National Aeronautics and Space Administration

Assessment of Fast-Time Wake Vortex Prediction Models

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Assessment of Fast-Time Wake Vortex Prediction Models

OUTLINE

- Background
- Objectives
- Evaluation
  - Selection of data sets
  - Candidate models
  - Analysis
- Key findings
- Future work

Need for Understanding Wake Vortices

- Current wake vortex spacing criteria based on rare events without consideration of meteorological influences on wake behavior
- Wake spacing criteria a limiting factor for improvements in NexGEN
- Increased traffic and changes in National Airspace System may impact current levels of safety

Wake Vortex Fast-Time Models -- Definition

- Empirical or semi-empirical algorithms that generate wake vortex information based on aircraft, airport, or weather conditions for operational, investigative, or research purposes

- Output could be:
  - Wake vortex track histories
  - Wake vortex circulation histories
  - Zones or regions with potential for wake hazard
  - Probability distributions

- Needed for many real-time and engineering applications
  - Investigation of safety & capacity benefits related to proposed concepts and procedures for management of aircraft traffic
  - Potential submodel in Aircraft Dynamic Spacing System
  - Development of aircraft separation standards
  - Re-categorization of current aircraft standards
  - Investigation of accidents and incidents influenced by inadvertent wake encounters

Three Types of Fast-Time Models

- Deterministic Fast-Time Models
  - Predict vortex position and strength histories
  - Examples
    - AVOSS† Prediction Algorithm (APA)
    - TASS* Derived Algorithms for Wake Prediction (TDAWP)
    - Deterministic 2-Phased (D2P) model
    - Vortex Prediction Routine (VPR)
    - Deterministic wake Vortex Model (DVM)

- Wake Zone Fast-Time Models
  - Predicts bounded area where wake may reside
  - May utilize deterministic models with bound predictions based on environmental and aircraft uncertainties
  - Examples: Rossow, Probabilistic 2-Phased (P2P)

- Probabilistic Fast-Time Models
  - Predicts probability that wake will be a particular distance from flight path and/or weakened below a certain strength
  - May use deterministic model for its basis

†AVOSS – Aircraft Vortex Spacing System
*TASS – Terminal Area Simulation System

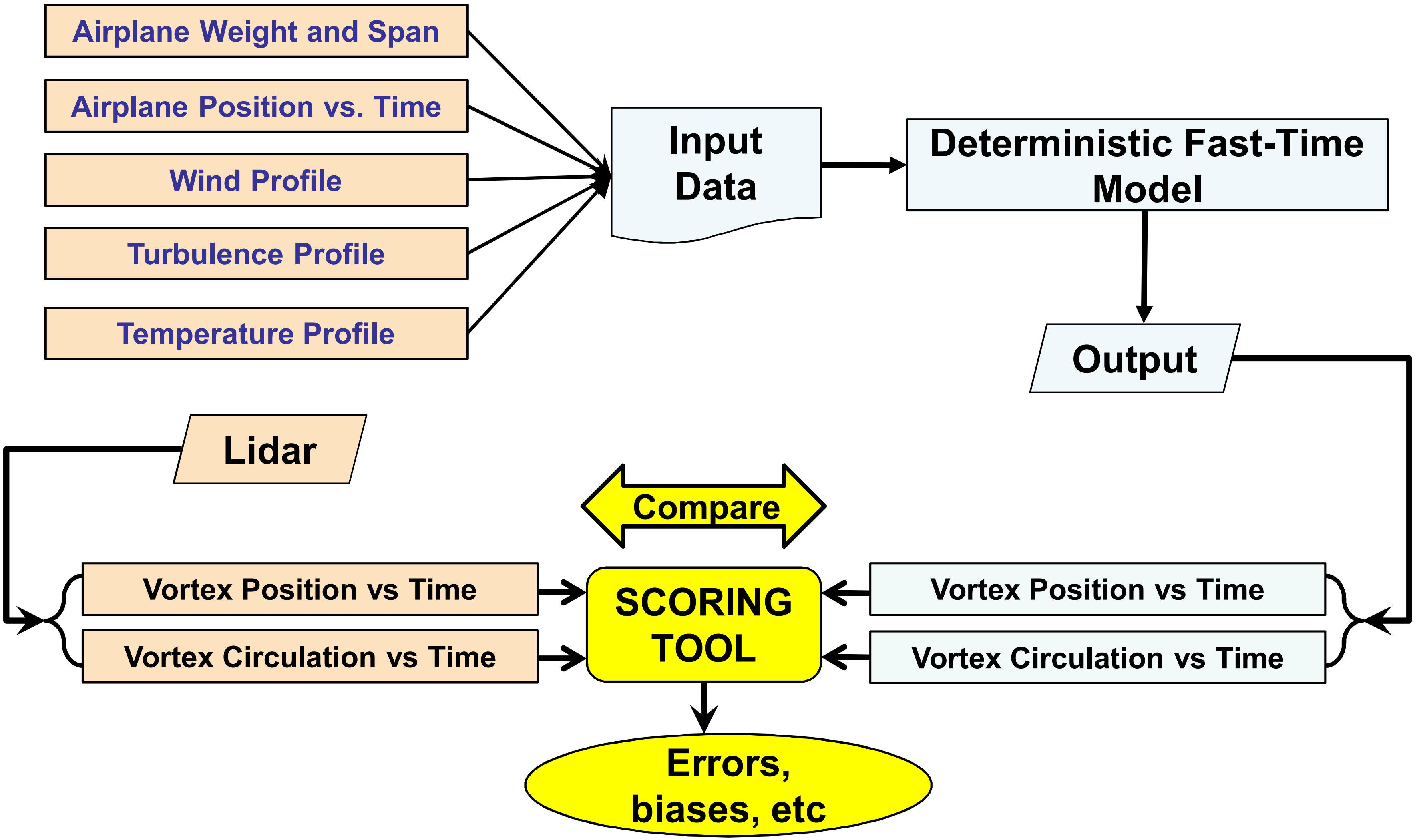
Objectives

- How "good" are deterministic fast-time models at predicting measured vortex trajectories and circulation histories?
- Which model(s) performs best?
- Where do they need improvement?

Deterministic Fast-Time Models Used in this Study

- Three versions of the AVOSS Prediction Algorithm (APA)
  - APA 3.2
  - APA 3.3
  - APA 3.4
- TDAWP version 2.1 *(NASA)*
- VPR version 1.0 *(FAA)*
- DVM version 4.3 *(Université Catholique de Louvain, Belgium)*

Evaluation of Fast-Time Wake Prediction Models



Field Data for Wake Model Evaluation

- Need special measurements for wake as well as meteorological data
  - Continuous Wave (CW) Lidar measurements of wakes
    - Limited range
    - Beam must be focused on vortex
  - Pulsed Lidar
    - Good position measurements
    - Accuracy of circulation estimates under study
  - Aircraft data (type, weight, position, speed, time)
  - Vertical profiles of wind, temperature, and turbulence

- Data sets collected by NASA at Memphis (MEM) and Dallas-Ft. Worth (DFW) during the AVOSS project
  - Wake tracks from CW Lidar
  - Wind data measured at airport but not in vicinity of wakes
  - Wake data limited to arrivals
  - Wake tracks from Pulsed Lidar only available for DFW-2000

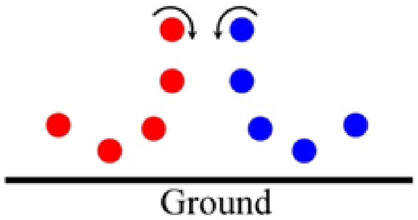
- Large amount of field data has been collected by FAA
  - Wake tracks from Pulsed Lidar
  - Limited usefulness, obtained by FAA for purpose other than evaluating wake models
  - Little or no meteorological data

- Almost no data exist at cruise altitudes

Evaluation of Fast-Time Models

- Evaluation divided into two studies:
  - Out of ground effect (OGE)
    - Wake vortex not influenced by ground
    - Initial vortex heights at least two wing spans above the ground
    - Wake vortices sink due to mutual interaction while advecting horizontally with wind

  - In/near ground effect (IGE/NGE)
    - Wake trajectory influenced by ground
    - Enhanced decay due to interaction with ground



Data Sets used in Study

- Observed data sets obtained from field studies at operational airports
  - Memphis (MEM) 1995   OGE and IGE
  - Dallas Ft-Worth (DFW) 1997 OGE and IGE
  - San Francisco (SFO) 2001 OGE (FAA)
- Model scoring analysis performed by NorthWest Research Associates under NASA contract
- Study divided into two parts: OGE and IGE

OGE Evaluation

(no ground influence)

OGE Study: Data Sets

Site	Crosswind	EDR	Stratification	Initial vortex spacing
MEM	Proxy	Measured	Measured	Nonelliptical
DFW	Proxy	Measured	Measured	Nonelliptical
SFO '01	Proxy	Estimated	MM5	Nonelliptical

MM5 – Mesoscale Weather Prediction model
SFO – FAA sponsored data set

Why use Proxy Crosswinds?

- Derived from Lidar vortex trajectory
- Closer match to wind experienced by vortices

Mean Residuals (model-data) vs Model

MEM OGE

Model	Lateral	Altitude	Circulation
APA v3.2	-0.02	0.19	-0.08
APA v3.3	-0.02	0.16	-0.03
APA v3.4	-0.03	0.14	0.01
TDAWP v2.1	-0.04	0.08	0.07
VPR v1.0	0.04	0.11	-0.04
DVM v4.3	0.09	0.13	0.10

SFO OGE

Model	Lateral	Altitude	Circulation
APA v3.2	0.02	0.06	-0.12
APA v3.3	0.02	0.06	-0.08
APA v3.4	0.02	0.04	-0.04
TDAWP v2.1	0.01	0.03	0.06
VPR v1.0	0.00	0.00	-0.07
DVM v4.3	0.00	0.00	0.07

Summary Table Models in OGE

Model	Lateral Position	Altitude	Circulation
APA v3.2	Good	Biased low at later wake age	Decays too fast when stratification strong
APA v3.3	Good	Biased low at later wake age	Decays too fast when stratification strong
APA v3.4	Good	Biased low at later wake age	Good, biased slightly high
VPR v1.0	Good	Biased low at later wake age; better prediction when stratified	Good
TDAWP v2.1	Good	Biased low at later wake age; better prediction when stratified	Initial circulation biased high
DVM v4.3	Good	Biased low at later wake age	Biased high

Summary of OGE Study

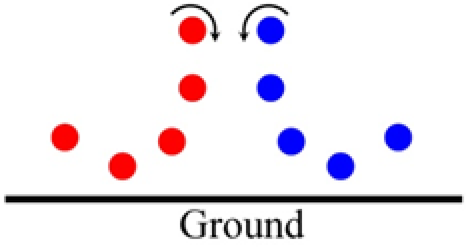
- Differences between models usually less than differences with Lidar data

- Lateral Position: Most residuals fall within ± ⅓ wingspan. Residuals change slowly with time

- Altitude: Most residuals within ±½ wingspan. Model predictions tend to be biased high at early wake ages and low at later ages

- Circulation: Most residuals within 30% of the initial circulation.
  - Decay too strong in APA 3.2 & 3.3 when environment is stratified
  - Early circulations predicted by TDAWP 2.1 and DVM 4.3 appear too high

IGE Evaluation
(ground influences wake behavior)



IGE Data Sets

Site	EDR	Temperature	Crosswind	Initial Vortex Separation
MEM	Measured	Measured	Proxy	Elliptical
DFW	Measured	Measured	Measured	Elliptical

- Cases selected based on initial vortex height below 2 wing spans
- Less data available than OGE

Summary of IGE Study

- Differences between models usually less than differences with Lidar data
- Lateral Position: Most residuals fall within ±1 wingspan. Predicted spreading between port and starboard vortices is underestimated relative to the spread indicated by Lidar
- Altitude: Most residuals within ±½ wingspan
- Circulation: Most residuals within 20% of the initial circulation
- More data is needed to determine which models perform best

Key Findings

- Differences between fast-time models and Lidar data are greater than differences between models
  - Uncertainties in the input conditions lead to uncertainties in the model predictions

- Better data sets are needed in order to assess fast-time model accuracies
  - Improved observation of the environment at the time and location of the wake measurement
  - Remove ambiguities in the observations of wake vortices, especially vortex circulation
  - Accurately determine the position, weight, type, and speed of the generating aircraft

Future Work

- Scoring with additional data sets
  - Including improved versions of current fast-time models
- Understanding accuracy and limitation of Lidar wake data
- Propose additional field measurements designed for evaluating wake models
  - IGE, OGE and cruise altitudes
  - Departures as well as arrivals
- Integrate into operational system that determines safe spacings between aircraft

End

- Questions?

Bibliography

- APA Suite 4.0*: Proctor, F.H., and D.W. Hamilton, 2009: Evaluation of Fast-Time Wake Vortex Prediction Models, AIAA 2009-0344.*

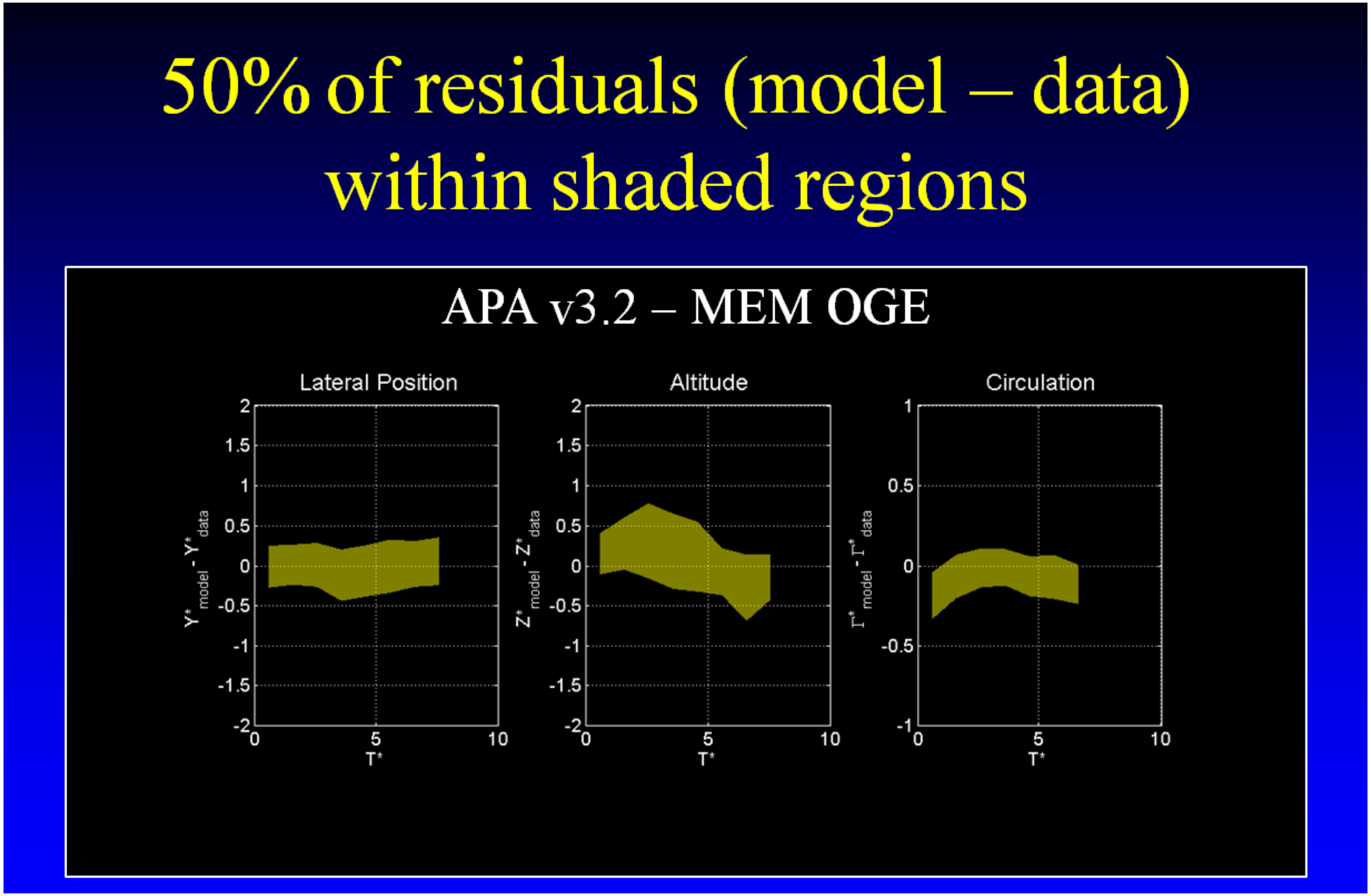
- TDAWP 2.0: *Proctor, F.H., D.W. Hamilton, and G.F. Switzer, 2006: TASS Driven Algorithms for Wake Prediction, AIAA 2006-1073.*

- AVOSS Prediction Algorithm (APA):
  - *Sarpkaya, T., Robins, R.E., and Delisi, D.P., 2001: Wake-Vortex Eddy-Dissipation Model Predictions Compared with Observations, Journal of Aircraft, Vol. 38, 687- 692.*
  - *Robins, R.E., and Delisi, D.P., 2002: NWRA AVOSS Wake Vortex Prediction Algorithm Version 3.1.1, NASA CR-2002-211746.*

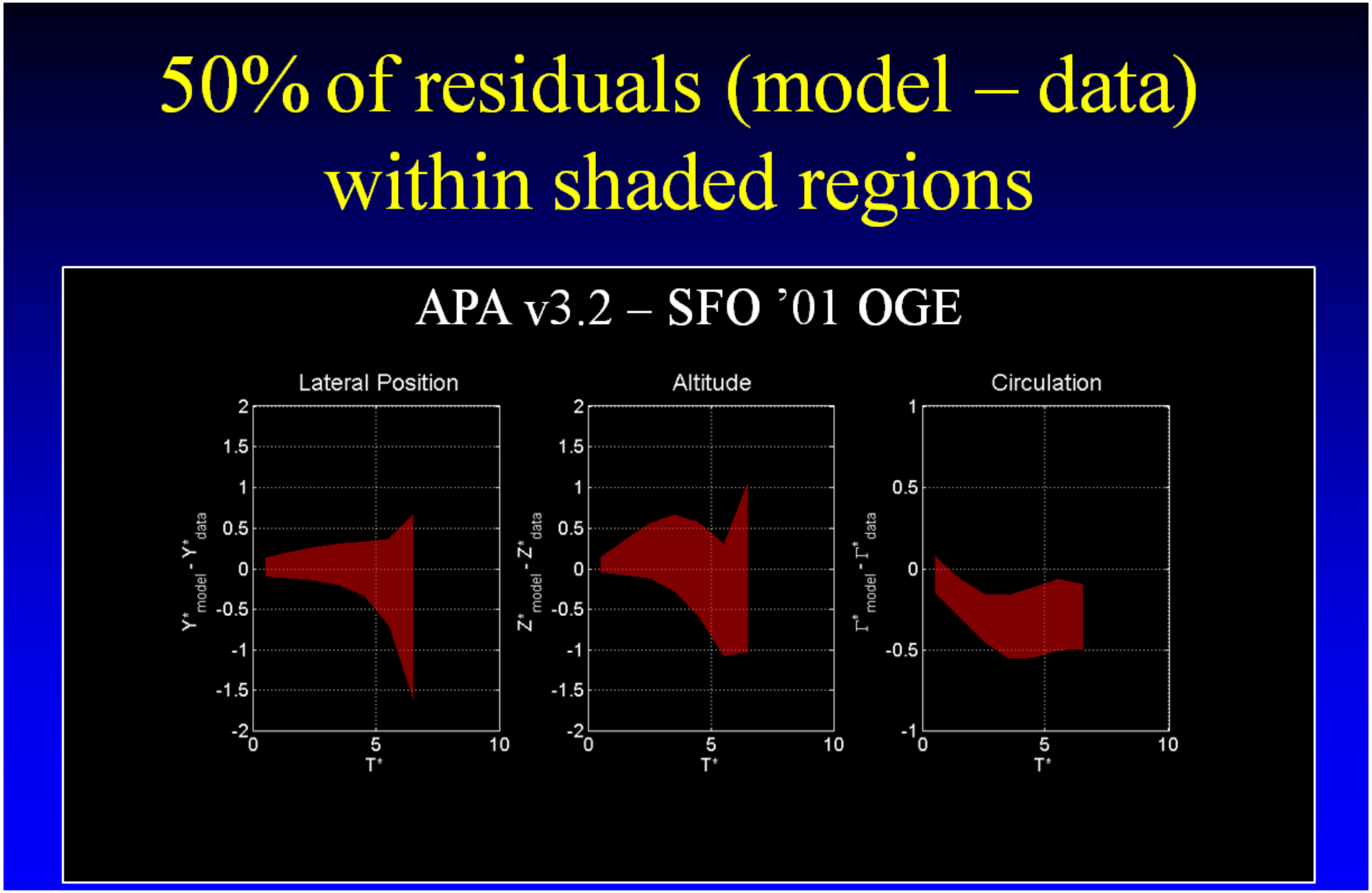
- Deterministic wake Vortex Model (DVM): *De Visscher, I., Winckelmans, G., Lonfils, T., Bricteux, L., Duponcheel, M., and Bourgeois, N., 2010: The WAKE4D Simulation Platform for Predicting Aircraft Wake Vortex Transport and Decay – Description and Examples of Application, AIAA 2010-7994.*

BACK-UP SLIDES

APA-3.2 Residuals with Wake Age at Memphis (OGE)



APA-3.2 Residuals with Wake Age at San Francisco (OGE)

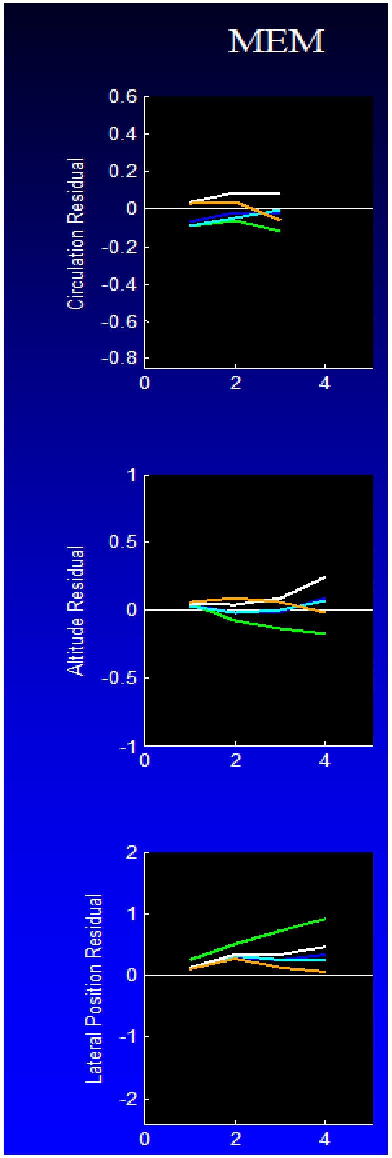


IGE: Bias of the Residuals as a Function of Time for MEM

Normalized circulation residuals vs normalized time

Normalized height residuals vs normalized time

Normalized lateral position residuals vs normalized time



APA 3.3

APA 3.4

TDP 2.1

DVM 4.3