What do we mean by Human Factors? A brief look at the history, important issues, and methodologies used by Human Factors researchers and practitioners

Ray Comstock
Crew Systems Branch
Airborne Systems Competency
NASA Langley Research Center

J. Raymond Comstock, Jr., Ph.D.
Crew Systems Branch, MS-152
Airborne Systems Competency
NASA Langley Research Center
Hampton, VA 23681-2199
james.r.comstock@nasa.gov 757-864-6643

Outline

- Defining Human Factors and Ergonomics
- A brief History of Human Factors and Ergonomics
- Major topic areas today
- Publications covering Human Factors issues
- Courses taught illustrate breadth of the field
- A few basic principles
- Some issues concerning the automobile
- Contributions to Aviation Safety
- When new testing is needed – experimental issues
- A continuum of research settings and methods
- Summary

Definitions

- Human Factors (HF), at its simplest, refers to designing for human use *(Sanders and McCormick, 1993)*
- Ergonomics – (from work measure {or law}) – term often used as synonym for HF, or as word applied to physical environment interaction with humans *(e.g., seating, location of controls, reaching required)*
- Engineering Psychology – the science of applying knowledge of human functioning, such as perceptual, physical, and cognitive capabilities to human interaction with mechanistic devices
- Human Factors Engineering – applying HF principles or research in the design of equipment or systems involving human-machine interaction

Some Milestones in Human Factors History (1)

- May have "unofficial" origins with users of military equipment of long ago
- 1857 – W.B. Jastrzebowski published "An essay on ergonomy, or science of labour, based on the laws of natural science."
- 1911 – Foundation for Classic Management principles introduced by Frederick Taylor
- 1914 – Research begins to assist in efforts to enhance Allied advantages in World War I
- 1919 – Foundations for Scientific Management Theory introduced by Frank and Lillian Gilbreth
- 1920 – Hawthorne studies (Western Electric)
- 1939 – Research continues to explore human performance issues during World War II

Some Milestones in Human Factors History (2)

- 1949 – Ergonomics Research Society (later named the Ergonomics Society) was formed in the U.K.
- 1957 – Human Factors Society was formed
  - First issue of Ergonomics was published
  - APA (American Psychological Association) Division 21, Society of Engineering Psychology was organized
  - Russia launched Sputnik which began the “Space Race”
- 1964 – Ernest McCormick wrote the 18 general principles of human engineering
- 1970s – Human Factors expands from military applications to various other organization types
- 1980s – Human Factors Society membership was 3000, up from 500 in 1960

Some Milestones in Human Factors History (3)

- 1980s (cont'd)
  - A series of nuclear accidents and explosions occur making safety a great concern *(Human Factors of nuclear plant control rooms is in the news)*
  - FAA expands human factors efforts to improve safety in aviation
  - Improvements in computer developments (e.g., PCs) fosters more research and gives new means by which it can be conducted
- 1990s – Organizational Safety and Health Administration (OSHA) continues to create ergonomic regulations for organizations
  - Human Factors is expanded into the area of medical devices
  - Quality of work life becomes a key issue in organizations
  - Human Factors Society becomes HF & Ergonomics Society

Human Factors Journal Major Topics (1)

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- ACCIDENTS, SAFETY, HUMAN ERROR
- AEROSPACE SYSTEMS
  - pilot, crew behavior
  - system design features
- AGING
- ATTENTIONAL PROCESSES
  - Automatic and controlled processing
  - dual-task performance
  - mental workload
  - multiple resources
  - situation awareness
  - vigilance, monitoring
- AUTOMATION, EXPERT SYSTEMS
  - expert-novice differences
  - function allocation
  - knowledge elicitation
  - mode awareness
- BIOMECHANICS, ANTHROPOMETRY, WORK PHYSIOLOGY
  - interventions
  - models and measures
  - physical work, loading
- COGNITIVE PROCESSES
  - decision making, naturalistic decision making
  - knowledge representation
  - language
  - learning, memory
  - mental models
  - problem solving, reasoning
- COMMUNICATION SYSTEMS
  - macro design features (networks, Web, conferencing, etc.)
  - micro design features (coding, media, etc.)
- COMPUTER SYSTEMS
  - graphics
  - groupware
  - human-computer interaction (HCI)
  - interface evaluation, usability
  - menus
- CONSUMER PRODUCTS, TOOLS
- DISPLAYS AND CONTROLS
  - auditory displays
  - display-control compatibility
  - haptic and other displays
  - keyboards
  - speech production and recognition

Human Factors Journal Major Topics (2)

- DISPLAYS AND CONTROLS (CONT'D)
  - trackballs, mice, joysticks, other output devices
  - visual, pictorial, object displays
- HEALTH AND MEDICAL SYSTEMS
- INDIVIDUAL DIFFERENCES
- MACROERGONOMICS AND THE ENVIRONMENT
  - ambient conditions
  - organizational behavior/design
  - workspace, "built environment" design
- MANUFACTURING, PROCESS CONTROL SYSTEMS
  - operations research
  - reliability issues
  - robotics
  - scheduling
- PSYCHOLOGICAL STATES
  - boredom, monotony
  - effort/motivation
  - fatigue
  - induced states (e.g., alcohol, drugs, sleep deprivation
  - stress
- PSYCHOMOTOR PROCESSES
  - eye movement, tracking
  - reaction time
  - skill (development, maintenance)
- SENSORY AND PERCEPTUAL PROCESSES
  - audition
  - detection
  - haptics and other senses
  - recognition
  - search
  - vision
- SIMULATION AND VIRTUAL REALITY
- SURFACE TRANSPORTATION SYSTEMS
  - driver behavior
  - highway and vehicle design
  - maritime issues
- TRAINING, EDUCATION, INSTRUCTIONAL SYSTEMS
  - embedded cross-, and team training
  - training technologies
- MISCELLANEOUS

Human Factors Related Journals

- Human Factors
- International Journal of Aviation Psychology
- Ergonomics
- Journal of Experimental Psychology: Applied
- Journal of Experimental Psychology: Human Perception and Performance
- Aviation, Space and Environmental Medicine
- IEEE Transactions on Systems, Man, and Cybernetics
- Office of Aviation Medicine (FAA)
- Journal of Applied Psychology
- Int'l Journal of Human-Machine Studies
- Journal of Safety Research
- Human Performance
- Applied Ergonomics
- Cognitive Science
- Journal of Applied Social Psychology
- Military Psychology
- etc.

Other HF and Aviation Publications

Non-academic journals relevant to crew-systems research in aviation

- NTSB Accident Reports
- AOPA - Safety Reviews
- Aviation Safety Review
- Flight Safety Digest
- Feedback (CHIRPS)
- ASRS Callback
- Ergonomics in Design
- Air Line Pilot
- ICAO Journal
- Flight Training
- Business and Commercial Aviation
- Airliner (Boeing Safety and Product Information Magazine)
- Aerospace (Royal Aeronautical Society Magazine)
- Airline Specific Safety Publications / Magazines
- etc.

Breadth of the field illustrated by courses (1)

Embry-Riddle HF courses include:

- Human Factors I: Principles and Fundamentals
- Human Factors II: Analytic Methods and Techniques
- Human Factors III: Ergonomics and Bioengineering
- Human Factors and System Safety
- Human Factors in Space
- Human Factors in Air Traffic Control
- Human Factors IV: System Design
- System Performance modeling
- Human Factors Engineering: Crew Station Design
- Human Factors in Simulation Systems
- Advanced Topics in Human-Computer Interaction
- Human Factors in Computer Systems Design
- Topics in Applied Experimental Psychology

Breadth of the field illustrated by courses (2)

Wright State HF courses include:

- Human Factors Engineering in Aerospace System design
- Advanced Human Factors Bioengineering
- Human Factors Engineering in Aerospace Medicine
- Human Factors Engineering Advanced Aerospace System design
- Human Factors Workload Analysis
- Human Factors Engineering: Crew Station Design
- Human Factors Engineering Advances in Visual Display Design
- Advanced Topics in Human Computer Interaction
- Experimental Research and Evaluation in HFE
- Advanced Ergonomics
- Application of Human Factors Engineering to Rehabilitation

Factors to consider in designing for human control

On a daily basis we may encounter controls for:

- Alarm clock, faucet/shower, kitchen appliances, telephone, doors and locks, automobile (host of controls), computers, phone answering devices, mechanical tools, job dependent controls on machinery / equipment / aircraft

- Some devices well designed…

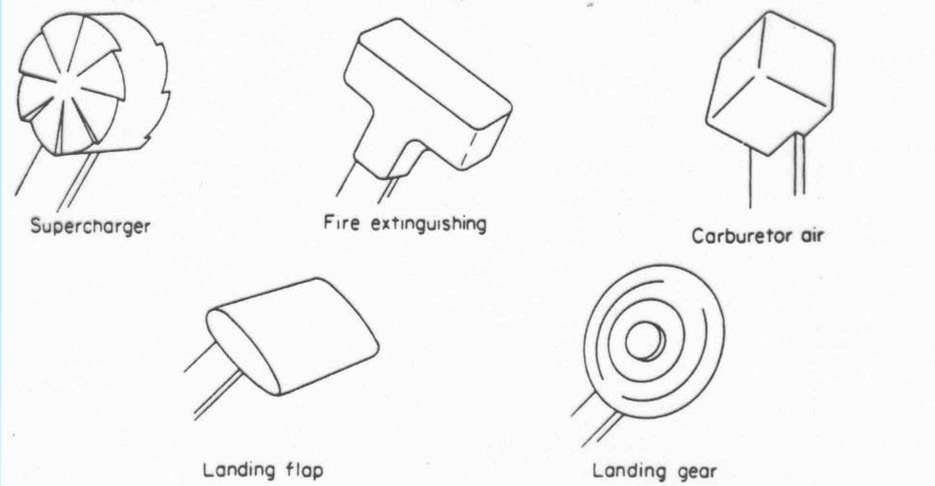
… and some not so well designed –

Next, a look at some basic knobs and dials issues

Compatibility & Expectations in Control Design

- Compatibility
  - Degree to which display / control is consistent with what human expects
  - Better compatibility can lead to:
    - Faster learning
    - Faster reaction time
    - Fewer errors
    - Increased satisfaction with system
    - Less training required
  - Expectations can be culturally dependent

FIGURE 11-4
Examples of some standardized shape-coded knobs for United States Air Force aircraft. A number of these have symbolic associations with their functions, such as a wheel representing the landing-gear control. (*Source: Air Force System Command, 1980.*)



Sanders & McCormick, 1993

Spatial and Movement compatibility

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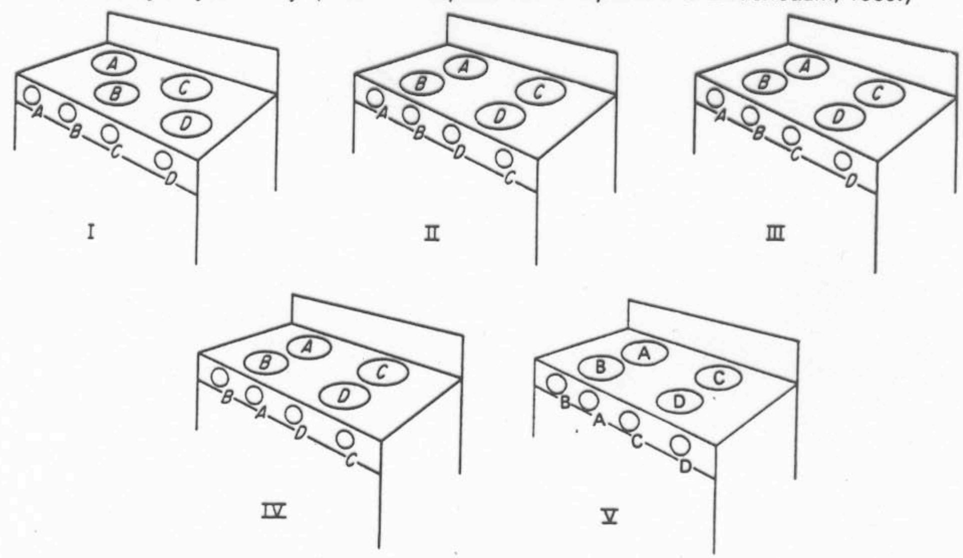
- Display and control compatibility
  - stove burner controls e.g.
- Movement compatibility
  - Population stereotypes
  - Rotary controls and rotary displays
  - Rotary controls and linear displays
  - Scale-side principle
  - Clockwise for increase principle (Warrick's principle, 1947)

FIGURE 10-3.
Control-burner arrangements of a simulated stove used in experiments by Chapanis and Lindenbaum, and by Ray and Ray. (*Source: Adapted from Chapanis and Lindenbaum, 1959.*)



Sanders & McCormick, 1993

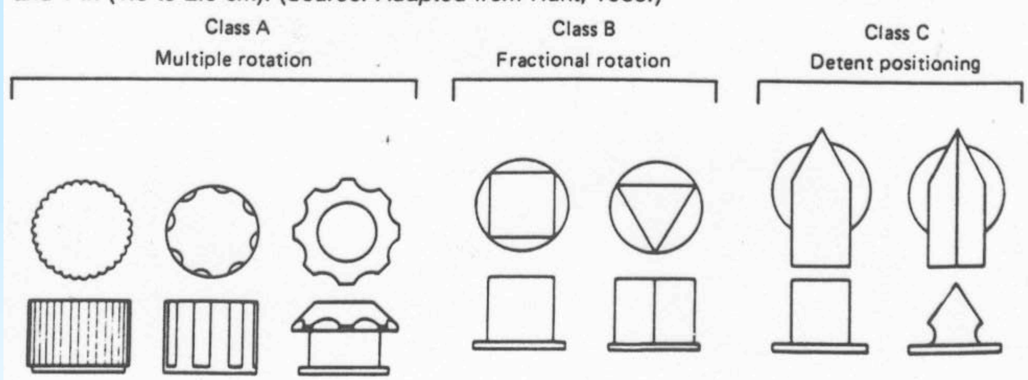
Percentage errors

Design	C&L 1959	R&R 1979
I	0	not tested
II	6	9
III	10	16
IV	11	19
V	n. t.	12

Controls and Coding

- To distinguish controls may use:
  - Shape coding
    - Multiple rotation knobs
    - Fractional rotation
    - Detent positioning
  - Texture coding
    - Feel (knurling of controls)
    - Size coding
    - Location
    - Color coding
    - Labeling
  - Use of redundant codes (e.g. shape and color)

FIGURE 11-2
Examples of knob designs for three classes of use that are seldom confused by touch. The diameter or length of these controls should be between 0.5 and 4.0 in (1.3 to 10 cm), except for class C, where 0.75 in (1.9 cm) is the minimum suggested. The height should be between 0.5 and 1 in (1.3 to 2.5 cm). (*Source: Adapted from Hunt, 1953.*)



Sanders & McCormick, 1993

Factors affecting human performance

- Control / response ratio
  - e.g. mouse with variable rate
- Physical feel of controls
- Deadspace (deadband)
- Backlash
- Stick-type controls
- Foot controls (e.g. auto accel and brake)
- Keyboards

Alternative control devices

- Speech
- Eye movement (e.g., camera focus)
- Brain-wave activity
- Sip / puff switches
- Eye blink

Some general display layout guidelines

Priority:

1. Primary visual tasks
2. Controls that interact with primary visual tasks
3. Control-display relationships
4. Elements used in sequence
5. Elements used frequently
6. Consistency with other layouts used within the system

Auditory Warnings and Displays

- take many forms:
  - Horns, klaxons, whistles, sirens, bells, buzzers, chimes, gongs, oscillators, synthesized sounds
- found in many domains:
  - Air traffic control
  - Aviation
  - Emergency services
  - Industrial plants
  - Manufacturing
  - Medicine
  - Military
  - Mining
  - Automobiles
  - Nuclear power

When to use (rather than visual)

- The origin of the signal is itself a sound
- The message is simple
- The message will not be referred to later
- The message refers to events in time
- The message calls for immediate action
- Continuously changing information of the same type is presented
- The visual system is overburdened
- Speech channels are fully employed
- Illumination limits vision
- The receiver moves from one place to another

Tools for physical space designing

- Applied anthropometry
  - 5th through 95th percentiles found in anthropometric tables
  - Can establish min and max dimensions
  - Cost benefit analysis important
- Mannequins can be used
  - Jack – 88 articulated joints, 17 segment torso, data on body contours and strength limits
  - Sammie – system for aiding man-machine interaction (SAMMIE CAD Ltd)
- Design software incorporating human data
  - e.g., CATIA
- Design for everyone
  - Offer product in different sizes (e.g. clothing)
  - Design adjustable products

Human Factors issues and the Automobile

Human Factors and Automobiles

"…the whole car will work very sweetly and will continue to do so with only a very small fraction of the attention that would be absolutely necessary for the care of a horse." – *Instruction Book for Chevy Copper-Cooled Motor Cars, 1923, p.19.*

Yet, these "sweet" machines have distinct human-machine issues and consequences:

- 500,000 killed, worldwide (yearly estimate)
- 15,000,000 injured
- In US alone 40-50,000 killed per year in auto accidents
- US has the lowest rate per 1000 registered vehicles (0.24)

(data from Sanders and McCormick, 1993)

Automobile Issues - Driver

- Research Categories: 1) Driver, 2) Vehicle, 3) Roadway
- *Driver Issues*:
  - Accident categories - mostly decision errors and recognition errors
  - eye-scan data *(where is attention directed)*
  - judgment of speed – adaptation occurs
  - risk taking and everyday driving
  - Age factors - "U" shaped curve (accidents vs age)
  - Perceptual style (field dependence)
  - Personality factors - Road rage? Red Light Running?
  - Fatigue effects (drowsy driver research)
  - Alcohol and drug effects - and interaction with fatigue
  - Distractions - e.g. cell phones; future in car e-mail, navigation systems, video systems

Automobile Radio / Navigation System

Pro: Hey, I don’t get lost!

Con: Distraction / Head down time

Moral: New Technology often drives the focus of Research

Automobile Issues - Vehicle

- Safety Improvements - Vehicle design factors
  - from the drivers seat - principles of workstation design can be applied (e.g., reach envelope)
  - control and display placement
  - standardization of critical elements (e.g. PRND…)
    - Other control elements not regulated
  - Anthropometric databases can assist designer in deciding seating, pedal, wheel, and control locations
  - Lighting, e.g., sidelights required in 1968
  - CHMSL - a real success story of mid 1980's
  - DRLs - required in some countries (vehicle conspicuity)
  - Occupant restraint and airbag systems (active and passive systems)
  - Anti-lock braking systems
  - Traction control
  - Crash testing - uncovering vehicle design flaws

Automobile Issues - Roadway

- Roadway factors (Environment)
  - Highway design
  - Signs (signage)
  - Font / readability issues
  - novelty effects
  - CMS (Changeable Message Signs) what do you display?
  - Roadway lighting
  - Weather (rain, ice, snow)

Automobile Issues - Evaluation

- Research Techniques for evaluating signs and traffic control devices
  - Lab studies
  - Slide presentations
  - Card sorting
  - Reaction Time and Glance Legibility
  - Eye-scan and dwell time studies
  - Lab simulations
  - Controlled field studies
  - "test track"
  - real-world instrumented vehicles
  - Field validation studies
  - traffic measures
  - before / after studies
  - matched group studies
  - important to overcome the novelty effect

Automobile Issues – Response Time

An illustration of technology enhancing driver performance:

- Brake lights made with LEDs (light emitting diodes)
- LEDs illuminate faster than incandescent bulbs – some 150 – 200 msec faster
- Result is faster response time for driver

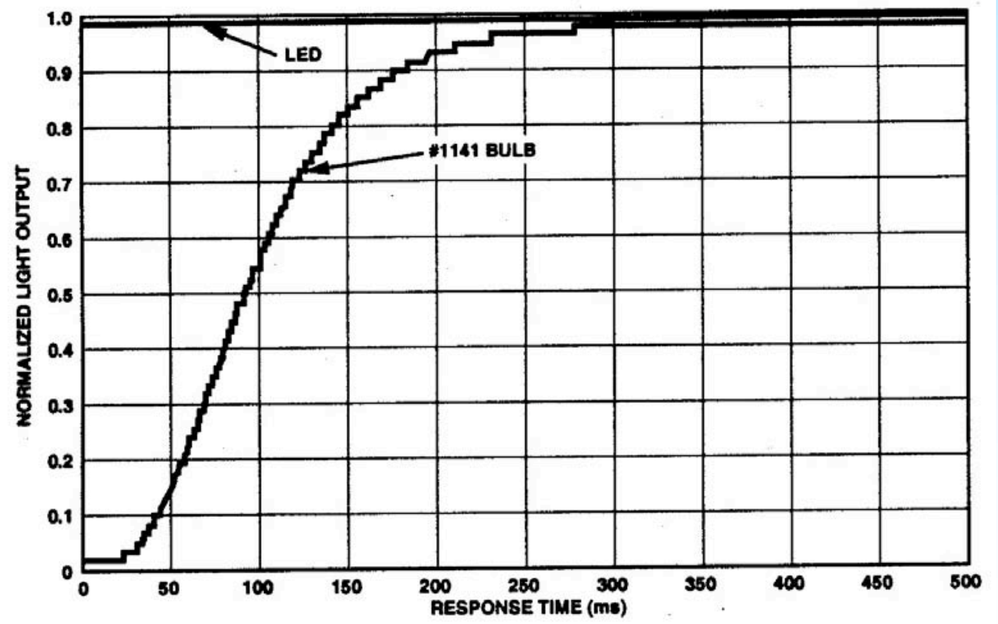


Figure 1. Typical turn-on times of #1141 incandescent filament bulb and LED signal light at 12.8 V.

Hewlett Packard
Application Note 1155-3

Automobile Issues – LED lighting

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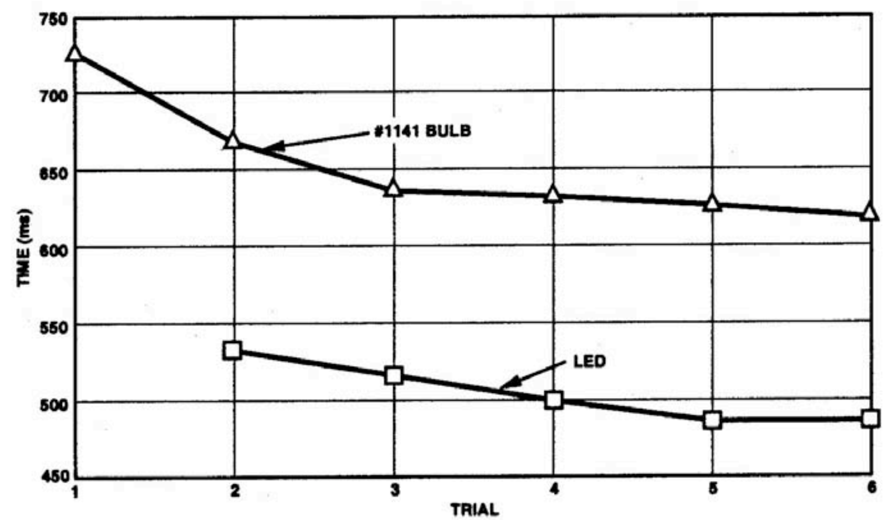


Hewlett Packard
Application Note 1155-3

Response Time:

Incandescent vs LED

Table 1. Turn-on time of commonly used automotive signal bulbs.

Bulb type	Application	Design V (V)	Design I (A)	Approximate candlepower (mscd)	0 to 90% response time (ms)
912	CHMSL	12.8	1.0	12	131
921	CHMSL	12.8	1.4	21	155
922	CHMSL	12.8	0.98	15	118
1141	CHMSL	12.8	1.44	21	164
1156	Rear Stop	12.8	2.1	32	225
1157	Rear Stop	12.8	2.1	32	219
2057	Rear Stop	12.8	2.1	32	218
3057	Rear Stop	12.8	2.1	32	245
3157	Rear Stop	12.8	2.1	32	246

Hewlett Packard
Application Note 1155-3

Contributions to Aviation Safety

- Much like the case of the automobile, HF & E contributions can be divided into Pilot (or Crew), Vehicle, and Environment factors
- Pilot / Crew issues that have been studied include:
  - Workload
  - Stress (job and life events)
  - Situation awareness
  - Work/rest duty cycles (fatigue countermeasures)
  - Time-zone changes
  - Team issues (e.g., CRM, team decision making)
  - Mandatory retirement age (commercial)
  - Training
  - High-G (military)
  - Transitioning between aircraft types

Vehicle Safety Contributions

Vehicle issues studied:

- Basic "knobology" - e.g., coding to differentiate controls
  - E.g., Gear and flap controls (early days)
- Display and control issues (major area of focus) include:
  - 3-pointer altimeter
  - 3 to 2-person crew (tasks and automation)
  - Electromechanical to glass displays
  - Field of view (windows early on, displays later)
  - Interaction with datalinked information
  - Various failure modes (e.g., frozen sensors, control surfaces)
  - "Mode" awareness
  - Interaction with FMC (Flt Mgmt Computer)
  - Advanced displays (SVS, WX, RIPS, self separation, etc.)
  - 3-D displays (stereopsis)
  - Interaction with advanced sensor displays
  - …and many more

Environment Considerations

Environment issues include:

- Communication (intra-crew, ATC, Ops)
  - Voice, datalink
- Air Traffic Control and Controller (many factors)
  - Decision aids
  - Workload, stress
- Air Traffic Management System
- Weather
- Terrain (approaches)
- Airport signage and low-vis lighting
- Chart legibility and symbology
- Electronic Charts (and use of color, symbology)
- Security (aircraft, airport, airspace system)

Experimental Design

While design guidelines exist and may be applied to many design questions, new technology often goes beyond existing guidelines and requires that new testing be conducted.

Experimental Design is the title applied to the process of designing experimental procedures so that the effect of extraneous variables (such as those noted previously) have minimal effect on the research results. Experimental design is concerned with controlling unintended effects or bias on the part of the subject, the experimenter, or the procedures used.

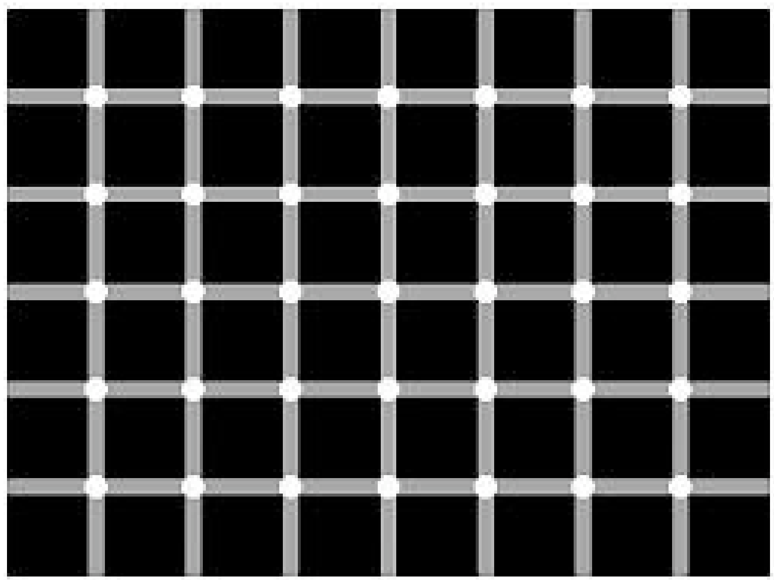
Human Subject Design Considerations

Experiments with human test subjects (most Human Factors studies) are different from most Engineering or Physics Experiments for the following reasons:

- Performance varies from test subject to test subject
- Performance varies for the same test subject from one time to another
- The subject's performance can be a function of context
- Performance may not be a unique function of the design variables
- The subject's history (experience, health, sleep the night before) is difficult to control

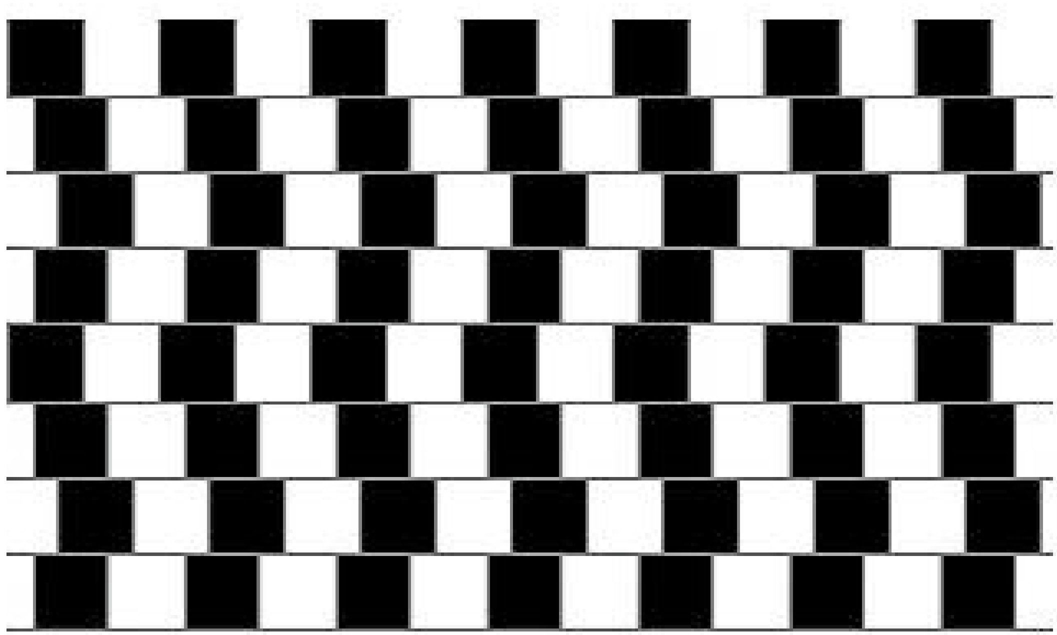
These are all normal occurrences for Human Factors Research

Our senses can be fooled



Count the black dots!

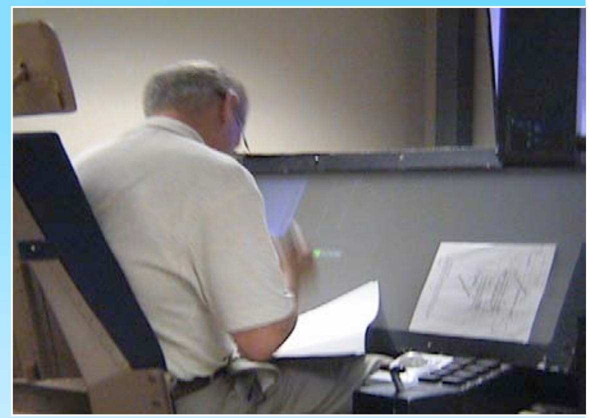
The Importance of Perception



Are the horizontal lines parallel or do they slope?

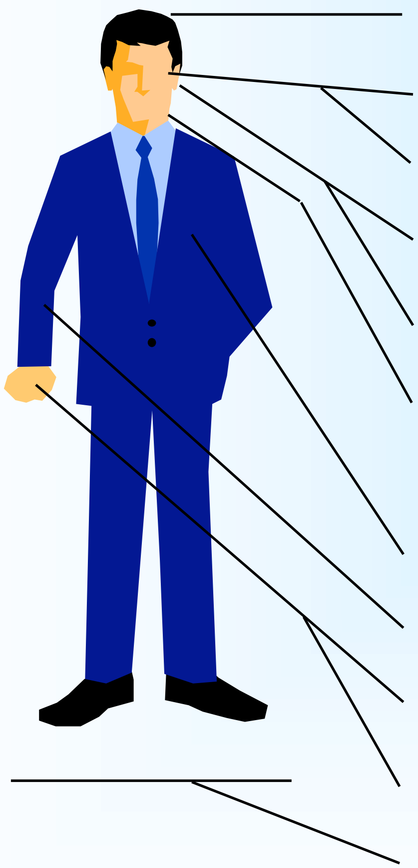
Performance assessment

Key Performance Assessment Areas:



- ***Flight Technical:*** Flight-path error; Airspeed maintenance; Display options chosen (e.g. Field of View); each by flight segment; Time to spot hazards or traffic
- ***Situation Awareness (SA):*** SA Ratings; modified SAGAT Technique (Sim only); Information/knowledge questions and comparisons (e.g., SA-SWORD)
- ***Mental Workload:*** NASA TLX; Modified Cooper-Harper
- ***Comments and Ratings:*** Post-run and post-experiment questions: At Eagle-Vail, 80 semi-structured interview questions covered operational and implementation issues
- ***Objective Human Operator Indices:*** Eye-movement monitoring to study information acquisition (Simulation); Heart Rate, muscle activity, and peripheral skin temperature

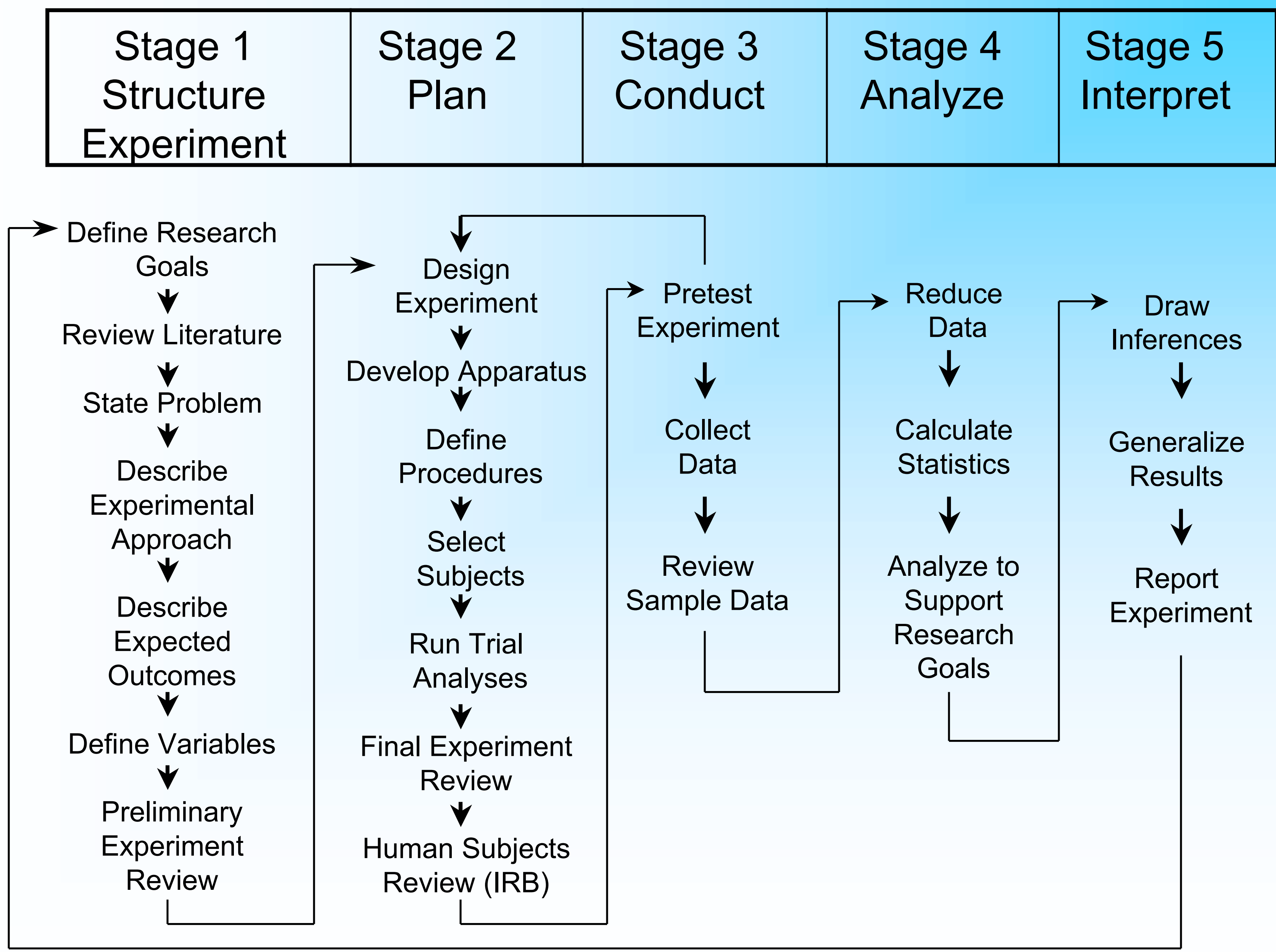
Measuring the Human Operator (Physiological Measures)



- EEG / ERP
- Eye-movement / Oculometry / PD
- EOG / Eyeblink
- Auditory Stimuli for ERP
- Auditory Warning Sounds for ERP
- Voice Stress Analysis

- ECG *(Heart Rate and HR Variability)*
- EMG *(Muscle activity)*
- EDR *(Skin conductivity)*
- Peripheral Skin Temperature
- Overt Movement *(Ultrasonic / Video)*

Flow Diagram of Experimental Research Stages



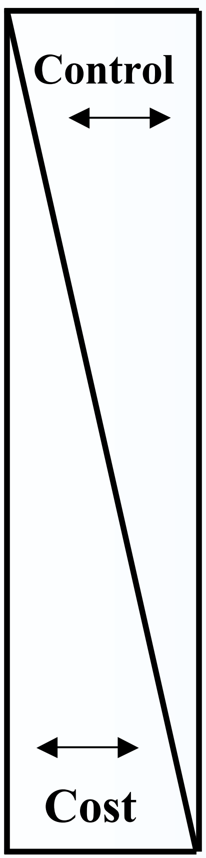
Technology Eval versus Deriving Principles

(1) Do as much pilot testing as it takes to convince yourself that you understand the phenomena under study. Then design a formal experiment to convince the rest of the world that you are right. (Dick Pew, BB&N)

(2) The best experiment is one that answers a practical question at the same time that it contributes to the research literature. (Dick Pew)

(3) When technology evaluation is not your goal, design experiments to derive principles that are technology independent. (Dick Pew)

Tradeoffs in Research Settings and Control



- **Type 1**: Highly controlled laboratory experiments
  - often need to simplify situation
- **Type 2**: Less controlled but more complex laboratory experiments *(may include part-task simulation)*
  - increased generalization
- **Type 3**: Evaluations conducted in high fidelity simulators or in the field
  - may have limited application domains (specific context)
- **Type 4**: Qualitative, descriptive field studies
  - yield understanding of pressing significant problems

Desktop Attitude Task

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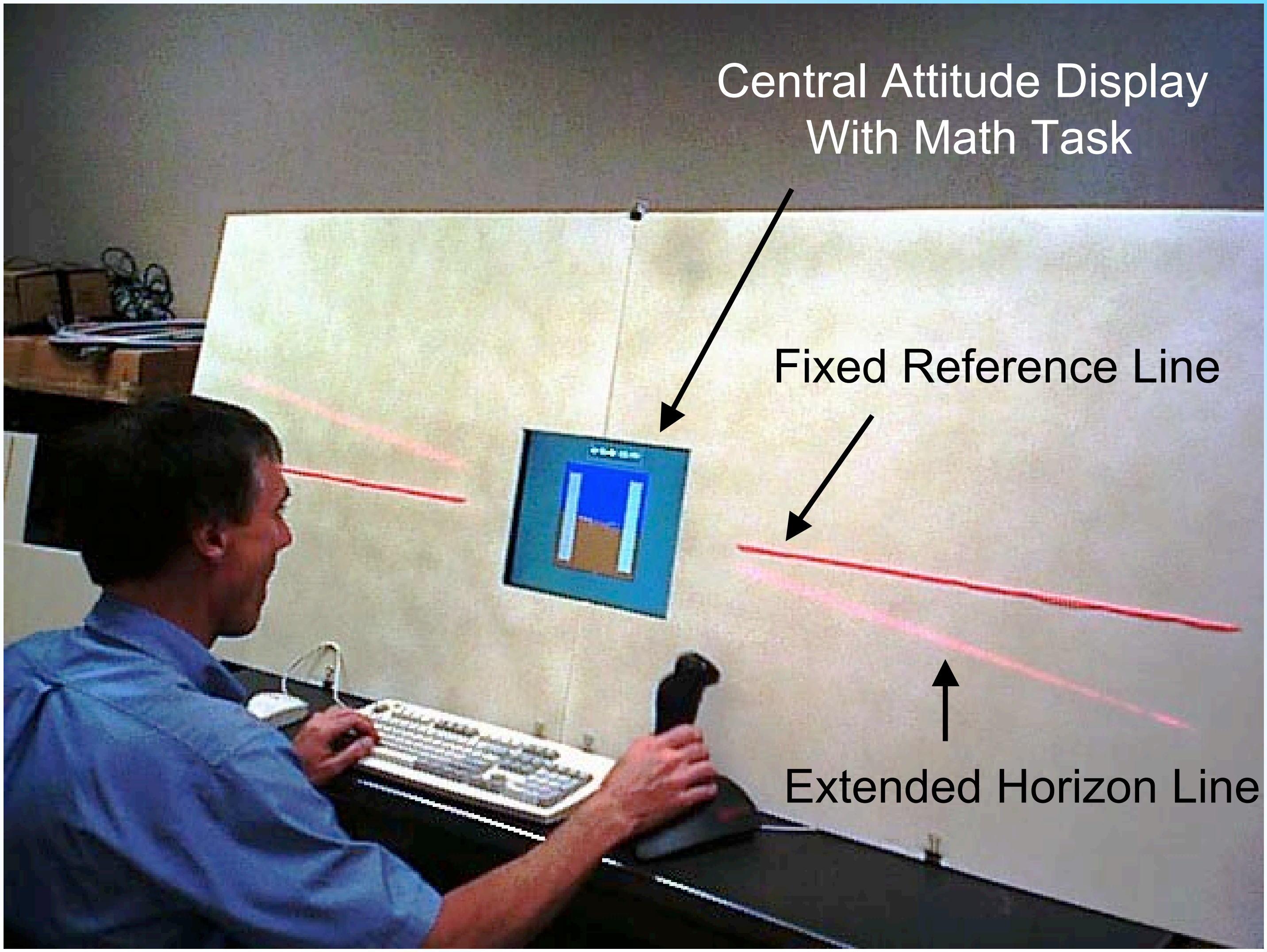
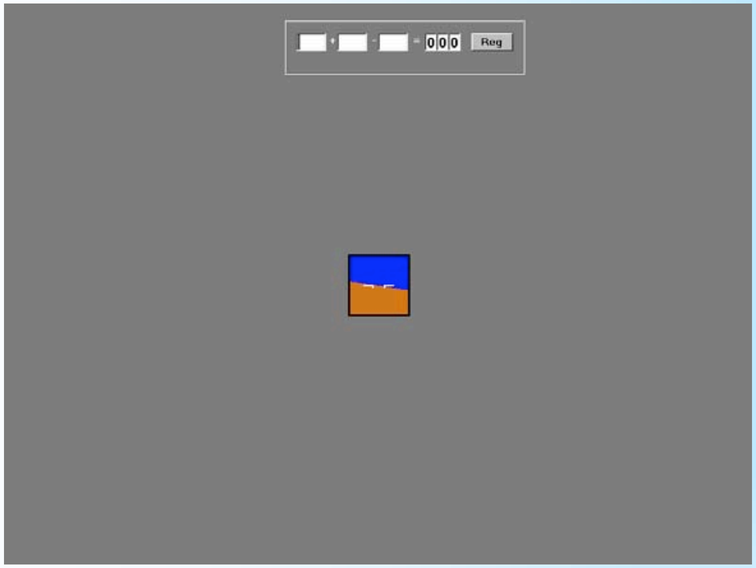
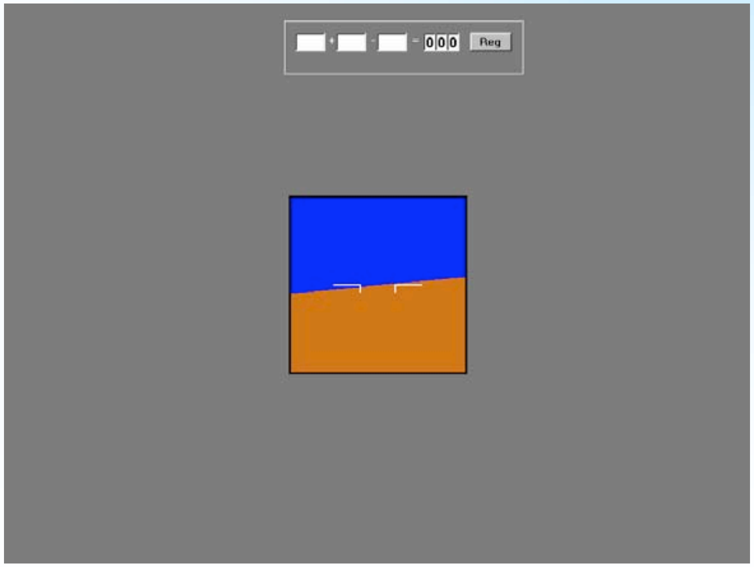


Attitude Display Sizes Tested (1 of 3)

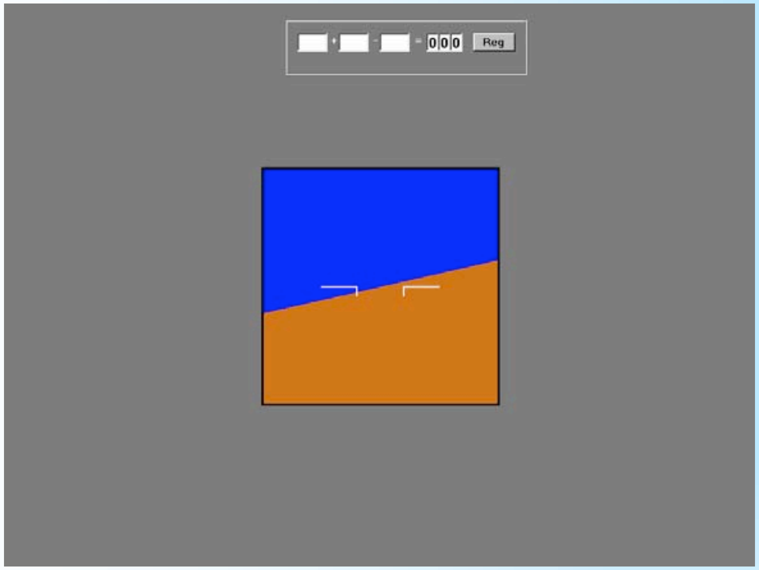


1”   2.39° Visual angle



3”   7.15° Visual angle

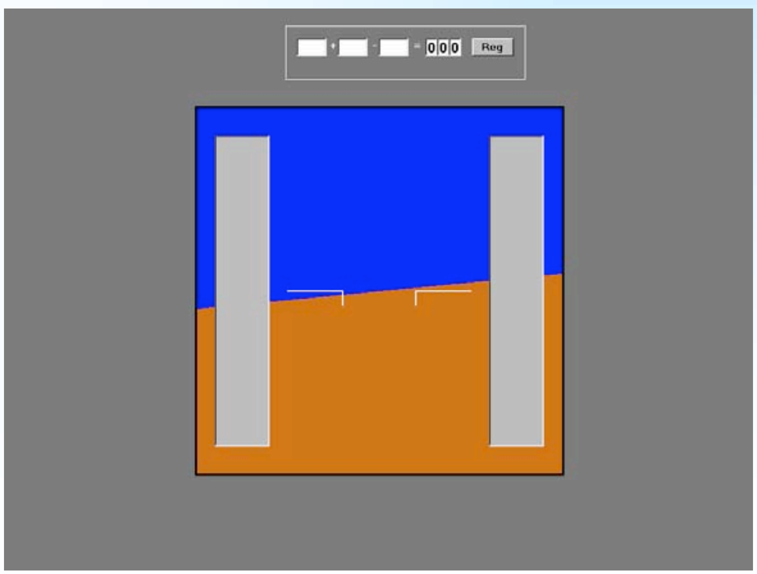
Attitude Display Sizes Tested (2 of 3)



Size “D” (3.75”)

8.93° Visual angle

Size of PFD on Boeing 777 and 747-400

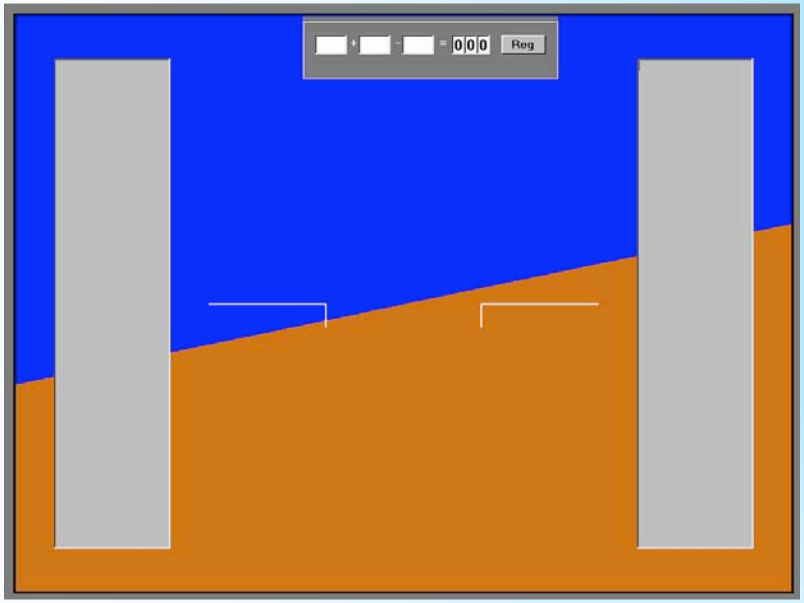


Size “D+” (5.88”)

13.96° Visual angle

Adds small area beyond Airspeed and Altitude tapes

Attitude Display Sizes Tested (3 of 3)

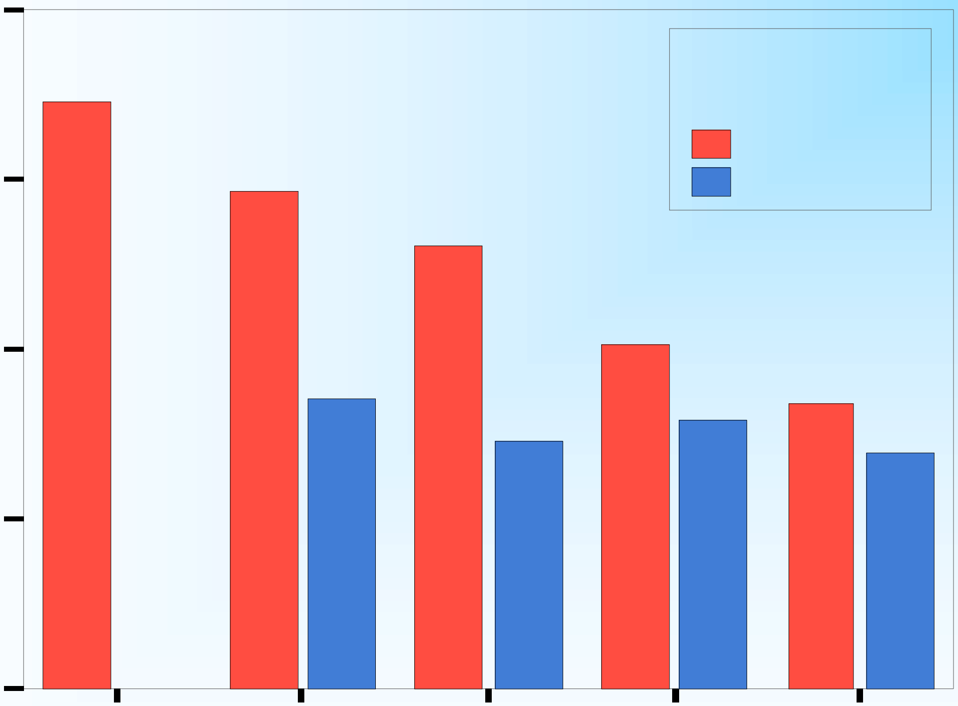


LCD Panel (11.75” Horizontal x 8.75” Vertical)

Visual angle:
27.51° Horizontal x
20.66° Vertical

Attitude Task RMS Error

OffOnExtendedhorizon12345Display Condition5.006.007.008.009.00



1 = 1”
2 = 3”
3 = size “D”
4 = “D” + beyond tapes
5 = full size of LCD (11.75” H)

Lower is better!

Centrifuge for Performance at High “G”

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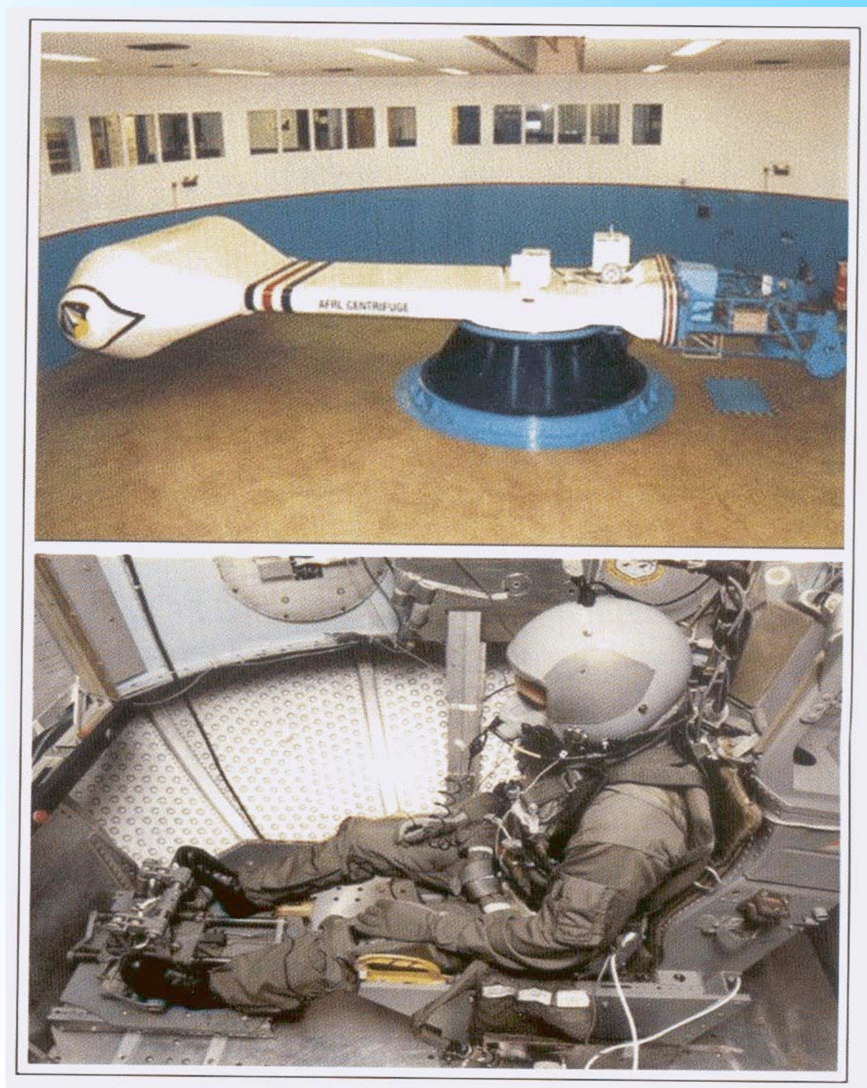

Human Systems IAC Gateway, Vol XIV (4)

HSR Taxi Simulation

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Example of a Part-Task Simulator (SOREV)

Gulfstream G-V at Reno for SVS tests

Interior of Gulfstream G-V

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HUD and Displays for SVS test

Summary

Over its brief history significant transformations have occurred in the Human Factors and Ergonomics area:

- Earliest approach was to fit person to job or equipment
- Fitting job or equipment to person required new designs and engineering
- Issues of importance to the field have changed with changing technology
- Field is much more diverse with much more effort outside of military related issues
- More specialization is required today as many HF & E areas require unique knowledge and techniques

?? Questions

For additional information Contact:

J. Raymond Comstock, Jr., Ph.D.
Crew Systems Branch, MS-152
Airborne Systems Competency
NASA Langley Research Center
Hampton, VA 23681-2199
james.r.comstock@nasa.gov 757-864-6643