Spacing and pressure to characterise arrival sequencing

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What are the questions?

- How sequencing is performed?
- How to characterise it?
- How spacing converges?
- How sequence density evolves?
- Are there differences or similarities among airports?
State of the art

• Arrival operations performance
  • Notions of minimum (unimpeded) and additional time
  • Black box analysis, 40NM from the airport
  • Extend the notions to any point in approach
• Impact of new concepts for arrivals
  • Observable effects to inform on controller sequencing activity
  • Spacing evolution not part of the analysis
  • Reuse analysis over time/distance, focus on spacing evolution
• Airborne spacing algorithm performance
  • Spacing accuracy (control error) vs speed changes (control effort)
  • Simple cases with both aircraft following pre-defined known paths
  • Extend the spacing analysis to the general case
• Macroscopic analysis
  • Flow based metrics, not specific for sequencing
  • Develop notion of pressure for sequencing
Motivation and approach

• To understand and characterise sequencing at four European airports

• Method purely data driven presented in 2017

• Application on real data (new)

• Three indicators for three perspectives
  • additional time, single aircraft
  • spacing deviation, pair of aircraft
  • sequence pressure, sequence of aircraft (new)
  • relying on minimum time (improved)

Conducted as part of SESAR2020 (PJ01-02)
Minimum time

• *Unimpeded time* (PRU) = transit time in non-congested conditions in an area around the airport (eg 40NM)

• Can be generalized to any point in the area

• Minimum time = minimum time along all possible paths (graph 500k nodes + Dijkstra)

• Now global minimum, previously local
Additional time

- Additional time (PRU) = difference between transit time and unimpeded time
- Can be generalized to any point in the area
- Remaining delay to absorb
Additional time example
How to define spacing?

• The controller builds his/her own estimation of the spacing during the sequencing

• It is part of the cognitive process and is not accessible

• How to define spacing between two aircraft vectored on different paths?
Spacing deviation

- **Constant time delay** (NASA 1983, 1984)
- **spacing deviation** \( \text{(t)} = \text{min time (trailer (t))} - \text{min time (leader (t – s))} \)
Spacing deviation example
Sequence pressure

- Aircraft density in the sequence
- *Sequence pressure = number of flights with same min time ±45 seconds (runway slot)*
Sequence pressure example
A typical sequence
Case study

- Four European airports, different types of sequencing, 120NM area
- Position reports (update rate 30s, 1min for LFPG)
- 80 days, daytime operations

*Sequencing technique presented at ATM 2007
Minimum time map

- A map of minimum times for each runway
- Square cells 2/3NM, split by 30 degrees heading
- Other factors may be considered: altitude, aircraft type, wind, ..
Peak hours and aircraft pairs

- Focus on peak periods (one hour with average additional time > 75\textsuperscript{th} percentile)
- In total 1200 hours and 28000 flights

- Focus on “close” aircraft pairs (final spacing < 200 seconds) for spacing deviation
- In total 14000 pairs
Data analysis

- Three indicators: **additional time** (single aircraft), **spacing deviation** (pair of aircraft), **sequence pressure** (sequence of aircraft)

- Evolution at different time horizons, starting at 15 minutes to final

- Two views
  - **Time to final**, aircraft view
  - **Min time to final**, controller view
Additional time

Additional time: samples, median and 90% containment

Additional time (min)

Time to final (min)

Minimum time to final (min)
Spacing deviation

Spacing deviation: samples, median and 90% containment

- EDDF
- EIDW
- LEMD
- LFPG

Time to final (min)

Minimum time to final (min)
Sequence pressure

Pressure: samples, median and 90% containment

<table>
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<th>EDDF</th>
<th>EIDW</th>
<th>LEMD</th>
<th>LFPG</th>
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Time to final (min) vs Minimum time to final (min)
Sequence pressure map

- Map of average pressure for one runway
Discussion

- Additional time, a necessary cost
  - Should be kept as low as possible in particular near final, however a certain amount is inevitable during peak periods to keep pressure and flexibility
  - Quite high at 15 minutes to final (3 runway slots), acceptable at 5 minutes (below 1 minute)?

- Spacing deviation, an operational objective
  - Should progressively converge to zero starting with a spread at entry depending on the need to optimise the landing sequence
  - Significant at 15 minutes (3 runway slots) but landing sequence optimised?

- Sequence pressure, a way to maximize runway utilization
  - Should be maintained at an appropriate range, not too far from final, when operating close to maximum runway capacity
  - Varied situations: Too low for LFPG? Too high at entry for LEMD? Moderate/low for EDDF? Moderate/high for EIDW?
In perspective

• The characteristics observed
  • are related to operational objectives (runway throughput, ..) and constraints (airspace, environment, ..)
  • may also result from the way working methods have been developed over years

• This type of analysis
  • may support adjustment or re-design of routes or operating methods, to better adhere to the desired characteristics, specific to each environment