Center of Excellence for Commercial Space Transportation

Summary of Research Theme 3 Workshop:

Human Spaceflight

May 21-22, 2018

University of Colorado, Boulder

As part of the Center of Excellence for Commercial Space Transportation (COE CST) activities, a day-and-a-half workshop was hosted on May 21-22, 2018 at the University of Colorado in Boulder. The workshop was organized by three PIs from the COE CST: David Klaus, (CU), Jim Vanderploeg (UTMB/Baylor) and Ondrej Doule (FIT). The purpose was to gather input from, foster discussion among, and stimulate collaboration between our colleagues in academia, government and industry to provide recommendations for future potential COE CST research topics.

The outcomes from the workshop are summarized in this report to help identify and prioritize near-term (1-3 years), mid-term (3-5 years) and long-term (>5 years) research needs of interest to the commercial space community. The emphasis here was on research theme 3, human space flight, broadly organized around the following 3 topic areas:

1) **Vehicle Design and Operations** (Klaus)
2) **Human Factors** (Doule)
3) **Occupant Health and Fitness-to-Fly Criteria from a Medical Perspective** (Vanderploeg)

The workshop agenda and list of attendees are provided as an appendix to this report. The list includes attendees who were present in person (27), those who called in remotely (25), and others who were interested in the event but tentative on participation (12). There is not a definitive record of everyone who called in, so the tentative participants, as well as others possibly not identified here, may have been online at different points during the workshop. A little over 100 personal invitations were emailed to contacts compiled from D. Klaus, J. Vanderploeg and O. Doule, from which a total of 64 individuals spanning academia, industry and government confirmed and contributed. Note that this report summarizes the collective inputs, but does not identify anyone's specific recommendations by name.

Research goals across all topics are primarily focused on various aspects of safety. The FAA *Recommended Practices for Human Space Flight Occupant Safety* (Version 1, August 27, 2014) document was used as a framework to strategically align proposed future research directions with FAA interests. Of particular interest in the 'mid-term (3-10 years)' per the FAA's working version of the Commercial Space Research Roadmap in this area (Human Ops and Spaceflight) include:

- Generic ECLSS Model
- HSP Training Template
- ECLSS Tradeoff Models
- Human Factors Standards
- HSP Physiological Limits
- Emergency Medical Standards

These general topics were well represented across the three workshop categories, indicating similar goals and interests exist in academia, government and industry. The workshop breakout groups facilitated invigorating discussions on the relevant subtopics with callers and attendees moving between categories throughout the day. The outcomes of this interdisciplinary effort indicate the main areas of interest and importance raised by all parties. An original record of the workshop is presented on the following pages in PART I. Individual breakout sessions captured the discussions differently within each discipline. The outcomes recorded in PART I are synthesized as user or system needs in PART II.

PART I – Workshop Discussion Record

1) Vehicle Design and Operations (Klaus)

1.1 Transfer / Diffusion of knowledge - How do you facilitate the transfer of academic research data to the end operational users?

This was an interesting tangent that arose during the meeting with a lot of conversation back and forth with highlights paraphrased below ranging from comments to questions to suggestions to ideas.

a. Is enough knowledge being generated?
b. What areas of research are needed?
c. Hiring PhD students who are deep in the literature is a great method of knowledge transfer
d. Open access vs. subscription-based journals
e. Special topic seminars / lecture series
f. Use the COE CST as a point of contact for establishing a knowledge transfer link to industry?
g. Distributed function in highly specialized fields?
h. Diffusion of innovation
i. Boeing and SpaceX have benefited from the commercial crew program with close ties to NASA engineers
j. Info also available to others via non-funded space act agreements
k. AIAA short course series on Bioastronautics

It is not completely clear how this list translates to research directly, but we felt was worth capturing here for further consideration by the COE CST in general.

1.2 Technology and implementation of technology

This discussion was also somewhat tangential to the main purpose, but similarly identified a number of thought-provoking ideas that might be incorporated in a number of different potential COE CST research tasks going forward.

a. Conduct research using the hardware in context, vs. it flew on ISS, which doesn't prove it will work for the intended utilization on the specific vehicle configuration
b. How to test, what are you testing?
c. Integrated testing at the system level
d. Verification process? Requirements checklist vs. flight test
e. What is adequate for verifying long term ECLSS testing?
f. Even through it might not be needed for a long time out, tests take a long time
g. Should testing be conducted in 1g or in flight?
h. Test as you fly and fly as you test
i. Consider timescales appropriate for analog / micro-g testing
j. Identify 'lessons learned' where 1g testing worked but ISS failed – e.g., thermal switch
k. Identify other factors that can influence functionality besides microgravity
l. What are the environmental factors and timescales that matter for the test and all components?
m. Robust ECLSS vs. mass efficiency
n. What are the available test facilities to use?

1.3 Radiation impacts to vehicle systems, including software and biological systems - what types of radiation environments are expected?

a. Software effects
b. Architecture selection trade – rad hardened vs. redundant voting schemes
c. Crew perspective is a big issue for commercial aviation

1.4 Software maintenance - **system evolution with software updates, version control**

a. Uniformity of software between flight and simulator
b. NASA SMS had different SW than the orbiter
c. Development process – cannot test enough to evaluate all ops permutations
d. Section in Recommended Practices doc pretty sparse
e. Fine line between over-specifying items in recommended practices and running risk of limiting industry options vs. leaving at very high level that doesn't add much insight
f. File corruption, bit flips, SEU/SELs, uplinks, backups, real time issues?
g. DFMR strategy – how is it defined for commercial applications? Who certifies?
h. NASA document exists, fairly old, maybe too rigorous and not consistent
i. JSC doc may have different info that KSC document for example
j. Leverage from commercial aviation industry
k. What ECLSS provisions are needed for emergency return capacity from a human tolerance standpoint? Determined as a function of time margin from onset to recovery
l. Sizing margins from a generic trade space analysis
m. Post flight recovery lag time accounted for dependent on water or land landing

1.5 Framework is needed for defining human tolerance to off nominal conditions and correlating this to ECLSS requirements

a. Dynamic environments – g loading human tolerance, launch, landing, splashdown
b. NASA tends to err on conservative side
c. g's, acoustics, vibration loads
d. Framework for g-loading – integrated from LV to spacecraft to occupants
e. Brinkley model not validated for all relevant environments
f. Human entry factors
g. Reference Mike Gernhardt's work with NASCAR and DCS
h. Can a standard be established?
i. How are the impacts measured?

1.6 Fire suppression

a. Requirements derived from FAA aircraft cabin atmosphere and fire extinguishing, maybe detection
b. Prevent, detect and suppress fires
c. Not necessarily looking for solutions, but good practices, summary of body of knowledge
d. What is the approach? DFMR? Design for system safety?
e. Tradeoff between atm discharge of suppressant and having to don masks, or pressure hull implications, atm contaminations
f. Framework / literature review of events and outcomes and solution tradespace
g. Can a SFP operate a fire extinguisher onboard?
h. Personnel training?
i. Add to recommended practices document
j. Fire detection community is separate from the aerosol community – different measurement units, accuracy needs, etc.

1.7 Industry Standards

a. ASTM committee on commercial spaceflight, subcommittee on suborbital vehicles
b. Assumes if safety analysis process is good, you will get to necessary system safety level

c. Concern that we have a lot of different views that may be conflicting, FAA, ASTM, NASA if defining standards independently
d. Some discussion about AST moving to Dept of Commerce, but not looking likely
e. Space traffic management is moved to DoC

1.8 Define/Clarify FAA AST role, regulatory agency for commercial space activities (but no authority over **occupant safety** or **orbital flight?**)

a. authority for occupant safety under moratorium until 2025 currently or should a catastrophic loss occur sooner (onboard or public), authority over orbital flight is limited by jurisdiction
b. **FAA recommended practices** – what FAA thinks industry can do re. occupant safety, not regulatory

1.9 Explore collaboration potential with other organizations

a. **ASTM** – goal is to develop industry standards during the time in which there is a moratorium, involved in part 400 FAA rewrite, expectation is that these will eventually be adopted into the regulations or inform them
b. **AIAA, SAE, ASCE** (lunar colonies), **ASMA** (international training standards and guidelines) also working on various forms of standards… -- need better communication between the different groups
c. RTCA – aircraft oriented
d. International Deep Space Interoperability Standards - https://www.internationaldeepspacestandards.com/
e. **COE CST** – conducting research of interest to FAA and industry interests

1.10 Air quality and particulate monitoring

a. What is needed on the GUI for an aerosol monitor – right amount of info for user to digest and use for decision making
b. Air quality index for spacecraft environment – high, medium low 'stoplight assessment'
c. Differences from Earth based
d. Low gravity, toxicity
e. New technologies able to differentiate between different compounds (e.g., dust and smoke)
f. Machine learning approach to distinguish between compounds
g. Recent Fire Safety Journal – can't detect smoke from Teflon fires, Kapton also difficult, important for post event clean up too

1.11 How does all this data get passed along to relevant flight teams?

Similar to the discussions summarized in 1A and 1B above, this is more of an implementation practice to be explored in various contexts.

a. Capturing design goals into flight rules
b. Close the lifecycle between hardware developers and operators
c. Personnel training extended to flight control team as well as onboard team

1.12 Habitable volume determination

a. Duration and mission objectives
b. Reconfigurable (nesting) of functions (ref. old ICES paper?)
c. Long duration flights most important
d. Optimizing layout and utilization
e. Standardizing the measurement?

1.13 ECLSS

a. Maintainability and reliability
b. Robustness – define and verify
c. Logistics train – ECLSS, prop, consumables, ISRU
d. Nutrition needs and water
e. Pre-flight meal guidelines?
f. Define ECLSS model mapping human needs to ECLSS functions and technology options

1.14 Fault tolerance

a. Fault tolerance and reliability combined
b. DFMR – holistic approach to system safety and means of verification need to be addressed
c. Dissimilar redundancy
d. Degraded performance
e. Different for spacecraft than launch vehicles
f. Factor of safety
g. Design margin

1.15 Manual vs. automated task allocation and The internet of things

a. How do the different vehicle systems talk to each other? In particular, on Mars.
b. How can 'Smart Systems' bests be incorporated
c. Machine to machine communication, autonomous operation
d. External interface standards
e. Oil and gas and mining industries using this for operating complex machinery and keeping people in the loop
f. More generic communication pathways
g. Machine learning and information distribution

1.16 Autonomous reentry

a. In 2012, FAA had to grant SpaceX a waiver to do autonomous reentry for Dragon to return from ISS, how will this be accomplished going forward?

2) Human Factors (Doule)

Near term (1-3y) LIFE CRITICAL - Requested topics/scope updates:

2.1 Air quality & slow decompression O2, CO2 monitoring/ existing systems req insufficient (1.3.8):

a. Monitoring, warning interface for the crew (GUI) should be part of vehicle human-system interfaces in the cockpit.
b. Definition of levels of automation, interaction (levels of interaction are function of mission duration), scenario based should include manual override without exception
c. Microgravity poses specific requirements on monitoring: Monitoring methods and effects must be function of gravity
d. Monitoring req. must be function of the duration due to different human and system functions, equipment (mechanical systems, material degradation, abrasion)
e. Regulatory structure should provide clear rules for the quality levels
f. Crew is concerned about the quality, not SFPs. SFP must have communication means with the crew (PO)
g. Define separate metric for monitoring gasses and particles real-time
h. Intgrate air q monitoring methodology & interface with fire detection system / relate to microbial monitoring (3.3.7.).
i. Provide explanation for an IVA spacesuit as another layer of protection

Near term (1-3y) LIFE CRITICAL - Requested topics/scope updates:

2.2 Fire detection and suppression

a. Define extinguishing methods as function of duration, gravity and atmospheric condition
b. Define a model for the crew and SFPs involvement/function before, during and after detection and suppression (3.5.7.)
c. Require HITL simulations in the new CST vehicles /to certify the system/ of all procedures in flight prior commercial operations
d. Provide explanation for an IVA spacesuit as another layer of protection

Near term (1-3y) INCREASE EFFICIENCY OF THE DOCUMENT - Requested topics/scope updates:

2.3 Scope

- Distinguish the scope for different operators. Current scope is vast – expression of bureaucracy (not wanted). We want a streamlined manual e.g., divide recommendations in chapters according to scope:
  a. PART 1 – Suborbital
  b. PART 2 – Earth-Orbital
  c. PART 3 – Lunar
  d. PART 4 – Martian
  e. PART 5 - Orbital

e.g., Suborbital max 3h < 1orbit

a. Earth Orbital : position, eccentricity, inclination, duration of decay etc. couple with ITU
b. Martian, Orbital: AG, sustainability, medical autonomy etc.

Near term (1-3y) LIFE CRITICAL - Requested topics/scope updates:

2.4 Medical interfaces and operations

a. Lack of general procedural guidance (protocol) for different flight scopes: see point 3. The level of medical attention is a function of a human spaceflight scope and cannot be easily generalized.
b. Focus on suborbital and Earth Orbital first
c. Why is only the serious injury the concern noted? Clarify semiotics.
d. Monitoring: Chronical exposure to extreme/artificial environment is omitted. The document should provide informative guidance for mitigation of risks of chronical exposure how to monitor and should link to separate topics (procedures) :
   i. Variable gravity
   ii. Radiation
   iii. Air quality
e. Provide the scope of medical examination

Near term (1-3y) INCREASE EFFICIENCY OF THE DOCUMENT - Requested topics/scope updates:

2.5 Alignment of the document

a. Consider A119 Office of management and Budget: “Preference for industry standards rather than regulation”
b. Make advisory recommendations to FAA for life critical flight components in relevance to the scope and duration of the flight mission, and public safety, crew, SFPs.
c. Do not repeat mistakes that aviation went through. Avoid trial and error with Humans In The Loop (HITL). Use safe HITL Simulations. Define fidelity level and reps. of simulation prior test flights or commercial operations
d. Establish safety baseline for occupants in regards to the vehicle, cabin and cockpit (e.g., # of successful test flights # of successful simulations)

Near term (1-3y) LIFE CRITICAL - Requested topics/scope updates:

2.6 Display and controls design

a. Extreme environments affect possibility to use nominal controls and displays. Depending on vehicle class or flight profile; D/C should be designed according to the most critical scenario
b. Users have to have access to information in variable g, acoustic noise, power down etc.
c. Provide guides or requirements on multimodal displays inclusive multi sensory interaction specifically in hyper g

Near term (1-3y) LIFE CRITICAL - Requested topics/scope updates:

2.7 Un-Restraining operation requirements

a. Possibly limit (temporarily or as a function of flight mission, flight duration etc.) un-restraining the crew and/or SFPs until certain experience / number of successful flights is achieved (enough statistical data): there is potential for too risky and too many emergent behavioral phenomena
b. Provide recommendation for restraining procedures in variable g

Near term (1-3y) LIFE CRITICAL - Requested topics/scope updates *(JSC, Ellen Snook)*:

2.8 Egress: Use existing CST-REQ-1130

a. Differentiate the scope: Egress requirements are function of duration
b. Coordinate with industry at very early stage of design/development of vehicles
   i. 1.4.16 - https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20150010757.pdf
   ii. 1.14.17 – CST REQ-1130: 4.3.5.1.6

Near term (1-3y) LIFE CRITICAL - Requested topics/scope updates:

2.9 Safety attendant function

a. Consider function of safety attendant that would support SFPs (untrained agents with unpredictable emergent behavior)
b. No safety attendant implies, thorough SFPs training, increase cost, increase risk, lower customer turnaround and ultimately results in lower profit and higher insurance cost. (consult insurance providers)

Near term (1-3y) LIFE CRITICAL - Requested topics/scope updates:

2.10 Automation

a. General: Avoid overreliance on automation. Life critical control system should have manual override. Automation is a complex component that is a function of mission duration, flight capacity, system criticality, autonomy requirements.
b. Examples of automation threatening to passengers on airline aircrafts should be given as avoid-examples.

Near term (1-3y) LIFE CRITICAL - Requested topics/scope updates:

2.11 Radiation

a. Statistical information that would provide general information for chronical and acute risks is missing
b. Requirements on shielding is missing

Near term (1-3y) LIFE CRITICAL - Requested topics/scope updates:

2.12 Other

a. 1.2.1: High g load effects in other axes should be noted inclusive impaired movement, potential injuries if not supported by proper seating structure and interfaces for both SFPs and Crew. Regulation to provide safety operational interfaces for both crew and SFP should be provided. E.g., one cannot operate overhead switches in 6gs (unless you are The Rock)
b. 1.2.3: Should be renamed. It can be confused *with* solar flares, galactic cosmic rays, magnetic field trapped particles, solar proton
c. 1.3.1 Resilience engineering should be recommended as a solution (F tolerances and Redundancies)
d. 1.3.12 Modifications to software and controls are missing

3) Occupant Health and Fitness-to-Fly Criteria from a Medical Perspective (Vanderploeg)

Ideas:

3.1 Motion sickness
3.2 Anxiety
3.3 Integrate medical support/issues with vehicle design
3.4 Medical screening & monitoring
3.5 Best practices for monitoring of physiological parameters
3.6 Short vs. long duration
3.7 Anxiety with extreme behavior
3.8 Database capture of adverse events
3.9 Depressurization protocol
3.10 Attributed causality
3.11 Cabin atmosphere assessment (particulates) – correlation with medical physiological data
3.12 Data collection
   a. What data elements
   b. What format and hardware
   c. What associated metadata
   d. "Give us best practices for data collection"
   e. Give us legal parameters to protect data
3.13 Disorientation
3.14 Anxiety screening methods
3.15 Identify "stabilizers" who can be the glue that holds a crew together
3.16 Radiation

Prioritized time frames indicated for the medical needs identified in section 3 (with additional topics included in the table not noted above):

Priority	1 - 3 years	3 – 5 years	5+ years
	Shared database	Cardio-vascular status	Radiation
	Data collection and medical screening		“Stabilizers” for crew
	Categorize risks across S versus O and relative urgency for answers		Anxiety leading to extremes of behavior
	Anxiety	Cabin atmosphere - particulates	Cabin atmosphere - particulates
	Motion sickness	Motion sickness	
	Disorientation	Air cleaning and air quality	
	Common set of monitoring parameters (including radiation)		
	Adverse event monitoring and reporting	Adverse event analysis and response	

PART II – CST Workshop Outcome Summary

This part provides a structured view of all discussed CST user (designer, manufacturer, operator, occupant) and system perspectives during the workshop with estimated timeframe priority. This outcome summary format is related to the goals of COE CST Task 353 in providing recommendations to the FAA in terms of normative, technical, qualitative and quantitative data in review of the Recommended Practices for Human Space Flight Occupant Safety document (Version 1, Aug 27, 2014).

TOPIC AREA			QUESTIONS / GAPS	PRIORITY		
				1 – 3 years	3 – 5 years	5+ years
1	**Vehicle Design and Operations**	1.1	**Transfer / Diffusion of knowledge** a. Is enough knowledge being generated? b. What areas of research are needed? c. Hiring PhD students who are deep in the literature is a great method of knowledge transfer d. Open access vs. subscription-based journals e. Special topic seminars / lecture series f. Use the COE CST as a point of contact for establishing a knowledge transfer link to industry? g. Distributed function in highly specialized fields? h. Diffusion of innovation i. Boeing and SpaceX have benefited from the commercial crew program with close ties to NASA engineers j. Info also available to others via non-funded space act agreements k. AIAA short course series on Bioastronautics	X	X	X
		1.2	**Technology and Implementation of Technology** a. Conduct research using the hardware in context, vs. it flew on ISS, which doesn't prove it will work for the intended utilization on the specific vehicle configuration b. How to test, what are you testing? c. Integrated testing at the system level d. Verification process? Requirements checklist vs. flight test e. What is adequate for verifying long term ECLSS testing? f. Even through it might not be needed for a long time out, tests take a long time g. Should testing be conducted in 1g or in flight? h. Test as you fly and fly as you test	X		

			i. Consider timescales appropriate for analog / micro-g testing j. Identify 'lessons learned' where 1g testing worked but ISS failed – e.g., thermal switch k. Identify other factors that can influence functionality besides microgravity l. What are the environmental factors and timescales that matter for the test and all components? m. Robust ECLSS vs. mass efficiency n. What are the available test facilities to use?			
		1.3	**3. Radiation impacts to vehicle systems, including software and biological systems - what types of radiation environments are expected?** a. Software effects b. Architecture selection trade – rad hardened vs. redundant voting schemes c. Crew perspective is a big issue for commercial aviation		X	X
		1.4	**Software maintenance** a. Uniformity of software between flight and simulator b. NASA SMS had different SW than the orbiter c. Development process – cannot test enough to evaluate all ops permutations d. Section in Recommended Practices doc pretty sparse e. Fine line between over-specifying items in recommended practices and running risk of limiting industry options vs. leaving at very high level that doesn't add much insight f. File corruption, bit flips, SEU/SELs, uplinks, backups, real time issues? g. DFMR strategy – how is it defined for commercial applications? Who certifies? h. NASA document exists, fairly old, maybe too rigorous and not consistent i. e.g., JSC doc may have different info than KSC doc j. Leverage from commercial aviation industry k. What ECLSS provisions are needed for emergency return capacity from a human tolerance standpoint? Determined as a function of time margin from onset to recovery l. Sizing margins from a generic trade space analysis m. Post flight recovery lag time accounted for dependent on water or land landing *Consider ISO 26262*[1]	X		

[1] ISO 26262 is a standard utilized by certain corporations (e.g., DiSTi's GL Studio) currently supporting cockpit software development: Part 6.7

		1.5	**Human tolerance to off nominal conditions in correlation to ECLSS requirements – framework** a. Dynamic environments – g loading human tolerance, launch, landing, splashdown b. NASA tends to err on conservative side c. g's, acoustics, vibration loads d. Framework for g-loading – integrated from LV to spacecraft to occupants e. Brinkley model not validated for all relevant environments f. Human entry factors g. Reference Mike Gernhardt's work with NASCAR and DCS h. Can a standard be established? i. How are the impacts measured?	X		
		1.6	**Fire suppression** a. Requirements derived from FAA aircraft cabin atmosphere and fire extinguishing, maybe detection b. Prevent, detect and suppress fires c. Not necessarily looking for solutions, but good practices, summary of body of knowledge d. What is the approach? DFMR? Design for safety? e. Tradeoff between atm discharge of suppressant and having to don masks, or pressure hull implications, atm contaminations f. Framework / literature review of events and outcomes and solution tradespace g. Can a SFP operate a fire extinguisher onboard? h. Personnel training? i. Add to recommended practices document j. Fire detection community is separate from the aerosol community – different measurement units, accuracy needs, etc.	X		
		1.7	**Industry standards** a. ASTM committee on commercial spaceflight, subcommittee on suborbital vehicles b. Assumes if safety analysis process is good, you will get to necessary system safety level c. Concern that we have a lot of different views that may be conflicting, FAA, ASTM, NASA if defining standards independently d. Some discussion about AST moving to Dept of Commerce, but not looking likely e. Space traffic management is moved to DoC	X		
		1.8	**Define/Clarify FAA role** a. Regulatory agency for commercial space activities but no authority over **occupant safety** or **orbital flight?**	X		

			b. Authority for occupant safety under moratorium until 2025 currently or should a catastrophic loss occur sooner (onboard or public), authority over orbital flight is limited by jurisdiction c. **FAA recommended practices** – what FAA thinks industry can do re. occupant safety, not regulatory			
		1.9	**Collaboration potential with other organizations** a. **ASTM** – goal is to develop industry standards during the time in which there is a moratorium, involved in part 400 FAA rewrite, expectation is that these will eventually be adopted into the regulations or inform them b. **AIAA, SAE, ASCE** (lunar colonies), **ASMA** (international training standards and guidelines) also working on various forms of standards… -- need better communication between the different groups c. RTCA – aircraft oriented **d.** International Deep Space Interoperability Standards https://www.internationaldeepspacestandards.com/ e. **COE CST** – conducting research of interest to FAA and industry interests	X	X	X
		1.10	**Air quality and particulate monitoring** a. What is needed on the GUI for an aerosol monitor – right amount of info for user to digest and use for decision making b. Air quality index for spacecraft environment – high, medium low ‘stoplight assessment’ c. Differences from Earth based d. Low gravity, toxicity e. New technologies able to differentiate between different compounds (e.g., dust and smoke) f. Machine learning approach to distinguish between compounds g. Recent Fire Safety Journal – can’t detect smoke from Teflon fires, Kapton also difficult, important for post event clean up too	X		
		1.11	**CST requirements and data sharing** a. Capturing design goals into flight rules b. Close the lifecycle between hardware developers and operators c. Personnel training extended to flight control team as well as onboard team	X		
		1.12	**Habitable volume determination** a. Duration and mission objectives b. Reconfigurable (nesting) of functions c. Long duration flights – Volume is most important d. Optimizing layout and utilization e. Standardizing the measurement	X	X	X

		1.13	**ECLSS:** a. Maintainability and reliability b. Robustness – define and verify c. Logistics train – ECLSS, prop, consumables, ISRU d. Nutrition needs and water e. Pre-flight meal guidelines? f. Define ECLSS model mapping human needs to ECLSS functions and technology options	X	X	X
		1.14	**Fault tolerance:** a. Fault tolerance and reliability combined b. DFMR – holistic approach to system safety and means of verification need to be addressed c. Dissimilar redundancy d. Degraded performance e. Different for spacecraft than launch vehicles f. Factor of safety g. Design margin	X	X	X
		1.15	**Manual vs. automated task allocation and IOT** a. How do the different vehicle systems talk to each other? In particular, on Mars. b. How can 'Smart Systems' bests be incorporated c. Machine to machine communication, autonomous operation d. External interface standards e. Oil and gas and mining industries using this for operating complex machinery and keeping people in the loop f. More generic communication pathways g. Machine learning and information distribution	X	X	X
		1.16	**Autonomous re-entry** a. In 2012, FAA had to grant SpaceX a waiver to do autonomous reentry for Dragon to return from ISS, how will this be accomplished going forward? FAA may need to provide a structured guidance.	X		
2	**Human Factors – Human-System Integration**	2.1	**Air quality monitoring, slow decompression monitoring** f. Monitoring, warning interface for the crew (GUI) should be part of vehicle human-system interfaces in the cockpit g. Definition of levels of automation, interaction (levels of interaction are function of mission duration), scenario based should include manual override without exception h. Microgravity poses specific requirements on monitoring: Monitoring methods and effects must be function of gravity i. Monitoring req. must be function of the duration due to different human and system functions,	X		

			equipment (mechanical systems, material degradation, abrasion) j. Regulatory structure should provide clear rules for the quality levels k. Crew is concerned about the quality, not SFPs. SFP must have communication means with the crew (PO) l. Define separate metric for monitoring gasses and particles real-time m. Integrate air q monitoring methodology & interface with fire detection system / relate to microbial monitoring (3.3.7.)[2]. n. Provide explanation for an IVA spacesuit as another layer of protection			
		2.2	**Fire detection and suppression** a. Define extinguishing methods as function of duration, gravity and atmospheric condition b. Define a model for the crew and SFPs involvement/function before, during and after detection and suppression (3.5.7.)[3] c. Require HITL simulations in the new CST vehicles /to certify the system/ of all procedures in flight prior commercial operations d. Provide explanation for an IVA spacesuit as another layer of protection	X		
		2.3	**Classification of CST according to scope/duration** Distinguish the scope for different operators. Current scope is vast – expression of bureaucracy (not wanted). We want a streamlined manual e.g., divide recommendations in chapters according to scope e.g.,: a. PART 1 – Suborbital b. PART 2 – Earth-Orbital c. PART 3 – Lunar d. PART 4 – Martian e. PART 5 - Orbital	X		
		2.4	**Medical interfaces and operations** a. Lack of general procedural guidance (protocol) for different flight scopes: see point 2.3. The level of medical attention <u>is a function of a human spaceflight scope/duration and cannot be easily generalized</u>.	X		

[2] FAA, 2014, Recommended Practices for Human Space Flight Version 1.0, FAA Office of Commercial Space Transportation, Washigton, DC, (TC14-0037)

[3] FAA, 2014, Recommended Practices for Human Space Flight Version 1.0, FAA Office of Commercial Space Transportation, Washigton, DC, (TC14-0037)

			b. Focus on suborbital and Earth Orbital first c. Why is only the serious injury the concern noted? Clarify semiotics. d. Monitoring: Chronical exposure to extreme/artificial environment - Provide informative guidance for mitigation of risks of chronical exposure how to monitor and should link to separate topics (procedures) : i. Variable gravity ii. Radiation iii. Air quality e. Provide the scope of medical examination			
		2.5	A**lignment of CST Recommendations with HSF Safety** a. Consider A119 Office of management and Budget: "Preference for industry standards rather than regulation" b. Make advisory recommendations to FAA for life critical flight components in relevance to the scope and duration of the flight mission, and public safety, crew, SFPs. c. Do not repeat mistakes that aviation went through. Avoid trial and error with Humans In The Loop (HITL). Use safe HITL Simulations. Define fidelity level and reps. of simulation prior test flights or commercial operations d. Establish safety baseline for occupants in regards to the vehicle, cabin and cockpit (e.g., # of successful test flights # of successful simulations)	X		
		2.6	**Display and controls design:** a. Extreme environments affect possibility to use nominal controls and displays. Depending on vehicle class or flight profile; D/C should be designed according to the most critical scenario b. Users have to have access to information in variable g, acoustic noise, power down etc. c. Provide guides or requirements on multimodal displays inclusive multi-sensory interaction specifically in hyper-g	X		
		2.7	**Un-restraining operation requirements** a. Possibly limit (temporarily or as a function of flight mission, flight duration etc.) un-restraining the crew and/or SFPs until certain experience / number of successful flights is achieved (enough statistical data): there is potential for too risky and too many emergent behavioral phenomena b. Provide recommendation for restraining procedures in variable g	X		

		2.8	**Egress: Use existing CST-REQ-1130** a. Differentiate the scope: Egress requirements are function of duration b. Coordinate with industry at very early stage of design/development of vehicles i. 1.4.16 ii. 1.14.17 – CST REQ-1130: 4.3.5.1.6	X		
		2.9	**Safety attendant function** a. Consider function of safety attendant that would support SFPs (untrained agents with unpredictable emergent behavior) b. No safety attendant implies, thorough SFPs training, increase cost, increase risk, lower customer turnaround and ultimately results in lower profit and higher insurance cost. (consult insurance providers)	X		
		2.10	**Automation** a. General: Avoid overreliance on automation. Life critical control system should have manual override. Automation is a complex component that is a function of mission duration, flight capacity, system criticality, autonomy requirements. b. Examples of automation threatening to passengers on airline aircrafts should be given as avoid-examples.	X		
		2.11	**Radiation** a. Statistical information that would provide general information for chronical and acute risks is missing b. Requirements on shielding is missing	X		
		2.12	**Other** a. 1.2.1: High g load effects in other axes should be noted inclusive impaired movement, potential injuries if not supported by proper seating structure and interfaces for both SFPs and Crew. Regulation to provide safety operational interfaces for both crew and SFP should be provided. E.g., one cannot operate overhead switches in 6gs b. 1.2.3: Should be renamed. It can be confused *with* solar flares, galactic cosmic rays, magnetic field trapped particles, solar proton c. 1.3.1 Resilience engineering should be recommended as a solution (F tolerances and Redundancies) d. 1.3.12 Modifications to software and controls are missing			

3	**Medical - Occupant Health and Fitness to Fly Criteria**	3.1	**Motion Sickness**	X	X	
		3.2	**Anxiety**	X		
		3.3	**Integrate medical support/issues with vehicle design**			
		3.4	**Medical screening and monitoring** a. Common set of monitoring parameters (including radiation)	X		
		3.5	**Best practices for monitoring of physiological parameters**	x		
		3.6	**Short vs. Long Duration** (factors)			
		3.7	**Anxiety -** *Extreme behavior*			X
		3.8	**Database capture of adverse events**	X		
		3.9	**Depressurization protocol**			
		3.10	**Attributed causality**			
		3.11	**Cabin atmosphere assessment** a. Particulates b. Correlation with medical physiological data		X	X
		3.12	**Data collection and medical screening** a. What data elements b. What format and hardware c. What associated metadata d. "Give us best practices for data collection" e. Give us legal parameters to protect data	X		
		3.13	**Disorientation**	X		
		3.14	**Anxiety -** *Screening methods*	X		
		3.15	**"Stabilizers" for the crew**			X
		3.16	**Radiation**			X
		3.xx	**Categorization of risks across S versus O and relative urgency for answers**	X		
		3.xx	**Cardio-vascular status**		X	
		3.xx	**Air cleaning and air quality**		X	
		3.xx	**Adverse event analysis and response**		X	

Appendix Contents

For additional general information on the COE CST, see: http://www.coe-cst.org.

A1. FAA Center of Excellence for Commercial Space Transportation (COE CST) - http://www.coe-cst.org
Research Workshop to be held on May 21-22, 2018 at the University of Colorado in Boulder

The purpose of this working meeting is to gather input from, foster discussion among, and stimulate collaboration between our colleagues in academia, government and industry. The outcome will be compiled in a report to help identify and prioritize near-term (1-3 years), mid-term (3-5 years) and long-term (>5 years) research needs of interest to the commercial space community.

The emphasis for this workshop is on RESEARCH THEME 3, HUMAN SPACE FLIGHT, with topic areas including 1) vehicle design and operations, 2) human factors, and 3) occupant health and fitness-to-fly criteria from a medical perspective, all primarily with a focus on safety.

AGENDA

Monday May 21
0830 – 0900 Coffee, tea and light refreshments

0900 – 1000 Welcome and FAA COE CST Research Overview
Ken Davidian (FAA), Dave Klaus (CU), Jim Vanderploeg (UTMB/BCM), Ondrej Doule (FIT)

1000 – 1100 Round-the-Room Introductions

1100 – 1130 Breakout Groups Organized

1130 – 1300 Lunch (various options on campus or nearby in town)

1300 – 1630 Working Groups (medical, vehicle and human factors)
Medical lead – Jim Vanderploeg, Vehicle lead – Dave Klaus, HF lead – Ondrej Doule

1630 – 1700 Wrap up and Plans for Summary

Call in windows for remote participants (phone numbers to be provided):
Monday – 0900-1130 MT (general room) and 1 pm – 5 pm (call in to one of the 3 breakouts)

Dinner on your own, form small groups, lots of good microbreweries and restaurants in the area…

Tuesday May 22
0830 – 0900 Coffee, tea and light refreshments

0900 – 1000 Breakout Group Summaries

1000 – 1145 Breakout Group Briefings (~30 minutes each)

1145 – 1200 Wrap up and Forward Plans

Call in windows for remote participants: Tues– 1000-1145 MT (general room)

CU Bioastronautics Lab tours, if desired

A2. List of attendees and affiliations

total responses	attended	remote	tentative		last name	organization
1	x			William	Acromite	Acromite Law Office
2	x			Jeff	Ashby	Blue Origin
3	x			Guigi	Carminati	Caminati Law, Denver
4	x			Ben	Easter	CU Anschutz
5	x			David	Klaus	CU Boulder
6	x			Jim	Nabity	CU Boulder
7	x			Jim	Zimmerman	Danish Aerospace
8	x			David	Zuniga	Danish Aerospace
9	x			Ken	Davidian	FAA-AST
10	x			Henry	Lampazzi	FAA-AST
11	x			Ondrej	Doule	FIT
12	x			Mark	Shelhamer	Johns Hopkins
13	x			Ellen	Snook	KBRWyle
14	x			Nathan	Shupe	Lockheed Martin
15	x			Todd	Sullivan	Lockheed Martin (Tuesday only)
16	x			Meytar	Sorek Hamer	NASA ARC USRA
17	x			Marit	Meyer	NASA GRC
18	x			Mike	Acromite	Naval Aerospace Medical Institute / Sovaris
19	x			Grant	Anderson	Paragon
20	x			Michael	Schmidt	Sovaris
21	x			Kent	Tobiska	Space Environment Technologies
22	x			Rachel	Ellman	SpaceX
23	x			Christine	Fanchiang	The Space Research Company
24	x			Steven	Fry	ULA
25	x			Melissa	Sampson	ULA
26	x			Dana	Levin	UTMB
27	x			Jim	Vanderploeg	UTMB
28		x		Jonathan	Clark	Baylor CSM
29		x		Erika	Wagner	Blue Origin
30		x		Ryan	Kobrick	Embry Riddle
31		x		Dick	Leland	Environmental Tectonics Corporation
32		x		Lynda	Bottos	FAA
33		x		Carla	Hackworth	FAA CAMI
34		x		Paul	Wilde	FAA-AST
35		x		Melchor	Antunano	FAA-CAMI
36		x		Tristan	Fiedler	FIT
37		x		Dan	Buckland	GWU

38	x		Ted	Bonk	Honeywell
39	x		Oscar	Garcia	Interflight Global Corporation
40	x		Kim	Seaton	KBRWyle
41	x		Robert	Hadden	Mayo Clinic
42	x		Jan	Stepanek	Mayo Clinic
43	x		Kris	Lehnhardt	NASA JSC & BCM
44	x		Anne Joan	Meier	NASA KSC
45	x		Chris	Mertens	NASA LaRC (Monday only)
46	x		Logen	Johnson	SAE
47	x		Tom	Goodwin	Sovaris
48	x		Anil	Menon	SpaceX
49	x		Ed	Morris	Stratolaunch Federal Inc.
50	x		Daniel	Sternberg	Stratolaunch Federal Inc.
51	x		Becky	Blue	UTMB
52	x		Chris	Haas	UTMB
53		x	Brett	Alexander	Blue Origin
54		x	Christie	Iacomini	Blue Origin
55		x	David	Gerlach	FAA-AVS
56		x	Don	Platt	FIT
57		x	Christine	Smith	KBRWyle
58		x	Brian R	Shmaefsky	Lone Star College - Kingwood
59		x	Pat	Hynes	NM Space Grant Consortium
60		x	Chad	Davis	Orbital ATK
61		x	Skip	Smith	Sherman Howard
62		x	Rachel	Forman	SpaceX
63		x	Chad	Healy	SpaceX
64		x	George	Whitesides	Virgin Galactic

CU grad students participating: Emily Matula, Tobias Niederwieser, Jan Junker, Kimia Seyedmadani

Sovaris Aerospace and Carminati Law are COE CST Affiliate Members.