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## Novel Mobile Gravity Off-loading System (MOGOS)

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### Abstract

Space Applications Services (Belgium) has developed a Novel Mobile Gravity Off-loading Technology which will be used by the European Space Agency (ESA) and the German Space Agency (DLR) to simulate lunar activity in reduced gravity. The system provides gravity off-loading to multiple crew, vehicles and equipment allowing each to freely move and interact without the usual constraints of crane-based solutions. The system, consisting of a ceiling rail structure and ceiling crawlers outfitted with gravity off-loading devices, allows physically close interactions and can accurately follow the natural movements of a person hanging/walking below the vehicle. The gravity off-loading device is a passive system based on a Constant Force Mechanism, providing simulated reduced gravity in the range of 0.1g to 1g, suitable for both Lunar and Martian gravities. Future technology developments aim to enable simulated micro-g environments as well.

The Novel Mobile Gravity Off-loading System (MOGOS) is available as Commercial-Off-The-Shelf (COTS) product with the option to tailor to specific customer needs. In view of the upcoming Artemis missions, and future Commercial Low Earth Orbit (LEO) Destination missions, this novel technology will allow Space Agencies, Research Institutes and Commercial Space Companies worldwide to perform astronaut training with multiple crew, test and train human-robot cooperation, and test equipment (Extravehicular Activity suits, rovers, etc.) in simulated reduced gravity conditions. This paper describes the MOGOS system and gives an insight in different use cases.

**Keywords:** gravity off-loading, astronaut EVA training, lunar rover tests

### Acronyms/Abbreviations

ARGOS = Active Response Gravity Offload System

AX3S = ARGOS 3 eXploration EVA Simulator

CFM = Constant Force Module

CSS = Commercial Space Stations

DLR = German Aerospace Center

DoF = Degree of Freedom

ESA = European Space Agency

EVA = Extravehicular Activity

HITL = Human-In-The-Loop

JSC = Johnson Space Center

MCC = Mission Control Center

MEDES = Institute for Space Medicine and Physiology

MOGOS = Mobile Gravity Off-loading System

NASA = National Aeronautics and Space Administration

## 1. Introduction

### 1.1 State-of-the-Art Gravity Off-loading Systems

The currently available 3DoF gravity off-loading devices are not so many: NASA's Active Response Gravity Offload System (ARGOS) [1], the Rysen [2] and Zero-G 3D [3]. Rysen and Zero-G 3D are developed as Body Weight Support systems for the medical world, they are available as medical equipment for (neuro-)locomotor rehabilitation centres. The main drawback of all of them is that they allow only a single person (or rover) to move omni-directional in a simulated reduced gravity environment. Furthermore, the working space of the above-mentioned devices is quite limited: around 72m<sup>2</sup> for ARGOS and around 45m<sup>2</sup> for the Rysen and the Zero-G 3D. To overcome the above-

mentioned drawbacks, Space Applications Services developed the Mobile Gravity Off-loading System (MOGOS) and NASA is in the process of building the ARGOS 3 eXploration EVA Simulator (AX3S), which will have a size of about 600 m<sup>2</sup>. AX3S will feature three bridge cranes allowing three subjects to be in the system simultaneously, but only two of them can come in close vicinity with each other, due to the kinematics of the bridge cranes [1].

### 1.2 Novel Mobile Gravity Off-loading System (MOGOS)

Space Applications Services (Belgium) has developed a Novel Mobile Gravity Off-loading System, called MOGOS. The system provides gravity off-loading to multiple crew, vehicles and equipment allowing each to freely move and interact without the usual constraints of crane-based solutions. The system, consisting of a ceiling rail structure and ceiling crawlers outfitted with gravity off-loading devices, allows physically close interactions and can accurately follow the natural movements of the person or object suspended below the vehicle. The first implementation of this novel technology is for the European Space Agency (ESA) and the German Space Agency (DLR) to train astronauts for lunar activities and test equipment in simulated reduced gravity in their brand-new LUNA lunar analogue facility at the DLR-site in Cologne, Germany [4]. However, MOGOS offers unique features making it a very attractive technology for myriad use cases.

Section 2 of this paper outlines the technical details of the different MOGOS components, while section 3 makes a deep dive in the different use cases. The conclusion, in section 4, wraps up the unique features of the Mobile Gravity Off-loading System and marks its importance in the current economic climate of commercial space and the foreseen boom of the LEO and Lunar economy, with Commercial Space Stations (CSS) and lunar surface operations.

## 2. MOGOS Components

### 2.1 High-level Overview

The MOGOS system comprises of a Ceiling Structure with T-profiles integrated with multiple CeiliX vehicles (ceiling crawlers), each equipped with a Constant Force Module (gravity off-loading unit), see Figure 1. Each CeiliX vehicle operates independently across the ceiling frame, featuring omnidirectional mobility to maximize the range of motion for individual payloads. The vehicles accurately track and respond to the natural movements of the persons/payloads beneath them. The Constant Force Module (CFM) employs an adjustable semi-passive mechanism based on a constant-force energy storage principle. This guarantees a high level of safety while providing a force output ranging from 0g to 1g. The system is engineered to be devoid of inherent inertia and with minimal internal friction, a crucial benefit that supports dynamic movements. A suspension cable ensures a secure connection between the off-loaded payload and its corresponding mechanism.

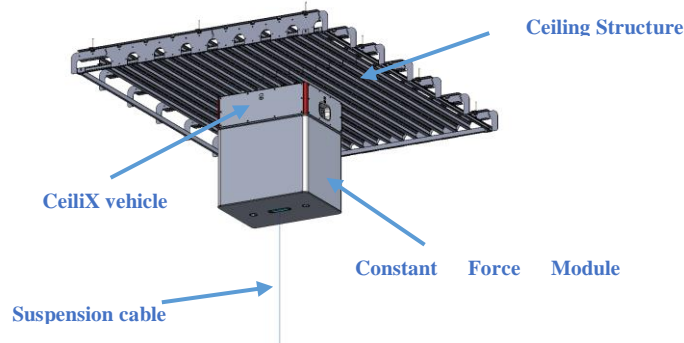


Figure 1: MOGOS high-level overview

### 2.2 Ceiling Structure

A specific ceiling structure supports the overhead locomotion of CeiliX vehicles. It is built based on sets of tiles. Each tile supports parallel aligned profiles that allow for mechanical interactions with the CeiliX locomotion system. The ceiling tiles can also feature an integrated power bus, to power the active CeiliX vehicles from the ceiling. This allows for ‘indefinite’ run times, compared to battery-powered CeiliX vehicles. The tile-based ceiling structure is by default a modular ceiling structure and fits to arbitrary building geometries, allows interconnecting separate work areas and getting around vertical obstacles such as pillars, pipes, or cable tracks (Figure 2). Furthermore, it enables the evolution of a test facility over the years, as the ceiling structure can be extended whenever there is the need (or the budget available) to move on to a bigger working surface area, i.e. a bigger ceiling structure. The ceiling structure can be provided on a Self-Standing Frame (limited to a maximum surface of 40m<sup>2</sup>) or as a Building Retro-fitted Structure (unlimited surface area).

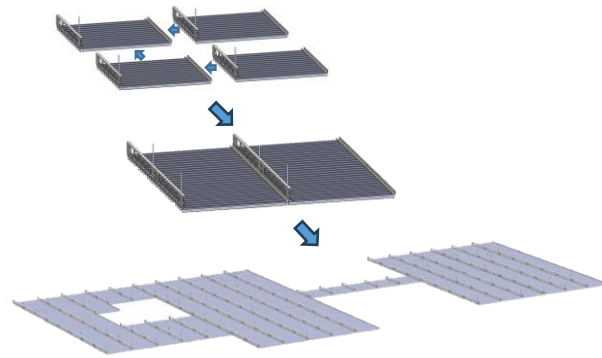


Figure 2: Modular and extendable Ceiling Structure, fitting arbitrary building geometries

### 2.2.1 Self-Standing Frame

For relatively small surface areas -up to maximum 40m<sup>2</sup>- MOGOS can be delivered and installed on a Self-Standing Frame, based on steel profiles and diagonal reinforcement beams, to provided structural stiffness (Figure 3, left). The frame needs to be anchored or bolted to the floor of the test facility. Maximum two CeiliX vehicles with integrated Constant Force Module can be operating simultaneously on a 40m<sup>2</sup> Self-Standing Frame, to keep the vibrations and eigenfrequencies under a certain threshold. The maximum frame measures 5m wide by 8m long, and 5m high.

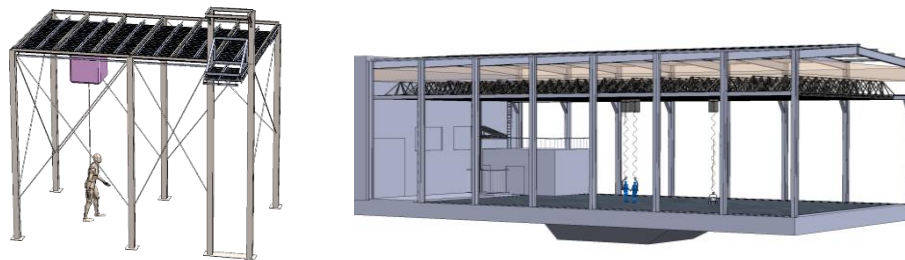


Figure 3: MOGOS on a Self-Standing Frame (Left), and MOGOS on a Building Retro-fitted Structure (right)

### 2.2.2 Building Retro-fitted Ceiling

One of the unique characteristics of the MOGOS system is that it allows to cover very big surface areas while allowing multiple users to freely move around simultaneously on that big ceiling structure, something which would be impossible with traditional bridge crane technology. For example, Space Applications Services will outfit the LUNA lunar analogue facility with 700m<sup>2</sup> of ceiling structure, as outlined in [4]. The attachment of the ceiling tiles to the original building ceiling is subcontracted to a local building/architecture company. This is the standard modus operandi for the Building Retro-fitted Structure (Figure 3, right). The ceiling and the vehicles are quite lightweight so the system can be installed onto an existing ceiling. For retrofitting only a lightweight truss structure is needed.

### 2.2.3 Vehicle Elevator

To allow easy maintenance of or adding vehicles, the ceiling structure can be equipped with a vehicle elevator (Figure 4). Vehicles can be driven to the elevator and lowered down for inspection and maintenance. Vice versa, new or spare vehicles can be 'loaded' on the elevator and easily placed on the ceiling structure, without the need of a mobile scissor lift platform or similar.

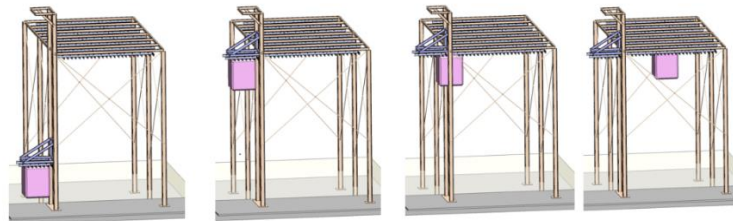


Figure 4: Vehicle elevator, allowing easy inspection and maintenance, or adding extra vehicles on the ceiling structure

### 2.3 CeiliX Vehicles

Bridge cranes allow reaching every point in their workspace. However, operations are highly constrained and do not allow for any vertical interruption (like a pillar). Also, the number and mobility of parallel-operating cranes are highly constrained by their kinematics. In contrast, overhead conveyors allow multiple transport units to operate close to each other. However, conveyors follow a predefined track and thus are also limited in mobility. The CeiliX vehicles combine all benefits of traditional overhead operation systems while minimizing constraints on motion and workspace.

CeiliX’ locomotion system uses a caterpillar-like mechanism that is modified to mechanically attach under a dedicated ceiling structure (section 2.2). This novel and patented locomotion technology enables a vehicle to traverse the ceiling structure in all directions (omnidirectional) and hence reach every point in the workspace. The locomotion system uses a form-fit connection to interact with the ceiling structure, i.e. at any point in time the same amount of ‘legs’ are grappling the ceiling structure. By design, this connection allows for high load capacity combined with a great level of safety. CeiliX vehicles exist in passive and active versions. The active one relies on omni-wheels to enable side motion, which combined with the track motion, allows for omnidirectional motions. Active CeiliX vehicles can be battery-powered or draw power directly from power lines embedded in the ceiling structure (Figure 5).



Figure 5: Small-size CeiliX vehicle, battery powered (left), and Medium-size CeiliX vehicle, ceiling powered (right)

By scaling up the CeiliX vehicle and the number of ‘legs’ of the locomotion system or by sharing the load between multiple vehicles, a higher load capacity can be reached. The current family of CeiliX vehicles consists of a passive small vehicle and an active small, medium and large vehicle. Table 1 provides the technical specifications of each vehicle. If certain use cases require higher load capacities either multiple vehicles can perform combined operations (to offer double or triple load capacity) or Space Applications Services can work on a customised design to reach a higher load capacity.

Table 1: CeiliX vehicles' technical specifications

	<b>S</b>	<b>M</b>	<b>L</b>	<b>Passive</b>
<b>Vehicle Dimensions LxWxH</b>	58x40x22 cm 23x16x9 in	75x79x25 cm 30x31x10 in	80x85x35 cm 32x34x14 in	70x75x20 cm 28x30x8 in
<b>Vehicle Weight</b>	25 kg 55 lbs	40 kg 88 lbs	60 kg 132 lbs	30 kg 66 lbs
<b>Load Capacity</b>	100 kg / 220 lbs	250 kg / 551 lbs	400 kg / 880 lbs	250 kg / 551 lbs
<b>Velocity (single axis)</b>	2.5 m/s / 8,2 ft/s			n/a
<b>Ceiling Peak Power</b>	Battery powered	2.5 kW	5 kW	n/a
<b>Human Rated</b>	No	Yes	yes	yes
<b>Positioning Sensor</b>	Odometry, Ultrasonic Ranging Sensors			n/a
<b>Connectivity</b>	5GHz mesh network			n/a

The vehicle's motion control system closely follows the movement of their payload below (person or rover) without relying on external control or pre-planned paths. Instead, the vehicle takes input from its on-board Rope Tracking Unit to adjust its position in real-time, ensuring smooth, unrestricted movement. The vehicle includes additional safety mechanisms to detect the ceiling's boundaries and avoid contacts with the other vehicles. In the event of an emergency or malfunction, the system automatically switches to a safe state to prevent any harm to the astronaut

or equipment. The vehicles do not need complex control loops to the main control center for directly always tracking and positioning themselves above their payload. This means that the motion of the CeiliX vehicles is completely transparent to the payload below. For example, a rover is doing tests and missions while the CeiliX vehicle is directly following it. There is no need for pre-synchronization nor pre-planning of the motions. In addition, each CeiliX vehicle is also equipped with an indoor absolute positioning system and direct communication to the main control center to allow the implementation of additional safety and commands protocols when multiple vehicles are moving on the same ceiling. The main control center receives complete telemetry from each of the CeiliX vehicles (hence e.g. rovers and their trajectory, speeds, etc.). Through a specific configuration of the main control center, you can define exclusions zones or send direct motion commands to individual vehicles (e.g. to go to the parking position or the vehicle elevator at the end of a test day).

#### 2.4 Constant Force Modules (CFM)

The Constant Force Module (CFM) is a semi-passive actuation system developed by Space Applications Services. This independent module generates an adjustable constant force output, which can be utilized for simulating or counteracting Earth's gravity force. The actuation kinematics of the CFM relies on a passive spring-based mechanism, effectively harnessing the potential energy exerted by the user, thereby eliminating the need for an external power supply. The Constant Force Module is composed of two segments: a "Battery", which utilizes tension springs to store potential energy, and a "Converter", which transforms the linear force exerted by the spring into a constant output force (Figure 6). A steel cable then transfers the output constant force to the designated application point. The internal mechanism used to generate the constant force, operates independently of the Earth gravity influence. Consequently, this system can operate effectively both on ground (at 1g) and in a microgravity environment (at 0g). The system is designed to be free of inherent inertia and with minimal internal friction, leveraging small moving internal components operating at low internal velocities. This characteristic is particularly advantageous for high-speed motion, such as during dynamic jumping. Depending on the selected unit, a hand lever or an integrated motor will drive the internal adjustment mechanism, permitting continuous modulation of the generated constant force from nearly zero force to its maximum value. Electrical power is only required when a change in the constant force output is requested.

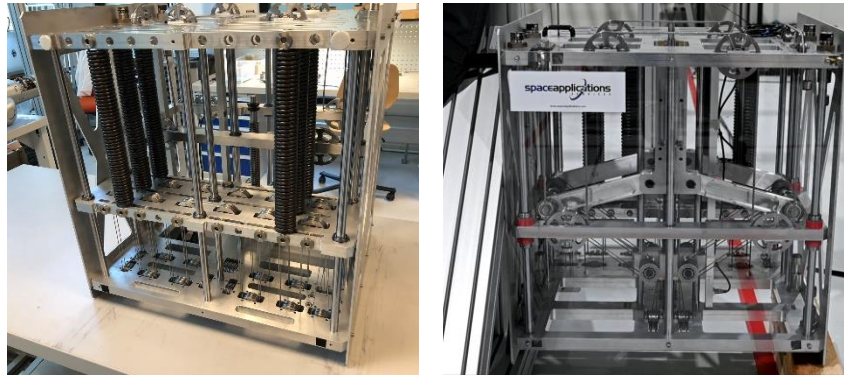


Figure 6: Constant Force Module, consisting of a 'battery' of springs (left), a mechanical 'converter' (right), and a steel cable

The current family of Constant Force Modules (CFM) consists of a small, medium and large module. Table 2 provides the technical specifications of each module. If certain use cases require higher off-loading capacities, Space Applications Services can work on a customised design. The large CFM has a range of 2 meters where the gravity off-loading is provided in a passive way and can be combined with an active winch allowing for further extension of the cable stroke up to 8m. For example, a rover can drive up a slope 2m high, all the time being in simulated lunar gravity, without having to use the active winch. As soon as the rover reaches a point 2 meters higher than the starting point, the range of the large CFM is fully utilized. The active hoist can be used now to adjust the whole CFM system to the 'new reference' which is 2 meters higher. From that moment on, the CFM provides again a 2m range for passive off-loading. The control of the active winch can be done remotely via the main control center or via a remote control.

Table 2: Constant Force Modules' technical specifications

	<b>S</b>	<b>M</b>	<b>L</b>
<b>CFM Dimensions LxWxH</b>	65x30x35 cm 26x12x14 in	70x52x62 cm 28x20x25 in	85x65x55 cm 34x26x22 in
<b>CFM Weight</b>	40 kg / 88 lbs	110 kg / 243 lbs	140 kg / 309 lbs
<b>Off-Loading Capacity</b>	1 – 100 kg 2 – 220 lbs	4 – 150 kg 9 – 330 lbs	5 – 250 kg 11 – 550 lbs
<b>Max Stroke Passive CFM</b>	1.0 m / 3,3 ft	2.0 m / 6,6 ft	2.0 m / 6,6 ft
<b>Max Stroke Active winch</b>	No	No	Yes (8m – 26 ft)
<b>Human Rated</b>	Yes	Yes	Yes

The Constant Force Modules in the Mobile Gravity Off-loading System (MOGOS) are integrated with the CeiliX vehicles and form as such a 3DoF gravity off-loading system, however the CFM is also available as a stand-alone 1 DoF gravity off-loading device (e.g. to be attached to an existing crane or to a static structure), or a 2DoF jump test rig with CFM and passive trolley (Figure 7), allowing linear movement in simulated reduced gravity conditions. Depending on the use case, one of the above options might be more suitable than the other.

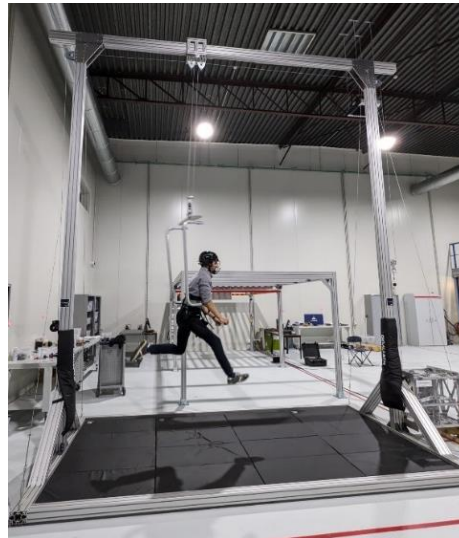


Figure 7: 2DoF jump test rig with CFM and passive trolley

### 3. MOGOS Use Cases

#### 3.1 MOGOS' Unique Selling Points

The MOGOS overhead operation technology enables unprecedented scalability as the system allows for extending the ceiling structure as deemed required, as well as adapting the number and type of vehicles deployed depending on actual needs. Multi-vehicle applications, heterogenic vehicle usage (small, medium and large vehicles can function simultaneously on the same ceiling structure), and cooperative vehicle operations to reach a higher load and off-loading capacity, are some key features of MOGOS.

The MOGOS gravity off-loading component - the Constant Force Module (CFM) - is a purely mechanical, passive system. This inherent safe system makes the verification, validation, and safety protocols to conduct training and test campaigns with MOGOS much easier, compared to active gravity off-loading systems.

Space Applications Services offers the MOGOS technology to the market as a COTS product, which can be customised for specific needs. Having an own MOGOS system in-house can be a big advantage for Space Agencies, research institutes, or commercial space companies. It allows to do more frequent (and earlier stage) testing, without having the logistic burden to book an existing gravity off-loading facility and transport all equipment and test personnel back and forth to that external test facility.

### 3.2 Astronaut Training and ConOps Tests

MOGOS is a very suitable system to train astronauts for future lunar surface activities, whether it is installing scientific experiments, building lunar surface infrastructure, working together with a lunar rover/robot, or practicing emergency drills rescuing an incapacitated crew member. MOGOS offers the unprecedented capability of having three (or more) astronauts working together in close vicinity in simulated reduced gravity conditions, with in addition the possibility to have also payloads or other materials the astronauts are handling off-loaded in the same reduced gravity conditions. The ARGOS 3 eXploration EVA Simulator (AX3S), currently under development at NASA Johnson Space Center (JSC), will have the capability of training three astronauts in parallel in simulated reduced gravity conditions, but because the overhead transportation is based on bridge cranes, only two astronauts will be able to work closely together, and they will not be able to cross each other’s path [1].

ESA will train astronauts for future Moon exploration missions in the LUNA lunar analogue facility, a 700m<sup>2</sup> regolith-filled lunar surface analogue area outfitted with a MOGOS system [4]. Providing astronaut training in a standard lab environment (without all the difficulties with the dusty regolith simulant), making use of VR/XR technology and potentially arm exo-skeletons under simulated reduced gravity conditions is another promising training use case [5, 6].

Besides fulfilling the astronaut training needs, MOGOS can also be used in earlier stages of payload or equipment design to perform Concept of Operations (ConOps) tests in a simulated reduced gravity environment. ConOps tests for any astronaut-robot interaction in simulated reduced gravity conditions can also be very valuable prior to fixing the robot design.

### 3.3 Scientific Research

#### 3.3.1 Locomotion Studies

Exposure to prolonged periods in microgravity is associated with deconditioning of the musculoskeletal system due to chronic changes in mechanical stimulation. Given astronauts will operate on the lunar surface for extended periods of time, it is critical to quantify both external (e.g., ground reaction forces) and internal (e.g., joint reaction forces) loads of relevant movements performed during lunar missions. Such knowledge is key to predict musculoskeletal deconditioning and determine appropriate exercise countermeasures associated with extended exposure to hypogravity [7, 8]. The "Movement in low gravity environments" (MoLo) programme simulates lunar gravity on Earth to investigate how human bodies adapt. The programme had several phases, starting with a refurbished ventilation shaft in ESA’s ground based facility “Locomotion On Other Planets” in Milan, Italy. A 17-metres pole was fitted with a bungee rope, allowing a person to do vertical jumps as high as six metres in simulated lunar gravity, and for the team to investigate the movement and its biomechanics. The second stage involves a parabolic flight, a special flight manoeuvre that simulates lunar and Mars-like gravity, allowing the team to study the effects of hypogravity on human balance [9]. A 2DoF jump test rig with CFM and a 3DoF full MOGOS system enable scientific research programmes like MoLo to advance their scientific research.

#### 3.3.2 Reduced Gravity Bedrest Studies

ESA regularly organises bedrest studies of varying lengths, with both men and women. Conducted in cooperation with the German Aerospace Center’s “:envihab” facility in Cologne, the French centre at MEDES in Toulouse, or the Planica Planetary Habitat Simulation Facility (PlanHab centre) near Kranjska Gora, Slovenia, they find ways of counteracting symptoms of spaceflight such as bone loss and changes in blood flow. Common practice with bedrest studies is that during prolonged periods of bedrest, patients – or better ‘test subjects’ – are not permitted to stand up unless a research programme demands it and must perform all daily activities in bed, including eating, showers and exercise. Micro-gravity bedrest studies involve lying in bed at an inclination of +6°, whereas e.g. lunar bedrest studies demand an inclination of +10° or +11°, an inclination which makes it quite difficult to perform relevant exercises while staying in bed, according to scientists. To overcome this hurdle, a rather small passive 3 DoF MOGOS system could be used to intermittently take the test subjects out of the bed and let them perform exercise sessions on an ergometer or treadmill, while staying all the time in simulated lunar gravity conditions. MOGOS offers for this use case a truly unique and innovative solution, opening-up new possibilities for reduced gravity bedrest studies!

### 3.4 Rover/robot Tests

In this era of commercial spaceflight, several companies worldwide are developing lunar or Martian rovers. A MOGOS system combined with an analogue terrain testbed, allows to drive and test rovers in simulated reduced gravity conditions. A 3DoF full MOGOS system enables the rover/robot testing use case.

The versatility of MOGOS and its individual components becomes evident in two related use cases:

- Rover tests on an analogue terrain with mobile obstacles: besides the MOGOS vehicle providing the gravity off-loading for the rover, a second (or more) CeiliX vehicle could be used to move specific obstacles (such as rocks) to desired 3D positions and along a defined trajectory. Those extra CeiliX vehicles do not need to be equipped with a CFM but can just feature a standard hoist system. The MOGOS MCC allows you to pre-programme the trajectory and desired 3D positions.
- Companies or research institutes who are developing walking robots can use MOGOS or the CeiliX vehicle without a CFM to accurately track and follow their robot and in addition provide specific fall prevention or fall protection.

### 3.5 *Spacesuit Tests*

In this era of commercial spaceflight, several companies worldwide are working on their own design of astronaut spacesuits. To properly test and iterate on the new suit designs, a suited human should perform activities in simulated reduced gravity conditions [10]. MOGOS continuously offloads a portion of a suited human's weight during all dynamic movements, which can include basic functional movements such as walking, running, and jumping, as well as a wide range of planetary surface activities. This system could be used as part of a metabolic-rate task characterization study to determine the workload associated with partial-gravity extravehicular activity (EVA). A 1DoF CFM placed above a treadmill, a 2DoF jump test rig with CFM and a 3DoF full MOGOS system enable this kind of spacesuit testing.

### 3.6 *Human-In-The-Loop (HITL) Tests*

In this era of commercial spaceflight, several companies worldwide are designing and building big lunar equipment (such as lunar terrain vehicles, lunar landers, and lunar habitats). With static high-fidelity mock-ups of the lunar equipment and astronauts suited up in a spacesuit and exposed to simulated lunar gravity conditions, Human-In-The-Loop (HITL) tests can be performed and are invaluable as crewmembers provide critical feedback on the lunar equipment's design functionality, evaluate display interfaces and controls, and help identify potential safety concerns or design issues [11]. A 3DoF MOGOS system allows HITL Tests with multiple astronauts simultaneously interacting with the same equipment.

### 3.7 *Robotic Arms and Large Deployable Structures Tests*

Robotic arms for space stations or rovers and large deployable structures like solar arrays, communication antennas, or deployable boom structures in general, are designed to be as lightweight as possible, keeping in mind the reduced gravity or microgravity environment they will have to operate in. This poses the engineering challenge how to best test those mechanical structures on Earth. A 3DoF MOGOS system can provide on Earth the simulated reduced gravity environment allowing those (segmented) robotic arm tests or deployable structures tests to take place.

## 4. **Conclusions**

The Mobile Gravity off-loading System (MOGOS) is an innovative system that provides gravity off-loading to multiple crew, vehicles and equipment allowing each to freely move and interact without the usual constraints of crane-based solutions. The MOGOS overhead operation technology enables unprecedented scalability as the system allows for extending the ceiling structure as deemed required, as well as adapting the number and type of vehicles deployed depending on actual needs. Multi-vehicle applications, heterogenic vehicle usage (small, medium and large vehicles can function simultaneously on the same ceiling structure), and cooperative vehicle operations to reach a higher load and off-loading capacity, are some of the unique features of MOGOS. The MOGOS gravity off-loading component - the Constant Force Module (CFM) - is a purely mechanical, passive system. This inherent safe system makes the verification, validation, and safety protocols to conduct training and test campaigns with MOGOS much easier, compared to active gravity off-loading systems.

Space Applications Services offers the MOGOS technology to the market as a Commercial-Off-The-Shelf (COTS) product, which can be customised for specific needs. Having an own MOGOS system in-house can be a big advantage for Space Agencies, research institutes, or commercial space companies. It allows to do more frequent (and earlier stage) testing, without having the logistic burden to book an existing gravity off-loading facility and transport all equipment and test personnel back and forth to that external test facility. In the current economic climate of commercial space and the foreseen boom of Commercial Space Stations (CSS) and lunar surface operations - both for the manned Artemis programme and for the unmanned commercial lunar rover programmes -, a drastically increased amount of gravity off-loading testing can be envisaged. Multiple (commercial) test facilities are expected to be

established in the years to come, complementing the capacity of the ARGOS, AX3S, LUNA, and other test facilities. MOGOS can support a variety of use cases in simulated reduced gravity conditions, like astronaut training and ConOps tests, scientific research (locomotion studies and reduced gravity bedrest studies), rover/robot tests, spacesuit testing, Human-In-The-Loop tests, or robotic arms and large deployable structure tests.

### Acknowledgements

The MOGOS product line is developed by the Robotics, Mechanism and Structure (RMS) team of Space Applications Services NV/SA.

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