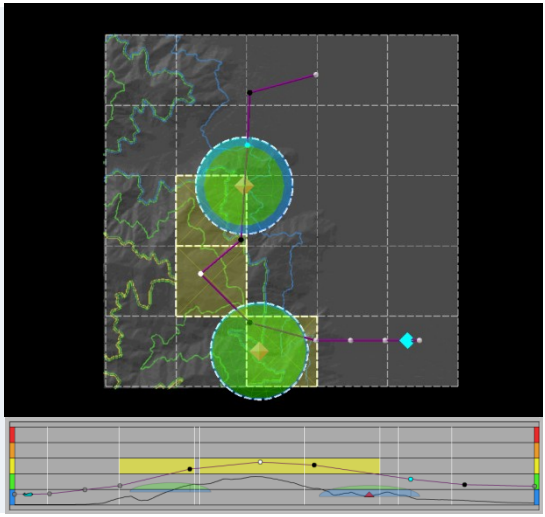
When Plans Change:
Task Analysis and Taxonomy of 3D Situation Awareness Challenges of UAV Replanning



Maia B. Cook, PhD and Harvey S. Smallman, PhD

Pacific Science & Engineering Group

San Diego, CA

15th ICCRTS, 22-24 June, 2010, Santa Monica, CA

Track 8: C2 Assessment Tools and Metrics

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UAV operator human factors challenges

- Complex tasks
- High workload
- Multiple competing constraints
- Dynamic environments
- Display-mediated interactions

From *U.S Customs and Border Protection*

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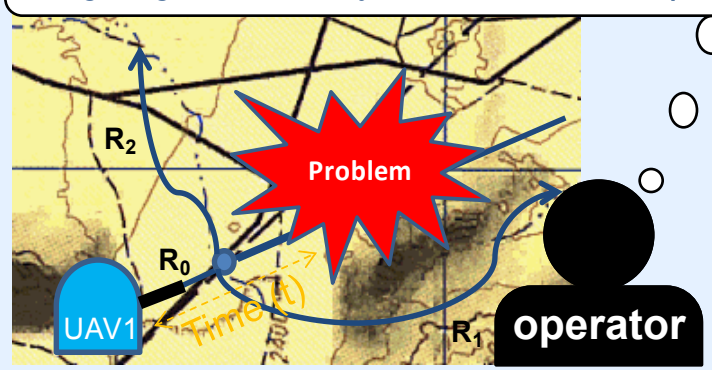
Project overview

- Problem: UAV operator challenge of rerouting UAVs on-the-fly
  - Complex 3D environment
  - Conflicting dynamic constraints

"Should I go left, right, up, down?"
"How will I get imagery?"
"If I go right, will I stay under closed airspace?"

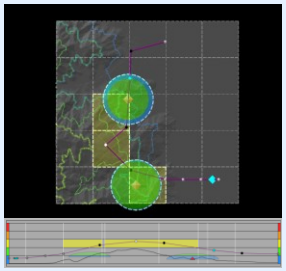


- Approach and solutions

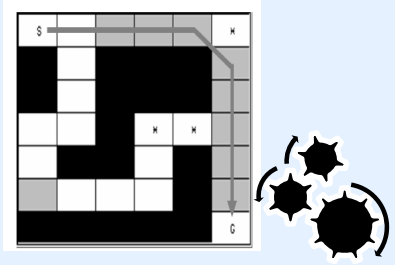
1. Analyze replanning problem

Cognitive Task Analysis
3D challenges of UAV replanning

2. Improve display visualizations



3. Introduce path planning automation (PPA)



- Benefits
  - Improved operator situation awareness
  - Faster, less error-prone rerouting

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Current work in wider context

- Complex multi-faceted UAV research space
- How is current work *unique*?
  - 3D spatial awareness replanning challenges
- Why is current work *necessary*?
  - Problem analysis is necessary precursor
  - Guides assessment and metrics
  - Guides design of display and automation solutions

McCarley & Wickens, 2005, for review

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Cognitive task analysis (CTA)

- Purpose
  - Enumerate specific 3D cognitive/perceptual challenges of replanning
- Method
  - Structured interviews w/4 Navy VC-6 Shadow UAV operators
  - Topic areas
    - » Background and context
    - » Replanning event triggers
    - » Replanning goals and strategies
    - » Current display features

Cognitive Task Analysis

3D challenges of UAV replanning

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Cognitive task analysis (CTA)

- General findings
  - Frequent need to replan
    - » Dynamic targets
    - » Congested airspace
  - Multiple event triggers, different shapes
  - Replanning entails understanding & resolving competing 3D constraints
  - Time-constrained replanning → satisficing strategy
  - Poorly supported by current displays

Cognitive Task Analysis

3D challenges of UAV replanning

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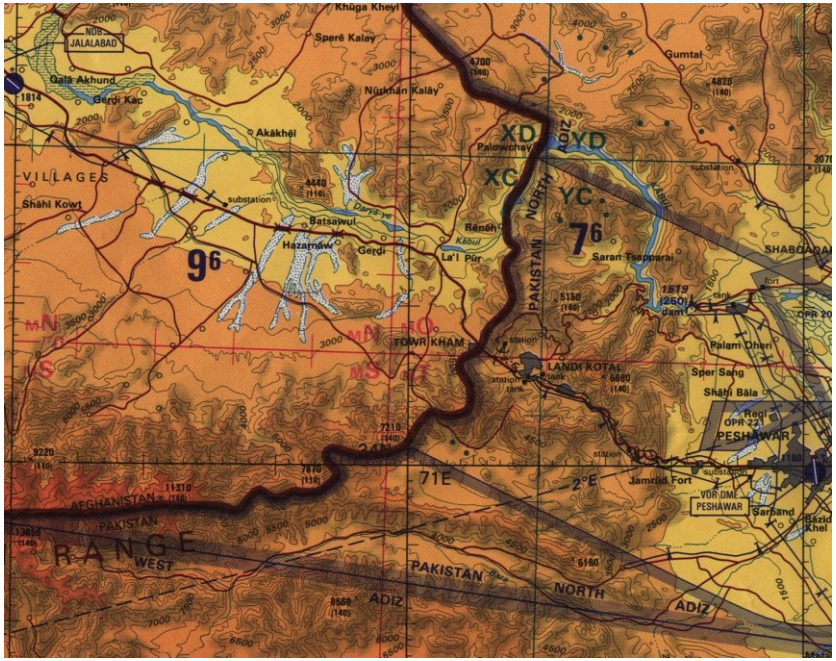
Current operator map displays

- 2D topo maps (TPC format)
- Terrain altitude
- Occasional profile view

- Display challenges
  - Cluttered
  - Limited in conveying shape & 3D scene layout (St. John et al., 2001)
  - Difficult to integrate top-down and profile views (Haskell & Wickens, 1993)



From *Tactical Pilotage Chart TPC G-6C, U.S. Defense Mapping Agency*

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CTA specific results

- Enumerated rerouting event triggers
  - Target tracking changes
  - Airspace availability
  - Aircraft avoidance
  - Counter-detection requirements
  - Weather avoidance
  - Terrain considerations
- Identified key attributes related to each event
  - Spatial requirements, and action (approach, avoid)
  - Relative frequency
  - Time pressure
  - HF display intervention

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CTA results codified in taxonomy

- Organized results into taxonomy
- Events ordered by spatial aspects and relative frequency
- Display requirements applied to task-display dichotomy (St. John, Cowen, Smallman & Oonk, 2001)
  - 2D for relative position
  - 3D for shape understanding and layout

Rerouting event trigger	Spatial aspects of rerouting goal	Other rerouting requirements	Relative frequency	Time pressure	Event shape understanding requirements	Event relative position requirements	Potential HF leverage points
New/change to target tracking requirement	Stay within LoS region for target ISR.	• Remain within cleared airspace • Avoid terrain • Avoid other aircraft	High	High	Target visibility profile shape	Distance and angles of target	Specify optimal coverage of target in 3 dimensions.
Change in airspace availability	Avoid restricted airspace. Stay within available airspace.	• Satisfy target tracking requirements • Avoid terrain • Avoid other aircraft	High	Medium	Configuration of available airspace	Distance and angles of available airspace	Make airspace boundaries explicit; Show available and closed airspace.
Aircraft avoidance	Avoid airspace region occupied by other aircraft.	• Satisfy target tracking requirements • Remain within cleared airspace • Avoid terrain	High	High	Aircraft avoidance region shape	Distance and angles of aircraft	Make location of other aircraft explicit. Provide airspace transit times, distances, and relative position.
Counter-detection	Avoid detection region.	• Satisfy target tracking requirements • Remain within cleared airspace • Avoid terrain • Avoid other aircraft	Low	Medium	Counter-detection region shape	Distance and angles of counter-detection region	Convey shape understanding of counter-detection regions and their relation to terrain.
Weather avoidance	Avoid weather region.	• Satisfy target tracking requirements • Remain within cleared airspace • Avoid terrain • Avoid other aircraft	Low	Medium	Weather avoidance region	Distance from weather region	Convey location and shape understanding information of hazardous weather.
Terrain	Avoid collision with terrain. Avoid LoS occlusion from terrain. Land safely on terrain.	• Satisfy target tracking requirements • Remain within cleared airspace • Avoid other aircraft	Constant	Medium	Gross terrain shape	Distance and angles of terrain	Convey both shape understanding about terrain and precise relative position information about distances.

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CTA results codified in taxonomy

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CTA results inform synthetic replanning task

Conducted CTA of 3D spatial awareness challenges of UAV replanning

Cognitive Task Analysis

3D challenges of UAV replanning

Replanning event taxonomy

Rerouting event trigger	Spatial aspects of rerouting goal	Other rerouting requirements	Relative frequency	Time pressure	Event shape understanding requirements	Event relative position requirements	Potential UI leverage points
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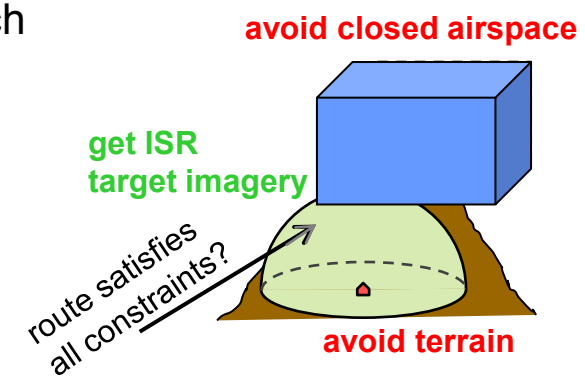
Designed synthetic replanning task with abstracted 3D constraints

- Actions: avoid, approach, avoid + approach
- 3D constraints: airspace, targets, terrain
- Kinematic constraints
- Time pressure



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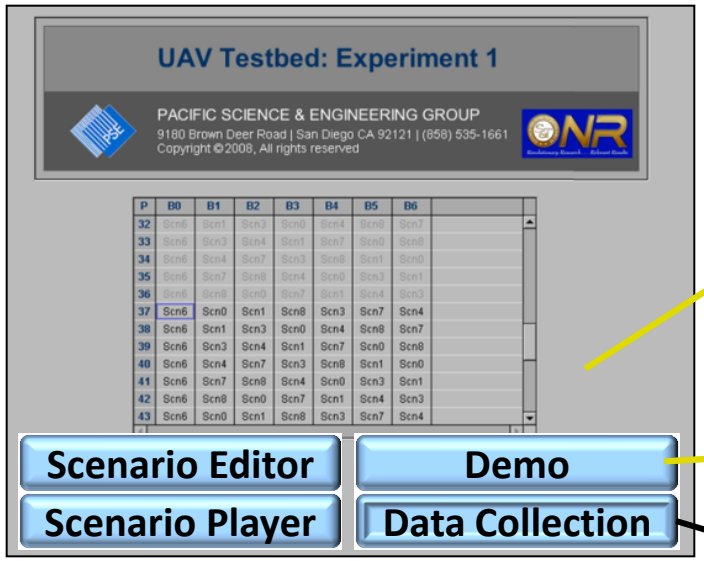
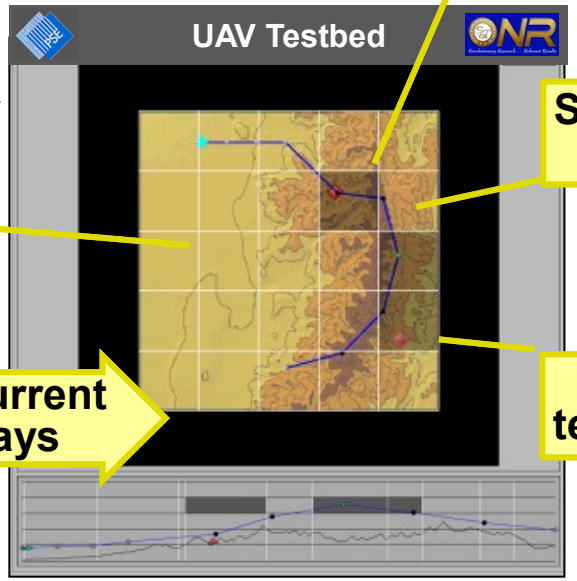
Testbed for studying UAV replanning



Operationally valid measures of performance

Alternate modes

Specific configurations of 3D replanning constraints



Synthetic task

Customizable display formats, interface settings

Key features of current GCS map displays

Real terrain

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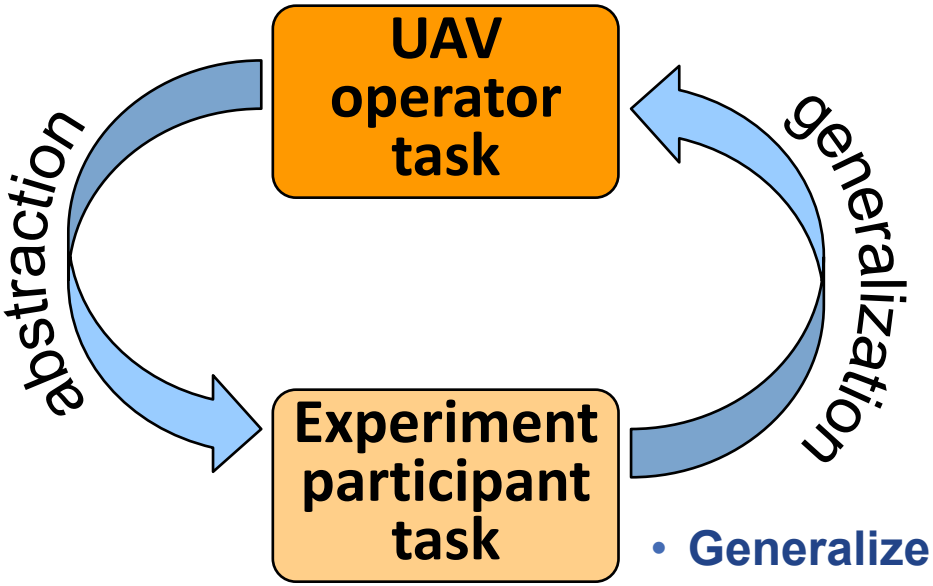
Synthetic task abstraction

- **Abstract** essential elements of real UAV replanning into synthetic task
  - Greater experimental control
  - Reduced time needed for simplified task
  - Consistency across participants
  - Allows sensitive measurement



- **Generalize** results back to real-world UAV replanning
  - Similar 3D replanning challenges
  - Similar display features
  - Similar time constraints

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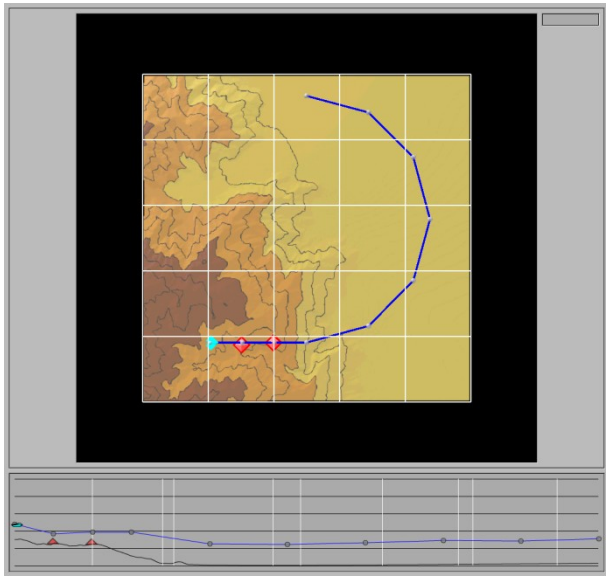
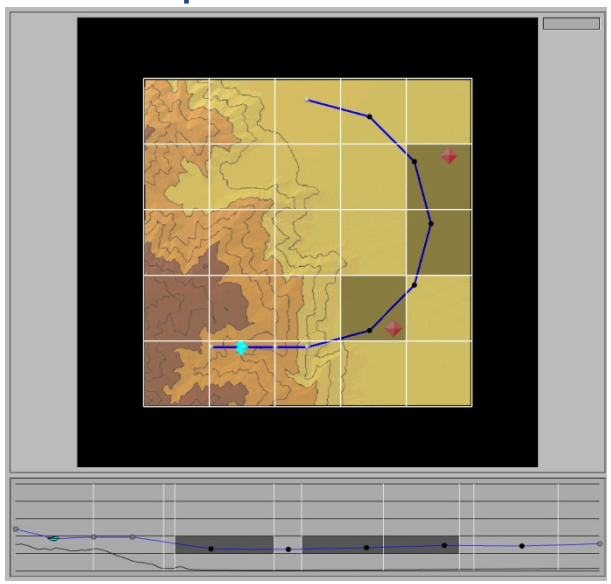
Exp 1: Validate CTA

- Purpose
  - Experimentally validate CTA, measure replanning
  - Baseline for replanning interventions
- Task: Replan UAV routes to satisfy emerging requirements (airspace, targets)

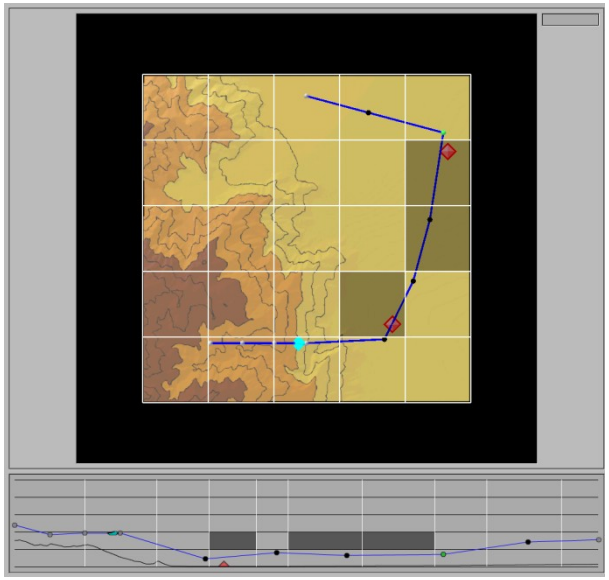
Route



Compromised route



Fixed route



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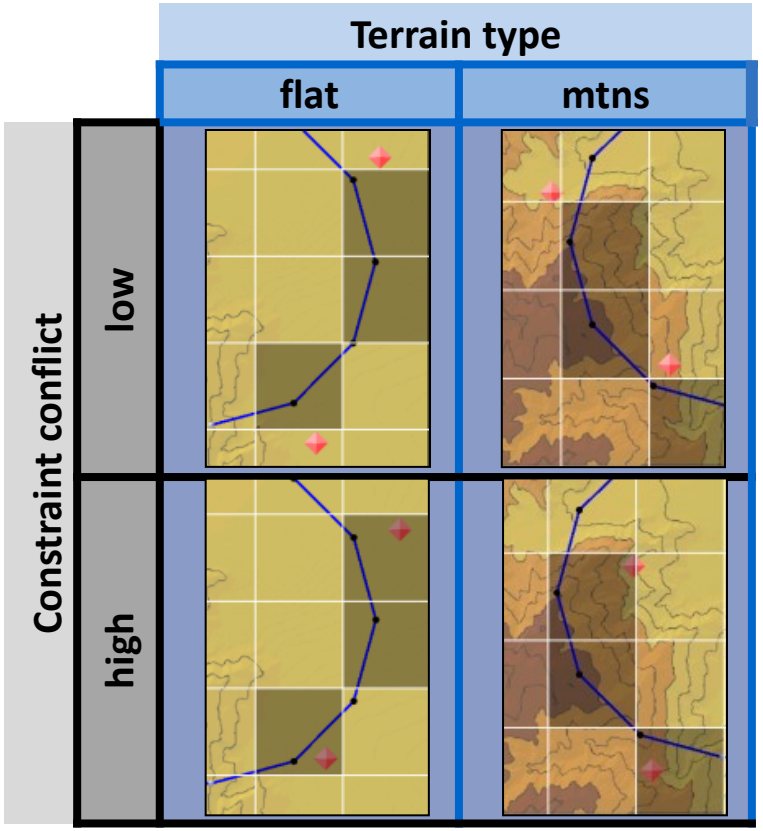
Cook, Smallman, Lacson, & Manes 2009 (HFES)

Exp 1: 3D replanning constraints

- Independent variables:
  - **Terrain**: flat, mountainous
  - **Constraint conflict**: high, low
- Replanning performance metrics
  - Operator efficiency
    - » Replanning RT
    - » Replanning movements
  - Mission success
    - » Accuracy (general)
    - » Violation types (specific)
  - Route efficiency
    - » Route length



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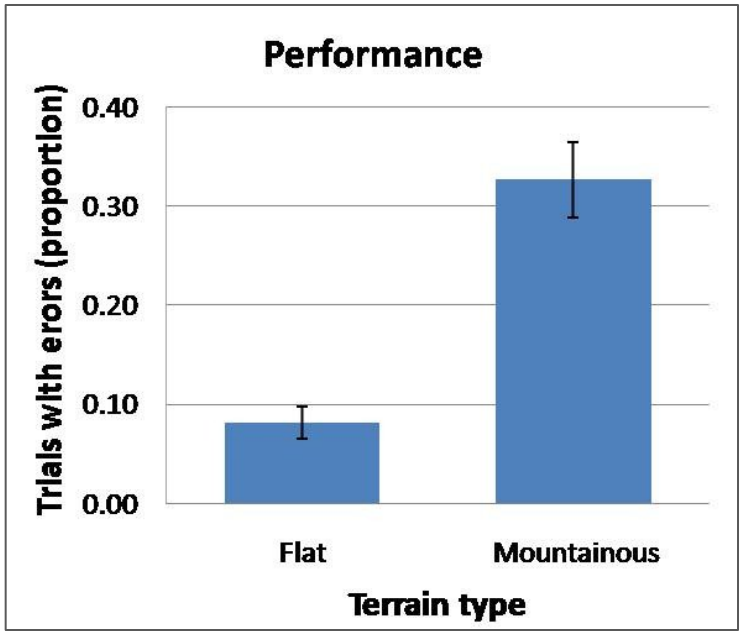
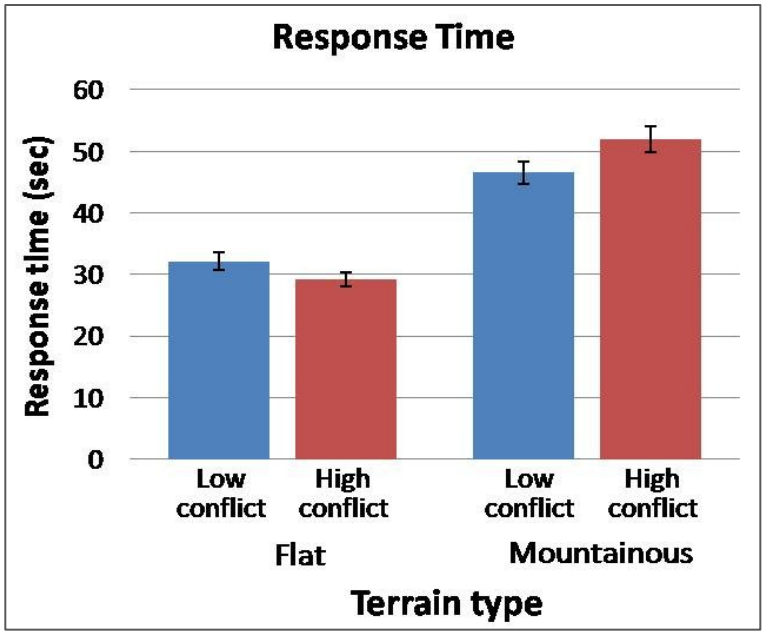
Cook, Smallman, Lacson, & Manes 2009 (HFES)

Exp 1: 3D replanning constraints

- Results
  - Lower mission success in mountainous terrain (accuracy)
  - Lower mission success for targets, then airspace, then terrain (violation types – specific)
  - Lower operator efficiency in mountainous terrain, especially for high conflict (replanning RT and movements)





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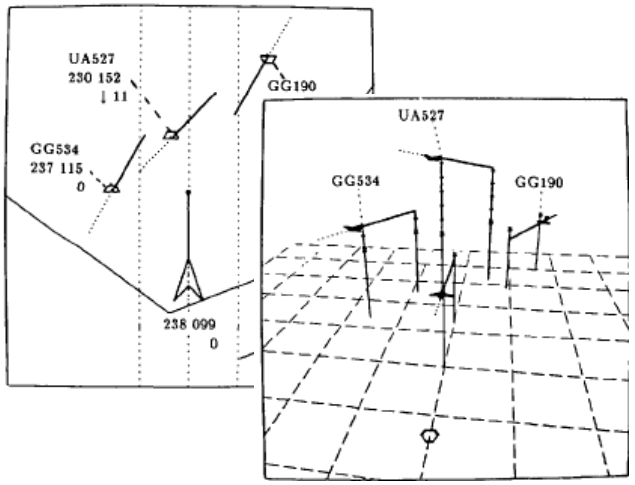
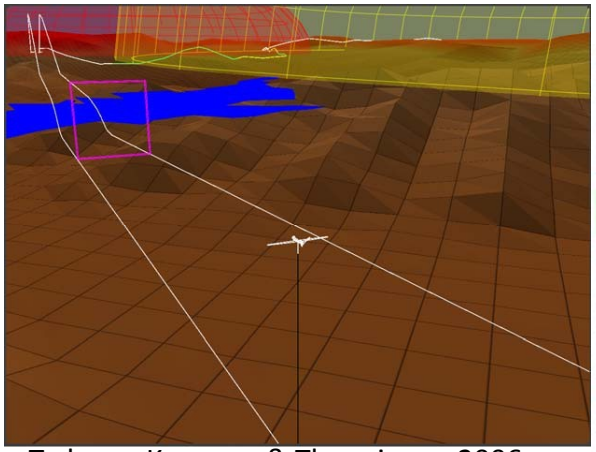
Cook, Smallman, Lacson, & Manes 2009 (HFES)

Design new visualizations for replanning

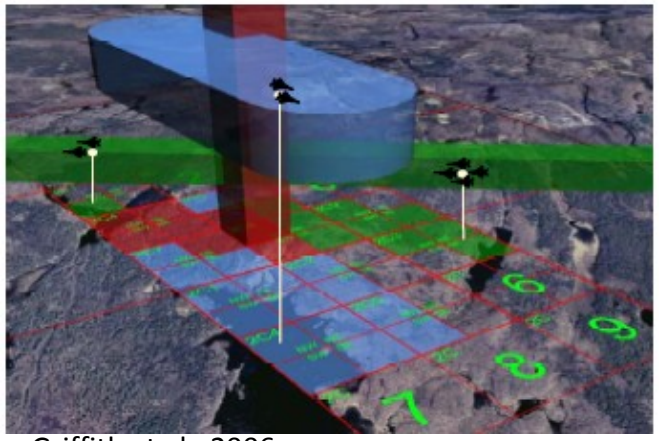
- Reviewed previous approaches for displaying scenes and attributes (including aviation, ATC, synthetic vision)



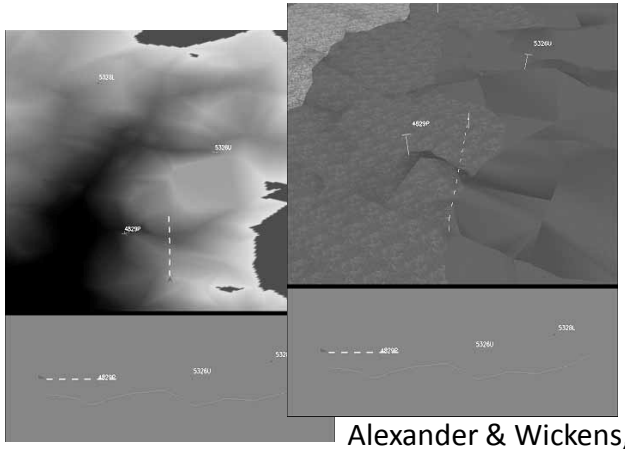
Ellis, McGreevy, & Hitchcock, 1987



Tadema, Koeners, & Theunissen, 2006

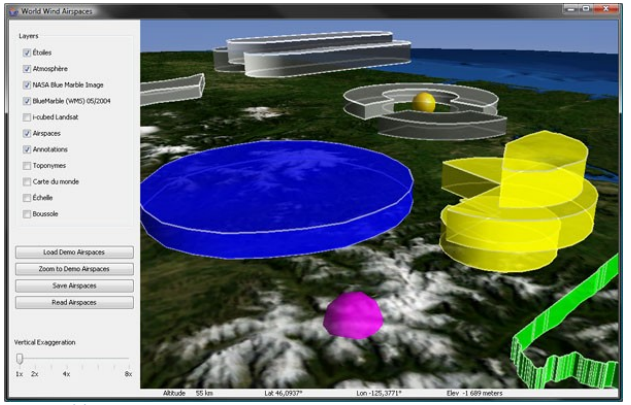


Griffith et al., 2006



Alexander & Wickens, 2004

http://interactive.usc.edu



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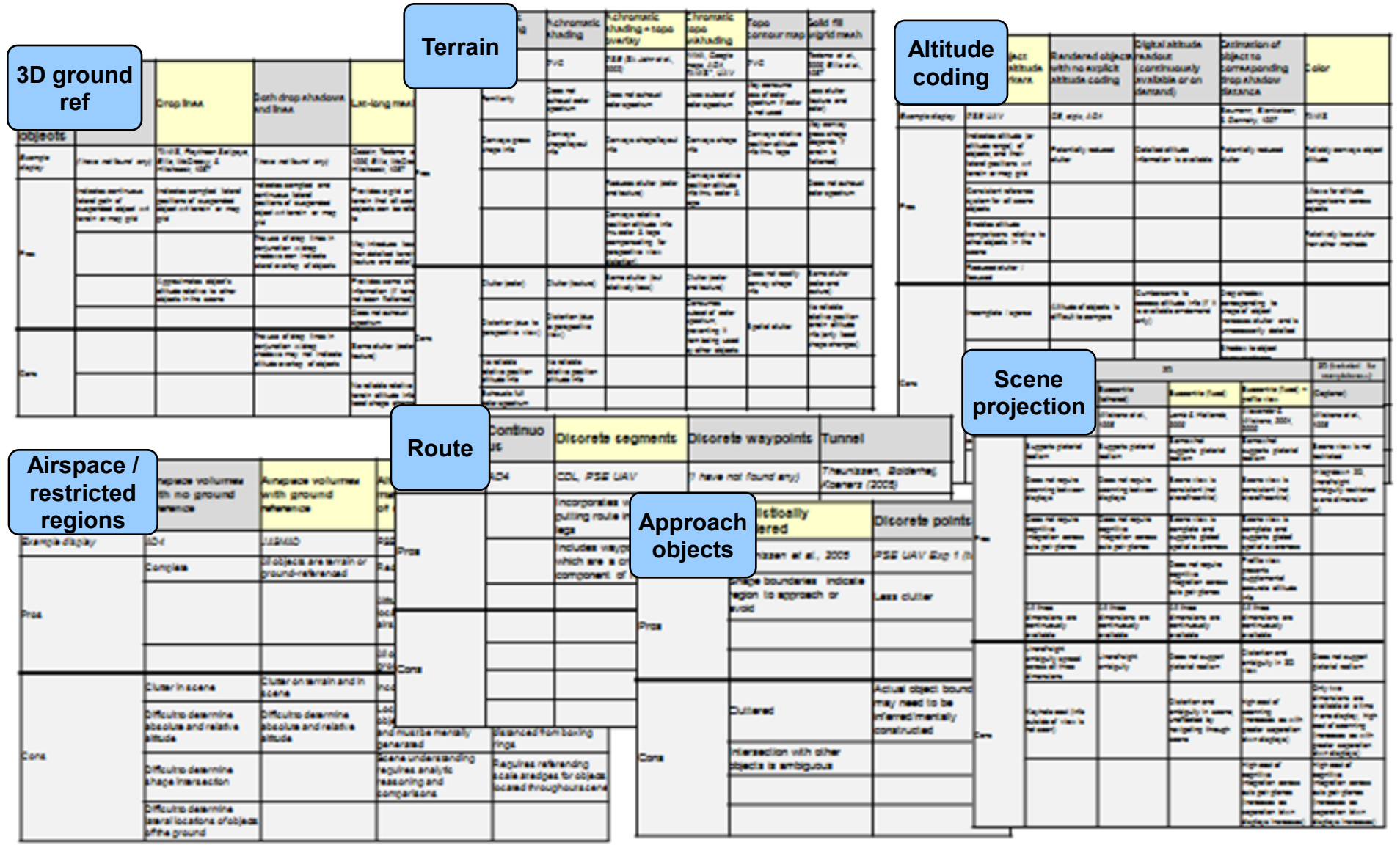
Display feature pro-con analysis



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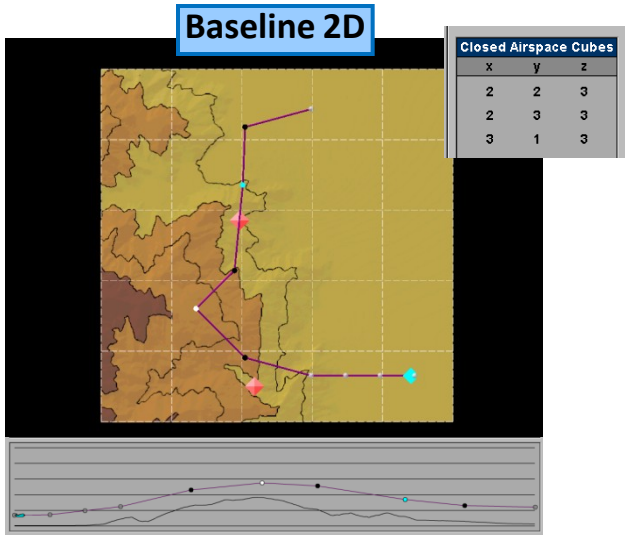
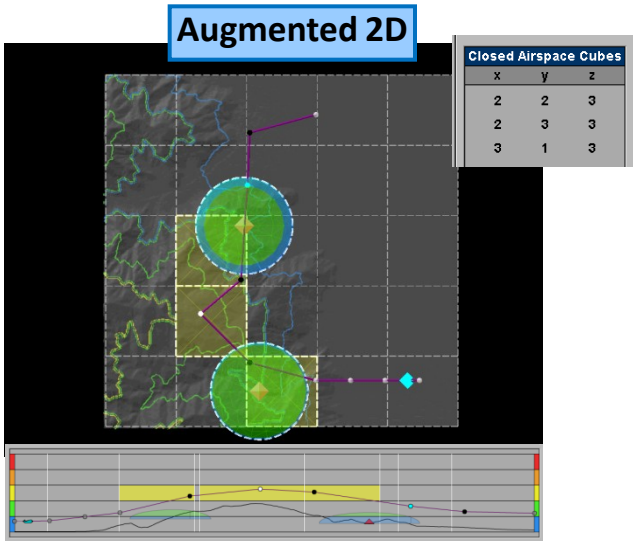
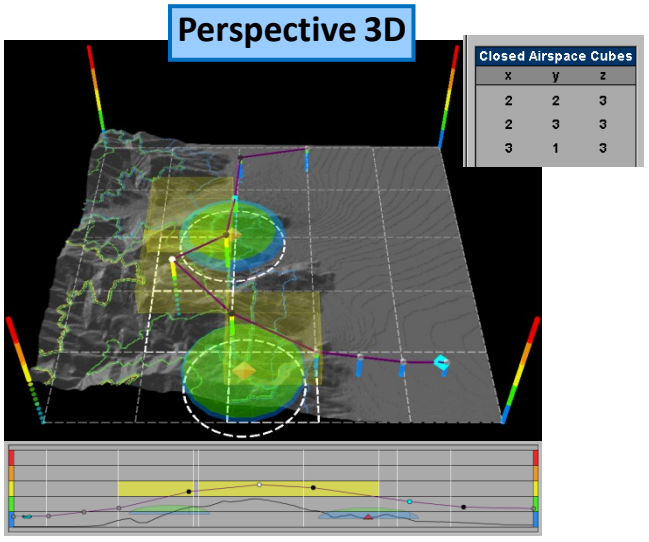
Design of new display visualizations

- Informed by
  - Replanning task and display requirements from CTA and taxonomy
  - Display feature pro-con analysis
  - ONR-sponsored PVC project, framework (Smallman, St. John, et al., 1998-2008)
- Constrained by experiment comparison







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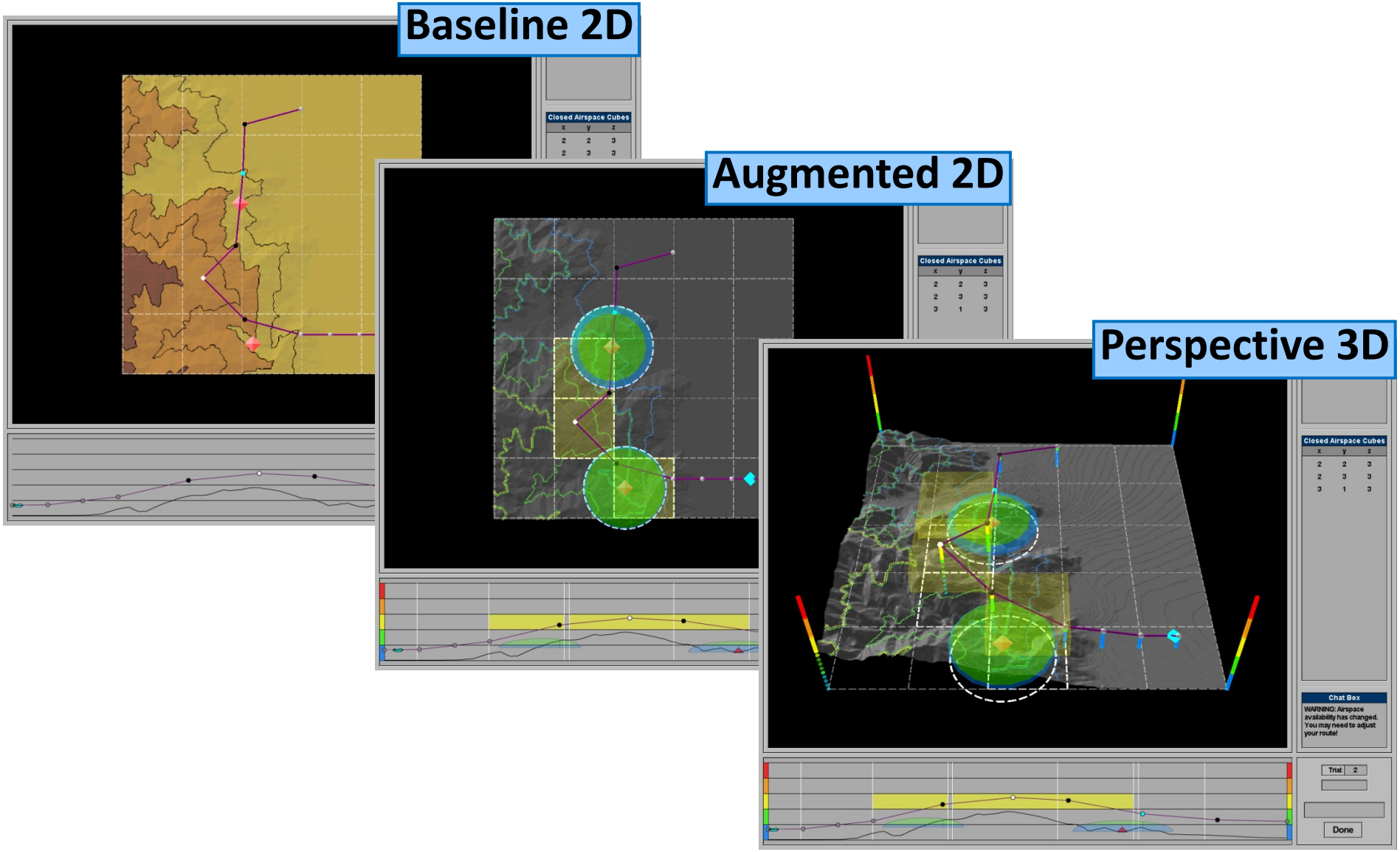
Exp 2 display conditions



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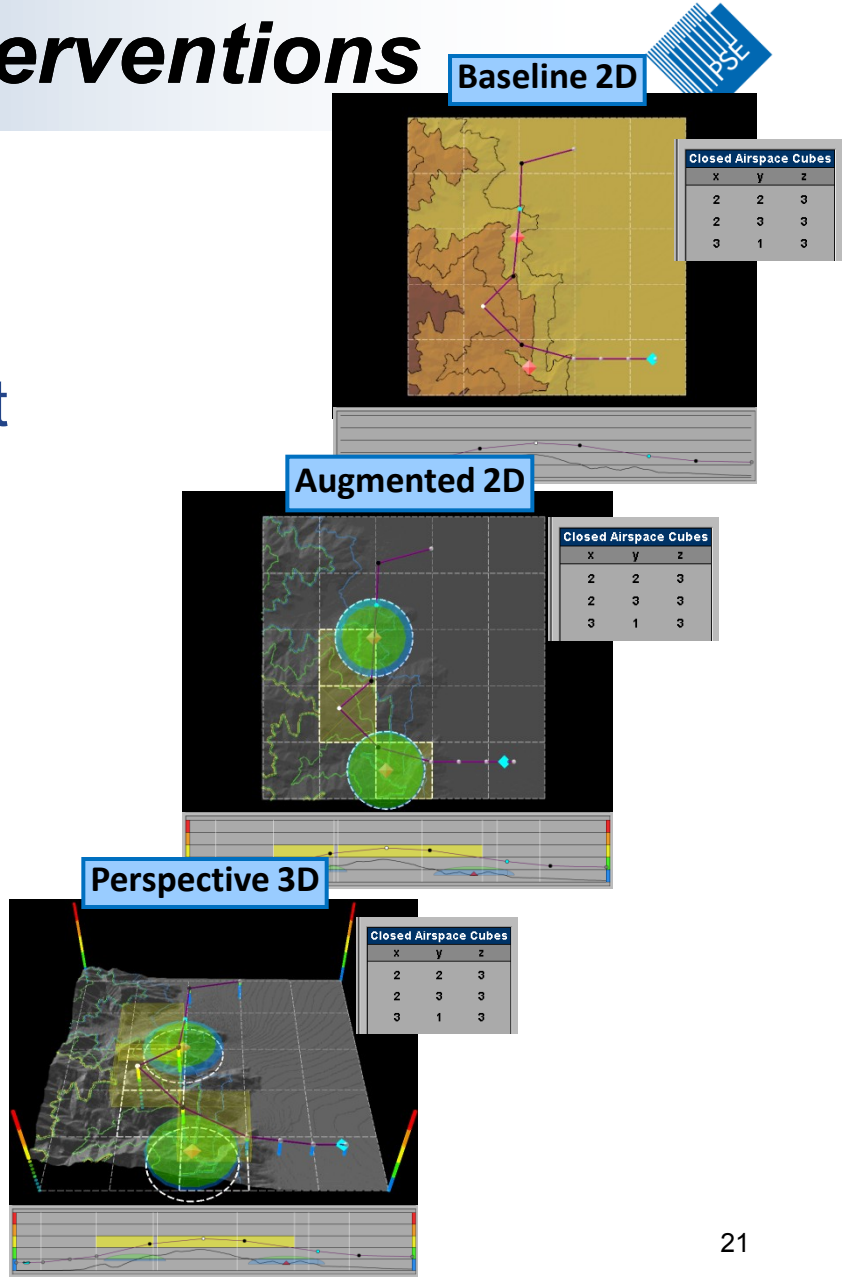
Exp 2: Visualization interventions

- Exp 2 focus
  - Display format
  - Intuitions and preferences
- Repeated Exp 1, + display format
- Replanning performance metrics
  - Operator efficiency
    - » Replanning RT
    - » Replanning movements
  - Mission success
    - » Accuracy (general)
    - » Violation types (specific)
  - Route efficiency
    - » Route length
  - Spatial ability
  - Display intuitions and preference



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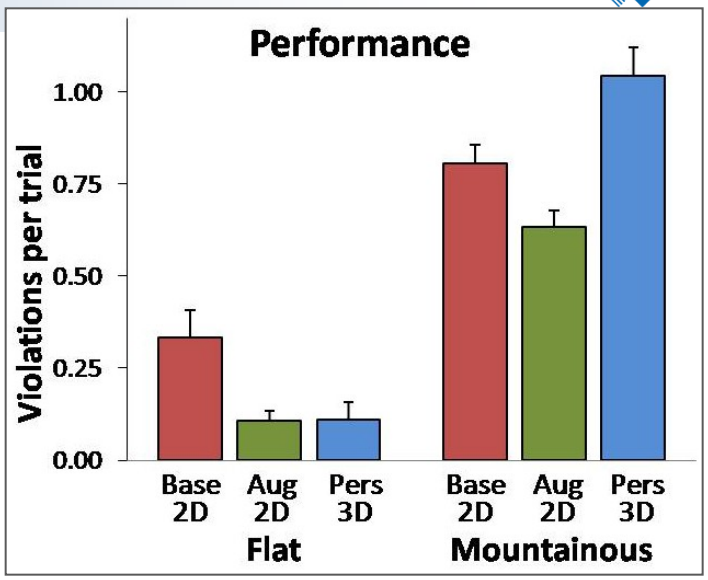
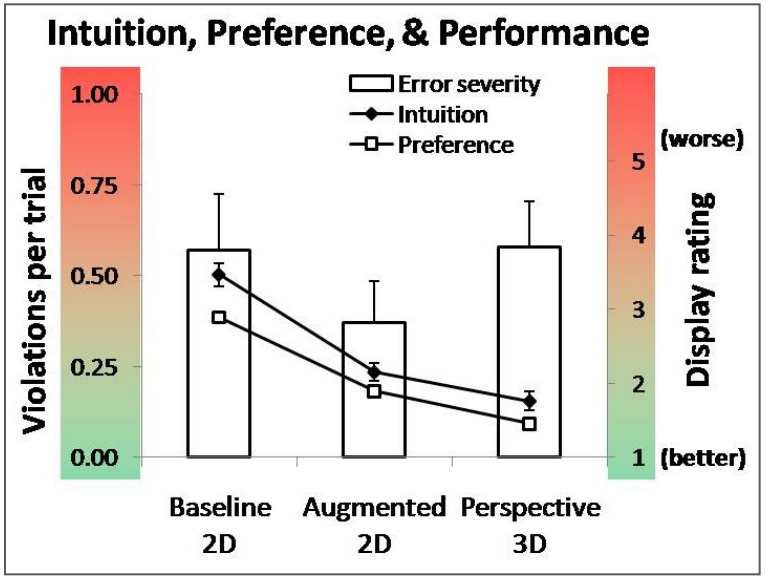
Exp 2: Results

- Display format
  - In mtns, highest mission success for Aug. 2D, lowest for Pers. 3D
  - Doing more with less
  - Perspective 3D ROI questionable



- Intuitions & preference
  - Intuition-performance mismatch
  - Caution against user configuration
- Spatial ability
  - Aug. 2D better performance, without requiring high spatial ability



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Summary and application

- Conducted, analyzed, and reported CTA & taxonomy
  - Generalizable to range of UAV environments/missions
  - Informs display design, algorithm requirements (algorithm type, considerations)
- Designed synthetic task to assess replanning performance
  - Adjustable 3D constraint configurations
- Developed operationally-relevant metrics focused on 3D spatial awareness needed for replanning
  - Validated in two controlled performance evaluations (Cook, Smallman, Lacson, & Manes, 2009, 2010)
  - Adaptable for evaluating other C2 systems involving planning, replanning, and routing tasks
- Designed UAV replanning testbed
  - Flexible environment to evaluate display and automation interventions

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Contacts

Maia B. Cook, PhD
MaiaCook@pacific-science.com

Harvey S. Smallman, PhD
Smallman@pacific-science.com

Pacific Science & Engineering Group
9180 Brown Deer Road
San Diego, CA 92121
858-535-1661

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