A European Look at Artemis and its Lunar Gateway

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After the breathtaking "race to the Moon" in the 1960s, dominated by NASA's Apollo program, the Moon now once again is in focus of human space flight through NASA's *Artemis* program. NASA has named its new lunar program after Apollo's mythological twin sister. Artemis not only has the Moon as its goal, but also to develop the necessary skills and technologies to take humanity farther into the universe, future exploration missions to Mars and beyond are already conceptually anticipated.

A major challenge of the Artemis program is the integration of various highly complex program components, some of which are provided by NASA and by other participating space agencies as well as commercial companies.

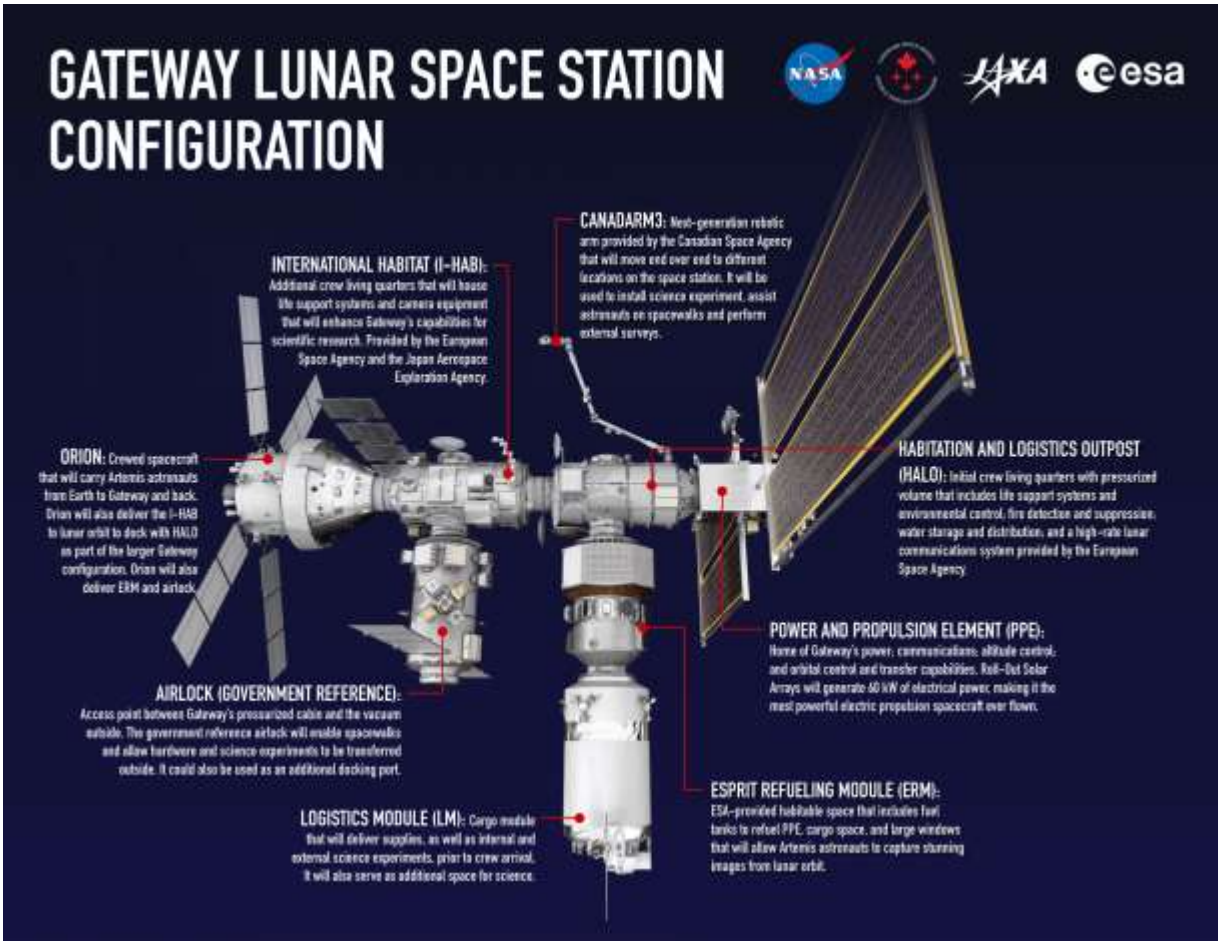

Fig. 1 Artist's conception of the Lunar Gateway Station with partner contributions (Image: NASA)

These components and their developers include:

- NASA's new Space Launch System (SLS) heavy-lift rocket.
- The *Orion* capsule including the *European Service Module* (ESM).

- The associated processing and integration facilities on the ground, the launch pads, including also the recovery logistics, referred to as Exploration Ground Systems.
- Deep Space Network and the relevant ground infrastructure to be upgraded accordingly.
- New spacesuits to allow extended extravehicular activities on the lunar surface.
- The *Human Landing System* (HLS) - Starship and Blue Moon by commercial providers (Space X and Blue Origin).
- The Artemis Base Camp is planned to be established near the south lunar pole.
- The *Lunar Gateway* space station (see Fig. 1).

The Lunar Gateway element is an important component that fundamentally distinguishes Artemis from Apollo. In this article, the focus will be on this temporarily crewed space station in lunar orbit.

As a space station, the Lunar Gateway has exactly the function that is already implied in its name, it represents an access route, primarily in a physical way to the lunar surface - but metaphorically, one can certainly also see the path into the future, towards Mars.

This approach gives rise to some conceptual implications: in the future there will not be a permanently crewed space station, but one that will be only temporarily inhabited by astronauts. Current plans envisage that the space station will be uncrewed for eleven months of the year and only crewed for around one month - precisely during phases when a mission to the lunar surface takes place. This requires a high degree of autonomy, as a fully staffed operations control team operating in permanent shifts can only be justified during crewed periods.

Scientific experiments will also not have the same importance as on the ISS - the preparation and follow-up of Moon sorties as well as station maintenance will take up a major part of the crew's time. The quality of the microgravity environment will not be comparable to that of the ISS, which is an exclusion criterion for experiments requiring undisturbed microgravity. Microgravity disturbances are caused on the one hand by the fact that the Gateway will be frequented by various visiting vehicles, at least during its crewed phases: Not only does the crew dock and undock with Orion within a short period of time, the crew that stays onboard must be supported by logistics transports and the excursions to the lunar surface requires the lander to be undocked and docked.

Long and frequent orbit correction maneuvers will also disrupt weightlessness: "Long duration maneuvers" are necessary because the space station is equipped with an electric propulsion system, and the corresponding orbit correction effect is not achieved by short, strong thrusts of the engines as with conventional chemical engines, but instead a "low thrust" must act over a correspondingly longer period of time.
On the other hand, the orbit corrections will be "frequent" because the selected orbit of the Gateway is not stable and must therefore be actively "maintained".
A special orbit type was chosen for the Gateway, which bears the somewhat unwieldy name "Near Rectilinear Halo Orbit" (NRHO) [1], which is very similar to a lunar polar orbit. At its farthest point from the Moon, the Gateway will be around 70,000 km away from the lunar south pole, while on the opposite side of its orbit the distance to the Moon is only 1,500 km. This orbit will ensure a long dwell time over the south pole of the Moon, with the duration of one orbit being around 6.5 days.
Hence, the Lunar Gateway offers long connection times with the excursion crew exploring the south pole of the Moon and better access to the preferred landing sites there.

The Gateway consists of several components provided by different partners. Like the ISS, the Gateway is an international project involving NASA and US companies as well as the European, the Canadian, the Japanese and this time also the United Arab Emirates Space Agencies.

Artemis Missions and additional Artemis Components

The Lunar Gateway station will be constructed in the course of the following Artemis missions with a couple of uncrewed missions in between.

Artemis I and Artemis II flights - the first, uncrewed test flight has already taken place at the end of 2022, the second flight is planned for late 2025 – and will be used for crewed verification of SLS and the Orion capsule. The Orion capsule is combined with a very significant European contribution, the *European Service Module* (ESM) [2].

The first crewed Moon landing in more than 50 years is planned as part of the Artemis III mission (see [5]). Here, the interaction with the new lunar lander that Space-X is developing, its *Starship* (see Fig. 2) will play a decisive role.
According to the current schedule, Artemis III will fly at the end of 2026 - until then, Space-X has to accomplish an ambitious development and test plan. Three test flights of the Space-X Starship have taken place so far, two times the flights ended prematurely. However, a longer in-flight time of the booster was achieved during the second flight test. During the third flight all 33 Raptor engines of the super heavy first stage ignited and second stage ignition was successful, a low earth orbit was achieved. However both, the re-usable super heavy stage and the reentry of the return vehicle were not successful, both were lost during reentry.
This shows clearly the progress in the development of the Starship. Nevertheless, the list of capabilities still to be demonstrated in the remaining 2-3 years is long: first flight, successful refueling in orbit, landing on the Moon and re-ascent are just a few of them.

Before the Artemis IV flight, an important uncrewed mission with a Space-X Falcon Heavy rocket is planned.
The mission is currently known as the Co-Manifested Vehicle (CMV) mission: The uncrewed *Power and Propulsion Element* (PPE) and the *Habitation and Logistics Outpost* (HALO) will use the PPE's electric propulsion to make their way to the Moon, which will take over a year (see also Fig. 1).

The PPE spacecraft, manufactured by the US company Maxar, is not pressurized and therefore uncrewed, but represents an important logistics component for Gateway station: The electrical energy for Gateway is generated via two solar arrays and the radio link to Earth is also established via this module. The gyros for the attitude control as well as the conventional chemical and electrical propulsion systems of Gateway are located on the PPE, too (see [4]). The fuels for both propulsion systems can be refilled via a refueling process using the ESA provided *ESPRIT Refueling Module* (ERM), see Fig. 1.

The PPE is connected to the *Habitation and Logistics Outpost* (HALO), second module from the right, see Fig.1. The Habitation and Logistics Outpost (HALO) is being manufactured by Northrop Grumman - in cooperation with European companies. In the future, astronauts will live and work in the HALO module during the crewed phase of the Gateway station, therefore a subsystem to provide, monitor and regenerate breathing air is integrated. The electrical energy received from PPE is temporarily stored in batteries and distributed to end users via a corresponding power distribution system. The waste heat generated is radiated into space via a two-stage circulation system using radiators attached to the outer walls. And most importantly, this module is also home to Gateway's central computer.

HALO has two lateral docking ports: On the starboard side is the docking port for the lunar module according to current planning. The ERM will be docked on the port side, see Fig. 1. In the forward direction, the path leads to the I-HAB, which will arrive with the Artemis IV flight.

Artemis IV will also see astronauts entering the Gateway for the very first time, starting the second crewed landing on the Moon after nearly 60 years, this time from the Gateway.
This historical flight is currently planned for 2028.

The *International Habitat module* (I-HAB) is the largest European contribution to the Gateway: like HALO, I-HAB is designed as a living and working module for the astronauts. Like HALO, I-HAB provides an independent air supply and monitoring systems, also has batteries and power distribution capacity, a cooling system with two circuits, but with radiators protruding from the side. I-HAB houses the crew's four sleeping cabins as well as other central "living elements" for the crew. I-HAB will also have three additional docking ports: On the port side is the airlock and the docking port facing forward is where the Orion spacecraft will dock. The starboard docking port could be used for future extensions, like a *Logistics Module* (LM). Key components of I-HAB's Environmental Control and Life Support System (ECLSS) will be provided by Japan.

The *ESPRIT Refueling Module* (ERM) will then be brought to the Gateway with Artemis V. This further European contribution, which was developed as part of the "European System Providing Refueling Infrastructure and Telecommunication" (ESPRIT) program, has the essential function of providing access to docked logistics modules and enabling refueling through them. In addition to these functionalities, ERM is also equipped with windows - otherwise the module's capabilities are rather sparse.

The United Arab Emirates recently joined the ranks of Gateway states. They are to provide the *Gateway's Airlock*, which is to be flown on one of the later Artemis missions.

The Canadians are - like for ISS - providing the important robotic component for the station: *Canadarm3*.

Operations Concept

Gateway's operating concept will be leaner and more integrated, but just as distributed as that of the ISS: Houston/Texas will play the central role. Here, the Artemis Flight Director will be located together with the experts for the main systems of the US elements. The team will be supplemented by a team in Huntsville/Alabama, which will again have a strong focus on the payloads.
The I-HAB and ERM will be operated from the *Human Exploration Control Center* (HECC) in close cooperation between ESA and DLR in Oberpfaffenhofen/Germany. The transformation of the existing Columbus Control Center (Col-CC) into the HECC is currently underway, combining Columbus operations and the operations of the European Gateway modules into one team. The major challenge will be the combination of the campaign mode of the Artemis/Gateway missions with the continuous Columbus/ISS mission in an effective setup in the upcoming years.
The scope of the HECC will be expanded to include all human exploration missions supported by Europe in the future. In addition, the HECC will be responsible for the European payloads and will provide the functionality of an engineering support center - not only for the European elements mentioned above, but also for the *HALO Lunar Communication System* (HLCS) [3], a communication terminal to expand the Gateway into a relay station between the lunar surface and Earth - another European contribution, albeit operated by NASA.

Due to increasing public interest in the renaissance of Moon’s exploration, ESA recently announced new, more catchy names for the main European contributions: ERM is renamed to *Lunar View*, HLCS is called *Lunar Link* and I-HAB is extended to *Lunar I-Hab*.

For all participants of the Artemis mission the next step for human exploration has already started, which offers an exciting outlook for human spaceflight in the next decades. The Human Exploration Control

Center (HECC) in Oberpfaffenhofen is prepared- based on the long-term Columbus operations experience - to support all missions to the Moon and beyond.

Fig 2: Artist's conception of the Starship HLS
The mission plan foresees to launch the Starship Human Launch System (HLS) into Earth orbit, where it will be refueled by multiple Starship tanker spacecraft before boosting itself into a lunar near-rectilinear halo orbit (NRHO). For Artemis III, it will rendezvous with a crewed Orion spacecraft that will be launched from Earth by a NASA Space Launch System (SLS) launcher. A crew of two astronauts will transfer from Orion to HLS, which will then descend to the lunar surface for a stay of approximately 7 days, including at least five EVAs. It will then return the crew to Orion in NRHO [6]. (Image Space-X).

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