AGOS - Artificial Gravity Orbital Station,
a possible successor of the ISS International Space Station

Werner Grandl*, Clemens Böck**

* *architect and civil engineer, Tulln, Austria,* archigran@gmx.at
** *mechanical engineer, Tulln, Austria,* boeck.clemens@gmail.com

ABSTRACT

The International Space Station ISS will probably be decommissioned in the mid-2020ies. This paper presents a design for a modular orbital station as a possible successor of ISS. The central rotating part of the station simulates artificial gravity (AG) by centrifugal forces. AGOS is built of cylindrical modules and structural framework. The design proposes light-weight constructions using thin aluminum sheets and trapezoid aluminum sheeting. The station can be enlarged in stages, the initial stage 1 has a mass of approx. 270 tons. 24 crew members can live and work in a 0.9 G environment. To establish the initial stage 15 launches to Low Earth Orbit (LEO) with payloads of 12-22 tons will be necessary. For launching we propose esp. the reusable SPACE-X Falcon launcher to minimize costs.

Keywords: Space station, Orbital station, Artificial gravity, Reusable launcher

Contents

1. Introduction

Living and working in space is usually associated with lack of gravity. During the last decades astronauts have stayed in zero-gravity-stations like Skylab, the Russian MIR and the present ISS. On the one hand zero-gravity is an advantage for scientific research, on the other hand weightlessness causes some danger for human health, such as bone demineralization, muscle atrophy and orthostatic intolerance [1]. Expecting the decommissioning of ISS in the 2020ies, there are few ideas for a new orbital station. This paper presents a possible successor for ISS, which could provide both zero-gravity modules and rotating living quarter modules with 0.9 G artificial gravity (AG).

First of all we give a compact overview of international post- ISS plans. Then we discuss the advantage of AG for future space missions. We describe various current and future launchers to lift heavy payloads into Low Earth Orbit (LEO). We give a detailed description of our AGOS design including possible enlargements. We present a technical solution for the joints between rotating and non-rotating parts of the station. Last not least we propose a time frame to plan, produce and erect AGOS, emphasizing international cooperation.

2. Post- ISS plans [2]

Due to restrictive space budgets all over the world space agencies carefully weigh up the merits of a project against its drawbacks. NASA and ESA focus a circumlunar station at a Lagrange point or in Lunar orbit. Europeans prefer lunar exploration with robots whilst the main target for NASA seems to be Mars exploration. Russia´s plans have not been officially announced yet but may provide a LEO platform [3]. China is currently developing its own orbital space station probably functioning by 2022 [4]. The German Aerospace Center (DLR) proposes the so called Modular Orbital-Hub, which combines hard-shell cylinders and nodes with inflatable structures, e.g. made by Bigelow Aerospace [5]. The Orbital-Hub may be a cost-effective design which combines public and private enterprise. But there is no actually published concept for an orbital station which provides AG to astronauts.

3. Artificial gravity (AG)

3.1. Former designs

Early concepts of rotating space stations have been made in the 1920ies [6]. In 1926 K. Tsiolkovsky first discussed the establishment of rotating colonies around the Earth. In 1928 H. Potocnic (pen name: Hermann Noordung) published drawings of a wheel-shaped orbital station, called "Weltraumrad", which became a prototype design for many succeeding toroidal concepts [7]. In the early 1950ies W. von Braun proposed a pneumatic torus, which was the first concept to use inflatable structures in orbit. In 1968 the famous movie *2001 – a Space Odyssey* showed a wheel-shaped space station to the public. During the 1960ies several NASA designs with rotating elements were based on the cylindrical payloads of the Saturn V launcher, but were canceled in the 1970ies when the US space budget was cut.

Meanwhile some ambitious designs for advanced space colonies with AG emerged from academia. The *Stanford Torus* of 1975 was a toroidal habitat largely made of lunar material. It should have a diameter of 1.6 kilometers and was considered to have a population of 10,000 people [8]. The most amazing designs for future space colonies were made by G.K. O´Neill, Space Studies Institute, Princeton, in 1975. Giant rotating cylinders entirely made of extra-terrestrial material, the biggest one 36 kilometers long and 6.5 kilometers in diameter, with a population of several hundred thousand inhabitants should be located in the Lagrange points L4 and L5 [9]. Inspired by O´Neill´s ideas A. Germano and W. Grandl published a detailed design of big space colonies in 1993, considering feasibility and safety and emphasizing structural engineering [6,10]. Maybe some of these utopian concepts will be realized in the 22nd century or later.

3.2. The comfort box

It is evident, that the simulation of gravity by the use of centrifugal forces will provide a more comfortable habitat for humans in space than a zero-gravity environment. The bigger the radius the better the conditions. At large radii and low rotation rates the Coriolis acceleration, which may disturb the vestibular sense, can be neglected. In 1987 NASA engineer J. von Puttkamer published the so called "comfort box" (Fig.1), which indicates acceptable living conditions in a rotating space station [11].

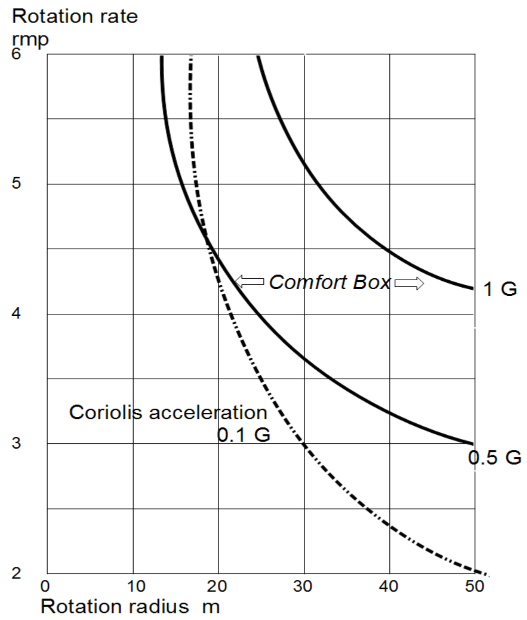

Fig.1 Comfort box defined by rotation rate and radius of a space station

According to Fig.1 a rotating space station should have a minimum radius of 30 meters. Shorter radius centrifugation generates AG levels that are different throughout the body; i.e., smaller at the head and larger at the feet. Also, inside a rotating vehicle, the AG level is constantly being distorted as the astronauts move about within the space station, except when they move along an axis that is parallel to the axis of rotation [12]. To simulate an AG of 0.9 G we may choose 40 m radius and a rotation rate of 4.2 rpm.

A future challenge for space architects and engineers should be the design of space habitats and interplanetary spaceships with a rotating device to provide an AG of 1 G.

4. Current and future launchers

There are just a few launch vehicles either now available or planned to be put into commission until 2030 with payload capacities we need to erect AGOS. To build a modular orbital station in LEO we assume typical payloads between 12 and 22 tons. Several providers in the USA, Europe and Russia could offer launching vehicles for this purpose (Table 1):

Table 1
Launch vehicles with payloads 15-70 tons to LEO (approx. 450-500 km altitude)

Provider	Launch vehicle	Payload to LEO (tons)	Availability
Roscosmos	Proton M	21	2001
ULA United Launch Alliance	Delta IV Heavy	23	2004
ESA European Space Agency	Ariane 5ES	20.25	2008
ILS International Launch Services	Angara	24	2014
SpaceX	Falcon 9 Full Thrust	22.8	2015
SpaceX	Falcon Heavy	54.4	2017 ?
Reaction Engines Ltd.	Skylon (HOTOL)	15	2022 ?
NASA	SLS Block 1	70	2022 ?

The SpaceX Falcon rockets have a fully reusable first stage. Thus payload costs to LEO may be reduced to $ 2700 per kg [13]. The Skylon vehicle is a HOTOL(Horizontal Take Off and Landing) spaceplane. It is propulsed by a SABRE engine (Synergistic Air Breathing Rocket Engine). At Mach 5.5 and 25 kilometers altitude the engine transitions to its rocket engine mode, using liquid oxygen stored on board. Sklyon is designed to achieve 200 flights to LEO and to reduce costs to approx. € 800 per kg [14]. The payload bay is just 4.6 m in diameter and 12.3 m long, so the size of modular payloads is limited.

5. The AGOS design

5.1. The initial stage

The fairing for payloads on top of launching vehicles is usually cylindrical or conical. A manned spaceship or a space station is a pressure vessel filled with air or oxygen. For these reasons we prefer cylindrical-shaped modules to build an orbital station. Although there is done much research on inflating structures, e.g. by Bigelow Aerospace, we propose hard-shell aluminum structures for the AGOS modules. By using prefabricated hard-shell modules with 7 m diameter and 14-18 m length we can reduce the fairing of the launcher to a small conic top. Metal-frame hard-shell modules can be lifted into orbit with their entire furniture and equipment, air locks, etc., whereas pneumatic structures are empty after inflation[15]. The AGOS station would be assembled by astronauts and assisting robots. The present ISS should be used as a "site hut" during the assembling of AGOS.

The initial stage of AGOS contains four rotating living modules with 0.9 G, four zero-G central modules (two of them rotate), a docking module, connecting tubes and structural framework to stiffen the entire structure (Fig.2).

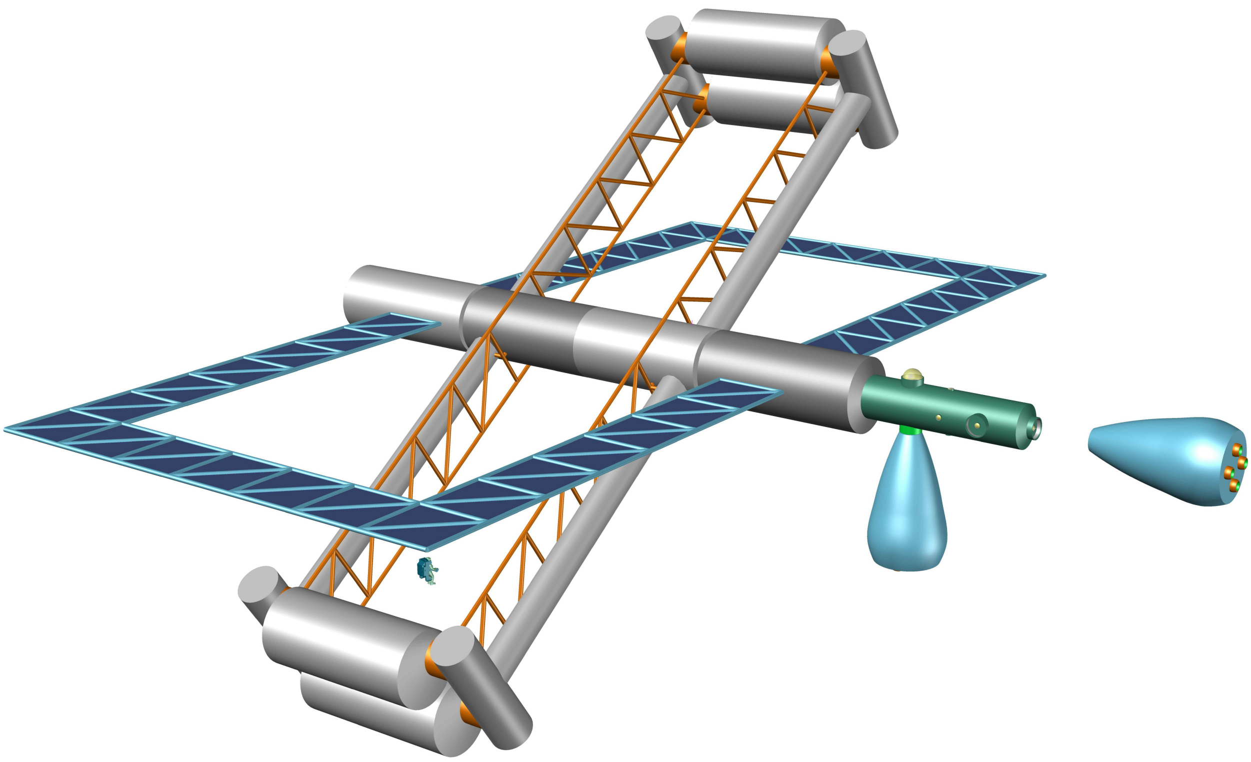

Fig.2 AGOS initial stage; length 78 m, span 102 m, rotation radius 40 m, rotation rate 4.2 rpm, crew: 24

The non-rotating framework carries 1600 m² solar panels. Two joints connect the rotating elements with the non rotating parts of the station (see section 5.4). The entire initial stage will have a mass of approx. 270 tons. Including the transport of robots, tools, etc., 15 launches will be necessary to establish AGOS.

The living quarter modules have two floors, the "upper" floor for living, cooking and working, the "lower" one is the dormitory for six persons. Each crew member has a private room of 9 m² including a small bathroom (Fig.3 and 4). The living quarter modules should have no windows, not to disturb the "gravity illusion" of the crew. Instead of windows high-definition screens could show the space environment to the crew, or simulate views of terrestrial landscapes. Windows should be provided just in the docking module because of micrometeorite and cosmic ray danger. A maximum crew of 24 persons could live and work in the initial AGOS stage and have a living area of approx. 600 m².

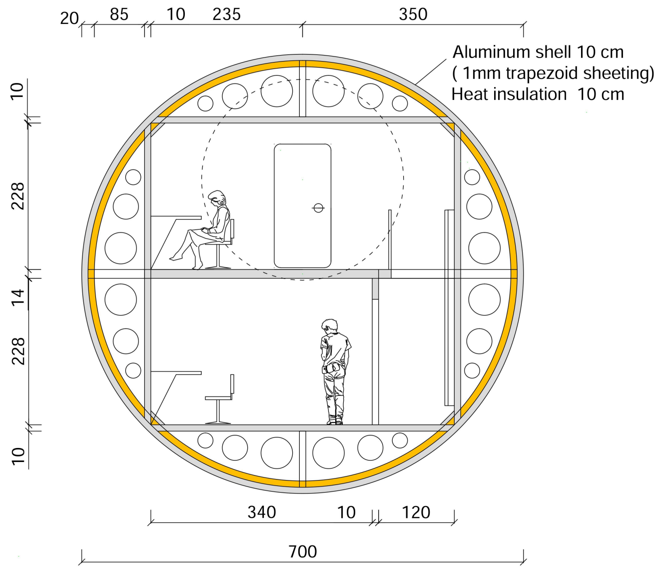

Fig.3 Section of a living quarter module

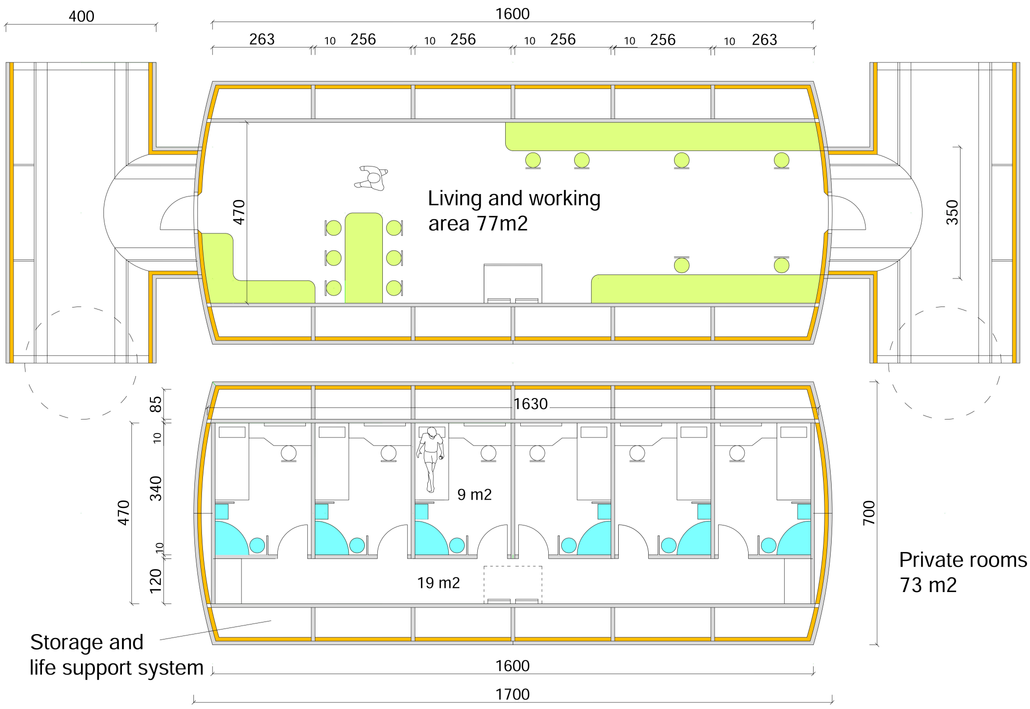

Fig.4 Floor plans of a living quarter module

5.2. Enlargements

Due to its modular design AGOS can be enlarged easily by “plug-in” of additional modules and structural framework. Figure 5 shows a possible stage 2 of AGOS with four additional living quarter modules. When the framework and the modules are mounted, the rotation has to be stopped temporarily. Figure 6 shows a possible final stage with a closed ring of 32 living quarter modules, which are connected by two lateral toroidal tubes. The maximum crew may be approx. 180 persons. Along the central axis additional non-rotating cylinders, solar panels, etc., can be provided.

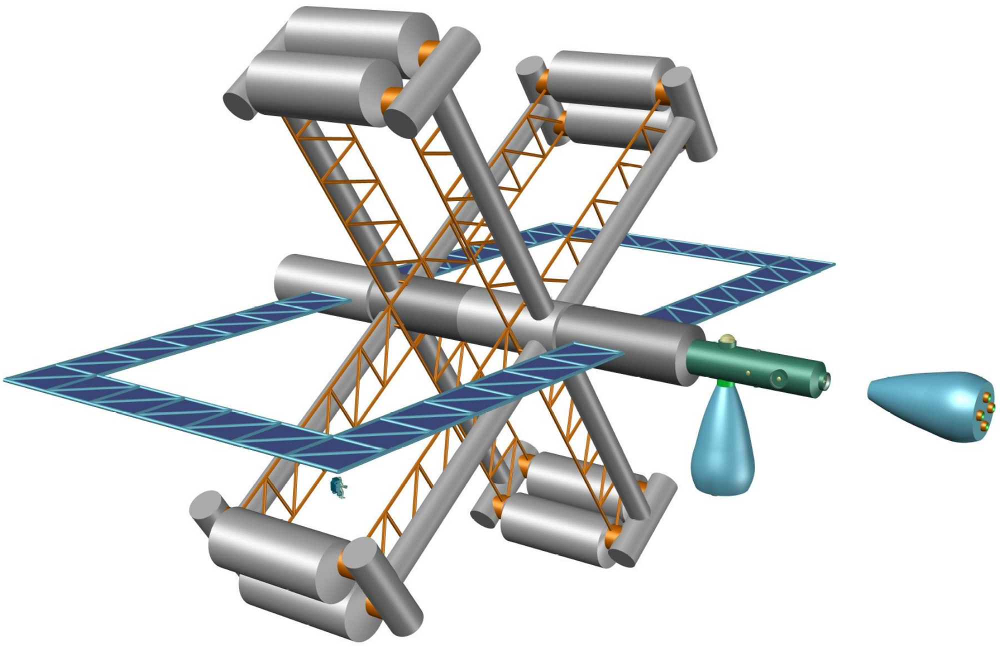

Fig.5 AGOS stage 2, with 8 living quarter modules , crew: 48

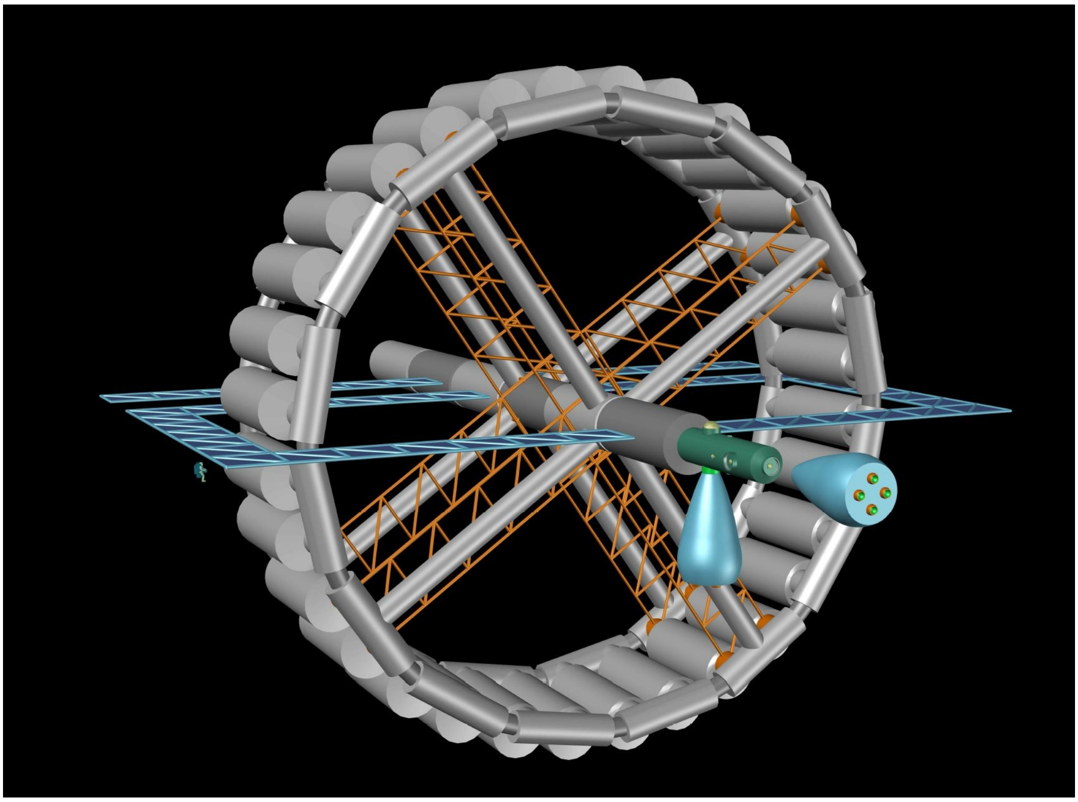

Fig.6 AGOS final stage, 32 living quarter modules, crew: approx. 180

5.3.Structural elements and mass

To minimize mass and launch weight nearly all structural components, the cylinders as well as the stiffening framework are made of thin aluminum sheets and small trapezoidal aluminum sheeting. The sheets are approx. 0.5 – 0.8 mm thick [16]. Thus a typical structural element like a cylindrical shell or a bulkhead has an average mass of 10 kg/m². Figures 7 and 8 show the lightweight construction of a bulkhead, built of trapezoid sheeting. Figure 9 is a cutaway drawing of a living quarter module.

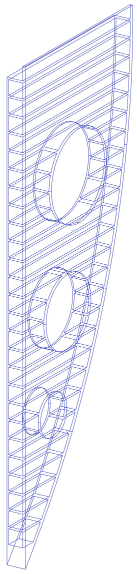

Fig.7 Bulkhead inside a living quarter module

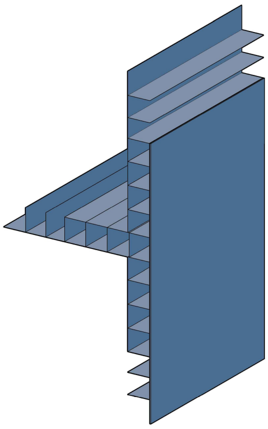

Fig.8 Bulkhead detailed rendering

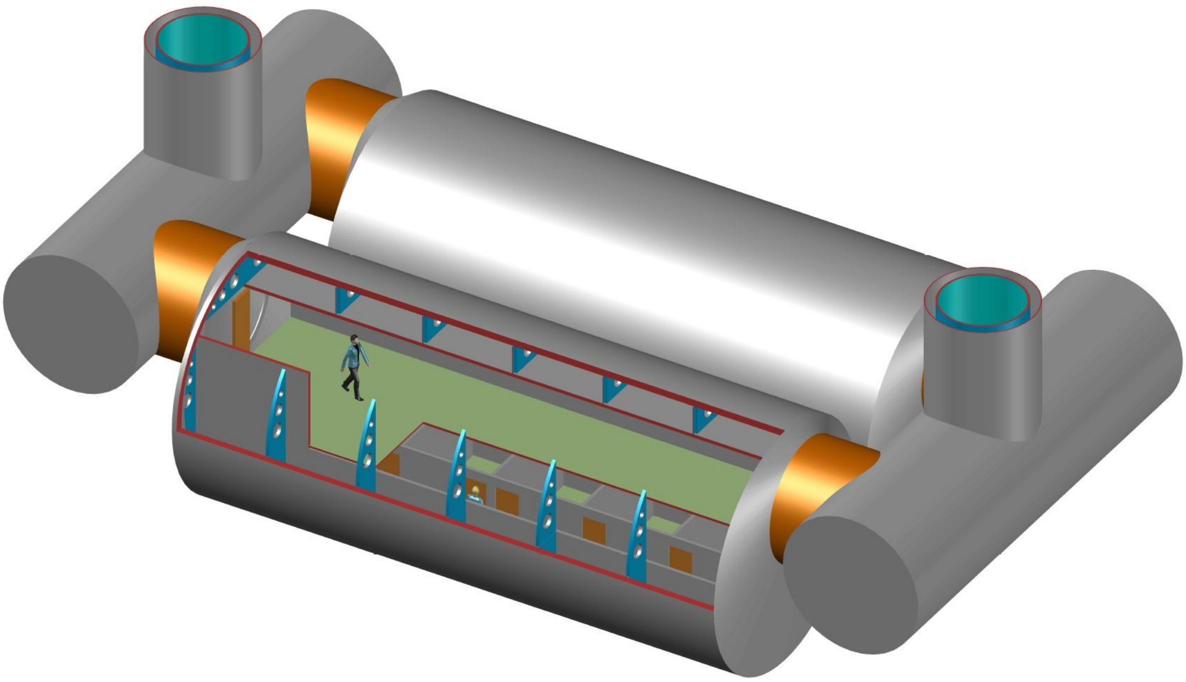

Fig.9 Cutaway drawing of a living quarter module

The furniture and technical equipment of the modules may be 40% of the structural mass. The entire payload and the number of launches for AGOS stage 1 is estimated in Table 2.

Table 2 Payload and number of launches for AGOS stage 1

Payload	Launches	Mass (tons)
4 living quarter modules (20 tons)	4	80
2 central rotating modules (20 tons)	2	40
2 central non-rotating modules (22 tons, including roto -joints)	2	44
1 docking module	1	20
4 radial "spokes" (3 m diameter, 2 x 20 m length)	1	20
4 connecting tubes (to connect living quarter modules)	1	12
1810 m tubes for structural framework (7.5 kg/m)	1	14
1600 m² solar panels (25 kg/m²)	2	40
Total	14	approx. 270 tons

If we assume one additional launch for machinery and the assisting robots we need 15 launches to assemble AGOS stage 1 in LEO.

5.4. The roto -joints

To connect the non-rotating cylinders with the rotating part of AGOS we propose two magnetic liquid rotary seals. Magnetic liquid rotary seals operate nearly without maintenance and extremely low leakage even in vacuum. They provide a hermetic seal by using a so called "ferrofluid", an oil-based liquid which is suspended in place by a permanent magnet [17] . Figure 10 shows the design of a roto – joint : the ferrofluid is held magnetically between the rotor and stator in a labyrinth seal. Additional ball bearings provide the centering of the rotor within the seal gap and support external loads.

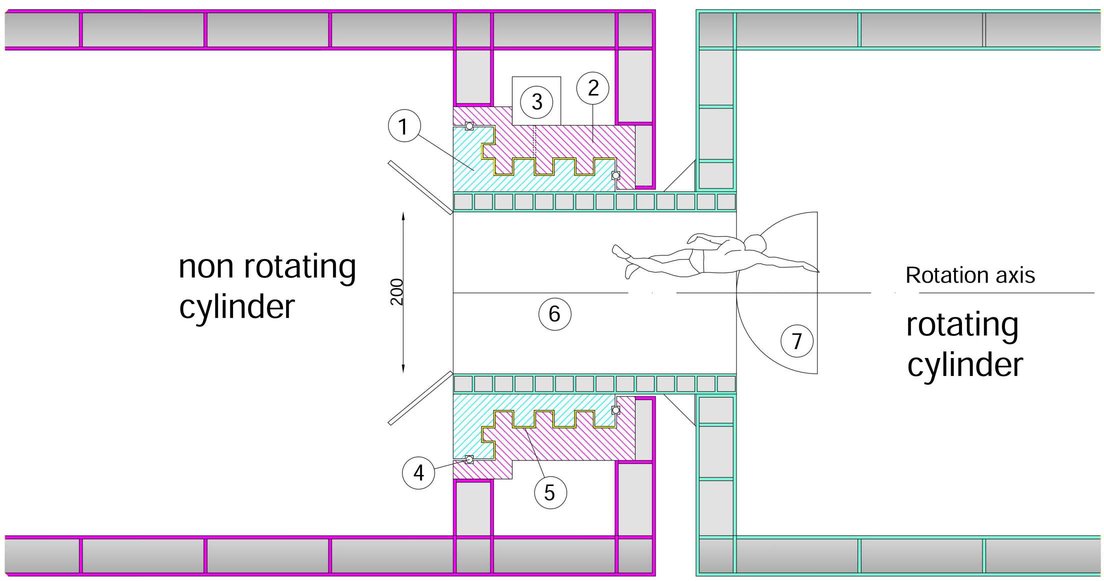

Fig.10 The roto -joint: (1) rotor, (2) stator, (3) auxiliary ferrofluid tank, (4) ball bearings, (5) seal gap filled with ferrofluid, (6) air lock, (7) fire door

The two roto -joints are also used as electric motors, which adjust the rotation of the non rotating part of AGOS. Additionally the rotating living quarter modules are equipped with small reaction control thrusters to accelerate or decelerate rotation. By modifying the rotation rate, different G-levels can be simulated to study their effects on human health. To know these effects may help to design future interplanetary spaceships with smaller rotating facilities.

6. Conclusions

To establish AGOS stage 1 in space a strong effort by international cooperation will be necessary. As shown in Table 2 we need at least 15 launches with payloads of 12-22 tons. According to Table 1 we assume five different types of launchers to be available now: one Russian rocket, one European launcher and three different US launchers. The *Space X Falcon 9 Full Thrust* is the only one which has a fully reusable first stage and may reduce costs significantly. Maybe in the 2020ies launchers with higher payload capacities will have been developed. To minimize the time frame for the entire project the US, Europe, Russia and other emerging space nations like China may coordinate their work and should time launches carefully. For research, planning and production of the modules and the entire construction one may assume ten years, the 15 launches and the assembling may take 18 months. In a best case scenario AGOS stage 1 may be completed in 2029. The present ISS should work until 2029 to be used as an auxiliary device during the assembling of AGOS. In any case a space station in LEO will be necessary, not only for scientific research but to keep the gate to the universe open for next generations.

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