Review of Significant Incidents and Close Calls in Human Spaceflight from a Human Factors Perspective

IAC-17-B3.9-GTS.2X38032

Jackelynne Silva-Martinez, Richard Ellenberger, Jonathan Dory

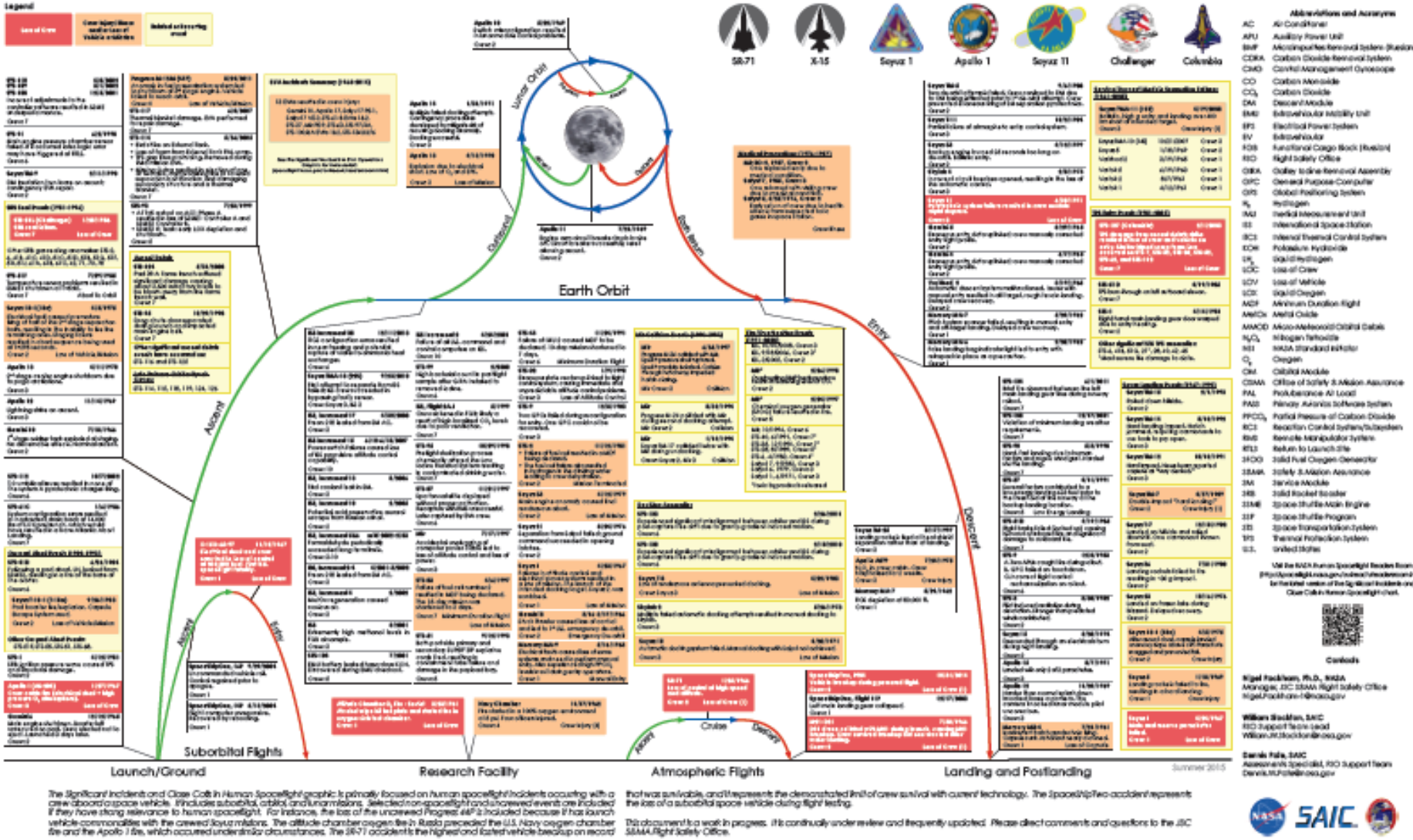
NASA Johnson Space Center

68th International Astronautical Congress, Adelaide, Australia

25-29 September 2017

Agenda

- Significant Incidents in Human Spaceflight Overview
- Assumptions and description of analysis of Significant Incidents Tool
- Human Factors Classification
- Recommendations for Significant Incidents and Preventive Measures
- Government Documents Review
- Next Steps
- Acknowledgments and References



Analysis of Significant Incidents in Human Spaceflight Tool

Analysis of Significant Incidents in Human Spaceflight Overview

Objectives:

- To perform a deep-dive analysis of significant incidents
- Classify them by human factors and human error during flight operations
- Verify that requirements address those incidents in current governing documents

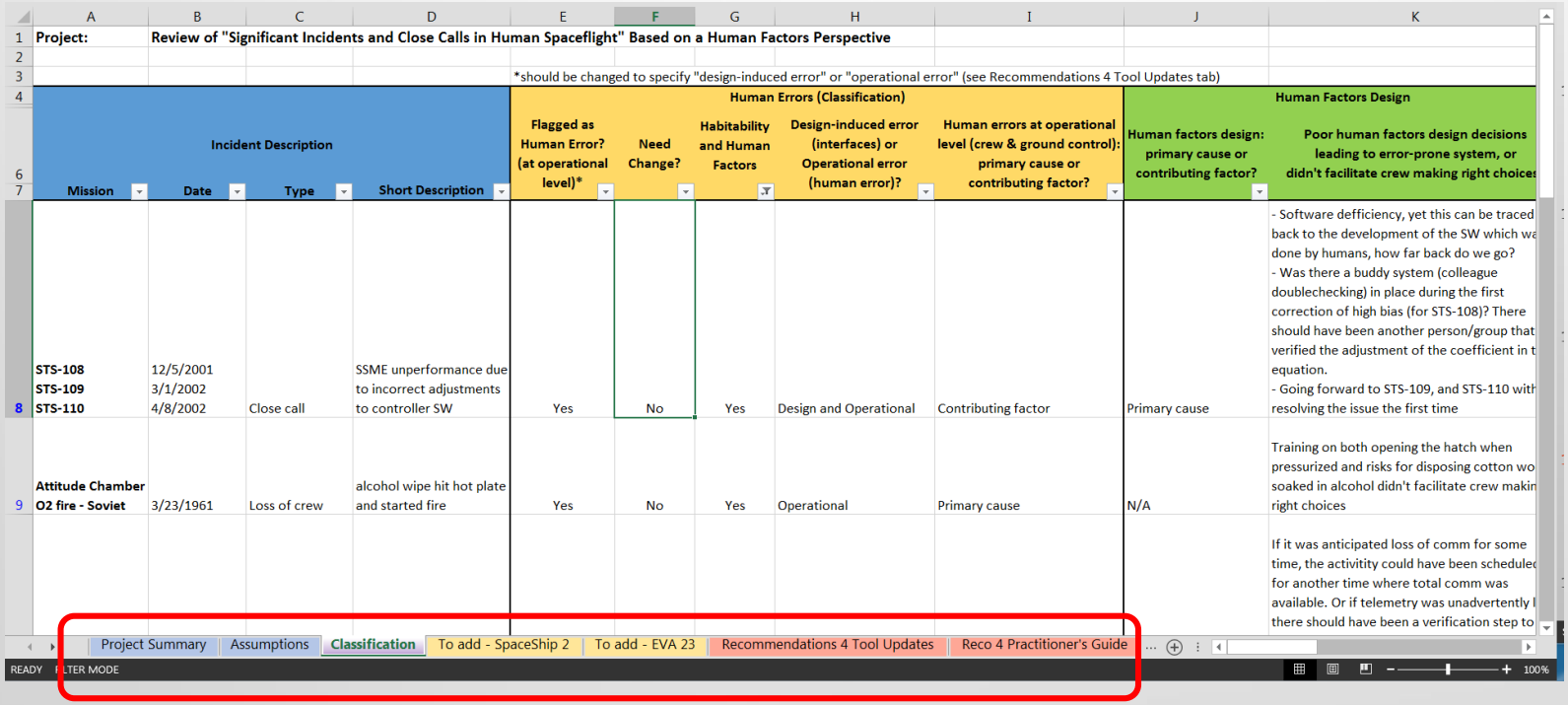
Assumptions:

- Although everything can be contributed to human error at some point, this classification focuses on human error at the operational level, and whether it was a design-induced error
- Human error considered was for cases when the errors led to an incident/close call
- This analysis does not account for human error having its source in organizational factors, processes, etc.
- Medical evacuations and EVA incidents were excluded from analysis

Human Factors Classification

Product:

Human Factors Classification of Significant Incidents and Close Calls in Human Spaceflight Tool divided into 6 tabs



	A	B	C	D	E	F	G	H	I	J	K
1	Project:	Review of "Significant Incidents and Close Calls in Human Spaceflight" Based on a Human Factors Perspective									
2											
3					*should be changed to specify "design-induced error" or "operational error" (see Recommendations 4 Tool Updates tab)						
4					Human Errors (Classification)					Human Factors Design	
6	Incident Description				Flagged as Human Error? (at operational level)*	Need Change?	Habitability and Human Factors	Design-induced error (interfaces) or Operational error (human error)?	Human errors at operational level (crew & ground control): primary cause or contributing factor?	Human factors design: primary cause or contributing factor?	Poor human factors design decisions leading to error-prone system, or didn't facilitate crew making right choices
7	Mission	Date	Type	Short Description							
8	STS-108 STS-109 STS-110	12/5/2001 3/1/2002 4/8/2002	Close call	SSME unperformance due to incorrect adjustments to controller SW	Yes	No	Yes	Design and Operational	Contributing factor	Primary cause	- Software defficiency, yet this can be traced back to the development of the SW which wa done by humans, how far back do we go? - Was there a buddy system (colleague doublechecking) in place during the first correction of high bias (for STS-108)? There should have been another person/group that verified the adjustment of the coefficient in t equation. - Going forward to STS-109, and STS-110 with resolving the issue the first time
9	Attitude Chamber O2 fire - Soviet	3/23/1961	Loss of crew	alcohol wipe hit hot plate and started fire	Yes	No	Yes	Operational	Primary cause	N/A	Training on both opening the hatch when pressurized and risks for disposing cotton wo soaked in alcohol didn't facilitate crew makin right choices
											If it was anticipated loss of comm for some time, the activitity could have been schedule for another time where total comm was available. Or if telemetry was unadvertently l there should have been a verification step to

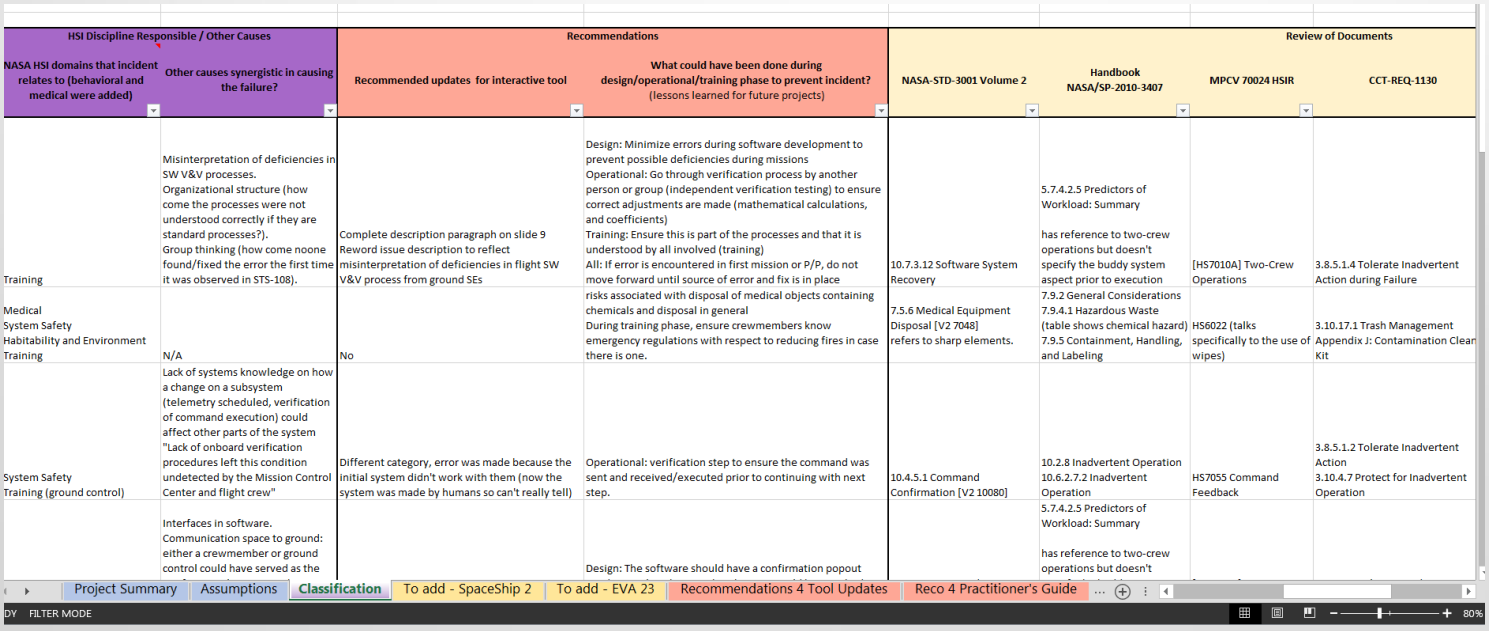
Project Summary | Assumptions | Classification | To add - SpaceShip 2 | To add - EVA 23 | Recommendations 4 Tool Updates | Reco 4 Practitioner's Guide

READY ALTER MODE 100%

Link to excel to show real-time

Sections of Human Factors Classification

- Incident Description
- Human Errors (Classification)
- Human Factors Design
- HSI Discipline Responsible
- Recommendations
- Review of Documents



HSI Discipline Responsible / Other Causes		Recommendations		Review of Documents			
NASA HSI domains that incident relates to (behavioral and medical were added)	Other causes synergistic in causing the failure?	Recommended updates for interactive tool	What could have been done during design/operational/training phase to prevent incident? (lessons learned for future projects)	NASA-STD-3001 Volume 2	Handbook NASA/SP-2010-3407	MPCV 70024 HSIR	CCT-REQ-1130
Training	Misinterpretation of deficiencies in SW V&V processes. Organizational structure (how come the processes were not understood correctly if they are standard processes?). Group thinking (how come noone found/fixed the error the first time it was observed in STS-108).	Complete description paragraph on slide 9 Reword issue description to reflect misinterpretation of deficiencies in flight SW V&V process from ground SEs	Design: Minimize errors during software development to prevent possible deficiencies during missions Operational: Go through verification process by another person or group (independent verification testing) to ensure correct adjustments are made (mathematical calculations, and coefficients) Training: Ensure this is part of the processes and that it is understood by all involved (training) All: If error is encountered in first mission or P/P, do not move forward until source of error and fix is in place	10.7.3.12 Software System Recovery	5.7.4.2.5 Predictors of Workload: Summary has reference to two-crew operations but doesn't specify the buddy system aspect prior to execution	[HS7010A] Two-Crew Operations	3.8.5.1.4 Tolerate Inadvertent Action during Failure
Medical System Safety Habitability and Environment Training	N/A	No	risks associated with disposal of medical objects containing chemicals and disposal in general During training phase, ensure crewmembers know emergency regulations with respect to reducing fires in case there is one.	7.5.6 Medical Equipment Disposal [V2 7048] refers to sharp elements.	7.9.2 General Considerations 7.9.4.1 Hazardous Waste (table shows chemical hazard) 7.9.5 Containment, Handling, and Labeling	HS6022 (talks specifically to the use of wipes)	3.10.17.1 Trash Management Appendix J: Contamination Clean Kit
System Safety Training (ground control)	Lack of systems knowledge on how a change on a subsystem (telemetry scheduled, verification of command execution) could affect other parts of the system "Lack of onboard verification procedures left this condition undetected by the Mission Control Center and flight crew"	Different category, error was made because the initial system didn't work with them (now the system was made by humans so can't really tell)	Operational: verification step to ensure the command was sent and received/executed prior to continuing with next step.	10.4.5.1 Command Confirmation [V2 10080]	10.2.8 Inadvertent Operation 10.6.2.7.2 Inadvertent Operation	HS7055 Command Feedback	3.8.5.1.2 Tolerate Inadvertent Action 3.10.4.7 Protect for Inadvertent Operation
	Interfaces in software. Communication space to ground: either a crewmember or ground control could have served as the		Design: The software should have a confirmation popout		5.7.4.2.5 Predictors of Workload: Summary has reference to two-crew operations but doesn't		

Project Summary | Assumptions | Classification | To add - SpaceShip 2 | To add - EVA 23 | Recommendations 4 Tool Updates | Reco 4 Practitioner's Guide

DY FILTER MODE 80%

Full list available in the paper

Government Documents Review

- NASA-STD-3000 Man Systems Integration Standards (1985)
  - Used by Shuttle and ISS programs
- NASA-STD-3001 Space Flight Human Systems Standards:
  - Volume 1 focuses on Crew Health
  - Volume 2 focuses on Human Factors, Habitability & Environmental Health
- NASA/SP-2010-3407 Human Integration Design Handbook
  - Details different HSI requirements developed from lessons learned in past human spaceflight missions.
  - Process is required by NPR 8705.2B Human-Rating Requirements for Space Systems, and NPR 7120.11 Health & Medical Technical Authority Implementation
- MPCV 70024 Human Systems Integration Requirements (HSIR)
  - Orion has addressed human errors in the HS7066 Crew Interface Usability, HS7080 Crew Cognitive Workload, and HS7003 Handling Qualities.
- NASA Human Factors Analysis and Classification System (HFACS)
  - Led by NASA's Mishap Program Working Group.

Specific Program Documents Reviewed for Analysis:

NASA-STD-3001 Volume 2	SP-2010-3407 Handbook
MPCV 70024 HSIR	CCT-REQ-1130

Example of Analysis Results:
Apollo ASTP: 7/24/2975, Crew injury

- Earth Landing System Auto/Manual Switch to Auto
- Not Flagged as Human Error
- Proposed to change to "Yes"

  Design-induced (interfaces) – primary cause, and

  operational error (human error) – contributing factor

- Poor human factors design decision leading to error-prone system or not facilitating crew making the right choices:

  Spacecraft displays didn't have an obvious visual cue for the pilot to realize that he was still operating in manual mode

  Procedures may have not had a step for commander to remind pilot to switch back to auto

- **NASA HSI Domains:**

  Human Factors Engineering, Safety, Training, Operations Resources

- **Causes synergistic in causing failure:**

  Displays may have not account with good visual cue to alert pilot of current state

Example of Analysis Results:
Apollo ASTP: 7/24/2975, Crew injury

- **Recommended Updates for Interactive Tool:**

  Divide description in 3 parts: Brief description of incident, Reason/causes/consequences, and Solutions

- **What could have been done during design/operational/training phase to prevent incident?**

  Procedures to include buddy system (confirmation by fellow crewmember) for callout to change to auto/manual as needed

  Have redundant systems to human, e.g. alarms, colors in text or activation of flashing mode

- **Recommendation for all documents:**

  Add a requirement that explicitly explains that second crewmember should acknowledge verbally prior to execution of first crewmember.

  HSIR: it has a requirement for manual control (HS7004 Manual Control) but doesn't specify it is required when automation is used, like in the other docs

Example of Analysis Results:
Apollo ASTP: 7/24/2975, Crew injury

Review of Documents:

- NASA-STD-3001 Volume 2: *Needs additional requirement*

  10.7.3.12 Software System Recovery,

  10.6.1.5 Automation Levels [V2 10104]

- SP-2010-3407: *Needs additional requirement*

  10.10.2.4 Levels of Automation

- MPCV 70024 HSIR: *Needs additional requirement*

  HS7010A Two-Crew Operations, HS7004 Manual Control

- CCT-REQ-1130: *Needs additional requirement*

  3.8.5.1.4 Tolerate Inadvertent Action during Failure, 3.2.6.1 Manually Override Software, 4.3.2.6.1 Manually Override Software

Recommendation for two-crew operations: Add a separate requirement that states commands/actions should be confirmed verbally by fellow crewmember (or ground control) before executing

Recommendations for Tool

- For each incident, it would be good to divide the description in 3 parts:
  - Brief description of incident
  - Reason/causes/consequences
  - Solutions (methods in place resulting from incident investigations, if any)
- Recommend dividing classifications in Main Page into three sections:
  - **Classification 1 - Incidents**
    Keep classification for:
    - Loss of Crew
    - Crew Injuries
    - Related or Recurring Events
    Add: Close Calls
  - **Classification 2 - Various**
    Make another box or section (maybe by color) of second classification:
    - Space Vehicles
    - Country (not sure you need this but ok)
    - Systems (see comment 3, maybe rename to "technical system")
  - **Classification 3 - Human Factors**
    Make another classification just for Human Factors Errors (maybe it's called HSI) [also distinguish from other classifications by color or box]:
    Suggested Classification:
    - Human Factors Design-Induced Errors
    - Operational Errors/Factors
    - Design Errors/Factors
    - Organizational Errors/Factors

Full list of recommendations available in the paper

Next Steps

- Share recommendations for tool updates with Safety and Mission Assurance group
- Compare information with mishap reports in:
  - NASA Lessons Learned Database (currently being reorganized)
  - NASA Human Factors Analysis and Classification System (HFCAS)
- Discuss topics in Standards meeting (assess if issues are/should be addressed as requirements in governing documents or in procedures at the operational level)
- Discuss with other Center organizations

Acknowledgments

- NASA Johnson Space Center
- Habitability and Human Factors Branch
- Human Health and Performance Directorate
- Safety and Mission Assurance Directorate

Thank you for your attention!

References

1. NASA (2015). Significant Incidents in Human Spaceflight. Johnson Space Center Safety and Mission Assurance Flight Safety Office. Retrieved from: http://spaceflight.nasa.gov/outreach/Significant_Incidents_Zcard2015.pdf [Accessed July 2016].

2. NASA (2017). Significant Incidents and Close Calls in Human Spaceflight Interactive Edition. Johnson Space Center Safety and Mission Assurance Flight Safety Office. Retrieved from: https://spaceflight.nasa.gov/outreach/SignificantIncidents/index.html [Accessed February 2017].

3. NASA (2015). NASA/SP-2015-3709 Human Systems Integration (HSI) Practitioner's Guide, NASA Johnson Space Center, November 2015.

4. Silva-Martinez, J. (2016**).** Human Systems Integration: Process to Help Minimize Human Errors, a Systems Engineering Perspective for Human Space Exploration Missions**,** Journal REACH - Reviews in Human Space Exploration. Volume 2, Issues 2–4, Pages 8-23, December 2016, Published by Elsevier.

5. NASA (2017). Significant Incidents and Close Calls during EVA Operations Interactive Edition. Johnson Space Center Safety and Mission Assurance Flight Safety Office. Retrieved from: https://spaceflight.nasa.gov/outreach/SignificantIncidentsEVA/index.html [Accessed March 2017].

6. NASA (2015). NASA-STD-3001, NASA Space Flight Human-System Standard Volume 2: Human Factors, Habitability, and Environmental Health, 12 February 2015.

7. NASA (2014). SP-2010-3407 Rev1 Human Integration Design Handbook. 5 June 2014.

8. NASA (2015). MPCV 70024 Orion Multi-Purpose Crew Vehicle Program: Human Systems Integration Requirements (HSIR), 4 March 2015.

9. NASA (2015). CCT-REQ-1130 ISS Crew Transportation Certification and Services Requirements Document, Revision D-1, 23 March 2015.

10. Silva-Martinez, J., Martinez, V. (2015). Using a Human-Centric Design Process for the Implementtion of Advanced Computer-Based Tools in Space Programs. 66th International Astronautical Congresss 2015. IAC-15,E5,1,6,X28356, Jerusalem, Israel.

11. Silva, J. (2012). Management's Role on the Application of Human Factors in the Aerospace Industry: Satellite Design and Manufacturing. ICES, San Diego, CA.

References

12. FAA AC120-51E (2004). Crew Resource Management Training Advisory Circular. US Department of Transportation.

13. Salas, E., Maurino, D. (2010). Human Factors in Aviation. Academic Press.

14. Silva-Martinez, J. (2015). Application of Crew Resource Management Techniques in the Aerospace Industry. IEEE Aerospace Conference 2015. 8.5 Human Factors & Performance.8.0504. Big Sky, MT.

15. Silva, J. (2013a). Incorporating Human Concepts in the Lifecycle of Aerospace Systems, INCOSE International Symposium, Philadelphia, PA.

16. Silva, J. (2013b). Crew Health for Space Vehicles in a Mars mission. Space 2013 Conference & Exposition. San Diego, CA.

17. Peldszus, R. Silva, J., Imhof, B. (2014). Contemporary Human Technology Interaction Issues in Space Architecture. 65th International Astronautical Congress 2014. IAC-14-E5.3.1.25092. Toronto, Canada.

18. NASA (2015). NASA-STD-3001, NASA Space Flight Human-System Standard Volume 1, Revision A: Crew Health. 12 February 2015.

19. NASA (2008). NPR 8705.2B Human Rating Requirements for Space Systems, 6 May 2008.

20. NASA (2012). CxP 70024 Constellation Program Human-System Integration Requirements, Revision E, 19 November 2010.

21. Holden, K., et al. (2013). Human Factors in Space Vehicle Design, Acta Astronautica, Volume 92, Issue 1, Pages 110-118.

22. NASA (2015). MPCV 72557 Orion Multi-Purpose Crew Vehicle Program Human Error Analysis, 29 April 2015.NASA (2010).

23. CxP 72242 Rev A Orion Display Format Standards, 8 September 2010