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NASA Deep Space Network Preparations for the Artemis II Crewed Mission to the Moon

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Abstract

NASA's Deep Space Network (DSN) is preparing to support the upcoming crewed missions that will return humans to the Moon, starting with the Artemis II mission slated to launch in the mid-2020's. With completion of NASA's Exploration Flight Test-1 (EFT-1) mission in 2014 and the more recent Artemis I mission in late 2022, which both involved testing of an uncrewed Orion spacecraft in a flight environment, the next step will be to send astronauts in Orion to fly by the Moon and return safely to Earth, in preparation for future lunar surface crewed missions. The Artemis II mission will provide this crucial link, bridging the gap between the uncrewed demonstration flights and the crewed lunar surface missions. DSN is slated to provide telecommunications coverage for Artemis II from the time the Orion spacecraft leaves the near-Earth vicinity through lunar transit, arrival, swing-by and departure, and return to the near-Earth vicinity. This paper describes work underway for DSN support of the Artemis II mission, with a focus on the pre-launch end-to-end space communications and RF compatibility test campaign. Differences between the Artemis II and Artemis I missions will be highlighted, including changes to the flight vehicle as well as the ground segment.

Acronyms/Abbreviations

Backup Control Center (BCC)
Beam Waveguide (BWG)
Canberra Deep Space Communications Complex (CDSCC)
Compatibility Test Trailer (CTT-22)
Consultative Committee for Space Data Systems (CCSDS)
Deep Space Network (DSN)
Deep Space Station (DSS)
DSN Lunar Exploration Upgrades (DLEU)
DSN Test Facility (DTF-21)
Deep Space Operations Center (DSOC)
Emergency Communications (EC)
Entry Interface (EI)
Exploration Ground System (EGS)
Exploration Mission 2 (EM2, EM-2, now Artemis II)
Federally Funded Research and Development Center (FFRDC)
Goldstone Deep Space Communications Complex (GDSCC)
Interim Cryogenic Propulsion Stage (ICPS)
James Webb Space Telescope (JWST)
Japanese Aerospace Exploration Agency (JAXA)
Jet Propulsion Laboratory (JPL)
Johnson Space Center (JSC)
Kennedy Space Center (KSC)
Low Density Parity Check (LDPC)
Lunar Reconnaissance Orbiter (LRO)
Madrid Deep Space Communications Complex (MDSCC)
Merritt Island Launch Annex (MIL-71)

Mission Control Center (MCC)
Multi-Purpose Crew Vehicle (MPCV), also referred to as Orion MPCV, or the Orion spacecraft
National Aeronautics and Space Administration (NASA)
Orion Artemis II Optical Communications System (O2O)
Radio Frequency (RF)
Reed-Solomon (RS)
Return Trajectory Correction (RTC)
Space Launch System (SLS)
Table Mountain Facility (TMF)
Tracking and Data Relay Satellite System (TDRSS)
Tracking, Telemetry and Command (TT&C)
Trans Lunar Injection (TLI)
White Sands Complex (WSC)

1. Introduction

NASA's Deep Space Network (DSN) is an international, multi-mission system which provides space communication services, including acquisition and transport of tracking, telemetry, and command (TT&C) data over the space links, as well as observational science utilizing those links [1]. The DSN is operated by NASA's Jet Propulsion Laboratory (JPL), a Federally Funded Research and Development Center (FFRDC) which also operates many of the agency's interplanetary robotic space missions [2]. In addition to supporting interplanetary robotic space missions, the DSN also supports human spaceflight missions to the Moon, and, eventually, to Mars [3].

The DSN consists of three antenna facilities around the world spaced at equal distances from each other (about 120 degrees apart in longitude), operated through the Network Operations Control Center at JPL, as shown in the figure below:

- The Goldstone Deep Space Communications Complex near Barstow, California
- The Madrid Deep Space Communications Complex near Madrid, Spain
- The Canberra Deep Space Communications Complex near Canberra, Australia

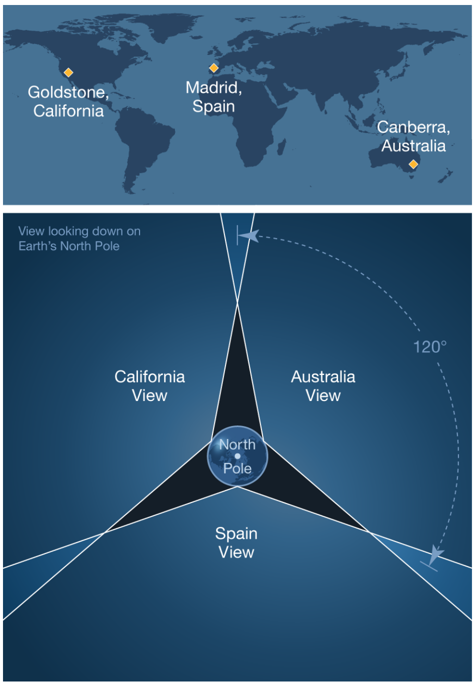
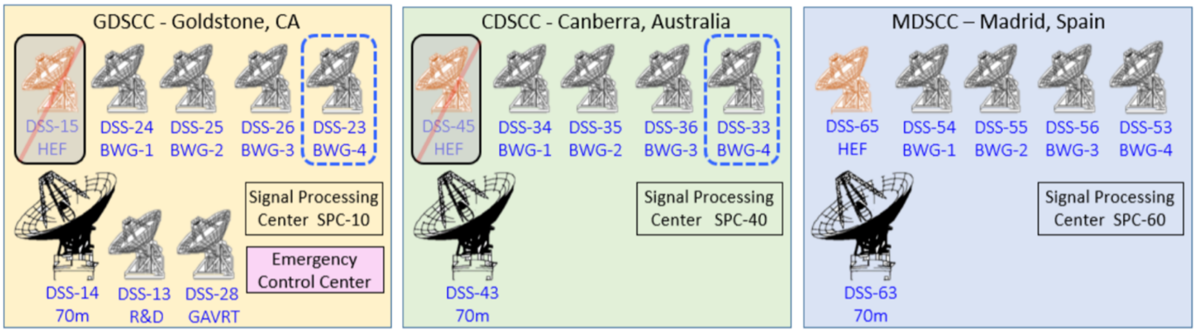


Figure 1: DSN Complex Locations and Views (image credit: Basics of Spaceflight [4])

The strategic placement of these sites permits constant communication with spacecraft as the Earth rotates. Before a distant spacecraft sets below the horizon at one DSN site, another site can pick up the signal and carry on communicating. All three complexes consist of at least four antenna stations, each equipped with large parabolic antennas and ultra-sensitive receiving systems capable of detecting incredibly faint radio signals from distant spacecraft [5]. Below is a summary of the Deep Space Station (DSS) antenna capabilities available at each DSN complex.



Freq. Band	S Up	S Down	X Up	X Down	Ka Up	Ka Down
Deep Space	2.11-2.12	2.29-2.3	7.145-7.19	8.4-8.45	34.2 – 34.7	31.8-32.3
Near Earth	2.025-2.11	2.2-2.29	7.19-7.235	8.45-8.5	25.5-27.0	22.55-23.15

Antenna	Sub-Net	S-Band		X-Band			K-Band		Ka-Band		Optical 1550nm	Est. Deliv. Dates
		Up	Down	Up	Down	Radar	Up	Down	Up	Down	Down	
DSS-14	70m	20kW•	√	20kW	√	500kW						8/2026
~~DSS-15~~	~~34m HEF~~	~~250W~~	~~√~~	~~20kW~~	~~√~~							
DSS-23	34m BWG			20kW	♦					♦	□	10/2025
DSS-24	34m BWG	20kW	√	20kW	√		250W	√		♦		8/2023
DSS-25	34m BWG			20kW	√				400W	√		5/2028
DSS-26	34m BWG	250W*	√	80kW	√		250W	√		√		
DSS-33	34m BWG			80kW	♦					♦		10/2029
DSS-34	34m BWG	20kW	√	20kW	√		250W	√		√		2/2024
DSS-35	34m BWG			20kW	√				1kW	√		8/2026
DSS-36	34m BWG	250W*	√	20kW	√		250W	♦		√		11/2022
DSS-43	70m	100kW•	√	80kW	√							
~~DSS-45~~	~~34m HEF~~	~~250W~~	~~√~~	~~20kW~~	~~√~~							
DSS-53	34m BWG			20kW	√					√		10/2029
DSS-54	34m BWG	20kW	√	20kW	√		250W	√		√		8/2026
DSS-55	34m BWG			20kW	√				1kW	√		5/2027
DSS-56	34m BWG	250W*	√	20kW	√		250W	√		√		8/2024
DSS-63	70m	20kW•	√	20kW	√							12/2028
DSS-65	34m HEF	250W*	√	20kW	√							

Figure 2: DSN Assets and Capabilities (source: DSN Service Catalog [1])

While many space vehicles tracked by the DSN are millions, or even billions, of miles away from Earth, there are also a number of missions operating in the near-Earth and cislunar regions which are supported by the DSN, including the Lunar Reconnaissance Orbiter (LRO) which is in orbit around the Moon, and the James Webb Space Telescope (JWST) which is in orbit around the Sun in the cislunar region at approximately one million miles from Earth at the second Lagrange point (L2) [6]. In addition to these scientific missions, the DSN is now also supporting human spaceflight vehicles from NASA's Artemis program [7] such as the Orion spacecraft, which serves as the exploration vehicle that will carry U.S. and international crew to deep space, provide emergency abort capability, sustain astronauts during their missions and provide safe re-entry from deep space return velocities [8]. Upon successful completion of the inaugural Artemis I uncrewed mission to the Moon, NASA will shift its focus and efforts to preparing for the crewed Artemis II mission to the Moon. The following section describes the upcoming Artemis II mission.

2. Mission Overview

Artemis II is the second scheduled mission of NASA's Artemis Program, and the first scheduled crewed mission of NASA's Orion spacecraft, currently planned to be launched by the Space Launch System (SLS) in 2024. The crewed Orion spacecraft will perform a lunar flyby test and return to Earth. This is planned to be the first crewed spacecraft to travel beyond low Earth orbit since Apollo 17 in 1972. Formerly known as Exploration Mission-2 (EM-2), the mission was renamed after the introduction of the Artemis program.

2.1 Flight System Description

The figure below illustrates the Orion spaceflight vehicle and the SLS [9]. This is the same configuration that was used during the Artemis I mission.

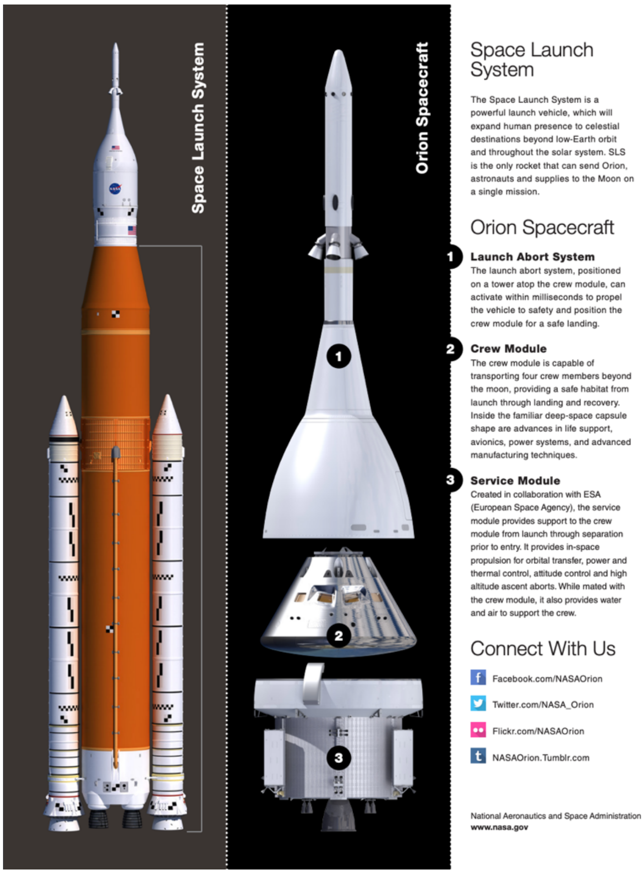


Figure 3: SLS and Orion Spacecraft (image credit: NASA)

The flight system will undergo pre-launch integration and testing at NASA's Kennedy Space Center under the auspices of the Exploration Ground System (EGS) organization.

2.2 Mission System Description

The Artemis II mission system is similar to the Artemis I mission system. The diagram below shows major components of the system and their interfaces for the deep space tracking aspect of the mission. DSN is the primary ground tracking asset during this phase, but other ground assets may be added to supplement the DSN tracking services. Additionally, an onboard experimental payload demonstrating optical communication capabilities is planned for Artemis II, as described below, but DSN will not provide the ground services for this demonstration.

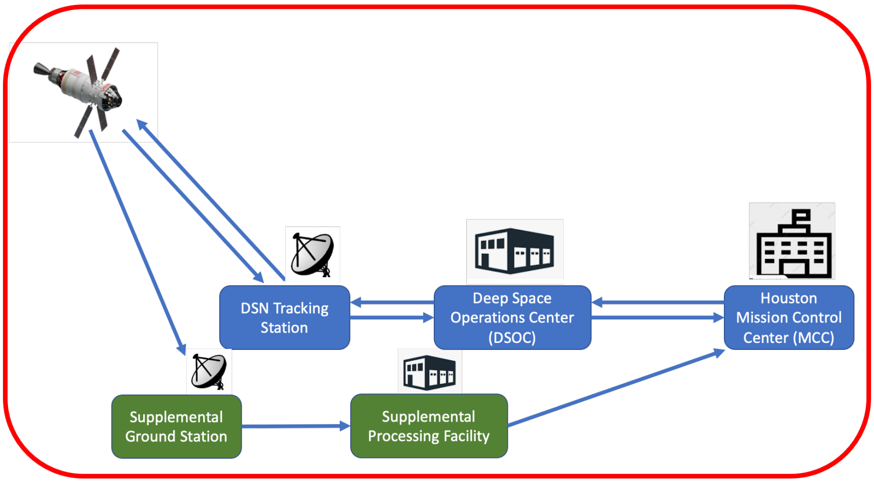


Figure 4: Artemis II Mission System Components for Ground Tracking During Deep Space Operations

2.2.1 Houston Mission Control Center

NASA's Mission Control Center (MCC) in Houston has served as the nerve center for American human spaceflight since June 1965. Perhaps the most visible aspect of human spaceflight, the MCC is the familiar scene on television of flight controllers monitoring all aspects of a mission on their consoles, with large screens displaying the location of the spacecraft on a world map. Following the establishment of the Manned Spacecraft Center (MSC), now NASA's Johnson Space Center (JSC), in 1961, and construction of the new facility, the mission control function shifted from Cape Kennedy in Florida to Houston. The concepts of mission control developed in the early years of the space program are still in use today, even as human missions have grown more complex and now include international and commercial partners. Starting with missions lasting only a few hours or a few days, monitoring is an ongoing round-the-clock activity. Over the decades, upgrades to the MCC have enabled it to keep up with the demands of the ever-growing complexity of America's human spaceflight programs [10].

Houston Mission Control Center at Johnson Space Center (image credit: NASA)

2.2.2 Deep Space Network Tracking Stations and Deep Space Operations Center

Artemis II is slated to use DSN for ground tracking during its deep space operations. DSN provides a number of functions such as command, telemetry and tracking to its mission customers. These functions utilize DSN tracking stations at complexes around the world, working in concert with DSN's central operations center (DSOC) at NASA's Jet Propulsion Laboratory in Pasadena, California, to process and distribute data. Once the data are processed at the complexes, they are transmitted to DSOC for further processing and distribution to science teams over a ground communications network.

2.2.3 Supplemental Ground Stations for Navigation Support

During the Artemis I mission, data from the DSN tracking stations were supplemented with additional tracking data from other stations, including JAXA-provided ground assets at Uchinoura and Usuda. These were used to provide additional tracking data to the Artemis I navigation team. This approach can be used on the Artemis II mission as well.

2.2.4 Orion Artemis II Optical Communications System (O2O)

Artemis II is slated to include an experimental optical communication payload which will utilize its own ground assets during the mission [11]. The operational concept for the ground segment is described in [12]. Optical communications are expected to provide data rates as much as a hundred times higher than current systems.

2.3 Mission Operational Concept

Artemis II will launch from NASA's Kennedy Space Center in Florida, sending four astronauts on a flyby of the Moon in the first crewed Orion vehicle. The mission, expected to last just over 10 days, is using the Block 1 variant of the SLS. The mission profile includes multiple departure burns to raise the spacecraft's orbit around Earth, eventually placing the crew on a lunar free return trajectory which will use Earth's gravity to naturally pull Orion back to Earth after flying by the Moon. While the Orion spacecraft is in high Earth orbit, the crew will perform various checkouts of the spacecraft's life support systems as well as an in-space rendezvous and proximity operations demonstration using the spent Interim Cryogenic Propulsion Stage (ICPS) as a target. When Orion reaches perigee once again, it will fire its main engine to complete the TLI maneuver which will send it to a lunar free return trajectory, before returning to Earth [13].

The diagram below provides a graphical map and timeline of the Artemis II mission.

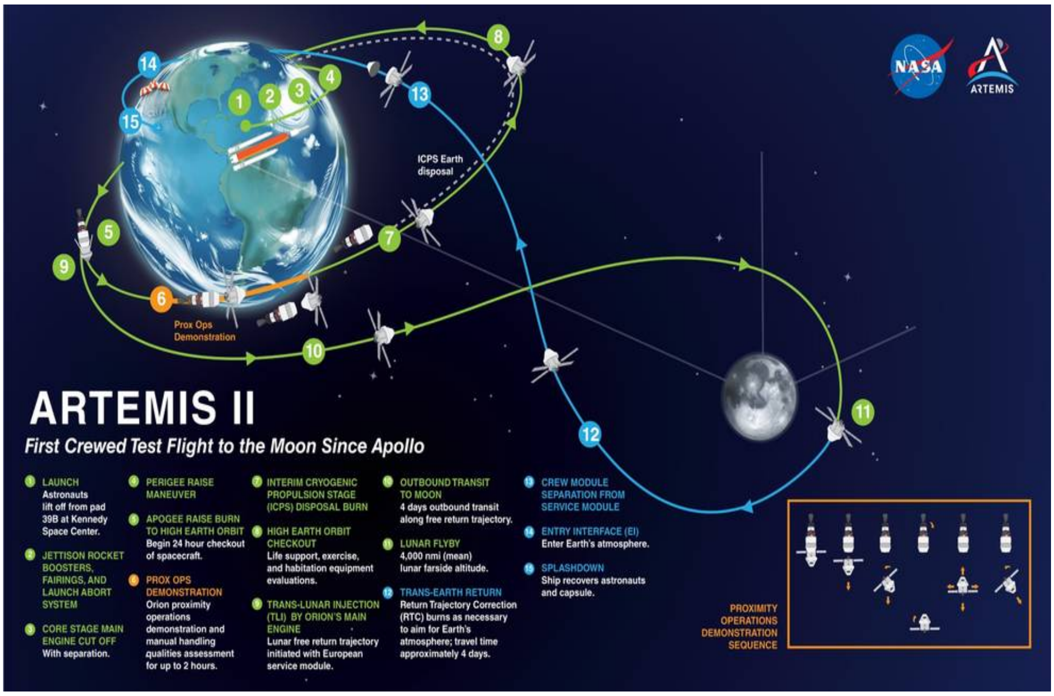


Figure 5: Artemis II Mission Map [image credit: NASA]

3. Changes from Artemis I to Artemis II

The following sections describe differences that are planned between the Artemis I and Artemis II missions, including both flight and ground aspects.

3.1 Changes to the Flight System

For Orion crewed missions (Artemis II+), Orion is adding several new communication capabilities to mitigate failure scenarios, support astronauts, and improve NASA's ability to disseminate information to the public. These will be utilized by crew (new audio subsystem, crew interfaces, and environmental systems) and crew devices (new crew tablets, H.265 encoder, handheld video camera).

(1) Emergency Comm subsystem: Orion is adding a completely dissimilar radio system that can be used without knowledge of Navigation state, time, or communication target, as well as during failures when spacecraft power and thermal cannot support the primary communication system. EC only supports two-way voice communications and two-way radiometrics, not spacecraft commanding nor telemetry. EC is also compatible with both TDRSS and DSN by using existing modulations and coding supported by both networks.

(2) Faster DSN uplink: By utilizing an unused TDRSS mode in the Orion transponder that is compatible with DSN, the DSN uplink data rate can be increased by 4x when two-way ranging is not required. This allows for two-way video-conferencing between crew and MCC, as well as faster file uploads. Due to LDPC coding, this higher uplink rate even has better link margins than the nominal DSN-Orion uplink.

(3) Faster DSN and Early Ascent downlinks: Using a Docking/Proximity data rate in the transponder that is compatible with DSN, the DSN downlink data rate can be increased by 50% (and the early ascent downlink by 6x) when two-way ranging is not required. This allows for better video quality and faster file downlinks.

(4) Faster DSN uncoded downlink data rate: By turning off LDPC coding at the same data rate as (3), the downlink information rate can be increased by an additional 2.2x. This is not usable at lunar distance to a DSN 34m dish due to limited spacecraft transmit power, but it can be used when closer to Earth, or when a DSN 70m antenna is available.

(5) Optical Communications (optical comm) Payload: Will demonstrate optical communications between a human spacecraft and Earth, including maintaining laser pointing during crew movement, waste dumps, station keeping thruster firings, etc. While the optical comm massively increases uplink and downlink data rates for video streaming and file downlinks, the commanding and telemetry of the Optical Comm Payload is via the Primary S-band subsystem.

3.2 Changes to the Ground Segment

3.2.1 Changes to Deep Space Network Services to be used by Artemis II

The primary DSN improvement that Artemis II will take advantage of is the addition of the capability to provide error correcting coding on the uplink data. The DSN has recently added the capability to perform CCSDS Low Density Parity Check (LDPC) and Reed-Solomon (RS) encoding, as defined in [14] and [15]. For Artemis I, the uplink data is sent uncoded. For Artemis II, the uplink to the main radio will be rate 1/2 LDPC encoded by the DSN exciter before it is transmitted to the spacecraft. Additionally, RS encoding will be provided to uplinks that are being transmitted to the Artemis II emergency radio.

Additionally, Artemis II will take advantage of the return data latency improvements that have been made to support the Gateway mission. The capability to support low latency (less than 10 seconds) for data rates up to 150 Mbps from a complex will be in place in the Artemis II time frame. Since the Artemis II data rate is significantly less than 150 Mbps (up 6 Mbps), Artemis II will see improvements in the data latency relative to Artemis I.

Finally, Artemis II will use the standard DSN monitor data delivery, providing the mission team with performance metrics of the uplink and downlink. The Artemis I mission did not subscribe to the DSN monitor data.

Note that DSN improvements for lunar support (known as the DSN Lunar Exploration Upgrade task, or DLEU) are being put into place in support of future lunar missions such as Gateway (e.g., K-band uplink and downlink, 150 Mbps). The Orion spacecraft used on Artemis missions is still S-band, with much lower data rates.

3.2.2 Changes in Other Ground Elements

As mentioned previously, Artemis II will include an optical communication demonstration payload which will bring laser communications to the Moon onboard as part of a Development Test Objective (DTO) during the mission. This payload will be supported by a ground segment which includes ground terminals at NASA's White Sands Complex (WSC) in New Mexico as well as NASA's Table Mountain Facility (TMF) in California.

Plans are also in-work to set up a backup control center (BCC) capability for the Orion spacecraft, to be utilized in case the primary mission control center (MCC) is rendered unusable during the Artemis II mission and beyond. This is a new capability and interface that requires implementation and testing prior to operational usage.

4. Pre-Launch Testing Campaign

DSN and Orion jointly designed a test campaign to ensure all the new Orion communications capabilities for Artemis II are compatible with DSN. This includes the following:

(1) Risk mitigation testing of EC radio at DSN's DTF-21 test facility
(2) Risk mitigation testing of new Primary S-band data rates and new EC subsystem at Orion test labs at Lockheed Martin's facility in Denver, using DSN's CTT-22 test van
(3) Multiple data flow tests between DSN and MCC
(4) Test-like-you-fly end-to-end data flow testing of new data types and sources through Primary S-band and EC using Orion test labs in Denver and DSN's CTT-22, to ensure that spacecraft, DSN, and MCC all generate, transport and process data correctly.
(5) RF Compatibility Testing at Kennedy Space Center (KSC) Neil Armstrong Operations & Checkout building with the Artemis II spacecraft using DSN's MIL-71 test facility. This will test Primary S-band and EC, and support Optical Comm installation and checkout.
(6) RF Checkout in NASA's Vehicle Assembly Building using DSN's MIL-71 test facility after the spacecraft is attached to the rocket

5. Other Preparations

In addition to utilizing DSN tracking stations, the Artemis I mission utilized additional ground stations to provide supplementary tracking data (three-way Doppler measurements) to aid in spacecraft navigation activities. Supplementary tracking data for the Orion spacecraft was collected at ground stations from the Japan Aerospace Exploration Agency (JAXA) and processed and delivered to the mission via DSN ground assets. Under guidance from an international agreement, JAXA provided tracking data to NASA for select tracking passes during the Artemis I mission, with DSN serving as a coordinator between the Artemis I mission and JAXA [16]. This capability may be used for Artemis II, and if so, similar preparations would be performed pre-launch.

6. Conclusion

DSN preparations for the upcoming Artemis II mission are well underway. Changes from Artemis I to Artemis II that impact existing DSN services have been identified. DSN upgrades to be utilized by Artemis II are in-place and ready for verification with the mission. A thorough pre-launch testing campaign has been laid out and will be executed over the upcoming months. In summary, the DSN is ready to complete its pre-launch activities in support of Artemis II, as NASA prepares to launch humans back to the Moon during this historic mission.

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