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Artificial Gravity Orbital Station (AGOS)-the simulation of gravity in a rotating space station

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Abstract

The International Space Station ISS will probably be decommissioned in 2030. This paper presents a design for a modular orbital station as a possible successor of ISS. The rotating elements of the station simulate artificial gravity (AG) by centrifugal forces. AGOS is built of cylindrical modules and structural framework. We compare inflatable structures with prefabricated rigid modules, with regard to transport, safety and practicability. The resulting design proposes light- weight constructions using thin aluminium sheets and trapezoid aluminium sheeting. The station can be enlarged in stages, the initial stage 1 has a mass of approx. 270 tons and a diameter of 102 meters. 24 crew members can live and work in a 0.9 g environment. To establish the initial stage 16 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. By changing its rotation rate AGOS stage 1 can be used as a testbed to study the influence of different g-levels on human health. We give a detailed description of our AGOS design including possible enlargements. The final enlargement provides a closed rotating ring of 32 living quarter modules for approx. 180 persons. If lunar material is available within the next decades, a rotating Agricultural Sphere could be attached to AGOS to provide nutrition for the inhabitants. We also present a technical solution for the joints between rotating and non-rotating parts of the station. Last not least we propose a frame to plan, produce and erect AGOS, emphasizing international cooperation.

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

Preface

This paper has been created by humans only. No Artificial Intelligence has been used, neither for the text nor for the figures.

Acronyms/Abbreviations

International Space Station (ISS)
Artificial Gravity (AG); while it would be more correct to talk about simulated gravity, in scientific literature the term "AG" is often used when rotating space stations are described;
Low Earth Orbit (LEO)

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 2030, there are few ideas for a new orbital station. We present a possible successor for ISS, which could provide both zero-gravity modules and rotating living quarter modules with approx. 0.9 AG.

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 on a circumlunar station in 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 building its own orbital station [4]. The German Aerospace Center DLR proposes the so called Orbital-Hub, which combines hard-shell cylinders and nodes with inflatable structures, e.g. made by Bigelow Aerospace [5]. J. Stone from the British Interplanetary Society is currently proposing to ESA the *Island Zero* design, built of a central hub and 8 rotating modules to simulate gravity.

3. Artificial gravity (AG)

3.1 Former designs

Early concepts of rotating space stations have been made in the 1920ies [6]. In 1926 K. Tsiolkovski 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 space. 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 cancelled in the 1970ies when the US space budget was cut.

Meanwhile some ambitious designs for advanced space habitats 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 km and was considered to have a population of 10,000 [8]. The most amazing designs were made by G. K. O´Neill, Space Studies Institute, Princeton, in 1975. His *Island One* was designed as a rotating sphere for 10,000 people. In the far future giant rotating cylinders made of extra-terrestrial material, the biggest one 36 km long and 6.5 km 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 habitats in 1993, considering feasibility and safety and emphasizing structural engineering [6, 10].

3.2 The comfort box

It is evident that the simulation of gravity will provide a more comfortable habitat 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* (see Fig.1), which indicates acceptable living conditions in a rotating space station [11].

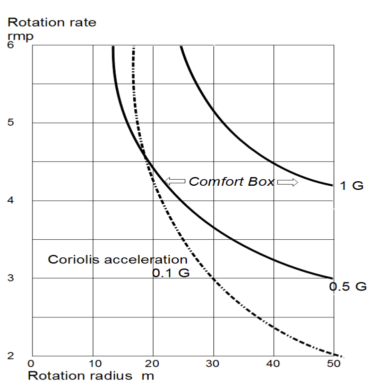

Fig.1 Comfort box, defined by rotation rate and radius

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 distorted as the astronauts move around within the 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.

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. Whilst Russian and ESA launchers are not reusable, the SPACE-X Falcon rockets have a fully reusable first stage. Thus payload costs may be reduced to $ 2700 per kg [13]. The future British *Skylon* vehicle is a HOTOL (Horizontal Take Off and Landing) spaceplane. It will be propulsed by a SABRE engine (Synergistic Air Breathing Rocket Engine). At Mach 5.5 and 25 km altitude the engine transitions to its rocket engine mode, using liquid oxygen stored on board. Launching costs for payloads are considered to be reduced to approx. € 800 per kg [14]. The payload bay is just 4.6 m in diameter and 12.3 m long.

5. The AGOS design

5.1 The initial stage 1

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 AGOS. Although there has been done much research on inflating structures, e.g. by Bigelow Aerospace, we propose rigid aluminium structures for the modules. By using prefabricated rigid 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 rigid modules can be lifted into orbit with their entire furniture and equipment, whereas pneumatic structures are empty after inflation [15]. The AGOS station would be assembled by astronauts and assisting robots. The initial stage 1 of AGOS contains four rotating living quarter modules with 0.9 g, four zero-gravity central modules (two of them rotate), a docking module, connecting tubes and structural framework to stiffen the entire structure (see Fig.2).

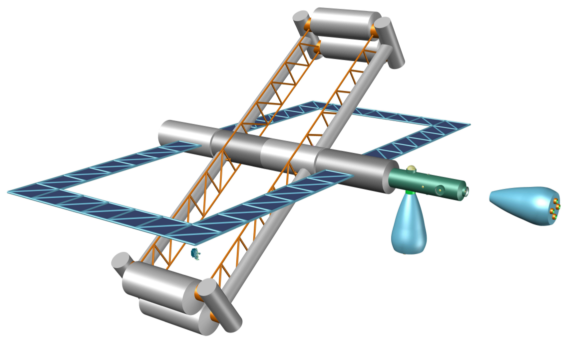

Fig.2 AGOS initial stage 1, length 78 m, span 102 m, rotation radius 40 m, rotation rate 4.2 rpm, crew 24

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 metric tons. Including the transport of robots, tools, etc., 16 launches will be necessary to erect AGOS stage 1.

The living quarter modules have two floors, the "upper" floor for living, cooking and working, the "lower" one is the dormitory for 6 persons (see Fig.3,4). Each crew member has a private room of 9 m2 including a small bathroom. A maximum crew of 24 persons could live and work in the initial AGOS stage 1, having a living area of approx. 600 m2.

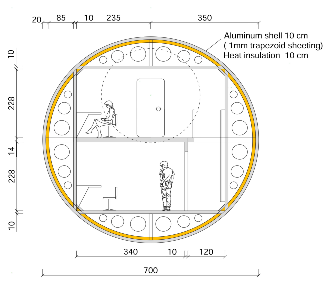

Fig.3 Section of a living quarter module

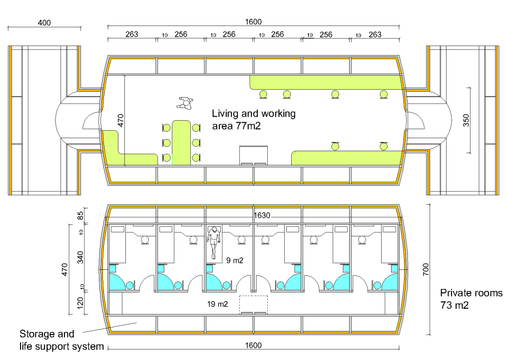

Fig.4 Floor plans of a living quarter module

5.2 Enlargements

Due to its modular design AGOS can be enlarged easily by "plug-in" of additional modules and structural framework. When the framework and the modules are mounted, the rotation has to be stopped temporarily. Fig.5 shows a further stage 2 with four additional living quarter modules and the final stage of AGOS 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.

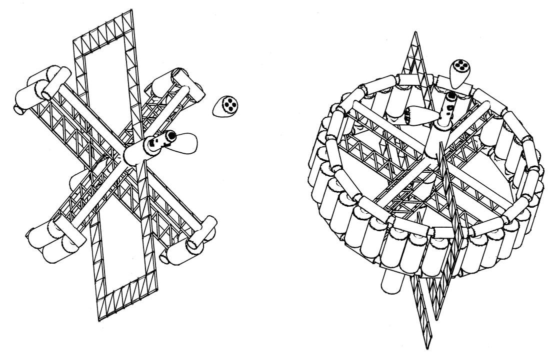

Fig.5 AGOS stage 2 and AGOS final stage (crew 180)

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

Table 1. Payload and launches for AGOS stage 1

number	payloads	launches	metric tons
4	Living quarter modules (20 t)	4	80
2	Central rotating modules (20 t)	2	40
2	Central non-rotating modules (22 t)	2	44
1	Docking module	1	20
4	Radial spokes (3 m diameter, 40 m)	1	20
4	Connecting tubes	1	12
1810 m	Structural framework tubes 7.5 kg/m	1	14
1600 m2	Solar panels 25 kg/m2	2	40
	Additional launch for machinery	*1*	-
	Launch for 1st astronaut crew	*1*	-
Total		16	270 tons

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]. Fig.6 shows the design of a roto-joint: the ferrofluid is held magnetically between the *rotor* and the *stator* in a labyrinth seal. Additional ball bearings provide the centering of the rotor within the seal gap and support external loads.

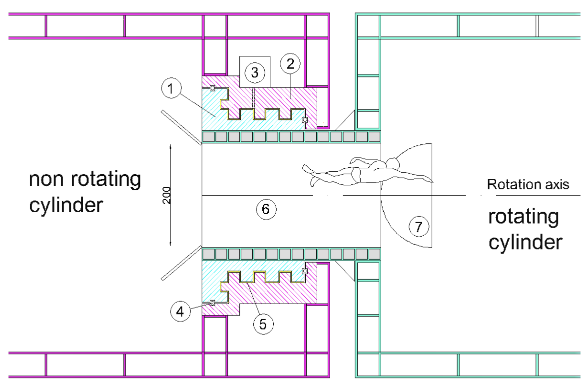

Fig.6 The roto-joint: (1) rotor, (2) stator, (3) auxiliary ferrofluid tank, (4) ball bearings, (5) seal gap filled with ferrofluid, (6) air lock, (7) fire door

The two roto-joints are the electric motors, which provide and adjust the rotation of the central 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 and future scope

To establish AGOS stage 1 in LEO a strong effort by international cooperation will be necessary. As shown in Table 1 we need at least 16 launches with payloads of 12 -22 metric tons. The SPACE-X launchers are currently the only ones with reusable stages and may reduce costs significantly. To minimize the time frame for the entire project the US, Europe, Russia, Japan and other emerging space nations like India or Brazil may coordinate their work carefully. For research, planing and production of the modules and the entire construction one may assume ten years, the 16 launches and the assembling may take 24 months. In a best case scenario AGOS stage 1 may be completed by 2035. The present ISS should work until 2035 to be used as an auxiliary device during the assembly of AGOS. After some years the final stage of AGOS may be completed. If lunar material is available then, we could attach a rotating Agricultural Sphere to AGOS to provide nutrition for the inhabitants (see Fig.7). Building such a sphere could be a proof of technology for a future spherical or cylindrical habitat like G.K. O´Neill´s *Island One*.

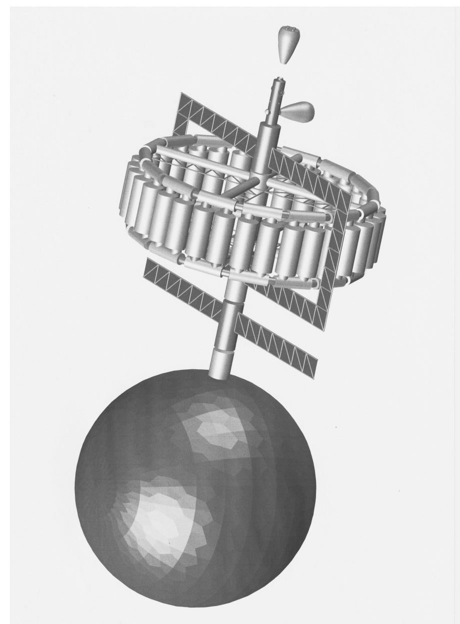

Fig. 7 AGOS final stage with Agricultural Sphere to provide food for 180 inhabitants

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