A Survey of Space Settlement Designs

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I. Summary

The author compiled every known orbital space settlement design into a database. Grouped into chronological 'eras,' the database describes basic information for each design: population capacity, dimensions, gravity level, energy source, etc. Using this information one can conclude that interest in space settlement is increasing, 1g is the preferred gravity level, solar power is the preferred energy source, and a torus is the preferred geometry. As for location, Earth-Moon Lagrange points dominate but there is a budding movement to place settlements in low Earth orbits. The database is accessible at http://www.nss.org/settlement/journal/Space-Settlement-Designs-Database-12.19.16.pdf.

II. Introduction

Interest in space settlement is on the rise. The National Aeronautics and Space Administration (NASA) is making slow and steady progress on its journey to Mars[1]. Elon Musk, billionaire founder of commercial space company SpaceX, recently announced a plan to colonize Mars[2]. When a marketing company announced plans to offer a one-way trip to the Red Planet, over 200,000 people volunteered[3].

While efforts to settle Mars garner most media coverage, there is a significant, albeit less publicized, level of interest in orbital space settlement—that is, permanent human settlement in structures orbiting around a celestial body rather than on its surface. Well-heeled startups Bigelow Aerospace, Virgin Galactic and Blue Origin have all made commitments to expanding the human presence in orbit. It's not just the startups, though: established aerospace giant United Launch Alliance is planning for hundreds of people living and working in orbital space in the coming decades[4]. Even President Obama is strongly in favor of the concept of space settlement[5].

In light of the burgeoning interest in orbital space settlement, this survey was assembled to facilitate education and research on the topic. The accompanying database collects all known, detailed plans for orbital space settlements. The database is a work in progress

[1] NASA's Journey to Mars, http://www.nasa.gov/content/nasas-journey-to-mars, accessed 14 Dec 2016

[2] "IAC Mars Talk, Revised," SpaceX, http://www.spacex.com/sites/spacex/files/mars_presentation.pdf, accessed 14 Dec 2016

[3] Landau, Elizabeth, "200,000 people apply to live on Mars," CNN, 10 Dec 2013, http://www.cnn.com/2013/12/10/tech/innovation/mars-one-plan/, accessed 14 Dec 2016

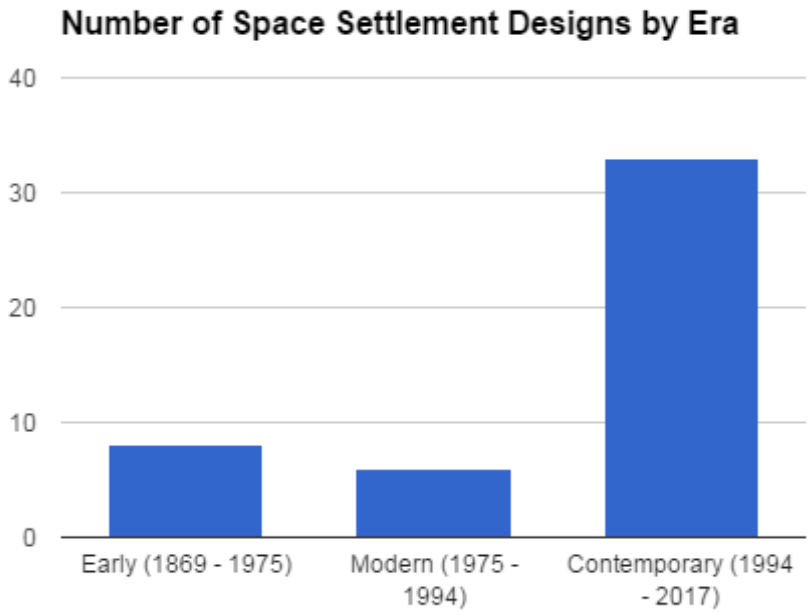
[4] "Transportation Enabling a Robust Cislunar Economy," United Launch Alliance, 9 April 2016, http://www.ulalaunch.com/uploads/docs/Published_Papers/Commercial_Space/2016_Cislunar.pdf, accessed 14 Dec 2016

[5] "We have set a clear goal vital to the next chapter of America's story in space: sending humans to Mars by the 2030s and returning them safely to Earth, with the ultimate ambition to one day remain there for an extended time." President Barack Obama, 11 Oct 2016, CNN, http://www.cnn.com/2016/10/11/opinions/america-will-take-giant-leap-to-mars-barack-obama/index.html?adkey=bn accessed 14 Dec 2016

and will be refined as time goes on. Despite this, space scholars and space settlement architects are encouraged to use this report as a starting-point for further research.

III. Key Data Findings

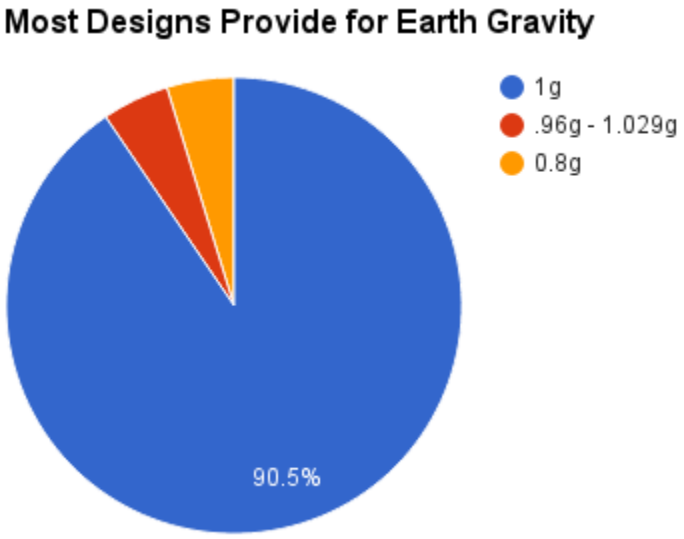
A. It appears interest in orbital space settlement is increasing. Specifically, the number of space settlement designs published in the past twenty-two years increased versus the previous 125 years. The database contains forty-seven designs. Eight designs were created in the 'early' era before 1975 i.e. from Hale's *Brick Moon* in 1869 until Dandridge Cole's *Bubbleworld* in 1964. In the modern era, from 1975 to 1994, six designs were created. 1975 was selected as the start of the 'modern era' because it was the first year of the O'Neillian designs. Dr. Gerard K. O'Neill and his team applied viable engineering solutions in an attempt to solve the challenges of orbital space settlement. His book, *The High Frontier*, inspired thousands to build upon his work. As a result of the work in the modern era, the pace of design picks up in the 'contemporary era,' which begins in 1994. This is the year the NASA Ames Space Settlement Contest started[6]. The contest is responsible for most of the designs in the database. Since 1994 thirty-three designs were created, with twenty designs announced in the past ten years. The increasing numbers of designs in shorter time periods is evidence that interest in orbital space settlement is increasing.



B. Designs share common characteristics, first and foremost regarding gravity. Every design rotates in some way to provide artificial gravity. Of the eleven

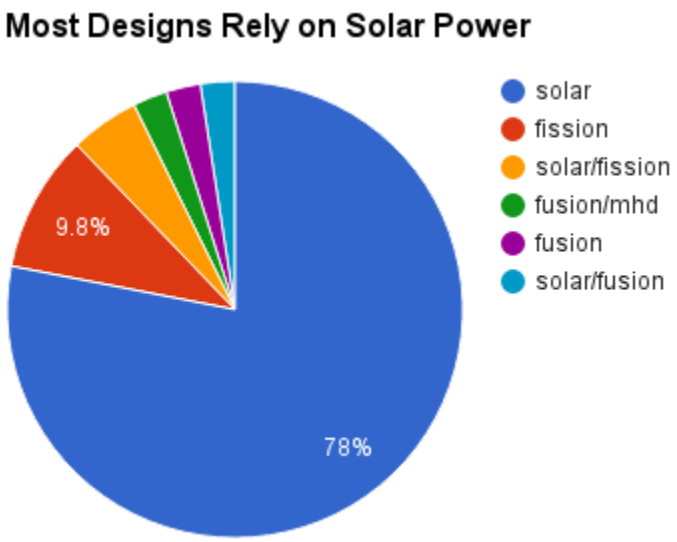
[6] NASA Ames Space Settlement Contest, https://settlement.arc.nasa.gov/Contest/ , accessed 19 Dec 2016. "This annual contest, co-operated by NASA Ames Research Center, San Jose State University, and the National Space Society (NSS) is for all students up to 12th grade (18 years old) from anywhere in the world."

designs that specified the internal gravity level, all provided approximately 1g. This uniformity in design likely reflects the absence of experimental data regarding how much gravity a human being needs (or can tolerate) to thrive in space. Thus all designs are built around a conservative baseline of delivering approximately 1g. This is especially interesting to note because NASA recently stated the gravity issue is "solved"[7] and likely will not provide artificial gravity on future long-duration NASA missions. Furthermore, settlements on the Moon or Mars cannot easily rotate to provide 1g. If a critical mass of space settlement designers have all agreed that 1g is needed in orbit, do a similar critical mass agree that 1g is needed for settlers on planetary sized bodies? If so, how will this drive the design of these settlements or even months-long visits (as is planned by SpaceX, ESA and others)?



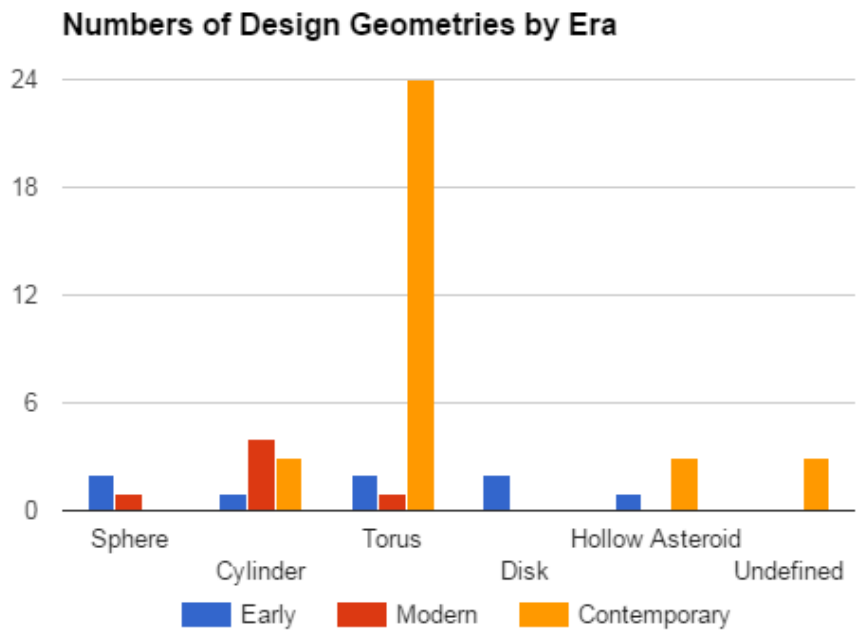
C. Most designs incorporate solar electric or solar thermal power for electricity production. Several incorporate nuclear reactors and three rely on fusion power. Note: of the 47 designs in the database, six did not specify the type of power source used for electrical energy generation.

[7] "Gerstenmaier and Kornienko spoke at the IAC a day after Elon Musk rolled out his Mars mission architecture, and, in questions after his talk, he deflected any concerns about the effect of microgravity on his spaceships' crews. "I think those are essentially solved problems," he said, arguing that long-duration ISS missions are much longer than his planned Mars transits. "It's fairly straightforward."" Foust, Jeff "The weak pull of artificial gravity," *The Space Review*, 31 Oct 2016, http://www.thespacereview.com/article/3094/1, accessed 14 Dec 2016



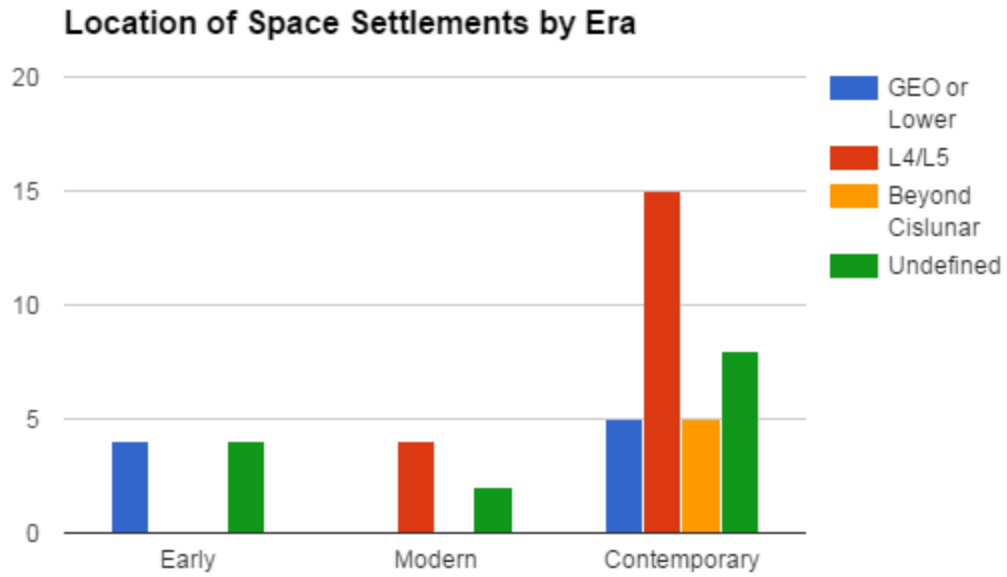
IV. The Evolution of Space Settlement Design

A. **A Preference for Tori.** Most contemporary designs are toroidal while earlier designs were more varied in their geometries. Several modern era designers were attracted to hollow asteroids and cylindrical designs but this preference disappears the closer we get to the present day. This is likely an acknowledgement that tori are a more efficient shape for containing atmosphere and maximizing internal land use and, with increasing knowledge about asteroid composition, designers today feel that the challenges of hollowing out an asteroid are greater than that of building a structural shell 'from scratch' in orbit. It is unclear from the data if any of the hollow asteroid designs call for a toroidal shape inside the asteroid.



B. **Locally-Grown.** Early designs were located primarily in Earth orbit. In the modern era and most of the contemporary era designers preferred the Earth-Moon Lagrange points. In very recent years, however, a few designs are returning to Earth. Moving settlements closer to Earth is a recognition by some designers that if large space populations are going to be built in our lifetimes, they are going to be built as close to Earth as possible in geosynchronous orbit or below. Additionally, the recent discovery[8] of low radiation levels in equatorial low Earth orbit (ELEO) increased the appeal of placing settlements in Earth orbit. Also of note: most of the very recent GEO and lower settlements do not use in-situ resources for construction. This is a signal that the designers expect launch costs to become relatively low in the foreseeable future. However, it appears that the Earth-Moon Lagrange points are still the location of choice for most space settlement designers.

[8] Globus, Al, "Space Settlement: an Easier Way," San Jose State University, June 2016, http://space.alglobus.net/papers/Easy.pdf, accessed 14 Dec 2016.



V. Conclusion and a Request

For over 150 years, humans have dreamed of building communities in orbit. It was an obscure phenomenon and continues to be so today, with relatively small groups of dedicated people continuing to discuss the idea. However, as access to orbit improves and robotic technologies advance, the possibility of building a permanent settlement in orbit will become more feasible.

Thus, more entries will be added to this database and, hopefully, more people will find it useful. Therefore a request: if you find errors or oversights, or if you have thoughts on how to improve the database, please email thisorbitallife (at) gmail (dot) com to suggest your feedback.

Ad astra!