Technology Demonstrator for a Rotating Space Station

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This paper presents an overview of a design for a large-scale Technology Demonstrator for a rotating space station. Its purpose is twofold: to acquire knowledge on the behaviour, operation and control of a large rotating structure to inform the design of a future rotating space station; to simulate Moon, Mars, Earth and other Solar System gravities in Earth orbit for the first time. The design envisions a truss structure formed into a circular open ring that resembles a giant hula-hoop. It dispenses with the bicycle-wheel approach by resolving the spin tensile forces through the ring's circular structure rather than through spokes and a hub. The ring has a provisional overall diameter of 217 m and a structural cross-section of 8 m. It spins up and down through a range of angular velocities to simulate different gravities. Microgravity occurs at rest and Earth gravity at full spin rate. Low-thrust engines provide spin up, spin down, attitude control and stationkeeping. Photovoltaic blankets provide electric power. Six launches can deliver the entire Technology Demonstrator to orbit in stowed segments that deploy and assemble under ground control. At mission end, the ring is dismantled and its curved segments converted to straight beams for follow-on applications.

Keywords: Technology demonstrator, Rotating station, Deployable structure, Artificial gravity

1 BACKGROUND

Wheel-shaped space stations and settlements that spin to provide simulated gravity around the rim have been the subject of visionary space studies since the dawn of the 20th century and the work of Russian scientist Konstantin Tsiolkovsky. The German rocket scientist Hermann Noordung featured a concept in his treatise on spaceflight in 1929 [1] and the former German rocket engineer Wernher von Braun imagined a 76 m diameter wheel station for an 80-person crew in a magazine article in 1952 [2]. A NASA-led 1975 summer study at Stanford University in California envisioned a huge rotating settlement 1.8 km in diameter to house 10,000 people [3]. In the mid-1980s, a Hughes Aircraft proposal for a wheel-shaped station based on used Space Shuttle tanks was shortlisted with others by NASA for a study for what later became the International Space Station [4]. Over the years, aerospace companies and start-up ventures alike have explored ideas for wheel-shaped stations.

The International Space Station (ISS) has been in operation with permanent crews for over twenty years, during which time over 240 astronauts and cosmonauts have spent time on board. A priority among the myriad of research projects and topics on ISS has been the study of the effects of exposure to long-term microgravity on human physiology. Known from earlier missions were the debilitating effects of microgravity on the human musculoskeletal system with weakening of bones and muscles. The completion of NASA's Twins Study involving astronaut twins Scott Kelly (on ISS) and Mark Kelly (on the ground) showed that negative changes to human physiology are widespread, ranging from the molecular and genetic to the cognitive and cardiovascular [5]. The return and adaptation to Earth gravity is particularly stressful. While some physiological functions revert to their terrestrial state before spaceflight, others do not. Now proved beyond doubt is that long-term exposure to microgravity has harmful and lasting effects on the human body.

ISS is a first-generation station that is now well past its life-cycle halfway point. The Biden Administration has committed NASA to extend ISS operations up to 2030 [6] and NASA has defined a refocused programme of ISS research up to that date [7]. However, Russia's space agency Roscosmos has announced that it may abandon ISS in 2025 and launch its own station by 2030 [8]. Cracks recently reported in one of the Russian modules are causing concern [9]. If wear and tear on ISS compromises crew safety, its decommissioning may be accelerated. Compounding the uncertainty are negative statements from Roscosmos about Russia's continued participation in ISS following that country's invasion of Ukraine in 2022. At the time of writing, NASA is holding a competition for a privately-developed US successor to ISS [10], though it remains to be seen if and how a credible business case can be made for a commercially-based approach. Widely acknowledged is ISS's excellent performance as an international laboratory and that continuity of its valuable scientific research is vital. Given the timespan necessary to design, develop and deliver a new space station – for ISS it was twenty-seven years from go-ahead to completion [11] – the start of work on its successor is long overdue. Faced with confirmation on the harmful effects of lack of gravity on human health, the next station ought to provide a range of artificial gravity conditions for research. NASA now recognizes this. Its commercial space station competition has a goal to "perform human-scale artificial gravity research… to simulate Moon and/or Mars surface gravity for experiments or as a countermeasure to the effects of microgravity on crew health and performance" [12]. The competition's requirements suggest, however, that the outcome may result in a scaled-

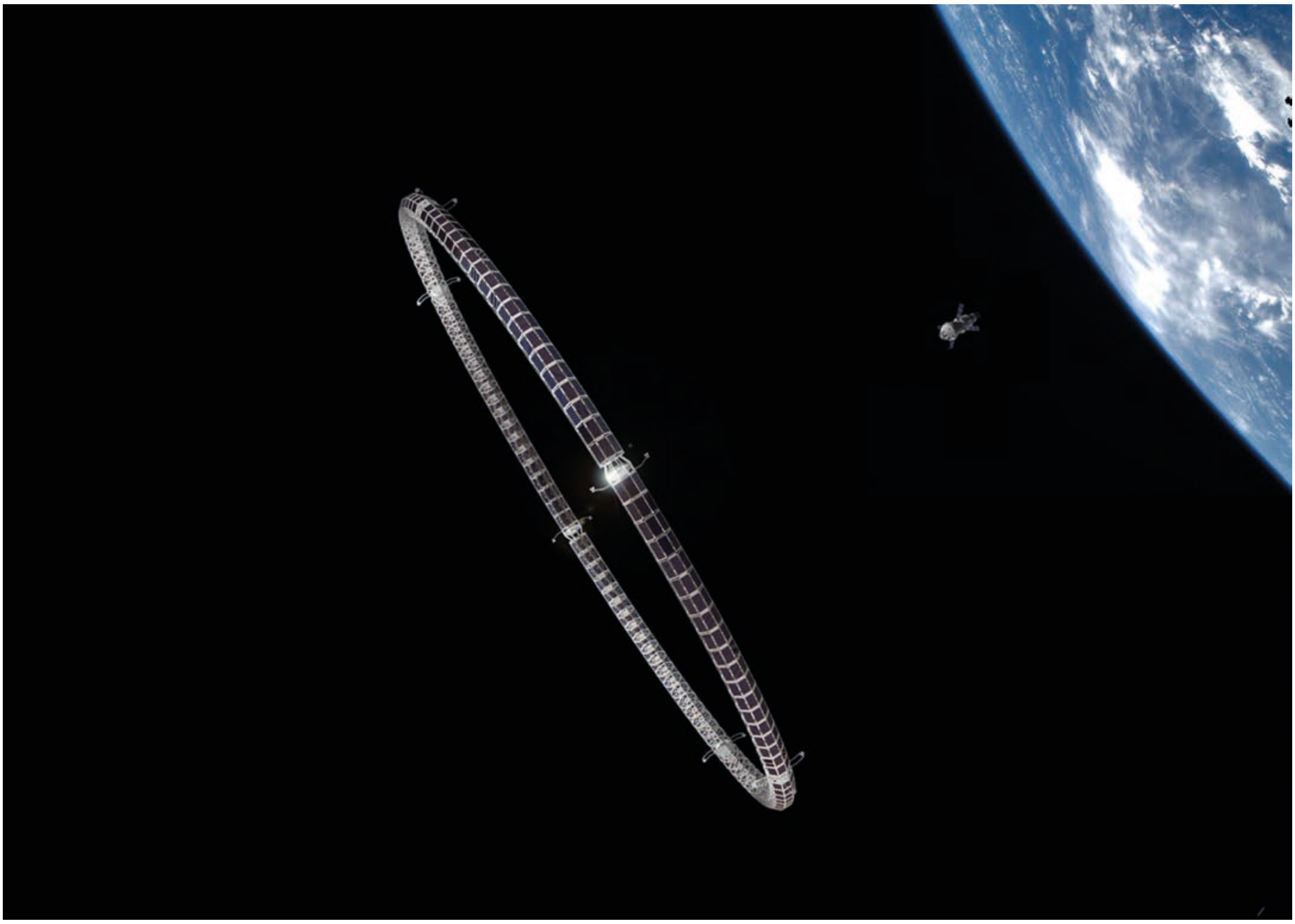

Fig.1 Artist's impression of the Technology Demonstrator in orbit.

down successor to ISS as a near-term commercial objective with minimal non-American participation. Absent will be the international ambition, cooperation and partnership that led to the success of ISS as a global venture.

The provision of artificial gravity in space requires a rotating structure of some kind in which the phenomenon of simulated gravity is induced around its rim as it revolves. Designs can range from twin modules tethered in a 'dumbell' arrangement to 360° circular wheel-shaped structures. Common to all is the physics which involves three variables: the radius of the structure; the angular velocity of its rim; and the level of its artificial gravity13]. To achieve the equivalent of full Earth gravity typically requires a structure with a radius of at least 500 metres that limits the angular velocity or rate of spin to around 1.2 revolutions per minute [14]. This ensures a human comfort zone around the rim that avoids exposure to motion sickness and other negative effects that result from high spin rates. However, there is no reason why such a station would have to operate at full Earth gravity for 100% of the time. It could offer a multi-gravity capability that includes Earth gravity for extended periods as well as a range of conditions that simulate the fractional gravities of the Moon and Mars, the barely perceptible gravities of small objects such as the Martian moon Phobos and perhaps the gravities of distant moons of exploration interest such as Europa or Enceladus. Such a station could cycle through a regime of different gravitational conditions and spend periods of time at each, offering a range of new and unique simulated Solar System environments for research.

The main obstacle to the consideration of a rotating space station is the complete lack of knowledge about the controllability, reliability and safety of such a large object in a space environment. Nothing like it has ever been attempted before. While much know-how exists on the space performance of a 'kit-of-parts' microgravity station like ISS, there has been no plan to send even a small-scale testbed of a rotating station to orbit as an experiment to obtain the most fundamental data. Nearly half a century after the NASA-Stanford study, rotating space stations have yet to reach Level 1 on NASA's Technology Readiness Level scale [15] in which basic principles are observed and reported. The Technology Demonstrator envisioned in this paper is a prototype and testbed that implemented, would raise the Technology Readiness of a future rotating station to Level 7 with a prototype demonstration in the space environment. A successful outcome would stimulate and support the development of a rotating space station as an ideal candidate for a second-generation international station and a worthy successor to ISS.

2 CONFIGURATION CONCEPT

The Technology Demonstrator concept is a truss structure of octagonal cross-section formed into a circular open ring that resembles a giant hula-hoop. Fig. 1 shows an impression of it in orbit. The design is not intended to support any habitat installations or tests though crewed vehicle visits to a suitable stand-off distance may be possible. Its role is confined to prototyping, demonstration and automated control and testing. It dispenses with the bicycle-wheel approach by resolving the tensile forces that build up during spin through the ring's circular structure rather than through spokes and a central hub. Avoiding a hub-and-spoke design simplifies the ring's assembly in orbit, standardizes the type of payloads for its construction and limits the number of launches. Shown is an overall ring diameter of 217 m between truss structure centrelines and a side-to-side dimension of 8 m across the truss's octagonal section. The aim of choosing these dimensions is to achieve the greatest overall ring diameter and truss section size that are possible within payload size and mass constraints of the largest available launch vehicles. The dimensions proposed are provisional, consistent with an early design that has yet to be analyzed. Dimensional and structural optimizations and trade-offs will be major drivers in establishing the feasibility of the concept.

The configuration comprises 120 interconnected truss bays that form the whole ring structure. There are two types of truss bay: a standard bay and an engine bay. Each standard bay comprises a hinged assembly of bulkheads, longerons and X-braces. All standard bays are flatpacked for launch, opening out into their final shape in orbit in a phased sequence. Each engine bay comprises a fixed assembly of bulkheads, struts, berthing mechanisms, a propellant tank, and three extendable low thrust engines. The incremental angle changes that form the curve of the circular ring occur on all the bulkhead lines. Each bulkhead is bifurcated with the two halves opening in orbit like a clamshell to form a 3° angle. 120 bulkhead lines multiplied by the 3° angle results in the complete 360° ring. The 120 bays divide into six identical segments of 20 bays each with each segment comprising 19 standard bays and one engine bay at one end. Fully deployed, each curved segment subtends a 60° arc. Fully stowed, each segment forms a single payload. Six launches can loft the entire ring into orbit. Roll-out photovoltaic arrays on the solar-oriented faces of all the standard bays provide the electric power. Array unrolling is governed by and synchronized with the deployment of the bay structure. Ground-controlled robotic arms mounted on the ring move around it to grapple incoming segment payloads and berth them during the assembly phases. No astronaut presence is required to assemble the ring.

3 RING TRUSS STRUCTURE

Between 1975 and 1985, NASA and its aerospace contractors carried out a series of development studies on very large space structures to be built in orbit using the Space Shuttle, then in the process of entering service. Their original purpose was to function as solar power, antenna and communications platforms. The studies explored automatically fabricated trusses, then preassembled deployable trusses, and then astronaut assembled erectable trusses. Among the studies were two by Rockwell International and Vought Corporation that examined self-deploying structures with hinged joints that folded up compactly for launch, complete with integrated utility systems, and then expanded to their final shape once in orbit. The two contractors focused on systems of struts and hinged joints that formed into rectangular box or triangular prism trusses. The structures would arrive in orbit as the space equivalent of flatpacks stowed in the Shuttle's payload bay. Rockwell examined single-fold trusses in which a structure deploys on one axis [16] while Vought examined double-fold trusses in which it deploys on two axes [17]. At the time of the Space Station's go-ahead in 1984, NASA had terminated this line of studies and chosen an astronaut-assembled truss structure to form the backbone of the 1984 'Power Tower' reference design [18]. NASA abandoned this approach after the 1985 Shuttle *Challenger* disaster and went ahead with a fully-prefabricated truss for the Space Station, since which time further work on large deployable structures has remained dormant. The Technology Demonstrator aims to carries on where NASA's earlier studies left off. It is an evolution of NASA's investigations into deployable structures of the 1970s and 1980s. It utilizes a single-fold deployable methodology for the truss structure but takes it one stage further by incorporating curvature into the geometry, making a fully-circular ring possible. Fig. 2 shows a standard bay in stowed, half-deployed and fully-deployed positions. Each standard bay comprises two octagonal bulkhead frames, eight longerons with hinged end joints and spring-loaded cen-

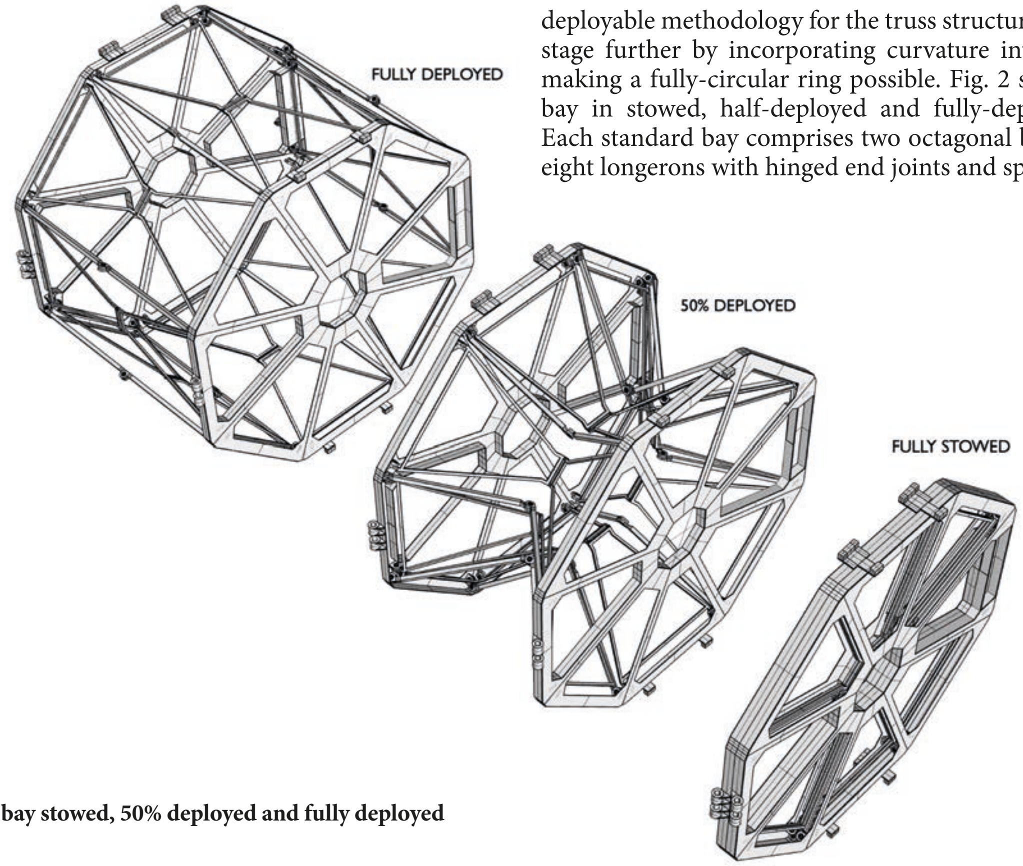

Fig.2 Standard in-bay stowed, 50% deployed and fully deployed positions.

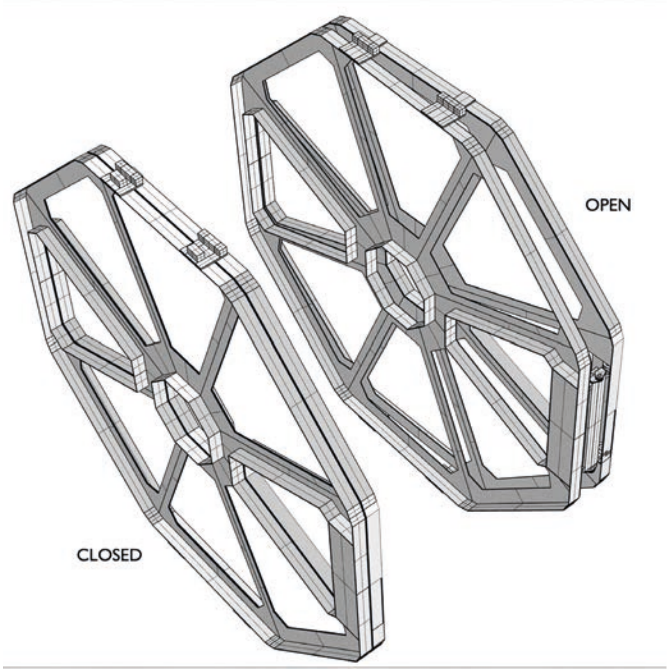

Fig.3 Birfurcated "clamshell" bulkhead.

tre joints and eight X-braces with hinged joints at their ends and centres. In the fully-stowed position from launch to rendezvous at the assembly site in orbit, the two bulkhead frames of every standard bay pack flat against each other with no gaps. Folded closed and stowed inside the voids between the closed bulkheads are the longerons and X-braces. Contained at each longeron centre joint is the stored energy to open the bay. Once released, springs in the joint force the longeron halves to rotate from their stowed positions to their in-line positions when they lock together automatically. The simultaneous unfolding action of all eight longeron centre joints ensures that the bulkhead frames remain parallel as they separate.

The bays are joined end-to-end at their bulkheads. The bulkhead frame of one bay is connected to the corresponding bulkhead frame of the adjacent bay to form a bifurcated bulkhead. In the payload launch and delivery mode, the two frames stack flat against each other in the stowed position. At the assembly site in orbit, they open out like a clamshell to the deployed position at a precise 3° angle. Repeated 120 times, this achieves the curvature of the whole ring. Fig. 3 shows a bifurcated bulkhead in closed and open positions. The two frames hinge together on their inner edges that face towards the centre point of the ring. On the frame outer edges is an opening and closing control mechanism comprising electric motors, gear reduction drives and actuator flaps. This locks in place at the 3° angle, as do four movement stays on the frame upper and lower edges. The advantage of the bifurcated bulkhead is that it enables the truss structure to assume a gradual curve while ensuring that all longerons and X-braces follow standardized designs without variations.

4 LAUNCH AND ASSEMBLY

The constraint on the cross-sectional size of the ring that, in turn, is the constraint on the ring's overall diameter is the volumetric capacity of the payload compartments of the launch vehicles that will deliver the segments to orbit. It is the development of a new generation of powerful launch vehicles in the US that makes this Technology Demonstrator concept possible. At the time of writing, the Space Launch System expendable launch vehicle under development by NASA and a Boeing-led contractor team is expected to be able to offer two vehicle configurations – Block 1B with a 8.4 m diameter and 19.1 m long fairing and Block 2 with a 8.4 m diameter and 27.4 m long fairing – that can both deliver payloads with masses in the 89-103 t range to 556 km altitude orbits [19]. Similarly, the Starship fully-resuable launch vehicle under development by SpaceX is expected to be capable of lofting a 100 t mass payload to a 500 km altitude orbit in a 8.0m diameter by 22 m long fairing [20]. An early estimate of the maximum mass of a single segment payload is in the 75-80 t range and within the limits of all these launch vehicles.

Fig. 4 shows one segment stowed inside a 8.0 m diameter payload fairing. Flatpacked for launch are all the standard bays. Achieving a high ratio of deployed to flatpacked size is an important study aim. In the truss concept shown here, the ratio is nearly 14:1. Above the standard bays is the engine bay which is a rigid frame as it contains engines, a propellant tank and various utilities and subsystems. The engine bay frame tapers to fit into the conical volume in the upper fairing. Segments arrive at the orbital site as six payloads with their own propulsion and navigation abilities.

Orbital assembly comprises eight steps. In Step 1, the first segment with a robotic arm stowed in the flatpack voids arrives and self-deploys to form a 60° curved arc. In Step 2, the second segment arrives and the activated robotic arm berths it to the rear of the first segment. Fig. 5 shows the robotic arm

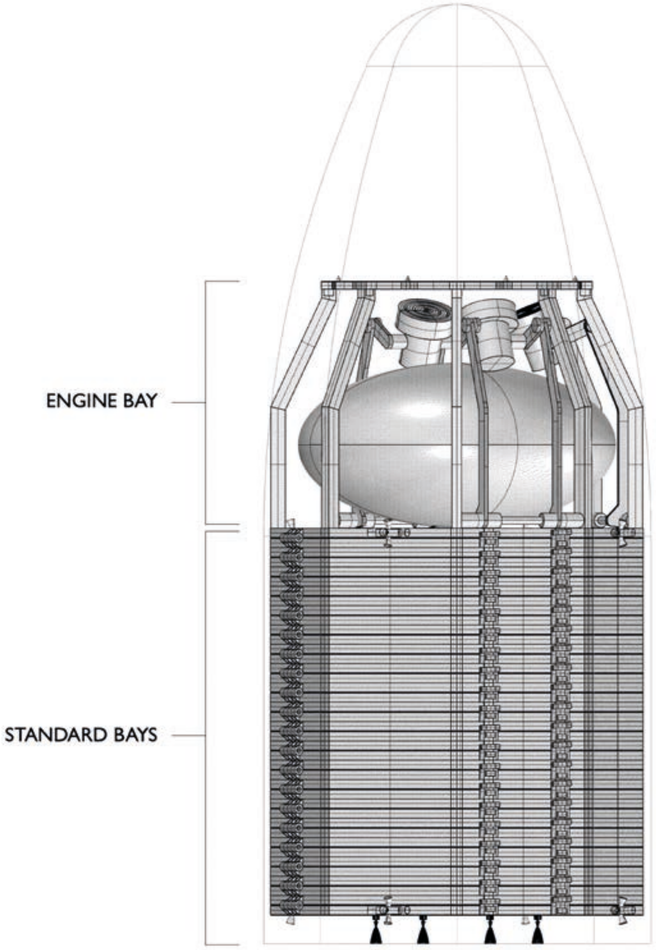

Fig.4 Single segment payload.

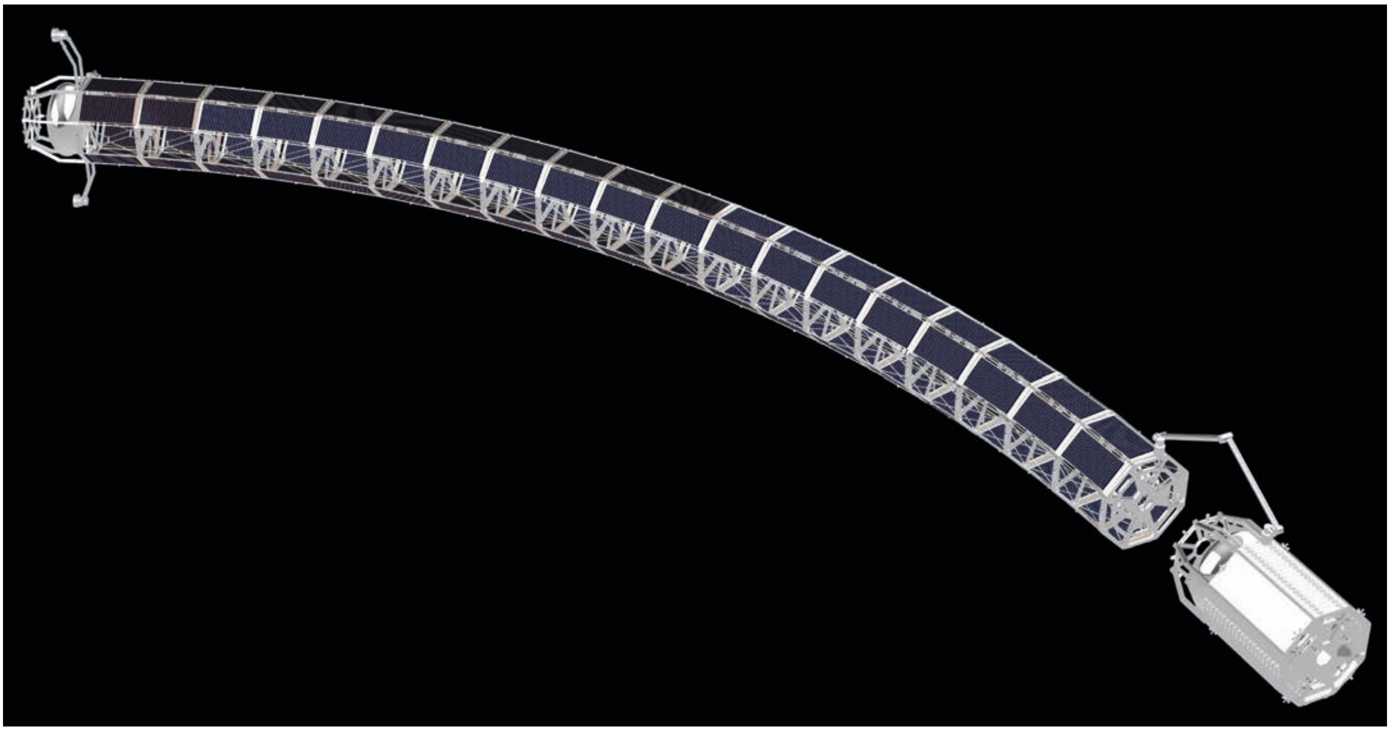

Fig.5 Step 2 of the ring assembly sequence.

grappling the second segment payload and about to bring it into the first segment's berthing interface. Berthing typically follows the procedure used for joining truss sections of the International Space Station carried out by astronauts at control consoles on board the station with dual control back-up from the ground. The procedure involves grappling the incoming payload, then coarse and then fine stud-and-cup mating, then bolting in that order [21]. In the Technology Demonstrator's case, all assembly is controlled from the ground. Once firmly bolted together the new segment self-deploys and the arc increases. Step 3 is similar to Step 2 with the third segment extending the ring's arc to 180°. Steps 4, 5 and 6 repeat Steps 1, 2 and 3 for the second 180° arc, assembled separately from the first and at some distance from it for safety. A second robotic arm arrives in Step 4. In Step 7, the two 180°arcs manoeuvre and reposition themselves in orbit so that their four open ends (two each) face each other. In Step 8 (potentially the most challenging) they gradually close the separation distance and berth together using both robotic arms. Fig. 6 shows the complete Technology Demonstrator ring with each of the six deployed segments clearly visible.

Two robotic arm technologies developed for ISS may be suitable for use in the assembly of the Technology Demonstrator. They are the Canadarm 2 [22] produced by the Canadian Space Agency and the European Robotic Arm [23] produced by the European Space Agency. Canadarm 2 was highly successful during the construction phases of ISS and is now used to berth visiting spacecraft. These robotic arms were designed to operate in microgravity and will need structural stowage and restraint in folded form against the truss structure under all simulated gravity conditions except when the Technology Demonstrator is at rest.

5 PROPULSION, ARTIFICIAL GRAVITY, ROTATION AND ATTITUDE CONTROL

Once the segment payloads arrive in orbit and separate from the launch vehicle, they must navigate and transfer to the orbital site. Each will be required to function like an independent spacecraft. Providing the necessary propulsion will be main engines located at the base of each stowed segment. A flight-proven engine developed for past space applications is desirable to help to limit the amount of new technology required for the ring's development. A typical example of such an engine is the R-4D-11 bi-propellant engine originally manufactured by Aerojet [24]. These engines were used on the Automated Transfer Vehicle built by Europe as a cargo delivery vehicle to ISS. Positioned at the base of each payload stack will be the engines and the bi-propellant tanks recessed inside the standard bay flatpack

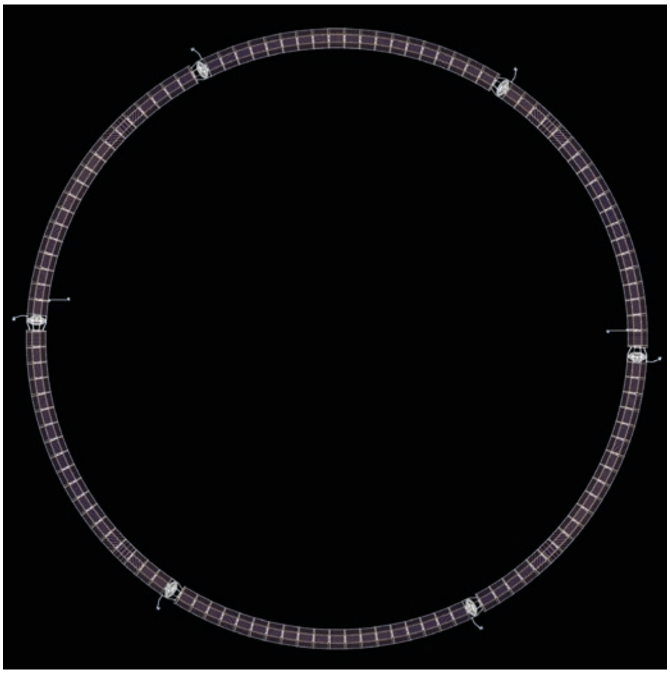

Fig.6 The complete technology demonstrator ring.

voids. Cold gas thruster clusters placed at multiple points on the exterior of the segment payload will provide attitude control. The Technology Demonstrator will rotate at angular velocities that simulate a range of gravities. These include Earth gravity (1 g), Mars gravity (0.38 g), Moon gravity (0.17 g), microgravity (weightlessness – 0 g), as well as gravities of distant moons of special exploration interest such as Phobos, Enceladus and Europa. Artificial gravity will vary with the angular velocity or rate of spin of the ring. For a given diameter, the spin rate increases the artificial gravity's strength. Earth gravity requires the fastest spin. For a ring with an overall diameter of around 217m, the angular velocities to simulate Earth, Mars and Moon gravities are in the order of 2.9, 1.8 and 1.2 rotations per minute (rpm) respectively. It is important to note that 2.9 rpm is considered to be beyond the limit of around 2.0 rpm for human comfort and endurance based on present criteria [25], inducing adverse reactions such as motion sickness if the ring was an actual space station. A rotating space station will require a diameter of around 500 m or more to meet acceptable human comfort conditions under simulated full Earth gravity. An important early task will be to identify, analyze and evaluate the range of static and dynamic loads and accelerations that the ring will experience in its various flight modes. As an example, the quasi-static stresses on the truss structure while spinning at maximum angular velocity of 2.9 rpm for Earth gravity are likely to produce the highest operational tensile loads on the longerons and X-braces.

Low-thrust engines are sufficient to provide Technology Demonstrator rotation in orbit. Indeed, high-thrust engines to generate fast rotation are a disadvantage as an occupied space station will never spin up or spin down quickly. A potential propulsion technology for rotational acceleration, rotational deceleration, flight attitude control and altitude boost should utilize the Sun as an energy source in preference to conventional chemical propellants. The emerging technology of electric ion engines may provide a solution. Powered by photovoltaic arrays mounted on all the solar-pointing faces of the ring, electric ion engines (known as Hall thrusters) accelerate streams of electrically-charged xenon ions to generate thrust. This propulsion technology is now a favoured candidate for advanced Solar System exploration applications at NASA [26]. Fig. 7 shows the installation of three of these engines in an engine bay. On the right, the engines stow in the payload delivery mode. On the left, they swing out to their final positions. The present state of electric ion engine technology poses a challenge due to their extremely low thrust. With six engine bays, the Technology Demonstrator will have eighteen engines delivering a potential total thrust of 90 newtons based at present on a 5-newton engine as a provisional model. With such very limited thrust, the spin-up time taken to reach the equivalent of 1.2 rpm Moon gravity from rest will measure weeks with several more weeks required to achieve 1.8 rpm Mars and then 2.9 rpm Earth gravities. Another challenge will be the high power input to low thrust output performance of these engines. It is conceivable that not more than one engine at a time per segment may be active given the available photovoltaic array area in sunlight on the ring's surface as it orbits the Earth. A further challenge will be the operational endurance of the engines and hence the number of cyclical changes through different gravities that are possible. This will depend on the available propellant and limited by the capacity of the six xenon storage tanks housed inside the engine bay rigid frames.

6 SCIENTIFIC AND COMMERCIAL OPPORTUNITIES

The Technology Demonstrator will offer a unique platform for small scientific and commercial payloads preintegrated into each of the six ring segments and accommodated in the voids between the structural members. Following in the footsteps of ISS with its array of exterior-mounted instruments [27], leading science opportunities will cover Earth observation and the monitoring of global warming, climate change and climate impact. The Technology Demonstrator will probably fly with its plane of rotation perpendicular to the nadir-zenith axis as implied in Fig. 1 to minimize the negative gravity gradient effects on such a large structure. The ring's circle would always face the Earth. In this orientation, the ability to position cameras 200m

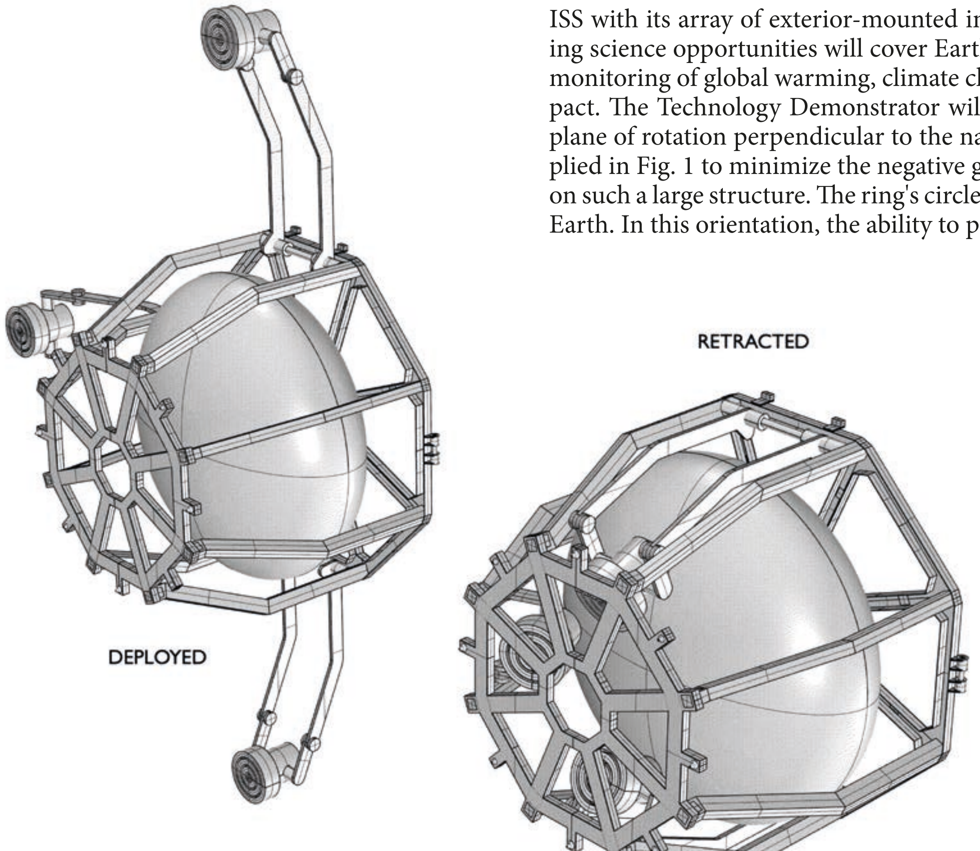

Fig.7 Engine bay with engines deployed (left) and stowed.

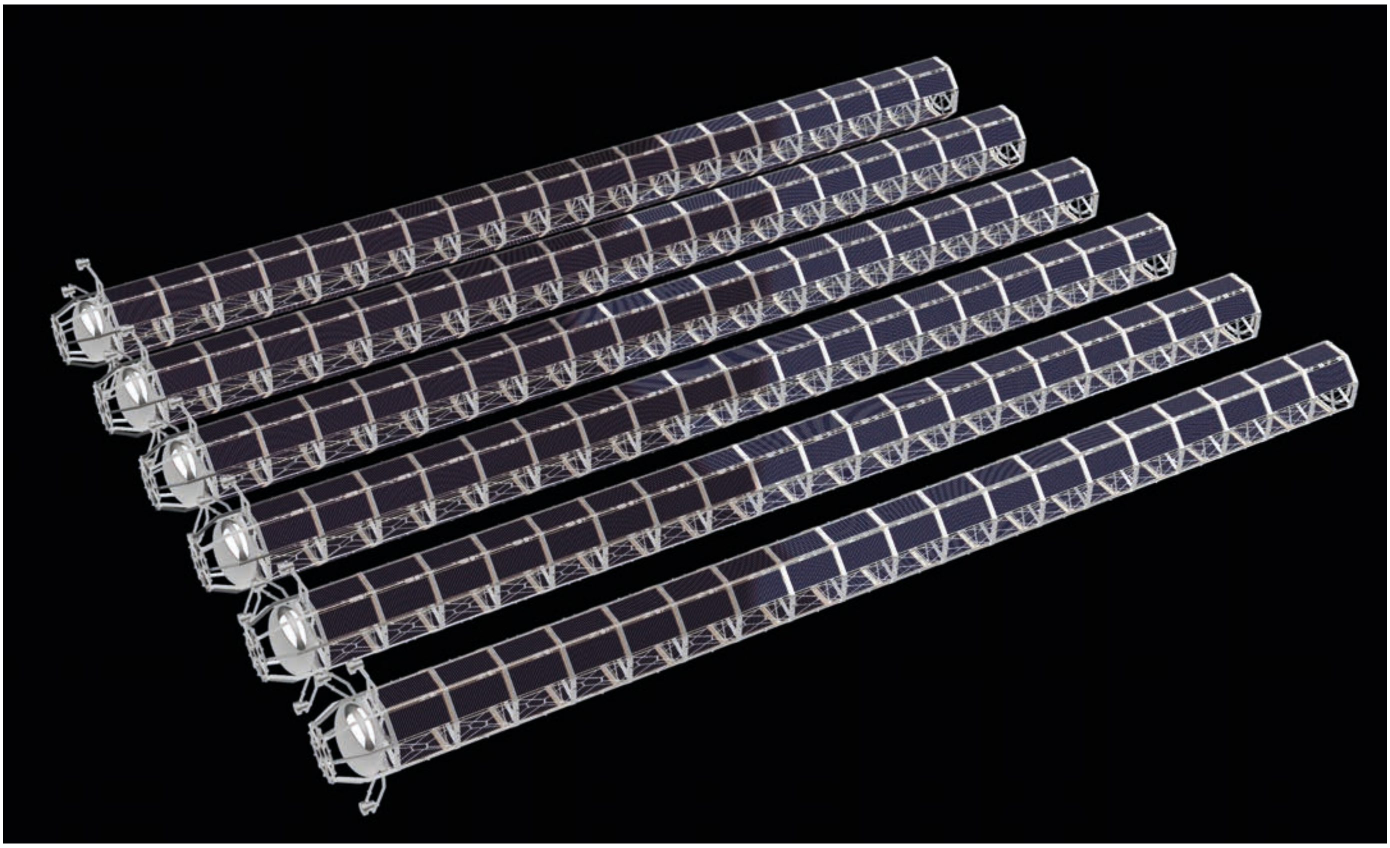

Fig.8 **Dismantled and straightened segments for a follow-on mission**

or more apart on opposite sides of the ring, or even at multiple points around its circumference, may offer new possibilities in the field of high-definition stereo photography. Another possibility may be a linked optical interferometer telescope array which, at 200m diameter, may be capable of offering very high resolution. ISS was originally due to include a centrifuge that NASA viewed as a requirement for variable-gravity biological studies [28] but this was cancelled as a budget reduction measure. The Technology Demonstrator will function as a giant centrifuge, offering a renewed opportunity for the multigravity biological research originally planned for ISS.

The emerging commercial field of 3-D printing in space will benefit from the artificial gravity range on the Technology Demonstrator, enabling opportunities to develop advanced 3-D printing machines designed to perform in different gravities, such as lunar or Martian gravities, with results that would raise the Technology Readiness Level of space 3-D printing towards space exploration goals. The Technology Demonstrator itself will encourage innovation opportunities for a new generation of mechanical and structural components. The truss structure proposed in the concept configuration offers possibilities for the standardized design, development and manufacture on an industrial scale of 912 struts, 912 X-braces, 912 stored-energy joints, 240 bulkhead frames, 240 electric motors, 18 solar ion engines and 11,000 m^2 of roll-out photovoltaic blanket. For the first time, true industrialized manufacturing of a space structure, with the economies of scale it will bring, will become possible.

7 LIFE CYCLE REPURPOSING

The Technology Demonstrator is a prototype and testbed and its mission will be measured in years rather than decades. A typical mission length may be as little as five years, enough time to accumulate operating knowledge and compile data on its performance that will drive the next steps in the engineering evolution of a rotating space station. The question arises as to the ring structure's future beyond its initial mission and what form that takes. The aim will be to avoid its disposal by destructive re-entry and maximize value for money by extending its life cycle and repurposing it for a follow-on mission that serves other uses. This can be much more than a salvage operation if it utilize features incorporated into the design that are dormant during its initial mission but activate for its follow-on mission. It is unlikely that the circular ring shape will be useful for other purposes but with disassembly it can convert and metamorphose into other structures. Dismantling the Technology Demonstrator will follow reverse assembly procedure. The release of berthing mechanisms used to attach the segments together will follow Steps 1 to 8 in reverse order, resulting in six separate curved segments. Straightening the curves will involve closing all the birfurcated bulkheads using the same actuator mechanisms that opened them. Fig. 8 shows the six long trussed beams that will result.

8 ANALYSIS OF FEASIBILITY

A critical first step in the development of a rotating space station is to begin to investigate the feasibility of building and operating a large prototype in orbit. Using the Technology Demonstrator described in this paper as a starting point, an initial feasibility analysis will examine a range of construction, launch, assembly, performance and operations issues, identify critical challenges, highlight major opportunities and propose a baseline configuration. This will raise the Technology Readiness Level from below Level 1 where it is now towards Level 2 in which a technology concept and application is formulated. Consistent with its investigative nature, an initial feasibility analysis will typically cover the following tasks:

1 Concept Configuration Affirm a concept configuration that aims to combine maximum overall diameter and maximum truss section diameter with minimum structural mass and minimum payload volume.

2 Artificial Gravity Affirm the configuration's ability to offer a range of rotation rates equivalent to Earth gravity, Mars gravity, Moon gravity, minimal gravities (such as Phobos), and microgravity.

3 Loads Analysis Define the launch loads and the range of quasi-static loads, dynamic spin-up/spin-down loads, altitude boost loads, gravity gradient effects and structural vibration modes that the configuration will experience in orbit.

4 Structure and Mechanisms Develop a truss structural and mechanical design and associated mass distribution with frames, struts, joints and mechanisms of sufficient strength and stiffness to accommodate launch, orbital loads, accelerations and vibration damping while maintaining stowage efficiency for launch.

5 Orbital Assembly and Deployment Review the use of robotic arms for grappling and berthing of incoming segment payloads and stored-energy mechanisms for the controlled unfolding and deployment of the truss structure standard bays, engine bays and bulkheads.

6 Spin and Attitude Control Examine the potential of ion engine and propellant systems that utilize solar electric power as the energy source to provide thrust and attitude control for spin up, spin down, altitude boost, roll and pitch correction, as well as issues such as variable engine performance and engine failures.

7 Electrical Power Evaluate the electrical energy generation of the photovoltaic array system and its ability to provide required power levels to the solar ion engines and clusters throughout their operational range.

8 Orbital Propulsion Investigate the use of existing flight-proven propulsion systems for payload transfer from launch vehicle separation to assembly rendezvous point.

9 Launch Vehicles and Payloads Evaluate launch vehicles that offer the greatest payload compartment diameter, volume and mass capability consistent with the proposed flatpacking and stacking methodology for the payload segments.

10 Scientific and Commercial Opportunities Assess the ability of truss structure volumes and attachment points to accommodate compact payloads and instruments in fields of scientific research, Earth sensing and observation and commercial applications.

11 Life Cycle Repurposing Explore the repurposing potential of the configuration at the end of its initial mission through reverse assembly of the truss structure segments and their conversion into six trussed beams for other life cycle uses.

12 Baseline Configuration Coordinate and synthesize the results of the feasibility analysis tasks and feed back and input into the configuration concept to produce a revised configuration.

9 CONCLUSIONS

Nearly half a century after the NASA-Stanford Torus study, the world's space powers have made zero progress on moving forward with the vision of a rotating space station. It remains purely a vision. The "kit-of-parts" International Space Station has been a fine technological and political achievement but its competing successors are following a different agenda with their commercial, US-centric business approaches. Lost will be the continuation of a teamed international research effort with the ambition, support, expertise and goodwill of partnering nations. Needed is a reinvigorated technological campaign to design, develop and build a visionary successor to ISS that embodies the state-of-the-art in space habitation and scientific research while maintaining an open door to spacefaring nations everywhere. It must provide an artificial gravity environment for the first time, tailored to human physiology and health while opening up new opportunities in the barely-explored field of partial gravity research. The vast complexity and embedded risk in building a rotating space station will demand that its development follows a path of measured, empirical steps to gain new experience and build technical confidence. The Technology Demonstrator proposed in this paper represents a big step on this path but a vital one.

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