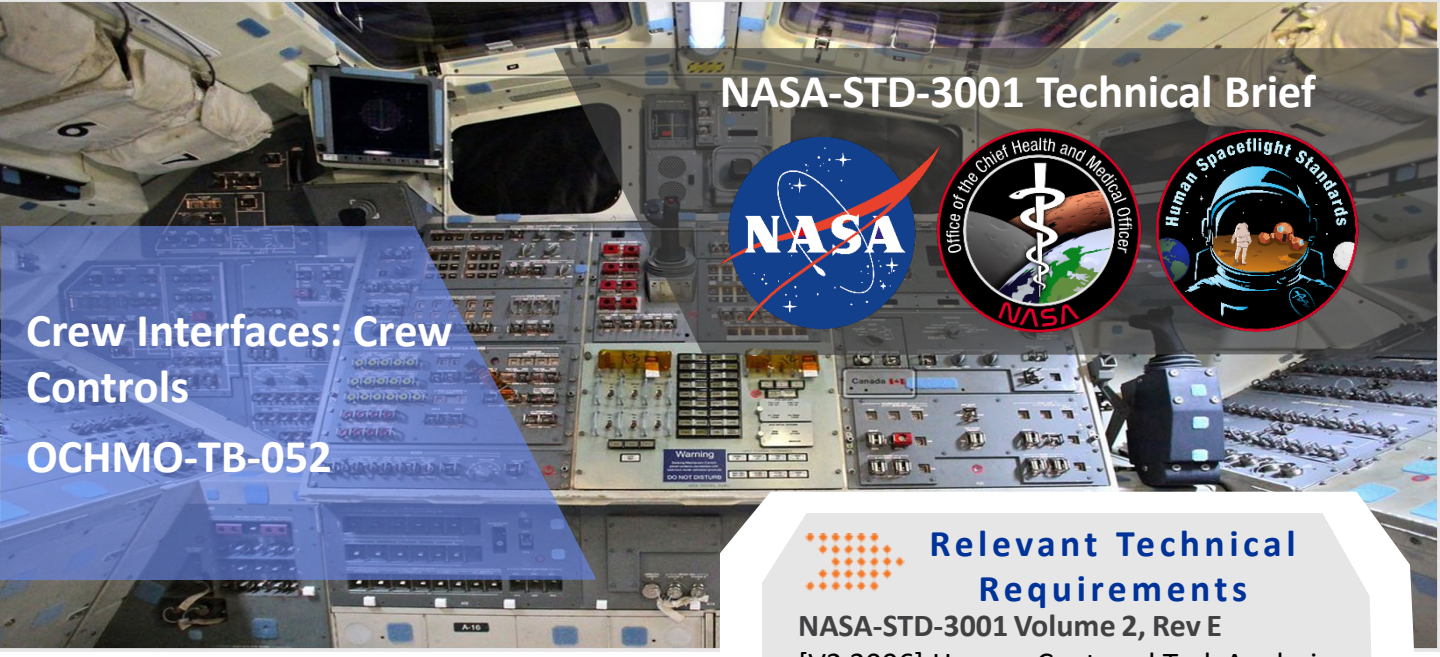


NASA-STD-3001 Technical Brief

Crew Interfaces: Crew Controls

OCHMO-TB-052

Executive Summary

The user interface of a system – referred to as a *crew interface* – is any part of a system through which information is exchanged between the crewmember and the system. Well-designed crew interfaces, through which static and dynamic information is exchanged between the crew and the system, are critical for crew safety and productivity. Categories of crew interfaces include displays, controls, audio and communications systems, video systems, alerts and annunciations, automation and robotics interfaces, and information management. This technical brief focuses on control design, operation, and crew-system interaction.

Controls in a spacecraft include any method of interaction in which the user enters information into a system. They may be in the form of physical cockpit flight controls (hand controllers and switches), or computer input devices such as a mouse, touch screen, or keyboard. The type of device needed for a task depends on the type of task, the user, and the environment. Specifically, the manipulation of controls during spacecraft acceleration, vibration, oscillatory motion, or while in a spacesuit, requires unique consideration.

Relevant Technical Requirements

NASA-STD-3001 Volume 2, Rev E

[V2 3006] Human-Centered Task Analysis
[V2 3102] Human Error Analysis
[V2 3101] Iterative Developmental Testing
[V2 4102] Functional Anthropometric Accommodation
[V2 4103] Body Mass, Volume, and Surface Area Data
[V2 4104] Crew Operational Loads
[V2 4105] Withstand Crew Loads
[V2 4013] Muscle Effects
[V2 10003] Operability
[V2 10001] Usability
[V2 10002] Design-Induced Error
[V2 5007] Cognitive Workload
[V2 10200] Physical Workload
[V2 5006] Situation Awareness
[V2 5051] Legibility
[[V2 5053] Controls for Human Error
[V2 10027] Protect Against Unintended Operator Actions
[V2 10028] Error Detection and Recovery
[V2 6094] Hand Vibration

Section 10: Crew Interfaces
Appendix F Display Standard from NASA-STD-3001 Volume 2 provides consistent and uniform technical requirements for the design, selection, and application characteristics and capabilities for the development of displays across spaceflight programs that support operator task performance.

Control Design Considerations

Tactile displays are closely linked to crew controls and provide feedback to the crewmember when interacting with the system through controls, such as vibration, force feedback and mechanical stops, switch detents, and button clicks.

The size of a control should ensure optimal operation by the expected body part (e.g., finger, hand, foot) of the smallest and largest crewmember, including the expected clothing such as a spacesuit, boots, and gloves. For example, a knob that must be turned by a suited glove must be large enough that it can be activated comfortably with at least two fingers of any crewmember.
Control size is often an indication of how it is to be used, and aids in recognition.

- Use large controls (e.g., lever on a hatch) for high forces and gross motor actions.
- Use small controls (e.g., a trackball) for low forces and high precision.
- To prevent accidental actuation, the resistive force should be sufficient to support the resting weight of the operating body part (e.g., finger, hand, foot). The resistive force must be large enough to prevent unintended drifting or changing of position due to vehicle movements.
- Controls must be operable by the weakest crewmember, taking into account the effect of any 0g or partial-g deconditioning.
- For repeated operations, the force should not be great enough to cause fatigue.

Types of Control Devices

1. Push Button
2. Foot-Operated Switches
3. Keyboard
4. Toggle Switch
5. Legend Switches
6. Rocker Switches
7. Slide Switch
8. Discrete Push-Pull
9. Printed Circuit Switch
10. Levers
11. Displacement (Isotonic) Joysticks
12. Hand-Operated Displacement Joysticks
13. Finger-Operated Displacement Joysticks
14. Thumb tip/Fingertip-Operated Displacement Joysticks
15. Isometric Joystick (Two-Axis Controller)
16. Hand-Operated Isometric Joysticks
17. Stylus
18. Mouse
19. Touch Screen
20. Pedals
21. Rotary Selector Switches
22. Discrete Thumbwheel
23. Continuous-Adjustment Thumbwheel
24. Knobs
25. Cranks
26. Hand Wheels (Two-Hand Operated)

Reference Section 10.4.2 Control Devices of the Human Integration Design Handbook for detailed guidance on each type of device.

See OCHMO-TB-049: Anthropometrics and Crew Physical Characteristics for additional information on design requirements for crew size and strength.

Control Design Considerations

Feedback/Positive Indication – Provides feedback to the user to positively indicate the control activation, such as snap feel, audible click, associated visual or audio display, or integral light. The feedback is important to ensure that the resulting action is the one intended by the user. This is especially important for commands that are critical or potentially hazardous.

Channel or Cover Guard – Provided when accidental actuation of a control needs to be prevented. When a cover guard is in the open position, it should not interfere with operation of the protected device or adjacent controls.

Dimensions, Resistance, Displacement, and Separation – Design of controls between adjacent edges includes recommended separation dimensions for operation to permit error-free manipulation. Resistance should be sufficiently high to avoid inadvertent actuation under expected use conditions. Resistance should gradually increase, then drop when a control is activated. Sufficient travel (displacement) of controls should permit immediate recognition of a control engaging.

Orientation – Controls should be vertically oriented with OFF in the down position. Horizontal orientation and actuation should only be used for comparability with the controlled function or equipment location.

Interlocks or Barriers – Mechanical interlocks or barriers may be used instead of spacing requirements.

Compatibility of Movement
Displays and controls should be designed so that movement of a control corresponds to a movement on a display. The type or mechanism of control should match the user's expectations; that is, the most commonly experienced control for specific functions should be selected. Control activation should build on the users' past experience with the same or similar controls, especially during emergency conditions, where response time is critical, control of the spacecraft must be intuitive. The table below shows the relationships between commonly expected function of a system and movement of the control.

System Function	Control Movement
On	Up, right, forward, pull
Off	Down, left, rearward, push
Right	Clockwise, right
Left	Counterclockwise, left
Up	Up, rearward
Down	Down, forward
Increase	Up, right, forward, clockwise
Decrease	Down, left, rearward, counterclockwise

Control Design Considerations

Protection Against Inadvertent Actuation

Actions or commands can be initiated accidentally as a result of numerous types of human error (e.g., accident, fatigue, inexperience). When designing a system that interacts with a user, it is important to implement certain precautions to prevent these errors from occurring and if they do occur, to have easy procedures in place to recover from the error. When commands cannot be reversed, such as an abort, steps should be taken to make the command more difficult to initiate to prevent the user from executing an inadvertent command. Protective measures may include switch guards, covers, separation from other controls, or elements such as command confirmation or multi-step sequences. If an inadvertent operation occurs, the system should provide for rapid recovery.

Errors can range from minor to severe. The precise mechanisms for avoidance and recovery vary with the severity of the consequences of the error.

- Minor Consequences – For minor commands, the user should be able to undo an action (procedural step) if an error is made (e.g., selecting the wrong key on a keyboard or navigating to the wrong screen). In these cases the easiest solution is to have a button in place to allow the user to go back to the previous step.
- Significant Consequences – For critical commands, multiple steps must be in place to complete the command and users should be able to correct or undo a command (as with minor consequences).
- Confirmation of Choice – On a display, confirmation may come in the form of a message that requires the user to affirm their choice, and if the command could have severe consequences, the system should require confirmation at every step in the process.
- Multiple Keystrokes – Requiring multiple keys to be depressed simultaneously (for example, Control-Alt-Delete) helps to ensure that the user intends to perform that action. The likelihood that those keys would be simultaneously depressed by chance is rare.
- Confirmation Message – A message to confirm the initiation of the command is beneficial as an additional precaution.
- Multiple Control Movements – Requiring two or more movements to actuate the control, such as pushing and turning the knob on the stove to light it, turning the knob on a combination lock clockwise, counterclockwise, and then clockwise to open it, or requiring the user to disable a cover over a button to access the button, makes the command difficult to initiate and thus less likely to be done inadvertently.

Use of Stops

The use of a control stop, also called a limiter or a hard stop, is primarily based on the type of control, the control operation, or the possibility of an unsafe action occurring if a limiter is not employed. More often than not, most control knobs have a detent in addition to a stop. Detents provide tactile feedback to the user on the status of the control knob (e.g., a multi-position control knob). The most common knobs that use detents and stops are rotary knobs. Rotary control knobs are multifunctional in that they can control software (e.g., manipulating a focus box through an array of targets) or hardware settings (e.g., low, medium, and high).

Control Design Considerations

Use of Coding

The use of a coding mode (e.g., size and color) for a particular application should be governed by the relative advantages and disadvantages of each type of coding (see table below). Where coding is used to differentiate among controls, application of the code should be uniform throughout the system.

	TYPE OF CODING					
	LOCATION	SHAPE	SIZE	MODE OF OPERATION	LABELING	COLOR
ADVANTAGES						
Improves visual identification	X	X	X		X	X
Improves nonvisual identification (tactual and kinesthetic)	X	X	X	X		
Helps standardization	X	X	X	X	X	X
Aids identification under low levels of illumination and colored lighting	X	X	X	X	(when trans-illuminated)	(when trans-illuminated)
May aid in identifying control position (settings)		X		X	X	
Require little (if any) training; is not subject to forgetting					X	
DISADVANTAGES						
May require extra space	X	X	X	X	X	
Affects manipulation of the control (ease of use)	X	X	X	X		
Limited in number of available coding categories	X	X	X	X		X
May be less effective if operator wears gloves		X	X	X		
Controls must be viewed (i.e., must be within visual areas and adequately illuminated)					X	X

From: MIL-STD-1472F

Control Design Considerations

Size Coding

- No more than three different sizes should be used to code controls for discrimination by absolute size.
- Controls used for performing the same function on different items of equipment should be the same size.
- When knob diameter is used as the coding parameter, the differences between diameters should be not less than 13 mm (0.5 in.).
- When knob thickness is the coding parameter, the differences between thicknesses should be not less than 10 mm (0.4 in.).

Shape Coding

Shape coding may be used to ensure identification of control knobs or handles by "feel" where visual identification is not possible.

- Shapes must be associated with or resemble the control function, and not alternate functions.
- The shape must not interfere with ease of control manipulation.
- Shapes should be identifiable by hand and by eye regardless of the position and orientation of the control knob or handle.
- Shapes must be tactually identifiable when gloves must be worn.
- The number of shapes to be identified by each operator based on absolute discrimination should be not more than 10.
- Shape-coded knobs and handles should be positively and non-reversibly attached to preclude incorrect attachment when replacement is required.

Color Coding

Colors may be used only to supplement other control-coding methods.

- Color coding should be done on the control's label and not on the control itself.
- The color of controls should be a neutral gray or black so that they are consistent across the cockpit. The label associated with each control will vary across the cockpit to provide the functional or descriptive information for each control.
- If color coding is required, not more than five colors should be used. Only the following colors should be selected for control coding:
    - Red
    - Green
    - Orange-yellow
    - White
    - Blue (only if an additional color is absolutely necessary)
- Gloss finishes should not be used on controls where specular reflection (glare) or reduced friction could degrade task performance.
- Color coding should be compatible with anticipated ambient light during the mission.

Control Design Considerations

Coding for emergency controls
Coding for emergency controls should allow the operator to distinguish them from other controls. It has been shown that operators react more quickly to simple coding such as colors and pictures than they do to written labels.

Restraints for control operation
The crew should have a means of reacting to any required control input forces without letting those forces push them away from the control. This helps the crew maintain position and apply required control forces. Operator's arms/legs should be supported and/or restrained to allow for accurate control inputs to remain within task performance limits during elevated g conditions and to prevent inadvertent control inputs during high-g nominal and abort scenarios.

High-g operations
Over 3g – Controls should be operable by a restrained, suited operator. IN suited subjects, there is a 6% reduction in forward reach displacement at 3g, 18% at 4g, and 32% at 5g (Schafer & Bagian, Aviation, Space, and Environmental Medicine, 64: 979, 1993). Above 3 g, the accuracy of gross limb movements is compromised; thus, control action under these conditions should be limited to hand and wrist motions alone.
Over 2g – Between 2g and 3g, controls should be operable by a restrained, suited operator. Suited subjects on average exhibited little impact at 2g but did show a 6% reduction in maximum forward reach displacement at 3g (Schafer & Bagian, Aviation, Space, and Environmental Medicine, 64: 979, 1993). Reaches will begin to show errors above 2g, and so control actions should be limited to hand/wrist motions or forward arm movements within a +/- 30-degree cone (apex at the shoulder joint, aligned with the axis of acceleration).

- For tasks requiring rapid response times or for deconditioned crew, a more conservative approach should be taken – controls should be placed to minimize reach.
- Awkward shoulder/elbow postures, which could result from reaches to displays/interfaces at close distances, will increase fatigue and errors and should therefore be avoided.

Cursor controls

- Movement times with cursor control devices are generally slower under vibration conditions that may be experienced during launch and descent. Reference NASA-STD-3001 Volume 2 [V2 6094] Hand Vibration.
- Extravehicular activity gloves reduce tactility even when they are not pressurized. Thus, performance with cursor control devices that require fine motor movements is negatively affected when wearing gloves: movement times are slower and accuracy is also reduced. Some devices are less affected by the lack of tactility.
- Continuous devices are faster than discrete devices; however, there are more opportunities to commit errors than with discrete devices.

Crew-System Interaction

Feedback

System feedback is provided on user actions and system changes. The feedback should be clear, easy to understand, and specific to the action. If further actions are required from the user, the feedback should be specific and timed to allow sufficient consideration and execution. Different types of feedback include:

- Visual – A simple change of background color on a display may indicate that the user has moved into a specific submenu, but a flashing, pop-up message may indicate a more important change of system status, such as a low fuel level.
- Auditory – Effective in communicating important messages as they easily grab the user's attention, even when the user is away from the system. For example, changes in pitch, volume, or rate can indicate changes in the severity of a situation. Auditory alerts function well in conjunction with visual feedback conveying the same message. Presenting the information in both visual and auditory modalities increases the likelihood that the message will be received and responded to in a timely manner by the user.
- Tactile – Used to signal the status of events to the user. This may be especially helpful when the other modalities are restricted, such as during ascent or descent. For example, if a button stays depressed, this state may indicate that the function is proceeding, and when it releases the function has stopped. Vibration may also be used to convey a message to the user, or alert the user to an approaching performance limit, such as occurs with a stick- or pedal-shaker in aircraft flight controls.

Timing of Feedback

Feedback must be delivered directly after the event to ensure that the user correctly associates the response with the input, and in time to allow the user to perform any needed adjustments and follow-on tasks. Timely feedback to inputs is critical for crew to feel they are interacting with a responsive system. Slow response times can result in redundant inputs to the system, which can add to crew confusion and errors. The timing of feedback, either continuously or at the conclusion of a command, depends on the nature of the event and its consequences.

Immediate feedback is also very important for preventing the user from initiating an action twice. If the feedback occurs long after an event, the user may believe that the event was not properly received and initiate it again. For some events this can have dire consequences, and it should be avoided through the use of prompt feedback. If there is to be a delay in system feedback greater than 2.0 seconds, the user should be given some indication that the system is processing the request. The indication can be in the form of a symbol (e.g., hourglass), animation (e.g., running list of dots…… or filling progress bar), or text message (e.g., "Processing…", "Please wait," "This request will take several minutes to complete."). The primary goal is to inform the user that the system is not "locked up" or malfunctioning but is processing the user's request. Desensitization occurs when users stop responding to the alert because they have heard it too many times. Presenting unimportant or noncritical messages to the user at very short intervals will cause the user to become desensitized to them. Therefore, determining the frequency of the feedback is important to ensuring that the message is properly received.

The optimal timing of feedback is important in 1) delivering the desired information to the user and 2) preventing the user from initiating the action twice.

Crew-System Interaction

Maximum System Response Time(s) – *From NASA-STD-3001 Volume 2*

System Response	Example	Maximum Time(s)*
Continuous input: cursor and onscreen dynamic elements	Cursor and symbol motion	0.07 (15 Hz)**
Discrete input: Indication of a visual, auditory, or tactile discrete input	On-screen keystroke echo; click or beep; detent/physical feedback; integral light illuminating	0.1
Update to local element	Display of popup menu	0.5
Display of a requested Graphical User Interface (GUI)	Calling up a new display or display component	1.0
Display of updated data on crew command of a state change	Status of "on" when commanded on; status of "open" when commanded open	1.0
Feedback for commands that cannot be completed within 1 second: Indication that a command or process is in progress	A progress bar showing time remaining or a progress message (i.e., Graphical progress bar, animated swirl, message followed by animated dots)	1.0
Status of the command/process after request completed	After request is completed – status message of success/fail/unknown (i.e., "Command Rejected", "Success", telemetry change "ON" to "OFF")	1.0

** System response time variability with respect to mean response time shall be <= 5%. Note that systems with "Short time to effect" scenarios may require faster response times, as determined in the task analysis.*
*** Polling rate, DPI, and screen refresh rate are factors that affect cursor and screen dynamic elements*

Other Feedback Considerations

State Information – The user should have access to the status of the system at all times to determine the next course of action and avoid initiating a change of status if that change has already been made. Consider: the type of status indicator, the method used to deliver that status information, and the timing or precision of the information delivery.

Types of Status Indicators – Most common types on a computer include lights, selection (e.g., using highlighting, color, or handles around an object), accessibility indicators (e.g., when a button is available or able to be formatted, the font is bold and black, and when it is unavailable the font is gray), an indented appearance to buttons, and a check or dot next to an item.

Methods of Indicating Status – Such as visual change, text label or message, and/or auditory tone. The number of status indicators needed for each status message needs to be evaluated when a system is being designed.

Precision of Status – The user should be provided timely and precise status information.

Back-Up

Referenced Technical Requirements

View the current versions of NASA-STD-3001 Volume 1 & Volume 2 on the OCHMO Standards website

NASA-STD-3001 Volume 2 Revision E

[V2 3006] Human-Centered Task Analysis Each human spaceflight program or project shall perform a human-centered task analysis to support systems and operations design.

[V2 3102] Human Error Analysis Each human spaceflight program or project shall perform a task-based human error analysis (HEA) to support systems and operations design.

[V2 3101] Iterative Developmental Testing Each human spaceflight program or project shall perform iterative human-in-the-loop (HITL) testing throughout the design and development cycle.

[V2 4102] Functional Anthropometric Accommodation The system shall ensure the range of potential crewmembers can fit, reach, view, and operate the human systems interfaces by accommodating crewmembers with the anthropometric dimensions and ranges of motion as defined in data sets in Appendix E, Physical Characteristics and Capabilities, Sections E.2 and E.3.

[V2 4103] Body Mass, Volume, and Surface Area Data The system shall accommodate the body characteristic data for mass, volume, and surface area as defined in Appendix E, Physical Characteristics and Capabilities, Sections E.4, E.5, and E.6.

[V2 4104] Crew Operational Loads The system shall be operable by crew during all phases of flight, including prelaunch, ascent, orbit, entry, and postlanding, with the lowest anticipated strength as defined in E, Physical Characteristics and Capabilities, Section E.7.

[V2 4105] Withstand Crew Loads The system shall withstand forces imparted by the crew during all phases of flight, including but not limited to prelaunch, ascent, orbit, entry, and postlanding, as defined in Appendix E, Physical Characteristics and Capabilities, Section E.7 without sustaining damage.

[V2 4013] Muscle Effects The effects of muscle endurance and fatigue shall be factored into system design.

[V2 10003] Operability The system shall provide crew interfaces that enable tasks to be performed successfully within the appropriate time limit and degree of accuracy.

[V2 10001] Usability The system shall provide crew interfaces that result in a NASA Modified System Usability Scale (NMSUS) score of 85 or higher.

[V2 10002] Design-Induced Error The system shall provide crew interfaces that do not exceed the maximum observed error rates listed in Table 5.1-1—Maximum Observed Design-Induced Error Rates.

[V2 5007] Cognitive Workload The system shall provide crew interfaces that result in Bedford Workload Scale ratings of 3 or less for nominal tasks and 6 or less for tasks performed under degraded system conditions.

[V2 5006] Situation Awareness Systems shall provide the Situation Awareness (SA) necessary for efficient and effective task performance and provide the means to recover SA, if lost, for anticipated levels of crewmember capability and anticipated levels of task demands.

[V2 5051] Legibility The system shall provide crew interfaces that are legible under expected operating conditions.

Referenced Technical Requirements

View the current versions of NASA-STD-3001 Volume 1 & Volume 2 on the OCHMO Standards website

NASA-STD-3001 Volume 2 Revision E

[V2 5053] Controls for Human Error The system shall control for human error according to the following precedence: a. Design the system to prevent human error in the operation and control of the system. b. Design the system to reduce the likelihood of human error and provide the capability for the human to detect and correct or recover from the error. c. Design the system to limit the negative effects of the error.

[V2 10027] Protect Against Unintended Operator Actions The system shall protect against inadvertent activation of controls.

[V2 10028] Error Detection and Recovery The system shall provide the capability to detect and recover from human error and inadvertent changes in system status.

[V2 6094] Hand Vibration The system, including tools, equipment, and processes, shall limit vibration to the crewmembers' hands such that the accelerations, as computed according to ANSI/ASA S2.70-2006, Guide for the Measurement and Evaluation of Human Exposure to Vibration Transmitted to the Hand, do not exceed the Daily Exposure Action Value defined by ANSI/ASA S2.70-2006, Annex A, Figure A.1.

Section 10: Crew Interfaces from NASA-STD-3001 Volume 2 covers the crew interfaces through which static and dynamic information is exchanged between the crew and the system (primarily through controls and displays). Well-designed crew interfaces are critical for crew safety, optimal human performance, and minimize training.

Appendix F Display Standard from NASA-STD-3001 Volume 2 provides consistent and uniform technical requirements for the design, selection, and application characteristics and capabilities for the development of displays across spaceflight programs that support operator task performance.

Reference List

1. Human Integration Design Handbook – NASA/SP-2010-3407/Rev1. (2014). Section 10: Crew Interfaces. https://www.nasa.gov/human-integration-design-handbook/
2. Schafer, L. E. and Bagian, J. P. (1993). Overhead and forward reach capability during exposure to +1 and +6 Gx loads. *Aviat Space Environ Med, 64*, 979–984.

Related OCHMO Technical Briefs

OCHMO-TB-032: Cognitive Workload

OCHMO-TB-018: Human-in-the-Loop (HITL)

OCHMO-TB-005: Usability, Workload, Error

OCHMO-TB-024: Occupant Protection