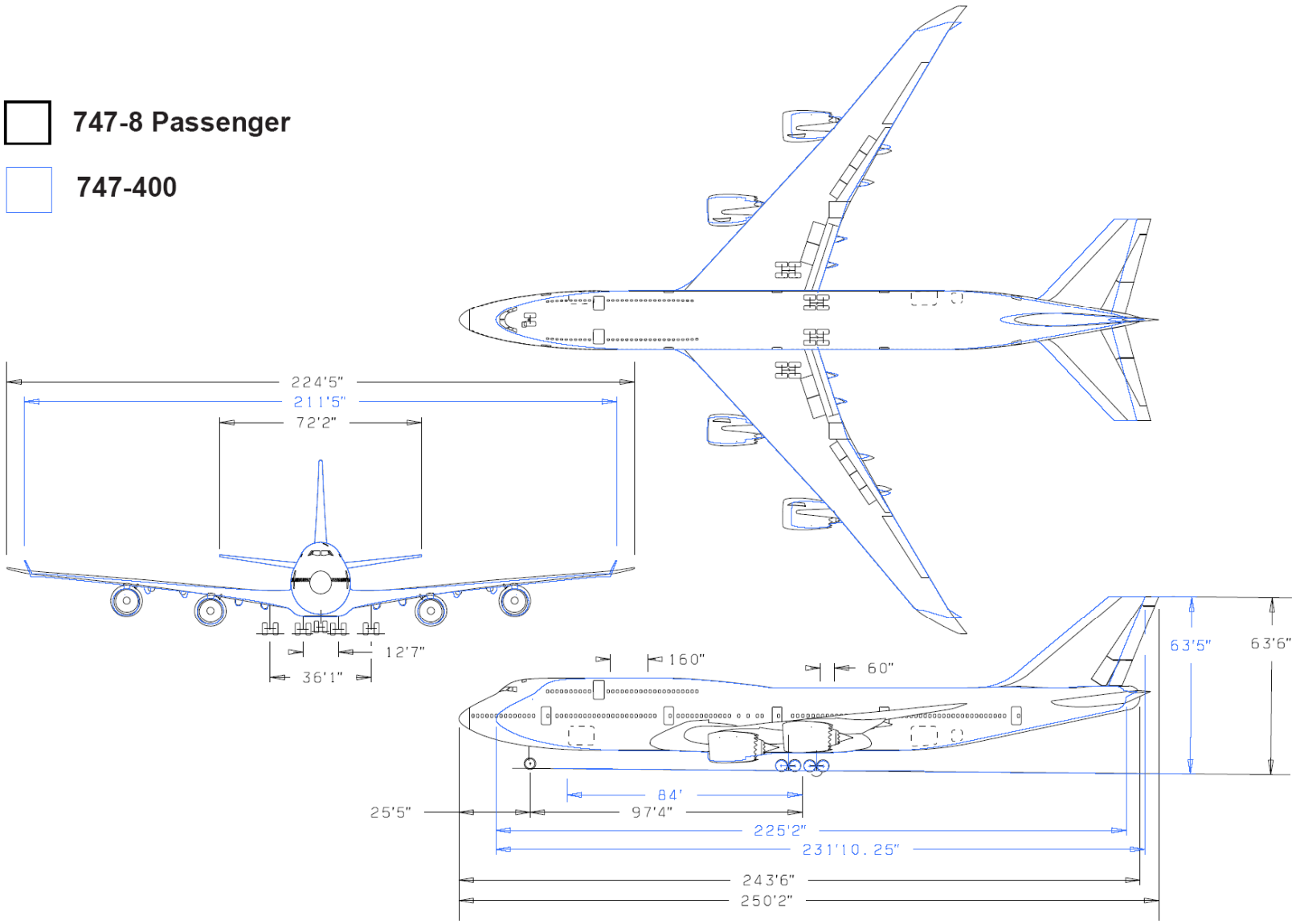
Boeing Commercial Airplanes

Comparative wake-turbulence assessments
(overview)

- ⇨ A relative assessment of different airplane wakes
  - ⇨ Current system considered safe
  - ⇨ Seek to assess relative safety of two operating aircraft
    - Both severity and likelihood

- ▫ B747-8 Experience and Findings
  - ▫ Assessment approach
  - ▫ Flight testing and results
  - ▫ Safety Case, ICAO guidance, Safety Assessment Report (SAR)
- ▫ More general approaches to wake assessment

3-view comparison of B747-8 and B747-400



B747-8 passenger & freighter design weights

Design Weight	747-8 Passenger	747-400
MTOW (% increase)	987,000 (+8.5%)	910,000
MLW (% increase)	682,000 (+5%)	652,000

Design Weight	747-8 Freighter	747-400F
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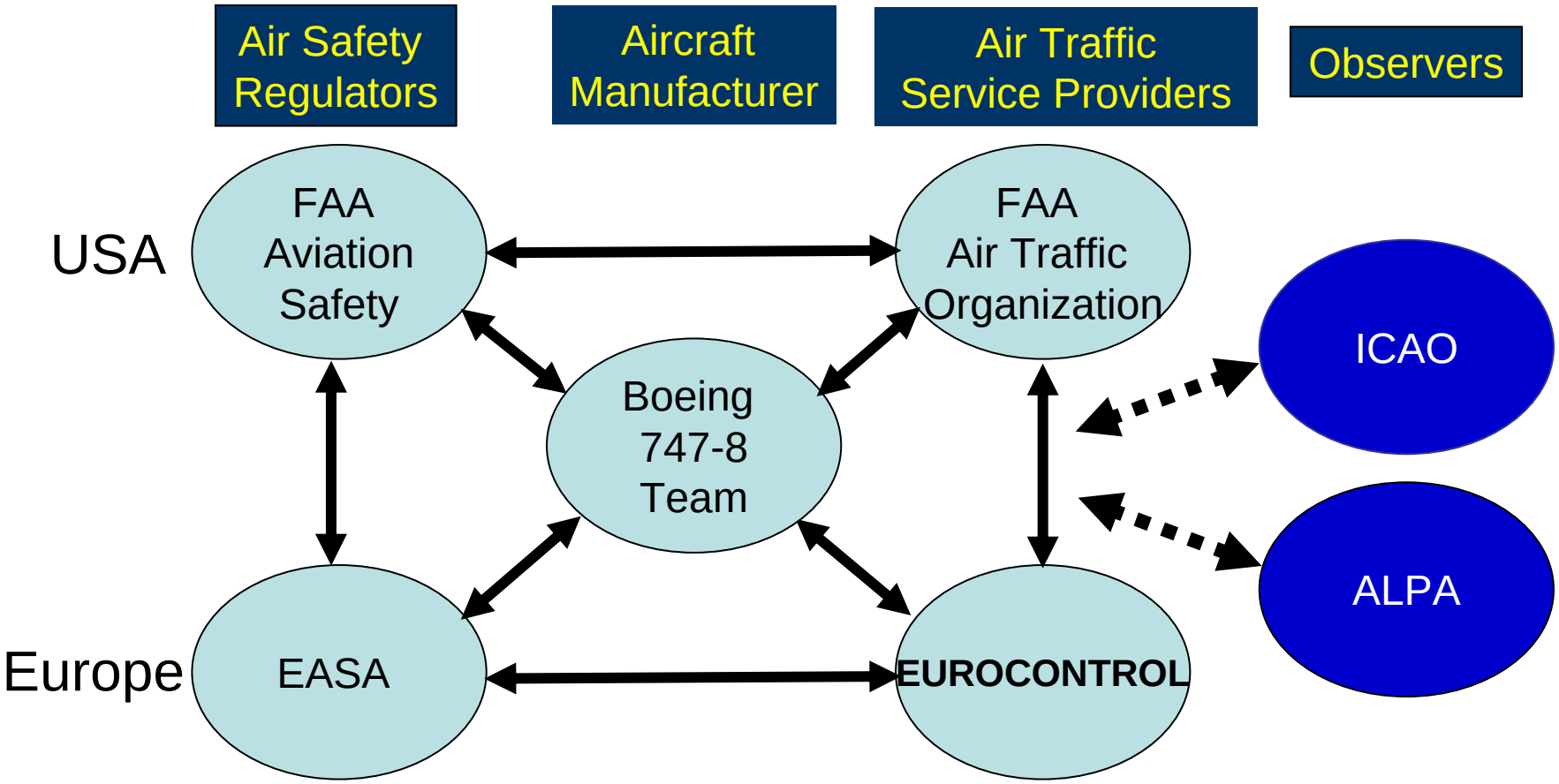
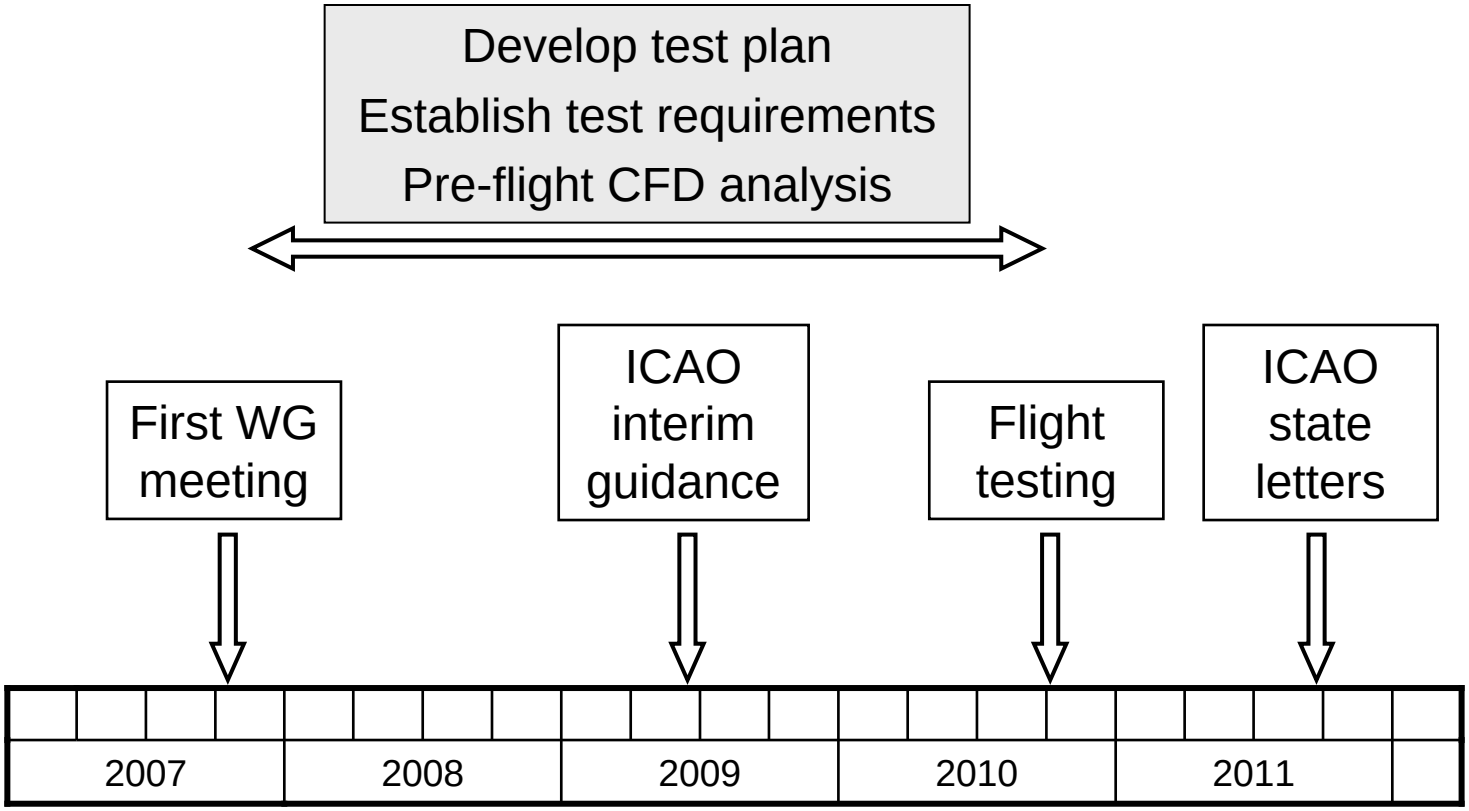
Weight increase suggests a potential increase in wake strength (& wake risk)

B747-8 Steering Group / Working Group structure

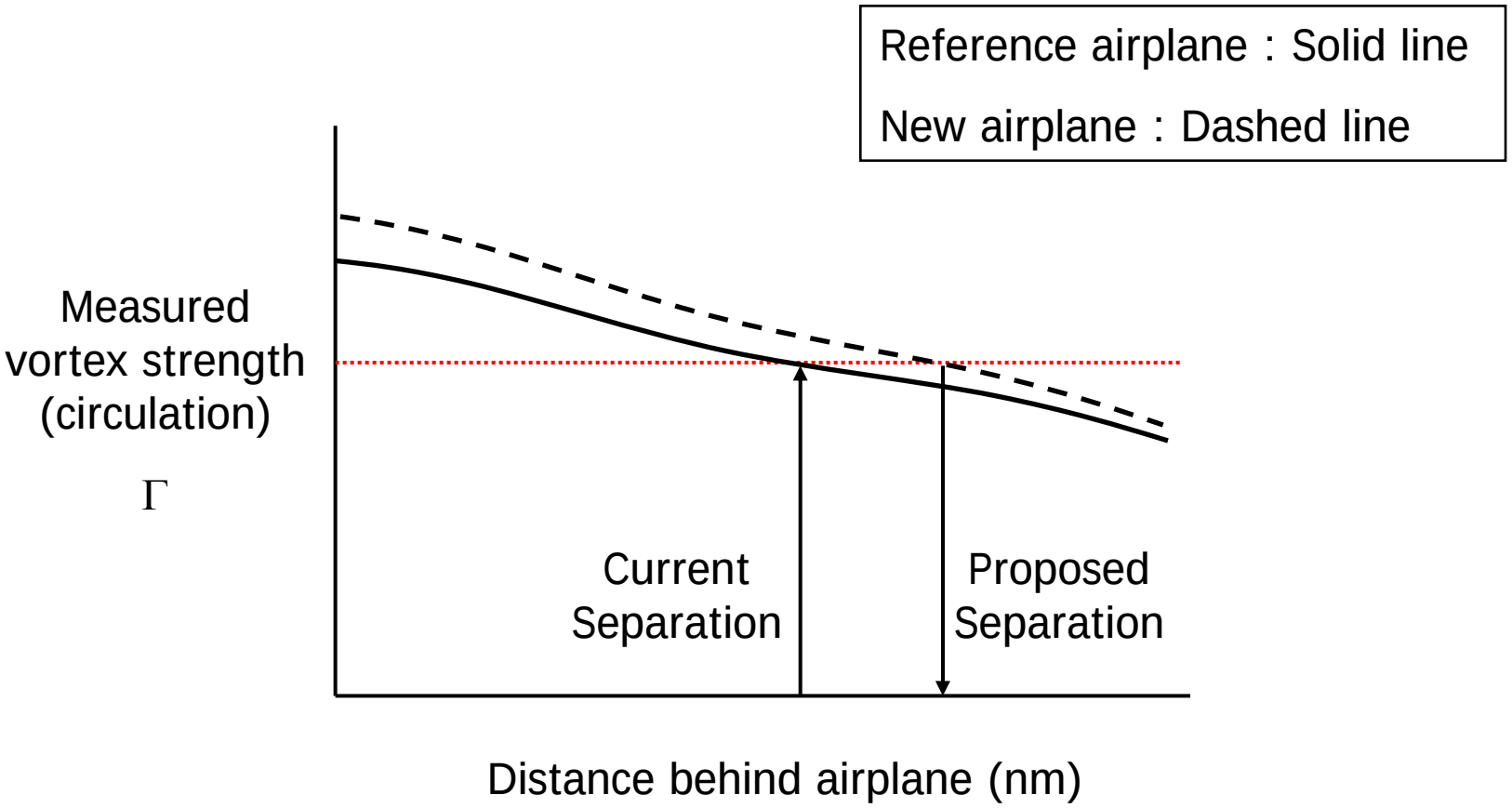


W.Bryant (FAA)

B747-8 Working Group timeline



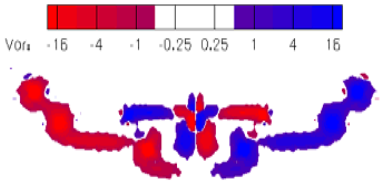
Equivalent level of safety approach



Basic assessment approach similar to A380

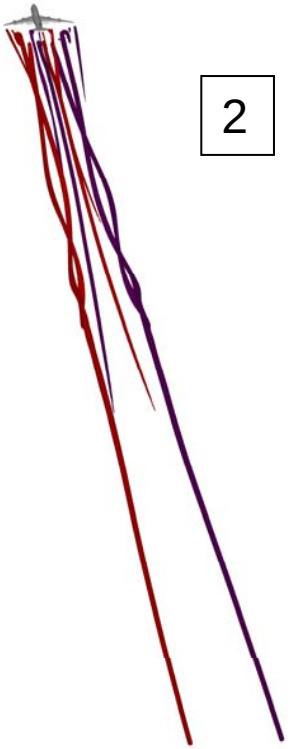
Pre-flight CFD analysis of the B747-8 and B747-400

1. Start with wake survey at tail of aircraft
2. Run Parabolized RANS CFD code to calculate wake evolution
3. Extract relevant parameters at distances of interest



Tail survey
(from wind tunnel or full-airplane CFD)

1



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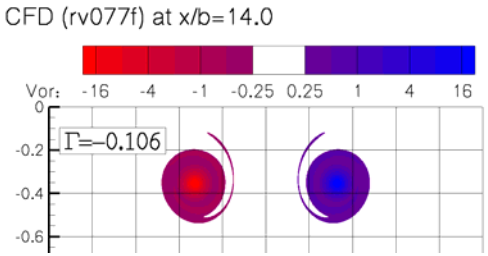
3

Downstream assessment (Γ,b_0)

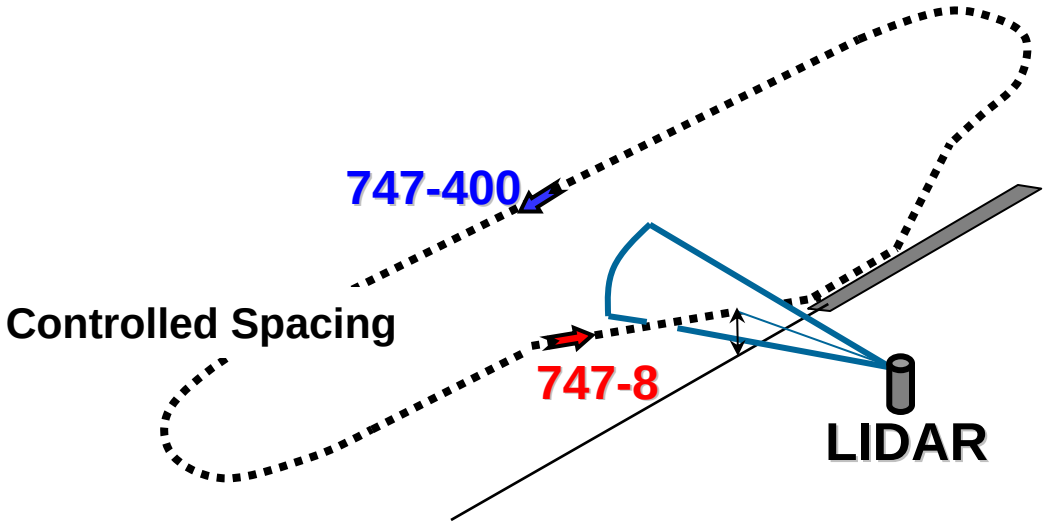


B747-8 wake flight testing

Compare B747-8 wake to a reference aircraft (B747-400)

Fresno, CA selected as test site based on weather, SNR and availability

Flight-test procedures



B747-8 and B747-400 flown sequentially in a circuit to enable pair-wise comparisons at approximately one wingspan above ground (most hazardous scenario)

Environmental conditions carefully restricted (reasonably worst case)

Airplane settings and trajectories carefully controlled

For each approach, measurements were made of airplane parameters, met conditions, and wake characteristics

Volpe Center supported ground measurements under contract to Boeing

Flight-test data analysis

Flight testing complete: mid October 2010

Data provided to Working Group: late November 2010

Data analyzed by: FAA, EUROCONTROL, EASA, Boeing

Multiple analysis methods used

Multiple assessment approaches:

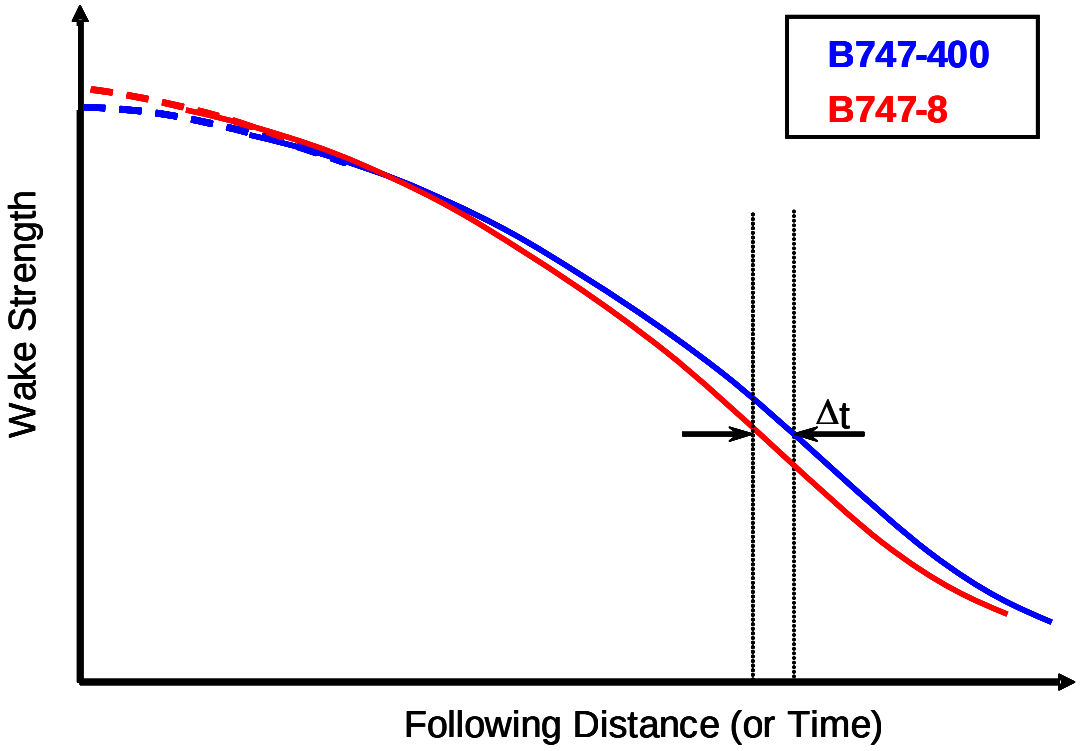
- Consider strength at fixed distance
- Consider delta distance for equal strength
- Compare encounter likelihood

Quantitative assessment of WVE severity: Wake strength

Strength of vortices as a function of time (or distance) behind aircraft

Data analyzed using many different approaches (representative result)

Example graph showing the B747-8 wake strength less than or equal to the B747-400



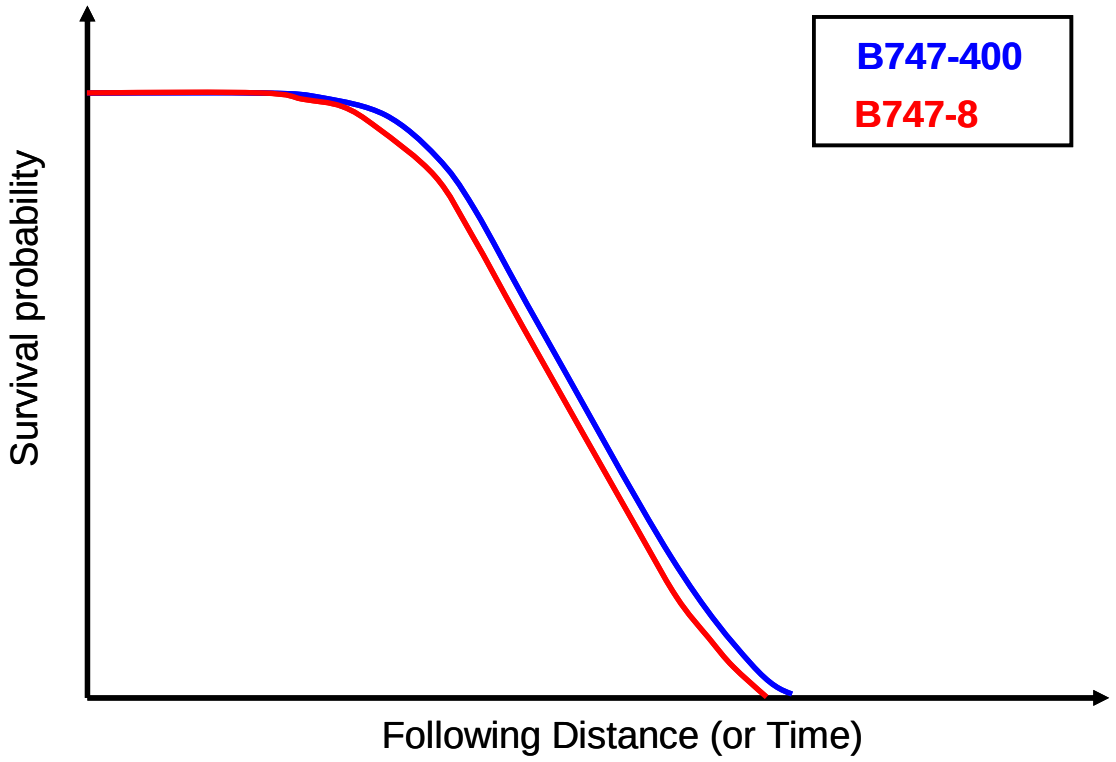
⇨ Similar result seen in analysis of rejected cases

Quantitative assessment of WVE likelihood: Survival probability and lifetimes

Vortex-lifetime comparisons for B747-400 and B747-8

Probability of vortices lasting to a given time (or distance)

Example graph showing the B747-8 survival probability is less than or equal to the B747-400



Flight-test data findings

Flight test results in agreement with pre-flight CFD

Results show B747-8 wake strength less than or equal to the B747-400 at distances of interest

B747-8 vortices are closer together, resulting in more rapid descent and decay

B747-8 wake-assessment documentation

Safety Assessment Report (SAR)
from B747-8 WG

BOEING PROPRIETARY DOCUMENT

Limited access on a need-to-know basis – with Proprietary Information Agreement

Contact: Terry L McVenes (BCA, Operational Regulatory Affairs)

⇩

Safety Case
from B747-8 WG/SG

PUBLIC DOCUMENT provided to ICAO

Available on request

Contact: Jeffrey Tittsworth (FAA, ATO)

⇩

State Letters
from ICAO

PUBLIC DOCUMENT provided to ANSPs

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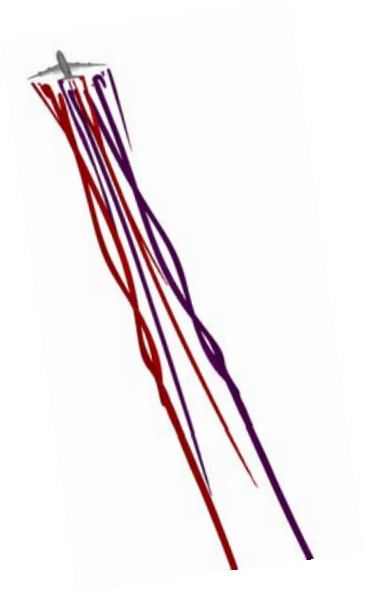
The challenge of relative WVE risks assessments

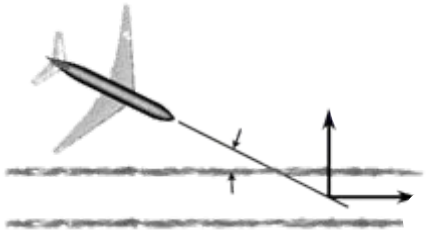
How does an airplane modification translate into a change in WVE risk?

Differences of interest may be overpowered by other factors

Generating Airplane	⇨	Wake Generation	⇨	Wake Evolution	⇨	Wake Encounters	⇨	Encounter Response and Likelihood
		Airplane Parameters		Airplane Parameters Environmental Factors		Airplane Parameters Environmental Factors Encounter Geometry Encountering Airplane		

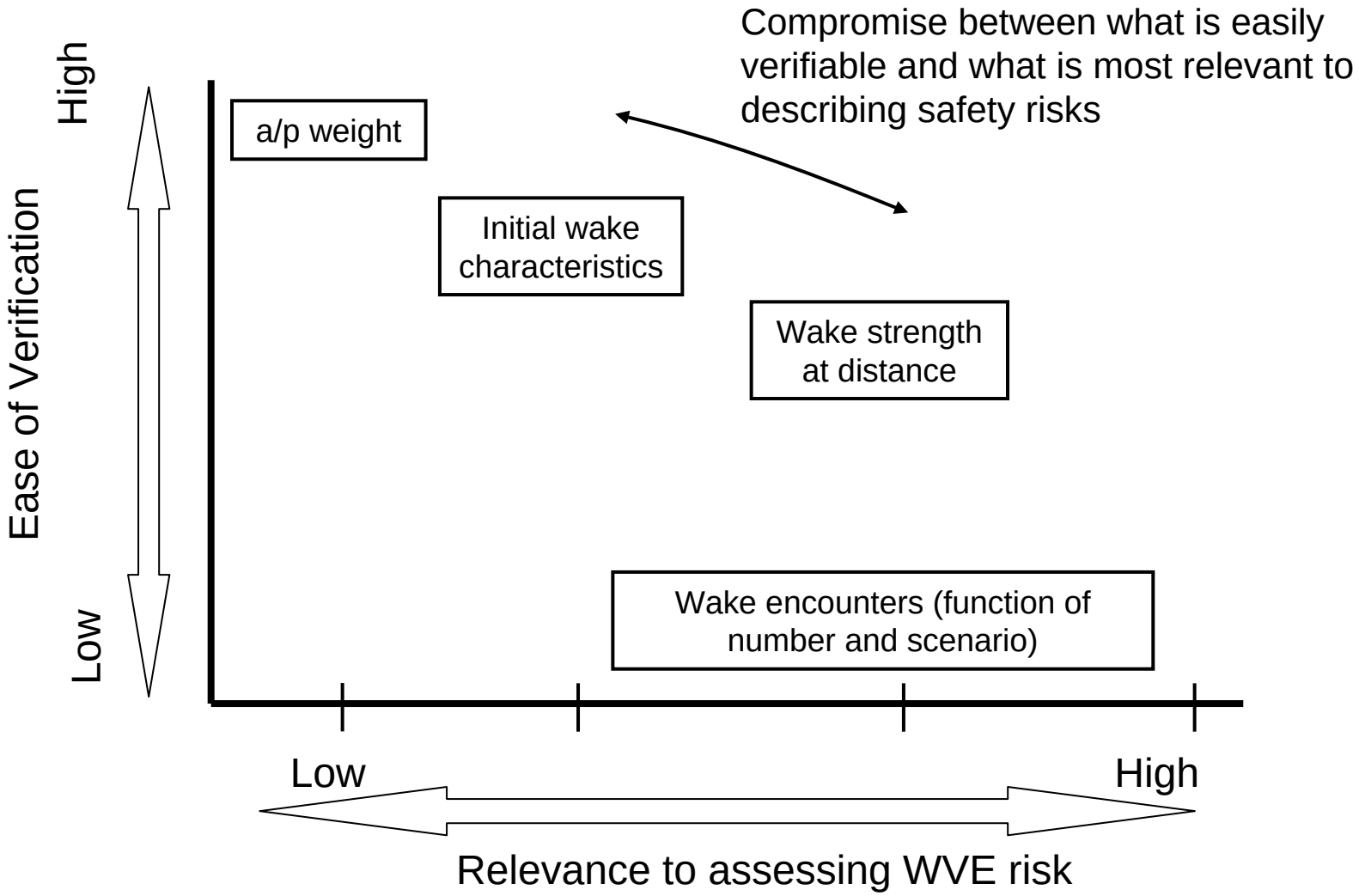
Δ Airplane





Δ WVE risk

WVE risk assessment: Verification vs. Relevance



Alternative approaches to WVE risk assessment

Hierarchy of methods to assess wake strength and encounter likelihood

1. Weight comparisons (e.g. current ICAO)

   MTOW, MLW

2. Estimated strength at distance (e.g. RECAT)

   Weight and span

   (Need model for wake evolution, wing loading)

3. Predicted wake characteristics from CFD

   Weight, wing loading, near-field evolution, interaction w/ ground

   (Need CFD tool and models for turbulence and instabilities)

4. Measured wake characteristics from flight (e.g. B747-8)

   Weight, wing loading, near-field evolution, far-field evolution, interaction with ground – all at full scale

   (Need suitable test site and measurement system. Influenced by environmental conditions, a/p operation and measurement limitations)

Summary

A relative safety argument was used to assess the B747-8 wake-vortex encounter risks based on wake strength and wake lifetime

- Documented in ICAO Safety Case
- Supported by Boeing Safety Assessment Report

Future wake-assessment efforts should benefit from increased confidence in CFD and even simpler assessment methods