

Simulating Bird Strikes in Fast-Time

Isabel C. Metz

15 August 2019

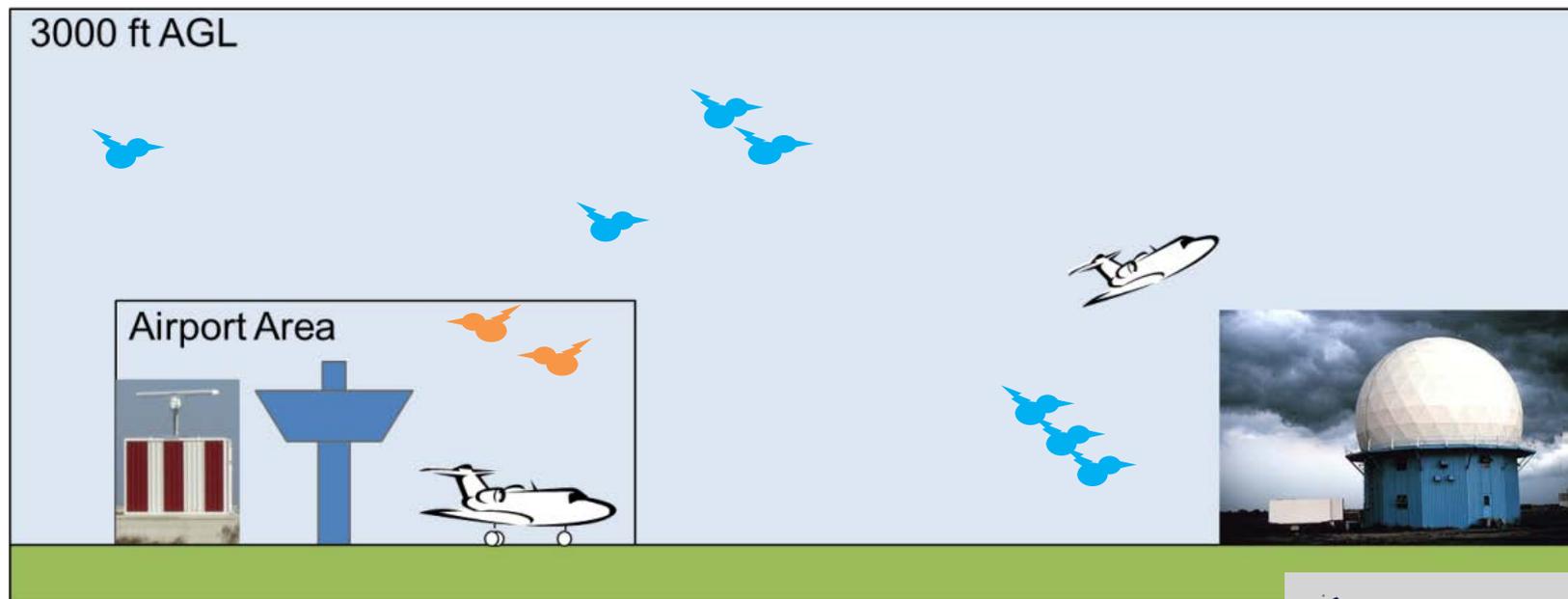
North American Bird Strike Conference

A satellite-style image of the Earth from space, showing the curvature of the planet, blue oceans, green landmasses, and white clouds. The text "Knowledge for Tomorrow" is overlaid on the right side of the image.

Knowledge for Tomorrow

Simulation Environment

Fast-Time Simulation of Air Traffic and Bird Movements



Royal Netherlands Air Force



Royal Netherlands
Meteorological Institute
Ministry of Infrastructure and the
Environment



Simulation Environment

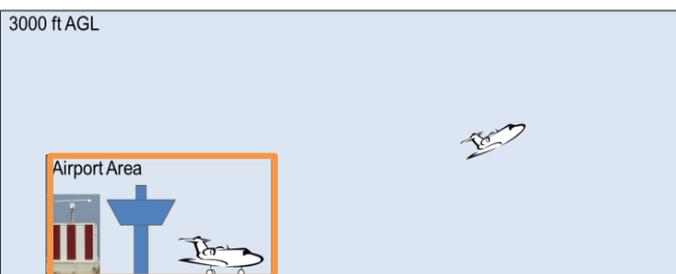
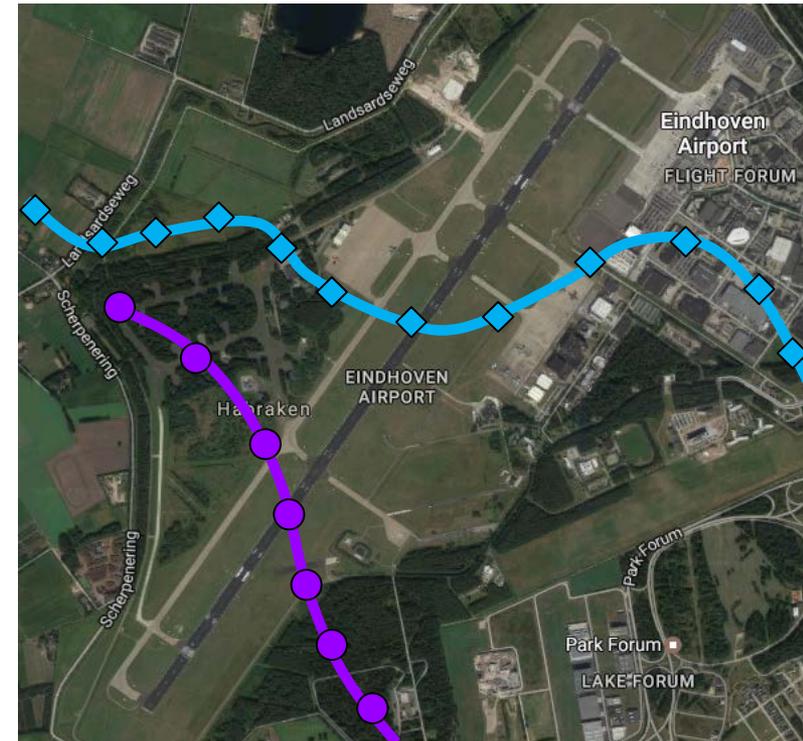
Bird Movement Model: Direct Airport Environment

input

- time-stamped 2D positions
- id
- category

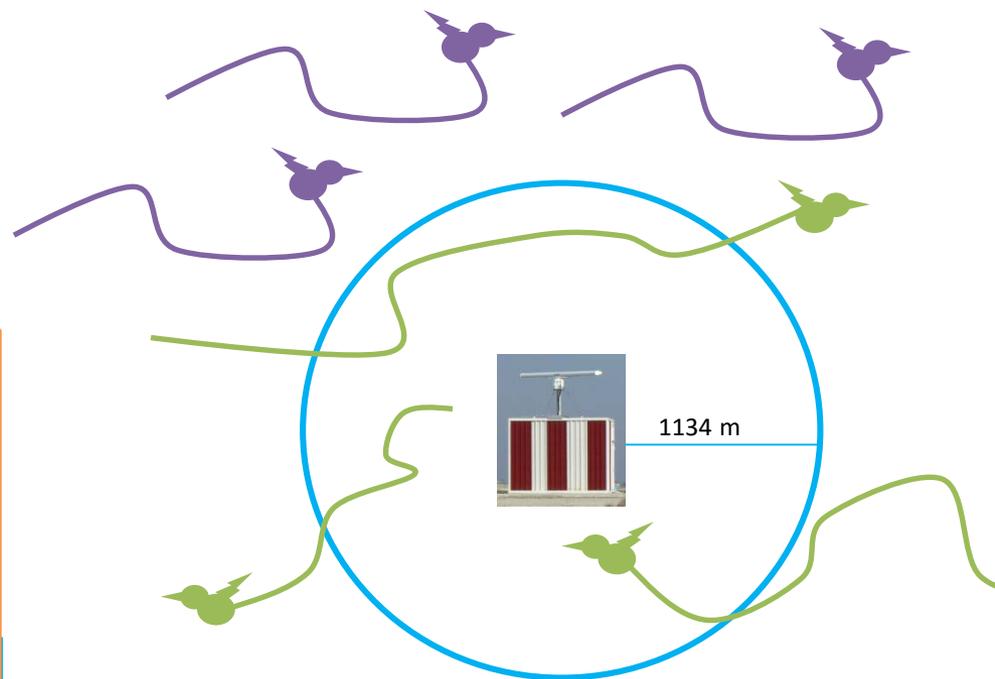
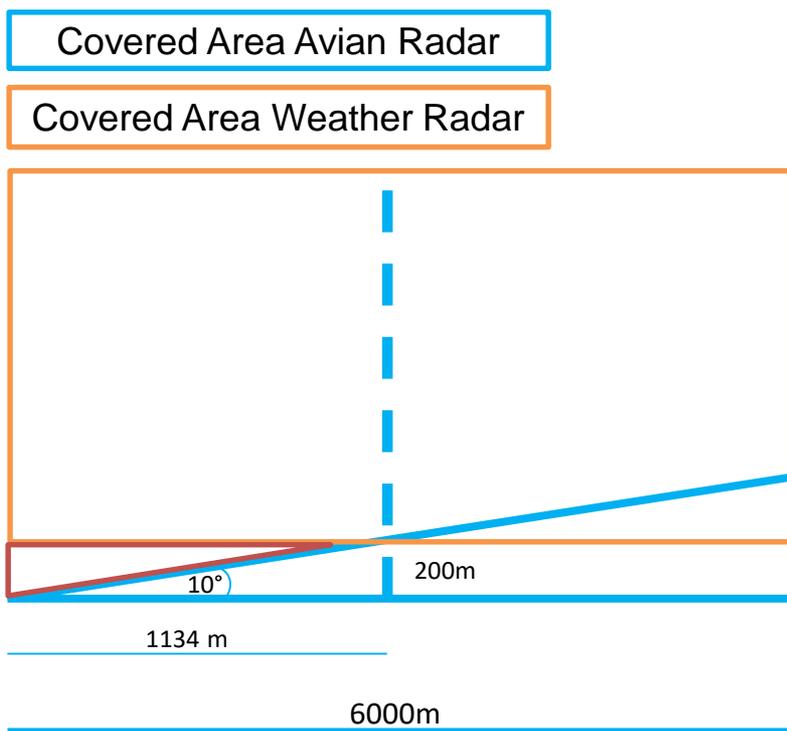
processing

- at least 20 positions per bird
- categories: small, medium, large, flocks



Simulation Environment

Bird Movement Model: Direct Airport Environment



altitude	day	night
0-200m	48%	35.1%

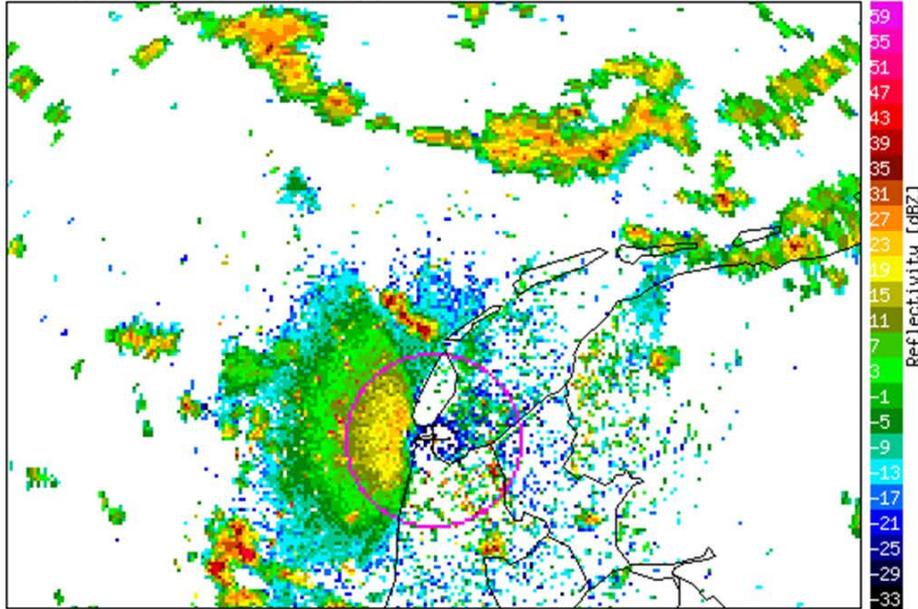
source: Shamoun-Baranes et al. 2017



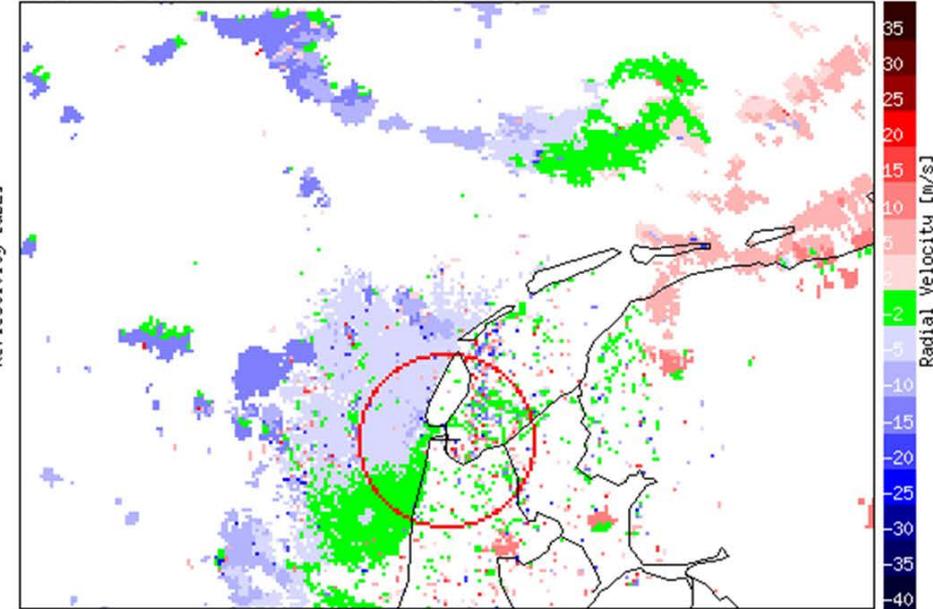
Simulation Environment

Bird Movement Model: Extended Airport

0000 UTC 20081017 - 0001 UTC 20081017

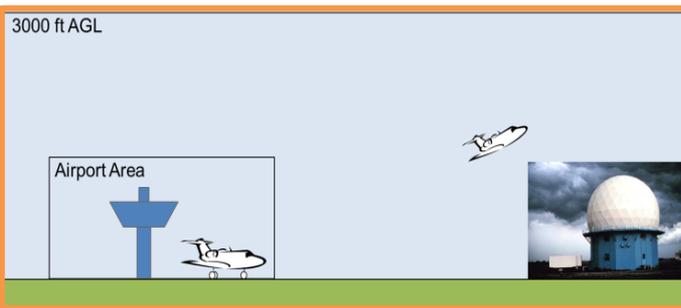


0000 UTC 20081017 - 0001 UTC 20081017



- reflectivity
→ -10 and 10dBZ

- radial velocity
→ min. 2m/s
→ high variability



sources: Dokter et al. 2010, Dokter 2017



Simulation Environment

Bird Movement Model: Extended Airport

input

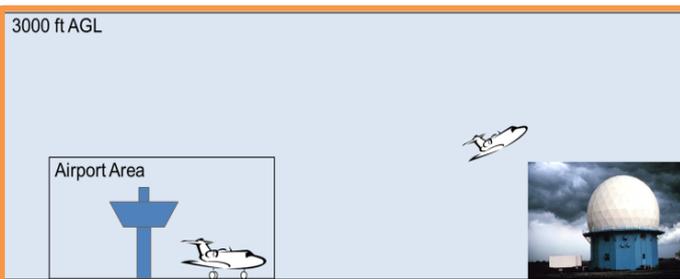
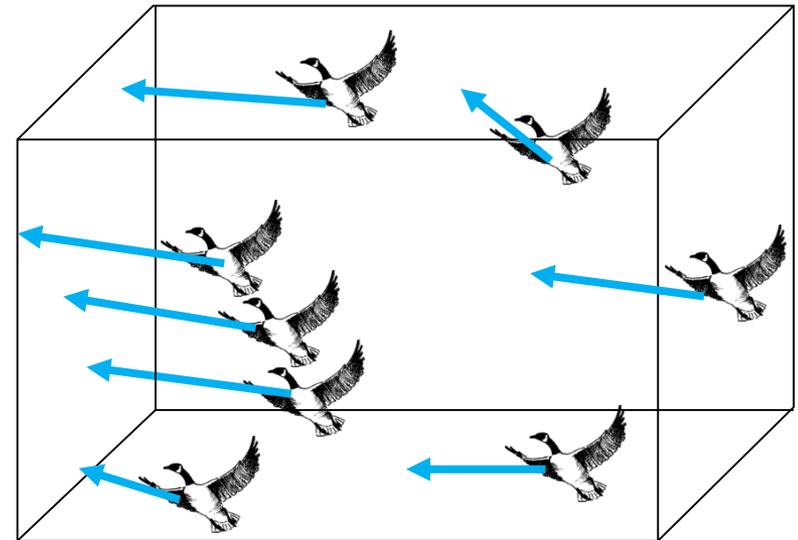
- bird reflectivity

$$\eta = \overline{\rho_{bird} \sigma_{bird}} \left[\frac{cm^2}{km^3} \right]$$

- velocities in u and v direction

processing

- bird number ($\sigma_{bird} = 11 cm^2$)
- constant speed ($SD = 5 \frac{m}{s}$)
- constant direction ($SD = 45^\circ$)

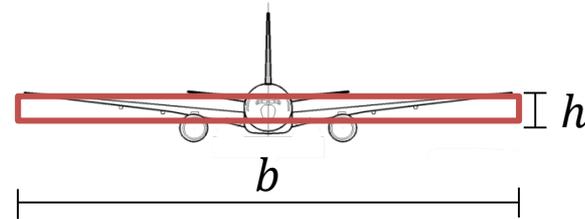
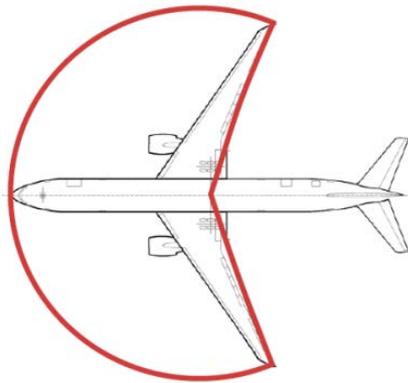


Method based on

- van Gasteren et al. 2008
- Dokter et al. 2010
- Lensink & Kwak 1985
- Hüppop et al. 2006

Simulation Environment

Collision Model: Protected Zone Aircraft



$$S_{front} = b * h = \underbrace{(b - 2 * r_f) * h_w}_{\text{wings}} + \underbrace{n_e * r_e^2 * \pi}_{\text{engines}} + \underbrace{r_f^2 * \pi}_{\text{fuselage}}$$

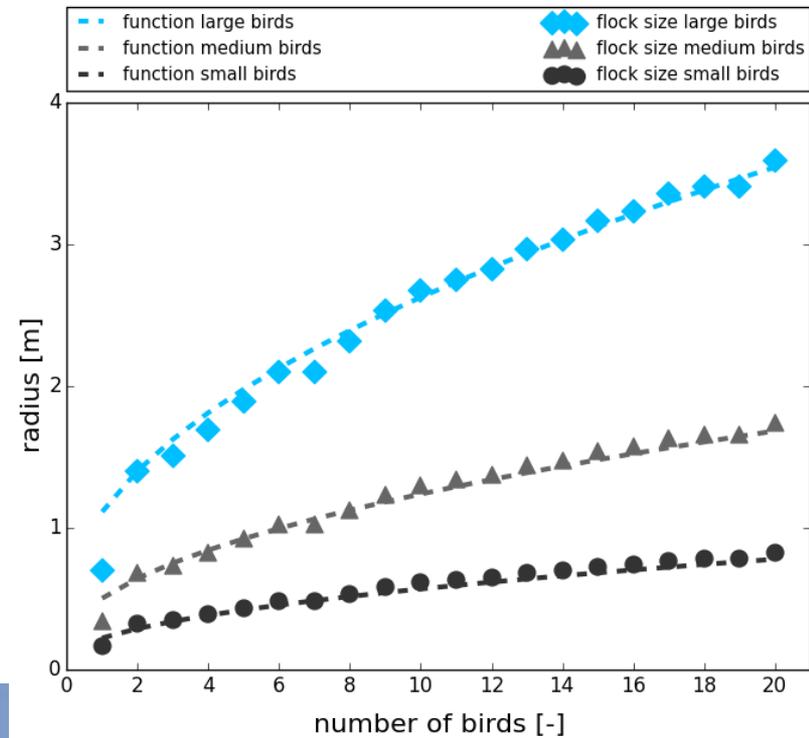


Simulation Environment

Collision Model: Protected Bird



$$r = \sqrt{n_{birds}} * \frac{b}{2} + c$$



based on Graham 1996



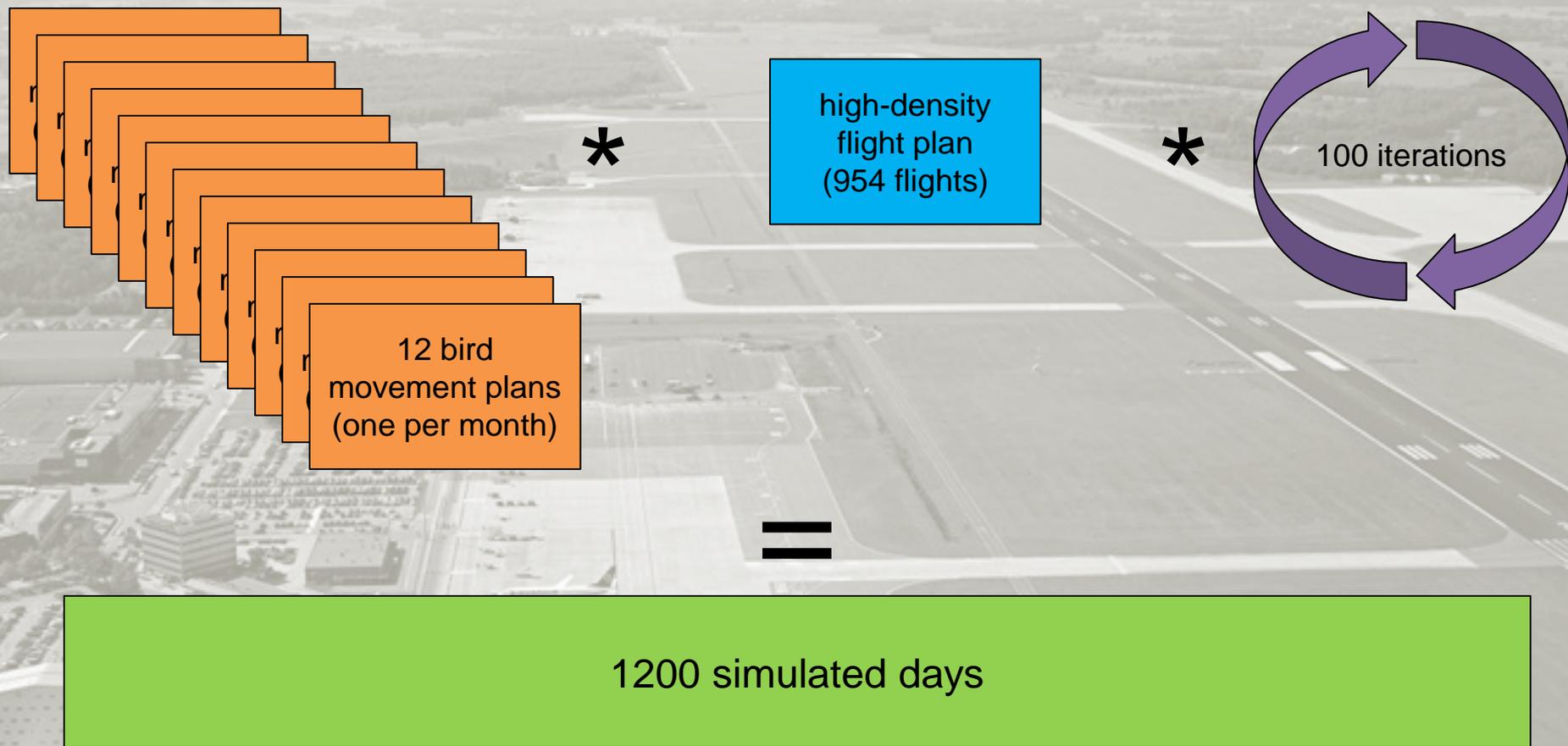
Simulation Environment

Demo Video



Verification

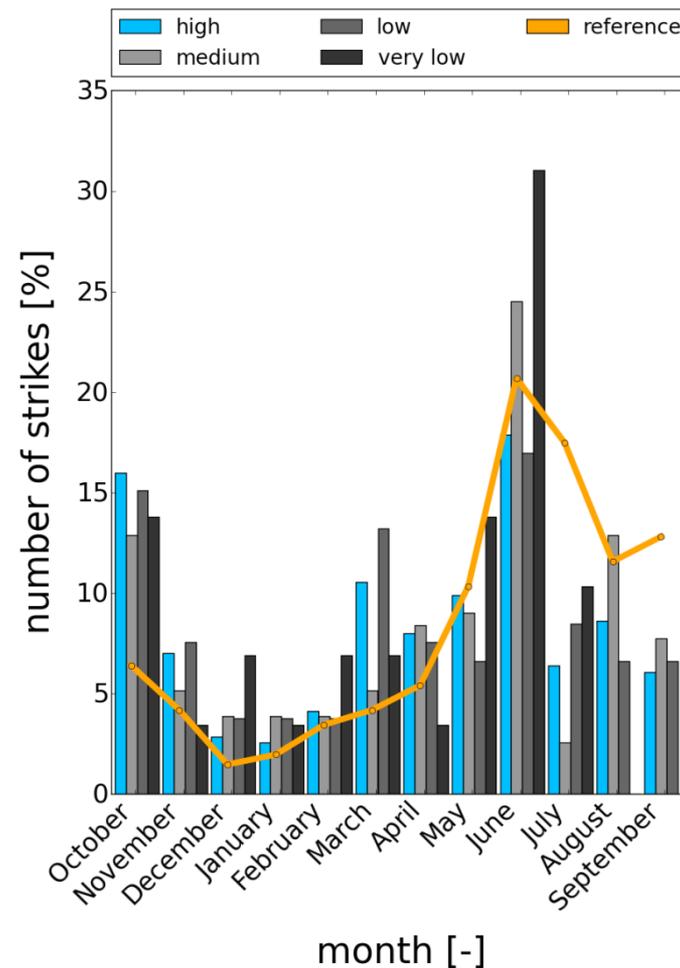
Monte Carlo Simulations



Simulation Environment

Outcome

- ca. 3x higher bird strike rate
- seasonal correspondence
- reproducibility (MC simulations)



Applicability of the Model

→ analysis of bird strike risk

→ analysis of risk-reducing measures



Applicability of the Model

→ analysis of bird strike risk

→ analysis of risk-reducing measures



Tuesday



Applicability of the Model

→ analysis of bird strike risk



what is the risk of damage?

→ analysis of risk-reducing measures



Certification Requirements EASA and FAA

Large Aeroplanes (CS & FAR 25)



Certification Requirements EASA and FAA

Large Aeroplanes (CS & FAR 25)



Certification Requirements

EASA and FAA



Certification Requirements

EASA and FAA

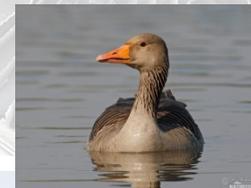
withstand without penetration
(4 lb, V_{cruise})



capable of successfully completing a flight
(4 lb, $0.85 V_{cruise}$ 8000 ft
or
4 lb, V_{cruise} sea level)



- no Hazardous Engine Effect
- complete test cycle
(6 lb, 200 kts)



capable of successfully completing a flight
(8 lb, V_{cruise})



sufficient separation



Certification Requirements

EASA and FAA

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(4 lb, V_{cruise})



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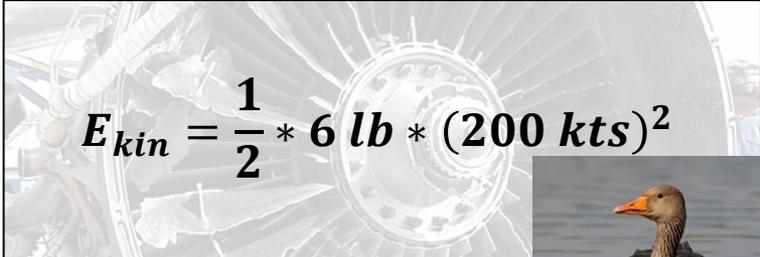
sufficient separation

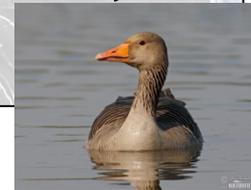
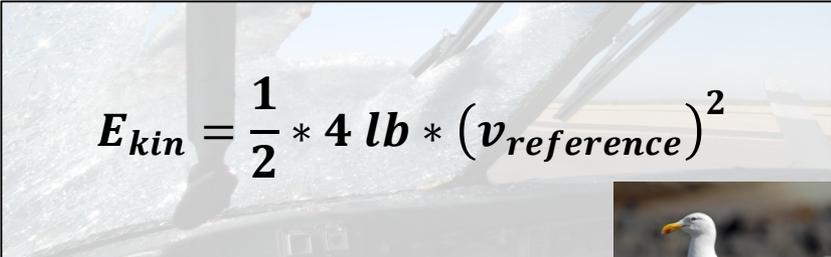


Evaluation of Potential Damage

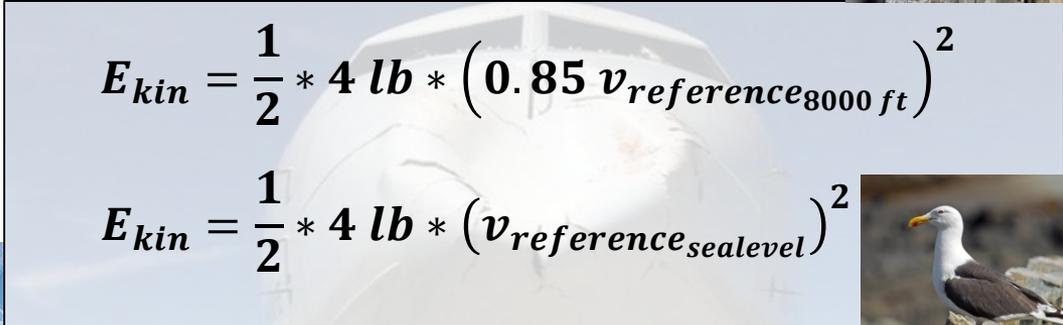
Kinetic Energy

$$E_{kin} = \frac{1}{2} * m * v^2$$

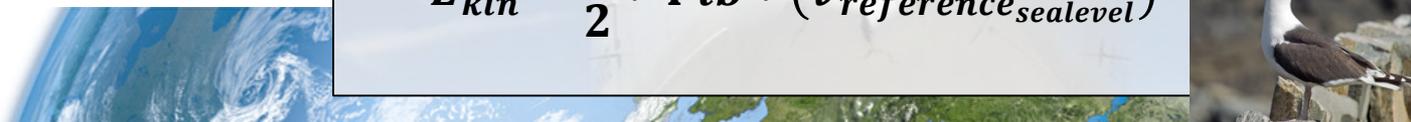


$$E_{kin} = \frac{1}{2} * 6 \text{ lb} * (200 \text{ kts})^2$$



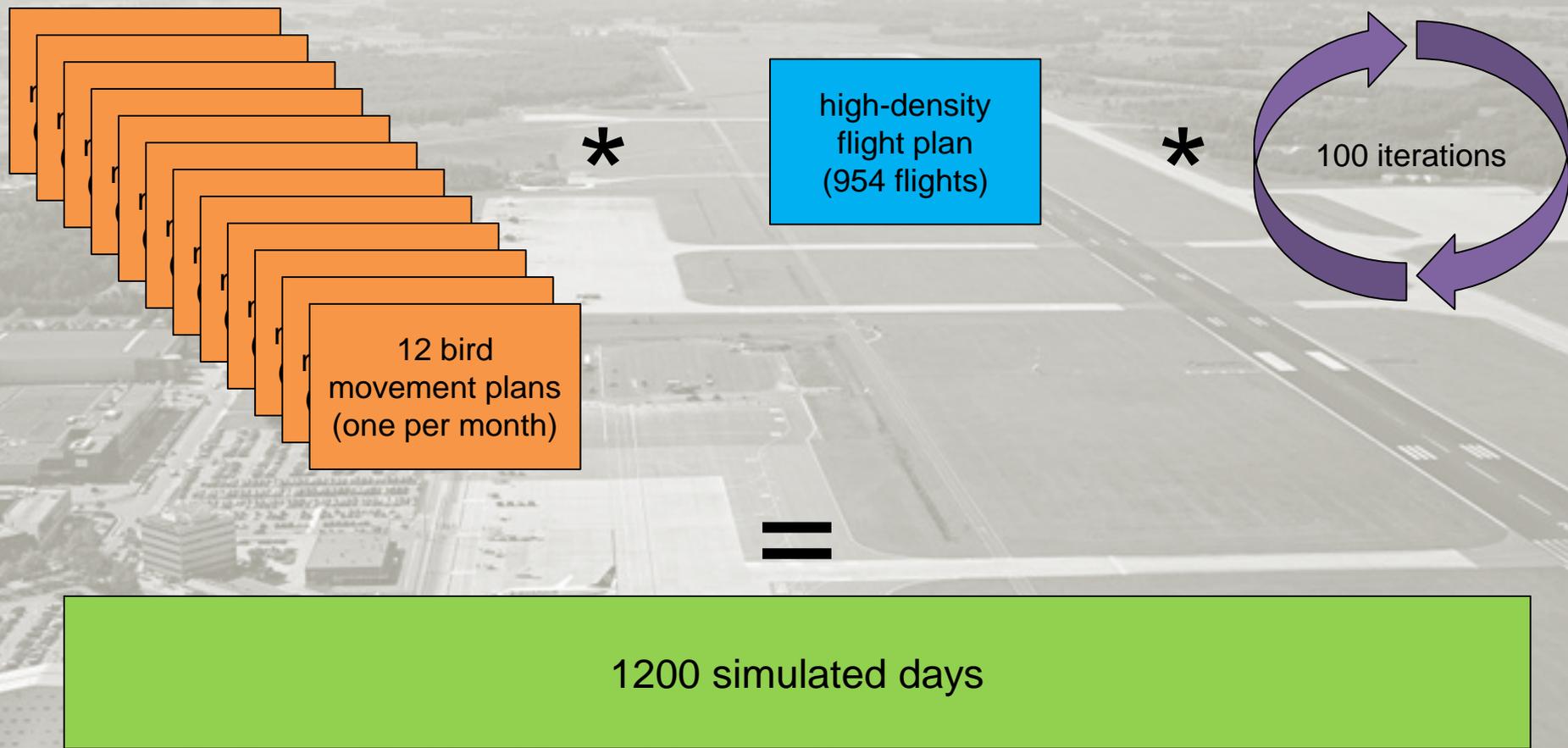
$$E_{kin} = \frac{1}{2} * 4 \text{ lb} * (v_{reference})^2$$



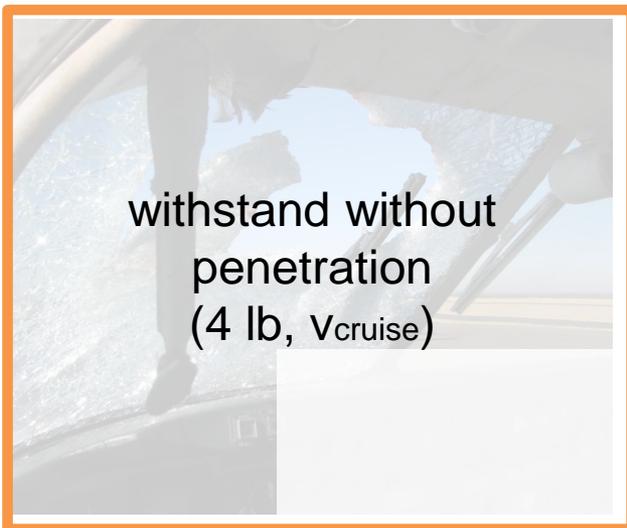
$$E_{kin} = \frac{1}{2} * 4 \text{ lb} * (0.85 v_{reference_{8000 \text{ ft}}})^2$$

$$E_{kin} = \frac{1}{2} * 4 \text{ lb} * (v_{reference_{sealevel}})^2$$


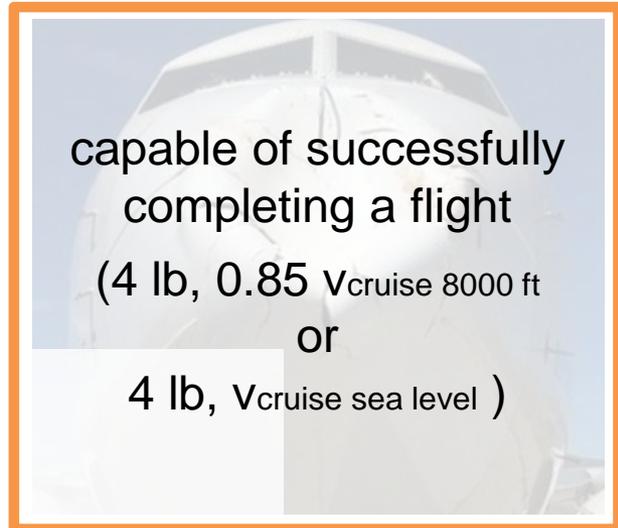
Simulation Setup



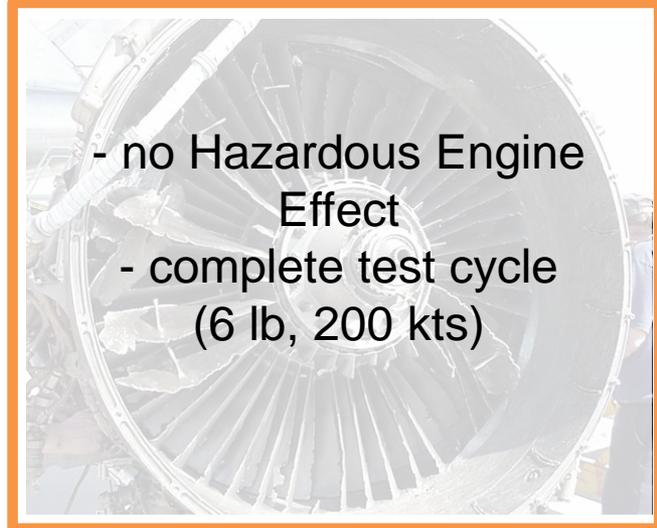
Results



withstand without
penetration
(4 lb, V_{cruise})



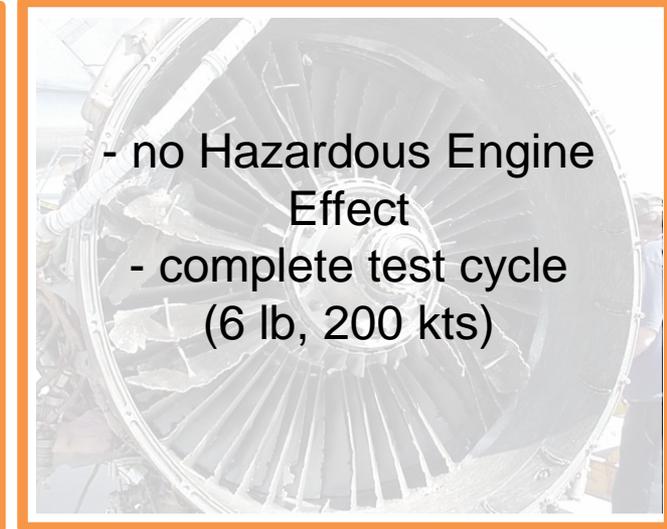
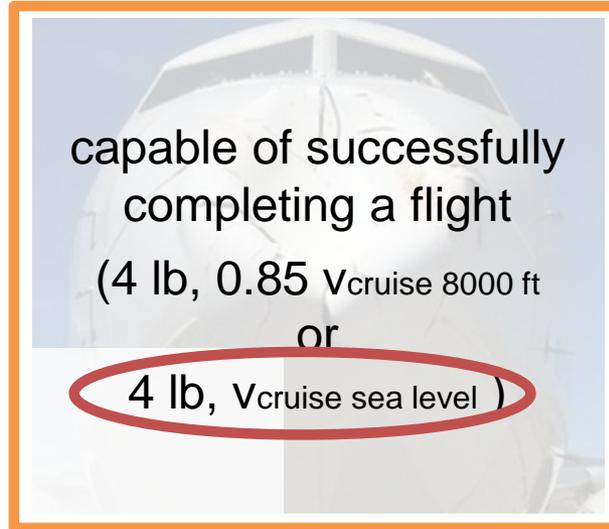
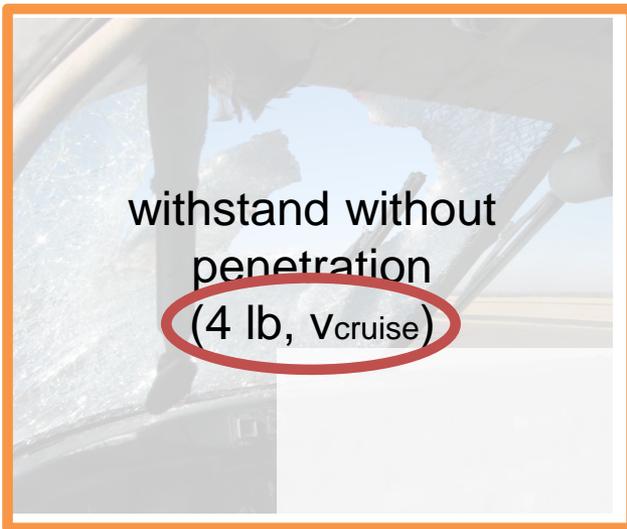
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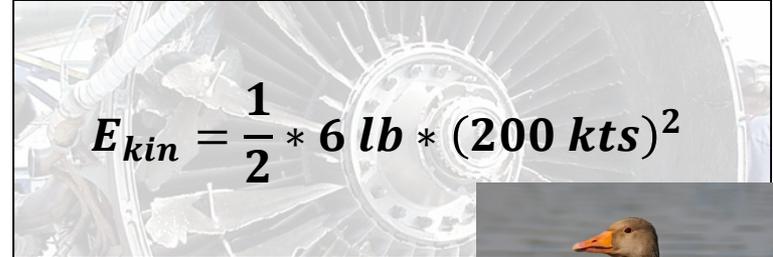


- no Hazardous Engine Effect
- complete test cycle (6 lb, 200 kts)



Results

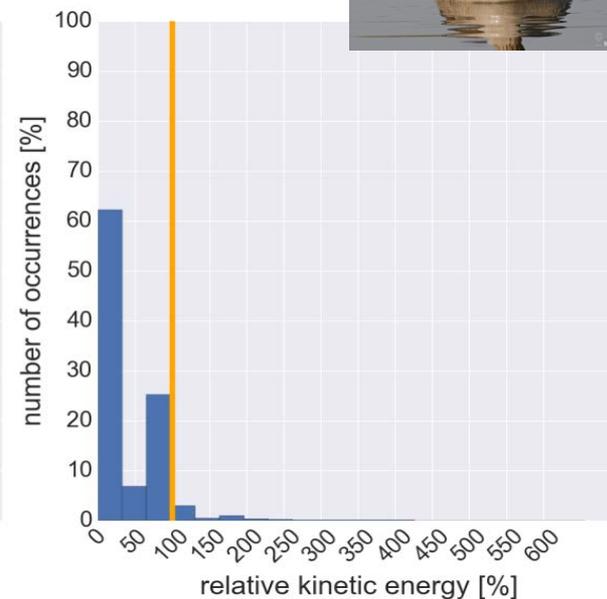
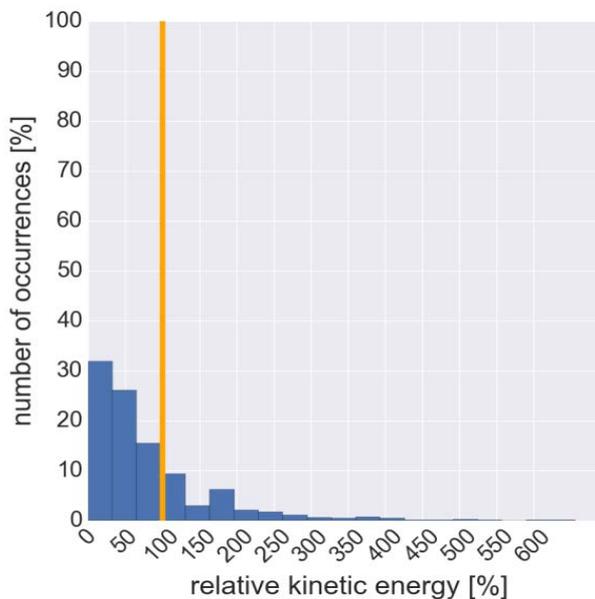
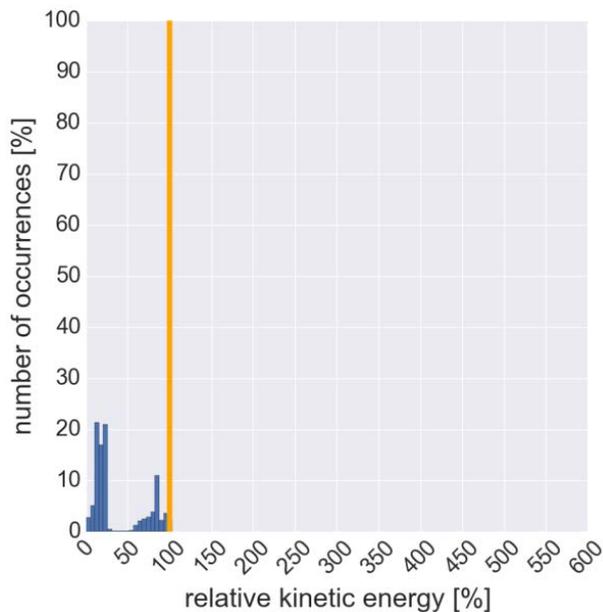




$$E_{kin} = \frac{1}{2} * 6 \text{ lb} * (200 \text{ kts})^2$$

Results

Engines



individuals

strikes

6703

damages

37 (0.6%)

flocks

1176

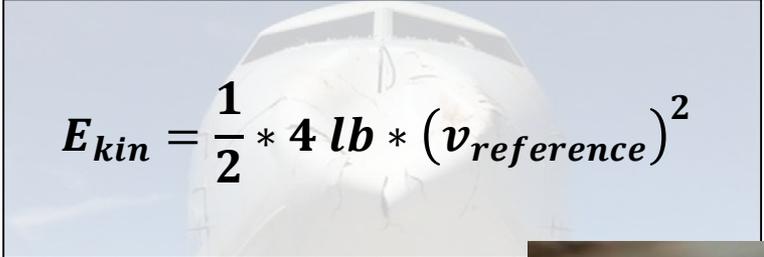
307 (26.1%)

all birds

7879

344 (4.4%)



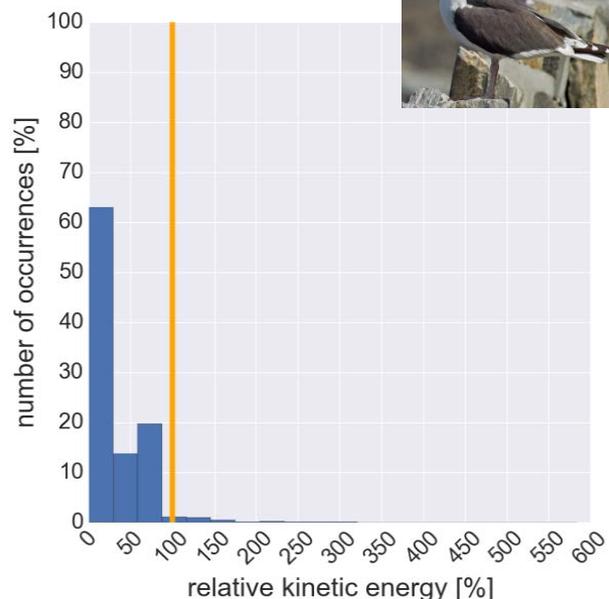
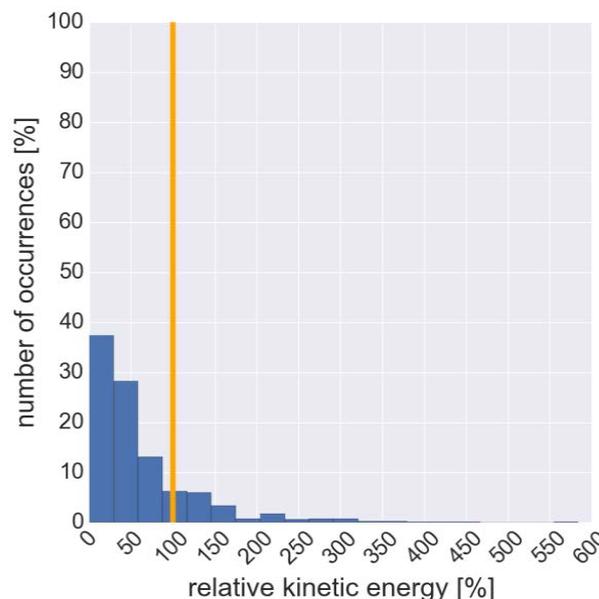
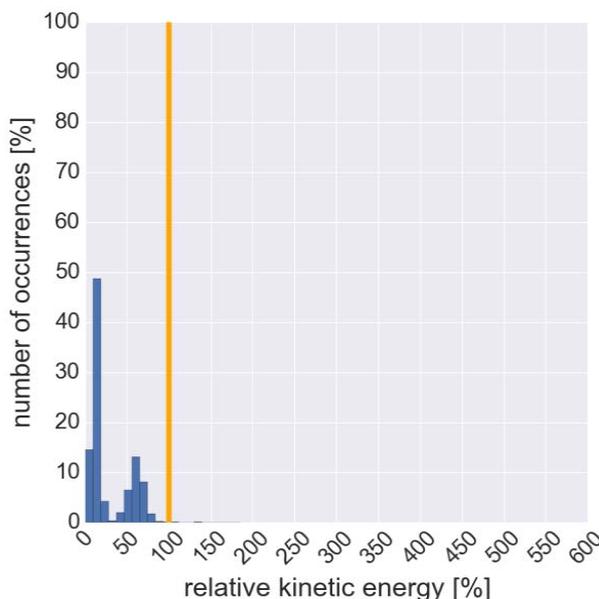


$$E_{kin} = \frac{1}{2} * 4 lb * (v_{reference})^2$$



Results

Structure and Windshield



	individuals
strikes	6703
damages	7 (0.1%)

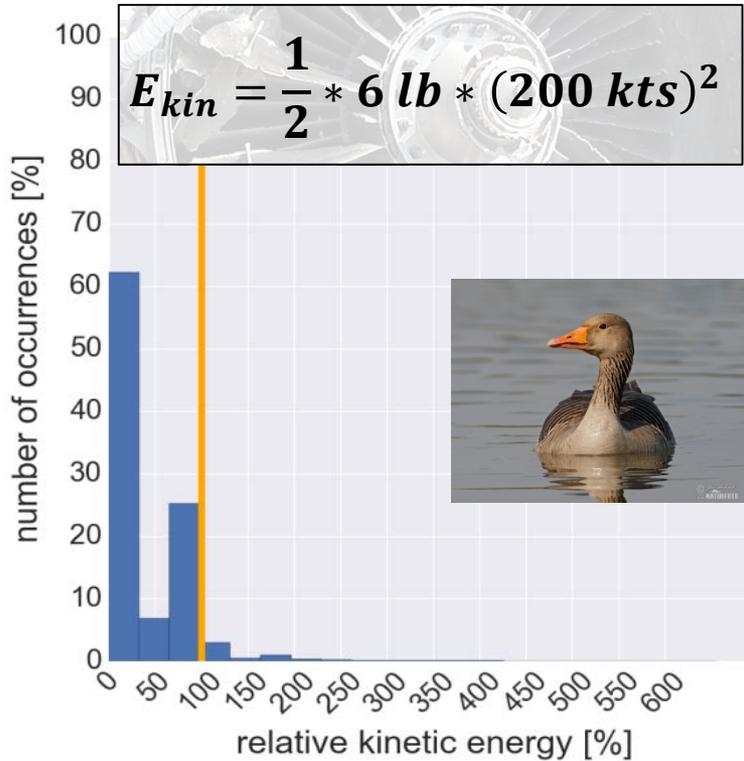
	flocks
strikes	1176
damages	213 (18.1%)

	all birds
strikes	7879
damages	220 (2.8%)



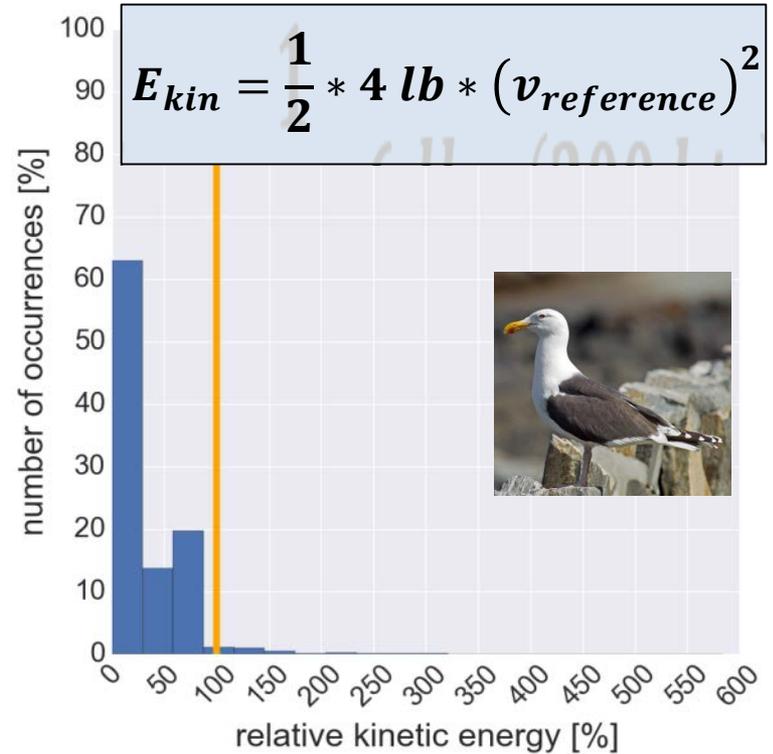
Results

Engines vs Structure and Windshield



all birds

344 (4.4%)



all birds

220 (2.8%)

damages



Verification

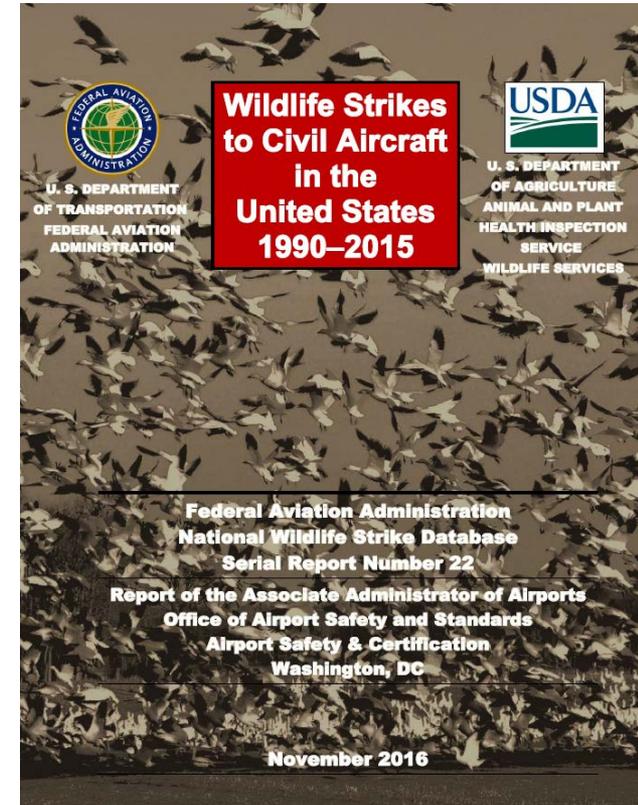
Comparison to Reference Data

damage categories

- none
- unknown
- minor
- uncertain
- substantial
- destroyed

part hit

- nose
- wings
- fuselage
- tail
- engines
- windshield
- gear
- propeller
- radome
- pitot
- lights
- rest



Verification

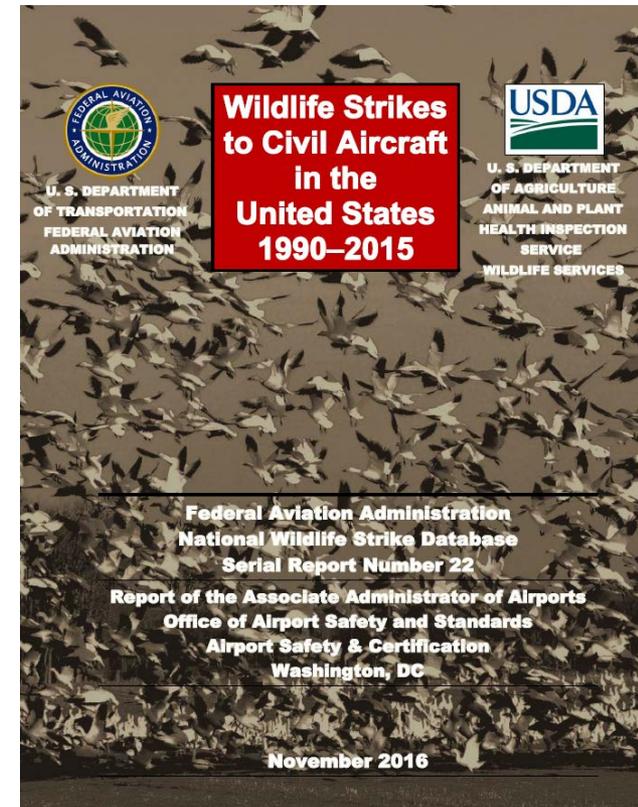
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- **windshield**
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- pitot
- lights



Results

Damaging Strikes



simulation

- individual
- flocks
- **all**

reference

0.1

18.1

2.8

0.6

0.1

18.1

2.8

0.7

0.6

6.1

4.4

0.1



Summary and Outlook

- simulation environment
 - reproducible number of strikes
 - seasonal correspondence
- damage estimation
 - strong influence of flocks
 - useful as a first estimate (high n)
 - risk-reducing measures



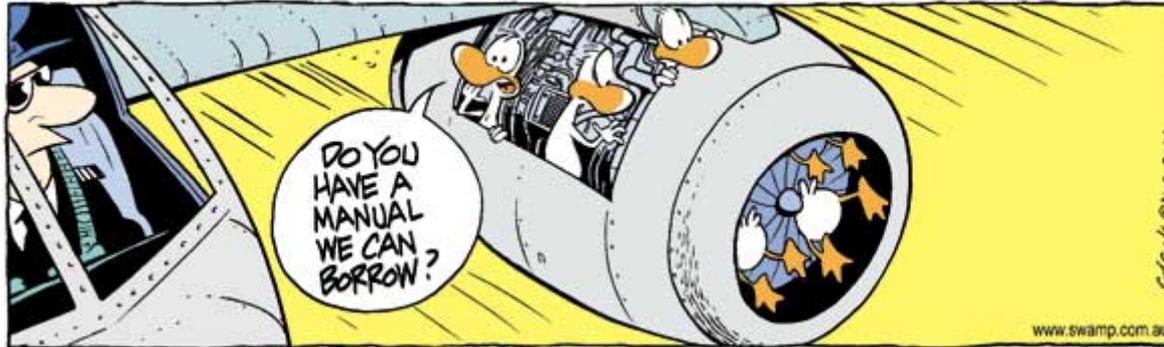
Summary and Outlook

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- validation with
- European bird strike reports
 - US-american bird model

Thanks!



Questions?



Bird Strike Prevention – An Operational Approach

Isabel C. Metz,

13 August 2019

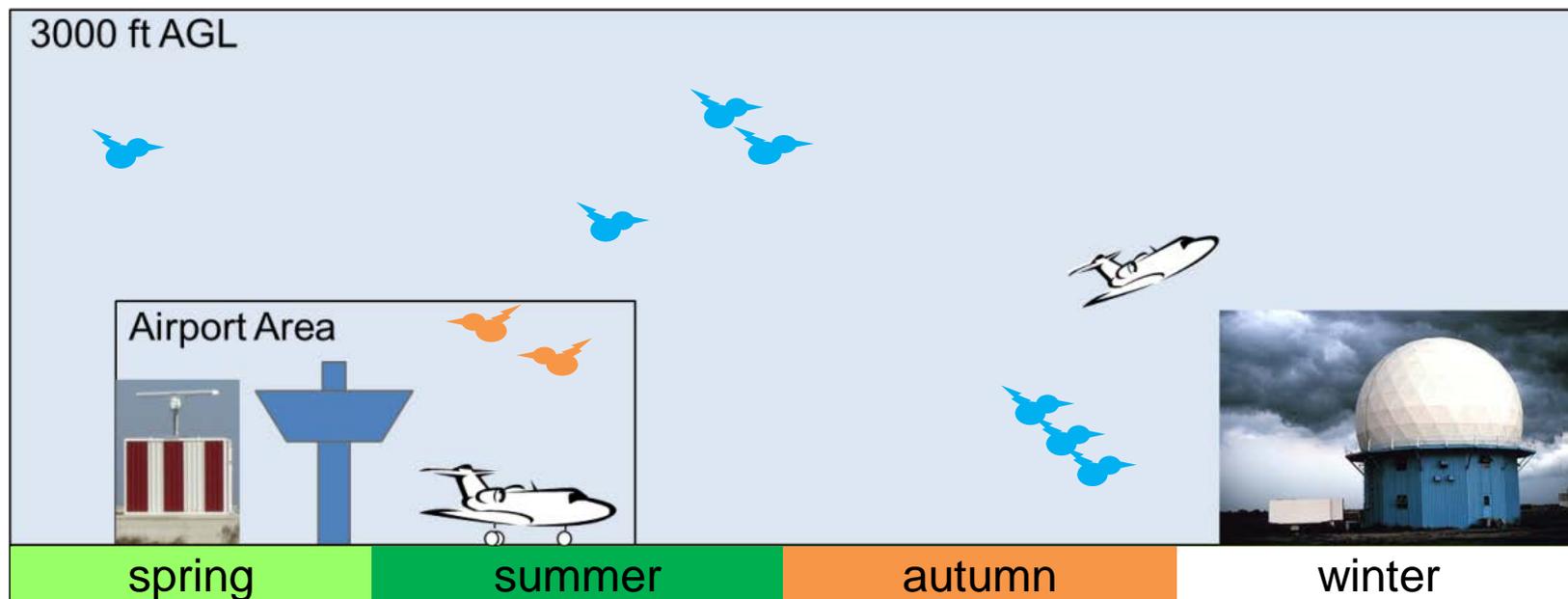
North American Bird Strike Conference



Knowledge for Tomorrow

Simulation Environment

Fast-Time Simulation of Air Traffic and Bird Movements



Royal Netherlands Air Force



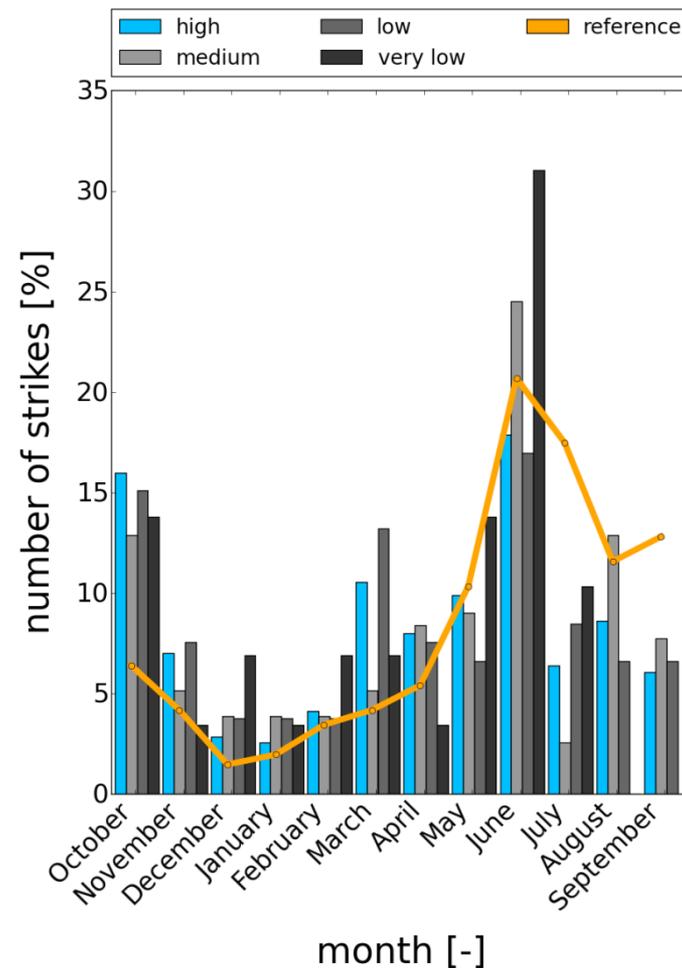
Royal Netherlands
Meteorological Institute
Ministry of Infrastructure and the
Environment



Simulation Environment

Outcome

- ca. 3x higher bird strike rate
- seasonal correspondence
- reproducibility (MC simulations)



Applicability of the Model

→ analysis of bird strike risk

→ analysis of risk-reducing measures



Applicability of the Model

→ analysis of bird strike risk



Thursday

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Applicability of the Model

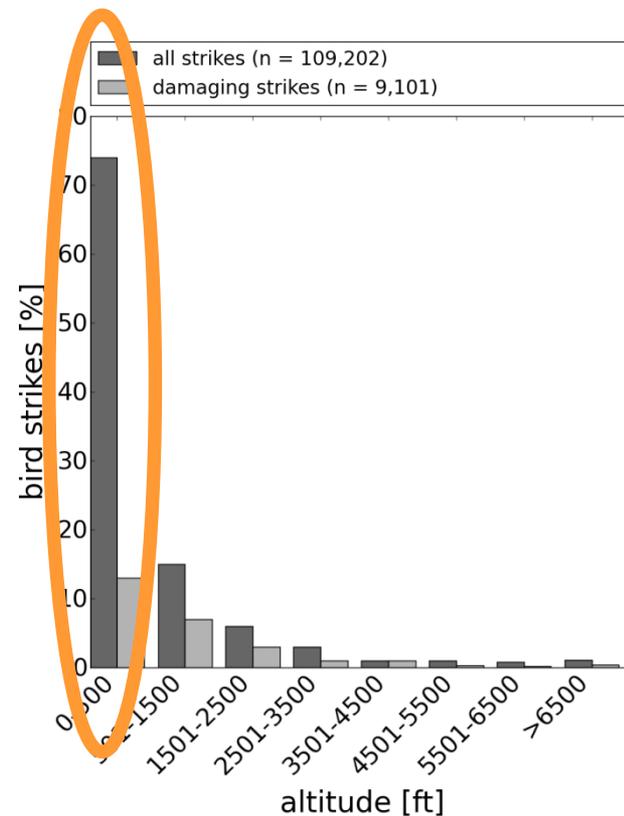
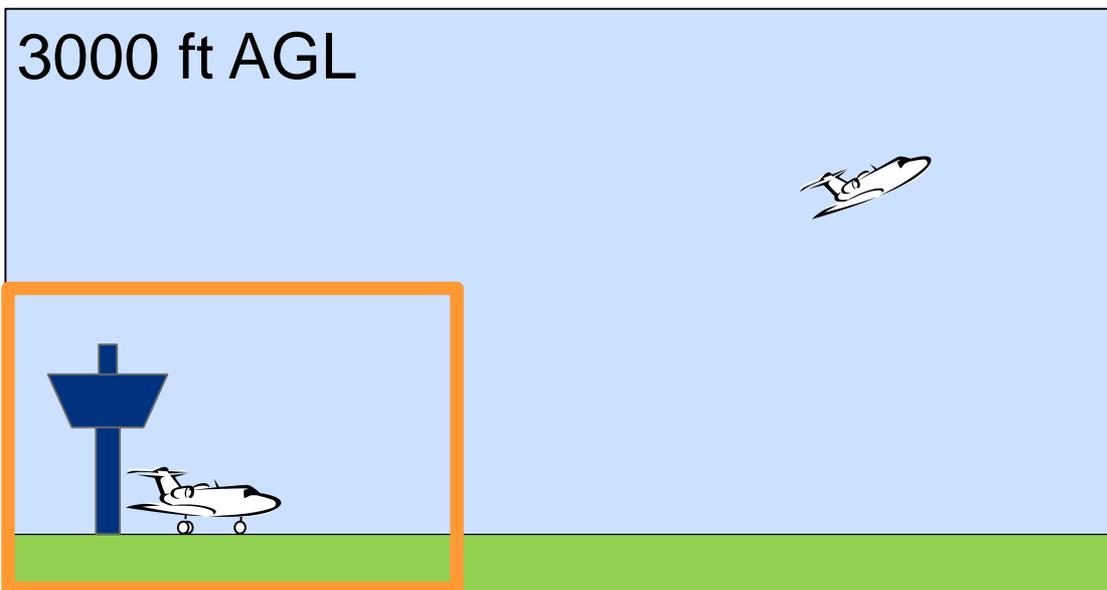
→ analysis of bird strike risk

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Motivation

Bird Strike Risk

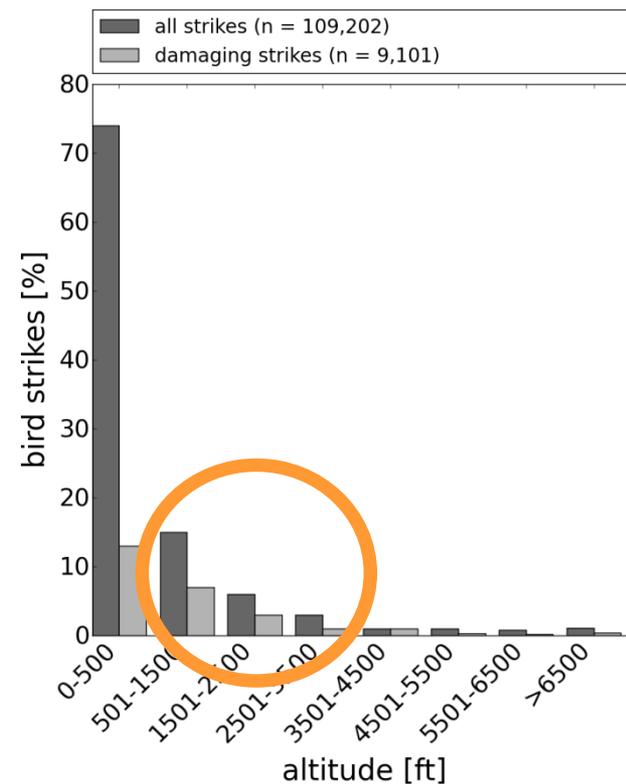
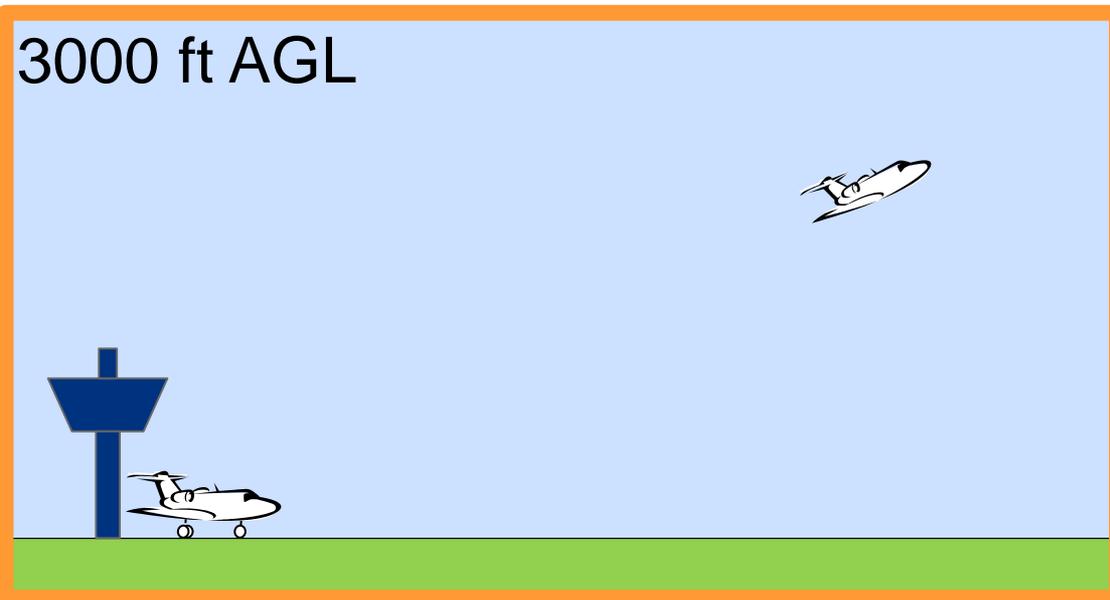


Source: FAA



Motivation

Bird Strike Risk

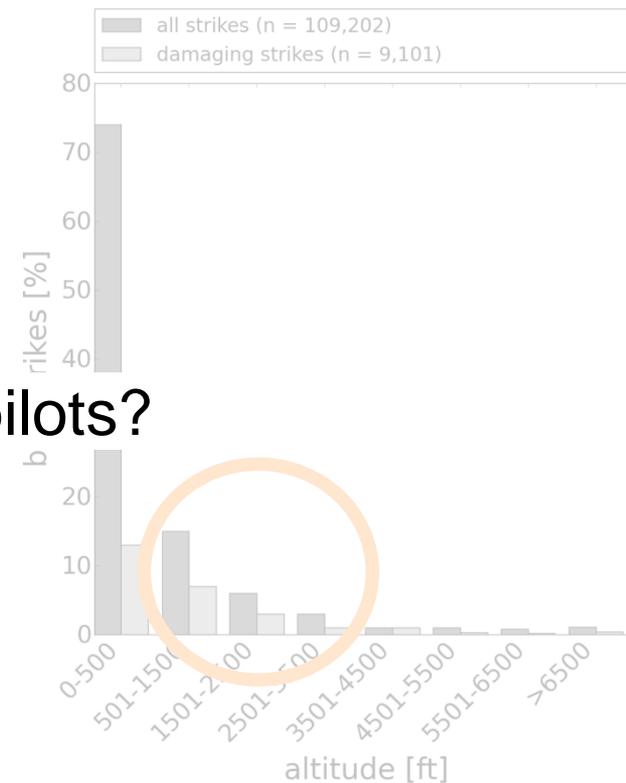


2,818 ft

Source: FAA

Motivation

Bird Strike Risk



Altitude distribution of bird strikes in the US between 1990 und 2015

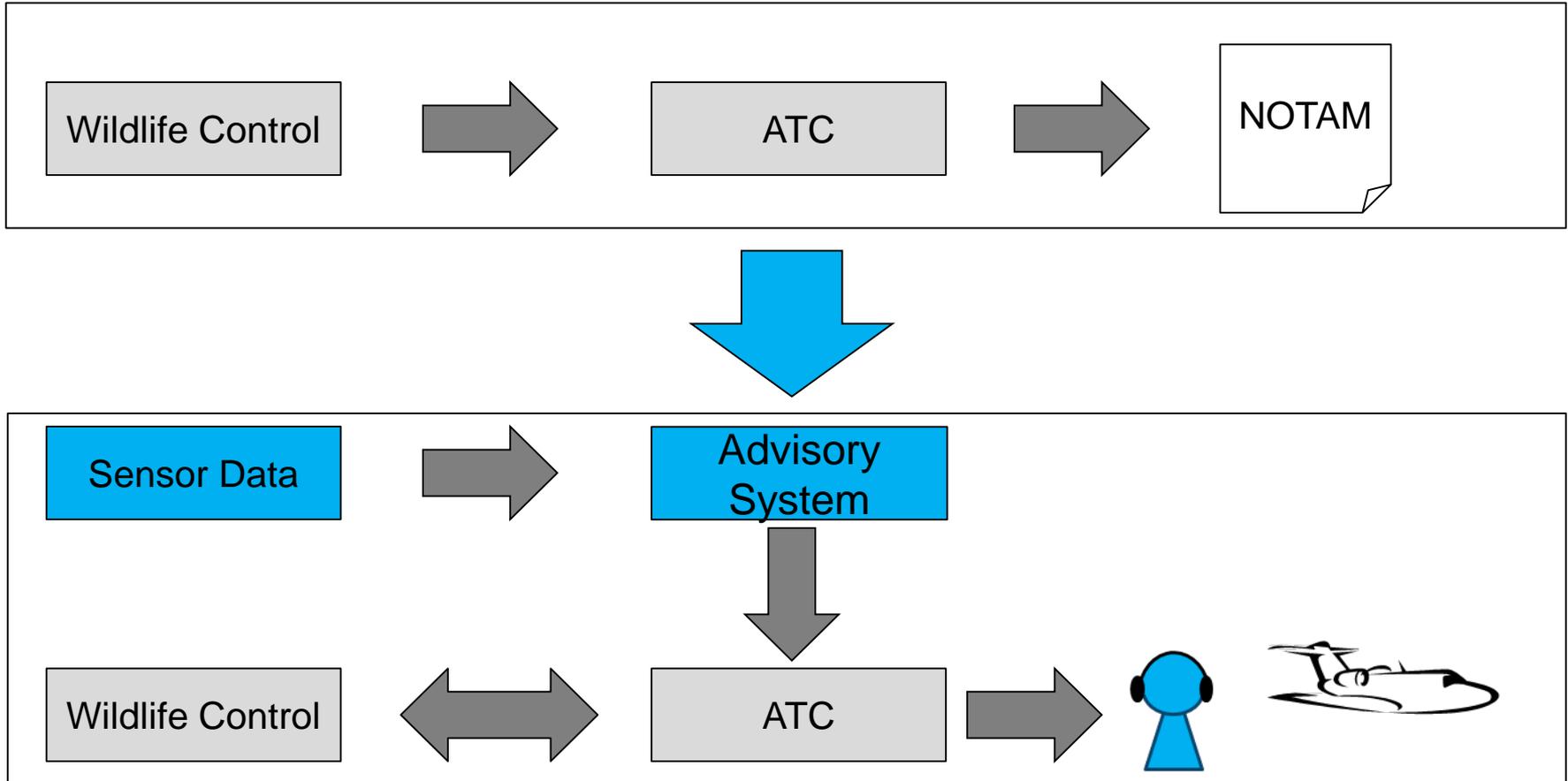
Source: FAA



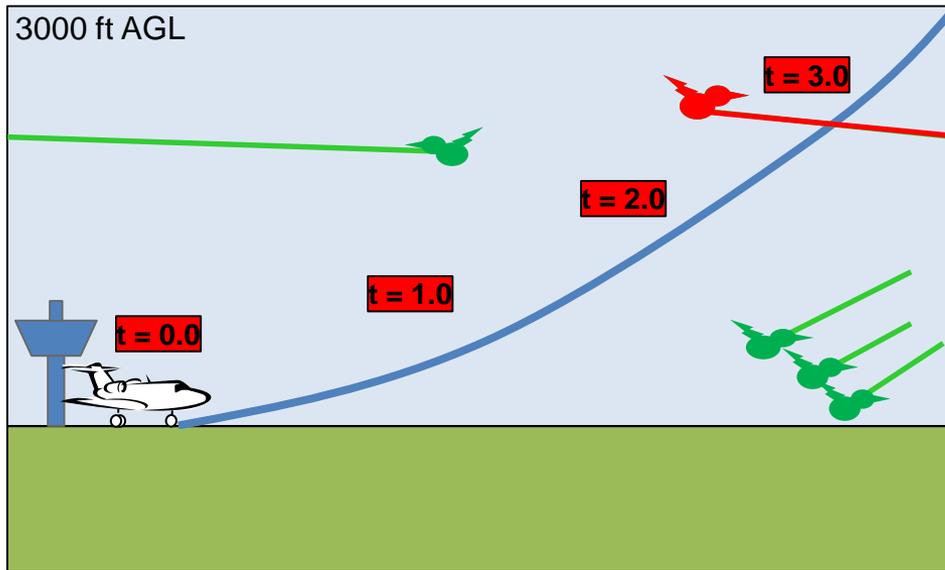
2,818 ft

Motivation

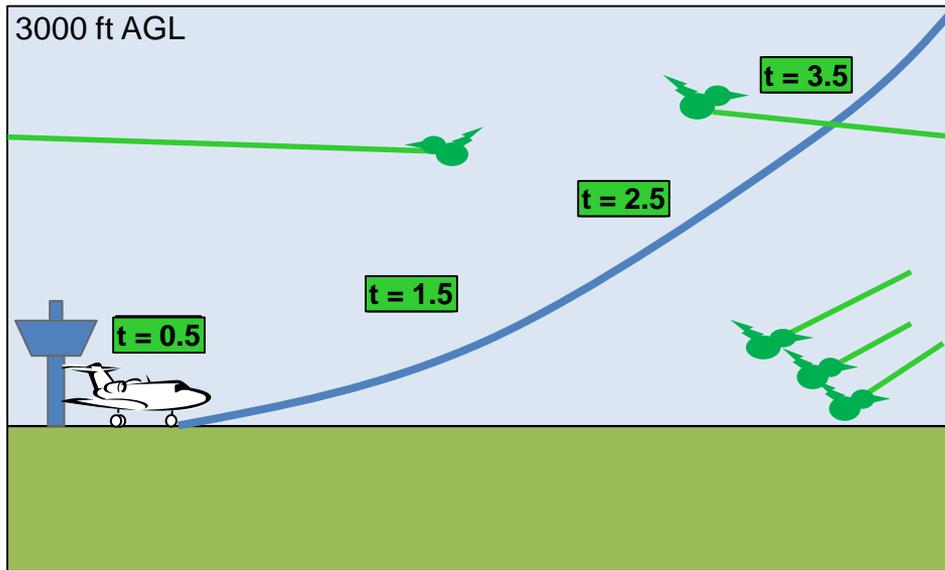
Involving ATC and Pilots



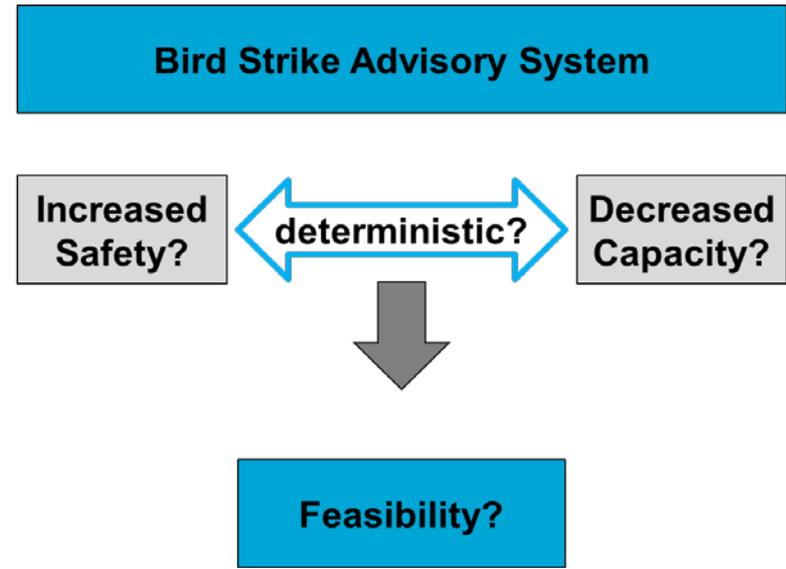
Concept



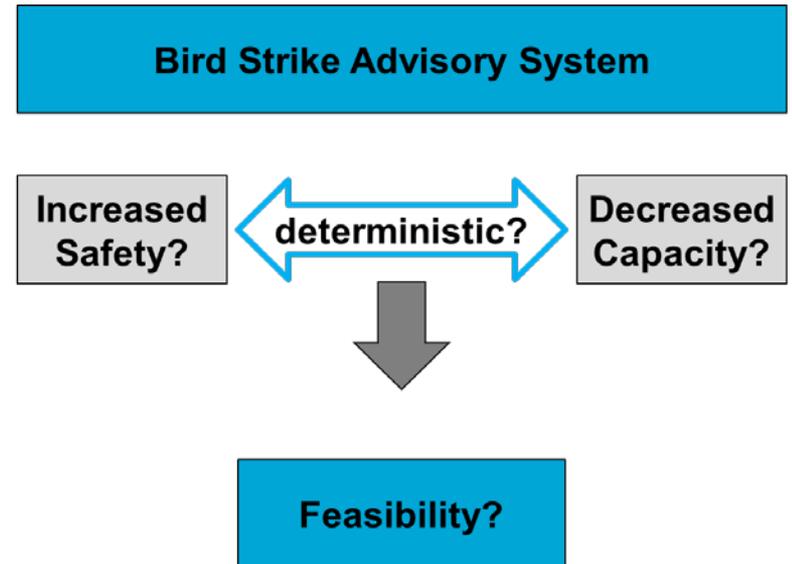
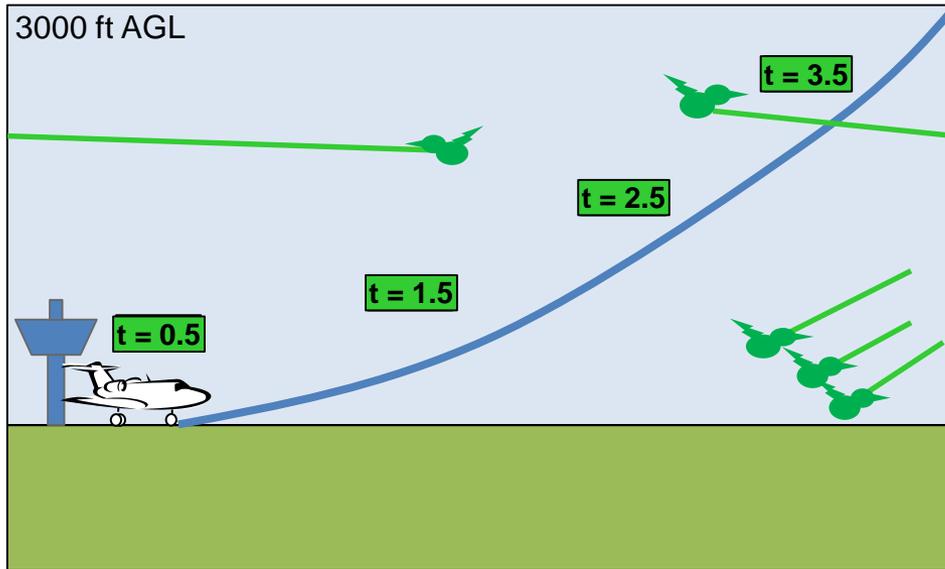
Concept



Concept



Concept

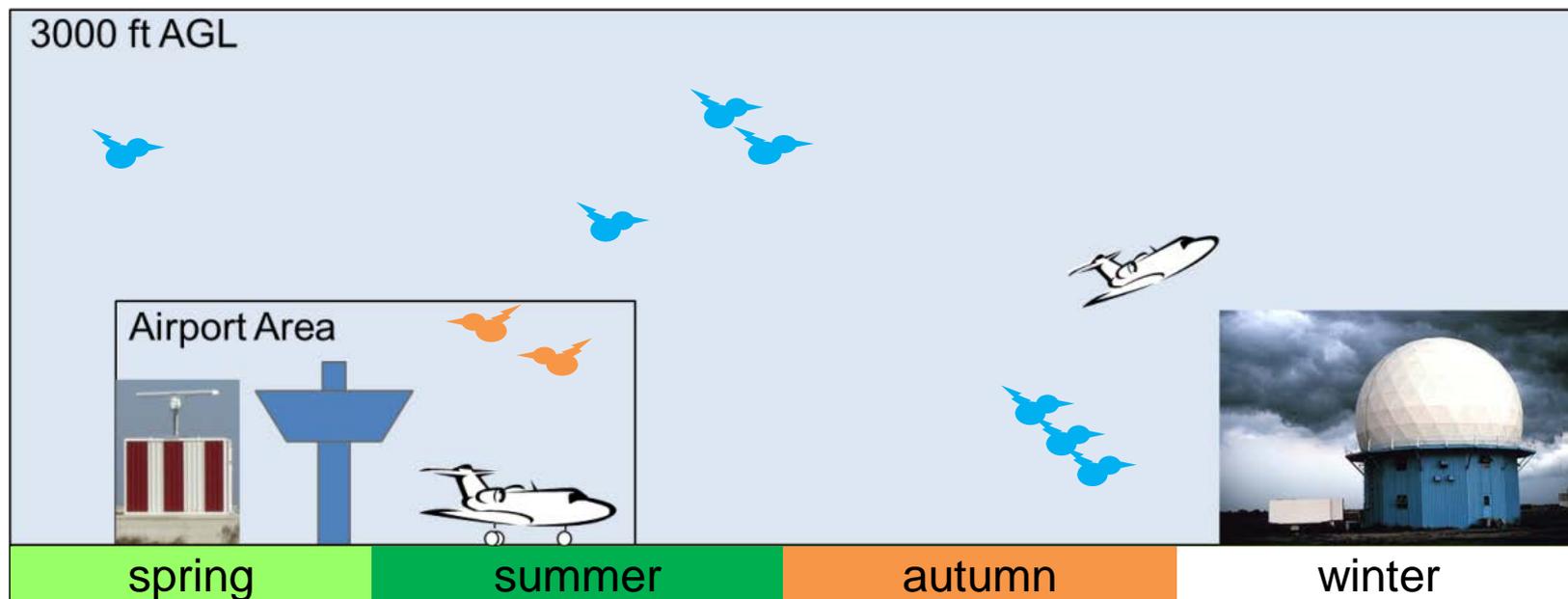


fast-time simulations



Simulation Environment

Fast-Time Simulation of Air Traffic and Bird Movements



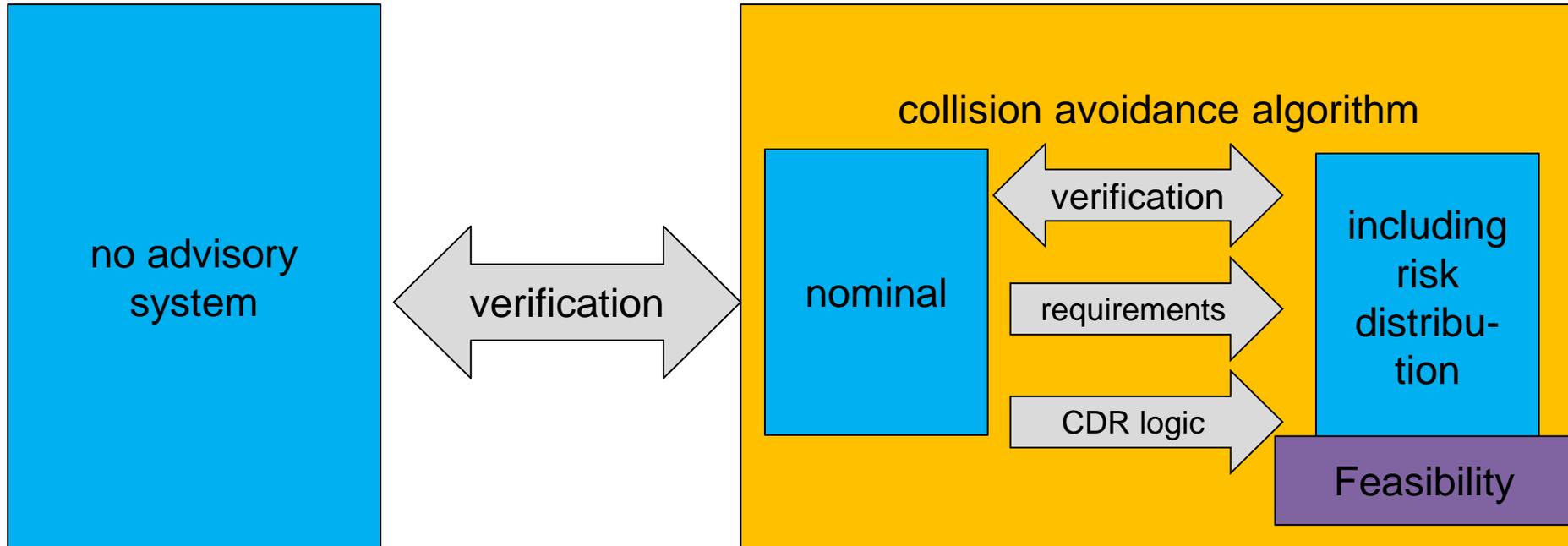
Royal Netherlands Air Force



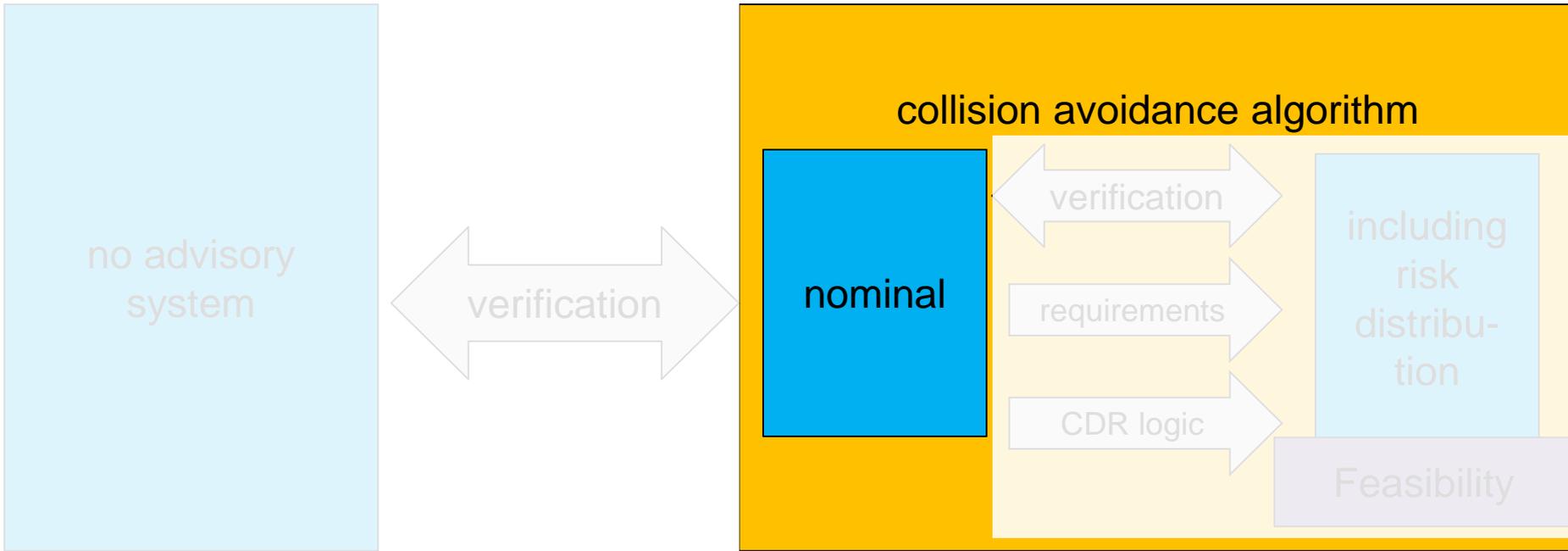
Royal Netherlands
Meteorological Institute
Ministry of Infrastructure and the
Environment



Approach



Approach



Key Questions

- how many bird strikes can be prevented?
- how many false alerts are generated?



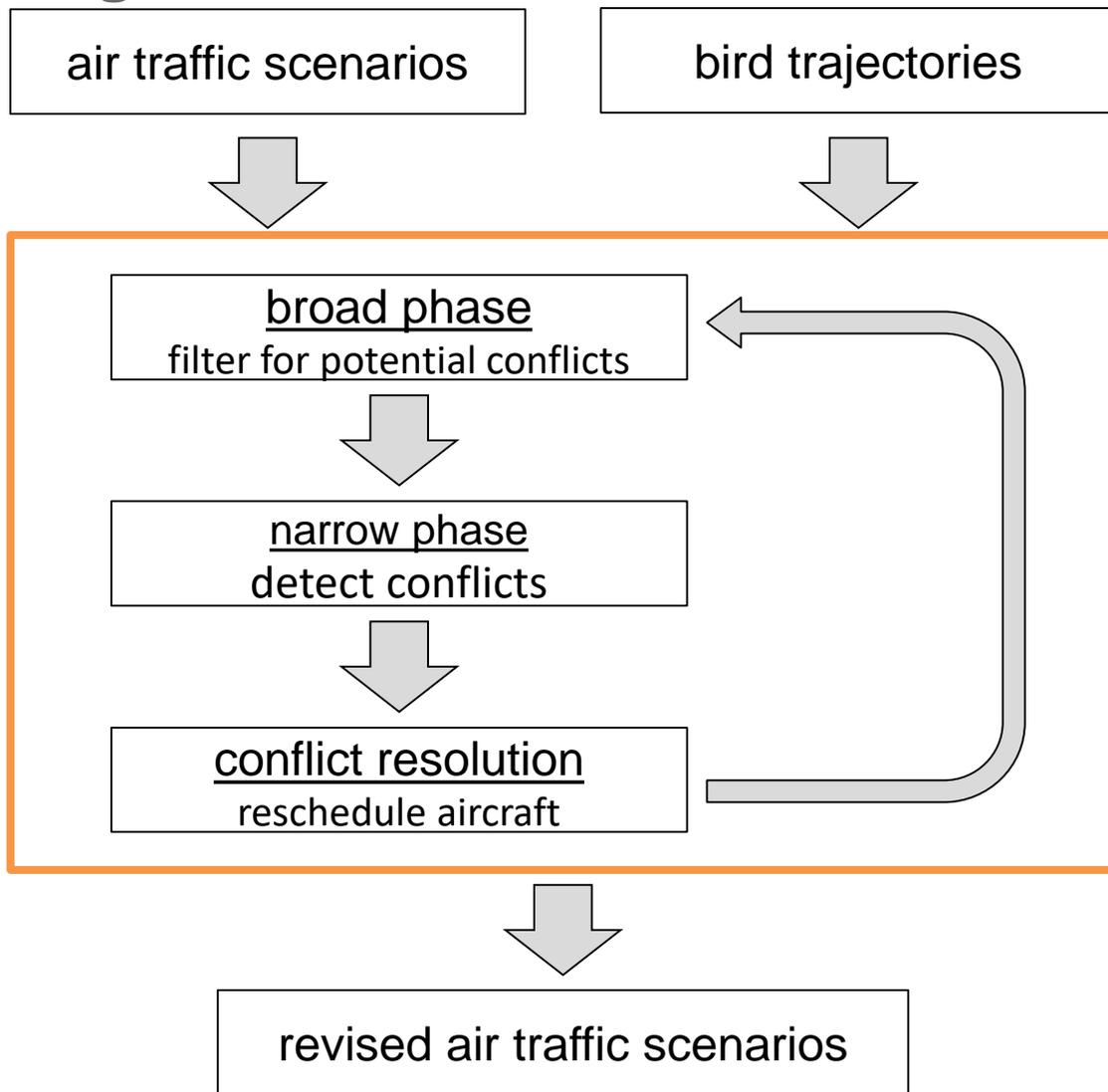
- how much delay is generated?
- what are the economic consequences?

SAFETY
CAPACITY



Collision Avoidance Algorithm

Concept



based on
Kuenz, Alexander. *High Performance Conflict Detection and Resolution for Multi-Dimensional Objects*. DLR-Forschungsbericht Vol. 2015. No. 31. 2015.



Collision Avoidance Algorithm

Concept – broad phase

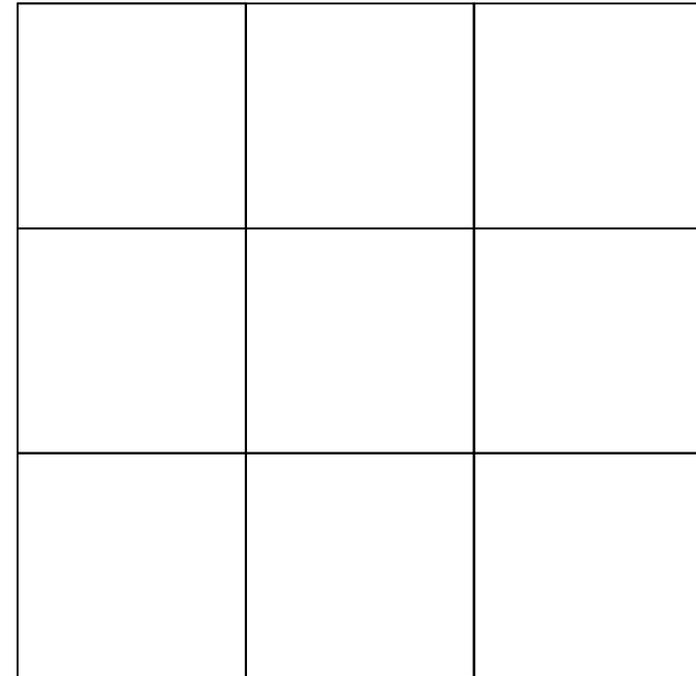
1. generate four-dimensional grid
 - time: 10 seconds
 - latitude & longitude: 1000 m
 - altitude: 100 m
2. assign birds to tiles
3. test against aircraft
 - only birds sharing tiles are relevant
4. forward birds to test to narrow phase



Collision Avoidance Algorithm

Concept – broad phase

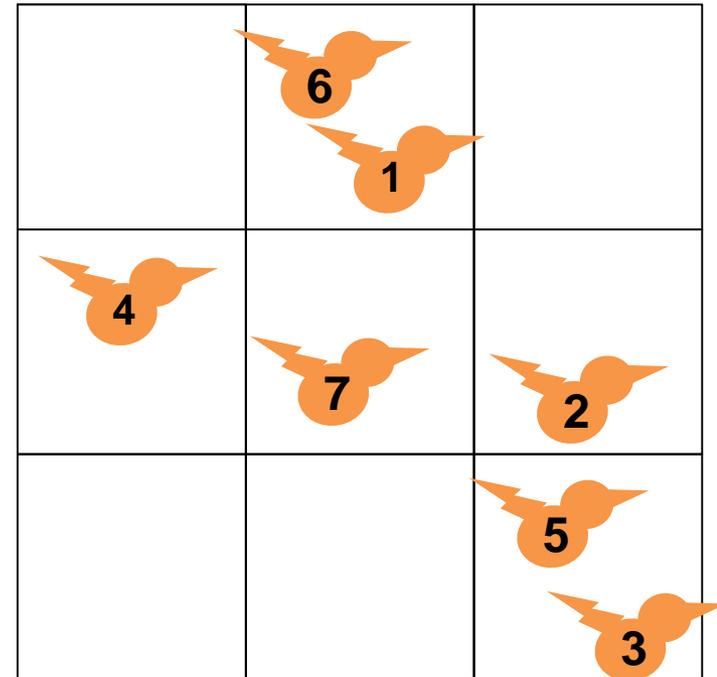
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Collision Avoidance Algorithm

Concept – broad phase

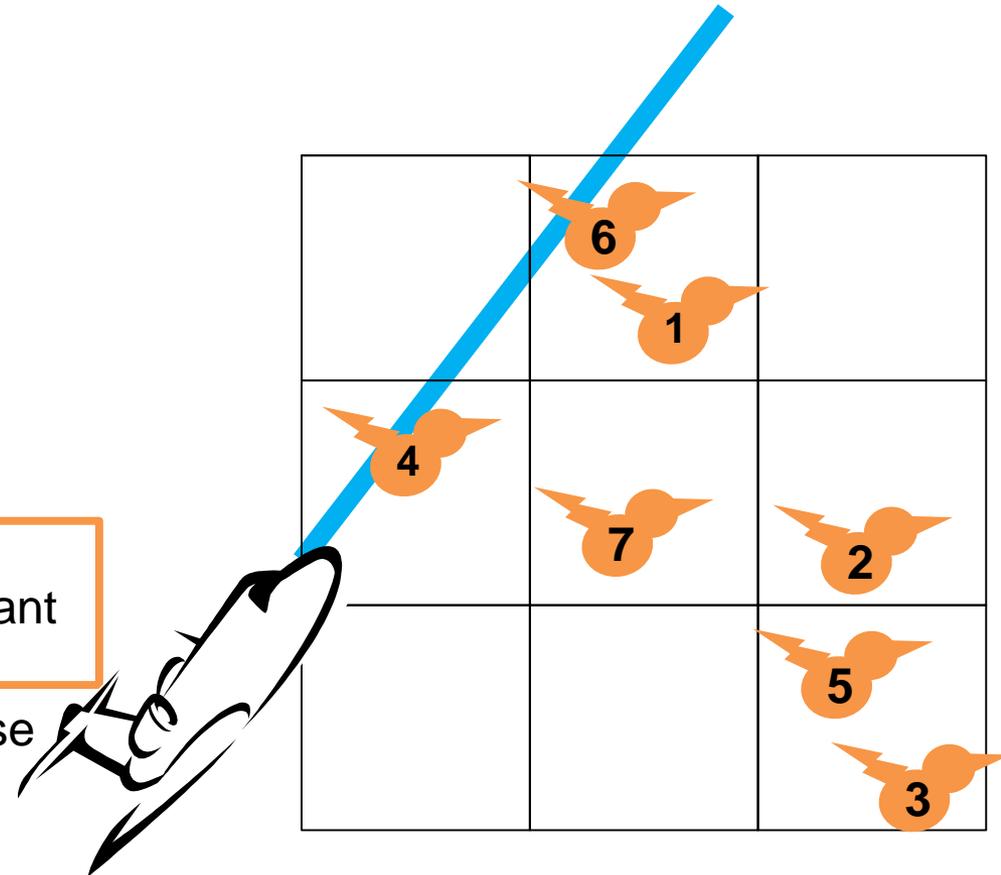
1. generate four-dimensional grid
 - time: 10 seconds
 - latitude & longitude: 1000 m
 - altitude: 100 m
2. assign birds to tiles
3. test against aircraft
 - only birds sharing tiles are relevant
4. forward birds to test to narrow phase



Collision Avoidance Algorithm

Concept – broad phase

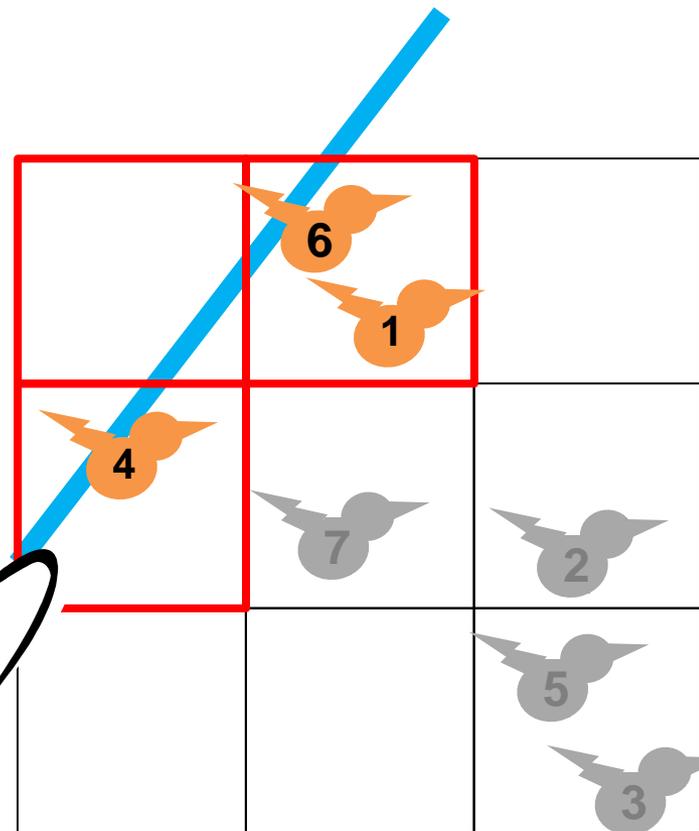
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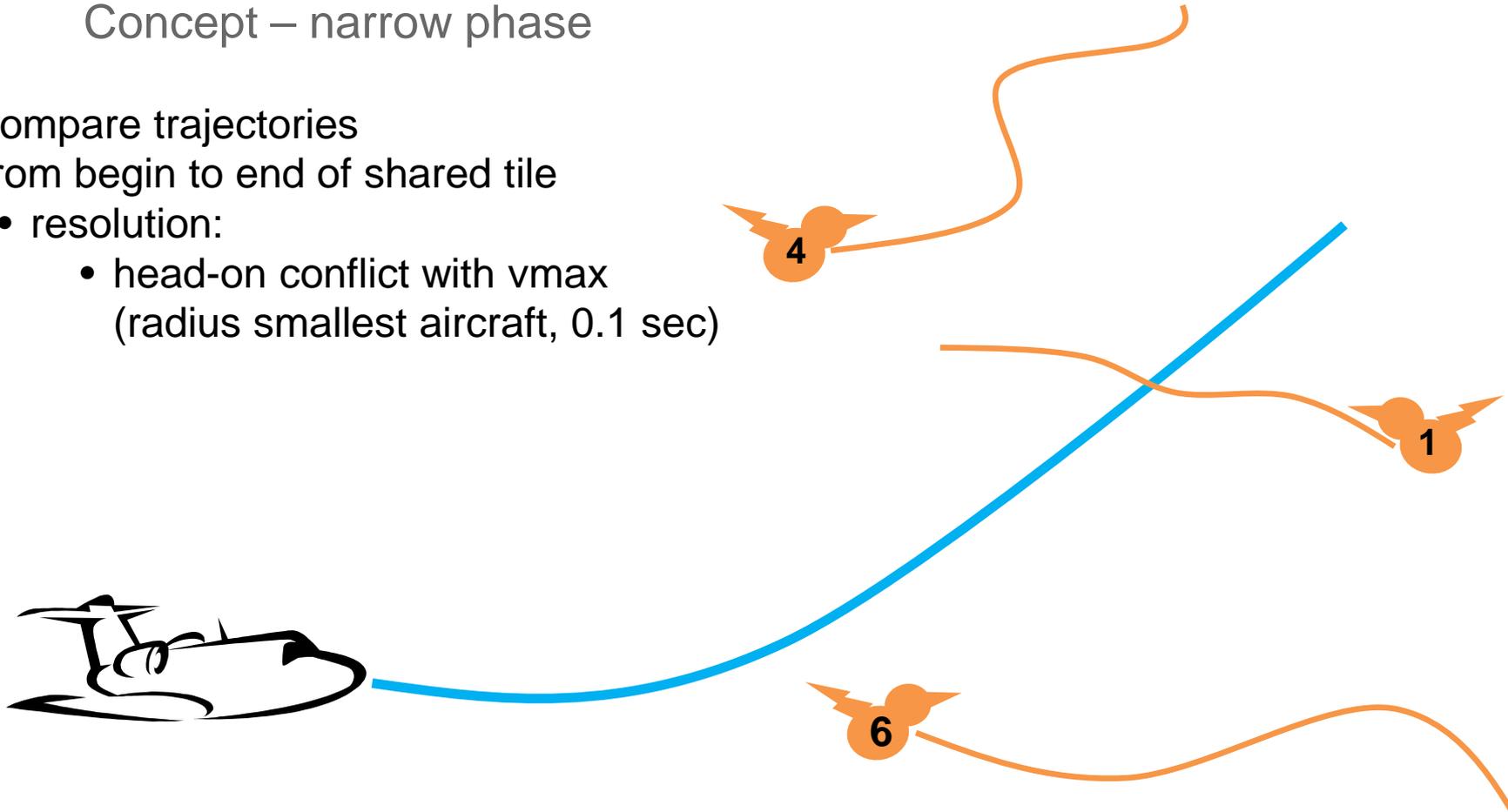
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Collision Avoidance Algorithm

Concept – narrow phase

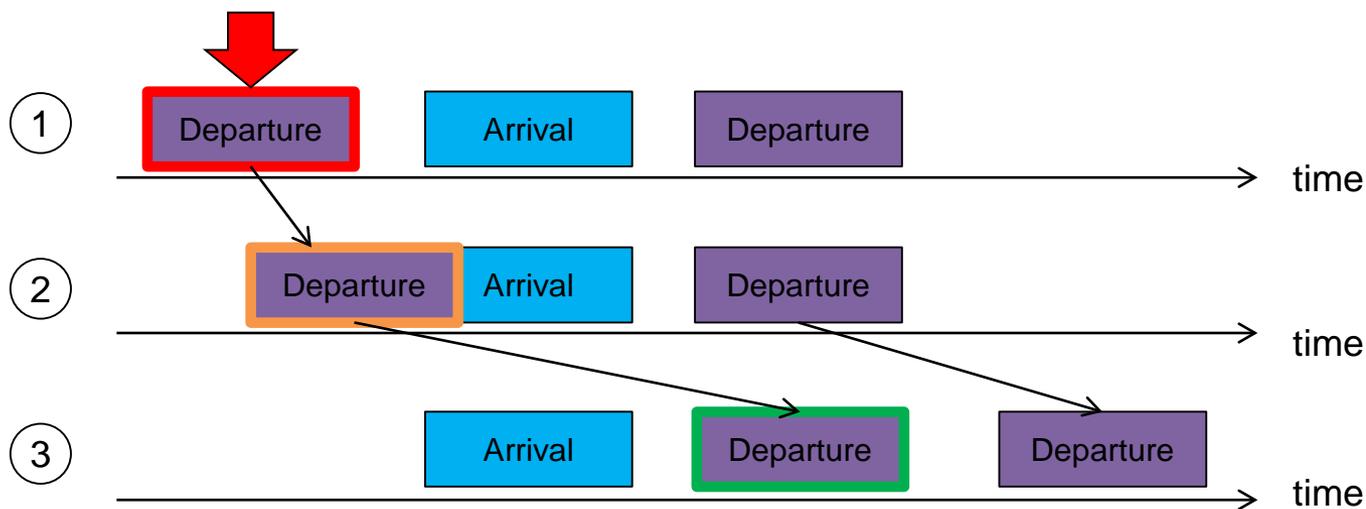
1. compare trajectories
from begin to end of shared tile
 - resolution:
 - head-on conflict with v_{max}
(radius smallest aircraft, 0.1 sec)



Collision Avoidance Algorithm

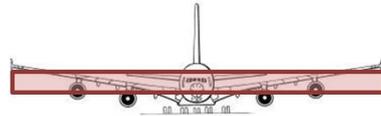
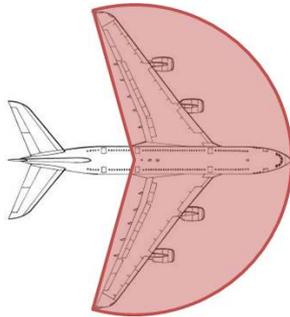
Concept – Conflict Resolution

- reschedule aircraft
 - 5 seconds
 - minimum separation to previous arrival



Simulation Specifications

- protected zones birds and aircraft



source: Metz, et al. 2017



Simulation Specifications

- simulated data
 - birds
 - one week per month within one year
 - aircraft
 - airports with one operational runway

intensity	number of flights	opening hours
high	954	17 hours
medium	501	
low	305	



Results

- how many bird strikes can be prevented?
- how many false alerts are generated?

} verification

- how much delay is generated?
- what are the economic consequences?

SAFETY
CAPACITY

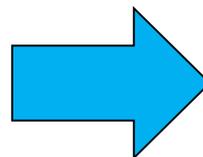


Results

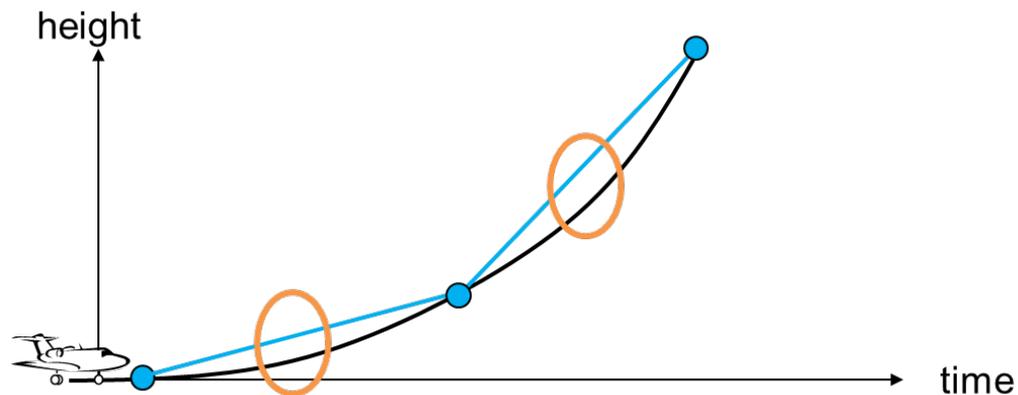
Verification

- Criteria

- max 5% remaining strikes
- max 5% false alerts

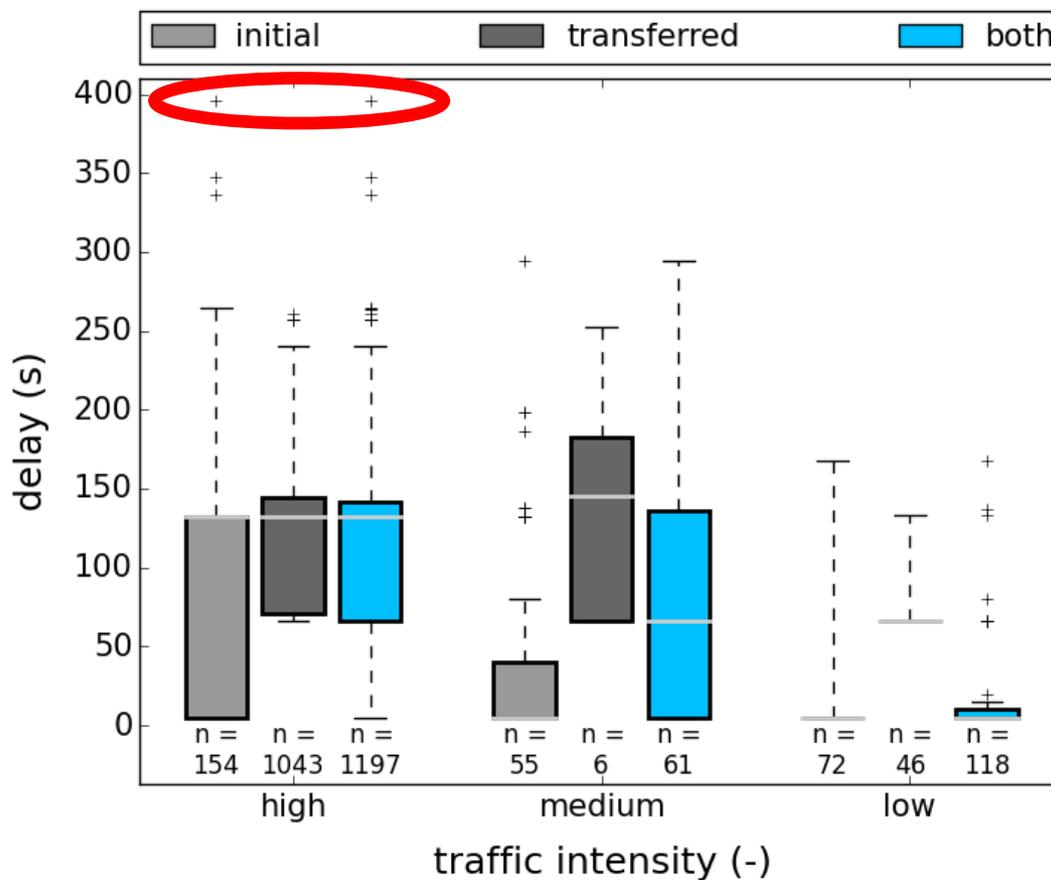


97 % prevented strikes (360/369)
2 % false warnings (6/369)



Results

generated delays



- affected flights: 3.14 % (high intensity)
- lost departure slots: 27 (high intensity)
- departures after opening hours: none

Results

economic consequences

- assumptions

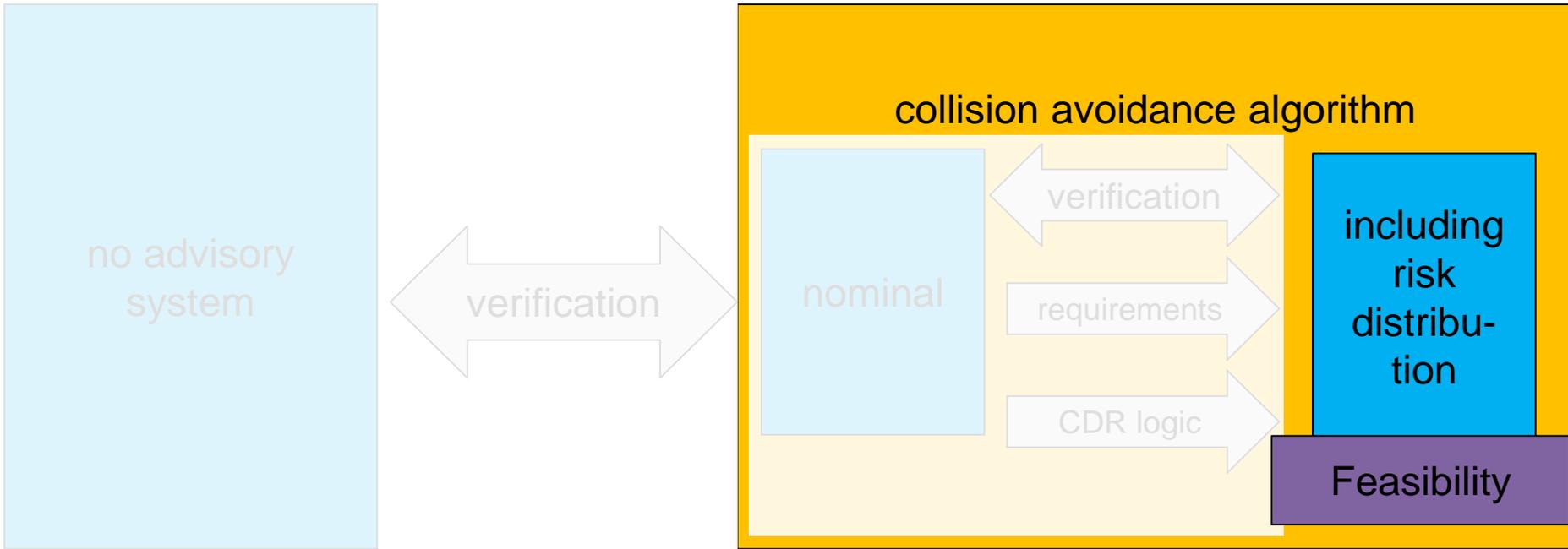
cost per bird strike: €24.947 (FAA)

cost per delay minute : €35 (University of Westminster)

traffic intensity	prevent ed bird strikes	saved costs	sum delay minutes	delay costs	saved costs per caused costs
high	149	3,717,103	2,455	85,925	43
medium	68	1,696,396	150	5,239	324
low	53	1,322,191	19	676	1957



Approach



Collision Avoidance Algorithm

Including Risk Distribution

how predictable is bird movement?

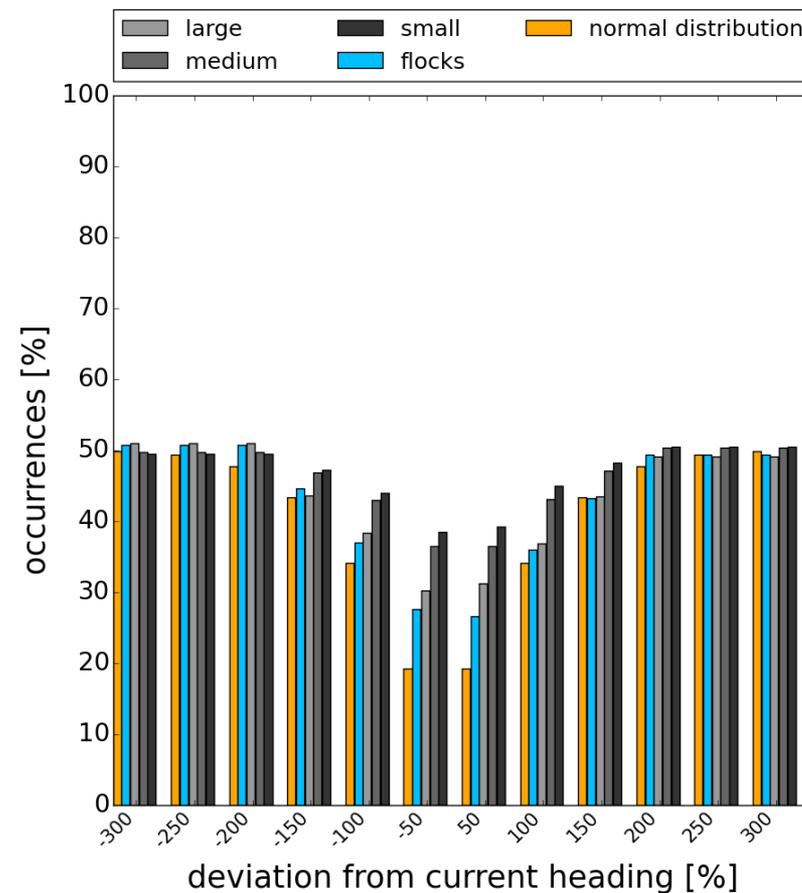
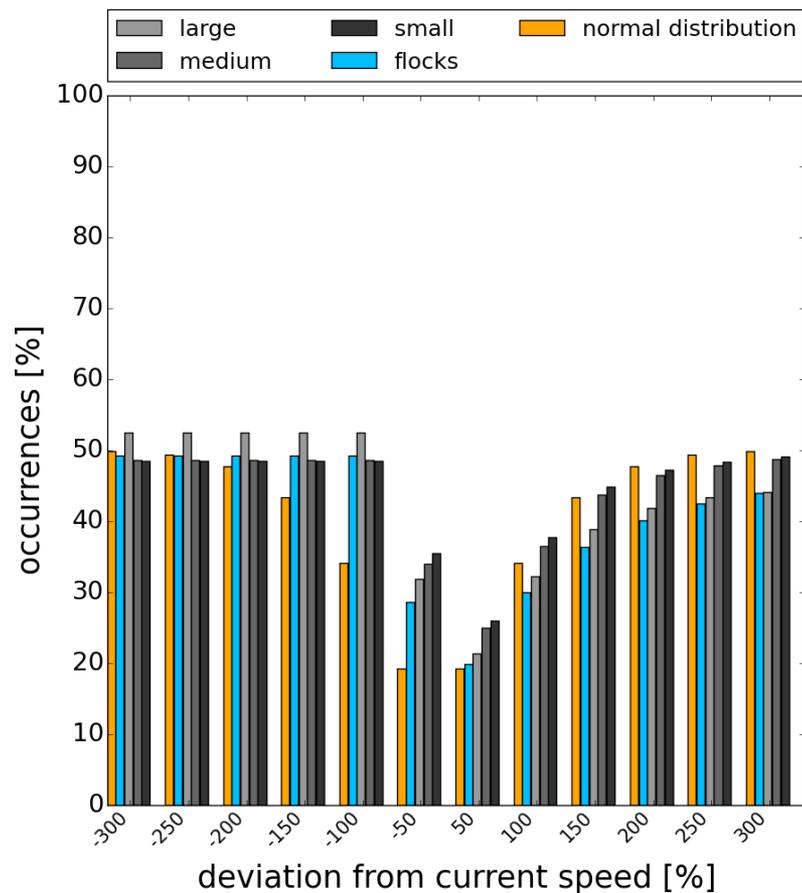


variation in speed and heading



Collision Avoidance Algorithm

Including Risk Distribution

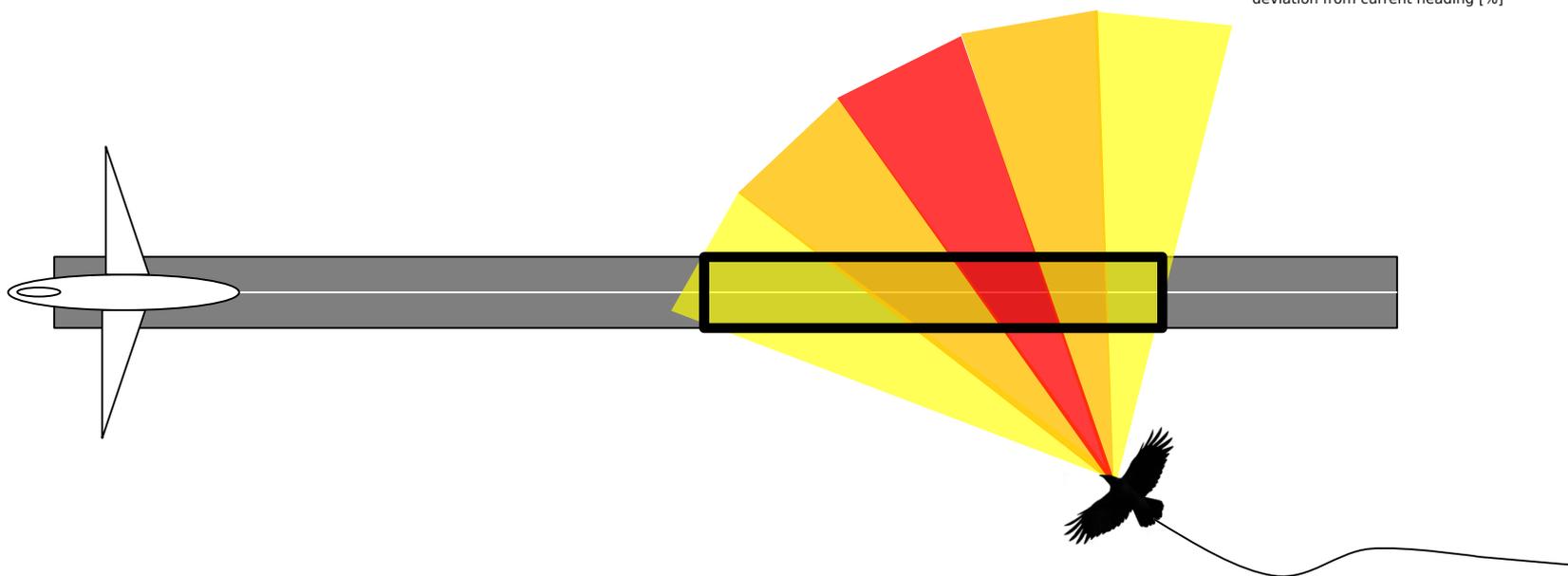
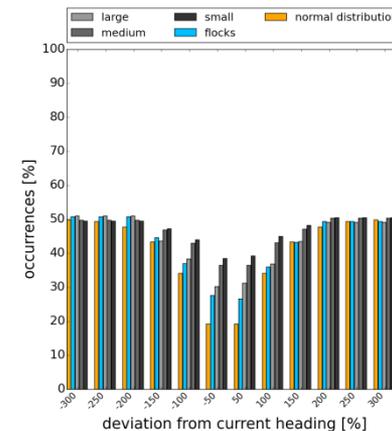


Collision Avoidance Algorithm

Including Risk Distribution

Risk is a function of

- probability speed * probability heading
 - kinetic energy
- risk of damage



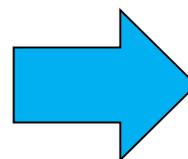
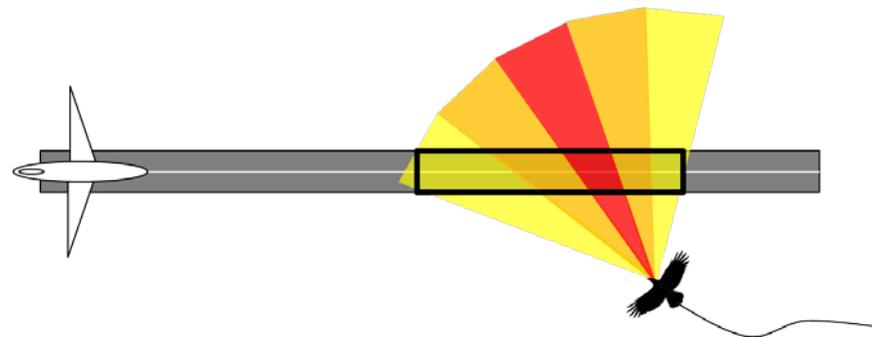
Summary and Outlook

- simulation environment
 - reproducible number of strikes
 - seasonal correspondence
- deterministic collision avoidance algorithm
 - 97 % prevented strikes
 - 2 % false warnings
 - very limited impact on capacity
 - high potential for cost reduction



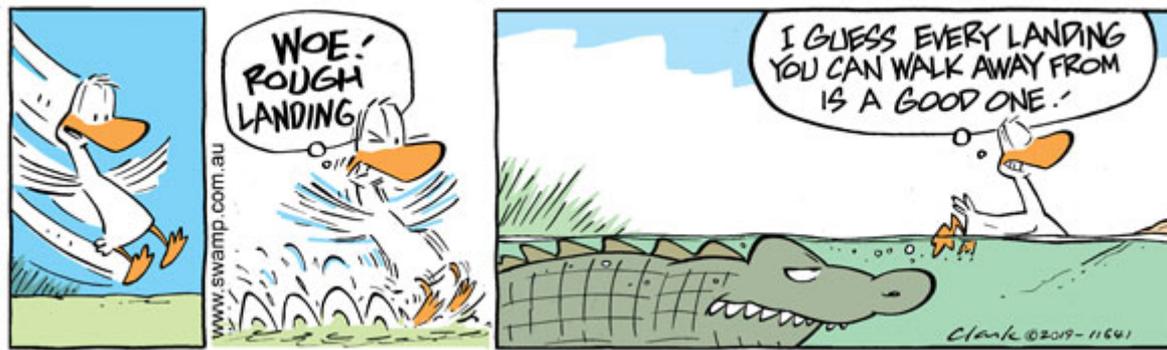
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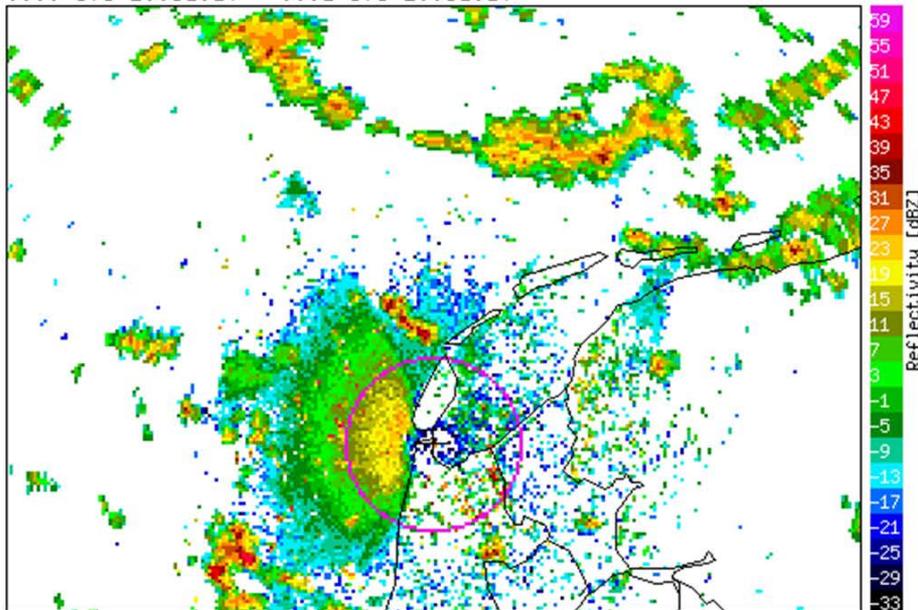
next step:
including uncertainty
in bird movements

Thank
you!

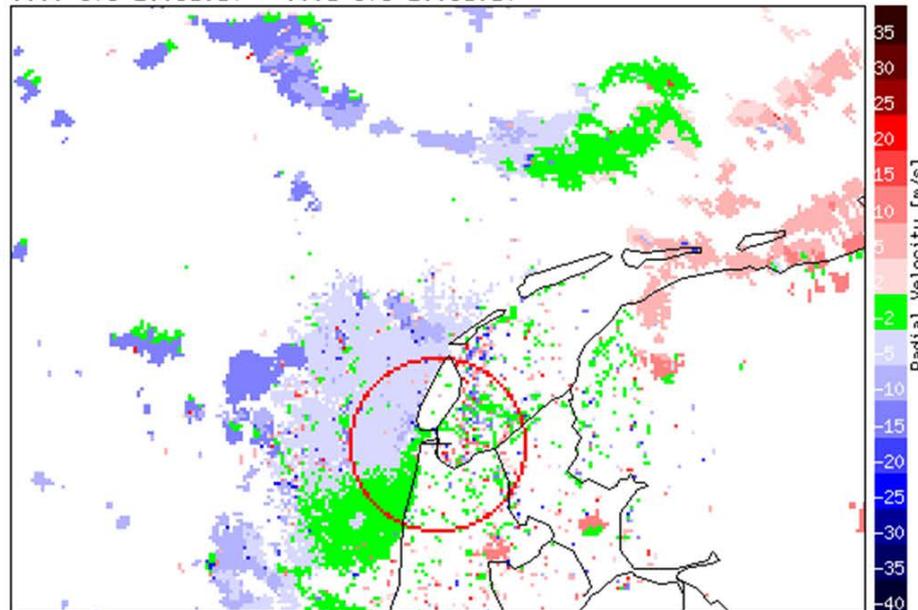


Questions?

0000 UTC 20081017 - 0001 UTC 20081017



0000 UTC 20081017 - 0001 UTC 20081017



distinction:

- reflectivity
→ -10 and 10dBZ

- radial velocity
→ min. 2m/s
→ high variability



Simulation Environment

Bird Movement Model: Extended Airport

input

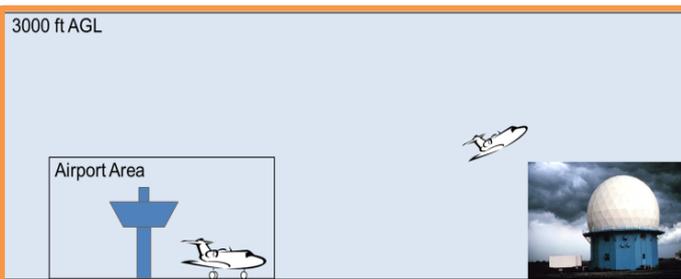
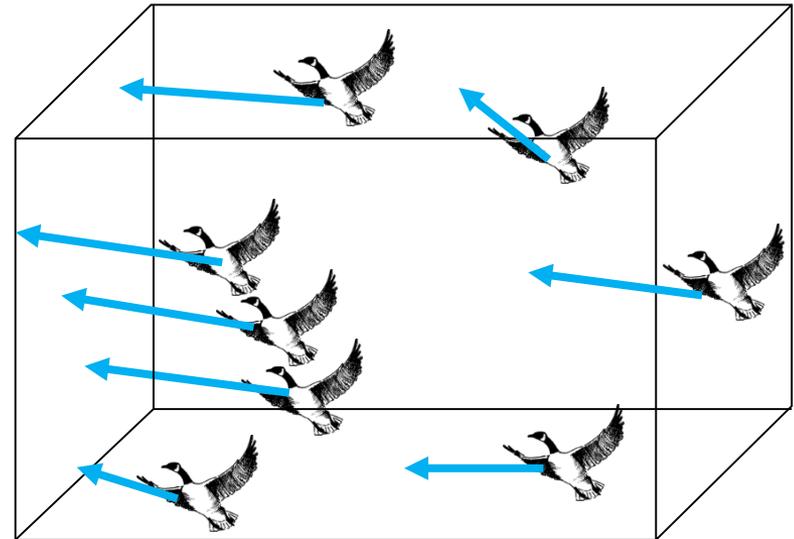
- bird reflectivity

$$\eta = \overline{\rho_{bird} \sigma_{bird}} \left[\frac{cm^2}{km^3} \right]$$

- velocities in u and v direction

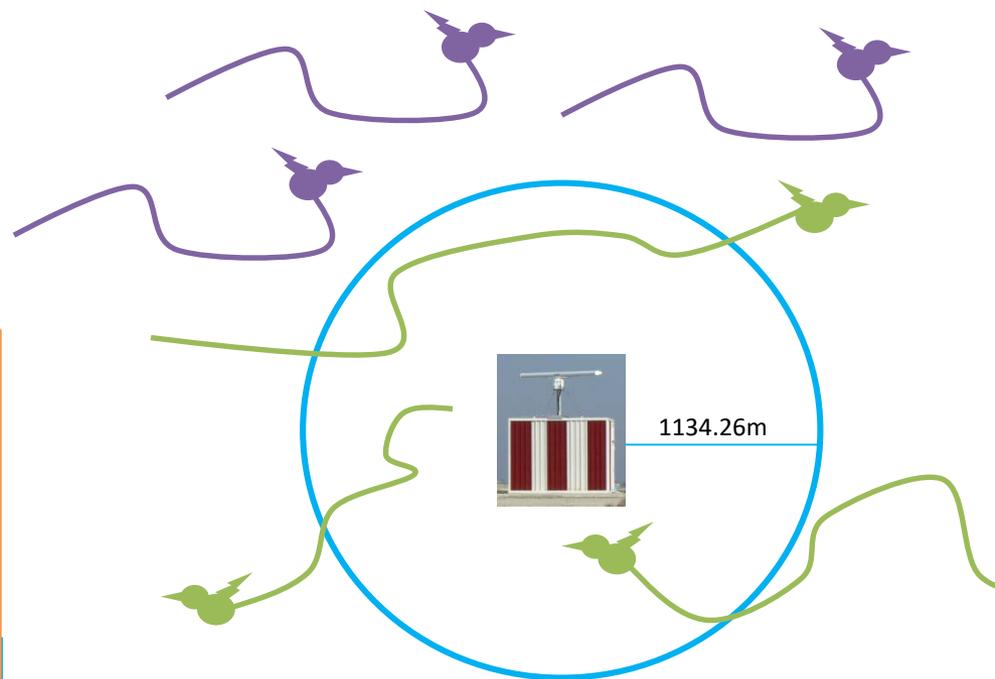
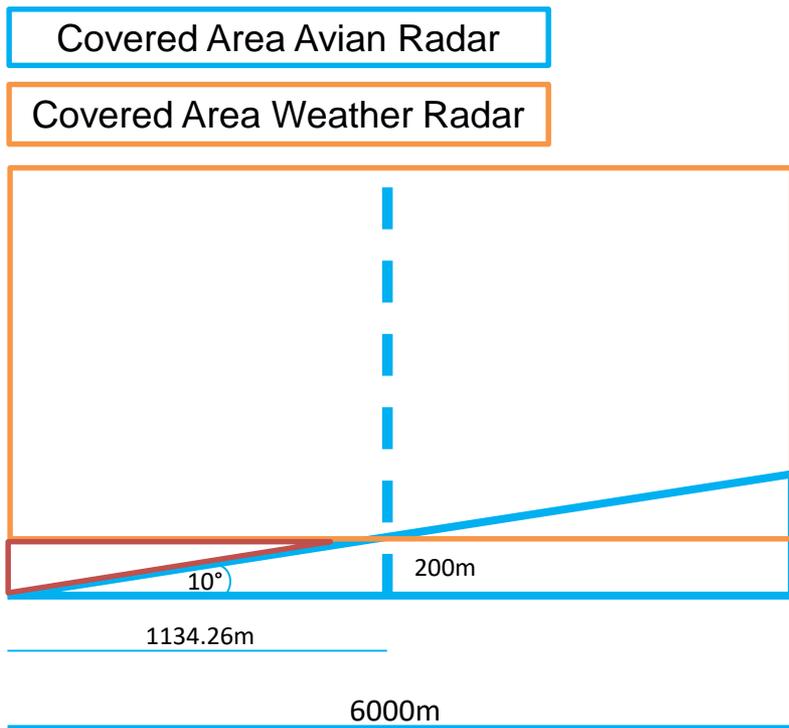
processing

- bird number ($\sigma_{bird} = 11 cm^2$)
- constant speed ($SD = 5 \frac{m}{s}$)
- constant direction ($SD = 45^\circ$)



Method based on

- van Gasteren et al. 2008
- Dokter et al. 2010
- Lensink & Kwak 1985
- Hüppop et al. 2006



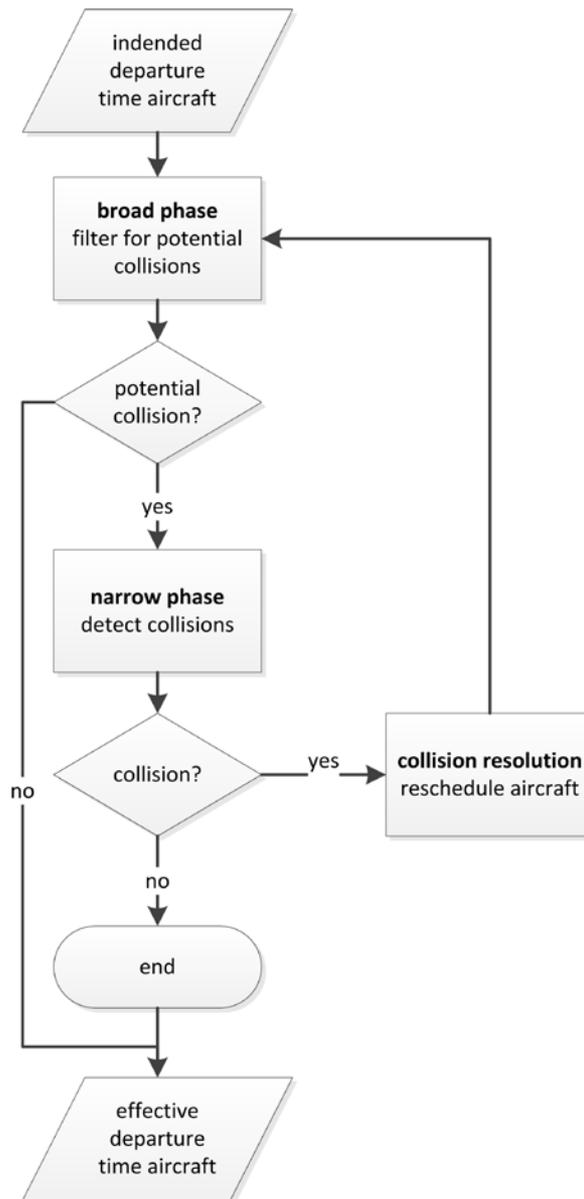
altitude	day	night
0-200m	48%	35.1%

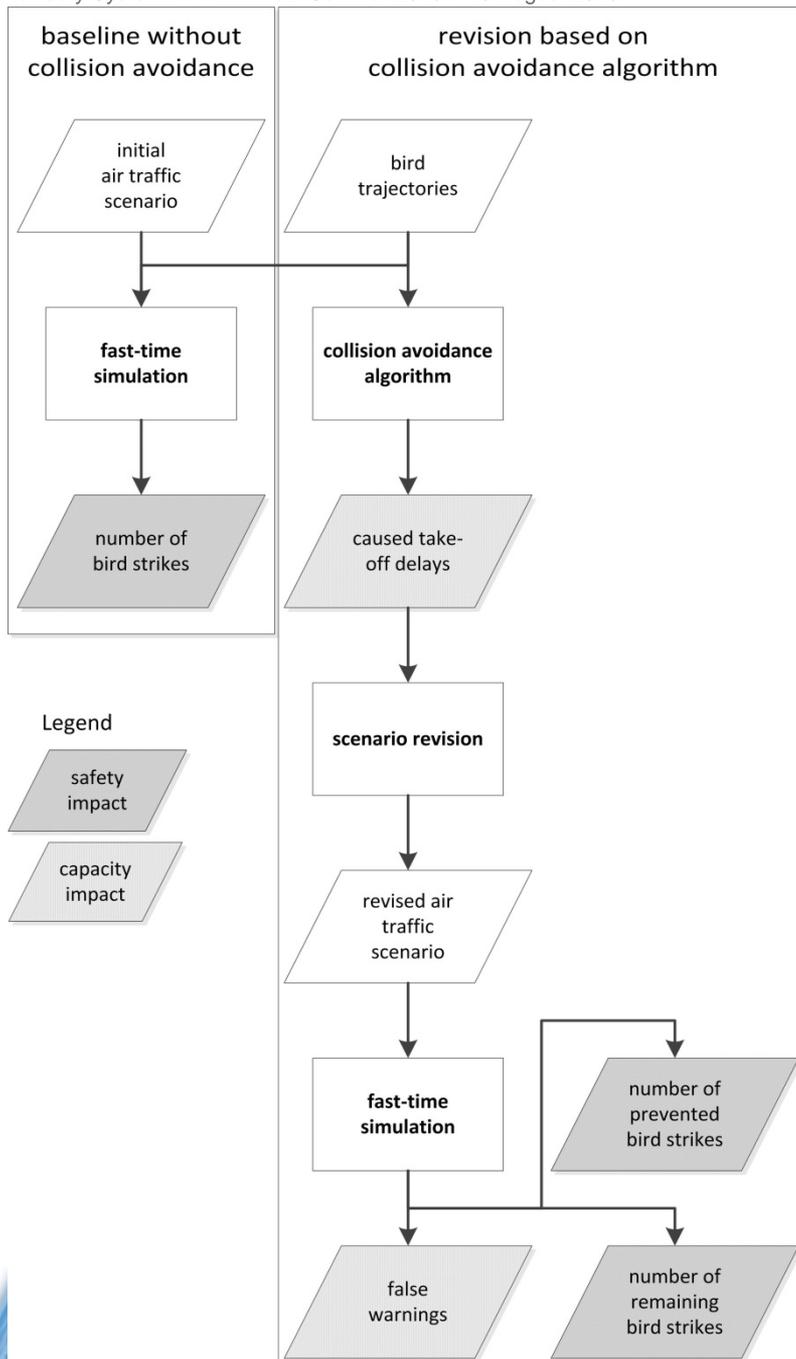
Shamoun-Baranes et al. 2017



Traffic Intensity	Affected Flights (%)	Number Transferred Delays per Prevented Strike (-)	Number all Delays per Prevented Strike (-)	Average Delay per Strike (s)	Average Delay per Day (s)	Potentially Lost Departure Slots per Day (-)
high	3.14	6.77	7.77	120.1	1753.57	14
medium	0.58	0.64	1.64	76.10	106.91	1
low	0.48	0.11	1.11	2.50	13.79	1

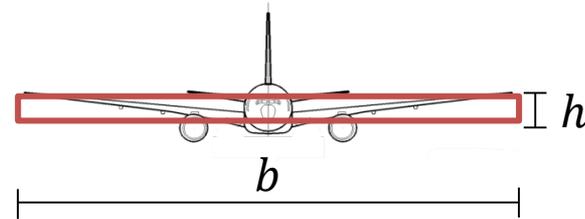
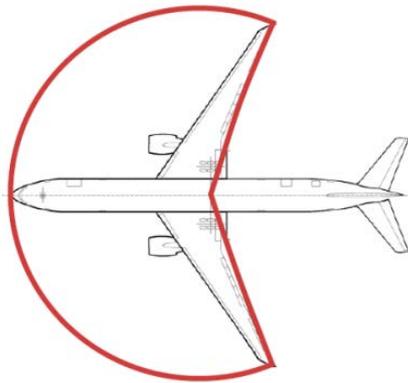






Simulation Environment

Collision Model: Protected Zone Aircraft



$$S_{front} = b * h = \underbrace{(b - 2 * r_f) * h_w}_{\text{wings}} + \underbrace{n_e * r_e^2 * \pi}_{\text{engines}} + \underbrace{r_f^2 * \pi}_{\text{fuselage}}$$

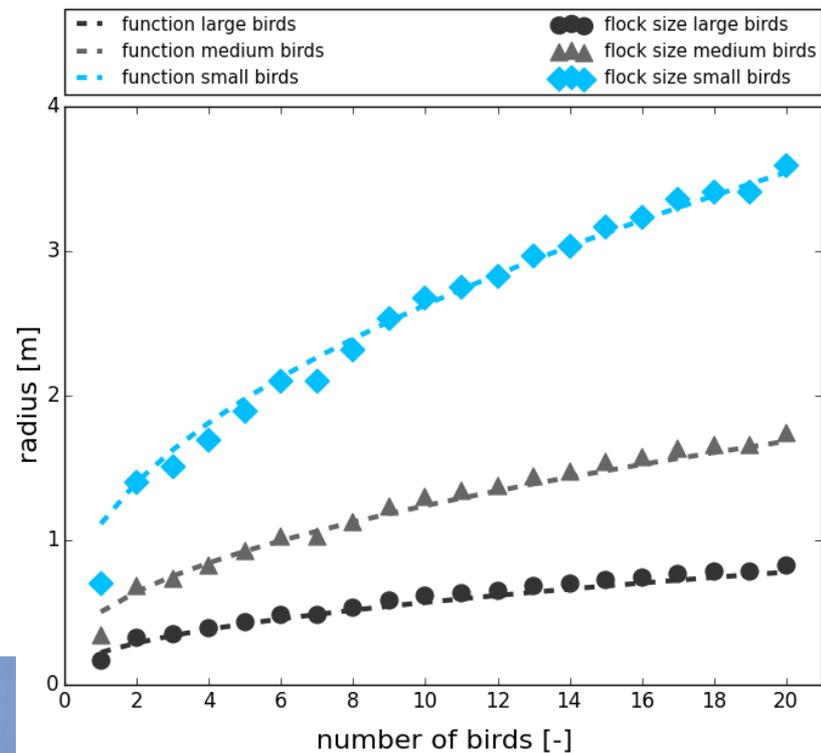


Simulation Environment

Collision Model: Protected Bird



$$r = \sqrt{n_{birds}} * \frac{b}{2} + c$$

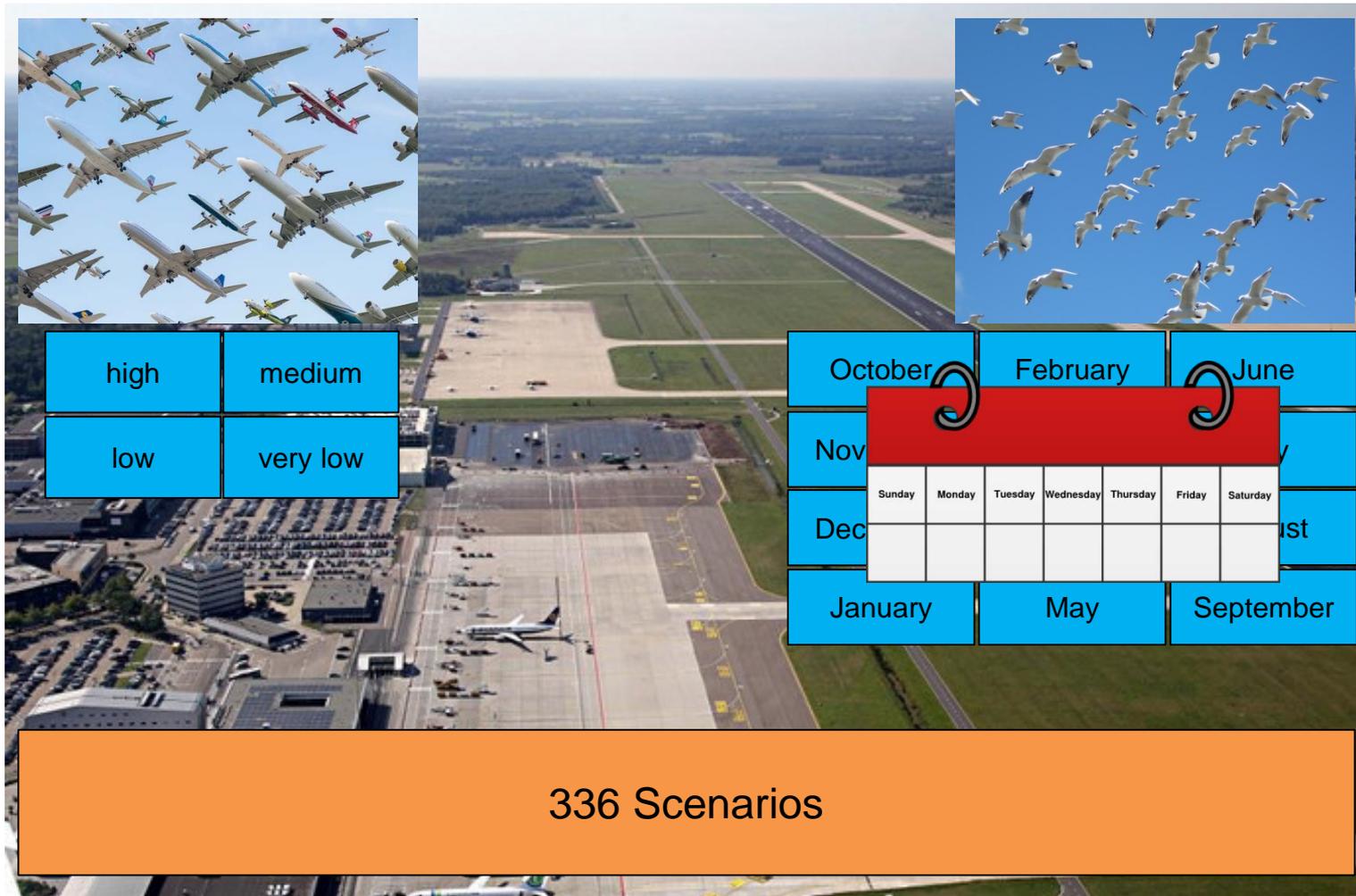


based on Graham 1996



Verification

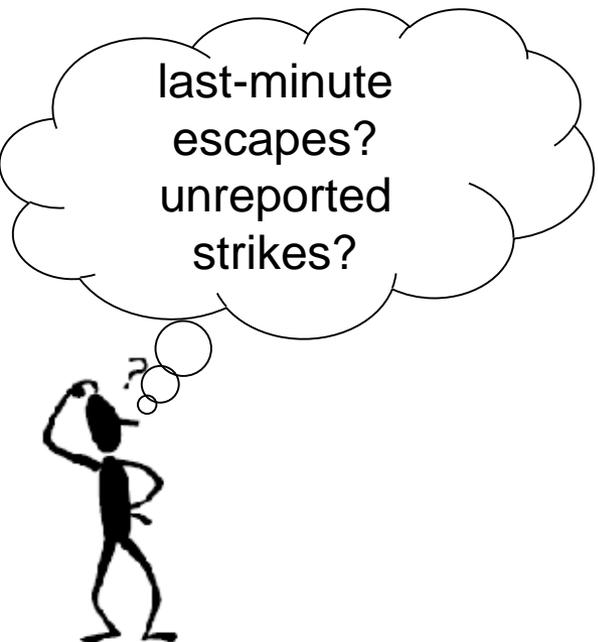
Simulation Setup



Results

Bird Strike Rate: Number of bird strikes per 10,000 flights

Air Traffic Intensity	Bird Strike Rate
high	21.59
medium	19.48
low	21.78
very low	15.07

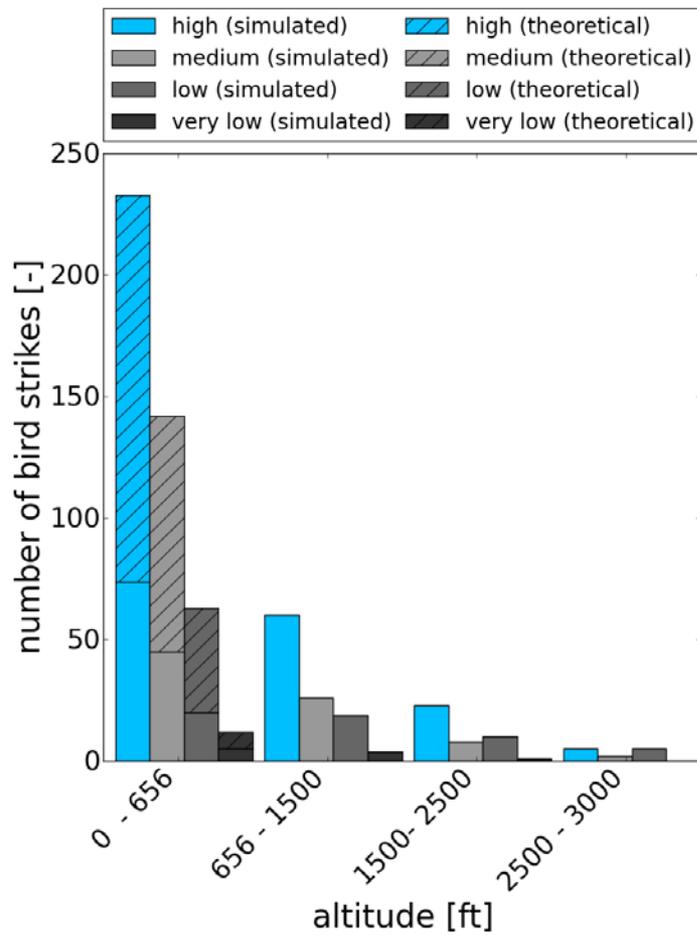


last-minute
escapes?
unreported
strikes?



Results

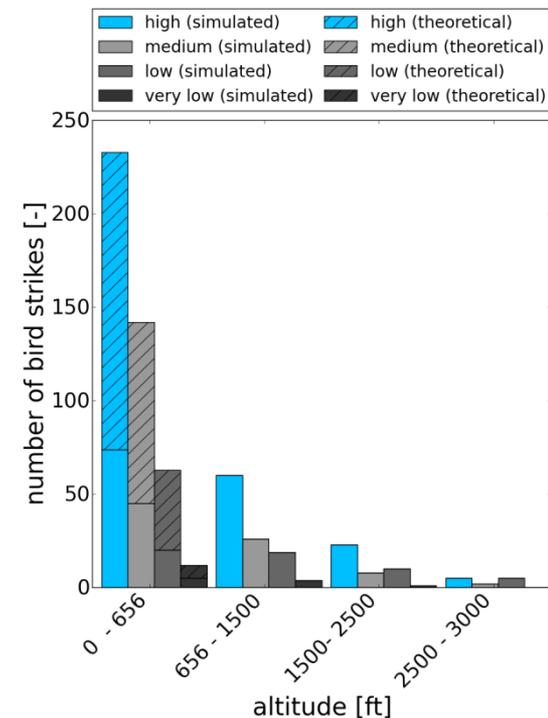
Altitude Distribution



Results

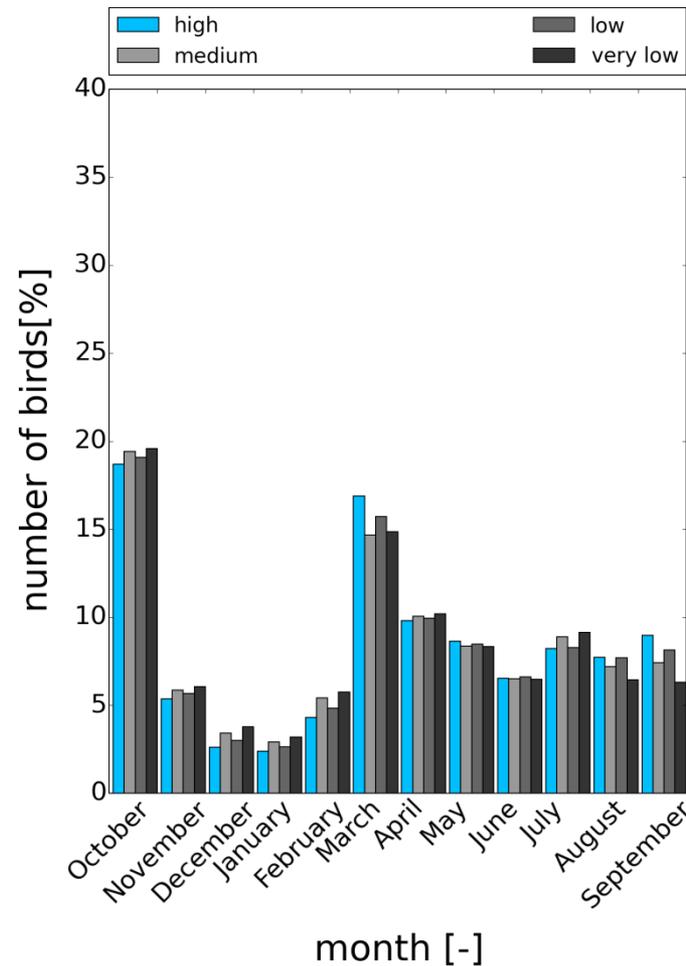
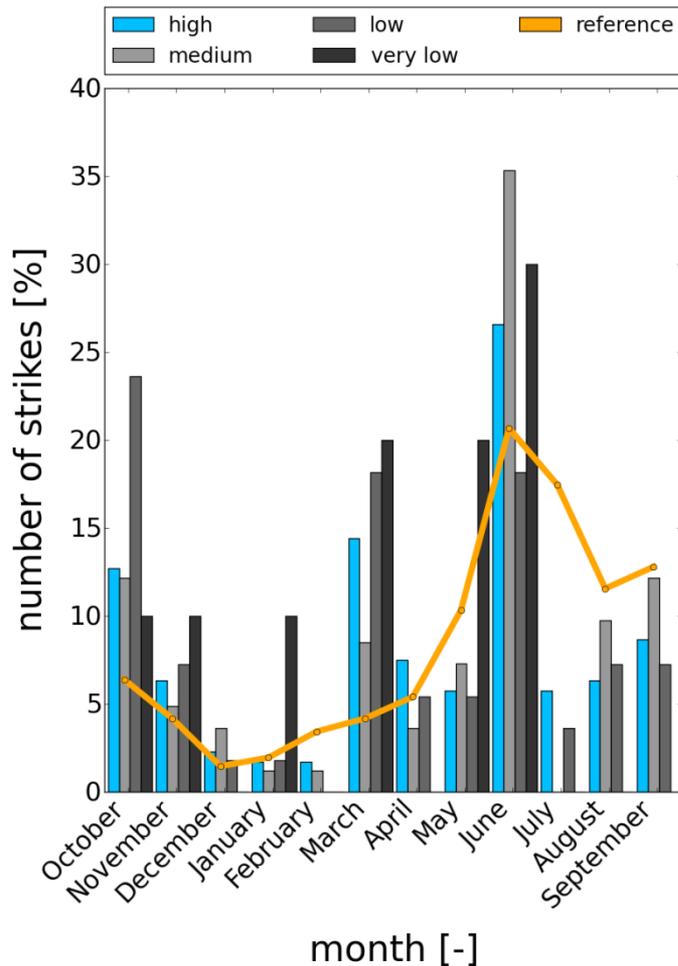
Bird Strike Rate and Altitude Distribution

Airport	Bird Strike Rate	Bird Strike Rate (theoretical)
high	21.59	41.43
medium	19.48	42.43
low	21.78	38.25
very low	15.07	25.62
<i>Eindhoven (reference)</i>		12.33



Results

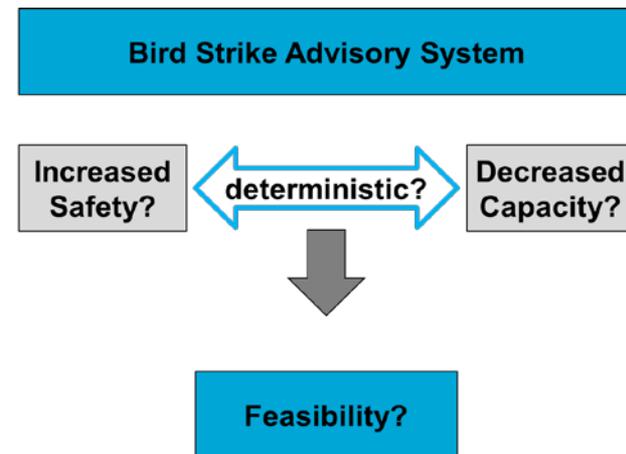
Seasonal Distribution



Conclusions

- simulation environment developed
 - bird movement and collision model
- promising results achieved
 - bird strike rate
 - altitude distribution
 - seasonal distribution
- next step
 - develop collision avoidance algorithm

→ Monte Carlo Simulations



Thanks!

Questions?



