Toward the characterisation of sequencing arrivals

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Introduction

• Objective: to understand and characterise the sequencing of arrivals

• Motivation: to develop a method to report on different operating methods, route structures or environments

• Approach: by analysing the spacing evolution over time between consecutive aircraft

• Case study: three sequencing techniques on the same approach environment using track data from simulations
State of the art

- Arrival operations performance
  - Notions of minimum (unimpeded) and additional time
  - Black box analysis, 40NM from the airport

- Impact of new concepts for arrivals
  - Observable effects to inform on controller sequencing activity
  - Spacing evolution not part of the analysis

- Airborne spacing algorithms performance
  - Spacing accuracy (control error) vs speed changes (control effort)
  - Simple cases with both aircraft following pre-defined known paths
Our contribution

• 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 algorithms 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*
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 with resume paths unknown in advance?

- To estimate spacing a-posteriori based on flown tracks.

- Data driven method not relying on local operational knowledge.
3 key indicators

- minimum time *
  - additional time *
    - single aircraft
  - spacing in time
    - pair of aircraft

* Generalisation of the notions introduced by the PRU
3 key indicators

- **minimum time**
  - additional time
    - single aircraft
  - spacing in time
    - pair of aircraft
Minimum time

- **red** shortest/fastest trajectory passing through point P
- **blue** other trajectory passing through point P
- **gray** trajectory not considered (not passing through P)
Minimum time, an example
Minimum time, an example
Minimum time, an example
Minimum time, an example
Minimum time, an example
Minimum time, an example
3 key indicators

- **minimum time**
- **additional time**
  - single aircraft
- **spacing in time**
  - pair of aircraft
Minimum time to final from P = 8 minutes
Actual flight: time to final from P = 9 minutes
Time to absorb from P = 9 – 8 = 1 minute
Additional time

Minimum time to final from P = 8 minutes
Actual flight: time to final from P = 9 minutes
Time to absorb from P = 9 – 8 = 1 minute
Minimum time to final from P = 8 minutes
Actual flight: time to final from P = 9 minutes
Time to absorb from P = 9 – 8 = 1 minute
Additional time at P = 2 minutes
3 key indicators

- **minimum time**
  - additional time
    - single aircraft
  - spacing in time
    - pair of aircraft
Spacing

\[ Spacing_{ij}(t) = \min \text{time to final } P_j(t) - \min \text{time to final } P_i(t) \]

Min. time to final

Spacing = 11 - 10
Spacing

Spacing = 10 - 9
Spacing

Spacing = 10 - 8
Spacing

Spacing = 9 - 7
Spacing

Spacing = 8 - 6
Spacing

Spacing = 2 - 0
Spacing, an example
Spacing, an example
Spacing, an example
Spacing, an example
Spacing, an example
Spacing, an example
Spacing, an example
Spacing, an example
Spacing, an example
Case study

- 3 sequencing techniques tested
- Same approach environment
- High traffic load

- Track data from human in the loop simulations conducted at EEC as part of SESAR (680 flights in total)

*Vectoring* (Vectoring onto ILS)

*Intermediate* (Vectoring+final segment to ILS)

*Point-Merge* (Arcs+final segment to ILS)
Minimum time
Additional time

- Vectoring
- Intermediate
- Point-Merge

From TMA entry to FAF

Additional time (minute) vs. Time to Final Approach Fix (minute)
Additional time

From TMA entry to FAF

Median curves
Additional time absorption areas
Spacing deviation

![Graph showing spacing deviation over time for different scenarios ( Vectoring, Intermediate, Point-Merge)]
Spacing deviation

![Graph showing spacing deviation over time for Vectoring, Intermediate, and Point-Merge conditions.](image-url)
Spacing deviation

Time when 2 minutes spacing containment span is reached

5

5.5

7.5
Typical sequencing patterns

- **Vectoring**
  - Graph showing spacing deviation over time to Final Approach Fix fix (minute).
  - From TMA entry to FAF.

- **Intermediate**
  - Graph showing spacing deviation over time to Final Approach Fix fix (minute).

- **Point-Merge**
  - Graph showing spacing deviation over time to Final Approach Fix fix (minute).
Conclusion and next steps

• The proposed approach, data driven, enables to characterise how spacing evolves over time.

• It reveals differences among the three techniques tested
  • Spacing convergence speed
  • Typical patterns suggesting differences in sequencing anticipation
  • Cases of non-monotonous variations

• Next steps
  • Identify good characteristics from both sequencing and ‘human control’ perspectives
  • Apply the approach on actual track data, in different environments, on extended horizons
Thank you!

- Questions and answers.