# TIM$_E$TIM

# The Autonomous Mission Operations Project:

# Impacts of Time Delay on Human Spaceflight Mission Operations

Jeremy Frank

NASA Ames Research Center

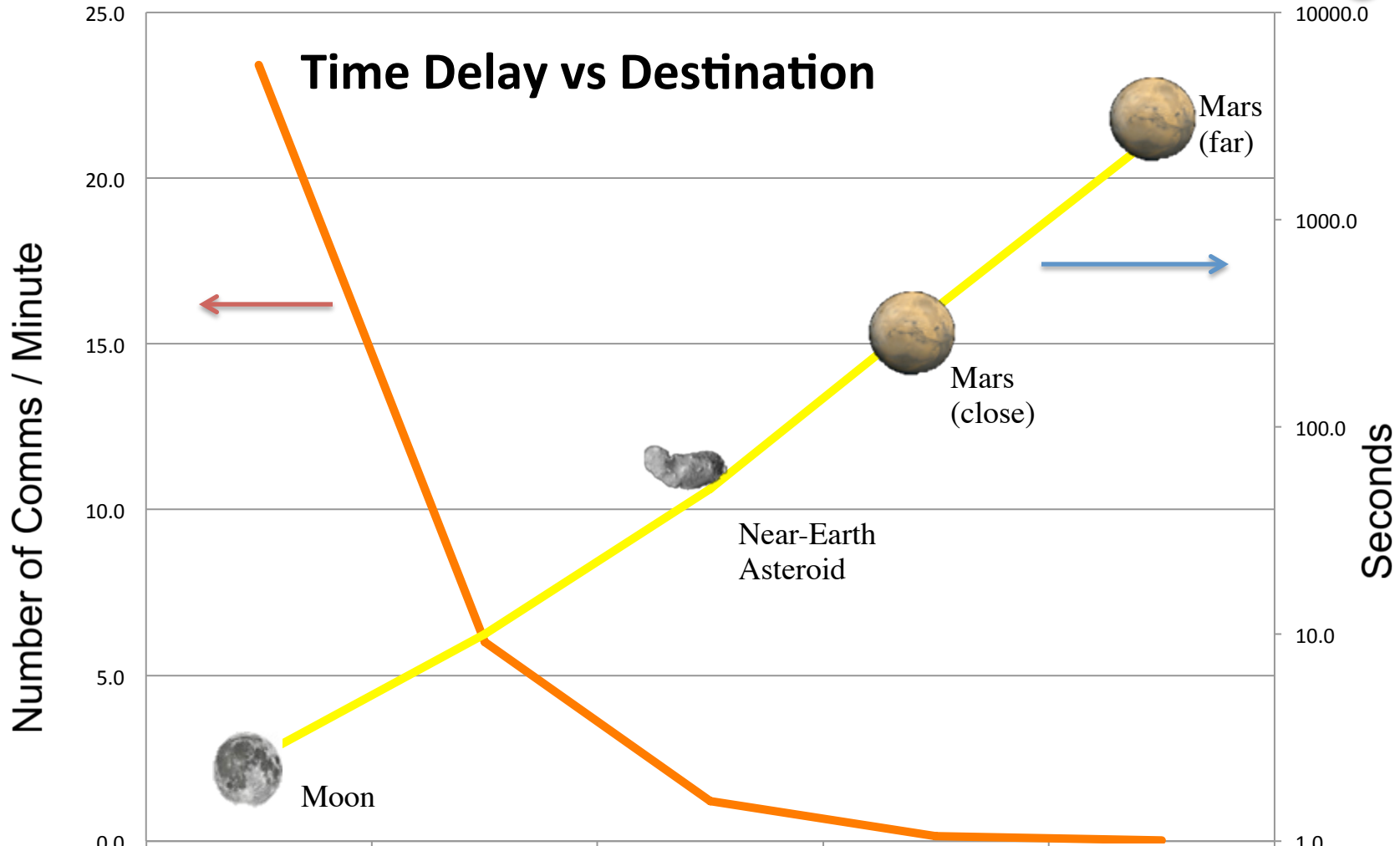
# Outline

- AMO Overview
  - Purpose
  - Timeline
  - Experiment Design
  - Baseline and Mitigation Configurations
- Measurements
  - Subjective Measurements
  - Objective Measurements
- Analysis
  - Simulation Fidelity
  - Workload
  - Coordination
  - Task Completion
  - Communications Analysis
- Conclusions and Future Work

# Outline

- AMO Overview
  - Purpose
  - Timeline
  - Experiment Design
  - Baseline and Mitigation Configuration
- Measurements
  - Subjective Measurements
  - Objective Measurements
- Analysis
  - Simulation Fidelity
  - Workload
  - Coordination
  - Task Completion
  - Communications Analysis
- Conclusions and Future Work

# Purpose



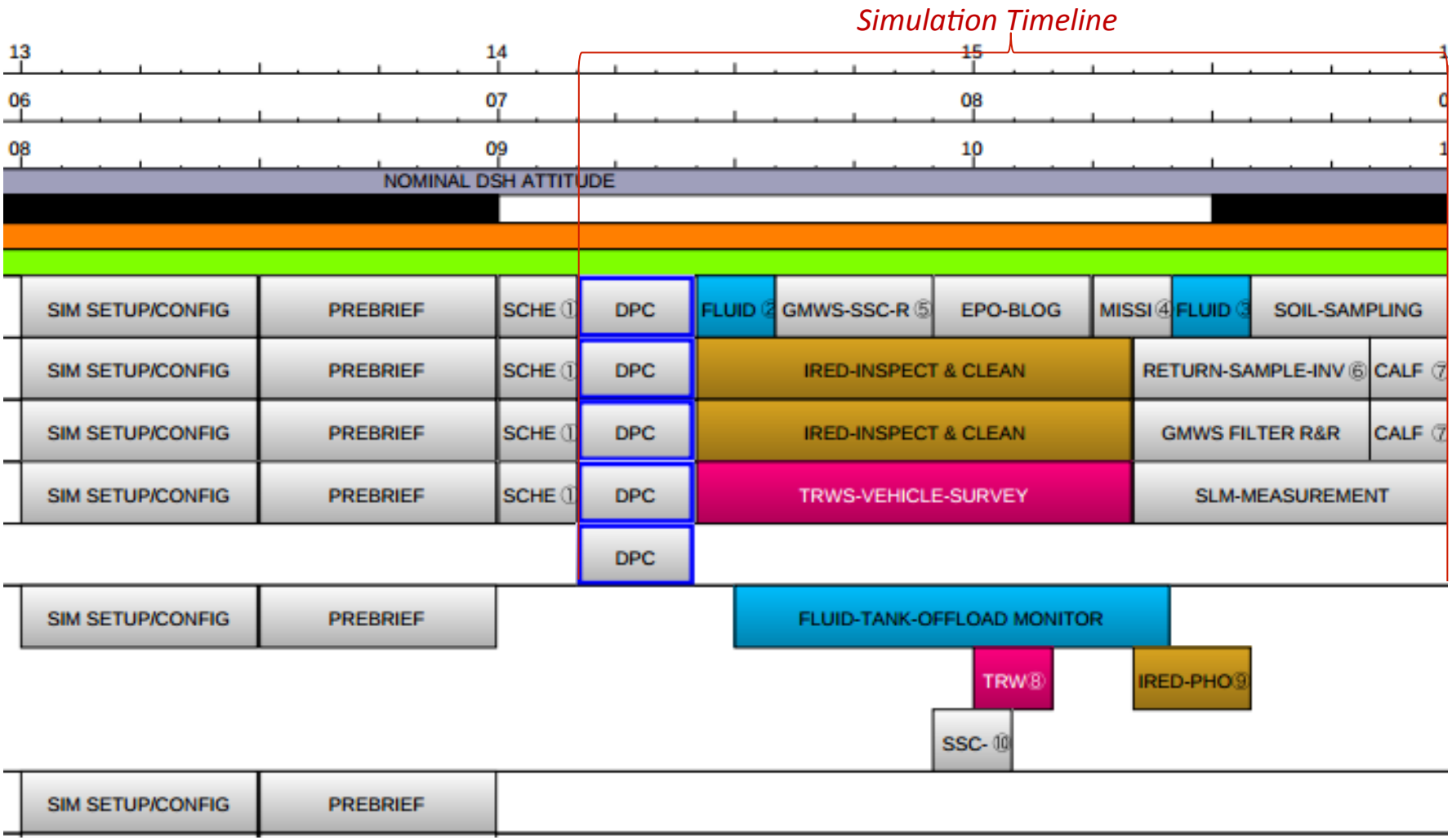

| | Lunar | S-E L1/2 | NEO | Mars (min) | Mars (max) |
|---|---|---|---|---|---|
| # Comms per Min | 23.4 | 6 | 1.20 | 0.16 | 0.02 |
| Roundtrip Time (Secs) | 2.6 | 10.0 | 50.0 | 373.3 | 2673.3 |

TIM$_E$TIM

# Purpose

- The goal of AMO experiments was to answer the following question: What aspects of mission operation responsibilities should be allocated to ground based or crew based planning, monitoring, and control in the presence of significant light-time delay between the vehicle and the Earth?
- To answer the question we:
  - Constructed a 2 hour quiescent mission timeline
  - Inserted various unexpected events (systems failures, crew medical emergency) into the timeline
  - Varied the time delay (low, 50 second, 300 second one-way light-time delay)
  - Varied crew responsibility, communications and support tools (baseline: ISS-like; mitigation: crew autonomy)
  - Analyzed task completion, communications, crew workload, and team coordination for both flight controllers and crew

# Timeline






TIM$_E$TIM

# Timeline

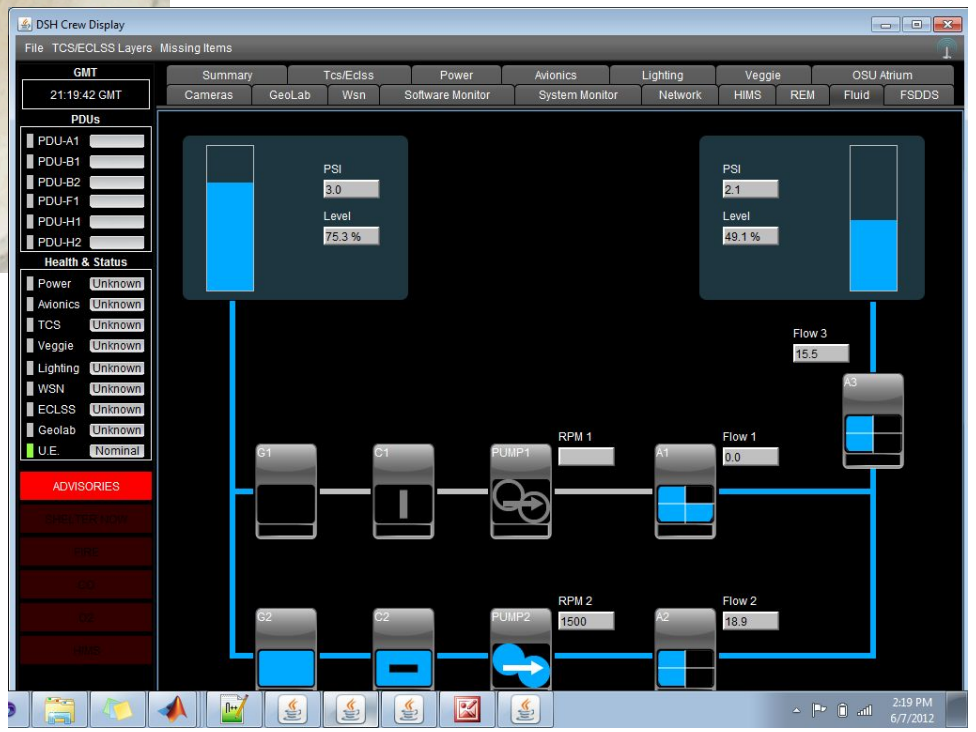
| Crew | Responsibilities |
|---|---|
| FE1 | *Computer repair, sample inventory* |
| FE2 | *Repair, filter changeout, calf measurement* |
| FE3 | *Medical, vehicle survey, equip. inspection* |
| CMDR | *Fluid transfer, inspection, soil sample* |

| Console | Disciplines |
|---|---|
| CAPCOM | *Traditional CAPCOM* |
| FLIGHT | *Flight Director* |
| PSYCHE | *Biomedical Engineer / Surgeon* |
| IRIS | *Robotics* |
| KALI | *Operations Planning / Public Affairs* |
| JUNO | *Power and Life Support Systems* |
| VESTA | *Operations Support and Mechanical* |
| CERES | *Payload/Science* |

# Timeline

Sample Inventory

Fluid Transfer



# Timeline

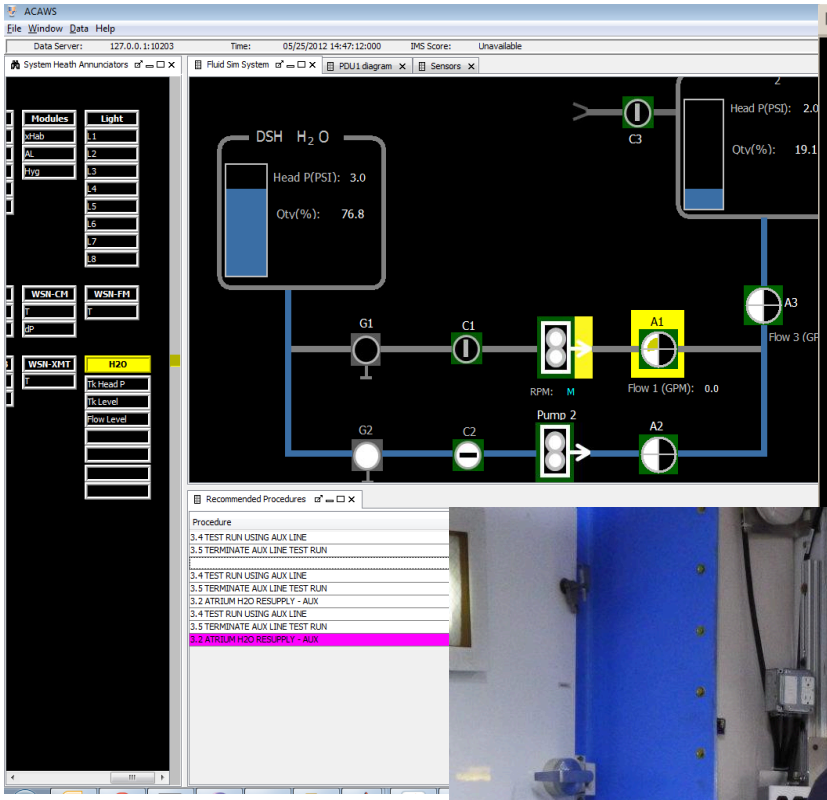
Equipment Inspection

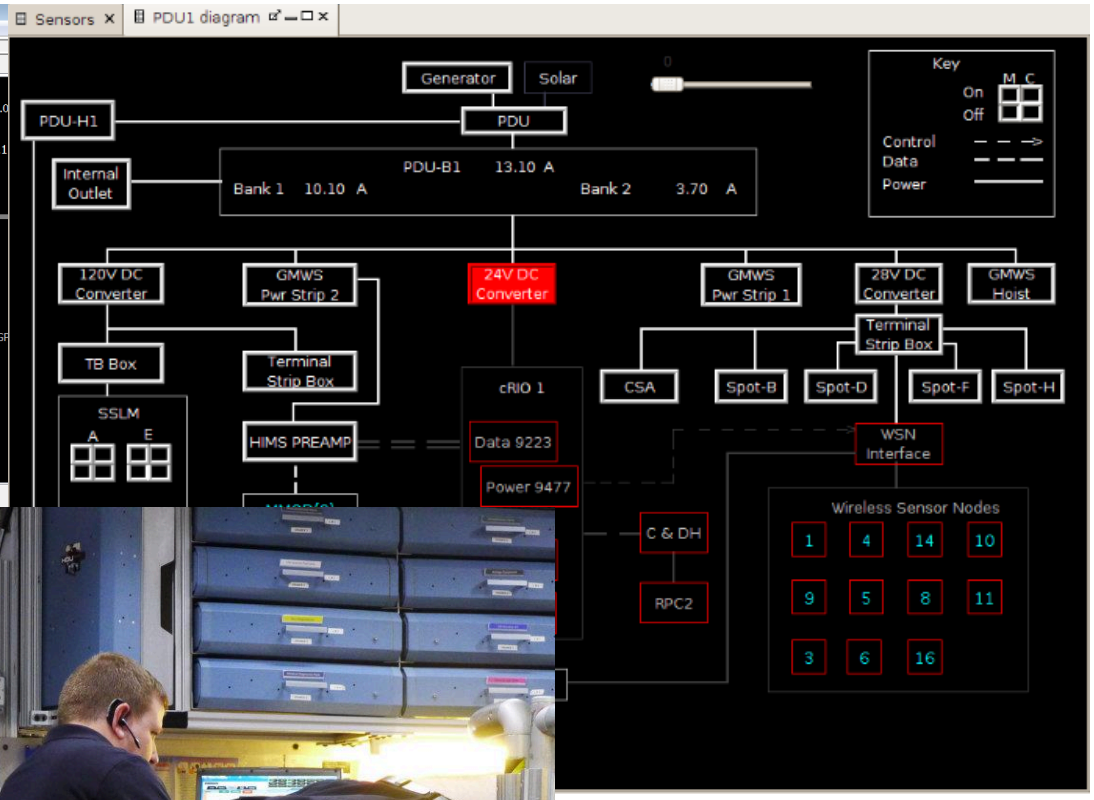
Soil Sampling

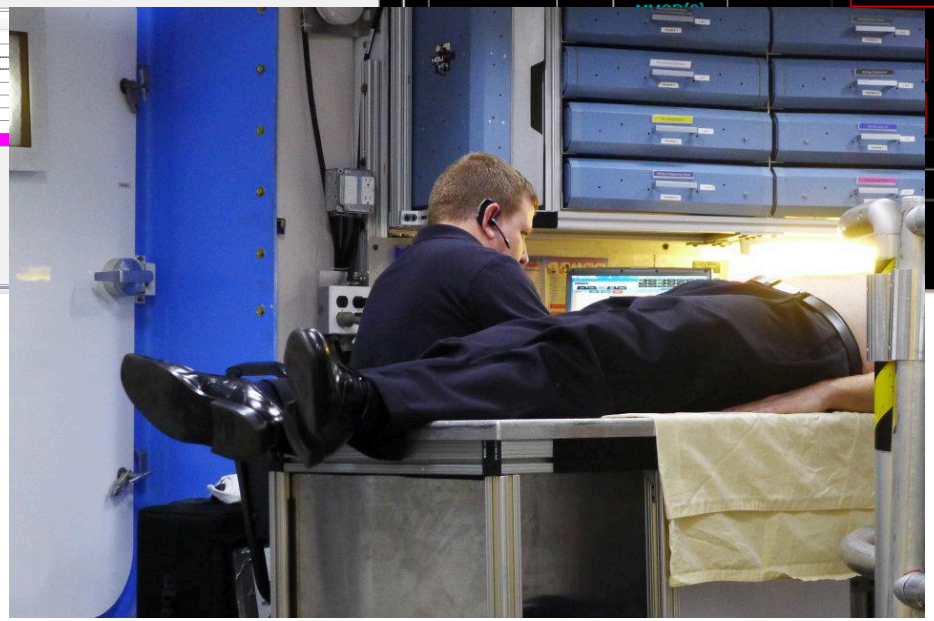
# Timeline

- Systems Failures
  - EPS failure (power converter failure)
  - Fluid transfer failure (valve stuck open)
  - Fault isolation procedures and workarounds required in both cases
- Crew Medical Emergencies
  - Urinary Retention
  - Kidney Stone
  - Ultrasound diagnosis required in both cases

# Timeline



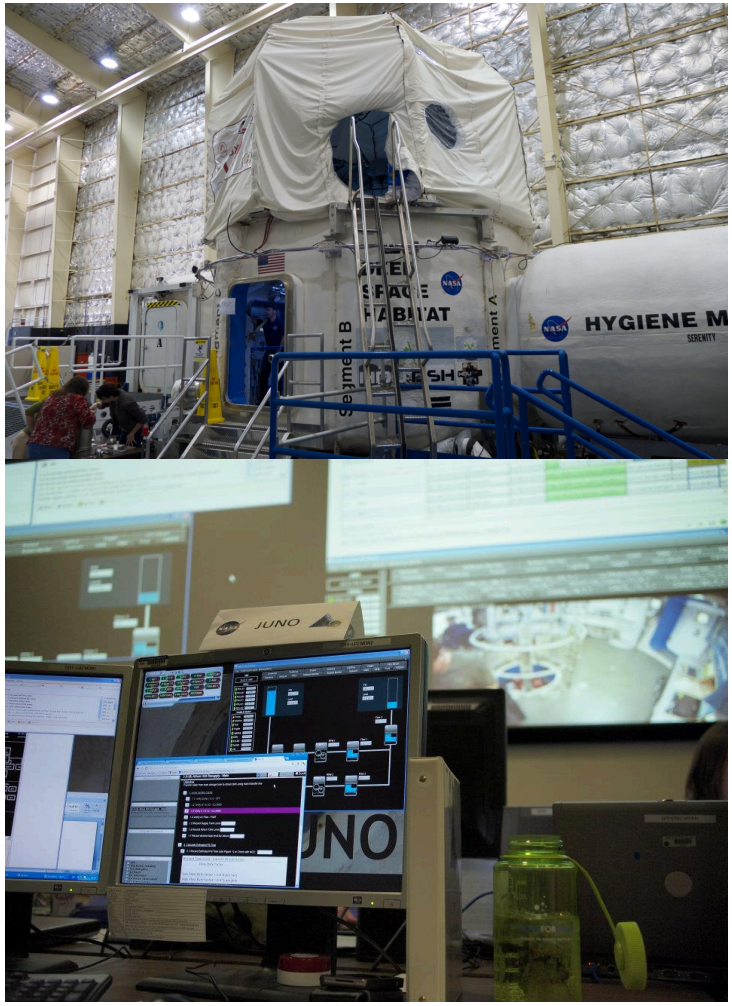
Fluid Transfer Failure

EPS System Failure

# Experiment Design

- The Deep Space Habitat (DSH) served as the analog spacecraft with one astronaut serving as CDR and three MOD flight controllers/trainers (one of whom is Chief Medical Officer)

- Certified Flight controllers and Flight Directors staffed the Flight Control Team located in the Operations Technology Facility (OTF)



# Experiment Design

| Time Delay | | |
|---|---|---|
| Low | 50 Second | 300 Second |
| Nominal | Nominal | Nominal |
| Nominal | Systems Failure | Systems Failure |
| | Systems Failure | Systems Failure |
| | Urinary Retention | Urinary Retention |
| | Urinary Retention | Urinary Retention |

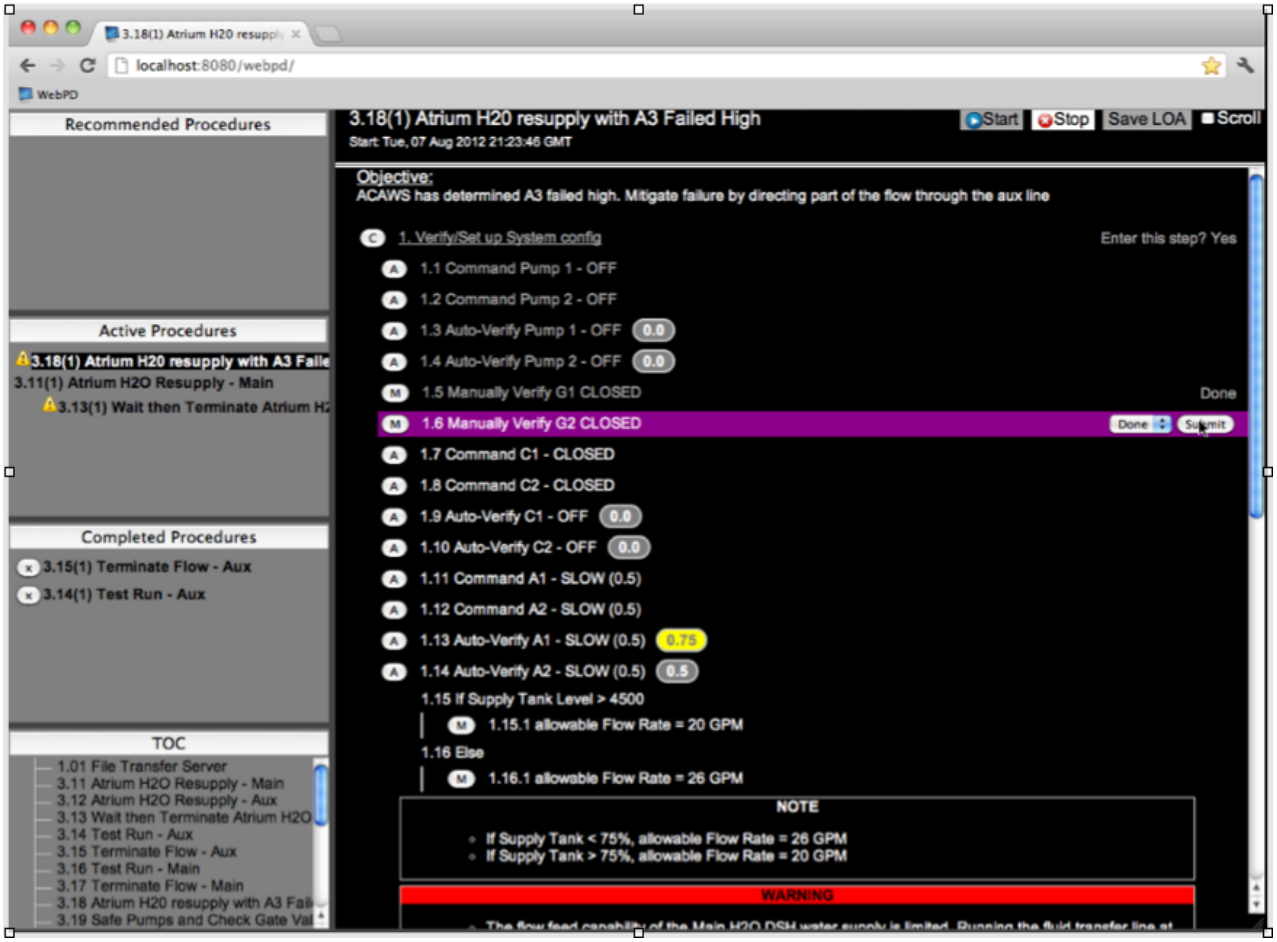
# Experiment Design

- 4 distinct crews, each crew has one astronaut
  - Commander
- Each crew experiences every long* time delay
  - * 50 and 300 second!
- Each crew experiences every scenario variation
  - Not all combinations of time delay and scenario variation were evaluated
- Each crew experiences the same combination of time delay / scenario in both Baseline and Mitigation configurations

# Baseline and Mitigation Configurations

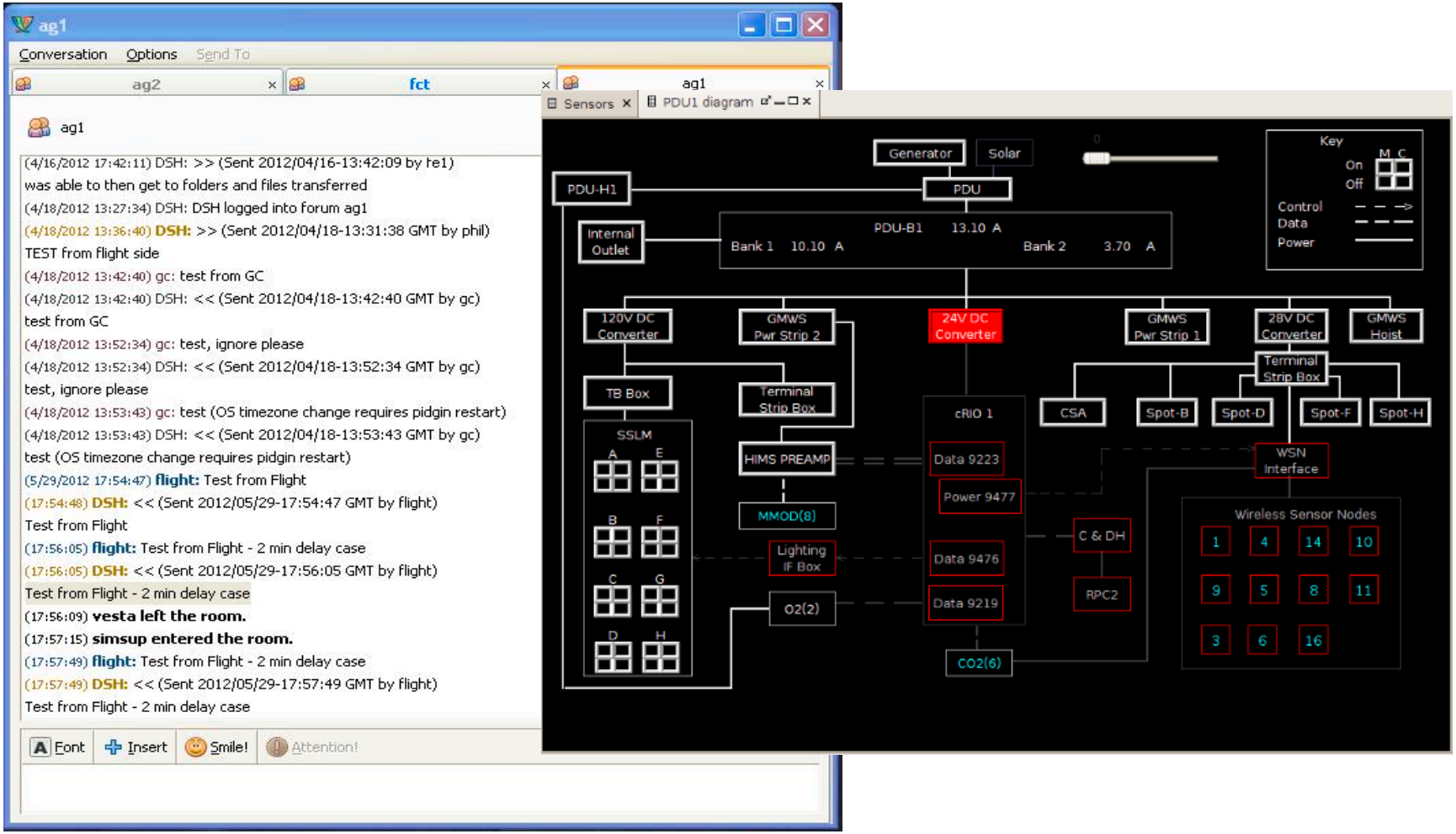
| | Communications | Fault Management | Procedure Format | Situational Awareness |
|---|---|---|---|---|
| Baseline | Voice | Limit Checking | PDF | Voice |
| Mitigation | Voice + Chat | Advanced Caution and Warning | Electronic Procedures | Voice + Electronic Procedures |

# Baseline and Mitigation Configurations




WebPD

# Baseline and Mitigation Configurations




Chat

ACAWS

# Outline

- AMO Overview
  - Purpose
  - Timeline
  - Experiment Design
  - Baseline and Mitigation Configurations
- Measurements
  - Subjective Measurements
  - Objective Measurements
- Analysis
  - Simulation Fidelity
  - Workload
  - Coordination
  - Task Completion
  - Communications Analysis
- Conclusions and Future Work

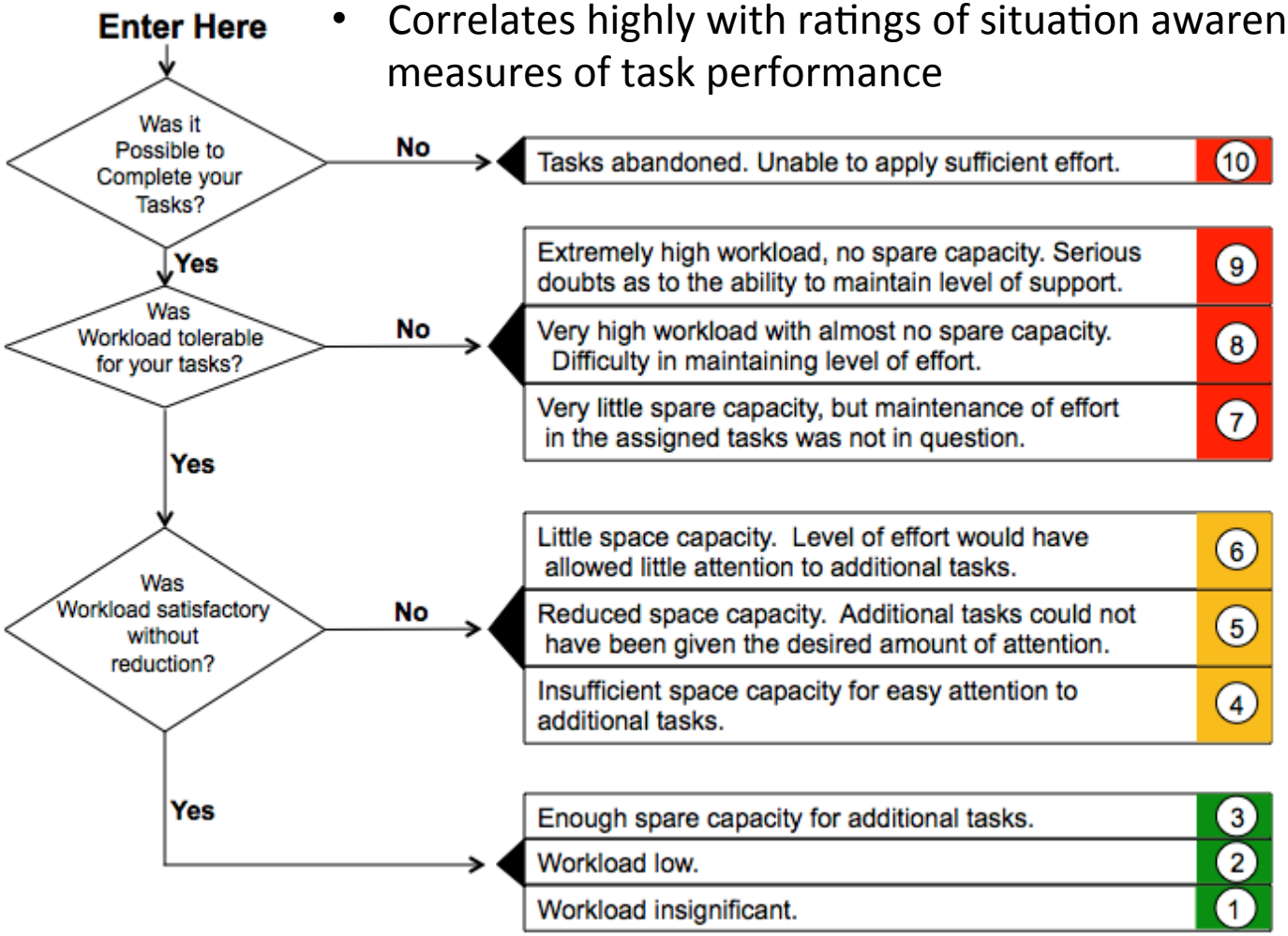
# Subjective Measurements

- Questionnaires
  - After each 2 hour run
  - After participant completed all runs
- Ratings
  - Bedford (Workload Rating)
    - Anchored 10 point scale
  - Likert (Coordination Difficulty Rating)
    - 5 point scale
- Flight controller and crew comments
  - Explanations of ratings
  - Assessment of simulation fidelity
  - Value of mitigation tools

# Subjective Measurements

Bedford Workload Rating Scale:

- Anchored scale: Attentional capacity to perform additional tasks
- Correlates highly with ratings of situation awareness and objective measures of task performance




Red Zone: Workload intolerable

Yellow Zone: Workload Unsatisfactory Without Reduction

Green Zone: Workload Satisfactory Without Reduction

TIM$_E$TIM

# Subjective Measurements

- Likert Scale (Unanchored) Team Coordination Ratings:
  "In the run you just completed, how difficult was it to coordinate activities with crew/ground" (1 = very easy to coordinate, 3 = moderately difficult to coordinate, 5 = very difficult to coordinate, 6 = Not Applicable)."

- Operator Comments:
  "If your rating on question 2.1 was less than 3, what made coordination easy? If your rating was 3 or more, what made coordination moderately to very difficult? (**please type in area below unless you selected N/A**)"

# Subjective Measurements

- Tool Evaluation and Opinions, e.g.
  "Provide three things you liked about PIDGIN:"
  "Provide three things you didn't like about PIDGIN:"

- Simulation Fidelity Ratings:
  "Taking into consideration all the scenarios, tasks, procedures, operational protocols, etc. that you experienced on this project, how would you rate the fidelity of the operations testing environment compared to an actual mission? (1 = very low fidelity, 3, = medium fidelity, 5 = very high fidelity)"

  "Please explain your fidelity rating on the question above. If your rating was in the "low" or "medium" range, what aspects of the experience distinguished it from a "day in the life" of an actual mission? What recommendations would you have to enhance the fidelity of DSH-based operations testing?"

# Objective Measurements

- Empirical Measures of Performance
  - Number of Tasks Completed
    - Recorded by flight controllers and crew
    - (Task start/end times recorded; no discernable pattern)
    - (Procedure execution data being analyzed)
  - Number and type of Communications Acts
    - Voice activation / deactivation recorded
    - Audio transcripts
    - Pidgin messages recorded

# Outline

- AMO Overview
  - Purpose
  - Timeline
  - Experiment Design
  - Baseline and Mitigation Configurations
- Measurements
  - Subjective Measurements
  - Objective Measurements
- Analysis
  - Simulation Fidelity
  - Workload
  - Coordination
  - Task Completion
  - Communications Analysis
- Conclusions and Future Work

# Analysis: Simulation Fidelity

"Taking into consideration all the scenarios, tasks, procedures, operational protocols, etc. that you experienced on this project, how would you rate the fidelity of the operations testing environment compared to an actual mission? (1 = Very low fidelity, 3 = Medium fidelity, 5 = Very high fidelity)"

- Average response for FCT and the Crew were both 3.1: clearly a *Medium Fidelity* study.
- Representative Comments:

  *"The test was very well thought out and executed. The lack of fidelity had to do with systems not being really flight like".*

  *"These sims were useful for testing new tools and comm delays with the crew - but not high enough fidelity for real procedure and execution tests. I suspect time delays in malfunction scenarios with far more complicated procedures would be far more challenging than we experienced in this lower fidelity environment."*

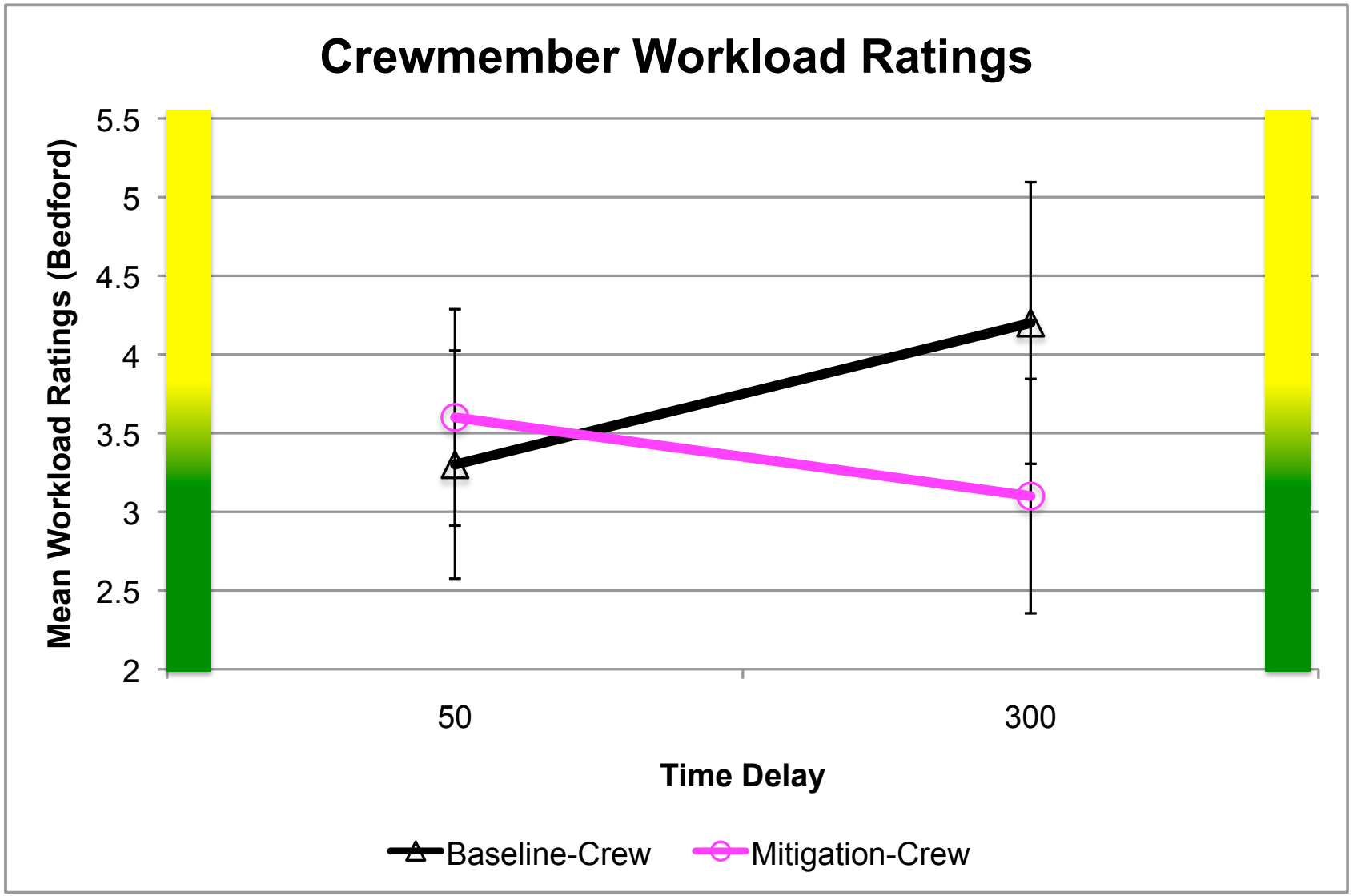
# Outline

- AMO Overview
  - Purpose
  - Timeline
  - Experiment Design
  - Mitigation Configuration
- Measurements
  - Subjective Measurements
  - Objective Measurements
- Analysis
  - Simulation Fidelity
  - Workload
  - Coordination
  - Task Completion
  - Communications Analysis
- Conclusions and Future Work

# Analysis: Workload

- How did the Crew's workload change with time delay?
- How did the Crew's workload change between Baseline and Mitigation Configuration?
- How did the FCT's workload change with time delay?
- How did the FCT's workload change between Baseline and Mitigation Configuration?

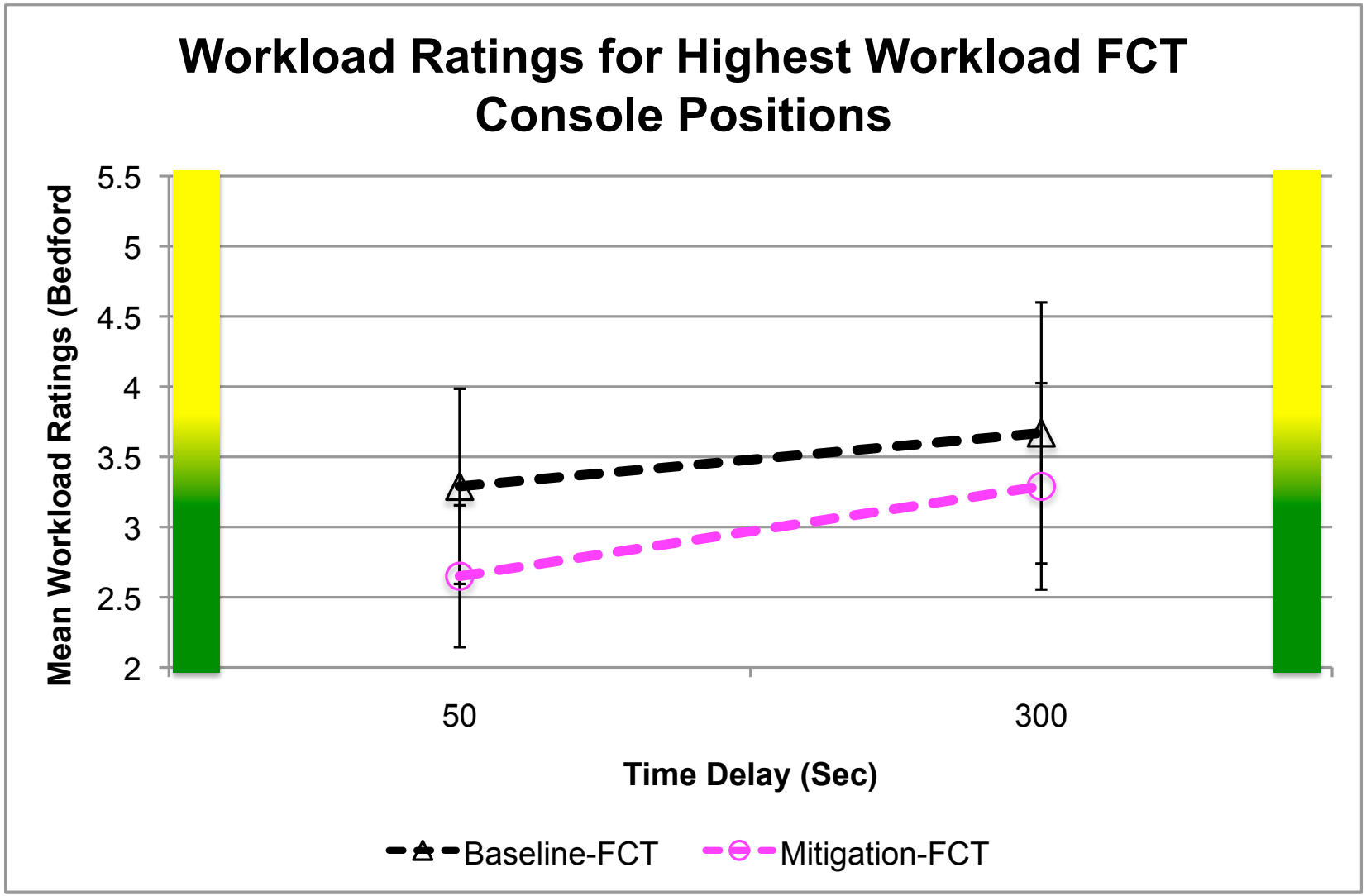
# Analysis: Workload



# Analysis: Workload

- Crew Workload *increased* between 50 and 300 seconds for Baseline Configuration
- Crew Workload *decreased* between 50 and 300 seconds for Mitigation Configuration
- Crew Workload *decreased between Baseline and Mitigation Configurations* at 300 seconds
- Average ratings fell outside the Green (Workload Satisfactory Without Reduction) range

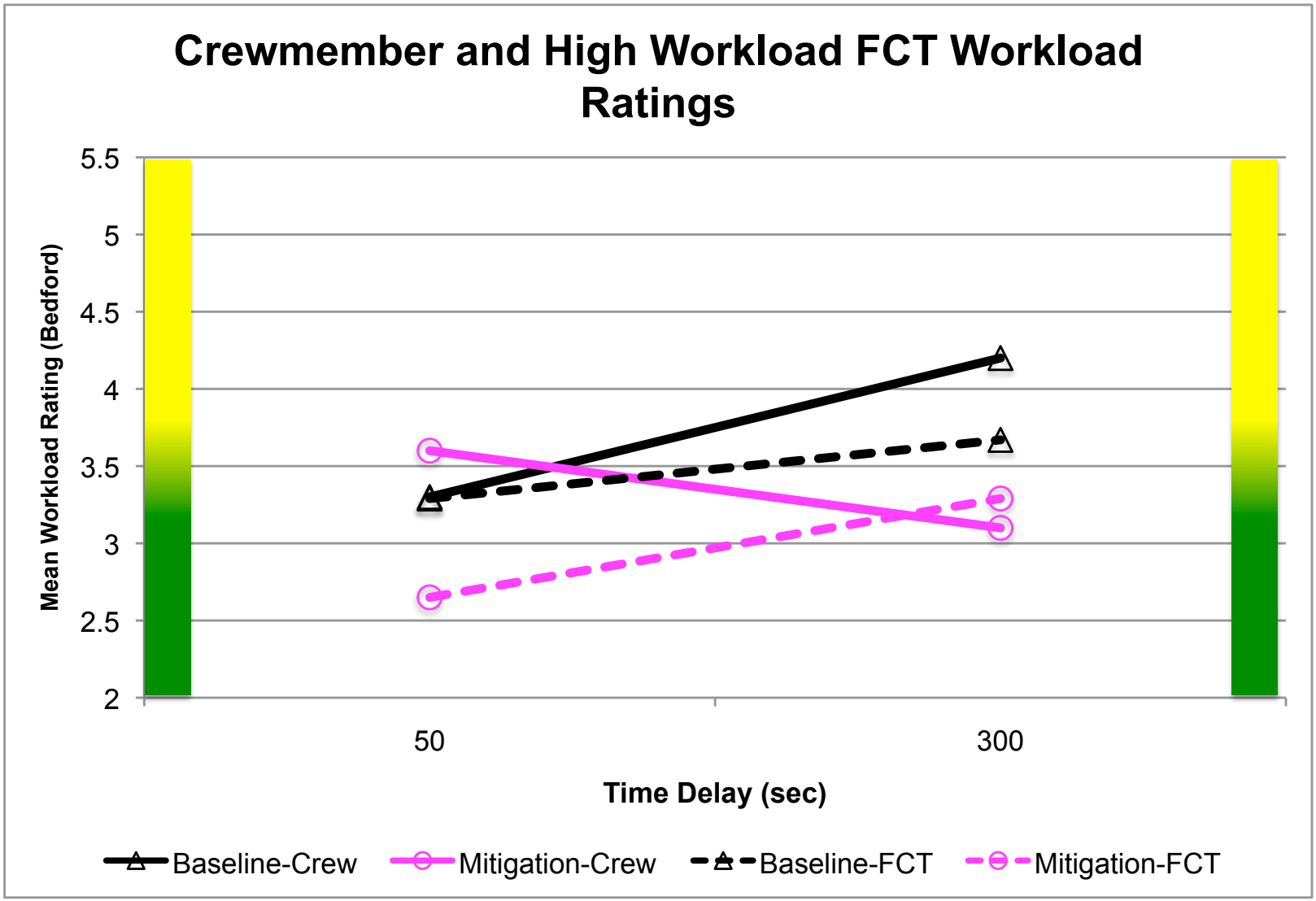
# Analysis: Workload



# Analysis: Workload

- FCT Workload *increased* between 50 and 300 seconds
- FCT Workload *higher* in Baseline than Mitigation Configuration
- Average ratings close to, or outside, the Green (Workload Satisfactory Without Reduction) range at 300 seconds
- Note the difference in patterns of FCT and Crew workload responses to both time delay and configuration!

# Analysis: Workload

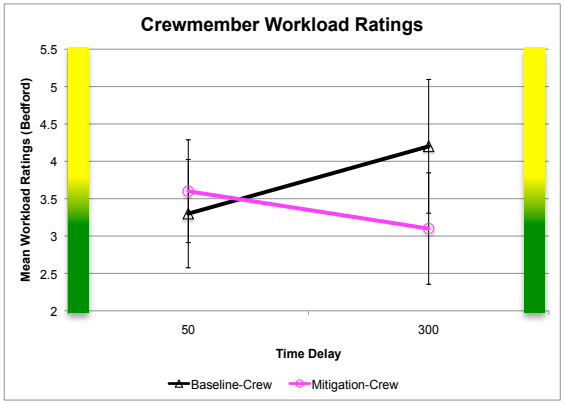


# Analysis: Workload

- What contributed to workload increase from 50 to 300 sec for Crew in Baseline?

- Crewmember comments:
  *"Coordinating with MCC caused delay while working procedures. To keep from falling behind in the timeline tasks were started early and ended up overlapping"*
  *"Time delay made it difficult to do voice comm and still keep your place in procedures since the time is long enough the crew moves onto other tasks while waiting for the MCC to get back in touch for further direction"*

- Increasing Task Overlap Yields:
  - More requirements for task coordination
  - More task switching requirements.
- Both factors candidates for increased workload

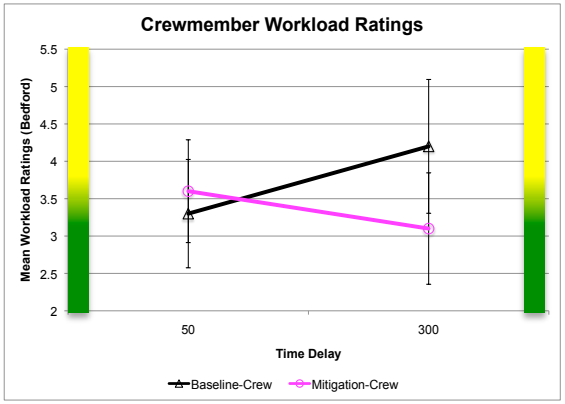


# Analysis: Workload

- What contributed to workload increase from 50 to 300 sec for Crew in Baseline?

- Crewmember comments:
  *"Waiting for delay for response was distracting - suggests some possible mitigation aids - ie a "egg-time" preset for the delay that would let you know at a glance when to expect response from MCC so you could do something else more efficiently during delay times."*

- Time delay required monitoring for ground communication
- Crewmember forced to spread available attention across current task and monitoring task
  - Plausible candidate for increasing ratings for workload

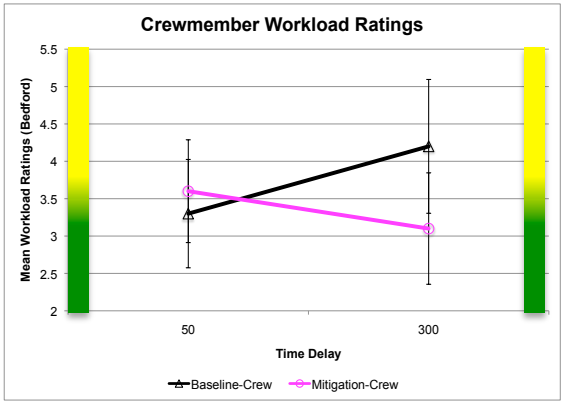


# Analysis: Workload

- What contributed to workload increase from 50 to 300 sec for Crew in Baseline?

- Crewmember Comments:
  *"No satisfying feedback that any transmission if [sic] info (voice, files, crew notes) was being received or buffered at the ground in a timely enough manner that it didn't exceed the length of my short term memory. So I had to write info down in case I got a "say again" or "file not received" message back from MCC minutes after I'd dumped the details from my buffer."*

- Time delay forced crew to engage in additional activities that they didn't have to carry out when real-time communications with the ground was available
- Task loading is a plausible candidate for increasing rated workload



# Outline

- AMO Overview
  - Purpose
  - Timeline
  - Experiment Design
  - Baseline and Mitigation Configurations
- Measurements
  - Subjective Measurements
  - Objective Measurements
- Analysis
  - Simulation Fidelity
  - Workload
  - Coordination
  - Task Completion
  - Communications Analysis
- Conclusions and Future Work

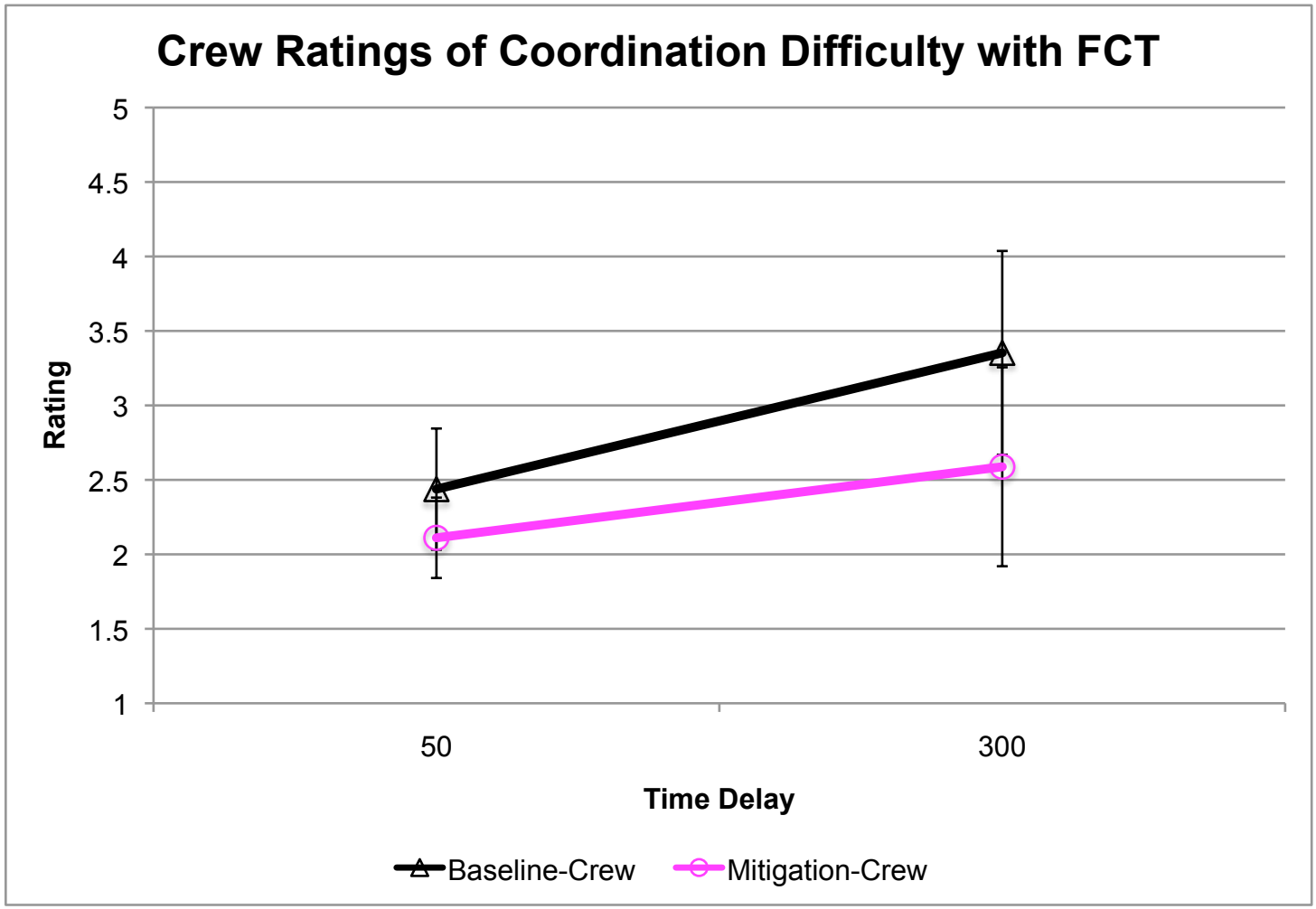
# Analysis: Coordination

•What contributed to workload increase from 50 to 300 sec for Crew in Baseline?

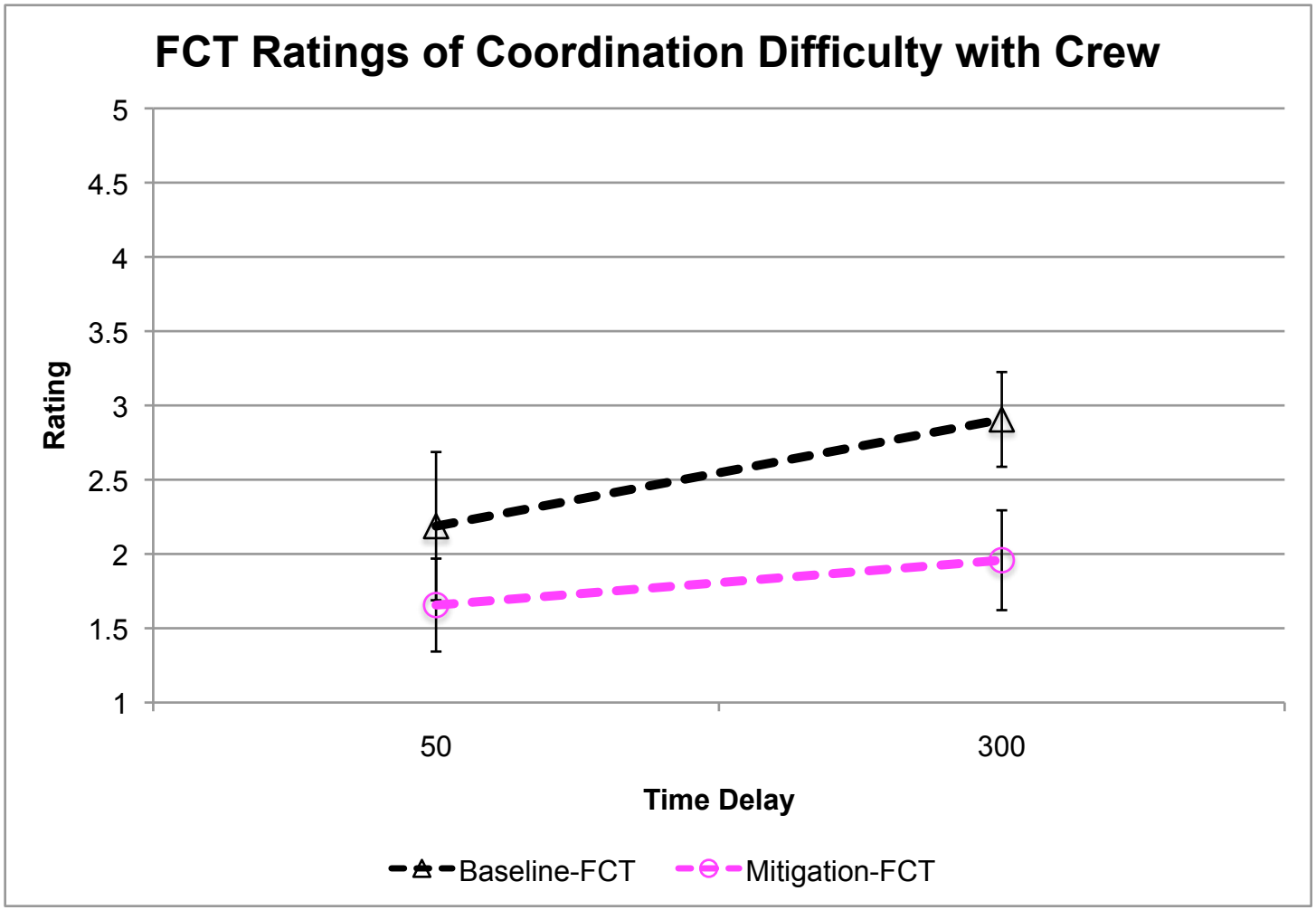
•Comments indicate a significant component of workload for crew in Baseline was coordination difficulties with ground
•Additional Evidence: Crew-Ground Coordination Question

"In the run you just completed, how difficult was it to coordinate activities with the ground"? (1 = not at all difficult to coordinate, 3 = moderately difficult to coordinate, 5 = quite difficult to coordinate)."

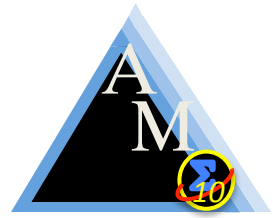
# Analysis: Coordination



# Analysis: Coordination



# Analysis: Coordination




- Coordination *more difficult* at higher time delays
- Coordination *more difficult* in Baseline than in Mitigation
  - Both Crew to FCT, and FCT to Crew

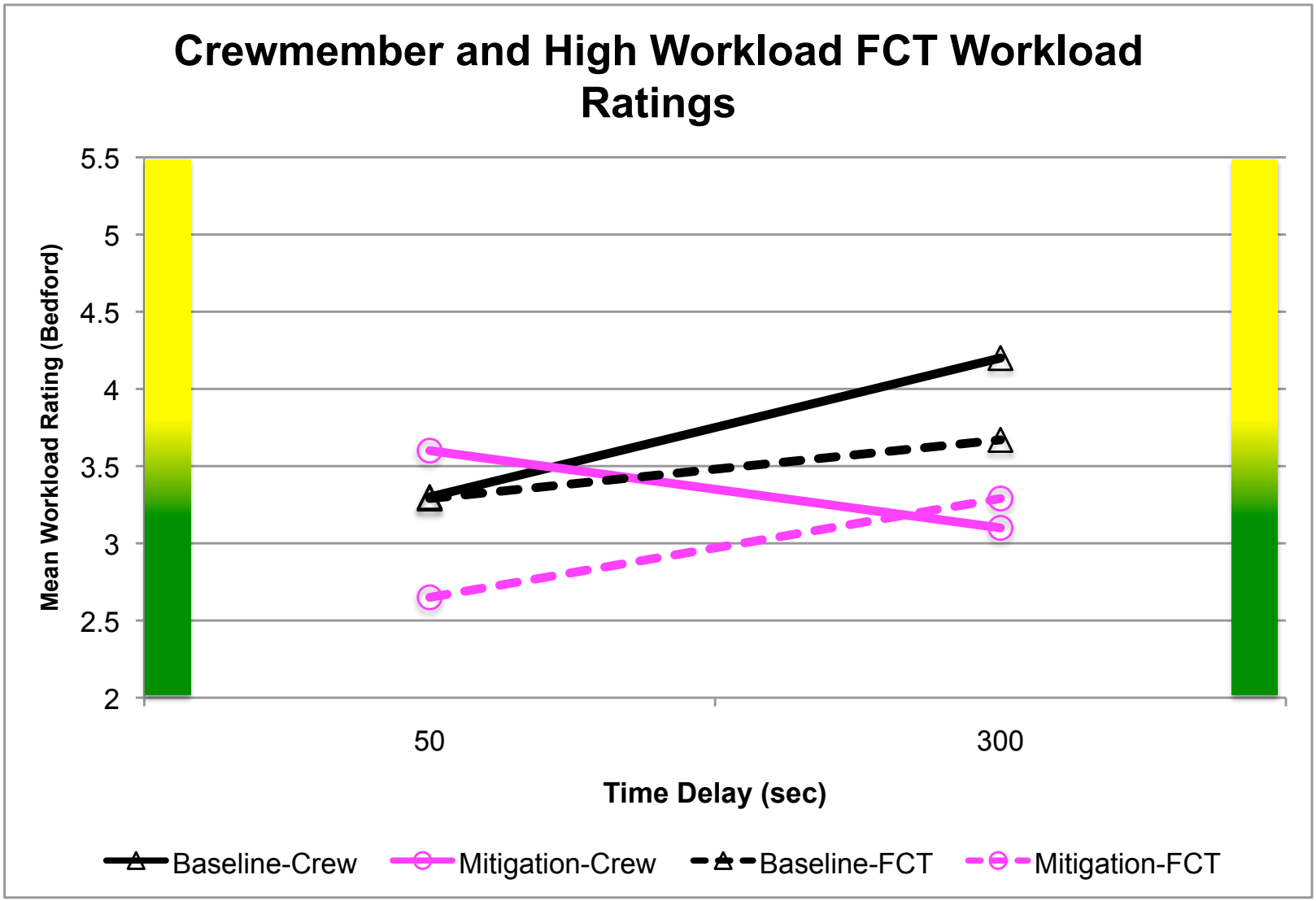
# Outline

- AMO Overview
  - Purpose
  - Timeline
  - Experiment Design
  - Baseline and Mitigation Configurations
- Measurements
  - Subjective Measurements
  - Objective Measurements
- Analysis
  - Simulation Fidelity
  - Workload (Revisited)
  - Coordination
  - Task Completion
  - Communications Analysis
- Conclusions and Future Work

# Analysis: Workload

- Why did Workload stay flat (or possibly decrease) for Crew between 50 and 300 sec of Time Delay in Mitigation?
- Why did workload for FCT show a very different pattern?
  - FCT Workload consistently higher in Baseline than in Mitigation
  - FCT Increased between 50 and 300 sec of Time Delay in both Baseline and Mitigation

# Analysis: Workload



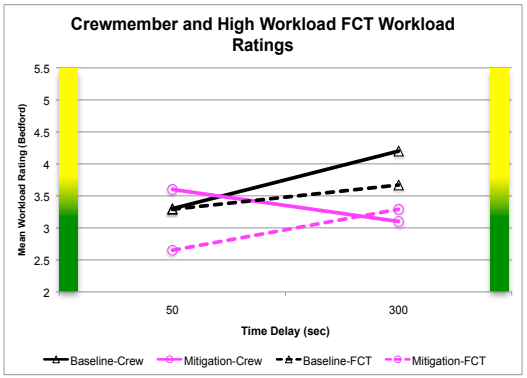
# Analysis: Workload

- Crewmember comments about Chat:
  *"Time delay made it difficult to do voice comm and still keep your place in procedures since the time is long enough the crew moves onto other tasks while waiting for the MCC to get back in touch for further direction. Chat was more effective than voice since we could go back and refer to the various recommendations from the ground."*

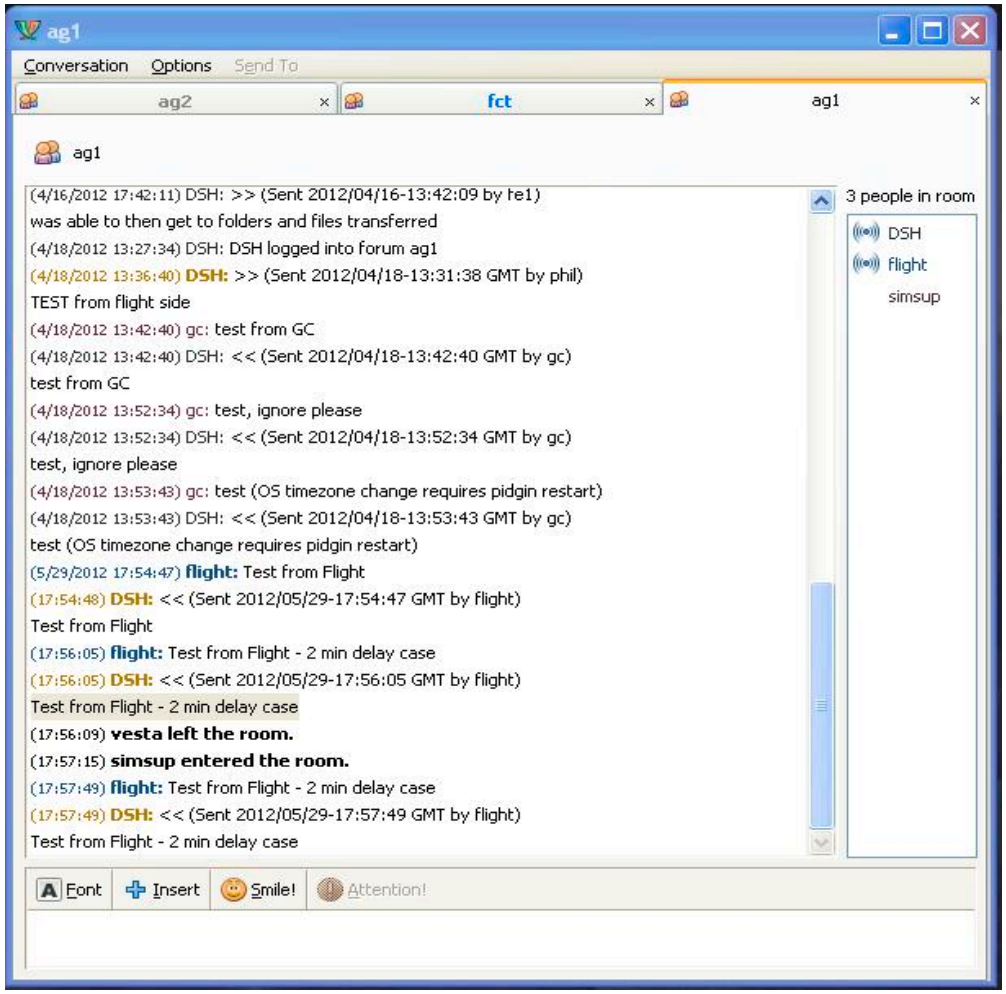
  - Chat removed the need to monitor auditory channel (voice loops) for delayed ground communications.
    - Freed up more attention to manage multi-tasking environment
    - Freed up attentional resources that could have been allocated to additional tasks, should they have been impose

*"Ground or crew could go back and read IM [instant message] transmissions if they forgot or needed to reference for any reason"*

- Chat removed the need to write down verbal communications so that they weren't forgotten
- Chat reduced the additional task and memory load imposed in Baseline by Time Delay.



# Analysis: Workload



# Analysis: Workload

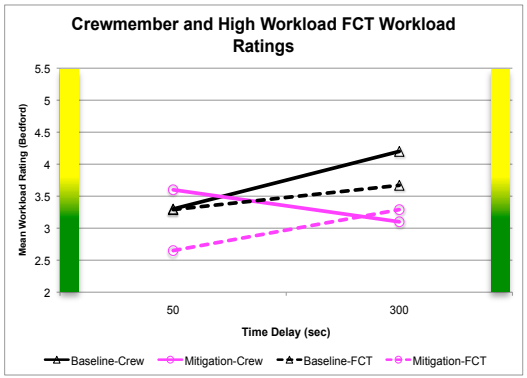
- FCT Comments about Chat

*"Workload for CC was much lower by adding Chat capability. My job switched from a listening mode to scanning/monitoring mode – watching the crew-progress in WebPD and watching for new chat messages"*

  - Less requirement for monitoring auditory channel

*"Workload was higher because with Text I had to monitor what conversations were on text and which ones were on audio"*
*"Two separate chat windows plus voice loops made more things to monitor"*

  - More requirement for monitoring!



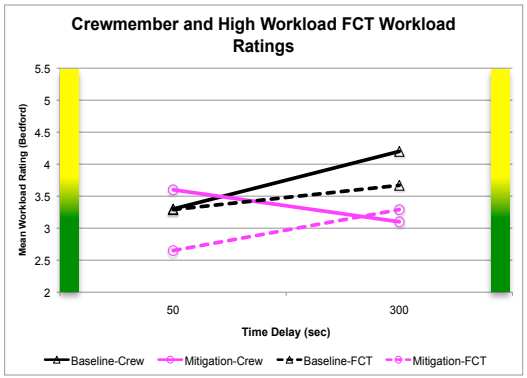
# Analysis: Workload

• FCT Comments about WebPD:
*"Helped because I didn't have to ask them about activities".*
*"WebPD made it very easy to follow along in the procedures even with the time delay".*

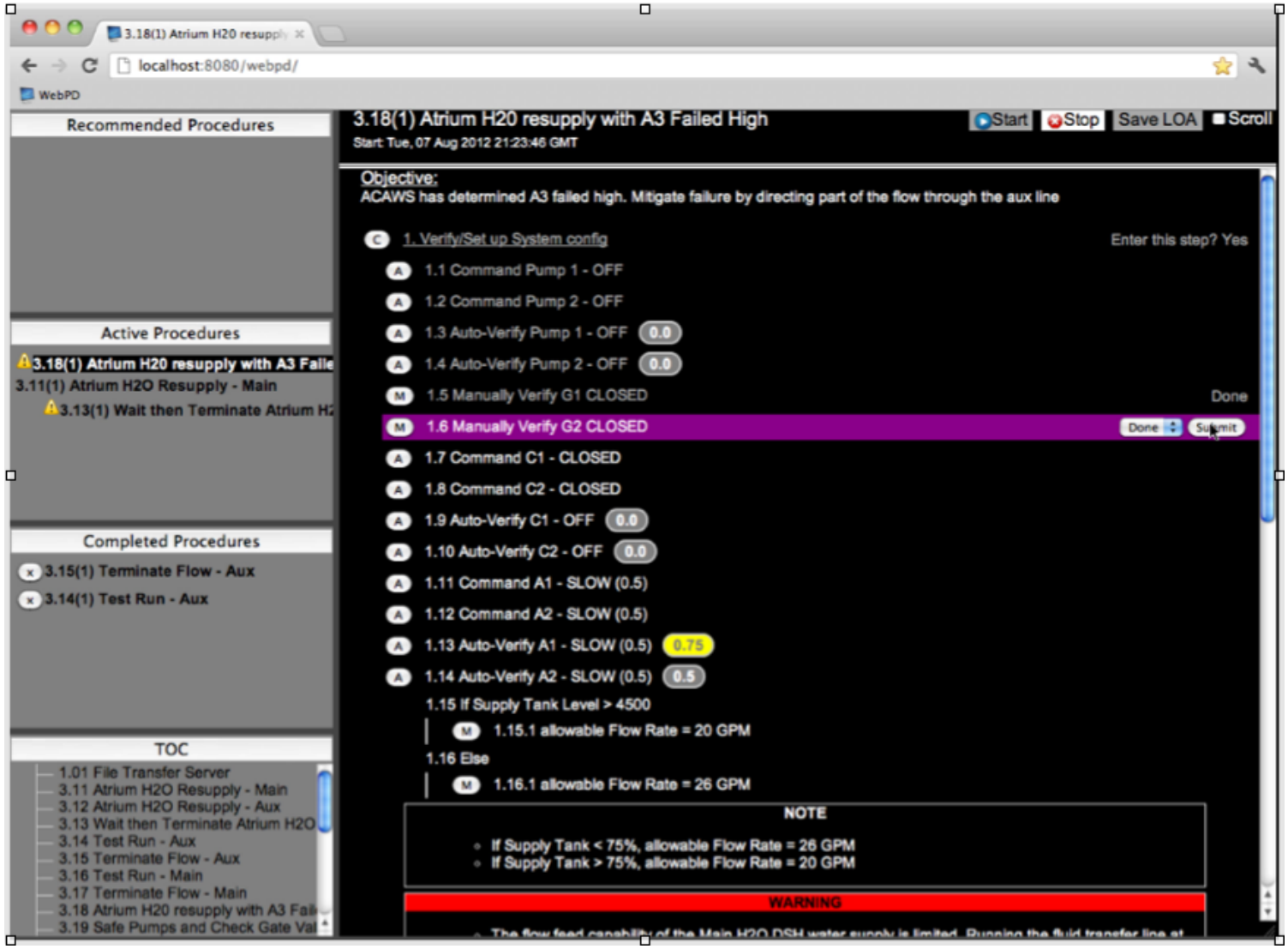
- Reduced need for voice communications
- Enhanced FCT situation awareness of crew activities and progress
- Situation Awareness and Workload highly intercorrelated measures

*"Workload was actually more noticeable because we actually had insight into the progress of the procedure from WebPD".*

- Increased awareness => increased work



# Analysis: Workload



# Analysis: Workload

- Why did workload for FCT show a very different pattern [than crew]?
- In summary, the Mitigation Configuration:
  - *Reduced* FCT workload compared to Baseline because they enhanced FCT situation awareness of Crew activity status and progress
  - *Enhanced* FCT workload because they provided more channels of information to monitor
- Increased monitoring requirements may have to some extent counteracted the more general workload-reducing benefits of the Mitigation Configuration
  - Result: Unlike Crew, higher workload at the 300 sec time delay compared to 50 sec.

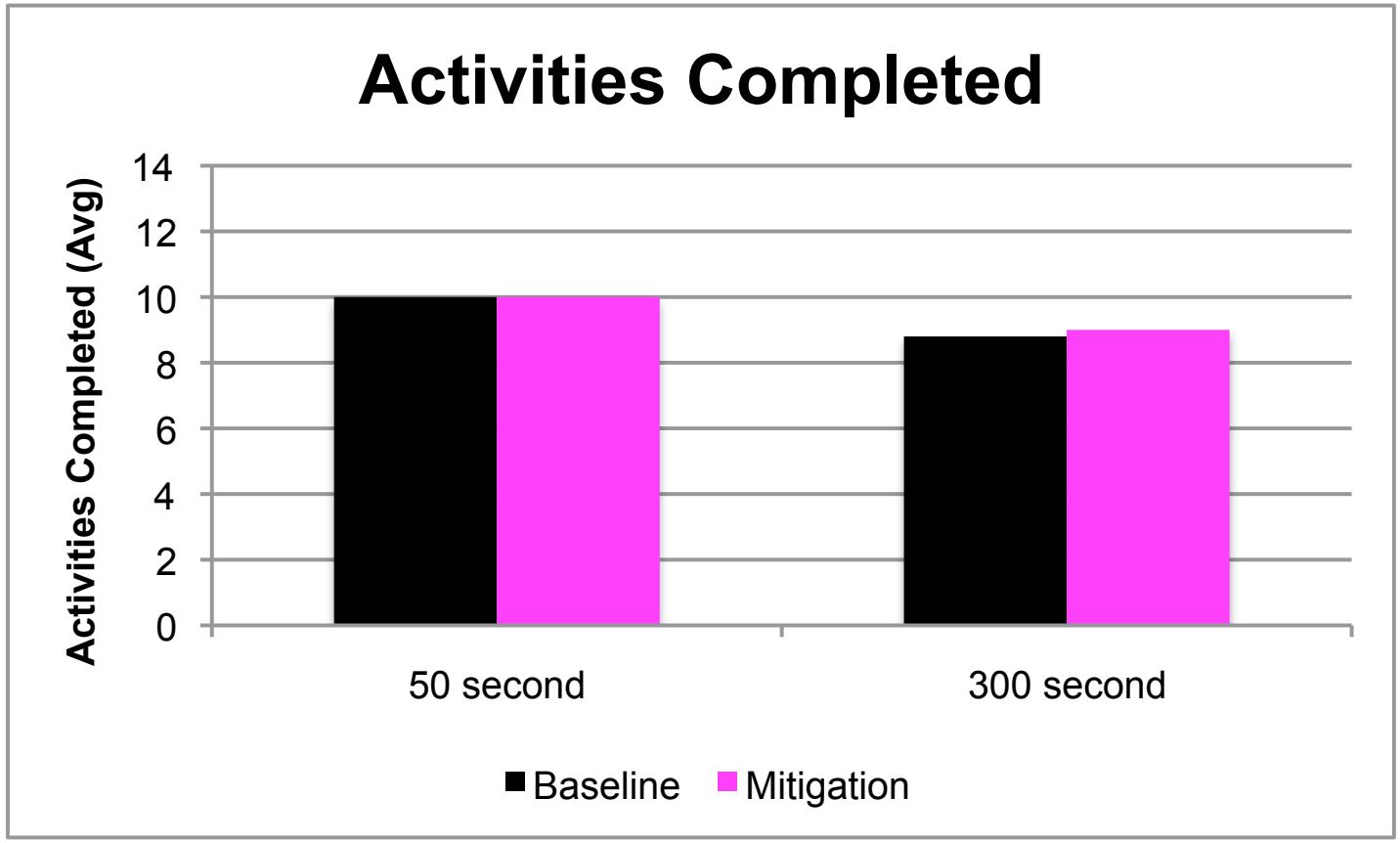
# Outline

- AMO Overview
  - Purpose
  - Timeline
  - Experiment Design
  - Baseline and Mitigation Configurations
- Measurements
  - Subjective Measurements
  - Objective Measurements
- Analysis
  - Simulation Fidelity
  - Workload
  - Coordination
  - Task Completion
  - Communications Analysis
- Conclusions and Future Work

# Task Completion

- Were fewer tasks completed at higher time delays?
- Some differences in activity completion rates based on
  - Scenario (one fewer activity in Mitigation)
  - Time delay
- Small sample sizes (3-5), scenario fidelity, incomplete record keeping, and issues during testing make rigorous analysis of activity completion differences unreliable

# Task Completion



# Outline

- AMO Overview
  - Purpose
  - Timeline
  - Experiment Design
  - Baseline and Mitigation Configurations
- Measurements
  - Subjective Measurements
  - Objective Measurements
- Analysis
  - Simulation Fidelity
  - Workload
  - Coordination
  - Task Completion
  - Communications Analysis
- Conclusions and Future Work

# Communications Analysis

- How did time delay affect communications?
  - Voice communication *dropped* with time delay
  - Some of the drop was *accounted for by use of chat*, but not all

| Total talk time (s) | | | |
|---|---|---|---|
| Delay | Baseline | Mitigation | Ratio (M/B) |
| 50 | 16158 | 12893 | 0.80 |
| 300 | 17060 | 11384 | 0.67 |

# Communications Analysis

- Estimate time required to utter Pidgin messages
  - 2 word / sec(*)
- Re-compute communications 'time'

| Total Voice + Chat Time | | | | | | |
|---|---|---|---|---|---|---|
| | Chat | Voice | Mitigation Total | Baseline | Ratio (M/B) | Voice only (M/B) |
| 50 | 1702.5 | 12893 | 14595.5 | 16158 | 0.90 | 0.80 |
| 300 | 1856.5 | 11384 | 13240.5 | 17060 | 0.78 | 0.67 |

- *(very unscientific methodology used!)

# Outline

- AMO Overview
  - Purpose
  - Timeline
  - Experiment Design
  - Baseline and Mitigation Configurations
- Measurements
  - Subjective Measurements
  - Objective Measurements
- Analysis
  - Simulation Fidelity
  - Workload
  - Coordination
  - Task Completion
  - Communications Analysis
- Conclusions and Future Work

# Conclusions

- The experiment was a *medium fidelity* simulation of space mission operations.
- Workload and coordination difficulty *increased* with time delay.
- Workload and coordination difficulty were *reduced* by the mitigation configuration.
- Communications *decreased* in mitigation configuration; the decrease was larger at longer time delay.

- Flight controller workload and coordination responded differently to time delay and configuration variations than crew workload and coordination.
- Communications patterns were influenced by the mitigation configuration.

# Conclusions

- Note workload is between satisfactory and unsatisfactory for
  - Medium fidelity simulation
  - Quiescent flight phase operations
- Reasonable to assume that implications of time delay for real spacecraft, serious failures, more difficult mission phases are more profound

# Future Work

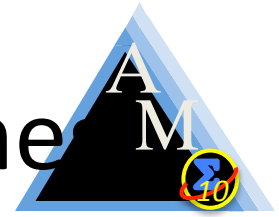
- Reasons for less communication still murky
  - Shared procedure execution or tools? Or something else?
- Give crew autonomy but no tools: what happens?
- Higher fidelity simulations
  - SSTF, ISS failure cases
  - Better able to asses task completion, refine assessments of workload and coordination
- Is time delay of 50 seconds really acceptable?
  - Analysis of activities at cis-Lunar time delays with high fidelity
- More analysis of audio transcripts and chat to characterize communications more deeply

# Future Work

- Many tools recommendations, including:
  - Better interoperability between tools (e.g. cut-copy-paste, WebPD-Score notifications)
  - Score Marcus-Bains line indicating time delay
  - MobileScore horizontal instead of vertical layout
  - WebPD flexibility to skip, undo procedure steps, goto step, clear completed procedures
  - Audibles in Pidgin to announce incoming messages

# BACKUP

# Consistency of Presentation Meme




- Plot colors / types
  - Baseline=Red, Mitigation=Green
    - One person confused & thought these were Bedford scale; consider changing plot colors
  - Crew=solid lines, Ground=Dotted lines
- Bedford scale on plots
  - Green Yellow Red along y axis
  - No color coding for Likert plots
- Survey Questions
  - Quoted and colored, e.g. "Why did you do that?"
  - No bullets!
- Our questions arising because of analysis:
  - Unquoted purple, e.g. Why did workload increase?
- Crew Responses
  - Quoted and italicied, e.g. *"Because I felt like it."*
- Result we want to hilight
  - Italicied, e.g. Crew workload *reduced* in mitigation.

# Nitlist

- Redo Rob's Excel plots
  - Titles
  - Legends at bottom
  - Eliminate import artifacts
  - Import as PDFs to enhance clarity
  - Clean up text layout if possible
- Animation
  - present one slide w. Baseline workload, then Mitigation and Baseline together (to better explain the plot legend) (maybe for first of workload slides only?)
- Justification of text on all slides

# Experiment Design

| BASELINE CONFIGURATION EXPERIMENTS | | | |
|---|---|---|---|
| **Crew A** | **Crew B** | **Crew C** | **Crew D** |
| 1.2 Seconds Nominal | 300 Seconds Nominal | 50 Seconds Nominal | 1.2 Nominal |
| 300 Seconds Systems | 300 Seconds Urinary Retention | 300 Seconds Systems | 300 Seconds Urinary Retention |
| 50 Seconds Urinary Retention | 50 Seconds Systems | 50 Seconds Urinary Retention | 50 Seconds Systems |
| | | | |
| MITIGATION CONFIGURATION EXPERIMENTS | | | |
| **Crew D** | **Crew A** | **Crew B** | **CrewC** |
| 5 Seconds Nominal | 5 Seconds Nominal | 300 seconds Nominal | 50 Seconds Nominal |
| 300 Seconds Kidney Stone | 300 Seconds Systems | 300 Seconds Kidney Stone | 300 Seconds Systems |
| 50 Seconds Systems | 50 Seconds Kidney Stone | 50 Seconds Systems | 50 Seconds Kidney Stone |

# Timeline

| Activity | Responsible Console | Description |
|---|---|---|
| SSC Hard Drive Swap Out | VESTA | Repair and test of a SSC Hard drive |
| Muscle Atrophy | PSYCHE | Measuring the calf and bicep muscle for atrophy – representative of a nominal medical procedure |
| Return Sample Inventory | CERES | Inventory and sorting of asteroid samples being returned to Earth |
| Air Filter R&R | VESTA | Replacement of DSH Air Filters |
| Sound Level Meter (SLM) Measurements | PSYCHE | Measurement of ambient sound levels within the DSH |
| Vehicle Survey | IRIS | Camera survey of the DSH exterior to survey potential MMOD damage |
| IRED Inspection and Cleaning | VESTA | Disassembly of an IRED Canister, cleaning and reassembly. |
| Exercise | PSYCHE | Crew Exercise (Crew members participating in the study do not have to actually perform exercise if they so desire). |
| Ovoid Canister Location | JUNO | MCC has schedule some time for the crew to search for the lost item onboard |

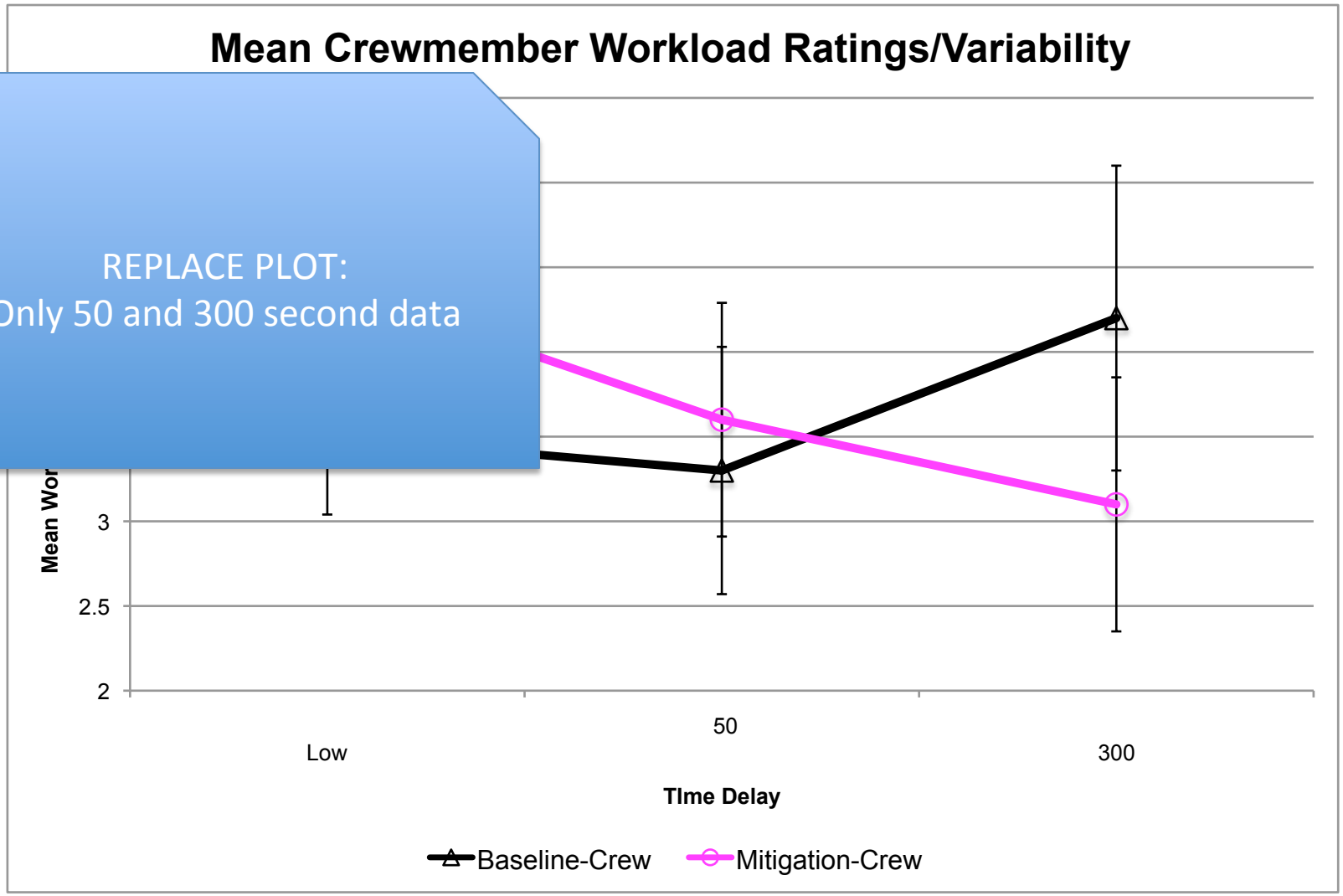
# Timeline

| Activity | Responsible Console | Description |
|---|---|---|
| Schedule/Prep-Work | KALI | Time set aside for the crew to review the timeline, prep their work, and meet as a team. During the mitigation runs only, the crew can also use this time to change the timeline if they desire using Desktop SCORE. |
| Daily Planning Conference (DPC) | FLIGHT | Traditional DPC as with ISS: tag up between the crew and the ground to discuss system status and activities of the day |
| Atrium Tank Fluid Fill | JUNO | Crew will initialize water transfer into the atrium tank and then terminate the flow when complete |
| EPO-Blog | KALI | Crew members will compose a blog entry about their day aboard the Cabot and the communication time delay – **NOTE:** These blogs will actually be posted on a PAO website! |
| Soil pH Determination | CERES | Determination of the soil pH for 5 plants |
| PAO Event | KALI | Most of the time this will be a fake PAO event and it is used as a placeholder for a time critical activity at the end of the simulation timeframe. However, in a few cases this will be a real EPO activity. |

# Baseline vs Mitigation Configuration

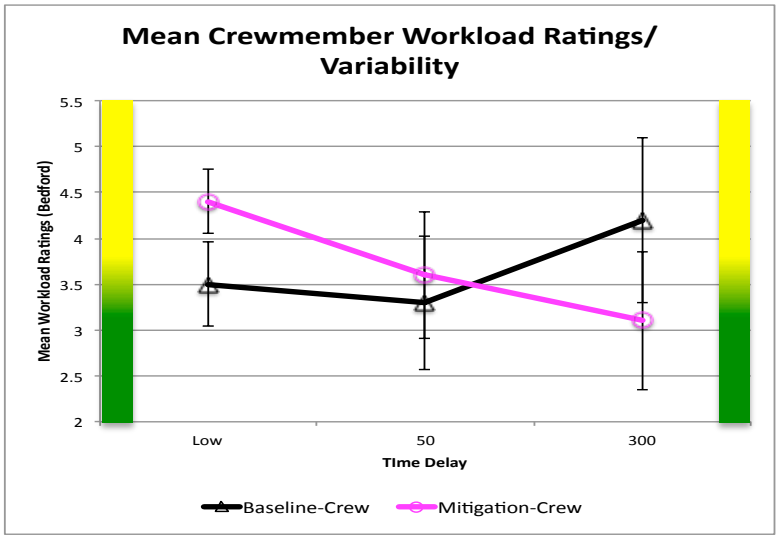
| Console/Crew (Roles) | Baseline Tools | Additional Mitigation Tools |
|---|---|---|
| Flight, Capcom | Crew Display, Mobile Score, VCOM | WebPD, Pidgin |
| Psyche<br>(Medical/ Flt Surgeon) | Crew Display, Mobile Score, VCOM | WebPD, Pidgin |
| Juno<br>(Electrical / Life Support) | Crew Display, Mobile Score, VCOM, MSOffice | WebPD, Pidgin, ACAWS |
| Kali<br>(OpsPlanner) | Score, Mobile Score, VCOM, MSOffice | WebPD, Pidgin |
| Iris<br>(Robotics) | Crew Display, Mobile Score, VCOM, MSOffice | WebPD, Pidgin |
| Vesta<br>(Mechanical Systems) | Crew Display, Mobile Score, VCOM, MSOffice | WebPD, Pidgin |
| Ceres<br>(Payloads) | Crew Display, Mobile Score, VCOM, MSOffice | WebPD, Pidgin |
| CMDR<br>(Fluid transfer, inspection, soil sample) | Crew Display, Mobile Score, VCOM, MSOffice | WebPD, Pidgin, Score, ACAWS |
| FE1<br>(Computer repair, sample inventory) | Crew Display, Mobile Score, VCOM, MSOffice | WebPD, Pidgin, Score, ACAWS |
| FE2<br>(repair, filter changeout, calf measurement) | Crew Display, Mobile Score, VCOM, MSOffice | WebPD, Pidgin, Score, ACAWS |
| FE3<br>(Medical, vehicle survey, equip. inspection) | Crew Display, Mobile Score, VCOM, MSOffice | WebPD, Pidgin, Score, ADUS |

# Analysis: Workload



# Analysis: Workload

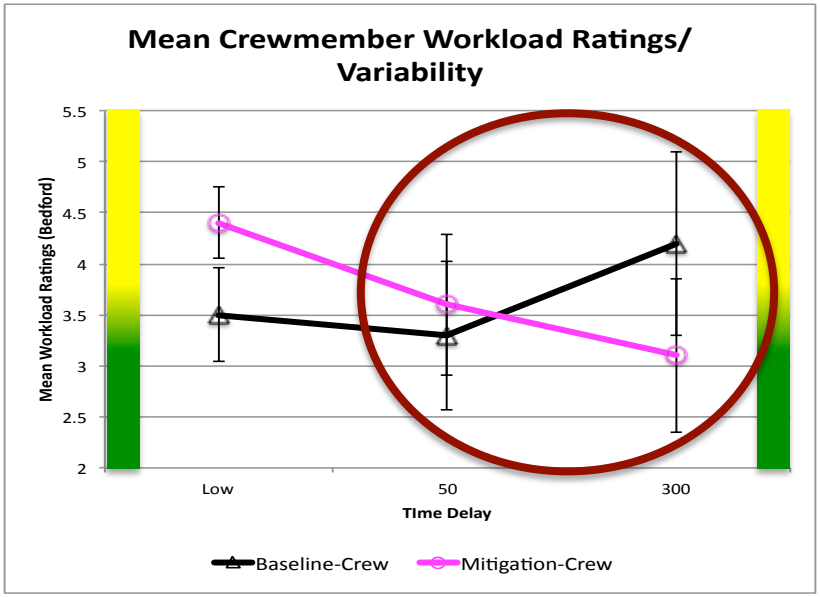
- Inflated "Low" Time Delay ratings likely due to lack of familiarity/ training with the DSH tasks, procedures, and crew-vehicle interface
  - Participants given limited "hands-on" training prior to runs
  - Low-Time Delay runs the first of the three in each day
- Low Time Delay Mitigation Ratings Higher than Baseline Ratings due to increased number of tools



# Analysis: Workload

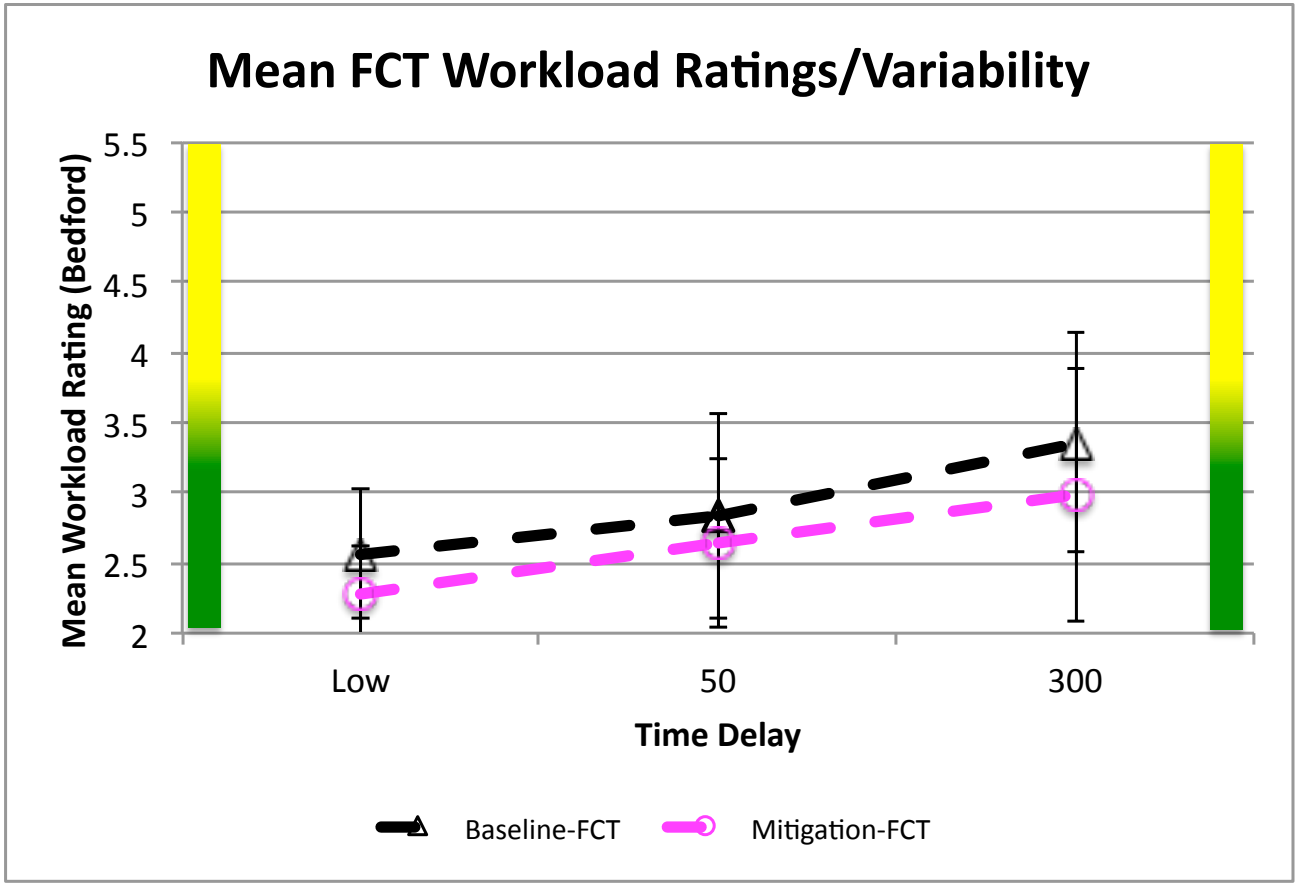
- 3-factor Analysis of Variance (ANOVA) for remaining data:
  - 4 (Crews)
  - 2 (Configuration; Baseline versus Mitigation)
  - 2 (Time Delay; 50 versus 300 sec)

- Results:
  - No main effect of Crew or Time Delay
  - Significant interaction of Configuration and Time Delay, $F[1,12] = 10.36$, $p < .01$.
    - Difference between 50 and 300 sec significant for Baseline, not for Mitigation



# Flight Control Team Workload

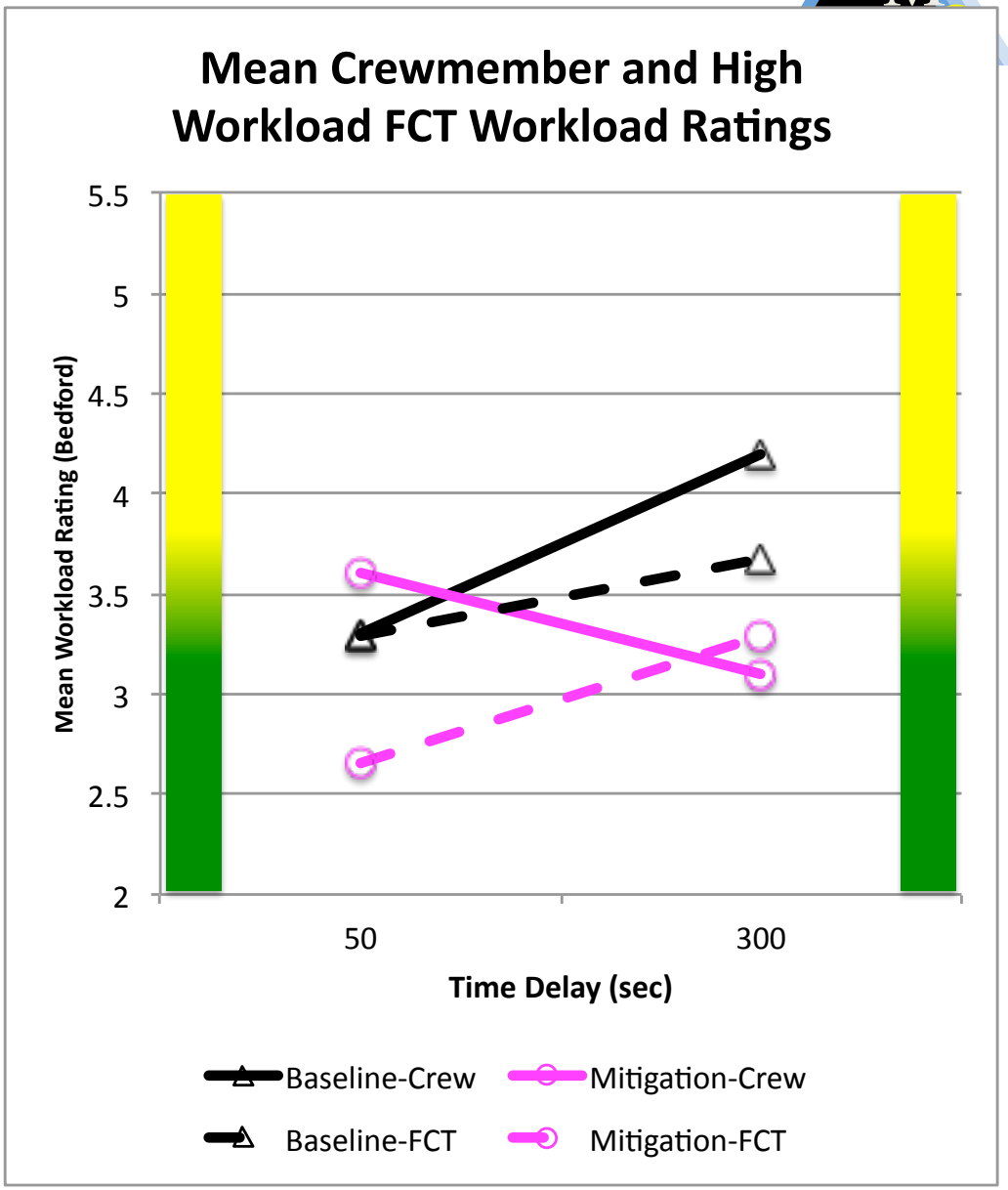
- 4 of 8 console positions yielded average workload ratings of 3 or below (green zone) in Baseline
- Flight, Capcom, Kali, Ceres rated workload above three
- To avoid floor effects, we analyzed FCT data with only these high workload console positions included



# Analysis: Workload

- FCT pattern different than crewmembers
  - Baseline workload consistently higher than Mitigation
  - Workload increased from 50 to 300 sec

- ANOVA results:
  - Main effects of Configuration and Time Delay approached significance, *F*'s (1,12) = 3.99 for Configuration and 4.12 for Time Delay, both *p's* <0.07.
  - Configuration by Time Delay Interaction not significant

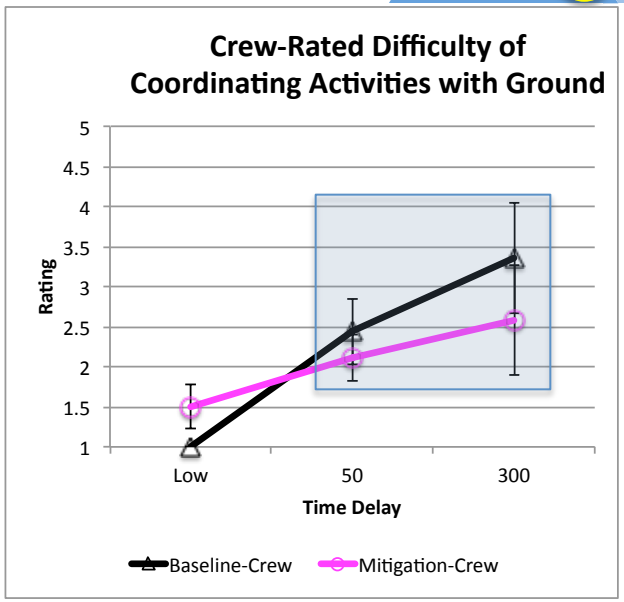


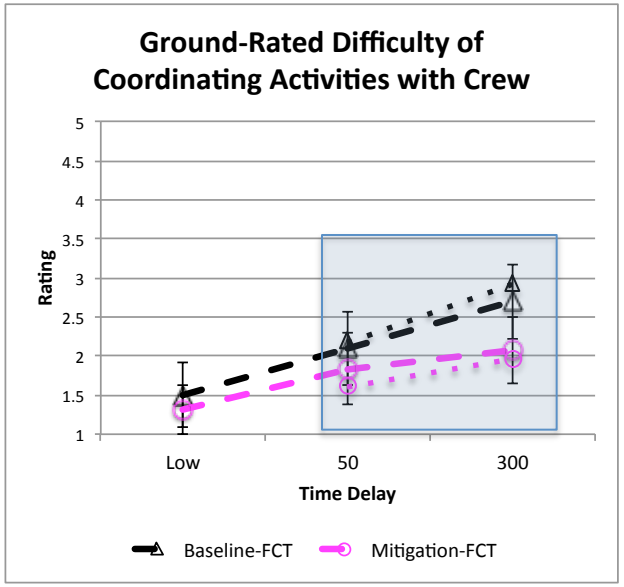
# Analysis: Coordination

- What contributed to workload increase from 50 to 300 sec for Crew in Baseline?

- ANOVA for Crew (Excluding low TD condition):
  - Coordination more difficult in Baseline than in Mitigation
    - $F(1,12) = 9.55$, $p < .01$
  - Coordination more difficult on runs with 300 sec of Time Delay compared to 50 sec
    - $F(1,12), 7.57, p<.01$

- ANOVA for FCT (Excluding low TD and low workload console positions):
  - Coordination more difficult in Baseline than in Mitigation
    - $F(1,12) = 14.5$, $p<.01$
  - Coordination more difficult with 300 seconds of Time Delay than with 50 seconds (but with lower significance threshold)
    - $F(1,12) = 5.31$, $p<.05$



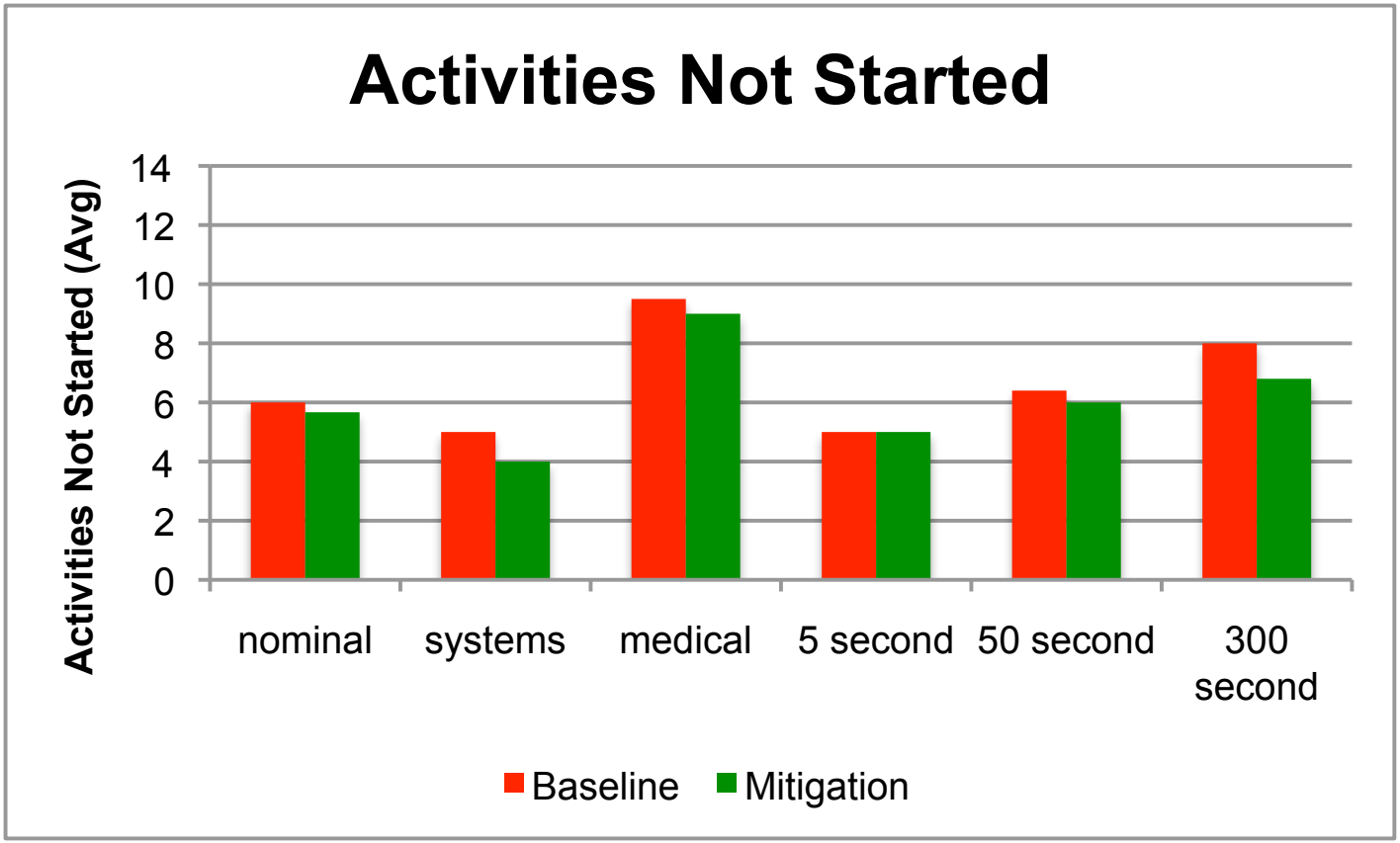
# Analysis: Coordination

•What contributed to workload increase from 50 to 300 sec for Crew in Baseline?

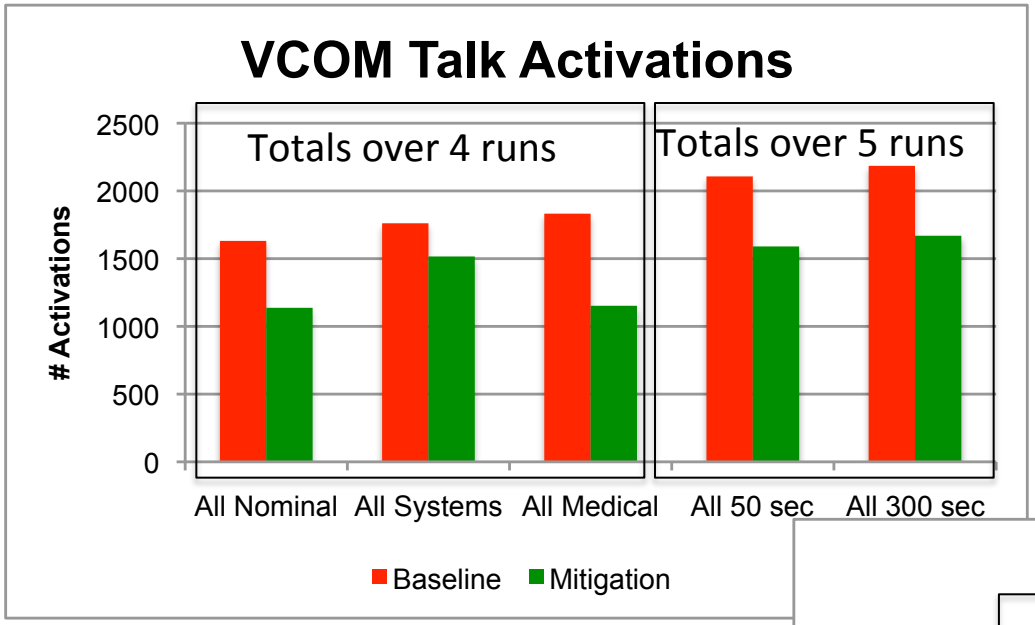
•Comments suggest a significant component of workload for crew in Baseline was coordination difficulties with ground
•Additional Evidence: Correlation coefficients between rated workload and coordination difficulty:

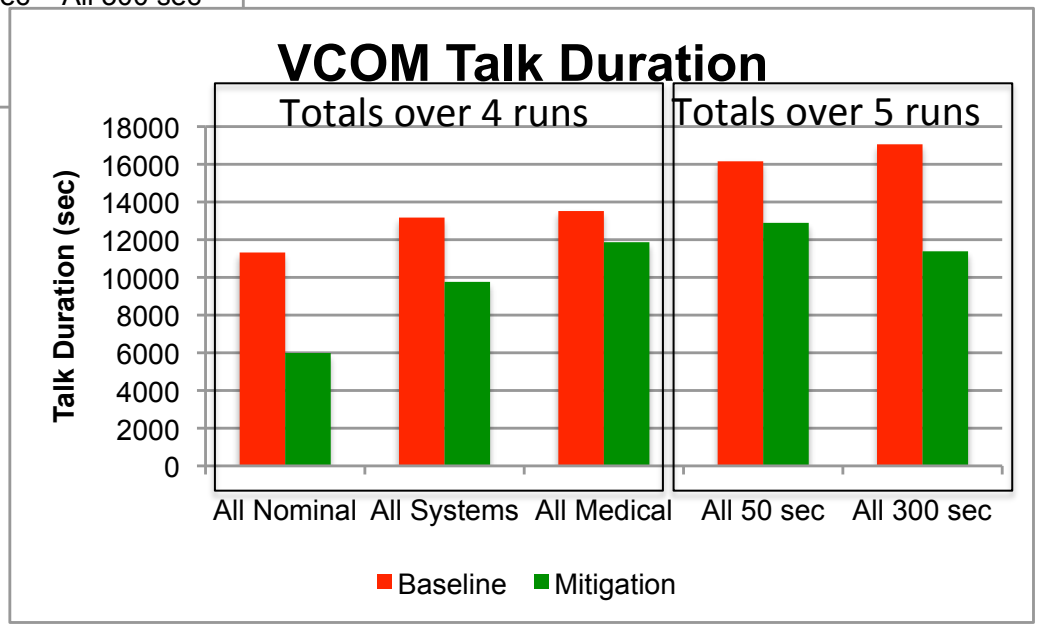
| | Crew | FCT |
|---|---|---|
| Baseline | .43 | .51 |
| Mitigation | .29 | .51 |

# Task Completion

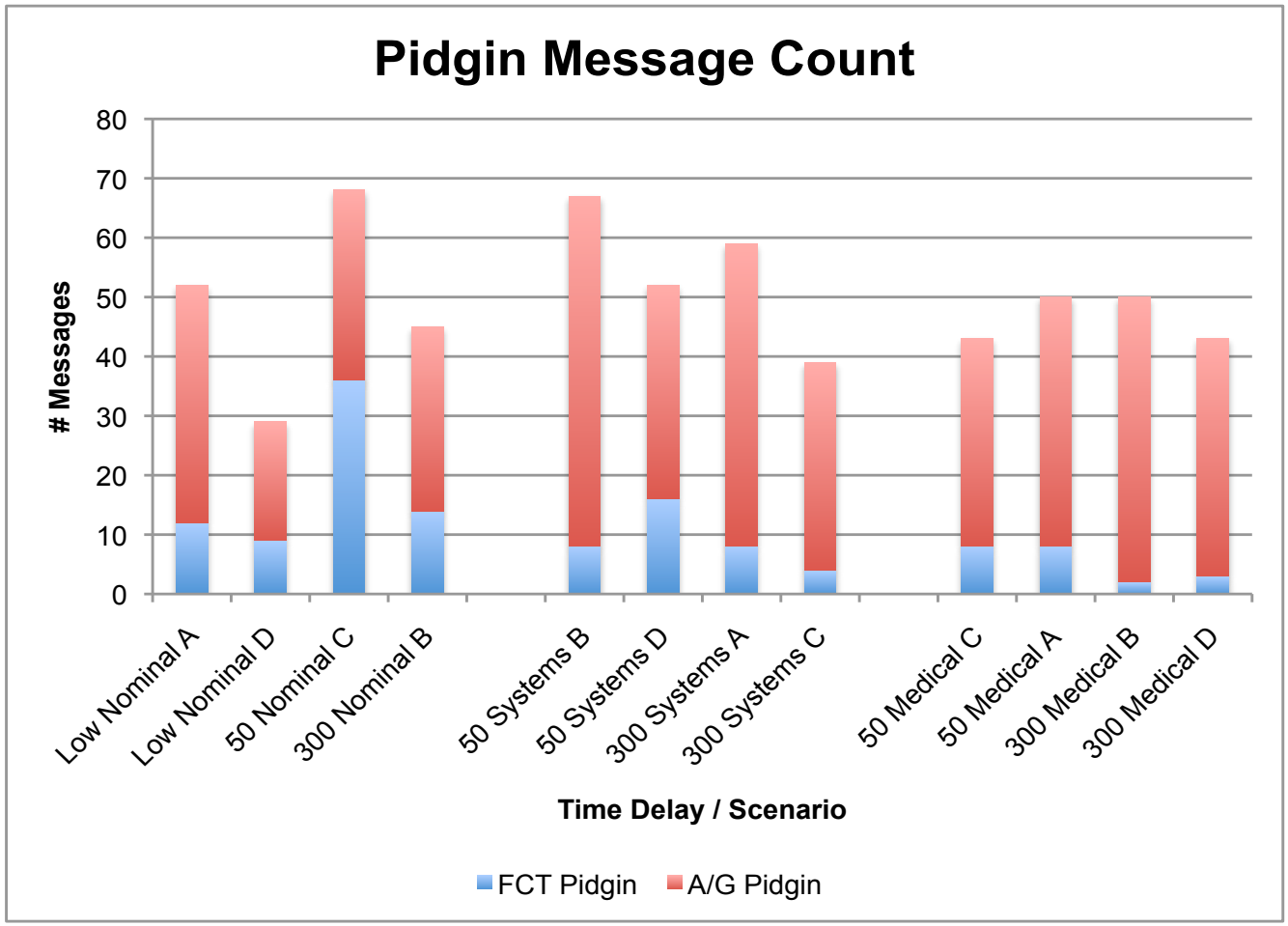


# Communication Analysis

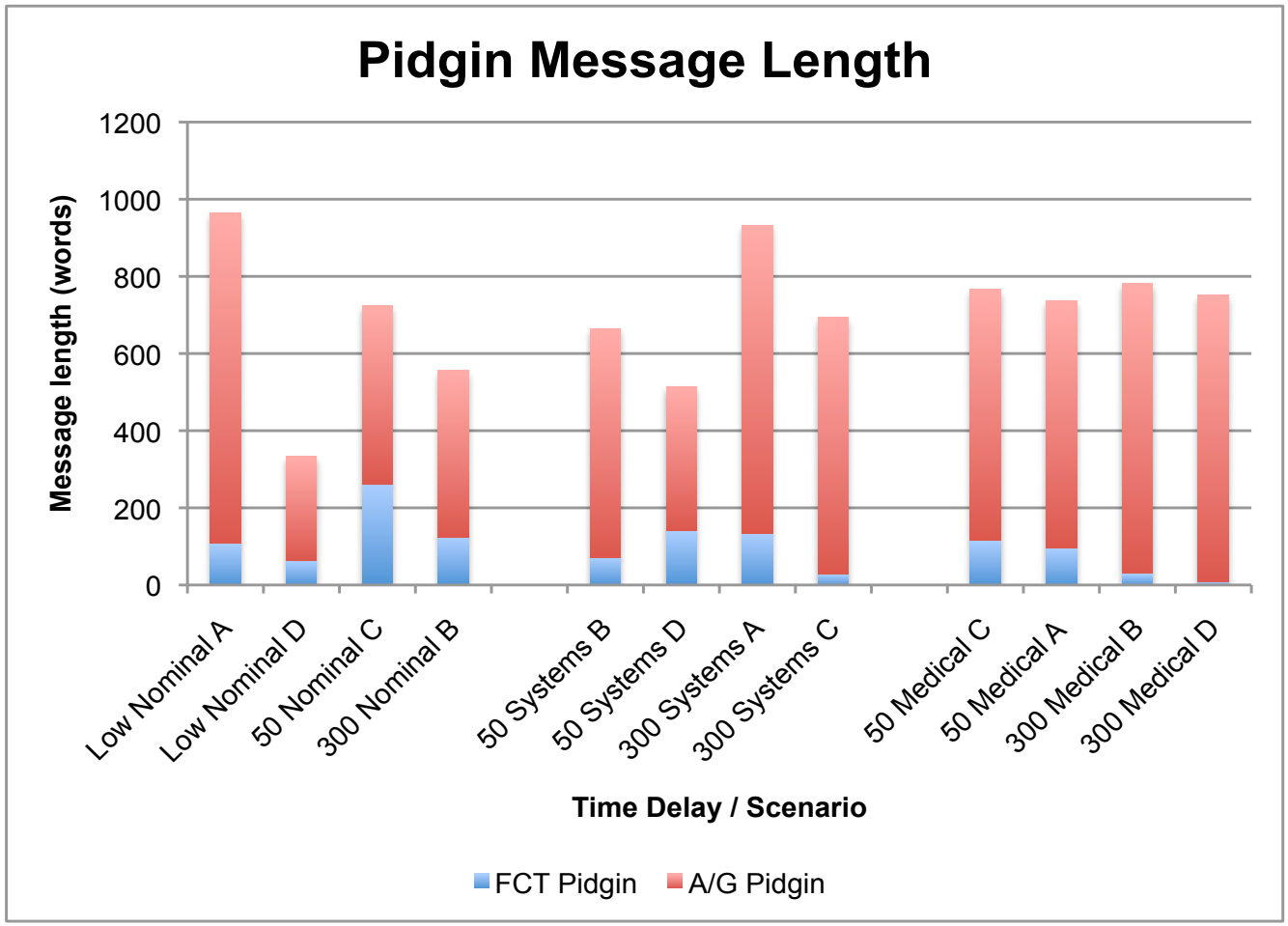


# Communication Analysis



# Communication Analysis



# Communication Analysis

| | Total talk time (s) | | |
|---|---|---|---|
| Delay Scenario Crew | Baseline | Mitigation | Ratio (M/B) |
| All Nominal | 11320 | 5988 | 0.53 |
| All Systems | 13173 | 9762 | 0.74 |
| All Medical | 13520 | 11867 | 0.88 |
| All 50 sec | 16158 | 12893 | 0.80 |
| All 300 sec | 17060 | 11384 | 0.67 |

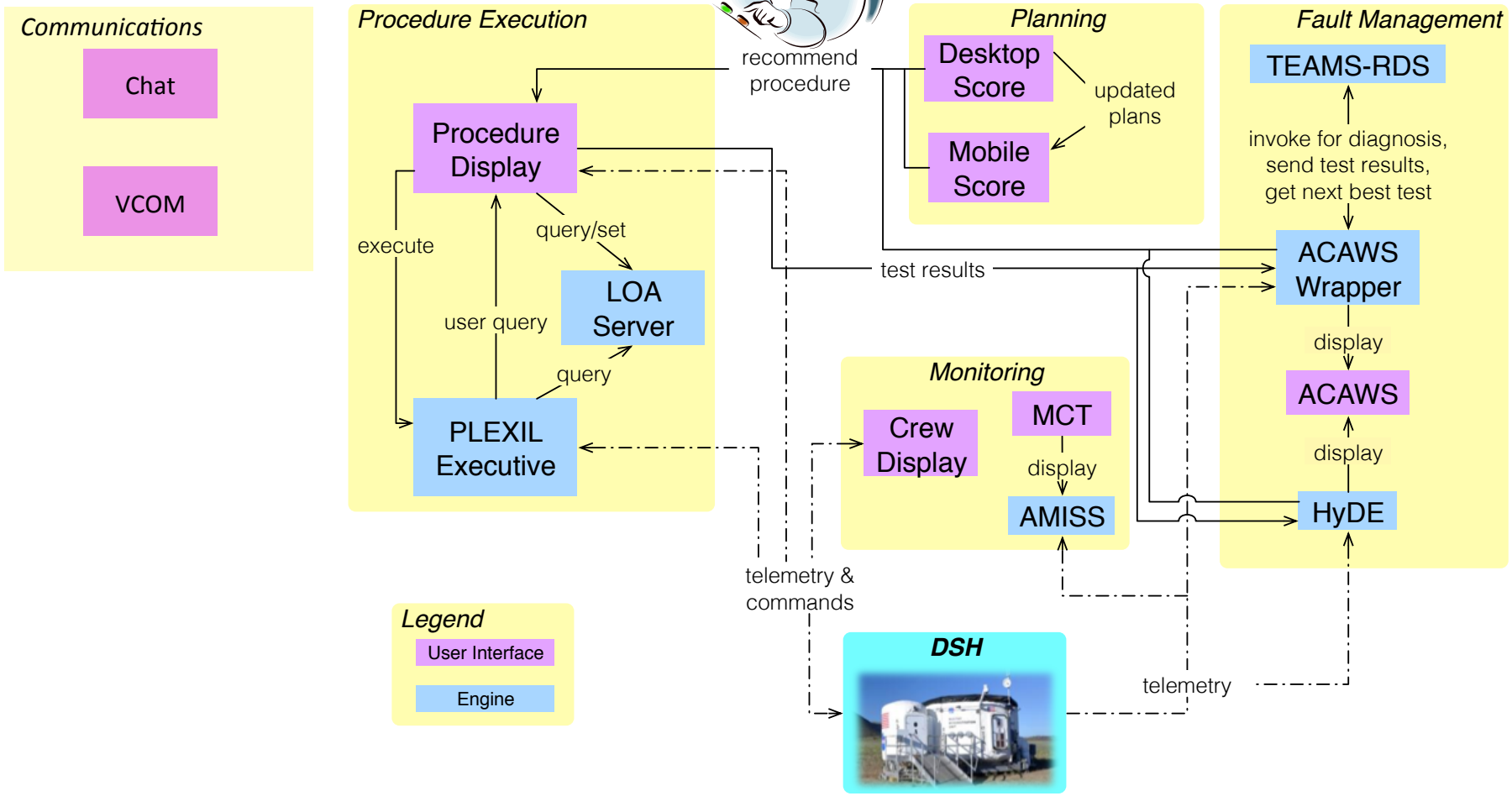
# Communication Analysis

- Why did communication go down so much in Mitigation?
- Three potential explanations:
  - Shared procedure execution status (eliminate communication)
  - ACAWS (eliminate communication)
  - Chat (replace communication)

# Communication Analysis

- Estimate time required to utter Pidgin messages
  - 2 word / sec(*)
- Re-compute communications 'time'

| Total Talk+Pidgin Time | | | | | | |
|---|---|---|---|---|---|---|
| | Pidgin | VCOM | Mitigation Total | Baseline | Ratio (M/B) | Talk only (M/B) |
| All nominals | 1288.5 | 5988 | 7276.5 | 11320 | 0.64 | 0.53 |
| All systems | 1402 | 9762 | 11164 | 13173 | 0.85 | 0.74 |
| All medical | 1517.5 | 11867 | 13384.5 | 13520 | 0.99 | 0.88 |
| All 50 Sec | 1702.5 | 12893 | 14595.5 | 16158 | 0.90 | 0.80 |
| All 300 Sec | 1856.5 | 11384 | 13240.5 | 17060 | 0.78 | 0.67 |

- *(very unscientific methodology used!)

# Mitigation Configuration