AvSP SWAP Human Performance Modeling

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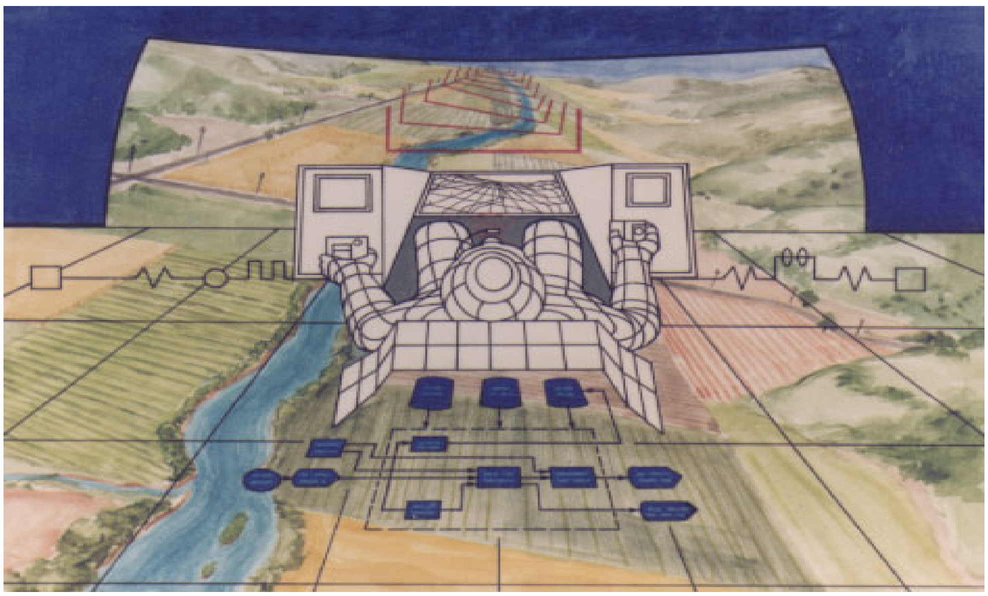
Interim Workshop on Human Performance Modeling



NASA Ames Research Center
March 6, 2003

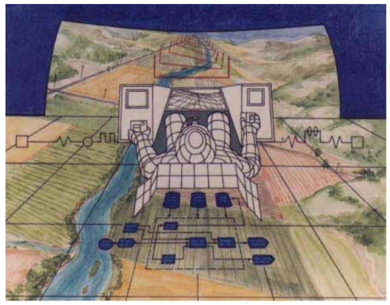
NASA Aviation Safety Program (AvSP)
System-Wide Accident Prevention (SWAP) Element
Human Performance Modeling (HPM) Element

Human Factors
research and technology

AvSP Interim Workshop on Human Performance Modeling AGENDA

8:00 AM	Registration
8:30	Welcome & Agenda
8:45	Overview
9:10	Cognitive Task Analysis
9:45	Simulation & Scenarios
10:20	Break
10:40	D-OMAR
11:30	ACT-R
12:20 PM	Lunch
1:30	IMPRINT/ ACT-R
2:20	A-SA
3:05	Break
3:25	Air MIDAS
4:15	Discussions
5:00	Adjourn

System-Wide Accident Prevention: Human Performance Modeling Overview



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Problem, Approach and Goal

Problem

- Accident precursors are complex interaction of latent error in a system design or procedure (and dynamic interaction of design, human operation and environment)
- Difficult to observe rare error and error precursors in aviation environment ($1x10^{-n}$)
- Design cycle (design, build, evaluate, field, revise) is difficult, expensive, and time-consuming

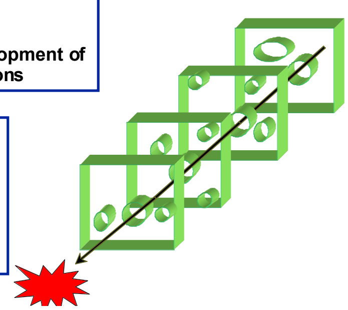
Approach

- Identify scenarios with high probability of human error
- Identify/model precursors to errors
- Assess technological and procedural solutions via development of computational models of scenarios and candidate solutions

Goal

Develop modeling capability to:

- Assess technological and procedural solutions via development of computational models of scenarios and candidate solutions
- Test potential mitigation strategies



Plan FY00-FY04

Two Development Tracks

Human Performance Modeling*

- Aviation Error Contexts
- Taxiway Errors
- Approach / Landing w/ Aug. Displays
- Multiple A/L Scenarios w/ Aug. Displays
- Validation

Review of Models

RFP Letter (formal review)

Error Detection Modeling - Crew Activity Tracking System (CATS)

- Off-line Flight Data Analysis
- Error Mechanism
- Error Simulation with CATS Agents

* Multiple models addressing same operational problem

Plan Constraint: limited resources for supporting empirical work

Selected Modeling Frameworks

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Characteristics of selected models

- Operator level, cognitively oriented
- Comprehensive, mature and validated systems
- Integrative computational frameworks
- Output is generative, stochastic, context sensitive

Model	Type	Research Team	Demonstrated Sources of Pilot Error
ACT-R/PM	Low-level Cognitive with Statistical Environment Representation	Mike Byrne, Rice University; Alex Kirlik, University of Illinois	* Time pressure * Misplaced expectations * Memory retrieval problems
Air MIDAS	Integrative Multi-component Cognitive	Kevin Corker, Brian Gore, Eromi Guneratne, Amit Jadhav & Savita Verma, San Jose State University	* Workload * Memory Interference * Misperception
A-SA	Component Model of Attention & Situational Awareness	Chris Wickens, Jason McCarley, Lisa Thomas, University of Illinois	* Misplaced attention * Lowered SA
D-OMAR	Integrative Multi-component Cognitive	Stephen Deutsch, Richard Pew, BBN Technologies	* Communications errors * Interruption & distraction * Misplaced expectation
IMPRINT/ ACT-R	Hybrid: Task Network with Low-level Cognitive	Rick Archer, Micro Analysis and Design, Inc.; Christian Lebiere, Dan Schunk, & Eric Biefeld, Carnegie Mellon University	* Time pressure * Perceptual errors * Memory retrieval * Inadequate knowledge

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Progressive Implementation Strategy

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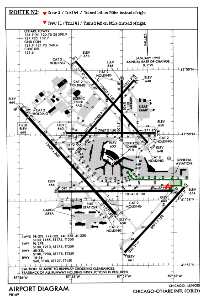
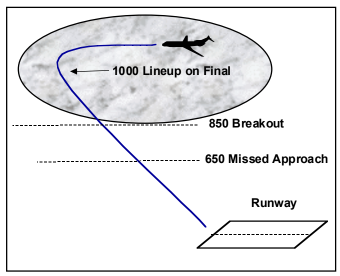
Advancing cognitive models into increasingly complex real-world applications

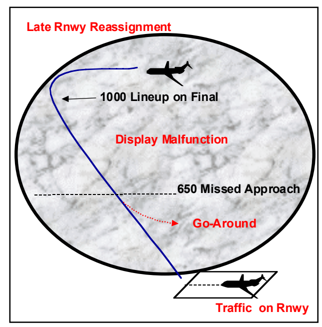
'01 Modeling
Taxi-Navigation Errors

'02-'03 Modeling
Nominal Approach/Landing with and without SVS

'03-'04 Modeling
Multiple Off-Nominal Approach/Landing with and without SVS







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Implementation Plan Status

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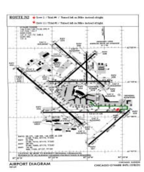
'01 Modeling
Taxi-Navigation Errors

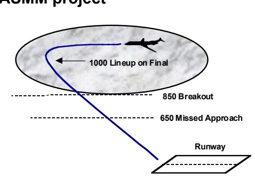
- Technical report on context of aviation errors
- Development of 5 models of surface operations
- Workshop 10/18/01



Proof-of-Concept: replication and causal explanation of various observed pilot taxi-navigation errors committed in high-fidelity simulation

'02-'03 Modeling
Nominal Approach/Landing with and without SVS

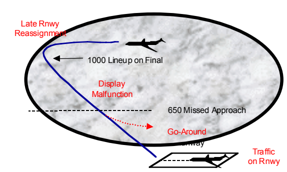
- Cognitive Task Analysis
  - •Baseline approach& landing
  - •Augmented display approach & landing
- Part-task Pilot-in-loop Simulation
  - •Eye-tracking data
  - •Display monitoring/ usage data
  - •Multiple scenarios (late runway reassignment, system failure, etc.)
- Models of Approach / Landing
  - •Initial model development
- Workshop scheduled 3/6/03
- Operator model provided to AvSP ASMM project



Demonstrated: 3 working models of pilot performance during nominal approach/ landing: good correlations between simulation outputs and observed pilot eye tracking/ visual attention allocation

'03-'04 Modeling
Multiple Off-Nominal Approach/Landing with and without SVS

- Models of Approach / Landing
  - •Develop advanced models
  - •Investigate off-nominal scenarios
  - •Identify error susceptibilities
  - •Evaluate mitigation strategies
- Model Verification/Validation Approaches
  - •Determine "choke points" (e.g., workload, SA at transition points)
  - •Cross scenario
  - •Cross model
  - •Emergent behaviors



Objective: prediction of pilot attentional allocation, decisions, and actions during off-nominal operations with & without SVS

Human Factors
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Publications to Date

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Journals, Books, Conference Proceedings

Callantine, T. (2002). A representation of air traffic control clearance constraints for intelligent agents. In A. El Kamel, K. Mellouli, and P. Bourne (Eds.), Proceedings of the 2002 IEEE International Conference on Systems, Man, and Cybernetics, #WA1C2, (CD-ROM).

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Callantine, T. (2001). Agents for analysis and design of complex systems. Proceedings of the 2001 IEEE International Conference on Systems, Man, and Cybernetics, 567-573.

Callantine, T. (2001). Analysis of flight operational quality assurance data using model-based activity tracking. SAE Technical Paper 2001-01-2640. Warrendale, PA: SAE International.

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Deutsch, S. & Pew, R. (2002). Modeling human error in a real-world teamwork environment. Proceedings of the Twenty-fourth Annual Meeting of the Cognitive Science Society (pp. 274-279), Fairfax, VA

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McCarley, J. S., Wickens, C. D., Goh, J., and Horrey, W. J. (2002). A computational model of attention / situation awareness. Proceedings of the 46th Annual Meeting of the Human Factors and Ergonomics Society. 1669-1673. Santa Monica: Human Factors and Ergonomics Society.

Note: All papers listed above are available for download from the Human-Centered Systems Lab (HCSL) website: http://human-factors.arc.nasa.gov/ihi/hcsl/publications.html#HPMPubs

Publications to Date

AvSP SWAP — Human Performance Modeling

Ames Research Center

Technical Reports

Byrne, M. D., & Kirlik, A. (2003). Integrated Modeling of Cognition and the Information Environment: A Closed-Loop, ACT-R Approach to Modeling Approach and Landing with and without Synthetic Vision System (SVS) Technology. Technical Report AHFD-03-4/NASA-03-3, Institute of Aviation. University of Illinois at Urbana-Champaign.

Byrne, M. D., & Kirlik, A. (2002). Integrated Modeling of Cognition and the Information Environment: Closed-Loop, ACT-R Modeling of Aviation Taxi Errors and Performance. Technical Report AHFD-02-19/NASA-02-10, Institute of Aviation, University of Illinois at Urbana-Champaign.

* Callantine, T.(2002).CATS-based agents that err. NASA Contractor Report 2002-211858. Moffett Field, CA: NASA Ames Research Center.

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Deutsch, S., & Pew, R. (2003). Modeling the NASA baseline and SVS-equipped approach and landing scenarios in D-OMAR. BBN Report No. 8364. Contractor Report.

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* Keller, J. W., and Leiden, K. (2002). Information to Support the Human Performance Modeling of a B757 Flight Crew during Approach and Landing: RNAV. Contractor Report.

* Keller, J. W., and Leiden, K. (2002). Information to Support the Human Performance Modeling of a B757 Flight Crew during Approach and Landing SVS Addendum. Contractor Report.

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* Leiden, K., Keller, J. W., and French, J., (2002). Information to Support the Human Performance Modeling of a B757 Flight Crew during Approach and Landing, Contractor Report.

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* Leiden, K., Keller, J. W., and French, J.W. (2001). Context of Human Error in Commercial Aviation. Contractor Report.

* Newman, R. L. (2002). Scenarios for "rare event" simulation and flight testing. Monterey Technologies Inc. / Crew Systems TR-02-07A.

* Uhlarik, J. and Prey, C.M. (2002). Functional Allocation Issues and Tradeoffs (FAIT) Analysis of Synthetic Vision Systems (SVS). Contractor Report.

Wickens, C. D., & McCarley, J. S. (2001). Attention-Situation Awareness (A-SA) Model of Pilot Error (Final Technical Report ARL-01-13/NASA-01-6). Savoy, IL: University of Illinois, Aviation Research Lab.

* Wickens, C. D. (2002). Spatial Awareness Biases (ARL-02-6/NASA-02-4). Savoy, IL: University of Illinois, Aviation Research Lab.

Wickens, C. D., McCarley, J. S. and Thomas, L. (2003). Attention-Situation Awareness (A-SA) Model, Contractor Report.

Note: *denotes papers that are available for download at http://human-factors.arc.nasa.gov/ihi/hcsl/publications.html#HPMPubs

Publications to Date

Upcoming

Byrne, M. D., & Kirlik, A. (in prep). Marrying cognitive and ecological analyses to support computational modeling of dynamic decision making in aviation. To appear in: A. Kirlik (Ed.), Working with Technology in Mind: Brunswikian Resources for Cognitive Science & Engineering. New York: Oxford University Press.

Byrne, M. D., & Kirlik, A. (in prep). Integrating cognitive architectures and ecological analyses: Closing the loop. Manuscript to be submitted to Cognitive Science.

Byrne, M. D., & Kirlik, A. (in prep). Modeling to support error diagnosis in commercial taxi operations. Manuscript to be submitted to The International Journal of Aviation Psychology.

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Miscellaneous

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Micro Analysis & Design

Aviation Safety Program
Human Performance Modeling Workshop
March 6, 2003

Cognitive Task Analysis for Approach Phase of Flight

Ken Leiden
Micro Analysis & Design

Micro Analysis & Design

Overview

- Background
- CTA Objectives
- Baseline CTA
  - Approach
  - Findings
- SVS CTA
  - Approach
  - Findings

Micro Analysis & Design

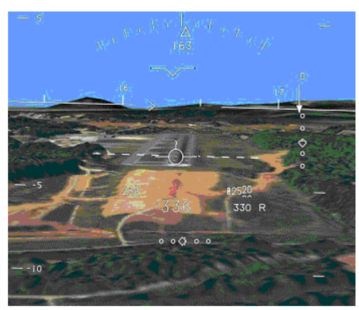
Background

- In FY01, two teams from MA&D were awarded contracts for AvSP HPM project
  - One team to use IMPRINT/ACT-R for HPM of “taxiway errors”
  - Other team (Ken Leiden, Ron Laughery, John Keller, Jon French) asked to forgo HPM (intended to use IPME)
    - Instead, review current state of HPM applicability to “human error prediction” and document in a white paper
- Since that time, this team has assumed a “modeling support” role to the AvSP HPM effort

Micro Analysis & Design

CTA Objectives

- Provide the FY02 HPM teams with primarily *qualitative* information to model the flight crew of a B757 during approach phase of flight
  - Baseline condition – initially an instrument landing system (ILS) approach with nominal flight deck displays
    - Later changed to Area Navigation (RNAV) non-precision approach to reflect human-in-the-loop simulation capabilities
  - Augmented display condition – synthetic vision system (SVS) display depicting terrain in 3-D



Micro Analysis & Design

Baseline CTA Approach

- A thorough CTA begins with a thorough Task Analysis
  - Perform literature search of existing task analyses
  - Gather enough background information so modelers understand how pilot tasks affect aircraft dynamics and vice versa
- 9 approaches in Ames B747-400 full motion simulator (some resulting in go-arounds) under varying visibility conditions
- Good preparation for CTA interviews with SMEs

NASA Ames B747-400 full motion simulator

Micro Analysis & Design

Baseline CTA Approach

- CTA interviews with four SMEs
  - Current American Airlines first officer with 6,000 hours
  - Retired line check airman and Associate Professor at Embry-Riddle with 21,500 hours
  - Retired United Airlines captain with 25,000 hours
  - Current Delta Airlines captain with 18,000 hours
- Used critical decision method for expert knowledge elicitation
  - Incident identification
  - Recognized flags
  - Get story behind story

Baseline CTA Results

- The information collected from both the literature review and the SMEs was compiled in a 61 page report delivered on March 1, 2002
  - "Information to Support the Human Performance Modeling of a B757 Flight Crew during Approach and Landing"
  - American Airlines & Embry-Riddle SMEs proofread report
    - found only two content errors
- Organized into 6 topics (blue italics discussed in more detail)
  - Background info about approach procedures and flight deck instruments
  - *Behavioral task analysis of the approach and landing*
  - Discussion of B747-400 simulator runs
  - *Cognitive decision points during approach*
  - Recommended reading for modelers
  - Summary of 4 accident investigations where errors during approach resulted in crashes – provide insight into how error chains develop

Behavioral Task Analysis

- Task descriptions – qualitative descriptions of 19 tasks performed during approach or landing (e.g., how pilot sets flaps)
  - Event timeline and task analysis
    - Sequential tasks
    - Non-sequential tasks (e.g., party line communication)
  - Potential problems or errors due to:
    - Localizer intercept
    - Aircraft spacing
    - Stabilization gates
    - Speed brakes
    - FMC reprogramming
    - Switching radio frequencies
    - Distractions

Give modelers insight into ramifications of human error

Event Timeline

- 5-page event timeline and task analysis begins with start of approach phase and ends with wheel touch
  - Description of event that begins task sequence (i.e., glide slope alive)
  - Tasks assigned to pilot flying (PF) and pilot not flying (PNF)
  - Approximate task duration
  - Task type – discrete, continuous, intermittent

Final Flaps and Landing Checklist

•The task sequence associated with this event takes less than 30 seconds to complete.

Event / Task Description	Operator	Type
"Flaps 30"	PF	Discrete
Set flaps 30 & "flaps 30"	PNF	Discrete
Call for landing checklist	PF	Discrete
Get list or starting from memory	PNF	Discrete
"Gear Down?"	PNF	Discrete
Check gear lights	Both	Discrete
"Down and checked"	PNF	Discrete
"Down and checked"	PF	Discrete
"Flaps 30?"	PNF	Discrete
Check flap settings	Both	Discrete
"Flaps 30"	PNF	Discrete
"Flaps 30"	PF	Discrete
"Speed brakes armed?"	PNF	Discrete
Check speed brakes	Both	Discrete

Cognitive Decision Points

When to execute a missed approach (i.e., go around)

- e.g., too high on approach – aircraft could overshoot the runway
  - Quantitative factors:
    - Where do I think I can safely touch down based on where I'm at now?
    - How much runway do I need once I touchdown?
    - How much will the runway provide?
      - How long is it?
      - Or, do I have to land and hold short of an intersecting runway?
    - What are the conditions on the surface of the runway (ice, snow, water, worms)
    - Are my aircraft systems operational (brakes, thrust reversers)?
    - How much fuel do I have (might not have enough fuel for a 20 minute missed approach)?
    - How heavy am I (an empty airplane stops very quickly)?
  - Qualitative factors that may weight decision to continue with descent when quantitative factors are borderline:
    - Maintaining schedule
    - Passengers with missed connections
    - I've been on this plane for 11 hours and want to get off

Cognitive Decision Points

When to execute a missed approach (cont)

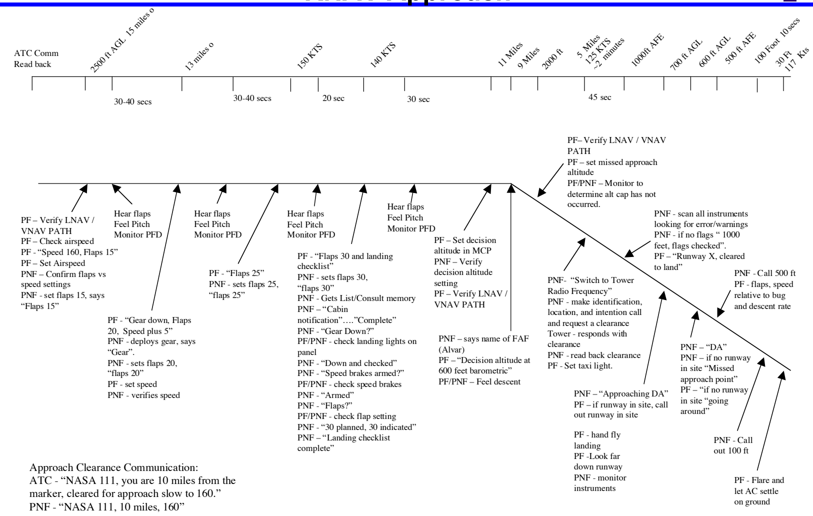
- e.g., visibility factors (ILS approach)
  - Pilots have already received a report of the cloud ceiling altitude
  - As aircraft approaches the ceiling altitude, the pilots have an expectation of seeing the clouds begin to break up.
  - Below the ceiling altitude, but above decision height:
    - If there is no indication that clouds are breaking up, the pilots mentally prepare for a missed approach.
    - If the clouds are breaking up, the pilots plan to continue with the descent.
  - Just prior to decision height:
    - The pilots are looking for any changes in visibility to reaffirm or disprove their earlier predisposition to:
      - continue the landing (most likely the runway is in sight by this time).
      - execute a missed approach (most likely the runway will not appear).
  - At decision height, unless something very unusual happens (e.g., the aircraft punches through a very well-defined cloud layer), the pilots have already made their decision and react accordingly.

RNAV Update

- Original report, which assumed ILS, was updated to include RNAV approach
  - ILS functions in human-in-the-loop simulation for quantitative data collection not working properly
  - SME input from one pilot (United captain)
  - Change in procedures, use LNAV and VNAV Path flight modes
  - Updated event timeline and task sequence

Micro Analysis & Design

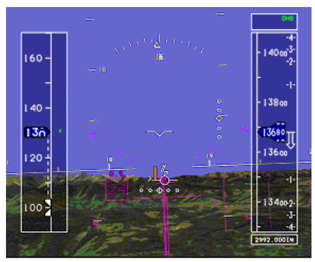
RNAV Approach

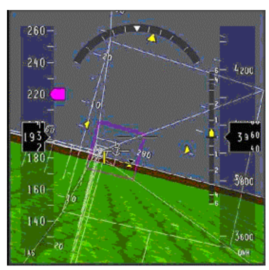


Micro Analysis & Design

SVS CTA Approach

- Information about SVS collected from available sources – primarily NASA Langley
- One SME available – SVS test pilot Rick Shay





SVS CTA Results

- Assumed that basic task sequence (for ILS or RNAV approach) is unchanged with SVS
- However, SVS does impact pilot interaction in several ways:
  - Closure and crossing rate interpretation
  - Tunnel navigation
  - SVS aid to visual transition
  - Situational awareness in IMC (SVS vs. no SVS)

Closure/Crossing Rates

- Closure and crossing rates are interpreted by the perceived rate of change of the size of features ahead and around the aircraft.
- Terrain map feature of SVS provides closure and crossing rate cues similar to those available during daytime VMC
- SME stated photo texturing of the NASA concept was easier to interpret crossing rate cues compared to the Rockwell Collins concept

Tunnel Navigation

- The tunnel allows pilots to follow a visual representation of the approach rather than relying on their interpretation of instrument cues to maintain the approach profile (e.g., flying a visual glide slope)
- However, one Langley report indicated that the use of tunnel navigation did not increase the pilots situational awareness
  - Perhaps the ease of using the tunnel navigation to maintain the approach path may somehow be reducing the amount of information required for the task

SVS Aids Visual Transition

- Instrument approach procedures are designed to aid the pilot during IMC to a point where visual contact with the runway and continuing the approach to a landing are possible.
- SME indicated that when first breaking out below the clouds there is an adjustment period between using the ILS instruments and becoming oriented based on the visual inputs out the window.
- The difficulty making this adjustment may relate to identifying terrain features and correlating that to aircraft position.
- SVS should aid in this transition as the pilot will already have an idea of the features and their orientation prior to breaking out below the clouds.

Situation Awareness in IMC

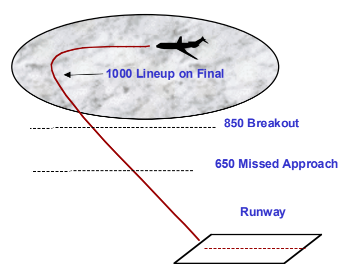
- Without SVS requires integration of information from several sources
  - e.g., elevation of terrain from approach plates
    - mentally overlaying that on navigation display
- For a missed approach, SVS terrain combined with the velocity vector ensures terrain clearance
- SVS provides another means to crosscheck instruments

HPM-SVS Part-Task Simulation: Characterizing Pilot Approach and Landing Performance With and Without Visual Aiding

Allen Goodman
Human Performance Modeling Element
March 6, 2003

Outline of Topics

- Study Objectives
- Simulator Description
- Scenarios and Test Plan
- Data Collected
- Comments on Observed Performance

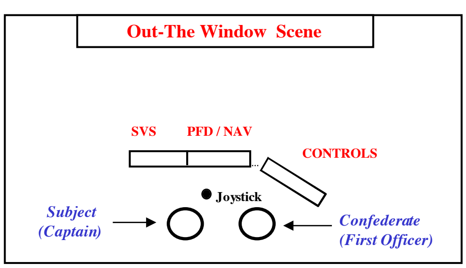


Study Motivation and Objectives

- **Support extension of taxi-navigation models into more complex application domain**
  - Approach and landing operations
  - SVS usage
  - Robust nominal performance and scanning behaviors
- **Generate empirical data and information to guide model development and validation**
  - Specification of the task-environment
  - Detail scenario conditions of interest
  - Collect pilot performance, ratings, and eye-tracking data

Simulator Configuration

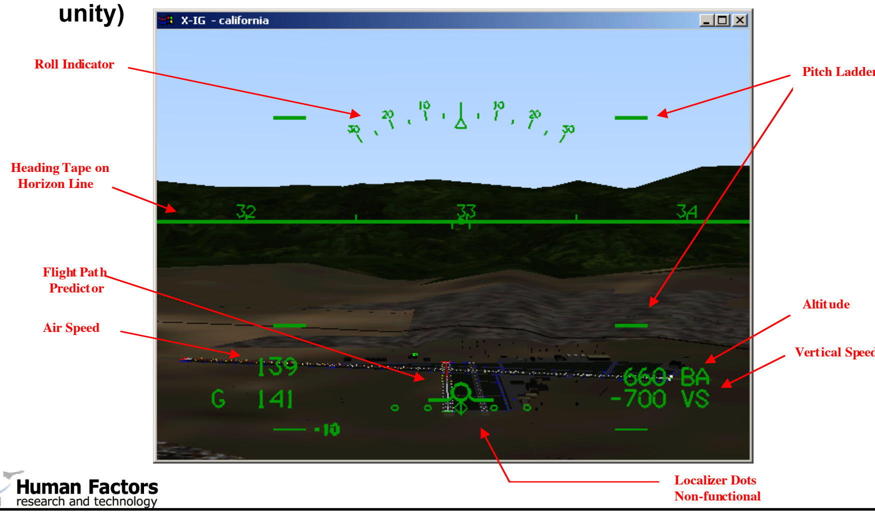
- **PC-based simulator approximates instruments and controls B-757**
- **4 display components and joystick with throttle**
- **Visual data base of Santa Barbara Airport with surrounding terrain and cultural features**



Generic Synthetic Vision Display

AvSP SWAP — Human Performance Modeling

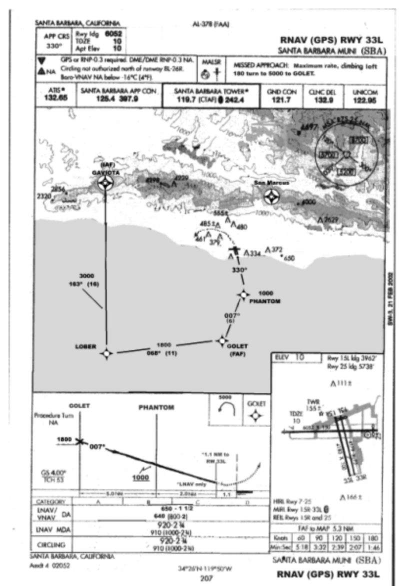
- Head-down SVS display measured 10"x 7.5"
- Display presented terrain imagery overlaid with flight symbology
- Field of view set at 31˚ x 23˚ (provided wide-angle perspective relative to unity)



Basic Scenario Description

AvSP SWAP — Human Performance Modeling

- RNAV (GPS) approach to Runway 33L
- Daylight operations under calm winds
- Flown fully coupled to autopilot until DH (650')
- Experimenters served as FO and ATC



Test Plan

AvSP SWAP Human Performance Modeling

- Data collected on 3 commercial-rated airline pilots
- Pilots flew each of 10 scenarios in test matrix once
- Prior to trial run pilots told only of expected visibility and SVS availability

	Display Configuration	Baseline	Baseline	SVS
	Visibility	VMC	IMC	IMC
Approach Event	Nominal Approach (nominal landing)	*Scenario #1*	*Scenario #4*	*Scenario #7*
	Late Reassignment (side-step & land)	*Scenario #2*		*Scenario #8*
	Missed Approach (go-around)	*Scenario #3*	*Scenario #5*	*Scenario #9*
	Terrain Mismatch (go-around)		*Scenario #6*	*Scenario #10*

Human Factors research and technology

Data Collected

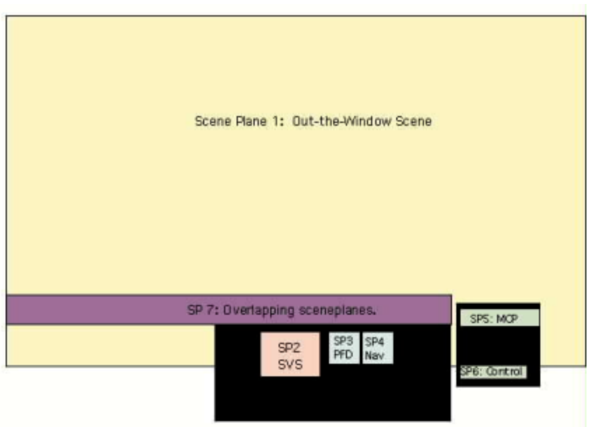
AvSP SWAP Human Performance Modeling

- Time-referenced digital variables collected at 20 Hz
  - Aircraft position and state
  - Pilot control inputs
  - Eye-gaze information
- Post-trial ratings
  - Workload by approach segment
  - Situational awareness by approach segment
- Video Recordings
  - Eye-tracking camera with superimposed fixations cursor
  - Ambient room camera

Human Factors research and technology

Eye Tracker Data

6 areas of interest (AOI's)

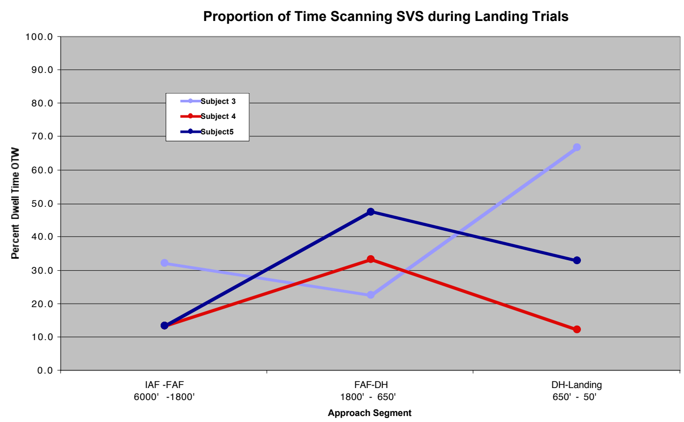


Specifying Scanning Performance

- ***Where do pilots look?***
  – Dwell count
- ***How long do they look?***
  – Mean dwell duration
  – % dwell time distribution
- ***What is their usual pattern of looking?***
  – Dwell sequence transitional tables
  – Dwell sequence conditional probabilities
  – Dwell sequence joint probabilities

Example of Scanning Performance Analysis

Divergence in Usage Strategies



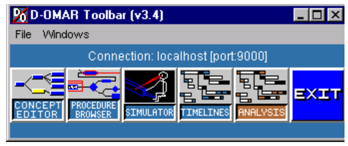
Questions of Interest

(1) How does the availability of a synthetic vision display during approach and landing impact the allocation of visual attention between the various areas of information within the cockpit?

(2) How is visual attention transitioned from the synthetic vision display to the out-the-window view during the critical break-out phase of landing?

(3) How does the usage of a synthetic vision display effect pilot workload and situational awareness?

(4) Are there individual differences in SVS usage strategies between inexperienced users?



Modeling the NASA Baseline and SVS-equipped Approach and Landing Scenarios in D-OMAR

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NASA Ames Research Center
Human Performance Modeling Workshop
March 6-7, 2003

Outline

- General description of the model
- Specific implementation of the model
- Exercising the model
- Findings and implications
- Validation
- Future Directions

Human Performance Models for the Aircrews (and ATCs)

Domain-specific capabilities

- **Pilot-flying (PF)**
  - Aviate/navigate—execute approach, landing, and taxi procedures
  - Monitor ATC radio communication
  - Execute ATC directives
  - Maintain dialog with PNF
- **Pilot-not-flying (PNF)**
  - Aviate/navigate--support approach, landing, and taxi procedures
  - Handle ATC radio communication
  - Cross-check ATC directives
  - Maintain dialog with PF

Basic-person proactive and reactive capabilities

- Intentions and actions evolve from a mix of goals, expectations, and the current event sequence
- Perceptual, cognitive, and effector capabilities support action selection and execution
- Ability to address concurrent task demands

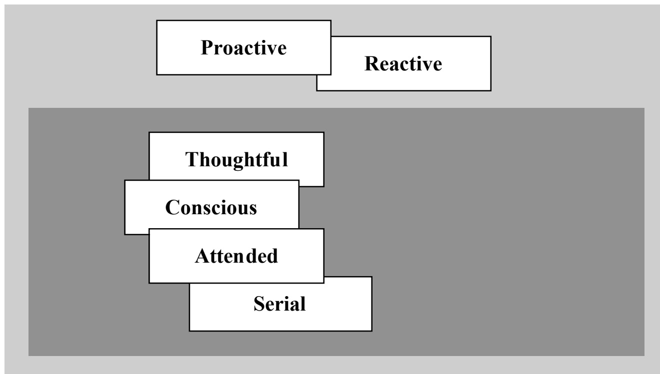
We seek to model expertise in a high-tempo multi-tasking environment

Expertise in Human Performance

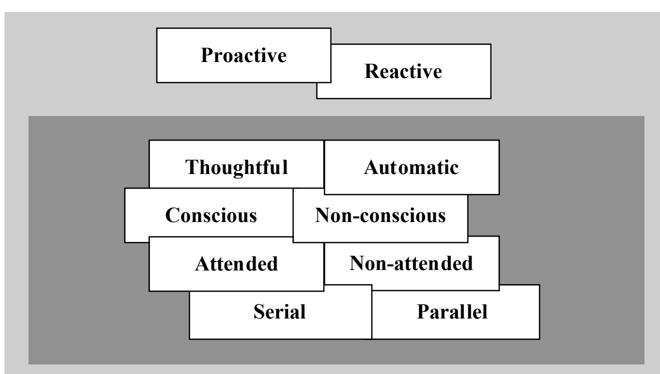
- **Problem spaces and rules - Alan Newell**
- **Proficiency and expertise - Hubert Dreyfus and Stuart Dreyfus**
- **Skills, rules, and knowledge - Jens Rasmussen**
- **"... look more broadly for automatic processes. They need not be restricted to procedural knowledge or perceptual motor skills but may permeate the most intellectual activities in the application environment." - Gordon Logan**

Expertise as skill-based interactions with patterns of events evolving in time

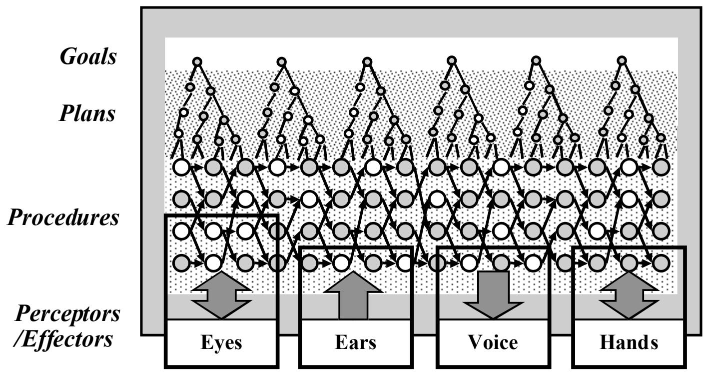
Modeling Surface Behaviors



Support for Expertise and Multiple Task Behaviors



An Architecture for Perception, Cognition, and Action



One missing box is the one for *working memory*!

Working Memory and Long-term Memory

- **Working memory is broadly distributed**
  - **Memory items migrate—they are transformed and interpreted**
  - **Sometimes they are volatile and sometimes less so**
    - » **"descend to *1800* feet for GOLET"**
    - » **"descend to *2100* feet for GOLET"**

> **"… memory evolved in service of perception and action in a three-dimensional environment, … memory is embodied to facilitate interaction with the environment." (Glenberg, 1997)**

- **Goals and procedures—what we know how to do--are the stuff of long-term memory**

Multi-tasking and Procedure Contention in a Distributed Execution Environment

"Flaps 25" as an interrupt to on-going tasks

Procedures are classified as *contending* or *non-contending*

- **In a complex procedure hierarchy only particular subsets of procedures are in contention**
- **at a low level in the hierarchy contention governs *resource* utilization**
  - **contention among procedures requiring the eyes or the control-pedestal hand**
- **at an intermediate in the hierarchy contention establishes *policy***
  - **contention between in-person aircrew and ATC party-line radio conversation**

Mediating Procedure Contention

Among contending procedures, priority drives procedure activation:

- **lower priority procedures are suspended, or**
- **for a *winner-take-all* competition, procedures are specialized to fail when suspended**

Procedure contention is:

- **supported by functions for *interrupting* and *resuming* procedures**
- **provided with flexibility in the selection of a *restart point***

Procedure Activation Operationalized

When a new procedure is ready to execute:

- check to see if it belongs to a class such that it is in conflict with an executing procedure
- if so, its priority is computed and compared with that of the executing procedure:
  - either, the new procedure begins execution and the running procedure is suspended
  - or, the new procedure is suspended and the running procedure continues to execute
- procedure priorities are monitored for a change in relative strength pending the completion of the executing procedure

Procedure contention is mediated *without* a central executive

Scenario Development

We were asked to complete the "late reassignment"scenarios with the baseline flight deck in VMC and with the SVS-equipped flight deck in IMC

Scenario Development Strategy

- Develop an RNAV approach (based on the Keller and Leiden task analysis) for VMC using the baseline flight deck
- Add an 800-foot cloud ceiling (limiting the out-the-window view of the runway) for IMC in the baseline approach
- Add SVS equipment and procedures for the approach in IMC
- Add a second aircraft to the scenario to force the late reassignment and increase aircrew workload in VMC
- Run the two aircraft scenario with SVS-equipped flight decks in IMC

Scenario Development Status

<u>We have five of the NASA part-task simulation scenarios running</u>

Scenario 1: nominal approach using the baseline configuration in VMC

Scenario 2: late reassignment approach using the baseline configuration in VMC

Scenario 4: nominal approach using the baseline configuration in IMC

Scenario 7: nominal approach using the SVS configuration in IMC

Scenario 8: late reassignment approach using the SVS configuration in IMC

Scenario 9: missed approach using the SVS configuration in IMC

- Added go-around procedure execution as landing-decision outcome
- Added an IMC with an announced 800-foot ceiling, but actual cloud cover extending to ground level

Scenario 10: terrain mismatch using the SVS configuration in IMC

- SVS misalignment such that the aircraft was not lined up with the runway when it broke out of the cloud cover at 800 feet

Flight Deck Model

Basic flight deck elements include:

- PFD
- HSI
- MCP
- (FMC flight plan)
- Yolk, throttle, landing gear, and speed brake levers
- Mode annunciators
- SVS

Scanning Flight Deck Instruments

- **The scans are modeled as independently controlled scans of the basic flight deck instruments: the PFD, the HSI, the out-the-window view, and the SVS**
  - **Individual scans are adjusted for frequency (e.g., scan HSI more frequently around way points)**
  - **Individual scan may be suspended (e.g., the HSI scan is suspended shortly after the decision to land)**
  - **The publish-subscribe protocol is used to make scan information available to one or more procedures requiring the information as input**
- **High-tempo processes (e.g., PNF monitoring and reporting decreasing ground speed following weight-on-wheels) preempt the background scanning**

What is Seen

- **Out-the-window view**
  - **Sighting of the runway to support the decision to land**
  - **Tracking the runway for the side-step maneuver and landing**
- **PFD**
  - **Heading, speed, altitude, and altitude rate**
- **SVS**
  - **Heading, speed, altitude, and altitude rate**
  - **Sighting the runway once it comes into the field of view**
- **HSI**

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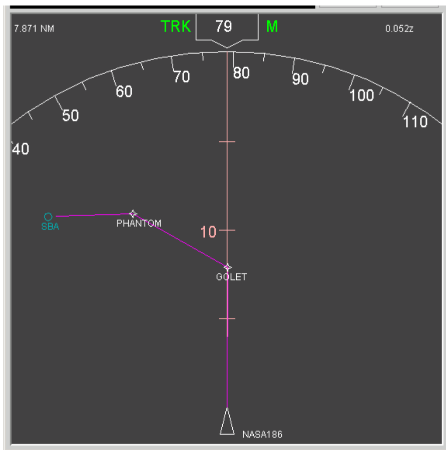
Looking at the HSI



- View heading, distance to next waypoint, and display scaling
- Name of the next waypoint
- Verify that heading is converging on desired heading
- Noting last waypoint on the approach

What is Seen, cont.

- Reading flight-deck documentation
  - Approach plate provides the route plan, altitudes at fixes, decision height, and go-around information
  - Checklist execution
  - Airport diagram for runway and taxiway information

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Findings and Implications

- **In the nominal and late reassignment scenarios there were large individual differences in SVS usage from decision height to landing**

	Sub3_Scen7_Phase4, DH to End				Sub4_Scen7_Phase4, DH to End				Sub5_Scen7_Phase4, DH	
		Sub3_Scen8_Phase4, DH to End				Sub4_Scen8_Phase4, DH to End				Sub5_Scen8
	Nominal	Late			Nominal	Late			Nominal	Late
	Segment	Segment			Segment	Segment			Segment	Segment
AOI_Name,	Fix_Dur_%,	Fix_Dur_%,			Fix_Dur_%	Fix_Dur_%,			Fix_Dur_%	Fix_Dur_%,
off	1.61	0.57			14.89	3.17			6.71	3.76
OTW	4.36	5.66			20.79	61.08			45.89	21.76
SVS	48.75	78.38			10.4	4.3			15.79	38.65
PFD	33.42	7.13			18.78	23.84			17.11	23.47
NAV	3	0			2.22	3.24			0	0
MCP	0	0			32.59	0			1.14	0
CONTROLS	7.45	2.8			0	1.49			0	0
OVERLAP	1.41	5.47			0.33	2.88			13.36	12.36

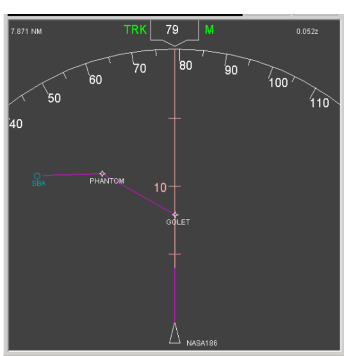
Findings and Implications, cont.

- **Two attitude displays or one?**
  - **When the SVS was added to the flight deck, it impacted time spent monitoring the HSI**
    - » **This was true during approach phases where the HSI provided essential waypoint transition information**
    - » **We found a similar effect in the part-task simulation data**
  - **Getting attitude information from two separate instruments may establish sub-optimal behaviors**
    - » **When time is short and attitude information in needed, a two instrument scan can impose a decision (to go to a single instrument scan) that could have been avoided**
    - » **In fact, the decision is between two sub-optimal options**
  - **If feasible, an SVS with basic PFD functionality as a fail-safe capability might offer a better alternative**

Findings and Implications, cont.

- High workload is hard on aircrews, but good for model development
  - Adding a second closely spaced aircraft highlighted a missing feature in the conversation model—the first officer had to speak through an ATC communication with the following aircraft to inform the captain of the descent to decision height
  - Scenario complexity leads to models that exhibit more robust behaviors--they are better suited to probing for sources of human error

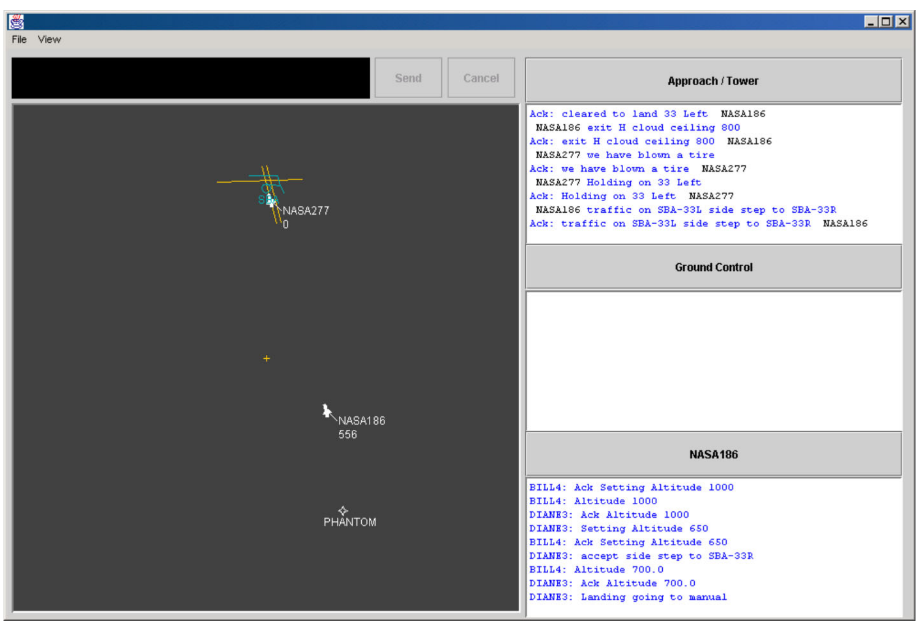
Findings and Implications, cont.

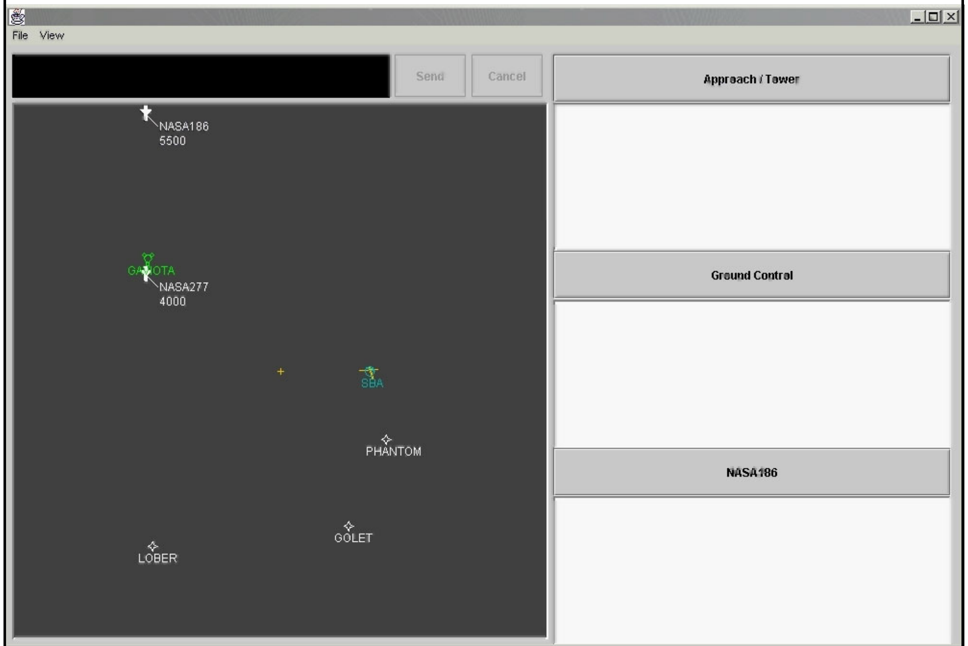


- GOLET is a busy waypoint with several potentially competing multi-step procedures to complete:
  - The captain and first officer are configuring the aircraft for landing
  - They need to complete the landing checklist
  - The aircrew needs to initiate and monitor the transition to the leg to PHANTOM
  - There is the transition to the tower controller, the clearance to land, and the pending decision-to-land
  - And there are controller transactions with other aircraft

Model Validation

- Analysis tools support model validation
  - Plan view display
  - Scenario event trace
  - Task timeline
- Event recording provides the data for the analysis tools
  - Standard event types are built in
    - » Procedure events: status, start and end times, priority, parent procedure, interrupts
    - » Signal-events record publish-subscribe activities
  - Domain and scenario specific event types are defined as needed
    - » Communication events
    - » Visual events
    - » Flight-deck action events
    - » Aircraft events





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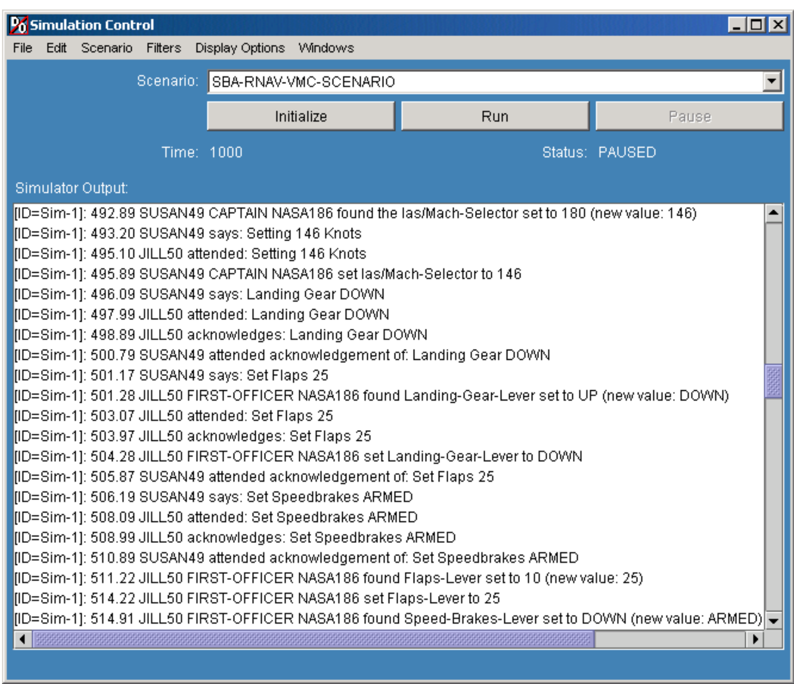

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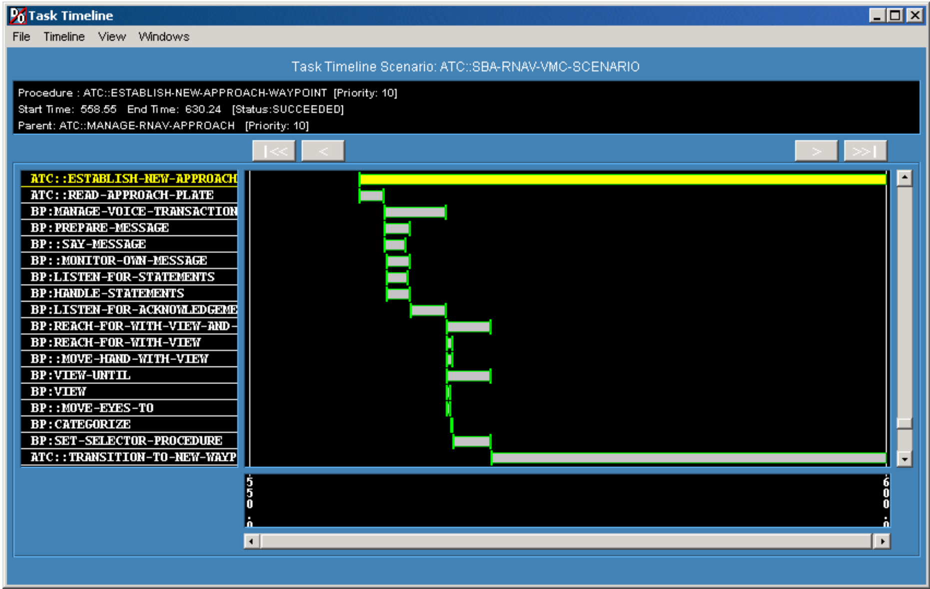

Future Directions

- Compare performance using an SVS and a PFD, with using an SVS that replaces the PFD
- Add a first officer's SVS to the flight deck
- Compare performance between forewarned runway event (i.e., blown tire) and non-forewarned event (e.g., vehicle crossing runway)
- Examine use of SVS capabilities outlined in the Concept of Operations
  - SVS appearance of vehicles encroaching on runway
  - Use of the SVS to support self separation
  - Use of the SVS to support reduced minima
- Individual differences in SVS usage

A Closed-Loop, ACT-R Approach to Modeling Approach and Landing with and without Synthetic Vision Systems (SVS) Technology

THE COMPUTER-HUMAN INTERACTION LABORATORY AT RICE UNIVERSITY

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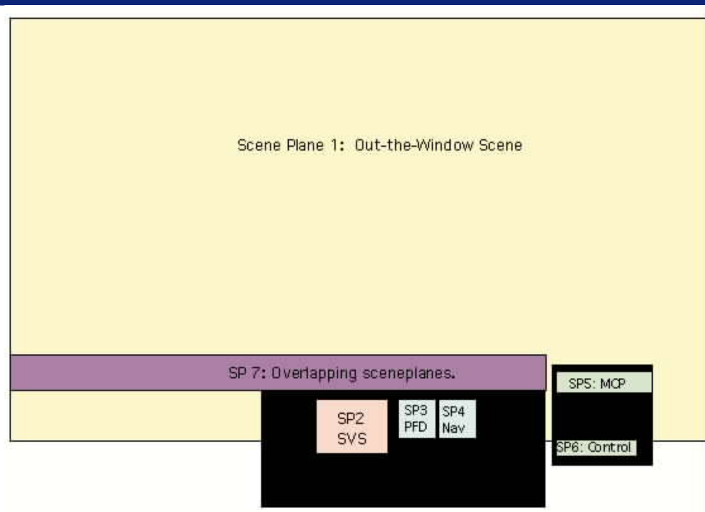
Overview

- Empirical Questions
- Empirical Results
- Modeling Approach and Specifics
- Preliminary Findings and Implications
- Future Work
- Demo

Empirical Research Questions

- What variance is there to explain?
  - Time from start to 50' has few control actions (until the very end)
  - Not very rich set of data to model
    - SVS doesn't seem to affect this much, either
- Because the SVS is such an obvious presence in the visual field, look to visual behavior
  - Attention allocation
  - Thanks for eye-tracking data!
- How does the SVS change things?
  - Simply a proxy for out the window (OTW)?
  - If not, when and how is it used?

Display Setup



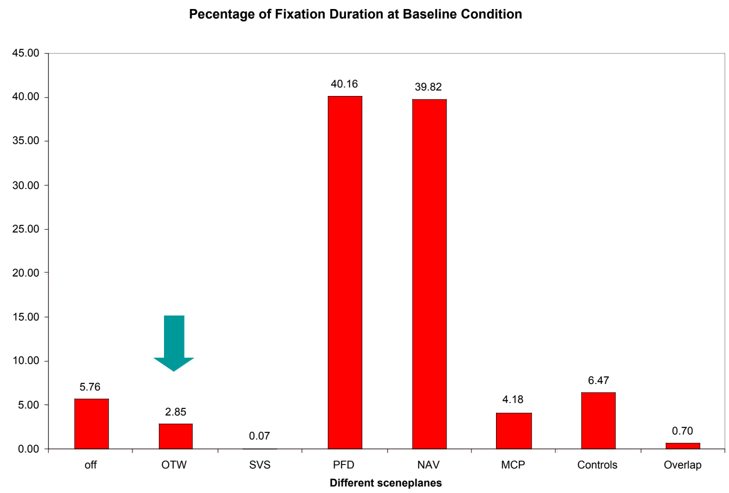
Review

- Regions of interest in the visual scene
  - Out the window (OTW)
  - Synthetic vision system (SVS)
  - Primary flight display (PFD)
  - Navigation display (NAV)
  - Mode control panel (MCP)
  - Controls
- Other eye-tracking outputs
  - Off (blink, nowhere, etc.)
  - Overlap (ambiguous between OTW and others)

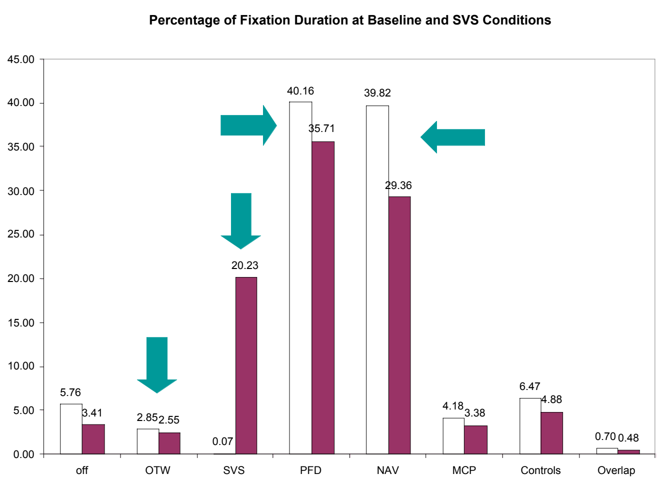
Review and Dependent Variable

- Flight phases
  - 1: Start to initial approach fix (IAF)
  - 2: IAF to final approach fix (FAF)
  - 3: FAF to decision height (DH)
  - 4: DH to end (50' above runway)
- Primary dependent variable
  - Trying to assess how pilots allocate visual attention, thus
  - Percentage of total dwell time on each region
  - Could also look at % of fixations, but this yielded almost identical results
    - Implies roughly uniform fixation duration

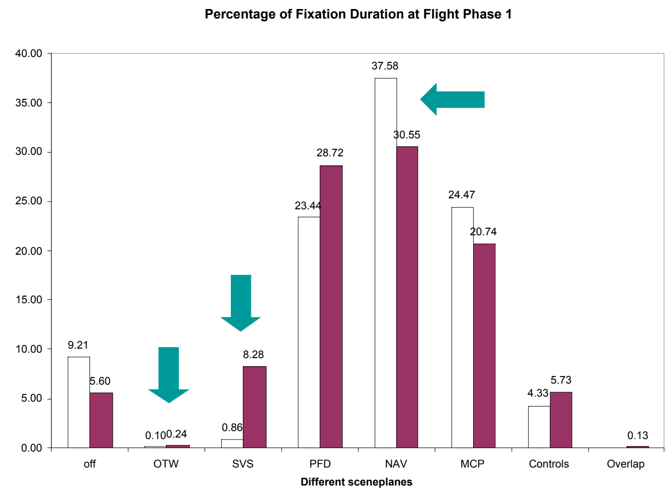
Results: All Phases, No SVS



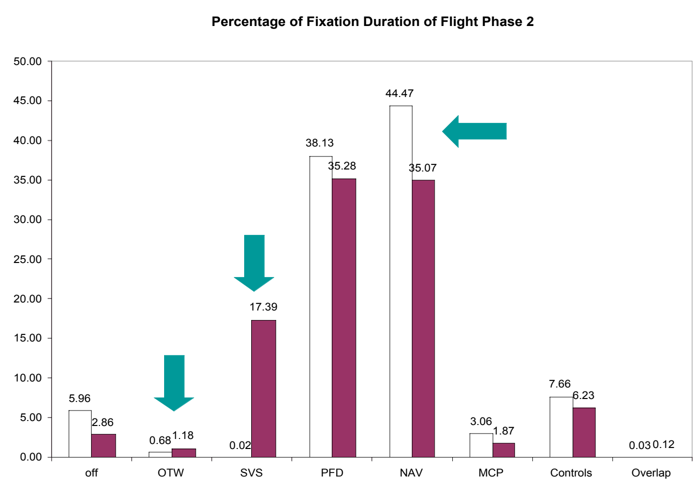
Results: All Phases, SVS vs. no-SVS



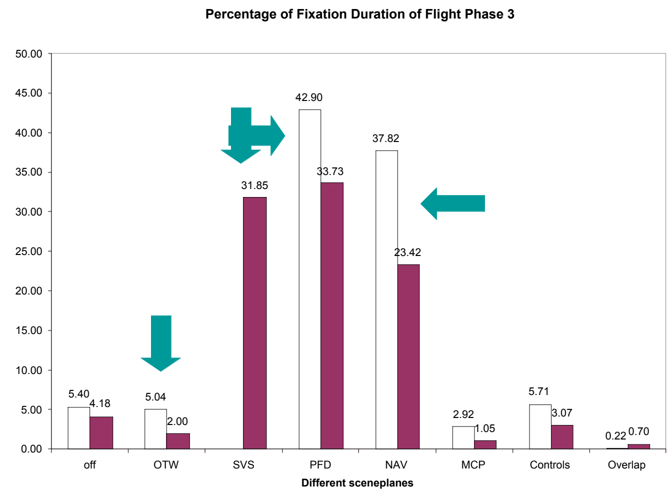
Results: Phase 1, SVS vs. no-SVS



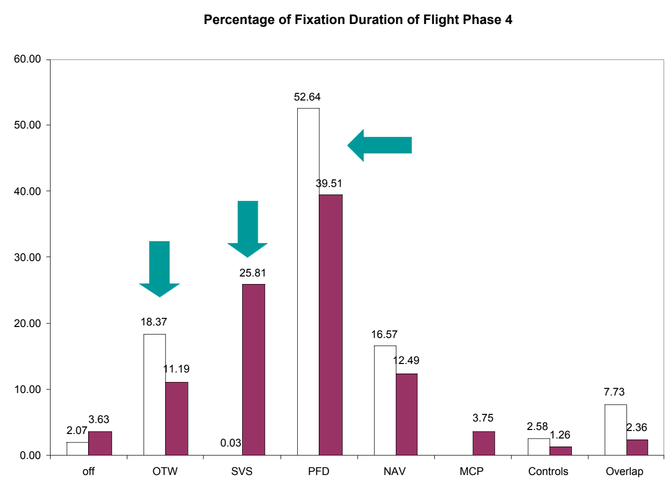
Results: Phase 2, SVS vs. no-SVS



Results: Phase 3, SVS vs. no-SVS



Results: Phase 4, SVS vs. no-SVS



Summary of Results

- Note: it's also interesting to break down phases 3 and 4 by scenario type
  - Nominal approach, missed approach, etc.
- SVS is clearly not just a proxy for OTW
- Appears to take on functionality of PFD and NAV
  - How?
  - Working hypothesis: Symbology overlaid on SVS

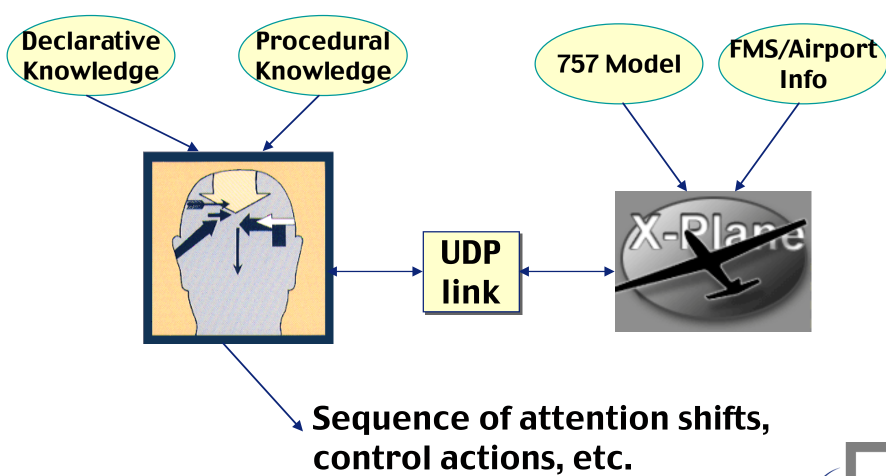
Modeling Approach

- Task Analysis
  - Documents supplied by NASA
  - Our own GOMS-like breakdown
  - Consultations with our subject matter expert (SME)
- ACT-R
  - ACT-R 5.0 (Anderson, Bothell, Byrne, & Lebiere, 2002)
  - End-to-end model of human-in-the-loop at fine temporal resolution
- Extant attention allocation accounts
  - For example, Senders (1964), Wickens (2002)
  - Sampling based on importance and bandwidth

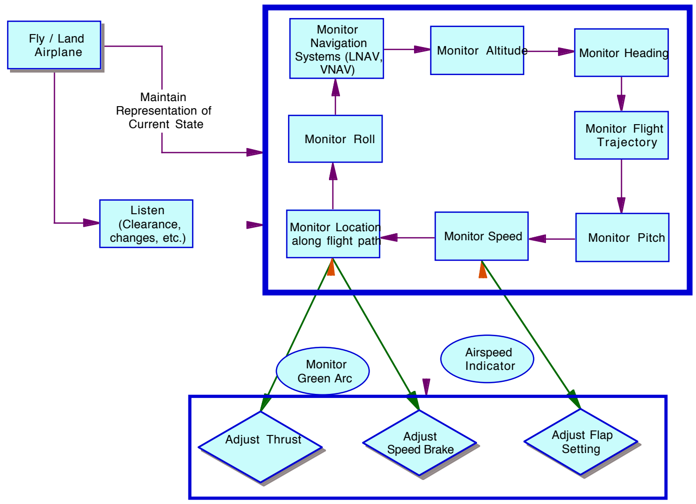
Modeling Approach

- Model both the human and the evaluated system
  - Dynamically
    - System model responds to inputs from human model
    - Human model responds to inputs from system model
  - In detail
    - Perception of displays as they appear to the pilots
    - Human model produces timestamped sequence of actions at the level of shifts of visual attention
- Taxi modeling work revealed importance of the dynamic coupling
- High level attention allocation emerges from information needs and low-level mechanisms

System Configuration



Knowledge Engineering



Issues

- Adapted pilot
  - Unlike Senders (1964), knowledge about "value" and "bandwidth" confounded
  - No modeling of learning
- Level of comparison of model performance to human performance
  - Examining individual shifts of attention probably not useful, too low-level
  - % dwell time too coarse?
  - Examining intermediate levels (e.g., transitions)
- Implementation issues
  - For example, OTW not sent over UDP by X-Plane

Initial Findings

- Based on
  - Initial task analysis
  - Static analysis of model
  - Simple assumptions about SVS use
- Can derive predictions distribution of gaze across the various display regions

Region of Interest	*Data, no SVS*	*Model, no SVS*	*Data, with SVS*	*Model, with SVS*
NAV	0.39	0.30	0.28	0.27
PFD	0.38	0.44	0.33	0.30
MCP	0.07	0.19	0.03	0.20
OTW	0.03	0.07	0.03	0.03
SVS	-	-	0.21	0.20

Other Implications

- Those predictions based largely on the symbology overlaid on the SVS
- Model should eventually be able to make predictions about the utility of different overlays
  - For example, should heading be included?
- Preliminary recommendations
  - Render the waypoints on the SVS
  - Condition overlays based on phase of flight
- Should ultimately be able to consider other, non-SVS, cockpit technologies

Future Work

- Completely debug the “closed loop”
  - Examine fully dynamic model performance
  - Validate against eye data
- Deeper exploration of go/no-go decision
- Manual control?
- Provides some specification for abstract HF terms
  - Workload
  - Situation awareness
- Look into abstract, de-adapted task analysis into pilot model

Demo

- One machine running X-Plane
- One machine running ACT-R and an a mockup of the display which is “visible” to ACT-R

Micro Analysis & Design

Carnegie Mellon

Approach and Landing

IMPRINT/ACT-R

Micro Analysis & Design

Rick Archer
Christian Lebiere
Dan Schunk

Carnegie Mellon University

Eric Biefeld

Army Research Laboratory

Laurel Allender
Troy Kelly

Micro Analysis & Design

Carnegie Mellon

Modeling approach

Discrete Event
(task network)

Cognitive
Architecture

Micro Analysis & Design

Carnegie Mellon

NASA simulation plan

Vectored Approach

Late Runway Reassignment

Missed Approach

Terrain Mismatch

Micro Analysis & Design

Carnegie Mellon

IMPRINT

Models the Aircraft

speed

altitude

flaps

Landing gear

Other controls

Other displays

Models the environment

altitude at which ground can be seen

altitude at which runway can be seen

set up to include more environmental variables

Micro Analysis & Design

Carnegie Mellon

ACT-R

Models the Pilot

what displays to look at

what controls to manipulate

what to do next

Micro Analysis & Design

Carnegie Mellon

Sources of model data

Background documents

CTAs

Videos

Spreadsheets

United pilot

Micro Analysis & Design

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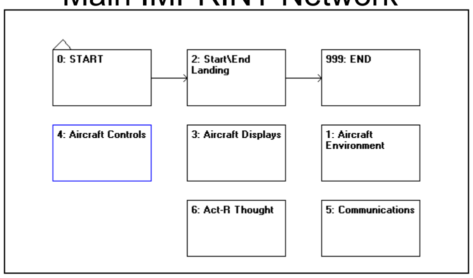
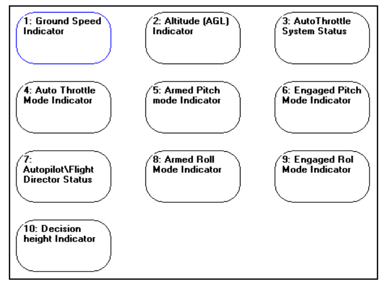
The IMPRINT model

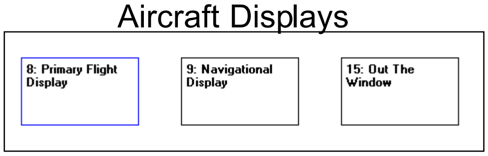
Main IMPRINT Network



Primary Flight Display



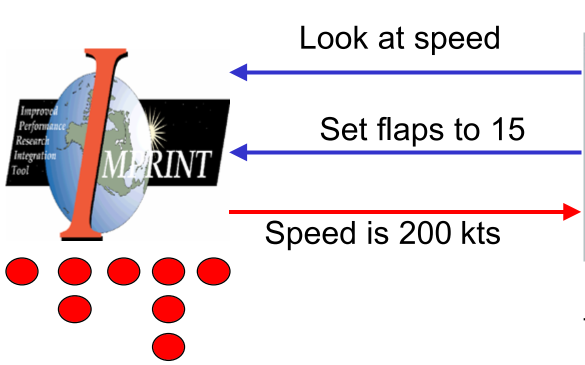
Aircraft Displays

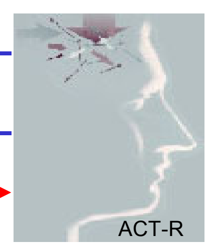


Micro Analysis & Design

Carnegie Mellon

IMPRINT/ACT-R interaction





If speed <= 200 then set flaps to 15

Micro Analysis & Design

Carnegie Mellon

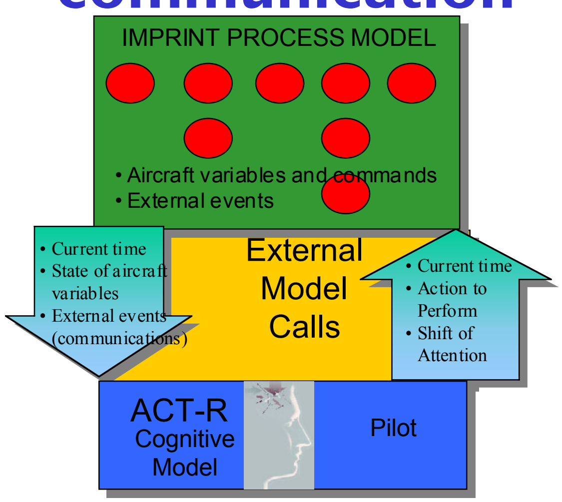
IMPRINT/ACT-R Model

- ACT-R model is embodied through perceptual/motor modules and inherits human limitations from architecture
- Generalized interface between IMPRINT and ACT-R model can be reused flexibly for other models
  - EMC
  - LIA
- ACT-R and IMPRINT are now synchronized to operate in parallel to improve interruptibility and flexible behavior

Micro Analysis & Design

Carnegie Mellon

IMPRINT/ACT-R communication



ACT-R Cognitive Architecture

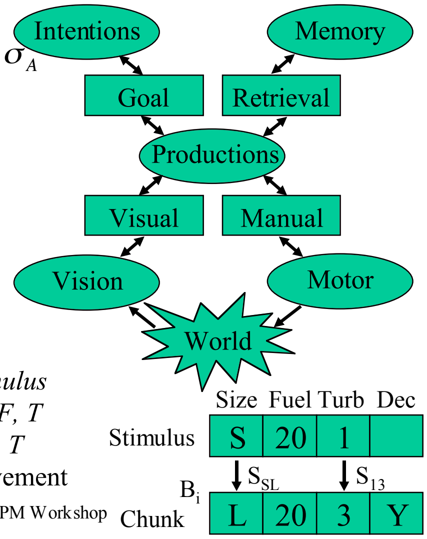
Activation $A_i = B_i + \sum_j W_j \cdot S_{ji} + \sigma_A$

Learning $B_i = \ln \sum_j t_j^{-d}$

Latency $T_i = F \cdot e^{-A_i}$

Utility $U_i = P_i \cdot G - C_i + \sigma_U$

Learning $P_i = \frac{Succ_i}{Succ_i + Fail_i}$



IF the **goal** is to categorize new *stimulus*
and **visual** holds *stimulus* info *S, F, T*
THEN start **retrieval** of chunk *S, F, T*
and start **manual** mouse movement

Errors and Parameters

- We chose to first focus on errors as our primary measure of performance. Other measures include deviation from ideal path, response latency, eye movements, etc.
- There are primarily two sources of errors in the model:
  - Time limitations
  - Decision errors
- We study performance sensitivity to various parameters:
  - Architectural parameters corresponding to each module
  - Linked to individual differences, fatigue, simulation conditions

Micro Analysis & Design

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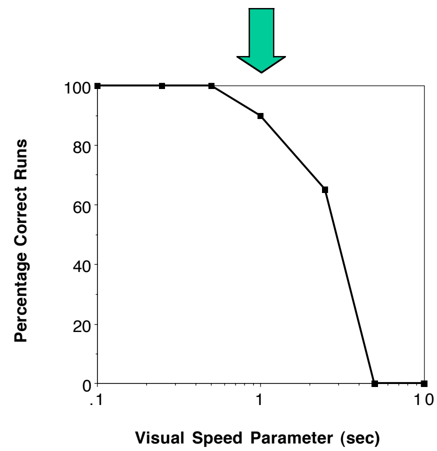
Sensitivity to Visual Speed

- Performance is very sensitive to speed of visual shifts
- Improving by factor of 2 yields perfect performance
- Impairments lead to rapid deterioration



Micro Analysis & Design

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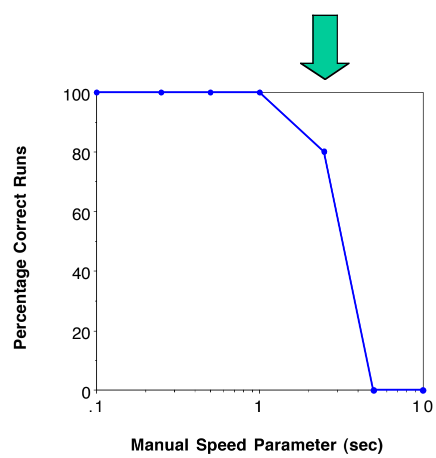
Sensitivity to Manual Speed

- Performance is highly sensitive to speed of manual operations
- Supports division of labor between PF and PNF



Micro Analysis & Design

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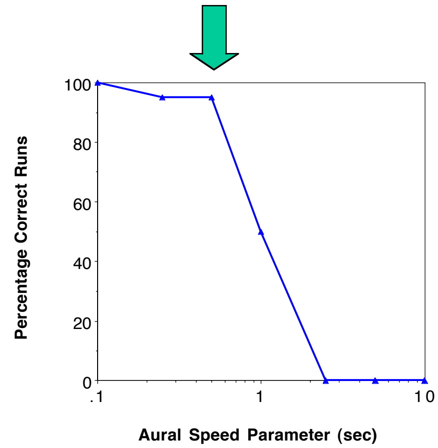
Sensitivity to Communications

- Performance is highly sensitive to overhead of communications
- Impact is hard to eliminate because of random schedule of events
- Increase in number or durations lead to rapid deterioration



Micro Analysis & Design

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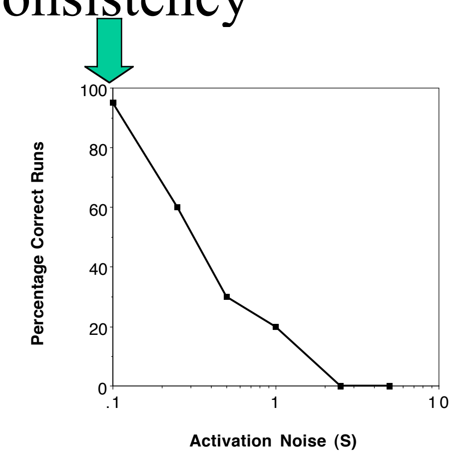
Sensitivity to Decision Consistency

- Performance degrades gradually with activation noise that controls retrieval of decision instances
- Most promising remediation is training to increase number of instances and/ or proceduralization



Micro Analysis & Design

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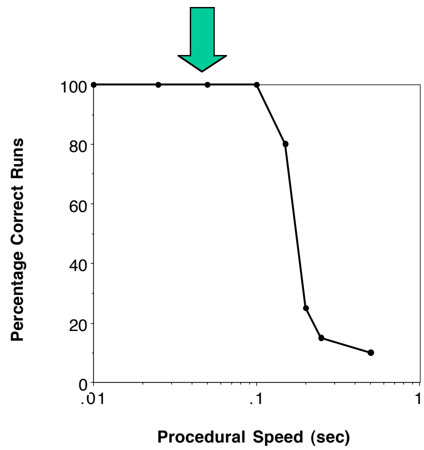
Sensitivity to Procedural Speed

- Because of the central nature of productions, performance degrades very sharply with speed of cycle
- Fortunately, there is a safety factor of 2 before degradation occurs



Micro Analysis & Design

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Validation

Procedures

•CTA
•Videos
•Spreadsheets
•United pilot

Errors

Videos

Micro Analysis & Design

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Future Directions

Increase accuracy of decision making procedures

Better representation of perceptual/motor factors

Better representation of division of labor

New baseline scenarios

New cockpit technologies

Attention and Situation Awareness (A-SA) Model

Report for NASA HPM-SWP Grant

Christopher D. Wickens,
Jason McCarley,
and
Lisa Thomas

SEEV MODEL

P(Attend) = aSalience – bEffort + cExpectancy + dValue (or CEV)

**"Capture"
Contrast
Onset
Eccentricity**

**Scan Distance
Foveal/Eye/Head Field**

**Concurrent
Workload**

**Probability
Cueing**

**Value of Event
Value of Task
Relevance of event
for valued task**

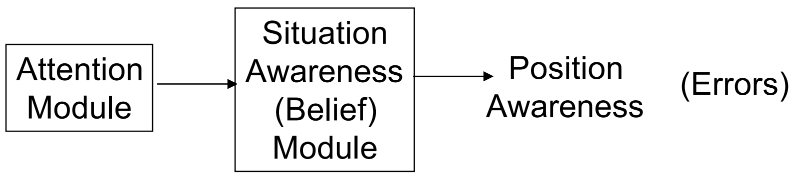
<u>Optimal</u>

P(Attend) = cExpectancy + dValue (if calibrated)

Designer: Reduce Effort Make Salient

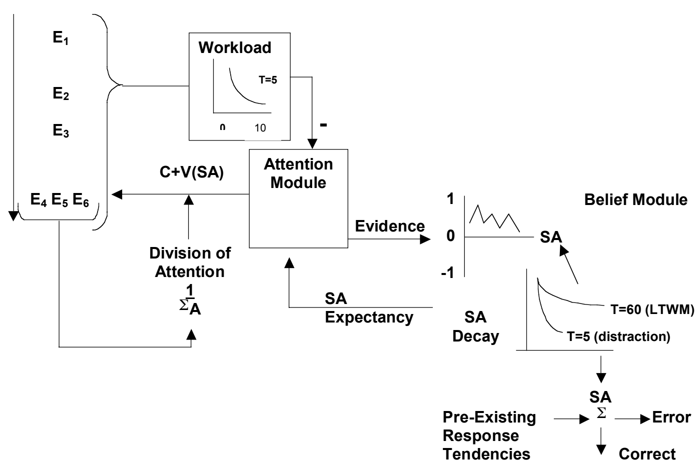
Applications to the Taxi Scenario

- Event Salience (User Coded)
- Relevance (User Coded)
- Effort (Workload)
- Taxi, Data: Rich in Discrete Events
  Rich in Errors (Loss of SA)



EVENTS

E(C,V): Conspicuity, Info Value (relevance to situation of interest)

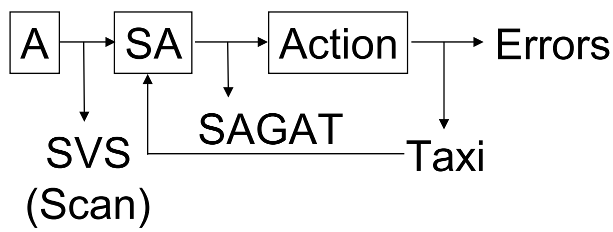


A-SA Model for taxi-way error prediction

The SVS Project: Landing with SVS System

- Loss-of-SA measures scarce (No SAGAT)
- Discrete events scarce (cannot define salience)
- Limited data (N) for validation (3 pilots)

  BUT
- Visual scanning data: Output of attention module



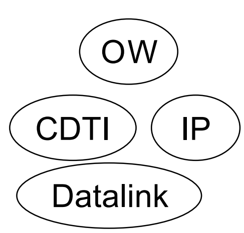
Wickens, Helleberg, Goh, Horrey, & Talleur (in press). Expected value model of aviation scanning

$$P(\text{Fixate AOI}) = \sum_{\text{across tasks}} BW \times R(A/T) \times V(T)$$

Bandwidth (Expectancy)

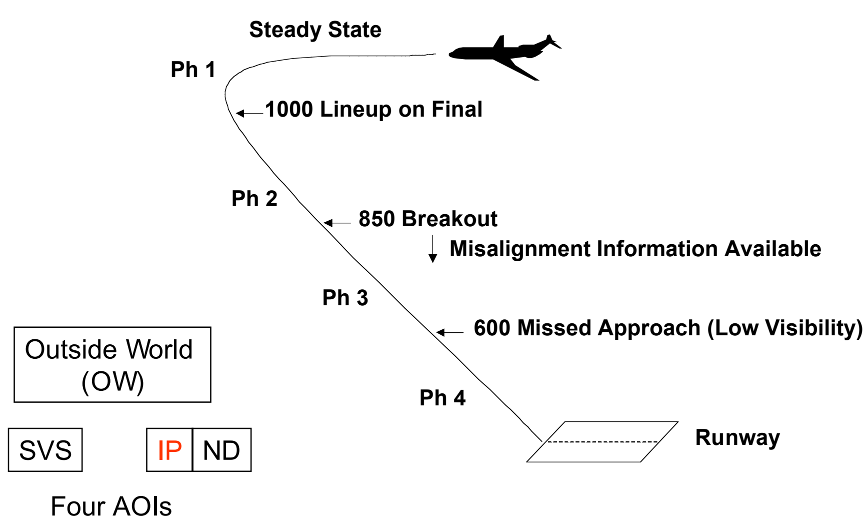
Relevance of AOI to Task

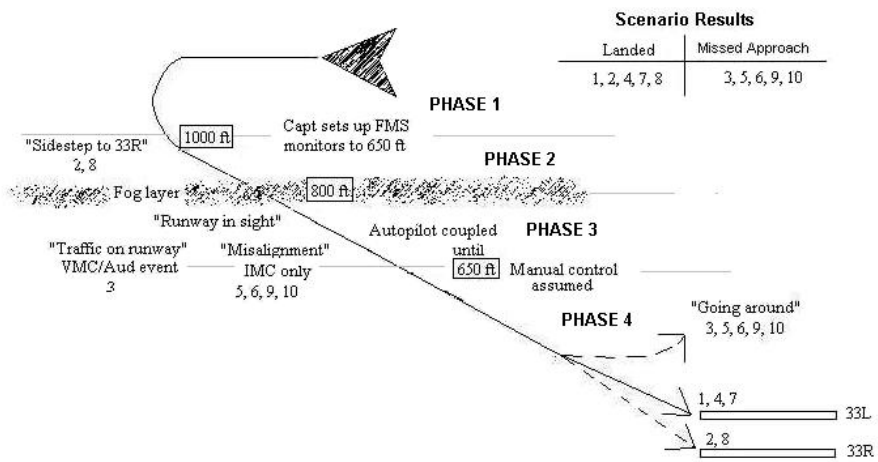
Value (Importance) of Tasks Aviate, Navigate, Communicate)



OW = outside world
CDTI = cockpit display of traffic information
IP = instrument panel

Four phases of flight, defined by different AOI's “activated” on some scenarios





• Analyzed videos for discrete events.

• Choose for intense modeling:

Scenario 6: Baseline IMC with OW-IP mismatch (loss-of-SA predicts delay noticing mismatch)

Scenario 10: SVS IMC with OW-SVS mismatch (loss-of-SA predicts delay noticing)

Focus on scanning in Phase 3 (when mismatch should be noticed)

Four Analysis Approaches

	General (Avg Pilot)	Specific Individual Differences	
Performance	Scenario Differences What makes SA hard?	Good – Bad (Scenarios 6, 10)	
Scan	Model the Average Average the Models Advantage of Effort All scenarios	PDT Diff MDD Dwell Model Diff	Time-Line Differences 6, 10 Lisa's Analysis

Coefficients

AOI: Instrument Panel (IP), Outside World (OW), Nav Display (ND), SVS Display (SVS)

Tasks: Aviate, Navigate

Coefficient Assignment: Least integer ordinal. Some assumptions:

Priority
•Aviate > Navigate
•Navigation increases priority on final (precision)
•Priority of AV & NAV increases on missed approach

Bandwidth:
•No information (BW=0) (OW in IMC, SVS in baseline)
•OW = SVS
•BW increases with more instruments (IP>OW=SVS)

Relevance (SEEV model assumptions from Wickens et al., in press)

S6

Parameter		Above 1000 ft	1000-800	800-650	Below 650
Bandwidth (B)	IP	3	3	3	5
	OW	0	0	2	3
	ND	1	1	1	1
	SVS				
Relevance (R)	IP (av)	2	2	2	4
	IP (nav)	1	1	1	3
	OW (av)	0	0	1	1
	OW (nav)	0	0	2	4
	ND (av)	0	0	0	0
	ND (nav)	2	3	2	2
	SVS (av)				
	SVS (nav)				
Priority (V)	Aviate	2	2	2	4
	Navigate	1	2	2	3

Coefficient Values for Scenario 6

S10

Parameter		Above 1000 ft	1000-800	800-650	Below 650
Bandwidth (B)	IP	3	3	3	5
	OW	0	0	2	3
	ND	1	1	1	1
	SVS	2	2	2	3
Relevance (R)	IP (av)	2	2	2	3
	IP (nav)	1	1	1	2
	OW (av)	0	0	1	0.5
	OW (nav)	0	0	2	1.5
	ND (av)	0	0	0	0
	ND (nav)	2	1	1	2
	SVS (av)	1	1	2.5	0.5
	SVS (nav)	1	2	2	1.5
Priority (V)	Aviate	2	2	2	4
	Navigate	1	2	2	3

Coefficient Values for Scenario 10

The SVS Attention Model

P(A) = F(BW, R, V)

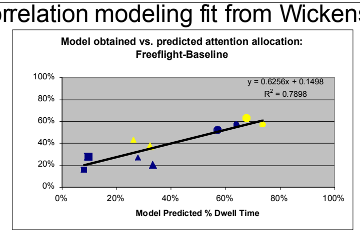
Dynamic Scanning Assumptions

- AOI with greatest attentional weight captures attention
- Probabilistic: $P(A) = \dfrac{W(A)}{\Sigma\, W(A\text{-}N)}$
- Upon capture, relevance = 0 (forces scan to leave)
- Effort inhibits longer scans (distance between AOI center)
- Model scan transition matrix

$$
\begin{array}{ccc}
 & & \text{AOI}_N \\
 & & \begin{array}{ccc} x & y & z \end{array} \\
\text{AOI}_{N-1} & \begin{array}{c} x \\ y \\ z \end{array} & \begin{array}{|c|c|c|} \hline & xy & xz \\ \hline yx & & yz \\ \hline zx & zy & \\ \hline \end{array}
\end{array}
$$

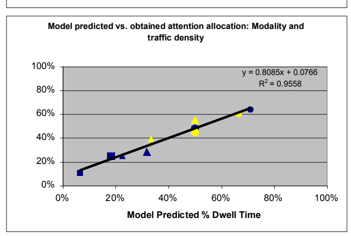
Column Mean = P(A) $\longrightarrow$ X Y Z

Example of correlation modeling fit from Wickens et al. (2003, in press)



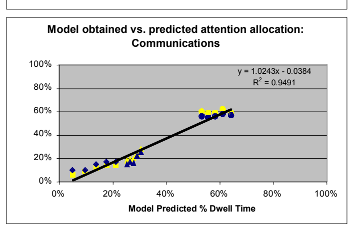
E1

Model Fit



E2

Validation



E3

Actual Probability of Scanning to AOI

Model Predicted P(AOI)

Model predictions of pilot scan (correlation)

Model fitting Approaches. There were many.

•For each scenario x phase x pilot (10x4x3)
•Predicting transitions ☹ vs. predicting average scan ☺
•Predictions with ☺ and without ☹ effort
•Predictions of average scan behavior across pilots ☺ vs. average prediction across pilots ☹
•Prediction of “good” pilot (P5: quick missed approach on #6, #10) vs. “less good” pilots (P3, P4)

<u>Key Findings</u>

•Correlations (model fits) are generally positive.

Without Effort: Mean value =0.74 (55% variance)
With Effort: r=.81 (65%)
Effort parameter adds 10% to model fit

•Pilot differences (based on performance differences in responding to off-normal):
Scenario 6 phase 2 (scan behavior just before misalignment is visible). Conventional IP.

Pilot 3 ☹ r≈.04
Pilot 5 ☺ r=.99
No scan data for Pilot 4

Scenario 10 phase 2 (scan behavior just before misalignment is visible). SVS.

Pilot 3 ☹ r=.59
Pilot 4 ☹ r=.88
Pilot 5 ☺ r=.80

Poorer pilot: poorer model fit.

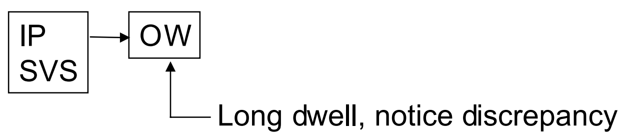
Micro Strategies: Scan paths between AOIs and dwell durations.

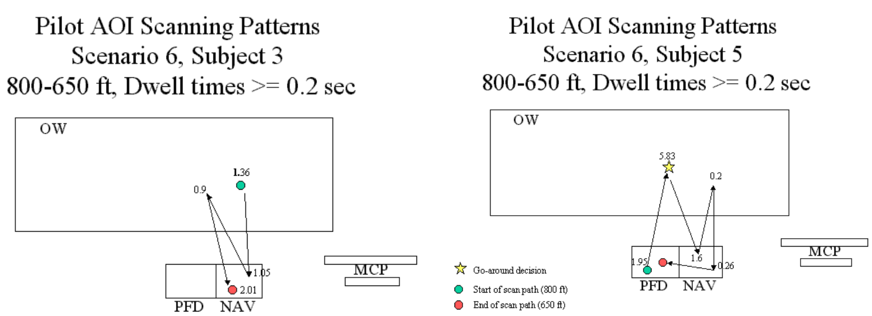
Phase 3: When information for misalignment becomes available from IP and OW (scenario 6), from SVS and OW (scenario 10).

Pilot 5 ☺ has:

- Direct scan between relevant AOIs for detection (OW&IP or OW&SVS)
- Long dwell (>5 sec) on OW
- Go-around initiated within 1 second after

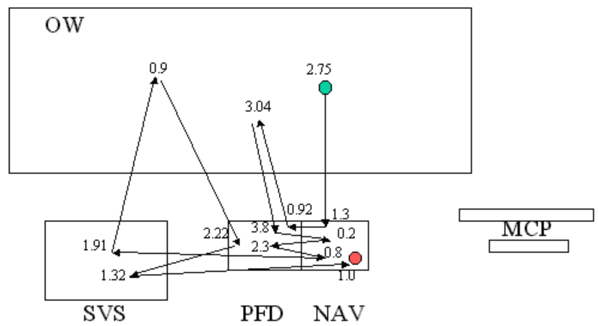
Neither Pilots 3 or 4 have both features (particularly long OW dwell)





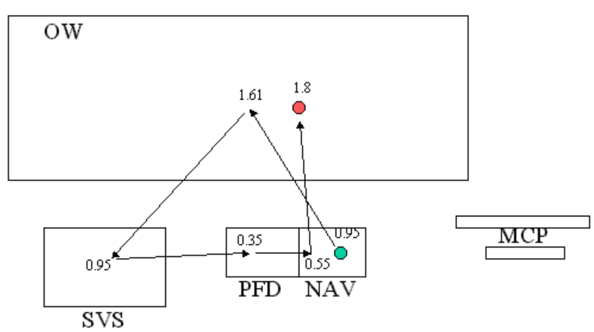
Scan path in Scenario 6

Pilot AOI Scanning Patterns
Scenario 10, Subject 3
800-650 ft, Dwell times >= 0.2 sec



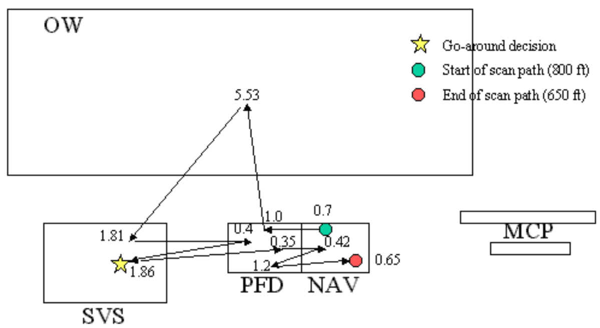
Scan path is scenario 10.

Pilot AOI Scanning Patterns
Scenario 10, Subject 4
800-650 ft, Dwell times >= 0.2 sec



Scan path is scenario 10.

Pilot AOI Scanning Patterns
Scenario 10, Subject 5
800-650 ft, Dwell times >= 0.2 sec



Scan path is scenario 10.

Conclusions

- Good model fitting. Correlations generally positive and high.
- Effort (conservation) needs to be incorporated
- Dwell duration may be important (not yet modeled)
- More data (pilots) needed
- More validation criteria needed (i.e., SAGAT)
  (Illinois SVS System)

Illinois SVS System

Human Performance Modeling of Approach and Landing Operations: A Concept Examination of Synthetic Vision Systems

AvSP Interim Workshop on Human Performance Modeling

Human Automation Integration Laboratory

Brian Gore, Savita Verma, Kevin Corker

San Jose State University

March 6, 2003

Human Automation Integration Laboratory

NASA SVS Design Challenge

- Visibility is required to safely land an aircraft.
  - Develop augmentative technologies to provide information required for approach and landing under limited visual conditions
    - Tunnel-in-sky, follow-me aircraft
    - Computer –generated terrain
    - Flight director information
    - Traffic information

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Methods of Analyses

- Human in the loop (HITL) processes: NASA
  - Low, mid and high fidelity simulations
  - Part task and full mission
- Human out of the loop (HOOTL) processes: SJSU
  - Air Midas used to predict the visual sampling and procedural sequences of the pilot flying and the pilot not flying on approach with and without the synthetic vision system

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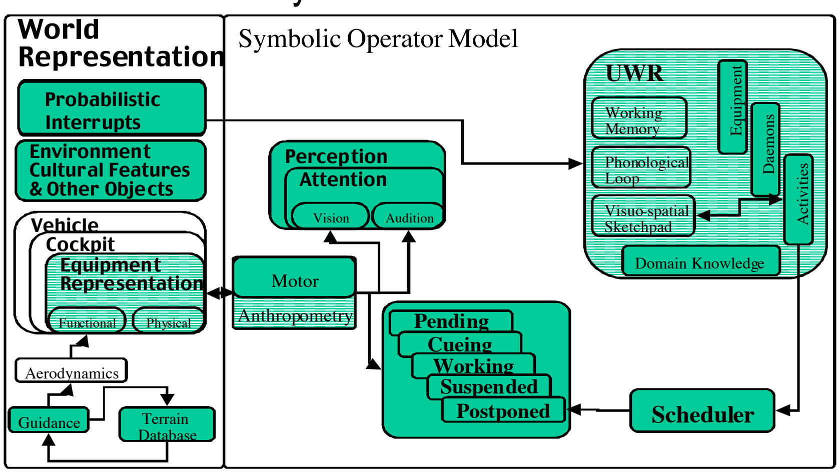
Human-System Performance Model



- Air MIDAS Development Requirements
  - Visual system augmentation
  - Simulation Scenario Coding
  - Procedural specification and encoding
  - Behavior output is a function of the integrated models that are activated

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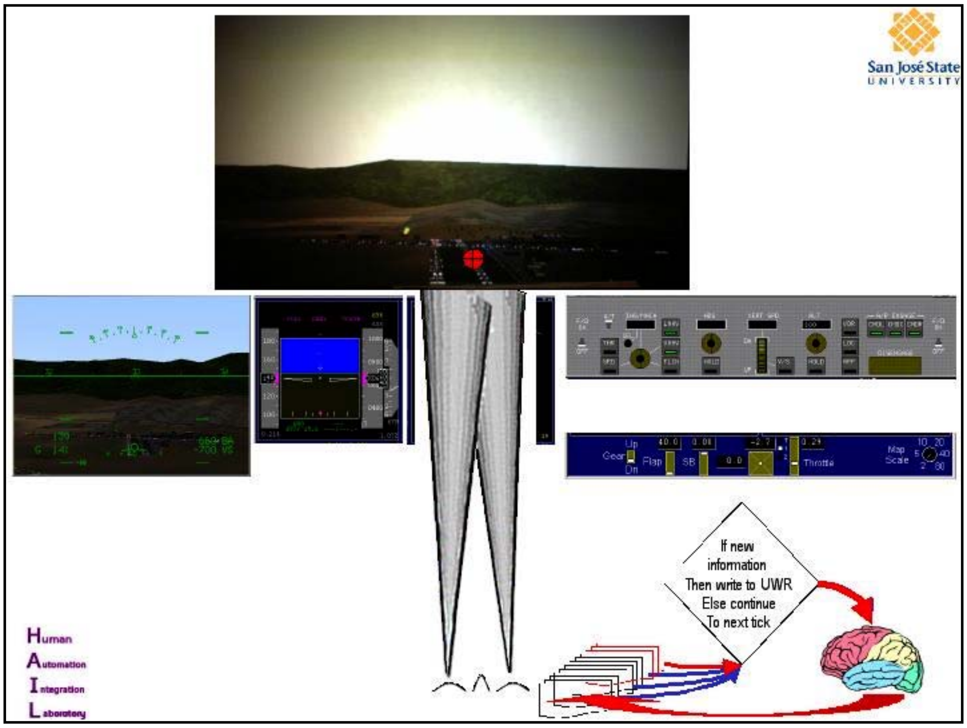
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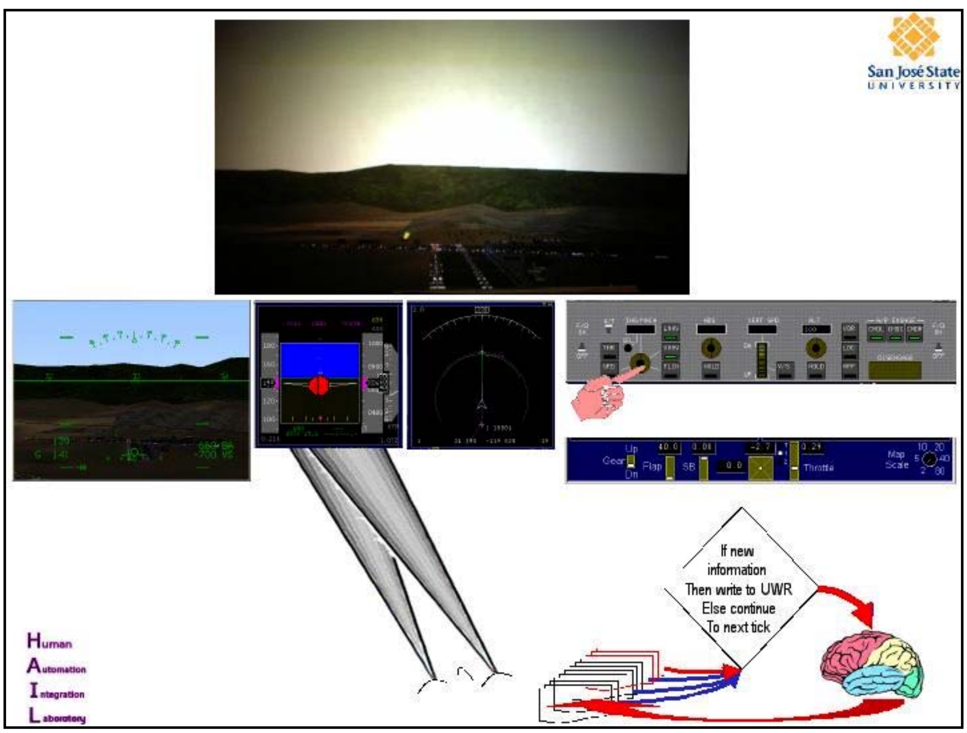
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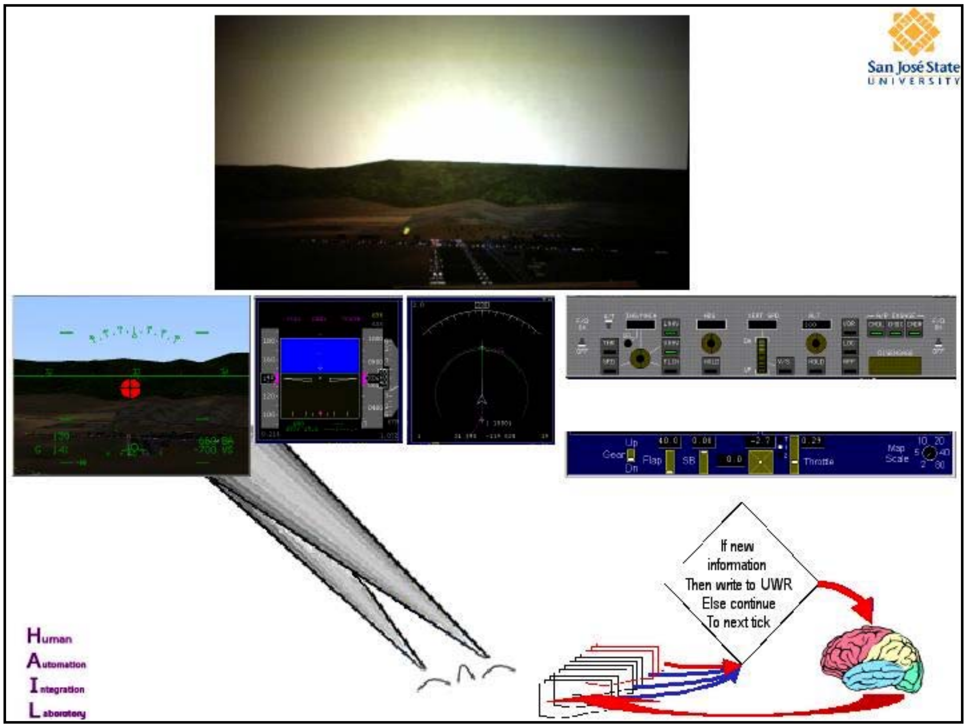
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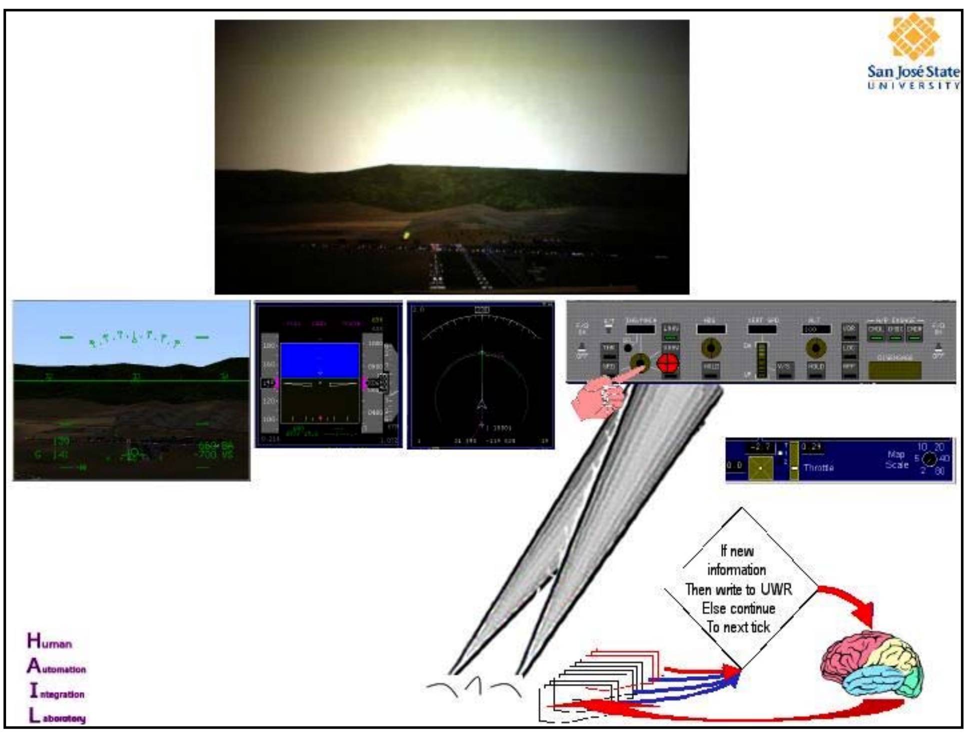
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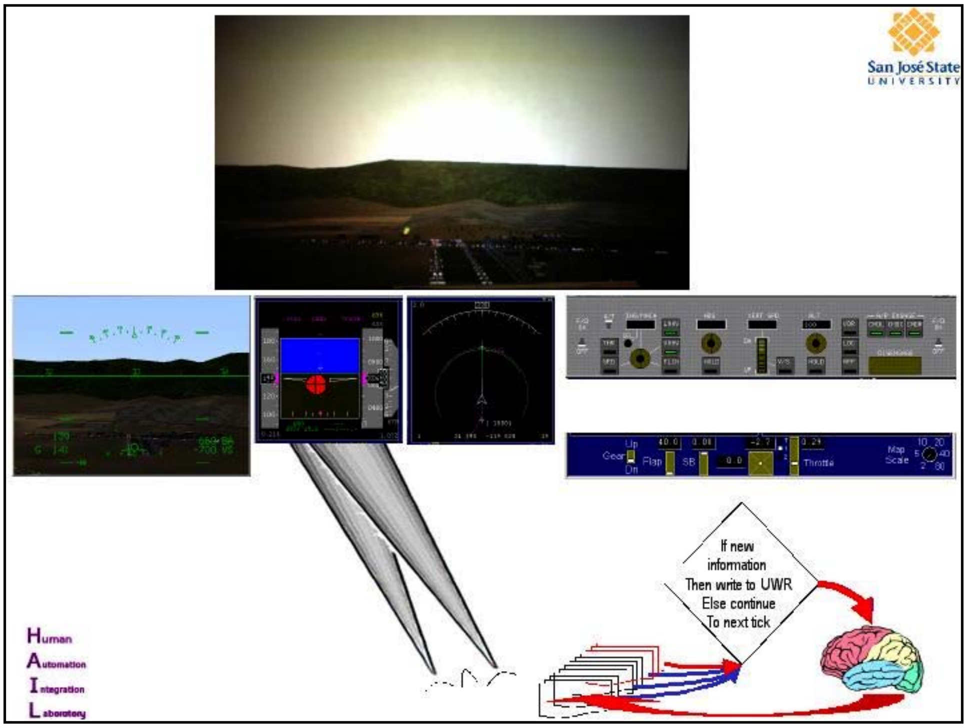
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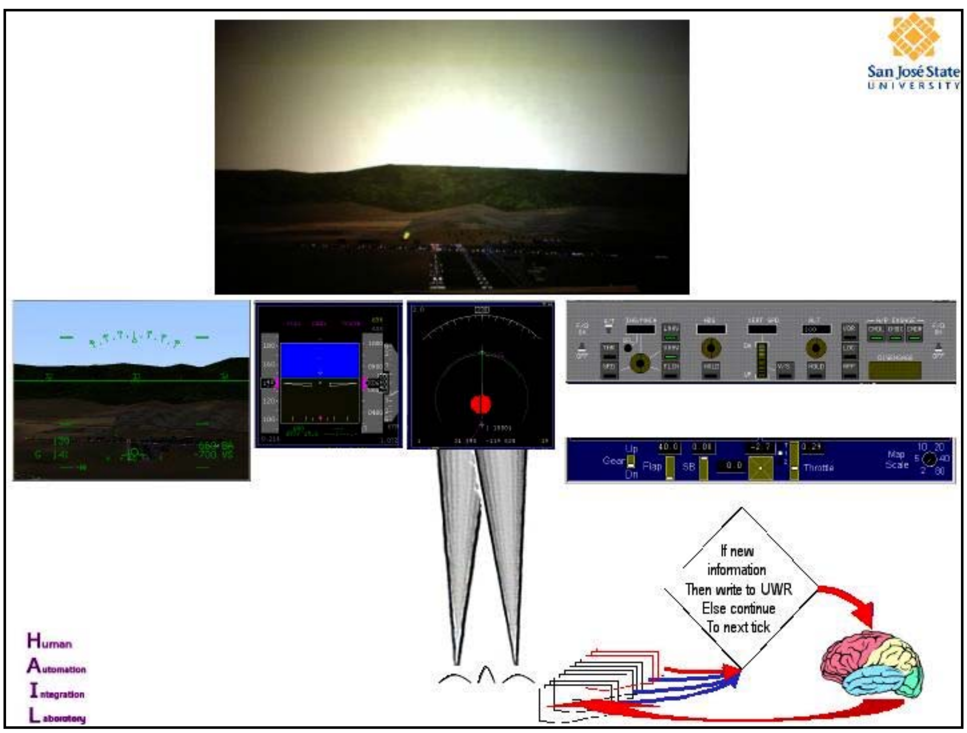
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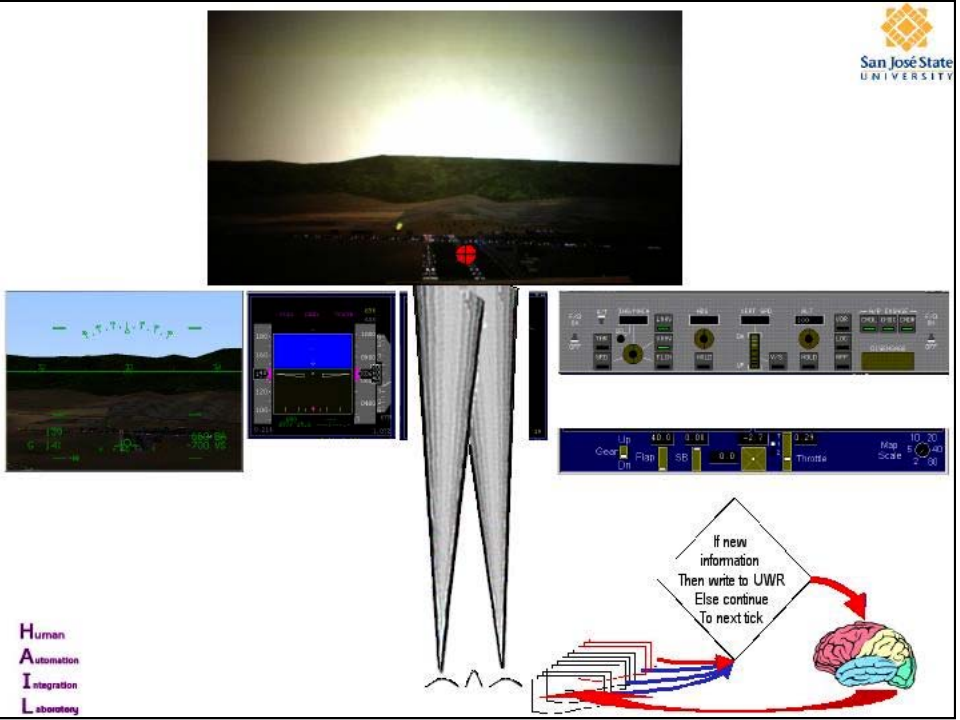

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Method

- Calibrate Air Midas Visual Sampling Model
  - Mumaw et al. 2000 Boeing field approach and landing simulation – with standard cockpit instrumentation
- Verify model operation running the model on the same approach
- Generalize the model to Santa Barbara approach (new geometry, new procedures)
- Validate Model Output against baseline NASA HITL data
- Generalize the model to use of the SVS on a standard approach and approach with side step.

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Percent Fixation Correlations[1]

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Air MIDAS to Boeing Sim

- Baseline:
  - r = 0.9936
- Baseline with SVS:
  - r = 0.9955
- SVS with sidestep:
  - r = 0.9948

Verification

Air MIDAS to NASA Sim

- Baseline:
  - r = 0.7608
- Baseline with SVS:
  - r = 0. 8782
- SVS with sidestep:
  - r = 0. 5538

Validation

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1: Pearson Product Moment

HPM & Mumaw Results: PF scan pattern

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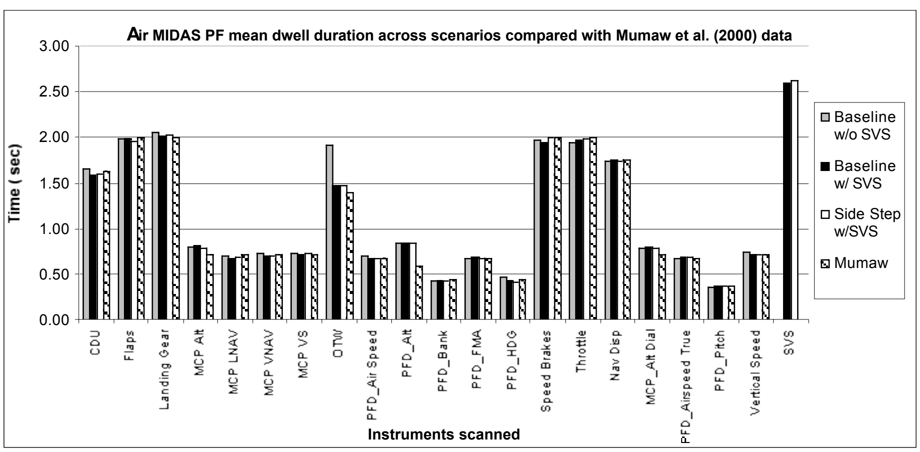

- Model prediction data is roughly congruent with the input PF data.

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HPM & Mumaw Results: PNF scan pattern

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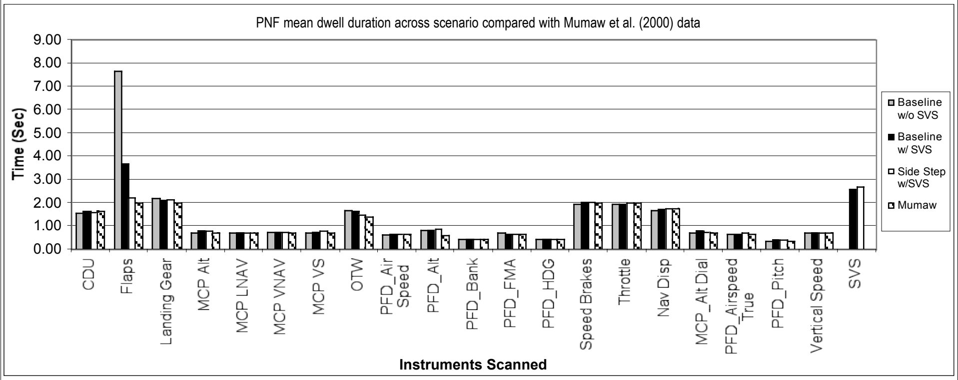

- Procedural and visual sampling behavior largely replicates human performance source data serving to verify that the model behaves as designed
- Does not corrupt the human performance data with which it was calibrated.

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HPM & NASA Simulation Results: Fixation Percent - Baseline without SVS

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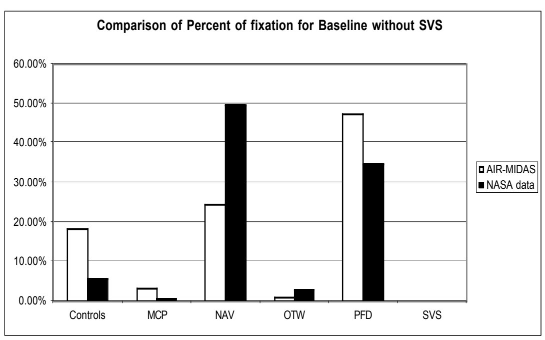

– Air MIDAS has higher fixation on the controls, MCP and PFD and lower fixation on the Nav and OTW
– Different rules guiding the model/human behavior

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HPM & NASA Simulation Results: Fixation Percent - Baseline with SVS

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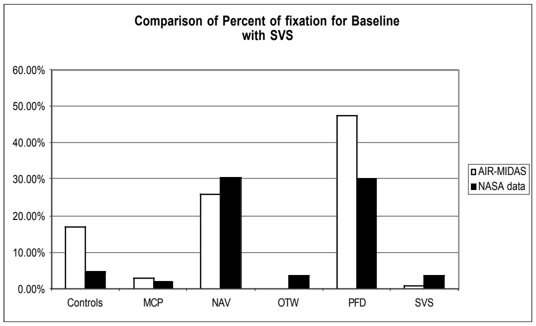

- Air MIDAS -higher fixation on the controls, MCP and PFD than the NASA HPM (2002) SVS simulation and lower fixation on the Nav, OTW and SVS
- Human flight crew received PFD information from overlays in the SVS and the Air MIDAS model required looking at the PFD (not the SVS) for that information. The Air MIDAS operator looked at PFD about 50% of times while the human operator looked at the PFD and SVS about 25% of the time.

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HPM & NASA Simulation Results: Fixation Percent - Sidestep with SVS

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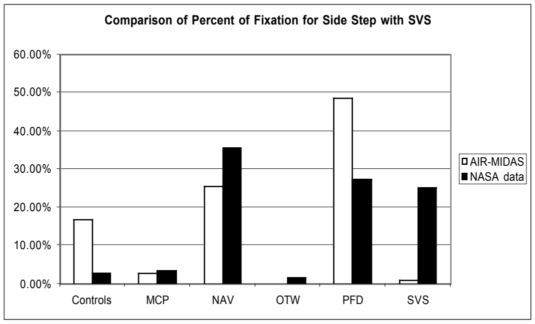

- Correlation is the least in the side step maneuver scenario as it is the furthest procedurally from the model baseline parameters.
- Procedures associated with sidestep and SVS use show reduced correlation with the HITL performance.

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Scan Data Summary

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- Team HAIL data accurately produced the Mumaw et al. (2000) scan patterns and correlated well with the NASA part-task simulation.
- Model behavior is congruent with the human operators' visual scan performance across experimental conditions with the least similarity in the side-step SVS condition.

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Procedural Activity Examination: Baseline without SVS

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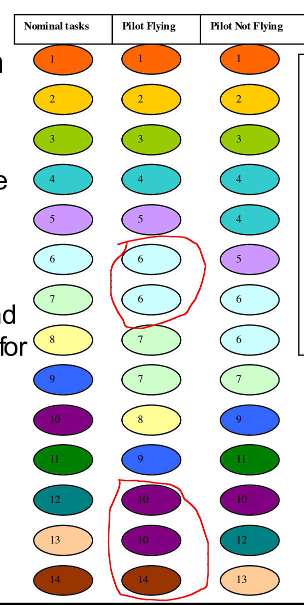
- The goal decomposition diagrams provide two types of information
  - (i) on the sequence of the goals to be completed,
  - (ii) on the comparison between the expected model's goal behavior and the actual goal behavior for the three conditions.



1. Set Precision FMS approach
2. 2500 callout
3. GS captured callout
4. LOC captured callout
5. Outer marker Callout
6. Final Descent Checklist
7. Receive ATC Clearance for runway
8. Check Procedure Turn
9. 1000 ft Callout
10. Set Flaps 30
11. 500 ft Callout
12. 100 ft above Decision Height Callout
13. Decision Height Callout
14. Check for stability and decide to land or go-around

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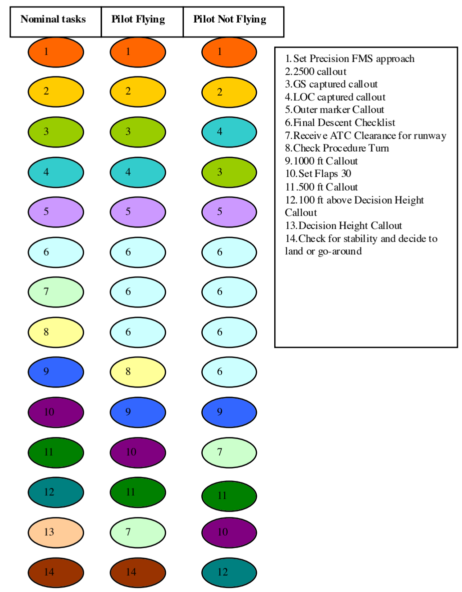
Procedural Activity Examination: Baseline with SVS

- Goals have to be completed by at least one of the operators
- Some goals appear several times because of task interruption and task resumption



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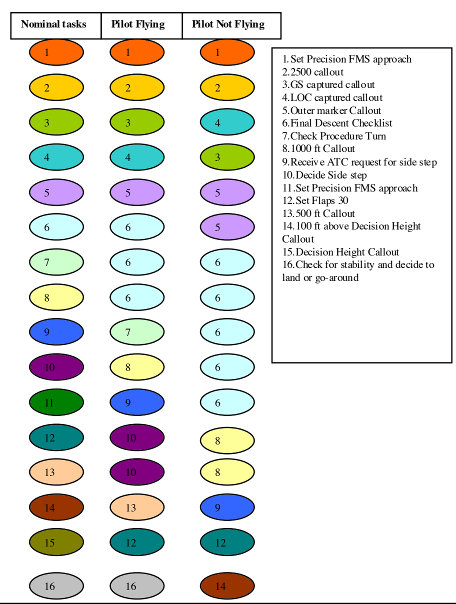
Procedural Activity Examination: Sidestep with SVS

- The three procedural activity examination charts demonstrate the different goals that are being completed by the respective operator
- These behavioral differences are critical aspects of predicting emergent human performance.



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Implications for SVS Use

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- Procedural differences exist among the three simulation conditions
  - Represented in various procedures being omitted, flipped, and extended.
  - May lead to system vulnerabilities.
  - PF and PNF engage in behaviors that differ in length and completion success.
    - Evidence for early procedural completion by one operator and later procedural completion by the second operator.
    - Possible desynchronization of crew coordination
    - One of the operators may possess a resource scarcity while the other operator may possess a resource surplus and may possess sufficient resources to take over and assist the resource deficient operator.

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Model Predictive Capability

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- Frequency of fixation data appear representative.
- Duration of fixation mode subject to variation.
- Behaviors are emergent and utilize segments of the augmented visual information critical for input data use and perception.
- We have created a model that demonstrates a real extension of taking input data and generating a prediction of operator performance.

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Concluding Remarks

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- Certain areas of divergent performance indicate a model refinement requirement.
- Implementation of augmented vision model is expected to continue in subsequent years of the HPM funding (FY 04).
- Augmented vision model will be used in a second model application for a go around procedure.

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