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)
  – 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; tabletop CWCS/controls & displays mockup
Risk Mitigation

Management

PLSS Hardware

Power, Avionics & Software

Design & Analysis

Manufacturing Engineering

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-CO2/low H2O
    • 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) CO2 with low H2O – 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 CO2 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 CO2 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 CO2 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., CO2 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/Proges 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 CO2 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

• CO2 removal for Mars
  – What looks good, or at least, feasible?
## AES Advanced EVA Project Roadmap

### Subsys

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### Suit

- **Z-1 Suit**: Procure, Deliver
- **Z-2 Suit**: Procure, Deliver
- **Z-3 Suit**: Procure, Deliver, Tested

### PLS

- **PLSS 1.0**: Design, Deliver
- **PLSS 2.0**: Deliver
- **PLSS 2.5**: Deliver
- **PLSS 3.0**: Deliver
- **PLSS 3.1**: Deliver

### PAS

- **AEMU**: PDR, Test
- **Ch B**: Flight, DTO

### AEMU

- **Phase 1**: HR & FMEA
- **Phase 2**: HR & FMEA
- **Phase 3**: HR & FMEA

### HI-FI Mockups on Z-1,2

AES Phase 1 Funding

AES Phase 2 Funding

- **Z-1 Suit Procure**
- **Z-2 Suit Deliver**
- **Z-2 Suit Design**
- **Z-3 Suit Deliver**
- **Z-3 Suit Procure**
- **Z-3.1 Suit Deliver**
- **Z-3.1 Suit Procure**
- **Pls 2.5 Design**
- **Pls 2.0 Deliver**
- **Pls 2.5 Deliver**
- **Pls 3.0 Deliver**
- **Pls 3.1 Deliver**
- **Pls 4.1 Deliver**
- **AEMU AEMU**
- **Ch B 1.0 Test**
- **Ch B Flight Accept**
- **Suitport**
- **Phase 1**
- **Phase 2**
- **Phase 3**
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 CO2 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…