ENRI International Workshop on ATM/CNS (EIWAC)
Tokyo, Japan

Trajectory Management for Aircraft Noise Mitigation

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6th March 2009
Introduction

- Increasing air traffic demand
- Increasing population around airports
Introduction

• Aircraft noise reduction
  • Source (aircraft)
  • Propagation (trajectory)
  • Receiver (population)

Noise Abatement Procedures (NAPs)
Noise Abatement Procedures

- Lateral Trajectory Management
  - Noise Preferential Routings (NPRs)
    - RNAV

- Vertical Trajectory Management
  - Arrival/approach strategies
  - Depart strategies
RNAV = Area Navigation

- A method of navigation which permits aircraft operation on any desired flight path within the coverage of station-referenced navigation aids, or a combination of these.
RNAV system

RNAV navigation

DME/DME
VOR/DME

GNSS
(with augmentation system)

INS/IRS
(Loran C)

FMS + DB

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RNAV procedures

- Fly-Over waypoints
- Fly-by waypoints

With RNAV the aircraft flies according to the data base not the charts!!!

WAYPOINTS + PATH and TERINATORS

Fly-over

Fly-by

No lead radials
RNAV Path and Terminators

- Transform **procedures** into **coded** flight path
- **How to navigate from** a starting point/location to a **terminating point/condition**

**Example:**

TF: Track between Fixes
RNAV Path and Terminators

- Transform procedures into coded flight path
- How to navigate from a starting point/location to a terminating point/condition

Example:
DF: Direct to a Fix
RNAV Path and Terminators

- Transform procedures into coded flight path
- How to navigate from a starting point/location to a terminating point/condition

Example:
CF: Course to a Fix

77°
RNAV Path and Terminators

- Transform procedures into coded flight path
- How to navigate from a starting point/location to a terminating point/condition

Example:
RF: Radius to a Fix

RF

R
RNAV Path and Terminators

Track Dispersion

DF
RNAV Path and Terminators

Track Dispersion

RF
RNAV and NAPs

- **RNAV** is a major enabler for new and efficient noise abatement procedures.
- There is still some **track dispersion** in Fly-by or Fly-Over turns. Aircraft determine turn path on a “ad-hoc” basis (highly FMS dependant)
- Much **higher accuracy** throughout the turn when using **Radius to Fix (RF)** path terminator

**RF leg:**
- recommended function P-RNAV equipment
- requirement for future RNP 1 equipment
RNAV and NAPs

Conventional Navigation

RNAV Navigation
RNAV and NAPs

All aircraft

RNAV + RF equipped aircraft

Courtesy of Theo van de Ven (KLM)
RNAV and NAPs
Noise Abatement Procedures

- Lateral Trajectory Management
  - Noise Preferential Routings (NPRs)

- Vertical Trajectory Management
  - Arrival/approach strategies
  - Depart strategies
Arrival/Approach strategies

- Low Drag-Low Power (LDLP) approach
- Higher ILS interception altitude
- Higher ILS glide-slope angle
- Dual landing thresholds
- Continuous Descend Approach (CDA)
- Three Degree Descelerating Approach (TDDA)

Compromise vs. airport and TMA CAPACITY
Depart strategies

- Thrust cut-out
- Reduced thrust take-offs
- Different climbing (airspeed) profiles
Optimisation of NAPs?

- Generic Procedures for specific problems
- Local sub-optimal solutions
- Noise annoyance partially assessed
NAPs optimisation framework

Input data
- Airspace
- Navigation
- Cartography

Aircraft Performance

Meteorology

Airport

Geography

Trajectory Constraints

Optimization

Aircraft Dynamics

Optimization Criteria

Scenario

Noise Annoyance Model

Noise Model

Trajectory
Fuzzy logic annoyance model

Residential Zone

![Diagram showing a 3D graph with axes Lmax (dBA) and Hour of Day, with color gradients representing annoyance levels in a residential zone.]
Fuzzy logic annoyance model

Residential Zone

School
Fuzzy logic annoyance model

Industrial zone

Hospital
Trajectory optimisation

- Several noise annoyance values:
  - Hospital → $A_H$
  - Industrial Zone → $A_I$
  - Residential Zone → $A_R$
  - School → $A$

Minimize $A_H, A_I, A_R, A_s$ ??

Multiobjective optimization
Multiobjective optimization

\[
\min_{\bar{z} \in \mathcal{Z}} \left[ J_1(\bar{z}), J_2(\bar{z}), \ldots, J_{n_j}(\bar{z}) \right]
\]

“Average” trajectory

\[
\min_{\bar{z} \in \mathcal{Z}} \sum_{i=1}^{n_j} w_i J_i(\bar{z})
\]

“Fair” trajectory

\[
\min_{\bar{z} \in \mathcal{Z}} \left[ \max_i (\Delta_i) \right]
\]

\[
\Delta_i = J_i - J_i^*
\]
Multiobjective optimization

\[
\min_{\vec{z} \in \mathcal{Z}} \left[ J_1(\vec{z}), J_2(\vec{z}), \ldots, J_{n_j}(\vec{z}) \right]
\]

Egalitarian principle:

*the system is no better-off than its worse-off individual*

“Fair” trajectory

\[
\min_{\vec{z} \in \mathcal{Z}} \left[ \max_i (\Delta_i) \right]
\]

\[
\Delta_i = J_i - J^*_i
\]
Application example

Girona (LEGE) international airport

Airbus A340-600 departure

Hospitals (Annoyance < 0.25)

Residential

Industrial zones
Application example

Girona (LEGE) international airport

Airbus A340-600 departure

- 04 am
- 10 am
Conclusions

• RNAV and RNP are major enablers for efficient Noise Abatement Procedures
• Trajectory multi-objective optimisation problem to be solved
• Noise annoyance can be taken into account by using a fuzzy logic model
• Egalitarian principle for noise abatement multi criteria optimisation
Thank you!

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