

Toward the “Cognitive Cockpit”: Flight Test Platforms and Methods for Monitoring Pilot Mental State.

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And

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Project Team

- Neural Avionics Team

- Operator Performance Laboratory (OPL)

- Neurology
 - Fixed Wing Flight Testing
 - Human factors engineering
 - Academic program component

- National Research Council Canada (NRC)

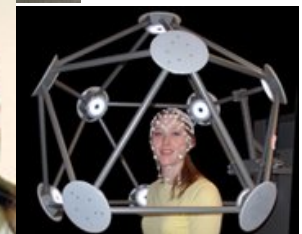
- Rotary wing flight testing
 - Flight equipment engineering
 - Pilot performance assessment

- NASA Langley Integrated Intelligent Flight Deck Team

- Foundational research
 - Flight safety research and NGATS

- Electrical Geodesics Incorporated

- Leader in dense array EEG equipment development
 - Signal processing



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Project Goals

- Competency in brain-computer-interaction as it relates to flight
 - Develop methods to collect physiological data in **ecologically valid context of flight**
 - **Flight and Simulator (Ground) environments are NOT the same**
 - Investigate sensors to monitor operator state
 - Build model to characterize operator state and to provide context relevant feedback
-
- **Foster positive and prevent negative states in pilot behavior**



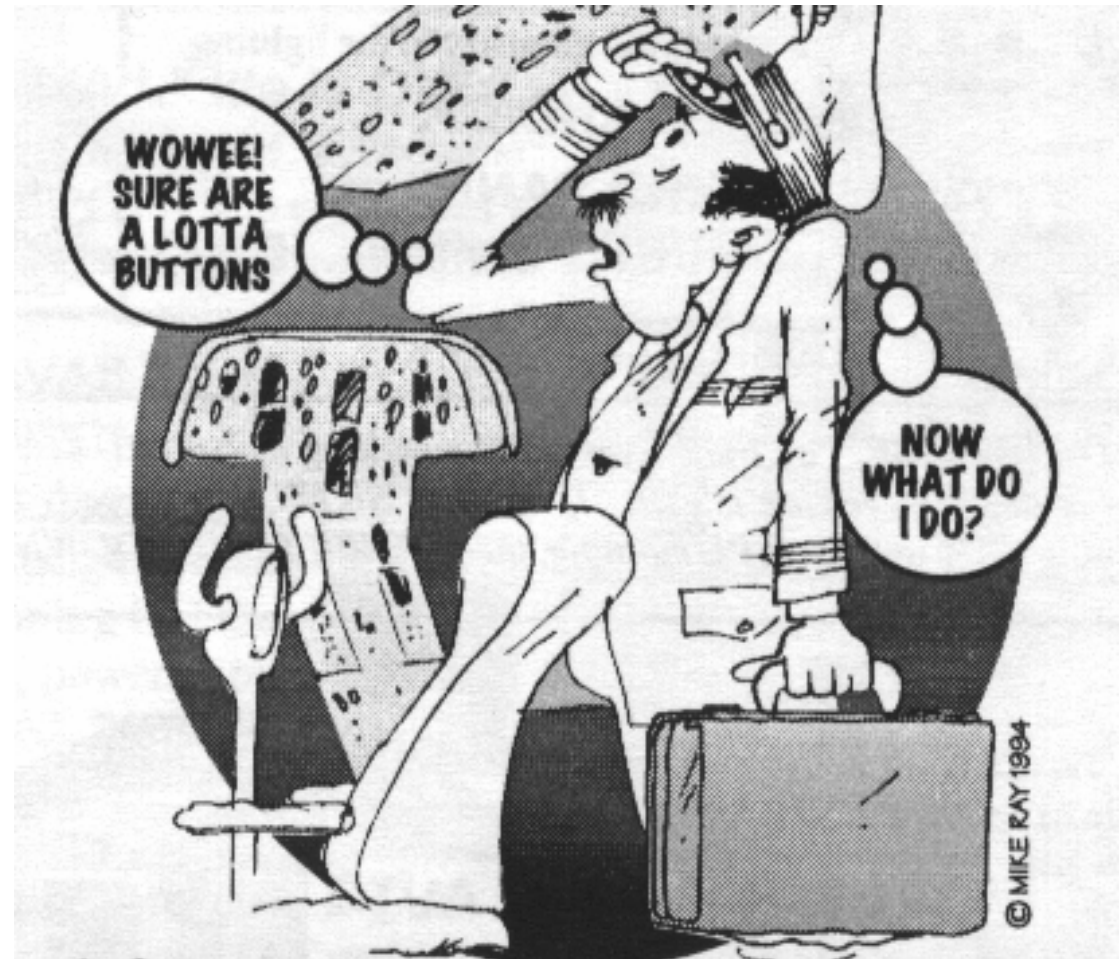
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Neural Avionics

- Complex avionics may reach or exceed pilot cognitive and workload limits
- Especially in non-normal conditions
- Reduce false alarms, provide highly context relevant information



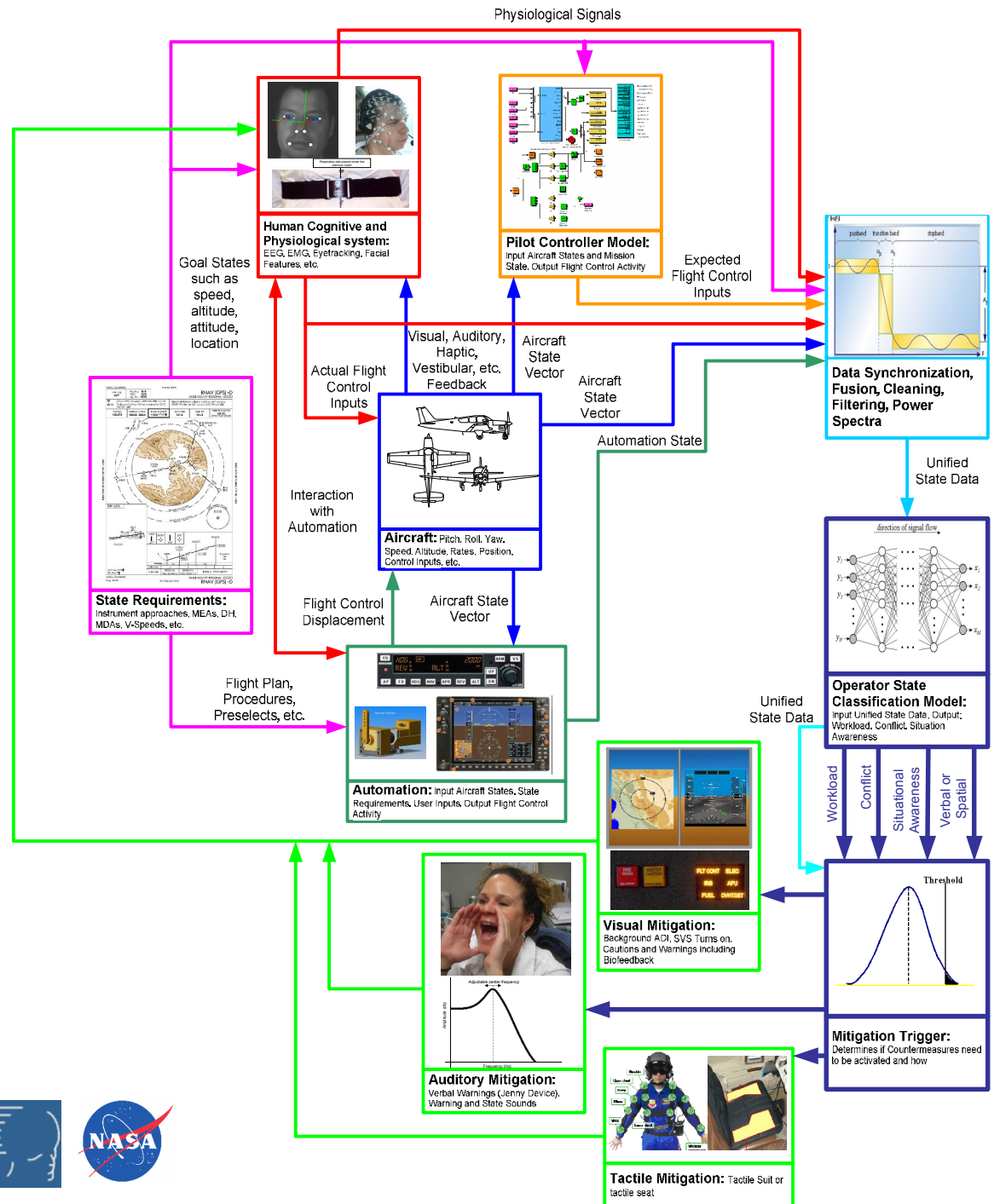
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Neural Avionics Model

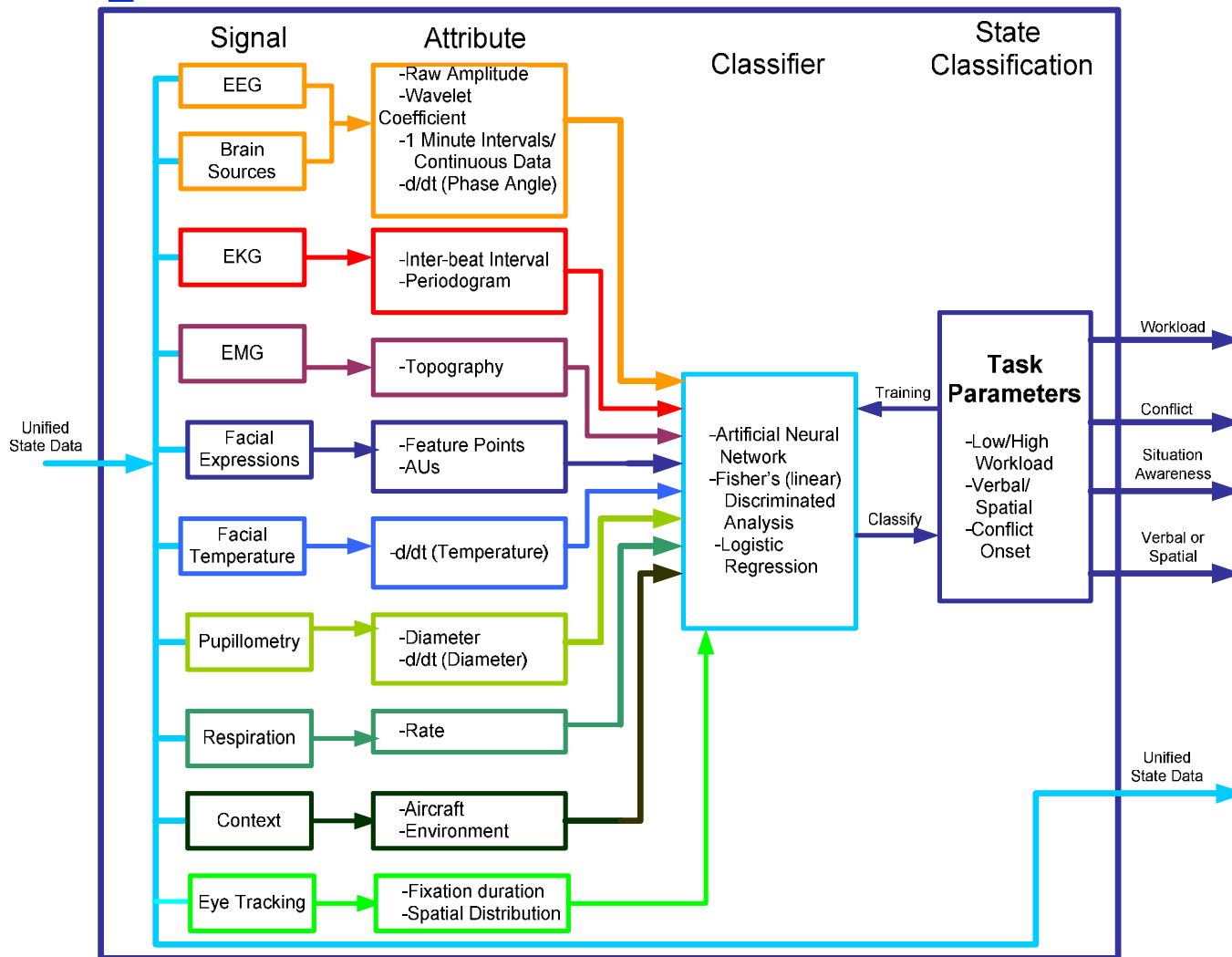
- State data
 - Aircraft
 - Mission
 - Automation
 - Human
- Classification System
 - Synchronize
 - Remove artifacts
 - Characterize state
- Mitigate
 - Visual
 - Tactile
 - Auditory



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Operator State Classification



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Flight Test Platforms: CARP



Tactile Seat Computer

PFD Computer

Novatel GPS

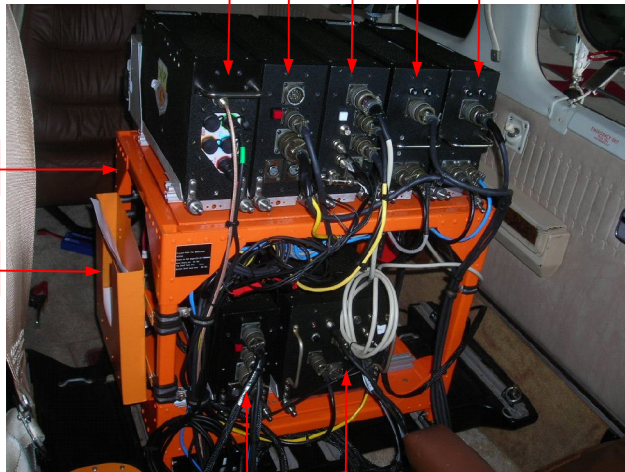
4 Channel DVR

MFD Computer

Global Scene Camera for Smarteye

FAA Approved Instrument Rack

Document and Keyboard Holder



Ship Interface Connector Bulkhead

I/O Computer

Smarteye Eye Tracking and Facial Feature Computer

Smarteye Camera and Illuminator



Forward Looking Camera ahead of Compass

Right Smarteye Camera and Illuminator

PFD SFB Daylight Readable XGA Display with USB and LVDS

PFD SFB Daylight Readable XGA Display with USB and LVDS

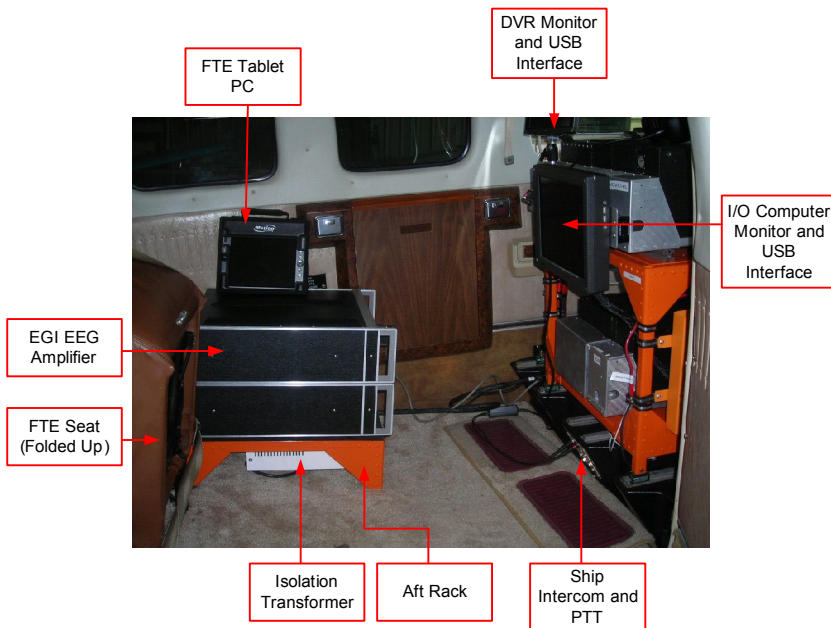
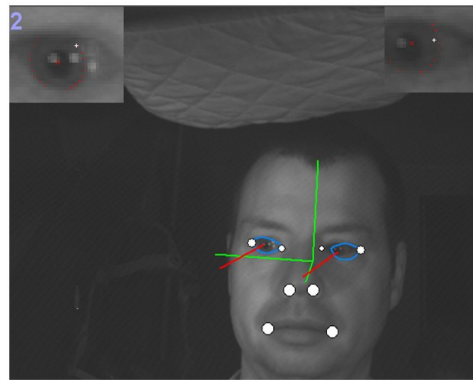


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Flight Test Platforms: CARP



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CARP-In-The-Loop flight simulator

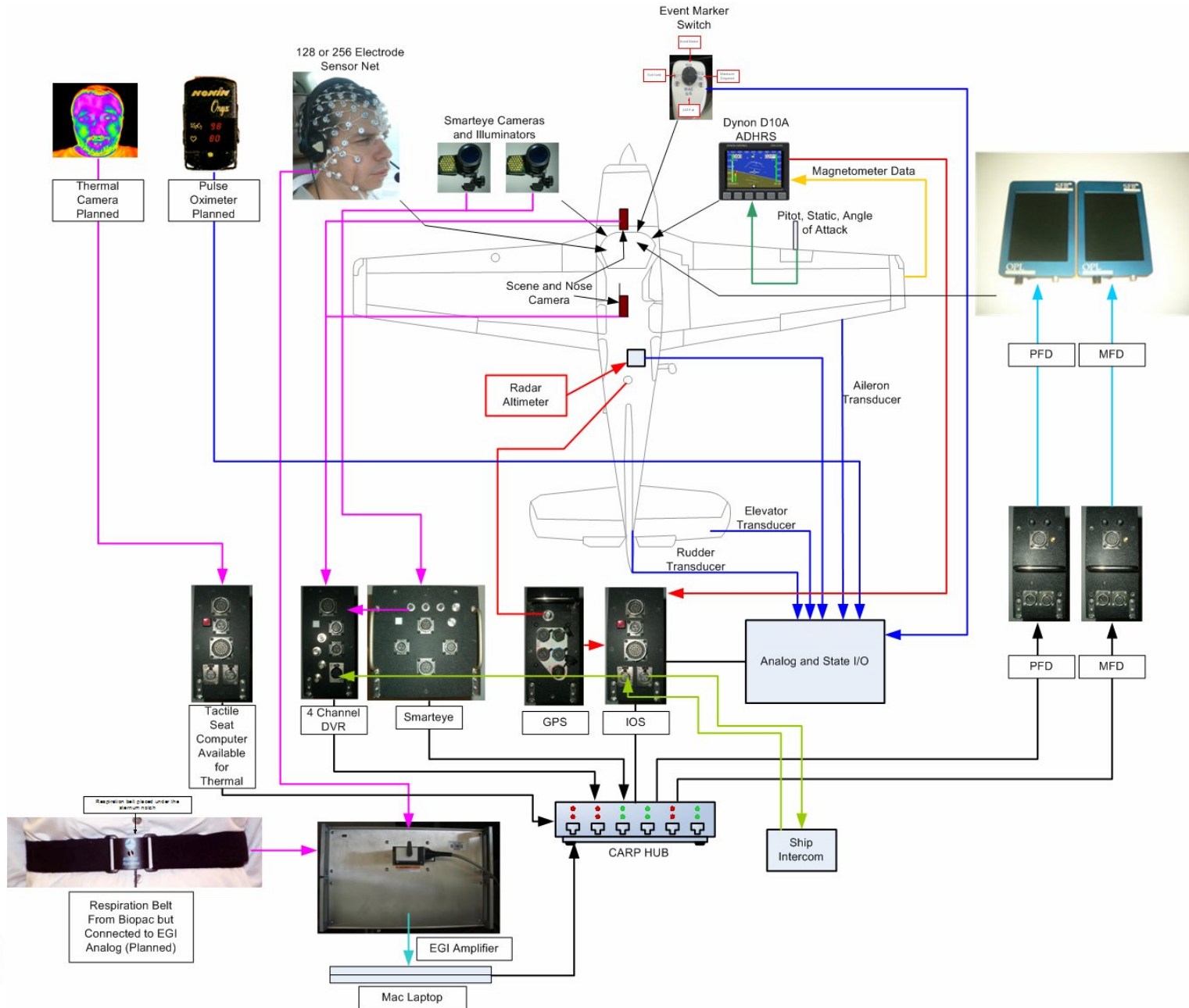


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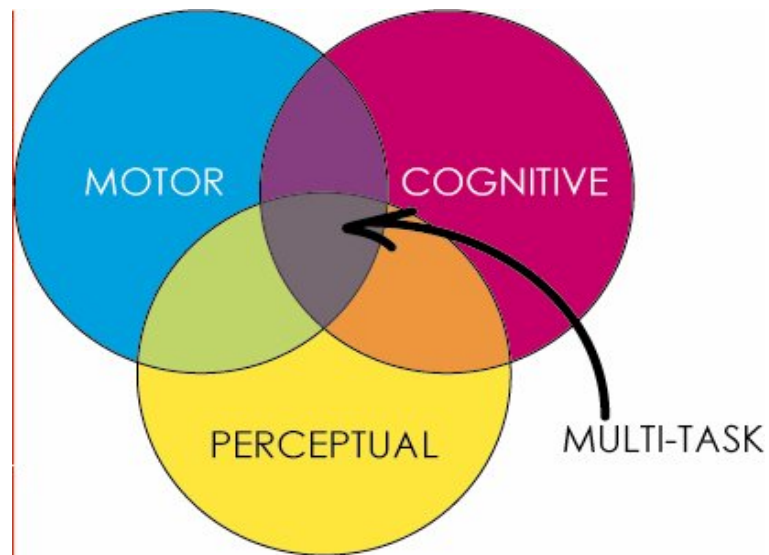
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Flight Test Platforms: CARP



THE FLIGHT TEST - FIRST PRINCIPLES

- Isolating Motor, Cognitive, and Perceptual Processes



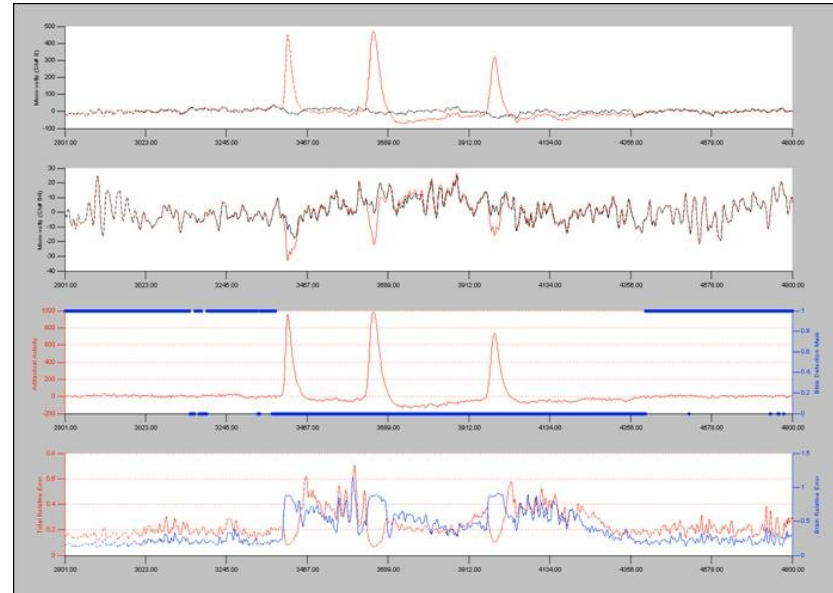
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THE FLIGHT TEST - FIRST PRINCIPLES

- Synchronization and artifact removal of real flight data
 - Flight state data
 - Expected pilot response data
 - Physiological data
 - Dense array EEG
 - EKG
 - Eye tracking
 - Facial feature points
 - Respiration
 - Thermal imaging of face



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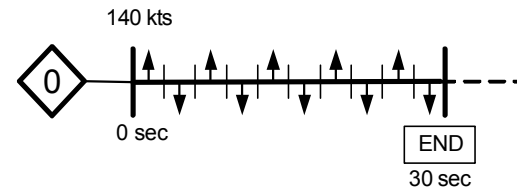
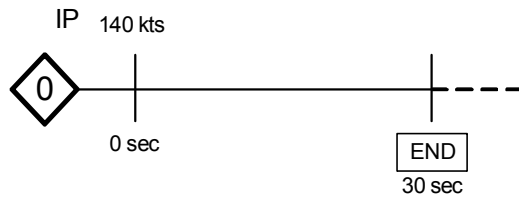
Flight Maneuvers

Alt 3000 ft
AirSpeed 140 kts
Heading As Req'd

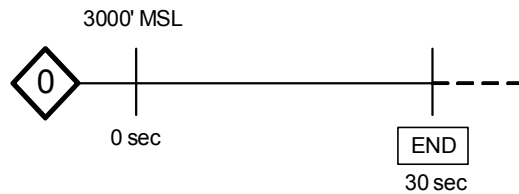
EEG 1
Sim Roll Capture

Alt 3000 ft
AirSpeed 140 kts
Heading As Req'd

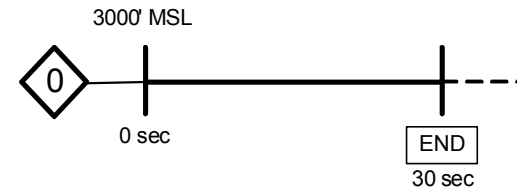
EEG 2
Roll Capture



Side View



Side View



EP eyes closed, relaxed posture, remain still
EP acts out maneuver using arms, then legs, then coordinated
On condition FTE calls "mark, arms", "feet" at 10s, "both" at 20s, "end" at 30s
EP opens eyes

EP eyes open
FTE marks data
EP to keep head straight
Roll +/- 30 deg @ 0.5 Hz
Maintain Speed & Altitude
At 30s, FTE calls end, SP takes control



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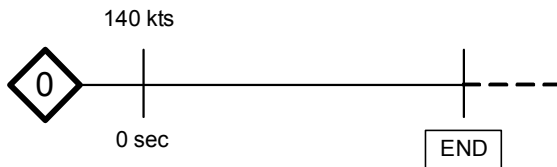
Flight Maneuvers

Alt 3000 ft
AirSpeed 140 kts
Heading As Req'd

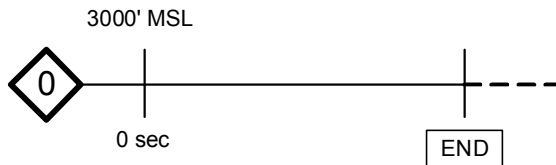
EEG 3
Baseline Cognitive

Alt 3000 ft
AirSpeed 140 kts
Heading As Req'd

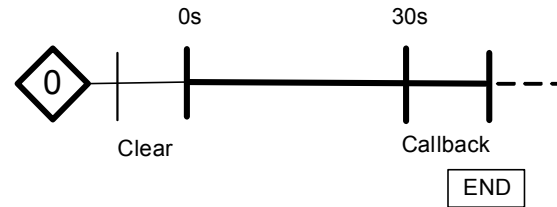
EEG 4
Clearance Callback



Side View



Side View



EP eyes closed, relaxed posture, remain still
On Mark from FTE, add digits of 10 digit phone number
EP calls out cumulative sum at end
FTE marks end of trial

EP eyes open, relaxed posture, remain still
SP to read clearance
FTE to time 30s & say "Callback"
EP to repeat clearance
FTE marks data



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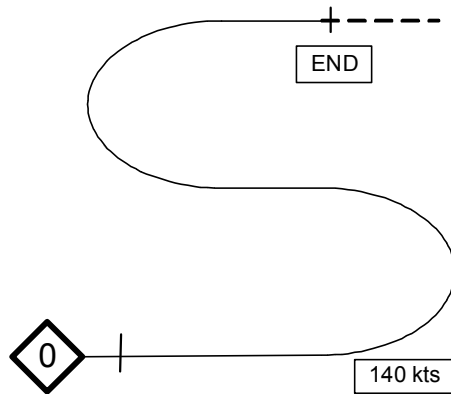


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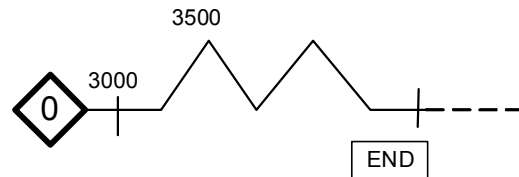
Flight Maneuvers

Alt 3000 ft
AirSpeed 140 kts
Heading Into Wind

EEG 5
Wing Over Observe



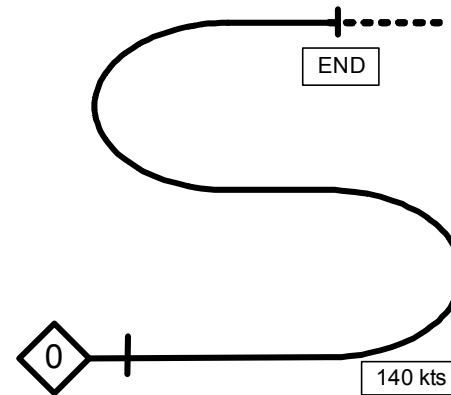
Side View



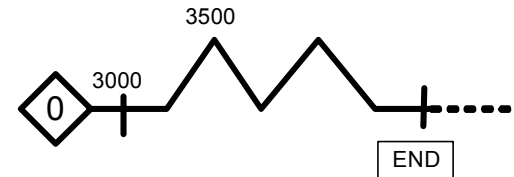
SP to call start of maneuver
On Mark from FTE, SP to fly wingover
Max Pitch: 30 deg; Max Bank: 60 deg
EP to observe as if they were flying
SP to call end of maneuver

Alt 3000 ft
AirSpeed 140 kts
Heading Into Wind

EEG 6
Wing Over



Side View



SP to establish flying conditions
On Mark from FTE, EP takes control
EP to fly wingover (symmetrical)
Max Pitch: 30 deg; Max Bank: 60 deg
EP to call end of maneuver



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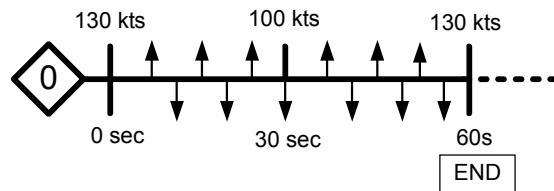


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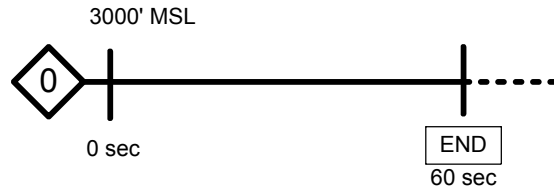
Flight Maneuvers

Alt 3000 ft
 AirSpeed 130 kts
 Heading Into Wind
 Prop 2400 RPM

EEG 7
 Comprehensive task



Side View



SP establish conditions
 On Mark from FTE,

EP (1) to smoothly decelerate from 130 to 100kts in 30s while rolling +/- 30deg @ 0.25Hz
 (2) smoothly accelerate from 100 to 130 kts in 30s while rolling +/- 30 deg @ 0.25Hz

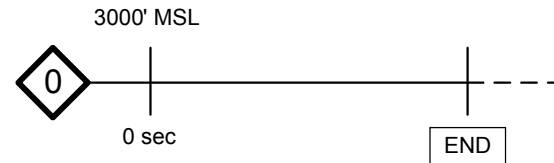
EP to call end of maneuver

Alt 3000 ft
 AirSpeed 140 kts
 Heading As Req'd

EEG 8
 Motor Cognitive



Side View



EP eyes closed, relaxed posture, remain still
 On Mark from FTE, add digits of 10 digit phone number while acting out maneuver using arms and legs
 EP calls out cumulative sum at end
 FTE marks end of trial



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EEG Sortie



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Background Flight Research Laboratory

- Pursue the goals of NRC-IAR in those R & D areas that require:
 - full-scale, aircraft-based experimentation,
 - understanding of interactions between the pilot and the aircraft,
 - skills and knowledge for successful integration of systems into the airborne environment,
 - expert level knowledge of aircraft performance, stability and control, and flight dynamics,

Or

- is a direct non-aeronautical application of the skills and expertise resident at FRL

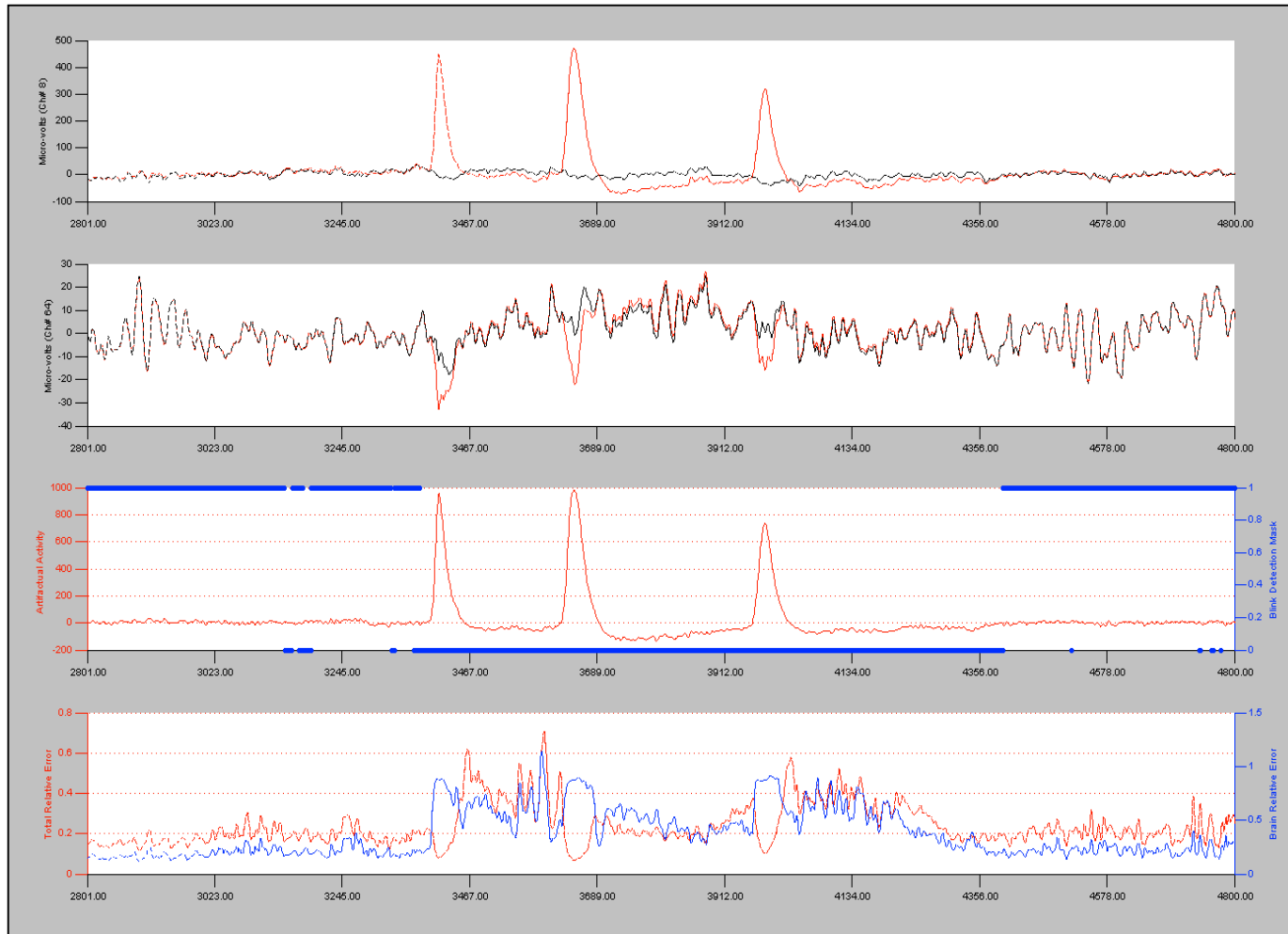


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Artifact Removal



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Calibration (EEG)

- EEG tracks electrical activity in cortex
- Orientation and position of activity are crucial
- Each individual's cortex is shaped and organized uniquely
- Conduct standardized neuropsychological experiments to calibrate brain model for each subject



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Facial Expression Recognition

Methodology (CMU or Smart Eye):

1. Facial feature tracking => 2D picture to 3D volume
2. Extract S_i = shape parameters = $f(\text{facial features})$
3. $AU_j = f(S_i - S_{\text{neutral face}})$
4. $P(\text{expression}_k) = f(AU_j)$

AU = “action units” in Facial Action Coding System (FACS)

<http://www.cs.cmu.edu/afs/cs/project/face/www/facs.htm>

Link AU scores to emotion (happiness, sadness, etc.) scores with FACSaid dictionary

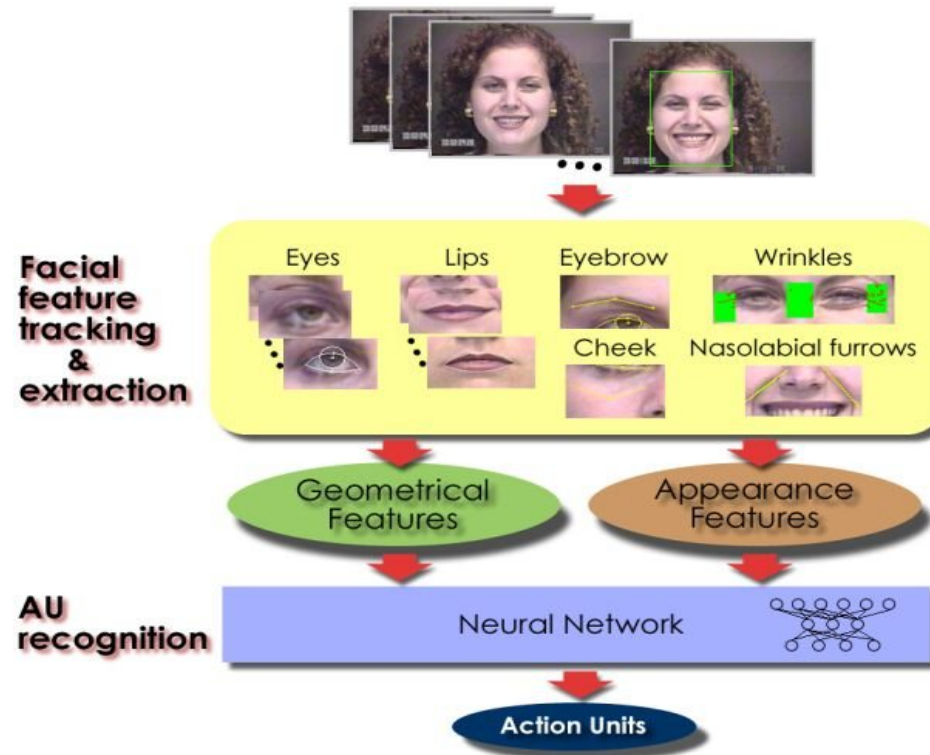


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Facial Expression Recognition



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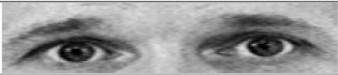










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Facial Expression Recognition

FACS - Facial Action Coding System (2002 Revision is [here](#))

([Ekman](#) and Friesen 1978)

AU	Description	Facial muscle	Example image
1	Inner Brow Raiser	<i>Frontalis, pars medialis</i>	
2	Outer Brow Raiser	<i>Frontalis, pars lateralis</i>	
4	Brow Lowerer	<i>Corrugator supercilii, Depressor supercilii</i>	
5	Upper Lid Raiser	<i>Levator palpebrae superioris</i>	
6	Cheek Raiser	<i>Orbicularis oculi, pars orbitalis</i>	
7	Lid Tightener	<i>Orbicularis oculi, pars palpebralis</i>	
9	Nose Wrinkler	<i>Levator labii superioris alaquae nasi</i>	
10	Upper Lip Raiser	<i>Levator labii superioris</i>	
11	Nasolabial Deepener	<i>Zygomaticus minor</i>	

Initial Modeling Effort

EEG: Correlate spectral power with
workload conditions/tasks

Overall: Discriminant Analysis

$$\text{Workload}_{\text{level}} = f(\text{EEG})$$

$$\text{Workload}_{\text{level}} = f(\text{EEG}, \text{EKG}, \text{EMG}, \\ \text{respiration}, \text{facial expression})$$



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Analysis

Filter data into frequency bands:

- Delta ($< 4\text{Hz}$)
- Theta ($4 - 7\text{Hz}$) \Rightarrow workload/memory processes/(performance & conflict monitoring)
- Alpha ($8 - 12\text{Hz}$) \Rightarrow motor activity
- Beta ($13 - 20\text{Hz}$)
- Gamma ($> 30\text{Hz}$) \Rightarrow (perceptions/attention)

Calculate power in each frequency band (e.g average for 30sec intervals)

Method: Fourier Transforms

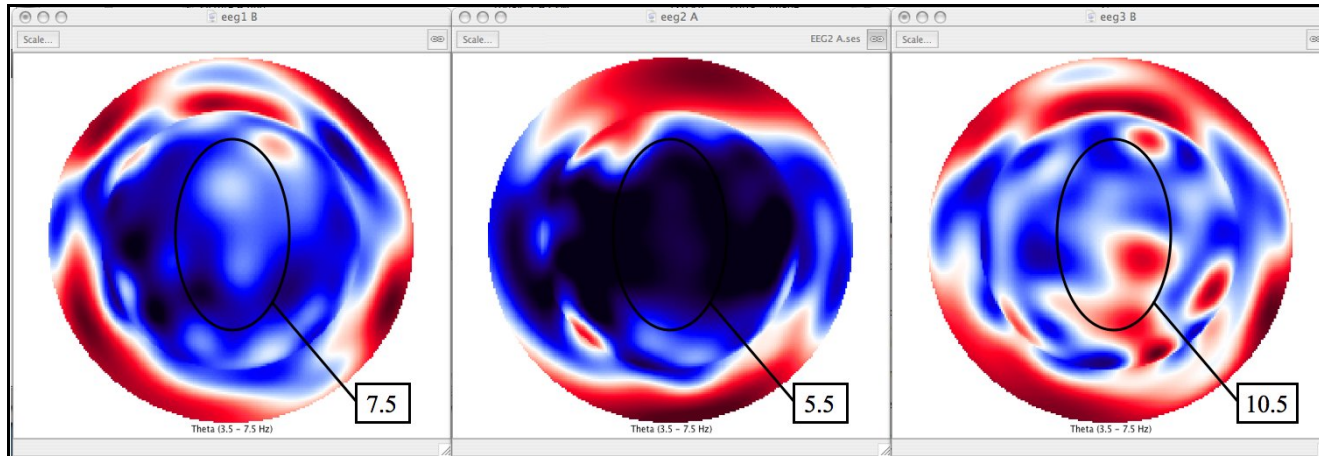


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Results



- Working memory-processes are reflected as oscillations within the EEG theta band

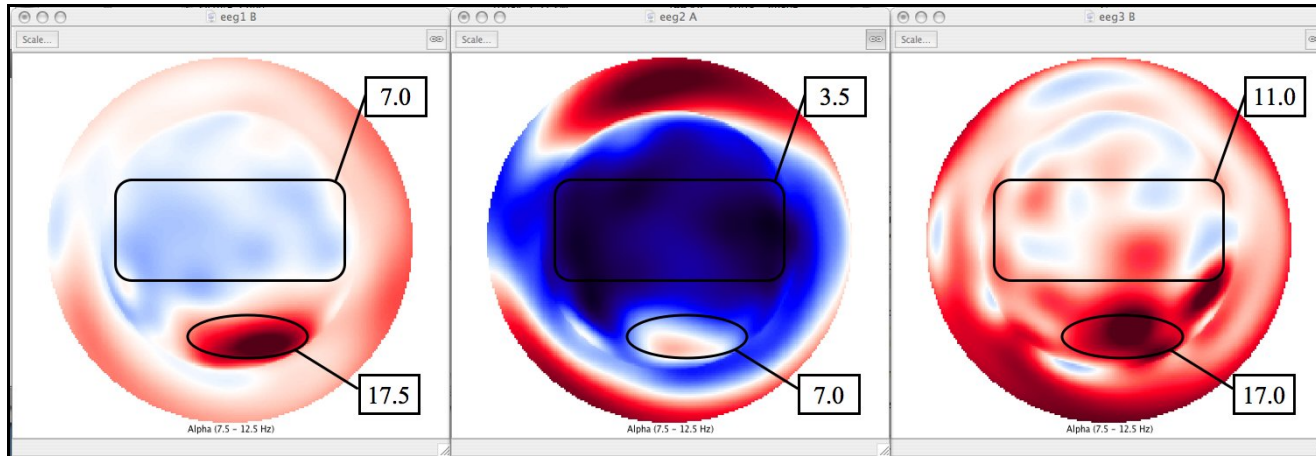


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Results



- Alpha activity represents a sort of "idle" state.
- Normally fairly large over the back third of the brain (mainly occipital areas) when the eyes are closed and the subject is awake.
- Disappears when a person either becomes mentally busy or becomes drowsy.
- For voluntary movements (e.g. finger tapping), EEG activity is desynchronized in alpha ranges over sensorimotor areas.



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Analysis

Task	Theta Midline	Alpha	
		Occipital	Lateral motor
1	7.5	17.5	7
2	5.5	7	3.5
3	10.5	17	11
5	7	9.5	4
6	8	10.5	4.5
7	10.5	11	5



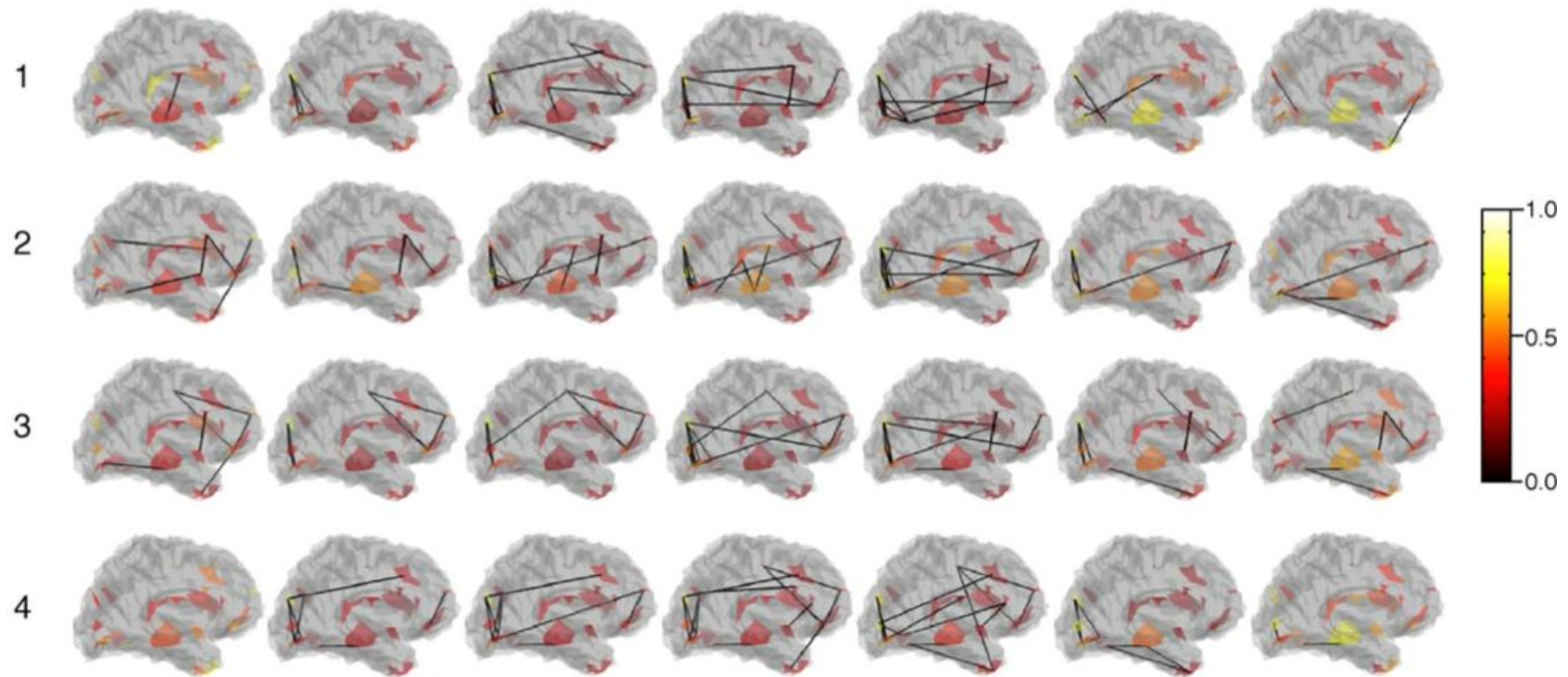
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Next Steps: EEG Coherence

D. Cosmelli et al. / NeuroImage 23 (2004) 128–140



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Building Augmented Cognition Internationally

The NRC is leading a team of Canadian researchers consisting of 1) Canadian Universities, Corporate Partners and other government departments (e.g. DND, DRDC, and Transport Canada)

The collaborative efforts of the University of Iowa and the Flight Research Laboratory have established new physiological monitoring capabilities in fixed and rotary wing aircraft.

THE THRUST OF THESE COLLABORATIVE EFFORTS IS TO DEVELOP A NEW AIRBORNE TEST CAPABILITY ACCESSIBLE TO THE BROADER COMMUNITY OF RESEARCHERS STUDYING AUGMENTED COGNITION.



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The FRL Research Aircraft Fleet



45 years of experience of Fly-By-Wire

- First variable stability helicopter developed from Bell 47's in 1962!
- Bell 205 Airborne Simulator - Acquired in 1969, FBW in 1971
 - Extensive use in defining rotorcraft/VSTOL handling requirements
- Bell 412 Advanced Systems Research Aircraft (ASRA)
 - Higher control power and bandwidth
 - Acquired 1993, First FBW engagement in February 2001
 - First major project – Sikorsky Aircraft Fall 04



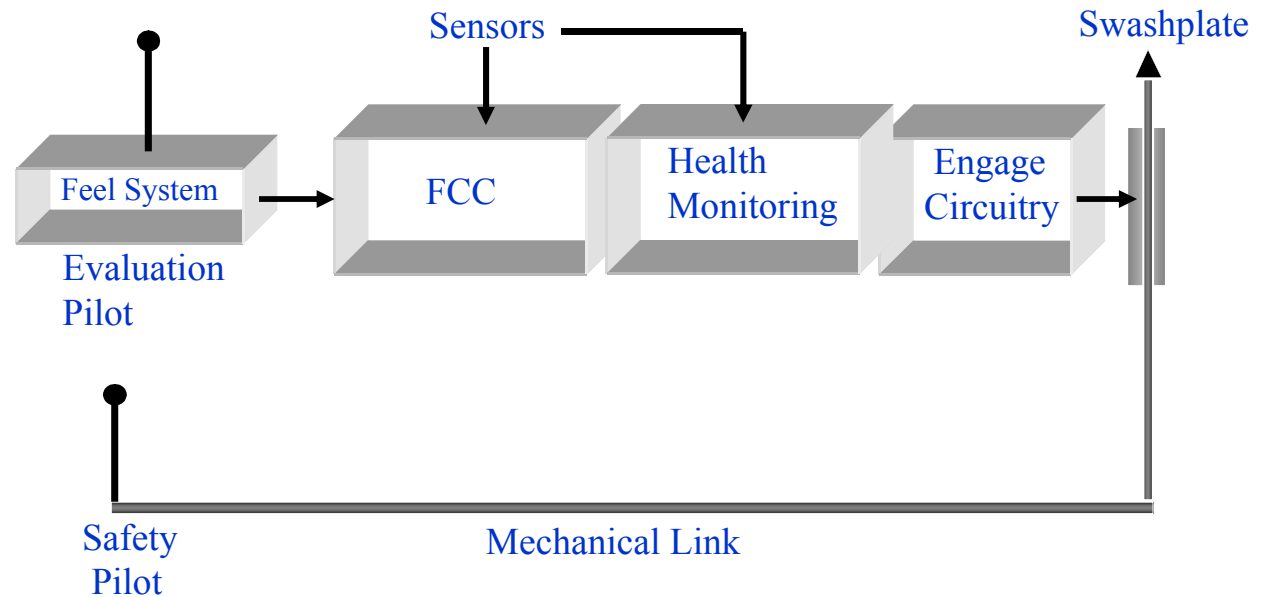
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ASRA FBW Design Philosophy

- Simplex control system
 - “single string”
- Full authority
- Full envelope
- Safety pilot constitutes the core safety system



With our two “fly-by-wire” helicopters, we study how to make helicopters easier to fly



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Advanced Systems Research Aircraft (ASRA)



ASRA, can be airborne test facility
or fixed base simulator.

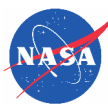
CAPABILITY TO VARY WORKLOAD

Similar approaches to CARP.

1. Validate, assess, and develop recording technologies,
2. Enhance data analysis techniques in rotary environment
3. Study neural mechanisms contributing to flight.
4. Implemented platforms for real cockpit evaluations.



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