Orbital Can - a next-generation modular space station architecture

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Abstract

With the advent of new low-cost super heavy lift launch systems, many have begun to recognize the economic potential of medium-sized space stations in low Earth orbit. This paper lays out a design for realising this potential, in the form of a low-cost, standardised architecture of station modules designed to form the basis of orbital development for the next decade. The Orbital Can Station leverages simple manufacturing techniques and commercial off-the-shelf components, to create a versatile pressurised volume which customers can outfit appropriately for their application with minimal modifications required. This paper lays out technical detail for two standard sizes of module —with volumes of 70 and 580 cubic metres— along with a range of standard subsystems including thermal management, power, environmental control, life support, and payload storage. All of these systems have been designed with future expandability in mind, allowing the Orbital Can Station to mitigate obsolescence and provide logistics support to both near-term monolithic volumes and longer-term development of large modular space stations.

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Acronyms/Abbreviations

CBM = Common Berthing Mechanism
ECLSS = Environmental Control and Life Support System
EVA = Extravehicular activity
IDSS = International Docking System Standard
ISPR = International Standard Payload Rack
ISS = International Space Station
LEO = Low Earth Orbit
LV = Launch Vehicle
MMOD = Micrometeorites and Orbital Debris
OCS = Orbital Can Station
SS = Starship/9m/1000 tonne + payload
SSO = Sun-synchronous orbit
UBM = Universal Berthing Mechanism

1. Introduction

Notoriously, space stations of the past have been very expensive projects taken on by only governments and large organizations. From the old architecture of the Soviet Салют (Salyut) and American Skylab programs to the modern-day multinational effort with the ISS and Chinese 天宫 (TianGong), the key driving reason has always been scientific discovery. As technology evolves, augmenting our space-based capabilities, it opens a new frontier for humanity as a whole. Expanding scientific progress and space tourism are both on the rise, requiring technologies to adapt. In recent years, many companies have proposed their projects for such a change, including Northrop Grumman's Habitation and Logistics Outpost (HALO) and Sierra Nevada Corp.'s Large Integrated Flexible Environment (LIFE). The newest addition to this list is our Orbital Can, an expandable, modular, fully adaptable alternative architecture. With the everchanging launch market, costs are at an all-time low, exacerbated by the large-scale production of Orbital Can.

The largest costs come from specialized construction of very specific modules when replaced with common design and manufacturing methods where only the interior is adapted to each client. This allows for the introduction of specialized equipment which can be reused, similar to a line factory. With such high demand for LEO operations, it is paramount to create a decline in cost per unit mass to orbit, providing a wider range of people access to space. With the size of the Orbital Can, much more is possible, enabling comfortable stays in LEO that tight, crowded stations could not provide. The newest LV technology allows for larger and heavier modules to be lifted into orbit, a capability that needs to be capitalized on in the near future. With this in mind, the Orbital Can Station's dimensions are based on the SS Payload User's Guide to make the most of this new operational capacity.

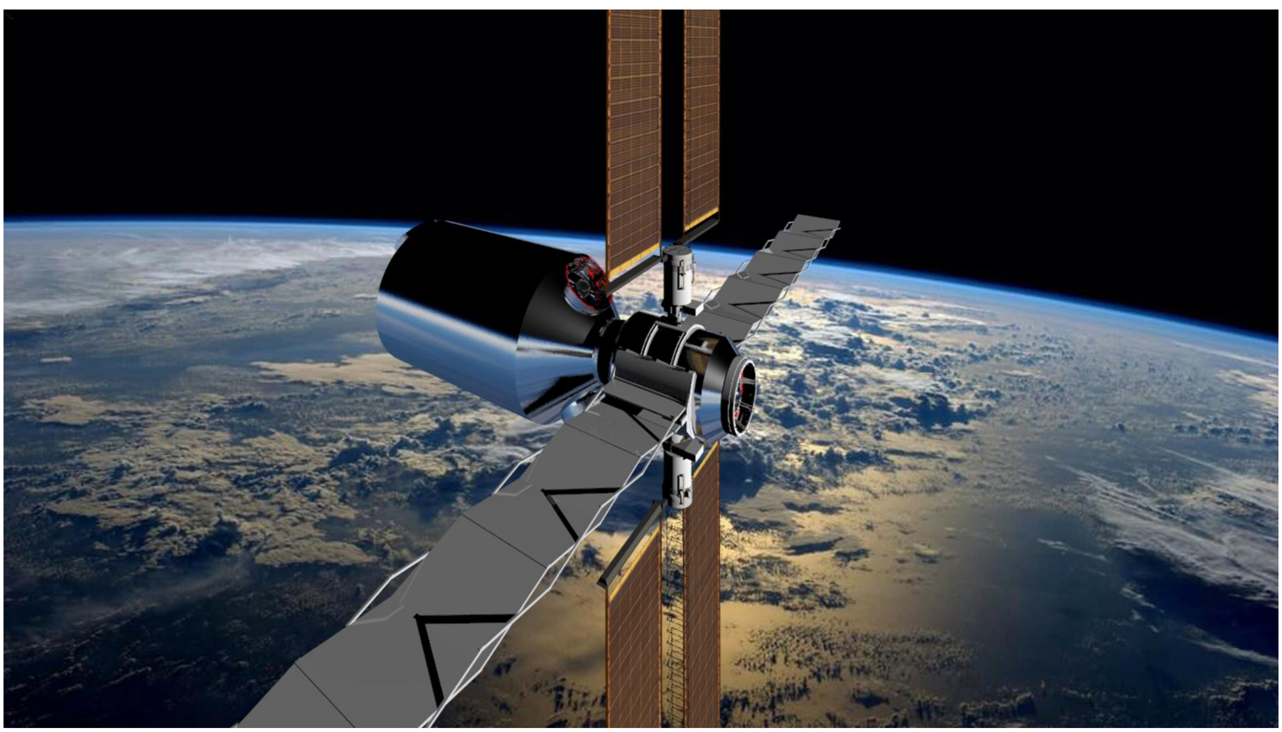

Fig.1: Rendered view of the Orbital Can Station in Low Earth Orbit (Enrico Trolese)

2. Design Details

The Orbital Can Station (OCS) will be the largest pressurized component launched into orbit on all counts. With 627 cubic meters of usable volume per module, slightly more than two-thirds the total volume of the ISS, the volume to surface area ratio is optimized. The diameter of each cylindrical section of each module is 8 meters, with a length of 10 meters, each side capped with a 45 degree tapered cone leading to a 3 meter external diameter UBM port. The symmetry of the system simplifies construction and development. This also allows for all accessories to be placed in a fashion that puts the Center of Gravity as low as possible for launch. The skin of Can is three layered, providing a whipple shield that ensures MMODs pose little to no threat to the structure while in use. Between the two inside layers is located all the piping and systems, including power, data and fluids. To one of the endcaps would be attached an ECLSS module, as portrayed in Figure 1, allowing for no sacrificed volume from Can, instead acting as a lifeboat, containing everything required to keep the station operational. The aspirational plan is to be able to directly attach Can to a LV's payload adapter with UBM, but this can be changed as necessary. The average person takes up close to 0.0664 cubic meters of space, with 627 cubic meters to use, it is evident just how many people can fit comfortably, as well as equipment.

2.1 Orbit selection

For choosing serviceable orbits, factors such as abort corridors, radiation, accessibility, and decay had to be taken into account. As Can is meant to be a crewed station, crew safety is paramount. When launching, there must be the constant ability to safely abort. Different launch sites provide different capabilities, therefore, each station would require a pre-set orbit based on what it would be used for and launch site availability. Keeping the orbit within 300-500km optimizes radiation safety with time to decay the orbit. The station architecture allows for similar radiation shielding to the ISS, therefore, it will be safe to operate for long periods of time. One of the most limiting factors of the orbital height, however, will be payload mass. Orbital debris also plays a key role, both in avoidance and prevention. Can's whipple shielding will provide safety in case of a small MMOD strike, but large ones must be avoided, as Can will not be able to alter its orbit significantly enough in a small period of time.

2.2 Structure

The external structure will be welded stainless steel barrels additionally strengthened with internal ribs or stringers, allowing the module to withstand launch conditions and the mounting of internal as well as external accessories. As shown in Figure 3, the skin will be built of two layers, inside and outside layers, with all piping in between. In the case that simulations prove structural integrity during launch can cause failure, the internal pressure can be raised to a minimum of 2 BarA. Over the external skin, a whipple shield made of aluminum will be placed with structural connections to ensure effectiveness. On each end of a Can module will be located 1 or 2 UBM modules, with all piping hermetically sealed to prevent any leaks which can impart unwanted thrust on the structure.

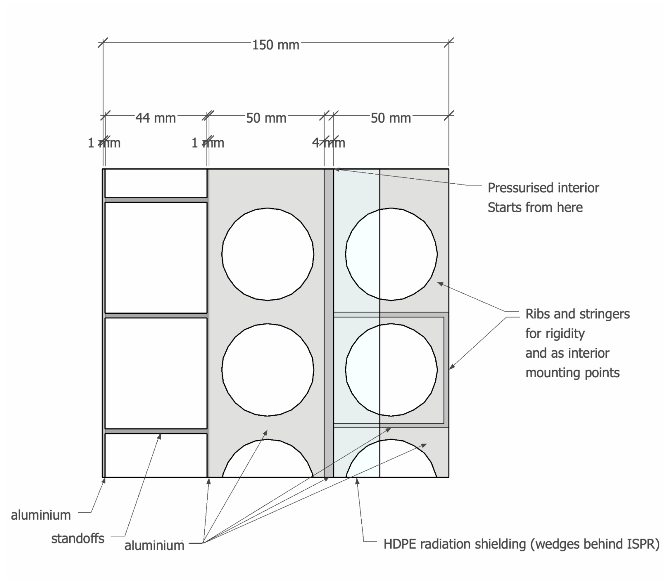

Fig. 2: Detailed section of hull design (Koen Kegel)

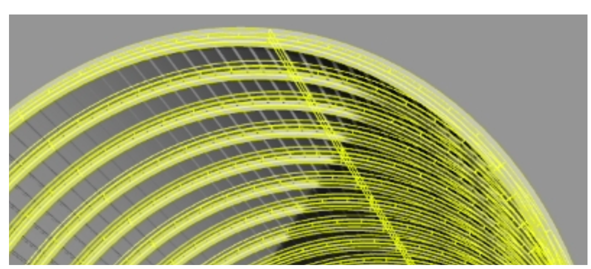

Fig.3: Internal aluminium structure, with ribs and stringers (Enrico Trolese)

2.3 Attitude control and orientation

For small stations there is substantial advantage to orienting the platform in a constant orientation relative to the Sun. It negates the need for any rotation, slip rings or rotary joints on the solar and radiator systems. This orientation requires additional torque from the station's control moment gyros, since the station is not resting in equilibrium, but removes a substantial amount of complexity and cost.

However, for larger stations a constant orientation relative to velocity vector is preferable. This reduces torque requirements and can aid in approach/docking operations. At this scale a number of approaches can be taken. As with the ISS, an entire truss can be mounted to a rotary joint/slip ring. This is a well-understood system but requires EVA activity to construct and a complex fluid slip-ring for radiators. An alternative is to mount a beta gimbal with a relatively small range of motion on the circumference of a vertically-pointing module. This allows the radiator orientation to be controlled. The solar panels can then be attached to this beta ring with small trusses, each mounting an independent alpha gimbal joint. This configuration bears substantial similarity to the "Power Tower" concept developed in the Space Station Freedom program.

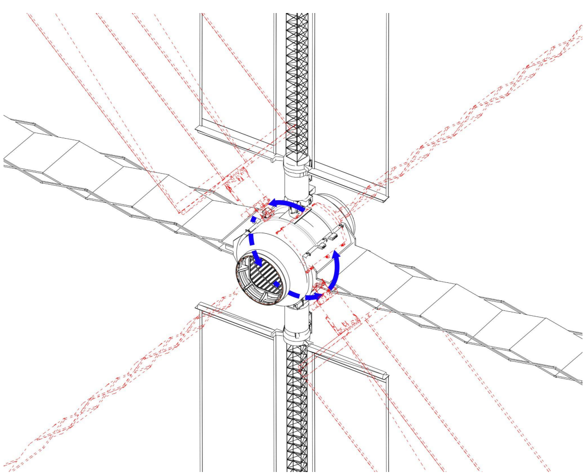

Fig.4: The alpha and beta gimbal for solar panels and radiators, provided by rotation around the exterior of a 4.5m module. (Enrico Trolese)

2.4 Electrical system

The estimated power budget was determined by scaling subsystems on the ISS either by volume, crew count or station mass. Substantial margin was included for growth, and the very large allocation for payload acts as a reserve in the event of any one system proving more power-intensive than planned.

Table 1: Power budget for OCS station

Subsystem	Power requirement (kW)
Command, data handling, and flight control	10
Electrical power storage	3
ECLSS	9
Thermal control	15
Payload	50
Subtotal	87
Total including margin	**100**
Required peak output	**180**

In order to meet this requirement, around 500m2 of solar panel is required with modern efficiencies of 30%. The scale of this, which should be provided in a single launch, presents potential issues with deployment and stowage. The natural solution is roll-out flexible cells as pioneered by Deployable Space Systems and currently being deployed on the ISS. The packing density of these systems is extremely high (exceeding 40kW/m3) and they can be wrapped conformally around a module for efficient use of space. They are also extremely light, at 90W/kg. However the use of high-efficiency space-rated cells also makes them expensive - the estimated price floor is 500/W[1] even with large batch production. This would bring the cost of solar for the station to above $100M. A cost-saving alternative would be to use lower-efficiency or shorter-life cells. This would require more launch mass and cost, but for a short-lived station may be an acceptable tradeoff.

A similar tradeoff exists for energy storage, of which the station needs around 100kWh. Existing space-rated systems are extremely lightweight and durable, with long lifespans, but at extreme cost. An alternative architecture would use heavier industrial-grade batteries and include substantial extra capacity to limit the cycle life of each cell and prolong the lifespan. Batteries could also be made compact and mounted inside the station to facilitate easy replacement by crew without the need for EVA.

[1] Personal communications, Deployable Space Systems

2.5 Thermal system

Thermal management is a major issue, especially considering the high volume:surface area of the OCS architecture. The estimated heat rejection is on the same order as electrical usage, 100kW. We aimed to to minimise cost and complexity, while maximising crew safety and repairability.

The thermal control system is in three sections: the external heat rejection radiators, internal coolant loop and heat exchanger between the two. Existing solutions for heat rejection with ammonia circulation are mass-efficient and relatively cheap, so no substantial consideration was given to them. Unlike the ISS, the Can utilises a single primary loop throughout the interior which circulates water. The need for an external loop is largely negated by moving much of the heat-intensive processes inside the pressure envelope. This water is assumed to have a small temperature delta of around 5°C to prevent condensation buildup.

Since the station is intended for large-scale modularity, the maximum capacity of the cooling loop is grossly oversized. The core plumbing can handle a throughput of 500kW of coolant (12kg/s) at reasonable speeds with pure water and a small temperature delta . If there is demand beyond this - for example, a highly heat-intensive process such as metallurgy, or a large modular station with heat rejection concentrated in one area - the capacity can be increased by simply increasing temperature delta. This could be achieved with larger radiators (to reduce heat exchanger output temperature), a heat pump rather than exchanger to increase radiator efficiency and addition of antifreeze to the primary loop to facilitate lower temperatures.

The demands of each module will vary substantially and so it will likely be necessary to include small secondary loops, interfacing with the main coolant circuit via module-internal heat exchangers.

2.6 Propulsion and station keeping

Unlike small satellites, the large size of a Can station means that electric propulsion for reaction wheel desaturation and orbit reboost is not feasible in the near term. 30-40kW of constant power consumption would be required for Hall effect thrusters, and plasma thrusters are not available in the immediate future or at low cost. A more reasonable solution is traditional liquid thrusters (hypergolic or pump-fed) in the 5-10kN range to provide regular boosts. These could be integral to the Can or be on visiting resupply vehicles.

2.7 ECLSS

2.7.1 OCS ECLSS

The ECLSS will be nested in the service module, where the radiator panels and the solar panels are connected. This provide some advantage points:

- At the end of its life cycle, the Service Module can be undocked from the main module, decommissioned and replaced with a newer one. This allows complete replacement of the ECLSS, solar and radiator panels separately from the main module.

- Having most, if not all of the biggest components of E&M systems in one place allow more space in the main module

- Connections to power source (solar panels) and external thermal management system (radiator panels) is streamlined and integrated in one module.

The ECLSS subsystems (Air revitalization, Atmosphere control and supply, Water management, Waste Management, Thermal and Humidity management, Fire/Smoke detection and suppression) have been extensively tested in the ISS, and in some spacecraft like the Shuttle, SpaceX Dragon capsule, etc. Their initial development costs have been mainly on the shoulders of Government Space Agencies like NASA and Roscosmos, but now, with the adoption of such systems in the new era of commercial space stations, their cost will keep decreasing while reliability will improve.

The ECLSS System in the OCS is sized to allow up to 9 crew members at every time, and it is conveniently modular using the ISPR as base module. Even if some ECLSS manufacturers developed their own standardized modular system (Jonathan O'Neill , Jason Bowers , Roger Corallo , and Miguel A. Torres, Collins Aerospace), the ISPR will be used as a general module for everything from experiments to storage, and using it for ECLSS as well will help us to simplify the hardware specification for the OCS at this initial concept stage. After the completion of the initial phase design review, options other than ISPR will be considered in particular for the ECLSS system.

The ECLSS consists of 11 ISPR units, all contained by the Service Module. Other 5 ISPR units are used for storage and spare parts. The Carbon dioxide removal unit, the Oxygen Generation unit, and the WC unit all have a space unit.

2.7.2 Closed Loop vs Open Loop

The cost of launching mass to orbit has been decreasing, and it will have another massive discount once the Starship system is available.

We are therefore studying the possibility that, from an economic standpoint, supplying the station with consumables like water and oxygen may at some point become cheaper than using a closed loop system.

Option A - Closed Loop :

The system has a certain initial cost, and it will have a maintenance cost in terms of space parts, consumables like cartridges, liquid top up etc, then disposal at the end of its functional life.

With this system, that at the moment is not 100% closed, consumables like water and O2 will still need to be supplied to the station. Being a more complex system than an open loop, there is statistically more probability of technical problems, lowering reliability over the life-cycle of the hardware.

Option B - Open Loop :

The initial cost of the system would be 0, because no recovery of water from urine and air moisture will be done and air will not be produced from recovered water.

The only initial cost will be the tanks and the outlets to trap the moisture from the air, as well as the waste management system to seclude the urine.

The cost of maintenance of such a reduced system will be very limited, and the other cost would be to supply the station with a bigger quantity of water and O2 compared to the Option A (Closed Loop).

The baseline of this future study is:

- the station to be in LEO. Out of LEO, especially for Mars bounded stations / cyclers, the cost of re-supply obviously will be much higher or not feasible, and therefore a closed loop ECLSS is necessary.

- The costs of option A and B are compared over a long term period, 10-15 years (Basically the hardware life cycle duration). This allows like-for-like comparisons.

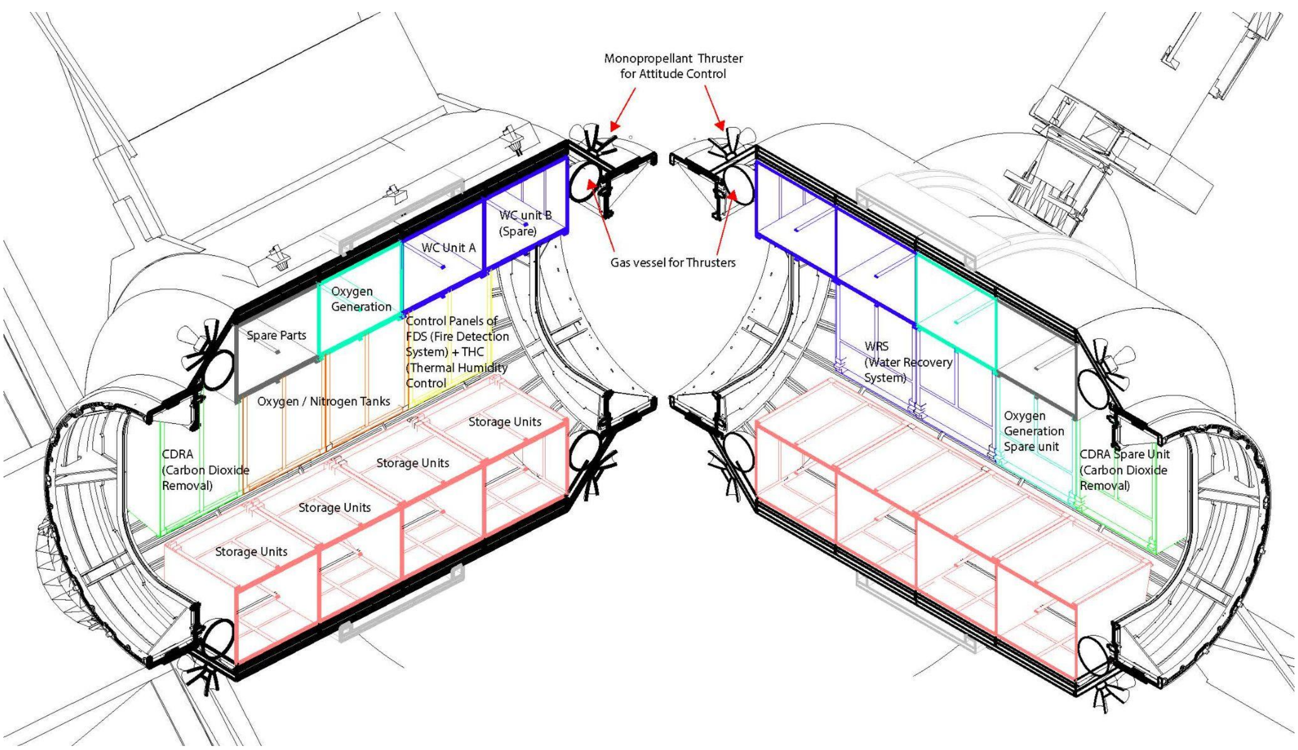

Fig.5: ECLSS Internal Layout (Enrico Trolese)

- Consider the whole life-cycle costs: design & development, production of the hardware, launch to the station, maintenance (replace faulty parts during the hardware lifetime, top up and / or replace consumables like fluids, cartridges, chemicals etc), decommissioning and disposal of the hardware.

The trade off between the cost of the assemblies of the Option A vs the cost of resupply of Option B will need to be studied in more details, in particular the cost of the most recent and optimized closed loop ECLSS hardware, including the cost of maintenance and spare parts.

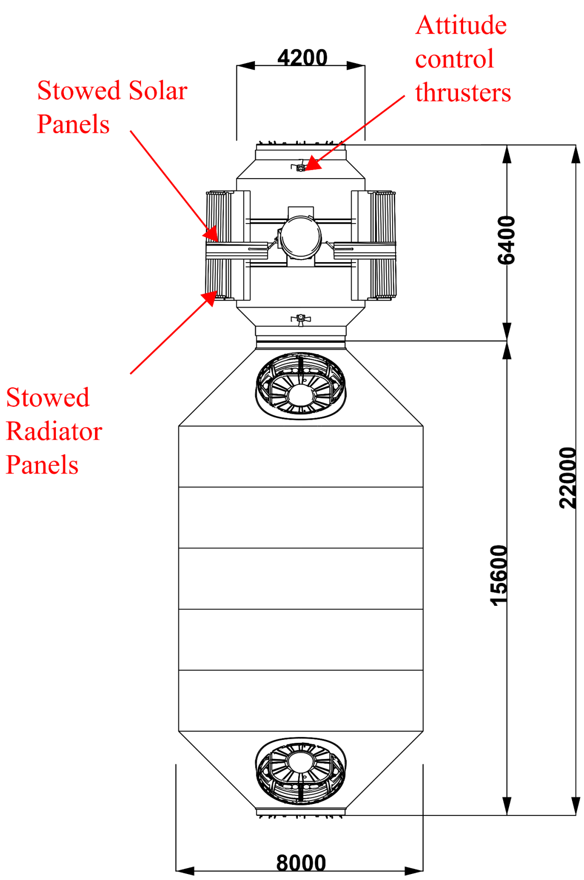

Fig.6: Stowed configuration, fitting the Starship internal payload volume. 70m3 Small Can on top of Large Can on the bottom of 580m3 (Enrico Trolese)

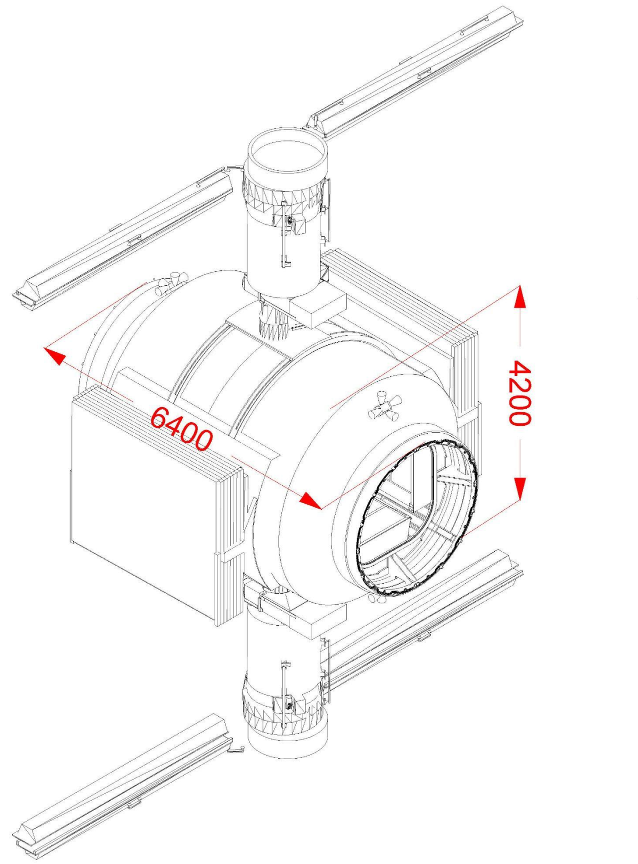

Fig.7: Stowed Configuration, Small Can, used as the Service Module (Enrico Trolese)

2.8 Manufacturing

The design has been optimised to reduce manufacturing costs and effort where possible. The current paradigm of milled or rolled aluminium isogrids is very mass effective but extremely labour and cost intensive, and effectively unneeded when we have extreme upmass capability and very low cost per kg. The next-generation launchers like SpaceX's Starship reusable launcher, will have a huge payload mass capability, likely to be 100-150t. This enables the prioritization of lowering manufacturing and materials costs, rather than saving mass, as is the current standard in aerospace manufacturing. Making mass-manufacturing similar to the scale of airplane manufacturing a real possibility.

Our chosen manufacturing method of rolled aluminium with welded ribs and stringers sacrifices mass for rapid low-cost assembly that is well-suited to automation. Many internal components (dividing spaces, payload racks) can be made in standardised batches and installed en masse to reduce cost. The

large size will make Can hard to transport by road, rail or air so the manufacturing site may ultimately have to be near a launch facility or will need to be accessible by barge.
Additionally, it is possible to take advantage of lower launch costs and choose less mass-optimal systems that allow cost savings. This includes COTS hardware for subsystems like electrical harnesses and non-critical control computers, and reuse of existing ISS-era hardware where suitable. Pushing this argument to a logical endpoint, tradeoffs can be made between equipment life and initial purchase cost. As detailed above in section 2.4, a substantial fraction of total station cost is the high-grade space rated solar panels at around $100M. Through the use of panels with 25% the usable lifespan, substantial savings may be made at the expense of more frequent replacement.

2.9 Human factors

Unlike ISS modules, the Orbital Can Station is large enough to be split into multiple modules. Allowing for a clear division between living space, experimental and work areas, engineering and storage. The ultimate layout would be determined by the specific requirements of the user but a number of concepts have been designed. These generally revolve around "floors" with sector-oriented rooms around a central access shaft. Mounting equipment to external walls better for structural and commodity reasons, plus allows internal division.

2.10 Safety

Building stations with the Can architecture allows for a number of improvements in crew safety. Primarily, the high redundancy in a large modular multi-can station means that damage to any one component can be survived with minimal loss of performance. This is aided by the large volume:surface area ratio of the Can (by virtue of large diameter) which means that any leak or impact damage can be withstood for longer.
In addition, a great deal of design work has gone into minimising the need for EVA at any stage of station construction. This reduces crew work during pre-commissioning operations and also substantially increases crew safety.

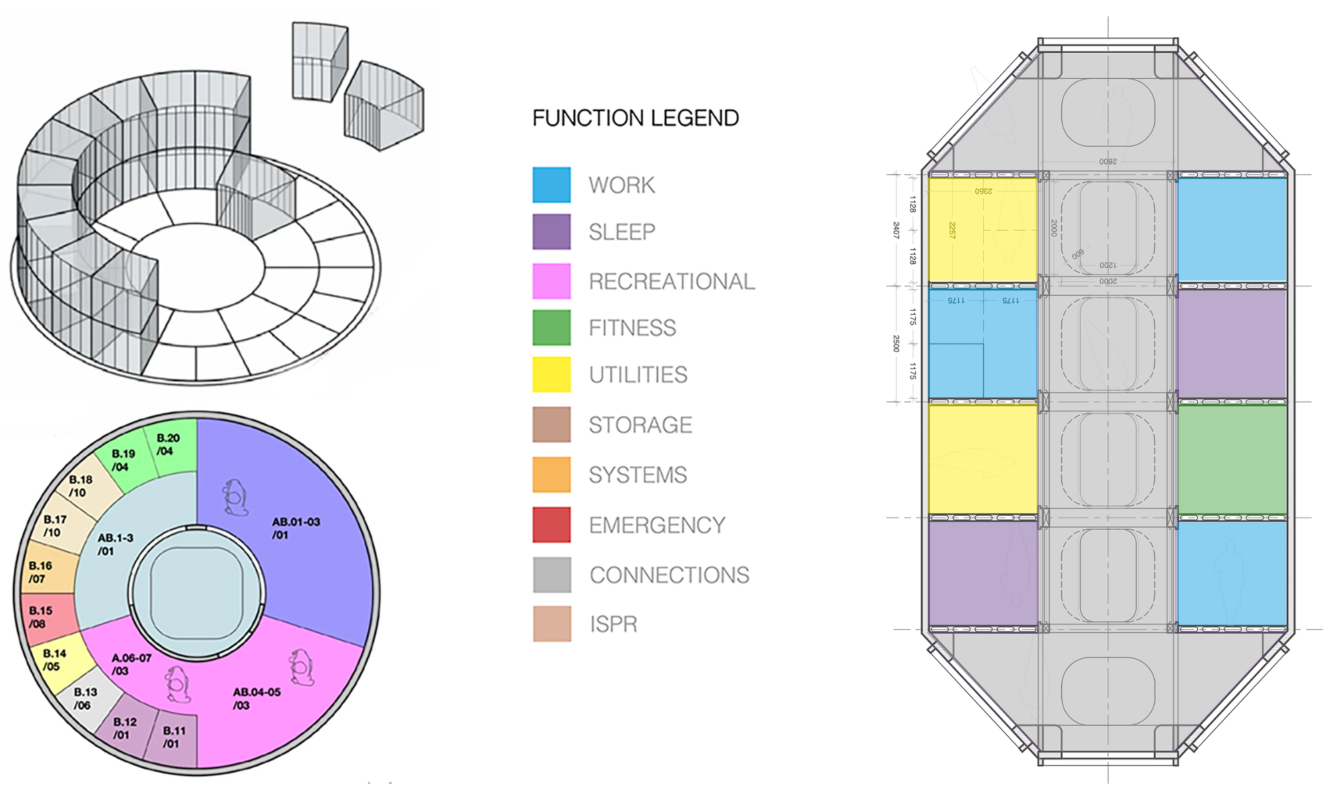

Fig.8: Interior layout concept of the 8m diameter Large Can module (Paul King)

3. Can operational concepts

Many concepts are possible with the Can - it is intended as a versatile base for building a large number of potential missions.

3.1 Single-launch station

For commercial entities wishing to use a Can for private operations - manufacturing, research, tourism etc - it is likely that one Can volume will be more than sufficient. Furthermore, there is an incentive to minimise loiter time on orbit before full commissioning, as this represents lost earnings potential and substantial expense in mission control operations. For this reason, a major design objective for the Can was to reach full operational capacity within a single launch of Starship.

This is made possible with the simultaneous launch of the main station module with an ECLSS module already secured to the top berthing ports. Solar and power systems, radiators, ECLSS storage and processing and control systems are all included in this smaller volume (see section 2.7) while the main volume remains free for the customer to modify or fill as they require.

3.2 Large modular space stations

Utilising the basic building blocks of the 8m diameter Large Can and 4.5m Small Can, a great many geometries are possible. While the cost of such a project would of course be large, it may benefit from scaling effects to reduce effective cost to end users.

A very large fraction of the system cost is from expensive subsystems (particularly power) which scale favourably with size. To cater to this future expansion, many of the Can systems (thermal, power, ECLSS) have been designed to support throughputs and capacities of a station composed of at least 5 Cans or 3x ISS volume without any substantial design changes. Above this, it is possible to go larger with various “up-conversions” such as DC-DC step-up in the power system and heat pumps to increase radiator power density as discussed above.

Furthermore, larger stations may benefit from the need for more regular resupply and crew changeover missions - this reduces per-launch cost and allows for shorter (and thus cheaper and more accessible) flights for the tourist market. The likely limit on the ultimate size of a Can-based station is likely operational rather than technical.

3.3 Artificial gravity station

Artificial gravity while in space, can have health benefits for astronauts on long-duration space missions. While the Orbital Can allows for large scale artificial gravity by connecting two modules by a large truss and spinning them, our 8 meter diameter Large Can module, allows for an interesting alternative, which we call L.A.R.G.E (Large Artificial Rotation Gravity Environment). LARGE is made up of two rings, filled with pods, which can speed up and slow down, to enable gravity on demand for the occupants. Certain tasks can become easier under gravity conditions, such as bathroom visits, while sleeping and working large parts of the day in such a gravity environment, allows for general strength and health benefits for the crew as well.

3.4 Orbital tourism

The market for orbital tourism is very large, and is growing rapidly. Short or medium stays on orbit may be increasingly popular. The Can provides a station with lower cost life support, larger volumes and allows for large scale orbital tourism, enabling lower

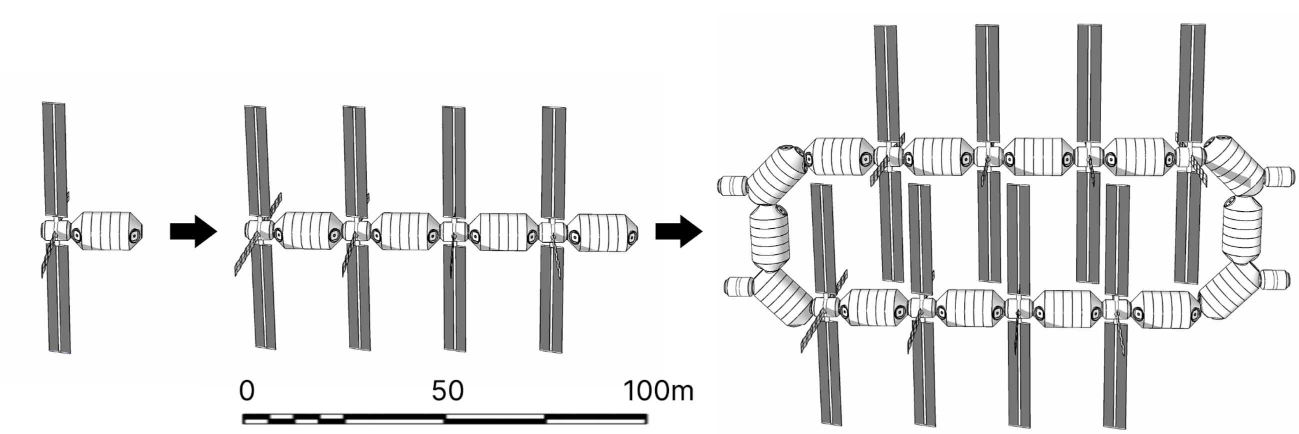

Fig.9: Growth of a Multi-Can station (Koen Kegel)

costs for tourist stays. The 8 meter diameter Large Can, allows for interesting experiences for tourists to discover.
The Orbital Can Station will be especially beneficial once super heavy-lift launch vehicles are able to ferry hundreds of people to Low Earth Orbit each launch. Multi-Can stations allow for a destination large enough to be a destination for all these people.

3.5 Manufacturing
The large dimensions of the Can allow for substantially more effective on-orbit manufacturing than many existing proposals. The modular power and thermal system supports this - the default bus has capacity to support up to 500kW and hence highly intensive industries like metallurgy. The Can could support essentially every near-future form of orbital manufacturing and on-orbit servicing. This includes production of materials for return to Earth, refining and processing for use in space, and construction of spacecraft in zero gravity. The latter case could be enabled by the large diameter of the berthing ports - or even a modification that allows the entire endcap to hinge away and use the entire volume as a “dry dock”. The internal dimensions of the Can hugely exceed many commercial satellites and even crew capsules which supports usage as a servicing hub.

3.6 Research station
Many of the Can’s systems were designed in reference to the ISS, so a new station could clearly be an effective ISS replacement. The large volume with subdivisions provides a huge amount of rack space for housing experiments, and the use of ISPR-compatible berthing ports means entire payload racks can be transported to orbit. This is a capability that has been largely abandoned in the pursuit of standardisation toward the IDSS design, but would allow for larger and more complex experiments with less crew involvement.

3.7 Multi-use large station
Since a large fraction of the cost of operation of a Can space station comes from resupply and crew exchange missions (especially with a massively reduced cost of mass to orbit) it is highly desirable to maximise the “utilisation” of the station. Various applications have different priorities for usage of station commodities so an ideal provider would balance applications so all systems are running near full capacity at all times. In the case of single-launch stations this could take the form of a station used for manufacturing and research (which are relatively high-power but low-volume activities) but also tourism (which is the opposite).
For larger modular stations, common habitation and split working areas allows for sharing of expensive systems like ECLSS and food processing,

3.8 Surface base
The Can envelope has potential use cases as a surface base on both the Moon and Mars. It would require rotation of a Can module to “horizontal” orientation, with interior decks. Consideration for unloading from the transport system needs to be taken into account. Once large-scale manufacturing of Can modules has been set up, this might prove to be an affordable way to create a permanent Moon base, partially or completely buried in lunar regolith.

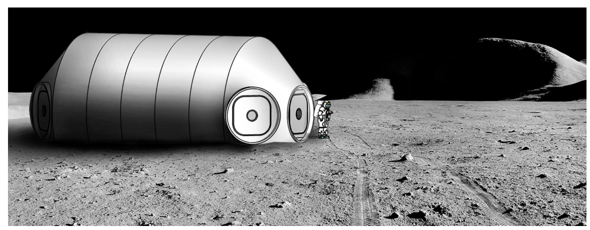

Fig.10: Render of partially buried Large Can module on the Moon’s surface (Paul King)

4. Conclusion
The Orbital Can station has the potential to lower the cost of access to space by orders of magnitude by providing a low cost, mass manufacturable, interconnectable and single launch space station.
It is, however, highly dependent on next generation super heavy lift launch vehicles such as SpaceX’s Starship to succeed. Such a reusable launch vehicle is a prerequisite in order to launch 100-150t Orbital Can Station modules of 8m diameter of 650m3 pressurized volume, directly into LEO.
The components used in the proposed design, allow for future expansion by launching additional modules. The large payload capacity allows us to design more economically, by using faster and cheaper construction methods and commercial off the shelf components.

5. Acknowledgments

We would like to thank the Nexus Aurora community of volunteers, who strive to make life multi-planetary. They offered their time and expertise to enable this first step towards a more affordable access to space, by providing a potential large-scale destination in LEO with this next generation space station design. A special mention goes out to our anonymous user Mars Done Right, who wishes to remain anonymous, but contributed greatly during this process.

Our Patreon supporters who contribute to the Nexus Aurora community by monthly donations, enable projects like this one to thrive.

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