



Lessons learned: WakeScene

Results of quantitative (Monte Carlo) simulation studies

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Lessons learned: WakeScene-D

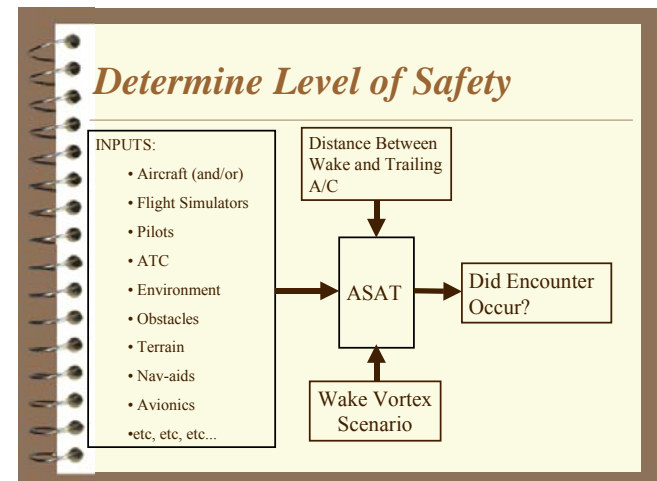
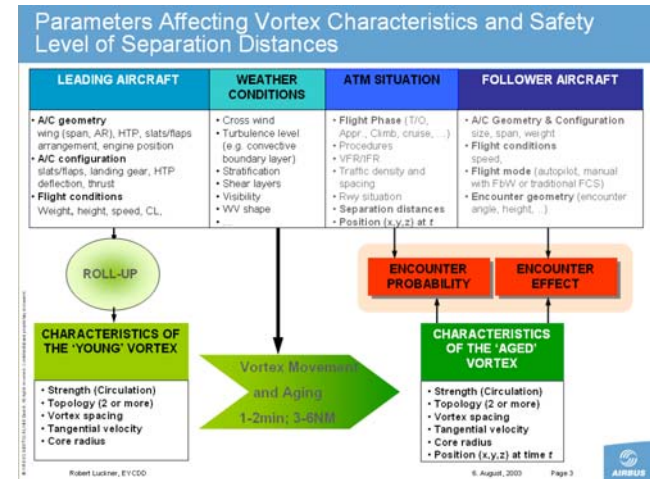
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- Comparison of WakeScene Results

Lessons learned: WakeScene-D

History of WakeScene

- Beginning of development triggered by Airbus in 2003
- Functionality:
 - Traffic Scenario
 - Trajectory
 - Atmospheric Conditions
 - Wake Vortex Model
 - Hazard Assessment
- Purpose: alternative to ASAT for WVE probability

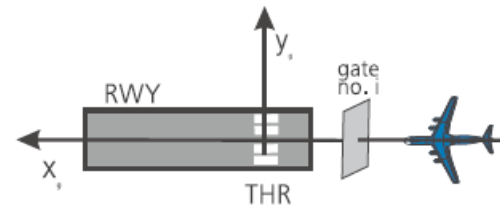


Lessons learned: WakeScene-D

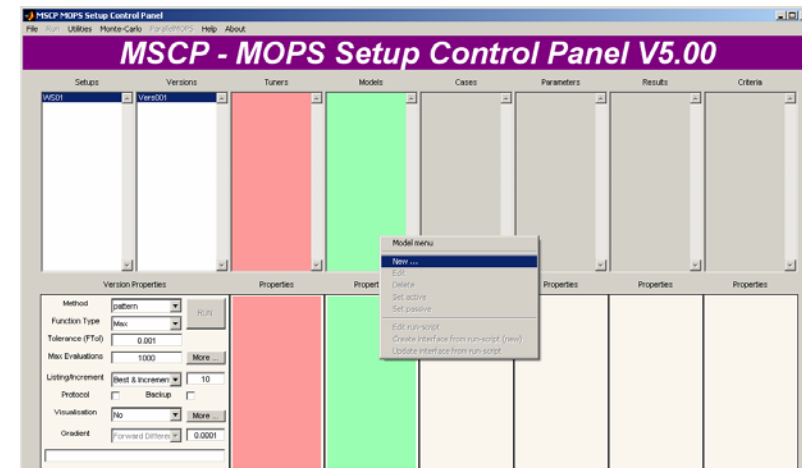
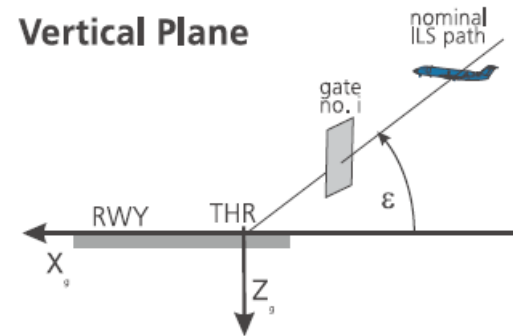
History of WakeScene

- WakeScene P1 developed in 2004
- Modules:
 - Meteo Database NOWVIV by DLR-PA (data for one month)
 - WVM "D2P" by DLR-PA (alternative APA, ACTIV)
 - "SHAPE" Hazard Assessment Module by DLR-FT
 - Lo-fi (A/C Speed) Traffic and Trajectory Module by DLR-FL
 - Interface to VESA Tool by Airbus
 - Implemented in Matlab Environment MOPS by DLR-RM
- WV evolution and interaction with follower a/c in gates
- Installation at Airbus
- Used for A380 Wake Vortex Research

Horizontal Plane



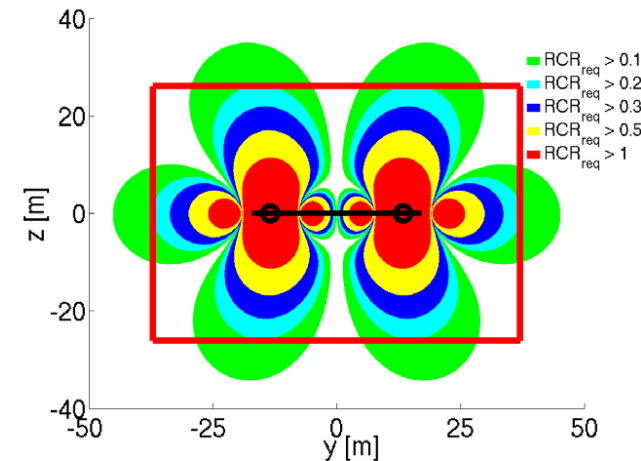
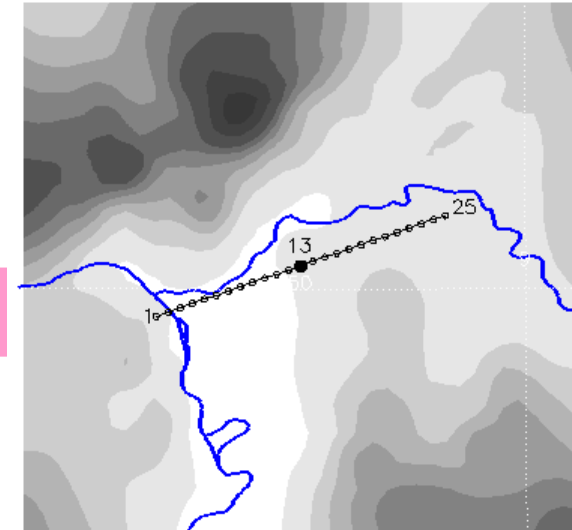
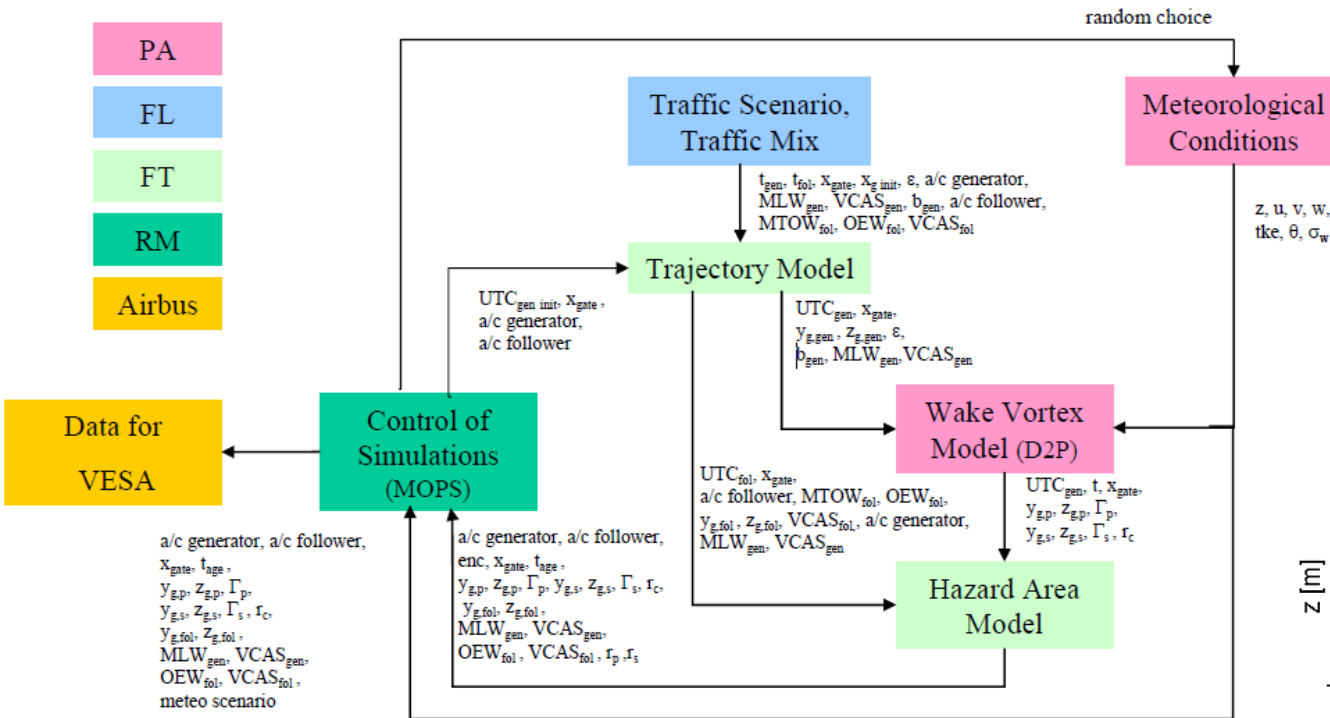
Vertical Plane



Lessons learned: WakeScene-D

History of WakeScene

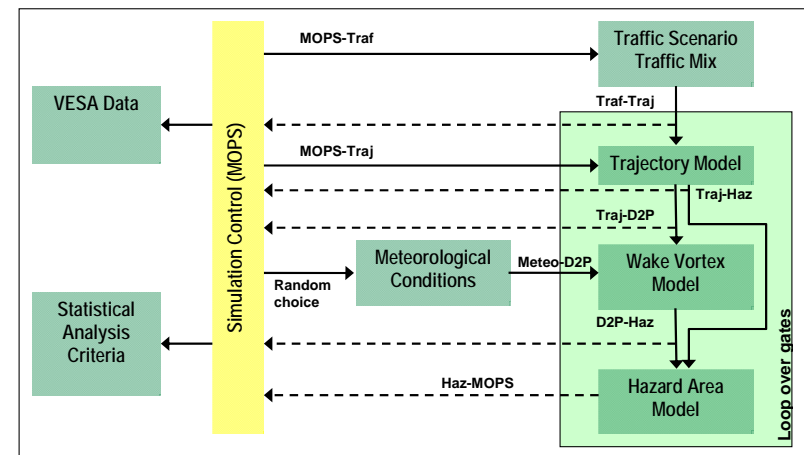
➤ WakeScene P1 flow chart



Lessons learned: WakeScene-D

History of WakeScene

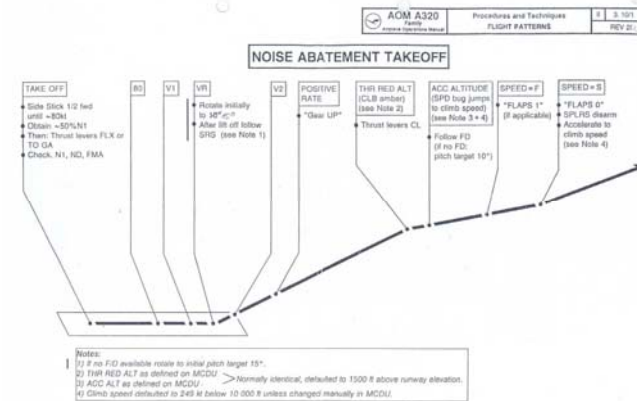
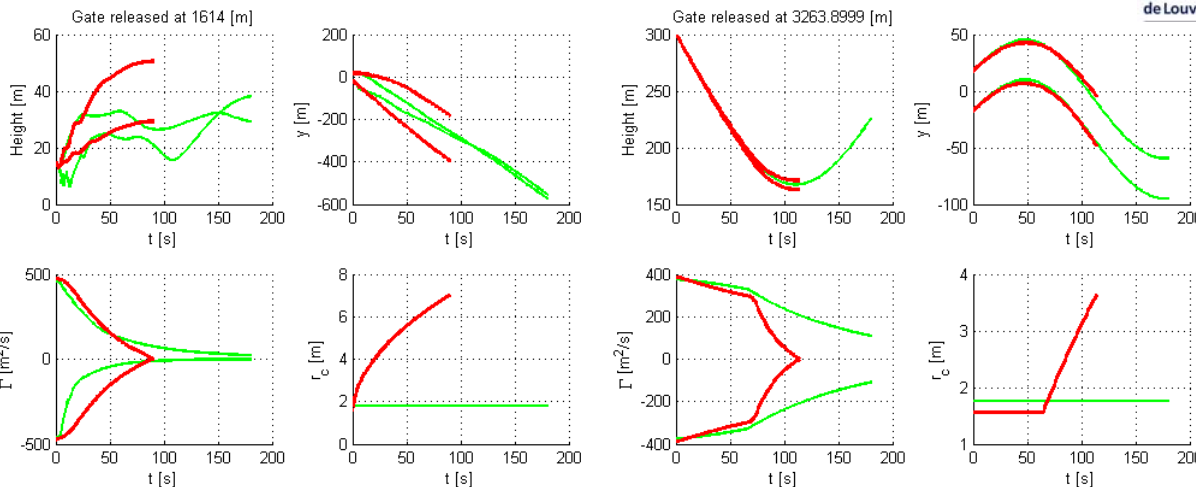
- WakeScene P2 developed in 2005
- Better Traffic Model by DLR-FL
- NOWVIV meteo database with data for one year 11/2003–10/2004
- Improvements in speed (i.e. mex instead of file i/o)
- Increased number of gates
- Parallel computing



Lessons learned: WakeScene-D

History of WakeScene

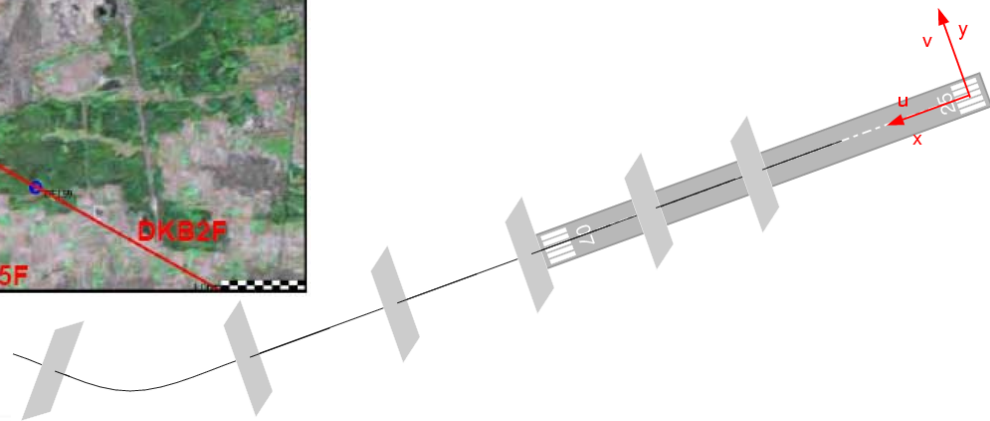
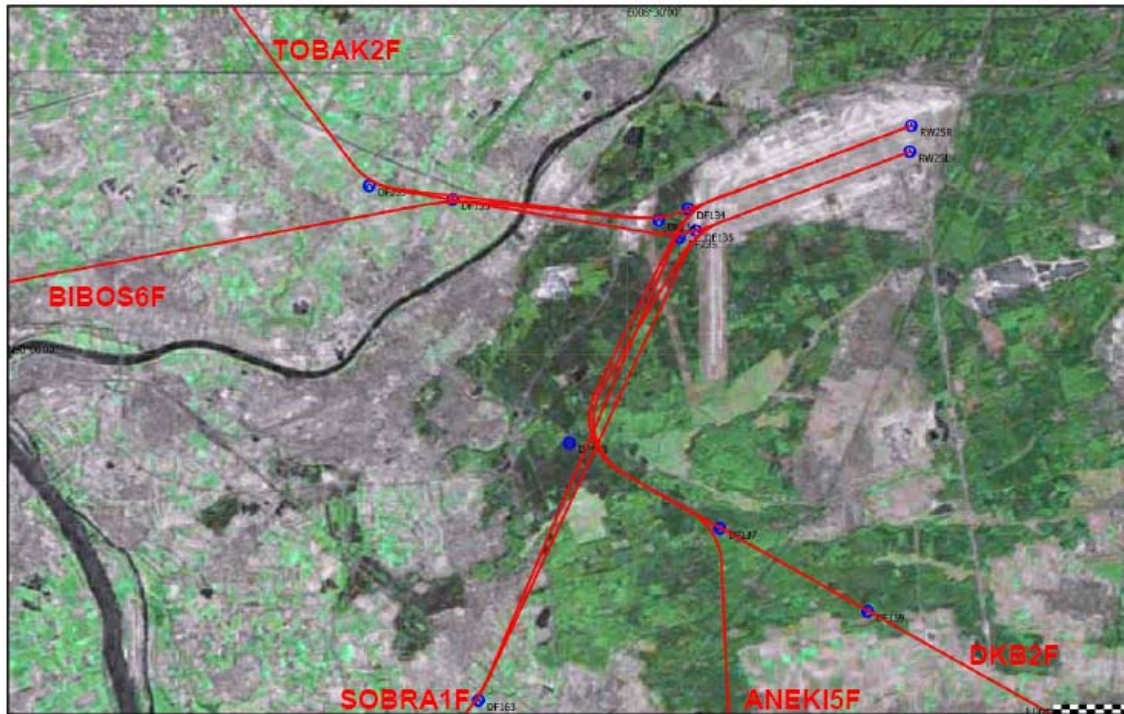
- WakeScene-D (departure) development started in 2007 for EU Project CREDOS
- 3DoF Traffic Model by DLR-FL together with TU Berlin
- NOWVIV meteo one year database
- Alternative WVM "DVM" by UCL



Lessons learned: WakeScene-D

History of WakeScene

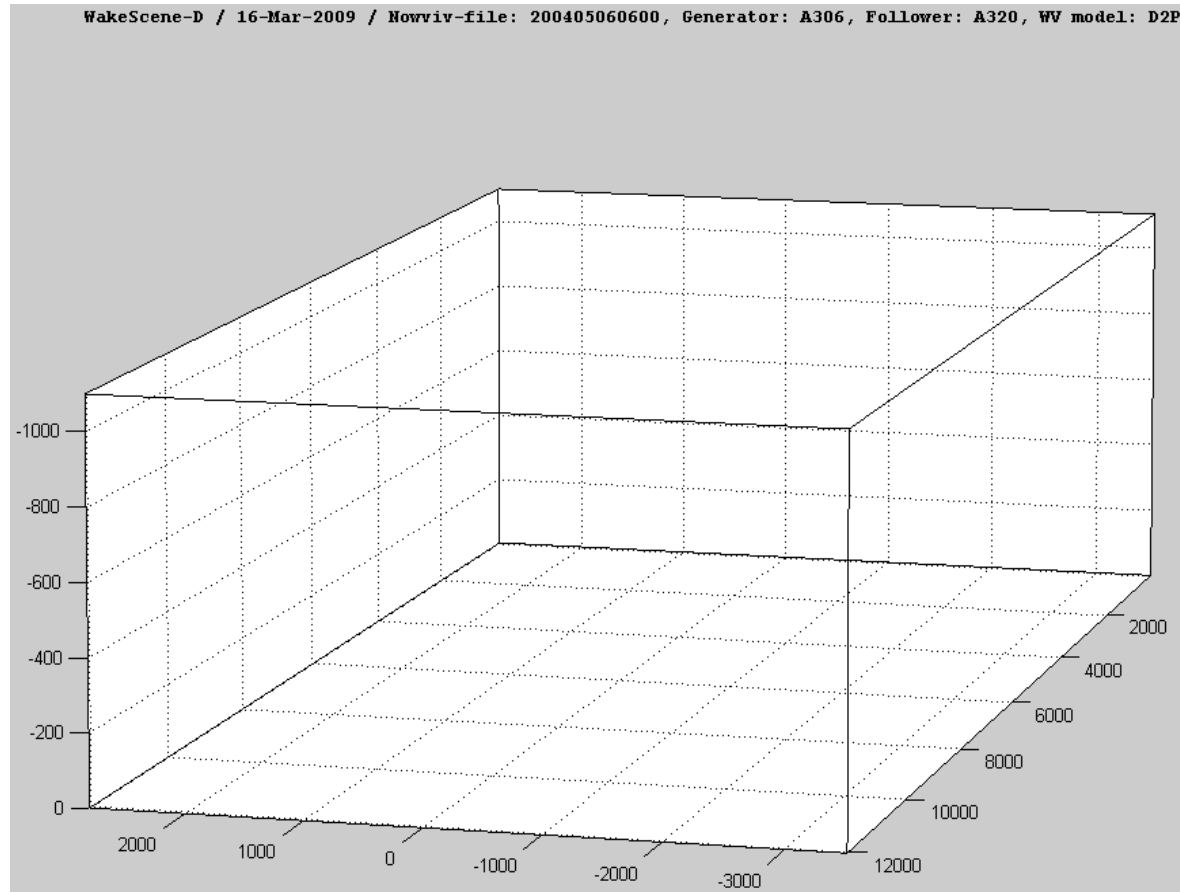
➤ WakeScene-D departure routes and gate concept



Lessons learned: WakeScene-D

History of WakeScene

➤ WakeScene-D 3D-animation



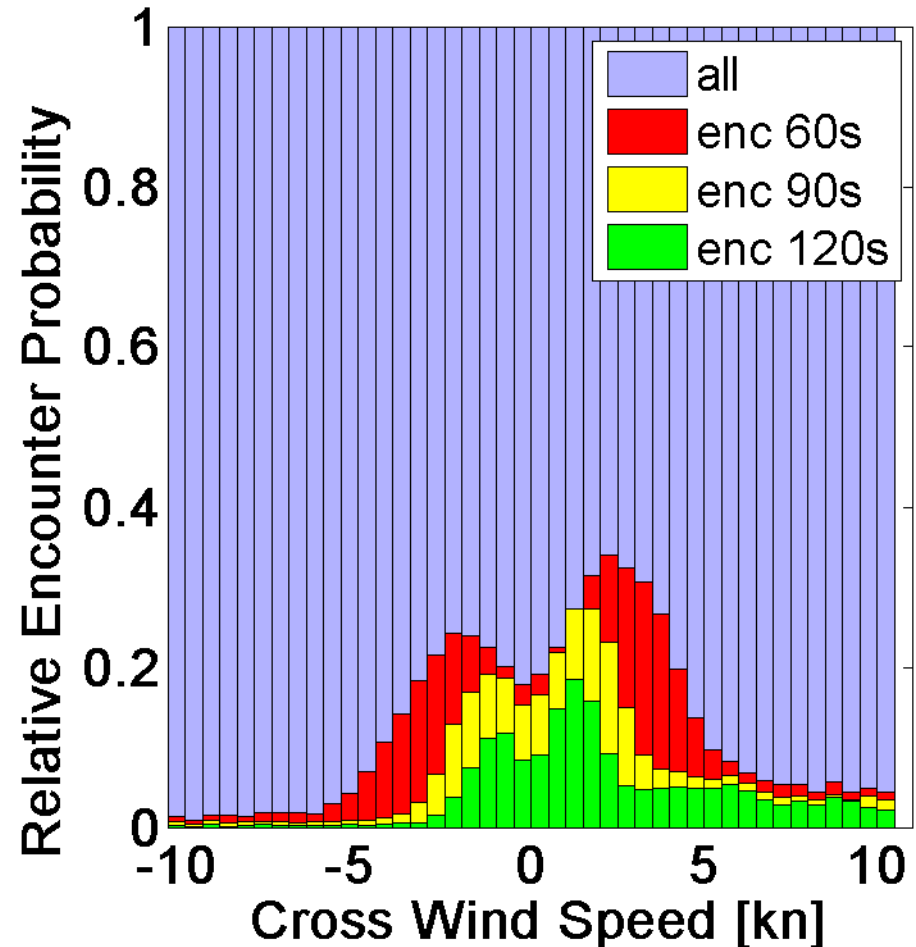
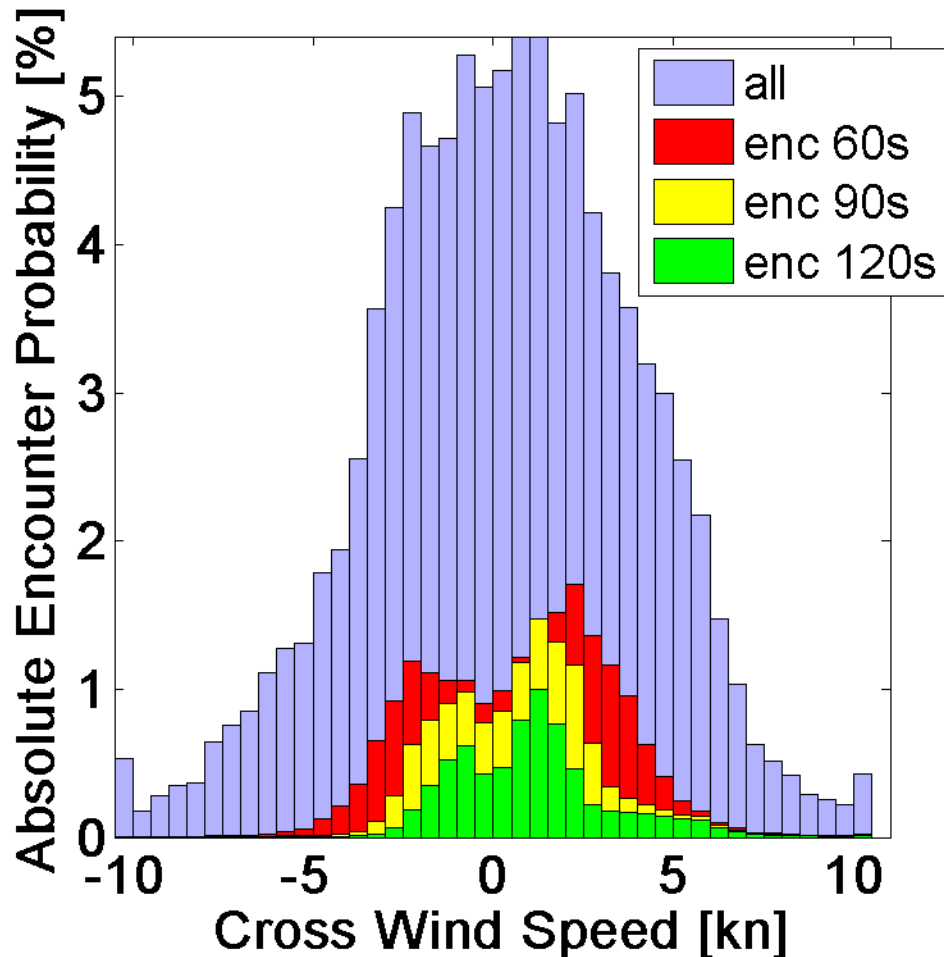
Lessons learned: WakeScene-D

Scenarios WakeScene-D

- Reference scenario
 - 120 s ICAO separation, Heavy-Medium
 - 1,000,000 aircraft pairings
 - Operational hours 06:00 – 23:00
 - No tailwinds > 5 knots
- Target scenarios
 - 60 s + 90 s separation
 - ***crosswind thresholds 0, 2, 4, ... 10 knots***

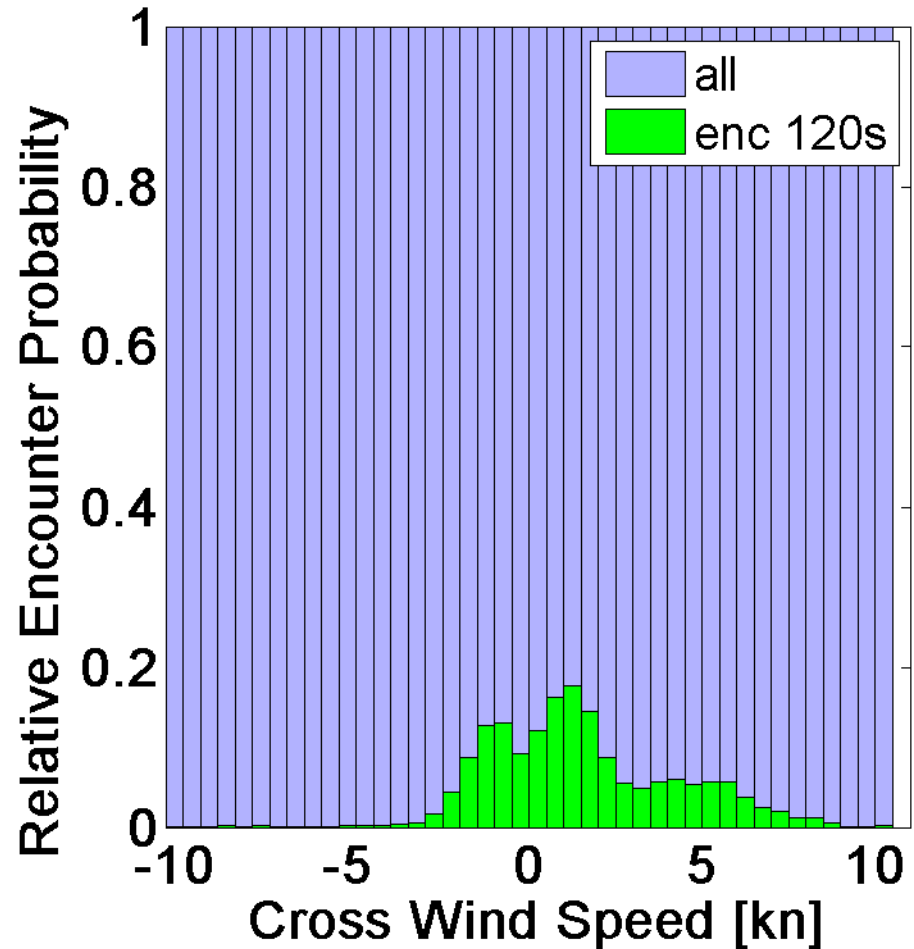
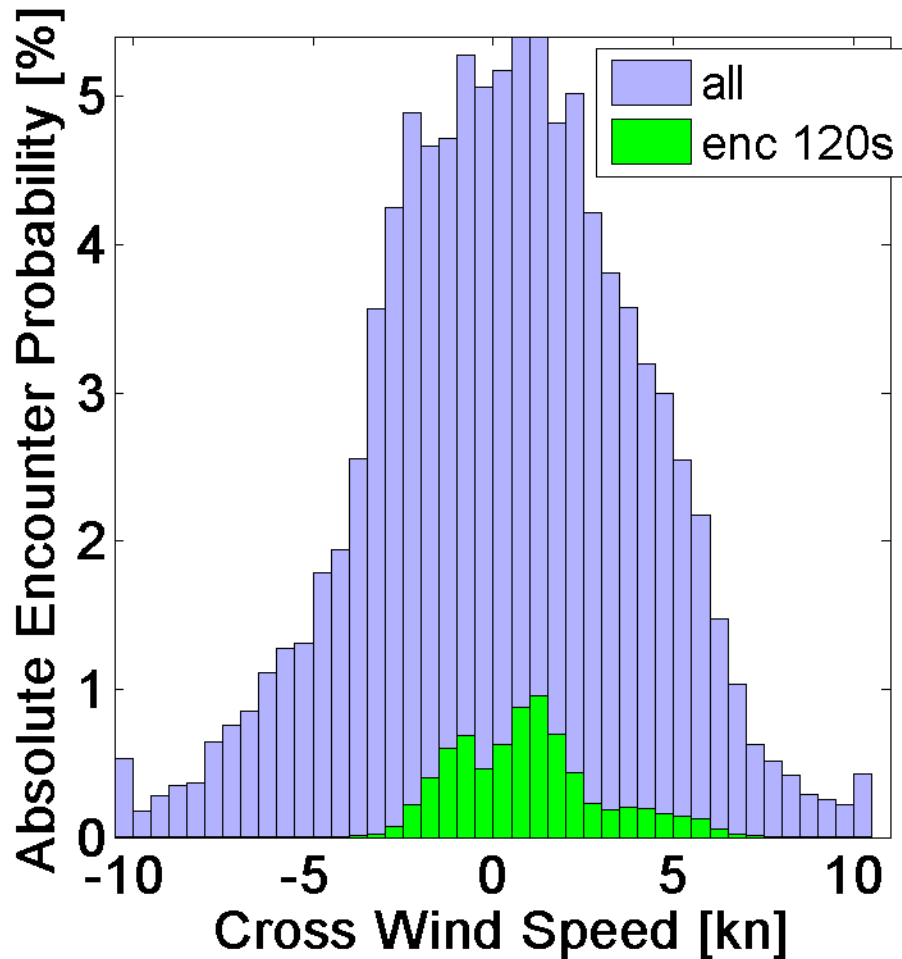
Lessons learned: WakeScene-D

Results, Probability vs. Crosswind PDD, Reference Scenario



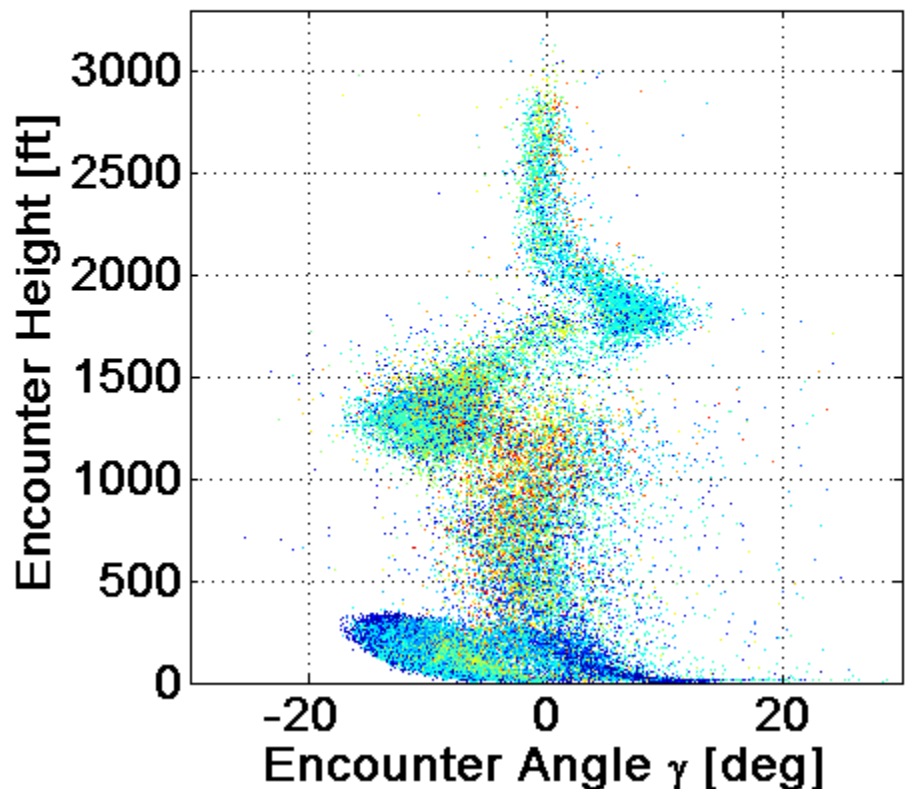
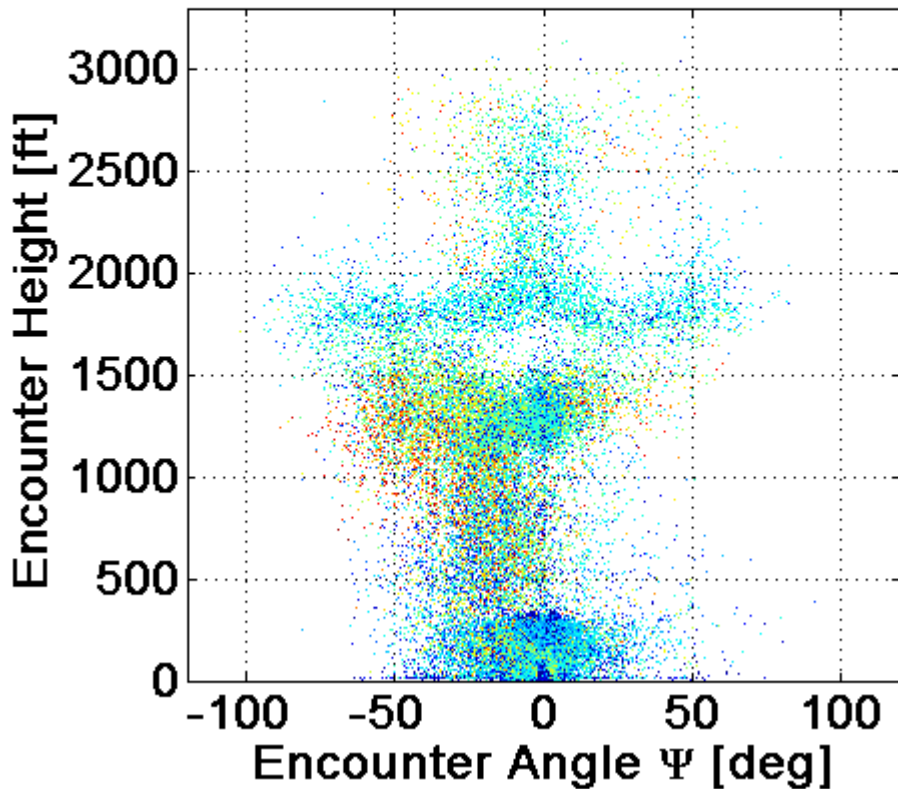
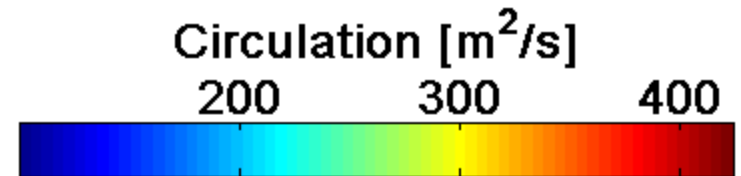
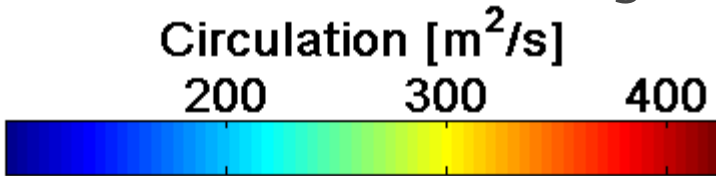
Lessons learned: WakeScene-D

Results, Probability vs. Crosswind PDD, Straight-Out Dep.



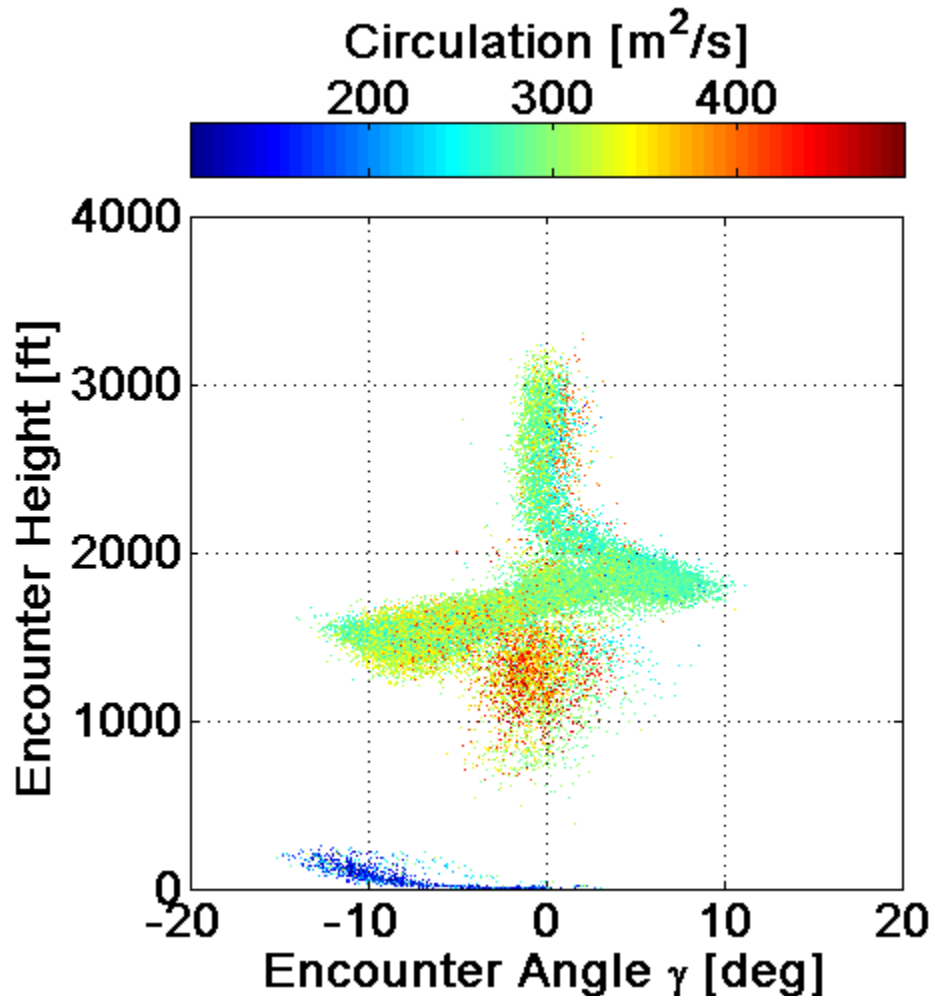
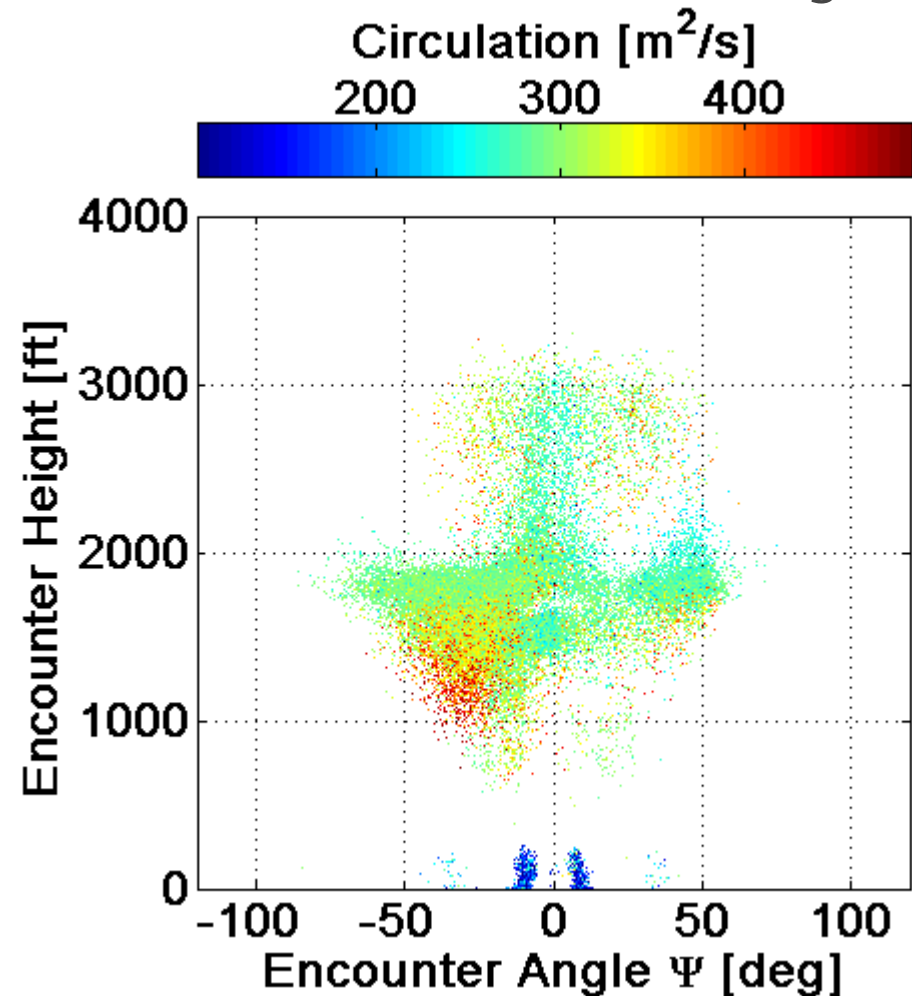
Lessons learned: WakeScene-D

Results, Encounter Angles, Reference Scenario



Lessons learned: WakeScene-D

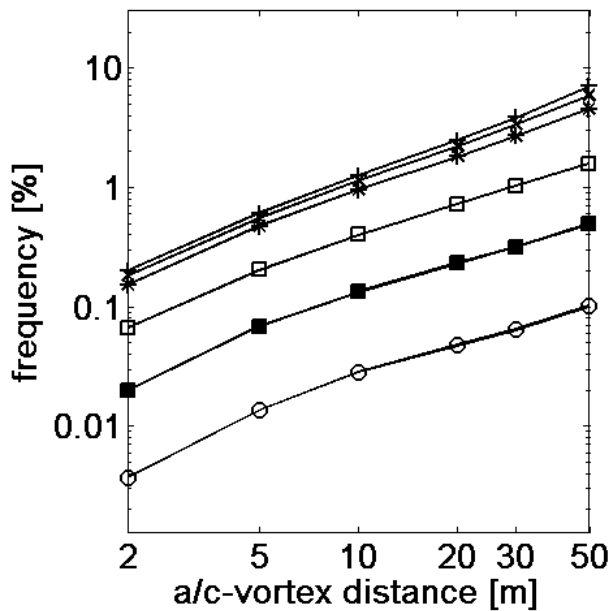
Results, Encounter Angles, CW6 Scenario 60 s



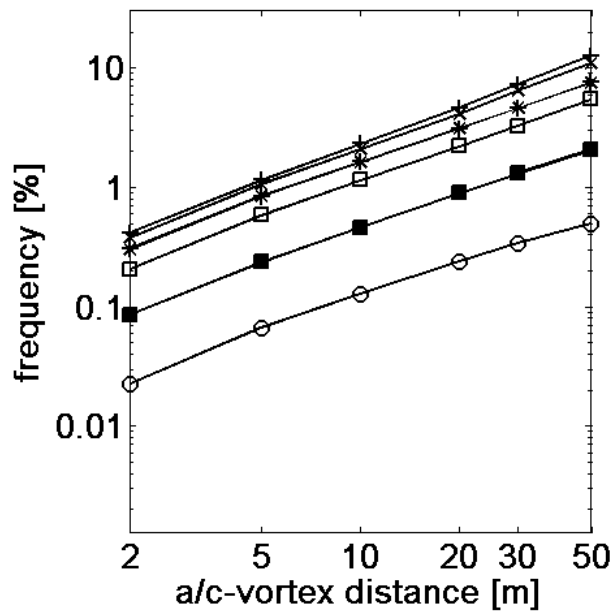
Lessons learned: WakeScene-D

Results, Encounter Probability, Reference Scenario

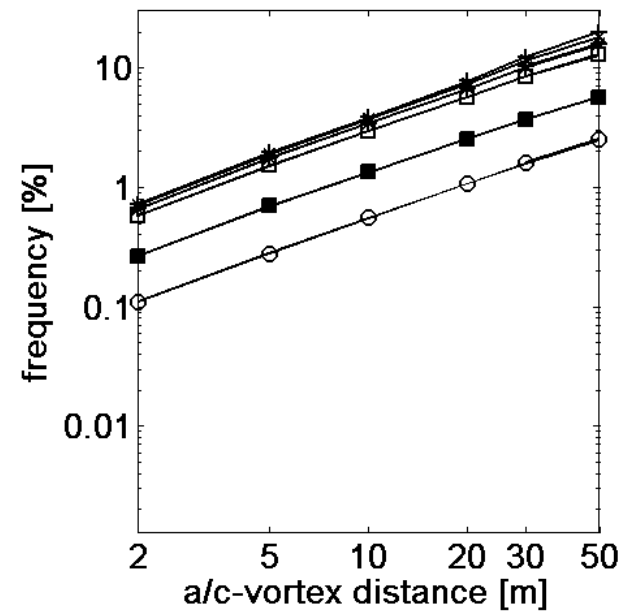
Ref 120 s



Ref 90 s



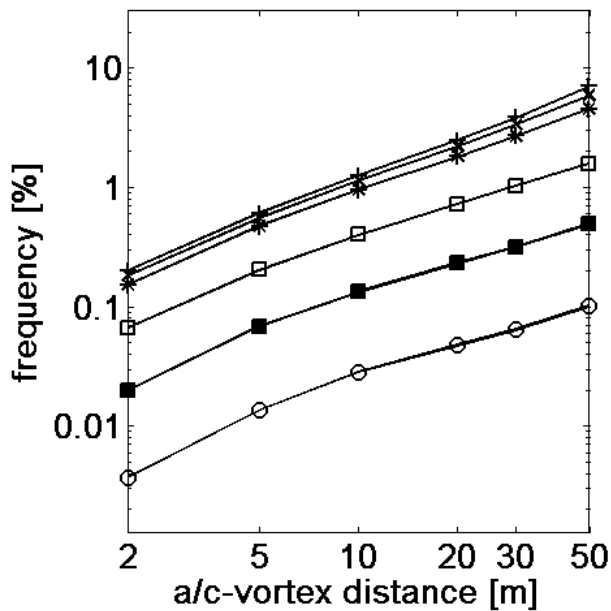
Ref 60 s



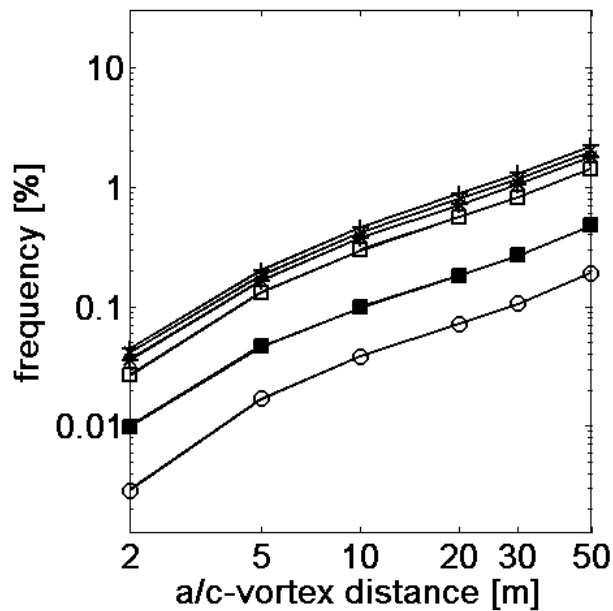
Lessons learned: WakeScene-D

Results, Encounter Probability, Reference Scenario + CW8

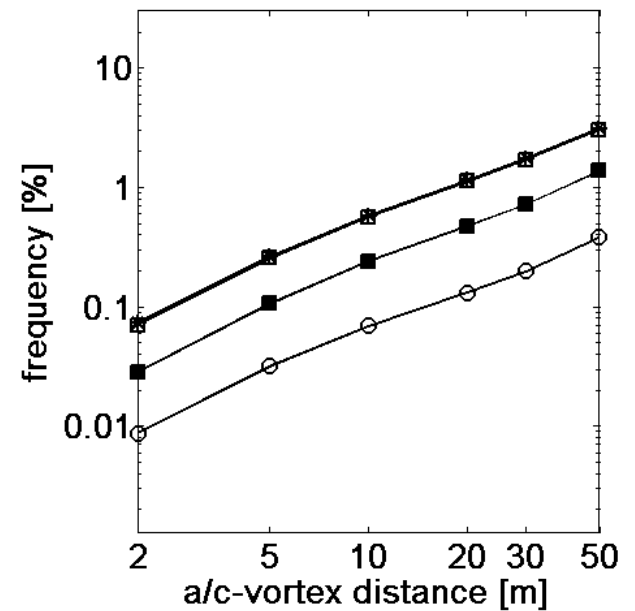
Ref 120 s



CW8 90 s



CW8 60 s



Lessons learned: WakeScene-D

Results, Target Scenarios - Synopsis

scenario	120 s all CWs	90 s 60 s all CWs	90 s 60 s CW > 2kts	90 s 60 s CW > 4kts	90 s 60 s CW > 6kts	90 s 60 s CW > 8kts	90 s 60 s CW > 10kts
total encounter frequency	7.0%	12.8% 19.9%	7.5% 17.7%	3.7% 8.3%	2.6% 3.8%	2.2% 3.1%	1.9% 2.7%
encounter frequency below 300 ft	4.6%	9.4% 15.8%	2.9% 13.1%	0.057% 3.5%	0.0003% 0.10%	0.0002% 0.0056%	0.0% 0.0044%
worst case encounter frequency	0.0037%	0.023% 0.11%	0.011% 0.056%	0.0073% 0.020%	0.0041% 0.010%	0.0026% 0.0086%	0.0017% 0.0025%

Lessons learned: WakeScene-D

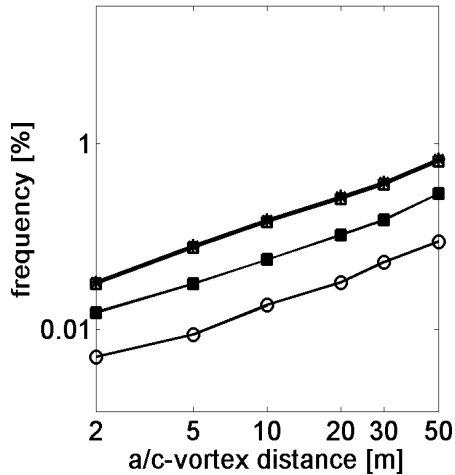
Results, Target Scenarios - Synopsis

- total encounter frequency ($\Gamma > 100 \text{ m}^2/\text{s}$ & distance $< 50 \text{ m}$) doubled for 90 s and tripled for 60 s separations (all CWs)
 - total encounter frequency below reference scenario for CW $> 4 \text{ kts}$ (90 s) and for CW $> 6 \text{ kts}$ (60 s)
 - further increased CWs marginally reduce total encounter freq.
 - worst case encounter freq. ($\Gamma > 350 \text{ m}^2/\text{s}$ & distance $< 2 \text{ m}$) below reference scenario for CW $> 8 \text{ kts}$ (90 s) and for CW $> 10 \text{ kts}$ (60 s)
- ⇒ encounters below 300 ft effectively reduced by moderate CWs
- ⇒ stronger CWs only marginally reduce encounters above 1000 ft

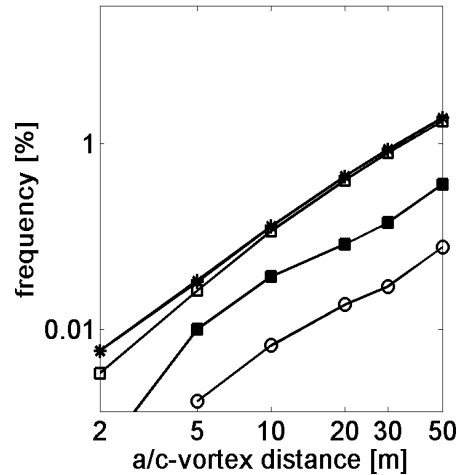
Lessons learned: WakeScene-D

Results, Target Scenarios - Synopsis

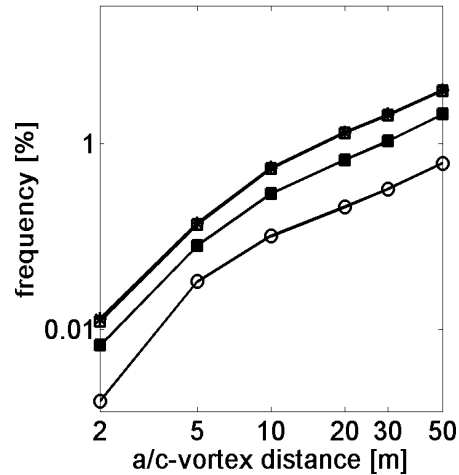
cw8 scenario, NN SIDs



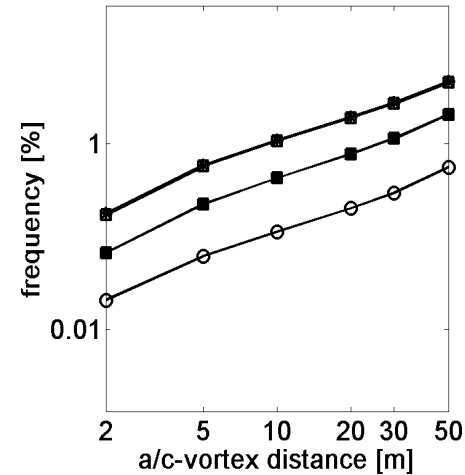
cw8 scenario, NS SIDs



cw8 scenario, SN SIDs



cw8 scenario, SS SIDs



- close encounters reduced on NS and SN SIDs

⇒ possible CREDOS procedure for e.g. 60 s separation:

- CW > 8 knots significantly reduce encounter frequencies close to the ground
- alternating SN and NS SID combinations reduce encounter risks aloft

- procedure could be refined by using only SID combinations where leading aircraft is flying on the downwind SID.

(would require at least knowledge of wind directions aloft)

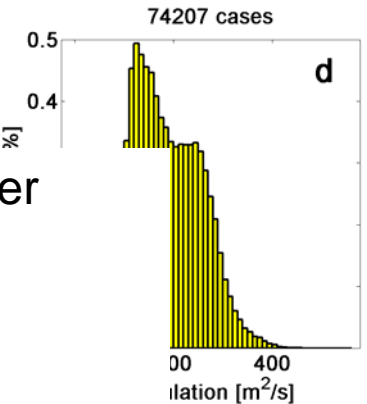
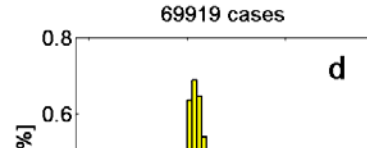
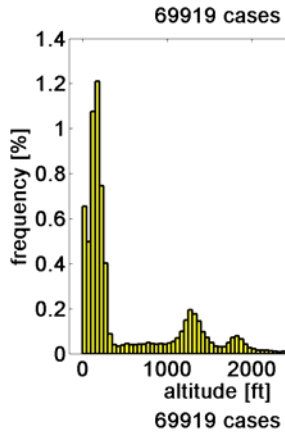
Lessons learned: WakeScene-D

Results, Wake Vortex Models

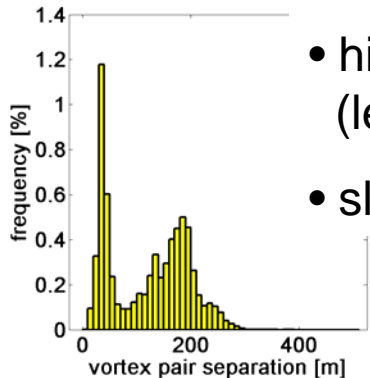
D2P

Ref 120s

DVM

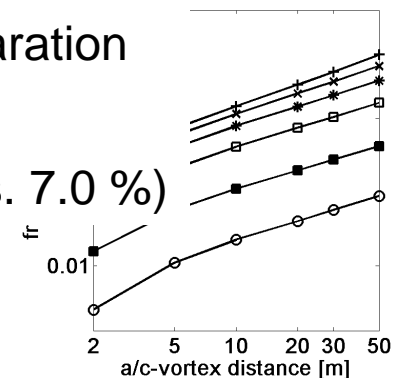
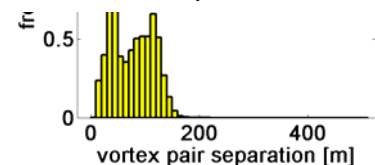
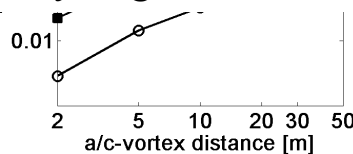


- DVM delivers lower circulation values due to faster decay (earlier second phase decay)
- DVM: 55 % encounters < 300 ft
D2P: 65 % encounters < 300 ft



- higher encounters lead to lower vortex pair separation (less encounters in ground effect)

- slightly higher encounter rate for DVM (7.4 % vs. 7.0 %)



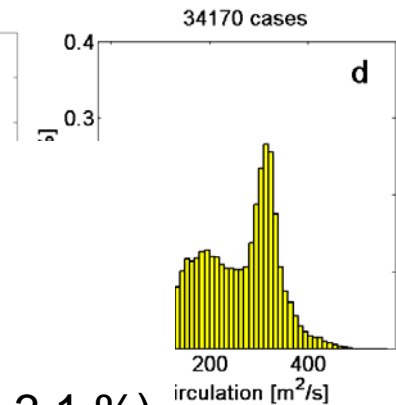
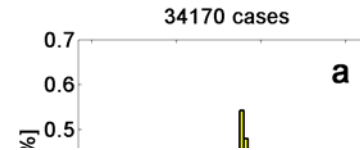
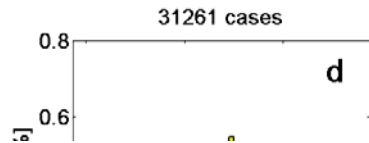
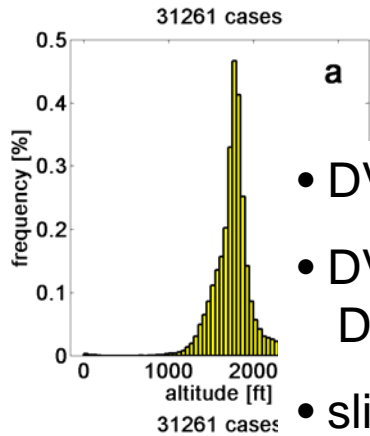
Lessons learned: WakeScene-D

Results, Wake Vortex Models

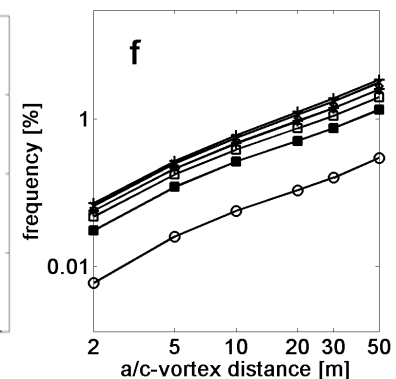
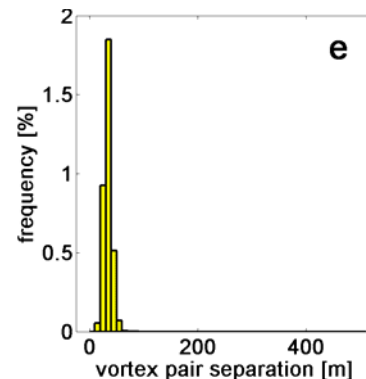
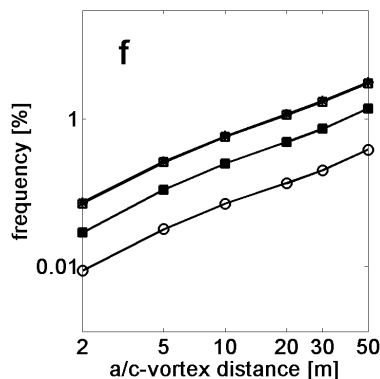
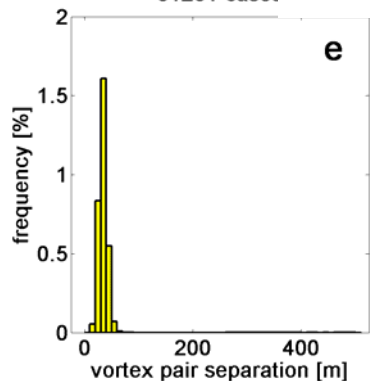
D2P

CW8 60s

DVM



- DVM with higher decay in 60 s scenario
- DVM: 0 encounters < 300 ft
D2P: 0.17 % encounters < 300 ft
- slightly higher encounter rate for DVM (3.4 % vs. 3.1 %)



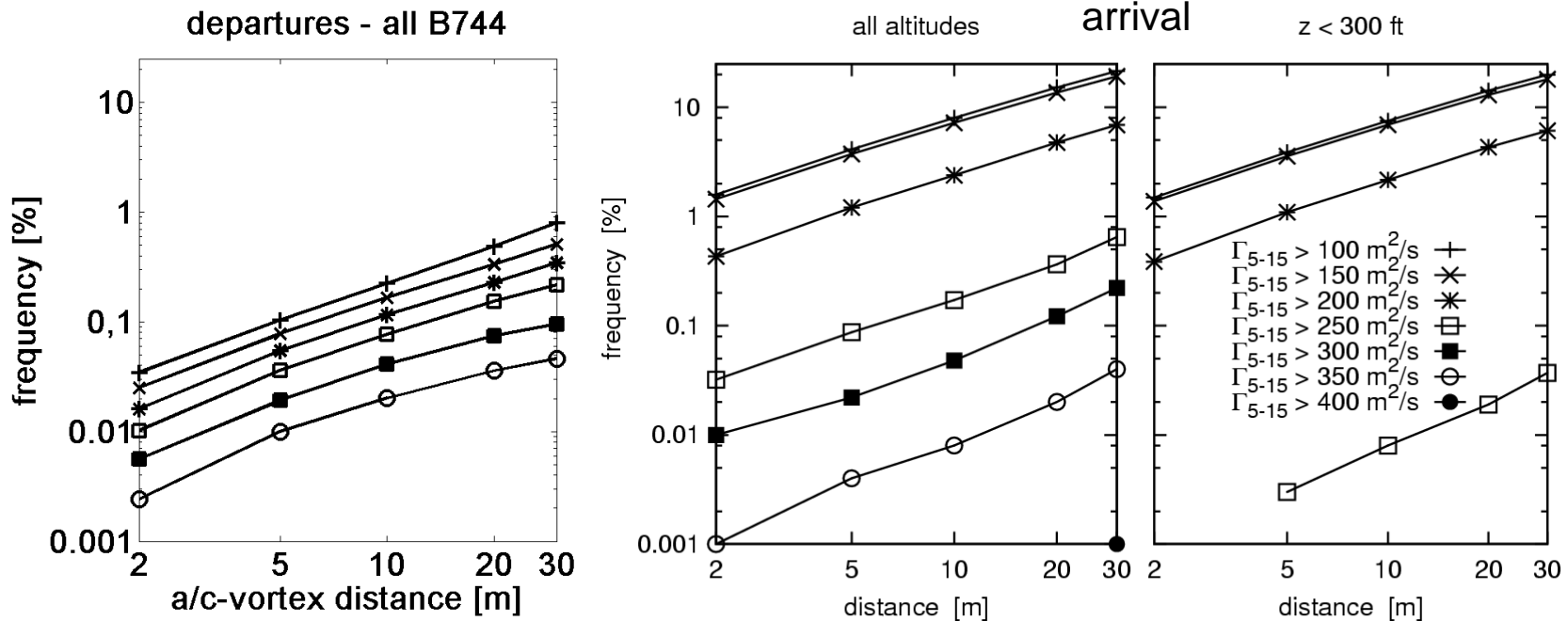
Lessons learned: WakeScene-D

Results, Aircraft Combinations

P(enc) mean(Γ_{enc}) max(Γ_{enc})	A306 (20.5 %)	A310 (2.7 %)	A333 (10.4 %)	A343 (14.8 %)	B744 (41.2 %)	B772 (10.3 %)
A320 (49.9 %)	9.9 % 195.0 m ² /s 303.2 m ² /s	13.2 % 191.1 m ² /s 275.1 m ² /s	17.9 % 236.8 m ² /s 369.0 m ² /s	13.7 % 227.5 m ² /s 410.5 m ² /s	2.0 % 199.5 m ² /s 423.6 m ² /s	3.6 % 224.0 m ² /s 395.4 m ² /s
AT45 (3.7 %)	4.8 % 186.6 m ² /s 272.7 m ² /s	6.8 % 180.9 m ² /s 253.1 m ² /s	5.2 % 227.7 m ² /s 331.2 m ² /s	2.1 % 218.1 m ² /s 352.6 m ² /s	0.2 % 172.7 m ² /s 370.7 m ² /s	0.3 % 171.8 m ² /s 259.3 m ² /s
B733 (33.0 %)	10.7 % 193.9 m ² /s 303.2 m ² /s	14.1 % 188.9 m ² /s 282.2 m ² /s	18.2 % 233.5 m ² /s 358.0 m ² /s	15.3 % 232.1 m ² /s 402.7 m ² /s	2.4 % 179.2 m ² /s 418.9 m ² /s	3.9 % 219.7 m ² /s 381.8 m ² /s
CRJ1 (13.3 %)	5.5 % 185.2 m ² /s 283.0 m ² /s	10.4 % 184.8 m ² /s 268.6 m ² /s	7.9 % 219.9 m ² /s 345.4 m ² /s	6.6 % 227.5 m ² /s 379.4 m ² /s	0.8 % 161.9 m ² /s 382.8 m ² /s	1.1 % 204.7 m ² /s 322.9 m ² /s

Lessons learned: WakeScene-D

Comparison to Arrival Situation



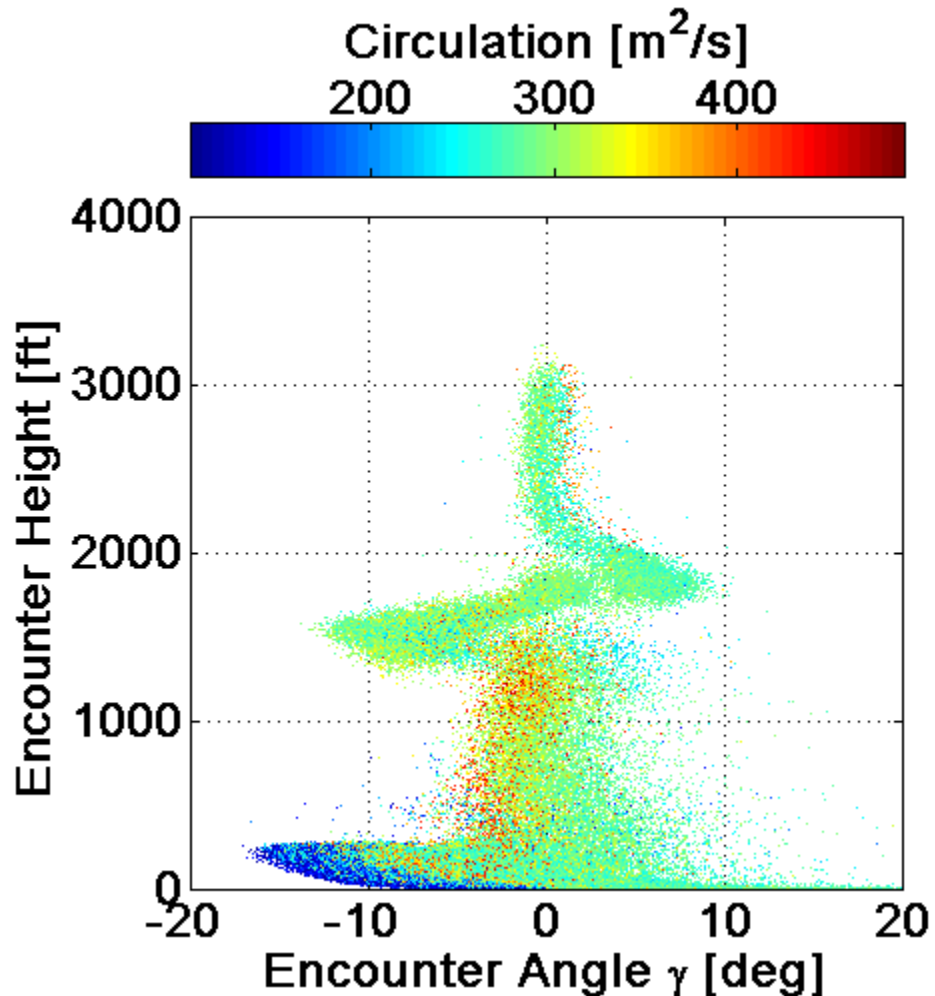
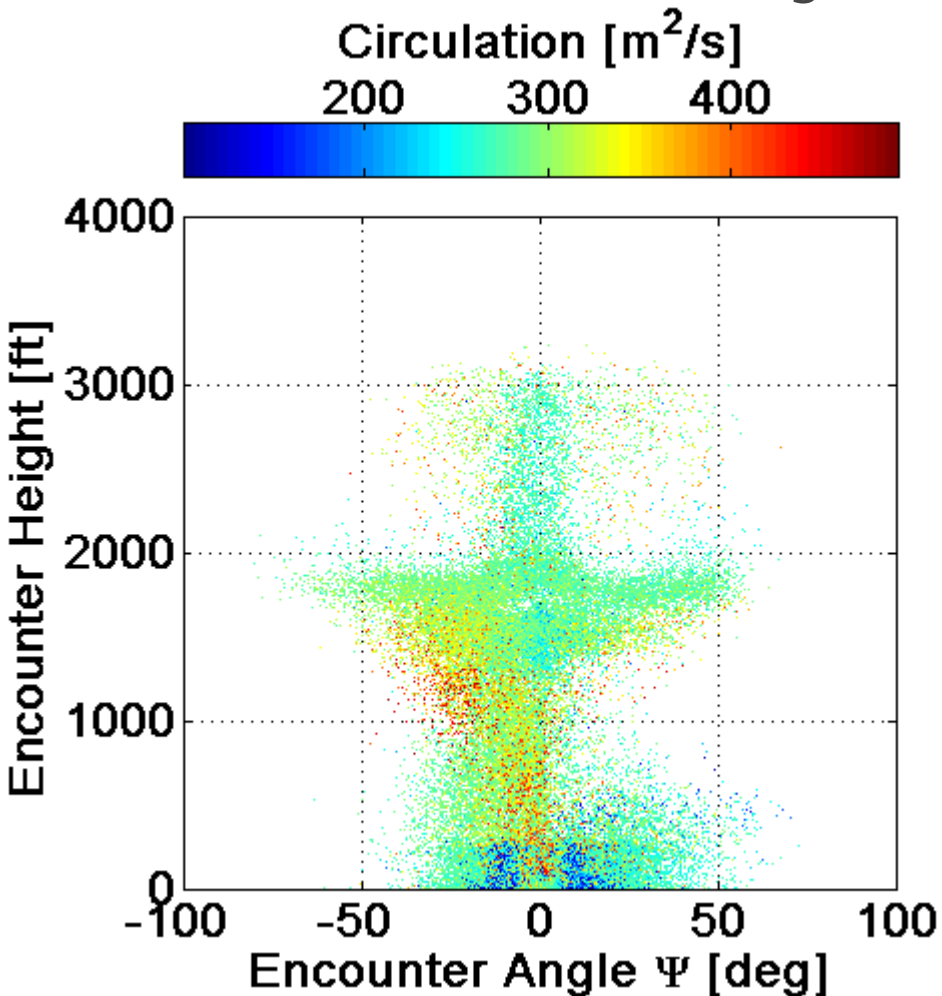
- encounters less frequent for departures than for arrivals
 - strong encounters ($\Gamma > 350 \text{ m}^2/\text{s}$) more frequent for departures
 - less encounters below 300 ft for departures (95%)
- ⇒ more pronounced spreading of aircraft trajectories for departure situation



Thank You for Your Attention!

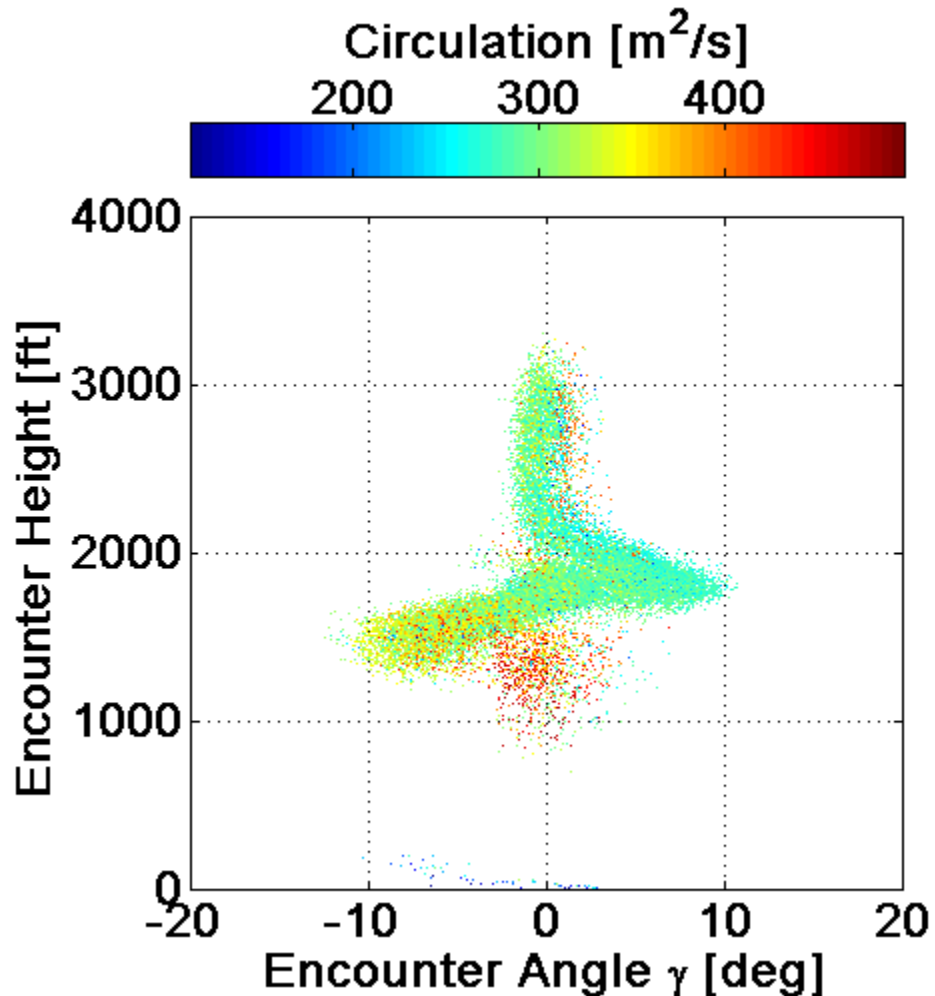
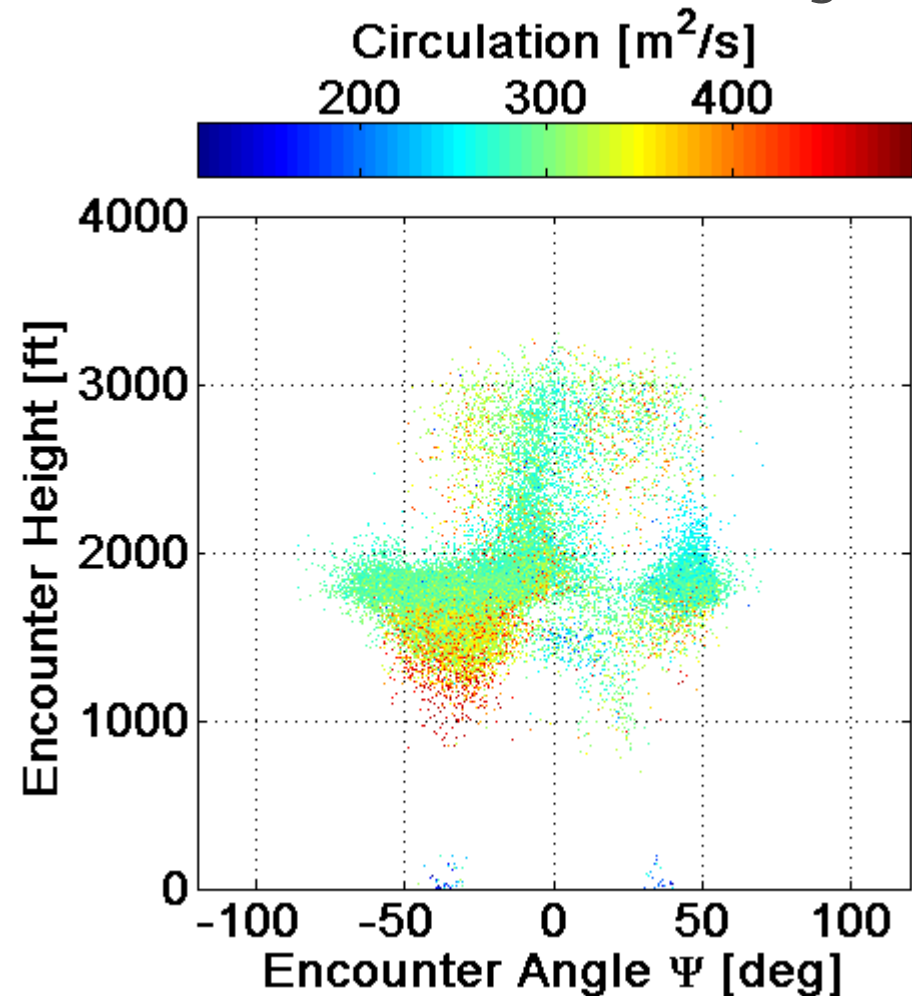
Lessons learned: WakeScene-D

Results, Encounter Angles, Reference Scenario 60 s



Lessons learned: WakeScene-D

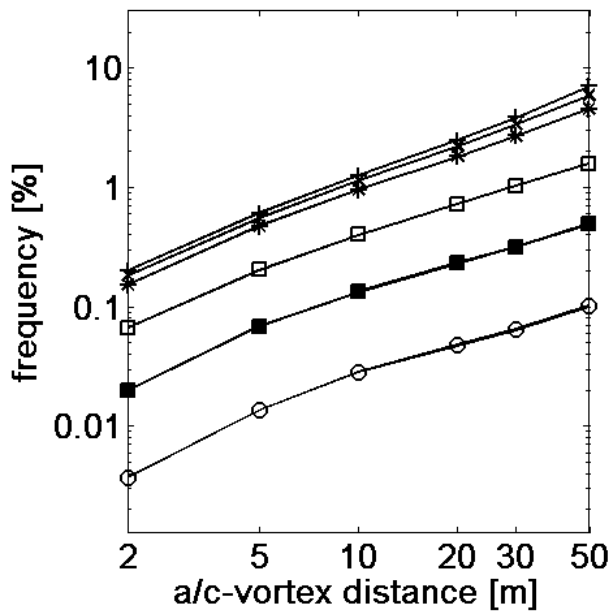
Results, Encounter Angles, CW8 Scenario 60 s



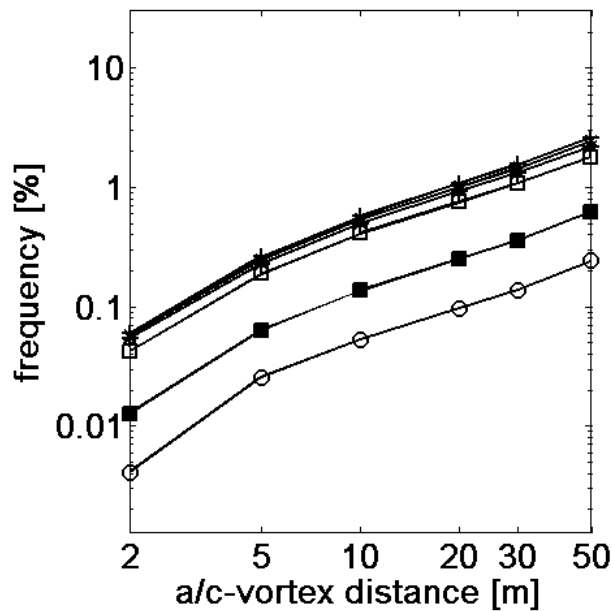
Lessons learned: WakeScene-D

Results, Encounter Probability, Reference Scenario + CW6

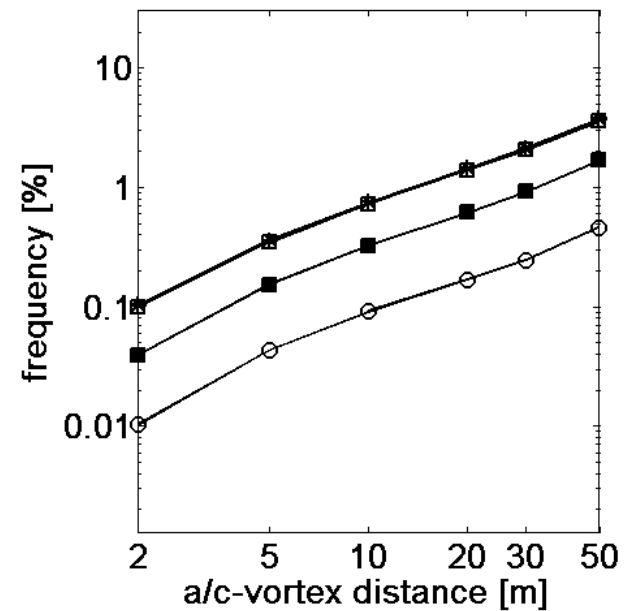
Ref 120 s



CW6 90 s



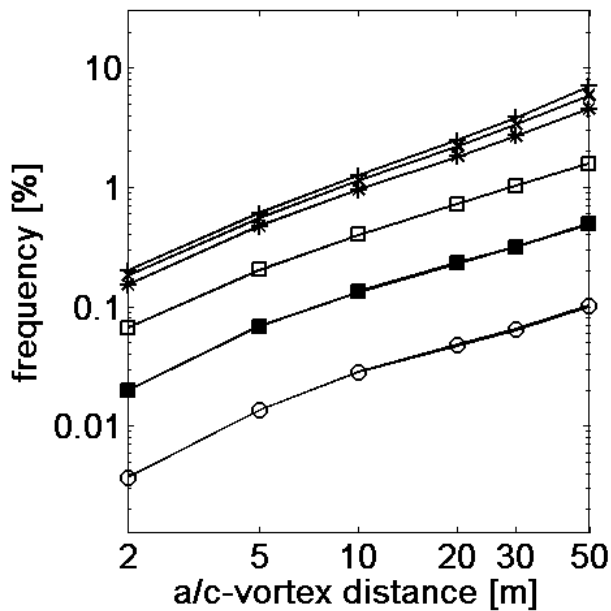
CW6 60 s



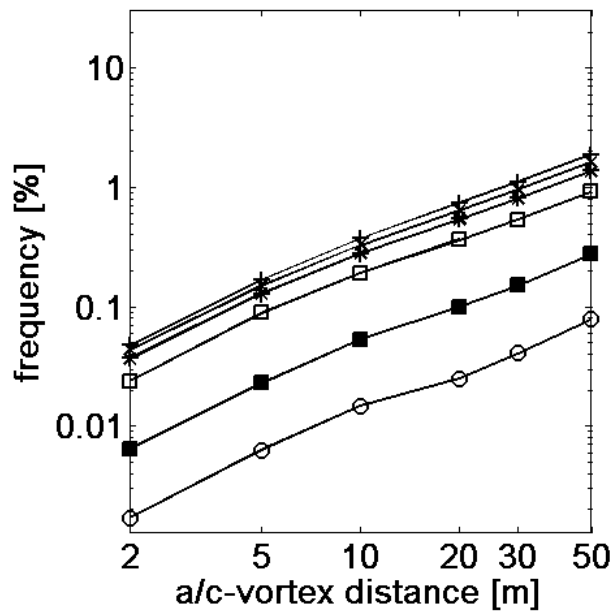
Lessons learned: WakeScene-D

Results, Encounter Probability, Reference Scenario + CW10

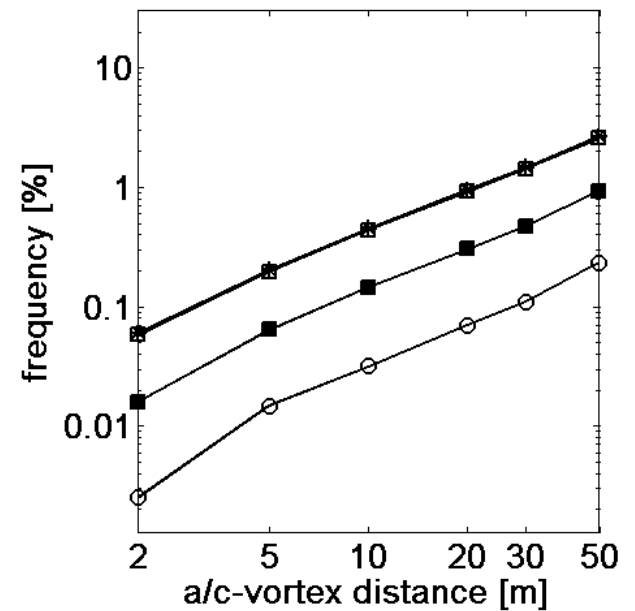
Ref 120 s



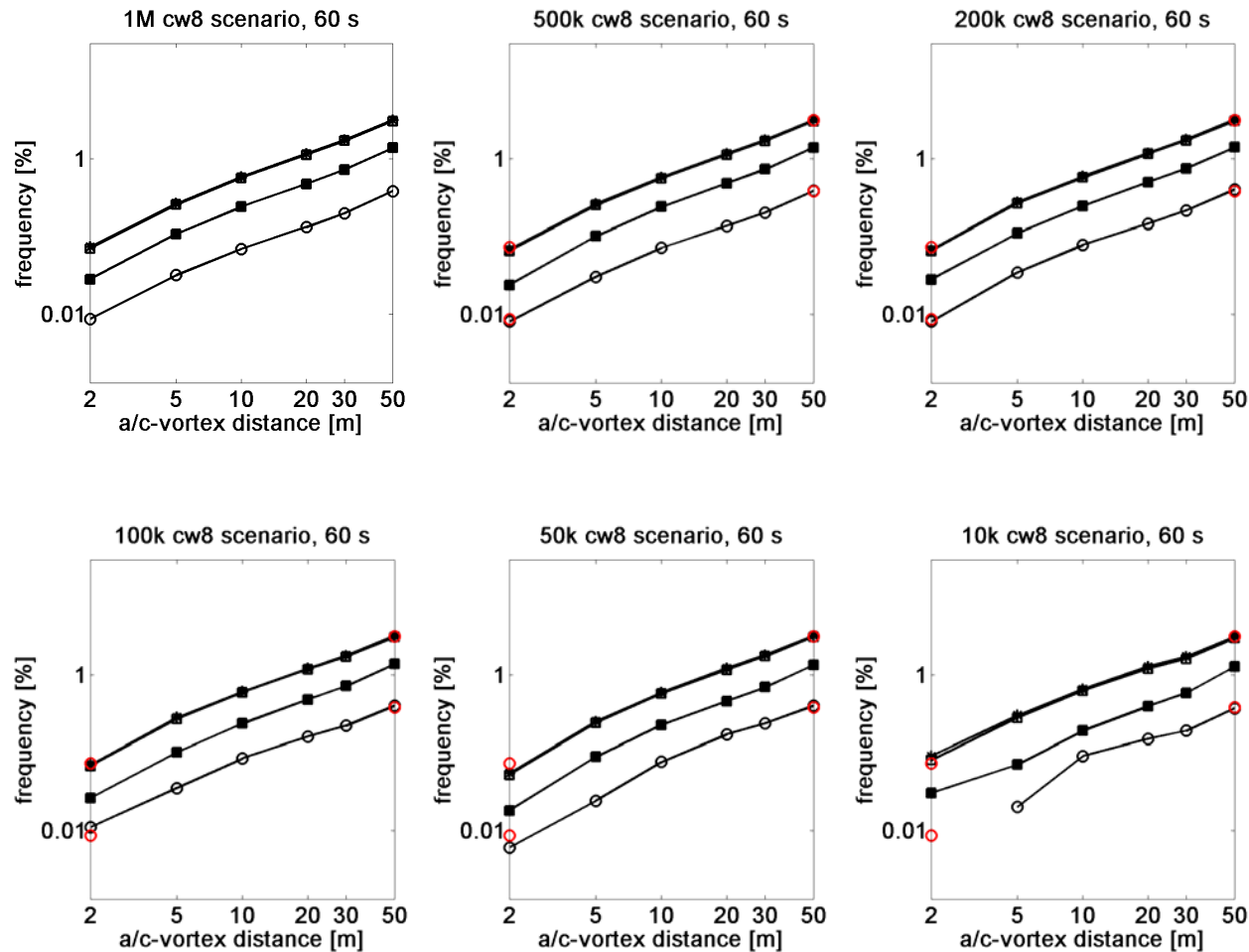
CW10 90 s



CW10 60 s



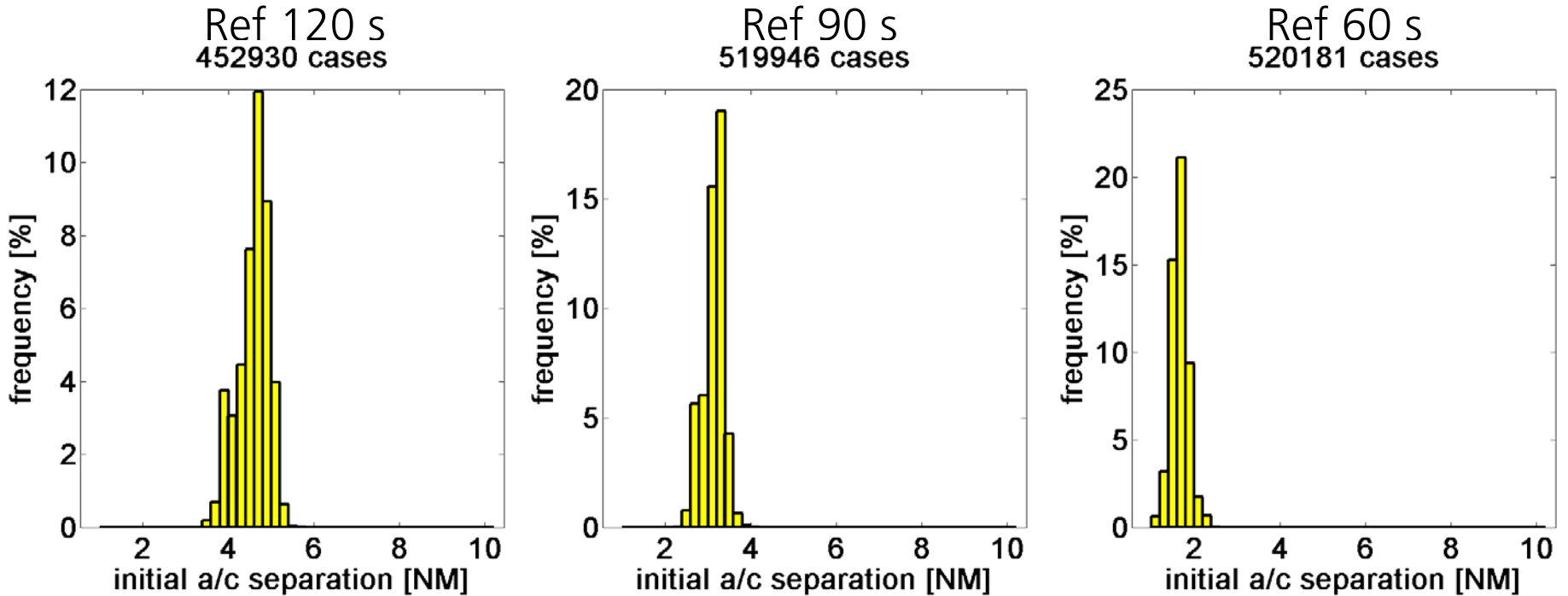
Sample Size



- reasonable representation of most critical and rare encounters requires sample sizes of 500,000 departures
- 1,000,000 sample size guarantees well converged statistics.

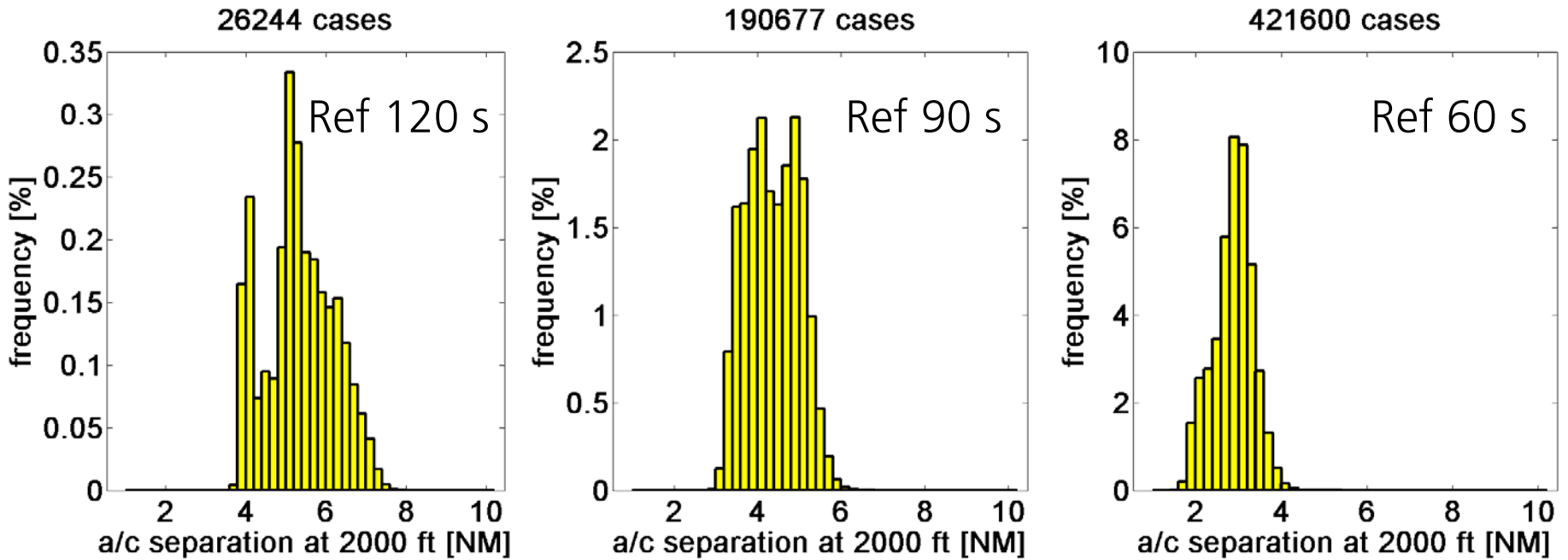
Lessons learned: WakeScene-D

Results, Pull Away Effect – Initial Separations



Lessons learned: WakeScene-D

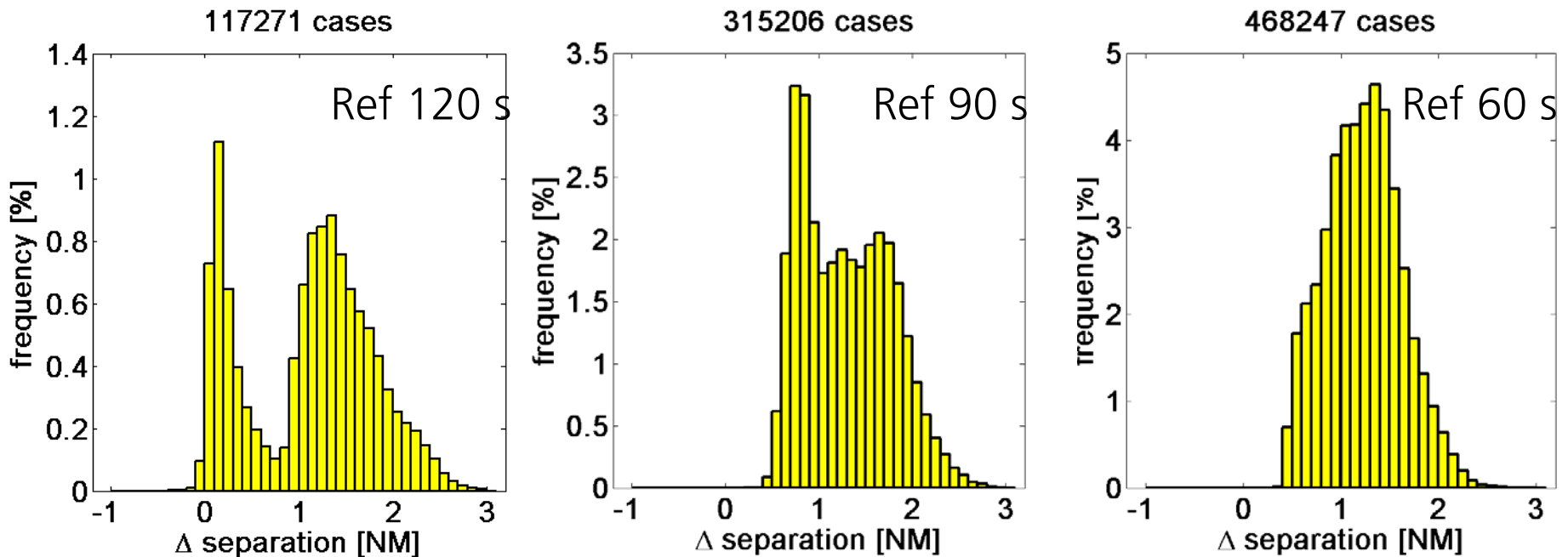
Results, Pull Away Effect – Separations at 2000 ft AGL



- already at 120 s sep. large part of a/c separated by less than 5 NM
(corresponds to reality? consequences?)
- for 90 s separations most aircraft pairings do not comply with required separation
- for 60 s separations all followers are closer than the required 5 NM
- only aircraft separations beyond 7 NM reliably prevent encounters (not shown)

Lessons learned: WakeScene-D

Results, Pull Away Effect – Separation Gain at 2000 ft AGL



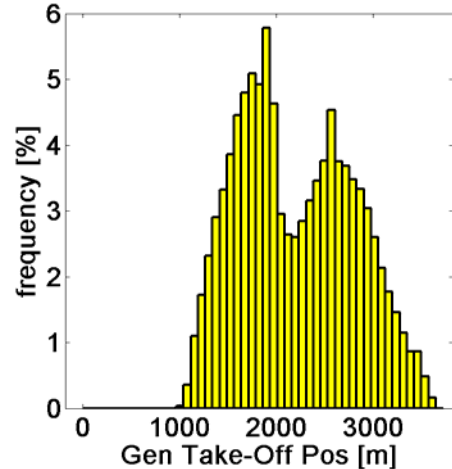
- pull-away effect increases separation
- effect is more pronounced for reduced separations
- minimum separation is guaranteed

Lessons learned: WakeScene-D

Results, Aircraft Combinations, Lift-Off Points

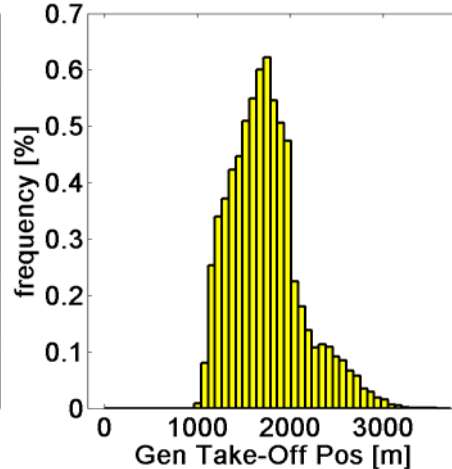
Generator

999996 cases



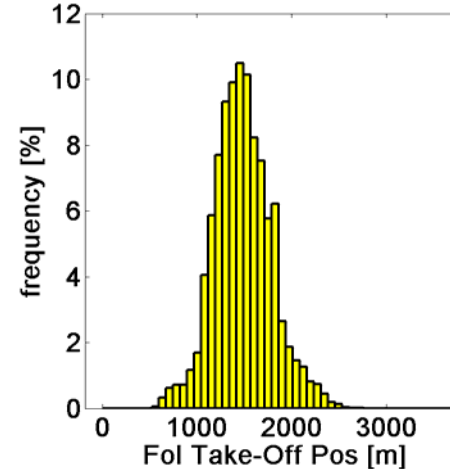
Generator Encounters

70167 cases



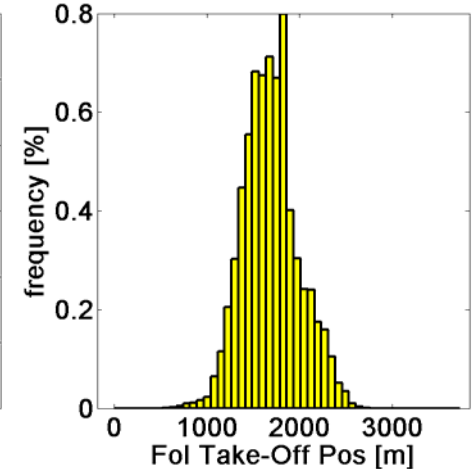
Follower

999996 cases



Follower Encounters

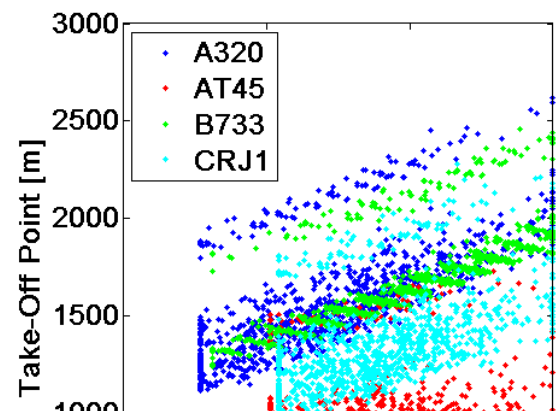
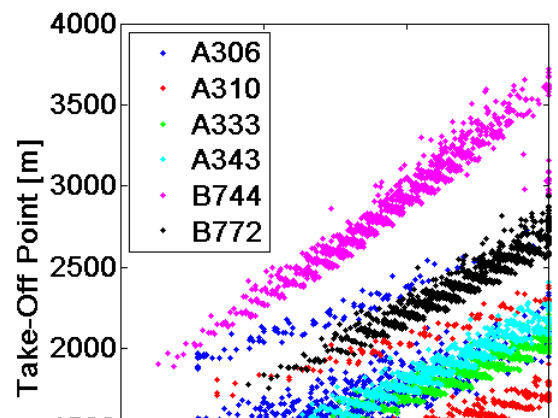
70167 cases



- strongest encounters behind most heavy aircraft
- encounters are correlated with early take-off of leading aircraft and late take-off of follower aircraft
- A320 represents conservatively the other follower aircraft types for VESA (most frequent follower aircraft & achieves almost highest encounter frequencies)



Take-Off Weight



- strong impact of T/O weights on T/O positions & climb rates
- high encounter rates: leaders take off early and climb steeply whereas followers take off late and climb slowly
- T/O positions & climb rates have influence on encounter frequencies for aircraft type combinations and **within** specific aircraft type combinations

