Human-Autonomy Teaming and Function Allocation

“***The civil aviation community <u>does not currently have a</u> rigorous, systematic method for defining and analyzing the architecture of <u>human-autonomy teams</u>***, *particularly with regards to their safety.*
The architectures typically assumed today are fundamentally limited by concerns with brittleness and legal designations of responsibility. ... Prediction of the task load placed on the human operators – or, where possible, ***workload experienced by the human operators – is a valuable metric of function allocations***.”

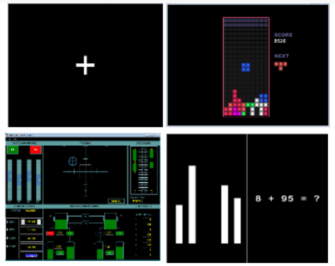
Pritchett, A.R., Portman, M., & Nolan, T. (2017). Research and Technology Development for Human-Autonomy Teaming A Literature Review. NASA Contractor Final Report. NNL16AA07C.

Teaming is key to achieving Advanced Air Mobility

image credit: NASA

Human Physiological Monitoring System

image credits: NASA/TASA team

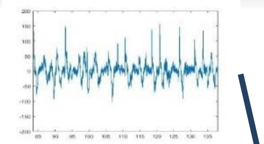


Benchmark Task Performance → Train

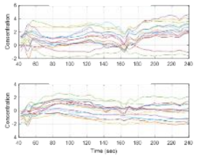
Photo credit: Angela Harrivel

Simulated Flight Performance → Predict

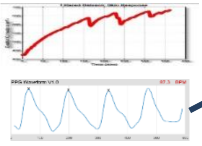
EEG and ECG *with Muse* — **Bluetooth** →



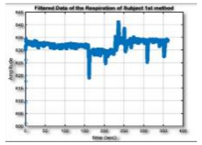
fNIRS *with ISS Inc. Imagent* — **wired** →



GSR and BVP *with Empatica E4* — **Bluetooth** →

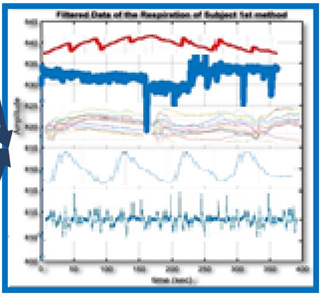


Respiration *with Spire*



Eye-tracking *with Tobii Pro* — **wired** →

image credit: NASA/CSM team



NeuroPype by Intheon and Lab Streaming Layer for real time data acquisition

→ **Classification Algorithms**

↓

Real Time Display of State Prediction

Data Acquisition	Signal Processing	Feature Extraction	Data Synchronization	Machine Learning

The best real-time-compatible methods used autoencoding to deal with biological noise, and two 6-layer dense neural networks. Non-nominal attentional states are identified at a rates > 0.8.

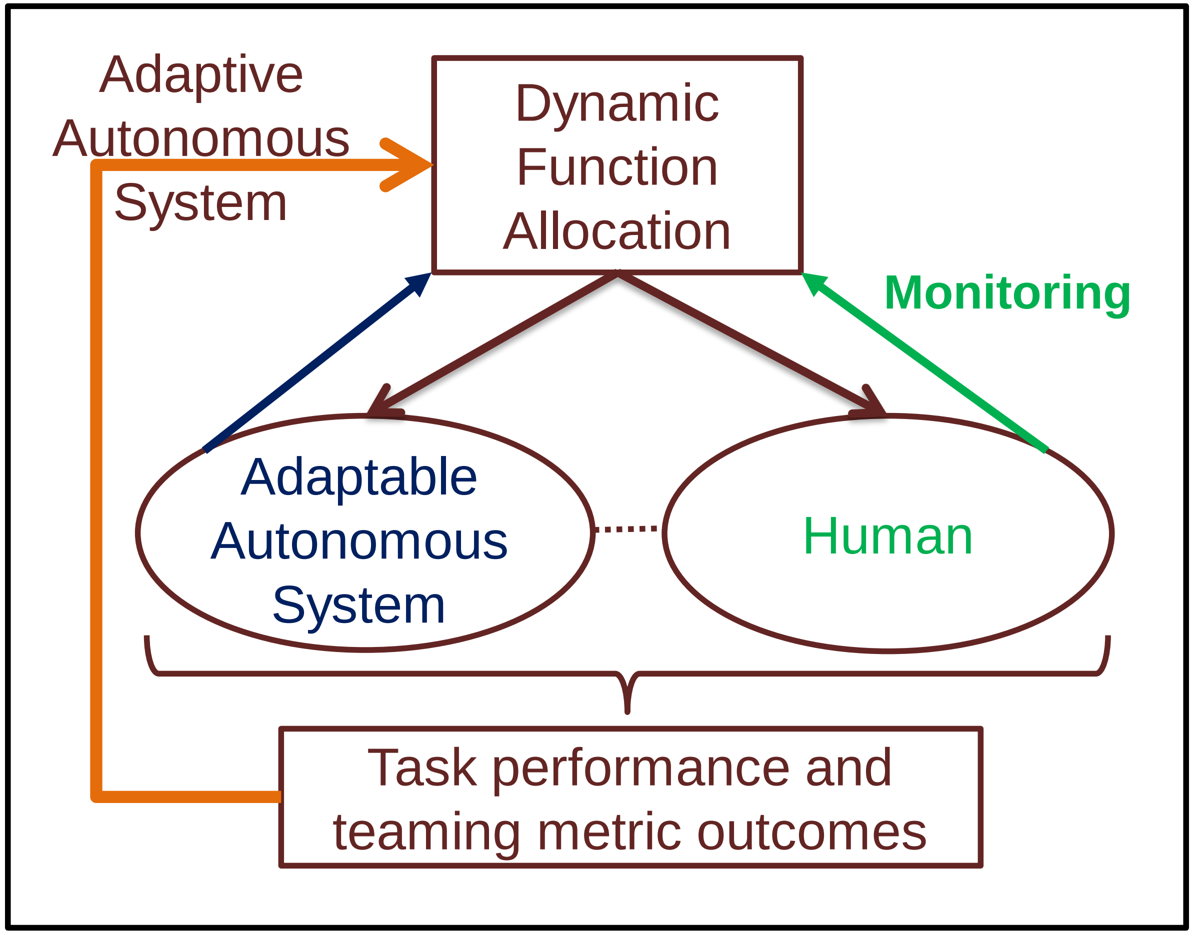
Terwilliger, P., Sarle, J., Walker, S., Harrivel, A. A ResNet Autoencoder Approach for Time Series Classification of Cognitive State, MODSIM World 2020, Paper No. 0053, (virtual event).

LAR-18996, US Patent 10 192 173
https://technology.nasa.gov/patent/LAR-TOPS-88

Human Monitoring for Human-Autonomy Teaming (HuMHAT), or "Trust in the Human Operator"

CSAOB is developing and combining tools to study Human-Autonomy Teaming:

- flight and autonomous system **simulation** development
- human monitoring tools
- human performance metrics



Monitoring allows the system to support the operator at the right time to avoid the pitfalls of sub-optimal states.

We have developed real-time tools to identify suboptimal mental states

- Incapacitation / impaired crew performance
- High and Low workload
- Channelized Attention
- Diverted attention
- Startle or surprise

System and Method for Human Operator and Machine Integration
LAR-19051, US Patent 10,997,526
https://technology.nasa.gov/patent/LAR-TOPS-301

Example DFA Simulation Scenarios, UAM contexts

Human state	Adaptable Autonomous System (AAS) state	Potential Teaming Metric dependencies	Dynamic Function Allocation (DFA) change
Passed out / Incapacitated (video)	(does not matter)	• Lack of control input • Lack of communication • Envelope excursion	AAS assigned full control, heads toward medical facility
Attentive and situationally aware	Working, Nominal	• Divergent / incongruent actions based on human hazard detection • Lack of shared situational awareness	Human takes / is assigned full control, remains engaged and avoids over-reliance
Overloaded / Attentional Lapse (Distracted)	Working, Nominal	• Lack of control input • Lack of communication	AAS shares the burden where it can, avoids under-reliance
Bad actor	Adapting to accommodate flight parameter exceedances or unexpected control inputs	• Incongruent actions • Flight plan divergence • Lack of shared intent • Lack of communication • Envelope excursion	AAS assigned full control, restricted controls

Investigations Enabled by HuMHAT

Realizing a safe future UAM market requires new trials, new solutions, and answers to many remaining R&D questions:

- How can increasingly autonomous systems be designed while properly considering what human pilots do to “save the day”?
- Can the effectiveness of Human-Autonomy Teaming be optimized using adaptive automation and dynamic function allocation informed by operator state?
- How can human performance decrement best be mitigated in these new contexts?
- How many vehicles per ground-station monitor are optimal under what conditions to maintain safety?

image credit: NASA

- Can human-operated vehicles be successfully simulated at scale for mixed-airspace simulation studies?
- How does human performance change depending on air traffic density, and other variables such as route re-planning frequency?

HuMHAT UAM simulation flyer, CSM connections

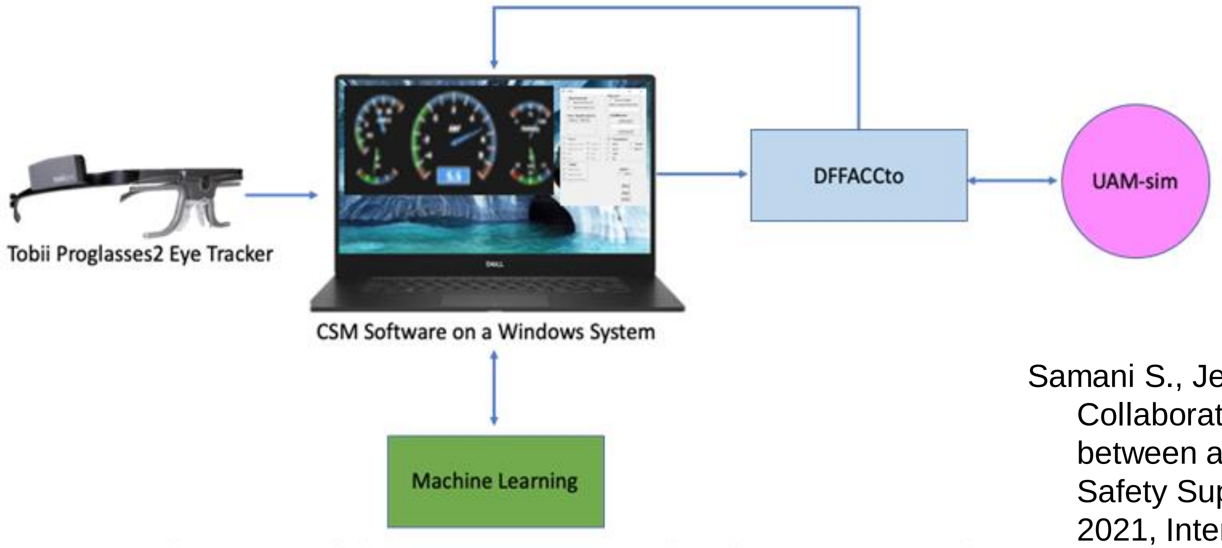


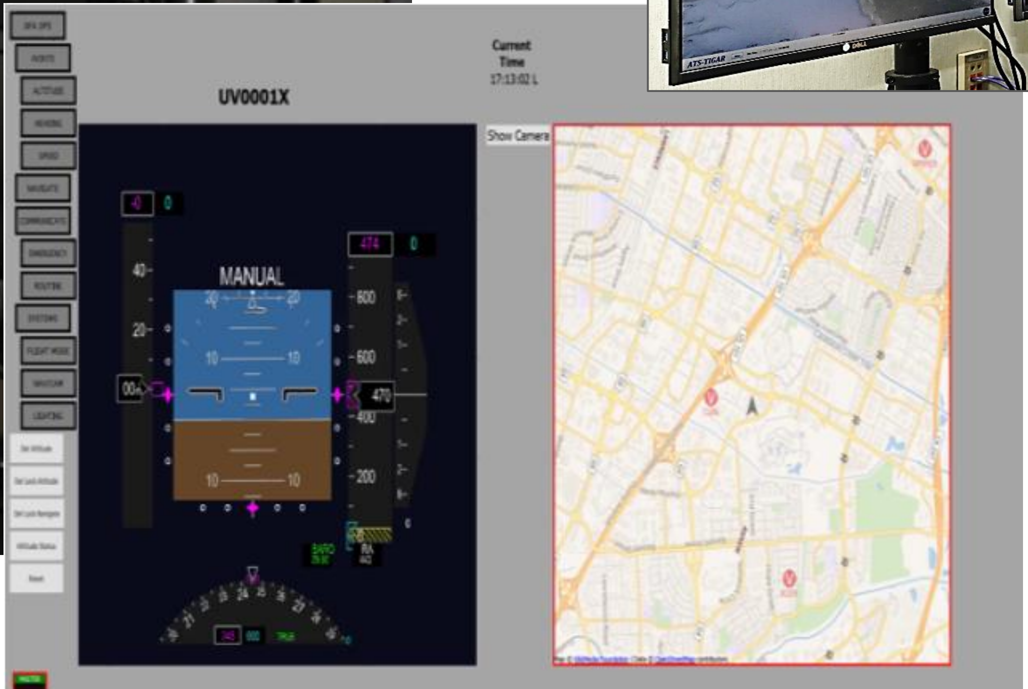
Fig. 1. Diagram of the CSM-UAM simulator connection

Simulation Methods for Human Operator and Machine Integration
LAR-19978-1

Samani S., Jessop, R., Harrivel, A. Collaborative Communications between a Human and A Resilient Safety Support System, IEEE ICAS 2021, International Conference om Autonomous Systems, August 11-13, 2021, Montreal, Canada

HuMHAT Incapacitation simulation demonstration

- ✓ Challenge context
- ✓ Prior LaRC work
- ✓ Technology, scenarios, investigations enabled
- ❑ Recent demonstration



(video)

Simulation Methods for Human Operator and Machine Integration
LAR-19978-1

References and Backup

SE211 Research and Development

Stephens, C.L., DeHais, F., Roy, R., Harrivel, A.R., Last, M.C., Kennedy, K.D., & Pope, A.T. (2018). **Biocybernetic Adaptation Strategies: Machine Awareness of Human Engagement for Improved Operational Performance**. Lecture Notes in Computer Science series, Volume 10915.

- A method developed for adapting an automated flight control system to user state has been applied to the process of biofeedback training.
- This repurposing enables alternative mechanisms for delivering physiological information feedback to the trainee via a method referred to as physiological modulation.

Harrivel, A., Heinich, C., Milletich, R., Comstock, J., Stephens, C., Last, M. C., Napoli, N., Abraham, N., Toro, K., Kennedy, K., Pope, A. (2018). **Comparative EEG Sensor Analysis for Attentional State Prediction**. *The Aerospace Medical Association's 2018 Annual Scientific Meeting*. Dallas, TX.

- State prediction accuracy using a small 4-channel electroencephalography (EEG) device (among multiple additional physiological sensors) was found to be comparable to that with a more cumbersome EEG system for channelized attention at 60%,
- and to be only slightly lower for startle at 67%. These results warrant continued development of real-time classification of AHPLS using less-obtrusive sensors.

Stephens, C., Prinzel, L., Harrivel, A., Comstock, J., Abraham, N., Pope, A., Wilkerson, J., Kiggins. D. (2017). **Crew State Monitoring and Line-Oriented Flight Training for Attention Management**. *International Symposium on Aviation Psychology*. Dayton, Ohio.

- This report described the successful development of methods and scenario details to inform the commercial aviation community of the techniques employed by the NASA SE-211 team for creating realistic flight simulation scenarios that reliably induce AHPLS.
- Simulated flight scenario event sets were designed in collaboration with SMEs and line-operational commercial airline pilots.

SE211 Research and Development

Harrivel, A., Liles, C., Stephens, C., Ellis, K., Prinzel, L., Pope, A. (2016). **Psychophysiological Sensing and State Classification for Attention Management in Commercial Aviation**. *AIAA Science and Technology Forum and Exposition.* San Diego, CA.

- With respect to a unimodal case using EEG signals, multi-modal classification using galvanic skin response (GSR) in addition to the EEG signals produced increased state discrimination accuracy (90% vs. 86%).
- Using EEG, GSR, and heart rate variability, multi-state (channelized attention, diverted attention, and workload) accuracy averaged 89%.

Harrivel, A., Weissman, D., Noll, D., Huppert, T., and Peltier, S. (2016). **Dynamic filtering improves attentional state prediction with fNIRS**. *Biomedical Optics Express. 7*(3), 979-1002.

- Study participants performed an attentional task while their brain activity was monitored with functional near infrared spectroscopy (fNIRS).
- Higher state prediction accuracy using support vector machines was observed when noise in the fNIRS hemoglobin signals was filtered with an adaptive model compared to static regression (84% $\pm$ 6% versus 72% $\pm$ 15%).

Harrivel, A., Stephens, C., Milletich, R., Heinich, C., Last, M. C., Napoli, N., Abraham, N., Prinzel, L., Motter, M., Pope, A. (2017). **Prediction of Cognitive States during Flight Simulation using Multimodal Psychophysiological Sensing**. *AIAA Science and Technology Forum and Exposition, Applications of Sensor and Information Fusion*. Grapevine, TX.

- Using a select set of features and a combined classifier training method, multistate (channelized attention and startle) prediction accuracy averaged 0.64 +/- 0.14 across thirteen participants
- and was significantly higher than that for the separate classifier training case.

Less-obtrusive sensors - Electrical Brain Measures

- ✓ Challenge context
- ❑ Prior LaRC work
- ❑ Technology, scenarios, investigations enabled
- ❑ Recent demonstration

Comparative EEG Sensor Analysis for Attentional State Prediction

We are interested in what is measured and learning how valuable it is, regardless of how it is *currently* measured.

Image credit: NASA

Advanced Brain Monitoring
B-Alert product

one example for less-obtrusive EEG sensing

InteraXon
Muse product

Photo credits: Angela Harrivel

Harrivel, A., Heinich, C., Milletich, R., Comstock, J., Stephens, C., Last, M., Napoli, N., Abraham, N., Toro, K., Kennedy, K., Pope, A. Comparative EEG Sensor Analysis for Attentional State Prediction. AsMA 2018, Sensors and Symptoms: Research in Physiological Events, May 7, 2018, Dallas, Texas.

Using less-obtrusive sensors

Comparative EEG Sensor Analysis for Attentional State Prediction

Image credit: NASA

State prediction accuracy using a small 4-channel electroencephalography (EEG) device
(among multiple additional physiological sensors)
was found to be:

- comparable to that with a more cumbersome EEG system for channelized attention at 60%,
- and to be only slightly lower for startle at 67%.

These results warrant continued development of real-time classification of AHPLS using less-obtrusive sensors.

Harrivel, A., Heinich, C., Milletich, R., Comstock, J., Stephens, C., Last, M., Napoli, N., Abraham, N., Toro, K., Kennedy, K., Pope, A. Comparative EEG Sensor Analysis for Attentional State Prediction. AsMA 2018, Sensors and Symptoms: Research in Physiological Events, May 7, 2018, Dallas, Texas.

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Angela Harrivel, Chad Stephens, Robert Milletich, Christina Heinich, Mary Carolyn Last, Nicholas Napoli, Nijo Abraham, Lance Prinzel, Mark Motter, Alan Pope. Prediction of Cognitive States during Flight Simulation using Multimodal Psychophysiological Sensing. AIAA SciTech 2017, Applications of Sensor and Information Fusion, January 11, 2017, Grapevine, Texas.

Angela Harrivel, Charles Liles, Chad Stephens, Kyle Ellis, Lance Prinzel, Alan Pope. Psychophysiological Sensing and State Classification for Attention Management in Commercial Aviation. AIAA Science and Technology Forum and Exposition 2016. Oral Session: SEN-02, Novel Sensor Systems and Sensing Techniques II, January 6, 2016.

Angela Harrivel, Daniel Weissman, Douglas Noll, Theodore Huppert and Scott Peltier (2016) Dynamic filtering improves attentional state prediction with fNIRS. Biomed. Opt. Express. 7:3. 979-1002. doi: 10.1364/BOE.7.000979, invited talk at Frontiers in Optics, 2017

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Angela Harrivel, Daniel Weissman, Douglas Noll, and Scott Peltier (2013) Monitoring attentional state with fNIRS. Front. Hum. Neurosci. 7:861.
Stephens, C. L., Scerbo, M. W., and Pope, A.T. Adaptive Automation for Mitigation of Hazardous States of Awareness, Chapter 26 in The Handbook of Operator Fatigue edited by Matthews, Desmond, Neubauer, and Hancock, Ashgate 2012.

Pope A. T., Stephens C. L. (2012) Interpersonal Biocybernetics: Connecting through Social Psychophysiology. In: ACM International Conference on Multimodal Interaction, Santa Monica, CA, USA, 2012. ACM

Pope, A. T.; and Stephens, C. L. (2011) MoveMental: Integrating Movement and the Mental Game. Presented at CHI 2011, Brain and Body Interfaces: Designing for Meaningful Interaction, May 7-12, 2011, Vancouver, Canada.