Incredible engineering

Japan's construction giant, Obayashi Corporation, has a vision for a space elevator that draws on NASA's earlier work

By Rob Coppinger

Constructing a space elevator will cost about $130 billion in 2022 US dollars and that money will come from transporting and operating the space based solar power systems that the world needs, according to a study carried out by Japan's Obayashi Corporation. Obayashi is one of Japan's largest construction companies with more than 15,000 employees and it carried out its space elevator study a decade ago. In 2012, Obayashi's white paper, *The space elevator construction concept: a 100,000 kilometer tower connecting the Earth to outer space*, stated that at the time "current technology does not yet allow the construction of the space elevator." But it also states that it could be achievable "within a few decades with the required research and development". One key technology advance in the last ten years is candidate tether materials (See pages 24-27). Tether material that would be the "elevator cable" the payload carrier climbs have been created in laboratories. Production systems can also now produce them at useful lengths such as a kilometre. The Obayashi study assumed a tether material with a tensile strength of 150 GPA and candidates as strong as that can now be made in industrial quantities.

A space elevator broadly consists of four parts. Its fixed point on the surface, the Earth port, the tether that extends up to 144,000 km above, the tether climber and an apex anchor point at the tether's end (See pages 16-17). The tether is kept under tension and stationary over a single position on Earth due to the competing forces of gravity at the planetary end and the other end's outward centripetal acceleration. Obayashi estimated that tether and climber development would take about 20 years, while the Earth port would take a mere five years to design and another five years to build. The firm sees the space elevator as an international project with no one country or company undertaking this daunting task.

The space elevator transportation system architectures do not assume just one elevator on Earth, rather they envisage a number of them (See pages 16-17), perhaps grouped together or placed around the equator. The Obayashi elevator concept would also be based at the equator. The construction company's Earth port concept is to have one part offshore and the other, the supporting facilities, onshore. They would be connected by a 10 km long tunnel. The offshore part would be where the tether is fixed to the planet's surface.

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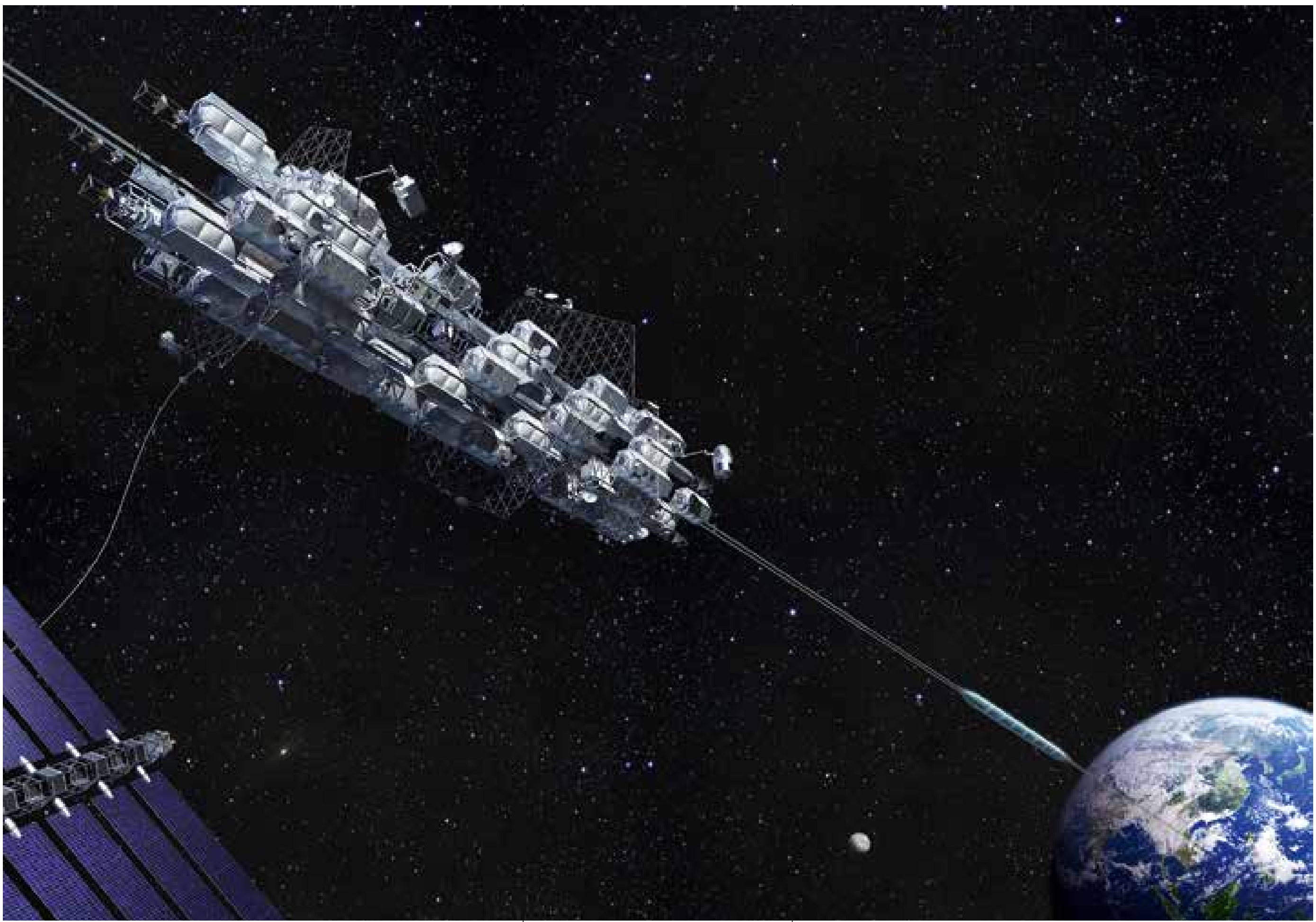
Being offshore, if debris or a climber fell they would land in the sea and not a potentially populated area onshore. The tether is also expected to be more easily be captured out at sea, and more safely for terrestrial populations, and transported to the port. This is where the tether descends from a spacecraft for the elevator's construction (See below). Obayashi states that sea water can also be used for adjusting the tension of the cable by filling and draining the water in a ballast tank. The offshore part of the port would have a floating concrete base.

The Earth Port consists of an upper building and that concrete floating body. Inside the underwater concrete floating structure is a parking lot. The upper building has a 400 m diameter and is built primarily for the climbers. As well as this arrival, departure area, the upper building includes medical and quarantine areas, a hangar and a climber service bay, a facility management area, workers' cabins and cargo bays. In total, the offshore Earth port displaces four million tons (3,628,738 tonnes) and has about 5,000 employees. The Obayashi paper states the largest tanker ships in 2012 displaced 600,000 tons.

CONCRETE SEMI-SUBMERSIBLES

The concrete floating body is manufactured in multiple pieces onshore and assembled after it is put on the water. It is then towed to the Earth port site by tugboats. This concrete floating structure is based on what is called a "semi-submersible type". This means it consists of an underwater floating hull, deck and connecting hollow columns. It is used mostly for seas where the sea state can be heavy with high waves for long periods. These floating hulls are moored to the



PHOTOS: OBAYASHI CORPORATION

sea bottom using high tensile steel tension legs attached to buried suction anchors. This all stops the port drifting away. But the port is also mobile. It can be disconnected from those suction anchors and moved to another site.

While the offshore section of the port is connected to the onshore facilities by an undersea tunnel, this tunnel is constructed in the same way. Like the offshore port, the tunnel consists of concrete sections produced onshore and moved into position and held in place by high tensile steel tension legs attached to buried suction anchors. Once in place, the tunnel can be connected to the shore and offshore platform and the water pumped out. The onshore supporting facilities would include an airport, hotels for the general public, offices and light industrial facilities for enterprises engaged in utilisation of space resources, and factories and warehouses.

The tether that extends upwards from this port can theoretically be as long as 144,000 km but can be shortened using a counterweight at the apex. Obayashi found that the tether length can be between 36,000 and 144,000 km. Obayashi decided that the length should be 96,000 km. This was decided because 96,000 km means the tether is not susceptible to lunar tidal forces, it is a length that can impart a velocity to a spacecraft for missions to Mercury or Saturn and for construction purposes, the overall length of the cable should be a multiple of 12,000 km.

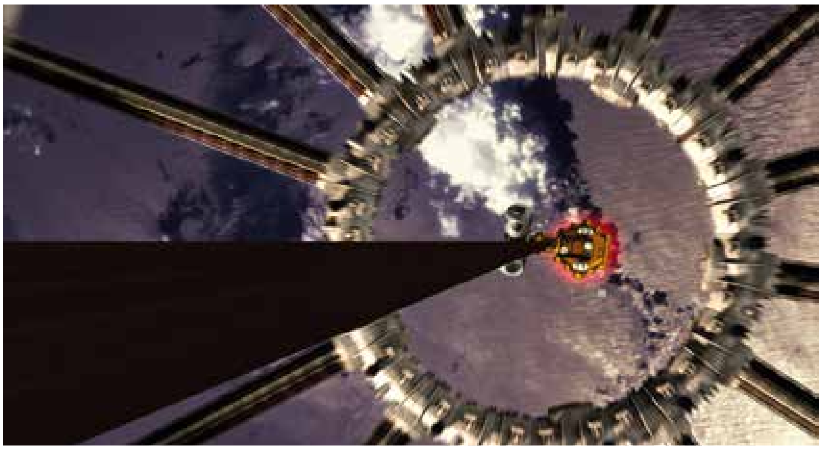
The tether is not launched from the ground, like string attached to a rocket. Instead, a spacecraft with the tether onboard is launched and the tether is

FROM TOP

Dozens of climbers are off loading and loading cargo at the elevator's geostationary station.

The space elevator's geostationary station is where payloads can continue upwards for an apex launch to planetary destinations or be carried by space tugs to other geostationary orbital inclines.

lowered through the atmosphere. In the Obayashi plan, seven United Launch Alliance Delta IV Heavy rockets launch what is needed for the construction spacecraft in low Earth orbit (LEO). The whole spacecraft is assembled at LEO and the total payload is 125 tons. This includes two 20-ton tethers, the »



36.8-ton spacecraft which acts as the apex counterweight and then the "thruster" that will lower the Earth port end of the tether. Then there is the fuel for the tether thruster and the spacecraft itself.

The spacecraft uses its fuel to raise itself to a geostationary orbit. From there, the two tethers are reeled out and the thruster de-orbits the two tethers' Earth port end. The tethers are reeled out at a speed of 40 km per hour. It will take about 100 days for the two tethers' Earth ends to reach the planet's surface and the port. Once the tethers are fixed to the Earth Port, the thruster is replaced with the Port's aforementioned sea water ballast system. The first climber with a mass of 422 kg climbs up by taking hold of the two tethers which simultaneously reinforce the two cables.

NASA

Obayashi states that it "basically followed" the construction processes set out in the 2002 book by Dr Bradley Edwards and Eric Westling, *The Space Elevator: A Revolutionary Earth-To-Space Transportation System*. Edwards led a NASA Innovative Advanced Concepts (NIAC) study whose report, *The Space Elevator NIAC Phase II Final Report*, was published on 1 March 2003. It states that "the space elevator could be operational in 15 years for $10 [billion]". Ten billion US dollars in 2003 would have been worth in 2022 $16 billion, far below the Obayashi 2012 estimate, whose cost is a scale similar to NASA's Apollo and Artemis programmes.

Edwards and Westling's construction approach begins with an 8 in (203 mm) tether, referred to as a ribbon. Like the Obayashi scenario, the ribbon is attached to anchor spacecraft 62,000 miles (99,779 km) above the Earth's surface. There would be four spacecraft and they would be placed into orbit by four "expendable launch vehicles". On Earth, the ribbon will be attached to an "ocean-going anchor platform located in the eastern equatorial Pacific". The first few climbers will ascend the ribbon and add to it until a complete elevator system is achieved.

The final system will have a ribbon that is 3 ft (0.914 m) wide and thinner than paper with mechanical climbers climbing up and down it, capable of delivering 13-ton payloads to any Earth orbit. Edwards and Westling's candidate ribbon material is carbon nanotubes. The climbers receive energy using laser power beaming and the port has a debris tracking system. The total payload capacity of the elevator system will be about 1,000 tons per year at an operating cost of $100 (2003 US dollars) per pound to any Earth orbit.

In the 20 years since that NIAC study, Edwards has continued to develop the technical knowhow to realise a space elevator. His firm, The Space Elevator Company is his vehicle to further advance the cause of this transportation system. Its website summarises the conclusions from the last 20 plus years of work. Power beaming is still the preferred method to deliver power to the climber. Using the ribbon, the tether was found to encounter the problem of high electrical resistance in the material.

The climbers, which will have photovoltaic arrays to collect the beamed power, would use off-the-shelf electric vehicle motors and controls, composite structures, and flat rubber tires to grip the tether. An automotive firm is expected to be able to build the climbers required initially. Edwards cites the climber competitions that have seen battery and laser powered climbers reach speeds of 100 kph on ascents of hundreds of metres. Edwards expects the first few climbers will ascend this initial ribbon and attach additional ribbon to the existing one. These climbers will reach the top of the tether and stay there, along with the original four spacecraft, as part of the apex counterweight.

200 CLIMBERS

Edwards expects that after about 200 climbers have ascended, the elevator will be ready to carry 25 ton climbers for commercial operations. The tether and climbers are susceptible to space debris. With Edwards concept, commercial debris tracking services will be used alongside an "upgraded system to track all debris down to 1 cm diameter". Once the debris is tracked the lower end of the ribbon anchor station can be moved to avoid collisions. With existing debris levels, Edwards expects to move the lower end of the ribbon on average a kilometre every 12 hours.

On his firms' website, Edwards estimates the first

The Earth Port consists of an upper building and that concrete floating body. Inside the underwater concrete floating structure is a parking lot

FROM ABOVE

Artist Alan Chan's impression of a climber passing through a space station structure built around the elevator at a geosynchronous altitude.

Alan Chan's impression of an equatorial Earth port beaming its power upwards for the tether climbing the elevator tether.

PHOTOS THIS PAGE: THE SPACE ELEVATOR COMPANY

PHOTOS THIS PAGE: ADRIAN MANN

elevator would take eight years to build at a cost of $8 billion. While studies have continued in the United States including ground-based climber competitions, Japan has actually tested tether technologies in space. The two tether missions were Space Tethered Autonomous Robotic Satellite – Cube (STARS-C), which occurred in 2017, and Space Tethered Autonomous Robotic Satellite – Elevator Cubesat (STARS-EC) which took place in 2021. Both mission cubesats were built by Japan's Shizuoka University. The STARS-C microsatellite was a 2U cubesat and STARS-EC was a 3U cubesat. Both were deployed from the International Space Station's (ISS) Japanese "Kibo," Japan Experimental Module (JEM). It has a small satellite deployment system called JEM Small Satellite Orbital Deployer or J-SSOD.

The STARS-EC microsatellite re-entered the Earth's atmosphere on 17 April last year. It had been launched to the ISS on 21 February 2021 onboard a Northrop Grumman Cygnus resupply ship. Built by Shizuoka University's faculty of engineering, STARS-EC consisted of three 1U cubesats and contained a 22 m tether. STARS-EC was deployed by JEM-SSOD on 14 March 2021. The experiment was to separate the three cubesats, so the two either side of the middle cubesat became the two ends of the 22 m tether. The middle cubesat would then move up and down the tether. The experiment was carried out in April and May 2021.

The earlier STARS-C mission was deployed from the ISS by JEM-SSOD on 19 December 2016, the experiment was caried out in early 2017. Its mission was to verify two basic technologies required for a space elevator, the tether deployment technology and the climber. STARS-C consisted of a mother satellite and a daughter satellite connected by a 100 m tether. The mother and daughter satellites' mission was focused on studying the tether dynamics during the deployment. The goal was to improve the smoothness of future tether deployments for missions including a space elevator. The mother and daughter satellites had common power, communication, and command and data handling systems, and tether spool and reel mechanisms.

From the Earth port to the tether deploying spacecraft assembled in orbit after multiple commercial launch vehicle missions, there is a great deal of the space elevator technology that already exists and some of it is even flight proven. While producing a 99,000 km long tether of carbon nanotubes is still a huge challenge, the greatest challenge for space elevators now is finding the $10-100 billion needed over 15-30 years required to fully construct this bridge to the stars. SF

FROM TOP
Space elevators' bases will be equatorial.

A captured asteroid could be the apex counterweight for a space elevator. Facilities located here could help manage and maintain the elevator.