Air Vehicle Factors Affecting Occupant Health, Comfort, and Productivity

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Background

- Urban Air Mobility (UAM) vehicles will need to meet both the safety and comfort expectations of passengers and crews.
- Existing Federal Aviation Administration airworthiness standards for airplanes and rotorcraft are unlikely to adequately address these needs.
- In addition to human-automation interaction, operator displays and controls (D&C), training, equipment maintenance, and other related “workplace” matters, both space and UAM vehicle developers must also contend with the vehicle occupants’ induced dynamic environment (acceleration, vibration, and sound).
- Some insight may be gained from NASA’s approach to human-systems integration standards and guidelines that promote astronaut health, safety, and performance.

Problem Statement:

- At present, commercial UAM vehicles under development, including those using vertical lift technologies, follow FAA regulations (14CFR) Parts 21 and 23 for small aircraft and (14CFR) Parts 27 and 29 for rotorcraft.

- The regulations documents cited above set requirements largely for airframe design, but offer little direct guidance on matters of crew performance or passenger acceptance.

Today's Goal:

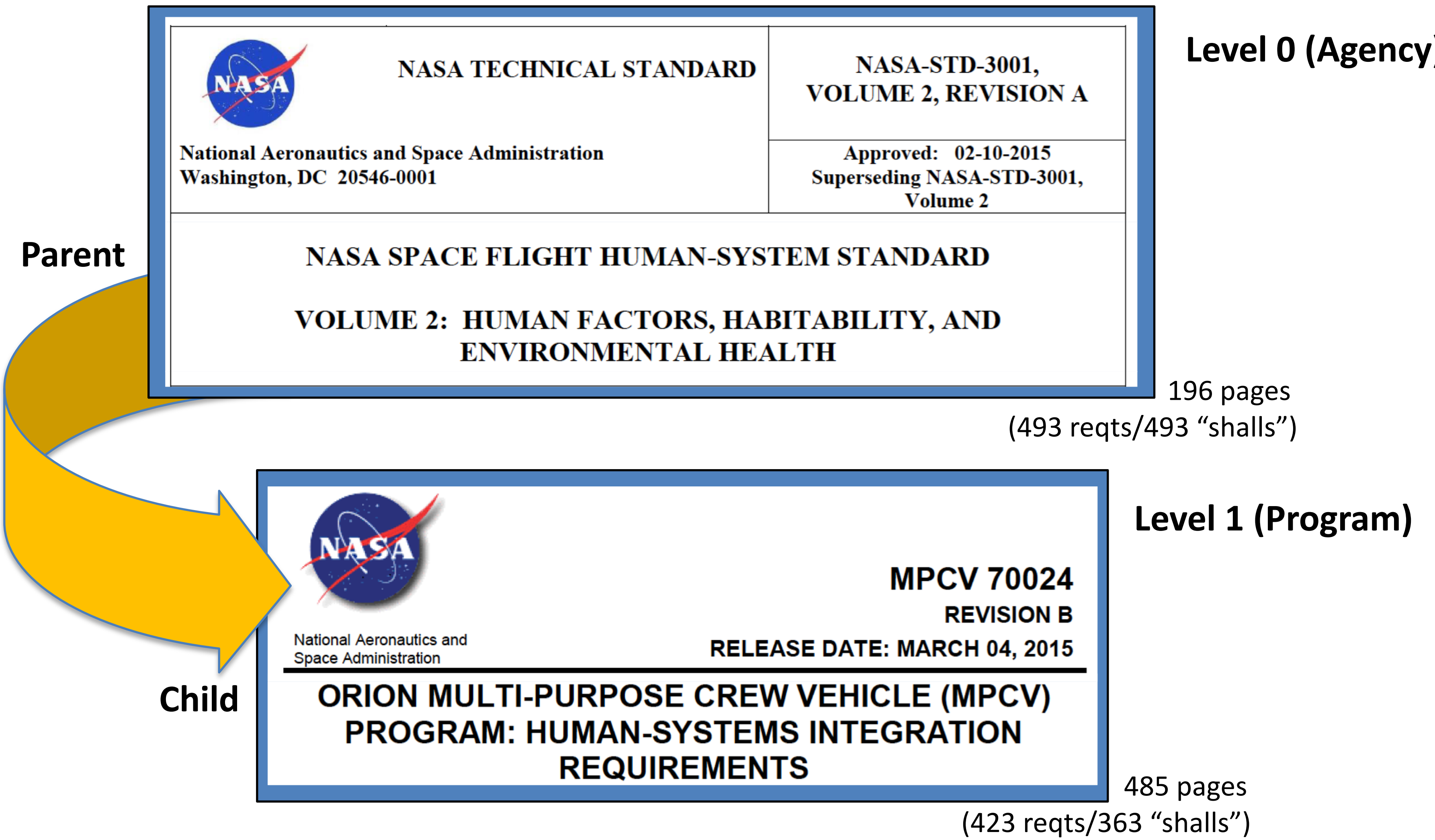
1. Not encourage more regulation.

2. Offer pointers to someinformation (i.e., standards and guidelines) that may help fill some gaps in the FAA regulations noted above.

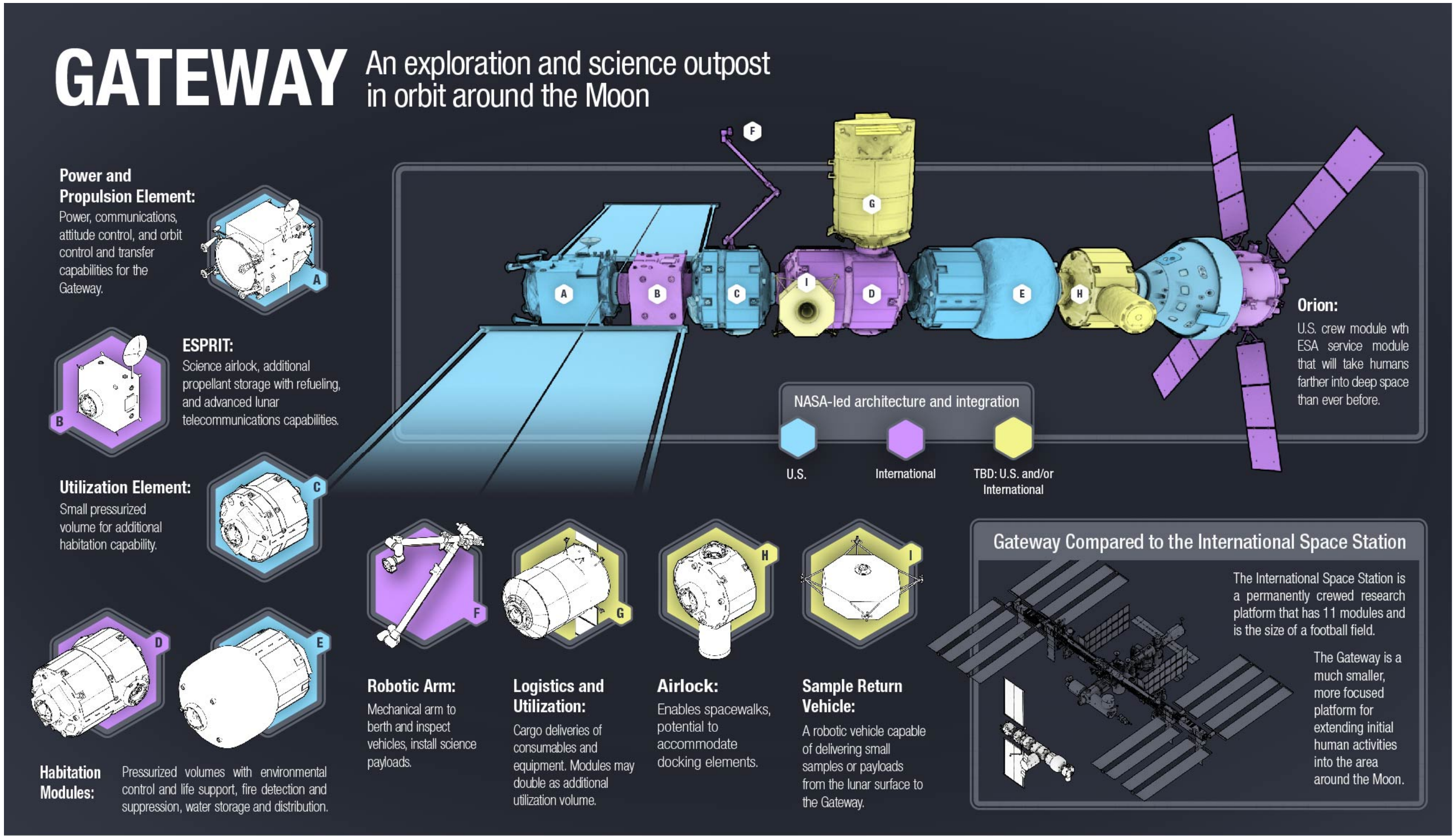
3. Provide an overview of NASA/FAA/DoD operator performance requirements pertinent to various types of vehicles and fixed-base work stations

4. Focus more specifically on critical factors defining the vehicles' interior environment such as vehicle vibration and acceleration (i.e., ride quality) and noise—all of which impact pilot performance and occupant comfort (e.g., potential for motion sickness), as well as passenger acceptance (e.g., ability to use personal digital devices while onboard).

NASA Human Research Program (HRP)
Human Capabilities Assessments for Autonomous Missions
Standards & Guidelines Task



Human Exploration and Operations Mission Directorate: Proposed Gateway Program



Lunar Orbit space station is intended to serve as an all-in-one solar-powered communications hub, science laboratory, short-term habitation module, and holding area for rovers and other robots.

- Uncrewed Utilization & Operations
- Human Lunar Surface Access
- Science Platform
- Cislunar Tug

HRP Standards & Guidelines Task
(Human Capabilities Assessments for Autonomous Missions)

HF-STD-001B
December 30, 2016

U.S. DEPARTMENT OF TRANSPORTATION

FEDERAL AVIATION ADMINISTRATION

HUMAN FACTORS DESIGN STANDARD

753 pages
(4380 reqts/2431 “shalls”)

MIL-STD-1472G
11 January 2012

DEPARTMENT OF DEFENSE
DESIGN CRITERIA STANDARD

HUMAN ENGINEERING

381 pages
(2883 reqts/2820 “shalls”)*

NASA, FAA, DOD, HF Standards: Scope

BOOK	Not NASA Relevant	Natural, induced, and Internal Environments	Workspace/Vehicle Sizing	Human-Vehicle Maintenance	All Else: Interfaces, D&C, etc
NASA-3001-v2a	0	84	138	75	196
MPCV70024B	0	142	93	87	101
FAA (001B)	116	812	68	149	3235
DOD (1472G)	416*	359*	131*	273*	1704*

* "estimated"

NASA, FAA, DOD, HF Standards: Styles (for Rationale)

- NASA-STD-3001/MPCV70024_revB: Extensive rationale narrative for each requirement
- FAA HF-STD-001B_2016: “Discussion” narrative with some requirements; also “Additional Information”
- MIL-STD-1472G: Some rationale embedded in section headers and some requirements

Note: FAA HF-STD-001B_2016 treats disability accommodation, accessibility

NASA, FAA, DOD, HF Standards: Req’t Count by Keyword

	Autonomy	Automation / Robotics	VR/AR/MR (see through, head mounted, heads up)	Multimodal (multisensory) / audio/auditory/tactile/ touch	Procedures/ proceduralized instructions	Scheduling	Situation Awareness	Workload	Need for Information /feedback/ information-automation/-management	Decision support /Decision aiding	Troubleshooting / Problem solving	Trust in automation	Communication with MCC	Training	Intelligent Systems	Virtual Assistant	Adaptive Systems /Adaptive Automation	Inventory Management	Cognition/Cognitive	Mode(s)	**TOTAL**
NASA-STD-3001	0	19	1	2	11	7	7	5	33	3	3	1	9	11	0	0	0	7	5	0	**124**
MPCV70024	0	5	0	11	6	0	6	4	19	4	6	0	8	6	0	2	0	5	1	0	**83**
FAA HF-STD-001B	2	195	92	211	43	0	0	3	58	39	15	8	106	27	1	0	10	1	15	18	**844**
MIL-STD-1472G	0	171	81	236	0	0	5	8	59	34	3	6	170	2	0	0	0	0	8	11	**794**

NASA-STD-3001, VOLUME 2, REVISION A

TABLE OF CONTENTS (Continued)

SECTION

Parent Requirement (NASA-STD-3001)

6.7.1.5 Vibration Limits for Performance [V2 6093]

Crew task performance **shall** not be degraded by vibration.

Rationale: Tasks and associated equipment should be designed to avoid unacceptable performance degradation during periods of vibration. Thus, while vibration limits may depend on the specific task, specific tasks may be selected or designed to accommodate the associated vibration level. Performance criteria need to be established for tasks and then an assessment made for the impact of vibration on performance. The level and fidelity of assessment will depend on the criticality of the task.

Child Requirement (MPCV-70024)

[HS3135] Visual Performance Limits for Vibration During Launch

The system shall limit vibration due to thrust oscillation and other sources of the integrated launch vehicle in the range of 10-13 Hz in the axial (x) and lateral (y) directions as measured at the crew seat to not exceed the levels and exposure durations in HS3135, table Crew Limits for Vibration in the 10-13 Hz Frequency Band where the threshold columns identify relevant limits for peak and sustained vibration.

Rationale: The five-segment solid-rocket boosters on the Space Launch System (SLS) can produce 1L thrust oscillations in the 10-13 Hz frequency band at any point in Boost phase flight. These thrust oscillations may result in dynamic response in this frequency range throughout the vehicle, including the crew seat. Because human visual performance is sensitive to vibration in this frequency range, the ability of crew to monitor displays or perform other visually-mediated tasks may be impacted during critical phases of flight. Laboratory test data underlying this requirement indicate that the sensitivity of semi-supine observers differs significantly between x-axis (axial, i.e., chest-to-spine) and y-axis (lateral, i.e., left-to-right) vibration in this frequency band. X-axis vibration produces visual blur resulting from biodynamically induced head pitch motion. On the other hand, y-axis vibration resulted in very little head motion and, consequently, little impact on visual performance. While load cases producing concurrent lateral and axial may arise and be problematic, controlled studies of the visual impact of simultaneous x- and y-axis vibration on semi-supine were not performed. When main axis vibration at the threshold magnitudes in HS3135, table Crew Limits for Vibration in the 10-13 Hz Frequency Band, observations from the separate x- and y-axis tests indicate that off-axis (i.e., not the tested axis) vibration at amplitudes <0.15 g will have negligible additional effect on crew visual performance. SLS will track and provide information on vibration at the crew seat to MPCV through Section 4.2.10 Crew Health and Performance Vibration Limits in the SLS Technical Metrics Plan (SLS-PLAN-047).

TABLE 3.2.5-2 - CREW LIMITS FOR VIBRATION IN THE 10-13 HZ FREQUENCY BAND

	Peak Limit	Sustained Limit
Body x-axis	0.7 g_x zero-to-peak, up to one second	0.21 g_x RMS 5-second running average
Body y-axis	0.7 g_y zero-to-peak up to one second	0.5 g_y RMS 5-second running average

Motion Sickness-I

6.7.1.1 Vibration during Pre-Flight [V2 6089]

The system **shall** limit vibration to the crew such that the frequency-weighted acceleration between 0.1 to 0.5 Hz in each of the X, Y, and Z axes is less than 0.05 g (0.5 m/s^2) RMS for each 10-minute interval during pre-launch (when calculated in accordance with ISO 2631-1: 1997, Mechanical vibration and shock - Evaluation of human exposure to whole-body vibration - Part 1: General requirements. Annex D, Equation D-1).

Rationale: Low-frequency vibration, especially in the range between 0.1 and 0.5 Hz, has the potential to cause motion sickness over relatively short exposure periods. This may be encountered while the crew is in the vehicle during the pre-launch period, given that a tall vehicle stack may be susceptible to back-and-forth sway. Reducing the amount of sway will prevent the onset of motion sickness during the pre-launch phase. According to ISO2631-1: 1997, Annex D, the percentage of unadapted adults who may vomit is equal to 1.3 motion sickness dose value. The value 0.05 g weighted RMS acceleration indicates that approximately 17 percent or 1 out of 6 crewmembers may vomit. Although ISO 2631-1:1997 limits the acceleration measurement for assessing motion sickness to the vertical direction, this is based on the assumption that the human is in the seated upright posture. Since occupants of a vehicle are likely to be in the semi-supine posture, the requirement is applied to all three orthogonal axes (X, Y, and Z). The purpose of the 10-minute integration time is to constrain the deviations around the permitted average sway during a 2-hour pre-launch period.

Motion Sickness-II

[HS3065] Sustained Cross-Coupled Rotational Acceleration Limit

The system shall prevent the crew from being exposed to sustained cross-coupled rotational accelerations greater than 2 rad/s2.

Rationale: Crewmembers are not expected to be able to tolerate sustained cross-coupled rotational accelerations in excess of 2 rad/s2 without significant discomfort and disorientation. Sustained cross-coupled rotational accelerations exceeding this amount have been found to significantly impact human performance (e.g., neurovestibular performance via the "coriolis effect," physical reach, and cognition).

This requirement will be met by integrated systems with the details of each system's responsibility in individual system SRDs and in IRDs.

- **Stationary occupant head & cross-coupled two-axis vehicle rotation**
- **Rotating head wrt vehicle cross-couples w/ single-axis vehicle rotation**

Acoustics Requirements (titles)

V2 6073	Launch, Entry, and Abort Noise Exposure Limits
V2 6074	Hazardous Noise Level for Launch and Entry
V2 6075	Hazardous Noise Level for Launch Abort
V2 6076	Launch, Entry, and Abort Impulse Noise Limits
V2 6077	Hazardous Noise Limits for All Phases Except Launch, Entry, and Abort
V2 6078	Continuous Noise Limits
V2 6079	Crew Sleep Continuous Noise Limits
V2 6080	Intermittent Noise Limits
V2 6081	Narrow-Band Noise Limits
V2 6082	Impulse Annoyance Limit
V2 6083	Impulse Noise Limit
V2 6084	Narrow-Band Noise Limits
V2 6085	Infrasonic Sound Pressure Limits
V2 6086	Ultrasonic Noise Limits
V2 6087	Acoustic Monitoring
V2 6088	Individual Exposure Monitoring

Parent (NASA-STD-3001)

In conclusion

The aim today was to illustrate:

- UAM-induced flight factors that can impact occupant comfort, productivity, as well as safety;
- Government and industry standards could be built upon to help assure passenger acceptance of revolutionary Vertical Take Off and Landing (RVLT) aircraft technologies.

Acknowledgements

- NASA’s Human Research Program, Human Factors Behavior and Performance Element: “Human Performance Standards and Guidelines” (Directed Task)
- Drs. K.L. Holden, N. Russi-Vigoya, E.V. Cross, B.A. Munson (NASA-JSC)
- Drs. M.M. Connors, B.R. Beutter (NASA-ARC)

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