Towards a Comprehensive Characterization of the Arrival Operations in the Terminal Area

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Introduction

• Characterisation of TMA arrival operations
• Existing and new performance metrics
• Three European airports
• Different metering and sequencing techniques
Airports

• Chosen airports:
  o Dublin (EIDW) – point merge – rwy 28L
  o Stockholm-Arlanda (ESSA) – vectoring – rwy 01R
  o Vienna (LOWW) – trombone – rwy 16

• 220,000 to 270,000 aircraft movements annually
• Operations inside TMA boundaries for Arlanda and Vienna. 50 NM circle for Dublin to cover eastbound arrivals.
Point Merge - Dublin

• Main runway 10R/28L (used 95 % time)
• Sequencing legs in the shape of arcs for path stretching flown at level flight
• Merge point
• Designed to work in high traffic loads, improve runway capacity and reduce controllers’ workload
Vectoring – Stockholm-Arlanda

- Three runways
- Pair of parallel runways (used during busy hours)
- Mix of closed STARs and open STARs
- Runway 01R – open loop vectoring only
Trombone - Vienna

- Two intersecting runways
- Simultaneous usage
- Set of STARs and four IAFs
- Waypoints for path stretching and shortcuts
Data

• Historical database of the OpenSky Network
• 'States' data representing the parts of the arriving flight trajectories inside TMA
• Month with the highest number of arrivals at our 3 airports
• Full four weeks of October 2019
Data Cleaning

• Fixing all incorrect positioning using linear interpolation
• Gaussian filter to smooth the altitudes
• Removing the trajectories:
  o representing landings too far from the runway
  o that are incomplete within TMA
  o starting from an altitude lower than 600 m
  o representing go arounds within TMA
  o for some non-commercial flights
Dataset

- Peak-time periods in October 2019
- Calculate average per hour time in TMA for each airport
- 0.7 percentile removed from the set of values
- 2587 flights for Dublin, 1045 for Arlanda and 1641 for Vienna
Methodology

**Additional distance**

- To evaluate horizontal flight efficiency
- Clustered trajectories in each TMA
- Ideal reference trajectory
- Calculated as the difference between the actual path length and the length of the corresponding reference trajectory inside TMA
Methodology

Time of flight levels

• To evaluate the vertical flight efficiency

• VFE by EUROCONTROL: Level segment = vertical speed below 300 feet per minute for at least 30 seconds
Methodology

Vertical reference trajectories

• Two CDO reference trajectories per flight (RT1 & RT2) created with BADA v4.2
• RT1: same horizontal route as the real flight
• RT2: shortest route from TMA entry to final approach
Methodology

**Vertical deviation**

- Assessed as the vertical deviation from a CDO reference profile
- 10 minutes prior to final
Methodology

**Additional fuel burn**

- To evaluate environmental efficiency

- Difference in fuel consumption between the real trajectory and a reference flight performing a CDO at idle thrust, flying RT1 and RT2

- CDO profiles and fuel consumption calculated with Eurocontrol BADA v4.2, considering actual wind and temperature conditions from ERA5
Methodology

Cluster analysis

• Evaluation of flight efficiency per flow

• Horizontal, vertical efficiency, and additional fuel burn
Methodology

Minimum time to final

- A rectangular grid with the cell side of \( \approx 1 \) NM laid over the TMA
- The minimum time needed from any point within the cell of the grid to the final approach
- Infinite for the cells through which no trajectories pass
- Heatmap visualization
Methodology

Throughput

• The number of aircraft with the same minimum time to final within a given time window

• Iso-minimum time lines from 600 to 30s to final

• 30 seconds sampling rate over 5-minute periods
Methodology

Metering effort

• Difference between the throughput at the given time horizon and the one close to the final
• Quantifies the controller’s effort for metering
• Proxy to controller’s workload
Results

- Dublin shows higher median values for both additional distance and time flown level than Arlanda and Vienna
Dublin and Arlanda show similar median values for vertical deviation, while Vienna has the lowest. The spread is greater for Vienna.

Dublin shows the highest additional fuel burn, both for RT1 and RT2, followed by Vienna and Arlanda.
• Horizontal spread is 64% for Dublin, 59% for Arlanda, and 84% for Vienna
• Significantly higher minimum time to final values for Dublin
• Consistent with the results obtained for the Additional Distance
• The figures of metering effort indicate significant differences of entry conditions among the airports, with the traffic samples considered.
• Dublin is having by far the highest effort (3), followed by Vienna (2) and then Arlanda (1.2)
Results per cluster

Dublin

Arlanda

Vienna
Results per cluster

**Arlanda**
- Noticeable difference between RT1 and RT2 additional fuel burn
- High additional distance
- Moderate time flown level

**Dublin**
- Noticeable difference between RT1 and RT2 additional fuel burn
- High additional distance
- Moderate time flown level

- Noticeable difference between RT1 and RT2 additional fuel burn
- High additional distance
- Moderate time flown level
Results per cluster

**Arlanda**
- Small difference between RT1 and RT2 additional fuel burn
- Additional fuel burn mostly caused by vertical inefficiency

**Vienna**
- Negative difference between additional fuel burn for RT1 and RT2
- RT1 shorter horizontal trajectories
- Confirmed by low additional distance
- Additional fuel burn mainly caused by vertical inefficiency

**Dublin**
- RT1 additional fuel burn very low
- Vertical inefficiency still exists
- Turboprop a/c with low cruise altitudes
- Later RT1 ToD → cruise in TMA
Conclusions

• Evaluation of the arrival efficiency at three European airports with different airspace complexity and different sequencing and merging techniques

• Evaluation for all flights combined and per flow

• Reveals varied situations among three airports with similar number of yearly aircraft movements

• No fair comparison is possible without considering the entry conditions to the terminal area, and further studies would be required to analyze flight efficiency under comparable entry conditions

• Further work should also consider a breakdown of the two main sources of inefficiencies (airspace and operations), and take into account the weather conditions as well as other sources of perturbations and uncertainties
Thank you!