Terrain Portrayal for Head Down Displays (TP-HDD) – Flight Test

SVS-GA/FAA Workshop

October, 2002

SVS-GA Team

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TP-HDD Flight Test Objectives

- Validate critical simulation results
- Extend ground-based test capabilities
  - Real motion
  - Real world implementation issues
    - Sensors
    - Environment
    - System integration
- Augment simulation results
  - Replications
  - Focus on specific issues
    - 1 vs. 3 arcsec DEMs

Display Concept Elements

- Same options as TP-HDD sim
- Baseline concept: Blue sky/brown ground standard Primary Flight Display (BSBG-PFD) (i.e. no terrain data)
- SVS-PFD concepts
  - Tunnel on/off
  - Selectable FOV
  - Multi-resolution, multi-texturing

Digital Elevation Models

1. Low: 30 arc-second (900m/2953ft)
2. Med: 3 arc-second (90m/295ft)
3. High: 1 arc-second (30m/98ft)

Terrain Texturing

1. Constant color w/fishnet overlay
2. Terrain elevation-based generic texturing
3. Terrain elevation-based generic texturing w/fishnet overlay
4. Photo Realistic texturing
5. Photo Realistic texturing w/fishnet overlay

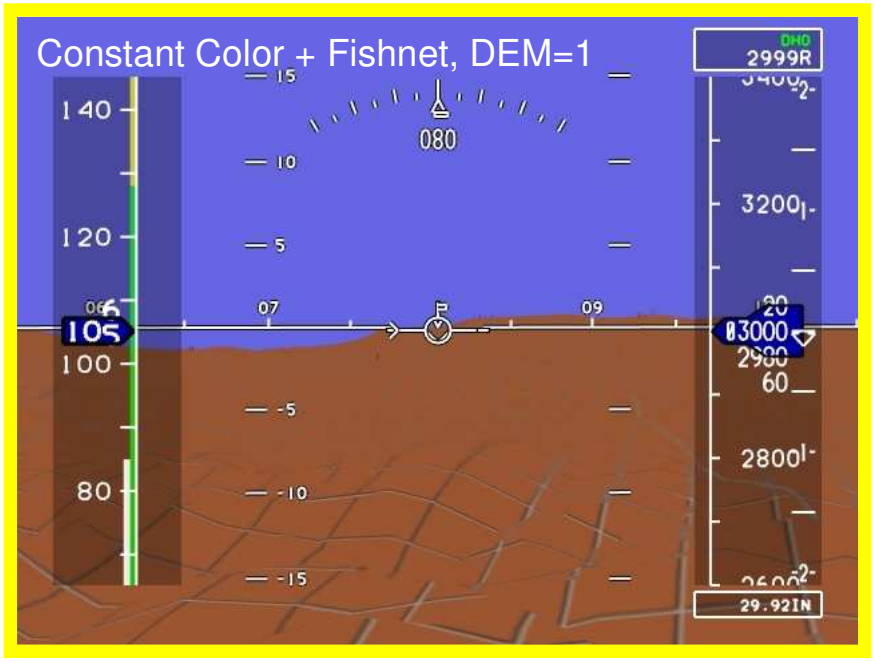
Experimental Test Matrix

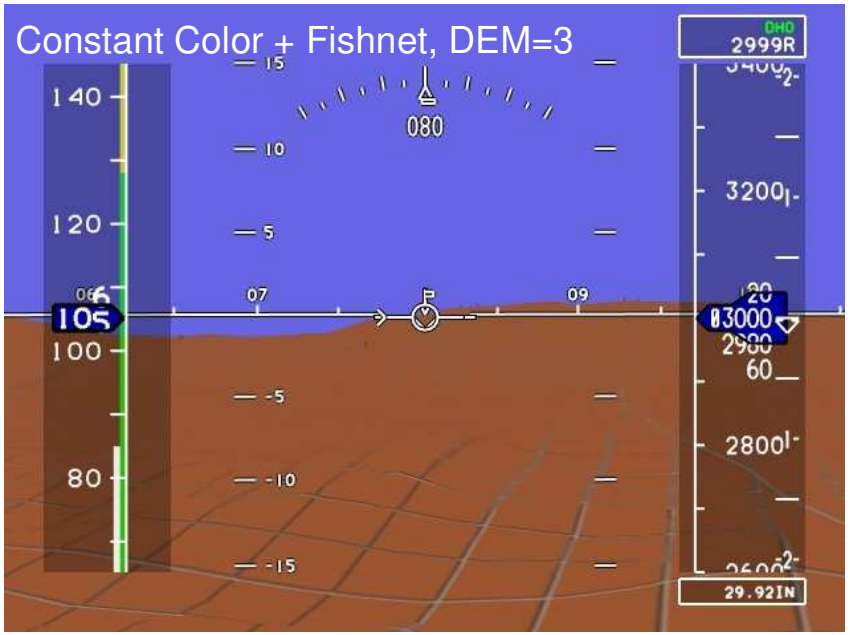
Texturing Concepts

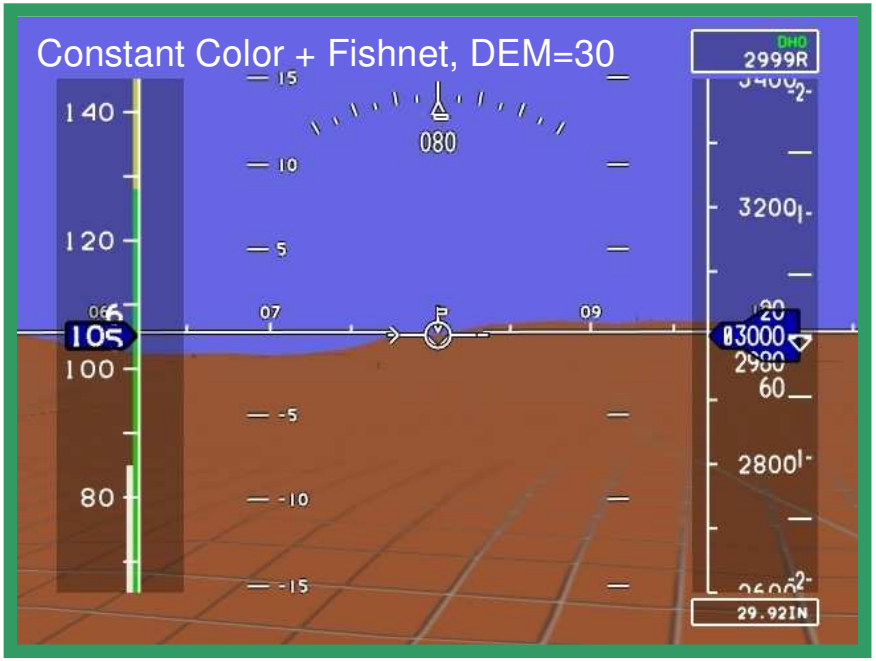
DEM (arc-sec)

	EBG	PR	CC+ FN	EBG+ FN	PR+FN
30			sim/flight	sim	sim
3	flight	flight		sim/flight	sim/flight
1	sim/flight	sim/flight		sim	sim

Legend for Texturing Concepts:
CC = Constant Color, EBG = Elevation-Based Generic, PR = Photo Realistic, FN = Fishnet



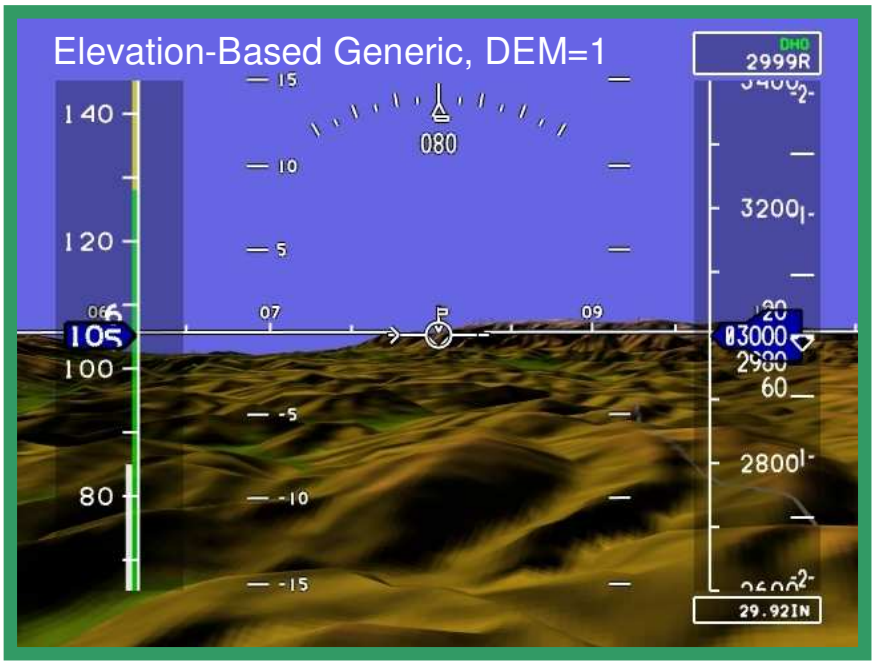


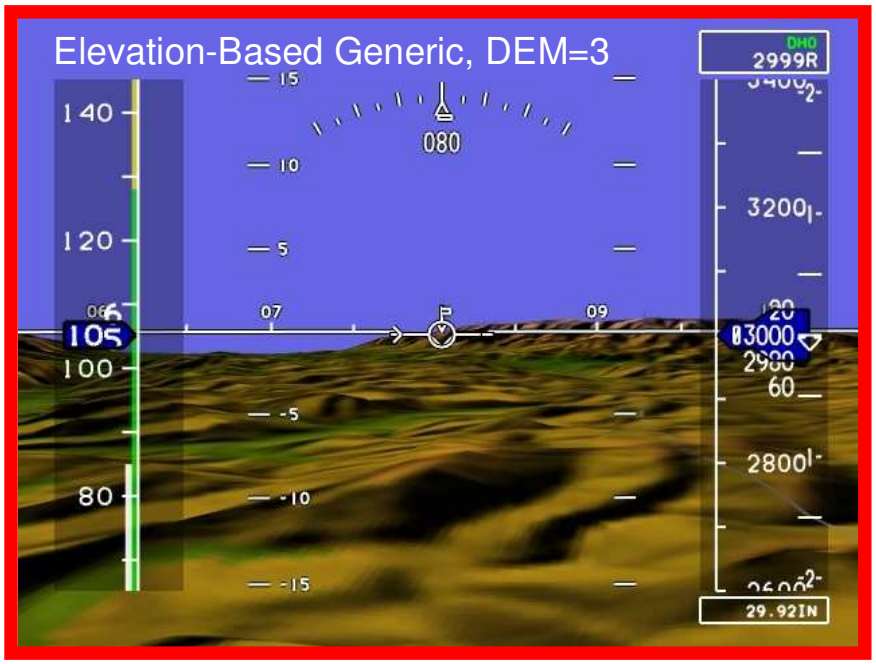


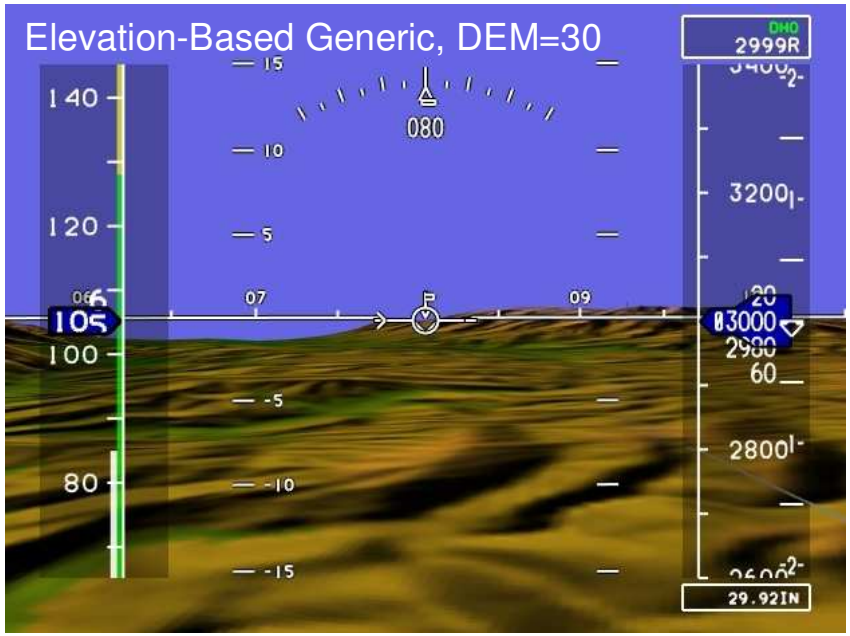
flight

sim

both



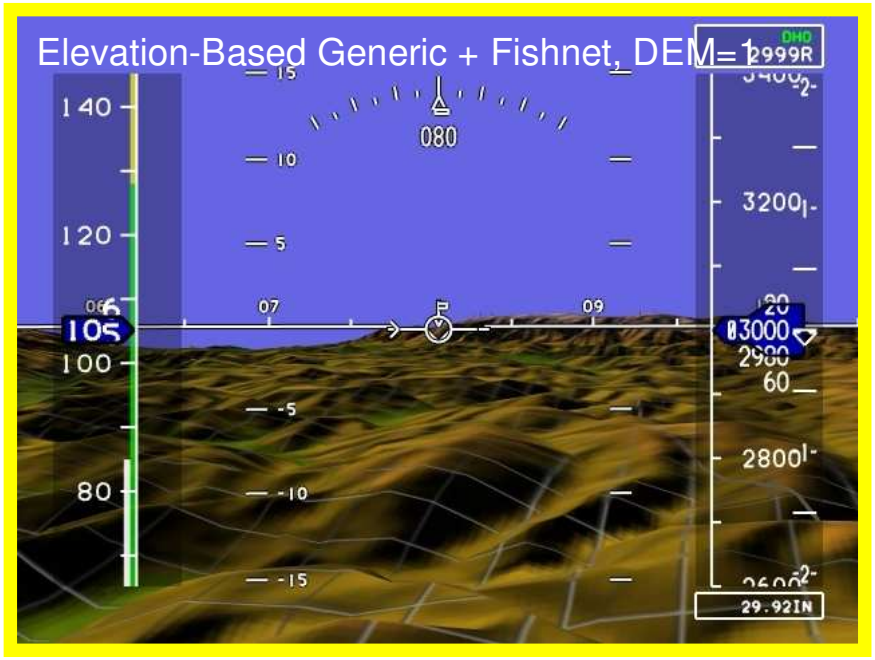


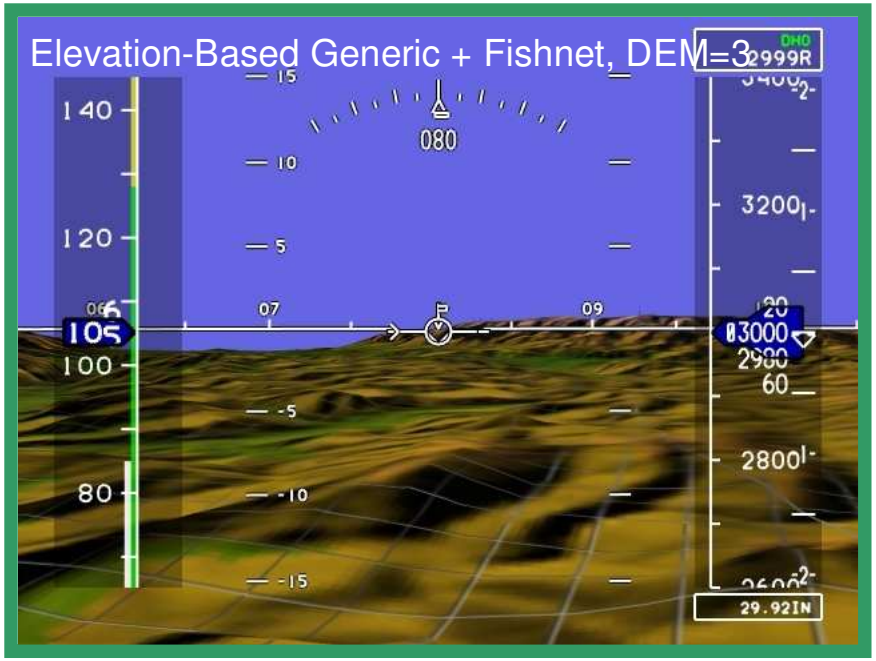


flight

sim

both

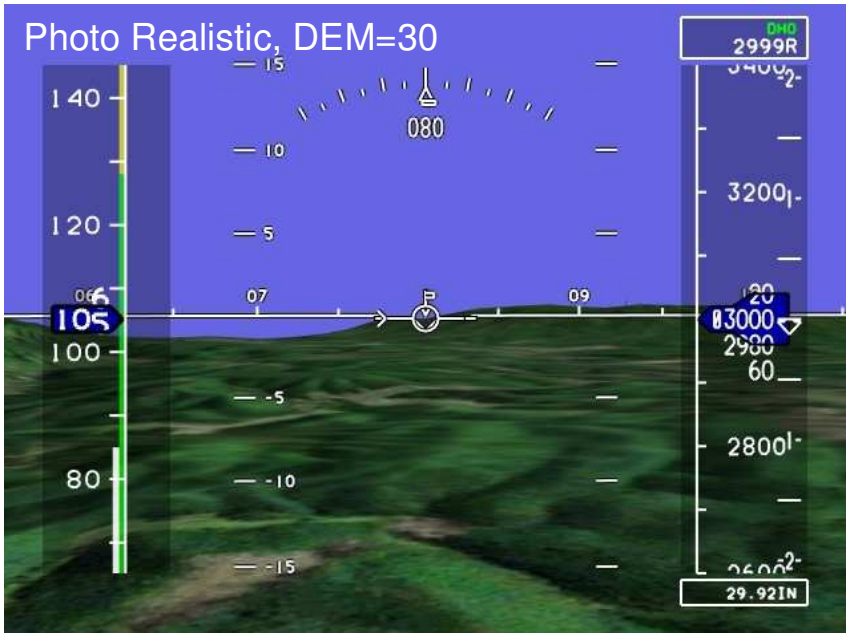




flight

sim

both



flight

sim

both

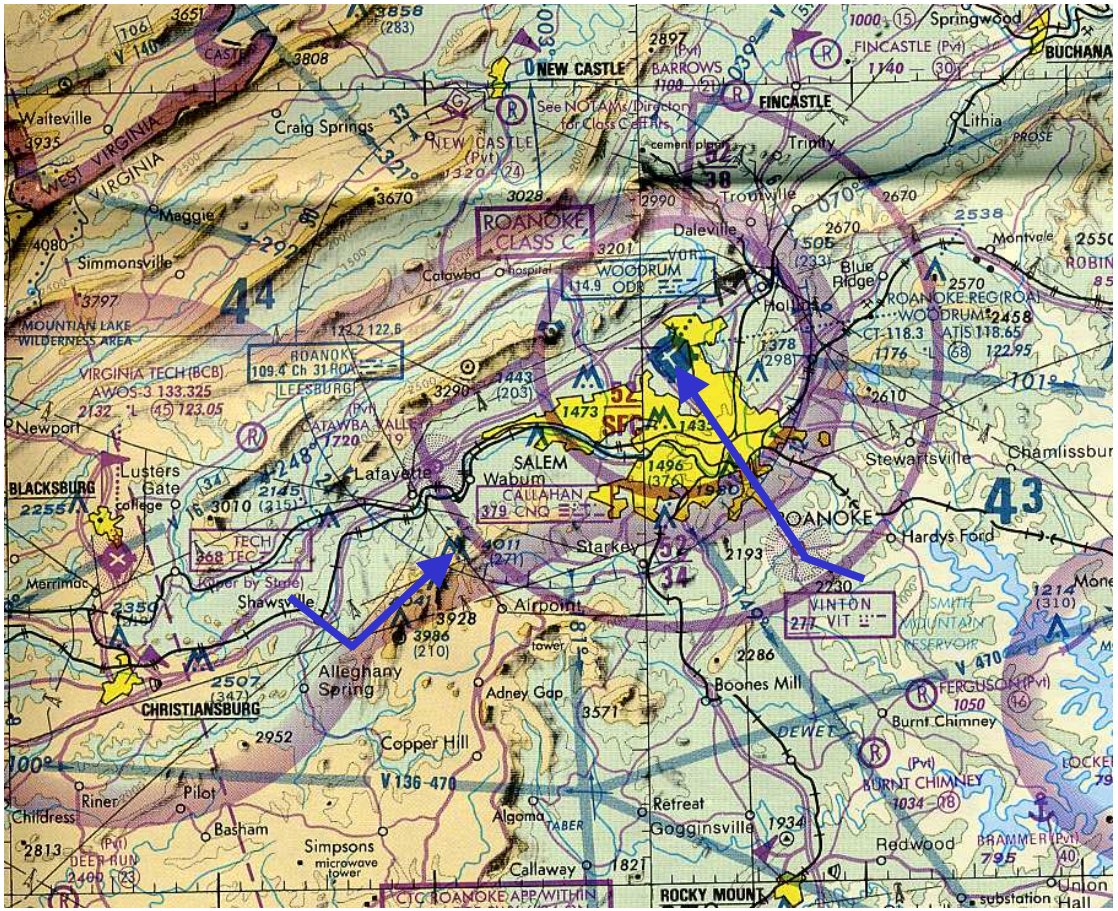
flight

sim

both

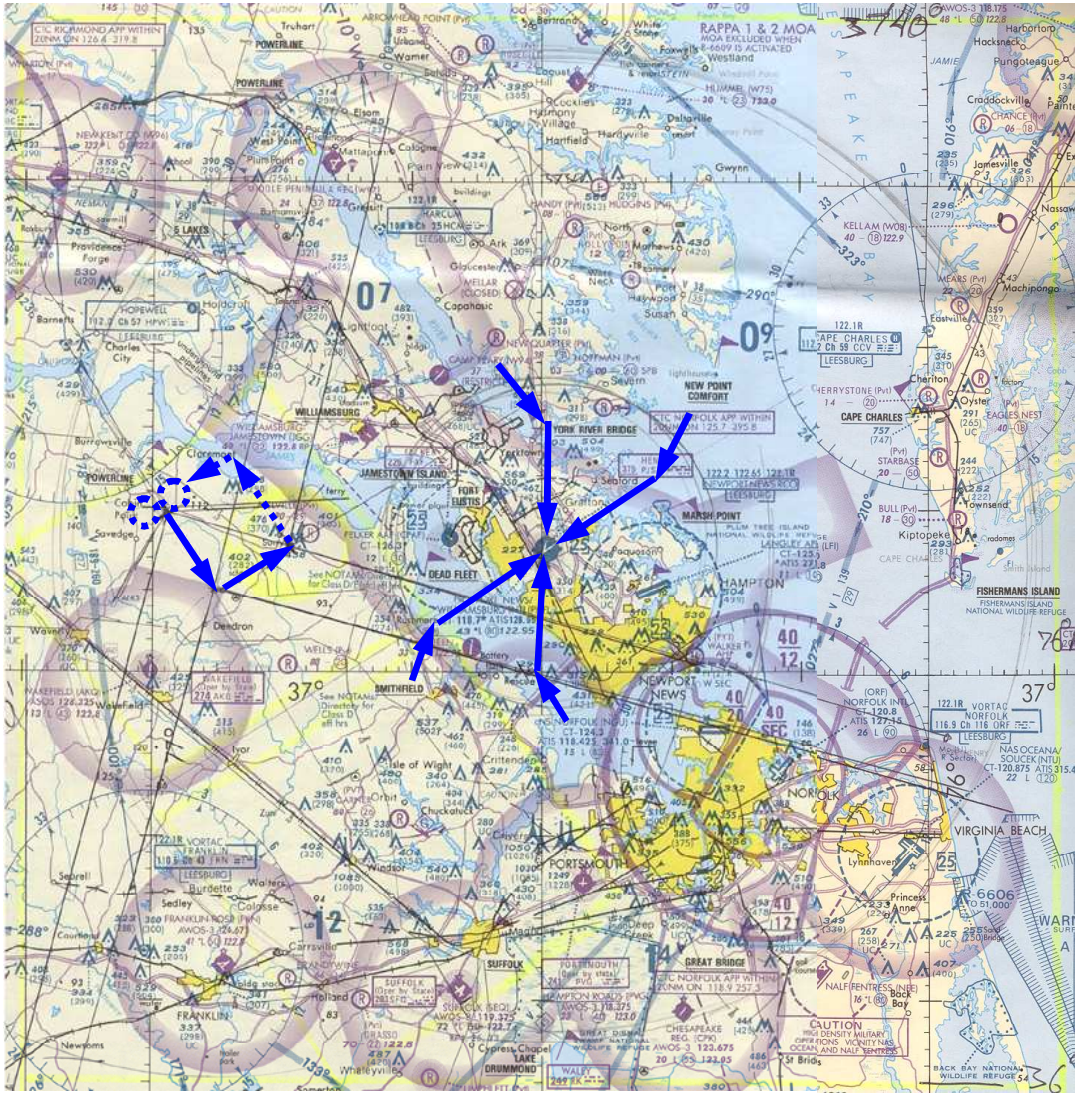
Area of Flight Operations (ROA)

- Selected for the mountainous environment
- Close proximity to LaRC
- Enabled enhanced operations support

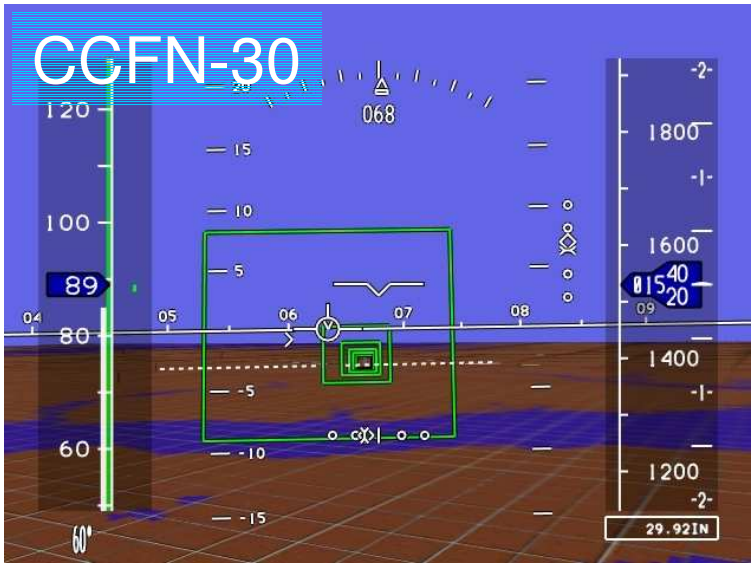


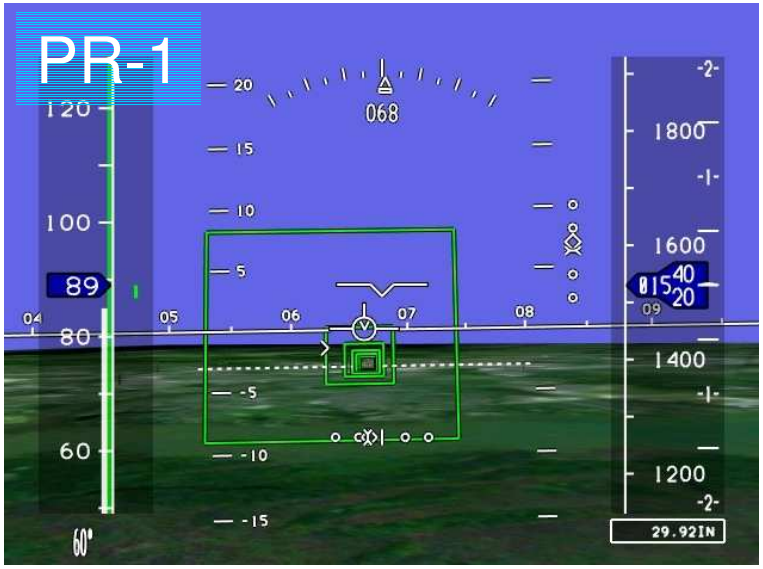
Area of Flight Operations (PHF)

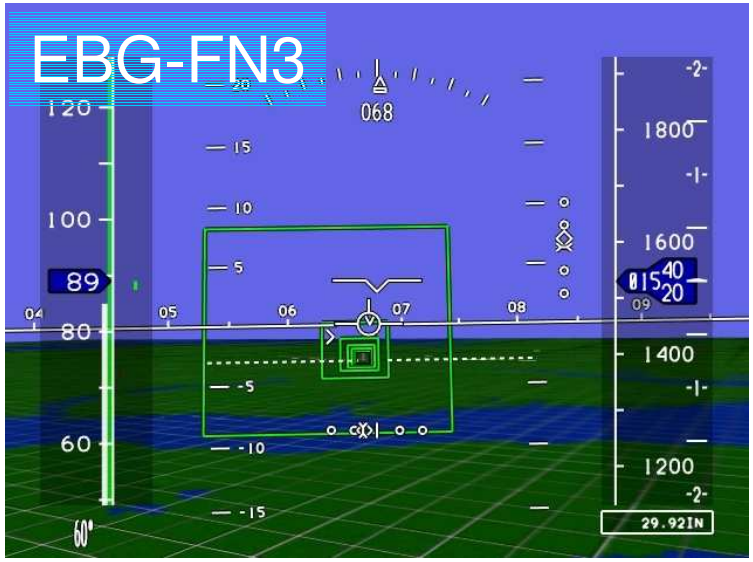
- Selected for the flat maritime environment
- Enabled local research operations

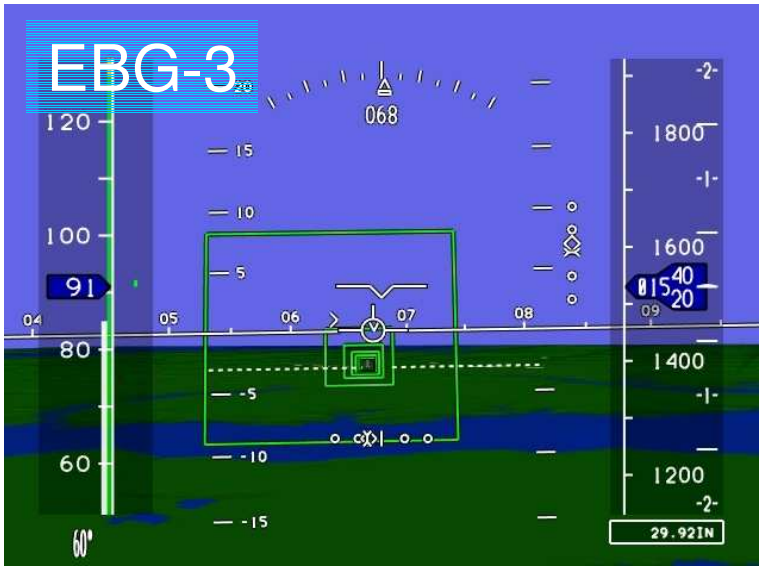


PHF Images



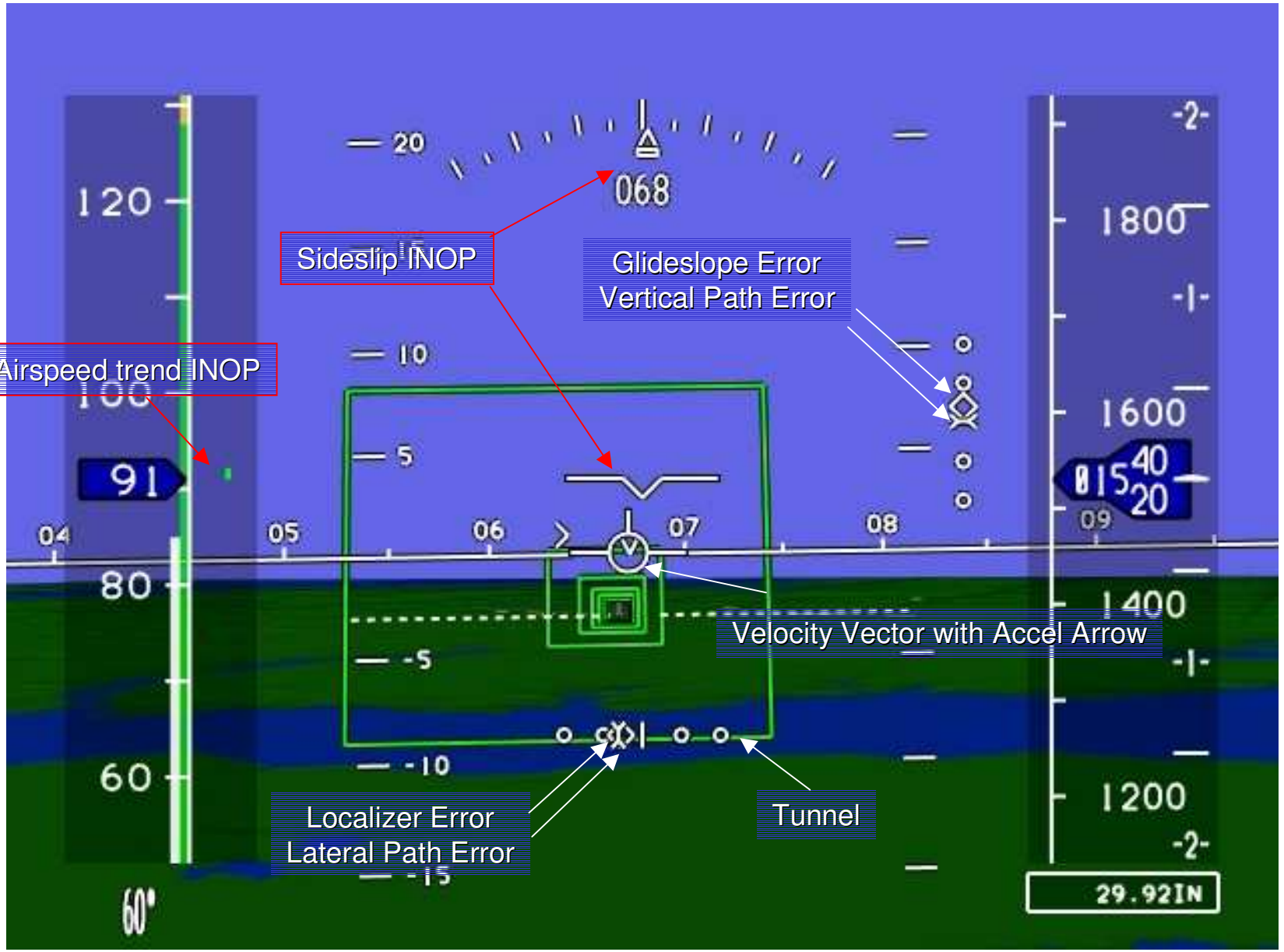






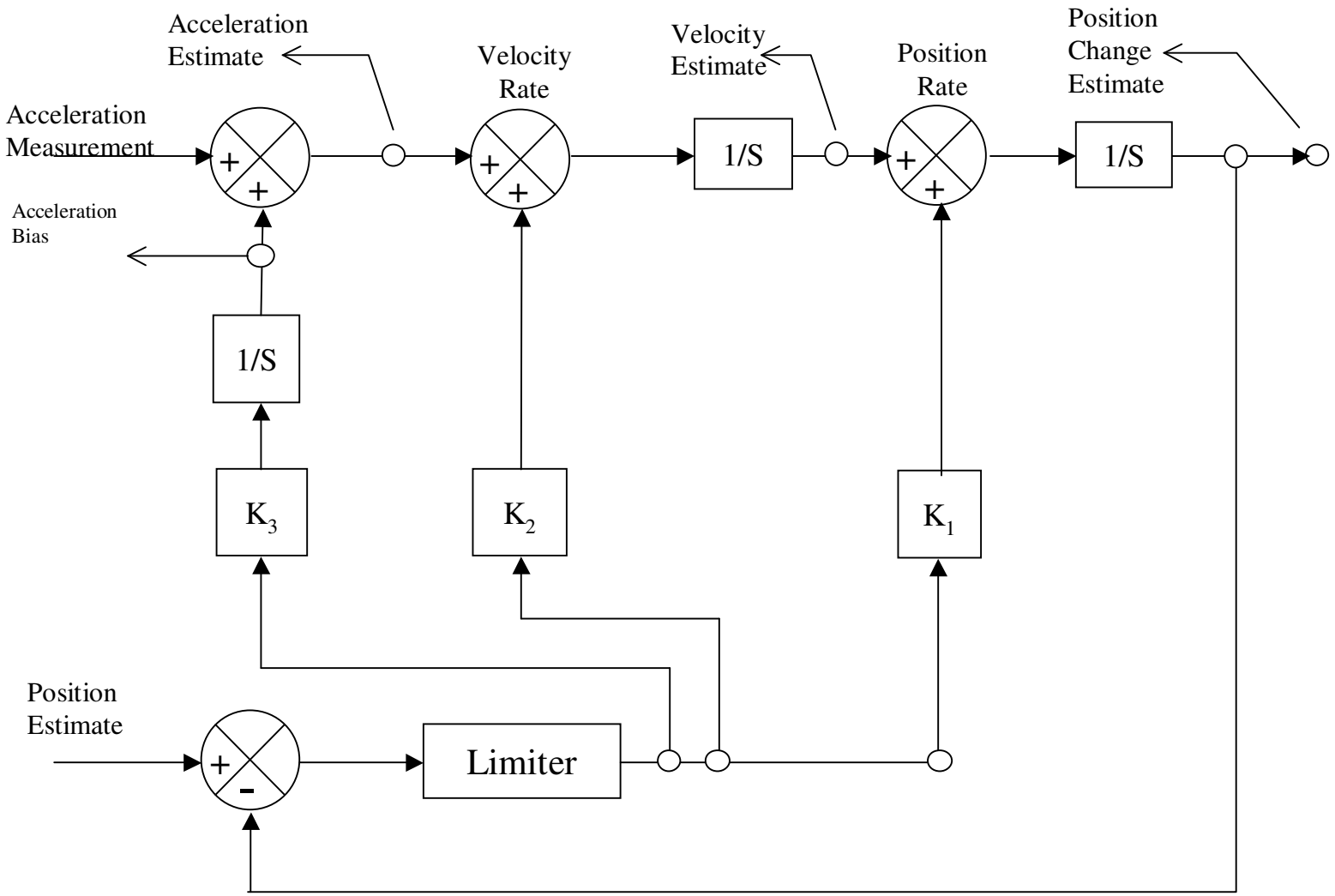
Images from top of Glideslope

Symbology


Sideslip INOP
Glideslope Error
Vertical Path Error
Airspeed trend INOP
Velocity Vector with Accel Arrow
Localizer Error
Lateral Path Error
Tunnel
120
80
60
91
068
20
10
5
-5
-10
-15
04
05
06
07
08
09
1800
1600
1400
1200
-2-
-1-
29.92IN

Hybrid Position Estimate

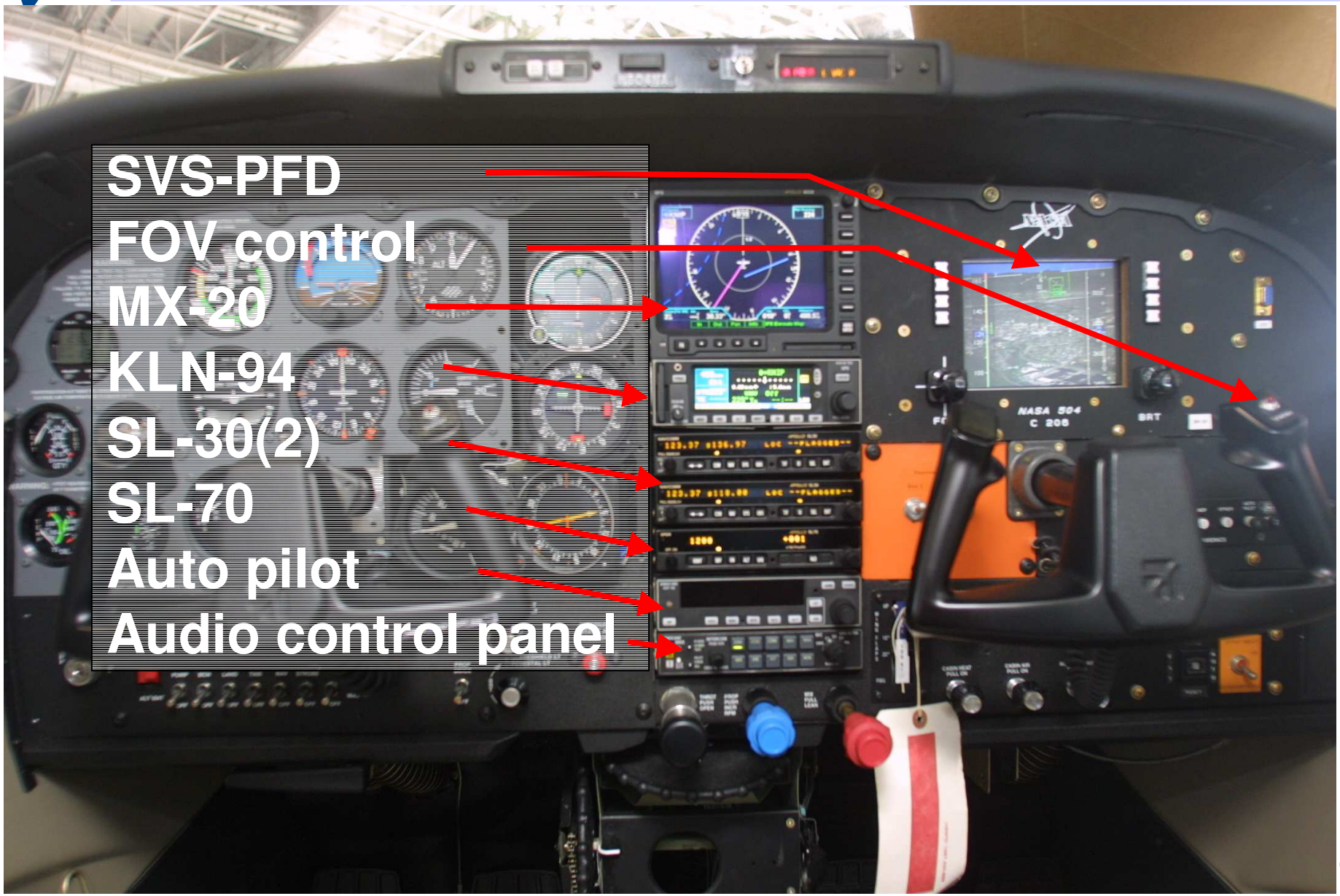
Third Order Complimentary Filter



Hybrid Position Estimate-2

- Calculates East, North, Down estimates
- Input:
  - GPS lat, long
  - Raw accelerometer measurements
  - Pressure altitude
- Generates:
  - High-rate position solution (50Hz)
  - Internal velocities used to drive the Velocity Vector
  - Body-axis accelerometer biases
    - Used for monitoring system performance

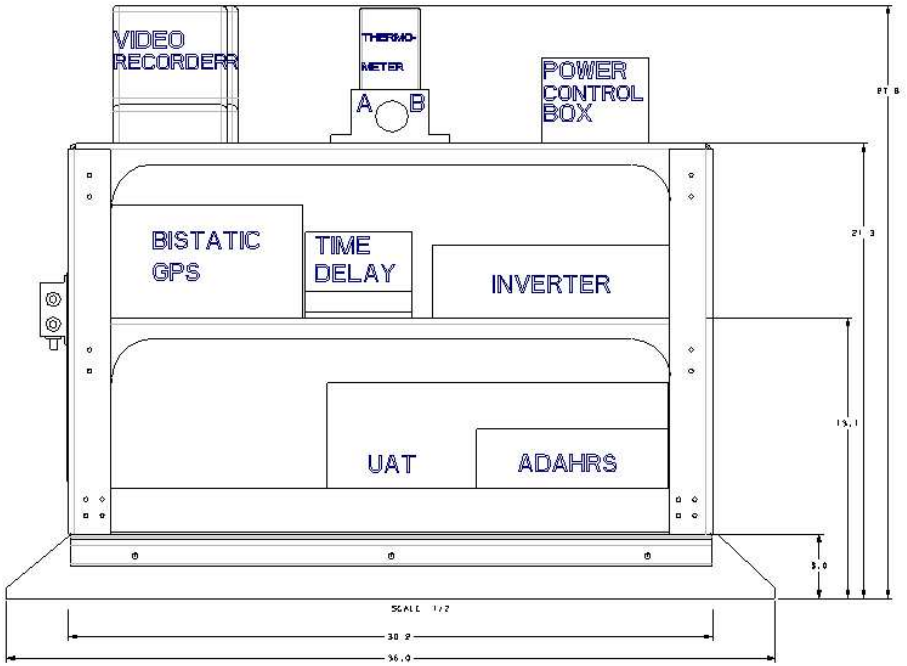
TP-HDD in the C-206



Overview of Cessna-206 modifications (Pallet)

- ADAHRS
- Bi-Static GPS
- UAT data link (not used)
- Power inverter
- Power control box
- Video recorders (2)
- Thermocouple monitor
- Video switch
- Video time inserter

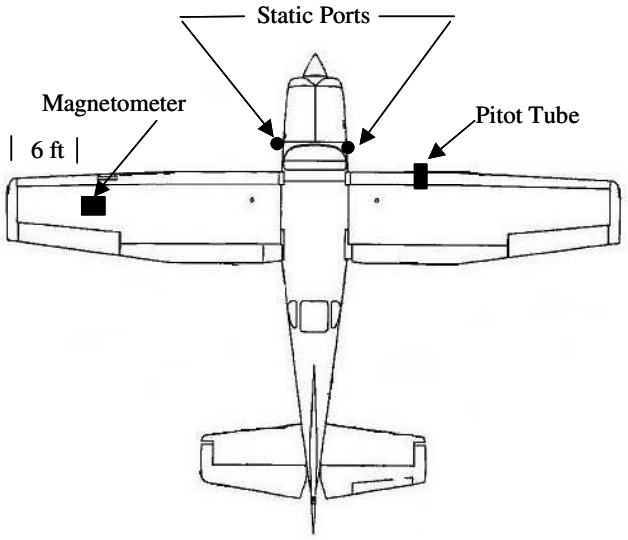
Pallet



Overview of Cessna-206 modifications (ADAHRS)

- Provided all position, orientation, and air-data information to the research system
- Direct serial link to the research computer
- Air-data provided by dedicated research pitot/static system
- Magnetometer in left wing

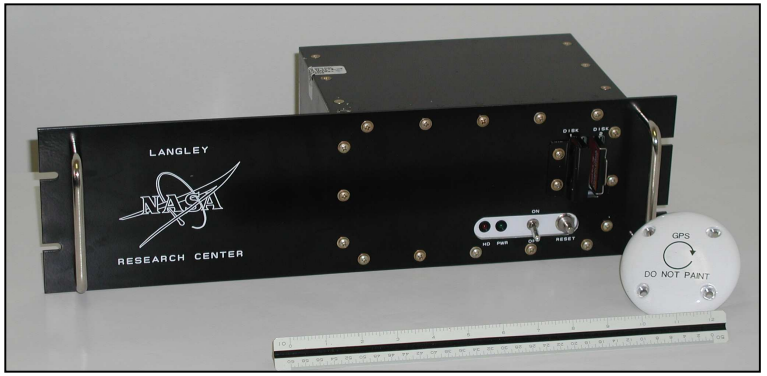
GIA-2000 ADAHRS



Overview of Cessna-206 modifications (Bi-Static GPS)

- Bi-Static GPS
  - Database integrity monitoring experiment
  - Estimates terrain elevations at the reflection points
  - Receives Earth-Reflected GPS signals
  - Polarized bottom-mounted GPS antenna
  - Testing conducted to evaluate signal strength and conceptual feasibility

Bi-Static GPS unit



Overview of Cessna-206 modifications (Zx10)

- Dual 1-GHz Pentium processors, 1 GB of RAM, Wildcat 4210 Graphics board
- Located in the aft cabin and cargo area
- Received data from the ADAHRS, CPTs, and event markers
- Generated SVS PFD imagery
- Recorded all data
- Max. ground surface temp=89 F for approaches

Zx10

Overview of Cessna-206 modifications

- Research Operators Display
  - COTS 15” display
  - Repackaged at LaRC
  - Strapped to the seat back
  - Used to monitor the SVS display as well as the Bi-Static GPS

MX-20

- Terrain mode selected
- Colors relative to ownship altitude
- Range scale to 10nm
- Provided
  - Strategic terrain display
  - Used to evaluate integrated terrain strategic/tactical terrain presentations
  - Additional lateral path guidance (approach)

Flight Test Conduct

- Briefing (1.5 hours)
- Training
  - At least one training run was performed for En Route and Approach maneuvers
  - Second training runs were performed for a few pilots
- Maneuver setups
  - Safety pilot set aircraft at altitude/airspeed/heading
  - Evaluation pilot completed the approach maneuver setup using the SVS display (i.e. flew into the tunnel)
- Vision restriction device
  - Employed a baseball hat pulled down low
  - IFR hoods were too restrictive (couldn't easily see MX-20 and SVS-PFD
  - C-206 has a large instrument panel (not much restriction was needed to be IFR effectively)
- SD maneuvering
  - SP would perform maneuvers similar to Spatial Disorientation training
  - Return aircraft to near-level trimmed flight for En Route maneuver
  - Only performed for the first 7 pilots (one pilot got ill)

Experiment Schedule and Estimated Duration

Time	Session	Duration
500	Pre-Flight Research Briefing (breakfast)	60 min
615	Group Pre-Flight Brief for First and Second Flights	15 min
630	Proceed to C-206	15 min
645	Takeoff (complete En Route block)	135 min
900	Land+taxi+leave C-206	15 min
915	Break	45 min
1000	Takeoff (complete Approach block)	135 min
1215	Land+taxi+leave C-206	15 min
1230	Lunch	60 min
1330	Post-block questionnaires/break	45 min
1415	Post-test questionnaire	60 min
1515	General wrap-up	15 min
Total Duration Estimation: 11 hrs (including lunch+breaks)		

Flight Test Operations Scenarios

- En Route
  - Scenario 1 (ROA)
    - Initial Conditions: Straight and Level at 6,500 ft MSL, 100 KIAS heading 140 degrees at the start point
  - Scenario 2 (PHF)
    - Initial Conditions: Straight and Level at 3,000 ft MSL, 100 KIAS heading 155 degrees at the start point
  - Turn left 90 degrees, descend 1,500 ft
- Approach
  - Scenario 3 (ROA)
    - Initial Conditions: Straight and Level at 3,000 ft MSL, 90 KIAS heading 300 degrees at the start point
  - Scenario 4 (PHF)
    - Initial Conditions: Straight and Level at 1,540 ft MSL, 90 KIAS heading 040 degrees at the start point
  - Follow the tunnel/guidance to 200 ft AGL

Totals slide

- Total hours — approx. 130
- Total research hours — approx. 83
- Total research approaches — 120
- Total research en route maneuvers — 120
- Actual flight schedule
  - First check flight — 7/9
  - Oshkosh — 7/19 to 7/30
  - Research data flights@ROA — 8/15 to 8/22
  - Research data flights@PHF — 9/11 to 10/10
  - Demonstration flights — 9/25 to ???

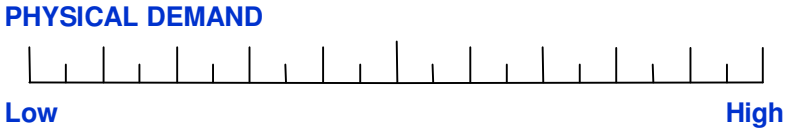
Subject Pilots

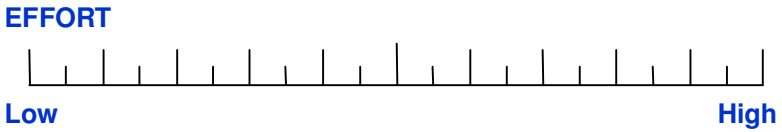
- 15 pilots participated in the experiment
- 6 low-time (LT) GA pilots (approx. 200 hours)
- 5 IFR GA pilots (approx. 600 hours)
- 4 high-time (HT) research pilots
  - 2 NASA research pilots
  - 1 Boeing test pilot
  - 1 FAA certification pilot (Capstone work)
- 7 pilots participated at ROA (LT=5, HT=2)
- 8 pilots participated at PHF (LT=1, HT=2, IFR=5)
- All (but one) participated in TP-HDD sim

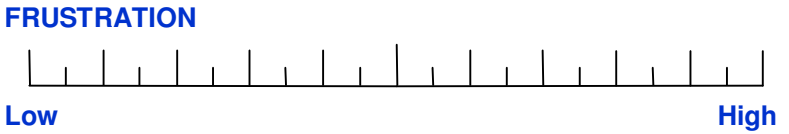
Dependent measures

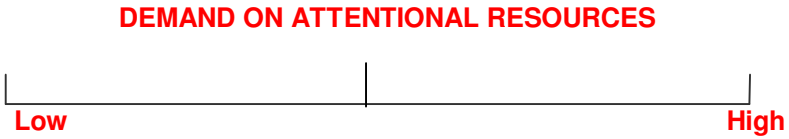
- Quantitative
  - Aircraft performance measures
    - Position (path error, ILS error, attitudes, etc.)
    - State data (airspeed, altitude, etc.)
  - Pilot control inputs
    - Pitch, roll, yaw, throttle, pitch trim
    - FOV settings
- Qualitative
  - Post-run Questionnaire
    - TLX, SART, Terrain Awareness, Stress, Cooper-Harper
  - Block Questionnaire
    - SASWORD
    - Rankings
    - Other questions
  - Post-test Questionnaire
    - SASWORD
    - Preference comparison
    - Rankings
    - Other questions

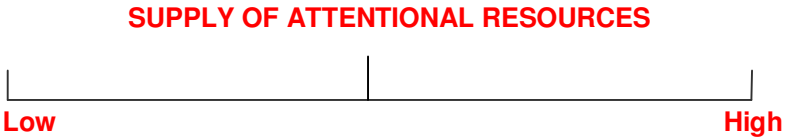
Run Questionnaire (front)

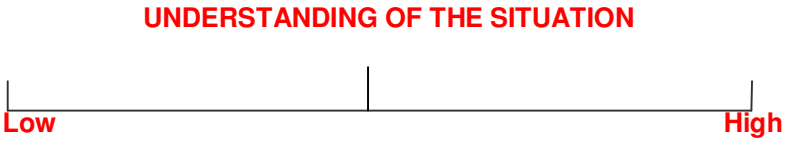


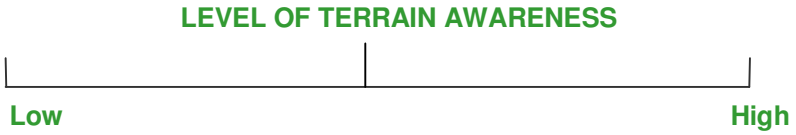






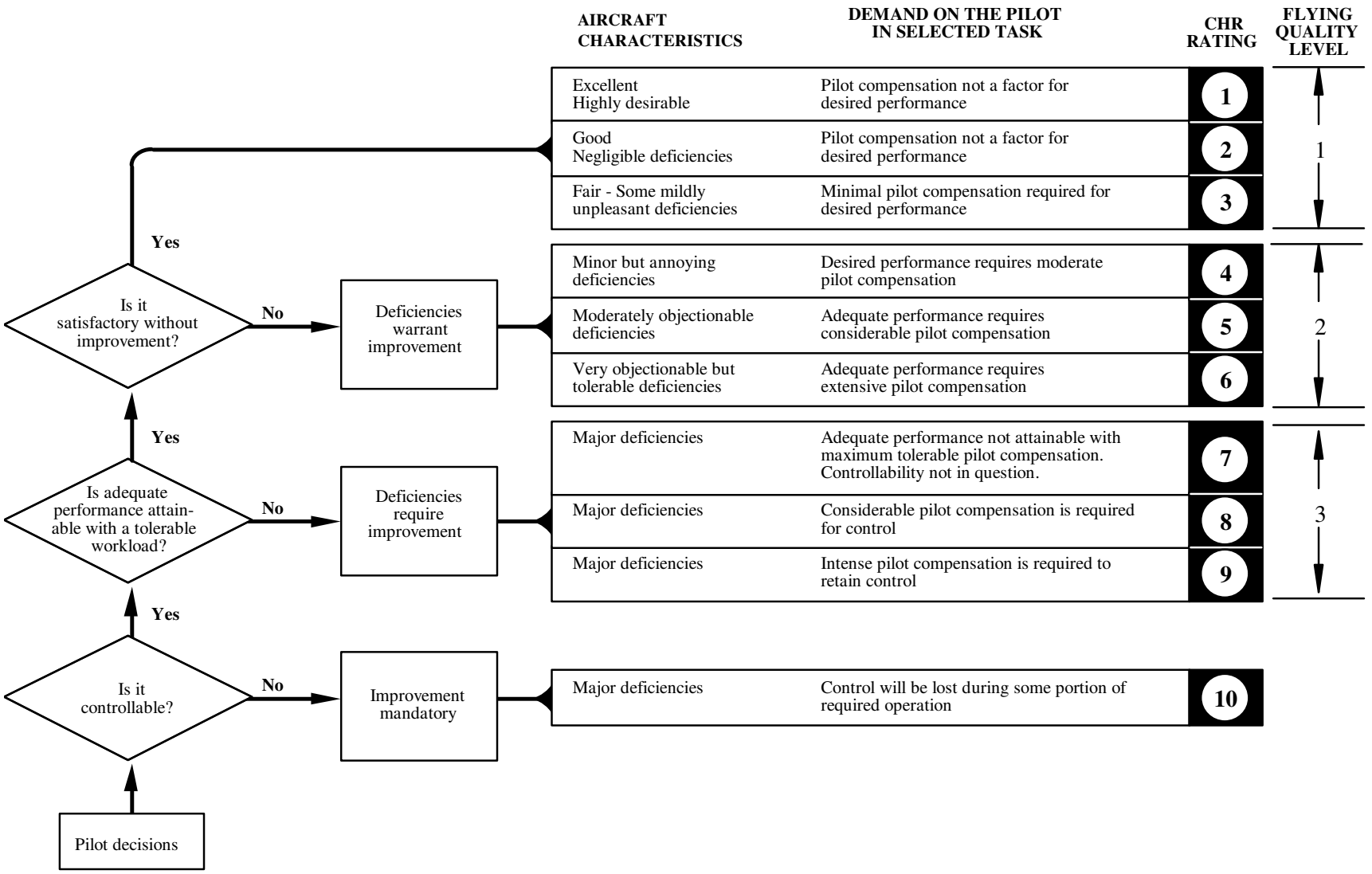






Workload:	*Situational Awareness:*
TLX – Blue	SART – Red
Stress – Purple	TA - Green

Run Questionnaire (back –Cooper Harper)



Pilot Performance Metrics

- Desired performance (keep within these parameters ~90% of the time) when appropriate:
  - Airspeed error ≤ ± 10 knots
  - Altitude error ≤ ± 100 ft
  - Heading error ≤ ± 10°
  - Bank Angle error ≤ ± 10°
  - Localizer error ≤ ± 1 dot
  - Lateral path error ≤ ± 1 dot
  - Glideslope error ≤ ± 1 dot
  - Vertical path error ≤ ± 1 dot
- Adequate performance (~90% of time between PTS and twice PTS) when appropriate:
  - Airspeed error between ≤ ± 20 knots
  - Altitude error between ≤ ± 200 ft
  - Heading error between ≤ ± 20°
  - Bank Angle error between ≤ ± 20°
  - Localizer error between ≤ ± 2 dots
  - Lateral path error ≤ ± 2 dots
  - Glideslope error ≤ ± 2 dots
  - Vertical path error ≤ ± 2 dots
- Below adequate performance (beyond twice PTS).

Block questions-1

1. SA SWORD for terrain concepts
2. Field of View questions (5)
3. Please provide an estimate of your performance while flying each of the display conditions?
4. Please provide an estimate of your terrain awareness while flying each of the display conditions?
5. Please indicate whether the provision of the tunnel significantly enhanced your SA while making the approach?
6. Please indicate whether the provision of the terrain significantly enhanced your SA while making the approach?

Block questions-2

- MX-20 Questions

1. What type of information was provided specifically by the MX-20?
2. What type of information was provided specifically by the SVS display?
3. What information was provided by both displays?
4. For what situations would the MX-20 provide most of the useful information
5. For what situations would the SVS provide most of the useful information

Final Questionnaire

1. Rank order texturing concepts
2. DEM difference discussions
3. Fishnet questions
4. Best 2 FOVs selections and rationale
5. Level of confidence in terrain separation for each concept
6. Rank order terrain concepts (en route, approach, emergency)
7. Best/worst features of each concept
8. Likelihood of CFIT and LVAU for each terrain concept
9. Comparison of simulation and flight tests
10. Other comments

Observations-1

- Photo-realistic (PR) texturing may not be most desirable
  - Pilot comments were received indicating that PR texturing slowed down their scan rate (similar to U of Iowa results)
  - May create information overload
  - Obstacles were harder to see
  - PR texturing may have provided enhanced situation awareness for pilots who were familiar with the area of operations (benefit)
    - Engine out situations
- Elevation-based generic was slightly favored
  - Easier to see obstacles
  - Several pilots who selected PR as the best in the simulation changed their selections to EBG
  - Actual terrain is easier to see (not masked by trees, etc.)
  - Did not appear to compromise scan rate as much as PR
  - EBG is much easier to implement
    - Storage and rendering needs are heavily reduced

Observations-2

- Almost all pilots heavily favored EBG and PR over the CCFN texturing concept
- DEM 1 vs. 3 arcsec
  - Pilot preference for higher resolution DEMS was consistent for most pilots
  - Obstacles were slightly easier to see in the lower resolution DEM for EBG
  - Less contrast changes for lower DEM resolutions (EBG)
- FN is not a must-have for PR and EBG texturing concepts
  - Pilots commented that the FN made it hard to see roads
  - Most pilots would do without the FN if it cost anything
  - Some pilots strongly opposed the FN
  - Some pilots thought is was beneficial
- Culture/feature data was widely favored
  - Provided substantial SA improvements
  - Enabled to pilots to more easily judge where they were

Observations-3

- Approach maneuvers
  - All pilots had some trouble with Glideslope (GS) error during the last mile of the approach (600 AGL to 200 AGL)
  - Tunnel is much wider than GS beam
    - About 3 times at 200 ft AGL
    - About equal at 600 ft AGL
  - All pilots were able to maintain lateral performance (i.e. less than +/-100 feet error)
  - All pilots had trouble managing the turn to intercept the localizer
  - Most pilots had to work to maintain airspeed (+/- 10kts)
  - Acceleration arrow may not be satisfactory (need tach?)
- En Route maneuvers
  - Provided great training for the approaches
  - Enabled pilots to get a good feel for the aircraft
  - Most pilots were able to be within desired performance for the entire time

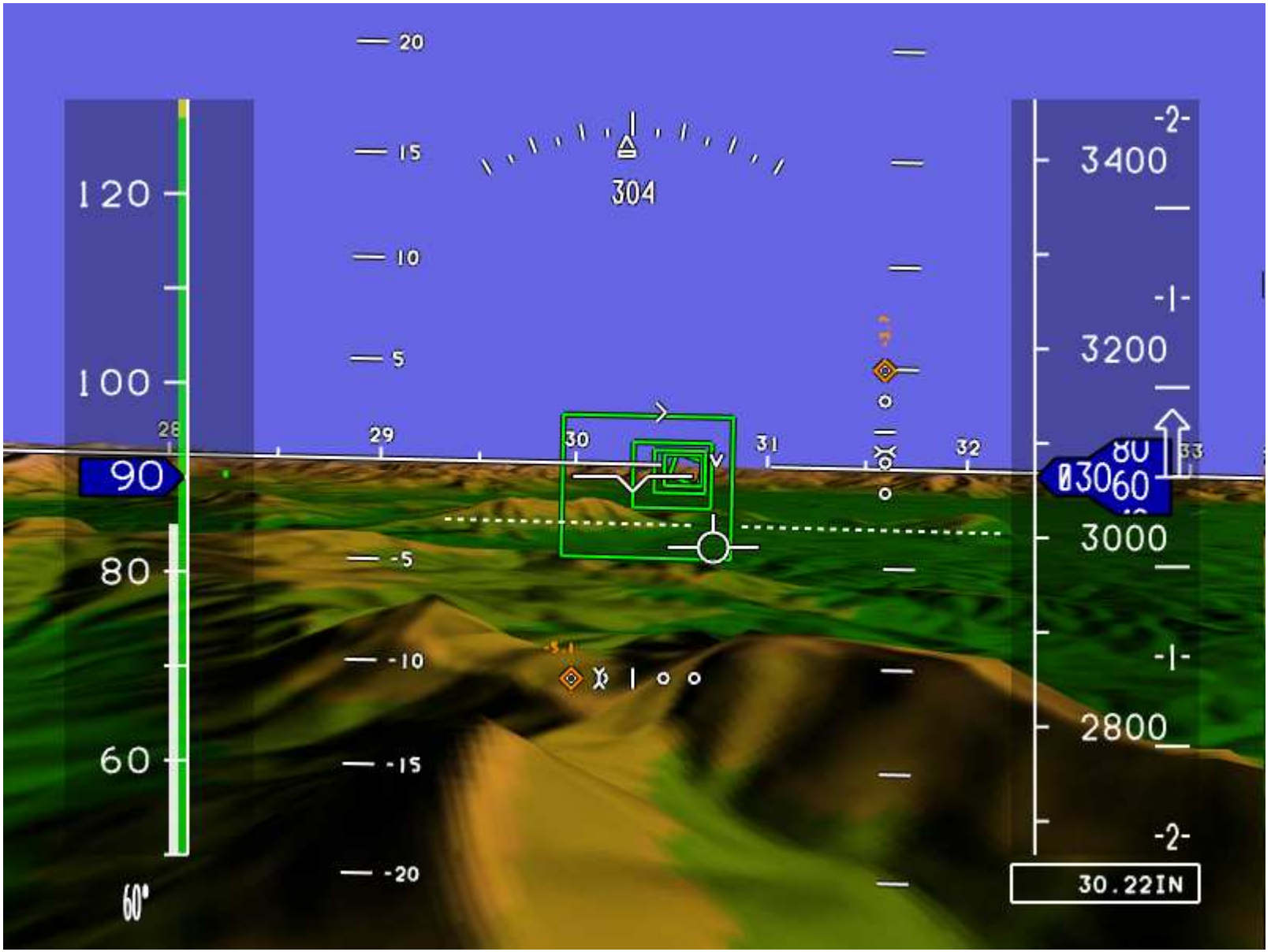
Observations-4

- Real-world effects:
  - GA platform motion characteristics
    - No yaw damper
    - Slower speeds (100 and 90 kts)
    - Low-wingloading aircraft
  - Increased attitude/heading motion due to turbulence, etc.
  - Increased crab angles
  - Velocity Vector movement reflected actual aircraft response
  - Selected FOV was generally higher than in sim
    - 60 Degrees was selected as the best most of the time
    - Calm conditions would permit lower FOVs (like 30)
    - Unity (22 deg) was unusable
    - 90 FOV was selected for some En Route maneuvers
- Symbology driving the boat (En Route/App)
  - Pilots were focusing on the symbology
  - Less aware of the underlying terrain
  - All pilots had preferences for the terrain portrayal concept

Observations-5

- No LVLOCs
  - Spatial Disorientation (SD) pre-maneuver maneuvering did not induce LVLOC
  - SD pre-maneuver was suspended after pilot #7 became ill
  - LVLOC and SVS needs to be looked at in a SD simulation
- Flight confirmed simulation data
  - Similar qualitative data (TLX, SART, TA, Stress, CH)
  - Pilots stated that the aircraft flew similarly to the simulation
  - Many pilots (4 or 5) stated repeatedly that the display looked "more real" in the aircraft
- Integrated strategic/tactical terrain
  - Best condition is to have terrain on the MFD colored based on absolute altitude (sectional view for MFD)
  - Enables more information to be presented on the MFD
  - Pilots commented that they really didn't look at the MFD very often

Movie from ROA flight



Plan

- Analyze data
  - Will proceed quickly since it will follow the simulation results
  - Transcribe pilot comments
- Write report(s)
  - NASA Technical Paper
  - Conference papers
- Wrap-up TP-HDD in March, 2003