EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF SCIENCE AND TECHNOLOGY POLICY
WASHINGTON, D.C. 20502

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MEMORANDUM FOR DEPARTMENTS AND AGENCIES PARTICIPATING IN THE WHITE HOUSE CISLUNAR TECHNOLOGY STRATEGY INTERAGENCY WORKING GROUP

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SUBJECT: Policy on Standardization of Lunar Reference Systems in Support of the National Cislunar Science & Technology Strategy

This memorandum outlines the Biden-Harris Administration's policy on the establishment of reference systems at the Moon to advance the *National Cislunar Science & Technology Strategy*.[1] The Office of Science and Technology Policy (OSTP) advises federal departments and agencies to align their planning and policies with this memorandum.

The Moon represents the first step in human exploration of the solar system. This approach to reference systems at the Moon will serve as a template for other celestial bodies. Reference systems provide a definition by which position and direction can be expressed. Operations in Cislunar space[2] require multiple reference systems and transformations between each. This essential set of reference systems and transformations should be fully defined in international standards and include:

1. A body-fixed reference system centered at the Moon,
2. An inertial reference system centered at the Moon,
3. Transformations between the lunar body-fixed and inertial reference systems (i.e., orientation parameters and ephemerides), and
4. Traceability to Earth's body-fixed and inertial reference systems.

A shared understanding of reference systems at the Moon is essential for safe navigation, scientific discovery, and commercial activity, just as it is at Earth. Space situational awareness, for example, relies on the ability to unambiguously describe the positions of all crewed and uncrewed vehicles, regardless of operator. Scientific investigations may require spatial alignment of data from multiple instruments or the ability to clearly communicate a site of interest to astronauts.

Lunar navigation relies on a diverse array of measurements, including lunar surface landmarks, radio navigation signals, and the arrangement of stars. Without standard reference systems, uncertainties in the

[1] National Science and Technology Council, 2022, "National Cislunar Science and Technology Strategy," https://www.whitehouse.gov/wp-content/uploads/2022/11/11-2022-NSTC-National-Cislunar-ST-Strategy.pdf
[2] For the purposes of this document, Cislunar space is defined as the three-dimensional volume of space beyond Earth's geosynchronous orbit that is mainly under the gravitation influence of the Earth and/or the Moon. Cislunar space includes the Earth-Moon Lagrange point regions, trajectories utilizing those regions, and the Lunar surface.

spatial relationships of these measurement sources will degrade navigation accuracy. A standards-based approach to these systems at Earth enables the interoperability necessary for national and international transportation, commerce, and scientific discovery. U.S. leadership on reference systems will advance the same robust ecosystem at the Moon.

Now is the time for the U.S. to lead a coordinated approach to establishing reference systems at the Moon, while these and complementary foundational standards for Cislunar activities are being defined and infrastructure at the Moon is being built. Accordingly, under the leadership of NASA, and in coordination with relevant international organizations, federal agencies should collaborate to develop common reference systems for the Moon. In support of this objective, NASA should provide an implementation plan for the formal establishment of these lunar reference systems to the Executive Office of the President no later than December 31, 2026.

1. Background and Definitions

The decade ahead is critically important for exploration of Cislunar space, including the lunar surface. The U.S. government, other countries, and private entities are all planning to send spacecraft into and through Cislunar space in the coming years. Architectures deployed for Cislunar operations should be designed to anticipate the emergence of innovative activities with requirements that cannot be predicted at present. Architecture based on broadly adopted technical standards can be adapted to emerging needs through coordinated revision of the underlying standards.

In 2024, OSTP released the Policy on Celestial Time Standardization, asking federal agencies to work through existing standards bodies and establish Coordinated Lunar Time.[3] This lunar reference systems policy complements celestial time standardization, establishing an approach to defining and developing unified lunar reference systems to support interoperable and scalable infrastructure in Cislunar space.

A *reference system* is a theoretical system of coordinates and standards sufficient to define the position and motion of objects in space and time.[4] One important component of a reference system is the *reference frame*. A reference frame ties the reference system to real points, commonly referred to as *realization points.*

International standards already define many components of a lunar reference system, but to meet the demands of a growing lunar ecosystem, the system must be *unified*. A unified system has components that align with each other and operate within a shared physics framework. This unification results in positions that are unambiguous and consistent, irrespective of the techniques or technologies used to navigate within that system.

A unified, *body-fixed* reference system consists of interconnected geodesy components. A body-fixed lunar reference system defines the self-consistent set of physical constants, models, conventions, and

[3] Office of Science and Technology Policy, "Policy on Celestial Time Standardization in Support of the National Cislunar Science and Technology (S&T) Strategy," 2024, https://www.whitehouse.gov/wp-content/uploads/2024/04/Celestial-Time-Standardization-Policy.pdf
[4] International Astronautical Union (IAU) Division I Working Group, 2007, "Nomenclature for Fundamental Astronomy," https://syrte.obspm.fr/iauWGnfa/NFA_Glossary.html

coordinate system needed to unambiguously define the coordinates of a point on or near the surface of the Moon. A unified *inertial* reference system centered at the Moon, by contrast, relates coordinates on or near the Moon to a celestial reference frame, i.e., an inertial reference frame constructed using the positions of distant extragalactic objects, such as quasars. A Moon-centered inertial reference system's physical constants, models, conventions, and coordinate system unambiguously and consistently define the coordinates of a point in space relative to the Moon's gravitational center of mass.

Space-based operations require coordinate transformations between body-fixed and inertial reference systems. This is achieved using orientation parameters and ephemerides. Orientation parameters describe the variable rotation and pointing of a celestial body, and an ephemeris describes the body's position over time. Transit between the Earth and Moon relies on transformations from Earth-centered to Moon-centered reference systems. This full set of transformations must be consistent with the reference systems themselves in a manner that allows seamless transitions between Earth and lunar operations.

2. Policy Guidance

This Memorandum asks federal agencies to collaboratively define the essential elements of lunar reference systems through international coordination and to realize, maintain, and evolve these systems according to the following guidance.

a) Under the leadership of NASA, and in coordination with relevant international organizations, U.S. federal agencies should collaborate to define standards for a lunar body-fixed reference system and a lunar inertial reference system to enable Cislunar operations.

The definition of these lunar reference systems will build upon international standards and incorporate best practices from reference systems used on Earth and at the Moon for surface and orbital navigation. These systems will include a unified, body-fixed reference system for navigation on and relative to the lunar surface; and a unified, body-centered inertial reference system for the safe navigation of satellites in lunar orbit and those transitioning to or from Cislunar space. These reference systems and associated transformations should be consistent with one another in a manner that allows efficient transitions between Earth and lunar operations.

b) NASA should, in coordination with the National Science Foundation and the Departments of Commerce, Defense, Interior, State, and Transportation, identify an approach for implementing a realization of the standards codified in section 2(a) for a lunar body-fixed reference system, a lunar inertial reference system, and supporting transformations.

This implementation approach should include collaboration with the international community, including standards bodies, and should address the foundational elements of navigation and communications at the Moon, to include:

- Deriving and maintaining the lunar body-fixed and inertial reference systems and the transformations between those Moon-centered systems, including the necessary lunar orientation parameters and ephemerides.
- Identifying and establishing supporting transformations to ensure traceability of the lunar body-fixed and inertial reference systems to established reference systems. This will include reference systems necessary for navigation between Earth and Cislunar space: the Earth-centered body-fixed reference system, the International Terrestrial Reference System (as

realized in World Geodetic System 1984), and the Earth-centered inertial reference system, known as the Geocentric Celestial Reference System.

- Determining how updates to lunar reference systems and transformation data should be configuration managed, including thresholds for updates and how these can be provided to users.
- Standardizing lunar cartographic products for navigation and ensuring their interoperability with a unified body-fixed reference system.

The overall approach should be suitable for application throughout the solar system, thereby providing a framework for reference systems at other celestial bodies, such as Mars.

c) NASA should provide an implementation plan for the formal establishment of these Lunar reference systems to the Executive Office of the President no later than December 31, 2026.

3. Conclusion

Cislunar space opens a new domain of human activity with opportunities for scientific discovery, economic development, and international collaboration. Through a shared purpose and vision, the United States can achieve the goal of leading the responsible, peaceful, and sustainable exploration and utilization of Cislunar space. We are grateful to those across the Cislunar science and technology community who have contributed to date, and to those who continue to shape our collective understanding of this topic as we move forward.