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Artemis I: Test Flight Buys Down Risk for Humanity's Return to the Moon

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Abstract

The Artemis program successfully demonstrated its foundational deep space human transportation system during the Artemis I test flight in late 2022. This bold mission put the Artemis program on a course to accomplish increasingly complex missions to return humans to the Moon and to prepare for Mars and other destinations. The Artemis I uncrewed mission tested the Space Launch System (SLS) rocket and the Orion spacecraft using the ground processing, launch and recovery services provided by the Exploration Ground Systems (EGS) program at the Kennedy Space Center (KSC). The Artemis team accomplished key mission priorities that deliberately bought down risk for upcoming crewed missions as part of a build-up flight test strategy. The Artemis I mission priorities were 1) demonstrate Orion heatshield at lunar re-entry conditions; 2) operate systems in flight environment; and 3) retrieve the spacecraft. The successful performance and demonstration of these primary mission objectives from lift-off thru orbital insertion, translunar injection, outbound transit towards the Moon, entry into lunar orbit, coast in the lunar Distant Retrograde Orbit (DRO), exit from lunar orbit, transit back to Earth, atmospheric re-entry, descent, splashdown and recovery successfully showed that NASA has a foundational deep space transportation capability in place for human class missions. In addition to the primary mission objectives, a set of scientific payloads, approved Flight Test Objectives (FTOs) and Development Flight Test Objectives (DFTOs) were incorporated into the nominal mission plan and were designated as secondary, or priority 4, and were considered "bonus objectives" in terms of crewed flight risk buy-down. During the mission, the team found itself in a position where it was comfortable achieving even more content than originally planned. As a result, DFTOs were added during the mission to further buy down risk to later crewed test flights. This paper presents an overview of the Artemis I test flight, including mission priorities and key test objectives, the launch campaign and as-flown mission profile, test objectives accomplished over the course of the 25.5-day mission, and implications to the crewed Artemis II and later test flight missions.

Keywords: Artemis, Space Launch System (SLS), Orion, Exploration Ground Systems (EGS), Distant Retrograde Orbit (DRO), Flight Test Objective (FTO)

Acronyms/Abbreviations

CM	Crew Module
DFTO	Development Flight Test Objective
DRO	Distant Retrograde Orbit
DSN	Deep Space Network
EGS	Exploration Ground System
FTS	Flight Termination System
ICPS	Interim Cryogenic Propulsion Stage
KSC	Kennedy Space Center
MET	Mission Elapsed Time
ML	Mobile Launcher
MMT	Mission Management Team
OPF	Outbound Powered Flyby
RPF	Return Powered Flyby
SLS	Space Launch System
SM	Service Module
SCaN	Space Communication and Network
TLI	Trans-Lunar Injection
TPS	Thermal Protection System
TSMU	Tail Service Mast Umbilical
VAB	Vehicle Assembly Building

1. Introduction

The primary purpose of Artemis I was to test and evaluate the baseline capabilities of the SLS rocket, Orion spacecraft, and EGS ground, launch and recovery systems in support of human rating for future missions. During the mission, SLS launched from Mobile Launcher 1 (ML-1) and enabled the uncrewed Orion to enter into a Distant Retrograde Orbit (DRO) around the Moon. Over the course of the 25.5 day mission, the Orion spacecraft travelled 1.4 million miles, re-entered the Earth's atmosphere at Mach 32, performed a skip-entry maneuver during atmospheric re-entry to the Earth, and executed a sub-sonic parachute deployment sequence that slowed the spacecraft down to 17 miles per hour (mph) at splashdown in the Pacific Ocean. EGS-led recovery operations included joint operations with the United States Navy to successfully recover the Crew Module (CM).

As the first integrated test flight of NASA's deep space transportation system for human exploration, and the first in a series of increasingly complex missions, NASA's risk buy-down strategy is reflected in the planned mission priorities, test objectives, and a stressing mission profile for the uncrewed test flight.

This paper presents an overview of the Artemis I test flight, including mission priorities and key test objectives planned prior to the mission, the launch campaign and as-flown mission profile, achievements relative to the planned and additional test objectives, and implications to the crewed Artemis II and later missions.

2. Mission Overview

2.1 Mission priorities

Mission objectives defined the goals and operational content of the Artemis I mission, which in turn drove the execution from lift-off to splashdown. These objectives were deliberately prioritized to enable a strategic focus on later crewed mission safety and success and to enable the broader manifest. The mission priorities for the Artemis I test flight were 1) demonstrate Orion heatshield at lunar re-entry conditions; 2) operate systems in flight environment; 3) retrieve spacecraft; and 4) complete remaining objectives.

The mission included Flight Test Objectives (FTOs) to gather engineering data in launch, flight, and post-landing environments and to evaluate the integrated system performance of SLS, Orion, and EGS in support of human rating and integrated system certification for later crewed missions. Also included in the mission were Orion-specific FTOs designed to assess spacecraft system performance limits, support risk reduction activities in preparation for future missions, and support real-time anomaly resolution.

There were also numerous secondary mission objectives. Ten 6U sized CubeSats were manifested and deployed from the SLS Orion Stage Adapter, and four secondary payloads flew inside the pressurized Orion Crew Module (CM) as part of mission priority 4, to complete remaining objectives. Orion Development Flight Test Objectives (DFTOs) were also included in the nominal mission plan as "bonus objectives" in terms of risk buy-down for future crewed flights.

2.2 Mission profile

A lunar DRO was selected as the mission profile on Artemis I because it was seen as a stressing case of the rocket and spacecraft in terms of performance, need to demonstrate large propulsive maneuver sequences to get into and out of lunar orbit that will be required on later crewed missions, and operations at extreme distances for testing the communication and navigation systems. The DRO also afforded additional dwell time in the deep space environment to collect test flight data while in a relatively stable and low propellant and consumable cost orbit away from the Earth's influences.

2.3 Launch opportunities

Launch opportunities for Artemis I were separated into two distinct classes of mission duration: short and long mission classes of ~26 or ~42 days, respectively.

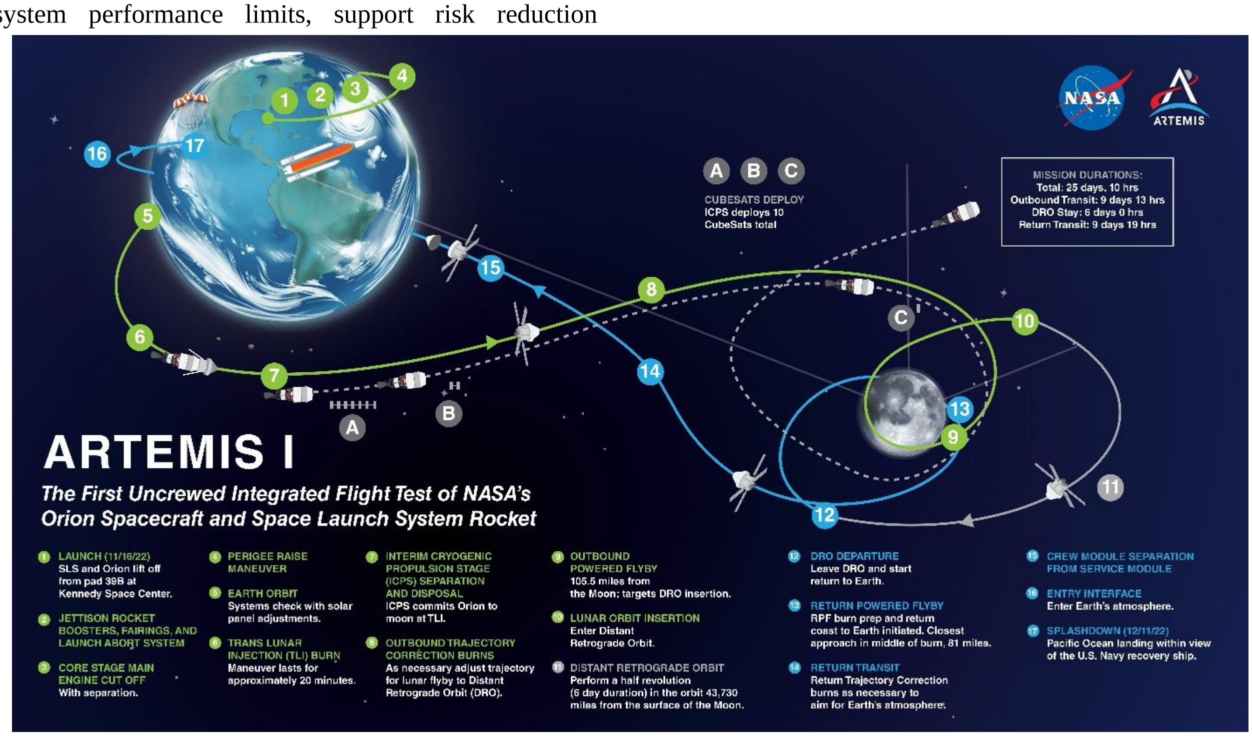

Fig.1. Artemis I As-Flown Mission Map

The class of mission was a function of the Earth-Moon position at launch, with the Orion performing half a lap in the DRO for a short class mission and one and a half laps for a long class mission. The variable mission duration afforded more launch opportunities and ultimately Artemis I flew a short class mission due to successful launch on November 16, 2022.

3. Artemis I Launch Campaign

Following robust ground testing campaigns during which the Artemis I Core Stage and Orion spacecraft underwent design certification testing, as well as an Integrated Test and Check-Out (ITCO) campaign with the integrated stack and ground systems, including Space Communication and Network (SCaN) assets, the SLS rocket and Orion spacecraft were rolled out to Kennedy Space Center (KSC) Launch Complex 39B on August 17, 2022 for an initial launch attempt. This roll-out date enabled final configuration of flight and ground systems at the launchpad in preparation for the launch attempt on August 29, 2022.

The Artemis I Agency FRR was held on August 22, 2022 and during that review it was acknowledged that the Liquid Hydrogen (LH_2) bleed and Core Stage engine kickstart were not accomplished during the Wet Dress Rehearsal (WDR) ground test campaign. As a result these ground test activities would be carried as open work into the launch attempt with a plan to demonstrate them during the launch countdown as a prerequisite to commit to launch.

3.1 First launch attempt

For an August 29, 2022 launch attempt, the launch window open was 08:33 Eastern Daylight Time (EDT) and window close was 10:33 EDT. Loading the SLS with cryogenicsstarted with Core Stage Liquid Oxygen (LO_2) tanking and began at approximately 02:07 EDT, followed minutes later by Core Stage LH_2 tanking. During the transition from Core Stage LH_2 slow fill to fast fill, a spike in LH_2 concentration was detected in the Tail Service Mast Umbilical (TSMU) purge can. The team was able to work past the LH_2 concentration issue and resumed Core Stage tanking, followed by ICPS tanking. While Core Stage commodities were in stable replenish and during the LH_2 bleed process to condition the RS-25 engines to the proper temperature range for engine start, a temperature sensor discrepancy was noted on Core Stage engine #3. Despite troubleshooting efforts, attempts to resolve the issue to meet the required conditions to launch using the planned sensor were unsuccessful. As a result of the inability to demonstrate all four of the RS-25 engines had achieved proper thermal conditioning, the decision was made to scrub the launch attempt.

At the scrub meeting held on August 30, the SLS Program Manager reported that the engine #3 LH_2 thermal conditioning issue was believed to be a sensor anomaly—meaning the engines were indeed properly thermally conditioned; however, due to a sensor issue on engine #3, it appeared to not be thermally conditioned. The engine #3 sensor was not intended for flight and was a ground-only engineering sensor planned for use during WDR testing that had previously performed properly. It was determined that alternative sensors and secondary cues like fluid flow rate and temperature measurements downstream of the engine would be used to confirm proper engine thermal conditioning for future launch attempts. The team set the next launch attempt for September 3, 2022, which gave the team some time to prepare for the next launch attempt and confirm engine thermal conditioning using the alternative measurements.

3.2 Second launch attempt

The launch window for a September 3, 2022 launch attempt was 14:17 to 16:17 EDT. The GO for SLS tanking, Core Stage LH_2 slow fill began at approximately 06:11 EDT. Early in the chilldown phase of cryo loading, an inadvertent over-pressurization of the LH_2 line occurred due to an operator error—the wrong valve was commanded. The issue was noticed and rectified in seconds. Following the inadvertent over-pressurization and during LH_2 loading operations, an LH_2 leak was detected at the TSMU that exceeded hazardous concentration limits, and LH_2 flow was stopped. The launch operations team attempted to resume LH_2 loading three times, and all three times had to halt LH_2 loading due to exceeding the hazardous concentration limits; as a result, LH_2 flow was stopped. All attempts to troubleshoot the LH_2 leak issue were unsuccessful. As a result, the launch attempt was scrubbed.

At the Post Launch Scrub Meeting held on September 3, the decision was made to proceed with access to the launchpad for umbilical demate and to remove and replace the QD 8-inch seal. A schedule assessment comparing launchpad remove & replace (R&R) activities versus rollback to the VAB for R&R was performed, and all options exceeded the days available in the late August to early September launch period.

3.3 Preparations for third launch attempt

Over the next six days, planned troubleshooting and removal and repair activities were successfully executed at the launchpad. By September 9, the teams had completed all hydrogen leak mitigation activities. To assess the performance of the Core Stage 8-inch QD following the removal and repair activities and validate the new cryo loading procedures prior to the next launch attempt, the decision was made to conduct a cryo demonstration test at the launchpad. The Cryo Demo Test was successfully performed on September 12 using a modified cryo loading procedure that used lower LH_2 pressure over a longer period to load the LH_2 tanks.

In the days following the Cryo Demo Test, a tropical depression formed in the Caribbean that developed into Tropical Storm Ian. With some weather models indicating some probability that the storm path could impact the launch site at KSC prior to the next available launch period, the decision was made on September 24 to forego the September 27 launch attempt and begin preparations to protect the vehicle and support rollback to the VAB. , By September 26, Tropical Storm Ian had strengthened into Hurricane Ian and by morning of September 28, the vehicle was safely back in the VAB.

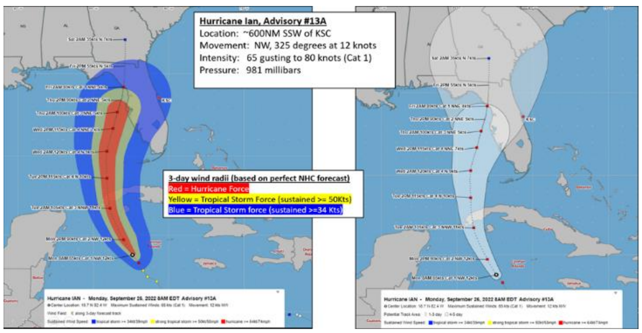

Fig 2. Hurricane Ian, September 26, 2023 Forecast

On September 29, 2022, the center of circulation for Hurricane Ian passed directly over KSC. That same day, the decision was made to target launch no earlier than the November 12-27, 2022 launch period. This would allow for careful evaluation of work scope driven by storm damage and personnel to return to work after taking care of their own families and homes.

While in the VAB, the teams performed inspections on the rocket and spacecraft, completed minor repairs, re-charged batteries as requested for accessible secondary payloads, replaced the Flight Termination System (FTS) batteries for the Core Stage, Boosters, and ICPS, and conducted testing to ensure flight readiness for the next launch attempt. Following a thorough damage assessment of Hurricane Ian of the Kennedy Space Center, on October 28, the date for the next launch attempt was set for November 14, 2022.

The integrated vehicle stack was rolled from the VAB to Launchpad 39B on November 4 for a planned launch attempt on November 14. By November 6, Tropical Storm Nicole had formed and was being monitored due to its projected path and weather models indicating some likelihood of hurricane-force winds after the storm made landfall.

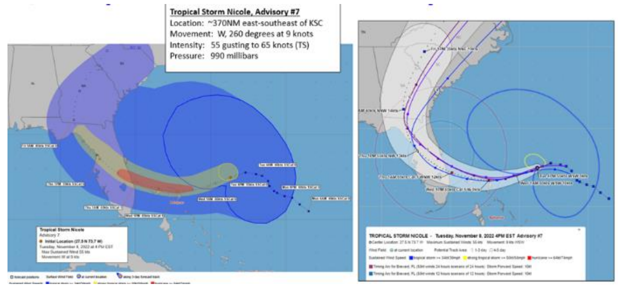

Fig 3. Tropical Storm Nicole, Nov 8, 2023 Forecast

At NASA board meetings on November 6 and 8, the teams discussed risk trades associated with riding out the storm versus the additional structural stress to the vehicle with rollback to the VAB. Based on known structural margin and the fact that the vehicle was designed to withstand heavy rains at the launchpad, combined with confidence in the storm models, the decision was made to ride the storm out at the launchpad. To prepare for the storm, the spacecraft hatches were closed and the vehicle secured to prevent water intrusion. By November 8, the Kennedy Space Center was closed due to projected tropical storm force winds. It was also decided that the next launch attempt would be re-targeted for November 16 to allow time for recovery efforts at KSC.

Hurricane Nicole made landfall in Florida on November 10. By November 11, the hurricane had transitioned south of and past the KSC area and the Center re-opened, allowing teams to perform thorough assessments of the launchpad, including the rocket and spacecraft. Based on an analysis of sensor data at the launchpad obtained during the storm that showed peak winds remained below 75% of SLS design limits, and confirmation of no water intrusion in the spacecraft, the decision was made to continue to target November 16 for the next launch attempt.

On November 13, teams reported damage from Hurricane Nicole had been fully assessed and identified issues were would not constrain the planned launch attempt if completed on time.

4. Artemis I Mission: Launch thru Recovery

The launch window for a November 16, 2022 launch attempt was 01:04 to 03:04 EST. The Following the GO to proceed with tanking, the launch operations team executed the modified cryogenics loading sequence that was demonstrated during the Cryo Demo Test.

During Core Stage cryo replenish, an intermittent LH_2 leak was detected on the ML tower itself. The LH_2 flow was stopped, and Red Crew personnel were authorized to enter the Blast Danger Area, access the launchpad and perform a troubleshooting procedure on the ML. The Red Crew operation was successful, and LH_2 loading and the launch countdown resumed.

4.1 Flight Day 1

The Artemis I mission launched at 01:47:44 EST on November 16, 2022, at a launch azimuth of 78.5 degrees. The SLS Boosters separated approximately 2 minutes later. Approximately 3.5 minutes into the flight, the Orion Service Module (SM) fairings and Launch Abort System (LAS) were jettisoned in series, followed minutes later by SLS main engine cut-off and separation of the Core Stage from ICPS/Orion. Following separation, the Core Stage followed a nominal disposal path to the Pacific Ocean, east of the Hawaiian Islands and west of California.

Fig 4. Artemis I lift-off

The TLI maneuver was followed by Orion separation from ICPS, after which ICPS performed a heliocentric disposal burn and then deployed ten Cubesats at several ‘bus stops’ along its disposal path.

4.2 Flight Days 2-9, Transit to the DRO

During Orion’s outbound transit towards the Moon, several outbound trajectory burns were executed that also served as system checkouts of the propulsion system on the Service Module (SM), which was provided by the European Space Agency (ESA).

Optical navigation (OPNAV) system certification passes using the Earth and Moon were successfully completed on Flight Days 2 and 3, allowing the team to, certify the OPNAV system for use in as an auxiliary method of navigation.

Fig. 5. Optical Navigation data taken of Earth

The Crew Interface Technology (CIT) payload, a joint technology demonstration effort between NASA, Lockheed Martin, Amazon and Cisco to test out voice-operated digital assistant and video conferencing capabilities during the Artemis I mission, was successfully checked out and had its first guest event with the payload on Flight Day 3.

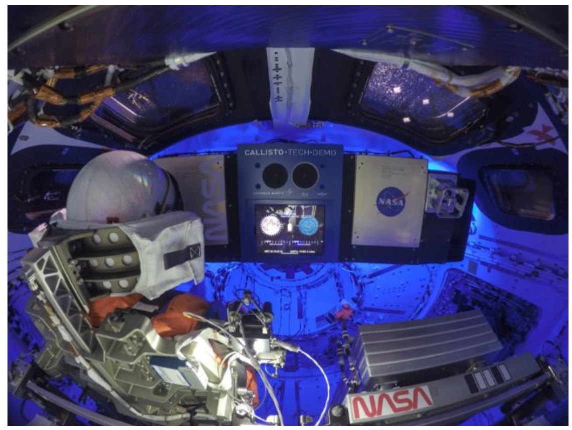

Fig. 6. CIT payload (aka Callisto) in Orion cockpit

The Orion team provided a ‘quick look’ of the spacecraft’s performance on Flight Day 3. Key findings included:

- Overall spacecraft thermal performance and environment was warmer (better) than anticipated.
- Orion power production was approximately 20% higher (better) than planned, with power use approximately 25% less (better) than anticipated.
- Solar array deployment was as expected.
- Propulsion systems performed as anticipated, including the Orion Main Engine (OME), the Auxiliary engines, and the RCS thrusters.
- Propulsion system propellant consumption was slightly less (better) than predicted.
- The propulsion system Gaseous Helium (GHe) pressurization system leak rate was less (better) than predicted.
- Cabin environment including cabin pressure and temperature were as planned, trending slightly cooler than predicted and leak rates less (better) than predicted.
- All other systems operated as planned and predicted.

The team noted several unplanned communication coverage outages that were quickly resolved. The outages were attributed to command errors or misconfigurations between the spacecraft, Mission Control Center (MCC), and Deep Space Network (DSN) assets. Some anomalous behaviour was also noted with the Orion spacecraft power system in the Power Conditioning Distribution

Unit (PCDU). The Latching Current Limiters (LCLs) unexpectedly tripped off without a command to trip. In all cases, the LCLs were recovered with ground commanding from MCC returning the vehicle to full capability in spite of the technical glitch in the power system.

The SLS rocket and EGS launch teams provided their 'quick look' performance summaries on Flight Day 4. SLS noted that all elements performed as planned, with Core Stage insertion altitude and ICPS PRM and TLI maneuvers meeting performance requirements and noted no significant anomalies in the rockets performance. EGS noted that all ground systems, including software command and control systems in the Launch Control Center (LCC) performed as expected. Some amount of damage was noted to the ML due to the SLS lift-off vibroacoustics and pressure wave from the rocket.

Based on the performance of the spacecraft, the decision was made on Flight Day 4 to proceed with the lunar OPF maneuver to commit the spacecraft to a non-Earth return trajectory and start the entry into lunar orbit as part of a two maneuver sequence. The OPF maneuver was executed on Flight Day 5. Orion entered an orbit around the Moon on Flight Day 6 and continued its transit to the DRO over the next four days. Pre-planned mission activities continued to be executed nominally, including Orion DFTOs trajectory correction burns, daily OPNAV passes, CIT payload events, and imagery for public outreach.

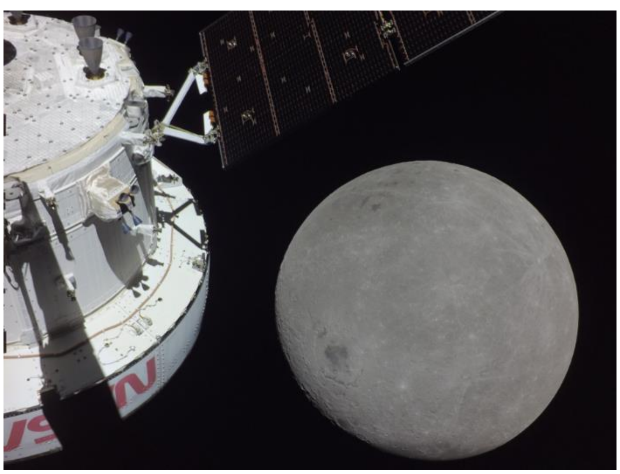

Fig. 7. Orion approaching the Moon on Flight Day 6

4.3 Flight Days 10-15, Orbiting the Moon in the DRO

On Flight Day 10, Orion successfully performed the DRO insertion maneuver and entered the DRO.

On Flight Day 13, the Orion team recommended adding new DFTOs to further test the spacecraft systems and acquire flight test data to further buy down risk for future flights given the stable spacecraft performance.

Over the course of the mission, a total of 21 additional real-time DFTOs were proposed, reviewed, approved and executed—above and beyond the DFTOs and other planned mission objectives that were in the mission timeline prior to launch.

Fig. 8. Orion at farthest distance from the Moon on Flight Day 13; a distance from Earth of 268,000 miles

4.4 Flight Days 16-20, DRO exit to RPF

On Flight Day 16, Orion exited the DRO and began heading towards the Moon for the Return Powered Flyby (RPF).

On Flight Day 18, as Orion continued toward the Moon on course to conduct the RPF burn, the Goldstone DSN site reported a sitewide outage affecting all customers, including Orion for an upcoming DSN pass on Flight Day 19. To mitigate impacts to Orion, other DSN customers graciously donated portions of their communications coverage at the Madrid site to the Artemis mission, allowing the MCC to extend Orion communications via Madrid by several hours. As a result, what would've been an 8+ hour loss-of-communications with Orion was reduced to ~4.5 hours followed by recovery of the Goldstone ground site prior to the next planned communications pass.

On Flight Day 20, Orion successfully completed the RPF burn, committing the spacecraft to Earth return on December 11. The team continued to evaluate Orion performance and conduct additional DFTOs to further test the spacecraft systems on the Earth return leg.

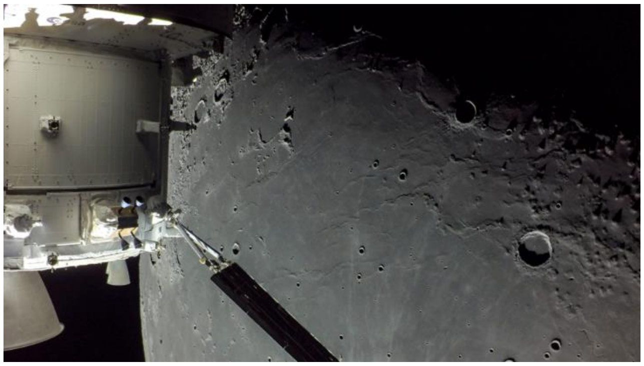

Fig. 9. Orion nearing closest approach to the Moon on Flight Day 20, prior to RPF

Based on weather briefings that indicated some potential for exceeding required weather criteria for both landing and recovery at the nominal landing site, off the coast of California in the Pacific Ocean, the decision to commit to deploy recovery forces a day later than planned to allow for greater accuracy of the weather forecasts at the nominal and alternate weather sites over the next few days.

4.5 Flight Days 21-25, Transit to Earth

On Flight Day 21, while Orion exited the Lunar sphere of influence and headed back to Earth and the team continued to evaluate additional DFTOs to further test the spacecraft systems.

The recovery team departed Naval Base San Diego on Flight Day 22 and began to sail out into the Pacific Ocean to prepare to meet the spacecraft for splashdown. Weather forecasts showed a strong cold front approaching the planned landing area off the coast of California with an increase in wind speeds that would impact spacecraft descent and recovery operations for the nominal landing site and the potential for flight through precipitation. Due to the cold front, the decision was made to set the landing site and position recovery forces 300 nautical miles due south of the originally planned landing location, . The new landing location was off the coast of the Baja peninsula and west of Guadalupe Island.

The CM RCS attitude control thruster system was activated on Flight Day 24 and had a successful hot fire test in preparation for landing on December 11. The flight team continued to execute DFTOs during Orion's transit back to Earth.

On Flight Day 25, the recovery ship arrived at the weather alternate landing site, observed favorable weather conditions in advance of the spacecraft's arrival, and confirmed the recovery team's readiness to support spacecraft recovery operations.

4.6 Flight Day 26, Re-entry, landing and recovery

CM/SM separation occurred at 09:00 Pacific Standard Time (PST) on December 11. Following separation, the CM executed the CM raise maneuver followed by a skip re-entry. The skip re-entry profile included roll maneuvers, which were executed as planned to enable greater accuracy of splashdown at the targeted landing. The spacecraft's velocity at entry interface at an altitude of 400,000 feet was 24,581 mph.

The series of parachute deployments began at 09:36 PST, with splashdown at 09:40 PST. All parachutes deployed nominally. The CM landed in the upright, or Stable 1 position, and all five Crew Module Uprighting System (CMUS) bags deployed nominally following splashdown and parachute line jettison. The velocity at splashdown under the Main parachutes was 17 mph. Landing was 2.1 nmi from the guided landing, well within expected landing accuracy.

Fig. 10. Orion at splashdown on December 11, 2022

Following splashdown, the CM powerdown occurred on 11:40 PST following a 2-hour period where the spacecraft was deliberately left powered on to obtain thermal soakback data as part of a planned FTO. After powerdown, recovery operations proceeded nominally, and the CM was hard-down in the well deck of the recovery ship by 15:37 PST on December 11, 2022, signifying the end of the Artemis I mission.

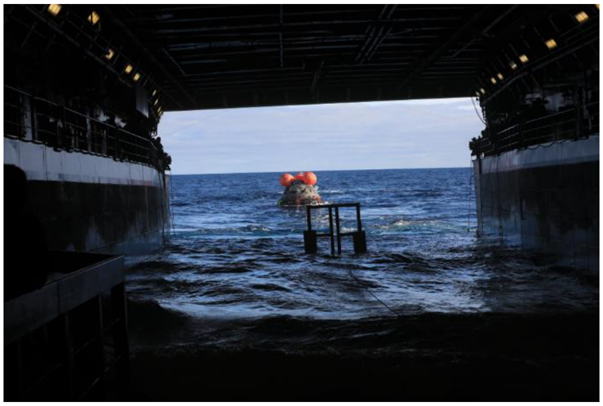

Fig. 11. Orion CM recovery into the well-deck of the USS Portland

5. Mission Accomplishments

Following the mission, the teams performed extensive analysis of engineering data obtained from the flight test, imagery data, and the flown hardware itself. Based on data analysis and hardware inspections, determinations were made regarding achievement of Artemis I mission priorities, FTOs and DFTOs. As of writing of this technical paper, the vast majority of the post-flight analysis work is complete, with some work remaining and plans in place to complete all work prior to the Artemis II crewed test flight. For cases where the teams determined that they had most data of sufficient quantity and quality to indicate with sufficient certainty that the FTO/DFTO will meet its measures of performance and success criteria to be considered successful, those objectives are shown as "partially achieved (plans to meet)." Objectives that were not completed are shown as "not achieved."

The following list establishes mission specific priorities accomplished during the Artemis I mission:

1) Demonstrate Orion heatshield at lunar re-entry conditions
   - Validate required system performance that is mandatory to support crewed missions, which can only be achieved in actual flight environment – *ACHIEVED, pending establishment of root cause and corrective action on heatshield char loss during CM re-entry*.
   - Demonstrate SLS ascent and launch vehicle operations including ascent separation events – *ACHIEVED*
2) Operate Systems in Flight Environment
   - Demonstrate Orion deep space environmental performance, communications, propulsion, and navigation systems – *ACHIEVED*
   - Demonstrate EGS and day of launch operations and support of EGS recovery forces if possible – *ACHIEVED*
   - Demonstrate Flight Operations management, execution, network management of Near Earth Network (NEN), Space Network (SN), and Deep Space Network (DSN) and facilities support systems – *ACHIEVED*
3) Retrieve Spacecraft
   - Position assets and demonstrate Orion crew module recovery when conditions maintain Orion within certified hardware capability and nominal operating limits – *ACHIEVED*
   - Retrieve Orion crew module, accepting risk of vehicle structure and Thermal Protection System (TPS) damage, when conditions are expected to exceed certified hardware capabilities, or when the crew module does not land at the nominal end of mission location – *ACHIEVED*
4) Complete Remaining Objectives
   - Provide lighted landing to support imagery collection during the entry, descent, and landing sequence – *ACHIEVED*
   - Complete additional time in deep space for system trending and analysis - *ACHIEVED*
   - Conduct optical navigation certification – *ACHIEVED*
   - Demonstrate redundant systems and downmode capability to the extent practical – *ACHIEVED*
   - Perform remaining ESD and Program FTOs and Program-specific activities – *ACHIEVED*, except where noted otherwise.
   - Most ESD FTOs (11 out of 12) – *FULLY ACHIEVED*
   - ESD-FTO-28, Identify any potential liftoff, ascent or separation debris capable of capture with available imagery – *PARTIALLY ACHIEVED*. Some loss of FTO imagery occurred during launch and ascent due to camera issues.
   - Most Orion FTOs (81 out of 123) – *FULLY ACHIEVED*
   - Orion FTOs not fully analyzed as of writing this report (15 out of 123 remain open) – *PARTIALLY ACHIEVED (PLANS TO MEET)*
   - Some Orion FTOs (25 out of 123) – *PARTIALLY ACHIEVED*. Of the partially achieved Orion FTOs, 19 are currently planned for repeat on Artemis II.
   - Recovery of the Orion Forward Bay Cover (FBC) and parachutes (2 out of 123) – *NOT ACHIEVED*. Total of 38 Orion DFTOs; 17 Planned and 21 Real-Time. The 21 Real-Time DFTOs were reviewed and approved and not a part of the mission baseline.
   - Most Orion DFTOs (30 out of 38; 16 Planned and 14 Real-Time) – *FULLY ACHIEVED*

- Orion DFTOs not fully analyzed as of writing of this paper (6 out of 21 Real-Time remain open) – *PARTIALLY ACHIEVED (PLANS TO MEET)*
- Small subset of DFTOs (1 out of 17 Planned; 1 out of 21 Real-Time) – *PARTIALLY ACHIEVED*
- Deploy SLS OSA secondary payloads – *ACHIEVED*
- Deployment signals were sent from the Interim Cryogenic Propulsion Stage (ICPS) to the Secondary Payload Avionics Unit in the OSA to initiate deployments.6 out of 10 CubeSats successfully established extended communications after deployment.
- Support NASA Office of Communications (OCOM) High Priority Public Affairs outreach activities – *ACHIEVED*
- Support CIT Payload activities – *ACHIEVED*
- Support remaining NASA OCOM outreach activities – *ACHIEVED*

6. Impacts to Artemis II

As of the writing of this report, there are no significant changes approved to the Artemis II crewed mission based on the results of the Artemis I test flight. While there is still open work for the pending objectives that could result in some change, the Artemis II mission remains largely unchanged from the previous technical baseline. To-date, the most significant changes that have been made pertain to hardening of the ML to mitigate launch-induced damage of ML systems on future flights, including the elevators, cameras, and other systems. Other changes worthy of note pertain to DSN ground system communications robustness and camera system readiness to capture lift-off and launch imagery. The remaining items shown as pending require additional work before changes, if any, are approved to the Artemis II mission and its technical baseline.

7. Conclusions

Artemis I was highly successful from an engineering and test flight perspective. In nearly all cases, it validated in the flight environment that the SLS rocket and Orion spacecraft performed as planned or better. The rocket's precision on its first flight was impressive and met every requirement. In a number of cases, the spacecraft exceeded performance expectations, specifically the power and thermal systems. The associated ground systems and mission teams also met expectations through assembly, integration, launch, flight and recovery phases. The mission successfully demonstrated the world's most capable rocket that can deliver crew and cargo to the point of TLI in one shot. While a few objectives were not accomplished, specifically those associated with retrieval of Orion's FBC and parachutes following entry and splashdown, those systems were previously tested during atmospheric drop tests and risk drivers have been mitigated to the extent practical. The remaining objectives shown as pending simply require additional time to conduct further data analysis, follow-on ground test or work to confirm results through model updates and correlations prior to crewed flight.

At present, NASA and its partners in the Artemis program continue to proceed towards increasingly complex mission with intent to fly astronauts and deploy lunar capabilities in the years to come with known open work Artemis I gave NASA and its international and industry partners optimism that the Artemis campaign is on the right path to return humans to the moon for the first time in over 50 years—this time, for a sustained presence. That said, NASA and its partners also recognize that they must remain vigilant and not let their guard down.