Human-Robot Interaction in High Vulnerability Domains

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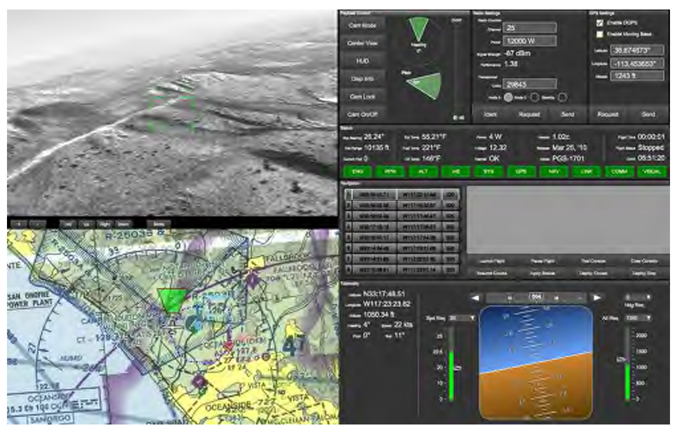
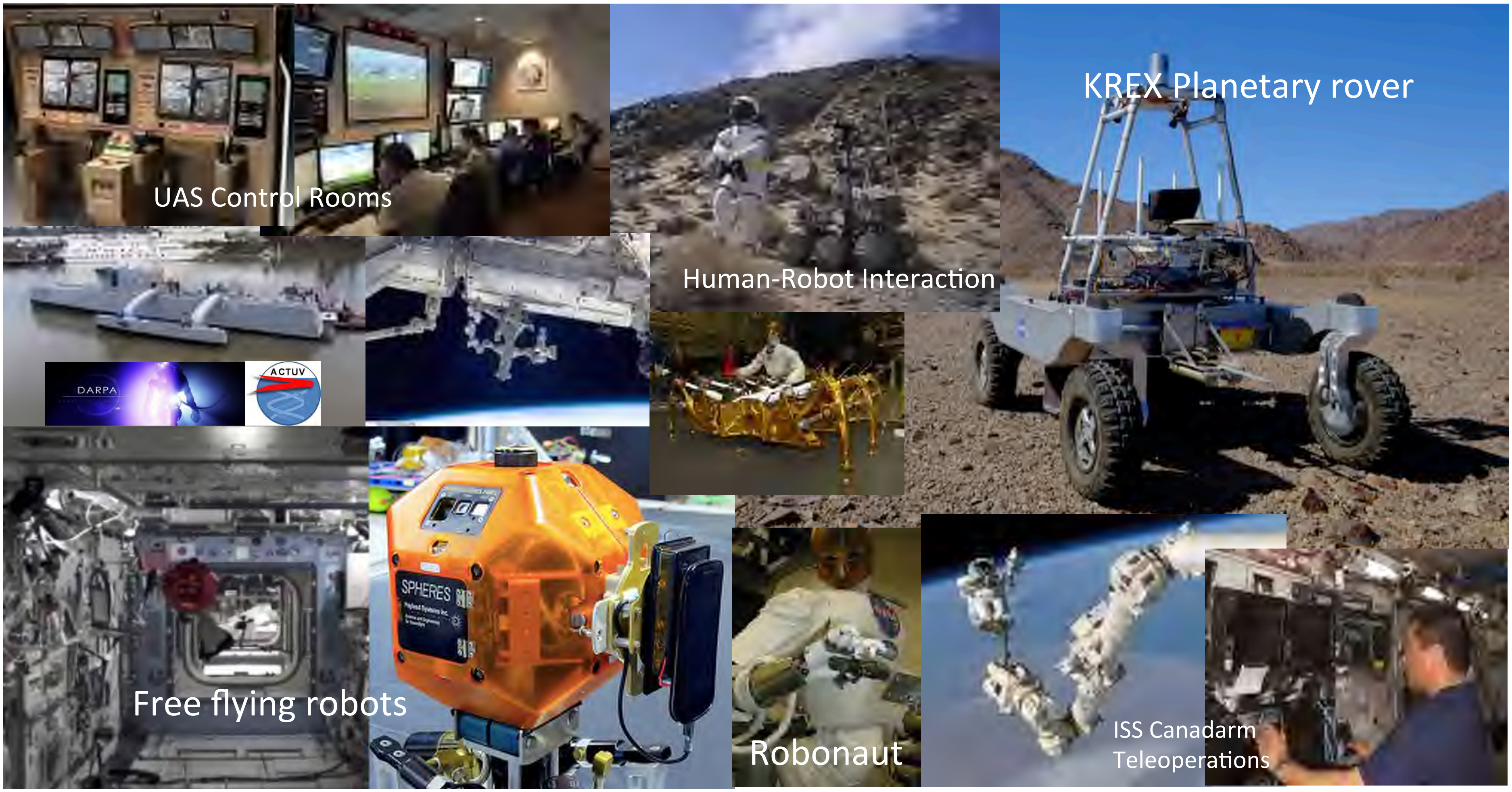
Motivation for the DARPA Research

- How is human workload coupled to the task and to the system via an user interface?
- What are the main drivers of workload that is due to the user interface design?
- What are the main drivers of workload that is due to the user interface design in a high vulnerability domain?
- Can we generate context-free workload drivers?



Some Illustrations



– Complexity of system integration requires that multiple measures and methods be used to predict system vulnerabilities in early designs

Workload and its Sources

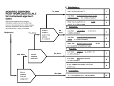
- A set of task demands, the effort to attain the task demands, or the accomplishment of the task demands*; relationship among attention resource demands of tasks and physical task demands**
- Workload is the effort invested by the human operator in task performance; it arises from the interaction between a particular task and the performer
- May be considered physical or cognitive (mental)
  - Cognitive workload can be suboptimal either because it is too low due to low arousal, or too high due to excessive task demands, poor equipment design, or difficult environmental conditions
- An operator's perception of the workload
- Little doubt that workload impacts performance, less agreement on precisely how workload influences performance

*Gartner, & Murphy, 1979; Gawron, 2008; **Moray, 1979, Gopher and Donchin 1986; Sarno & Wickens, 1995

Workload Measures, Workload Drivers

- Measures

  - Primary Task Performance Measures (speed, accuracy, response profiles)



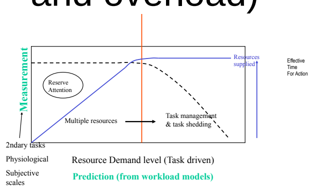
  - Secondary Task Performance Measures measuring residual attention or capacity

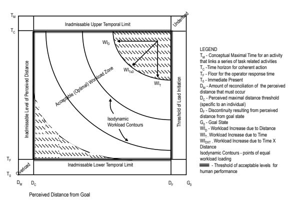
  - Objective Measures (Physiological)
  - Subjective Measures (Ratings)
- Issues

  - Intrusiveness of the measure
  - Context
  - Sensitivity
  - Reliability

  - Diagnosticity
  - Acceptability of relying on one primary measure or one secondary measure
  - Purpose of the workload measure

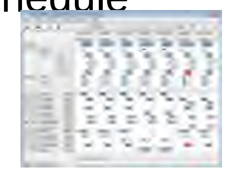
  - Affect, emotional states, and social factors
  - Workload threshold (notions of underload and overload)





- Workload Drivers

  - Task type
  - Task structure
  - Performance Criteria and schedule



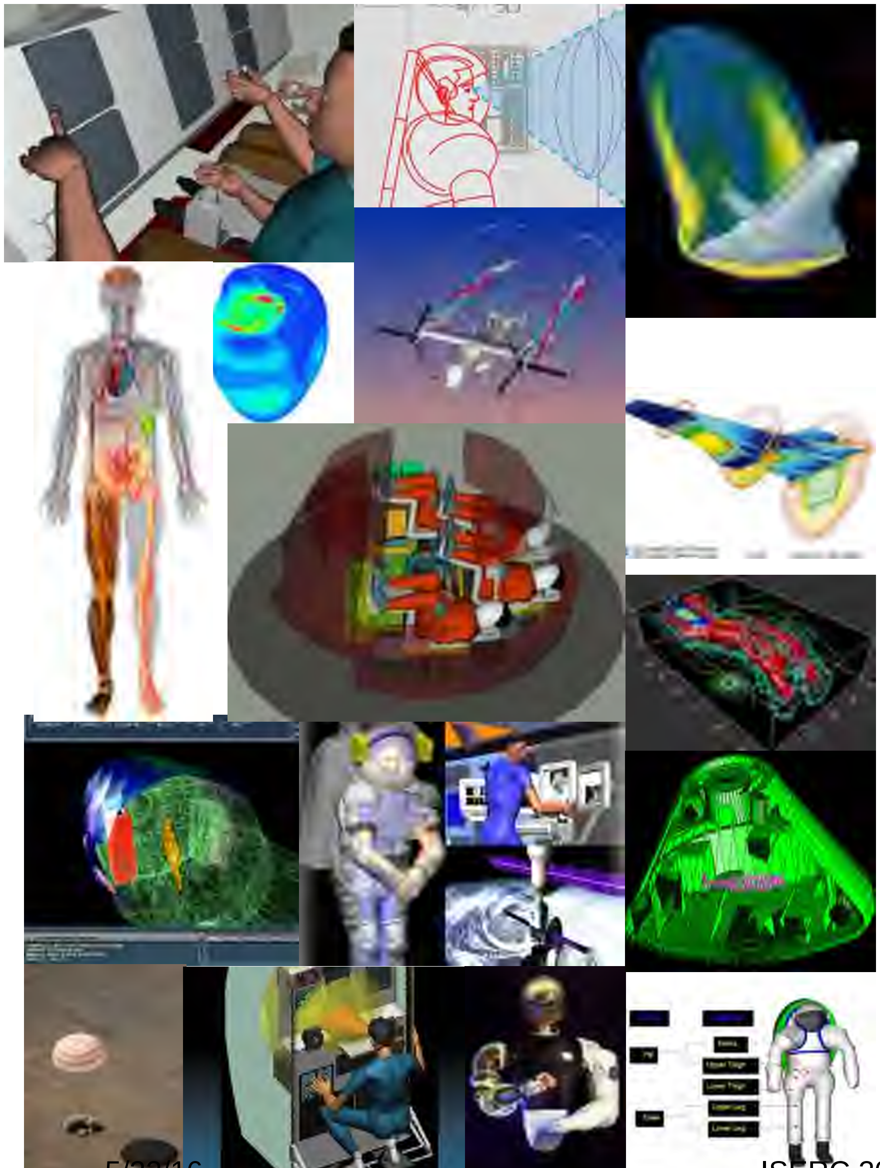
  - Task schedule
  - Rate of presentation / load
  - Complexity of task

  - Variability of task demands
  - Perception of performance
  - Stress (Direct and Indirect)

  - Task duration
  - Levels and type of automation

  - Autonomy and Remote teaming

Tools, Methods and Methodologies: Modeling and Simulation



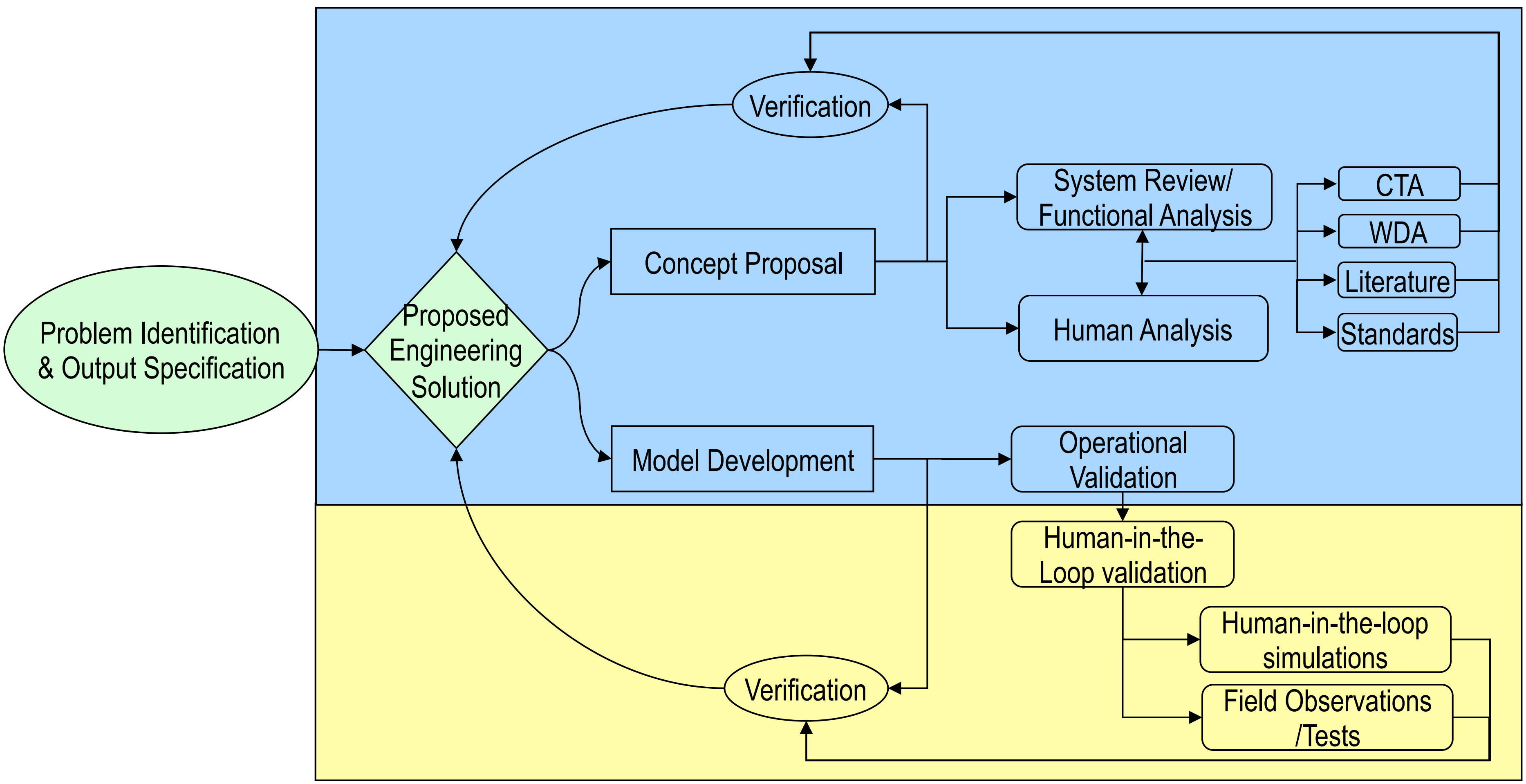
- Modeling and simulation are important tools for comprehensively studying new, complex human-system designs.
- Many different types of capabilities exist:
  - Human behavioral.
  - Human performance.
  - Anthropometric, biomechanic, volumetric.
  - Information processing.
  - Vision, auditory, memory, and other human processes.
  - Task network.
  - Physical structural models – Orion, aircraft, crewstations, other CAD renditions.
  - Airspace system.
  - Airflow and other CFD.
  - Oxygen and blood flow models.

Human Performance Models

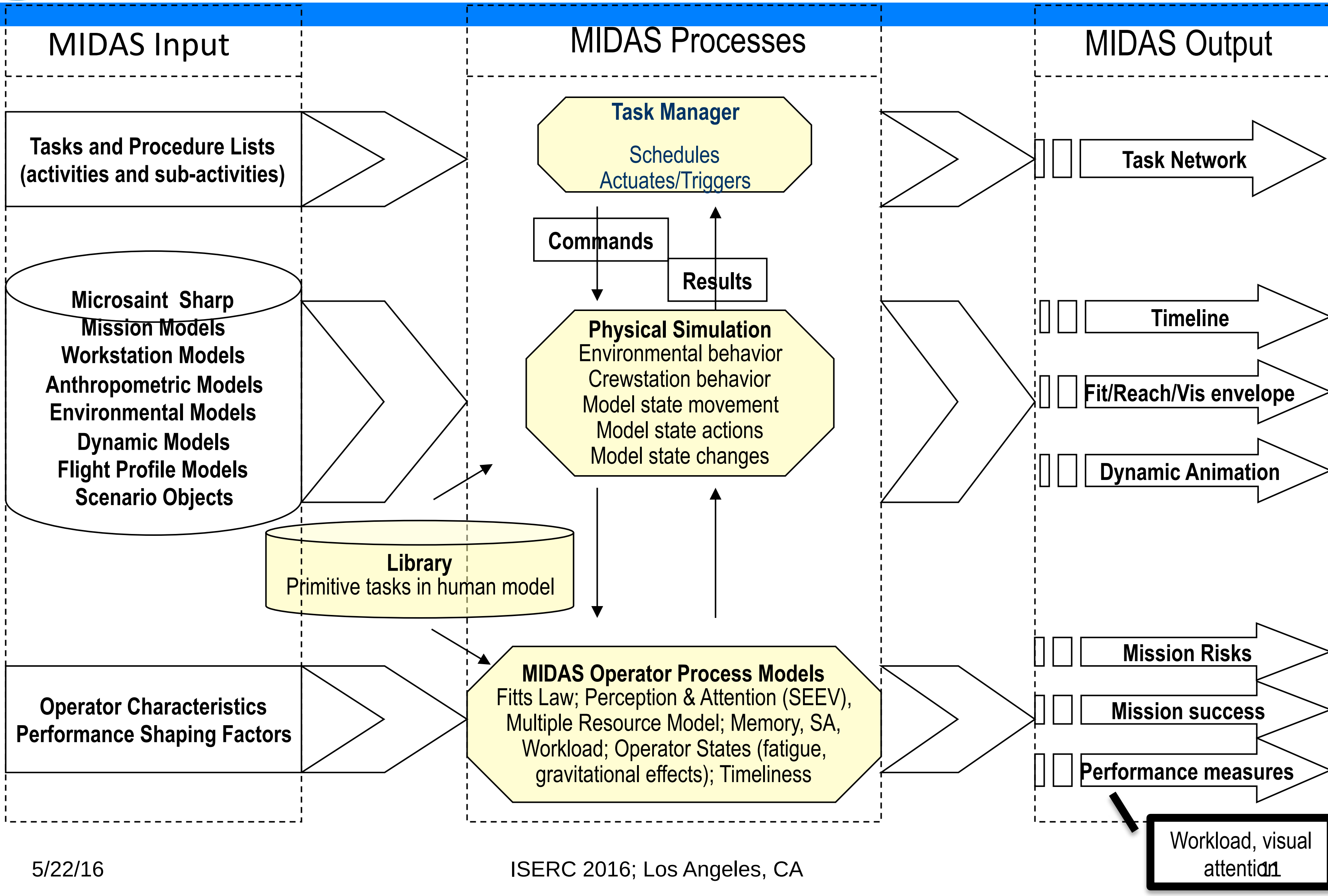
- As systems increase in complexity, there is an increased reliance on the human to *intervene* and correct system performance when systems are not operating correctly.
- Human Performance Models (HPMs) allow system designers the ability to model critical events that cannot be fully studied with empirical simulations.
- Models can be used to provide estimates of human-system performance when the concepts, technologies, or automation are too new, difficult, or dangerous for the human operator.

Gore, B.F. (2010). MIDAS v5: Augmentations, motivations, and directions for aeronautics applications, Human modeling of assistive technologies, Springer Verlag.

System Development Model Process



MIDAS v5 Structures



MIDAS Behaviors

- Breaks tasks down to a set of basic behavioral *primitives*
  - Operator Primitives (OP) and User-defined Primitives (UP)
  - 10 OPs represent non domain-specific human behaviors (e.g., reach, push and release, say message, information seeking)
  - UPs are tailored to the domain (e.g., acquire lead aircraft).
  - In both cases, the Task Analysis / Workload (TAWL [1,2]) is used as the basis for the task loads
    - US military personnel in the Army Light Helicopter Experimental (LHX) Program[1], further tested / validated using Army tank operators[3]

[1] McCracken & Aldrich, 1984; [2] Hamilton & Bierbaum, 1992; [3] Mitchell, 2000

MIDAS Workload Model

- Computes the workload of a multi-tasking operator using the MIDAS behavioral primitives with the Multiple Resources Theory (MRT[1]) when multiple tasks share resources
  – Interference increases with the resource demands of one or both of the time-shared tasks
  – Task pair is penalized according to the conflict between tasks on resource pairs
- Conflict matrix – the amount of conflict between resource pairs across tasks
  1. Combines a conflict matrix and task degradation functions, MIDAS completes the tasks and outputs workload without a limit on task performance, predicts workload spikes, task interference is directly proportional to predicted workload[1]
  2. Combines a conflict matrix with *strategies* that actual operators use when faced with a workload-overload situation, the task management model

MRT Conflict Matrix
Channel modality pairs

		Channel						
		Visual	Auditory	Cognitive Spatial	Cognitive Verbal	Fine Motor	Gross Motor	Vocal
Channel	Visual	0.7 -1.0	0.4	0.6	0.4	0.5	0.2	0.2
	Auditory		0.8	0.4	0.6	0.2	0.1	0.6
	Cognitive Spatial			0.8	0.5	0.5	0.2	0.2
	Cognitive Verbal				0.8	0.2	0.1	0.6
	Fine Motor					0.8	0.6	0.5
	Gross Motor						0.4	0.4
	Vocal							1.0

[1] Wickens, 1984, 2002

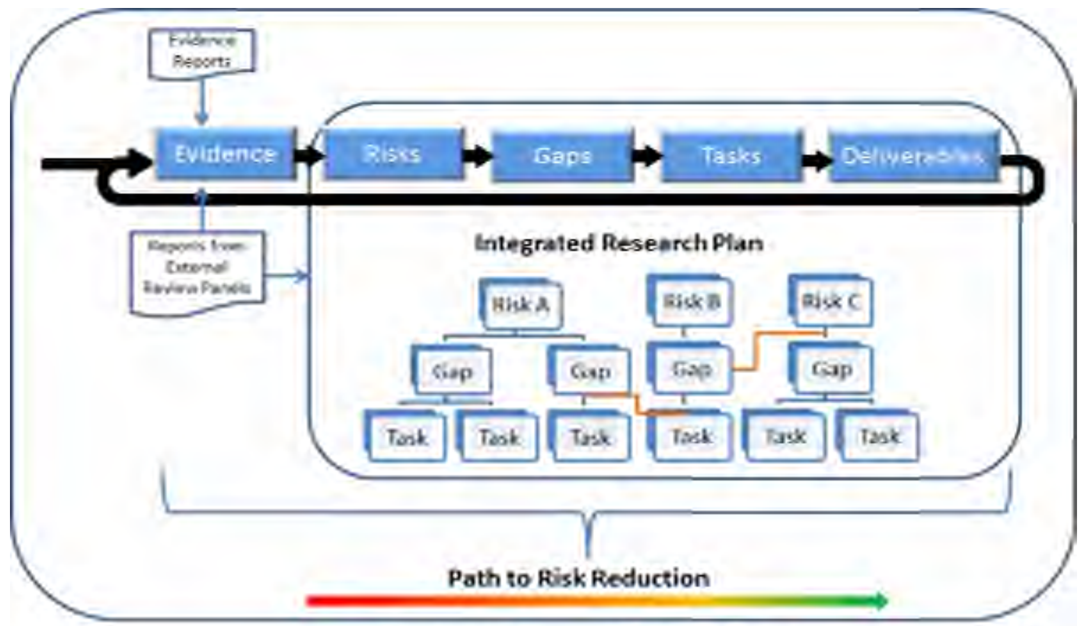
MIDAS Workload Applications

(http://human-factors.arc.nasa.gov/groups/midas/)

- **CSPO MIDAS** (FAA/NASA). Develop valid HPMs of approach & land operations, use these models to evaluate candidate NextGen concepts (Closely Space Parallel Operations, CSPO), develop guidelines regarding flight deck displays and pilot roles and responsibilities; Gore, Hooey, & Foyle (2013).
- **CSATK MIDAS** (FAA-NASA**)**. The MIDAS flight crew completed a number of baseline activities that are required for safely landing on the runway; workload and SA model refined; Gore, Hooey, & Wickens (2012).
- **FAMSS MIDAS** (NASA SHFE). Computational representation of pilot performance in response to advanced caution and warning system concepts being proposed for the Crew Exploration Vehicle display designs using the FAult Management Support System (FAMSS); Gore & McCann (2010).
- **SHUTTLE MIDAS - Initial Cockpit Upgrade for the Space Shuttle Vehicle** (NASA SHFE). Prepared a MIDAS model designed to quantify the workload effects given the changes in the display technology being introduced; Gore & McCann (2009).
- **ISS Experimentation – MIDAS**. (NASA) HPM was developed to test predictions of workload for a complex space-related biological experiment and the risk of error. Two procedural sequences highlighted different human performance profiles that raise risks, or vulnerabilities, in physical, cognitive, and psychomotor performance and task times; Gore & Smith (2002; 2006).

NASA's Human Research Program Mission

- The Human Research Program (HRP):
  - Expands the frontiers of knowledge, capability, and opportunity in space.
  - Investigates and mitigates the highest risks to human health and performance.
  - Provides human health and performance countermeasures, knowledge, technologies, and tools to enable safe, reliable, and productive human space exploration.
  - Implement a focused, applied research program comprised of six elements committed to protecting the health and safety of the crew and ensuring mission success

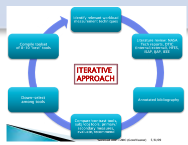


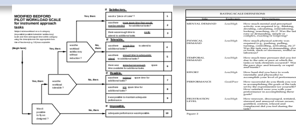
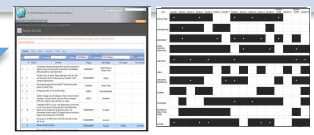
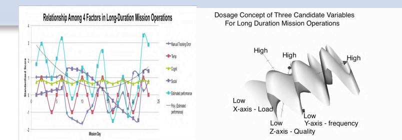
Human Research Roadmap

SHFH Human Performance Modeling of Workload on Long Duration Missions

Workload candidate tools identified and selected

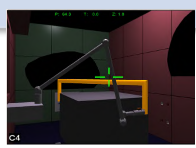
Workload Primer tool created	Workload Measures & Management Workshop completed	Research path identified, PRR documented, Crew notes, debriefs, previous flight data evaluated	Conceptual model on variables likely to impact performance on LDM

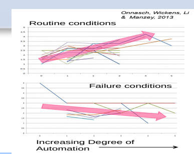


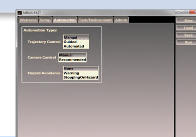




Conceptual model of LDM operations and automation implemented computationally

Research team selected one scenario to exercise the model	Levels and stages of automation in robotic operations	Allows users to evaluate multiple automation conditions to identify those that best support performance	MIDAS-FAST (MIDAS, BORIS, Robotics model)

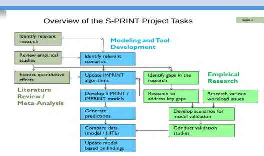


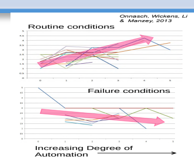


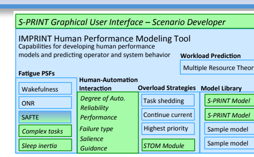


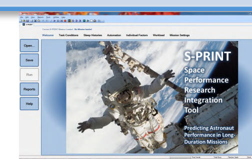

Implement of fatigue model into operational tool for LDM prediction

Research team built off of previous modeling effort to arrive at a tool that could be used by mission planners in their robotics task	develop algorithms or analytic models related to task completion time and accuracy for long duration operations	Include fatigue, automation (MIDAS-FAST), and overload	S-PRINT (BORIS and AutoCAMS)









MIDAS-FAST (2010-2012)

- MIDAS-FAST: Development and Validation of a Tool to Support Function Allocation
  - A. Sebok, Dr. C.Wickens, Dr. M. Gacy, M. Brehon, Dr. N. Sarter, H.Li, Dr. B. Gore, Dr. B. Hooey, Dr. T. Jones
- NASA Human Research Program grant NNX09AM81G

- Develop tools and guidelines that support human performance researchers, mission planners, automation designers, and astronauts in long-duration missions.
- The project addresses aspects of the work environment that are characterized by workload transitions that might occur during long-duration missions.
- Workload transitions are a potential worst-case scenario, in which astronauts performing routine operations or fatigued astronauts experience automation failures that require immediate diagnosis and intervention.

Challenge

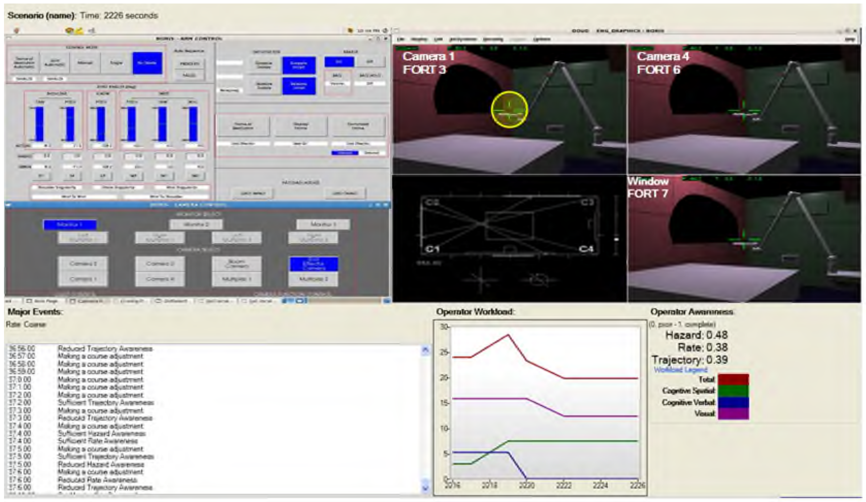
- Robotics systems are useful and necessary but are typically complex and difficult to use
  - Camera views, control dynamics
  - Need to monitor multiple moving parts for potential collisions
  - Monitor and avoid joint angle singularities
- Automation can potentially support better operator performance
  - BUT: Automation can fail, resulting in worse performance
- SO: How do we design these systems to support performance?

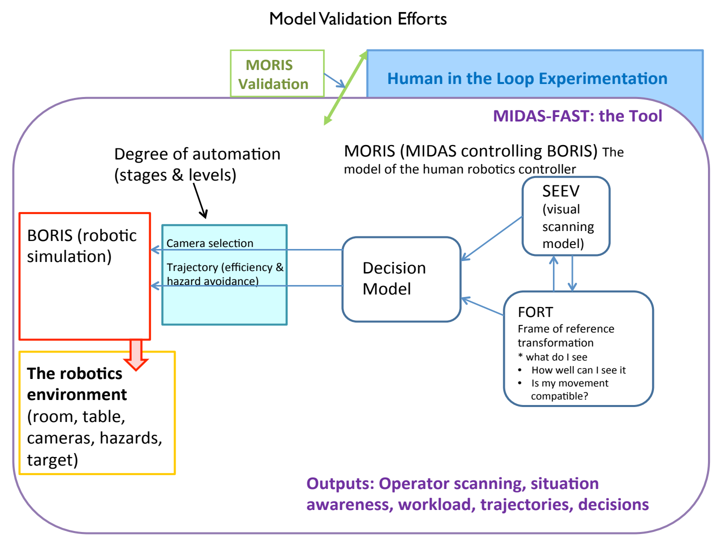
Solution to Address SHFH Risks

- Develop and empirically validate
  1. A model of the robotics operator and
  2. A model and simulation based tool to predict human performance in complex robotic systems
- Allows users to evaluate multiple automation conditions to identify those that best support performance
- MIDAS-FAST includes:
  - MIDAS * (Man-machine Integration Design and Analysis System) human performance modeling environment
  - Robotics operator model (MORIS)
  - BORIS** (Basic Operational Robotics Instructional System) robotic simulation
  - A user interface
  - Animations (Microsaint Sharp) and data files

- ***NASA ARC MIDAS POC Brian Gore**
- ****NASA JSC RMS Trainer**

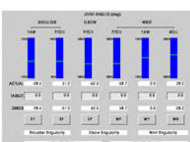
MIDAS – FAST Experiments



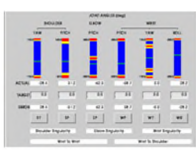


Experiment 1 – Compare different interface designs

- Updated Angle information
- Updated and integrated angle information
- Tactile presentation

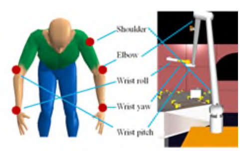


Original



1) Improved

2) (integrated)



3) Tactile Mappings

- All were improvements of the standard BORIS interface
- Compared all 3 types (within subjects design) in terms of
  - Response times (better for integrated and tactile than improved
  - Frequency of errors (singularities – most reduced in tactile)
  - Subjective preference (split between integrated and tactile)

Experiment 2 – Validation of Failure Response

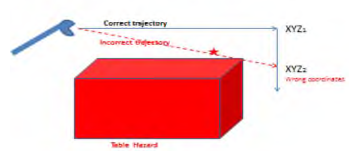
MICHIGAN
Fluency of automation failure response when

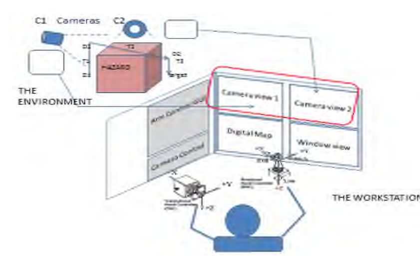
a. Wrong coordinates were given (trial 6, AC and AG conditions only). Greater tracking error
b. Protective warning fails to alert. More hazard violations

MORIS
SEEV-assumed increase in complacency with increasing stage of automation.
Reduced scanning to 2-mon display where evidence for automation failure is uniquely provided.

SEEV parameters predicted a-priori

The Automation Failure





****Research provided NASA with a validated tool that can support automation systems designers developing more effective function allocation strategies for HAI in robotic system design.

Conclusions and Items for Discussion

- How is human workload coupled to the task and to the system via an user interface?
  - An example of one robotic operation in space was presented to illustrate a candidate approach of using behavioral primitives with base levels of workload applied in the context of "advanced" interface designs
- What are the main drivers of workload that is due to the user interface design?
  - Interface characteristics drive basic human processes that are tied to empirically determined workload
  - Are there different approaches that should be considered?
- What are the main drivers of workload that is due to the user interface design in a high vulnerability domain?
  - Interface characteristics based on **context** drive basic human processes that are tied to empirically determined workload; can we use tactile drivers for interface designs?
- Can we generate context free workload drivers?
  - Still remains a question

Space Operations and Human-Robot Interaction: A High Vulnerability Domain