

NASA Planning for Orion Multi-Purpose Crew Vehicle Ground Operations

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Abstract—The NASA Orion Ground Processing Team was originally formed by the Kennedy Space Center (KSC) Constellation (Cx) Project Office’s Orion Division to define, refine and mature pre-launch and post-landing ground operations for the Orion human spacecraft. The multi-disciplined KSC Orion team consisted of KSC civil servant, SAIC, Productivity Apex, Inc. and Boeing-CAPPS engineers, project managers and safety engineers, as well as engineers from Constellation’s Orion Project and Lockheed Martin Orion Prime contractor.

The team evaluated the Orion design configurations as the spacecraft concept matured between Systems Design Review (SDR), Systems Requirement Review (SRR) and Preliminary Design Review (PDR). The team functionally decomposed pre-launch and post-landing steps at three levels of detail, or tiers, beginning with functional flow block diagrams (FFBDs). The third tier FFBDs were used to build logic networks and nominal timelines. Orion ground support equipment (GSE) was identified and mapped to each step. This information was subsequently used in developing lower level operations steps in a Ground Operations Planning Document PDR product.

Subject matter experts for each spacecraft and GSE subsystem were used to define 5th – 95th percentile processing times for each FFBD step, using the Delphi Method. Discrete event simulations used this information and the logic network to provide processing timeline confidence intervals for launch rate assessments.

The team also used the capabilities of the KSC Visualization Lab, the FFBDs and knowledge of the spacecraft, GSE and facilities to build visualizations of Orion pre-launch and post-landing processing at KSC. Visualizations were a powerful tool for communicating planned operations within the KSC community (i.e., Ground Systems design team), and externally to the Orion Project, Lockheed Martin spacecraft designers and other Constellation Program stakeholders during the SRR to PDR timeframe. Other operations planning tools included Kaizen/Lean events, mockups and human factors analysis.

The majority of products developed by this team are applicable as KSC prepares 21st Century Ground Systems for the Orion Multi-Purpose Crew Vehicle and Space Launch System.

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1.0 INTRODUCTION

This paper provides an overview of the Constellation Ares I/Orion/Ground Operations Elements and the Orion ground operations flow. The Orion ground operations planning process is described including six tools the Ground Operations team utilized during the planning process. These tools included concept of operations, functional flow block diagramming, timelines, modeling, and the use of a database to identify and manage tasks and related resources such as ground support equipment, safety hazards, personnel, and supporting systems. In order to maximize operability, Kaizen/Lean events, mockups, human factors analysis, and a watch list of operability issues were also utilized. The infusion of operability into the Orion flight and ground designs using the processes and tools described in this paper enabled the Orion flight and ground concepts and designs to move forward as NASA transitions to the three new Exploration Systems Directorate Programs MPCV/Orion, Space Launch System (SLS), and 21st

Century Ground Systems that will launch astronauts to beyond low earth orbit in the coming years.

cryogenic propellant servicing, launch countdown, and launch are performed.

2.0 CONSTELLATION ARES I/ORION/GROUND OPS ELEMENTS

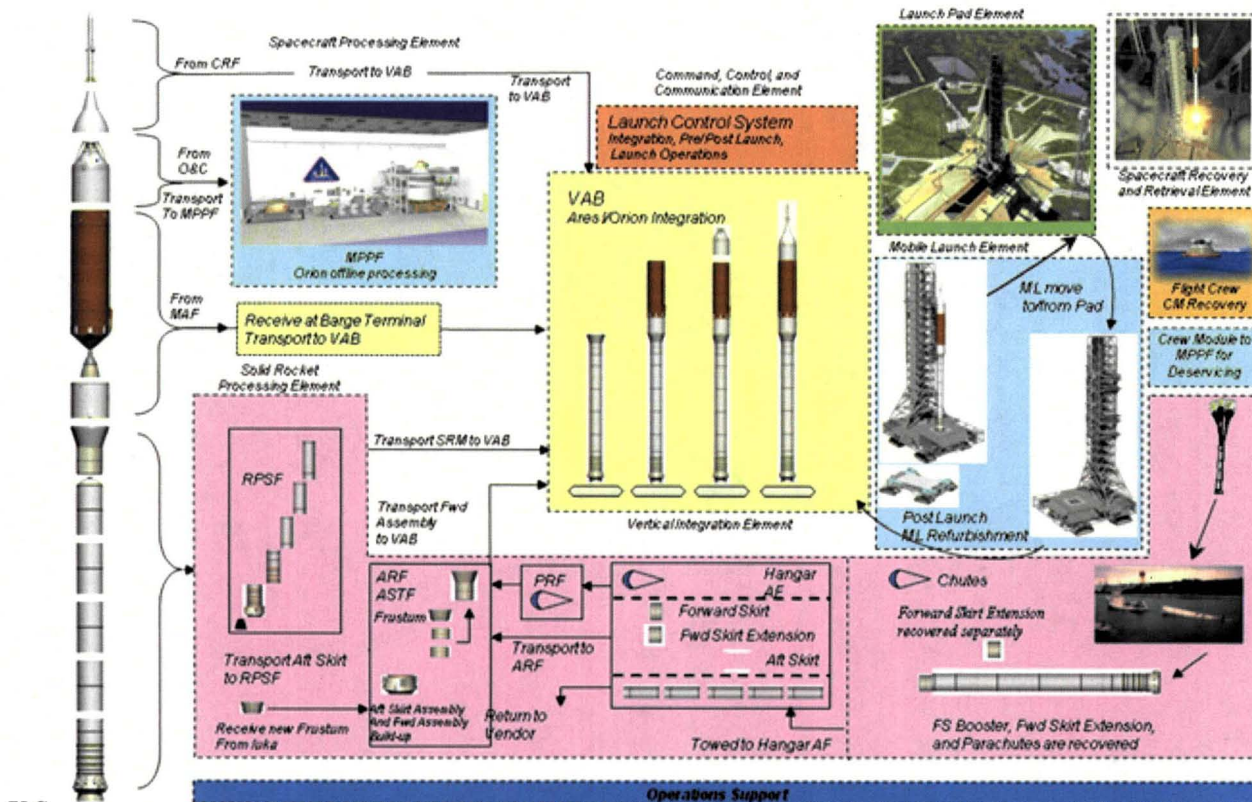
This section provides a general description of KSC Ground Operations in support of the Constellation Program, including pre-launch preparations, landing, and retrieval. Figure 1 illustrates the conceptual flow of the Ares I/Orion through the Ground Systems. The Constellation Ground System includes the facilities, facility systems, Ground Support Equipment, hardware, and software required to perform Ground Operations for spacecraft pre-launch processing, launch, landing, retrieval, and refurbishing at sites in support of the Constellation Program. The official configuration for the Ground System is captured in CxP 72197, Ground Systems Architecture Description Document (ADD). The Ground Systems Architecture for the Constellation Program is based on a clean pad concept. In this concept, the Launch Vehicle (LV) and Spacecraft Systems are processed in offline facilities in order to be outside of the integrated vehicle critical path and then transported to the Vehicle Assembly Building (VAB) for integration and test. Some elements and systems, such as the launch vehicle upper stage, are delivered to the launch site ready for integration and thus taken directly to the VAB. In the VAB, the integrated stack is assembled vertically atop a mobile platform. Once the vehicle has been completely integrated and checked-out on the ML, the ML and Ares I/Orion vehicle are moved to the Launch Pad at which final

NASA Roles and Responsibilities for Ground Operations

- Providing government oversight and integration of the ground processing contracts.
- Ensuring that appropriate Ground Operations requirements are attained before proceeding to the next processing milestone.
- Performing project management, baseline management and control, data management, budgeting, and scheduling. Responsibility also includes ensuring that contractors adhere to budgets and schedules.
- Planning and executing hands-on operations, as required (for example, cargo processing).
- Evaluating proposed changes to baselined ground operations and providing impacts as required.
- Implementation of approved changes to ground operations baseline.

Kennedy Space Center Responsibilities for Ground Operations

- Orion processing within the Multi-Payload Processing Facility (MPPF), VAB, Launch Complex (LC), and landing sites.
- Launch Abort System (LAS) integration with Orion within the VAB
- Launch Vehicle processing within the Assembly and Refurbishment Facility (ARF); Rotation, Processing and Surge Facility (RPSF); VAB; Hangar AF; and Parachute Refurbishment Facility (PRF).



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Figure 1 – Ares I/Orion Conceptual Ground Systems Flow

See reference [1] Ground Operations Planning Document: Volume 3: Operations; Document Number: CxP 72149-03 for more details on KSC ground operations planning.

3.0 ORION GROUND OPERATIONS FLOW

Crew Module (CM)/Service Module (SM) Integrated Ground Processing

CM/SM ground processing includes:

- ◆ Acceptance of an integrated CM/SM, transportation to the MPPF
- ◆ Portable Equipment, Payloads, and Cargo (PEPC) Integration
- ◆ CEIT (Crew Equipment Interface Test)
- ◆ Powered PEPC (Cargo/ FCE) to Orion Interface Verification Tests
- ◆ Un-powered Non-Time Critical PEPC (Cargo / FCE) Installation
- ◆ High pressure gas servicing (*GO₂*, *GN₂*, *GHe*)
- ◆ Ammonia servicing (*NH₃*)
- ◆ Propellant servicing (*N₂O₄*, *MMH*, *N₂H₄*)
- ◆ Closeouts.

Orion/Launch Vehicle Integrated Stack Processing

Orion/Launch Vehicle Integrated Stack processing includes integration of the Orion to the Launch Vehicle, interface testing, integrated testing, and preparation of the integrated stack for Launch. Lift and mechanical mate with the upper stage Instrumentation Unit (IU) is performed. This includes electrical mates, T-0 connections, and purge initiation. The the Launch Abort System (LAS) is lifted and mechanically mated to the CM. LAS to CM electrical mates are performed. LAS Interface Test & S&A rotation test (powered) can be performed at this time or after integration is complete. Ordnance mates are also completed. Once the LAS has been integrated to the CM, the four Ogive panels are installed, TPS is closed out, and internal white room access is established. After access has been established, full vehicle integrated testing is performed with a vehicle power up and health status, Interface Verification Test (including RF testing) and Countdown Demo Test (CDDT). A potable water sample is also taken at this time.

Pad and Launch Ops

After rollout from the VAB and connections at the Pad are established, Orion communications testing begins. Orion power-up and Pad IVT is performed along with communication system End-to-End testing. The LAS antennas are used at this point. Late stowage, ordnance operations, and LAS arm inhibit removals (S&A pins) are performed. Just prior to launch, crew ingress is performed along with hatch seal leak checks, cabin leak checks, white room seal retraction, and Crew Access Arm (CAA) retraction. Final countdown and launch is then performed.

Landing and Recovery

During descent updated landing coordinates are transmitted from Mission Control Center (MCC) at the Johnson Space Center (JSC) to the pre-staged recovery crew. Auto-safing of pyros & fluid systems are performed. A CM beacon transmits the location to the recovery crew. The CM is removed from the water with the crew on board. Crew egress is after the CM is secured on a well-deck ship. The pyrotechnics are manually safed and time critical PEPC is removed on the ship. Data retrieval may also be performed as early as on the ship if required. Data retrieval may also be performed at the port or at the deservicing location if not time critical. Upon arrival at the port, the CM is transferred to the dock and prepared for transportation back to KSC. The CM is then transported to the MPPF for deservicing.

CM Deservicing

Upon arrival at the MPPF, deservicing preparations are made. The CM is cleaned and moved into the MPPF deservicing stand. Once in the stand, the seats, and non-time critical PEPC are removed. Data retrieval is performed and deservicing is initiated. Deservicing includes the propulsion system, ammonia system, and high pressure gases that were servicing pre-flight. After the deservicing is completed, the CM is moved from the deservicing stand, configured for transport, and transported along with removed components to the O&C. A transfer of the CM and components from NASA back to Lockheed Martin (LM) is performed at this time and LM dispositions items for re-flight or disposal.

4.0 ORION OPERATIONS PLANNING PROCESS AND TOOLSET OVERVIEW

The primary objective of the Orion ground operations planning process was to optimize the "operations design" in conjunction with the flight and ground systems designs. In order to achieve this, high level operational concepts were developed during initial Program Formulation using conceptual models, deterministic timelines, and historical comparisons.

As the Program matured, task level operational concepts, detailed FFBDS, and off nominal events were defined using subsystem/task level modeling and design-informed probabilistic simulations. Many of these Orion ground processing products will carry over to the new 21st Century Ground Systems Program with some modifications to accommodate any new requirements. As the Orion Program and new 21st Century Ground Systems Program progress forward to Initial Operational Capability (IOC), the more detailed operations requirements, procedures, Launch Commit Criteria (LCC), and detailed mission schedules will

be produced using yet to be developed certified requirements verification models and operations contractor/government partnered manifest assessments.

4.1 CONCEPT OF OPERATIONS

The Concept of Operations formed the basis for ground operations planning by describing the Ground System architecture in an operational context. It provided a common understanding of ground operations and the supporting infrastructure to all relevant Government and commercial stakeholders. This included characteristics of the ground system, interfaces between the ground system and other projects, nominal and contingency operational scenarios, and system performance expectations. The concept of operations is not intended to provide specific implementation constraints to Ground System designers, as system design and operational requirements are levied only through technical requirements documents. Rather, the concept of operations is part of the overall architecture definition which facilitates the development of technical requirements documents by providing:

- a. An operational context for the development of technical requirements
- b. A framework within which system design and implementation alternatives can be evaluated
- c. Reference data for evaluating the completeness of the technical requirements
- d. A mechanism to communicate long term goals and near term plans in context to support lower level design trades.

A sample Concept of Operations spacecraft flow subsection is shown in Figure 2.

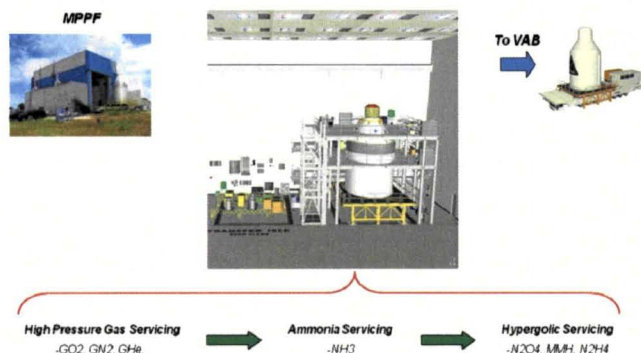


Figure 2 – Sample Concept of Operations (Spacecraft)

4.2 ORION PROCESS VISUALIZATION

The Ground Ops Project team leveraged powerful visualization capabilities to plan operations at KSC. The team utilized Pro E and Catia models of spacecraft, GSE, facilities and personnel from spacecraft flight hardware designers and ground systems designers. The visualization team imported the models into Delmia to enable operations and systems design interaction in a virtual reality environment. This capability was used many times to influence the design process, and make flight and ground systems more operable. The visualizations of the spacecraft operations in facilities (i.e., VAB platforms, launch abort system assembly, spacecraft servicing in MPPF) were also powerful communications tools for engineering development and milestone reviews such as GOP PDR.

4.3 FUNCTIONAL FLOW BLOCK DIAGRAMS

Cx Ground Ops Project required tools to collect, assess, and concisely communicate all of the Orion ground operations steps including servicing, integration, landing and recovery and de-servicing. One simple but effective tool was functional decomposition, using Functional Flow Block Diagrams (FFBDs), prepared with participation throughout the organization at KSC and JSC. Orion Ground Operations project led the FFBD effort and maintained the configuration control of the product. The first FFBD was developed in 2006 and updated on a regular basis depending on significant changes to the vehicle or ground systems. The use of FFBDs is a standardized practice per NASA Systems Engineering Handbook NASA/SP-2007-6105. The FFBD will continue to be updated periodically because it provides the simplest method of developing and communicating Orion operational tasks among different project and engineering organizations. It is a time based sequencing of the Orion ground operations flow in one product and enables functional decomposition of tasks as the flight and ground designs evolve and the related operations are better understood. The FFBD was also used to develop multiple/ lower level GOP products such as the nominal timelines, derived requirements, the Orion portion of Ground Operations Planning Document (GOPD), and the Orion portion of the Ground Operations Timeline Analysis Report integrated timeline. The FFBD and timelines were also used as input to Orion Ground Ops discrete event simulations, visualization tools and to resource planning efforts for future O&M.

FFBD Lessons Learned

- 1) Decide on level of detail up front
- 2) Decide on ground rules on what's in and out
- 3) Keep the level of detail at the functional level
- 4) Keep it simple
- 5) Establish some type of configuration control

- 6) Keep a reference version for the community to use (i.e. GOPD) and develop working versions for continual update and refinement as needed
- 7) Get the larger community involved early (Safety, Engineering, Operations, Logistics, Institution, etc.)
- 8) Use an application that everyone can use. Our team used MS Powerpoint.
- 9) Expect numerous changes.

Examples

Our team began with a very high level Tier 1 FFBD (Figure 3). As the operations became more understood, Tier 2 and Tier 3 levels were developed (Figures 4 and 5). For our team, the next level was the GOPD and the actual detailed procedures. The Constellation Program (CxP) did not reach the detailed procedure level before the program was canceled. Many of our FFBD and GOPD details will directly apply to the new Exploration Orion ground operations FFBD and GOPD. Procedure level details will evolve from these in the future.

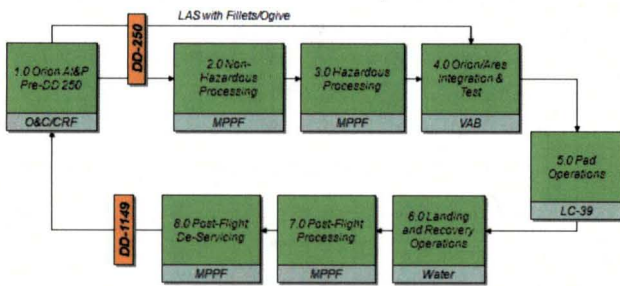


Figure 3 – Tier 1 Orion Ground Ops Functional Flow

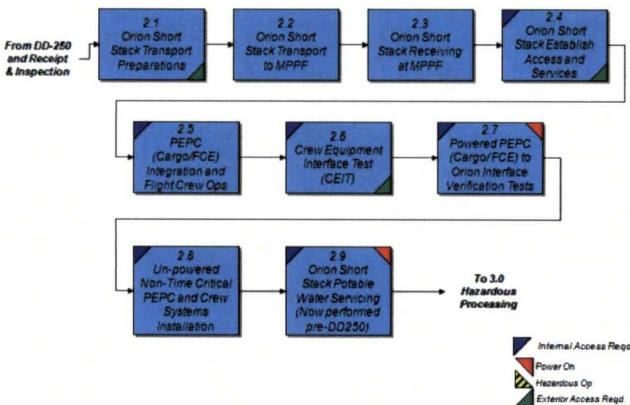


Figure 4 – FFBD Tier 2 Example

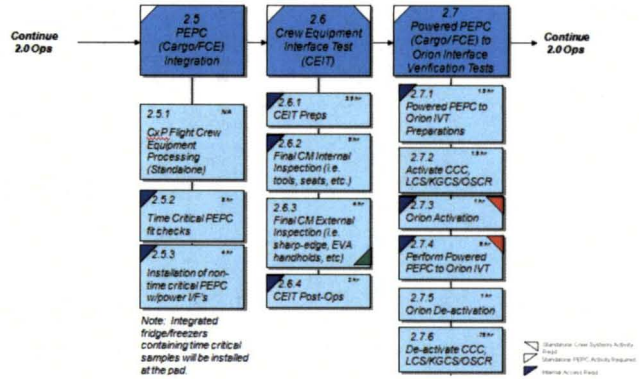


Figure 5 – FFBD Tier 3 Example

4.4 OPERATIONS TIMELINE DEVELOPMENT

Subsystems level ground processing expertise from Shuttle and ISS were used to estimate timeline durations and resource loading for Orion and the new Program. The Delphi method was used to develop durations based on multiple experts per subsystem. The timelines were then used to develop preliminary schedules. The schedules added learning curve, work shifting and special testing. Integrated operations at the VAB and Pad, and hazardous operations at the MPPF, were based on five days/three shifts per week and the remaining offline operations are based on five days/two shifts per week. The learning curve was based on ISS, Shuttle and Apollo historical data. This data set indicated that up to four times the estimated nominal steady state may be required to prepare for the first flight, and that the timeline duration could be reduced with each subsequent flight, until full learning was accomplished after the third flight.

Ground Operations Timeline Analysis Report (GOTAR)

The purpose of the GOTAR was to demonstrate the progress made by the Ares/Orion/GO Projects towards meeting the Program requirements. One requirement was to conduct ground operations for a single Ares I/Orion mission within a threshold critical path timeline of 879 hours. From GOTAR 1 to GOTAR 12 this time was reduced from 920 hours to 867 hours. Another requirement was to achieve a 45 calendar day launch interval once the Orion/Ares I system enters steady-state operations. The report provided the current assessment status of, and recommended improvements for, the overall ground operations responsiveness of the Orion/Ares I system. In order to accomplish this, the report officially documented the allocation of the 45 calendar day requirement into sequential segments. These segments were defined in serial work hours as follows:

1. Mobile Launcher (ML-1) Refurbishment
2. Mobile Launcher (ML-1) Preps in VAB High Bay 3

3. First Stage Stacking on Mobile Launcher (ML-1)
4. Upper Stage Stacking
5. Orion CEV/LAS Installation
6. Orion/Ares I Integrated Test and Closeouts
7. Orion/Ares I Pad Operations

The work described above was to be accomplished within 45 calendar days, inclusive of any contingency time accounting for: holidays, weekends, shift differentials, accumulation of unplanned work, and other variances.

The GOTAR report was an integrated source of detailed timeline allocations that provided more detailed Level III project information to guide the Level III Projects. In addition, the report provided timeline assessments against the currently known state of the flight and ground system designs, as well as quantifying timeline margin (deltas) between the assessments and the allocations. The GOTAR also provided recommendations for closing the gap between the assessment and the allocated requirements.

Example

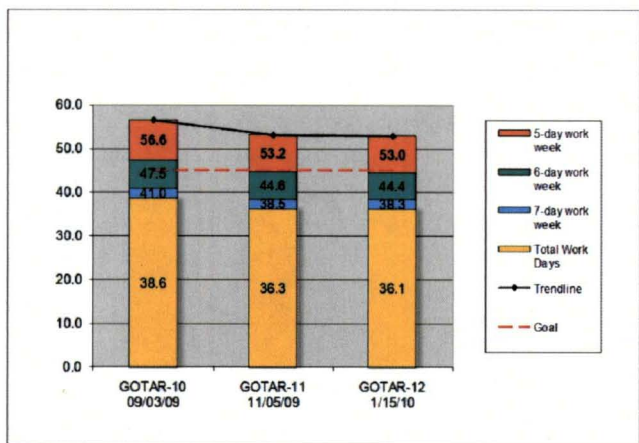


Figure 6 – GOTAR Example

The GOTAR example, shown in Figure 6, shows 7 day work week shifting would meet the 45 day requirement and that from September 2009 to January 2010 the integrated team leaned out 2 ½ days of additional efficiency in the integrated timeline.

4.5 DISCRETE EVENT SIMULATION (DES) MODELING

Discrete Event Simulation (DES) is a computer-based modeling technique for complex and dynamic systems where the state of the system changes at discrete points in time and whose inputs may include random variables. The related planning products used in our DES efforts included, integrated timelines, FFBDs, manifest scenarios, and project directed assumptions. The modeling guidelines were to model at the level of detail for which there is data, to model

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at the level of detail required to provide the answer, and to complete the DES analysis in time to be useful. The input analysis sources were Shuttle historical data, expert opinion, CxP documentation, and literature reviews. The Output File and output analysis products were designed to match requested analysis. DES analysis was performed for ground operations needs as follows:

- ◆ Maximum flight rate analysis for integrated operations at the Vehicle Assembly Building (VAB), Mobile Launcher, Pad, and for Orion offline operations at the MPPF
- ◆ Transporter study
- ◆ VAB Highbay selection study
- ◆ 90-Minute Launch separation study
- ◆ Probability of Meeting Planned Milestones Study
- ◆ Launch Probabilities and Launch Distributions for Preliminary Design Review (PDR)
- ◆ Hypergolic scrubber study.

4.6 GROUND OPERATIONS PLANNING DOCUMENT DATABASE (GOPDB)

GOPD

The GOPD (example shown in Figure 7) provides ground operations planning information to ground systems developers, flight system developers, ground operators and the KSC institution. It also provides lower-level operations concepts supporting ground system/subsystem development. Ground operators are provided with a framework for operational procedure development, requirements assessment, and workforce/budget planning. Also, the institution is informed of the capabilities and services required to support ground processing. Details managed within the GOPD are information such as tasks, related high level work steps, hazardous operations, required subsystems, required support services, required GSE, and timelines.

Example

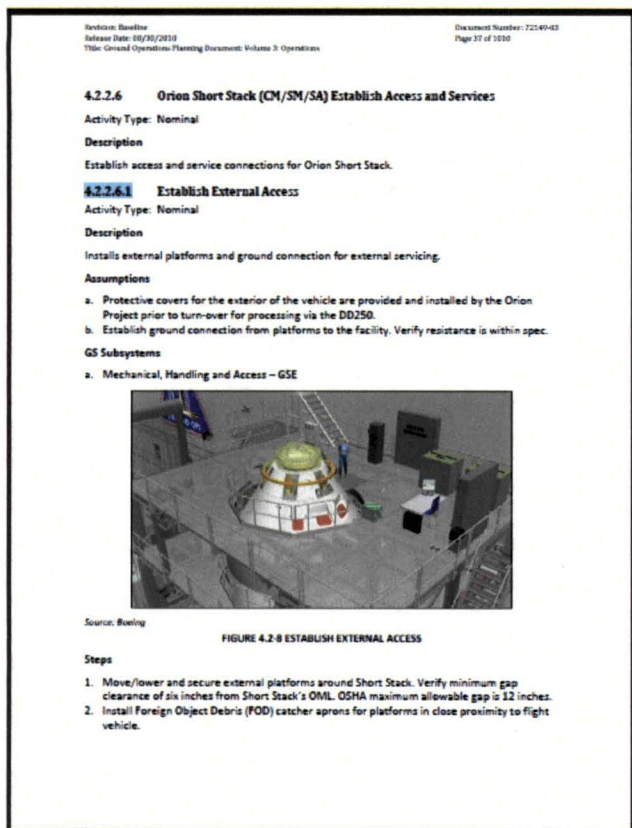


Figure 7 – GOPD Example.

GOPDb

The GOPDb is a custom web application that facilitates collaborative development of the GOPD. The GOPDb provides user-friendly data entry, review, approval and reporting of the GOPD task listings, resource listings, and nominal timelines. The GOPDb reduces costs and development time through real-time data integration, data governance, access control, and revision tracking of ground operations planning data. The use of the GOPDb eliminated the use of a separate application for capturing the concept of operations (ConOps) for ground operations planning documents and associated timelines.

GOPDb Enhancements

Recent GOPDb enhancements allow the smarter use of computing resources for data processing by utilizing both client-side and server-side resources. This greatly reduced the amount of IT hardware needed to host the application and provided greater flexibility in deploying the application. It now supports 200 concurrent users. Since GOPDb uses web-based software, no additional software installations are required. The system uses a RIA (Rich Internet Application) interface (Figure 8), which removes all browser incompatibilities. The GOPDb also provides real-time custom reporting with output to a variety of formats including Word, PDF, HTML and Microsoft Project XML format. The GOPDb allows comparison of two versions of a document side-by-side highlighting the difference between documents. This “versions” capability allows for “what-if” operational scenarios to be developed, reviewed, and

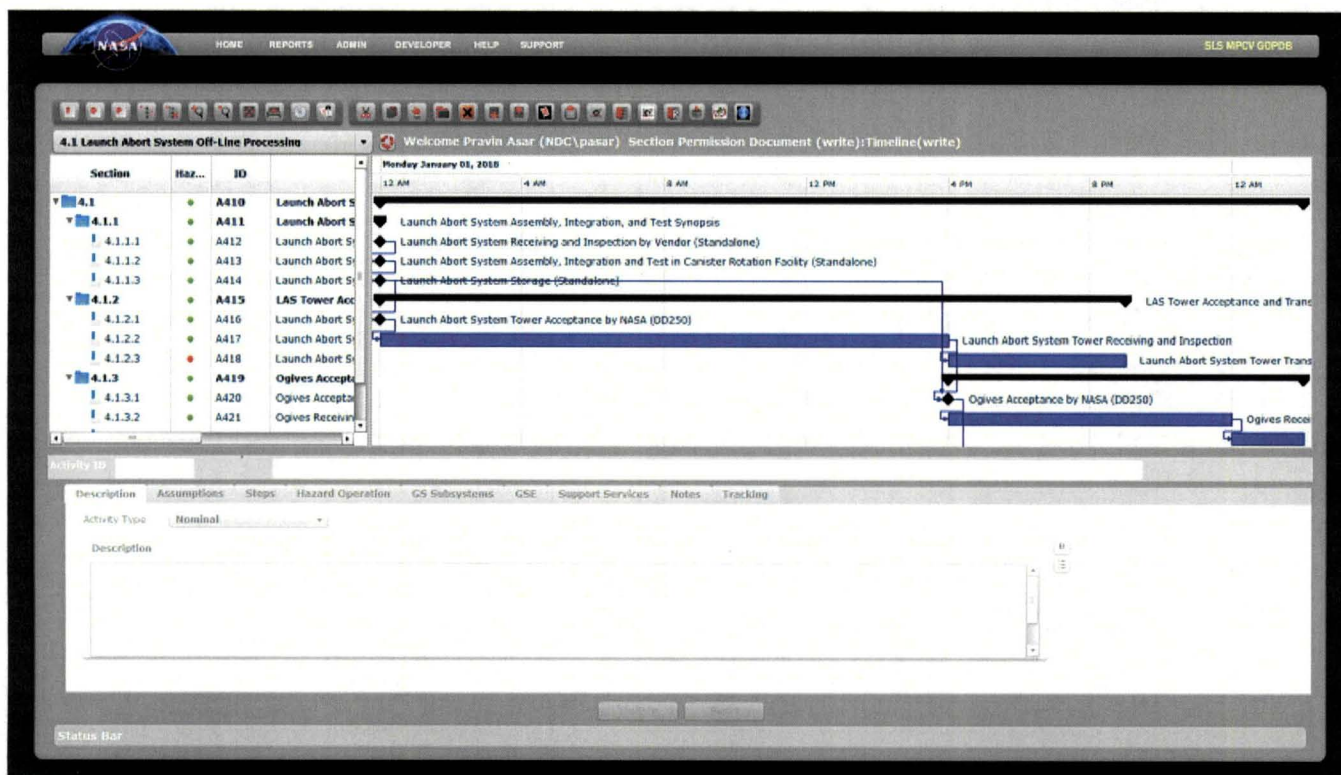


Figure 8 – Example of GOPDb Enhanced Screen Shot with Timeline and Related GOPD Data Fields

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compared to the baseline operational scenarios.

5.0 OPERABILITY IMPROVEMENTS USING OPERATIONS PLANNING TOOLS

Operability, in general, can be thought of as the extent to which the maximum mission objectives can be achieved at the lowest cost over the program lifecycle. Often, improving operability means optimizing several competing figures of merit. Operability figures of merit specific to Ground Operations include the following:

- 1) Improvement of safety to personnel and/or hardware
- 2) Maximization of throughput or flexibility to meet dynamic manifest needs, and minimization of processing critical path
- 3) Minimization of facility/industrial "footprint" required to support operations
- 4) Maximization of capability to launch on time
- 5) Minimization of touch labor.

Some examples of Orion ground operability successes that were achieved, by teamwork between the Cx Orion and Ground Operations Projects, are identified in Figure 9:

- A) The Orion design was changed to add an integrated lift capability. With this capability contingency

- B) One piece ogive lift capability allows the complex integration of the four ogive pieces to be performed offline out of the integrated vehicle critical path. Contingency de-integration is also much faster with less chance for hardware damage
- C) With the elimination of full vehicle power up for post flight de-servicing, the operation is much quicker and less GSE and personnel are required for this task
- D) With the Composite Overwrap Pressurized Vessel (COPV) design updated to meet the 100 day requirement before depressurization, integrated contingency schedules became more realistic. Without this capability, contingency operations would have become increasingly difficult to accomplish.

Additional significant operability successes were also achieved in: E) propulsion systems; F) Pyrotechnics, T-0 interfaces, and servicing panels; G) SM Fairing removal capabilities; and H) Launch Vehicle to Orion interfaces.

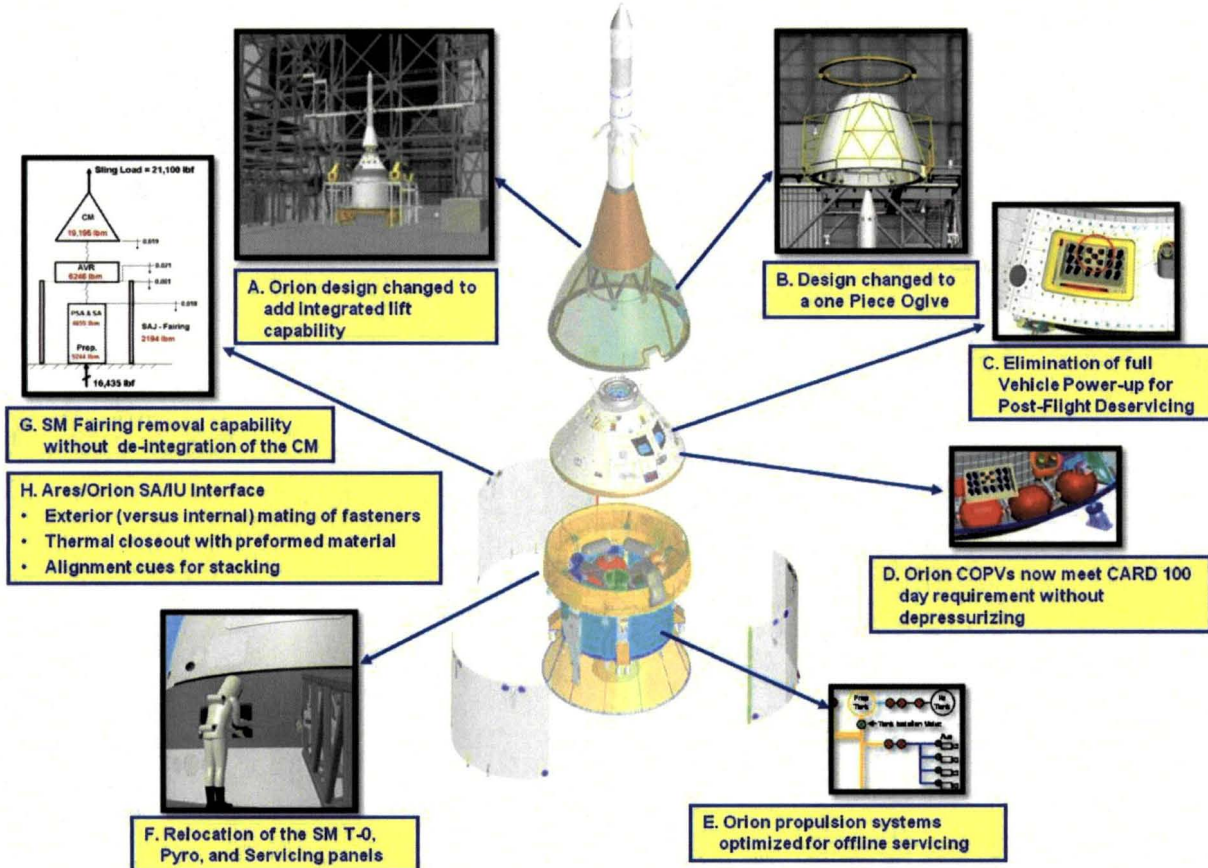


Figure 9 – Orion Operability Successes
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5.1 KAIZEN/LEAN EVENTS

Lean/Six Sigma (LSS) principles were used to improve operability and affordability in flight and ground systems designs. Certified LSS Black Belts led teams in focused streamlining and Kaizen events on a number of occasions. Such events sought to reduce non-value added activity, reduce waste and sources of variability, and improve processing efficiencies.

One example is the Launch Abort System (LAS) assembly streamlining event, where LAS processing and hardware improvements were offered by preassembling the ogive enclosure, reducing re-assembly and reducing fastener count.

Another example is the identification of improvements to project-to-project flight hardware delivery schedules. Improvements were identified that could reduce production to launch timelines, including hazardous commodity servicing streamlining, parallel operations, and use of pathfinders to reduce initial test flights' learning curve impacts.

5.2 MOCKUPS

Mockups are an invaluable tool in any new development program. Mockups provide a low cost alternative to pricey flight hardware. Mocks also provide the development team a quick and easy way to prove or disprove a design or operations. Mockups used early in the development cycle not only improve the final design, but also help reduce costly changes later in the design cycle.

Examples

KSC Ground Operations has used mockups extensively in the development of both the Orion flight system interfaces and the related ground operations systems. KSC used mockups of both the KSC "White Room" and JSC Orion Crew Module (Figure 10) to help demonstrate the interface between the "White Room" and the Ogive fairing. This led to a redesign of this interface.

KSC also was able to demonstrate Crew emergency egress from the Crew Module to the "White Room" (Figure 11). This was done with the Astronauts in their new prototype suits and KSC Fire and Rescue in their new prototype fire suits. This demonstration led to many improvements of the Orion Crew Module, Astronaut suits, Fire and Rescue suits, and "White Room".



Figure 10 – "White Room" to Ogive Fairing Interface

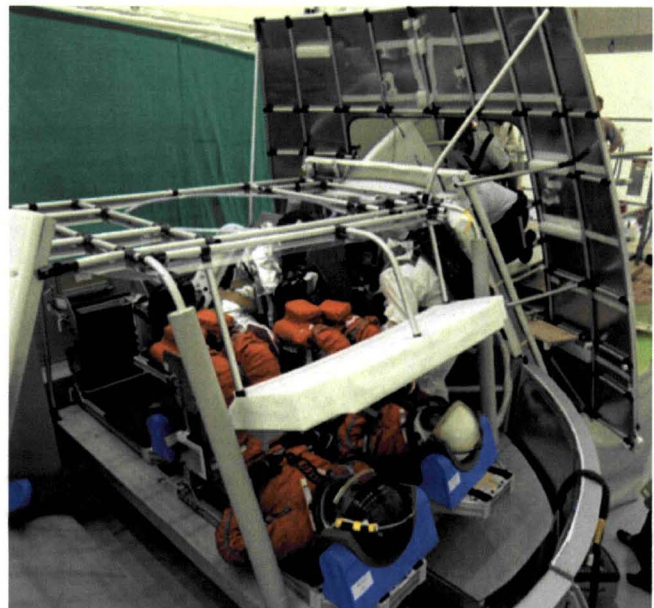


Figure 11 – CM Emergency with Fire Rescue

Another demonstration was the use of a full scale Orion Service Module mockup to help show that Orion could be serviced with existing KSC Ground Support equipment instead of more expensive new equipment. This gave the KSC Operations team confidence that if funding for new equipment wasn't available, they could still support an Orion flight. Lastly the full scale SM mockup was also used to show if servicing of the SM/CM could be done using temporary scaffolding (Figure 12). This proved that temporary scaffolding was not adequate from a safety standpoint. This was used to help justify better platforms for access to Orion.

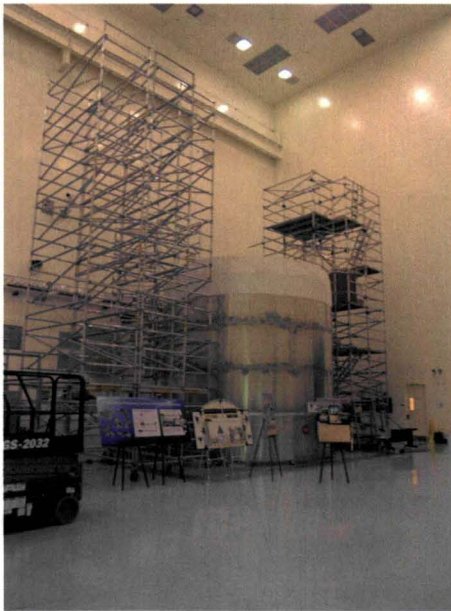


Figure 12 – SM with Scaffolding Access

5.3 HUMAN FACTORS ANALYSIS

A Human Factors Team was formed consisting of qualified human factors engineers, experienced spacecraft operations engineers, design engineers, and the design visualization team. This visualization team reviewed the flight and Ground Support Equipment (GSE) designs for human factors. By following the processing timeline, each Orion ground operation was analyzed in the KSC Design Visualization Lab with human factors and operations experts focusing on the hardware to human interactions affecting the human performance during assembly, maintenance, and inspection of Orion.

These important meetings with the operations and design engineers using the actual flight and ground designs loaded into the design visualization tools were a great help during the Human Factors Operability Engineering Analysis (HFOEA). The team used a modified version of a Human Factors Engineering Analysis (HFEA) tool developed by the KSC Engineering Directorate by re-arranging the analysis spreadsheet to show the timeline of Orion operations. For each of the operations, five data fields in the tool were populated, including: Human Interfaces, Issue, Processing Phase, Risk Analysis, and Recommendations.

When an issue was discovered in a specific operation, applicable human factors standards were identified and referenced with the issue. These standards mainly came from the Federal Aviation Administration (FAA) Human Factors Design Standards (HFDS). For each issue, design engineering was brought into the process in order to address the issue for human factors design improvements.

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Example

The task of moving the Orion short stack pallet into and out of the servicing bay was evaluated (Figure 13). Alignment of pallet into the servicing bay was considered an issue that required further evaluation. An action was taken to assure a method is put in place to prevent contact and misalignment of pallet with existing bay structure during installation/removal of short stack pallet. A human factors requirement was evaluated and applied to the task that states “Users shall be protected from making errors to the maximum possible extent”. A recommendation was provided to the design team to install guide rails on the floor. See reference [2] “Human Factors Operability Timeline Analysis to Improve the Processing Flow of the Orion Spacecraft” for more details on KSC ground operations human factors assessments.



Figure 13 – Orion Short Stack Pallet at servicing bay of Multi Payload Processing Facility (MPPF) building.

Human Factors Lessons Learned

Early collaboration and planning between the flight and ground hardware designers for human factors operability engineering analysis (HFEA) is necessary. The program level NASA Constellation human factors requirements document (HSIR) greatly promoted better human factors Systems Engineering and Integration. This improved the integration between ground systems and crewed vehicle designs for ground processing. Timeline analysis is great way to analyze and improve the design of ground and flight hardware interfaces for ground processing of the ground equipment, and the flight and ground hardware interface. Also, the use of qualified human factors engineers on the design team was critical.

5.4 ACTIVE TRACKING OF FLIGHT/GROUND ISSUES

A Microsoft Access database tool was developed in house to manage an integrated watch list of issues that affected ground operations cost, schedule and performance. Watch list database fields included a title, initiator, priority rating

of 1 thru 5, impact description, assigned subject matter expert, and status. A priority rating of 1 was high-impact to Ground Systems for cost, schedule and performance and required immediate management attention. A priority rating of 5 had minimum impact to GS in cost, schedule and performance. The database was set-up to allow the Flight Systems, Systems Engineering & Integration and other Project Office functions to evaluate the impacts against other disciplines. It provided management a quick-look of issues that affected or had the potential of affecting the Project Office. The database exported output reports to Power-point in order to provide easy reporting for multiple user needs.

Example

- Title: Propellant GSE port sizes to prevent cross connections (ID 221)
- Initiator: LX-C organization
- Priority Ranking: 3
- Impact Description: Currently the SM fuel & SM oxidizer service carts have the same size outlet ports. There is a requirement to prevent misconnection of commodities. Propellant GSE design needs to account for potential cross connection of commodities. This can be accomplished with different size outlets.
- Status: 10/8/10 - Design is planning to modify the SM Fuel service panel outlets so that they are different from SM oxidizer. However, waiting for final GSE-to-Flight Interface definition to close.

6.0. SUMMARY AND FORWARD PLAN

The Ground Operations team was able to bring the Cx Orion spacecraft infrastructure to Preliminary Design Review readiness level in 2010, using a combination of tools. FFBD decomposition, timeline development, discrete event simulation modeling, detailed GOPD planning and mockups were powerful tools in planning for operations as well as developing more operable ground and flight systems.

In the 2010 – 2011 timeframe, Constellation was cancelled, NASA formed the Exploration Systems Directorate, and the Orion Multi-purpose Crew Vehicle (MPCV), Space Launch System, and 21st Century Ground Systems Programs were initiated. The Orion MPCV design is very similar to the pre-existing design, so NASA plans to leverage existing operations, ground and flight systems designs and plans as much as possible. Designs will be updated and modified as needed for the new launch vehicle and flight rate requirements.

The 21 Century Ground Systems Program will use the operations development tools mentioned previously; they have proven their effectiveness in preparing for safe, operable human exploration missions in the 21st century.

REFERENCES

[1] Ground Operations Planning Document: Volume 3: Operations; Document Number: CxP 72149-03

[2] Human Factors Operability Timeline Analysis to Improve the Processing Flow of the Orion Spacecraft by Roland Schlierf & Damon B. Stambolian
 NASA Kennedy Space Center (KSC)
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 JFK Space Center
 KSC, FL 32899
¹ IEEEAC paper #1021, Version 3, Updated January 12, 2011

BIOGRAPHIES



Gary Letchworth is currently Chief of the Spacecraft Branch in the NASA Kennedy Space Center's 21st Century Ground Systems Program. Gary has over 25 years experience in launch systems and spacecraft development and operations. His previous employers include NASA Goddard Space Flight Center, Lockheed Martin at KSC, Skunk Works, and JSC, Rockwell International at JSC, and the US Air Force at Eglin AFB. His programs and projects include Orion, small launch vehicles and payloads, Space Shuttle, Shuttle upgrades, Airborne Laser, Orbital Spaceplane, X-33 and Venturestar, Crew Return Vehicle, and Heavy Lift Launch Vehicle concepts. Gary has a B.S.I.E from Auburn University, M.S.M.E. from Georgia Tech and M.S., Engineering Management from the University of Central Florida.



Roland Schlierf is currently the Offline Spacecraft Element Operations Manager (EOM) in the Spacecraft Branch in the NASA Kennedy Space Center's 21st Century Ground Systems Program. Roland has over 27 years experience in spacecraft, payload, and experiment development and operations. His programs and projects include Orion, International Space Station, Space Shuttle, and Spacelab. Roland has a B.S.E.E from the Florida Institute of Technology.