Automated Separation for CDO-enabled Arrivals within TMA

Tatiana Polishchuk
Henrik Hardell
Valentin Polishchuk
Christiane Schmidt
Optimizing Aircraft Descent for Environmentally Sustainable Aviation

🔗 Environmentally-friendly solutions
🔗 Energy-neutral descent
🔗 Fuel-optimal
🔗 Reduced noise

ODESTA project
CDOs: recap

Continuous Descent Operations CDOs have shown important environmental benefits w.r.t. conventional (step-down) approaches.
Goals

- Implement CDOs (Continuous Descent Operations) for all arrivals currently not widely used because of low predictability, hard to control

- Automated separation of arrivals within TMA to reduce complexity and ATCO’s workload
Motivation

COVID-19 impact: # flights spring 2019 vs spring 2020 (~89% reduction)
Motivation

Vertical inefficiencies within TMA
Motivation

Vertical inefficiencies within TMA and associated extra fuel burn

23 arrivals to Arlanda airport on May 4, 2020: ~1444 kgs (42% extra fuel burned)
Motivation

Horizontal inefficiencies

2020

2018
ODESTA, IFWHEN, TMAKPI

Optimizing Aircraft Descent for Environmentally Sustainable Aviation

- Punctuality
- Fuel efficiency
- Vertical efficiency
- Noise footprint
- Weather impact
- Trade-offs

Impact of Fleet Diversity and Weather on Emissions, Noise and Predictability

Towards Multidimensional Adaptive KPIs for operations assessment and optimization

Continuous Descent Operations: Optimized wrt. fuel and noise

Images showing data analysis and charts related to the impact and optimization of aircraft descent operations.
2-Phase Optimization

Individual aircraft trajectory optimization (realistic CDOs speed profiles)

Automated separation of *multiple* arrivals within TMA
Input

- Location and direction of the airport runway
- Locations of the entry points to the TMA
- Aircraft arrival times at the entry points for a fixed time period ($v_1$: fixed, $v_2$: flexible)
- Cruise conditions (altitude, true airspeed, distance to entry point) and aircraft type for CDO profile generation
Output

Optimal arrival tree that merges traffic from the entries to the runway ensuring safe aircraft separation for the given time period

= a set of time-separated CDO-enabled aircraft trajectories optimized w.r.t. the traffic demand during the given period
Grid-Based MIP Formulation

- Square grid in the TMA
- Every node connected to its 8 neighbours
- Snap locations of the entry points and the runway into the grid
- Grid cell side of the length $s$ (separation parameter)
- Problem formulated as MIP

*Based on flow MIP formulation for Steiner trees*
Operational Requirements

- No more than two routes merge at a point
- Merge point separation
- No sharp turns
- Temporal separation of all aircraft along the routes
- All aircraft fly energy-neutral CDO: idle thrust, no speed brakes (noise avoidance)
- Smooth transition between consecutive trees when switching
Operational Requirements

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Realistic CDO Speed Profiles

- The trajectory is divided in two phases: the cruise phase prior the top of descent (TOD) and the idle descent.

- The original cruise speed is not modified after the optimization process, so the two-phases optimal control problem can be converted into a **single-phase optimal control problem**.

- BADA V4 is used to model the aircraft performance.
Realistic CDO Speed Profiles

- The state vector represents the fixed initial conditions of the aircraft: TAS $v$, altitude $h$ and distance to go $s$.

- To achieve environmentally friendly trajectories, idle thrust is assumed and speed-brakes use is not allowed throughout the descent → energy-neutral CDO.

- The flight path angle is the only control variable in this problem → control vector $u$

\[
x = [v, h, s] \\
u = [\gamma]
\]

CDO speed profiles inside TMA

- A set of realistic alternative speed profiles for all feasible route lengths inside TMA
- Generated for all a/c types arriving to Arlanda during the given period
- Used as input to MIP

Example of A320 speed profiles for different path lengths inside TMA
Experimental Study: Stockholm Arlanda Airport

Data: Stockholm Arlanda airport arrivals

Data source: Opensky Network Database, BADA 4

Average and high-traffic scenarios: 1 hour of operation

Solved using GUROBI

Run on a powerful Tetralith server, provided by SNIC, LIU: Intel HNS2600BPB nodes with 32 CPU cores and 384 GB RAM
Moderate traffic scenario: October 03, 2017

**Tree 1:** time: 15:00 - 15:30 (10 a/c)

**Tree 2:** time: 15:30 - 16:00 (7 a/c)
$t = 15:00$
t = 15:03
$t = 15:04$
t = 15:05
t = 15:07
t = 15:08
$t = 15:09$
$t = 15:10$
t = 15:11
$t = 15:12$
t = 15:14
t = 15:15
t = 15:16
t = 15:17
t = 15:18
$t = 15:19$
$t = 15:20$
$t = 15:21$
\[ t = 15:22 \]
$t = 15:23$
t = 15:24
t = 15:25
$t = 15:26$
t = 15:28
t = 15:29
$t = 15:30$
$t = 15:30$
$t = 15:30$
$t = 15:30$
t = 15:31
$t = 15:32$
Moderate traffic scenario: October 03, 2017

**Tree 1:** time: 15:00 - 15:30 (10 a/c)

**Tree 2:** time: 15:30 - 16:00 (7 a/c)

$U = 23$ provides consistency between the trees

Separation: 2 min, $\sim 6$ nm

17 out of 22 arrivals scheduled

5 filtered out, because of:

- Initial violation of separation at entry points
- Potential overtaking problem
- In general, about 10-15% are not scheduled
Moderate-traffic scenario: Comparison against the actual trajectories
High-traffic scenario: May 16, 2018

- The busiest day in 2018, high traffic
- Separation: 2 min, ~6 nm
- All 30 a/c scheduled (entry time window ± 5 min)
- All 30 fly CDO!
- Average deviation from the initial entry time 2.27 min
- Average separation at the runway 2.14 min
High-traffic scenario: comparison against the actual trajectories

30 arrivals in 1 hour
Average time in TMA:
9.5 min vs. 15.1 min
High-traffic scenario: comparison against the actual trajectories

Fuel savings: 3590 kg (~ 54% reduction)
Conclusions

- Flexible optimization framework for dynamic route planning inside TMA
- Automated space and time separation
- Environmentally-friendly speed profiles (CDO) provide significant fuel savings
- May be used for TMA capacity evaluation
Future Work

- Account for uncertainties due to weather
- Consider fleet diversity
- Investigate on noise impact
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Thank you!

Questions?