Lessons Learned Briefing PLSS 2.0

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Preliminary Thoughts

- My preparation of this presentation prompted many questions which had not occurred to me during the May 31, 2012, briefing
  - Some questions are not specific to the PLSS 2.0 manufacturing and test topic, but I didn’t want to lose them
- Answers provided today will influence the final, written report to be provided after this briefing

Lessons Learned Briefing

- Made up of five components:
  - Comments on what I saw and heard during the briefing, related to my own experience
    - Including questions that I failed to ask earlier
  - Possible risks and some thoughts on how to mitigate them (may revisit some topics from above)
  - Thoughts on what needs to be done to have a complete EVA system (may revisit above comments)
  - Some comments on CTSD – ADV – 780 “Development Specification for the Advanced EMU (AEMU) Portable Life Support System (PLSS)”
  - Random comments

Briefing Material

- Overview – Carly Watts
  - Team – Unbelievable depth
    - Specialists for everything!
    - Very heavy on analysis; maybe short on design
    - Where is manufacturing support on the team?
      - Usually called manufacturing engineering
  - System/Component advancements
    - New technology items just about across the board
      - Up side: if they work as advertised, the system is a step function forward
      - Down side: significant problems with any one can pace the whole system

Briefing Material

- Overview – Carly Watts (cont'd)
  - Project Roadmap
    - Shows a luxuriously-paced schedule – e.g., three iterations after PLSS 2.0 to get a DTO item
    - No tie-in of CWCS 2.0 to PLSS 2.0 shown
      - This is a critical subsystem
      - Need to find problems as soon as possible
    - No tie-in of suit to PLSS 2.0 configuration shown
      - Crew evals with hi-fi mockups
    - Should maybe have an accelerated schedule in your "hip pocket" if funding gets tight, and you need an earlier DTO

Briefing Material

- Overview – Carly Watts (cont’d)
  - PLSS 1.0 findings
    - SWME backpressure valve; RCA pneumatic valve identified as areas for improvement – more on these later
    - Good to see the importance recognized of knowing the configuration, and how it relates to PLSS 2.0
      - Keep that philosophy throughout the program

Briefing Material

- Overview – Carly Watts (cont'd)
  - PLSS 2.0 Development
    - It may be not feasible, but if you could evaluate realistic airlock and suit port interfaces with PLSS 2.0, it could save time later

Potential Risks/Possible Mitigation Actions

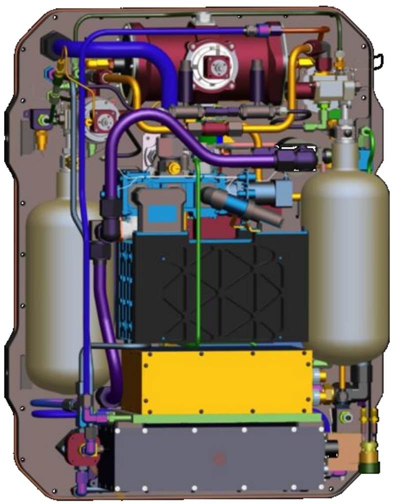
- Risk
  - Problems with manufacturing final version (post-PLSS 2.0)
    - E.g., accommodation of structural loads
  - Difficulty of coordinating "long distance" with Glenn on CWCS/PLSS 2.0 testing at JSC
  - Out-year funding problems and/or accelerated schedule
  - Problems in integration of suit, PAS, PLSS, Suit-port
    - Current plan seems to push integration out pretty far

- Mitigation
  - Incorporate Manufacturing Engineering for later versions (see next slide)
  - Have Glenn rep. on site for critical testing, starting with CWCS 2.0
  - Have "hip-pocket" schedule for getting to DTO configuration faster
  - Early evaluations of integrated system – hi-fi mockups; table-top CWCS/controls & displays mockup

Risk Mitigation

Management

PLSS Hardware



Power, Avionics & Software

Manufacturing Engineering

Design & Analysis

Suggested Addition

Briefing Material

- Test Objectives – Carly Watts
  - PLSS level test objectives
    - Glad to see you plan to run to failure – define that green squatcheloid!
    - Good review comment on demonstrating rapid turnaround – need to explore all the possible ways you can use (and abuse) the system
    - The metabolic simulations need to mimic how humans actually react, e.g., I think that you can hit the RCA with a 3000 btu CO2 load rapidly, but the corresponding water load may lag

Briefing Material

- Test Objectives – Carly Watts (cont'd)
  - PAS
    - Default modes and any manual backups need to be demonstrated – totally automatic makes me nervous
  - Vehicular Interfaces
    - Try to determine what the promising options are for vehicle power supplies
      - Try to simulate expected ripple, impedances, etc.
      - We got some unwelcome surprises in Shuttle
  - Lack of dynamic testing requirements leaves a hole…

Briefing Material

- Test Objectives – Carly Watts (cont’d)
  - I didn’t find anything specifically related to crew-operated controls and displays

Risk Mitigation

- Risk
  - Undesirable Reaction of RCA to early hi-CO_2/low H_2O
    - Sweat rate is reaction to increase in body core temp
  - Crew non-acceptance of controls and displays
    - Don't see much evidence of manual backup – does crew agree with current concept?
  - Vehicular power interface incompatibility
  - Packaging problems due to incorporation of system accommodation of dynamic environmental loads, e.g., brackets, line supports.

- Mitigation
  - Incorporate a profile with early high (~700w) CO_2 with low H20 – mimic human performance
  - Have crew evaluate C&D hi-fi mockups/table-top simulator
  - Get over/under voltage; impedance; and ripple requirements out there ASAP
  - Look at worst combination of Dragon and Progress loads and see effects on design.

Briefing Material

- PLSS Components – Colin Campbell
  - POR/SOR
    - Good to be using Monel from the start
    - Are seats Vespel?
    - Identical design should be a benefit
    - Statement made that POR/SOR may be orientation sensitive
      - This could be a risk area for dynamic testing
    - What happens if/when stepper motor fails?
      - Fails to change position
      - Fails open/Fails closed
  - Test article pressure vessel
    - Carbon overwrapped Al bottle – has JSC structures bought off on the bottle vis-à-vis static fatigue failure mode?
    - Arde cryoformed SS planned for flight bottle – Unaged?

Risk Mitigation

- Risk
  - Soft seat design incompatible with oxygen
  - POR/SOR may be damaged by dynamic loads, if orientation sensitive
  - Static-fatigue failure of test pressure vessel
  - Stress-corrosion sensitivity of flight cryoformed SS bottle
    - Aged material has higher strength than unaged, but is stress corrosion sensitive

- Mitigation
  - Use Vespel as early as possible
  - Impose dynamic loads (worst-case Dragon/Progress) and assess results
  - Have JSC structures validate safety
  - Assure unaged material used for flight bottle

Briefing Material

- PLSS Components – Colin Campbell (cont'd)
  - Fan
    - Speed controlled by flow sensor feedback
    - 4.7 CFM – is this constant volumetric flow rate independent of pressure? Is this enough to wash out CO_2 with representative helmet flow configurations at various met rates?
    - What happens if flow sensor feedback lost or out of spec high?

Briefing Material

- PLSS Components – Colin Campbell (cont'd)
  - Gas Sensor
    - Seems to be very different from straight IR absorption in the CO_2 band
      - Do the sensors require reference cells, or are they calibration-free in operation?
    - Is the 5 second response time for the sensor alone, or in the system? Specs should probably be more relaxed at the system vs component level to avoid eliminating good sensors
    - How do these sensors work to control the RCA?
    - Even though the system operation would seem to be biased towards dry conditions, what happens if liquid water enters the sensor? Are there steps being taken to eliminate/alleviate this potential condition?
    - Having the ability to monitor water and Oxygen in addition to CO_2 should be a very valuable engineering tool

Briefing Material

- PLSS Components – Colin Campbell (cont'd)
  - RCA
    - Vast potential improvement over Metox
    - RCA is perhaps the most significant "heavy-hitter" change to the PLSS schematic from previous systems
      - Goes one better than Metox – regeneration in place
      - Removes water – mixed blessing?
      - Has (theoretical) potential of exposing suit loop to vacuum
      - Interrupts flow to helmet
      - Depends on input from gas sensor(s?) for operation
      - Was not tested in all-up configuration in PLSS 1.0 tests
        - » No bypass valve
      - As I understand it, RCA will not work on Mars (4.3 mm ppCO2)
        - » What is the planned approach for Mars?
    - 1-3 minute cycle rate – why not simplify and go to fixed cycle rate?
    - What is overdesign margin on CO2 and H2O removal? What happens if water comes through?

Risk Mitigation

- Risk
  - Failure mode of exposing suit loop to vacuum during bed changeover
  - Flow interruption to helmet undesirable
  - Control system doesn't work, e.g., CO_2 sensor failure or controller failure
  - Bypass valve (if incorporated) fails to operate
  - RCA doesn't work for Martian atmosphere

- Mitigation
  - Verify through FMEA and design features that this cannot happen, or takes several sequential failures
  - Verify through design/test that either flow interruption OK, or bypass valve makes it tolerable
  - 1) Assure default configuration gives automatic adequate cycling for high met rate; or 2) have manual select
  - Have manual override
  - Use something like Metox

Briefing Material

- PLSS Components – Colin Campbell (cont'd)
  - Liquid-to-gas HX
    - Glad to see drain ports (you never know…)
  - Vent Flow Sensor
    - This is small, but a "heavy hitter"
      - It controls fan speed
      - It may be orientation sensitive – therefore, may be sensitive to dynamic environmental input
      - Previous questions about effects of VFS failures – default configuration

Risk Mitigation

- Risk
  - Moisture condensation in HX (e.g., due to breakthrough of RCA)
  - Vent flow sensor damaged by dynamic loads

- Mitigation
  - For PLSS 2.0, check drains periodically. If water found, determine cause and if viable for flight, incorporate water trap
  - Impose worst case Dragon/Progress loads and assess results – take action if required

Briefing Material

- PLSS Components – Colin Campbell (cont'd)
  - Trace contaminant control
    - Are there no SOA active contaminant removal systems?
    - A powered system might save quite a bit of weight and volume

Risk Mitigation

- Risk
  - Channeling of charcoal contents due to dynamic environments

- Mitigation
  - Impose worst-case Dragon/Progess dynamic loads and assess results

Briefing Material

- PLSS Components – Colin Campbell (cont’d)
  - Feedwater Supply Assembly
    - Is heat seal method used a mechanical or RF Type?
    - Any thought given to redundant seals?

Risk Mitigation

- Risk
  - Water tank seal leaks
  - Gas bubble prevents full fill (translucent design would show condition)
- Mitigation
  - Incorporate redundant seal
    - (Problem – how to check it?)
  - Assure feedwater supplies compatible with degassed water, OR, incorporate gas separator for fill

Briefing Material

- PLSS Components – Colin Campbell (cont'd)
  - Water pump
    - Have subatmospheric tests of the PLSS 2.0 pump been performed, and if so, what were the results?
    - Positive displacement is good from a pumping standpoint; requires the relief valve to prevent overpressurization
      - Will relief valve be checked as part of pre-use checkout?
      - In any event, with all the electronic controls, why not have an automatic shutdown at, say, 20 psid?

Risk Mitigation

- Risk
  - Pump cavitation
  - Pump relief valve fails closed (or open)

- Mitigation
  - Increase water tank supply pressure, if required
    - (pressurization line/regulator required, OR stretched bladder)
  - Check before use; assure failure in use detected by CWCS – shutdown primary; go to aux.

Briefing Material

- PLSS Components – Colin Campbell (cont'd)
  - Avionics coldplate
    - Prudent to design, build and evaluate this, even if eventual plans are not to require it
    - Plans change….

Briefing Material

- PLSS Components – Colin Campbell (cont'd)
  - Battery
    - Suggest individual cell protection circuitry in Li ion battery in case of internal short/runaway
    - Batteries are black art…
    - For final battery, look at all technologies - lithium ion polymer, nickel-metal hydride and silver-zinc need to be researched, along with any other promising technologies

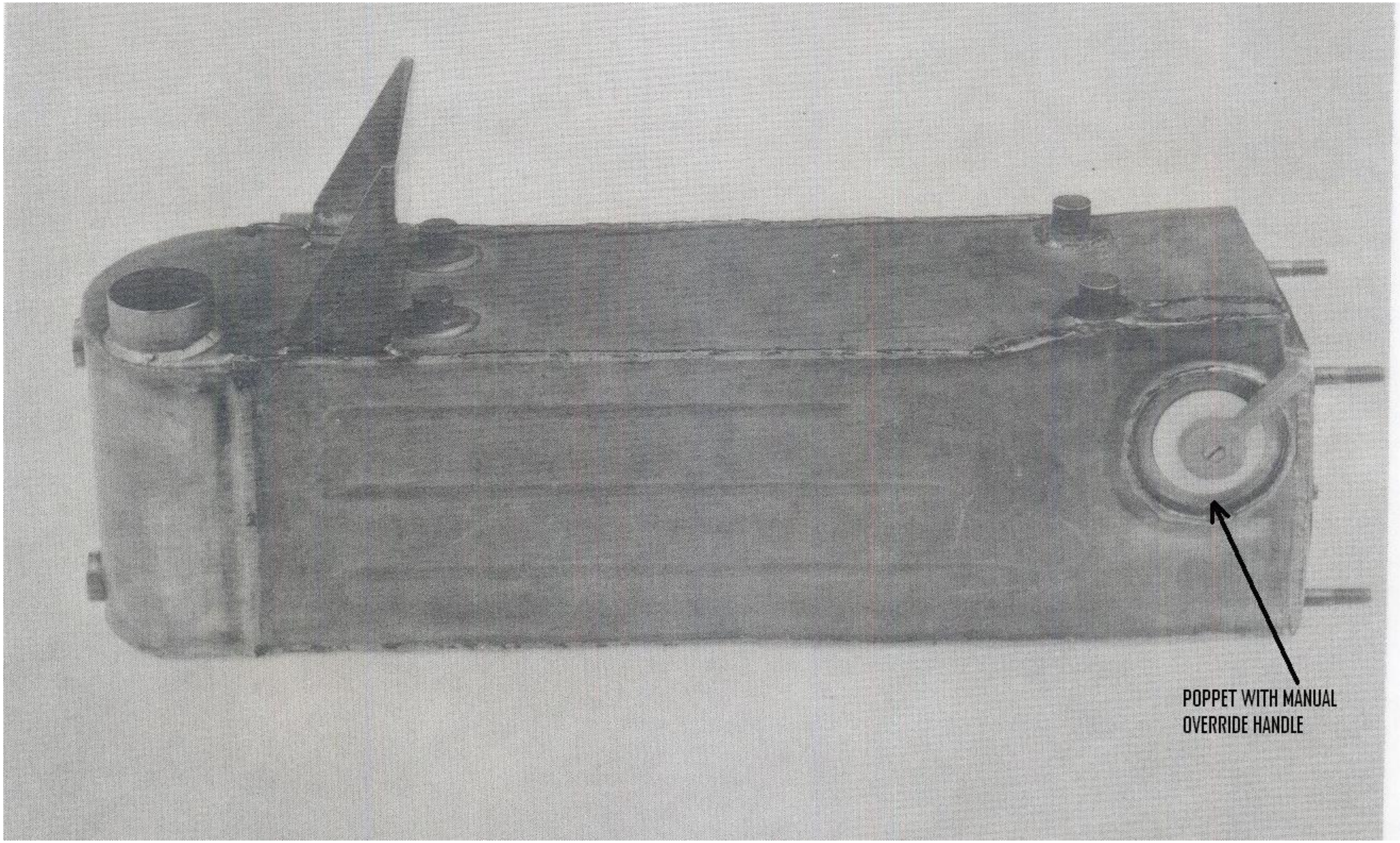
Briefing Material

- PLSS Components – Colin Campbell (cont'd)
  - SWME
    - Another "heavy hitter" in terms of new technology
    - Back-pressure controls had problems in the past
      - Apollo ECS 240 controller – had difficult problem statement: +/- 2 deg F. over wide range of equipment and environmental loads (IMU protection)
      - Gemini S/C and ELSS evaporators – Wax pellet (Vernatherm) expansion/contraction opened/closed steam valve – very coarse control
      - Extremely accurate control probably not required for spacesuit application
    - What happens to biocide upon evaporation of water?
    - What level of filtration is required?

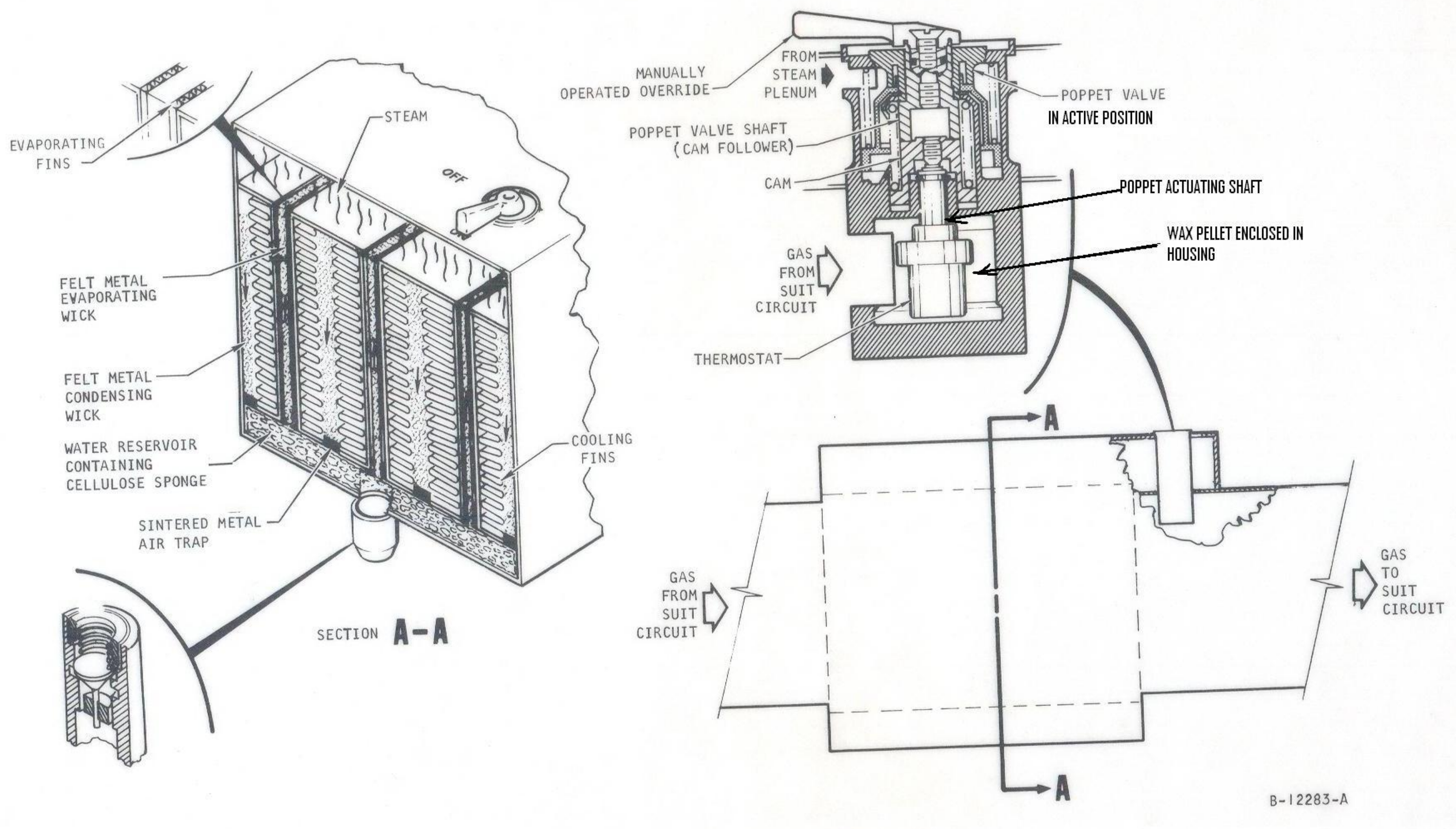
Risk Mitigation

- Risk
  - Biocide inhibits water boiling properties of HFM
  - Problems with back-pressure controller
- Mitigation
  - Test; if results show problem, investigate other biocides, e.g., silver ion
  - Investigate other means of back-pressure control (see next slides)

Gemini ELSS Heat Exchanger



Gemini ELSS Steam Control Valve



Briefing Material

- PLSS Components – Colin Campbell (cont'd)
  - Thermal control valve
    - Provides thermal control by varying flow (like Skylab) rather than by varying temperature (like Shuttle)
    - Skylab crews reported some cold spots, but nothing intolerable
    - Does CV have manual override?

Risk Mitigation

- Risk
  - Crew deems flow control (vs temp control) undesirable
  - Automatic control fails

- Mitigation
  - Re-plumb circuit a la Shuttle
  - Incorporate manual override

Briefing Material

- PLSS Components – Colin Campbell (cont’d)
  - Mini-ME
    - Looks like better packaging than full sized ME
    - Why not use same simplified controls on SWME?

Briefing Material

- PLSS Components – Colin Campbell (cont'd)
  - Positive Pressure Relief Valve
    - Needs to have fail-open flow < worst regulator low flow

Briefing Material

- PLSS Components – Colin Campbell (cont’d)
  – COTS/Other hardware
    - Need to have a good idea of what will be involved to make them compatible with oxygen

Briefing Material

- PAS – Scott Bleisath/Mike Lichter
  - CWCS
    - Significant change – adding the second “C”
      - Seven critical LSS controllers
    - “DCM” desktop – will it “look” like a prototype item for crew use?
    - Manual backup for critical control functions?
    - B/U plans for “long poles”?

Risk Mitigation

- Risk
  - Any problems with controllers
    - SWME
    - Fan
    - TCV
    - POR/SOR
    - RCA
    - Pump

- Mitigation
  - Have "hip-pocket" alternate paths
    - Vernatherm (mechanical)
    - Go to constant speed
    - Manual
    - Pneumatic (with var. settings)
    - Default setting (worst case)
    - Constant speed

Briefing Material

- Test Program – Carly Watts
  - Critical to have CWCS in PLSS 2.0 testing
  - Overall, CTSD-ADV-986 looks to be comprehensive
    - Have a rapid way to incorporate unplanned tests
      - Document the configuration, procedures and results, including unexpected findings

Briefing Material

- PLSS Development Lab – Dave Westheimer
  - Looks thorough – look forward to what will be required for oxygen use
    - Charging
    - Test panels
    - Isolation from nitrogen

Briefing Material

- Test Point Matrices – Carly Watts
  - Metabolic rate
    - Suggest a profile with a high (i.e., 700 W) spike at the end of the mission
      - Simulates difficulty in returning to habitat/vehicle at the end of EVA
  - Helmet CO_2 washout
    - Suggest STS testing of helmet duct configurations, manned testing on treadmill, varying metabolic rates
  - Manned evaluation of controls and displays
    - Suited, pressurized - STS

Briefing Material

- Analysis – Bruce Conger
  - Extensive boundary testing
  - Separate manned tests of red. Tube LCG with and without TCU

Briefing Material

- Hazards/Controls – Colin Campbell
  - Make sure you have overvoltage protection on power supplies
  - Make sure there’s no way to apply reverse polarity, OR have protection on the hardware

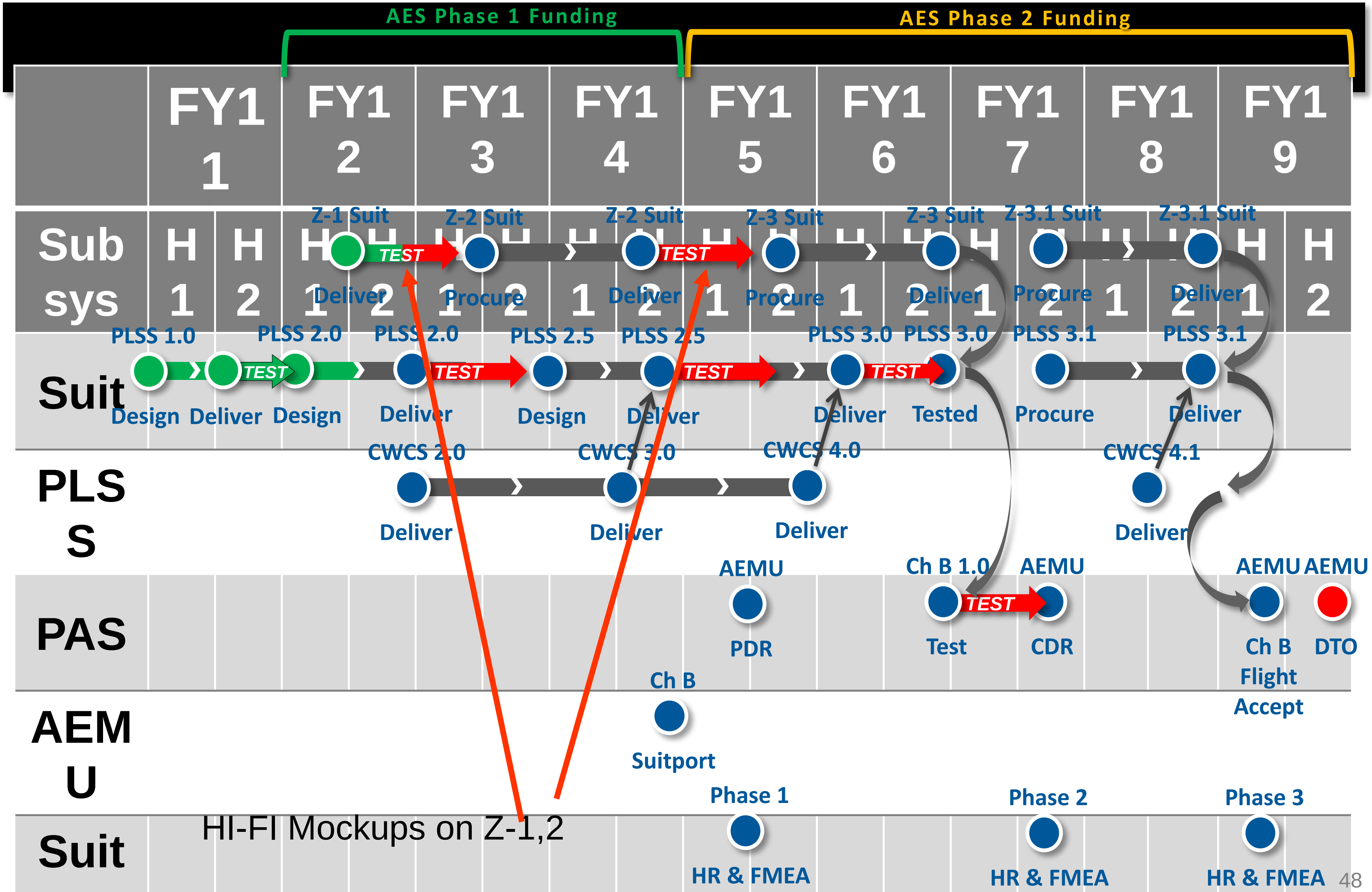
Briefing Material

- Test Operator Training and Forward Work – Carly Watts
  - Have tie-in process for oncoming team (overlap, briefing of new team by outgoing team)
  - Have a process for documenting, tracking, investigating and dispositioning anomalies

System-level considerations

- Early system-level evaluations
  - HI-FI mockups, or whatever you have
  - PLSS, C&D, Suit, Suit-Port
    - Also, any EVA accessories that people are thinking of – tools, carts, etc.
  - Multiple crew evaluations early on
- CO_2 removal for Mars
  - What looks good, or at least, feasible?

AES Advanced EVA Project Roadmap



System-level considerations

- If funding dries up and/or you get a chance for earlier DTO
  - Look at going from PLSS 2.0 to PLSS 3.1
    - Oxygen compatible; suitable for dynamic environments
  - Use same philosophy for suit, CWCS
- Try to get manned thermal vacuum testing with oxygen as early as possible
  - System level is where the tough problems come out

Comments on CTSD-ADV-780

- 3.2.1.1 Operating Life
  - Strongly suggest that during development, records of pressure cycles on all pressurized containers (e.g., bottles, water storage) be kept, along with powered time
    - History has shown that operational use may impose more cycles than planned
    - Similar concerned with powered-on time
    - May show that flight item requirements can be relaxed
- 3.2.1.4 Limited Life
  - Best case – no limited life; reality – be prepared for limited life items – be able to track

Comments on CTSD-ADV-780

- Table 3.2.5.1 Leakage rates
  - Worst case component leakages may exceed loop allowables
  - Suggest RMS approach for evaluating components
  - Otherwise, may have to “cherry-pick” components

Comments on CTSD-ADV-780

- Table 3.2.17.2-1 – Transient Metabolic Rates
  - Average inspired CO_2 concentration dependent on helmet duct configuration, and results of human tests
  - Suggest parallel tests of helmet/duct configurations with subjects of various sizes
- 3.2.18 Impact Tolerance
  - I think we also had a requirement for an impact with a 0.020” radius corner (like a filing cabinet)
    - System just had to hold together; didn’t have to operate in spec

Comments on CTSD-ADV-780

- 3.5.2 VENTILATION FLOW (FN-323)
  - May be able to get by with less, if testing of helmet/vent duct indicates
- 3.5.10.3 FREE WATER TOLERANCE - sensors
  - Very prudent to allow for free water – it’s likely to happen
- 3.5.10.4.4 RESPONSE TIME (CO2 sensor)
  - Make sure system level response time allows for physical location of sensor
    - Don’t tax sensor with needing to operate the same as it would as a component

Comments on CTSD-ADV-780

- 3.5.19 NEGATIVE PRESSURE RELIEF
  - Prudent to allow package space/accessibility for this in case it's needed
- 3.5.20.2 POSITIVE LOCKING AND CONFIRMATION (Purge Valve)
  - Suggest at least two separate and exclusive motions to open valve
- 3.6.7 THERMAL CONTROL VALVE
  - Suggest manual backup
  - Interested in crew response to flow variation vs temperature variation

Comments on CTSD-ADV-780

- 3.6.11 FEEDWATER QUANTITY
  - What is potential for a gas bubble forming when pressure decreases?
  - How do you deal with one, if it occurs?
- 3.6.18 OVER-PRESSURE PROTECTION for water loop
  - How is relief valve checked before use?

Comments on CTSD-ADV-780

- 4.1 VEHICLE INTERFACES
  - 4.1.1 POWER
    - Make sure that impedances and ripple are compatible with PLSS components
- 5.1.5 DYNAMIC LOADS
  - 5.1.5.1 RANDOM VIBRATION
    - Suggest looking at worst case combination of Dragon and Progress module launch/landing requirements

Random Comments

- Interfaces, Interfaces, Interfaces…
  - You've got 'em aplenty
    - With other pieces of hardware
    - With other centers
    - With unknown vehicles
  - The tie-in between the suit, PLSS, CWCS and suit port looks to be pushed downstream
- Get system-level testing done as soon as you can
  - You are working from the components outward
  - When you get to a system level, you find out how things REALLY work
  - This is where assumptions are verified or thrown out
  - Interfaces are really defined
- Suggest some residency by Glenn at JSC and vice versa
  - Communication tools are great, but nothing beats being on the spot
- The effects of dynamic environments on system design can be significant
  - Brackets, supports, etc. can complicate an otherwise clean design
  - Need to find these out as soon as possible
  - Design in margin

Random Comments

- The team is impressive
  - Lots of capable, motivated people
  - Seems to be short of manufacturing engineering
    - Probably should start involving them
- Schedule is laid-out; laid-back
  - Remember the other end of the spectrum: We went from a standing start from March 26, 1965 to the first USA EVA on June 3, 1965
  - Be prepared for acceleration, cutting back
  - Have ideas for system simplification in mind
- A lot of very new technology being pursued in parallel
  - Be open to back up/back out approaches

Concluding Remarks

- A lot of what I've said isn't directly applicable to PLSS 2.0
  - I didn't want to lose the thoughts
  - Use what seems to fit
- Most Important, enjoy today…this could be as good as it ever gets…