Linking Real-time Operator Behavior to Subjective Workload Ratings: Houston, We Have a Connection!

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Lessons Learned from Apollo 11
Operations: Workload

- Apollo Operational Workload Assessment:

"***The most difficult part [of the entire mission] from my perspective, and the one that gave me the most pause, was the final descent to landing***"

"far and away the most complex part of the flight"

"systems were very heavily loaded at that time"

"the unknowns were rampant"

"there were just a thousand things to worry about… It was hardest for the system and it was hardest for the crews to complete that part of the flight successfully"

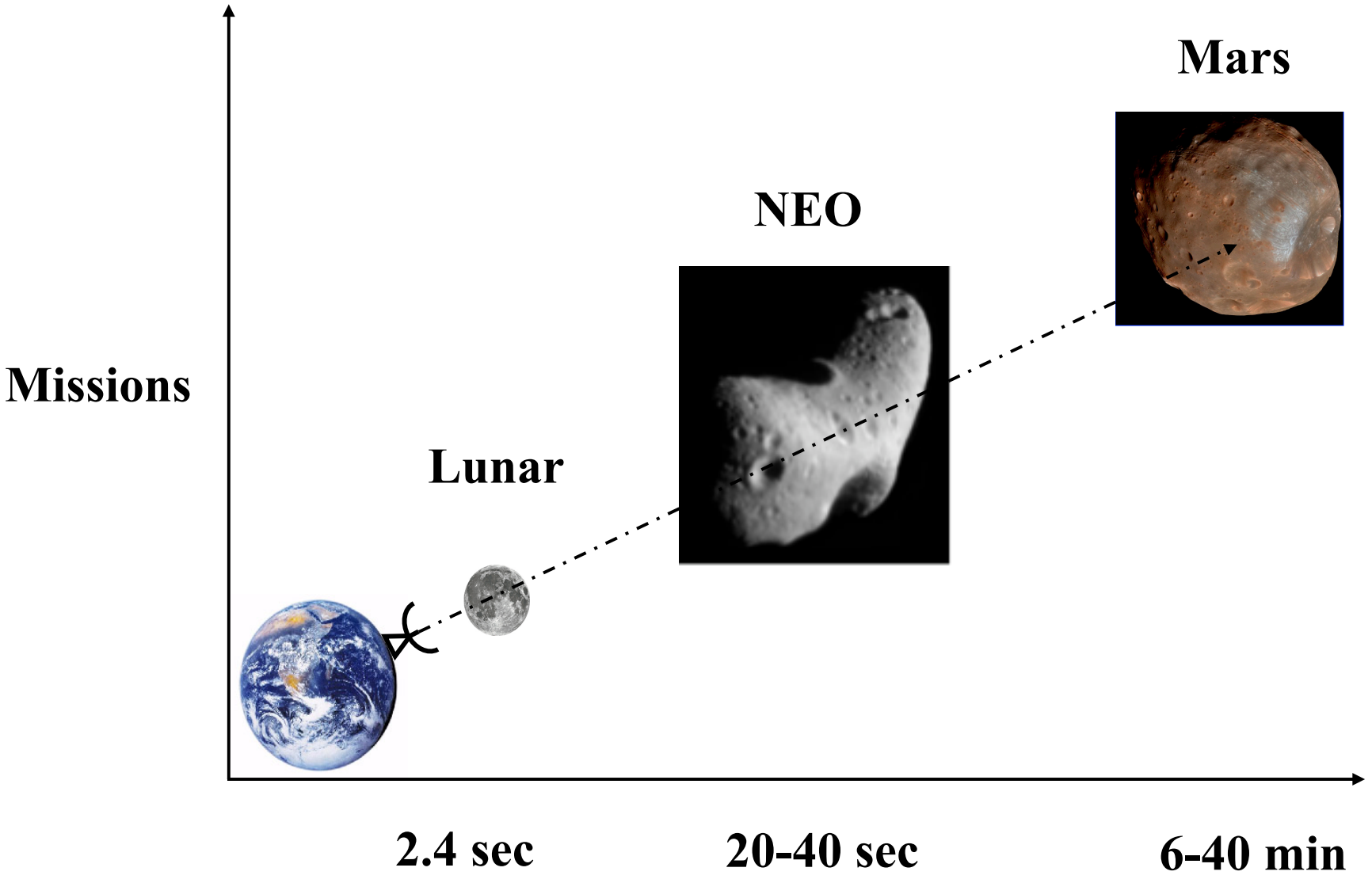
- Neil Armstrong, September 2001

Apollo 11 LEM Descent and Landing Operations

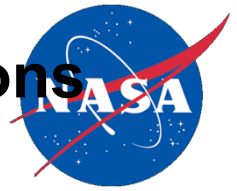
- 102:38:**26** Armstrong: (With the slightest touch of urgency) Program Alarm.
- 102:38:**30** Armstrong: (To Houston) It's a 1202.
- 102:38:**42** Armstrong (on-board): (To Buzz) What is it?
- (To Houston) “Give us a reading on the 1202 Program Alarm.”
- 102:38:**53** Duke: Roger. We got you...(With some urgency in his voice)

  “We're Go on that alarm.”

Round-trip Communications Delays



Operations Concepts for Deep-Space Missions



- Crewed missions beyond the Earth-Moon system
  - **Speed-of-light limitations break real-time contact with the ground**
    - Variable communications delays degrade and/or prevent real-time crew-ground collaboration
- Broad new requirements to:
  - Enhance onboard capability to process and integrate mission-relevant information
  - Enhance onboard capability to make time-critical decisions

- **Challenge:**
  - Enhance onboard capabilities while still keeping crew workload within manageable limits

Operations Concepts for Deep-Space Missions

- ***Real-time workload assessment ("redlining")***
  - **Support:**
    - Adaptive information displays
    - Adjustable automation

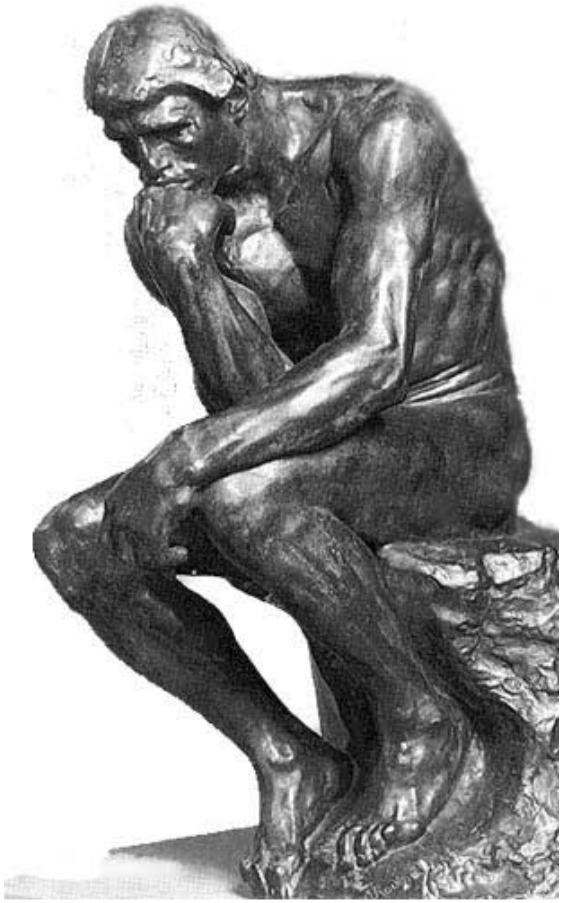
- Real-time analysis of crew information acquisition and commanding activities

Workload Assessment

- Current standard operating procedure to assess workload:
  - Run human in the loop simulation of operational concept
    - Collect workload ratings after trial is completed
    - Ask participants to integrate their experience throughout trial into a single numeric assessment

- How can we assess workload in real time?
  - One approach:
    - Look to see if we can connect current workload assessment techniques with actual operator behavior
      - *What aspects of operator task performance correlate with workload?*

- Make real-time workload assessments by analyzing those behaviors in real time



Workload assessments during spacecraft operations

- Evaluation of an Advanced Caution and Warning system for Orion Crew Exploration Vehicle

Primary Flight Display Task

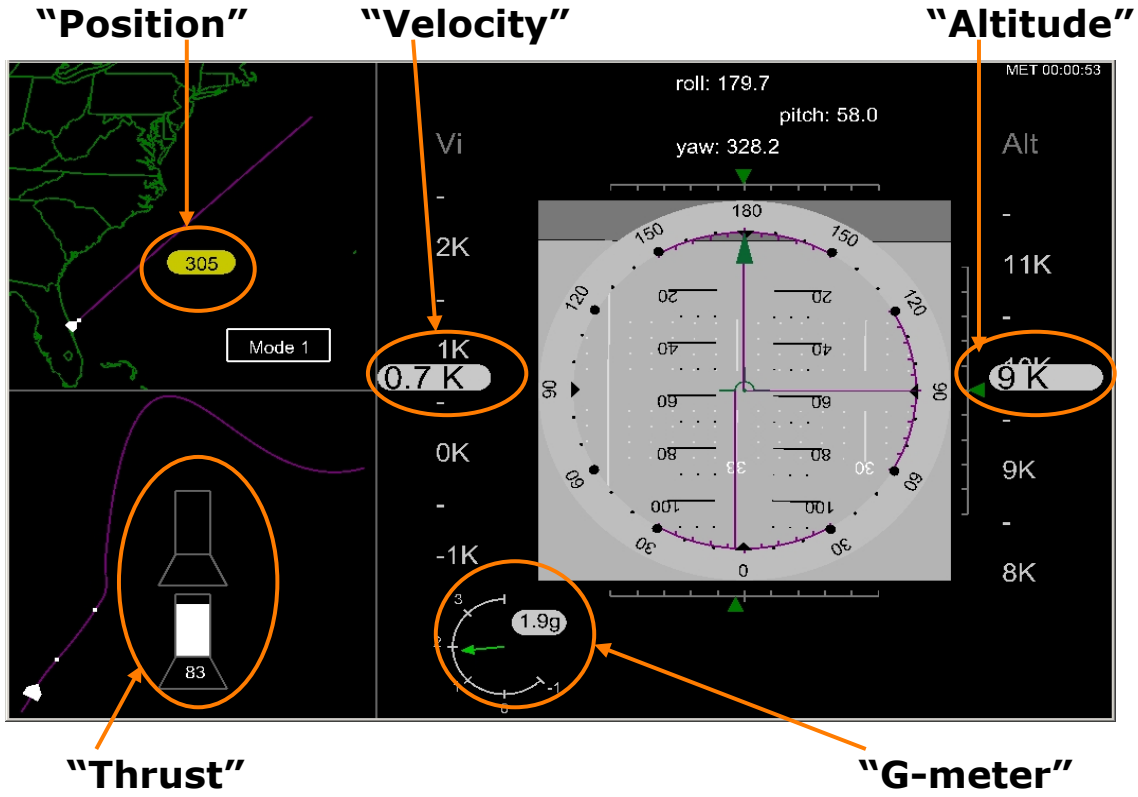
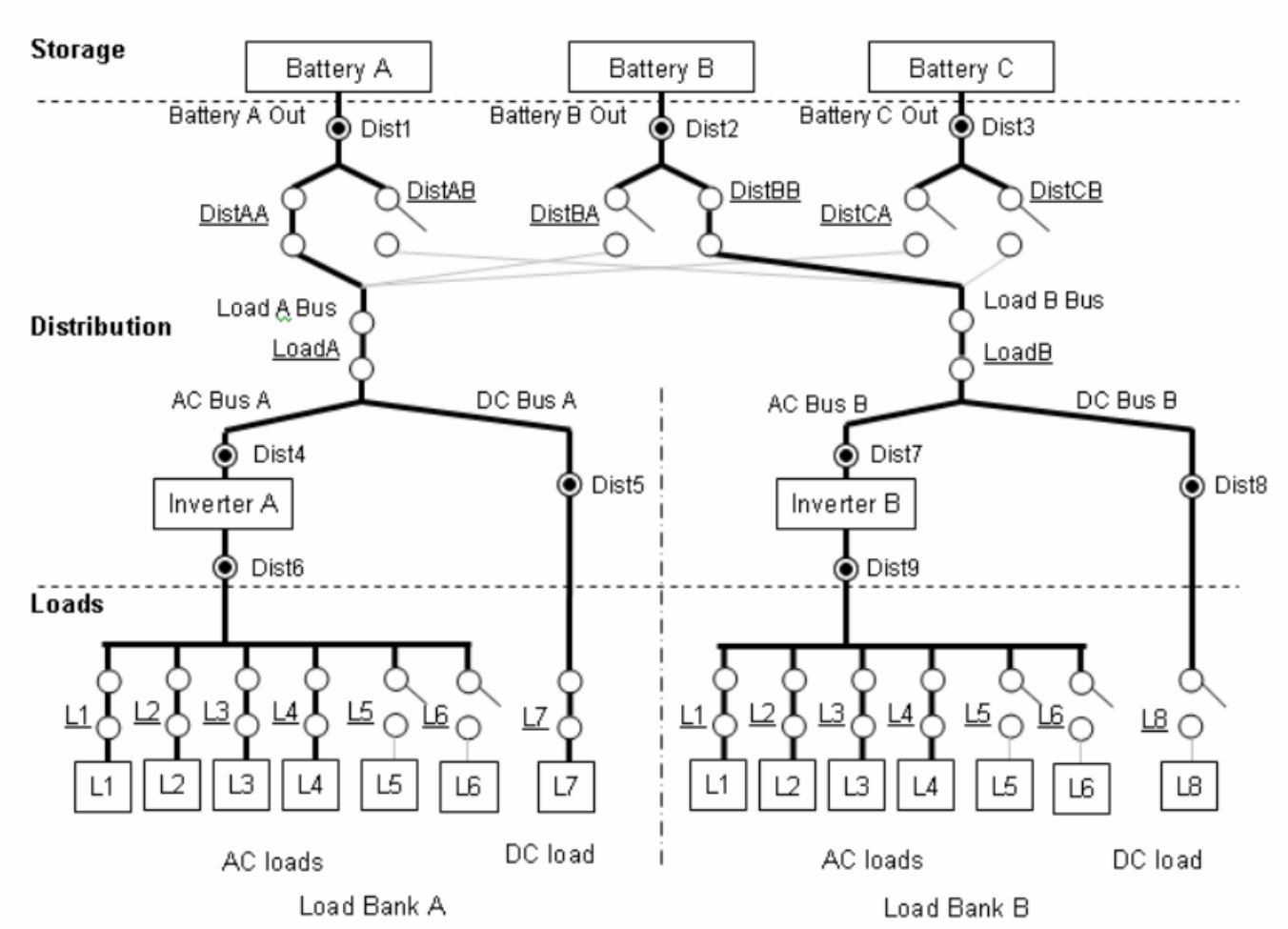


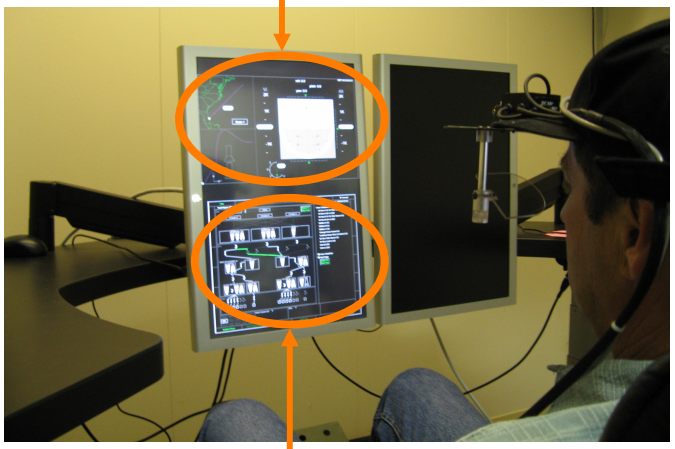
Figure XX. PFD and associated flight task. The upper left portion contained a notional horizontal situation display; the bottom left portion, a notional vertical situation display; the right side, an attitude director indicator and associated vehicle parameters. Every 20 sec, on average, one of the circled parameters turned yellow. Participants were instructed to make a speeded response to the color change by touching the location of the parameter on the screen and calling out the parameter 's name.

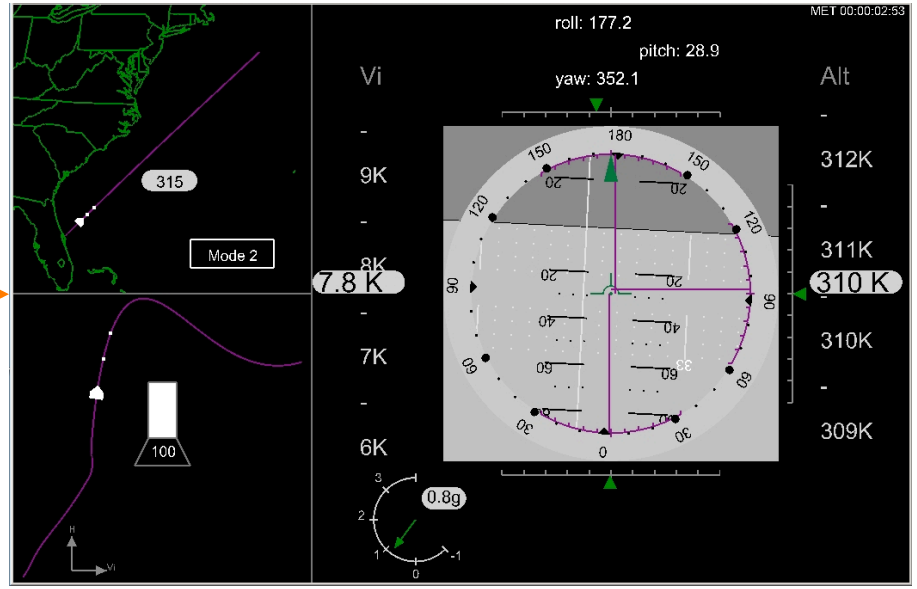
Electrical Power System Schematic



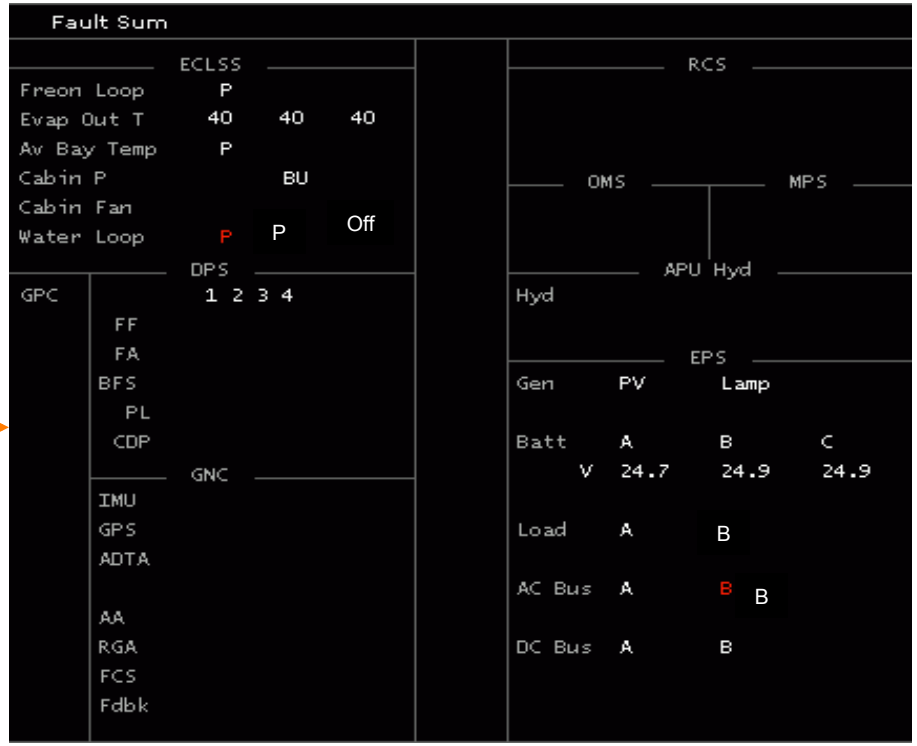
Nominal Display Configuration

Primary Flight Display





Health Management Display



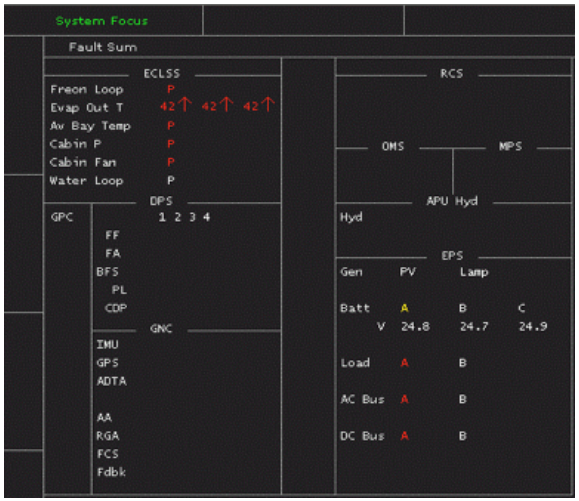
Study Methodology

Scenario #	Malfunction(s)
5	DistAA sw mismatch (restorable)
6	DistBB sw mismatch (restorable)
7	Battery A volts low
8	Battery B volts low
9	Inverter A failure
10	Inverter B failure

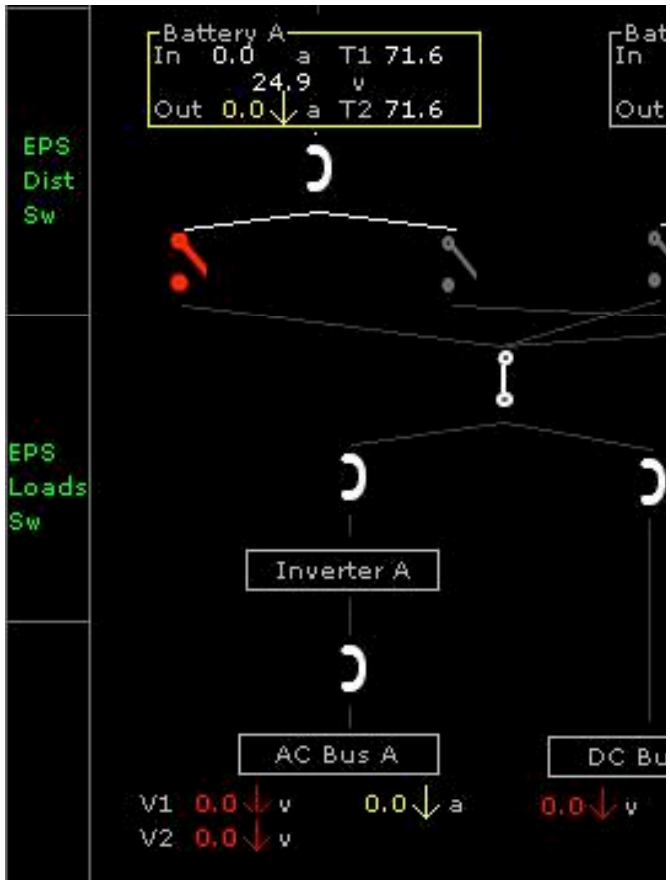
- 8 participants
- 4 participants completed each scenario in table
- Following end of each trial, Bedford and TLX workload ratings were collected
- One participant took over 8 minutes to complete one scenario
- Removing that run left 23 to analyze

Fault Management Task: Diagnosis Phase

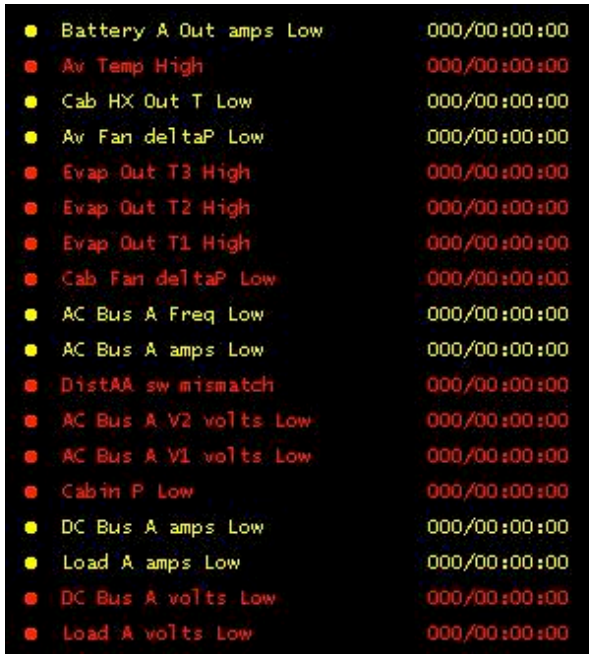
Fault Sum Display



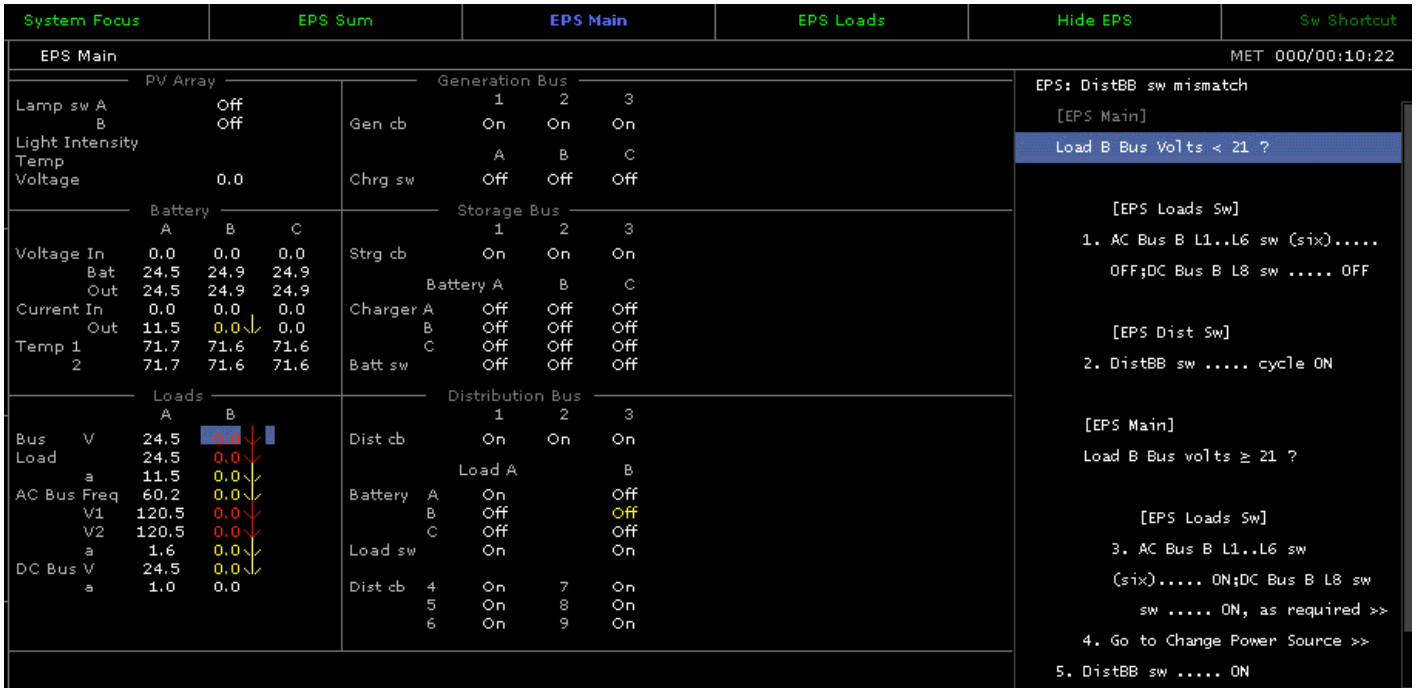
EPS Sum Display



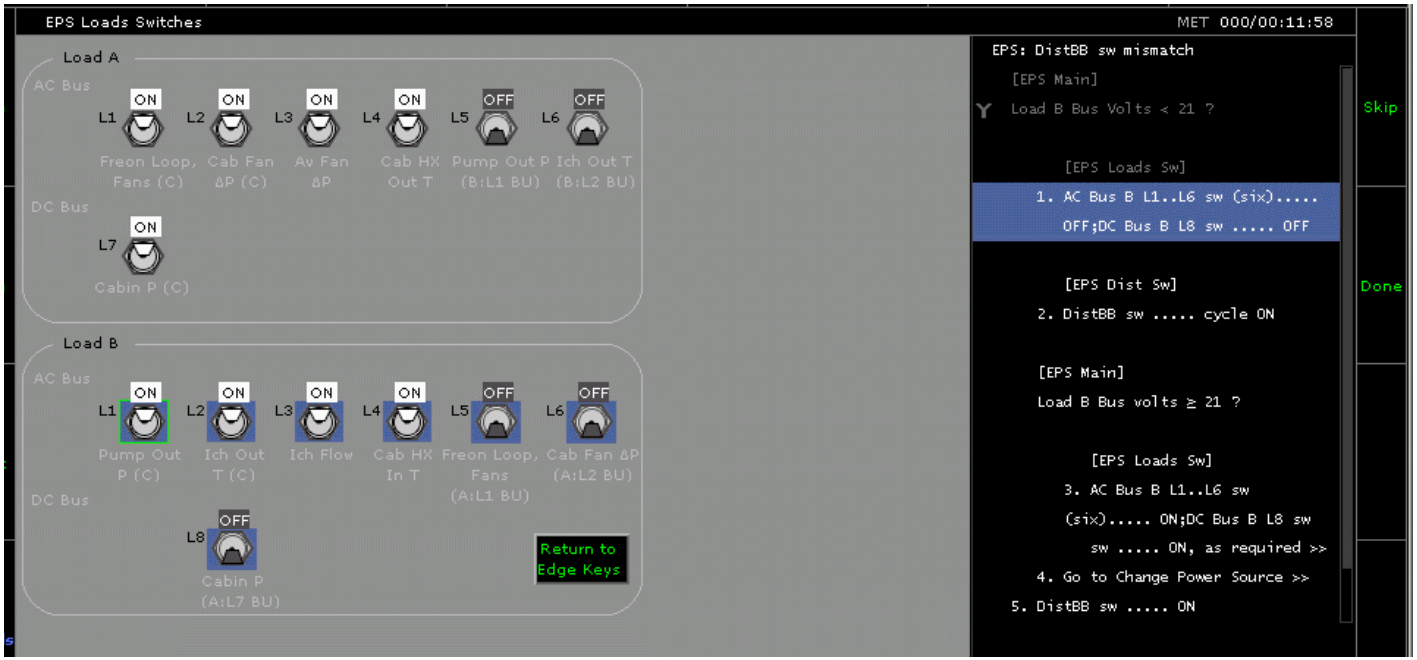
Fault Log Display



Fault Management Task: Start of Recovery Phase

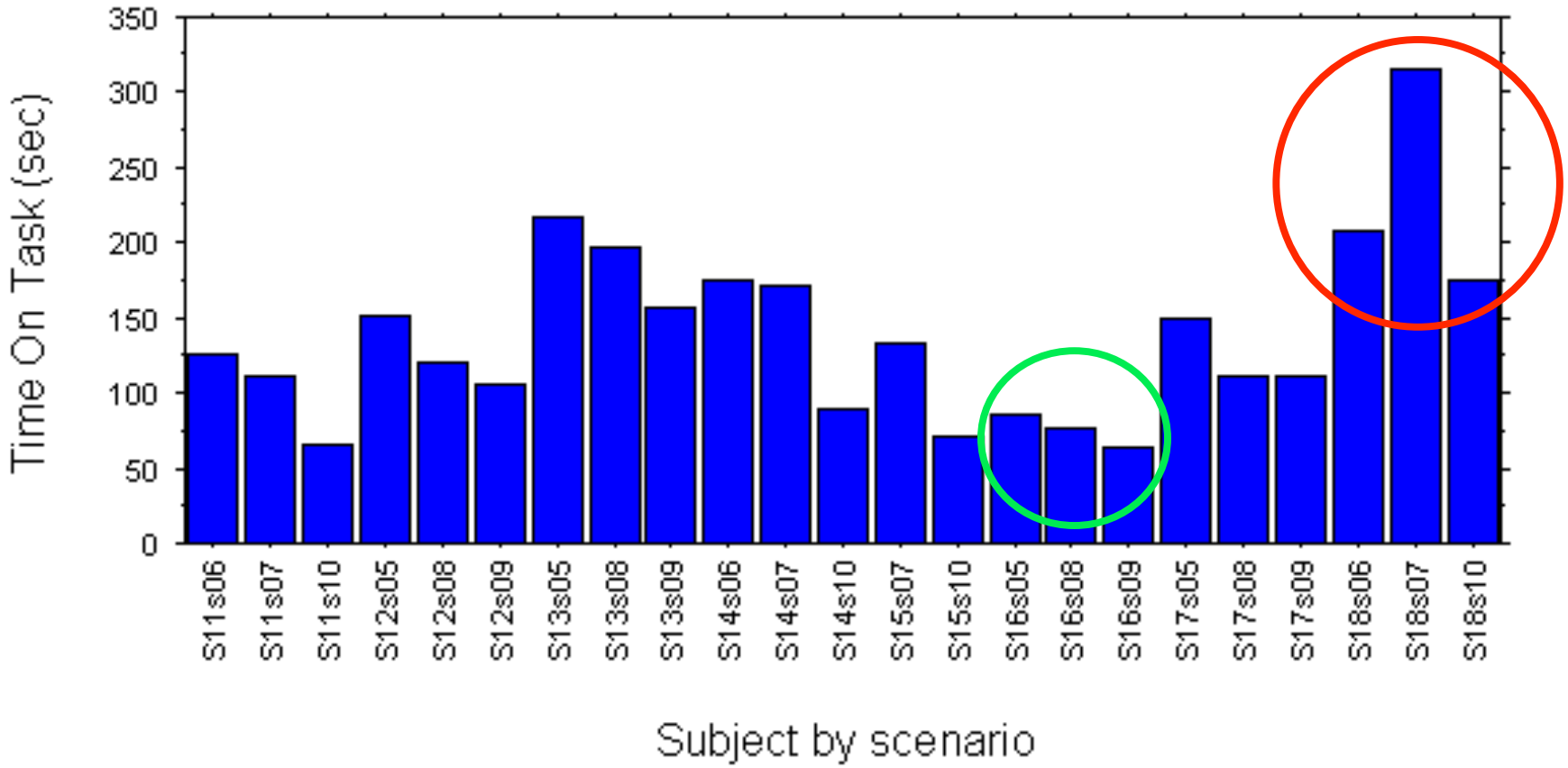


Check Procedure



Reconfiguration Procedure

Results Summary

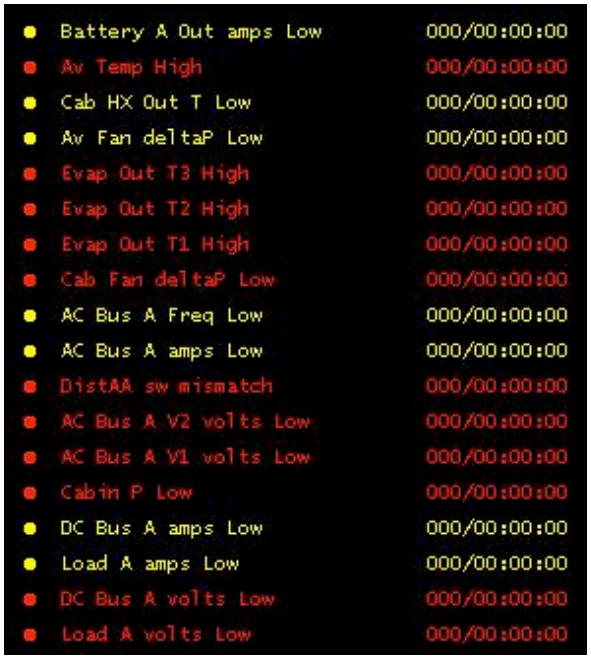


Results Summary

		Diagnosis	Recovery Acaws	Recovery Checklist	Recovery Total	Total (*)
Number of Fixations	Fast	74	105.09	45.63	150.72	282.81
	Slow	130.33	155.91	75.25	231.16	458.83

- Correlation between total number of fixations and task completion time: .914
- Fixation quantity, not individual fixation duration, separates efficient from less efficient operators

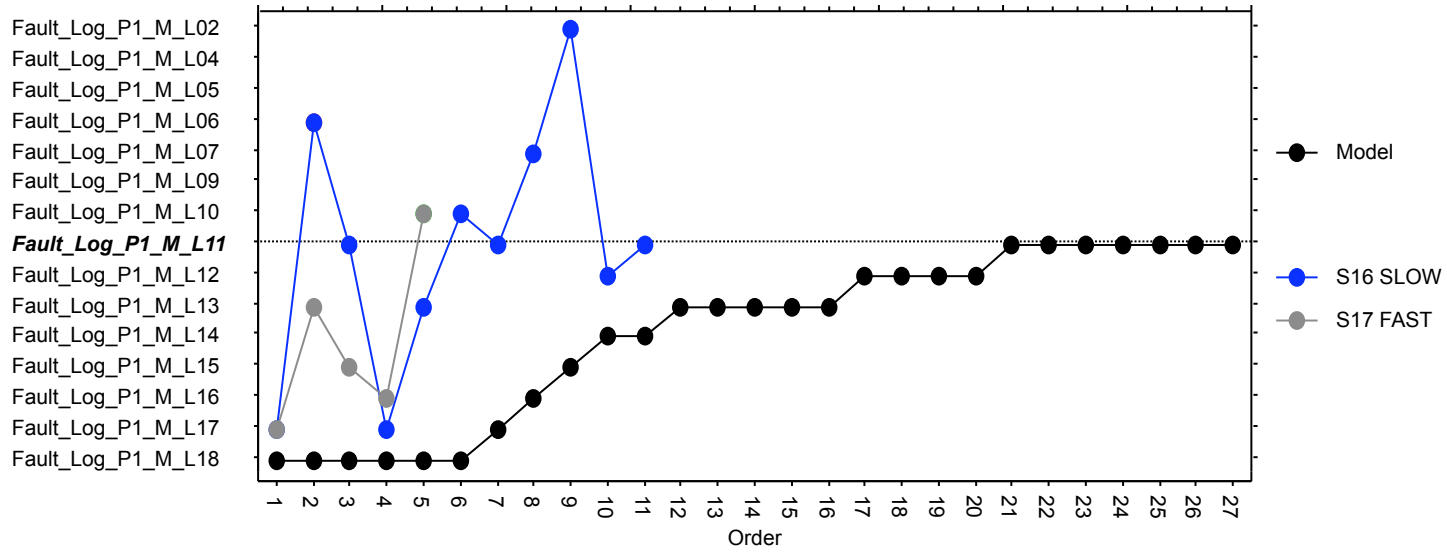
- Another aspect of fixation behavior separating efficient from inefficient operators:
- Probability of re-fixating on an element previously fixated
    - Example: Fault Log
        - 52% of fixations to Fault Log were revisits for Slower operators
        - 37% of fixations to Fault Log were revisits for Faster operators, $p < .05$ by Chi Square Test



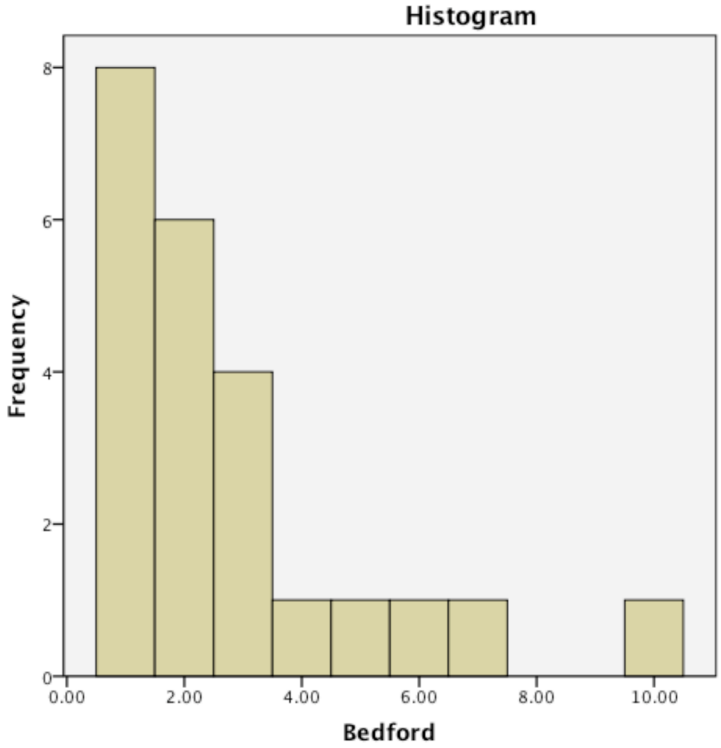
Root Cause (L11)

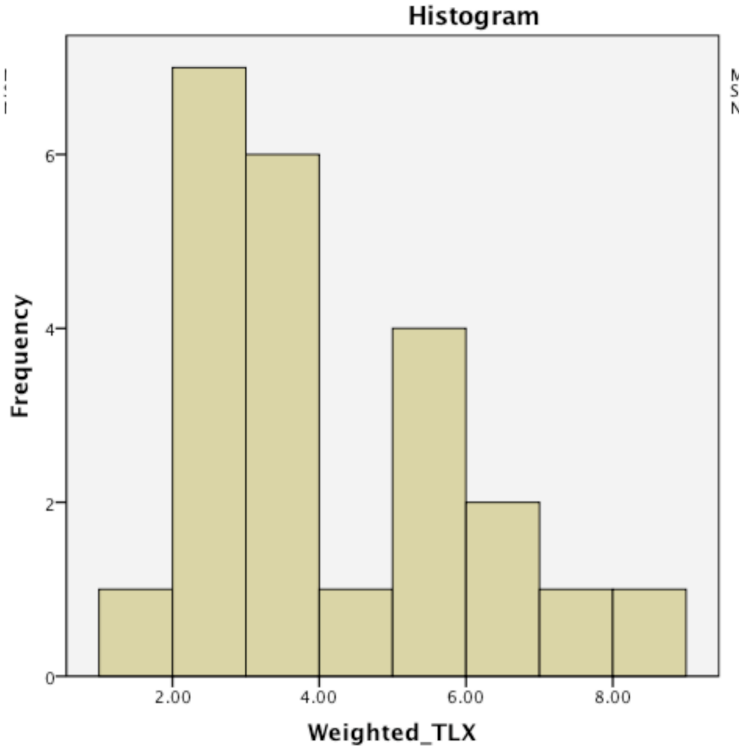
Battery B Out amps Low	000/00:00:50
Cab HX In T Low	000/00:00:50
Ich Flow Low	000/00:00:50
Ich Out T Low	000/00:00:50
AC Bus B Freq Low	000/00:00:50
AC Bus B amps Low	000/00:00:50
Pump Out P Low	000/00:00:50
DistBB sw mismatch	000/00:00:50
AC Bus B V2 volts Low	000/00:00:50
AC Bus B V1 volts Low	000/00:00:50
Load B amps Low	000/00:00:49
DC Bus B volts Low	000/00:00:49
Load B volts Low	000/00:00:49
Load B Bus volts Low	000/00:00:49

ROI=Fault_Log	5.77 sec	5.00 sec	10.73 sec	3.86 sec	17.39 sec



Results: Workload





- Bedford: Median = 2.00 (SD = 2.29)
- TLX: Median = 3.65 (SE = 1.84)

Correlations

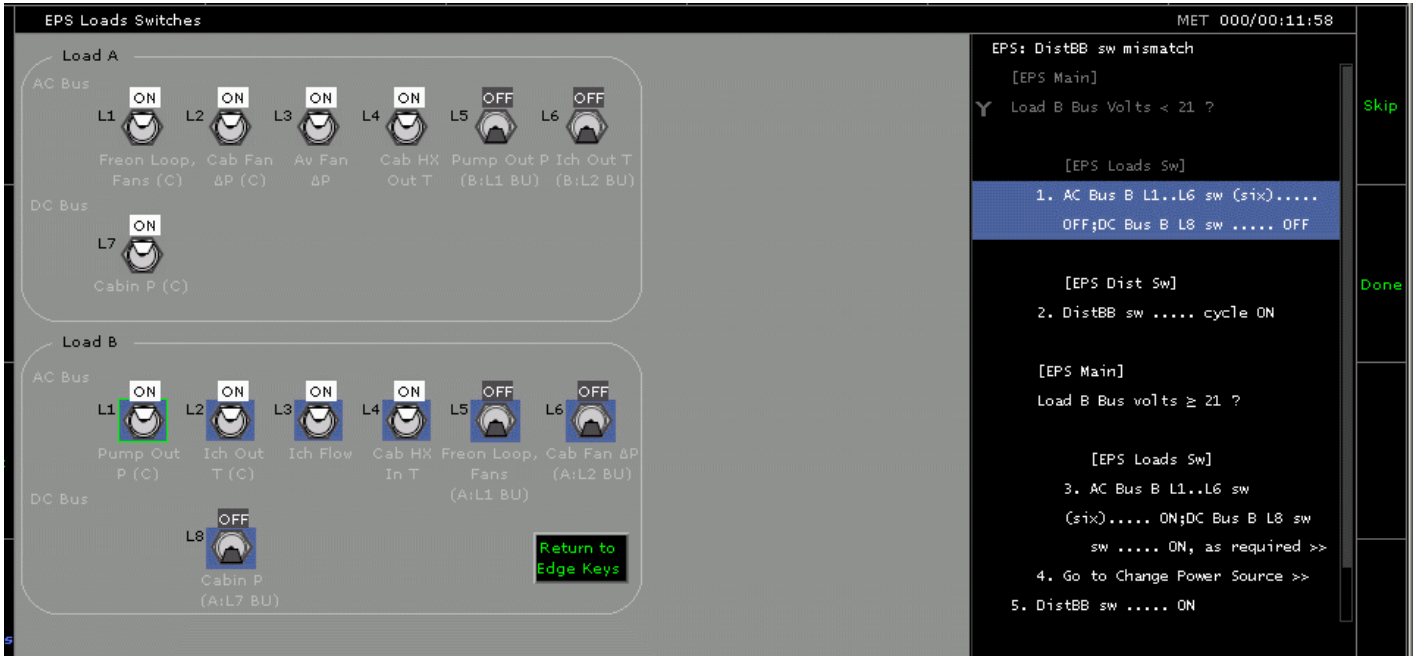
		Bedford	NASA_TLX	N_Fix Total	Time_On_Task Total
Bedford	Pearson Correlation	1	.561**	.497*	.694**
	Sig. (2-tailed)		.005	.016	.000
	N	23	23	23	23
NASA_TLX	Pearson Correlation	.561**	1	.586**	.549**
	Sig. (2-tailed)	.005		.003	.007
	N	23	23	23	23
N_Fix_Tot	Pearson Correlation	.497*	.586**	1	.934**
	Sig. (2-tailed)	.016	.003		.000
	N	23	23	23	23
Time_On_Tast_Tot	Pearson Correlation	.694**	.549**	.934**	1
	Sig. (2-tailed)	.000	.007	.000	
	N	23	23	23	23

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

- Workload correlates significantly with number of fixations on the fault management task

		Revisits Checklist_Index	Revisits Fault_Log	Sum_Revisits Diagnosis	Revisits Checklists	Sum_Revisits Total
Bedford	Pearson Correlation	.058	.158	-.040	.588**	.369
	Sig. (2-tailed)	.794	.473	.855	.003	.083
	N	23	23	23	23	23
NASA_TLX	Pearson Correlation	.032	.195	-.117	.439*	.218
	Sig. (2-tailed)	.886	.372	.596	.036	.318
	N	23	23	23	23	23



• Workload correlates significantly with *refixation frequency* to procedures in Electronic Procedure Viewer

Summary & Conclusions

- What aspects/elements/characteristics of real-time operator activity are captured by subjective end-of-trial omnibus workload ratings is starting to be revealed
- Preliminary results suggest that workload is tied to both number of fixations and refixation frequency to text elements on the Electronic Procedure Viewer
- Future research needed to abstract what particular cognitive resource is being indexed by refixation behavior
- Online analysis of oculomotor behaviors such as fixation quantity and refixation frequency offers promising tool for
    - non-invasive evaluation and assessment of operator workload in real time
    - training strategies