Agent-Based Modelling and Simulation of Trajectory Based Operations under Very High Traffic Demand

Dedicated to innovation in aerospace

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- **Motivation**
- A3 ConOps (advanced pure airborne self separation)
- Ground based versions of A3
- Agent-based model
- Simulation results
- Conclusions

Motivation

- Conventional ATM: Optimization between planning and tactical control through decades of evolutionary development

- SESAR2020+: Trajectory Based Operation (TBO); 4D plans (RBT's)
- What happens under various disturbances?
  - Meteo
  - Data
  - Human
  - Technical systems
- How to optimize collaboration between TBO/RBT and tactical layer?

- Powerful emergent behaviour has been identified within iFly project for a pure airborne collaboration of these layers (A3 ConOps)

Positive Emergent Behaviours of A3

iFly project identified positive emergent behaviours of A3 ConOps:

1. Tactical layer is very effective in the tactical resolution of uncertainties that are not timely resolved by the TBO layer.
2. Centerlines of 4D trajectory plans may be at minimum separation values: no need for any buffers.
3. No phase transition happens at traffic demands multiple times higher than 3x high 2010 en-route in busy sector.

EMERGIA project objective is to identify a ground-based TBO ConOps with similarly positive emergent behaviours

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A3 ConOps: advanced airborne self-separation

- Aircraft plan conflict-free 4D trajectories
  - Trajectory Based Operation (TBO)
- Each a/c broadcasts its current 4D plan and destination to other aircraft
- SWIM transfers each 4D plan over-the-horizon
- Conflict detection and resolution take all aircraft into account
  - Medium Term (5-15 mins)
  - Short Term (3-5 mins)
- Flow Control and ACAS are out of scope in this research

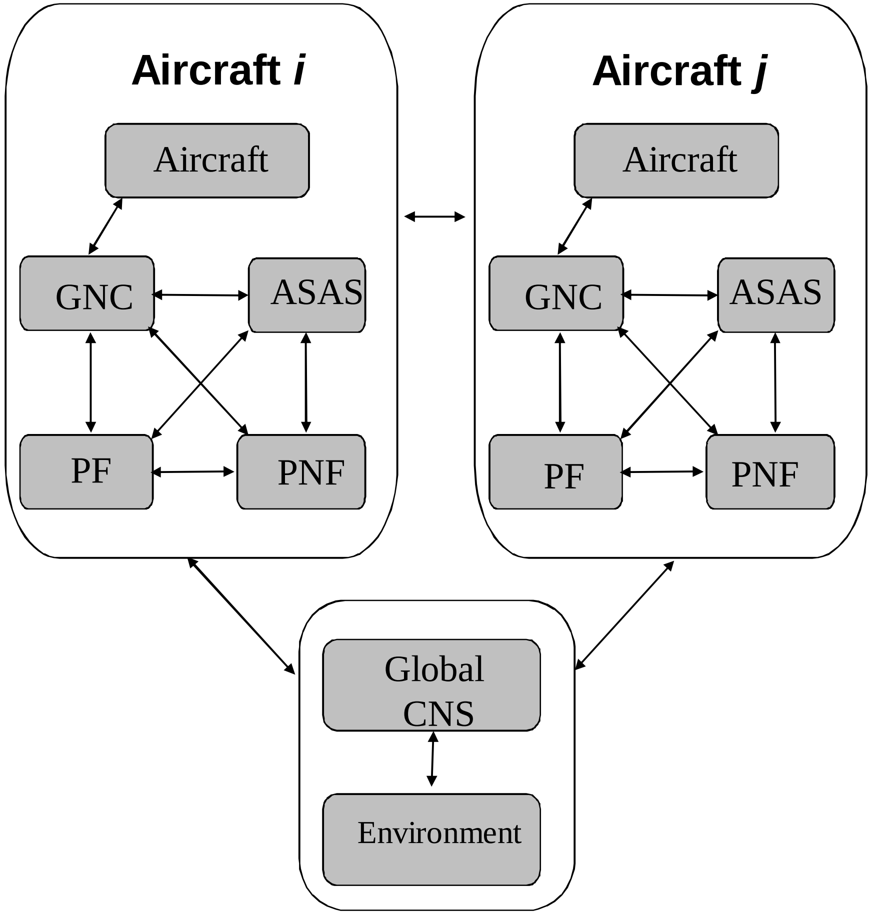
Medium Term CD&R (MTCR) approach

- Each aircraft detects conflicts (5NM/1000ft) 10 min. ahead.
- a/c nearest to destination has priority over other a/c.
- a/c with lowest priority has to make its 4D plan conflict free (15 min ahead) with all other plans.
- However, undershooting of 5Nm/1000ft is better than doing nothing if there is no feasible conflict free plan. It should not create a short term conflict.
- Then, the aircraft broadcasts its non-conflict-free 4D plan together with a message of being “Handicapped” (which is priority increasing).

Short Term CD&R (STCR) approach

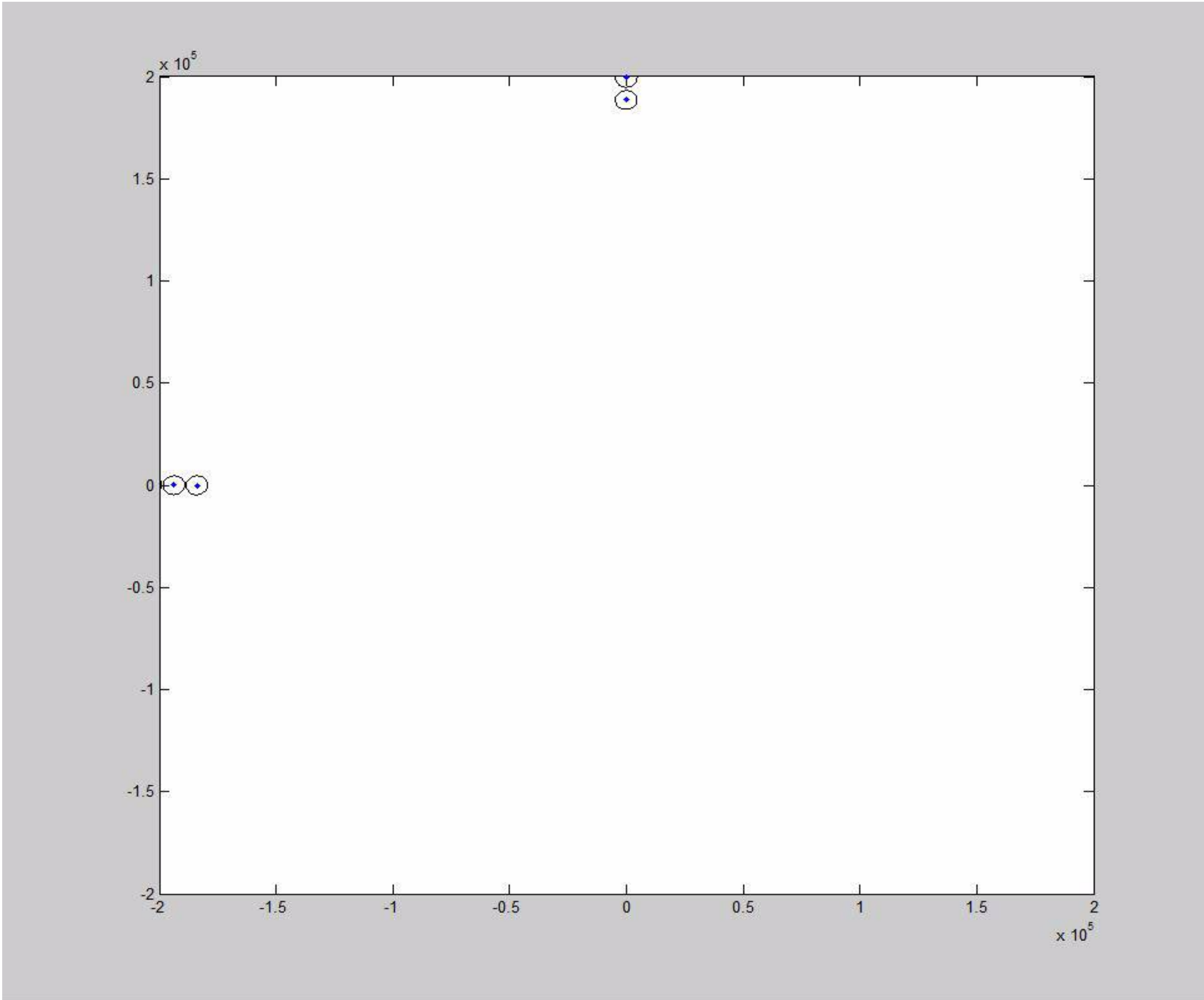
- a/c which detects conflict is obliged to resolve the conflict without awaiting any of the other aircraft.
- Course change is identified using Velocity Obstacles/Conflict Cones (3 min. ahead).
- Conflict free means 5Nm/900ft minimal predicted miss distance.
- However, undershooting of these values is better than doing nothing if there is no feasible alternative.
- Then, the a/c broadcasts its new course or rate of climb/descend.

Agent-Based Model of A3 ConOps

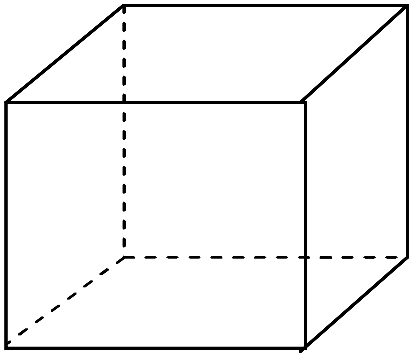


Two crossing traffic flows;

A3 agent-based model

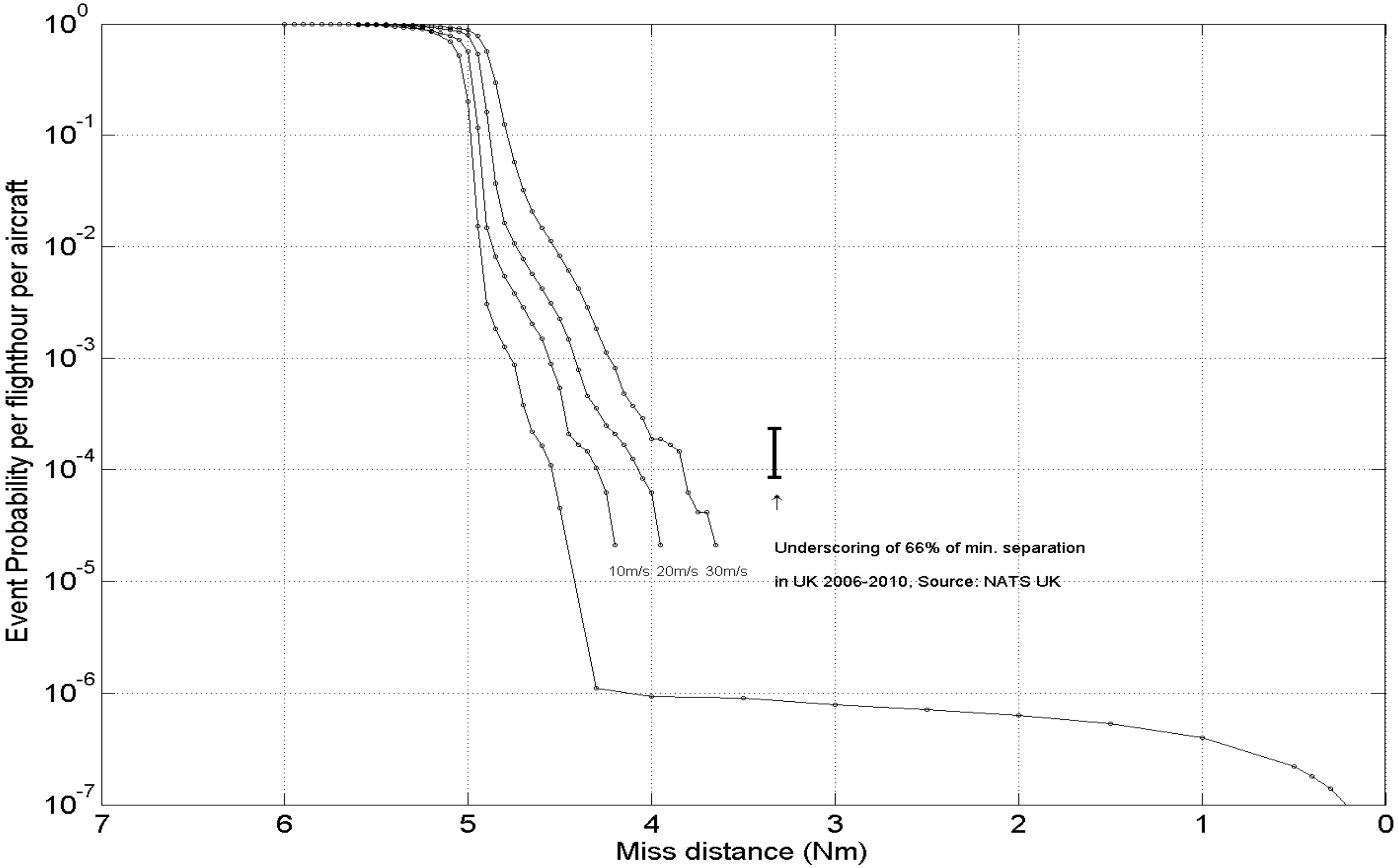


Random Traffic Scenarios

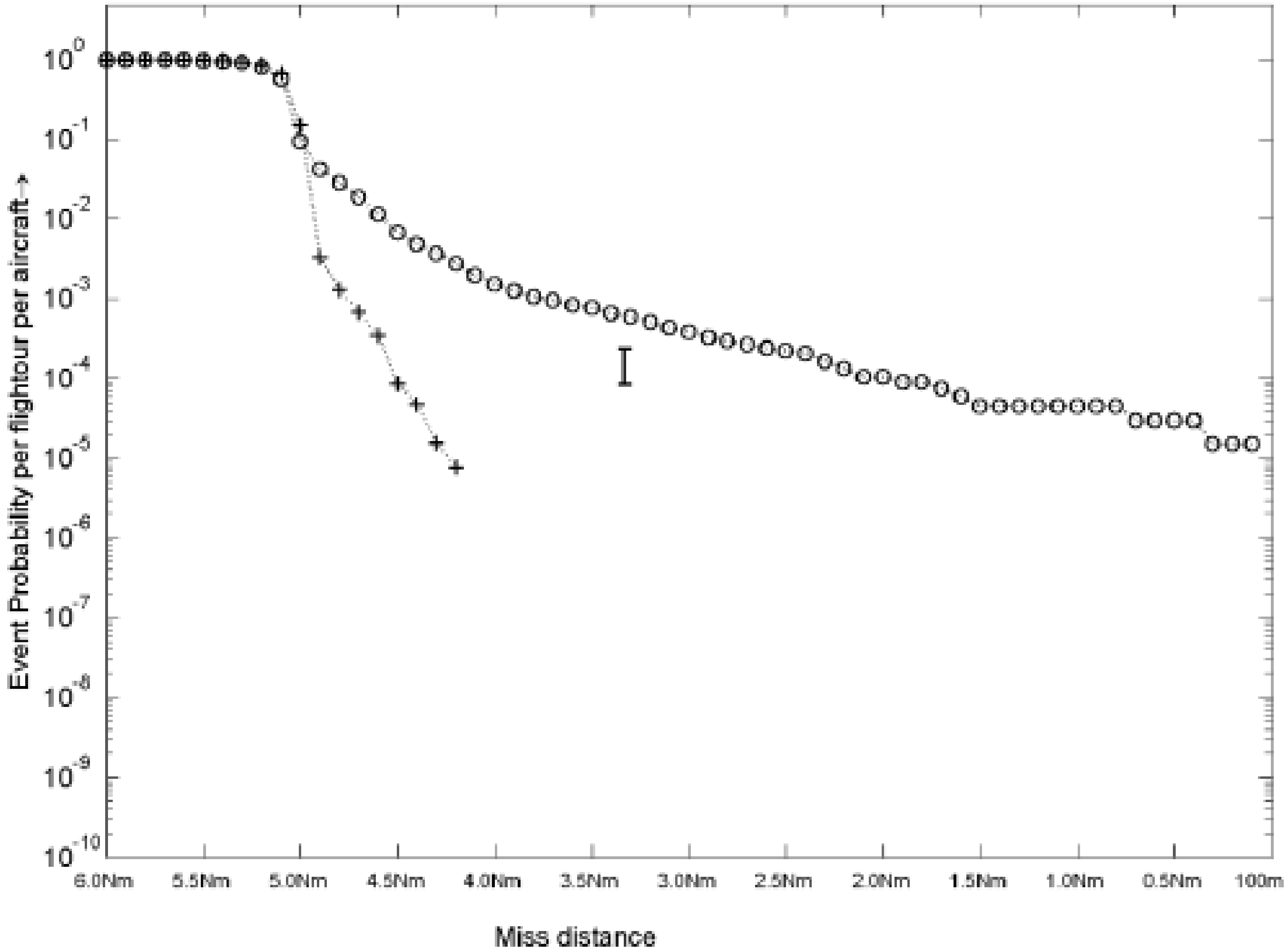


- Periodic Boundary Condition
- Eight a/c per packed box/ no climbing or descending a/c
- Vary container size in order to simulate:
  - 3x as dense as high density area in 2005
  - 6x and 9x as dense as high density area in 2005

A3 performance on 3x high 2005 random traffic Wind prediction errors of 0, 10, 20, 30 m/s



What happens when RBT's are not broadcasted?



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Ground-based versions of A3

- 2013: Development of ground-based TBO model (A3G) which imitates the well-working airborne TBO model (A3).
- 2014: Rare event Monte Carlo (MC) simulations show disappointing non-nominal performance by A3G.
- 2015: Independent design team use the feedback from these simulations to develop an improved A3G (iA3G).

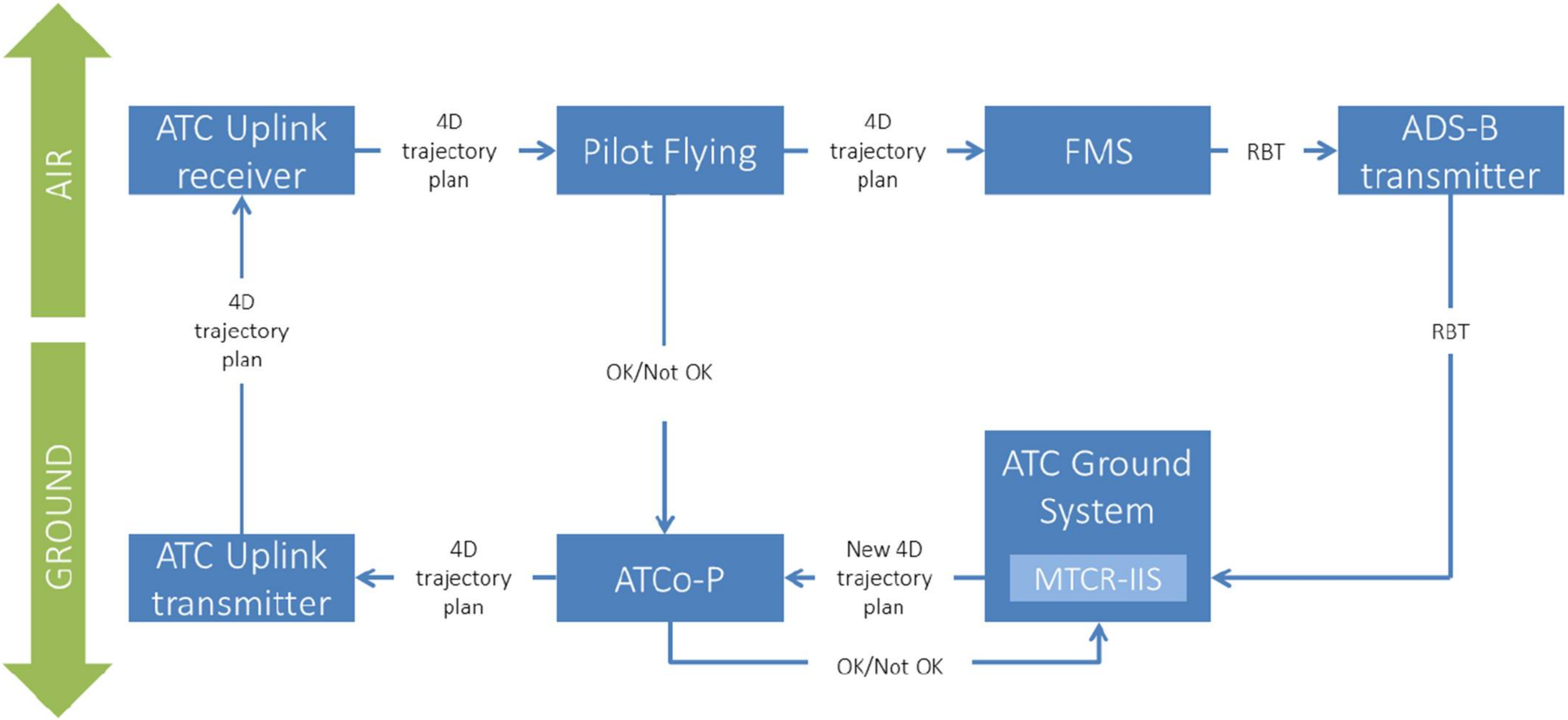
TBO layer iA3G improvements over A3G

1. Re-introducing a spacing buffer between the minimum distance between 4D plans and the horizontal separation minimum of 5 Nm;

2. Prior to involving the air traffic controller (ATCo) and pilots, the ATC system completes the iteration of MTCR's for all aircraft involved: MTCR-Internal Iteration System (MTCR-IIS)

3. Uplinking of resolution instructions is done according to a time-to-conflict prioritization criterion rather than A3G's First-In-First-Out principle.

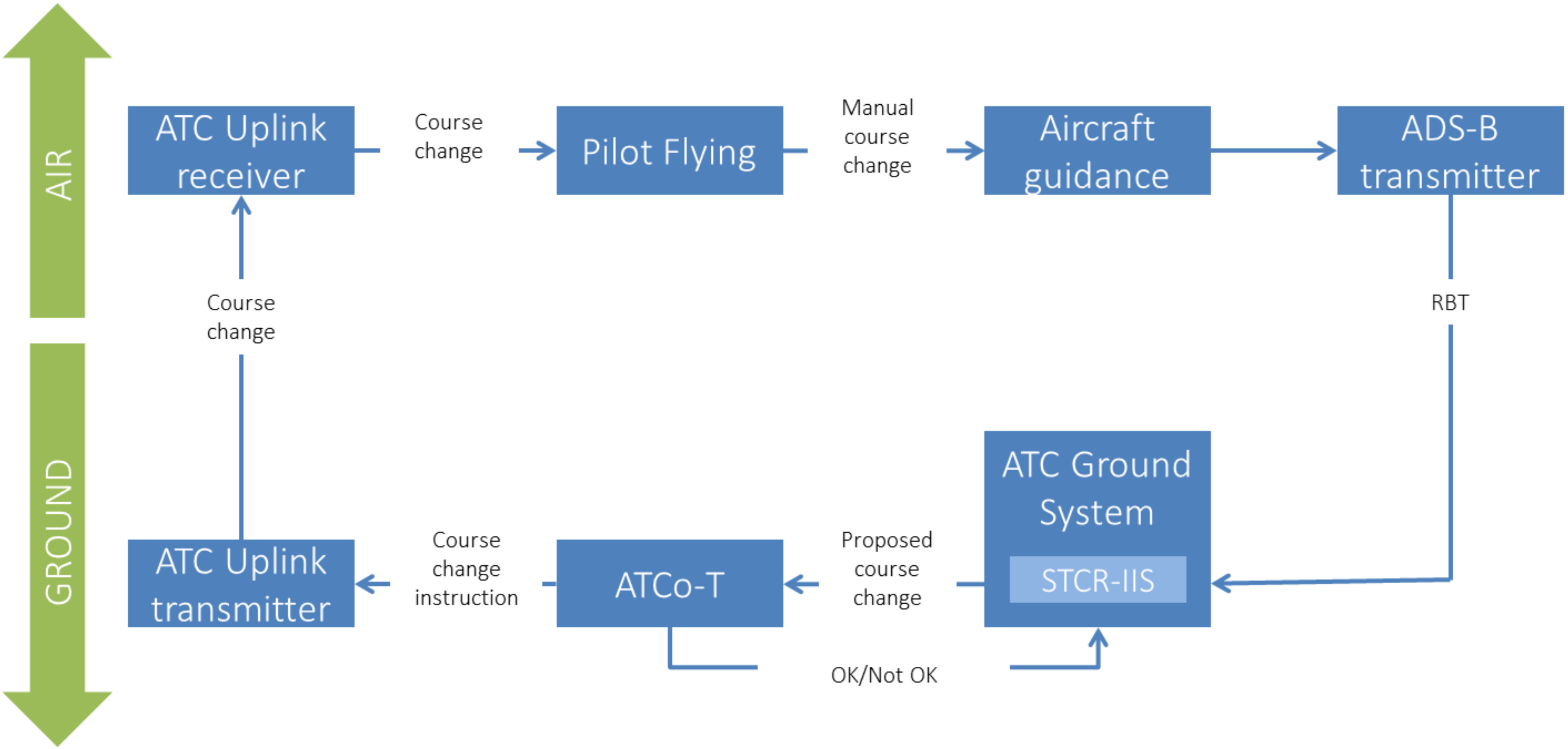
iA3G TBO control loop



Tactical layer iA3G improvements over A3G

1. The tactical ATCo is no longer in the direct loop of approving a tactical resolution proposal, as a result of which a tactical resolution by the ATC system is directly uplinked to the pilot;
2. Preventing that a tactical conflict resolution is opposite to a preceding tactical conflict resolution;
3. Short term conflict resolution algorithm on the ground will anticipate that the implementation of such tactical resolution will happen with some non-deterministic delay;
4. Uplinking of short term resolutions is done with higher priority than medium term resolutions, and according to a time-to-conflict prioritization criterion rather than A3G's First-In-First-Out principle;
5. Prior to uplinking a tactical resolution, the ATC system completes the iteration of STCR's for all aircraft involved: STCR Internal Iteration System (STCR-IIS)

iA3G Tactical control loop



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Agents in the iA3G agent-based model

For each aircraft i, with i = 1,..,N:

- Aircraft-i
- a/c-i’s Guidance, Navigation and Control (GNC)
- Pilot-Flying-i
- Pilot-Not-Flying-i

For the ATC system:

- ATC ground system
- MTCR-IIS within ATC ground system
- STCR-IIS within ATC ground system
- Air Traffic Controller (ATCo)
- Global Communication, Navigation & Surveillance systems

Total number of agents: 4N+5

Total number of entities: 46N+17

Tuning of iA3G parameter values

iA3G agent-based model parameters:

- Total: 164
- Varied within EMERGIA: 43

Strategy in Parameter value tuning:

1. Adopt parameter values from A3 model and known ATC system values
2. Evaluate performance of novel model on multi-aircraft encounters
3. Thighten parameter values until novel model performs similar to A3 model
4. For each thightened novel model value find out how much it can be relaxed
5. Test if the combination of relaxed novel model values performs as A3 model
6. If OK, then this defines the set of novel baseline model parameter values
7. Sensitivity analysis is done relative to novel baseline model parameter values

iA3G parameter tuning → requirements

P#	Key model parameter	Baseline
P0	ANP / Separation / Resolution minima	1/5/6 Nm
P1	GNSS receiver failure prob.	1.0E-7
P2	ADS-B transmitter failure prob.	1.0E-8
P3	ATC Ground system failure prob.	1.0E-7
P4	ADS-B ground receiver failure prob.	1.0E-7
P5	Uplink or ADS-B frequencies occupied	1.0E-7
P6	ATCo-T maximum response time	1 s
P7	ATCo-P maximum response time	30 s
P8	ATC uplink transmitter sending duration	1 s
P9	Pilot mean response time	5.7 s

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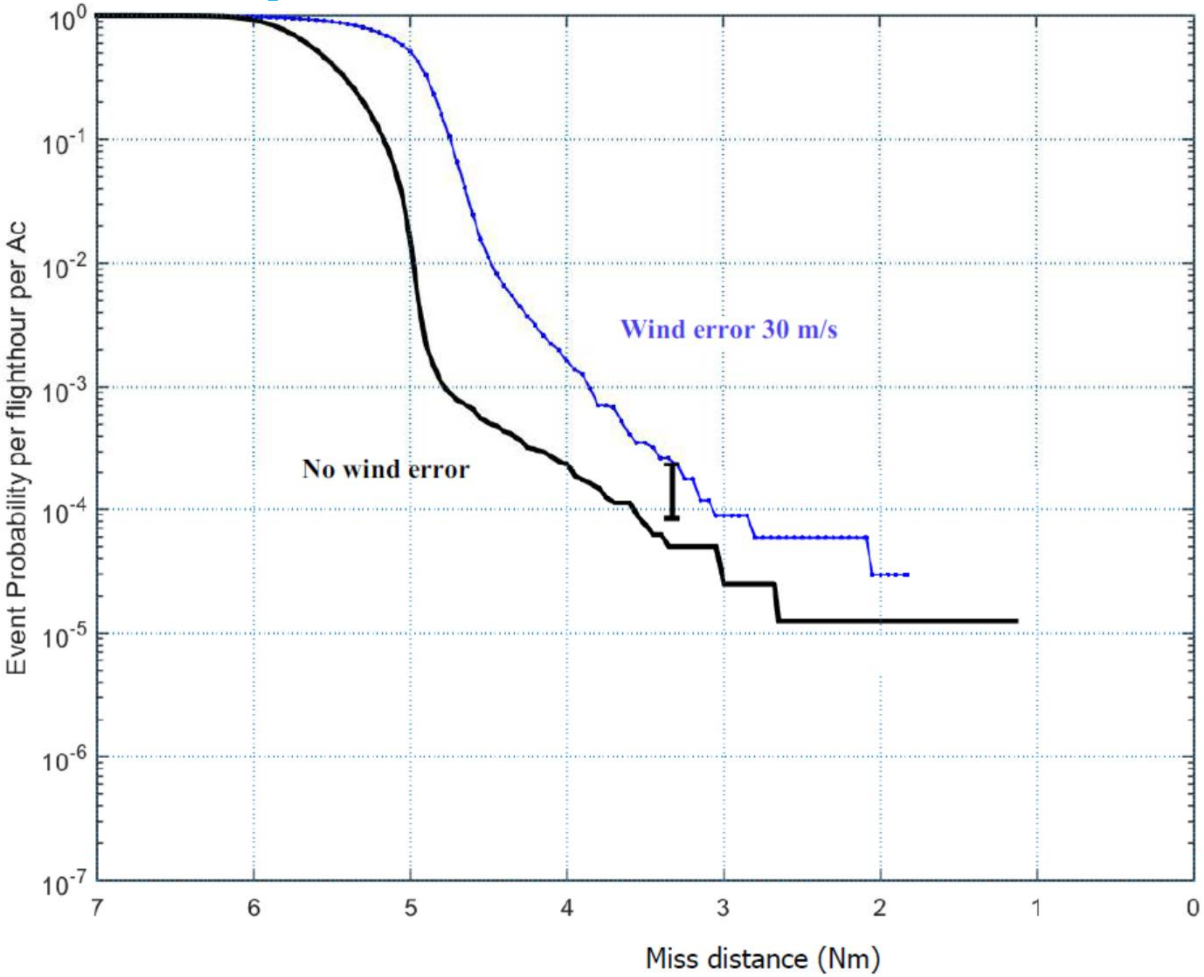
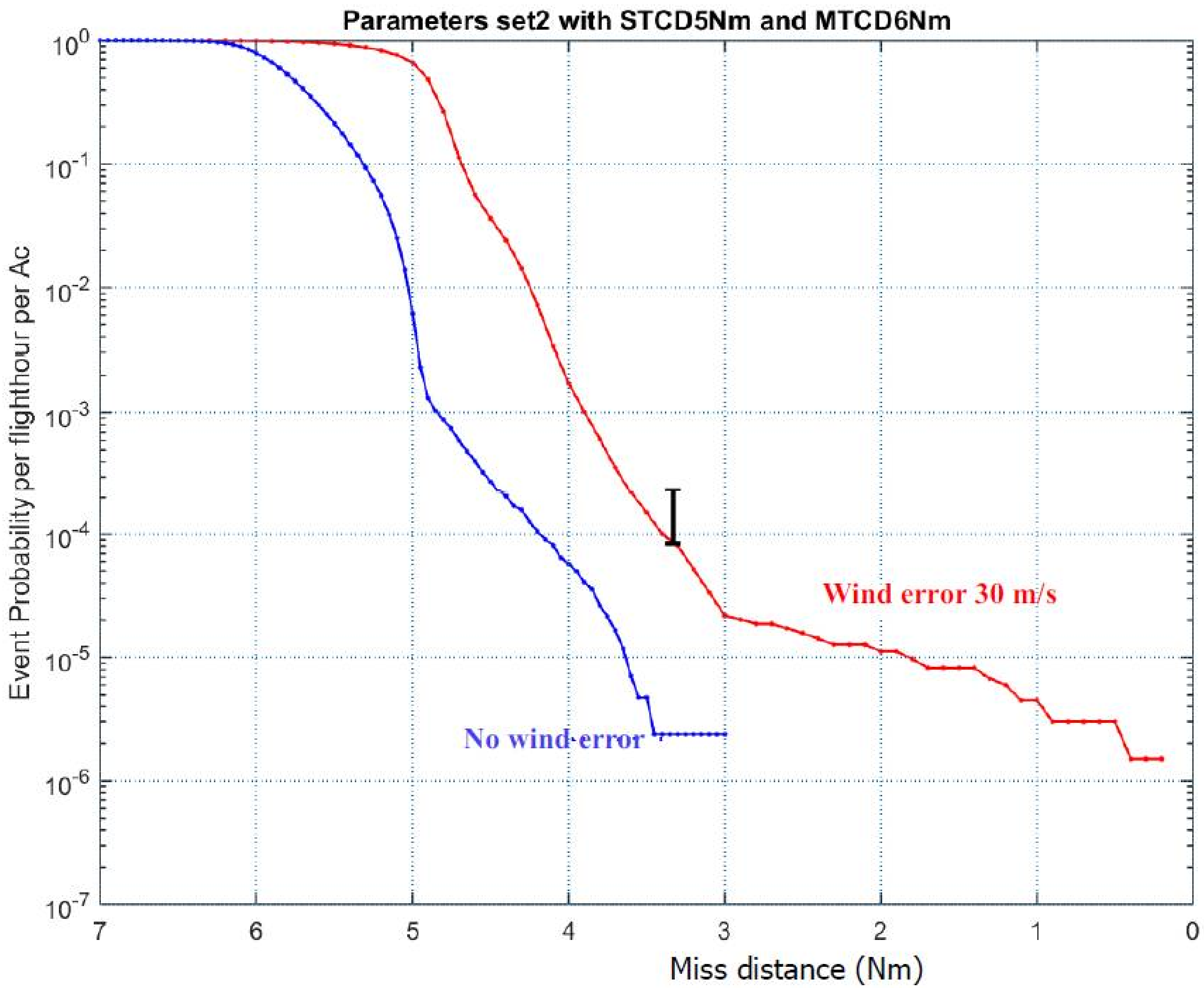


Additional tuning

- The value of the MTCR used horizontal separation minimum is increased from 5Nm to 6 Nm;
- The waiting time until a repeat of short term conflict detection is shortened from 15 s to 5 s;
- The maximal turn of an aircraft is reduced from 90 degrees to 30 degrees;
- Time slacks in the ATC ground system are increased.

Effect of additional tuning on iA3G performance



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Conclusions 1/2

- iA3G Conops has been developed that performs nominally similarly well as A3 ConOps does

- iA3G has less good non-nominal emergent behaviours:
  - Collaboration between TBO and Tactical layers takes more time
  - iA3G needs buffer, i.e. resolution spacing **>** minimum separation
  - ATCo Taskload puts limit on traffic demand
  - iA3G system requirements are much higher than A3's

Conclusions 2/2

- iA3G ConOps differs significantly from SESAR2020+:
  - Scope: Traffic demand & Equippage
  - TBO layer: Time horizon & MTCR system supporting ATCo-P
  - Tactical layer: Time horizon & STCR system supporting Pilots

- iA3G model useful in studying several of the differences with SESAR2020+ by modifying parameter values such as traffic demand, time-horizons, ATCo-T in the loop.

- For other differences (e.g. aircraft equipage, climbing/ descending aircraft, conflict resolution algorithms) iA3G agent-based simulation model has to be changed.

Time for questions

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