A REVIEW OF PATHWAY-IN-THE-SKY DISPLAYS

Presentation to: Synthetic Vision Workshop
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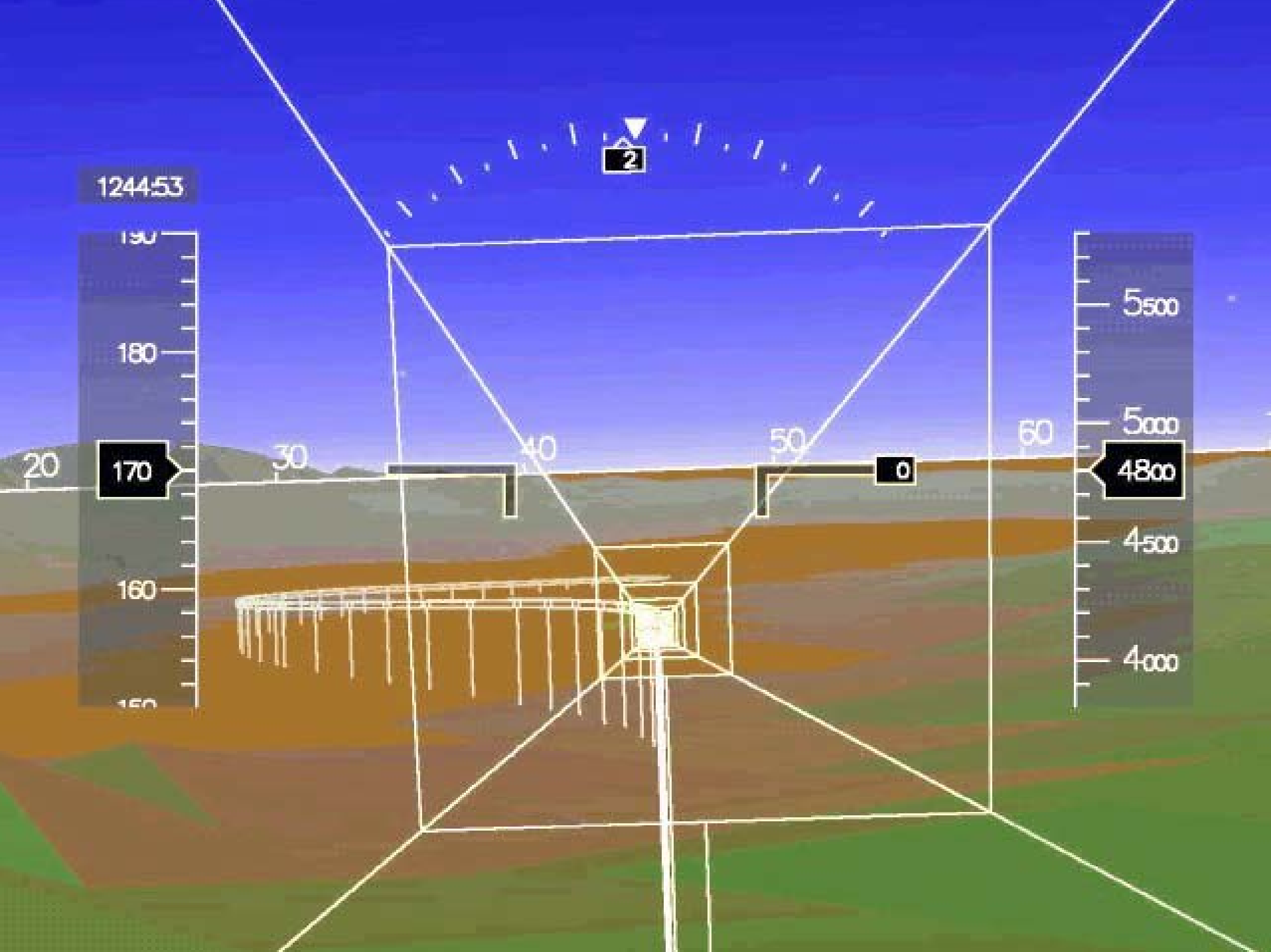
INTRODUCTION

- It has long been a desire to develop "natural" flight instrument presentations to make life easier for the pilot while flying without external visual cues.
- One approach to provide a "natural" flight display has been the pathway-in-the-sky
- This presentation is a adaptation of a survey paper on pathway displays presented at DASC in October 2003.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PATHWAY STUDIES

- La Russa (1971)
- Watler (1984)
- Way, *et al.* (1987)
- Parrish, *et al.* (1994)
- Regal and Whittington (1995)
- Snow, Reising, *et al.* (1998, 1999)
- Williams (2000)
- NASA Studies

PATHWAY STUDIES

- **La Russa (1971): pathway-in-the-sky to allow the pilot to "drive" the airplane.**
  - **No evaluation was reported.**
- Watler (1984)
- Way, *et al.* (1987)
- Parrish, *et al.* (1994)
- Regal and Whittington (1995)
- Snow, Reising, *et al.* (1998, 1999)
- Williams (2000)
- NASA Studies

PATHWAY STUDIES

- La Russa (1971)
- **Watler (1984)**
  - **egocentric vertical situation display**
  - **exocentric horizontal situation display**
  - **flown in JC-131 (TIFS) and F-14**
- Way, *et al.* (1987)
- Parrish, *et al.* (1994)
- Regal and Whittington (1995)
- Snow, Reising, *et al.* (1998, 1999)
- Williams (2000)
- NASA Studies

PATHWAY STUDIES

- La Russa (1971)
- Watler (1984)
- **Way *et al.* (1987)**
  - **Pathway symbology was not well received**
  - **Guidance back to the pathway was rejected by the pilots.**
- Parrish, *et al.* (1994)
- Regal and Whittington (1995)
- Snow, Reising, *et al.* (1998, 1999)
- Williams (2000)
- NASA Studies

PATHWAY STUDIES

- La Russa (1971)
- Watler (1984)
- Way, *et al.* (1987)
- **Parrish, *et al.* (1994)**
  - **Performance:**
    pictorial displays > FD EFIS > RD EFIS
  - **Segment dependent.**
  - **Conflict detection reaction times faster with pictorial display**
- Regal and Whittington (1995)
- Snow, Reising, *et al.* (1998, 1999)
- Williams (2000)
- NASA Studies

PATHWAY STUDIES

- La Russa (1971)
- Watler (1984)
- Way, *et al.* (1987)
- Parrish, *et al.* (1994)
- **Regal and Whittington (1995)**
  - **Compared tunnel with conventional FD**
    - **fewer flight path envelope excursions**
    - **lower workload**
    - **preferred by the pilots**
    - **was felt to provide greater SA.**
- Snow, Reising, *et al.* (1998, 1999)
- Williams (2000)
- NASA Studies

PATHWAY STUDIES

- La Russa (1971)
- Watler (1984)
- Way, *et al.* (1987)
- Parrish, *et al.* (1994)
- Regal and Whittington (1995)
- **Snow, Reising, *et al.* (1998, 1999)**
  - **Segmented pathway symbology**
    - **follow-me aircraft/scene linked "road signs**
  - **Standard symbology switched automatically**
  - **Pathway**
    - **better tracking performance**
    - **pilots reported better situation awareness**
- Williams (2000)
- NASA Studies

PATHWAY STUDIES

- La Russa (1971)
- Watler (1984)
- Way, *et al.* (1987)
- Parrish, *et al.* (1994)
- Regal and Whittington (1995)
- Snow, Reising, *et al.* (1998, 1999)
- **Williams (2000):**
  - **guidance augmentation strongly affect tracking performance**
  - **strong learning curve in the horizontal tracking, but not in the vertical.**
- NASA Studies

PATHWAY STUDIES

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- Watler (1984)
- Way, *et al.* (1987)
- Parrish, *et al.* (1994)
- Regal and Whittington (1995)
- Snow, Reising, *et al.* (1998, 1999)
- Williams (2000):
- **NASA Studies**
    - **Improved tracking performance**
        - **trade-off between clutter and performance**
    - **some pilots experienced cognitive capture**

UNUSUAL ATTITUDES

- Reising, Barthelemy, and Hartsock (1991) compared two HUD formats and a pathway format.
  - Pathway commanded recovery from the UA.
  - Pathway reaction times to the UA were significantly slower

ERROR NEGLECTING STRATEGY

- One of the benefits of the pathway in lateral tracking is that it presents a symmetrical presentation (Theunissen and Mulder, 1995)
- A tunnel might improve vertical tracking.
- Pilots could fly by avoiding the "walls" rather than trying to make the error zero.

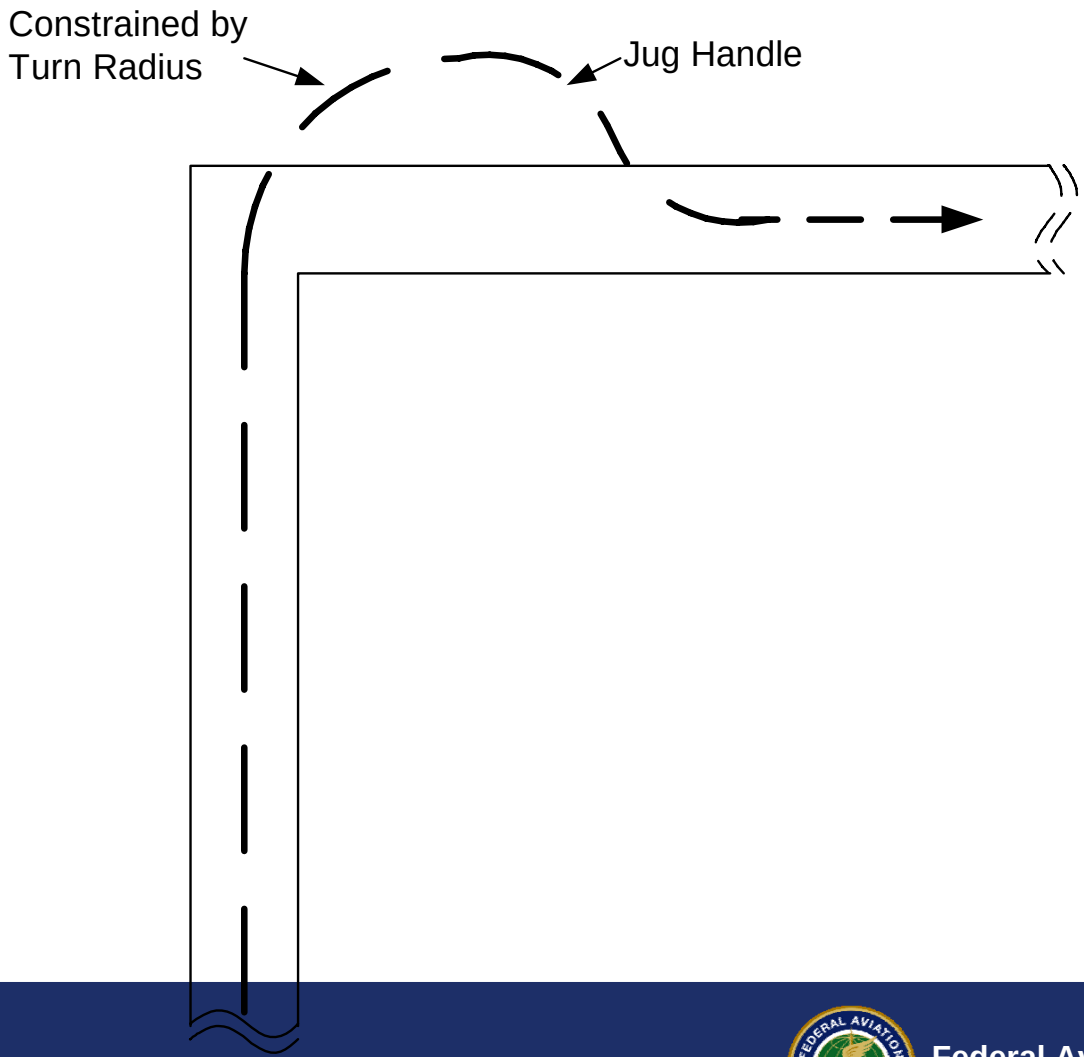
ERROR NEGLECTING STRATEGY

- This is characteristic of drivers driving in a lane.
  - Drivers do not make continuous corrections. Rather, they neglect deviations from the center of the lane until the vehicle is about to cross the lane markings, leading to the concept of the time-to-line-crossing.
- Gaussian vs bimodal error distribution

TURN ANTICIPATION

- It seems as if some of the comparative evaluation did not provide turn anticipation to the pilots on the non-pathway formats which may have contributed to a comparison more favorable to the pathway format.
- Many studies report leg-by-leg tracking errors, but it is not clear whether or not they are penalizing the turn radius of the aircraft.

JUG HANDLE



TURN ANTICIPATION

- Early RNAV
  - Turn anticipation to avoid “Jug Handles”
- Complicated path equations during curves
  - high order blending curves
  - clothoid equations
  - may not be easily created in real-time
- Current RNP practice
  - rather large turning radii
  - turn anticipation for most waypoints.

TUNNEL SCALING

- How Big Should the Tunnel/Pathway be?
- Situation Awareness Concept
  - Tunnel should match the tracking performance standards
- Tracking Performance
  - In general, the combination of good tracking performance combined with satisfactory workload is found with tunnel sizes significantly smaller than the RNP dimensions

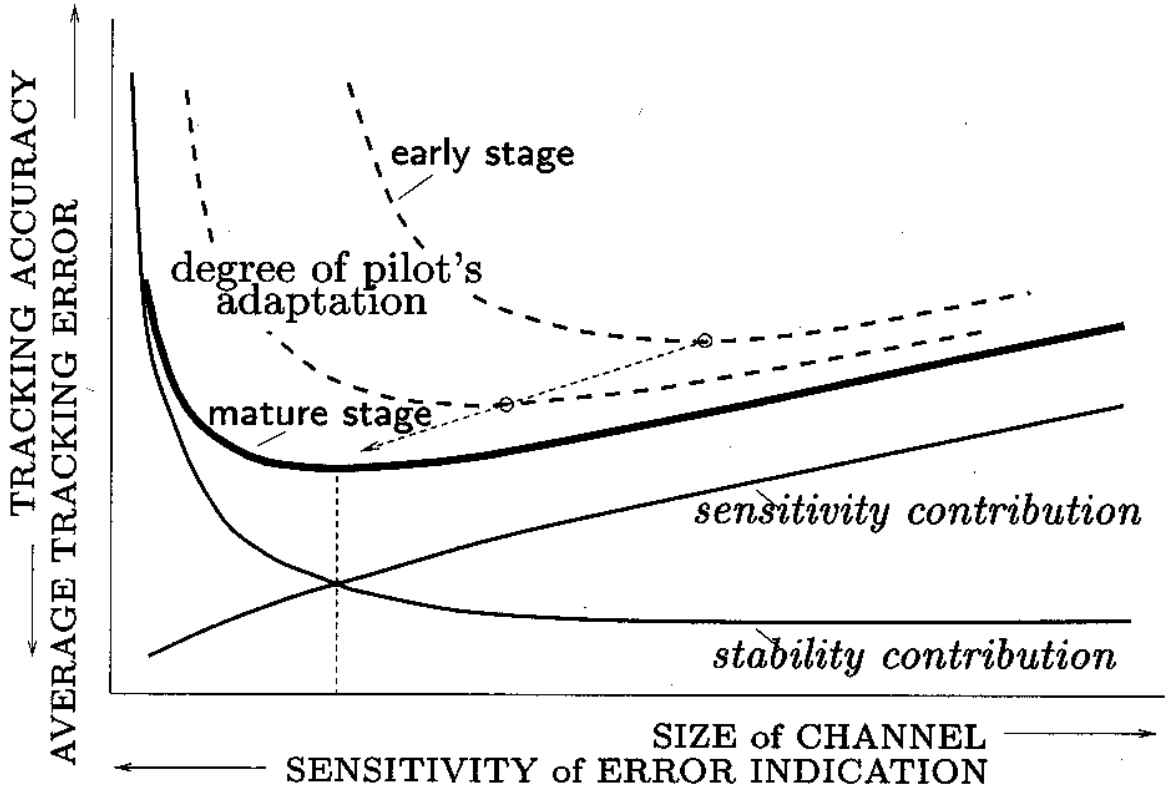
TUNNEL SCALING

- Situation Awareness Concept
  - Tunnel should match the tracking performance criteria
  - If the aircraft position is outside the tunnel, then the pilot/aircraft have not met the performance standards.
  - Follows from the highway traffic lane analogy
  - During terminal operations, the tunnel would be 40:1 lateral/vertical

TUNNEL SCALING

- Tracking Performance
  - Tunnel size significantly smaller than RNP dimensions
- Wilckens (1973) suggests that this is to be expected
  - further reductions in tunnel dimensions will lead to reduced tracking performance.
  - minimum in the tracking error as the size is reduced
  - location of this minimum moves to smaller sizes (and more sensitivity) as pilots adapt

SIZE Versus TRACKING



From Wilckens (1973)

TUNNEL SCALING

- The scaling appropriate for a proficient pilot will be much too sensitive for a pilot inexperienced with the display.
- This may explain why pilots with limited experience with image displays do poorly with conformal displays, but that experienced HUD pilots do well.

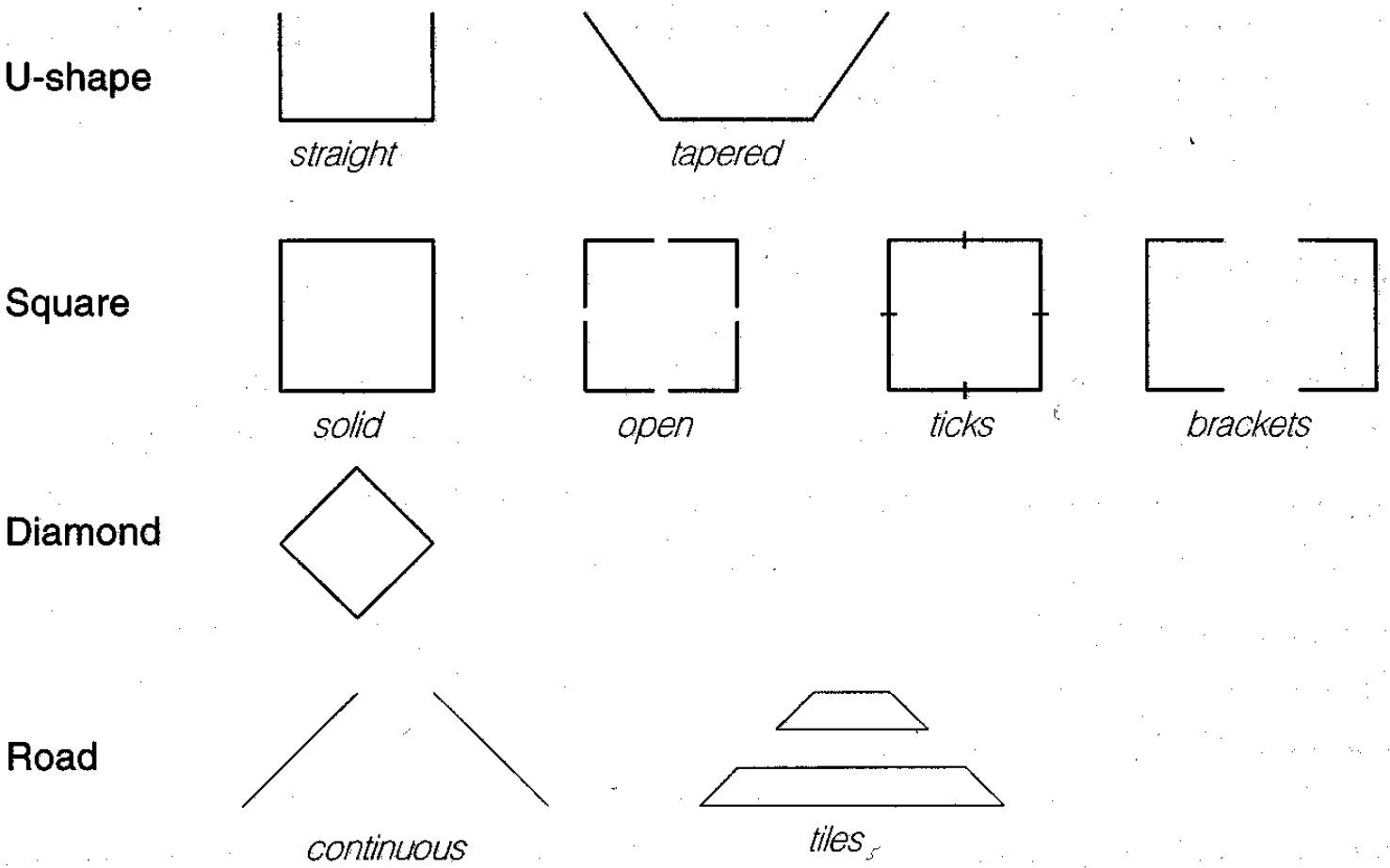
DIFFICULT TO GENERALIZE SCALING STUDIES

- Most studies have confounded the tunnel scaling with the display FOV.
- Not always clear from the published results exactly what the experimental conditions were.
- Display augmentation cues will likely change the effect of scaling.
- Again, most studies confound the data
- Generalizations are difficult.

PERFORMANCE ASSESSMENT

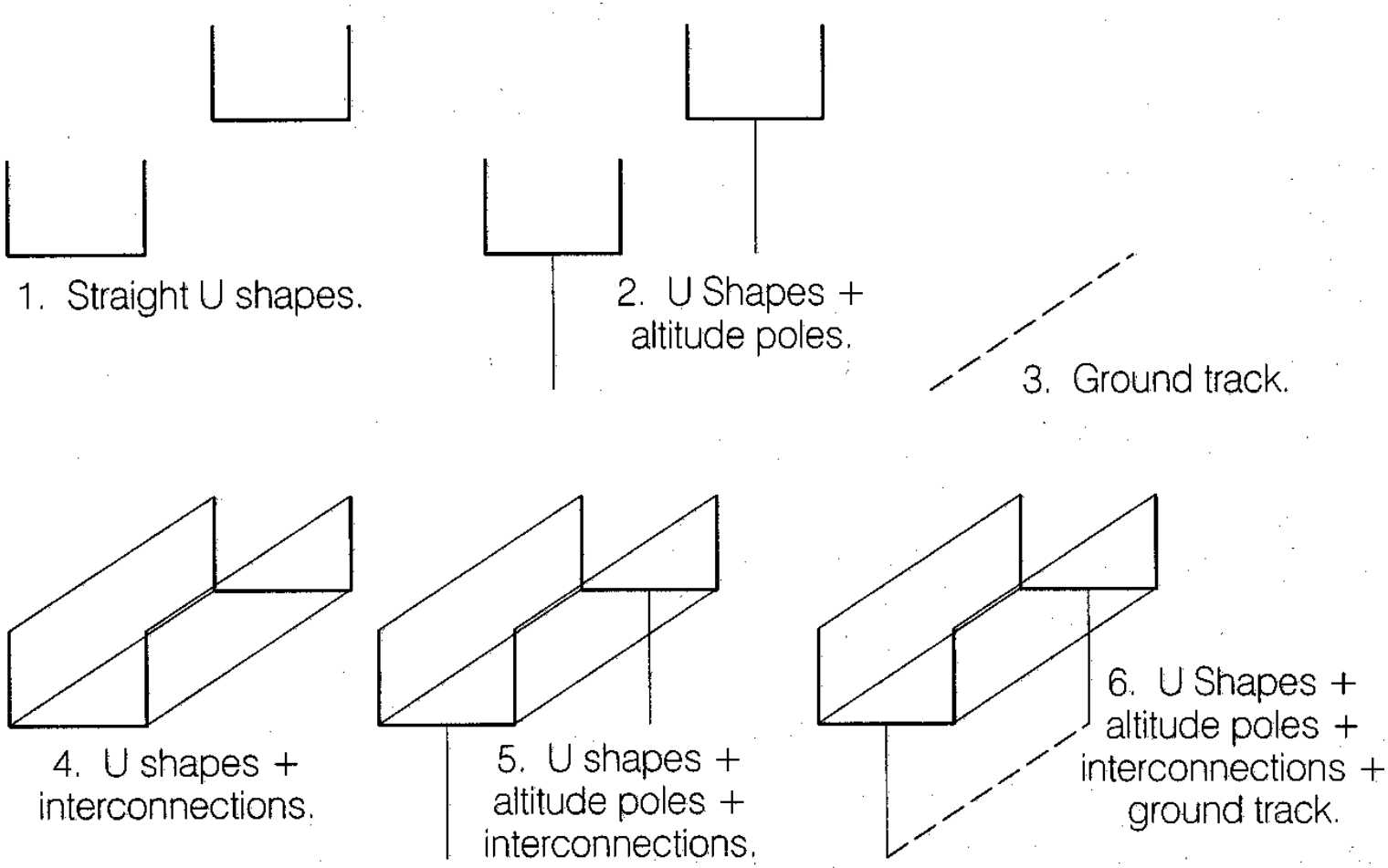
- Display must provide tracking performance cues
- If scaling is based on RNP, then that should suffice.
- If scaling is based on performance, the display will require deviation scales

SHAPE OF ELEMENTS



From Theunissen (1997)

SHAPE OF ELEMENTS



From Theunissen (1997)

TUNNEL VS PATHWAY

- Vertical and horizontal elements provide left/right and up/down information.
- Tile representations require additional cues for altitude control.
- Adding "walls" appears to drive the lateral tracking tolerances tighter than the simple highway.
- Adding a top to form a tunnel-in-the-sky tightens the vertical tracking.

TO TILT OR NOT TO TILT?

- Provides very compelling roll commands
- Requires real-time computation
  - based on groundspeed
  - desired radius of turn.
- Incorrect tilts can promote path departure
- Grunwald does not recommend Tilts
    - No performance benefit
    - Found it to be confusing

TUNNEL VERSUS PATHWAY CUES

- Connecting rectangular elements
  - produces optically invariant structures
  - leads to improved performance
  - also leads to clutter
- The tunnel symbology makes uses many vertical lines.
- Any such display must be carefully evaluated for unusual attitude recognition and recovery.

RNP IMPLICATIONS

- Tunnel displays must consider the containment criteria for RNP airways.
- RNP is a statement of the total system error
  - Specified RNP value ("x") is a 2-sigma boundary
  - There is a 4-sigma containment region (2x)
  - Data must provide prediction of the distribution tails.

RNP IMPLICATIONS

- Since any application of tunnel displays will have to comply with RNP, sufficient tracking data must be obtained to sup-port the prediction of the tails of the distribution
- Can’t assume a normal error distribution.
- To date, no published data has provided such data.
- Must include transitions from one RNP value to another.

INTENDED FUNCTION

- we need to consider all appropriate flight tasks, including
  - precision approaches
  - non-precision approaches
  - terminal maneuvering
  - climbs
  - enroute flight.
- We need to consider unusual attitude recognition and recovery.

PATH DEVIATIONS

- How do we present return-to-path information once the pilot has deviated from the pathway.
- Automatic construction of a return-to-path pathway has been proposed
- Direction arrows

COGNITIVE CAPTURE

- The tunnel symbology appears to capture attention.
- There are questions about the ability of the pilot to maintain SA and detect blunders.

MISLEADING CUES

- During climbs, most guidance systems direct vertical steering based on airspeed.
  - Would this appear as a flight path constraint?
  - It is not clear if we can avoid misleading vertical cues.
- If the "bottom" of a tunnel were driven with terrain cues, how would we show that the bottom limit had switched from an airspeed limit to a terrain limit.

TRAINING ISSUES

- Adaptation of pilots to scaling (learning curve) should be measured.
- Cross-training between tunnel formats and conventional displays should be evaluated for both general aviation and airline pilots.
    - Need a pilot be checked in both types of displays?
    - Negative transfer of training
    - Loss of proficiency in display not being flown

CERTIFICATION ISSUES

- The major certification issues will center around SA and workload issues.
  - Will the pilot be able to maintain a satisfactory awareness of threats to safe flight?
  - Will the workload be excessive?
  - Should the pilot be allowed to program the flight path in real-time?
- Detailed statistical descriptions of lateral and vertical tracking must be obtained.

CERTIFICATION ISSUES

- The applicant must demonstrate that the displayed data will not be misleading during nominal and off-nominal conditions.
- Unusual attitude recovery must be demonstrated.

RESEARCH RECOMMENDATIONS

- Future tunnel studies should include a variety of RNP sizes.
- Sufficient data should be taken to support the RNP containment requirements.
- A "return-to-flight-plan" symbology should be developed.

RESEARCH RECOMMENDATIONS

- The application of pathway displays to non-ground referenced flight must be assessed to ensure misleading cues are avoided.
- The use of tunnel displays for the landing flare task should be undertaken.

RESEARCH RECOMMENDATIONS

- Tunnel designs should be carefully evaluated for unusual attitude recognition and recovery.
- They should also be studied to ensure that excessive use of vertical and horizontal lines does not adversely affect pilots' ability to maintain spatial orientation.

RESEARCH RECOMMENDATIONS

- The effect of display scaling on pilot performance as pilots adapt to image displays should be determined.
- Studies to measure the degree of cognitive capture with pathway displays are recommended. These studies should include eye-tracking.

SUMMARY

- The pathway-in-the-sky has been proposed as an intuitive display format providing tactical situation awareness and good tracking performance.
- While most studies have "loaded the dice" against traditional display formats, the pathway/tunnel format does provide anticipatory cues about forthcoming flight path or course changes.

SUMMARY

- While the tunnel format is well suited to the approach and landing phases of flight, it seems less suited to other phases of flight.

Survey Papers

- Beringer, DB (2000), “Development of Highway-in-the-Sky Displays for Flightpath Guidance: History, Performance Results, Guidelines,” Proc. 43rd Annual Meeting of the Human Factors and Ergonomics Society, paper 3
- Newman, RL and Mulder, M (2003), “Pathway Displays: A Literature Review,” Proceedings 22nd Digital Avionics Systems Conference, Indianapolis, October 2003, paper 9D6

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