Designing a Flight Deck Predictive Weather Forecast Interface Supporting Trajectory-Based Operations

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The WIDB: A Conceptual Model

**Observations**
- Satellites
- Radars
- Aircraft
- Surface
- Soundings

**Forecasting**
- Numerical Modeling Systems
- Statistical Forecasting Systems
- NWS Forecaster
- Automated Forecast Systems
- Forecast Integration

**Integration into User Decisions**
- Decision Support Systems
- Custom Graphic Generators
- Custom Alphanumeric Generators

Source: National Weather Service
The WIDB: A Conceptual Model

This is what the past and present look like

This is our best guess for what the future looks like

What should I do based on what I know?
okay, but how?
A snapshot of current day Boeing 747-400 ND, middle of the night somewhere between Sydney and Fiji, en route to SFO

Display weather forecasts on the flight deck

Support for in-flight trajectory planning
A direct manipulation interface that supports the manipulation of the display of predictive weather forecasts and graphical in-flight trajectory planning.
Direct Manipulation Interface

Concepts

- **skill-based**
  - use provided methods to send commands and cause state changes in the system

- **rule-based**
  - determine what actions to take at the skilled-based level based on cues and feedback from the system

- **knowledge-based**
  - form a mental model of the system to help interpret cues and feedback
# Direct Manipulation Interface

## Implementation

### Concepts

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### Implementation

Able to view ownship represented in the interface and control its spatiotemporal trajectory, in ways similar to flying through the airspace

dynamically display both predicted aircraft position and weather development in a virtual 3D airspace
Cockpit Situation Display (CSD)
Providing CD&R and Route Planning Functionalities

3D Terrain and Traffic
2D/3D Weather
Conflict Detection and Resolution (CD&R)
Route Assessment Tool (RAT)
Route Assessment Tool (RAT)
Direct Manipulation Interface for Route Planning and Modification

Provides the ability to:
- create and visualize in-flight route modifications
- submit proposed route modifications to ATC
- receive and execute modifications

Direct manipulation features:
- Single-click waypoint creation at arbitrary positions along trajectory
- Drag-and-drop waypoint re-positioning
- Single-click way-point elimination
# Predictive Weather Viewing Methods

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Predictive Weather Viewing Methods

**Synchronous *Pulse***

- Users set the farthest predictive range in time ahead.
- A corresponding extrapolation of predictive weather and aircraft position over the specified time interval into the future is repeatedly shown as synchronous pulses.
Predictive Weather Viewing Methods

Time-Based **Slider**

- users set pinpointed time ahead by adjusting a time slider
- as time slider is being adjusted by hand on the slider, aircraft position indicator and weather forecast move accordingly to reflect prediction at the specified time ahead
Predictive Weather Viewing Methods

Space-Based *Route*

- users set pinpointed aircraft position ahead by directly manipulating an aircraft indicator on route
- as future aircraft position is being manipulated by hand on route, weather forecasts move accordingly to reflect prediction at the specified position ahead
## Predictive Weather Viewing Methods

### Feature Summary

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- Good for hands-free viewing/monitoring
- Good for inspecting/monitoring a specific time interval ahead
- Good for inspecting/monitoring a specific location of close weather/aircraft proximity ahead
Part-Task Experiment
Participants, Design, and Task

• Participants:
  – Eighteen transport pilots with high-altitude flight experience

• Design:
  – 3 viewing methods (Pulse, Slider, Route)
  – 4 weather encounter types
    • Middle
    • Initially clearing gap
    • Initially clearing edge
    • Clear later
  – 2 distances to weather (40 or 80 nm)

• Task:
  – Find a safe and efficient re-route around weather
Results
How well does the interface support weather avoidance?

- **Speed**
  - **evaluation time**: from trial start to RAT activation
  - **modification time**: from RAT activation to execution
  - **total time**: evaluation plus modification

- **Quality**
  - **path stretch**: increase in length of modified path compared to the original one
  - **closest point of approach (CPA)** to weather
Results

- Speed
  - total time: evaluation plus modification

Findings
- a main effect of encounter type
- an interaction between encounter type and distance to weather

Implication
- shorter time horizon made it more difficult to modify trajectories going through middle of storm but easier to handle those initially going through gaps
Results

• Speed
  – total time: evaluation plus modification

Finding
- an interaction between viewing method and encounter type

Implication
- a small advantage in using the route method when the encounter type requires more difficult maneuvers
Results

- **Quality**
  - **path stretch**: increase in length of modified path compared to the original one

**Finding**
- a main effect of encounter type
- an interaction between encounter type and distance to weather

**Implication**
- less path stretch with more imminent weather encounter, suggesting pilots were more willing to trade off risk for efficiency
Results

- Quality
  - closest point of approach (CPA) to weather

Finding
- a main effect of encounter type
- a main effect of distance to weather
- an interaction between encounter type and distance to weather

FAA Guidance is 20nm
Not so mysterious after all...

Current Finding
- pilots routinely modified trajectories to be further away from weather on “clear later” scenarios where trajectories were constructed to clear weather by 10 nm if left unchanged

Implication
- pilots use heuristics to exploit opportunities present in a given encounter, such as this one for increasing a safety margin

Figure 11. Illustration of an unclear deviation strategy. Pilot makes a large deviation in a region of benign weather, more than 100 km downwind from nearest convective cell.

Results
How well does the interface support weather avoidance?

• Subjective Evaluation
  – Pulse method received the highest ratings in terms of both implementation and utility, followed by Slider and Route
  – In general, all rated highly for their implementation and utility

• Overall
  – All methods supported the task about equally well
  – Preference for Pulse method likely attributable to the additional pulsing function
Final Thoughts
Implication on ATM Weather Integration

- Pilot weather avoidance strategy is affected by distance to weather.
- Models of weather avoidance behavior developed based on current day technologies, such as CWAM, may not be applicable to predict behaviors of pilots with access to long range of predictive forecasts.
Vielen Dank