HPC – ATM simulator for the performance assessment of TBO

L. Camargo, R. Dalmau, S. Ruiz and X. Prats

Presenter: Dr. Sergio Ruiz

Agenda

- Introduction
- Theoretical background
- HPC-ATM Simulator
- Test case: ATM case
  - Benchmarking results for decentralized components
  - Benchmarking results for centralized components
Introduction

Massive datasets & Complex simulations

High Performance Computing (HPC)

Computing time reduction
Introduction

High Performance Computing (HPC) + Air traffic management

Theoretical background
Introduction

Cluster of computers

Introduction

Computing time reduction

Robustness
Scalability
Reliability
Failure tolerance
Etc.

Real simulation
(representing a system in real operations)
Introduction

Trajectory-based operations

High Performance Computing (HPC)

HPC-ATM Simulator
ATM Performance

Avoid accidents & incidents (this is a must-have)

Stable and synchronised flight plans

ATC separation provision

Operator costs and sustainability

Safety nets (when present)

ATFCM (capacity and resilience mgnt)

ASM (Definition of routes and FLS)

Very long-term and static strategic de-confliction of flights

ATM cost efficiency

Minimum ATM cost

Predictability

Capacity (airport + airspace)

Allocate demand

Air Traffic Management (ATM)

Current ATM safety layers

Hazards

ATFCM (capacity and resilience mgnt)

ATC separation provision

Safety nets (when present)

Incident or accident
Future (ideal) ATM safety layers

ATFCM (dynamic capacity, complexity and resilience mgnt)
Strategic trajectory de-confliction
(new ATM layer)
ATC separation provision
Safety nets

All the layers will be much more integrated
(through the exchange of 4D trajectories)

Incident or accident

TBO-BASED ATM MODEL

Collaborative flight planning: exchange and negotiation of 4D Trajectories

COORDINATION
Centralised / decentralised decision making

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Project overview

Trajectory Planning

Traffic and Capacity Planning

User-preferred de-conflicted trajectories (negotiation process)

Airspace Planning

Strategically de-conflicted trajectories

Strategically de-conflicted trajectories with acceptable complexity and safety levels

Set of optimal trajectories and sector configurations to assess ATM performance

Meso- and macro-modelling

Complexity and risk assessment

Centralised view is better to control the safety, complexity and trajectory synchronization at network level

Centralised / decentralised decision making

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Centralized view is better to control the safety, complexity and trajectory synchronization at network level
HPC ATMSimulator

Phase 1. Strategic level

Phase 2. Strategic, pretactical and tactical level

Slave 1

Slave 2

Slave M

Master

Data Collector

CD&R input formatter

Distributed Conflict Detection and Resolution for optimized trajectories HPC software architecture

HPC-ATM Simulator

Test case
Experiment setup (basic test-case)

- 1319 flights operated with Airbus A320 over ECAC
- Data was obtained from the Eurocontrol Demand Data Repository 2 (DDR2)
- Cost index and payload: 45 Kg/min and 81% max payload
- Two profiles:
  - Conventional: direct routes with current FL Scheme
  - Continuous: direct routes with continuous vertical operations, including continuous cruise climbs

- 5 nodes, one (1) master and four (4) slaves.
- Intel Xeon 5148-2.33 GHz processor
- 1Gb RAM

Small scale HPC trial

Decentralized results (AUs)

\[ C = F + CI \cdot T \]

<table>
<thead>
<tr>
<th>KPI</th>
<th>Conventional</th>
<th>Continuous</th>
<th>Difference</th>
<th>Difference (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trip time [hours]</td>
<td>2,279</td>
<td>2,237</td>
<td>42</td>
<td>1.84</td>
</tr>
<tr>
<td>Fuel consumption [kg]</td>
<td>5,693,862</td>
<td>5,866,034</td>
<td>7,828</td>
<td>0.14</td>
</tr>
<tr>
<td>CO2 emissions [kg/km]</td>
<td>21,961</td>
<td>21,998</td>
<td>37</td>
<td>0.17</td>
</tr>
<tr>
<td>Average total cost [kg]</td>
<td>8,975</td>
<td>8,883</td>
<td>92</td>
<td>1.02</td>
</tr>
</tbody>
</table>
Decentralized results (AUs)

Flight levels Vs. Distance

- Cruise flight level
- One step climb
- Two step climb

Decentralized results (AUs)

Quantity of flights per flight level

- Flight level: 250, Quantity of flights: 17
- Flight level: 260, Quantity of flights: 13
- Flight level: 270, Quantity of flights: 6
- Flight level: 280, Quantity of flights: 10
- Flight level: 290, Quantity of flights: 16
- Flight level: 300, Quantity of flights: 12
- Flight level: 310, Quantity of flights: 18
- Flight level: 320, Quantity of flights: 21
- Flight level: 330, Quantity of flights: 27
- Flight level: 340, Quantity of flights: 61
- Flight level: 350, Quantity of flights: 147
- Flight level: 360, Quantity of flights: 348
- Flight level: 370, Quantity of flights: 517
- Flight level: 380, Quantity of flights: 517
Decentralized results (AUs)

![Graph showing altitude vs. along path distance with two lines representing continuous and conventional operations.]

Centralized results (NM/ANSPs)

<table>
<thead>
<tr>
<th>TABLE II</th>
<th>CONFLICT DETECTION RESULTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>KPI</td>
<td>Profiles comparison</td>
</tr>
<tr>
<td></td>
<td>Conventional</td>
</tr>
<tr>
<td>Trajectory average duration [s]</td>
<td>3,709</td>
</tr>
<tr>
<td>Quantity of conflicts</td>
<td>321</td>
</tr>
<tr>
<td>Average duration per conflict [s]</td>
<td>60.79</td>
</tr>
<tr>
<td>Standard deviation of duration per conflict [s]</td>
<td>99.76</td>
</tr>
<tr>
<td>Quantity of flights free of conflict</td>
<td>828 (63%)</td>
</tr>
</tbody>
</table>
Centralized results (NM/ANSPs)

Conventional profile

- Quantity of conflicts
- Duration (class interval: 10 s)

Continuous profile

- Quantity of conflicts
- Duration (class interval: 10 s)

Centralized results (NM/ANSPs)

- Conventional: 321 conflicts
- Continuous: 746 conflicts

- 169 conflicts (53 %) in common
- 594 conflicts (80 %) exclusive

Total conflicts: 915
Summary and Conclusions

- A software architecture for HPC has been presented as a test-bed to simulate and assess ATM scenarios in a timely manner and with large datasets.
- Some KPIs have been implemented for the assessment of the airlines operational efficiency (fuel, emissions, flight duration, total cost, among others) and the network safety (number of conflicts and their distribution in FLs).
- The ATM simulator has been tested with a particular case study to show the ability to (preliminary) reproduce future de-centralized and centralized decisions, in particular, de-centralized trajectory optimization (e.g., done on-board) and centralized traffic and conflict analysis (e.g., performed by the Network Manager).

Summary and Conclusions

- The results of the case study assessment show that a continuous vertical profile may impact positively to operational efficiency of AUs (in particular to the individual and total fuel consumptions and to flying times)
  - The AUs could benefit from around 1% of cost reduction and around 2% trip-time less (fuel and emissions remained similar)
- However, on a network level, the implementation of continuous trajectories might decrease the safety and capacity levels because of the notable increase of the number of potential traffic separation conflicts and traffic complexity.
  - The number of conflicts has increased from 321 conflicts in case of conventional vertical profiles to 746 conflicts in case of continuous operations, which suggests an increase in the complexity of the traffic that in turn could lead to major safety degradation.
Next Steps

- The anticipation of the trajectory de-confliction and traffic de-complexion tasks through a collaborative negotiation and with a performance-driven optimization of the traffic operations shall allow to reduce the air traffic complexity and to mitigate the potential traffic separation losses.

- For that purpose, next research steps to build in the ATM simulator will include strategic de-confliction and de-complexion mechanisms and more advanced performance KPIs. This also contemplates the parallelization (with the HPC architecture presented) of some traffic de-confliction tasks to reduce the computational burden of such highly combinatorial problem.
  - Concurrent multi-access relational database could be the foundation of the mixed decentralised/centralised architecture providing to it the ability of processing data on a full network level.
  - ATM simulator and the HPC software architecture integrated with the SWIM communication so that the computer slaves can be anywhere.

Questions
HPC ATM Simulator

Locally in the master node:
- ProjectFolder/
  - Software/
    - TrajOptimizer/
    - CD&R/
    - OtherComponents/
  - JobSpace/
    - Conv/
    - Cont/
    - Input/
    - Output/
    - CDR/

NFS-Shared folder

Quantity of flights (Folder per flight):
\[
\{1, 2, \ldots, N\}
\]