Can ground-based separation accommodate very high en route traffic demand as well as advanced self-separation?

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Advanced Self-separation: A3 ConOps

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Aircraft plan conflict-free 4D trajectories

- Trajectory Based Operation (TBO)

Each a/c broadcasts its current 4D plan and its 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 the scope of this research

Medium Term CD&R approach

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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 approach

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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 Stochastic Model of A3 ConOps

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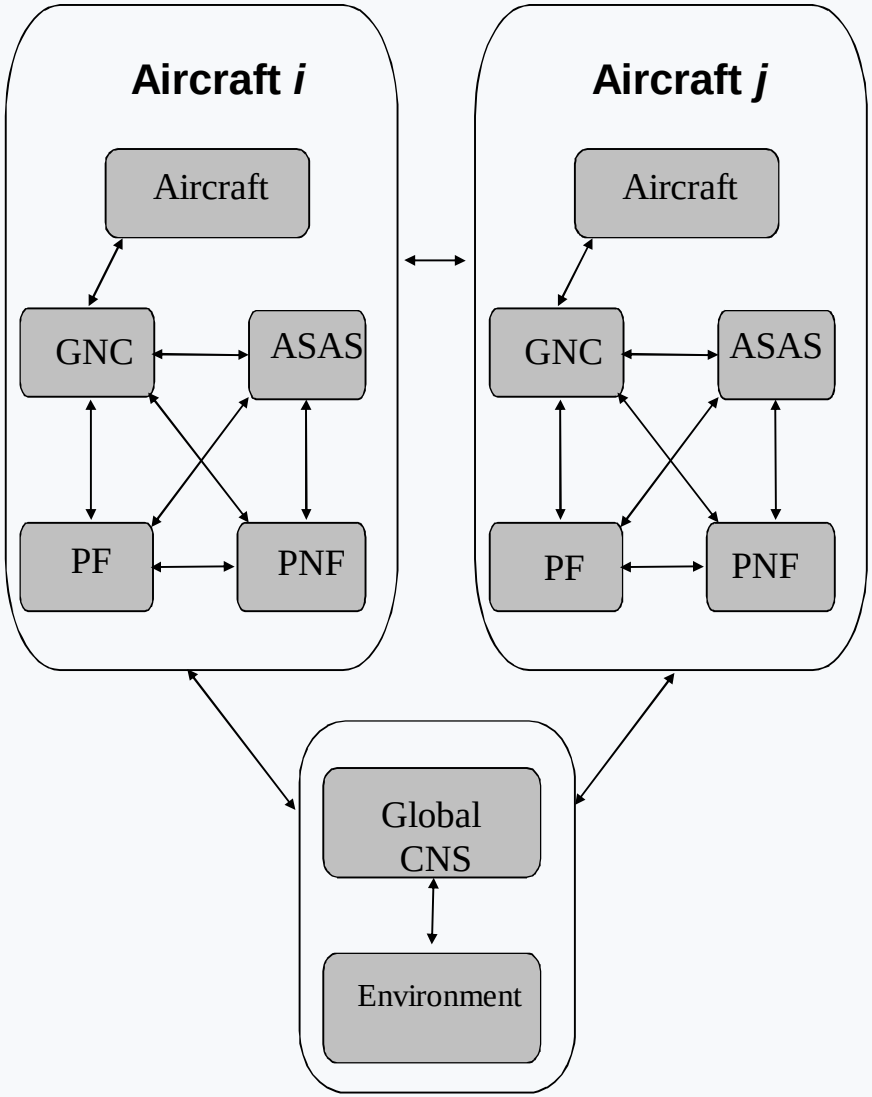

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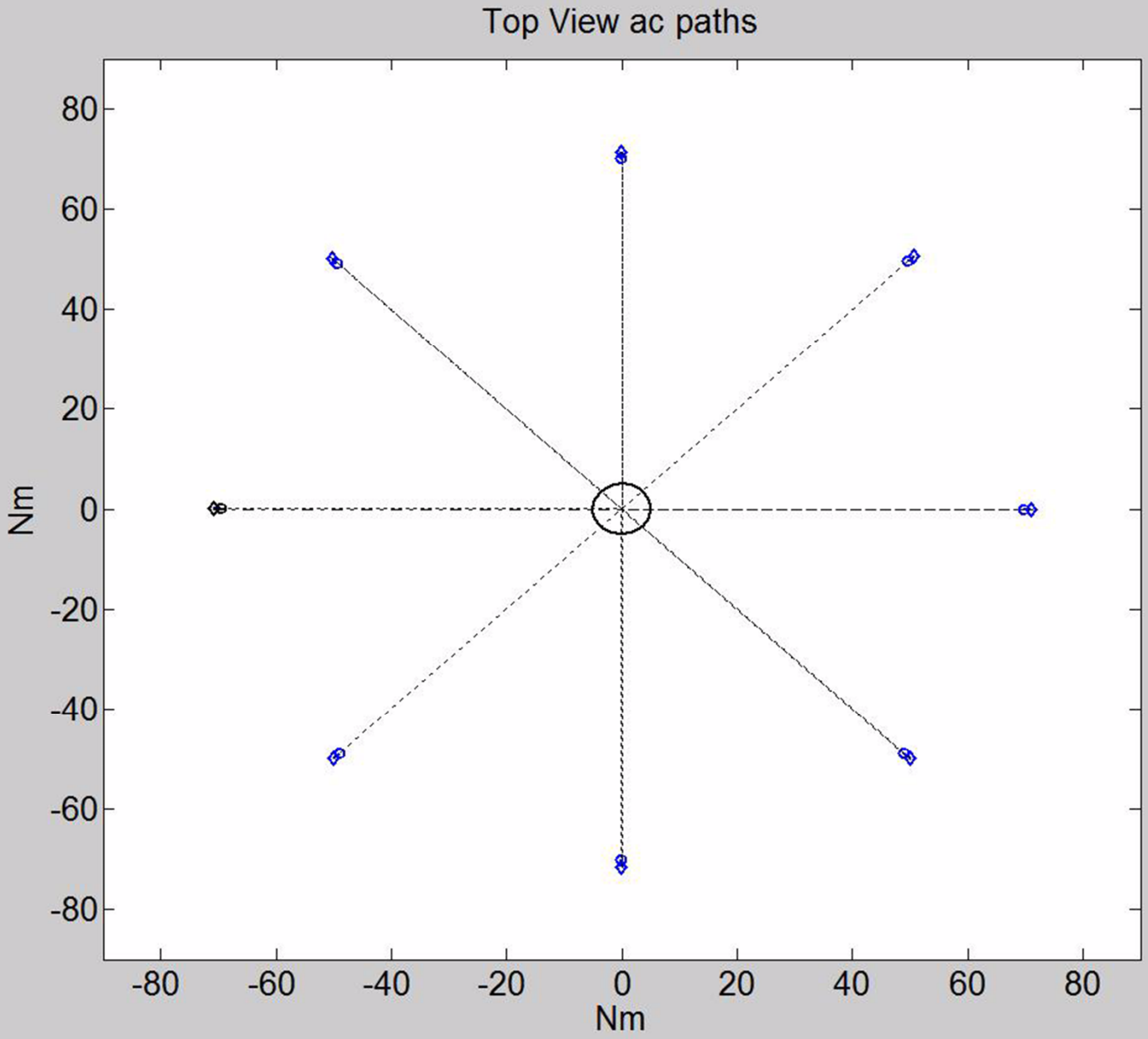
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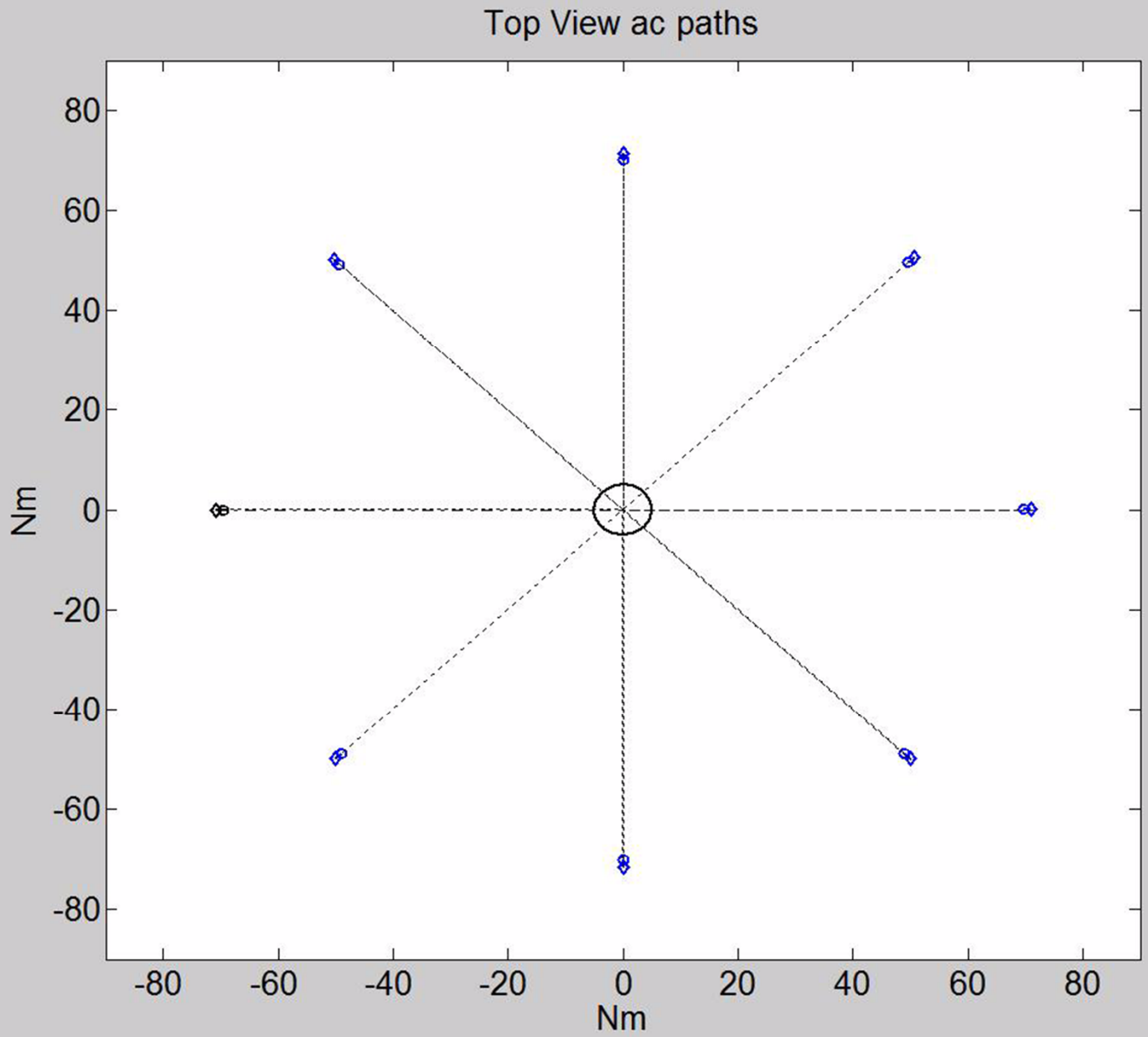
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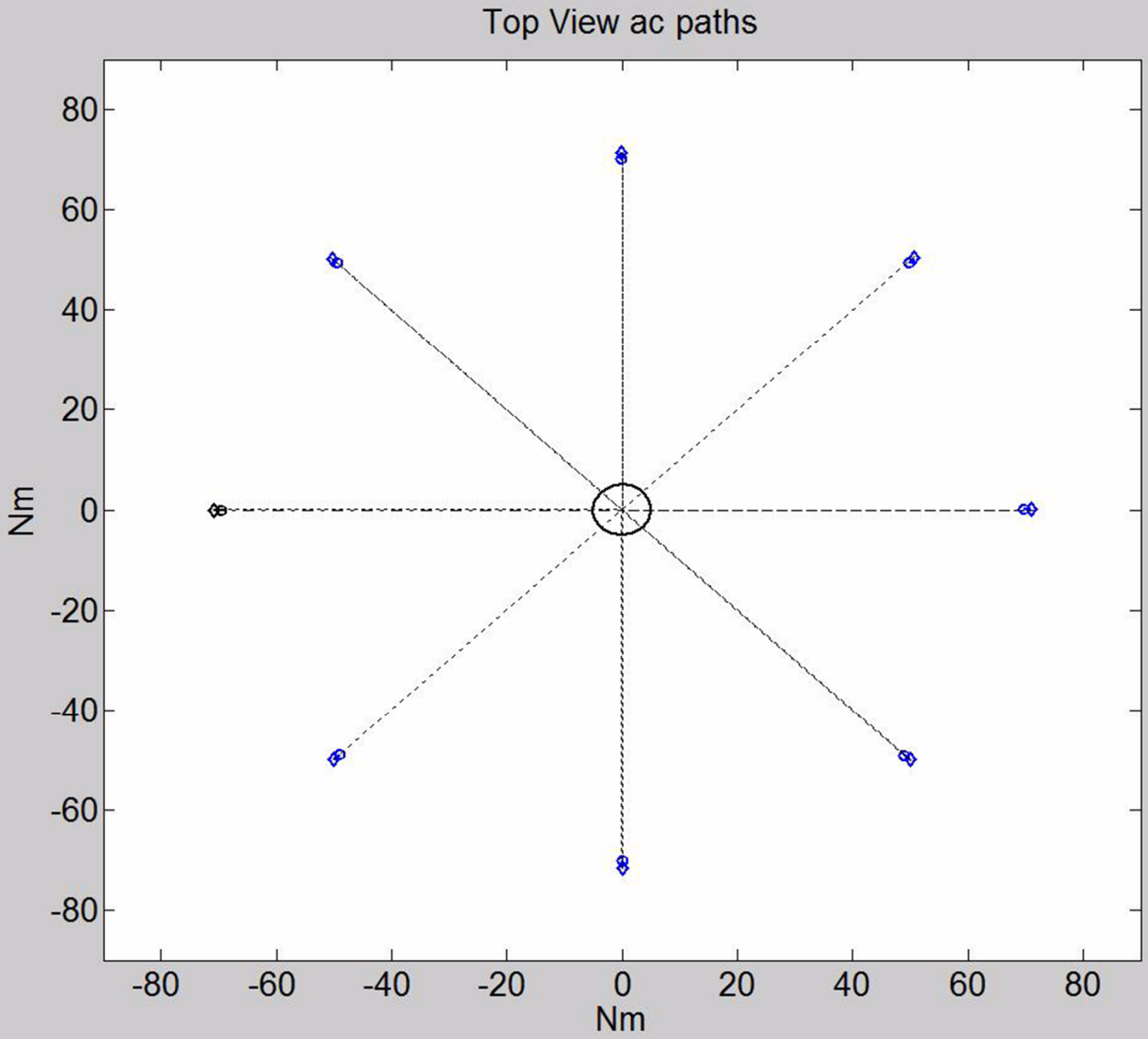
Run #3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Random Traffic Scenarios

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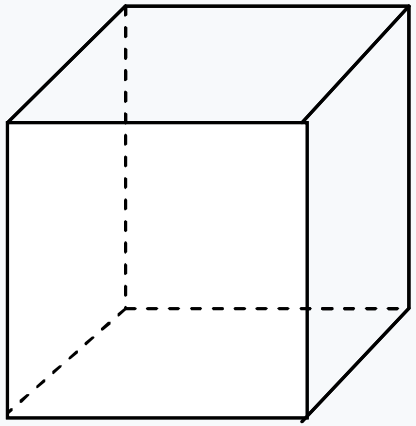

Periodic Boundary Condition

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 as dense as high density area in 2005

3x high 2005 random traffic

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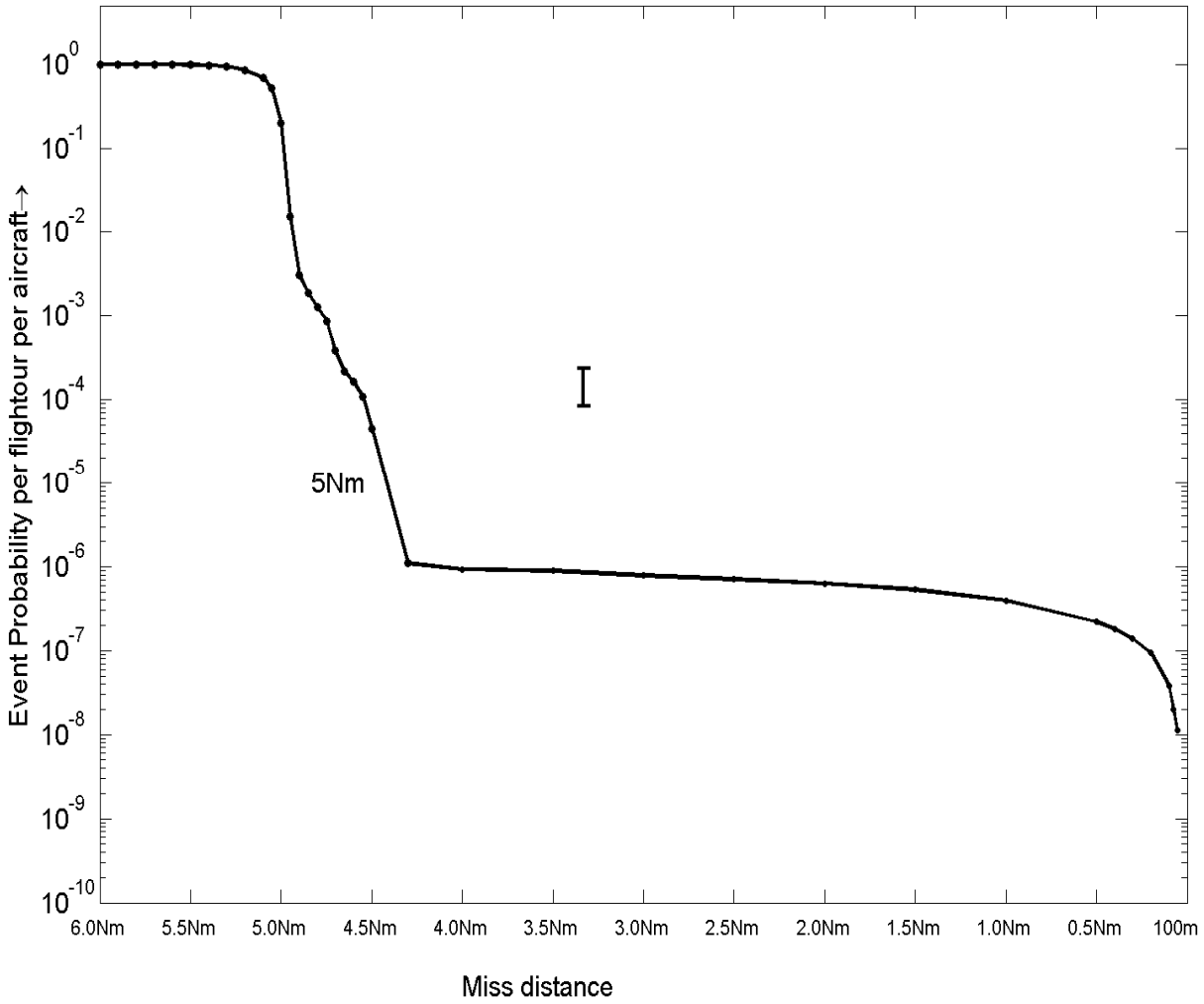

3x high 2005 traffic + systematic wind error

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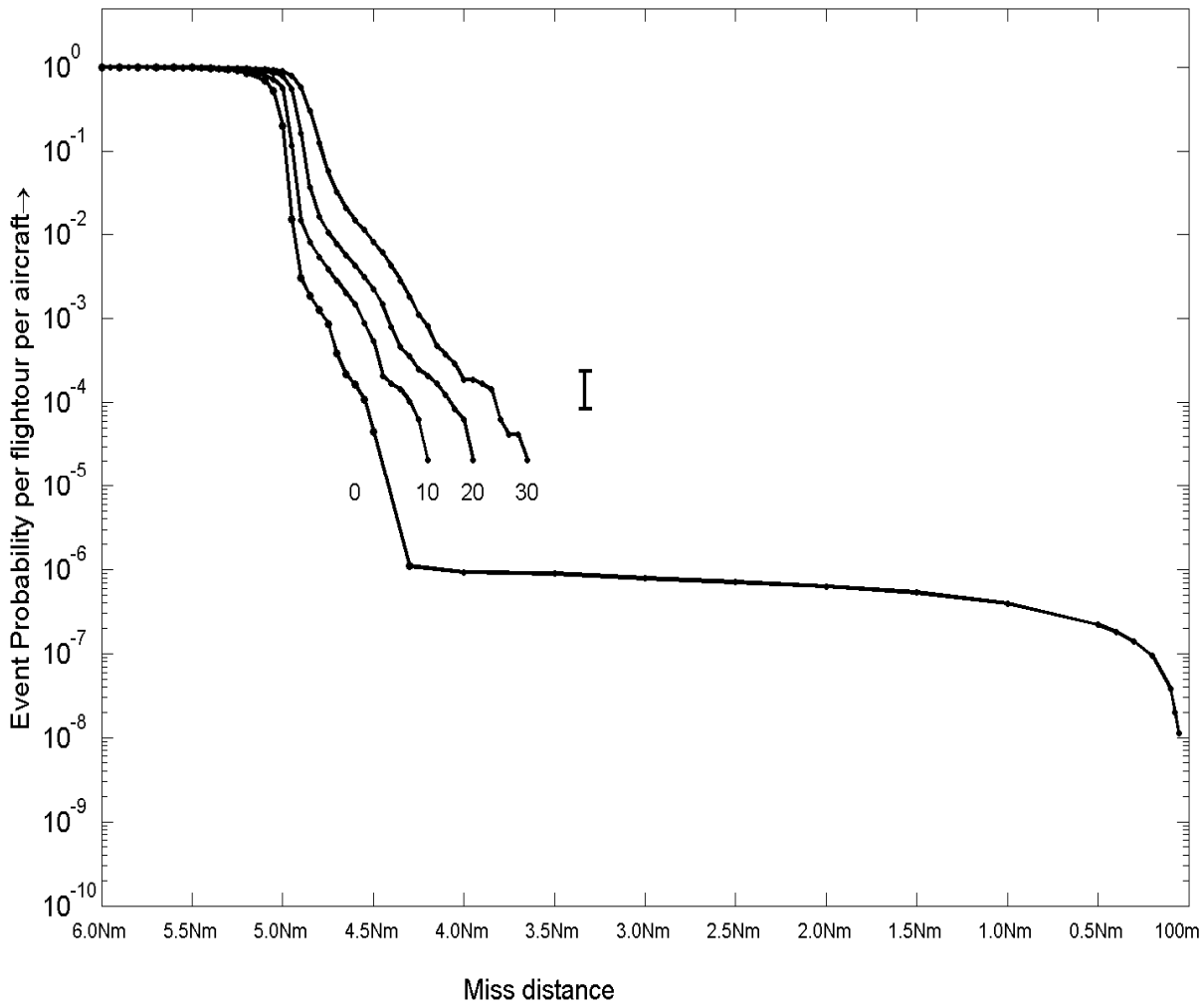

What happens when RBT's are not broadcasted?

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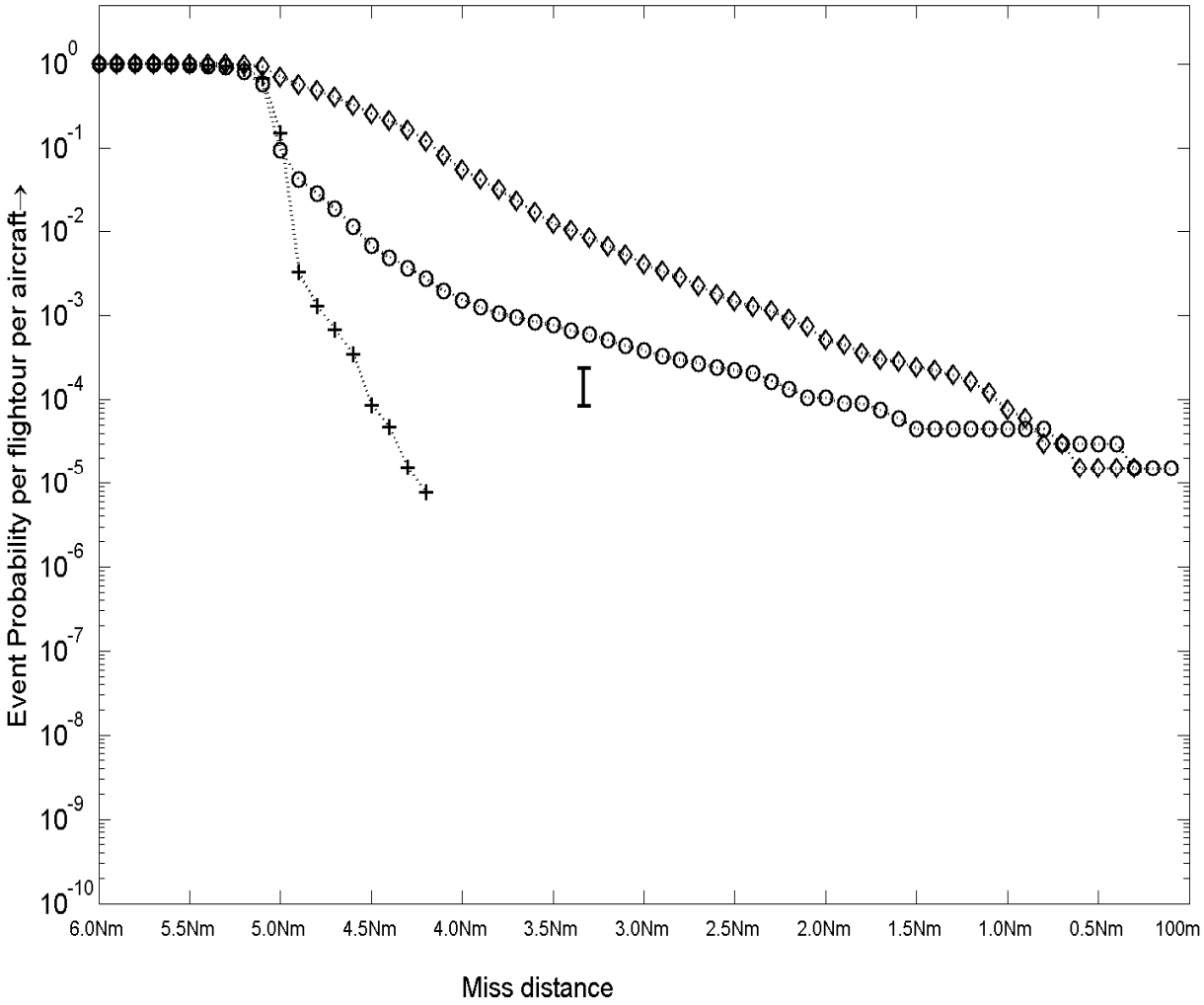

Positive Emergent Behaviours identified for the A3 ConOps

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1. A proper tactical conflict detection and resolution layer makes it possible for the pilot to resolve tactical situations under which its 4D plan has lost the conflict-free quality.
2. There appears to be no need to keep centerlines of conflict-free 4D plans further away from each other than the tactical separation minimum.
3. In addition to safely accommodating 3x busy en-route 2005 traffic demand, above this level no phase transitions: flight efficiency deteriorates in a gradual way.

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A³G ConOps: Ground based version of A³ ConOps

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The A³G Concept of Operations (Conops):

En-route Trajectory Based Operation controlled from ground-based Air Traffic Centre (ATC)

Each aircraft flies according 4D trajectory plan:

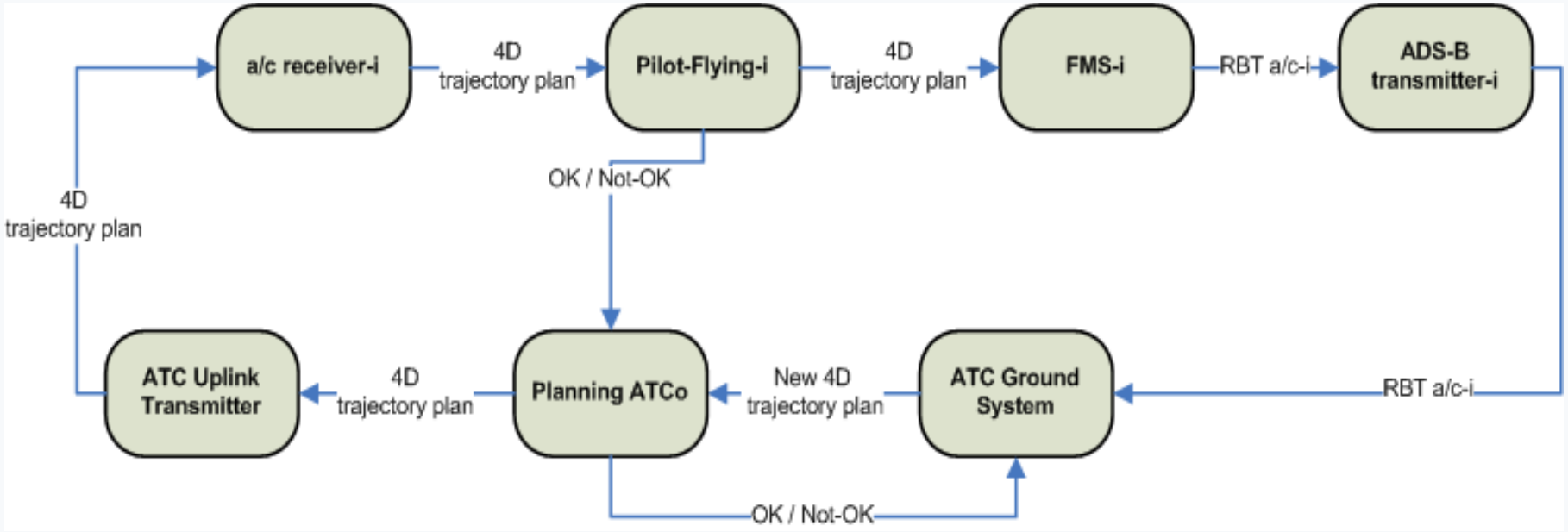
4D trajectory plans are generated and instructed by ATC

ATC ground detects and resolves conflicts:

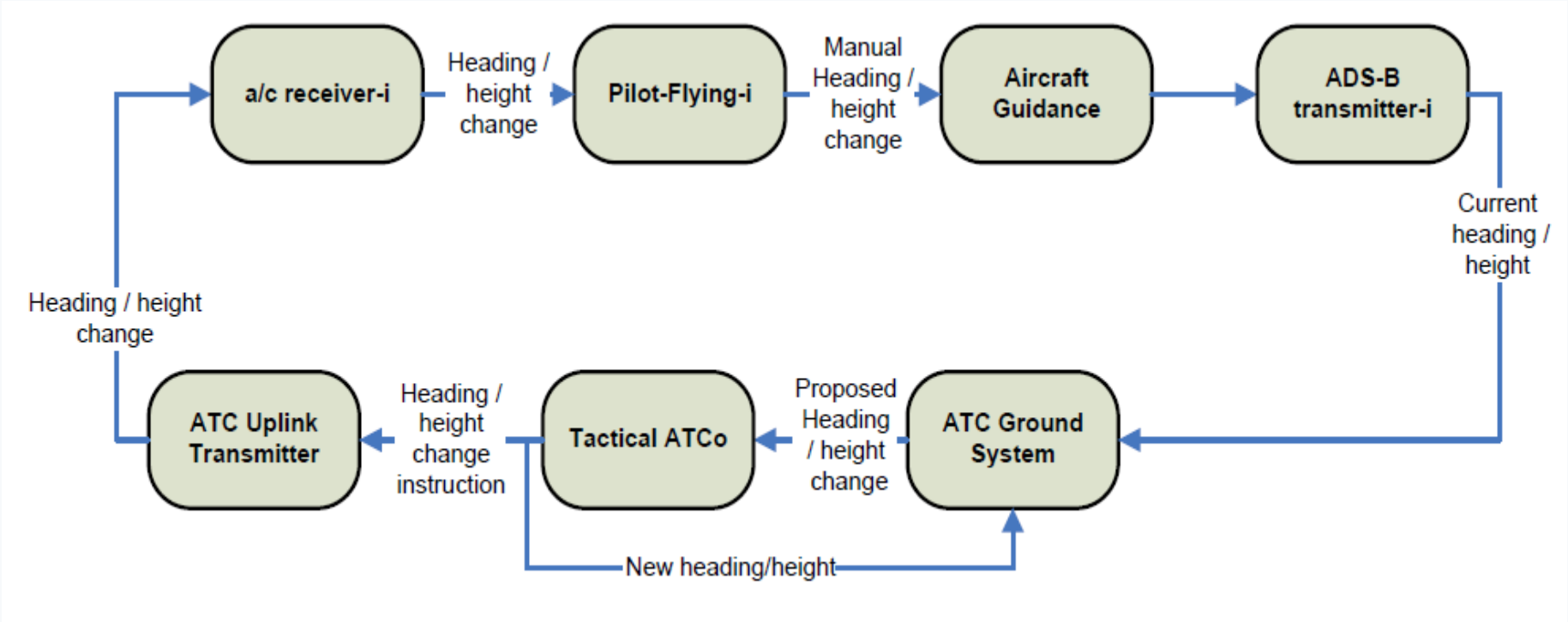
- Between 4D trajectory plan
- Tactical conflict resolutions (using 4D pplan and state information)

Each aircraft broadcasts 4D plan that is active in its FMS

A³G ConOps MTC resolution process



A³G ConOps STC resolution process



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A^3G model assumptions have been taken from A^3 model

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A0. All aircraft fly on the same altitude

A1. All aircraft are identical and have the same speed

A2. No emergency situations considered

A3. ATC works without SSR or Primary Radar, i.e. ADS-B/C only

A4. ATC considers an FMS-unconfirmed 4D plan unreliable

A5. No ground based navigation support, i.e. GNSS/IRS only

A6. Reliability and availability of ground system equal to ASAS

A7. Mean duration of global uplink being down is 1 hour

A^3 model versus A^3G model for 2 opposite a/c encounters (both using their baseline parameter values)

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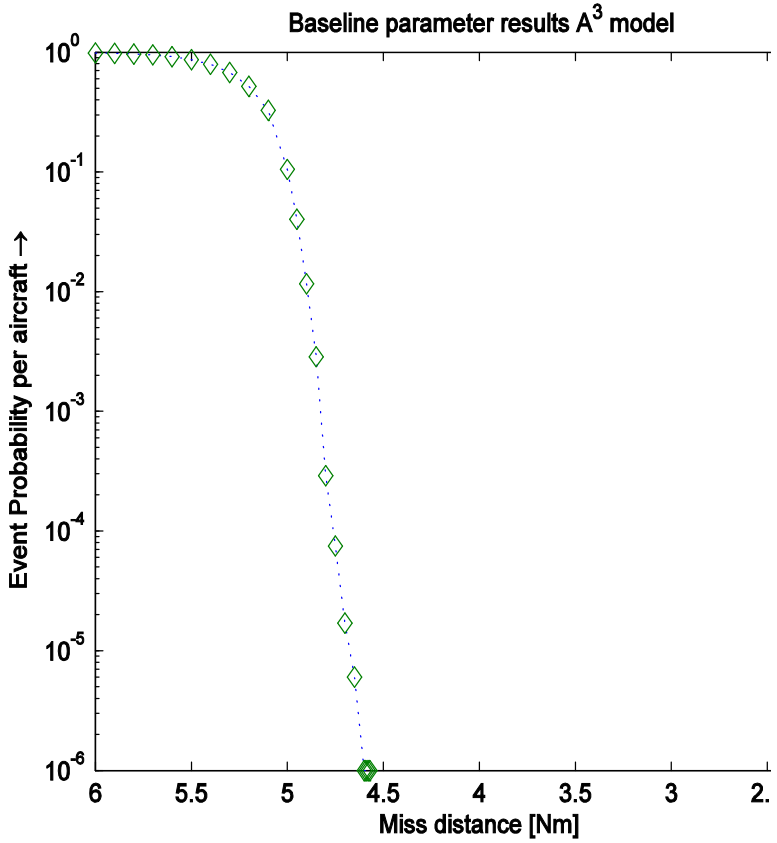
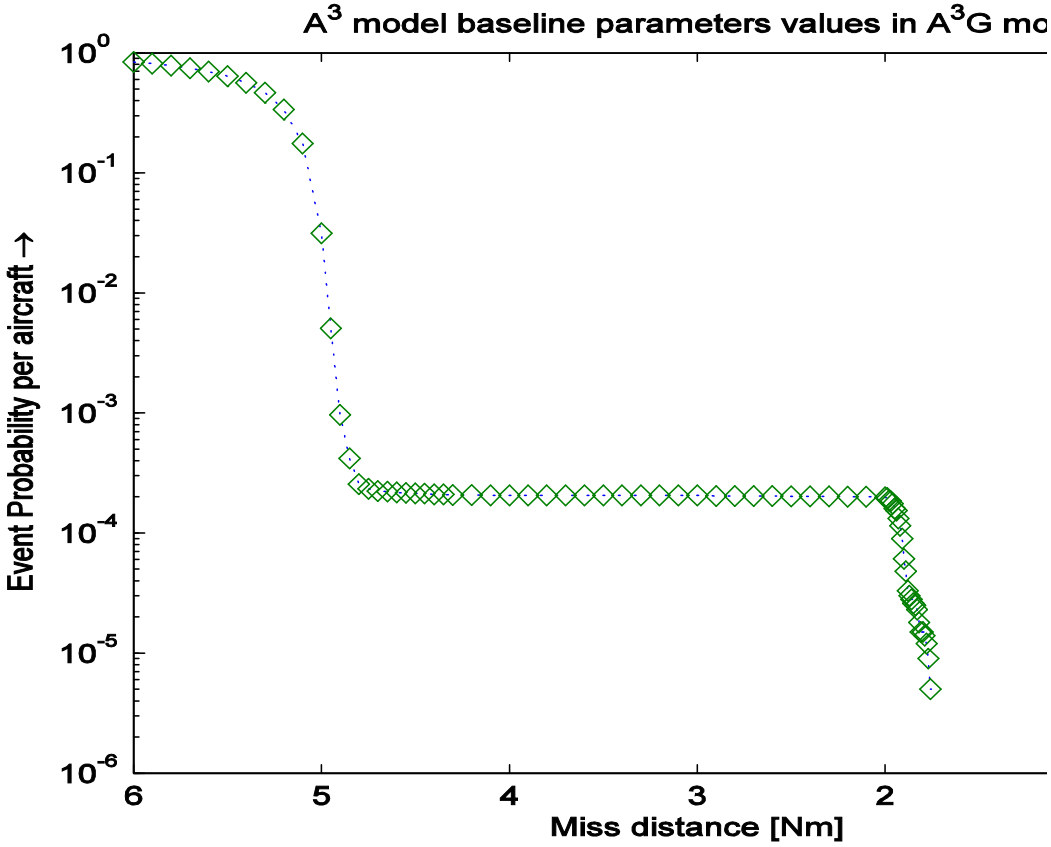
A^3 model results



A^3G model results



By improving its parameter values, the A³G Model can produce the same results as the A³ Model for 2a/c

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Parameter	Effect	Due
Airborne GNSS receiver failure	Significant	A5
ADS-B transmitter failure	Large	A4
ATC ground system mode failure	Large	A6
ADS-B ground receiver failure	Large	A3
Global ATC Uplink occupied	Large	A7
ATCo Planning response time	Negligible	-
ATCo Tactical response time	Significant	-
Uplink transmitter sending duration	Large	-

Why is the uplink delay so critical ?

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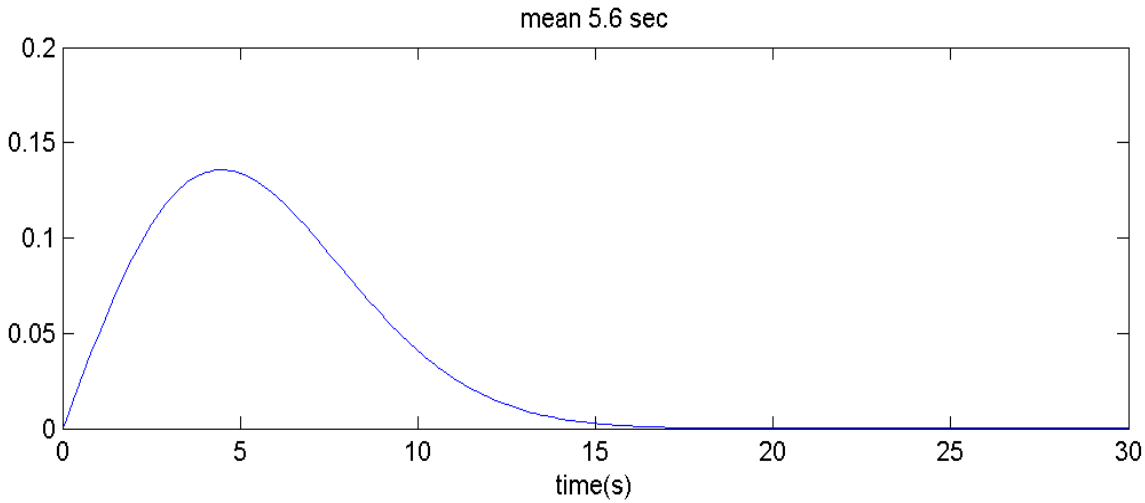
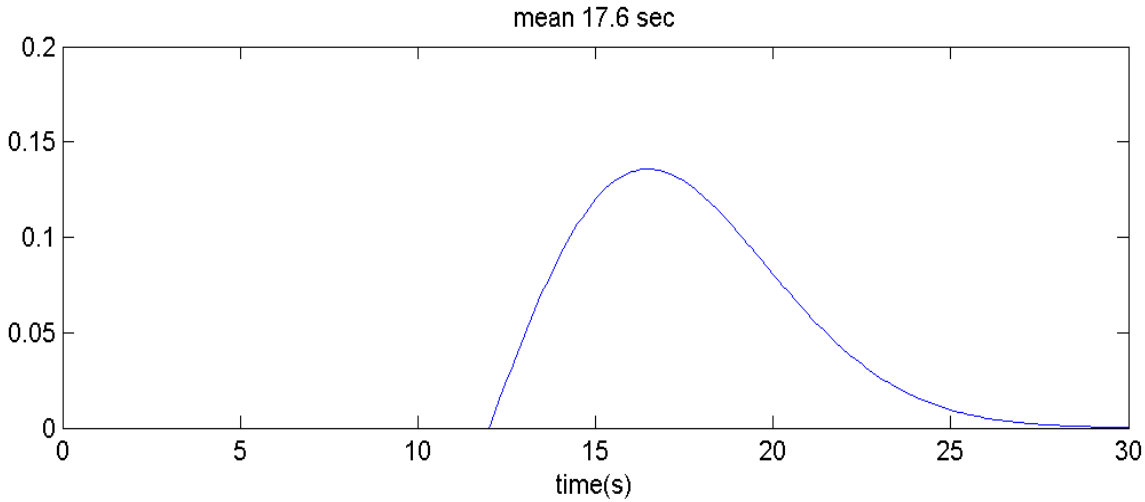
Pilot delay:
Rayleigh density

Mean delay: 5.6 s



Pilot + Uplink delay
Shifted Rayleigh density

Mean delay: 5.6 s + uplink delay



What happens in the tail of the latter density ?

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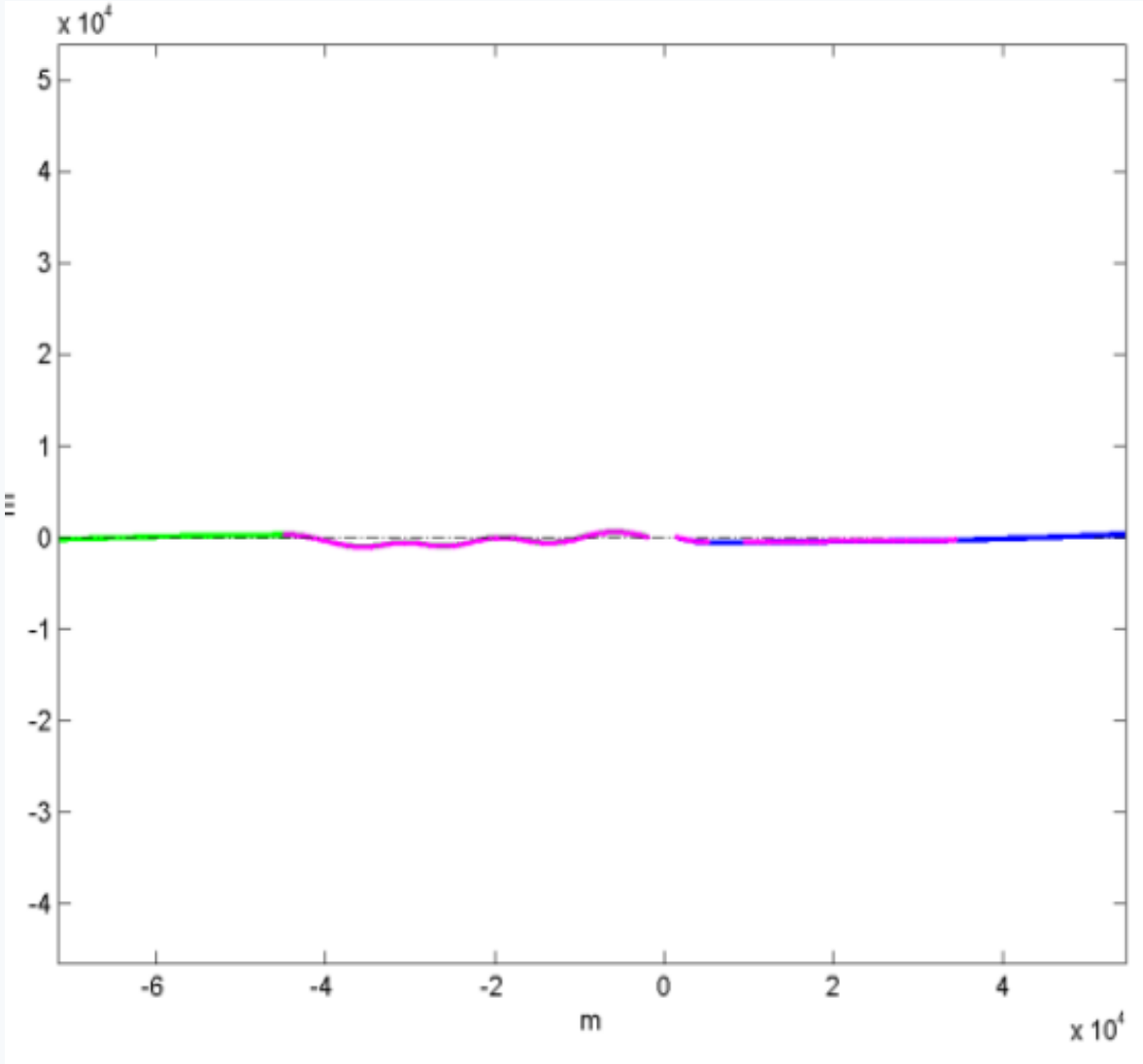
Once per 5000 encounters of 2 a/c:

Too much delay between ATCo STCR decision and Pilot implementation

Hence a/c deviates too much from 4D plan; which triggers new STCR activity, etc.



A³G problems further deteriorate for 8a/c encounters

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Very challenging parameter value requirements:

- **ATCo-Planning very fast response (1 second)**
- **ATCo-Tactical very fast response (1 second)**
- **Uplink transmitter small delay (1 second)**
- **Pilot very fast response (1 second)**

These are not practically realizable values !

Hence the evaluated A3G model is not a practically feasible option.

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Conclusions

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- For the A^{3}G model it appears possible (in theory) to produce similarly positive emergent behaviours as the A^3 model does.
- However this theoretical solution asks for parameter values that are practically unrealistic.

Follow-up:

- ATM ConOps design experts have identified practically feasible ways to improve the A^{3}G ConOps
  - EMERGIA report D3.1 on http://emergia.nlr.nl
- Agent-based modelling and rare event MC simulation of an improved A3G model.

Questions ?

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