Strategic planning in ATM with a stochastic anytime approach

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INTRODUCTION

- Higher levels of automation in ATM a fundamental challenge of SESAR [SesarJU May 12]
  - Increasing Air Traffic
  - Economics
- Conflict resolution problem is still open
  - NP-hard
  - Curse of dimensionality
- A cooperative trajectory de-confliction algorithm is proposed
  - Uses PSO
  - Can be applied in pre-departure and flight execution phase

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- Introduction
- **Problem Formulation and Objectives**
- Test battery design
- Algorithm Description
- Simulation and Experiments
- Conclusions and Future work

PROBLEM FORMULATION AND OBJECTIVES

- Multiple Aircrafts in a common 2D airspace
- Safety areas centered in the AVs cannot overlap
- Inputs of the system:
  - Sequence of waypoints for each AV to follow
  - Parameters of the model of each AV
- New AV trajectories → addition of intermediate waypoints

- Objectives
  - Detect potential collisions
  - Compute collision-free trajectories while minimizing the trajectory changes of each UAV

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Test Battery Design

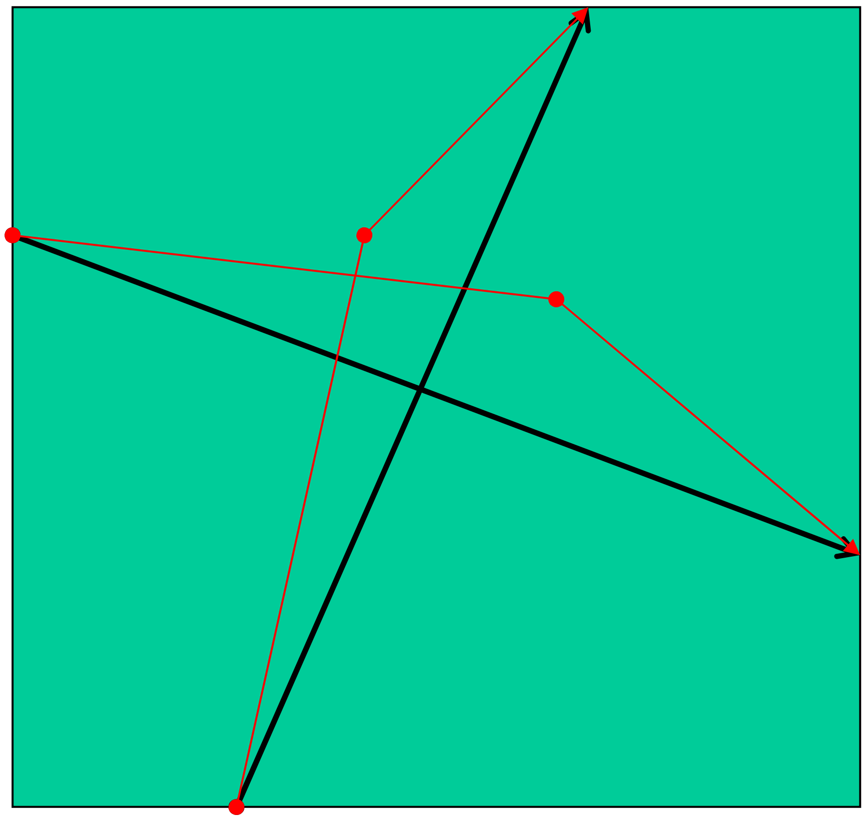
- No standard benchmark methods exist in literature
- Algorithms have to be tested in as many situations as possible

- Test battery generator designed
  - Random
  - With a configurable number of UAVs in the system
  - Scenario of 50kmx50km considered

Test Battery Design (II)

```
1. For each test
2.    While the test is not valid
3.       For each UAV
4.          Choose a random entry face
5.          Choose a random exit face from the resting 3
6.          Choose entry and exit points from the
            corresponding entry and exit faces
7.          Add M random intermediate waypoints
8.          Check for the plan validity
9.       end for
10.   end while
11.end for
```

Test Battery Design (III)



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Replanning Algorithm

- Characteristics
  - Particle Swarm Optimizer
    - Near-optimal
    - Evolutionary
  - Cost based

$$J = \sum_{i=1}^{N} L_i + \omega_c$$

Replanning Algorithm

- Characteristics
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$$J = \sum_{i=1}^{N} L_i + \omega_c$$

  - Best solution improves over the time
    - Can be stopped at any time and the current best solution will be returned
  - Each individual represents a new flight plan
    - Obtained adding waypoints
  - Drawbacks:
    - Intensive calls to two modules
      - Simulator
      - Collision Detector

ALGORITHM DESCRIPTION

Algorithm 1 Basic PSO algorithm

```
1.  for Each particle do
2.      Initialize particle position x_i with the desired probability function
3.      Initialize particle best position p_i ← x_i
4.      If f(p_i) < f(g) update the swarm best position g ← x_i
5.      Initialize the velocity vector v_i. An uniform distribution is usually used.
6.  end for
7.  repeat
8.      for Each particle do
9.          Pick random numbers r_g r_p with U(0,1)
10.         Update the particle's velocity:
            v_i ← ωv_i + φ_p r_p (p_i − x_i) + φ_g r_g (g − x_i)
11.         Update the particle's position: x_i ← x_i + v_i
12.         if f(x_i) < f(p_i) then
13.             Update the particle's best known position
14.             if f(x_i) < f(g) then
15.                 Update the swarm's best known position g ← x_i
16.             end if
17.         end if
18.     end for
19. until A termination criterion is met
```

Initialization (steps 1–6)

Iteration (steps 7–19)

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Velocity update

$$v_i \leftarrow \omega v_i + \phi_p r_p (p_i - x_i) + \phi_g r_g (g - x_i)$$

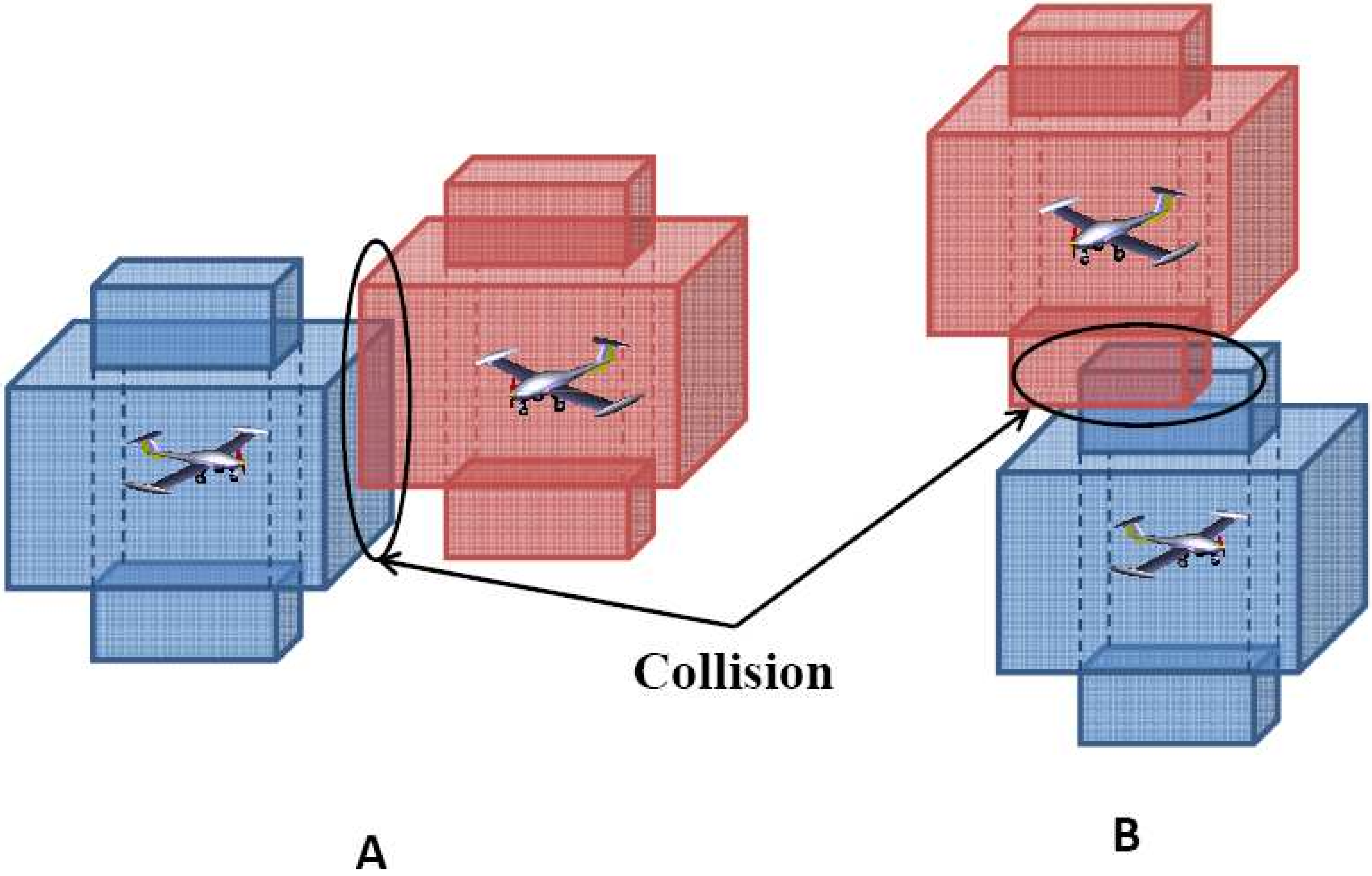
- Termination condition
  - Fixed number of iterations
  - Timeout conditions

CONFLICT DETECTOR

- Requirements
  - Simple: few parameters will describe the system
  - Fast
  - Accuracy is not very necessary

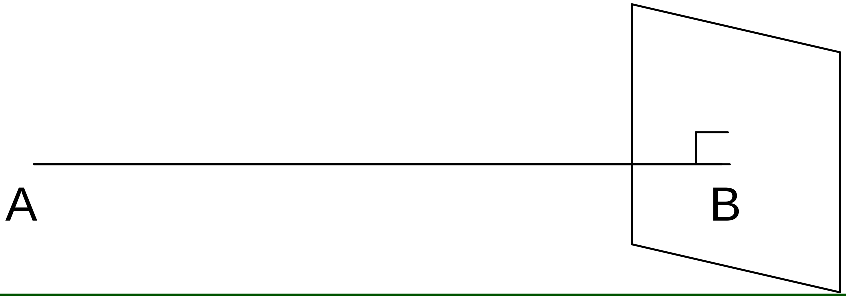
- Algorithm used
  - Minimum bounding boxes
  - System described as a set of boxes aligned with the coordinated axes
  - Six comparisons for each pair of boxes in the system

CONFLICT DETECTOR (II)



UAV MODEL

- Requirements
  - Simple as possible
  - Bounded estimation error
- Model used
  - Simple quadrotor model (Alejo et. al, 2009, Lymperopoulos et al, 2007, BADA Website)
- Waypoint tracker
  - Necessary
  - Identification is not trivial



AIRCRAFT MODEL

- Aircraft model → Simulation and evaluation of the generated trajectories
- Complex model can be used
  - BADA: Based of Aicraft DAta
  - I. Lymperopoulos, A. Lecchini, W. Glover, J. Maciejowski, and J. Lygeros, “A Stochastic Hybrid Model for Air Traffic Management Processes,” Univ. of Cambridge, U.K., Technical Report CUED/F-INFENG/TR.572, Feb. 2007
  - Simplified UAV models
  - Etc.
- Trade-off with the time of execution should be considered

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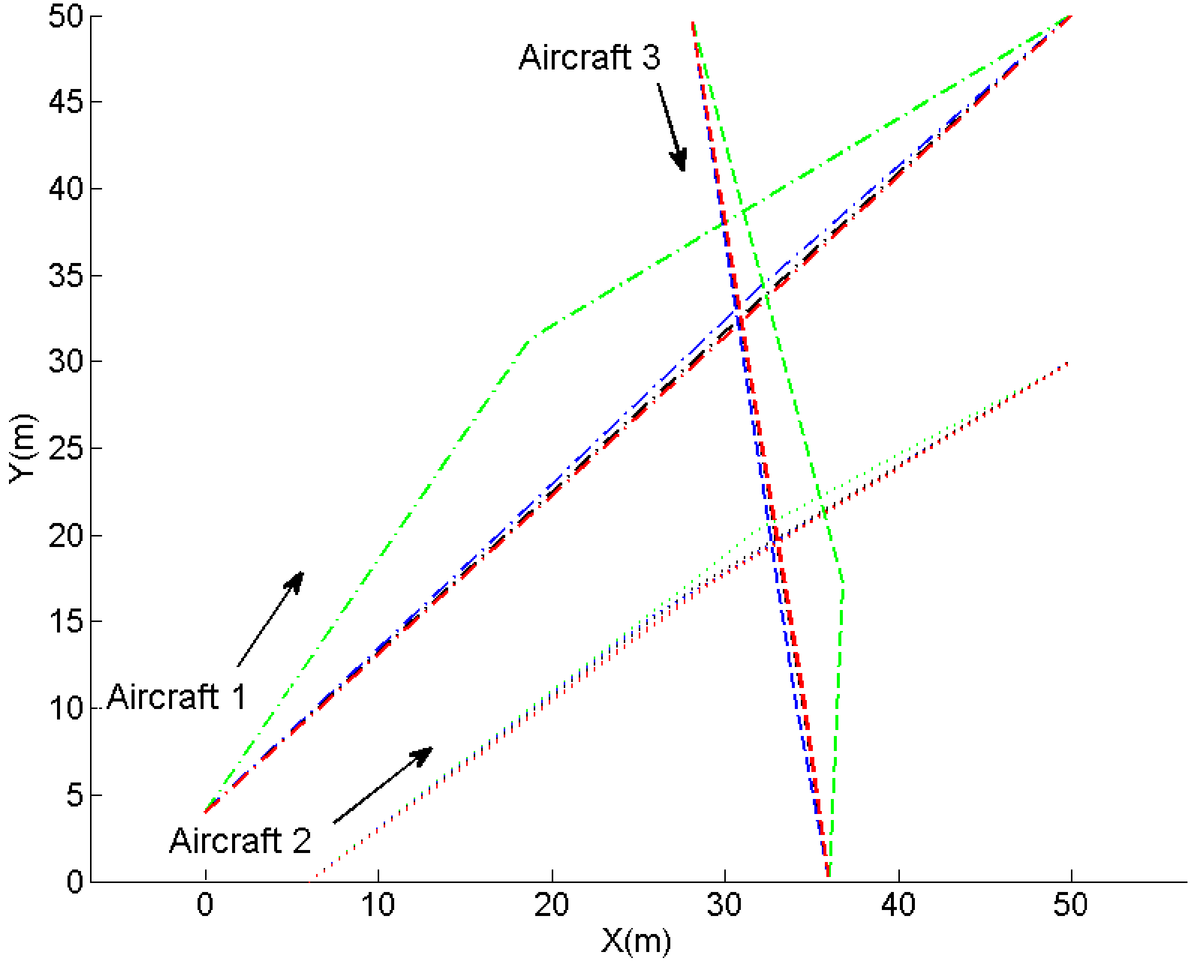
- **Simulations**
- Conclusions and Future work

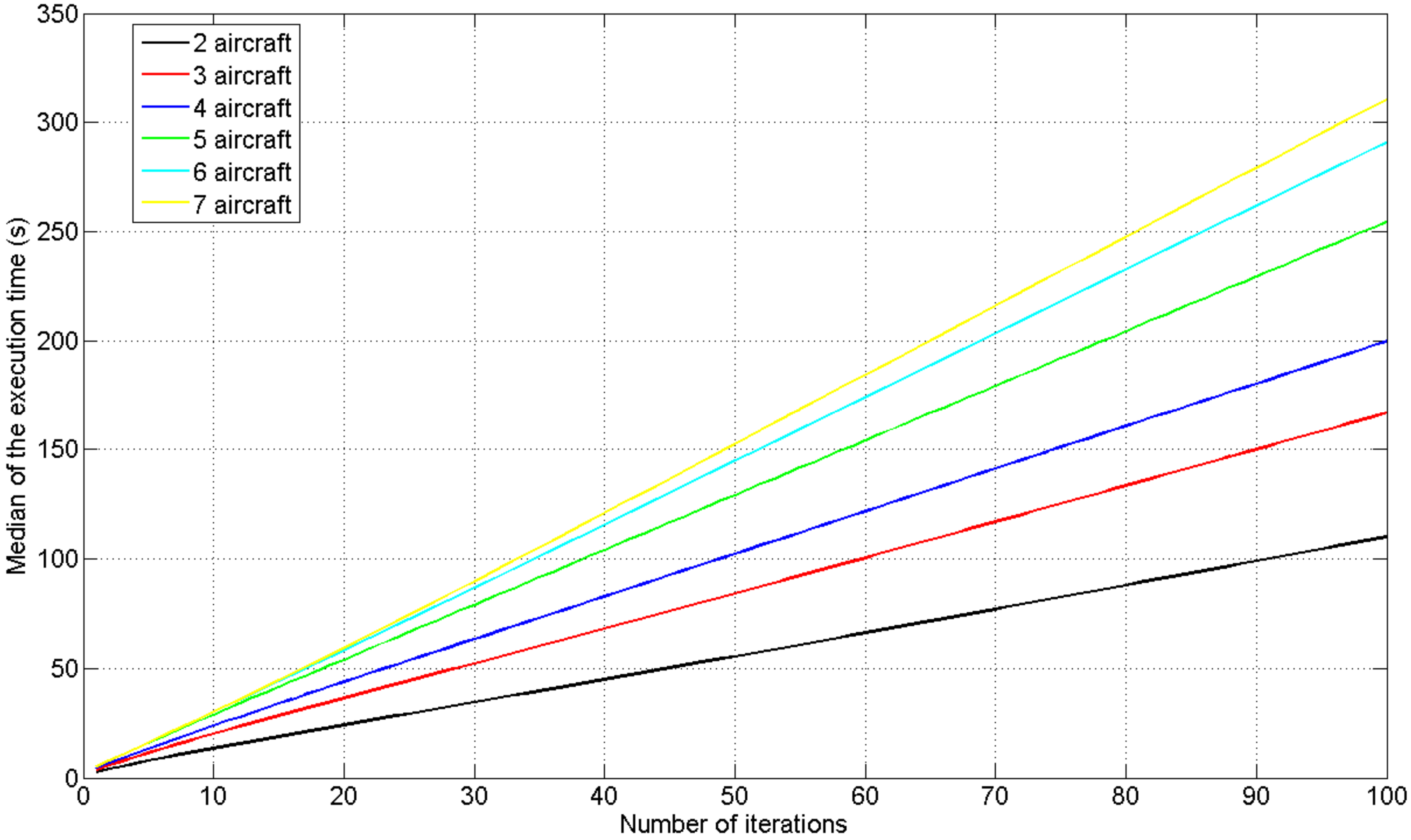
SIMULATIONS

- Computer used in the tests
  - PC with 2GHz AMD Triple Core Processor. 2 GB Ram
  - Kubuntu Linux 12.04 OS
- Development tools
  - gcc, gdb, etc
  - Kdevelop
  - Boost libraries
- 1200 simulations successfully carried out from the test battery
- Up to 7 simultaneous aircraft

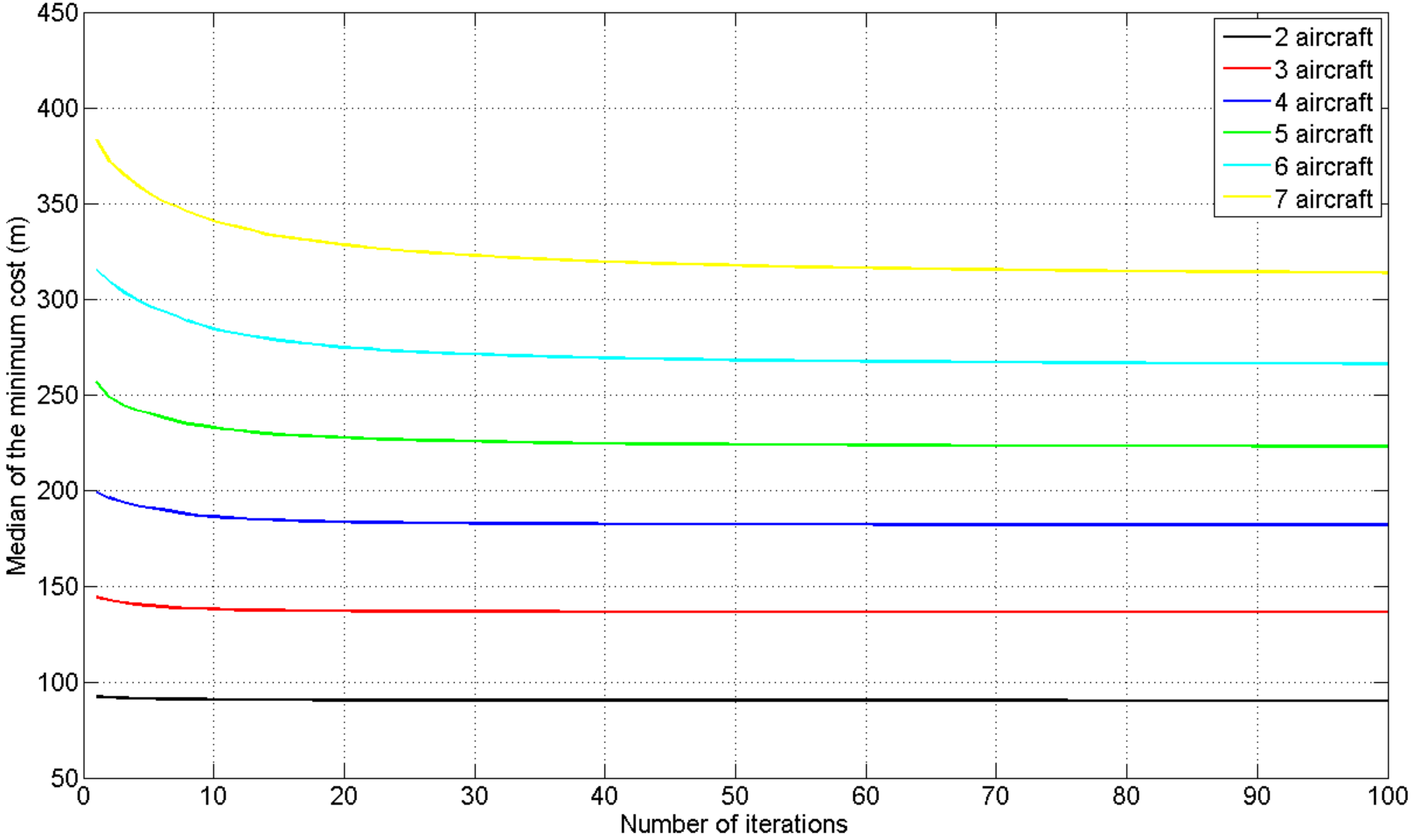
SIMULATIONS (II)



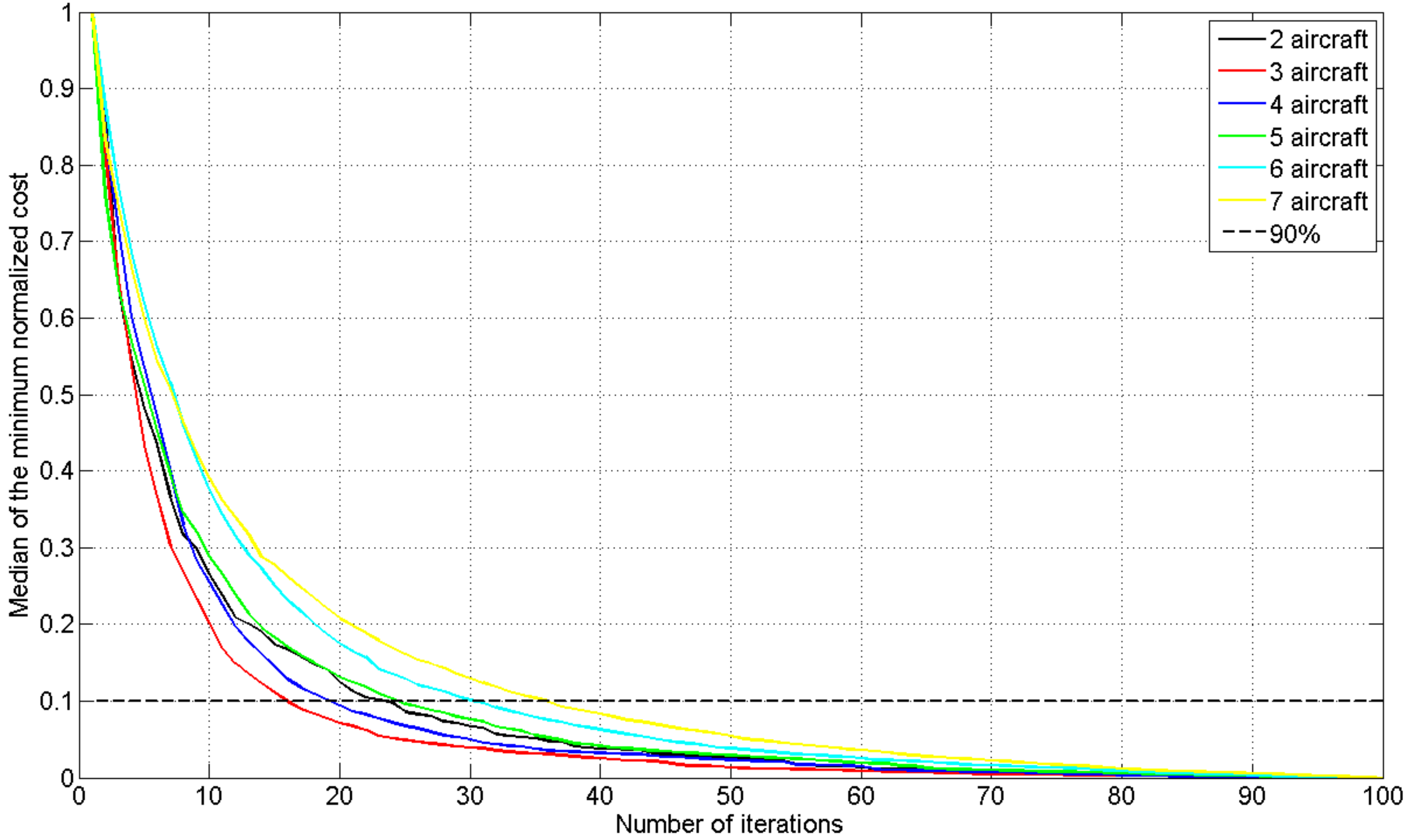
SIMULATIONS (III)



SIMULATIONS (IV)



SIMULATIONS (V)



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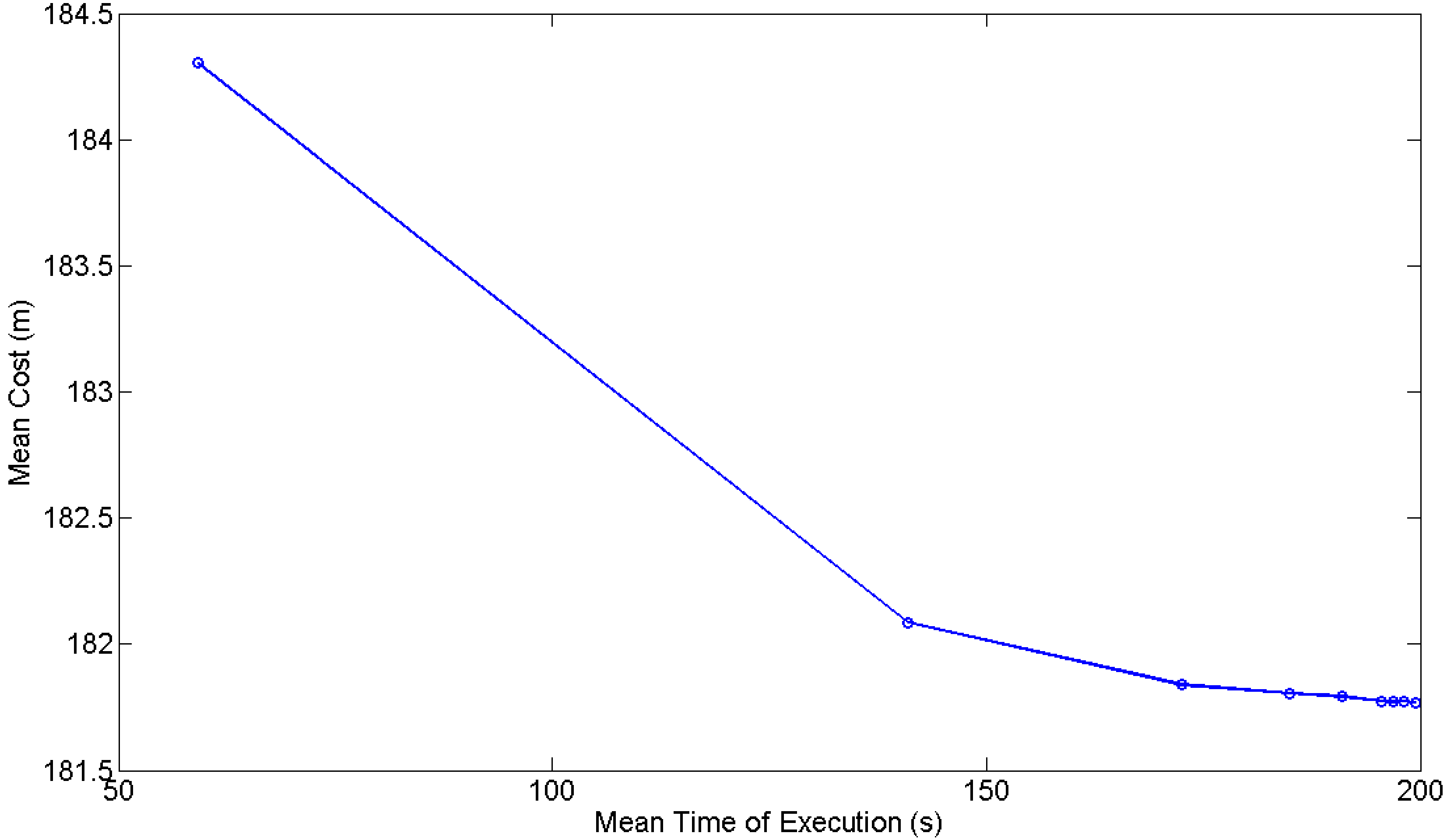
SIMULATIONS (VI)



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CONCLUSIONS

- A CDR algorithm has been designed
  - Flexible
  - Near-optimal

- Several simulations done
  - Designed a test battery of 90000 tests
  - Executed 1200 of these

- Stochastic any-time approach introduced
  - Quality of the solution depends on the look-ahead time.

FUTURE WORK

- Reduce computation time
  - Parallel computation
  - GPU computation [J.M. Li et al. 2007]

- Develop multi-objective evolutionary optimization

- Experimental tests
  - Up to 10 UAVs

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QUESTIONS?

THANK YOU!