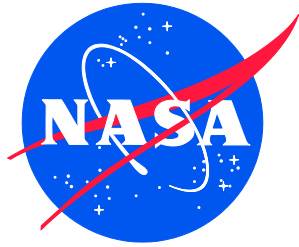


NASA/TM-20230004199
NESC-RP-20-01533



Human Factors Support for On-Orbit Servicing, Assembly and Manufacturing Mission 1 (OSAM-1)

*Cynthia H. Null/NESC
Langley Research Center, Hampton, Virginia*

*Jon B. Holbrook
Langley Research Center, Hampton, Virginia*

*Mary K. Kaiser and Bonnie B. Novak
Analytical Mechanics Associates, Hampton, Virginia*

NASA STI Program Report Series

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA scientific and technical information (STI) program plays a key part in helping NASA maintain this important role.

The NASA STI program operates under the auspices of the Agency Chief Information Officer. It collects, organizes, provides for archiving, and disseminates NASA's STI. The NASA STI program provides access to the NTRS Registered and its public interface, the NASA Technical Reports Server, thus providing one of the largest collections of aeronautical and space science STI in the world. Results are published in both non-NASA channels and by NASA in the NASA STI Report Series, which includes the following report types:

- **TECHNICAL PUBLICATION.** Reports of completed research or a major significant phase of research that present the results of NASA Programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA counterpart of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.
- **TECHNICAL MEMORANDUM.** Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.
- **CONTRACTOR REPORT.** Scientific and technical findings by NASA-sponsored contractors and grantees.

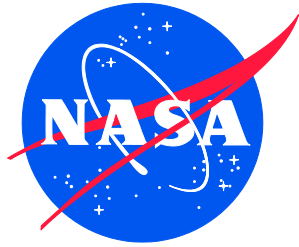
- **CONFERENCE PUBLICATION.** Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or co-sponsored by NASA.
- **SPECIAL PUBLICATION.** Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.
- **TECHNICAL TRANSLATION.** English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services also include organizing and publishing research results, distributing specialized research announcements and feeds, providing information desk and personal search support, and enabling data exchange services.

For more information about the NASA STI program, see the following:

- Access the NASA STI program home page at <http://www.sti.nasa.gov>
- Help desk contact information: <https://www.sti.nasa.gov/sti-contact-form/> and select the "General" help request type.

NASA/TM-20230004199
NESC-RP-20-01533



Human Factors Support for On-Orbit Servicing, Assembly and Manufacturing Mission 1 (OSAM-1)

*Cynthia H. Null/NESC
Langley Research Center, Hampton, Virginia*

*Jon B. Holbrook
Langley Research Center, Hampton, Virginia*

*Mary K. Kaiser and Bonnie B. Novak
Analytical Mechanics Associates, Hampton, Virginia*

National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23681-2199

March 2023

Acknowledgments

The NESC assessment team would like to recognize Rory Casey, Calvin Garner, Michael Prior, and Cliff Williams from the OSAM-1 for providing valuable insight during this assessment.

The team would also like to thank Steven Gentz, Robert Hodson, Megan Parisi, Joel Sills, and Mark Terrone for valuable discussions and peer review.

The use of trademarks or names of manufacturers in the report is for accurate reporting and does not constitute an official endorsement, either expressed or implied, of such products or manufacturers by the National Aeronautics and Space Administration.

Available from:

NASA STI Program / Mail Stop 148
NASA Langley Research Center
Hampton, VA 23681-2199
Fax: 757-864-6500



NASA Engineering and Safety Center Technical Assessment Report

Human Factors Support for On-Orbit Servicing, Assembly and Manufacturing Mission 1 (OSAM-1)

NESC-TI-20-01533

Dr. Cynthia H. Null

Dr. Jon B. Holbrook

March 14, 2023

Report Approval and Revision History

NOTE: This document was approved at the March 14, 2023, NRB.

Approved: TIMMY WILSON	Digitally signed by TIMMY WILSON Date: 2023.03.28 16:27:24 -04'00'
NESD Director	

Version	Description of Revision	Office of Primary Responsibility	Effective Date
1.0	Initial Release	Dr. Cynthia H. Null, NASA Technical Fellow for Human Factors, ARC	3/14/2023

Table of Contents

1.0	Notification and Authorization	5
2.0	Signatures.....	6
3.0	Team Members	7
3.1	Acknowledgments	7
4.0	Executive Summary	8
5.0	Scope.....	10
6.0	MOC Design.....	11
7.0	Methodology.....	12
7.1	Noise.....	13
7.2	Lighting.....	14
7.3	Information Displays	15
7.4	Multiple Channel Audio Communication System.....	16
7.5	Workstation Design	17
7.6	Physical Separation.....	19
7.7	Visitor Flow and Space Allocation	20
7.8	Notional MOC Schematic.....	21
8.0	Supplemental HF Analysis	22
8.1	Ancillary Rooms	22
8.2	Shift Schedule Guidance.....	22
9.0	HMI Style Guide.....	24
10.0	Summary	25
11.0	Findings, Observations, and NESC Recommendations.....	26
11.1	Findings	26
11.2	Observation.....	27
11.3	NESC Recommendations	27
12.0	Alternate Technical Opinion(s).....	28
13.0	Other Deliverables	28
14.0	Recommendations for the NASA Lessons Learned Database.....	28
15.0	Recommendations for NASA Standards, Specifications, Handbooks, and Procedures	28
16.0	Definition of Terms.....	28
17.0	Acronyms and Nomenclature	29
18.0	References.....	29
	Appendices.....	30
Appendix A.	HF Interview Protocol	31
Appendix B.	Shift Schedule Guidance.....	34
Appendix C.	HF Checklist	36

List of Figures

Figure 6-1. Initial Design, OSAM-1 MOC	12
Figure 7-1. Notional NESC Team MOC Schematic	21
Figure B-1. Examples 1 and 2.....	34
Figure B-2. Examples 3 and 4.....	35

List of Tables

Table 7-1. Minimum Requirements for Control Room Lighting.....	14
Table 7-2. Seated Standards for Workstation Design	18

Technical Assessment Report

1.0 Notification and Authorization

The NASA Engineering and Safety Center (NESC) Human Factors (HF) Technical Discipline Team (TDT) was requested by the Satellite Servicing Projects Division at Goddard Space Flight Center (GSFC) to provide support in assessing the design of the On-Orbit Servicing, Assembly and Manufacturing Mission 1 (OSAM-1) Mission Operations Center (MOC) in light of concerns about overcrowding and potential for distractions, as well as assistance in creating a Human-Machine Interface (HMI) style guide for OSAM-1 user interface design.

Dr. Cynthia Null, NASA Technical Fellow for HF, was the NESC lead for this assessment, and Dr. Jon Holbrook was the technical lead.

The key stakeholders for this assessment are:

- Mr. Michael Prior, OSAM-1 Deputy Ground Systems Manager, GSFC
- Mr. Clifford Williams, OSAM-1 Mission Operations Manager, GSFC

2.0 Signatures

Submitted by: NESC Lead

CYNTHIA NULL Digitally signed by CYNTHIA NULL
Date: 2023.03.28 12:37:56 -05'00'

Dr. Cynthia H. Null

Significant Contributors:

Jon Holbrook Digitally signed by Jon Holbrook
Date: 2023.03.24 09:31:05 -04'00'

Dr. Jon B. Holbrook

MARY KAISER Digitally signed by MARY
(affiliate) KAISER (affiliate)
Date: 2023.03.27 20:20:24
-07'00'

Dr. Mary K. Kaiser

BONNIE Novak Digitally signed by BONNIE
(affiliate) Novak (affiliate)
Date: 2023.03.23 15:58:15 -04'00'

Ms. Bonnie B. Novak

Signatories declare the findings, observations, and NESC recommendations compiled in the report are factually based from data extracted from program/project documents, contractor reports, and open literature, and/or generated from independently conducted tests, analyses, and inspections.

3.0 Team Members

Name	Discipline	Organization
Core Team		
Cynthia Null	NESC Lead	NESC/ARC
Jon Holbrook	Technical Lead	LaRC
Mary Kaiser	HF TDT Member	AMA/LaRC
Bonnie Novak	HF TDT Member	AMA/LaRC
Business Management		
Becki Hendricks	Program Analyst	LaRC/MTSO
Assessment Support		
Melinda Meredith	Project Coordinator	LaRC/AMA
Linda Burgess	Planning and Control Analyst	LaRC/AMA
Jenny DeVasher	Technical Editor	LaRC/AS&M

3.1 Acknowledgments

The NESC assessment team would like to recognize Rory Casey, Calvin Garner, Michael Prior, and Cliff Williams from the OSAM-1 for providing valuable insight during this assessment.

The team would also like to thank Steven Gentz, Robert Hodson, Megan Parisi, Joel Sills, and Mark Terrone for valuable discussions and peer review.

4.0 Executive Summary

The OSAM-1 is a robotic spacecraft equipped with the tools, technologies, and techniques intended to extend satellites' lifespans, even those not designed to be serviced on-orbit. During its mission, planned for 2025, the OSAM-1 servicer will rendezvous with, attach, refuel, and relocate a government-owned satellite to extend its life. The servicer will also manufacture a 32-foot-long lightweight composite beam to demonstrate on-orbit construction capabilities.

OSAM-1's capabilities are intended to provide satellite operators new ways to manage their fleets more efficiently and derive additional value from their initial investment. The successful completion of this mission will demonstrate that servicing technologies are available for incorporation into other NASA missions, including exploration and science ventures.

The NESC HF TDT was requested by the GSFC Satellite Servicing Projects Division to provide support with regard to:

- Assessing the MOC design for the OSAM-1 to address concerns about overcrowding and potential for distractions.
- Providing assistance in authoring a HMI Style Guide for design of OSAM-1 user interfaces. The OSAM-1 HMI Style Guide provides guidelines for the development of OSAM-1 HMIs that will be used in the OSAM-1 MOC. The guidelines promote visual continuity, workflow consistency, and a common look, feel, and functionality for all users.

The GSFC Satellite Servicing Projects Division requested NESC support in May 2020 because it had no resident HF expertise, but recognized that design decisions would affect human task performance. Due to the absence of access to the GSFC facility and product prototypes during the timeframe of this analysis due to COVID-19 travel and interaction limitations, the NESC assessment team adjusted its scope to provide best practices and guidance documents rather than on-site evaluations of physical room layouts and prototype equipment.

In addition, the NESC assessment team learned after starting the analysis that the OSAM-1 team planned to begin MOC facility construction in August 2020 in an already-selected location and was in the process of hardware acquisition. Therefore, the assessment team provided some early recommendations (i.e., prior to 9/30/2020) that were briefed to the NESC Review Board (NRB), specific to MOC design decisions that would directly affect or be affected by physical construction and hardware. The NESC recommendations in this report provide HF guidance based on best practices that, if implemented during the early stages of the design lifecycle, should lead to more efficient and effective operations of the MOC and its interfaces. Nonetheless, these recommendations incorporated the constraints of existing MOC design decisions.

This NESC HF assessment for the OSAM-1 MOC and HMI Style Guide contains human systems integration (HSI) best practices, guidance, references, and design suggestions related to noise, lighting, information displays, visual occlusion, physical separation within the room, visitor flow and space allocation, and workspace layout, provided via findings, observations, and NESC recommendations (see Section 11.0) for implementation by the Satellite Servicing Projects Division.

One critical observation made by the HF assessment team relates to the lack of OSAM-1 HF expertise, which limited the ability of the OSAM-1 team to understand and implement the NESC HF-related recommendations.

In summary, the GSFC Satellite Servicing Projects Division is aware of the need for HSI expertise and project evaluation. The OSAM-1 management team identified areas of design concern, and the NESC assessment team was able to provide best practice insights, guidance, and recommendations for an improved MOC and HMI design.

5.0 Scope

The MOC was being designed and built at the time of the NESC engagement; the OSAM-1 team wanted to use NESC guidance in the design and build process. They requested recommendations to provide controls that would minimize distractions to the flight control team during operations. In this context, such controls could include physical controls as well as behavior rules and associated enforcement mechanisms that MOC operations personnel would abide by.

Support for the OSAM-1 included two requested deliverables:

1. Recommendations for design of MOC room layout, workstations, and assignment of roles and responsibilities based on analysis of information needs and application of HF best practices while meeting existing space and resource constraints. This deliverable was intended to inform MOC design decisions. The NESC team learned, after starting the analysis, that the OSAM-1 team hoped to begin construction in the MOC facility in August 2020 and was in the process of making hardware purchases. Therefore, the NESC team provided early recommendations (i.e., prior to September 30, 2020) that were briefed to the NRB on January 25, 2021, specific to MOC design decisions that would directly impact or be impacted by physical construction and hardware.
2. Inputs to a HMI Style Guide, based on application of HF best practices. This deliverable was intended to support design of user interfaces within the OSAM-1 MOC. The NESC assessment team reviewed and provided comments on the draft prepared by an OSAM-1 team MOC system user. The OSAM-1 team wanted to ensure that the document contained the proper level of information and design characteristics. This was an iterative process worked over the course of several meetings with the OSAM-1 team.

The OSAM-1 team did not include anyone with HF expertise, which was the primary reason the OSAM-1 reached out to the NESC. The NESC assessment team, however, felt the HF support needed by OSAM-1 exceeded what the TDT could provide. In particular, the assessment team determined that OSAM-1 required ongoing, embedded support from a HF practitioner because the pace and range of HF decisions in designing the MOC did not align with the scoped engagement model used for NESC assessments. Over the course of the assessment, the NESC team met biweekly with the OSAM-1 team but was not fully embedded due to COVID-19 and resource restrictions. Many design decisions, however, were made by the OSAM-1 team outside of these meetings—decisions with implications for human task performance that were not recognized as such by the OSAM-1 team. As a result, in some cases, the NESC team did not learn of these decisions for weeks, often by serendipitous discovery during the biweekly meetings. This led to inefficiencies (e.g., re-performing analyses with new information and triaging design decisions that were non-optimal from a human performance perspective, but that could not be changed). Furthermore, the OSAM-1 team lacked the expertise to make informed trades involving human performance or measure the consequences of decisions for some of the NESC assessment team's recommended actions, even though they agreed with the recommendations themselves. Per NESC guidance, recommendations were written to refrain from providing direction on how to accomplish those actions. However, due to the lack of HF expertise within OSAM-1, recommendations without specific direction were of limited utility.

O-1. The OSAM-1 team did not include HF expertise.

The following recommendation is directed toward projects that would benefit from an embedded HF practitioner:

- R-1.** Include HF practitioners in project planning, complementary with NPR 7120.5(f) [ref. 1].
(O-1)

The NESC assessment team has worked with other projects to address the need for including HF practitioners and found value in engaging a HF graduate student intern when the availability of Agency HF SMEs and personnel funding are limited. HF/HMI/human-computer interaction (HCI) interns could provide day-to-day HF support and periodically call upon the resources of the NESC HF TDT, which could also be involved in formal evaluations and assessments.

For the scope of this analysis, Human Factors Engineering (HFE) is defined in the NASA HSI Handbook [ref. 2] as “designing and evaluating system interfaces and operations for human well-being and optimized safety, performance, and operability, while considering human performance characteristics as they affect and are affected by environments and operating in expected and unpredicted conditions.”

To conduct the MOC analysis, the NESC team collected data from applicable NASA OSAM-1 documentation, conducted interviews with personnel from GSFC and other launch facilities (Appendix A), and relied on data collected from previous NESC assessment site visits to NASA’s Wallops Flight Facility (WFF) in Virginia; Vandenberg Space Force Base (VSFB) and Point Mugu Naval Air Station in California; and Morrell Operations Center at Cape Canaveral Space Force Station (CCSFS) in Florida.

To provide inputs to the HMI Style Guide, the NESC team collected data from NASA, industry, and other government style guides; applied HF best practices; spoke with OSAM-1 operators on a biweekly basis regarding their needs; and analyzed tasks required for the development of OSAM-1 HMIs that will be used in the MOC.

This assessment addresses the MOC design and provides an overview of and examples from the HMI Style Guide. The NESC assessment team developed the MOC findings and recommendations and inputs to the Style Guide with the OSAM-1 Satellite Servicing Projects Division as part of a working group assembled to address these issues.

6.0 MOC Design

The MOC design arranges more than 50 console positions and the necessary software and hardware to conduct mission operations in one large room, although the number of operators present will vary as a function of mission phase. Many of these positions are support, planning, and analysis locations that have typically been segregated into separate rooms in past missions of similar complexity.

The initial MOC design presented to the NESC team is shown in Figure 6-1 [ref. 3]. This depiction shows the initial 53 positions situated in one operations center, which was a cause for concern to the OSAM-1 and NESC teams. Dedicated consoles for Command Controllers, Phase Leads, the Flight Director, and the Flight Operations Team are highlighted in blue. This arrangement presents an opportunity for distractions, noise, and visual cues that can lead to disruptions during critical mission operations.

It is understood that not all positions on console will be filled at all times, as there are plans for several arrangements of positions depending upon the current mission phase: Launch, Transit, and Checkout (30 days); Autonomous Rendezvous & Docking (32 days); Servicing (30 days); Departure (14 days); Assembly & Manufacturing (85 days); and Decommissioning.

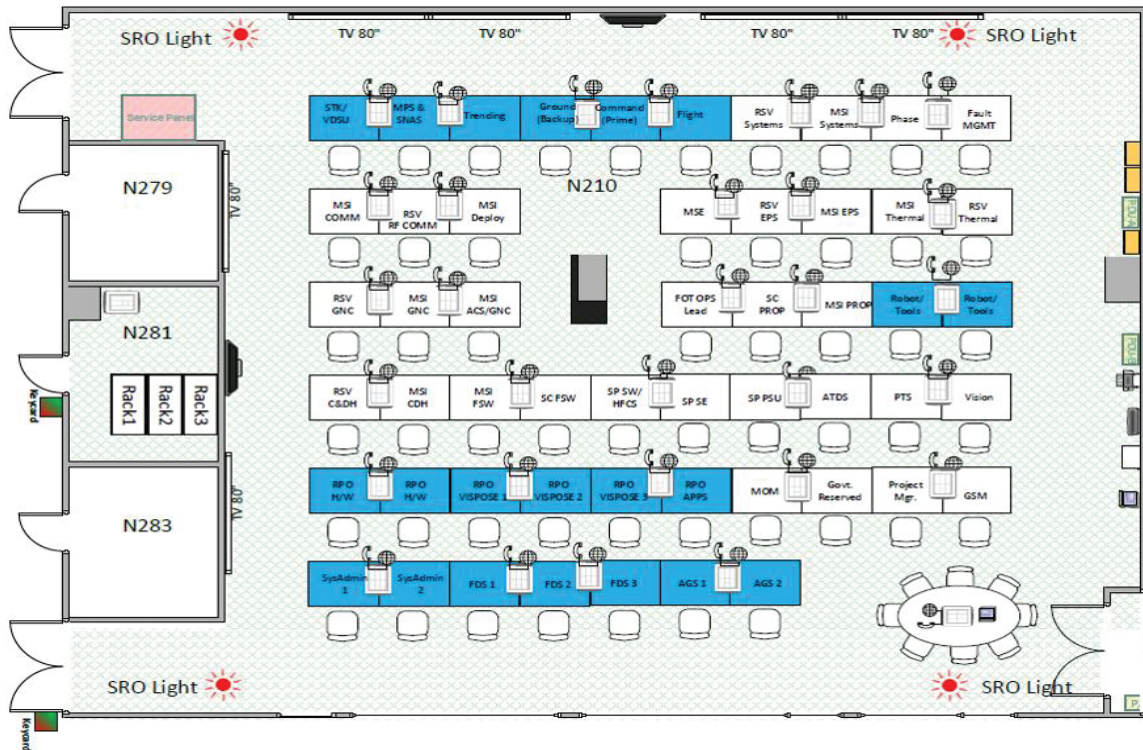


Figure 6-1. Initial Design, OSAM-1 MOC
(Console assignments shown are for the Launch, Transit, and Checkout mission phases.)

7.0 Methodology

The primary data sources for the MOC and operator displays were key reference documents provided by the OSAM-1 team, regular biweekly discussions, and structured interviews with OSAM-1 personnel (see Appendix A for interview protocol). This was due to the inability to conduct site visits and the early stages of construction. The NESC assessment team was not evaluating a finished product or completed design, but providing iterative inputs during the design process.

The NESC assessment team leveraged HF expertise, human performance standards, and related research to inform the OSAM-1 MOC decision process. The focus was not to direct the design team, but rather to teach team members how to think about MOC design from a perspective that included HF considerations, such as operator-based design factors in making a trade decision between using wall monitors or projectors. Flexibility was particularly important in evaluating the MOC design because the facility was still under development, decisions were still being made, and there were limitations on direct measurement and testing due to COVID-19 travel and interaction restrictions.

However, the NESC assessment team was able to present preliminary HF considerations. Those considerations were not limited to the performance of on-console tasks but included all the operations that take place within the MOC, traffic within the room (e.g., ingress/egress, visitors, and VIPs), on- and off-loop communications with colleagues for expected and unexpected reasons, shift handovers, and performance of necessary non-mission duties (e.g., checking email).

Some of the factors the NESC assessment team considered in developing inputs into MOC design included the following HF considerations that define and shape the operational environment:

- Noise
- Lighting
- Information displays (e.g., type, location, size)
- Visual occlusion (e.g., viewing angles, blocking line of sight to displays, co-workers)
- Physical separation within the room
- Visitor flow and space allocation

Consideration of these HF issues in MOC design decisions was intended to give operators more opportunity to succeed at their work by improving and facilitating access to mission-relevant information during operations.

7.1 Noise

The NESC assessment team's initial HF consideration for the MOC design process was noise level. It is important for designers and those procuring equipment to be sensitive to cumulative equipment noise effects. The cumulative ambient noise in the control room should not be above 65 decibels (dB), and every effort should be made to minimize noise distractions that could be generated inside or outside the MOC.

Standards and resources, such as MIL-STD-1474E [ref. 4] and the NUREG-0700 [ref. 5] that specify this dB level, were suggested by the NESC assessment team to serve as reference guides for designing to acceptable levels of unprotected hearing. The International Organization for Standardization (ISO) 11064-6:2005 Ergonomic Design of Control Centres [ref. 6] recommends 45 dB as the maximum ambient noise level for a control room. Therefore, a review of these standards indicates that a decibel level of 45–65 dB is appropriate for ambient noise levels.

In addition to providing recommended ambient noise level standards, the NESC assessment team presented the possibility that adding acoustic panels within the MOC or covering the windows with acoustic curtains could aid in noise dampening. The OSAM-1 team and NESC assessment team worked together to research available options as Commercial-off-the-shelf (COTS) purchases.

- F-1.** Standards documents prescribe acceptable ambient noise levels for control rooms (e.g., MIL-STD-1474E, NUREG-0700, and ISO 11064-6:2005).
- R-2.** Ensure ambient noise in the MOC, after equipment installation and during equipment operation, is lower than a maximum of 65 dB, preferably less than 45 dB. (*F-1*)
- F-2.** Based on discussions with the OSAM-1 team, the NESC assessment team understands that the walls in the MOC are an assortment of hard surfaces (e.g., drywall, glass).
- R-3.** Consider adding acoustic panels to selected walls within the MOC for additional attenuation of ambient noise. In addition, the windows at the back of the room could be covered with acoustic curtains, for sound absorption and to block visual distractions from activities in the adjacent room. (*F-2*)

7.2 Lighting

Due to the nature of the tasks being performed, appropriate lighting is critical. However, optimal lighting and the ability to read and interpret displays under certain lighting conditions are different for every person due to personal preferences, differences in eyesight, eye strain, or fatigue. Lighting needs could change over the course of a single mission or phase operation, since personnel can be called upon to work a shift on console for up to 12 hours. Therefore, individual tasks require adjustable lighting beyond the ambient light in the room. The NESC assessment team took note of lighting at other benchmarked facilities. Lighting was an issue identified and observed during prior control room site visits to WFF, VSFB, and CCSFS. The VSFB Range Safety Room has dimmable overhead lighting at each control station, which can be customized by each operator without affecting others nearby.

Another issue is diffuse glare caused by general environmental luminance levels, which can effectively reduce display contrast and make viewing difficult for users. This can be mitigated by adjusting display luminance levels, maintaining appropriate control room brightness levels, providing supplemental workstation light, and choosing the appropriate display type [ref. 7].

Best-practice mitigation strategies to minimize or eliminate glare in the MOC include:

1. Placing displays properly relative to light sources.
2. Using indirect lighting.
3. Using multiple dim light sources rather than a few bright ones.
4. Using anti-glare treatment, such as a diffusing surface or optical coating (provided it does not affect performance or violate requirements for luminance, contrast, and display resolution).
5. Filtering control of light sources [ref. 7].

ISO 11064-6:2005 [ref. 6] establishes minimum requirements for control room lighting, shown in Table 7-1. The standard also requires lighting to achieve a unified glare index (UGI) of less than 19 and a color rendering index (CRI) of more than 80. The CRI determines the perceived color of illuminated objects. An incandescent bulb has a CRI of 100, which allows clear distinction between perceived colors. Therefore, this standard indicates using triphosphor lights or fluorescent lights with a CRI over 90.

Table 7-1. Minimum Requirements for Control Room Lighting

Control Room Measurable	Illuminance in Lux (per m ²)
Maximum illuminance for control rooms with video displays	500
Maintained minimum illuminance level	200

Adjustable lighting on console should be provided if ambient lighting is not adequate for the operator to read hardcopy documents. Research conducted in the UK [ref. 8] suggests that where individuals are conducting different activities on consoles, they need control over local lighting. For example, a control and instrumentation engineer in a process control room illuminated at 300 lux may need a desk with a lamp to study a diagram or graphic display. Studies have shown that giving workers in open-plan offices local control of lighting can increase job satisfaction and decrease stress [ref. 9]. This aligns with feedback received from OSAM-1 team personnel, who

reported the desire to have local lighting controls at their workstations, in addition to the following:

- Backlight behind monitors with dimmers to add additional ambient lighting control.
- Overhead lights with dimmers to add additional lighting control for users.

The decision on lighting hardware at individual console positions has not been finalized. Therefore, the NESC assessment team presented the benefits of adjustable lighting in the MOC as well as on individual consoles. Adjustable dimmer switches can be an effective way to adjust MOC room brightness and optimize wall screen and workspace visibility.

F-3. OSAM-1 personnel indicated that they would like the MOC lighting to be adjustable.

R-4. Use dimmer switches to flexibly adjust MOC room brightness and optimize wall screen and workspace visibility. (*F-3*)

F-4. Research indicates that local lighting control can enhance individual performance.

R-5. Provide the capability for individuals on console to adjust the brightness at their workstations. (*F-4*)

7.2.1 Security Restricted Operations Lights

Four Security Restricted Operations (SRO) lights are positioned by the room's ceiling corners. These lights indicate when room access is to be restricted due to real-time telemetry analysis or troubleshooting operations that are deemed security restrictive. Although the SROs within the MOC were already installed, the NESC assessment team noted that ideally they should be placed in such a manner as to minimize distraction. The OSAM-1 team confirmed that the lights are not in the line of sight between operators and shared displays (e.g., wall monitors, mission-time clocks). While SRO lights need to flash, the brightness and frequency of the flash should be the minimum required; a rotating reflector or other technologies that ramp the off/on illumination is preferred.

7.3 Information Displays

Because of the potential for an operator to dedicate console displays to information for specific tasks, maintaining shared awareness of overall mission status is a control room design concern. Most modern control room designs with individual workstations or consoles also include large overview display panels, in part to address this concern. These overview displays are spatially dedicated (i.e., fixed in position), continuously displayed (i.e., do not have to be selected or called up), and visible to the entire operations team. The displays will help increase situational awareness for MOC personnel on console for enhanced coordination and collaborative decision-making. They also may help offset the tendency for an operator to become distracted by detailed information at their console. The OSAM-1 operators will endeavor to remain cognizant of the big picture of current mission operations, and a shared overview display may help them do so [ref. 10].

Shared displays need to be of sufficient size for all personnel in the room to view. A rule of thumb is to use proportional triangles with individual users' laptop computers to estimate how large a display must be to have readable text and graphics. Consider, for example, what text and graphics are readable when viewing a monitor with a 12-inch-wide display at a distance of 30 inches. To be equally legible from the back console of the MOC (~40 feet), the display would

need to be ~16 feet wide. Similarly, mission-time clocks and other shared displays must be sized and positioned for readability from all consoles.

Analysis of the room schematics for the initial MOC design indicate that size and placement of wall-mounted displays are constrained by existing equipment, a structural column, doors, and windows that cannot be relocated. Measurements and schematics provided by the OSAM-1 team showed that the MOC ceiling height is 9 feet, and chair headrests (which were already purchased) vary between 47 and 57 inches. This allows only around 4.5 vertical feet for displays, which could lead to visual occlusion from people standing up.

In addition, the NESC assessment team was able to discern from those schematics that the lateral viewing angles from console positions to wall-mounted displays range from 83 degrees for the front row of consoles to 23 degrees for the sixth (i.e., back) row, and viewing distances range from ~9 feet for the front row of consoles to ~39 feet for the back row.

Based on this analysis, the NESC assessment team worked with the OSAM-1 MOC design team to ensure that the shared displays would be positioned in such a way as to ensure visibility, readability, and freedom from obstructions within the room, including personnel.

- F-5.** Size and placement of wall-mounted displays are constrained by existing equipment, a structural column, doors, and windows that cannot be relocated.
- F-6.** The MOC ceiling height is 9 feet, and chair headrests can vary between 47 and 57 inches. This allows only around 4.5 vertical feet for displays, which could lead to visual occlusion from people standing up.
- F-7.** Based on room schematics of the initial MOC design, lateral viewing angles from console positions to wall-mounted displays range from 83 degrees for the front row of consoles to 23 degrees for the sixth (i.e., back) row, and viewing distances range from ~9 feet for the front row of consoles to ~39 feet for the back row.
- R-6.** Position shared displays and consoles to ensure display contents are readable from all console viewing angles. (*F-5, F-6, F-7*)

7.4 Multiple Channel Audio Communication System

The OSAM-1 team indicated that their intent was to allocate communication keyset units, used for voice-loop communications, on the console such that two people would be required to share one communication system and associated headset. This was presented as a cost savings to the project, which was limited in the number of units it could purchase. At a minimum, sharing units will have significant impact on seating placement. Existing concerns include, but are not limited to, reduced speed and availability of information over voice loops, increased complexity in use and management of voice loops, and reversion to off-loop communication.

- F-8.** OSAM-1 personnel indicated that, due to the expense of the units, communication keyset units would be shared among adjacent console positions.
- R-7.** Conduct a trade study on the impact of using shared voice-loop communication units against the cost of dedicated units at each console position. (*F-8*)

Full three-dimensional (3D) audio capabilities are not intended for use in the OSAM-1 MOC, as the OSAM-1 team has already implemented the NextGen Communications system. However, 3D audio technology has the potential to reduce operator workload in communications applications

beyond that afforded by dichotic listening. It can provide a directional audio cue for multiple audio channels, aiding users in identifying the transmission source [ref. 11].

The NESC team noted that 3D audio may be helpful for monitoring communications traffic, especially if it is modeled using spatially relevant patterns. This technology was reported as being helpful for operators on console at VSBF who were monitoring several communications channels at once. If full 3D audio cannot be supported, the MOC intends to assign a communication channel to either the left or right ear to support dichotic listening.

7.5 Workstation Design

The workstation is the physical space where operators perform their functions during all mission phases, as described in Section 6.0. A station typically includes the console/work surface, input/control devices, displays, communications equipment, and chair.

The console is the operator's principal workstation in the control room. For OSAM-1, project managers have selected rows of connected workstations. Each workstation is 4 feet wide by 2 feet deep and will accommodate two 24-inch side-by-side monitors, a keyboard and mouse input devices, and a control box for the multi-channel communication system. The NESC assessment team confirmed that these consoles adhere to HF best practices such that controls should be no more than 26 inches from the front edge of the console surface to meet 5th percentile female design considerations for functional reach, as indicated in Table 7-2.

Operators' performance may be affected by design characteristics that affect reach, vision, and comfort. Unique considerations for these types of workstations include the following:

- Workstation height, including clearances for legs and feet
- Depth for consoles (i.e., accommodations for reach to controls or input devices, provision of writing space or space for launch binders)
- Control device location (i.e., placement of highest and lowest controls; distance from front edge of workstation)
- Display device location (i.e., placement of highest and lowest display devices, orientation relative to line of sight, viewing distance, position of frequently and infrequently monitored display devices)
- Lateral spread of control and display devices at a console or workstation

Table 7-2. Seated Standards for Workstation Design

Seated	Bounding Measurements (inches)	
	5 th %ile Adult Female	95 th %ile Adult Male
Popliteal height (bend at back of knee)	14.8	18.6
Sitting height above seat surface (erect)	32.9	38.3
Eye height above seat, sitting erect	28.5	34.0
Shoulder height above seat surface	20.0	25.4
Elbow height above seat surface	7.7	7.9
Functional reach	26.7	34.9
Extended functional reach	28.9	37.1
Thigh clearance height	5.5	7.3
Buttock-to-popliteal length	18.2	21.5
Knee height	19.8	23.8

Source: NUREG-0700 [ref. 5]

For varying features, the designer would follow the guidelines described in the table. Additionally, it is good practice to ensure no controls are placed less than 3 inches from the front edge of the console surface, to prevent inadvertent activation.

The operator at a console would ideally be able to perform tasks with minimal to no repositioning. The amount of movement required will depend upon the arrangement of the controls and displays, laterally and vertically, on the console itself. The NESC assessment team noted that keyboards should be laterally aligned with the user position on console in the MOC. Monitor and keyboard misalignment, leading to deviations from the neck's natural posture, can be detrimental to general musculoskeletal, upper body, and physical health [ref. 12].

For operator safety and comfort, especially during extensive time on-console, the following HF and ergonomics questions should be considered when configuring the computer monitors:

- Is the viewing distance to the monitors between 18 and 30 inches?
- Is the top of the monitor screens approximately at eye level?
- Can a user who wears bifocals or trifocals view monitor screens or other items in the work area without having to tilt their head back?
- Are monitor screens free of glare and reflections?
- Are monitor screens easy to view in the room's ambient illumination?
- Are anti-glare screens in use?
- Are the monitor screens clean?
- Is the character size easy to read?

Keyboard height and distance should be adjustable, especially for operators who perform extensive data inputs. Likewise, operators should be able to adjust the position of the analog cursor control and choose between a mouse and trackball/pad for this function. The use of a keyboard tray also provides more space on the workstation for writing and hard-copy documents.

OSAM-1 personnel indicated that console desktops are at a standard 28-inch height, and design plans assume that monitors, keyboards, and pointing devices will rest on this surface. Although chairs and monitor stands afford some degree of adjustability, ergonomic positioning of input devices will be constrained when placed on a standardized non-adjustable surface.

F-9. Ergonomic positioning of input devices, such as monitors, keyboards, and pointing devices, will be constrained when placed on a standardized non-adjustable surface.

R-8. Provide height-adjustable trays that support keyboards and a range of pointing devices (e.g., mouse, trackball). (*F-9*)

During launch observations at WFF and interviews with VSFB and Point Mugu personnel, the NESC team noted that console areas were cluttered with input devices, headset cables, binders, laptops, and personal items [ref. 13]. Supplemental space would allow operators to place these items away from the console, but within easy reach, to reduce clutter during mission operations. One way to address this is by providing under-desk storage via a slim pedestal (10-12 inches wide) that can provide drawers or shelves for storage of mission binders, headsets, and personal items. Without a dedicated storage space, items tend to be placed on the floor, interfering with desk-chair rollers and the operator's feet. If central processing units (CPUs) are mounted under-desk, there may not be sufficient room for under-desk storage. In that case, other storage options must be provided.

F-10. NESC team observations at other mission operations and control facilities found mandatory equipment and personal items created clutter on console areas during operations.

R-9. Ensure design solutions mitigate clutter from mission-related and personal items on console during mission operations. (*F-10*)

7.6 Physical Separation

Physical separation effectively isolates the core command and control team from distraction during critical operations. A lesson learned from previous missions where such isolation was not provided is that pressure on the team, often occurring during anomalies, can lead to a breakdown in discipline and/or a lack of effective communication on the operations floor [ref. 13]. Such a breakdown can cause confusion, resulting in inappropriate command uplinks that pose a risk to the mission.

The OSAM-1 team suggested that such isolation need not require additional facilities. By making use of the mission's backup MOC (bMOC) and possibly further scrubbing the peak demand for console positions, a barrier could be erected in the current MOC facility that isolates the core command and control console positions from planning, analysis, and support console positions. The OSAM-1 team requested that any such physical barrier not inhibit ready access to backup command capabilities. The dimensions of the existing MOC are approximately 51 feet by 47 feet, with a central load-bearing column effectively dividing the space into 20-foot-wide and 30-foot-wide areas.

For OSAM-1, the NESC assessment team suggested that the divider between the main control room and back room consist of portable acoustic partitions (e.g., total height=6 feet, with the top 2 feet glass). The portability of the partitions will allow for reconfiguration; the glass will allow visual communication.

- F-11.** The OSAM-1 MOC design includes 51 console positions in one room, made up of the core command and control team as well as support, planning, and analysis positions.
- F-12.** The Satellite Servicing Projects Division has expressed the need for a barrier within the MOC facility to isolate the core command and control positions from distractions without inhibiting ready access to support, planning, and analysis capabilities.
- R-10.** Erect a configurable portable acoustic partition to create a main control room and back room within the MOC facility. (*F-11, F-12*)

7.7 Visitor Flow and Space Allocation

No dedicated space for visitors exists within the MOC, and the OSAM-1 team expressed a need to minimize the number of additional people in the MOC during launch operations. They desired only those operators critical for ongoing mission operations to be present in the main control room, with support personnel stationed in an adjacent back room.

However, it may not be possible to prohibit all visitors. Several OSAM-1 staff members have indicated that they would prefer visitors and observers to stand in the Flight Dynamics Facility (FDF) spaces along the windows in the back of the MOC, since the FDF's occupancy during all mission launch operation phases is decreased. However, there is no agreement that this will be possible or even the preferred approach by GSFC management.

In the MOC, or a dedicated space nearby, an area could be reserved for visitors to stand and observe mission operations; they would not be allowed to roam among controllers' consoles and disrupt operations. The dedicated visitor space could include listening access to communication loops relevant to the mission phase.

One possibility for accommodating MOC visitors is to create a corridor in Room N280, shown in Figure 7-2, that would allow access to a viewing area adjacent to the Main Control Room's back windows. This corridor could be accessible from a door in the back room to minimize disruption. The curtains covering the windows could be drawn back from the viewing area. A listening-only communication systems terminal could be mounted beneath the window, with individual headsets for each visitor and the host. The viewing area may require a platform so visitors can see over the primary controllers' consoles.

- F-13.** Based on room schematics of the MOC design, one wall is primarily composed of large glass panels between the MOC and an adjacent room.
- F-14.** OSAM-1 personnel indicated that the MOC design provides no space for visitors and observers.
- R-11.** Identify separate space and accommodations for visitors and observers to minimize distraction to console operators during mission operations. (*F-13, F-14*)

In addition, the MOC should be as free of foot traffic and extraneous activities as possible. To that end, ingress and egress should flow from the hallway through the back room to the Main Control Room. Common resources (e.g., copiers, printers, supply cabinets) should be kept in the back room.

As reported by the OSAM-1 team, console personnel often need access to work items such as storage racks, printers, scanners, and other hardware. Due to the nature and design of the consoles, it is neither effective nor efficient to include that hardware on the workstations.

Therefore, accommodations must be considered for locating hardware off-console in areas that minimize ambient noise effects and foot traffic.

F-15. Decisions on off-console hardware purchases (e.g., printers, storage for personal effects) and eventual location of that hardware within the MOC have not been finalized.

R-12. Position off-console hardware in locations that support access while minimizing ambient noise and foot traffic near the core command and control team. (F-15)

7.8 Notional MOC Schematic

The schematic in Figure 7-1 provides a notional layout of the OSAM-1 Main Control Room, back room, and visitor viewing area (in N280). This schematic has been vetted by the OSAM-1 team and discussed as a viable solution to minimizing distractions in the MOC as well as providing space for supporting positions.

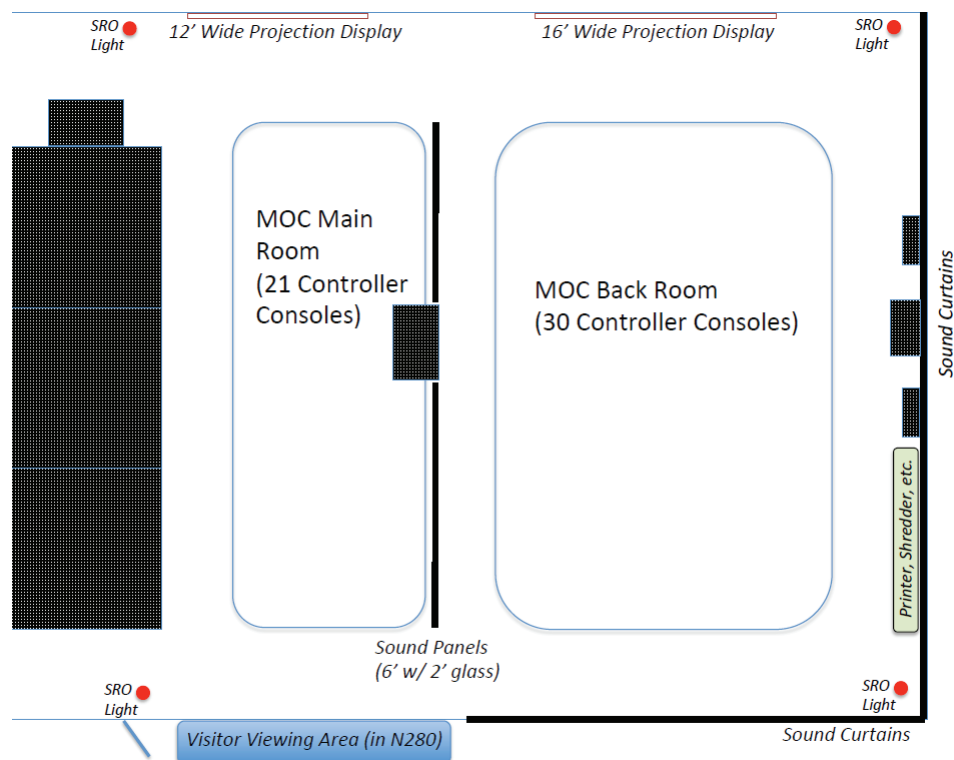


Figure 7-1. Notional NESC Team MOC Schematic

Three doorways provide entry to and exit from the MOC. Two doors open to the main hallway of the building, while a third provides access to a server room that supports multiple facility activities. The OSAM-1 team expressed concern that access to the server room through the MOC creates a distraction as workers not supporting MOC activities pass through to move equipment.

F-16. Personnel need to pass through the MOC to move equipment into and out of an adjacent server room.

R-13. Restrict normal ingress/egress through one of the two doorways that connect the MOC to the adjacent hallway to direct the flow of foot traffic into the MOC away from the location of the core command and control team. (F-16, F-17, F-18)

8.0 Supplemental HF Analysis

8.1 Ancillary Rooms

Quick access to food, restrooms, and similar facilities contributes to operators' comfort, health, and performance. As stated by the OSAM-1 personnel during interviews (Appendix A), the personnel on console prefer the ability to get food easily without having to travel too far from the room to heat up meals or retrieve food from a refrigerator. They often report for a 12-hour duty shift, and they desire easy access to food and beverages, including coffee. Therefore, the NESC assessment team advises that the OSAM-1 team consider including a dedicated space that can serve as a break room for personnel to hold informal conversations, conduct extended change-over discussions, and take meal/coffee breaks. Personnel may choose to store items in that space that are too bulky for under-desk storage. If possible, the break room should have windows to afford personnel a view of the outside world and exposure to natural sunlight.

F-17. OSAM-1 personnel have expressed a desire to have an off-console location for informal conversations and breaks.

R-14. Provide a location, within walking distance from the MOC, for personnel to have breaks, meals, and informal conversation. (*F-17*)

In addition to the Main Control Room and back room, MOC personnel should have access to a conference room, with whiteboards, communication systems, and displays, where personnel can hold discussions that would be too disruptive in the MOC or proposed break room. The original intent, suggested by the OSAM-1 team, was to add a conference table inside the MOC for easy access. However, through conversation with the NESC assessment team, they understood that this would be disruptive to MOC operators working on console and not provide necessary privacy. Generally, if three or more operators must confer, or if the topic of discussion is sensitive, the discussion should be moved to the conference room.

F-18. No dedicated group conferencing space is detailed in the MOC design schematic.

R-15. Provide access to a dedicated conference room for operational discussions that would be too disruptive or impractical to hold within the MOC or proposed break room. (*F-18*)

8.2 Shift Schedule Guidance

Initial discussions with OSAM-1 personnel indicated that they planned to have positions on console working in 12-hour shifts. Taking into account shift handover time, this could equate to 12.5-hour shifts. The NESC assessment team advised the OSAM-1 team to allow circadian rhythms time to adapt to changes in timing of work shifts. NPR 1800.1D [ref. 14] states that “working more than four consecutive 12-hour shifts is associated with excessive fatigue and ***strongly discouraged*** (emphasis added) since it may result in significant impact on performance of duties, mission, and safety.”

If the MOC intends to use this shift schedule, then a 12-hour allowable time off between shifts would be optimal to accommodate employee commute time and domestic and sleep needs. The OSAM-1 team is encouraged to provide opportunities for regular breaks, ensure food availability for all shifts/workers, and be proactive in ensuring workers are able to get home safely. In addition, recognize that time pressure and a commitment to getting the job done will cause operators stress, a common cause of insomnia. Management should look for fatigue and sleep loss as potential factors in employee health, attendance, retention, and mishap investigations.

After discussions with the NESC assessment team, the OSAM-1 team requested guidance on identifying known effects of shift duration on operator performance. The NESC team contacted the Fatigue Countermeasures Laboratory at NASA Ames Research Center (ARC), which provided a document outlining shift schedule guidance [ref. 15].

The NESC assessment team summarized the guidance on shift schedules for the OSAM-1 MOC in 16 principles, based on scientific literature on fatigue and circadian rhythms, as well as best practices identified by NASA's fatigue countermeasures experts:

1. Forward (clockwise) shift rotations are preferred (e.g., rotating forward from morning shift to afternoon to late-night, rather than rotating backward from morning shift to late night to afternoon).
2. Eight-hour shifts are generally safer than 12-hour shifts.
3. Fast-rotating shifts (1-3 days) are preferable to slow rotation (5 days), but extraneous factors (e.g., non-work responsibilities) may play a role.
4. Morning shifts should start after 7 AM.
5. Night shifts should not end between 1 and 7 AM (Circadian lull).
6. Consecutive workdays should not exceed five; fewer if working shifts longer than eight hours.
7. A minimum of 10 hours should elapse between day shifts, 12 hours between night shifts.
8. Shift swapping is allowable if the previous recommendations are met.
9. Prior to a mission, all operators should receive Fatigue Risk Management System (FRMS) training (e.g., use of light exposure, napping, caffeine). NASA-developed FRMS training is available for managers (<https://f.io/KEZkx-0a>) and employees (<https://f.io/LosuAvvm>).
10. If operators need to return to duty before their recommended time off, on-site sleep accommodations should be provided.
11. If extended or overnight work is required, operators should be provided with ride service home and/or on-site accommodations for naps.
12. More than one day off is required following two or more consecutive night shifts.
13. More than four consecutive 12-hour shifts (or five consecutive 8-hour shifts) are discouraged by the NASA Occupational Health Program Procedures.
14. There are advantages and disadvantages to fixed and rotating shift assignments. Acclimation to fixed night-shift assignments requires ~3 weeks.
15. Handovers should be scheduled, include completion of documents and checklists (to prevent loss of information), and involve verbal communication between outgoing and incoming operators.
16. Shorter "on-task" blocks of ~3 hours may be required for active-control tasks.

Much of this guidance is based on an evaluation performed for the Volatiles Investigating Polar Exploration Rover (VIPER) Program [ref. 15] together with input from the OSAM-1 team on preferred work processes and shift schedules.

F-19. Research indicates that risk of accidents/incidents steadily increases at shift durations of more than 8 hours [ref. 16].

R-16. Provide shift schedules that allow required time off for OSAM-1 MOC personnel, as stated in NPR 1800.1D, and balance mission logistical requirements with effects of shift duration on operator performance. *(F-19)*

The OSAM-1 team expressed preferences for slower-rotating shifts, and for the day shift to start no later than 7 AM to avoid heavy traffic in the GSFC commute area. After taking into account the research presented by the NESC assessment team, the OSAM-1 team indicated their preference for three 8-hour shifts per day, supporting 24/7 operations.

Balancing these concerns, the NESC team provided four illustrative example schedules (Appendix B) for the OSAM-1 team's consideration, adapted from the sample catalog of a commercial shift-scheduling software company.¹

All four schedules divide the workforce into four teams. It is assumed that members of all four teams are able to cover any of the three shifts and that some overtime hours are permissible. While the sample schedules show 8-hour shifts, it is assumed that operators will stay on an additional 15-30 minutes to support the shift changeover.

The NESC assessment team further suggested that the OSAM-1 team consult with ARC Fatigue Countermeasures Laboratory subject matter experts regarding their final shift-pattern design. This includes the impact of any planned deviations from the pattern to accommodate special mission requirements, such as ensuring a particular controller team is on-duty during critical mission operations.

9.0 HMI Style Guide

The NESC assessment team provided inputs to a HMI Style Guide, previously identified as Deliverable 2, based on the application of HF best practices. This deliverable is intended to support design of user interfaces within the OSAM-1 MOC.

The assessment team worked collaboratively with the OSAM-1 team in developing an HMI Style Guide for use in the OSAM-1 Ground Element MOC. Significant elements of the OSAM-1 MOC workstations will use COTS applications, which cannot be significantly modified. The assessment team focused on the software platform Advanced Spacecraft Integration & System Test (ASIST), which will host most of the MOC HMIs. Inputs were provided on:

- Ergonomics
- General display guidelines (e.g., simplicity, consistency, standardization)
- Text
- Labels
- Numbers
- Use of color
- Use of flashing
- Page formatting
- Workflow considerations

¹ SNAP Employee Scheduling Software: <https://www.snapschedule.com/blog>

Numerous style guides and interface design standards documents exist and are used primarily by those with expertise in interface design. The OSAM-1 team has no team members with HF expertise to decipher appropriate design characteristics. It would not have been useful for the NESC assessment team to provide copious interface design standards, the application of which often depends on soliciting appropriate information about the tasks being performed with those interfaces and how they are integrated into other necessary tasks, functions, and software limitations. Rather, the OSAM-1 team requested a “checklist” of HF display considerations that could be used by a non-HF expert as guidance for the design and evaluation of a prototype HMI.

The NESC assessment team developed such a checklist (Appendix C) that could be applied early in design or through planning phases, even before hardware or processes are finalized or implemented. The checklist is specific to telemetry displays, and guidance was provided with regard to terminology, measurement units, text legibility, color use, and leverage of display elements that are familiar to the intended user group. However, the assessment team encouraged the OSAM-1 team to work regularly with HF subject matter experts for more thorough design inputs to help them choose between alternatives, account for evolving requirements, and otherwise help ensure that they end up with interfaces that are fit for use.

10.0 Summary

The NESC assessment team provided HSI best practices, guidance, references, and design suggestions related to noise, lighting, information displays, visual occlusion, physical separation within the MOC, visitor flow, and space allocation for implementation by the GSFC Satellite Servicing Projects Division/OSAM-1 team. In addition, the assessment team participated in regular meetings with OSAM-1, reviewed documentation, contributed to the HMI Style Guide, and addressed implementation concerns.

Critical observations made by the NESC assessment team relate to the lack of HF expertise on the OSAM-1 team, which created challenges in anticipating the scope of HF support needed for the project, hampered work efficiency between the OSAM-1 and assessment teams, and impeded the ability of the OSAM-1 team to effectively implement HF recommendations.

The OSAM-1 team reached out to the NESC for HF support because they lacked resident HF expertise, but recognized that they would be facing design decisions that impacted human task performance. This lack of OSAM-1 team resident HF expertise has several consequences that manifested during the NESC support activity. The OSAM-1 team:

- Did not fully understand the scope of what they needed.
- Made design decisions that would affect human task performance without appreciating the tradeoffs against other aspects of task performance.
- Lacked the expertise to make informed trades involving human performance or measure the consequences of their decisions for some of the NESC assessment team’s recommended actions, which were written to refrain from providing direction on how those actions were to be accomplished, even though they agreed with the recommendations themselves.

11.0 Findings, Observations, and NESC Recommendations

11.1 Findings

- F-1.** Standards documents prescribe acceptable ambient noise levels for control rooms (e.g., MIL-STD-1474E, NUREG-0700, and ISO 11064-6:2005).
- F-2.** Based on discussions with the OSAM-1 team, the NESC assessment team understands that the walls in the MOC are an assortment of hard surfaces (e.g., drywall, glass).
- F-3.** OSAM-1 personnel indicated that they would like the MOC lighting to be adjustable.
- F-4.** Research indicates that local lighting control can enhance individual performance.
- F-5.** Size and placement of wall-mounted displays are constrained by existing equipment, a structural column, doors, and windows that cannot be relocated.
- F-6.** The MOC ceiling height is 9 feet, and chair headrests can vary between 47 and 57 inches. This allows only around 4.5 vertical feet for displays, which could lead to visual occlusion from other people standing up.
- F-7.** Based on room schematics of the initial MOC design, lateral viewing angles from console positions to wall-mounted displays range from 83 degrees for the front row of consoles to 23 degrees for the sixth (i.e., back) row, and viewing distances range from ~9 feet for the front row of consoles to ~39 feet for the back row.
- F-8.** OSAM-1 personnel indicated that, due to the expense of the units, communication keyset units would be shared among adjacent console positions.
- F-9.** Ergonomic positioning of input devices, such as monitors, keyboards, and pointing devices, will be constrained when placed on a standardized non-adjustable surface.
- F-10.** NESC team observations at other mission operations and control facilities found mandatory equipment and personal items created clutter on console areas during operations.
- F-11.** The OSAM-1 MOC design includes 51 console positions in one room, made up of the core command and control team as well as support, planning, and analysis positions.
- F-12.** The Satellite Servicing Projects Division has expressed the need for a barrier within the MOC facility to isolate the core command and control positions from distractions without inhibiting ready access to support, planning, and analysis capabilities.
- F-13.** Based on room schematics of the MOC design, one wall is primarily composed of large glass panels between the MOC and an adjacent room.
- F-14.** OSAM-1 personnel indicated that the MOC design provides no space for visitors and observers.
- F-15.** Decisions on off-console hardware purchases (e.g., printers, storage for personal effects) and eventual location of that hardware within the MOC have not been finalized.
- F-16.** Personnel need to pass through the MOC to move equipment into and out of an adjacent server room.

- F-17. OSAM-1 personnel have expressed a desire to have an off-console location for informal conversations and breaks.
- F-18. No dedicated group conferencing space is detailed in the MOC design schematic.
- F-19. Research indicates that risk of accidents/incidents steadily increases at shift durations of more than 8 hours.

11.2 Observation

- O-1. The OSAM-1 team did not include HF expertise.

11.3 NESC Recommendations

The following recommendations are directed toward projects that would benefit from an embedded HF practitioner:

- R-1. Include HF practitioners in project planning, complementary with NPR 7120.5(f). (O-1)

The following recommendations are directed toward the Satellite Servicing Projects Division at GSFC.

- R-2. Ensure ambient noise in the MOC, after equipment installation and during equipment operation, is lower than a maximum of 65 dB, preferably less than 45 dB. (F-1)
- R-3. Consider adding acoustic panels to selected walls within the MOC for additional attenuation of ambient noise. In addition, the windows at the back of the room could be covered with acoustic curtains, for sound absorption and to block visual distractions from activities in the adjacent room. (F-2)
- R-4. Use dimmer switches to flexibly adjust MOC room brightness and optimize wall screen and workspace visibility. (F-3)
- R-5. Provide the capability for individuals on console to adjust the brightness at their workstations. (F-4)
- R-6. Position shared displays and consoles to ensure display contents are readable from all console viewing angles. (F-5, F-6, F-7)
- R-7. Conduct a trade study on the impact of using shared voice-loop communication units against the cost of dedicated units at each console position. (F-8)
- R-8. Provide height-adjustable trays that support keyboards and a range of pointing devices (e.g., mouse, trackball). (F-9)
- R-9. Ensure design solutions mitigate clutter from mission-related and personal items on console during mission operations. (F-10)
- R-10. Erect a configurable portable acoustic partition to create a main control room and back room within the MOC facility. (F-11, F-12)
- R-11. Identify separate space and accommodations for visitors and observers to minimize distraction to console operators during mission operations. (F-13, F-14)
- R-12. Position off-console hardware in locations that support access while minimizing ambient noise and foot traffic near the core command and control team. (F-15)

- R-13.** Restrict normal ingress/egress through one of the two doorways that connect the MOC to the adjacent hallway to direct the flow of foot traffic into the MOC away from the location of the core command and control team. *(F-16, F-17, F-18)*
- R-14.** Provide a location, within walking distance from the MOC, for personnel to have breaks, meals, and informal conversation. *(F-17)*
- R-15.** Provide access to a dedicated conference room for operational discussions that would be too disruptive or impractical to hold within the MOC or proposed break room. *(F-18)*
- R-16.** Provide shift schedules that allow required time off for OSAM-1 MOC personnel, as stated in NPR 1800.1D, and balance mission logistical requirements with effects of shift duration on operator performance. *(F-19)*

12.0 Alternate Technical Opinion(s)

No alternate technical opinions were identified during the course of this assessment by the NESC assessment team or the NRB.

13.0 Other Deliverables

No unique hardware, software, or data packages, other than those contained in this report, were disseminated to other parties outside this assessment.

14.0 Recommendations for the NASA Lessons Learned Database

No recommendations for NASA lessons learned were identified as a result of this assessment.

15.0 Recommendations for NASA Standards, Specifications, Handbooks, and Procedures

No recommendations for NASA standards, specifications, or procedures were identified as a result of this assessment.

16.0 Definition of Terms

Finding	A relevant factual conclusion and/or issue that is within the assessment scope and that the team has rigorously based on data from their independent analyses, tests, inspections, and/or reviews of technical documentation.
Observation	A noteworthy fact, issue, and/or risk, which is not directly within the assessment scope, but could generate a separate issue or concern if not addressed. Alternatively, an observation can be a positive acknowledgement of a Center/Program/Project/Organization's operational structure, tools, and/or support.
Recommendation	A proposed measurable stakeholder action directly supported by specific Finding(s) and/or Observation(s) that will correct or mitigate an identified issue or risk.

17.0 Acronyms and Nomenclature

ARC	Ames Research Center
ASIST	Advanced Spacecraft Integration & System Test
bMOC	Backup MOC
CCSFS	Cape Canaveral Space Force Station
COTS	Commercial-off-the-Shelf
CPU	Central Processing Unit
CRI	Color Rendering Index
dB	Decibels
FDf	Flight Dynamics Facility
FRMS	Fatigue Risk Management System
GSFC	Goddard Space Flight Center
HCI	Human-Computer Interaction
HF	Human Factors
HFE	Human Factors Engineering
HMI	Human-Machine Interface
HSI	Human Systems Integration
ISO	International Organization for Standardization
MOC	Mission Operations Center
NESC	NASA Engineering and Safety Center
NPR	NASA Procedural Requirements
NRB	NESC Review Board
OSAM-1	On-Orbit Servicing, Assembly, and Manufacturing Mission 1
SRO	Security Restricted Ops
TDT	Technical Discipline Team
3D	Three-Dimensional
UGI	Unified Glare Index
VIPER	Volatiles Investigating Polar Exploration Rover
VSFB	Vandenberg Space Force Base
WFF	Wallops Flight Facility

18.0 References

1. NPR 7120.5F, NASA Space Flight Program and Project Management Requirements, August 03, 2021.
2. NASA/SP-20210010952 Human Systems Integration (HSI) Handbook, November 1, 2021.
3. RESTORE-L Ops Overview – PowerPoint.
4. Department of Defense (DoD). (2015). *MIL-STD-1474E: Department of Defense Design Criteria Standard Noise Limits*, Washington, D.C.

5. Nuclear Regulatory Commission. (2002). *Human-System Interface Design Review Guidelines*, NUREG-0700 Rev. 3, Washington, D.C.
6. International Organization for Standardization. (2005). *ISO 11064-6: Ergonomic Design of Control Centres – Part 6: Environmental Requirements for Control Centres*.
7. Ahlstrom, V., & Kudrick, B. (2007). Human Factors Criteria for Displays: A Human Factors Design Standard Update of Chapter 5. (DOT/FAA/TC-07/11). Atlantic City International Airport, NJ: Federal Aviation Administration William J. Hughes Technical Center.
8. Human and Safety Executive. (1997). *HSG38: Lighting at Work, 2nd Edition*. Sudbury, Suffolk, UK: HSE Books.
9. Joines et al., 2015, *Adjustable Task Lighting: Field study assesses the benefits in an office environment*.
10. EPRI and the U.S. Department of Energy. (2004). Human Factors Guidance for Control Room and Digital Human-System Interface Design and Modification: Guidelines for Planning, Specification, Design, Licensing, Implementation, Training, Operation, and Maintenance. Palo Alto, CA: EPRI and U.S. DoE.
11. E. M. Wenzel (1986). Effects of stimulus characteristics and task demands on pilots' perception of dichotic messages, *Proceedings of the Human Factors Society*, 30, 1177-1181.
12. Shikdar, Ashraf A., & Al-Kindi, Mahmoud A. (2007). Office Ergonomics: Deficiencies in Computer Workstation Design, *International Journal of Occupational Safety and Ergonomics*, 13:2, pp. 215–223.
13. NESC-18-01334, *Human Systems Integration for Safety-Critical Operations at Wallops Flight Facility*.
14. NPR 1800.1D, Occupational Health Program Procedures, September 11, 2019.
15. Glaros, Z., Carvalho, R., and Flynn-Evans, E. (2020). Volatiles Investigating Polar Exploration Rover: An evaluation of fatigue, workload, and performance. NASA ARC, San Jose State University, Intelligent Systems Division.
16. Folkard, Simon & Tucker, Philip. (2003). Shift work, safety, and productivity. *Occupational medicine* (Oxford, England).

Appendices

- Appendix A. HF Interview Protocol
- Appendix B. Shift Schedule Guidance
- Appendix C. HF Checklist

Appendix A. HF Interview Protocol

1. What was your position on console?
2. Were you or others cross-trained to cover other positions?
3. For what mission(s) did you sit on console?
4. What was the duration of this (these) mission(s)? What month(s) of the year were this (these) mission(s)?
5. For which phases of the mission(s) did you sit on console? If not all, what was the longest phase for which you sat (in other words, what was your longest stretch of console assignment)?
6. What shift(s) did you work while on console duty?
7. If more than one shift, how often did you switch shifts?
8. What was the duration of your shift? Did that include shift changeovers, debriefs, etc.? In other words, how long was your day onsite at GSFC?
9. What was your days on/days off schedule?
10. How long was your commute to/from work? Do you think that was typical for other members of your team?
11. Could you walk us through a typical day in your life when you were on console?
 - a. When you arrived at GSFC, did you go directly to the MOC or visit your office?
 - b. When you arrived at the MOC, what did you bring into the room with you (briefcase, backpack, purse, coat, lunch, coffee mug, etc.)?
 - c. Roughly how large was your console? What equipment was provided at the console? How was it laid out? Did you add any equipment/material to the console (laptop, binders, etc.)?
 - d. How often were you able to take a break? Did you leave the MOC during breaks? Where did you go (restroom, break room, outside)?
 - e. How long were your breaks? Were the breaks' timing defined by the mission (e.g., during eclipses)?
 - f. Did several team members take breaks at the same time? Was there much discussion of the mission during breaks? If so, was there any discussion that you would prefer non-team members not hear?
 - g. Did you drink or eat at the console? Were there any rules regarding this (e.g., no-spill mugs)?
 - h. During shift changes, where did you and your complement do the handoff (at the console, elsewhere)? How long were the shift changeovers?
 - i. Did all the controllers do their handoffs at the same time or were they staggered?
 - j. Did you have pre-briefs or debriefs before/after your shift? Where were they held? How many people attended? How long were they?
 - k. Were there any displays in the room other than those on your console? If so, where were they located? How large were they? Were you able to read them easily?
 - l. Did you have any issues with text legibility, color interpretation, or lighting in the displays?

- m. Regarding the MOVE units (or whatever communication system you used when you sat on console), did you share the comm panel with adjacent controller(s)? If so, how did you determine which channels to monitor (that is, did a “dominant” controller have power over the panel or did they negotiate about it)?
 - n. What was the best part of your day? What was the worst part? If you could change anything about the MOC layout or your work schedule to make things better, what would it be?
 - o. If the Flight Director needed to confer with an operator, was this done face-to-face or over the communication system? Were there any discussions you overheard on the comm system that you thought should have been held in private?
 - p. Were there any aspects of the communication system that you found interfered with effective communication (e.g., too many voices on a channel; too many channels that needed to be monitored at once)? Could you control which channels were assigned to you left or right ear? If so, did that help?
 - q. Was there a hands-free, push-to-talk functionality for the communications system? What was it and was it effective for you?
 - r. Did you wear headphones fulltime while at console? Did your headphones interfere with face-to-face communication (e.g., you didn’t realize someone was trying to get your attention)?
 - s. Did operators leave their seats to confer with other operators or was everything handled over the communication system?
 - t. When you arrived home, were you able to accomplish all your “home duties” without compromising your time for sleep? How many hours of sleep were you able to get on days that you worked console?
 - u. Would you feel comfortable performing console duty with the schedule you had for a seven-month mission?
 - v. Given the opportunity, would you seek future console assignments?
 - w. Were personnel on console seated in locations that helped or impeded the workflow operations?
 - x. During your shifts did you ever notice visitors or distinguished personnel observing operations? If so, how was this handled (seating and communications access)?
 - y. Did you ever experience issues with lighting at your workstation? Was there glare on your screen(s), adjustable lighting at your workstation, any other issues to note?
12. Did your console have buttons, switches, or touchscreen capabilities?
- a. Of those provided, did you have any issues with them?
 - b. Did you use job aids on console? If so, what were they?
13. Do you feel that your training was sufficient given your mission responsibilities?
- a. Where was the training held, how often was it provided, and how long was each training session?
14. Were there any federal holidays during your mission? If so, how was MOC staffing handled?
15. Did you or any members of your team take vacations (annual leave) during the mission? If so, how was MOC staffing handled?
16. Did you or any members of your team need to take sick leave during the mission? If so, how was MOC staffing handled?

17. Are there any aspects of the MOC or workstation layout or design that we haven't touched on yet in our conversation that made your work more difficult or challenging?
18. Are there any aspects of the MOC or workstation layout or design that we haven't touched on yet in our conversation that made your work easier or more successful?
19. Can you think of a time when working on console was particularly challenging or that stood out as different from a typical day? What made it challenging/different?
20. Is there anything you would like to tell us about your experiences working on console that we haven't already asked about?

Appendix B. Shift Schedule Guidance

Example 1 depicts an 8-day cycle, with each team rotating through day, swing, night, and off shifts on a 2-day rotating pattern.

Example 2 depicts a 28-day cycle, with each team rotating through day, swing, night, and off shifts of a 2x2x3x2-day rotating pattern. The advantage of this pattern is that it guarantees a free full weekend every 4 weeks instead of every 8 weeks, but at the cost of 7 consecutive workdays rather than 6.

1. Fast Rotation, 6-Day Workweek (Metropolitan Rotating)

Advantages include two days off every eight days, a maximum of two consecutive night shifts, and shifts limited to eight hours (plus changeover). The primary disadvantage is that operators have a free weekend (Sat-Sun) only once every eight weeks.

Metropolitan Rotating Shift Schedule | 24/7 Shift Coverage

This fast-rotating shift pattern uses 4 teams and three 8-hour shifts to provide 24/7 coverage. Each team rotates through a sequence of 2 day shifts, 2 swing shifts, 2 night shifts, and 2 days off over an 8-day cycle.

Team	Days 1-8							Hours	Shifts
1	Day	Day	Swing	Swing	Night	Night	Off	48.0	Day (8 hrs) 7 am-3 pm
2	Swing	Swing	Day	Day	Off	Off	Day	48.0	Swing (8 hrs) 3 pm-11 pm
3	Day	Day	Off	Off	Swing	Swing	Night	48.0	Night (8 hrs) 11 pm-7 am
4	Off	Off	Day	Day	Swing	Swing	Day	48.0	
Hours								192.0	

2. Fast Rotation, 7-Day Workweek (Continental Rotating)

Advantages of this pattern include a minimum of two consecutive days off, a free weekend every four weeks, and shifts limited to eight hours (plus changeover). Disadvantages include seven consecutive workdays and three consecutive night shifts every four weeks.

Continental Rotating Shift Schedule | 24/7 Shift Coverage

This fast-rotating shift pattern uses 4 teams and three 8-hour shifts to provide 24/7 coverage. Each team rotates through a sequence of 2, 2, and 3 consecutive day shifts, swing shifts, night shifts, or days off. The following is a typical team schedule for a 4-week (28-day) repeat cycle:

- Week 1 – 2 day shifts, 3 swing shifts, 2 night shifts
- Week 2 – 2 days off, 3 day shifts, 2 swing shifts
- Week 3 – 2 night shifts, 3 days off, 2 day shifts
- Week 4 – 2 swing shifts, 3 night shifts, 2 days off

Team	Days 1-7	Days 8-14	Days 15-21	Days 22-28	Hours	Shifts
1	Day	Day	Swing	Swing	168.0	Day (8 hrs) 7 am-3 pm
2	Swing	Swing	Day	Day	168.0	Swing (8 hrs) 3 pm-11 pm
3	Day	Day	Off	Off	168.0	Night (8 hrs) 11 pm-7 am
4	Off	Off	Swing	Swing	168.0	
Hours	168.0	168.0	168.0	168.0	672.0	

Figure B-1. Examples 1 and 2

Examples 3 and 4 are a slow-rotating shift pattern, in which each team stays on a given shift for 6–7 days instead of 2–3.

Example 3 rotates teams through a six-on, two-off pattern over a 24-day cycle.

Example 4 rotates teams through a seven-on, two-to-three-off pattern over a 28-day cycle. This pattern, like Example 2 above, has the advantage of allowing for 3 consecutive days off once during each cycle.

3. Slow Rotation, Six-Day Workweek

This slow-rotating pattern moves each team through a sequence of six days working and two days off for the day, swing, and night shifts over a 24-day cycle. Advantages include two days off every eight days. Disadvantages include six consecutive workdays and six consecutive night shifts every 24 days.

6 On, 2 Off Shift Schedule | 24/7 Shift Coverage

This relatively slow-rotating shift pattern uses 4 teams and 3 8-hour shifts to provide 24/7 coverage. Each team rotates through the following sequence every 24 days: 6 day shifts, 2 days off, 6 swing shifts, 2 days off, 6 night shifts, 2 days off.

Team	Days 1-8	Days 9-16	Days 17-24	Hours	Shifts
1	Day (8 hrs) 7 am-3 pm			144.0	
2		Swing (8 hrs) 3 pm-11 pm		144.0	
3			Night (8 hrs) 11 pm-7 am	144.0	
4				144.0	
Hours	192.0	192.0	192.0	576.0	

4. Slow Rotation with Three Days off After Night Shifts

This pattern rotates each team through a sequence of seven day shifts, two days off, seven swing shifts, two days off, seven night shifts, and three days off over a 28-day cycle. Advantages include at least two days off after any seven working days and three days off after seven consecutive night shifts.

Rotating 8-Hour Shift Schedule | 24/7 Shift Coverage

This slow-rotating shift pattern uses 4 teams and 3 8-hour shifts to provide 24/7 coverage. Each team rotates through the following sequence every 28 days: 7 day shifts, 2 days off, 7 swing shifts, 2 days off, 7 night shifts, 3 days off.

Team	Days 1-7	Days 8-14	Days 15-21	Days 22-28	Hours	Shifts
1	Day (8 hrs) 7 am-3 pm				168.0	
2		Swing (8 hrs) 3 pm-11 pm			168.0	
3			Night (8 hrs) 11 pm-7 am		168.0	
4					168.0	
Hours	168.0	168.0	168.0	168.0	672.0	

Figure B-2. Examples 3 and 4

Appendix C. HF Checklist

Human Factors Checklist – OSAM-1 Project HMI Style Guide

Consider these human factors basics that can be applied early in design or through planning phases, even before hardware or processes are finalized or implemented. The checklist is a good place to start to supplement formal human factors evaluation. Consult a human factors professional for more thorough human factors analyses and assessments.

OSAM-1 Telemetry Display Specifics

- Use consistent terminology, labels, and measurement units
- Ensure measurements are always presented with units
- Use measurements units that are best associated with the task being performed
- Ensure text legibility given luminance, contrast, and viewing distance
- Ensure consistency in color-coding
- Use colors in conformity with conventional standards
- Use neutral gray surrounds where color judgments are critical
- Use terms, symbols, and images that are familiar to expected user group

Page Display Formatting

- Provide clear, legible, functional identifications
- Account for visual impairments of expected user group
- Employ text or alarms with color-coded indicators
- Provide glare mitigation
- Position information so visibility is not precluded
- Ensure color and format consistency across displays
- Design displays for simplicity
- Ensure display functions are obvious to expected user group
- Make unique functions distinctive
- Make displays, marking, coding, labeling, and arrangement uniform
- Maintain identical interfaces for identical functions
- Design for redundancy
- Provide timely and informative feedback
- Provide results to user actions that are predictable by expected user group
- Require confirmation for critical and/or irreversible commands

Human Factors Checklist – OSAM-1 Project HMI Style Guide

Consider these human factors basics that can be applied early in design or through planning phases, even before hardware or processes are finalized or implemented. The checklist is a good place to start to supplement formal human factors evaluation. Consult a human factors professional for more thorough human factors analyses and assessments.

OSAM-1 Telemetry Display Specifics

- Use consistent terminology, labels, and measurement units
- Ensure measurements are always presented with units
- Use measurements units that are best associated with the task being performed
- Ensure text legibility given luminance, contrast, and viewing distance
- Ensure consistency in color-coding
- Use colors in conformity with conventional standards
- Use neutral gray surrounds where color judgments are critical
- Use terms, symbols, and images that are familiar to expected user group

Page Display Formatting

- Provide clear, legible, functional identifications
- Account for visual impairments of expected user group
- Employ text or alarms with color-coded indicators
- Provide glare mitigation
- Position information so visibility is not precluded
- Ensure color and format consistency across displays
- Design displays for simplicity
- Ensure display functions are obvious to expected user group
- Make unique functions distinctive
- Make displays, marking, coding, labeling, and arrangement uniform
- Maintain identical interfaces for identical functions
- Design for redundancy
- Provide timely and informative feedback
- Provide results to user actions that are predictable by expected user group
- Require confirmation for critical and/or irreversible commands

Human Factors Checklist – OSAM-1 Project HMI Style Guide

Consider these human factors basics that can be applied early in design or through planning phases, even before hardware or processes are finalized or implemented. The checklist is a good place to start to supplement formal human factors evaluation. Consult a human factors professional for more thorough human factors analyses and assessments.

OSAM-1 Telemetry Display Specifics

- Use consistent terminology, labels, and measurement units
- Ensure measurements are always presented with units
- Use measurements units that are best associated with the task being performed
- Ensure text legibility given luminance, contrast, and viewing distance
- Ensure consistency in color-coding
- Use colors in conformity with conventional standards
- Use neutral gray surrounds where color judgments are critical
- Use terms, symbols, and images that are familiar to expected user group

Page Display Formatting

- Provide clear, legible, functional identifications
- Account for visual impairments of expected user group
- Employ text or alarms with color-coded indicators
- Provide glare mitigation
- Position information so visibility is not precluded
- Ensure color and format consistency across displays
- Design displays for simplicity
- Ensure display functions are obvious to expected user group
- Make unique functions distinctive
- Make displays, marking, coding, labeling, and arrangement uniform
- Maintain identical interfaces for identical functions
- Design for redundancy
- Provide timely and informative feedback
- Provide results to user actions that are predictable by expected user group
- Require confirmation for critical and/or irreversible commands

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.
PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.

1. REPORT DATE (DD-MM-YYYY) 03/30/2023	2. REPORT TYPE Technical Memorandum	3. DATES COVERED (From - To)
--	---	-------------------------------------

4. TITLE AND SUBTITLE Human Factors Support for On-Orbit Servicing, Assembly and Manufacturing Mission 1 (OSAM-1)	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S) Null, Cynthia H.; Holbrook, Jon B.; Kaiser, Mary K.; Novak, Bonnie B.	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER 869021.01.23.01.01

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) NASA Langley Research Center Hampton, VA 23681-2199	8. PERFORMING ORGANIZATION REPORT NUMBER NESC-RP-20-01533
---	---

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration Washington, DC 20546-0001	10. SPONSOR/MONITOR'S ACRONYM(S) NASA
	11. SPONSOR/MONITOR'S REPORT NUMBER(S) NASA/TM-20230004199

12. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified - Unlimited
Subject Category Ground Support Systems and Facilities
Availability: NASA STI Program (757) 864-9658

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The NASA Engineering and Safety Center (NESC) Human Factors Technical Discipline Team was requested by the Satellite Servicing Projects Division at Goddard Space Flight Center to provide support in assessing the design of the On-Orbit Servicing, Assembly and Manufacturing Mission 1 (OSAM-1) Mission Operations Center in light of concerns about overcrowding and potential for distractions, as well as assistance in creating a Human-Machine Interface style guide for OSAM-1 user interface design. This report contains the outcome of the NESC assessment.

15. SUBJECT TERMS
On-Orbit Servicing, Assembly and Manufacturing Mission; NASA Engineering and Safety Center; Mission Operations Center; Human-Machine Interface

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			STI Help Desk (email: help@sti.nasa.gov)
U	U	U	UU	43	19b. TELEPHONE NUMBER (Include area code) (443) 757-5802