Human Factors Implications of Continuous Descent Approach Procedures for Noise Abatement in Air Traffic Control

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Why use CDA Procedures?

- Noise impact on communities is one of the major limitations to air transportation infrastructure expansion.
- Noise target levels require improvements in both aircraft design + operational procedures.
- Continuous Descent Approach (CDA) procedures can reduce noise exposure by 3-6.5 dBA (3dB = 50% acoustic energy reduction).
- Keep aircraft higher and at lower thrust for longer than conventional approach.
CDA Concept - Vertical/Lateral coupling

- **Basic CDA**
  - **Controller:**
    - Retains lateral & speed control
    - Provides track distance estimate
  - **Pilot:**
    - Estimates descent rate using track distance

- **RNAV CDA**
  - **Controller:**
    - Clears aircraft for RNAV approach
  - **Pilot & FMS:**
    - Programmed approach
    - Optimized descent rate using altitude targets and speed

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**Diagram Notes:**
- Track distance 1
- Track distance 2
- Final Approach Fix
- "Turn left heading 180, Track Distance 20 nm"
- "Fly heading 210, Clear to descend, Track Distance 20 nm"
- "Fly heading 250, Clear to descend, Track Distance 30 nm"
- "Cleared RNAV approach"
Motivation for Investigation of CDA Human Factors Issues

- CDA procedures are significantly different than the conventional approach currently in use and have implications on controller cognitive processes, including projection.

- Implementation of the CDA procedures may present challenges with approach operations:
  - Traffic throughput
    - 50% throughput reduction compared with conventional approach in trials conducted by Clarke, Ho, & Ren, 2004
  - Controller acceptance of procedure (effect on cognitive processes)
  - Controller workload
Approach

- ATC Process Model Development
  - Incorporates Endsley’s Situation Awareness Model & Pawlak’s Decision Processes model
  - Modified based on U.S. ATC 7110.65 & Boston & NY SOPs
  - Site visits used to revise model (Boston, NY, Manchester, Reykjavik)

- Application of ATC Process Model to Final Approach Task

- Cognitive Difference Analysis performed using ATC Process Model as a means to identify cognitive issues with CDA procedures

- Experiment performed testing utility of an identified key approach abstraction

- CDA procedure implementation guidance provided based on results
ATC Process Model

ATC OPERATIONAL CONTEXT

AIR TRAFFIC SITUATION

STRUCTURE

PILOTS

Surveillance Path

Information / Display System

Task

Training/Experience Path

Control Path

Voice/Output System

COGNITIVE SPACE OF AIR TRAFFIC CONTROLLER

PERCEIVE

EXPERIENCE/TRAINING

CONTROL

Implementing

CURRENT PLAN

PROJECT

WORKING MENTAL MODEL

ABSTRACTIONS

COMPREHEND

DECISION PROCESSES

Monitoring

Evaluating

Planning
Controller’s Task

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COGNITIVE SPACE OF AIR TRAFFIC CONTROLLER

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Final Approach Control Task

Vector aircraft onto approach (laterally & vertically)

Manage separation:

• Compress traffic in periods of high demand

• Ensure minimum separation
  • 1000 ft vertical, OR
  • 3-6 nm (wake vortex) longitudinal

Other tasks
Surveillance Path

ATC OPERATIONAL CONTEXT

AIR TRAFFIC SITUATION

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COGNITIVE SPACE OF AIR TRAFFIC CONTROLLER

Surveillance Path

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Working Mental Model

ABSTRACTIONS

CURRENT PLAN

CONTROL

Implementing

DEcision Processes

Monitoring
Evaluating
Planning
Information/Display System
Detailed View of Dynamic Information

Surveillance Path

ATC OPERATIONAL CONTEXT

Primary Radar
4.8 sec update

Secondary Radar
4.8 sec update

Host Computer Data Processing
4.8 sec update

VHF Comm

Display Systems

AIR TRAFFIC CONTROLLER

voice

other
Control Path

ATC OPERATIONAL CONTEXT

AIR TRAFFIC SITUATION

STORAGE

PILOTS

Surveillance Path

Information / Display System

Task

Training / Experience Path

PERCEIVE

COMPREHEND

PROJECT

WORKING MENTAL MODEL

ABSTRACTIONS

EXPERIENCE / TRAINING

CONTROL

IMPLEMENTING

CURRENT PLAN

DECISION PROCESSES

MONITORING

EVALUATING

PLANNING
Control Path

- Procedures → Control Command Availability → Cognitive Abstractions
- Limited set of commands allow controller to modify the evolution of the situation at different levels:
  - **Position-based**
    - Vertical (e.g., descend and maintain <altitude> feet)
    - Lateral (e.g., Turn left/right to <heading> degrees)
  - **Velocity-based**
    - Lateral (e.g., change speed to <kts>)
    - Vertical (e.g., expedite descent)
  - **Trajectory-based** (e.g., cleared ILS 4R)
  - **Constraint**
    - Temporal (e.g., …until/after/before <time>)
    - Lateral (e.g., …until <fix>)
    - Vertical (e.g., …at/below/above <alt> ft)
    - Coordination (e.g., …until advised by <unit>)

- System cycle time limits response to system (~30 sec for TRACON)
  - Pilot response time
  - Aircraft response time
  - Surveillance update
- Reduces intent uncertainty
Final Approach Controllability

- Position-based (heading/altitude) and velocity-based controls are used most frequently
Comprehension & Projection

**COGNITIVE SPACE OF AIR TRAFFIC CONTROLLER**

**PERCEIVE**
- Working Mental Model
  - Integrate & Filter Information
    - Task filters
      - Agent-based abstractions
      - Context-based abstractions
      - Other abstractions...
  - Interpret data
    - Procedures
    - Static contextual information
    - Abstraction rules

**COMPREHEND**
- Perceived data (SA Level 1)
- Display symbology, Knowledge of surveillance system, etc.
- Information management strategy
  - Information strategy
- Strategy for projecting situation

**PROJECT**
- Working Mental Model
  - Project Situation into Future
    - Dynamic abstractions
    - Other abstractions...

**EXPERIENCE/ TRAINING**
- EXPERIENCE/ TRAINING
  - Control Path
  - Control
  - Commands available
  - Planned Clearances

**CURRENT PLAN**
- Strategy/ Technique
- Expectation of Behavior
- Action Sequence
  - Task strategy chosen

**ATC OPERATIONAL CONTEXT**
- AIR TRAFFIC SITUATION
  - Surveillance Path
  - Information / Display System
  - Task

**STRUCTURE**
- Training/ Experience Path
- Control Path
- Voice/Output System

**PILOTS**
- ATC OPERATIONAL CONTEXT
- AIR TRAFFIC SITUATION

**DECISION PROCESSES**
- Monitoring
- Evaluating
- Planning
Projection

- **Projection** is defined as the evolution of the mental model of the system into the future over the time required to execute and surveill a response to a command to keep the future behavior of the system within the task requirements.
Time of Projection

- Deterministic region
- Persistence region
- Uncertainty
- Probabilistic region
- Future propagation regions
- Limit of deterministic predictability
- Time into the future

Task-based Projection
- Requirement
  - Procedure
  - Controllability
Dynamic Abstractions

- Dynamic abstractions are the abstractions which support projection of the system dynamics, e.g.:
  - Constant Velocity
  - Constant Altitude
Constant altitudes (CA) (achieved either through clearances or through procedures) ensures that merging traffic flows will be separated in at least the vertical dimension.
Constant Velocity Abstraction

- Constant velocity (CV) is used as a way to establish a pattern to aid projection by equalizing distance traveled between updates.
- If minimum lateral separation between 2 aircraft is reached, controllers can ensure this separation throughout the approach by commanding the aircraft to proceed at the same speed.
Key Cognitive Differences

- Loss of abstractions (constant velocity & constant altitude)
- Reduction of controllability
Constant Velocity Abstraction Lost

Constant velocity case

Decelerating case

Over time
Constant Altitude Abstraction Lost

- **Constant Altitude**
- **Vertical?**
- **Lateral**
- **Altitude**
- **Alt. separation**
- **Lateral separation**
- **Vertical separation?**
- **Descent rate**
  - *(ILS unknown interception)*
- **Time**
Controllability Differences

Basic CDA

- Change altitude
- Heading
- Reduce Speed

RNAV CDA

- Change altitude
- Heading
- Reduce Speed
Reducing controllability increases the timescale over which projection required, making projection more difficult.
Dynamic Differences

- Controller may substitute lost abstractions with more complicated abstractions
  - Aircraft are descending at different rates (Basic & RNAV CDAs)
  - Aircraft may be in speed transition over longer periods (RNAV CDA)

- Variability of dynamics in CDAs may also increase
  - Dynamics vary with track distance & aircraft type in Basic CDA and vary with aircraft type & FMS logic in RNAV CDA
Workload Impacts in CDA Procedures

- Basic CDA
  - Track distance task is added
  - Vertical projection task more complicated

- RNAV CDA
  - Projection time into the future increases
  - Tactical control decreases
Primary cognitive differences:

<table>
<thead>
<tr>
<th></th>
<th>Basic CDA</th>
<th>RNAV CDA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Structure-based Abstractions</strong></td>
<td>Loss of Constant Altitude abstraction</td>
<td>Loss of Constant Altitude &amp; Constant Velocity abstractions</td>
</tr>
<tr>
<td><strong>Controllability</strong></td>
<td>Loss of altitude controllability; Addition of Track Distance control</td>
<td>Loss of state (heading &amp; altitude) and velocity controllability; Only “clear”/”abort” procedure</td>
</tr>
<tr>
<td><strong>Time into Future Req.</strong></td>
<td>No difference</td>
<td>Extended time into future projection requirement</td>
</tr>
<tr>
<td><strong>Complexity of dynamics</strong></td>
<td>Vertical complexity increases</td>
<td>Vertical &amp; Longitudinal complexity increases; Lateral complexity decreases</td>
</tr>
<tr>
<td><strong>Variability of dynamics</strong></td>
<td>Vertical variability increases</td>
<td>Vertical &amp; longitudinal variability increases; Lateral variability decreases</td>
</tr>
<tr>
<td><strong>Controller Workload</strong></td>
<td>May increase due to track distance estimations and vertical projection requirements</td>
<td>May increase due to requirement to project further into future due to lack of tactical controllability</td>
</tr>
</tbody>
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Constant Velocity Structure Experiment

- Constant Velocity was identified as a key abstraction in the Cognitive Difference Analysis
- Can controllers create new abstractions to replace lost constant velocity abstraction?

- **Hypothesis**: Periods of constant speed are a key structure-based abstraction used in improving projection performance.
- **Goal**: Determine if some benefits provided by constant speed structure lost during low noise approach can be recovered by using standard deceleration profiles
- Controllers’ Task: project the final separation of a pair of aircraft at different times, but **do not issue control commands**
Independent Variables

- Deceleration profile:
  - Both constant speed
  - Mixed: One constant speed, one decelerating
  - Both decelerating
- Endspeed of aircraft
  - Aircraft 1 faster (opening case)
  - Aircraft 2 faster (closing case)
  - Same
- Final separation is counterbalanced across cases
Task

- 3 projections of final separation must be made, each made by the time that Aircraft 1 passes a blue hash mark on the flight path
- Projection is recorded using red arrowheads
Dependent Variables

- **Accuracy of projection**
  - Difference between projected separation & actual separation when aircraft 1 crosses the threshold

- **Subjective rating of difficulty of constant versus decelerating aircraft projection and the strategy used to project separation**
Participants

- 8 French student controllers with an average of 1.25 years experience
- 5 were Approach/Tower controllers
- 2 were En Route Center Controllers
Controllers projected less accurately in the mixed speed profile scenarios (closing case: $t=2.021$, $p<.05$, equal case: $t=1.279$, $p<.15$)

When both aircraft decelerated at the same rate, projection accuracy equaled the accuracy when both aircraft proceeded at constant speed.
Subjective Responses

- Difficulty of constant speed vs. deceleration
  - 6 of 8 said that decelerating was more difficult
  - One mentioned that the mixed profile opening case was the most difficult

- Strategy during the task:
  - *Heuristic*: 6 of 8 mentioned sampling the separation at two points then estimating separation based on the difference between the two samples
  - 2 mentioned missing the speed vector on the radar display
Results Discussion

- Accuracy: Controllers were more accurate in projecting both constant or both decelerating aircraft than in projecting mixed profile aircraft.
- A simple mental calculation based on separation sampling could be established for the constant & both decelerating case because the relative separation change over time was either constant or appeared linear.
- Mixed profile scenarios: Possibility that no simple mental calculation could be established because the relative separation change was nonlinear.
The controllers’ task in this experiment was to project relative separation between the two aircraft.

Relative separation in the Mixed Profile case was an observable nonlinear function, making the projection task more difficult.
Conclusions

- Controllers’ acceptance & ability to project future behavior of aircraft on approach are a barrier to implementing low noise procedures
- Key differences between procedures affect cognitive processes:
  - Loss of simple dynamic abstractions → More complex dynamics to project & higher workload
  - Loss of controllability → Longer projection time required
  - Impact on workload due to changed tasks & projection requirements
- ATC support is required, possibly in the form of:
  - Reduction of projection requirement
    - E.g., Improving ATC speed controllability in RNAV CDA procedure-speed commands and/or speedbrakes control
  - Supporting the formation of new projection abstractions
    - E.g., Increasing predictability of dynamics- structured deceleration profiles