MODELLING AND ESTIMATION OF SEPARATION CRITERIA FOR AIRBORNE TIME-BASED SPACING OPERATION

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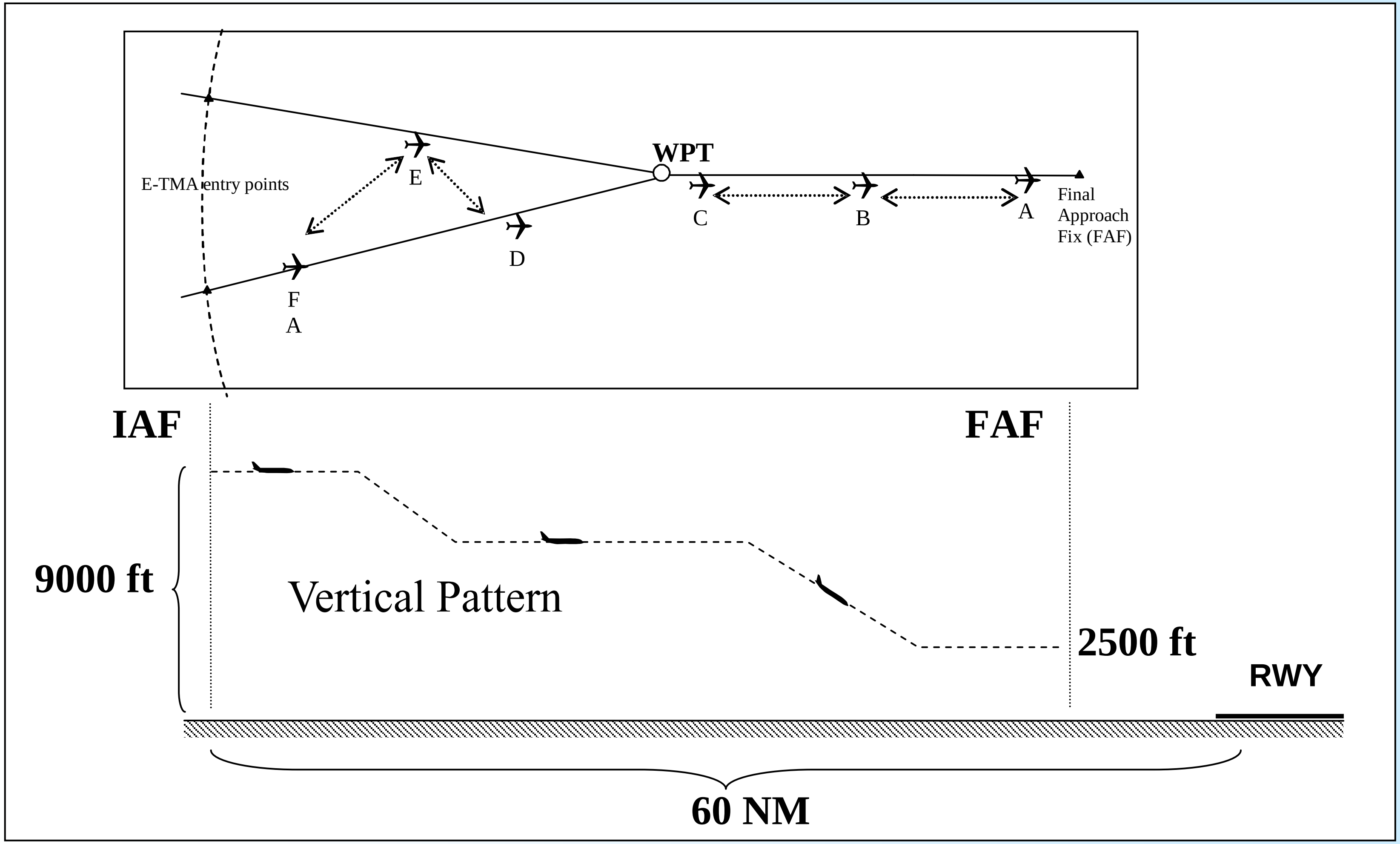
- **<u>Aim of this Paper</u>**
- Monte Carlo Simulation
- Simulation Results
- Interaction with ACAS
- Concluding Remarks

Aim of this Paper

- To gain insight on how collision risk depends of the minimum separation criterion for the Airborne Time-Based Spacing (TBS) operation;
- In order to achieve so, initial collision risk results obtained through modelling and simulation of Airborne TBS operation are presented.

Airborne TBS Operation

Focus on E-TMA airspace, until final approach fix



Airborne TBS Operation

New kind of ATCo instructions

Phase 1

-Select target

Phase 2

-Remain behind

-Merge behind

Tasks of flight crew

- Be aware of the surrounding traffic;
- Identify the target aircraft on the CDTI;

- Activate Merge/Remain mode
- Monitor spacing (when using spacing director);

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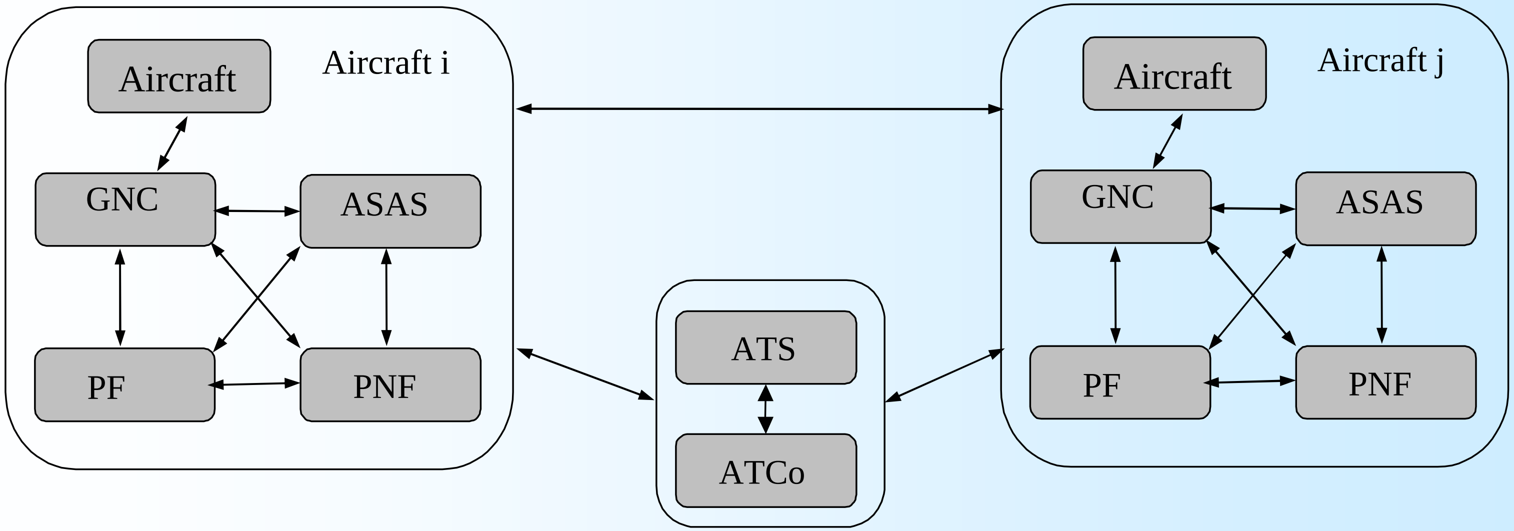
Monte Carlo Simulation

Multi-Agent Joint Cognitive System



Monte Carlo Simulation

Model parameterization, verification and validation

- A Multi Agent model is developed and coded in Java programming language;
- This JAVA code is used to run Monte Carlo simulations for the scenarios considered;
- The Multi Agent model enables systematic implementation, verification and validation, through the following steps:
  - Software code testing in hierarchical levels;
  - Numerical approximation testing, such as choosing an appropriate time step;
  - Parameterization, using several information sources;
  - Initial model validation under some dedicated scenarios;
  - Overall validation against real operational concept (not yet performed)

Monte Carlo Simulation

ASAS equipment loop probabilities of failure
(baseline values used in simulation model)

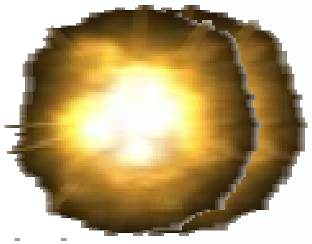
ASAS computer	0.0001
ADS-B transmitter	0.00005
ADS-Receiver	0.00005

Monte Carlo Simulation

Simulation of Separation Related Events

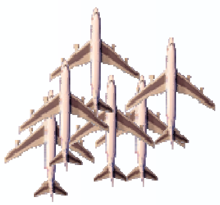
Event	Horiz. dist. (NM)	Vert. dist. (ft)	Pred. time (min)
Short Term Conflict (STC)	4.5	900	2.5
Minimum Separation Infringement (MSI)	4.5	900	0.0
Near Mid-Air Collision (NMAC)	1.25	500	0.0
Mid-Air Collision (MAC)	0.054	131	0.0

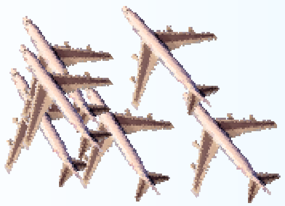
Straightforward Monte Carlo Simulation



N ***m***

p=2/6=1/3





- How to evaluate the collision probability using a Monte Carlo simulation model?
- The stochastic model is simulated *N* times using independent random samples
- When *m* collisions are counted, then the estimated collision probability is *m*/*N*

Speeding Up Monte Carlo Simulation

- In order to get a statistically valid result for a probability of **10exp-9**, some 100 collision occurrences should be counted; which requires to run the Monte Carlo simulation some **10exp11 times;**
- If one Monte Carlo simulation run takes 0.1 second, then the Monte Carlo simulation takes **317 years;**
- In order to reduce this to **1 day**, a Monte Carlo simulation speed up factor of **10exp5** is required;
- We accomplish this using advanced speed up methods from financial mathematics

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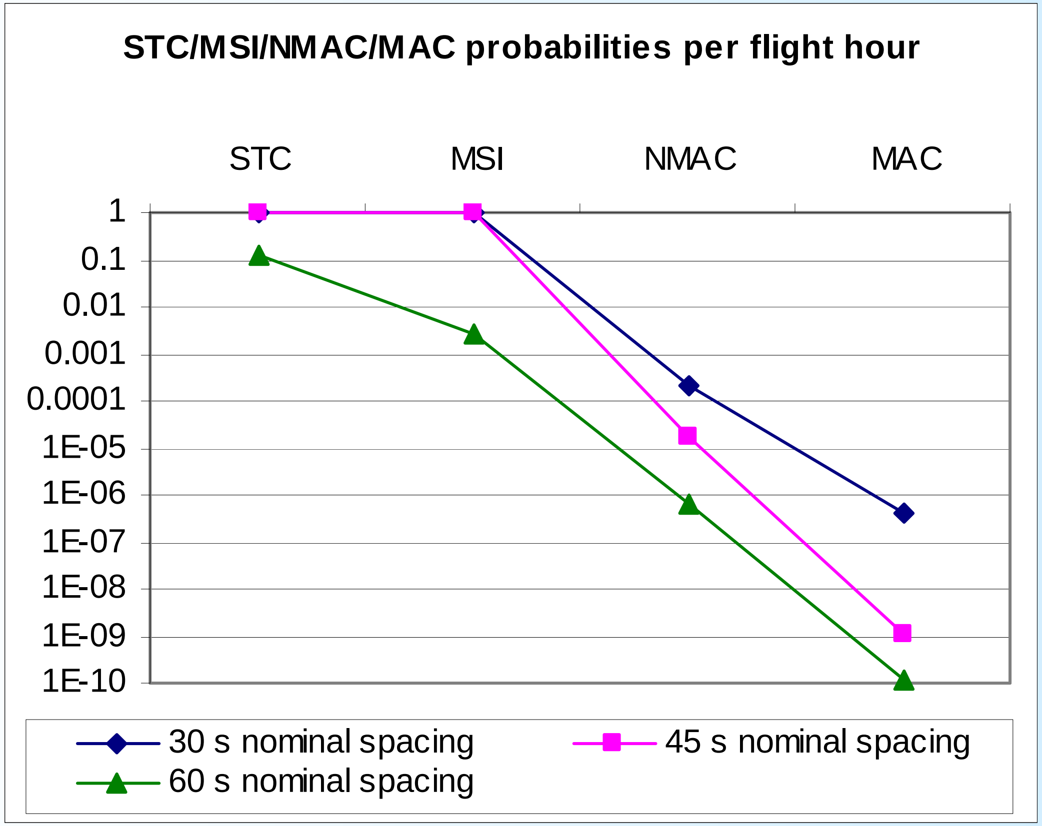
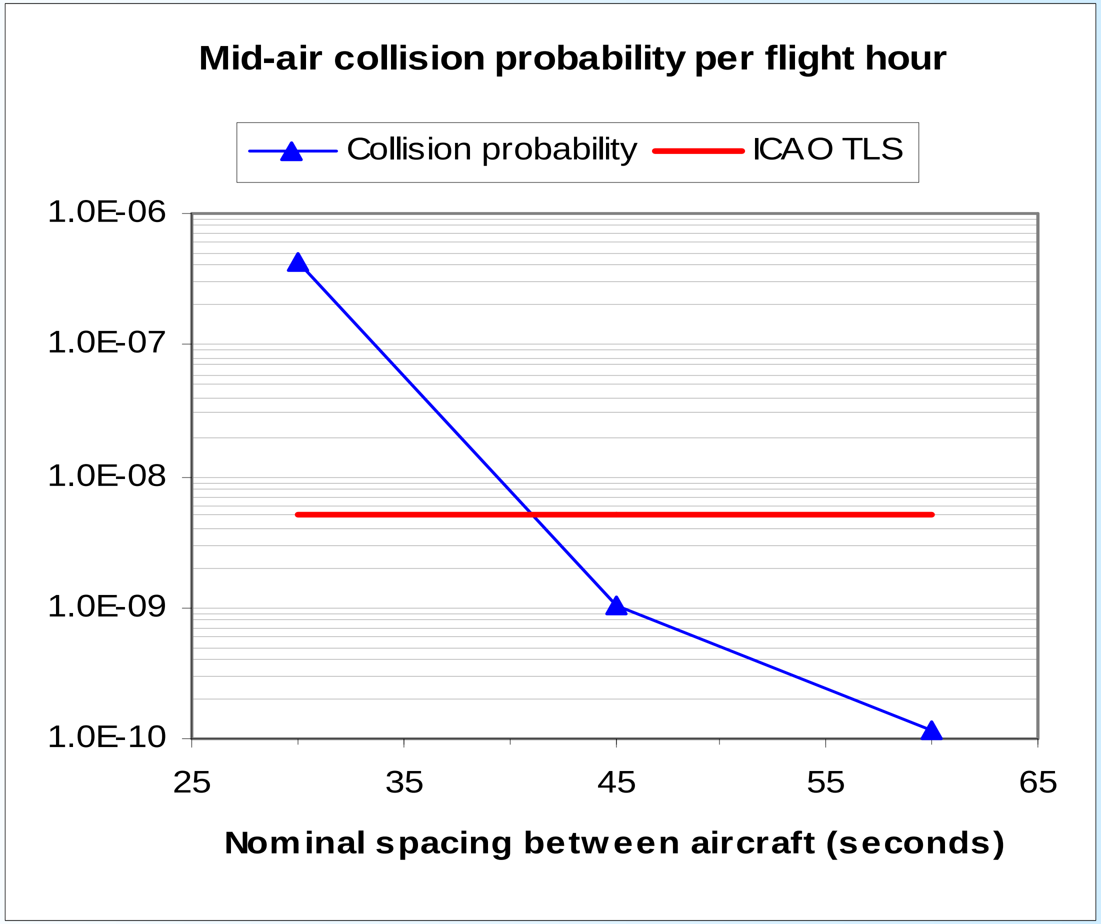
Simulation Results

Probabilities of Separation loss events

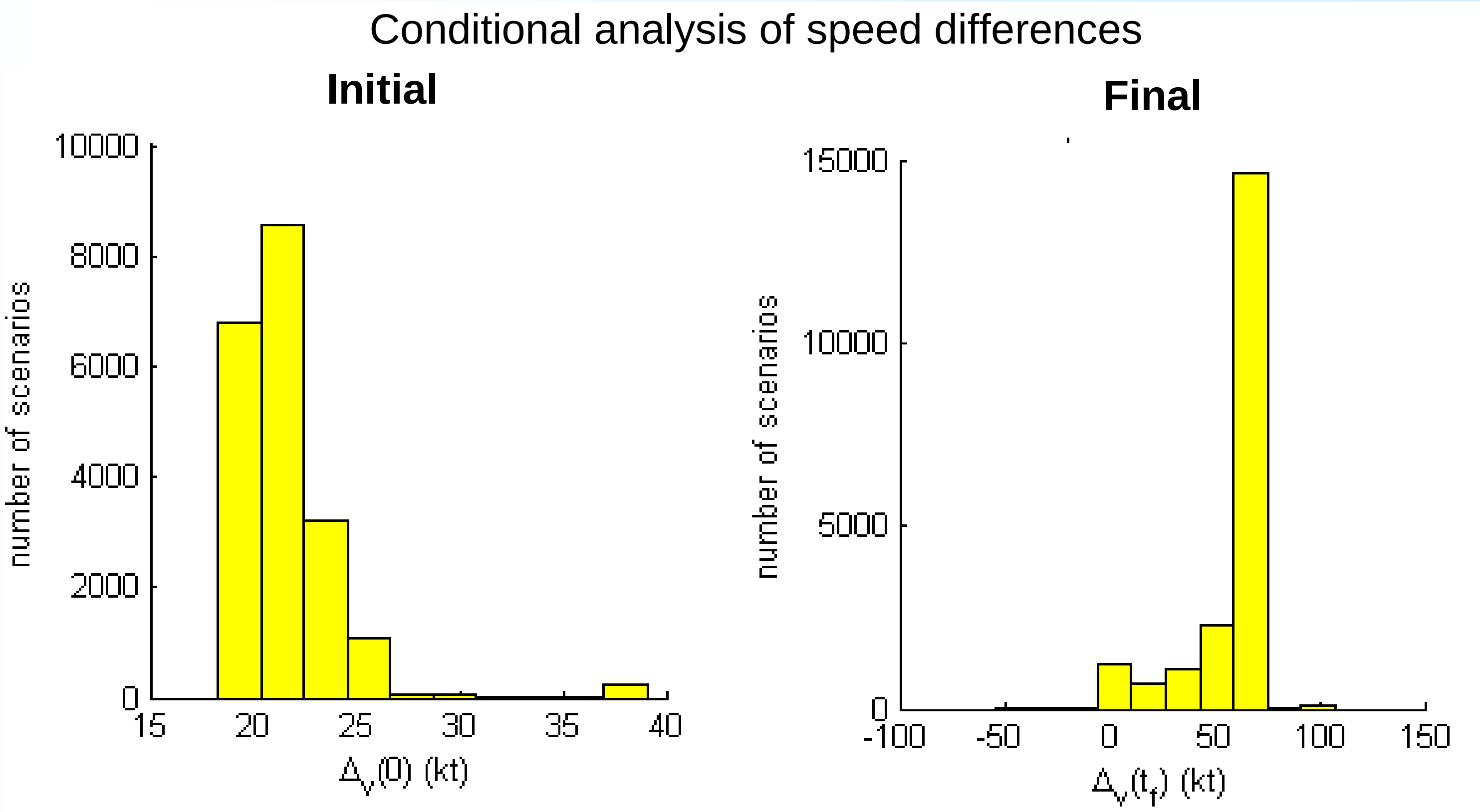


Simulation Results

MAC probabilities versus ICAO TLS



Speed difference of simulated cases which ended in MAC



Follower aircraft faster than the leader aircraft

Causes of higher speed of follower aircraft

– A drifting error existing in the aircraft sensors of airspeed and altitude;

– A peak in the speed caused by starting a descent;

– ASAS spacing failures (including ADS-B).

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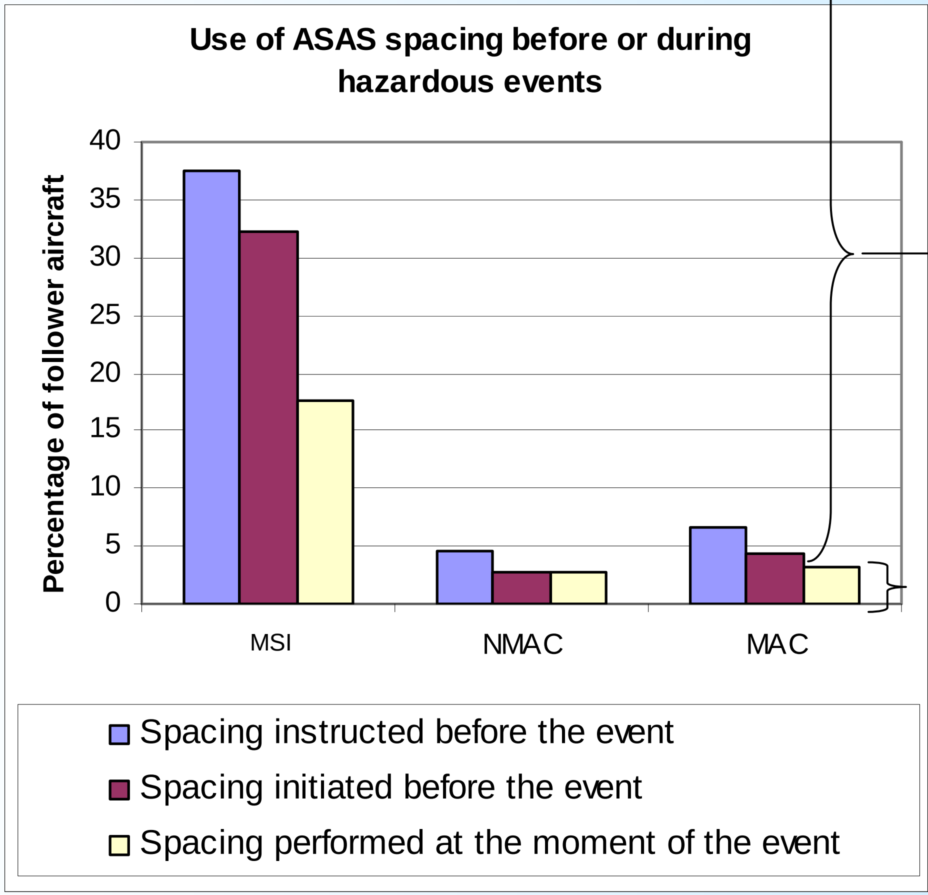
Simulation Results

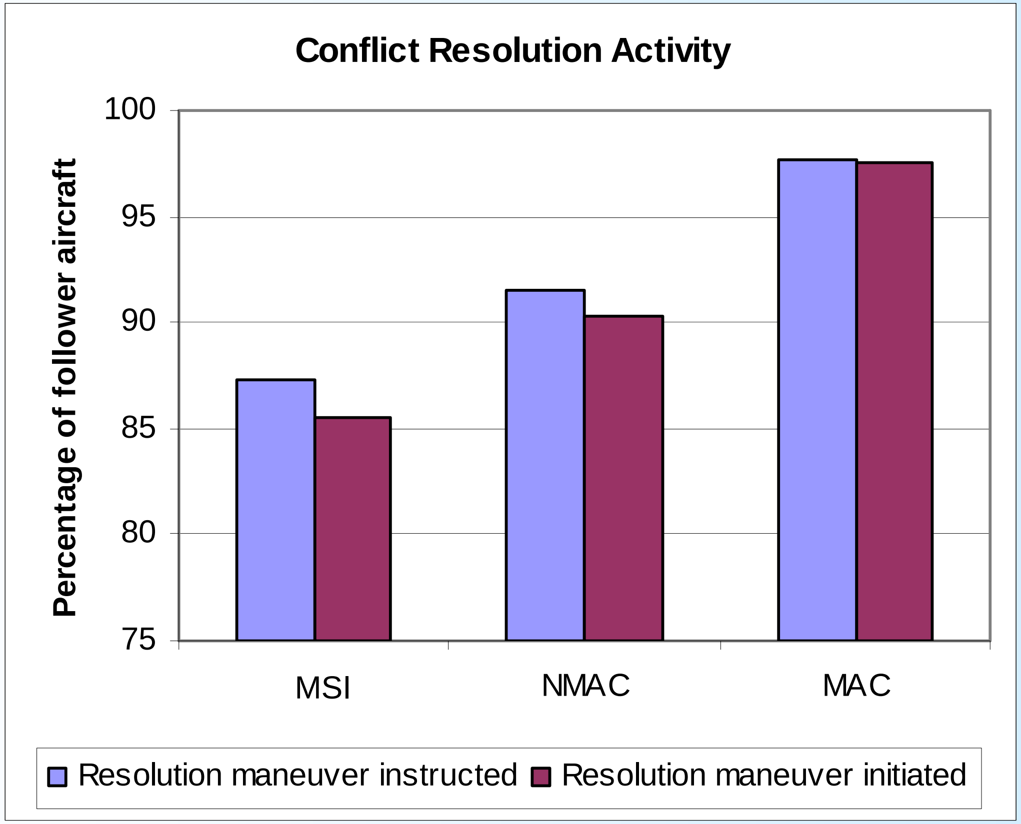
Working of ASAS for close encounters



ASAS not working at MAC

ASAS working at MAC

Conflict detection and resolution



Conflict resolution initiated, but not effective, typically too late

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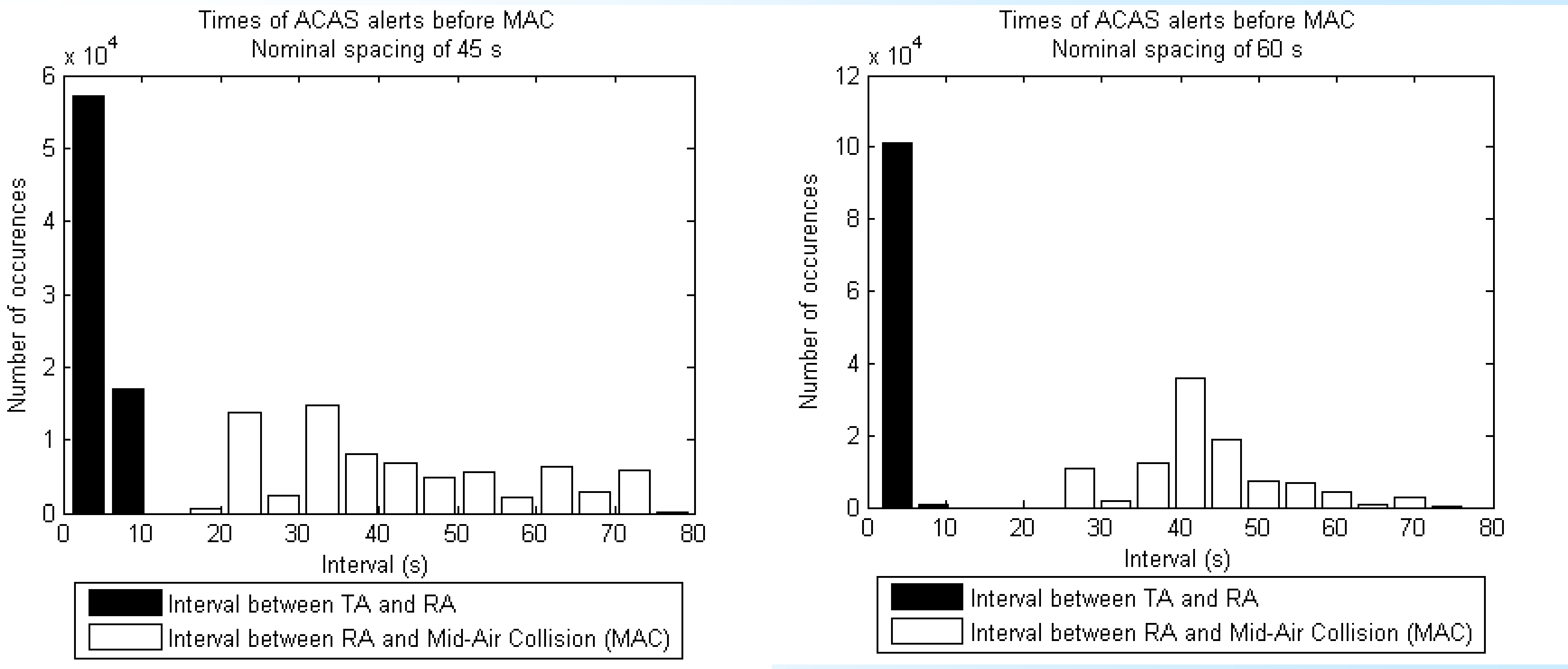
Interaction with ACAS

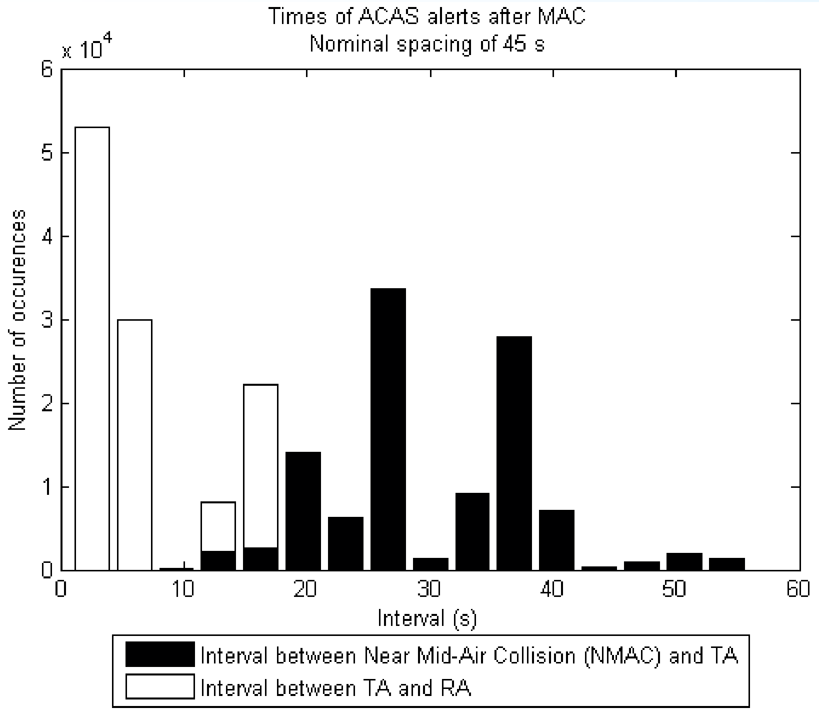
- ACAS was not explicitly taken into account in the Monte Carlo simulations;
- However, it is desired to know if ACAS works well with ASAS TBS;
- So ACAS logic has been run “hidden” from the simulated pilots;
- ACAS alerting times have been evaluated in the simulated cases ending in Mid-Air Collision

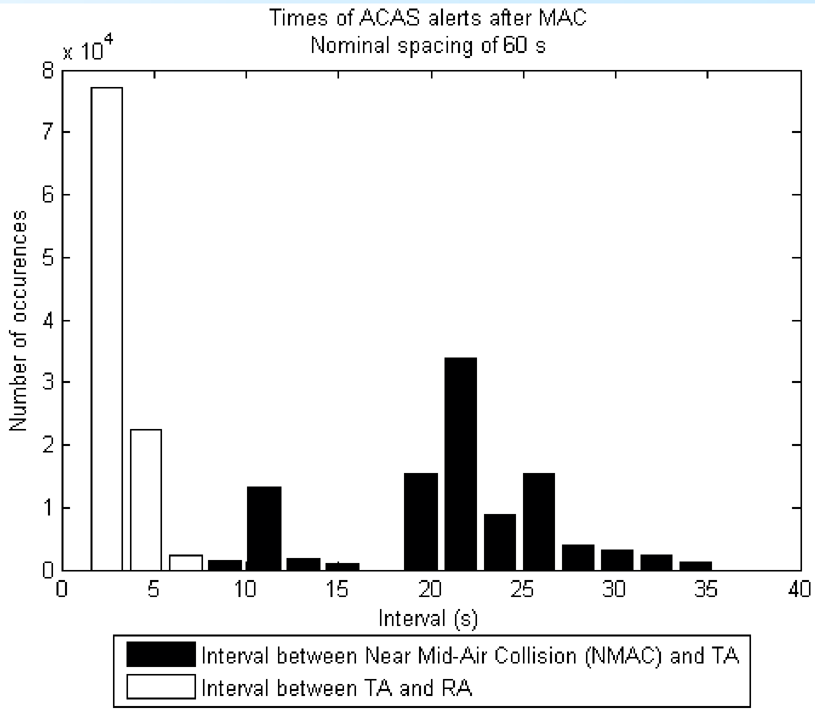
Intervals between ACAS and Mid-Air Collisions:



Interaction with ACAS

Intervals between NMAC and ACAS alerts:





- All alerts after NMAC

- This shows that ACAS does not interact too early with ASAS TBS

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Concluding Remarks

- ASAS TBS is both effective and safe on collision risk at nominal spacing of 60 seconds or more;
- For nominal spacing of 45 seconds, ASAS spacing operation failure is the main contributor for the collision risk, typically due to:
  - ASAS equipment failure;
  - Too small initial separation, from upstream sector;
  - Too large speed difference.

Concluding Remarks

- Nominal spacing going significantly below of 60 seconds seems to be an invalid option.
- Follow up reseach:
  - To assess the impact differences between model and reality have on the risk level;
  - Perform Monte Carlo simulations with multiple aircraft trailing;
  - Assess Wake vortex induced risk as fuction of time based nominal spacing value (for various pairs of aircraft).

The End

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