Pretending Architecture:

The Journey Towards Verne Station

by

Jamie Verdell Ferreira

A thesis

presented to the University of Waterloo

in the fulfillment of the

thesis requirement for the degree of

Master of Architecture

Waterloo, Ontario, Canada, 2025

© Jamie Verdell Ferreira 2025

Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

This is a record of pretend architecture, a journey of fabricating fantasy in the form of a virtual environment that is an *authentic fake*. This is an exploration inspired by the many fictional stories that I have encountered in order to create an interpretation of a space station. Framed by the harsh reality of space and contrasted by idealistic viewpoints in film, literature and video games, the end result presented is a far cry from initial expectations. It is a means to an end; a way to explore architecture in outer space with the use of constructs.

Verne Station exists as fragments of experiences; attempts to understand and discover the intoxicating ideals of a limitless frontier ruled by the harshest of living conditions. By use of the machine, one has the ability to create complex virtual environments to simulate and visualize space architecture concepts; a field that has historically been inaccessible to many. By simulating different scales of artificial gravity design, the real-time exploration of designed spaces can facilitate a clearer understanding and more effective visual feedback of potential space architecture designs.

This is a thesis about coming to terms with not arriving at your original destination, the one you imagine and expect to reach, but instead, the real one which you never quite anticipated.

Acknowledgments

To my lovely wife, Rosanne, for her unwavering support, and to my son, Logan, for whom I would bring the moon. To my parents and family, for their unconditional love and support throughout my life. To my friends and colleagues, for keeping things fun. To my supervisor, David Fortin, for his encouraging words of wisdom and incredible help in guiding me to finally complete and defend this chaos of a thesis. To my examining committee member, Robert Jan Van Pelt, for his insight and support over the years. To Brady Peters, for taking the time to serve as my external reader and for bringing his knowledge to the table. And to all the University of Waterloo staff and professors who supported me throughout my time at the School of Architecture, I thank you all. Without you, I would not have been able to complete this long journey.

Lastly, thank you to those who have helped make space travel and exploration a reality. We truly live in a remarkable age and I hope that one day the stars will be within reach for everyone who dares to venture into the vast, unknown beauty and mystery of outer space.

Land Acknowledgments

This thesis was written at the University of Waterloo School of Architecture which is located on the traditional territory of the Neutral, Anishinaabeg and Haudenosaunee peoples. The University is situated on the Haldimand Tract, the land promised to the Six Nations that includes 10 kilometres on each side of the Grand River.

TABLE OF CONTENTS

Author's Declaration ii
Abstract iii
Acknowledgments iv
Land Acknowledgments v
List of Figures viii
List of Acronyms xvii

01: Introduction **1**

Contents 5
Simple Beginnings 8
A Cautionary Tale 11
Preface 14

02: Anticipating Our Presence in Outer Space **17**

Acts of Pretending 21
Simulating the Journey 36
The View from Space 48
Manned Spaceflight 50
Understanding Living in Space 58
We Continue to Anticipate 66
The Evolution of the Medium 78

03: Virtual Experimentation **93**

Virtual Simulation 96
Human AR/VR Interface 106
Rise of the Simulator 109
Selecting the Game Engine 117
Ease of Use 118
Large Centrifuge Test 122
Small Gravity Test "Satellite" 125

04: What Might be Built **135**

Designing for Space 138
Mission Objective 140
Modular Construction 148
Artificial Gravity 152

Failure Points 156
Life Support Systems 160
Combating Isolation 162
Economic Reasoning 164
Tourism 170
Day and Night Cycle 172
Vegetation 173
Schematics 176
Phase 1: Command Module 178
Phase 2: Tethered Habitats 180
Phase 3: Main Axis Expansion 183
Phase 4: Main Pathway Chords 184
Phase 5: Main Ring Array 187
Phase 6: Microgravity Bio-Dome 192
Phase 7: Existence 204

05: Conclusion **209**

End Remarks 211
Afterword 216

Bibliography 219
Film/Movies 235
Video Game Software 237
Model Assets 238

LIST OF FIGURES

3. . . . . Figure – 1. 1 *Moby Dick Swam Swiftly Round and Round the Wrecked Crew*, Isaac Walton Taber, 1899

7. . . . . Figure – 1. 2 My beloved Nintendo Entertainment System, photograph by author, 2013

10. . . . . Figure – 1. 3 Taking the warp level shortcut in *Super Mario Bros., (1985)* screen capture

19. . . . . Figure – 2. 1 Stars Leave Streaks of Light in Concentric Circles, Photograph by Don Pettit, NASA, 2012, https://www.flickr.com/photos/nasacommons/9460163430/in/album-72157634973839148/

21. . . . . Figure – 2. 2 The Wolves Pursuing Sol and Mani, Guerber, H. A. (Hélène Adeline) (1909). Myths of the Norsemen from the Eddas and Sagas. London : Harrap.

24. . . . . Figure – 2. 3 *Otto Lilienthal with his small wing flapping apparatus near to the "Fliegeberg."* 1894; photographer Ottomar Anschütz, https://commons.wikimedia.org/wiki/File:Otto_is_going_to_fly.jpg

26. . . . . Figure – 2. 4 J.T Mastason had grown fat, Illustration, *From the Earth to the Moon*, Jules Verne, 1866, https://www.oldbookillustrations.com/illustrations/grown-fat/

26. . . . . Figure – 2. 5 The Interior of the Projectile, Illustration, *From the Earth to the Moon*, Jules Verne, 1866, https://www.oldbookillustrations.com/illustrations/interior-projectile/

27. . . . . Figure – 2. 6 *A Trip to the Moon*, Film Still, George Méliès, 1902

31. . . . . Figure – 2. 9 Dr. Robert H. Goddard observes the launch site from his launch control shack while standing by the firing control panel, 1940, NASA, https://digitalnm.unm.edu/digital/collection/roswell/id/901/rec/41

34. . . . . Figure – 2. 10 Bumper 8 launch at White Sands Test Facility, NASA, 1950, https://www.americaspace.com/2020/07/24/roar-of-the-bumper-remembering-the-capes-first-launch-70-years-on/

35. . . . . Figure – 2. 11 Apollo 11 Crew undergoing Lunar surface Training on April 22, 1969, NASA, https://images.nasa.gov/details/S69-32233

40. . . . . Figure – 2. 12 The Gimbal Rig (MASTIF), photograph, 1959, NASA, https://commons.wikimedia.org/wiki/File:Project_Mercury_-_AWT_Gimbaling_Rig_-_GPN-2000-000691.jpg

41. . . . . Figure – 2. 13 Mercury astronauts training in simulated weightless flight inside NASA's KC-135, a C-131 aircraft, 1961, NASA, https://commons.wikimedia.org/wiki/File:Mercury_Astronauts_in_Weightless_

Flight_on_C-131_Aircraft_-_GPN-2002-000039.jpg

43. . . . . Figure – 2. 14 Artist sketch of the Lunar lander mission simulator, NASA

43. . . . . Figure – 2. 15 Three astronauts inside the Command Module Simulator in Building 5 during an Apollo Simulation. Left to right, are astronauts Thomas P. Stafford, commander; John W. Young, command module pilot; and Eugene A. Cernan, lunar module pilot, (S68-15952) , 1968, NASA, https://images.nasa.gov/details/s68-15952

45. . . . . Figure – 2. 16 Apollo Mission Lunar Module Simulator, NASA, 1972, https://wikiarchives.space/picture.php?/54233/category/138

47. . . . . Figure – 2. 17 Earth Rise photographed during Apollo 8 flight. 12/24/1968 - NASA, 68-HC-870, https://www.flickr.com/photos/nasacommons/9460163430/in/album-72157634973839148/

49. . . . . Figure – 2. 18 The descent vehicle from the Vostok I spacecraft is seen at the landing site 700 km south-east of Moscow on April 12, 1961, https://www.irishtimes.com/life-and-style/people/the-man-who-fell-to-earth-1.567958

52. . . . . Figure – 2. 19 Astronaut Eugene Cernan drives the Lunar Roving Vehicle during first EVA, 1972 NASA, https://images.nasa.gov/details/as17-147-22526

53. . . . . Figure – 2. 20 *A Lunar Landscape*, Mural study. Oil on board. 5.5 x 20.5, Chesley Bonestell, 1957

55. . . . . Figure – 2. 21 *Saturn as Seen from Titan*, Chesley Bonestell, 1944

56. . . . . Figure – 2. 22 *The Conquest of the Moon*, Chesley Bonestell, 1953

57. . . . . Figure – 2. 23 Illustration of Skylab Orbital Workshop, NASA, 1973, https://www.flickr.com/photos/nasa2explore/10840607256/in/photostream/

59. . . . . Figure – 2. 24 The three members of the prime crew of the first manned Skylab mission dine on specially prepared Skylab space food in the wardroom of the crew quarters of the OWS trainer during training at the Johnson Space Center on March 1, 1973, NASA, https://www.flickr.com/photos/nasa2explore/11070751783/in/album-72157634791373199

59. . . . . Figure – 2. 25 Skylab crew running along the interior walls, NASA, 1973, film still retrieved from: https://youtu.be/JZNKVnDvQY4?t=253

61. . . . . Figure – 2. 26 View of the earth from the Cupola Module on the International Space Station, Photograph, NASA, 2024, https://www.nasa.gov/image-detail/gmt066_15_12_jasmin-moghbeli_sn1104_cupola-photos-of-carved-dreidel-2/

61. . . . . Figure – 2. 27 Freshly installed Destiny module on the International Space Station, Photograph, NASA, 2001, https://commons.wikimedia.org/wiki/

File:Destiny_as_just_installed.jpg

61. . . . . Figure – 2. 28 Destiny module over time, Photograph by NASA, 2014, https://www.esa.int/ESA_Multimedia/Images/2016/03/Destiny_module

64. . . . . Figure – 2. 29 Endeavour Space Shuttle docked to the International Space Station, NASA/Paolo Nespoli, 2011, https://www.nasa.gov/image-article/international-space-station-docked-space-shuttle-endeavour-2/

65. . . . . Figure – 2. 30 Cutaway view of Bernal Sphere, Rick Guidice, NASA Ames Research Center, 1976, https://www.flickr.com/photos/nasacommons/14052996976

67. . . . . Figure – 2. 31 Space Wheel Interior, Gouache on panel (25 x 35), Syd Mead, 1979

69. . . . . Figure – 2. 32 Construction along the torus rim, Don Davis, NASA, 1975, https://www.flickr.com/photos/nasacommons/14052995866/in/album-72157644439092941/

70. . . . . Figure – 2. 33 Interior view looking out through large windows, Rick Guidice, NASA, 1975, https://www.flickr.com/photos/nasacommons/14052998066/in/album-72157644439092941

71. . . . . Figure – 2. 34 Ron Herron, Archigram, *Walking City*, 1964, https://www.moma.org/collection/works/813

73. . . . . Figure – 2. 36 Plug in City, Peter Cook, 1963, https://www.dezeen.com/2020/05/12/archigram-plug-in-city-peter-cook-dennis-crompton-video-interview-vdf/

73. . . . . Figure – 2. 35 Archigram's Plug-In City concept allowed people to customise their pre-fabricated capsule homes, Archigram, 1966, https://www.dezeen.com/2020/05/12/archigram-plug-in-city-peter-cook-dennis-crompton-video-interview-vdf/

75. . . . . Figure – 2. 37 *Design Earth*, Neck of the Moon, 2015, image retrieved https://www.jacquesrougeriedatabase.com/project/neck-of-the-moon

77. . . . . Figure – 2. 38 Spacecraft entering Elysium's atmosphere, frame capture, *Elysium*, 2013

79. . . . . Figure – 2. 39 Interior of the Jupiter One's centrifuge, 2001: A Space Odyssey, 1968

79. . . . . Figure – 2. 40 The curved floors and ceiling interior of the Hilton Space Station V, *2001: A Space Odyssey*, 1968

81. . . . . Figure – 2. 41 The Endurance, *Interstellar*, 2014

81. . . . . Figure – 2. 42 Interior of the derelict space ship and Space Jockey, *Alien*, 1979, screen capture, https://movie-screencaps.com/alien-1979/page/19

83. . . . . Figure – 2. 43 The Hermes spacecraft, *The Martian*, 2015

83. . . . . Figure – 2. 44 Interacting with the Mars *Pathfinder* Lander to communicate with

NASA, *The Martian*, 2015

85. . . . . Figure – 2. 45 Sectional view of a four-person moon base using lunar regolith, Foster and Partners, 2016

85. . . . . Figure – 2. 46 Mars base illustration, Foster and Partners, 2016

87. . . . . Figure – 2. 47 Floorplan of NASA's Mars Dune Alpha habitat, designed by BIG and built by Icon in Houston, Texas

87. . . . . Figure – 2. 48 Interior room of NASA's Mars habitat, designed by BIG and built by Icon in Houston, Texas, 2023

89. . . . . Figure – 2. 49 *Moon Village*, concept rendering by Skidmore, Owings & Merrill (SOM), 2019

91. . . . . Figure – 2. 51 Aerial View - Lunar Base Illustration, Hassell Architects, 2023

91. . . . . Figure – 2. 50 Interior Illustration, Hassell Architects, 2023

91. . . . . Figure – 2. 52 Living Quarters Illustration, Hassell Architects, 2023

92. . . . . Figure – 2. 53 Frame capture, Lunar Horizons, Fortnite, 2023, https://www.youtube.com/watch?v=wLFOE9k8OUc

95. . . . . Figure – 3. 1 Concept of the Citadel for *Mass Effect*. Colored painting by Derek Watts and Matt Rhodes. 2007, https://masseffect.fandom.com/wiki/Bonus_Content_Disc/Environments:_Citadel?file=ME1_concept_citadel_1.png#Image_1

95. . . . . Figure – 3. 2 Citadel Interior, *Mass Effect: Legendary Edition,* Electronic Arts, 2016, digital image, https://www.pcgamer.com/mass-effects-citadel-is-one-of-the-best-virtual-cities-bioware-has-ever-created/

97. . . . . Figure – 3. 3 Screen capture, *Microsoft Flight Simulator 1.0*, 1982, Microsoft Windows, https://www.youtube.com/watch?v=NZLC5ekNJUY.

97. . . . . Figure – 3. 5 Screen capture, *Microsoft Flight Simulator* 2020, Microsoft Windows, https://www.youtube.com/watch?v=NZLC5ekNJUY.

97. . . . . Figure – 3. 4 Screen capture, *Microsoft Flight Simulator 95*, 1996, Microsoft Windows, https://www.youtube.com/watch?v=NZLC5ekNJUY.

99. . . . . Figure – 3. 6 Odin Gameplay level screen capture, *Call of Duty Ghosts,* Activision*, 2013*

99. . . . . Figure – 3. 7 Screen capture, *Halo: Combat Evolved,* Bungie Games, 2001, source frame retrieved: *https://youtu.be/fGalf5Qv7ck?t=22*

99. . . . . Figure – 3. 8 Screen capture, *Halo: Campaign Evolved,* Halo Studios, *2025,* source frame retrieved: *https://youtu.be/fGalf5Qv7ck?t=33*

101. . . . . Figure – 3. 9 Photograph of lunar surface simulation with VR headset and controllers, NASA, https://youtu.be/tOHYR2qanFE?t=1178

101. . . . . Figure – 3. 10 Atermis mission training DUST program, NASA, 2023

103. . . . . Figure – 3. 11 DUST program shadow rendering, NASA, 2023

103. . . . . Figure – 3. 12 DUST program rocks and craters, NASA, 2023

103. . . . . Figure – 3. 13 DUST program *Nanite* wireframe view, NASA, 2023

103. . . . . Figure – 3. 14 DUST Generated Terrain, NASA, 2023

103. . . . . Figure – 3. 15 Lunar Curvature Representation, NASA, 2023

104. . . . . Figure – 3. 16 Atermis mission lunar surface training DUST program, NASA, 2023, https://youtu.be/tOHYR2qanFE?t=933

107. . . . . Figure – 3. 17 NASA's Valkyrie robot, ready to be inhabited through virtual reality, Photograph, James Woodford, 2024, https://www.newscientist.com/article/2446831-i-took-control-of-nasas-valkyrie-robot-and-it-blew-my-mind/

108. . . . . Figure – 3. 18 NASA VR headset, 1986, NASA, Image credit Smithsonian Museum, https://www.si.edu/object/headset-virtual-reality-prototype%3Anasm_A19970613000

108. . . . . Figure – 3. 19 Apple Vision Pro AR/VR device, Apple, 2023, https://www.apple.com/ca/apple-vision-pro/

110. . . . . Figure – 3. 20 Detailed interior of Japan Experiment Module (Kibo) in ***ISS Simulator,*** SpaceData Inc. and JAXA, Screenshot, 2024, https://store.steampowered.com/app/3239970/ISS_Simulator/

111. . . . . Figure – 3. 22 Ship Builder Editor, *Starfield,* Bethesda, 2023, https://youtu.be/I6J8n2lbAQk?t=1029

111. . . . . Figure – 3. 21 Interior ship module, *Starfield*, Bethesda, 2023, https://www.youtube.com/watch?v=I6J8n2lbAQk

115. . . . . Figure – 3. 23 *Star Citizen,* Cloud Imperium Games, 2025, Digital Image, https://www.space.com/entertainment/space-games/800-million-13-years-and-still-no-release-date-the-state-of-star-citizen-in-2025

115. . . . . Figure – 3. 24 Screen capture, *Star Citizen,* Cloud Imperium Games, 2025, Digital Image, https://www.space.com/entertainment/space-games/800-million-13-years-and-still-no-release-date-the-state-of-star-citizen-in-2025

120. . . . . Figure – 3. 25 Toy Story (1995) frame capture compared to Kingdom Hearts 3 frame capture (2019), *Digital Foundry,* https://www.youtube.com/watch?v=tkDadVrBr1Y

121. . . . . Figure – 3. 26 Front view of Verne Station Cupola concept, Image by author, 2012

123. . . . . Figure – 3. 27 Interior Centrifuge screen capture of Space Verne Station in game

CryEngine, Image by Author 2012

123. . . . . Figure – 3. 28 Interior Centrifuge screen capture of Verne Station in CryEngine, Image by Author 2012

124. . . . . Figure – 3. 29 Frame capture of Verne Station concept in Earth orbit, CryEngine, Image by Author 2012.

124. . . . . Figure – 3. 30 Elevator Core and Social Hub, CryEngine screen capture, Image by Author 2012

126. . . . . Figure – 3. 31 Exterior render of *Satellite*, by Author 2012

127. . . . . Figure – 3. 32 Bow of *Satellite*, Not to Scale, Drawing by Author, 2012

128. . . . . Figure – 3. 33 Section of *Satellite* (Aft), Not to Scale, Drawing by Author, 2012

129. . . . . Figure – 3. 34 Cross Section (Port Side), *Satellite*, Not to Scale, drawing by Author, 2012

131. . . . . Figure – 3. 35 Exterior view of *Satellite*, screen capture, by Author, 2012

131. . . . . Figure – 3. 36 Solar sail arm and catcher for space debris objects, screen capture, by Author, 2012

132. . . . . Figure – 3. 37 Interior Crew Quarters section of *Satellite*, CryEngine screen capture, Image by Author, 2012

132. . . . . Figure – 3. 38 Lower level ring of *Satellite*, CryEngine screen capture, Image by Author, 2012

133. . . . . Figure – 3. 39 CryEngine Screen capture, main interior corridor of *Satellite*, by Author, 2012

133. . . . . Figure – 3. 40 Space debris storage compartment and collection module of *Satellite*, CryEngine screen capture, Image by Author, 2012

134. . . . . Figure – 3. 41 Descending by ladder to the outer level of *Satellite*, CryEngine screen capture, Image by Author, 2012

134. . . . . Figure – 3. 42 View from interior of the Canopus module looking at the Earth, *Satellite*, CryEngine screen capture, Image by Author, 2012

137. . . . . Figure – 4. 1 "The dawn of a new era in human spaceflight," photograph, Anne McClain/ NASA, 2019, https://www.nasa.gov/image-article/dawn-of-new-era-human-spaceflight/

141. . . . . Figure – 4. 2 Lunar Gateway Elements, NASA, https://www.nasa.gov/reference/gateway-about/

141. . . . . Figure – 4. 3 Payload mass to Low Earth Orbit, Geosynchronous Transfer Orbit, Trans Lunar Injection and Mars transfer orbit, 2021, https://commons.wikimedia.org/wiki/File:Space_Launchers.png

143. . . . . Figure – 4. 4 Tracked Satellites in Earth Orbit, 2008, ESA, https://www.esa.int/

ESA_Multimedia/Images/2008/03/Trackable_objects_in_orbit_around_Earth

143. . . . . Figure – 4. 5 Tracked Satellites Chart, 2017, ESA, https://sdup.esoc.esa.int/discosweb/statistics/

147. . . . . Figure – 4. 6 LIFE module roadmap, Sierra Space Corporation. 2025, https://www.sierraspace.com/commercial-space-stations/life-space-habitat/

147. . . . . Figure – 4. 7 Inflated LIFE module prototype, Sierra Space Corporation, 2023. https://www.sierraspace.com/press-releases/sierra-space-sets-the-stage-for-pioneering-full-scale-burst-test-of-expandable-space-station-module/

149. . . . . Figure – 4. 8 Habitat diagram LIFE 1 module of Orbital Reef, Hassell Architects, 2023. https://www.hassellstudio.com/project/orbital-reef-space-station

149. . . . . Figure – 4. 9 Interior render of LIFE module for Orbital Reef, Hassell Architects, 2023. https://www.hassellstudio.com/project/orbital-reef-space-station

151. . . . . Figure – 4. 10 Artificial gravity and tangential velocity forces, Peter H. Diamandis, https://ssi.org/programs/ssi-g-lab-project/artificial-gravity-peter-diamandis-1987/

151. . . . . Figure – 4. 11 Passing a ball to yourself in an O'Neill Cylinder, Screen capture, David Kann, http://www.davidkann.blogspot.com.au

151. . . . . Figure – 4. 13 Coriolis and centrifugal forces exerted on a passenger climbing a ladder up (left) or down (right) in a rotating environment., Figure by Gilles Clément and Angie Bukley, eds., *Artificial Gravity,* The Space Technology Library 20 (Springer New York, 2007), p 44

151. . . . . Figure – 4. 12 Comfort range chart for artificial gravity. Figure in Hall, Theodore W. "Artifical Gravity in Theory and Practice." http://www.artifical-gravity.com/sw/SpinCalc/SpinCal.htm#comfort

153. . . . . Figure – 4. 14 *Spin Gravity Compared*, directed by The Overview Effekt, 2024, 12:11, https://www.youtube.com/watch?v=C41gKfiihiM.

153. . . . . Figure – 4. 15 Basic and composite shapes of artificial gravity forms as identified in *Space Settlements: A Design Study*, NASA, 1977

155. . . . . Figure – 4. 16 Impact damage to spacecraft windows from meteoroids and orbital debris, "ARES | HyperVelocity Impact Technology | Impact Images | Space Shuttle," accessed October 6, 2025, https://hvit.jsc.nasa.gov/impact-images/space-shuttle.cfm.

157. . . . . Figure – 4. 17 MISSE 2 Atomic oxygen erosion samples, NASA, https://www.nasa.gov/materials-international-space-station-experiment-x-misse-x/

157. . . . . Figure – 4. 18 Hypervelocity Impact, NASA, https://www.esa.int/Space_Safety/Space_Debris/Hypervelocity_impacts_and_protecting_spacecraft

161. . . . . Figure – 4. 19 The interactions between the components of the ISS Environmental Control and Life Support System (ECLSS), NASA, https://commons.wikimedia.org/wiki/File:SpaceStationCycle.svg

166. . . . . Figure – 4. 20 Infographic of Potential Space Mining. Jeff Desjardins, "There's Big Money to Be Made in Asteroid Mining," *Visual Capitalist*, November 2, 2016, https://www.visualcapitalist.com/theres-big-money-made-asteroid-mining/.

169. . . . . Figure – 4. 21 Emily Calandrelli on board Blue Origin flight 28, Blue Origin, accessed October 16, 2025, https://www.blueorigin.com.

174. . . . . Figure – 4. 22 The first growth test of crops in the Advanced Plant Habitat aboard the International Space Station, NASA, 2018, https://www.flickr.com/photos/nasakennedy/26940469668/

174. . . . . Figure – 4. 23 A Zinnia flower grown inside the VEGGIE facility onboard the International Space Station, Photograph, NASA, 2016, https://www.flickr.com/photos/nasa2explore/24460739396/in/photostream/

177. . . . . Figure – 4. 24 Orthographic view of Verne Station, Phase 1, Image by Author 2025

179. . . . . Figure – 4. 25 Orthographic view of Verne Station, Phase 1, Image by Author 2025

181. . . . . Figure – 4. 26 Orthographic view of Verne Station during Phase 3, Image by Author 2025

184. . . . . Figure – 4. 27 Sectional View of module showcasing structural inner core surrounding by programming and the lower level mechanical and systems storage, Image by Author 2025

185. . . . . Figure – 4. 28 Phase 4 - Verne Space Station, Image by Author, 2025

188. . . . . Figure – 4. 29 Experiments in the formal expression of rotation in an artificial-gravity environment, Theodore W. Hall, 1999

189. . . . . Figure – 4. 30 Phase 6 - Verne Space Station, Image by Author, 2025

191. . . . . Figure – 4. 31 Lighting Study of Ring Module, by Author, 2025

191. . . . . Figure – 4. 32 Lighting Study of Ring Module, by Author, 2025

193. . . . . Figure – 4. 33 Final Phase of Space Verne Station, Image by Author, 2025

195. . . . . Figure – 4. 34 Interior rendering of Cupola Bio-Dome, Image by Author, 2025

195. . . . . Figure – 4. 35 Exterior view of Bio-dome Module, Unreal Engine screen capture, Image by Author, 2025

197. . . . . Figure – 4. 36 Exterior view of Verne Station, Unreal Engine screen capture, Image by Author 2025

198. . . . . Figure – 4. 37 Elevation, Front of Verne Station, Unreal Engine screen capture, Image by Author, 2025

199. . . . . Figure – 4. 38 Verne Station diagram, Unreal Engine screen capture, Image by Author, 2025

201. . . . . Figure – 4. 39 Elevation view of Verne Station, Unreal Engine screen capture, Image by Author, 2025

203. . . . . Figure – 4. 40 Exterior view of Verne Station, Unreal Engine screen capture, Image by Author, 2025

205. . . . . Figure – 4. 41 Exterior view of Verne Station, Unreal Engine screen capture, Image by Author, 2025

207. . . . . Figure – 4. 42 Exterior night view of Verne Station, Unreal Engine screen capture, Image by Author, 2025

215. . . . . Figure – 5. 1 *It was the body of Satellite*, by Emile Bayard, Engraving, 1870, Jules Verne's "*Round The Moon*"

LIST OF ACRONYMS

ISS	International Space Station
NASA	National Aeronautics and Space Administration
ESA	European Space Agency
JPL	Jet Propulsion Laboratory
JAXA	Japan Aerospace Exploration Agency
CSA	Canadian Space Agency
CNSA	China National Space Administration
NES	Nintendo Entertainment System
LEO	Low Earth Orbit (180-2000km)
LLRV	Lunar Landing Research Vehicle
LLTV	Lunar Landing Training Vehicle
GEO	Geostationary Orbit (36,000km)
L-Point	Lagrange points
CHAPEA	Crew Health and Performance Exploration Analog
ECLSS	Environmental Control and Life Support System
DUST	Digital Lunar Exploration Sites Unreal Simulation Tool
SPICE	Spacecraft Planet Instrument C-matrix Events
NHRO	Near-Rectilinear Halo Orbit
VEGGIE	Vegetable Production System
SICSA	Sasakawa International Center for Space Architecture
BIM	Building Information Modeling
CAD	Computer-Aided Design
UDK	Unreal Development Kit
UE4	Unreal Engine 4
UE5	Unreal Engine 5
RPM	Rotations Per Minute

01 Introduction

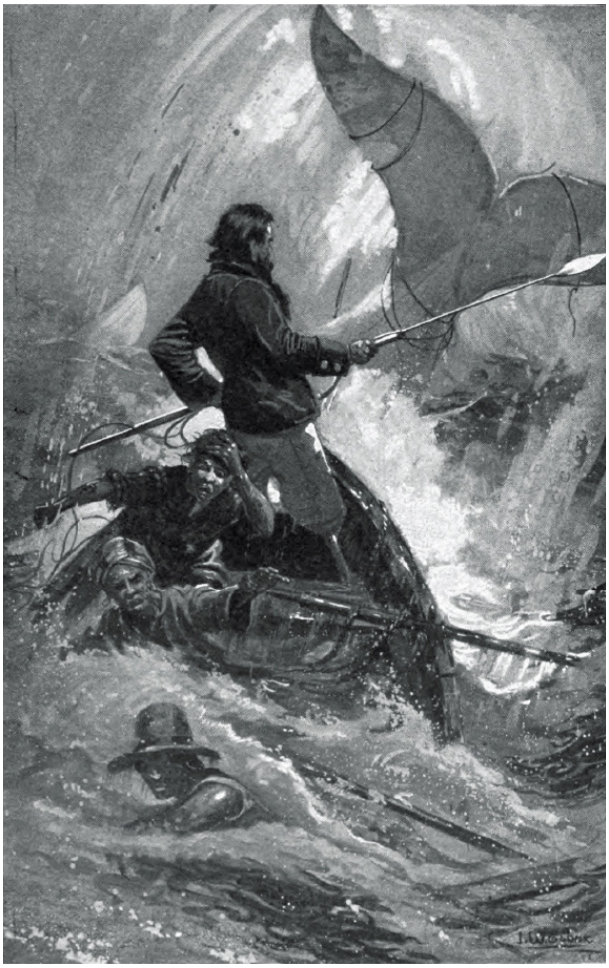


FIGURE – 1. 1 *Moby Dick Swam Swiftly Round and Round the Wrecked Crew*, Isaac Walton Taber, 1899

Towards thee I roll, thou all-destroying but unconquering whale; to the last I grapple with thee; from hell's heart I stab at thee; for hate's sake I spit my last breath at thee. Sink all coffins and all hearses to one common pool! and since neither can be mine, let me then tow to pieces, while still chasing thee, though tied to thee, thou damned whale! Thus, I give up the spear!

Herman Melville and Tom Quirk,
Moby-Dick, or, The Whale, Penguin Classics (Penguin Books, 1992). pg 263

CONTENTS

This thesis is sub-divided into three parts. The first part, *Anticipating our Presence in Outer Space*, is a cultural history of the idea of architecture in space. It has multiple layers, much like the A7L spacesuit first worn by the Apollo astronauts. Each layer presents an approach to understanding the inspirations and development throughout history of the idea of spaceflight, from its early influence as myth and fantasy, to realized projects. The methods of how people perceive and experience outer space exists in two modes: (1) a time originating before space travel became a reality, and (2) what came after its accomplishment, where the challenges of space travel influenced a more realistic approach and authentic representation.

The Second Part, *Virtual Experimentation*, investigates popularized space architecture ideas interactively through virtual simulation. Apart from film, literature and art, video games provide the user with an avatar to experience virtual environments in real-time, where the user's actions shape their own unique journey. Computer technology has advanced so dramatically in the past couple of decades, that video game engine software today is far more complex than its early beginnings, allowing developers to have the ability to create stunning, feature rich virtual worlds

with photorealism. They also allow for complex environments to exist, which allow impossible scenarios to take shape and form new innovative experiences and data collection.

Part Three, *What Might be Built*, focuses on the design and function of the space station, its construction over decades of time as it scales to accommodate newer functions and economies of space exploration missions. The idea of a human settlement in space is extraordinarily fascinating and may very well be an eventual future for humanity. The design of Verne Station is an exercise in pretend architecture. This orbital, mixed-use tourist and scientific destination can accommodate four hundred people. The architectural narrative and experience are worth investigating.



FIGURE – 1.2 My beloved Nintendo Entertainment System, photograph by author, 2013

SIMPLE BEGINNINGS

Christmas day, 1991. My sister and I received our most unusual present yet: The Nintendo Entertainment System (NES). After we had ripped apart the box and unpacked the system's contents from its Styrofoam dungeon, we began to wonder *what exactly did this thing do*? Holding the unit in my hands, I knew that this big rectangular unit was heavy and that it was also rather boring to look at thanks to its dull gray colour. (Figure – 1. 2) Looking back at the mess of parts and cables that we had earlier unboxed all over the floor, it was clear to me that our Nintendo was no ordinary present; it needed assembly.

Not knowing how to get it to work, we enlisted the help of our dad, who easily connected the system to our small Toshiba television, inserted the *Super Mario Bros.* game cartridge and powered on the unit. As I was looking at the vibrant imagery that appeared on the television, I thought I was watching a cartoon show, one with strange, blocky-looking characters. Already knowing that the real surprise was still to come, my dad placed the game controller in my hands, and told me to press the 'a' button. The moment I pressed that red button with my thumb, the character on screen, Mario, jumped up. *What did I just do?* I pressed the button once again with a similar outcome, and then again, pressing more buttons in combination with different effects. I was jumping and running in different directions. This form of control felt amazing. I was doing something that I had never experienced before - I was controlling the character on the television screen. *I was Mario*. Completely ecstatic with my new toy, I knew the best was still to come. My adventure with the game *Super Mario Brothers* was just beginning.

Through the controller, I was undertaking the monumental quest of saving Princess Toadstool from the evil King Bowser. The game rules were simple: as Mario, defeat or avoid the enemies and reach the end of the level before the timer reached zero in order to advance. This sounded simple enough, but it was actually a task that proved obscenely hard for me to do, and resulted in me unintentionally killing Mario hundreds of times. As I progressed through each level, I would eventually reach a castle and thought, this is it, I am about to rescue the princess and finally win the game. I just need to defeat the castle boss. To my disappointment, this was not the case. After defeating the level boss, an

on-screen message appeared from the mushroom looking character I just saved, "Thank you Mario, sorry, but our princess is in another castle.' Argh, *You're not the Princess!* Distraught, I continued the adventure only to end up dying a few moments later forcing me to start all over from the beginning. To this day I still harbour a deep hatred for Toadstool, as I have unwillingly saved 'it' more times than Princess Toadstool. I realized failure is a necessary part of any games learning curve. As long as I made it a bit further in the game, it was progress, I knew what to expect the next time.

So, what does this have to do with a thesis called *Pretending Architecture*? To the reader, you are most likely are wondering why is the author reminiscing about his childhood gaming days? The answer is quite simple: time changes us and this story has to start somewhere. Much like the idea of architecture in space, it too starts somewhere before everything evolves with time. Technology advances, progress is made, and dreams slowly become reality.

Whenever I revisit the game now, I know its patterns, routes, and secrets, as if it was second nature. What took me years to conquer as a kid, I could now accomplish in 10 minutes with the use of secret warp tunnels, extra lives and some luck. The game play was still fun, but my excitement and nostalgia eventually grew thin. I realized just how much the video game industry has evolved so much that the photo-realistic graphics and gameplay of modern games have made this game quite dated. In short, it is incredibly difficult to remain interested compared to the modern video games that exist today. Strangely enough, revisiting *Super Mario Bros.* as an adult became a completely different experience than anticipated. My trip down nostalgia lane never reached the same level of magic I experienced when I first got my NES. I no longer imagined myself as Mario anymore because I knew better. He was just pixels on screen that barely resembled a human being. The same 'imaginative' capacity to fill in the blanks and the sense of surprise I used to have as a kid, was now a memory. Instead, I was invested in dissecting the game's structure and revolutionary design for its time so long ago.

Super Mario Bros. existed as a 8-bit fantasy world; brick platforms could magically float in the air and be smashed by Mario to collect coins. Castles were designed as labyrinths, and secret pipe tunnels could teleport you to later levels. These levels were pure fantasy. Clearly, the real world did not apply. After all, game developers wanted to make something fun for people to be entertained by. And when this game did so back in 1981, it set the benchmark for every game afterwards. These were fake

adventures, but that was the beauty of being a kid, your imagination could fill in the glaring gaps or be amused enough that you ignored them. This is key understanding why we create fantasy worlds. To escape and experience the impossible, perhaps even to be inspired by them. Video games have been doing this for decades.



FIGURE – 1. 3 Taking the warp level shortcut in *Super Mario Bros., (1985)* screen capture

Super Mario Bros. is just one example of my video game experiences. (Figure – 1. 3) Of the countless games I have played over the years, there was one aspect that never did change, which was the constant push for greater graphics fidelity and gameplay features. When Super Mario 64 launched on the N64 in 1996, the game's 3D world launched Mario into a whole new dimension and ambitious experience. The ability to navigate and control Mario using a dynamic camera system to look around was exhilarating and opened up how you could explore the 3D game world.

Adventure games have brought me to fictitious locations within the confines of a small, badly lit room. I have interacted with some of the most unusual worlds. The underwater city of *Rapture* (an Art Deco style version of the mythical Atlantis) from the *BioShock* franchise, to large outer space colony of the Citadel in *Mass Effect*, worlds that exist in the most unusual sites of which the player can explore and play. Developers have a tool of which they can design and create different experiences for audiences beyond reality; environments limited by imagination.

For architecture, a profession of which buildings are designed and tested well before building approval, virtual representation is key to efficiently understand and explore proper design choices. With virtual environments today becoming even more advanced and realistic, these real-time game engine tools can be used to convincingly authenticate design choices and be shared within the public realm.

A Cautionary Tale

Back when I first started this thesis, I was told the story of *Many Moons* by professor Don McKay and it goes something along the lines of this:

> There was time when a little princess ate too many strawberry tarts (her favourite) and fell ill. The King, seeing his child in this state, asked the princess, 'what would make you feel better again and I'll get it for you?' Her reply was, 'the moon.' The King, wanting to see his child well again, called for his most trusted advisors. The first, the High Chamberlain, ran through a list of his achievements, before being asked by the King to procure the moon. He concluded that the moon, was too far away and too large to obtain. He was dismissed by the King. The second, the Wizard, also highlighted his achievements, before being told by the King to bring him the moon. He too, exclaimed that the moon would be far too large to fit in the Princess' room and thus would be an impossible feat. This angered the King, and made him turn to the last of his advisors, the Mathematician. Like the others, the mathematician also listed his successes, and also after being told to procure the moon, stated it would be impossible, for it was thousands of miles away. The King, now grief stricken, asked his court jester to play a depressing song to fit his mood. Instead, the Jester pointed out that all the advisors were unable to bring the King the moon, due to how they viewed the moon (too realistically). What they didn't consider, he said, was what the princess had thought the moon was. The King, enlightened by this news, assigned the Jester to find out exactly how the princess viewed the moon. She told the Jester that she saw the moon as something no bigger than the size of her thumb; it was a small object that disappeared from her window everyday, and that it would end up getting caught in the branches in a tree outside. The Jester asked her one more question regarding what was it made of, and her reply was 'gold'. The Jester then went to the goldsmith, and got him to make a golden moon necklace. When it was finished, he gave the necklace to the princess who immediately became well again. [1]

This metaphorically applies to my thesis. What I want most, which is a complete virtual world of a space station on the same level of detail as a modern video game - exists differently than expected based on perspective. To the reader, please keep these points in mind as you explore this thesis.

ONE, we are all explorers at heart. I found myself overwhelmed by the vast amount of history and information available on the subject matter and organizing and trying to put it all together the

1 James Thurber and Louis Slobodkin, *Many Moons*, Voyager Books (Harcourt Brace Jovanovich, 1971)., 1943

current state of space architecture. Of the many documents and literature I have poured over, I found aerospace architecture presented itself with significant potential to generate exciting experiences that can be applied to architectural projects today. But of the element gravity, which dictates to us as designers how we build our structures on the Earth - weight matters. In outer space, gravity behaves as a changing variable. It can be non existent, allowing everything to float freely. But on different planets, it can exist at a level greater than that of the Earth, hampering your movement. What it hopefully can do is inspire us to reflect upon how we may apply certain aerospace principles and methods to develop new space architecture. However, due to the very hostile environment of space and its immense cost, it is not easily accessible to architects. Space architecture is in its infancy. An avenue is needed to model and tests our ideas and play out the scenarios that instigate the exploration of outer space in an economical and safe manner. Through the virtual game engine, our understanding can grow to plausibly experience the profound and absurd new ideas that we seek to understand, even if navigating that environment is a mostly cerebral experience.

TWO, with the computer technology we have today, we have the ability to model complex scenarios in a virtual environment. Video game engines have evolved from simple two-dimensional 8-bit platforms to complex three-dimensional ones. The implementation of basic physics has made game environments behave realistically in real-time that is accessible to most people. Game world objects can be pushed, dropped and broken with convincing detail as one might expect it to in real life; cloth, hair and vegetation bend and sway as forces interact with them. The more computing power advances, so do these effects. However, learning, takes time. In the making of Verne Station, there are hurdles and challenges to face. Making mistakes is an inevitable and natural part of the learning process. In fact, trial and error was the best way for me to tinker within Crytek's CryEngine 3. The largest challenge is the time it takes to learn something new and understand the constraints faced. It is a process with no definitive conclusion - we never stop learning.

THREE, translating your vision or that idea in your head, drawing it out and communicating it, is hard and is never as good as you think it is. As much as I want to create a detailed video game experience, developing it involves considerable amounts of time, patience, and skill to make. Part of the journey of this thesis was learning new things and getting out of my comfort zone. There are many

elements to be considered — sound, lighting, user controls, narrative, and game-play. After spending a great deal of time and effort in the construction and research of this thesis' virtual environment, I find that I have a new appreciation towards video game developers. Although I could not fully complete what I envisioned, the journey alone has been an interesting learning process.

I can perhaps call this thesis experience of mine an act of pretending. I went into this quest acting as if the design needed to be completely realistic, and in doing so fell into the same pitfall as the King's advisors. Within the game engine — I needed to fake things, much like how the princess viewed the moon at face value. In my closing words to you, the reader, consider Verne Station to be an early concept, lost with the plethora of other space architecture designs that exist in the realm of fantasy.

PREFACE

Over the course of about three years (September 2010 to December 2013) I engaged in creating what is ultimately a fake experience of outer space. This *fake authentic*, was my idea of a space station shaped through the many constructs of space and explored within a virtual simulation. The problem though was that I could never quite figure it out. Today, it exists in a new form. There was a version of this thesis back in 2013 - I just could not see it myself. Finishing the remainder of this thesis is a process in itself.

My fascination with science fiction led me to seek out what were considered the important films of space travel. Some I had never heard of before, such as *A Trip to the Moon, For All Mankind,* and *Outland*. Some I had already seen before and been inspired by such as *Star Wars*, *Star Trek*, *2001: A Space Odyssey,* and *Aliens.* Years later, more prolific films such as *Interstellar* and *The Martian* have even had more credibility in the presentation and creation of their sets and aesthetic with the involvement of space agencies such as NASA and the ESA. It was my attachment to the fantasy worlds and characters in video game franchises such as *Mass Effect,* that truly inspired me to want to craft my own outer space fantasy. The character interaction at times felt realistic and conversation choices could greatly affect the outcome of the story. But more importantly, the breathtaking environments and game worlds could be explored. I wanted to engage in the act of pretending what architecture in space may be like through the lens of a game developer.

The ideas I wanted to test out, based on my experiences of things I enjoyed in science fiction film and games, completely captivated me. I had imagined scenarios, played them out in my head, and thought about how great it would be to make an interactive virtual environment to explore my design. However, weaving the story and game scenarios was far easier to imagine than it was to draw out on paper or implement in a game-engine. Good design is distilling a multitude of ideas into a coherent scheme and continually cutting the aspects that do not fit. The other half is realizing where to draw the line and figure out how exactly to make it.

When I first made the decision to make my space station in a video game engine called CryEngine, I knew very little about using it and never anticipated I would have so much trouble with it. I admit the task of creating a video game environment was in itself, overly ambitious, but I wanted the challenge. After a couple years, I was only able to make a small rough slice of what I wanted to create. The dazzling video

games I have been so impressed by for ages, take hundreds of skilled people and millions of dollars to create. In conclusion, pretending is hard when you need to show someone else the idea. You can pretend and envision the idea in your head all you want, but getting it built in the face of limitations is the hardest, grueling part that is more than often, prone to failure. The act of now writing about that failure is an even harder test to endure. It is an act of searching through the rubble, looking for that one piece, that with a bit polish, can hopefully still shine.

In Geoff Dyer's *Zona*, I came across a few sentences that summed up my experiences in the making and design of Verne Station.

> The past becomes a source of regret; you think of hopes that were unrealized, disappointments, betrayals, failures, deceptions, all the things that led to this point which could be so different, so much better, but which, however you reshuffle the deck, always ends up at this point, leaves you holding—and lacking—the same cards.[1]

It took me a while to notice there was a conversation happening between the pieces I was writing and the parts of the station I was sketching. All the ideas and visions people have already brought forth regarding space travel had a pattern, with similar motif. I was not designing anything original and the idea of a spaceship has not really changed. The aesthetic, function and believability of space ship concepts are a reflection of the times, creativity and styles of their respective authors. Anyone can think up their own fantasy, ignore any facts from reality and blissfully dream. For others, the illusion needs to be completely believable as if it was reality.

Much like the room in Andrei Tarkovsky's film *Stalker* (1979), entering it will mysteriously grant your utmost deepest wish. What you never expect once you get to its threshold, is how it makes you remember and reflect on all of your past experiences while on the journey there. The room forces you to search for that one desire of which to make peace with. It is subconsciously buried in your mind, is what you are afraid to discover, but exactly what you need in order to realize what is missing. Perhaps if I entered that room I would be thinking about a completed thesis and video game as I originally imagined; two things that over the years, I had partial bits and pieces of. Yet having them would not lead me closer to

1 Geoff Dyer, *Zona: A Book about a Film about a Journey to a Room*, 1st Vintage books ed (Vintage Books, 2012).

understanding why I wanted them or pretend what they were. Self-reflection is an important part of the process. We pretend in order to fill in the gaps for an idea that we cannot fully understand. We anticipate the future, but in reality, we can never fully predict it; we can only work with what we discover as time goes on and the journey continues. Needless to say, I would not have read *Zona*, nor would I understand how architecture in outer space is about pretending, not because it cannot be done, but because pretending it can and putting it on paper, allows us to look upon ideas, test them and move on.

We create fantasy in order to make sense of what we desire when it remains beyond reach. Visualizing an idea becomes a way of coming to terms with it and of clarifying what it is we seek. For many, seeing Neil Armstrong on the Moon during a nationally televised broadcast in 1969 was more than just a historic milestone for humanity, it showcased the expectation that space would be accessible to ordinary people at some point in their life. However, several decades later, general access to outer space does not exist unless you are extraordinarily wealthy. Two unmanned spacecraft, *Voyager* 1, launched in 1971 and *Voyager* 2 have both crept past the edge of our galaxy.[2] When, then, will astronauts be able to do the same?

The presence we have in outer space, is not the kind so many people, including myself, have become enthralled with and hoped would come to be a reality. Instead, we continue to anticipate and role-play using science fiction to fulfill our human imagination. The immense cultural impact of *Star Wars* and *Star Trek* franchises continues to flourish decades after their initial release. This gap between aspiration and reality echoes the multi-layered complexity of space architecture. As Nicholas de Monchaux illustrates in his book *Fashioning Apollo,* the 21 layers of the A7L spacesuit symbolize the intertwined technical, cultural, and conceptual forces that shape our relationship with space.[3] We have only begun to scratch the surface of the complex problem of space travel and the unknowns waiting to be discovered in the vastness of space. We have thousands of unmanned devices orbiting around our planet and exploring the galaxy, compared to the handful of astronauts in space. Approaching this thesis with several layers and constructs helps frames an authentic narrative from the multiple perspectives and sources available, and illuminating the process of transforming fictional ideas into something tangible.

---

2 NASA Science, *Voyager - NASA Science*, Missions, December 8, 2023, https://science.nasa.gov/mission/voyager/

3 Nicholas De Monchaux, *Spacesuit: Fashioning Apollo* (MIT Press, 2011).

02 Anticipating Our Presence in Outer Space

Before we invented civilization our ancestors lived mainly in the open out under the sky. Before we devised artificial lights and atmospheric pollution and modern forms of nocturnal entertainment we watched the stars.

Carl Sagan, Pale Blue Dot, 1994



Figure – 2. 1 Stars Leave Streaks of Light in Concentric Circles, Photograph by Don Pettit, NASA, 2012, https://www.flickr.com/photos/nasacommons/9460163430/in/album-72157634973839148/

Acts of Pretending

We are explorers. Our desire to search for meaning and purpose in our lives is one of the things that makes us human. From discovering the ends of the Earth, to looking up at the night sky and reaching for the stars, we as a species have been able to survive over time by exploring our natural environment and unravelling its mysteries. The theories that we have created about the world we live in are a direct result of the mystery of life itself. As Albert Einstein once commented:

> The most beautiful thing we can experience is the mysterious. It is the source of all true art and all science. He to whom this emotion is a stranger, who can no longer pause to wonder and stand rapt in awe, is as good as dead: his eyes are closed.[1]

Einstein understood that part of the wonder of life is how we constantly search for meaning. However, exploration can involve risk and uncertainty. When we step into the vast frontier of outer space, we rarely know all the mysteries and challenges that await us. Sometimes, we can prepare and anticipate in order to overcome these challenges, but most of the time, trial and error is the method that allows us to learn and grow, from failure, in order to eventually succeed.



Figure – 2. 2 The Wolves Pursuing Sol and Mani, Guerber, H. A. (Hélène Adeline) (1909). Myths of the Norsemen from the Eddas and Sagas. London : Harrap.

Our exploration of outer space, over our entire human history, starts with our ancestors' first attempts to unravel its mystery. Early civilizations lived under the stars in full view of their splendor;. What they observed and recorded in the night sky became part

1 Albert Einstein in Mein Weltbild (1931), as quoted in *Introduction to Philosophy* (1935) by George Thomas White Patrick and Frank Miller Chapman, p. 44

of their mythology and folklore, giving explanation and insight to the unknowable events they witnessed. For example, in Norse mythology, the sun and the moon became personified as Sol and Mani.[2] The Norse believed that these characters were always moving in the sky because they were being chased by wolves (See Fig 1.2). The Norse created this story to help explain the movement of these celestial bodies in space. It provided them with an answer or basic truth to begin de-mystifying the behavior of the universe. Today, the cosmos are still shrouded in endless mystery and we continue to imagine and search for meaning of the unknown.

Cosmological mythology allowed us to frame the unexplainable of the world around us into common knowledge. With the art of storytelling, early civilizations founded their earliest beliefs on myths. For instance, Selene (Luna) was the personification of the Moon and its movements for the ancient Greeks and Romans. As a female divinity, she presided over the passage of months. Her crown, symbolized the crescent shaped moon, and each night she rode a chariot across the heavens. She is described as follows in Greek hymn:

> The air, unlit before, glows with the light of her golden crown, and her rays beam clear, whensoever bright Selene having bathed her lovely body in the waters of Ocean, and donned her far-gleaming raiment, and yoked her strong-necked, shining team, drives on her long-maned horses at full speed, at even time in the mid-month: then her great orbit is full and then her beams shine brightest as she increases. So she is a sure token and a sign to mortal men.[3]

Selene represented the Moon calender and its cyclical nature of roughly 31 days. This gave people an early understanding of the months based on what they saw in the sky. The mythology of early civilizations were rich in knowledge because at their core, they were loosely based on truths, including perceived truth.

Although core elements of myths persevere through time and different cultures, myths remain relative. It is understood that our perceptions are flawed and ever-changing. Stories, when they are passed down generation after generation, can gradually change in details. Fiction starts to be considered fact, and the ever changing stories become accepted as new truths by society as part of their knowledge. The word myth

---

2 Snorri Sturluson and Jesse L. Byock, *Norse Mythology* (Penguin, 2005).

3 Hymn to Selene (32) 5–14 Hesiodus, Homerus, and Hugh G. Evelyn-White. Hesiod ; *The Homeric Hymns and Homerica*. Cambridge, MA: Harvard UP, 1982.

is derived from the Greek word *Mȳthos*, which means a story of unknown origin with no basis of fact or natural explanation.[4] Over time, myth has been understood as limited in nature as Joseph Campbell explains in his text: *The Power of Myth*. In it, Campbell states that "Mythology is not a lie, mythology is poetry, it is metaphorical. It has been well said that mythology is the penultimate truth–penultimate because the ultimate cannot be put into words. It is beyond words. Beyond images, beyond that bounding rim of the Buddhist Wheel of Becoming. Mythology pitches the mind beyond that rim, to what can be known, but not told."[5] Essentially, myth can never be ultimate truth because we are limited in our human understanding and experience of ultimate truth. We cannot define it, but that does not mean we cannot try to understand its metaphorical nature, symbols and archetypes.

The themes in myth are open to interpretation at any given point in time. A myth can hold several truths or lessons for different people, based on their perceptions and experiences at the time. In the *Tale of Daedalus and Icarus*, a story about human flight, there are many different truths to be interpreted. The story goes as follows:

> As legend goes, Daedalus, an architect and engineer was forced into exile on the Isle of Crete for the labyrinth he had created. Devising of a way of escaping, he drew inspiration from the sky, the last dominion not confined by King Minos. Daedalus set to work to fabricate wings for himself and his young son Icarus. He tied feathers together, from smallest to largest so as to form an increasing surface. He secured the feathers at their midpoints with string and at their bases with wax, and gave the whole a gentle curvature like the wings of a bird. When the work was done, the artist, waving his wings, found himself buoyed upward and hung suspended, poising himself on the beaten air. Upon their completion he gave one of the pairs to his son Icarus, and taught him to fly. When it was time to escape he told his son "Fly the middle way. Don't fly too high, or the sun will melt the wax on your wings, and you will fall. Don't fly too low, or the tides of the sea will catch you." Daedalus himself flew the middle way, but he watched his son become ecstatic with the exhilaration of flight and flew too high. The sun melted the wax, and the boy fell into the sea and drowned.[6]

---

4 "Meanings & Definitions of English Words," Dictionary.com, October 24, 2025, https://www.dictionary.com/browse/myth.

5 Joseph Campbell et al., *The Power of Myth* (Anchor Books Doubleday, 1991).

6 Ovid and D. A. Raeburn, *Metamorphoses: A New Verse Translation* (Penguin, 2004), p 246

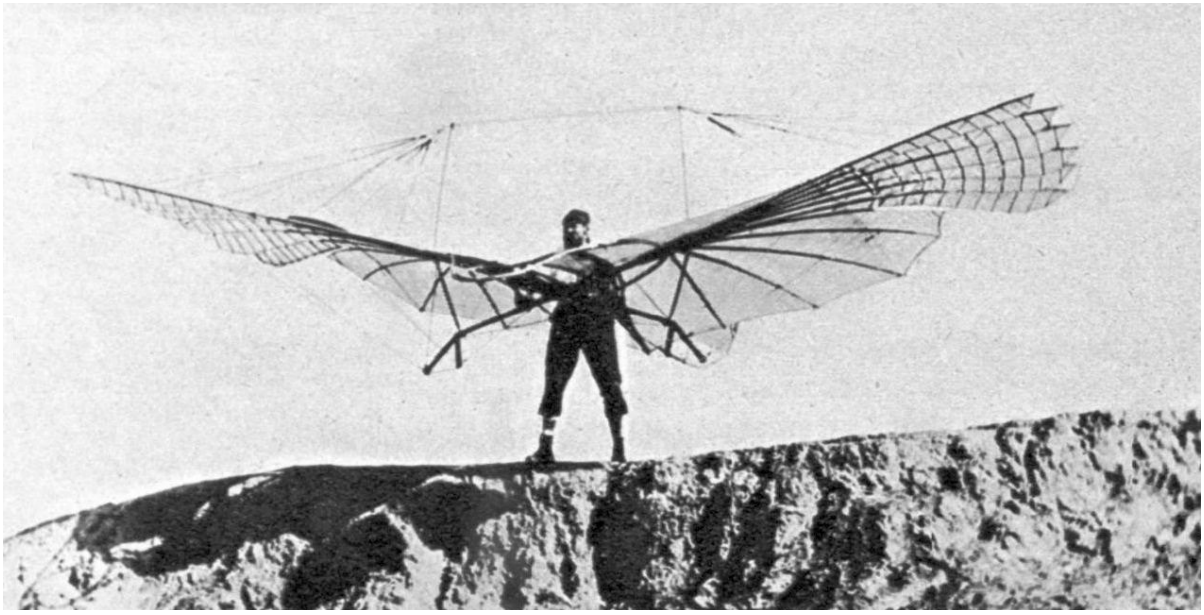


Figure – 2. 3 *Otto Lilienthal with his small wing flapping apparatus near to the "Fliegeberg,"* 1894; photographer Ottomar Anschütz, https://commons.wikimedia.org/wiki/File:Otto_is_going_to_fly.jpg

Many people view the fall of Icarus as a warning: that we should not be overly ambitious as to lose contact with reality and overestimate our own capabilities. Another interpretation of the text, aside from the tragedy of Icarus, society is similar to Daedalus. Together we have the ability and inventiveness to craft the tools that we need to achieve our goals, even if they seem impossible at the time. Yet, acts of ambition must be held in check. In the story, when Daedalus flew the middle way, his perseverance and control of both his flight and his emotions allowed him to succeed; balance was maintained. It was his foresight to see both the opportunity and limits in his design which had allowed Daedalus to land safely on free land. What he could not have anticipated however was Icarus' careless reaction to flight.

If we examine the text again on a larger scale, Daedalus is the embodiment of the creative act itself. Ideas can be limitless, but they require focus and grounding in reality. If we aim too high, the complexity of the idea results in unrealized concepts; if too low, then nothing is strived for towards pushing the boundaries of new invention. The necessary balance is achieved through research – the constant tinkering of theory and practice.

By gaining perspective through observation and drawing upon discovery from the natural world, the solutions to our desires are sometimes hidden in plain sight; they only need to be researched first to determine their usefulness. Otto Lilienthal's earliest working glider devices for manned flight were ambitious. They were constructed and based upon his study of bird flight. Test after test, Otto was

dedicated to his dream and aimed towards the goal of perfecting his invention, learning from it, and respecting each iteration. He stood upon an artificial hill and took a leap of faith, each time gradually sustaining longer flight with each improvement. Ultimately, he died by fracturing his neck when his glider stalled and fell to the ground. His spirit was not broken, and just before his death in a hospital, he told his brother, "sacrifices must be made." [7] His continuous interest in flight paved the way for others to follow, such as the Wright brothers, who were successful in creating the very first airplane. It is the combination of human ambition and discovery, as well as tragedy and sacrifice, that seems to create new technological eras in our civilization. Today, we live in an age of manned space flight because several generations of people before us took those first steps to create, learn and build the required foundations.

The act of pretending (or imagining), inspired by myths about the cosmos, began to evolve and be expressed in new ways over time. By the nineteenth century, the literary genre known as science fiction was a new vehicle for authors to explore a new kind of pretending. They began to invent plausible scenarios in regards to space travel based on accepted scientific truths and technology. This contrasted earlier myths that emphasized the *impossible* (superhuman figures, incredible beasts, etc.). Science fiction strove for real explanations behind story events by drawing upon systematically organized knowledge to form testable explanations and extrapolations. This new method of pretending helped to suspend disbelief while simultaneously inciting the reader's mind in a thoughtful manner. People could become excited about imagining outer space because the methods of travel were, in some sense, being presented as plausible—that one day in the future, with technological innovation and science, these fantasies could actually become reality.

Science fiction narratives laid the inspirational groundwork for early pioneering efforts in the aerospace industry, drawing upon ideas inspired by the scientific discoveries and technologies of the time to develop speculative aerospace theories. For example, the invention of hot air balloons allowed us to discover the lack of a breathable atmosphere as we ventured higher up into the sky; gunpowder served to show the incredible explosive velocity of which an object can travel; flying gliders and airplanes, courtesy of Otto

---

7 Otto Lilienthal and Gustav Lilienthal, Birdflight as the Basis of Aviation: A Contribution Towards a System of Aviation, (Markowski International Pub, 2001).



Figure – 2. 4 J.T Mastason had grown fat, Illustration, *From the Earth to the Moon*, Jules Verne, 1866, https://www.oldbookillustrations.com/illustrations/grown-fat/

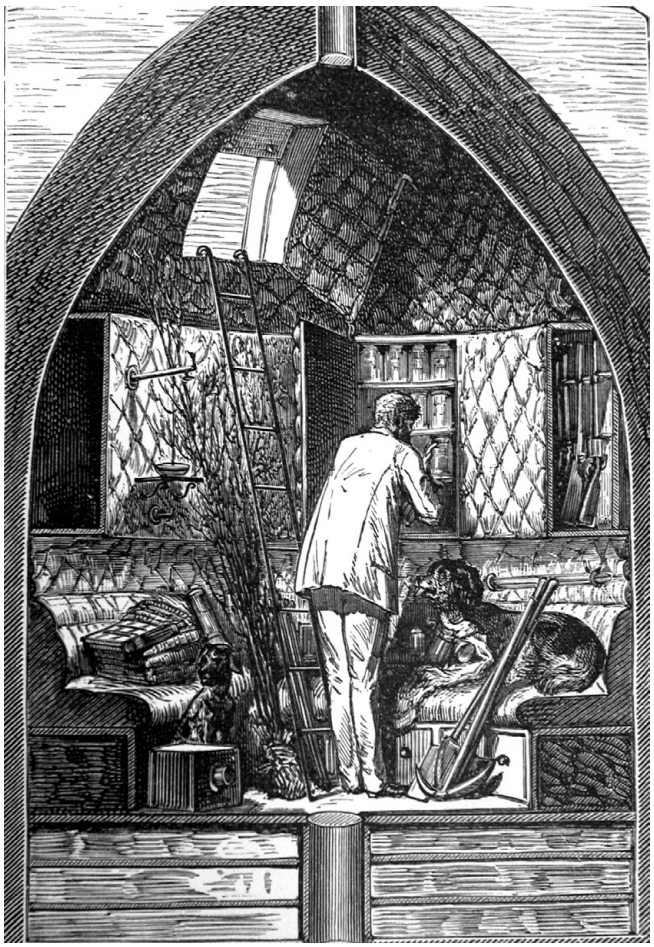


Figure – 2. 5 The Interior of the Projectile, Illustration, *From the Earth to the Moon*, Jules Verne, 1866, https://www.oldbookillustrations.com/illustrations/interior-projectile/

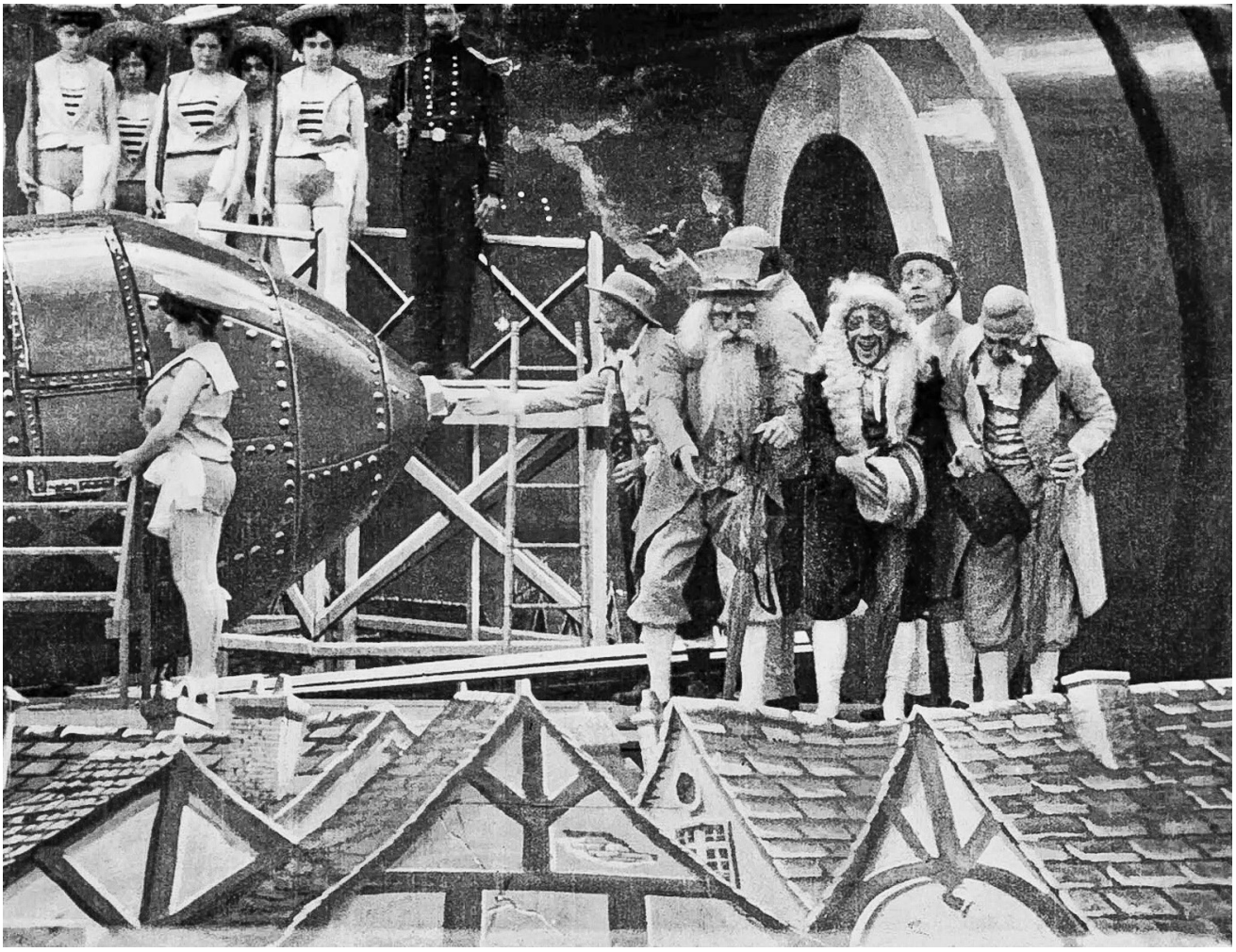


Figure – 2. 6 *A Trip to the Moon*, Film Still, George Méliès, 1902

and the Wright Brothers, allowed for humans to experience flight.

Jules Verne's novel, *From The Earth To The Moon*, proposed the crazy idea of firing a projectile carrying a team of astronauts to the moon from a very long canon. Verne used his scientific knowledge of gunpowder and extrapolated the physics behind it to make readers connect his fictional projectile to sound scientific principles: if his firing cannon could be powerful and large enough to shoot the bullet-shaped spacecraft to the surface of the moon, the equation then became a mere matter of scale. If a gun could fire a small bullet at incredibly fast speeds, then certainly a larger version could fire a bullet with enough force to allow it to escape the Earth's gravity. This "what if" mentality is at the heart of all science-fiction — that some future technology based on existing knowledge could be extrapolated into the realm of the plausible.

Science fiction experiences of space and space travel would later reach film in the twentieth century and captivated worldwide audiences with its imagery. *A Trip to The Moon* by Georges Méliès from 1902 was the first science-fiction film to be made.[8] The plot of the film is as follows:

> Over the course of about a quarter of an hour of screen time, Méliès' explorers will plan and execute a trip to, and return from the Moon. We see them choosing the team of adventurers, observing the construction of a massive gun and shell for the launch, before they are shot into the lunar surface, where they dream of celestial gods and goddesses before being captured by the Selenites who inhabit the satellite. Brought before the King of the Selenites, they manage a daring escape and plummet back down to Earth. They land in the sea, are packed up by a steamship and taken back to dry land, where a parade is held in their honour and a Selenite captive is put on display. [9]

In the film, a group of scientists propose to launch themselves to the Moon in a spacecraft, embodying an early cinematic fascination with space exploration. The imagery the audience witnesses is remarkably innovative for its time, incorporating early animation techniques that simulate motion and depth. These visual effects are partly grounded in real-world scientific expectations, reflecting contemporary understandings of technology and the cosmos. The carried over influence of literary ideas from both Verne

---

8 Elizabeth Ezra, *Georges Méliès: The Birth of the Auteur, French Film Directors* (Manchester university press, 2000). pg. 120–1

9 Dan North, *A Trip to the Moon / Le Voyage Dans La Lune (1902),* Spectacular Attractions, June 10, 2010, https://drnorth.wordpress.com/2010/06/10/a-trip-to-the-moon-le-voyage-dans-la-lune/.

and science fiction author H.G Wells, are present in Méliès film. The *Selenites*, the alien race that the explorers meet on the moon share similar characteristics to the alien race described in H.G. Wells book, *The First Man on the Moon*. The method with which the explorers venture to the moon, a small bullet-shaped craft fired from a cannon, draws on Verne's method in *From the Earth to the Moon*. For its time, *A Trip to The Moon* became a pioneering marvel because it explored the idea of space travel to the moon using moving pictures, inspired by literary works of the time.

The popularity of an idea, in this case, space travel, can also inspire innovation. The ideas tested and critiqued in the realm of science fiction became popularized and rooted in cultural work. Vernes, Wells, and Méliès are just some of the many people over time responsible for getting people to experience and imagine outer space. The public were not just curious about space travel anymore as an abstract fantasy; it became a part of their lives and consciousness. As more work and ideas about space travel proliferated people started to become inspired and theorize how to make the required technologies and develop the mentality that space travel was an opportunity and eventual path for human advancement.

Radical theories began to sprout in Russia, known as Cosmism.[10] These theorists viewed space as the inevitable step forward to human dominance of the galaxy. If we could master the stars with our technology, then we would truly become a technologically superior race in control of nature. Nikolai Fyodorovich Fyodorov, who started the Cosmism movement, would speak and share his ideas and theories to anyone who cared to listen to him. His most radical vision of the future, known as the Common Task,[11] was a project aimed at resurrecting all those who had passed away using science and launching humanity as a space faring species. This passing down of knowledge had a profound affect on Konstantin Tsiolkovsky, a major pioneer in the development of rocket technology and spaceflight in Russia. In his 1903 publication on space travel, *The Exploration of Cosmic Space by Means of Reaction Devices*, Tsiolkovsky acknowledged Jules Verne's idea of using a cannon for space travel, and refuted it to propose instead working theories of rocket propelled craft.[12] Tsiolkovsky's inspiration for spaceflight eventually led to the development of the theory of spaceflight, including the first serious description of weightlessness in space.:

---

10 Boris Grojs, ed., *Russian Cosmism* (e-flux, 2018). p 4

11 George M. Young, *Nikolai F. Fedorov, an Introduction* (Nordland Pub. Co., 1979).

12 "Konstantin E. Tsiolkovsky," New Mexico Museum of Space History, n.d., accessed August 27, 2025, https://nmspacemuseum.org/inductee/konstantin-e-tsiolkovsky/.

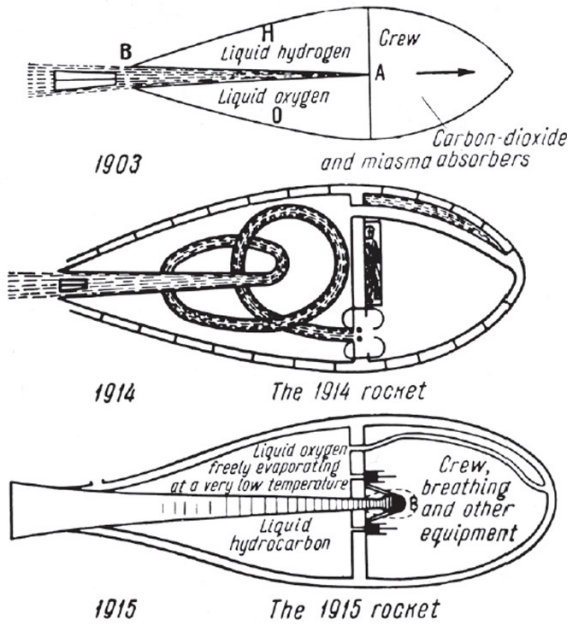


Figure – 2. 7. Tsiolkovsky's Sketch of a liquid rocket propelled spacecraft, 1903, https://blogs.esa.int/rocketscience/files/2012/10/9-13.jpg

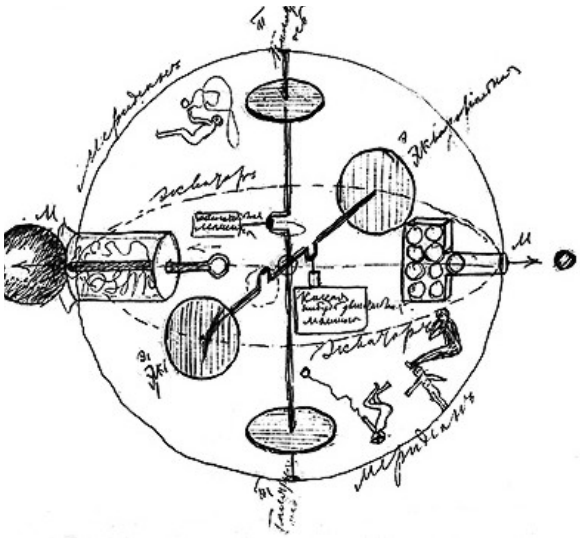


Figure – 2. 8. First space ship draft by Konstantin Tsiolkovsky, 1883, https://commons.wikimedia.org/wiki/File:Chertrg_Tsiolkovsky.jpg

> The observed body does not, in free space, exert any force on what lies beneath it, and vice versa. Therefore, if dwellings were needed in free space, they could not — however great their size — collapse because of their instability...There is neither up nor down, there. For example, there is no such thing as down, because 'down' is in the direction in which bodies move at accelerated speeds. . . . Just as the Moon hovers above the earth without falling down to it, so a man there can hover over a chasm which would be frightening to earthlings. He is not, of course, suspended by ropes but hovers like a bird; or rather, like a counterpoised aerostat, since he has no wings.[13]

Tsiolkovsky theorized how one would experience life and be able to move differently in space. Another work of his, *On the Moon,* is a more playful analysis of life on the moon as he experiences it during a dream. There was an excitement expressed by Tsiolkovsky in the pages of this text; a sensation one had to experience for themselves:

---

13 Konstantin E. Tsiokovsky, *Free Space: The First Serious Description of Weightlessness*, 1883.



FIGURE – 2. 9 Dr. Robert H. Goddard observes the launch site from his launch control shack while standing by the firing control panel, 1940, NASA, https://digitalnm.unm.edu/digital/collection/roswell/id/901/rec/41

> I moved chairs, opened wardrobes, took out my clothes, lifted various objects and—I could not understand a thing! Have I grown stronger? Why was everything now so ethereal? Why could I lift objects which I could not shift before? No! These feet, these arms, this body could not be mine! Mine were always heavy and moved with difficulty. How was it that my arms and legs were now so strong? .... why was I leaping instead of walking? Something was pulling me in the direction opposite to gravity, tensing my muscles and making me leap. I could not resist the temptation, I jumped. I seemed to have ascended rather slowly and descended equally slowly.[14]

Similarly in America, Robert Goddard began to develop the first liquid fueled rocket in 1923 after becoming fascinated with an article he read about H.G. Wells' *War of the Worlds.* In order for one to reach the moon, he realized that any device using solid fuel (gunpowder for instance) would not have enough power to escape the gravity of the Earth. His work began small, as a process of trial and error. Due to the limited success of his first rockets (only flying a few feet in the air), Goddard was subject to ridicule and from the press and academic society.[15] Regardless, he knew that the idea behind rocketry was sound, that a rocket powerful enough could reach the moon and operate in the vacuum of space. He continually built and tested his prototypes, watching them fail and refining the approach and the science. (Figure – 2. 9) Each time, he learned something new with which to modify his design to achieve success, which he did on March 16, 1926, when his liquid-fueled rocket reached an altitude of 41 feet, lasted two seconds and averaged about 60 miles per hour.[16] His work was an influential base to start from for the success of the Apollo space program years after his death.

Acts of pretending ultimately make you believe or disbelieve in a concept or idea; you continue pursuing it because you reach for a particular experience in reality. Myths are what help set the standards, a translation of the natural world we experience, core beliefs that are found in the themes and archetypes used in the stories. In our earliest times, we knew very little scientific facts about outer space, but it didn't

---

14 K. Tsiolkovsky, *The Science Fiction of Konstantin Tsiolkovsky* (University Press of the Pacific ; Distributed by International Scholarly Book Service, 1979).

15 "Dr. Robert H. Goddard, American Rocketry Pioneer", Goddard Space Flight Center, n.d., accessed October 24, 2025, https://www.nasa.gov/dr-robert-h-goddard-american-rocketry-pioneer/.

16 John Yuri, "95 Years Ago: Goddard's First Liquid-Fueled Rocket", NASA History, March 17, 2021, https://www.nasa.gov/history/95-years-ago-goddards-first-liquid-fueled-rocket/.

stop us from imagining what it could be like. As we would further discover our world, we eventually began to introduce those scientific discoveries into our stories, as seen in the genre of science fiction. Science provided a more "real" story, so that Verne and Wells could bring the idea of space travel to the forefront, and inspire people like Tsiolkovsky to theorize the correct vehicles of spaceflight, develop rocket science equations and specific theories of life in space. Goddard's invention of the first liquid-fuelled rocket, along with the pioneers of rocket technology, had great implications and is proof that fantasy can eventually inspire invention. (Figure – 2. 10) If rocket technology was the means to travel to outer space, then the process of arriving there was just beginning.



Figure – 2. 10 Bumper 8 launch at White Sands Test Facility, NASA, 1950, https://www.americaspace.com/2020/07/24/roar-of-the-bumper-remembering-the-capes-first-launch-70-years-on/

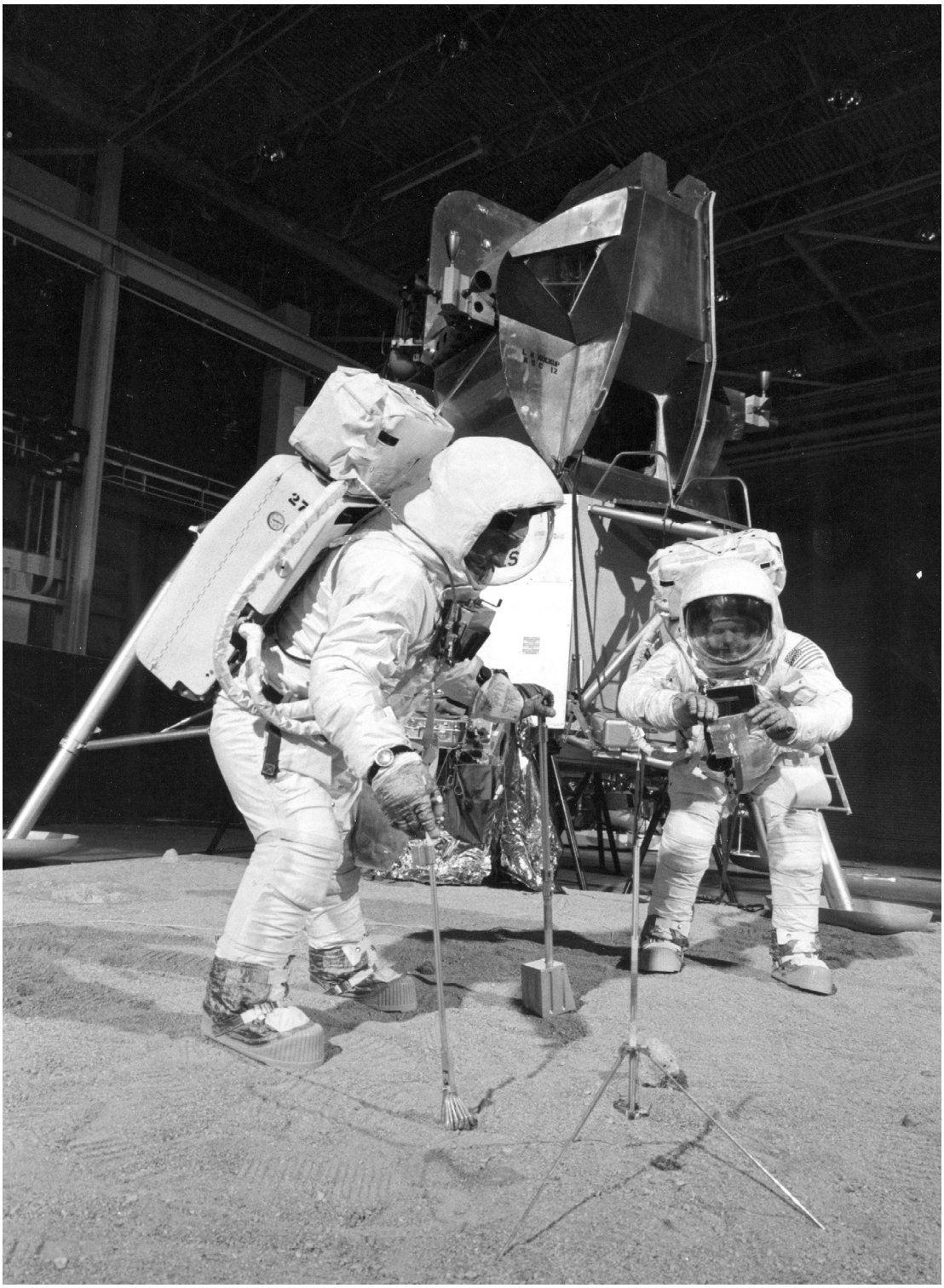


Figure – 2. 11 Apollo 11 Crew undergoing Lunar surface Training on April 22, 1969, NASA, https://images.nasa.gov/details/S69-32233

Simulating the Journey

The Vergeltungswaffe 2 (V-2) ballistic missile, researched and built by Germany during World War II, was the first of its kind capable of accurately striking targets located hundreds of miles away. Its technology was adopted by the United States and the Soviet Union at the end of the war and was quickly incorporated into their military operations. Over the years, the technical data compiled from countless rocket tests led scientists and engineers to conclude that later, improved versions could reach outer space. Post-war tension between the United States and the Soviet Union during the Cold War accelerated progress in rocket technology even further. In 1957, the Soviets launched *Sputnik*, the first satellite to orbit Earth.[1] This unbelievable feat led to immediate American concern and thoughts arose that if a satellite could be launched over America by the Soviets, then so could a nuclear missile.[2] No longer was the need to occupy outer space compelled by imaginative science fiction narratives, but instead, by a larger fear for maintaining American national security and military dominance. Manned spaceflight was a new priority and a national interest. In direct competition with the Soviets, and striving to be the first nation to occupy space, the Americans dedicated a governing body to tackle the growing complexity and scope of manned space flight. In 1958, the National Aeronautics and Space Administration (NASA) was formed, largely in response to the Soviet Union's early achievements in space in order to ascertain *how* to refine existing technology for space applications.[3] In his book, *Fashioning Apollo*, Nicholas de Monchaux describes how the race to manned space flight was linked to human biology. "The problem was not, as the popular imagination had it, "machine-rating the men" (i.e., extending the abilities of men to let them ride rockets). Rather, it was "man-rating" the machines - adapting the technology of early ballistic missiles to operate

---

1 John Uri, *65 Years Ago: Sputnik Ushers in the Space Age*, NASA History, October 4, 2022, https://www.nasa.gov/history/65-years-ago-sputnik-ushers-in-the-space-age/.

2 Columba Peoples, "Sputnik and 'Skill Thinking' Revisited: Technological Determinism in American Responses to the Soviet Missile Threat," Cold War History 8, no. 1 (2008): 55–75, https://doi.org/10.1080/14682740701791334.

3 John Uri, *65 Years Ago: The National Aeronautics and Space Act of 1958 Creates NASA*, NASA History, July 26, 2023, https://www.nasa.gov/history/65-years-ago-the-national-aeronautics-and-space-act-of-1958-creates-nasa/.

within the boundaries of human performance."[4] To operate within such physical boundaries meant that the human body and its limits needed to be tested where access to space was limited rather than become cybernetically enhanced as popularized in science fiction at the time. Not only did NASA need to learn how one could cope with the extreme acceleration forces of rocket flight, but they also had to determine how astronauts would function and train for the sensation of weightlessness in the vacuum of space itself.

In 1959, in preparation for the first manned spaceflight, American engineers and would-be astronauts began to tirelessly envision and prepare for space and its yet to be determined challenges. With Project Mercury, military test pilots were recruited as they were deemed the best candidates for the first human spaceflight program. Selected for their experience in flying unproven and dangerous aircraft prototypes, the *Original Seven* Mercury astronauts were determined pilots. Each dared to fly the fastest, the longest, and the farthest to prove to the world that they would rightfully fly into space first. In *The Right Stuff*, Tom Wolfe outlines why the 1950s Mercury pilots had the "right stuff" for the job -- "because they shared an unspoken code of bravery and machismo that compelled them to ride atop of dangerous rockets."[5] This attitude also served them to undergo experiments designed to highlight the stressful conditions of space and push the human body to new limits and anticipate what may lay ahead.

Human spaceflight simulation created a gateway for NASA to begin to understand what space flight would be like for astronauts. Preparing an astronaut's physical body to cope with the unexpected and dangerous forces that could occur during spaceflight demanded repeated simulations to ensure astronaut acclimatization and sustained control. One such simulator was the Multiple Axis Space Test Inertia Facility (or MASTIF) of which astronaut Virgil "Gus" Grissom best describes his experience:

> Your body lurches against the tight harness that straps you to the contour couch. Then you rotate faster and faster... It is a wild, sickening sensation. Your vision blurs. The cold sweat erupts.[6]

MASTIF allowed astronauts, like Grissom, to experience the intense g-forces during a simulated free-fall. This was a necessary, yet highly displeasing experience designed to expose astronauts to the negative

---

4 Nicholas De Monchaux, S*pacesuit: Fashioning Apollo* (MIT Press, 2011), p 151

5 Tom Wolfe, *The Right Stuff,* (Farrar Straus and Giroux, 1979), p 368

6 Virgil Grissom, "Wild 3-Way Tumbles in Mastif" *Life*, April 1960, p 58

physical feelings that would accompany a tumbling spacecraft. For astronauts to remain calm and in control of their spacecraft. Simulating a spacecraft in free fall, as opposed to testing a real one, also avoided putting the occupants in perilous danger.

Weightlessness training was another important simulation for the Mercury astronauts. It was accomplished by riding a Samaritan C-131 cargo aircraft: as the cargo plane rose and descended on a specific trajectory, spacesuit-clad astronauts experienced a brief feeling of weightlessness, and the initial nausea associated with it (hence, the plane's nickname, the "vomit comet"). See (Figure – 2. 13) NASA had designed the interior of the plane with soft padding so that the astronauts could freely and safely collide. Although each trip's mission time was miniscule, compared to a full orbit around the Earth in the Mercury program's first manned space flight, the experience was pivotal in ascertaining that in the vacuum in space, the human body *can* adapt without gravity.

As testing of the physiological applications of human space flight progressed with the Mercury program, the role of the astronaut needed to be more clearly defined. Preliminary thought envisioned manned space flight as being completely automated; however, if a situation arose that pilot intervention was required due to automated flight failing, then a reliance on total automation of machine could be disastrous. NASA eventually accepted that the astronauts needed control over the machine that was enabling them to venture into space. The fact that all of the Mercury Seven astronauts were previously trained as test pilots and knew what they needed in order to control and fly a craft was also persuasive.

Aside from gained credibility within NASA, The Mercury Seven would also be backed by an American public who had become enamoured with the astronauts themselves. In the public eye, these men were seen as successful and charismatic people; this aspect motivated NASA into making further preparations before sending the men on their first flight. NASA needed to be confident that when it came time for the "real" mission, there was no margin for error. In an era of live TV broadcasts, a failed launch, resulting in the loss of human life, would have greatly set back the space program by dissuading the American public from further support of such a costly effort. President Richard Nixon had at the ready a speech if the mission resulted in catastrophic failure.[7] Thus, with changes from an automated to a more

---

7 Bill Andrews, "If the Apollo 11 Astronauts Died, Here's the Speech Nixon Would Have Read," *Discover Magazine*, July 19, 2019, https://www.discovermagazine.com/the-sciences/if-the-apollo-11-astronauts-died-heres-the-speech-nixon-would-have-read.

manually piloted spacecraft, and pressures for success from an American public, NASA came to rely on flight simulations, and the process of trial and error, as a cost effective and safe way to establish the data it needed to make decisions to safely land a man on the Moon.

When president John F. Kennedy addressed congress and the American public with his dramatic speech in 1961, he challenged his nation to send a man to the moon and bring him back safely before the end of the 1960s. With the resulting increase in federal funding, NASA's previous experiences with the Mercury program became a stepping stone to designing more advanced systems and simulators in the Gemini and Apollo space programs. With Project Gemini, mission simulators began to incorporate a new, innovative display method termed the "Virtual Image Display." By rigging photographic transparencies with hand painted lunar models to the small windows of the capsule craft, astronauts could now view and perceive depth in a simulated landscape.[8] This 'virtual' display technique was the start of a more complex method of simulating exterior landscapes, and a substantial improvement over earlier Mercury simulators that ran on slow analog computers.

The advancement of computer generated "space" displays would coincide with increased computer technology adapted for spaceflight simulation. In 1964, General Electric and NASA introduced a revolutionary new system that used the IBM 360 computer. It simulated lunar approach and landing with a direct display of digital pixels. In addition, the main systems of the Apollo's guidance computer could be more effectively programmed and run as emulated software on it. This allowed missions to be programmed into the guidance computer without overloading the already delicate, experimental hardware systems that were aboard the craft. Astronauts now had a real taste of an upgraded "digital" landscape and it was arguably a better way to simulate a wide range of mission profiles:

> The GE system was the first true digital landscape of the space race...In its visual vocabulary of checks and crosses, the black and white cathode of the GE system is remarkable for its reduction of the lunar goal to its essence - a mastery not so much of earthly space or outer space, but the information of space.[9]

---

8 Nicholas De Monchaux, S*pacesuit: Fashioning Apollo* (MIT Press, 2011), p 171

9 Nicholas De Monchaux, S*pacesuit: Fashioning Apollo* (MIT Press, 2011), p 175



Figure – 2. 12 The Gimbal Rig (MASTIF), photograph, 1959, NASA, https://commons.wikimedia.org/wiki/File:Project_Mercury_-_AWT_Gimbaling_Rig_-_GPN-2000-000691.jpg



FIGURE – 2. 13 Mercury astronauts training in simulated weightless flight inside NASA's KC-135, a C-131 aircraft, 1961, NASA, https://commons.wikimedia.org/wiki/File:Mercury_Astronauts_in_Weightless_Flight_on_C-131_Aircraft_-_GPN-2002-000039.jpg

With the capabilities of this new digital system, astronauts could be further exposed to and anticipate possible equipment failures and corrective procedures.

> Having electronic simulators, in conjunction with working prototypes, became the main instruments for testing the actual flight systems for space crafts. The unproven physics of landing the Lunar Lander on the surface of the Moon became the source of countless hours of simulation for astronauts. Inside the Lunar Excursion Module (LEM). A full-scale mock-up of the Apollo craft, the LEM simulator was contained in a large warehouse. Among the Apollo 11 astronauts was mission commander Neil Armstrong, who spent almost 949 hours training, with roughly 285 of those hours being alone in the lunar landing simulator. His teammate, Buzz Aldrin, also spent a third of his own thousands of hours of simulation, just on the act of landing.[10]

The understanding of such "virtual" simulation was that it allowed for infinite scenarios. Testing mission flights through virtual displays provided the astronauts with the illusion of depth of field needed to calculate and predict the lunar landing; a place no one had ever ventured to yet.

Physical simulators were just as important as electronic ones because of the psychological aspect associated with flying a "real" craft. The digital world, while extremely useful, could never fully emotionally prepare the astronauts for their mission as the risks remained fictional. To address this, the Lunar Landing Research Vehicle (LLRV) appeared in 1964 with its successor, the Lunar Landing Training Vehicle (LLTV), in 1966. Both the LLRV and LLTV used a complicated gimbal and propulsion system that incredibly emulated one sixth of Earth's gravity for astronauts as if they were on the Moon. The flying of the craft was an awkward experience; the vehicle was dangerous to operate as it was susceptible to high winds and updrafts, forces not present on the Moon itself. In 1968, Neil Armstrong had to emergency eject from the LLRV he was piloting due to high winds during the flight.[11] Despite the crash, Armstrong would go on to acknowledge this airborne simulation device as being vital to the successful landing of the *Eagle One*, the first lunar module that landed on the Moon:

---

10 Nicholas De Monchaux, *Spacesuit: Fashioning Apollo* (MIT Press, 2011), p 176

11 55 Years Ago: Astronaut Armstrong Survives LLRV Crash - NASA, NASA History, May 4, 2023, https://www.nasa.gov/history/55-years-ago-astronaut-armstrong-survives-llrv-crash/

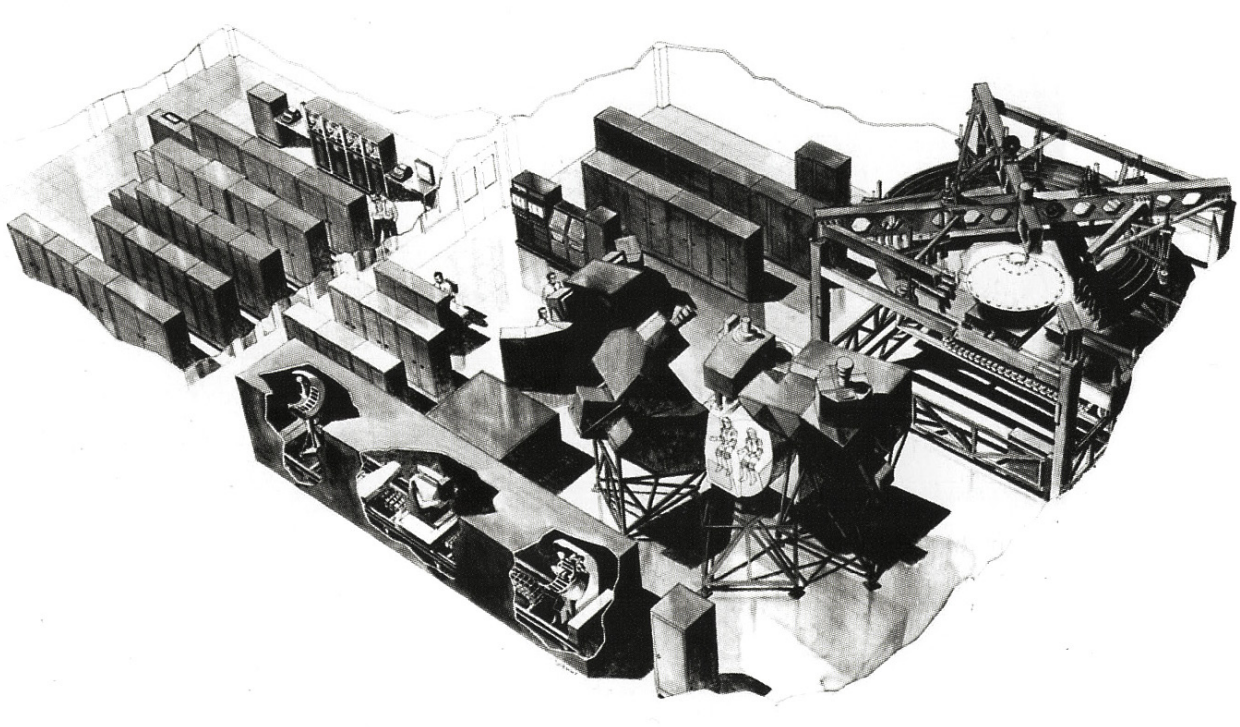


Figure – 2. 14 Artist sketch of the Lunar lander mission simulator, NASA



Figure – 2. 15 Three astronauts inside the Command Module Simulator in Building 5 during an Apollo Simulation. Left to right, are astronauts Thomas P. Stafford, commander; John W. Young, command module pilot; and Eugene A. Cernan, lunar module pilot, (S68-15952) , 1968, NASA, https://images.nasa.gov/details/s68-15952

> [The] Eagle flew very much like the Lunar Landing Training Vehicle which I had flown more than 30 times at Ellington Air Force Base near the Space Center. I had made from 50 to 60 landings in the trainer, and the final trajectory I flew to the landing was very much like those flown in practice. That of course gave me a good deal of confidence – a comfortable familiarity.[12]

Free flight simulators prevailed, because unlike virtual computer modules, they did not have a reset button or pause button. The act of being subject to real forces and consequences, pushed one out of their comfort zone, and one step closer to realism. Similarly, Apollo 10 and 17 Astronaut Gene Cernan highly valued his experience on the LLRT and LLTV because of the dangers associated with flying experimental machinery:

> I'm going to use the reset button as an example. You're in a simulator and you know you screwed up...and that's what simulators are for. And you know you do it again, and again and again, but stop and say let's go out to have a coffee and go talk to the instructor. 'Where did I screw up? What could have been done better?... So when I talk about the reset button that's what I referred to...You plan to shoot ten landings, which ones are the most important that you prepare for, the first one. That's your first shot. And that's what I'm trying to say, you don't have a reset button in a LLTV, you don't have a reset button in a Lunar Lander. There is no reset button. The LLTV puts you in that psychological environment. Your denying yourself the psychological impact of doing it, by going one step closer to the real world of landing on the moon. It's better to take the risks here, to get out of screwing up here, but I can't get out of screwing up there (space) ... In all simulations we can freeze time. In the real world we can't do that.[13]

Simulation provided NASA and its crew members with essential test data. It served as a methodological approach to replicating conditions anticipated in space but recreated on Earth, allowing participants to acquire practical, experience-based insights. Although the spacecraft and environmental conditions were not exact one-to-one representations, the opportunity to operate and evaluate and become familiar to the machinery ensured adequate preparation for the real thing. The value astronauts placed on physical

---

12 *50 Years Ago: The Lunar Landing Training Vehicle* - NASA, December 7, 2017. https://www.nasa.gov/history/50-years-ago-the-lunar-landing-training-vehicle/

13 Gene Cernan, LLTV Apollo conference, 2008 4 LLRV Apollo Conference Conversion.Mov, directed by ALETROSPACE, 2011, 44:29 https://www.youtube.com/watch?v=x2gerZtStJQ



Figure – 2. 16 Apollo Mission Lunar Module Simulator, NASA, 1972, https://wikiarchives.space/picture.php?/54233/category/138

training simulators fostered the confidence required for the success of the mission.

There are no second chances in space. Learning how to exist in space for the first time was a gradual process that involved understanding not only of the physiological elements of spaceflight, but of the psychological implications of having only one chance to pull off a successful mission to space. One could not directly train in outer space to gain the experience needed for operational successes; the multi-billion dollar costs to do so would be far too great, and the risks far too high if mechanical errors occurred. The use of both electronic and free flight (or physical) simulators, which replicated exact conditions and scenarios expected in space and on the Moon, are what astronauts and engineers used to evolve the design of the space craft and its use. They *pretended,* through repeated training exercises that simulated specific but partial experiences, to provide a real enough sensory experience that one could be confident enough to perform when it mattered. Not only did mission designers and software programmers need to work in tandem, both were required to manage, predict and code the scenarios astronauts would be facing.[14] If astronauts required hundreds of hours of simulation exercises, as well as crafts continually being refined and developed to meet operational needs, then the architecture of the Apollo space craft became a very different beast than expected. The final form of the Command Module and Lunar Lander changed significantly from early prototypes in order for it to be successful. For the general public, seeing Neil Armstrong touch down on the Moon on live television, was history being made without knowing all the behind-the-scene efforts and secrecy required. To the general public, reality was significantly different than what they had seen in science fiction. The elaborate fantasies that people had dreamed of, or had been shown about living in outer space would be changed in the face of reality. The romanticized view of space—with its sleek rocket ships and notions of luxury—was replaced by highly complex, purpose-engineered spacecraft featuring exposed structural frames, no guarantee for survival, and the iconic fabric spacesuit.

---

14 De Monchaux, *Spacesuit: Fashioning Apollo*, 172



Figure – 2. 17 Earth Rise photographed during Apollo 8 flight. 12/24/1968 - NASA, 68-HC-870, https://www.flickr.com/photos/nasacommons/9460163430/in/album-72157634973839148/

THE VIEW FROM SPACE

Having gotten away from the spacecraft I was able to really realize what this place was like that we had landed on. I had tried to anticipate what it would be like for many years, but it was obvious that there was no way one could have anticipated what it would be like to stand in the valley of Taurus-Littrow, a place deeper than the grand canyon and as equally as spectacular, see this brilliantly illuminated landscape with a brighter sun than anyone had ever stood in before, with a blacker than black sky, and then to top the whole scene off in this blacker than black sky, was a beautiful, brilliantly illuminated blue marble that we call the Earth.

Jack Schmitt, Apollo 17 (For all Mankind, 1989)



FIGURE – 2. 18 The descent vehicle from the Vostok I spacecraft is seen at the landing site 700 km south-east of Moscow on April 12, 1961, https://www.irishtimes.com/life-and-style/people/the-man-who-fell-to-earth-1.567958

Manned Spaceflight

After decades of research and preparation, manned space flight was achieved on April 12, 1961 when Russian cosmonaut, Yuri Gagarin, flew into orbit in the Vostok 1. The experience of flying into space was anticipated, tested and simulated well before it happened. Engineers and scientists had created the science required to enable astronauts to train for the mission at hand on known data. However, the gravity of being the first human in space was beyond anything one could predict, even for Gagarin. Minutes before launch, he gave this short speech before his flight into space:

> You must realize that it is hard to express my feeling now that the test for which we have been training long and passionately is at hand. I don't have to tell you what I felt when it was suggested that I should make this flight, the first in history. Was it joy? No, it was something more than that. Pride? No, it was not just pride. I felt great happiness. To be the first to enter the cosmos, to engage single handed in an unprecedented duel with nature - could anyone dream of anything greater than that? But immediately after that I thought of the tremendous responsibility I bore: to be the first to do what generations of people had dreamed of; to be the first to pave the way into space for mankind. [1]

When Yuri safely ejected from his Vostok capsule onto an open field, his spherical ship, scorched from the extreme heat of re-entry, (Figure – 2. 18) it proved that the dream of space travel was possible, but that it existed in a different form than initially presented. The sleek rocket ships depicted in science fiction before and during the space race were incredibly different in appearance and function compared to the stripped down, Vostok 1. It had no thrusters for a controlled descent or any luxuries. Gagarin needed to parachute to safety as the capsule crashed to an open field. It was engineered to only function with a specific goal: sending the first man into space.[2]

For Gagarin the experience of spaceflight was not like anything he imagined. The sight of the Earth from his narrow port window was hard for him to describe to others upon his return. In mission

---

1 Yuri Alekseyevich Gagarin, *Soviet Man in Space* (University Press of the Pacific, 2001).

2 ESA, "The Flight of Vostok 1," accessed July 21, 2025, https://www.esa.int/About_Us/50_years_of_ESA/50_years_of_humans_in_space/The_flight_of_Vostok_1.

transcripts, Gagarin was overwhelmed.

> What beauty. I saw clouds and their light shadows on the distant dear earth.... The water looked like darkish, slightly gleaming spots.... When I watched the horizon, I saw the abrupt, contrasting transition from the earth's light-colored surface to the absolutely black sky. I enjoyed the rich color spectrum of the earth. It is surrounded by a light blue aureole that gradually darkens, becoming turquoise, dark blue, violet, and finally coal black[3]

This account of the Earth from orbit was the first made by man, but not the last. Many astronauts have been awestruck by the beauty of the Earth from space. Known as the Overview Effect[4], it is the experience of witnessing the Earth as a fragile, small dot, hanging in the vast void of space. In space, the Earth does not exhibit the conflicts and struggles that divide people and nations.
Before the end of the 1960's, America followed with their own triumphant milestone when Apollo 11 astronauts stepped on the Moon.

Our achievements in outer space come from the work of thousands of people before our time. Those who thought and explored space travel from a theoretical and fictional viewpoint, to those who discovered and developed the technology for its existence. The crew of Apollo 11 made reference to Jules Verne's book during a TV broadcast, the mission's commander, astronaut Neil Armstrong, said:

> A hundred years ago, Jules Verne wrote a book about a voyage to the Moon. His spaceship, Columbia, took off from Florida and landed in the Pacific Ocean after completing a trip to the Moon. It seems appropriate to us to share with you some of the reflections of the crew as the modern-day Columbia completes its rendezvous with the planet Earth and the same Pacific Ocean tomorrow.[5]

This nod from Neil Armstrong to Verne's almost century-old prophetic vision, demonstrates that the accomplishment of space flight is built upon layers and generations of thought and ideas over time.

---

3 Yuri Alekseyevich Gagarin, Soviet Man in Space (University Press of the Pacific, 2001).

4 Frank White, The Overview Effect: Space Exploration and Human Evolution, Third edition, Library of Flight (American Institute of Aeronautics and Astronautics, Inc, 2014).

5 Neil Armstrong, Mission Flight Logs, NASA, https://www.nasa.gov/history/afj/ap11fj/25day8-reentry-stowage.html



FIGURE – 2. 19 Astronaut Eugene Cernan drives the Lunar Roving Vehicle during first EVA, 1972 NASA, https://images.nasa.gov/details/as17-147-22526



Figure – 2. 20 *A Lunar Landscape*, Mural study. Oil on board. 5.5 x 20.5, Chesley Bonestell, 1957

There is simply an unpredictability to the final form of the idea that results. Comparing the Lunar Lander spacecraft (Figure – 2. 19) to that of the *Columbia,* its form is completely different. From the traditional looking interior of the ship, to the lack of a space suit and the unrealistic depiction of the moon, it's depiction is wildly flawed compared to what we know and have achieved today regarding spaceflight. For its time, it was revolutionary. What it had right, was the spirit of space travel - discovering the unknown and exploring and dreaming beyond the horizon. It was a way to validate the creative idea through story in order to discover what a home in space would truly be like without all the data.

This pursuit of scientific accuracy was crucial to the work of Chesley Bonestell, an architect and illustrator whose technical knowledge and artistic skills brought astronomy alive and helped inspire many responsible for manned spaceflight. His paintings showcased stunningly accurate scenes set in outer space locations, such as the Moon, and gave people stunning views from space, before spaceflight existed. (Figure – 2. 20) – (Figure – 2. 22) Once real photographs of the Lunar surfaceemerged in the 1960's, his paintings of the Moon, which depicted jagged mountainscapes, no longer were accurate.



> No artist had more impact on the emerging popular culture of space in America than Chesley Bonestell. Through his visual images, he stimulated the interest of a generation of Americans and showed how space travel would be accomplished.[6]

Wyn Wachhorst describes Bonestell's spaceflight art as being the reason a qualitative leap to a larger space enthusiast audience in the forties occurred. Among those growing up in the forties and fifties who later became prominent in space fact or fiction, there are few who would not cite as a significant personal influence, the astronomical art of Chesley Bonestell.[7] *A Lunar Landscape* remains today, both a reminder of an era when humanity could only dream of space travel, and a casualty of a dream realized.[8] The romanticized versions of space are inspiring and hopeful up until they are changed from reality itself.

---

6 Howard E. McCurdy, *Space and the American Imagination*, Smithsonian History of Aviation Series (Smithsonian Institution Press, 1997). p, 416

7 Wyn Wachhorst, "*The Dream of Spaceflight: Nostalgia for a Bygone Future*," The Massachusetts Review (Amherst) 36, no. 1 (1995): 7–32.

8 *The Saga of A Lunar Landscape*, January 22, 2010, https://airandspace.si.edu/stories/editorial/saga-lunar-landscape.



FIGURE – 2. 21 *Saturn as Seen from Titan*, Chesley Bonestell, 1944

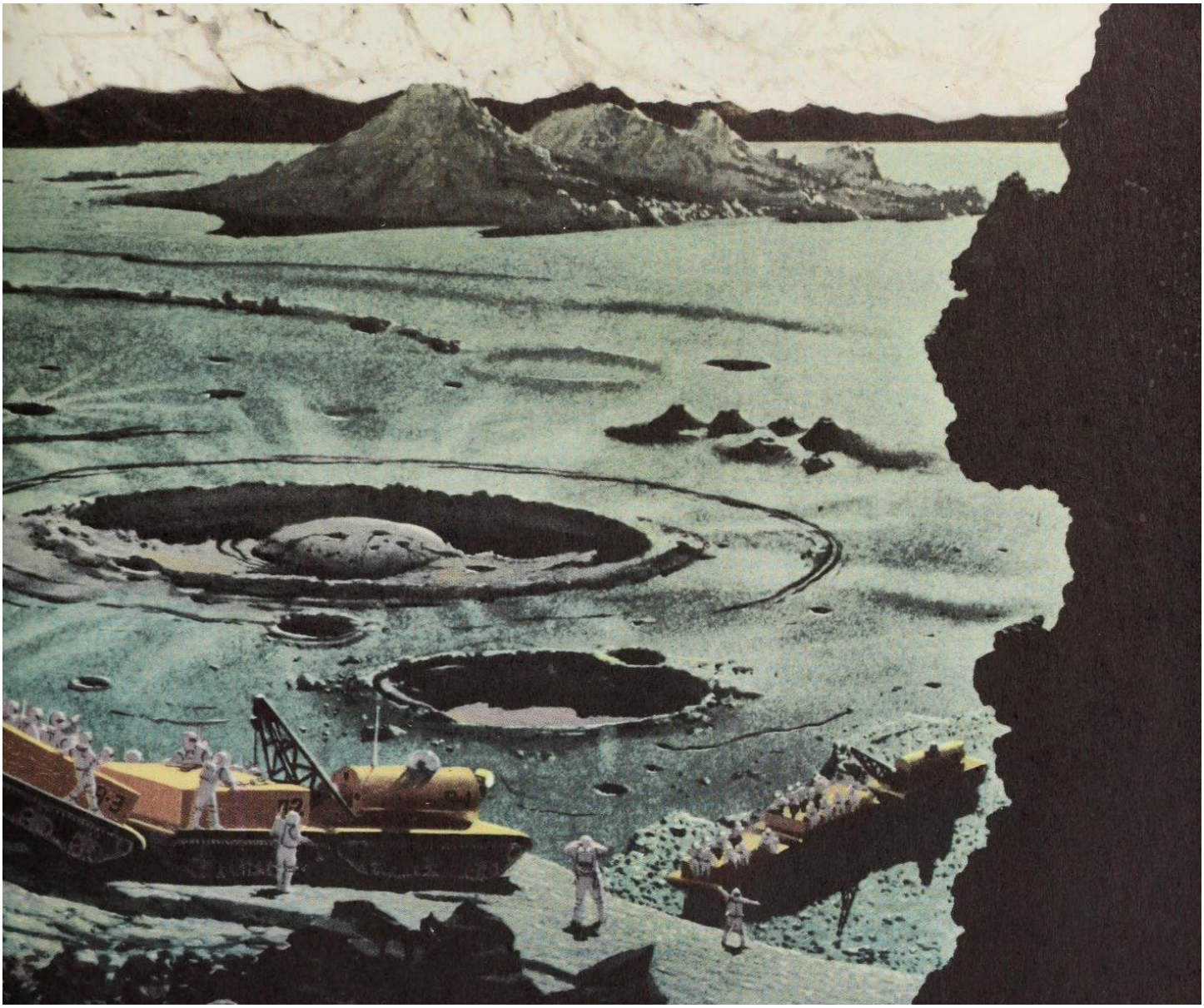


FIGURE – 2. 22 *The Conquest of the Moon*, Chesley Bonestell, 1953

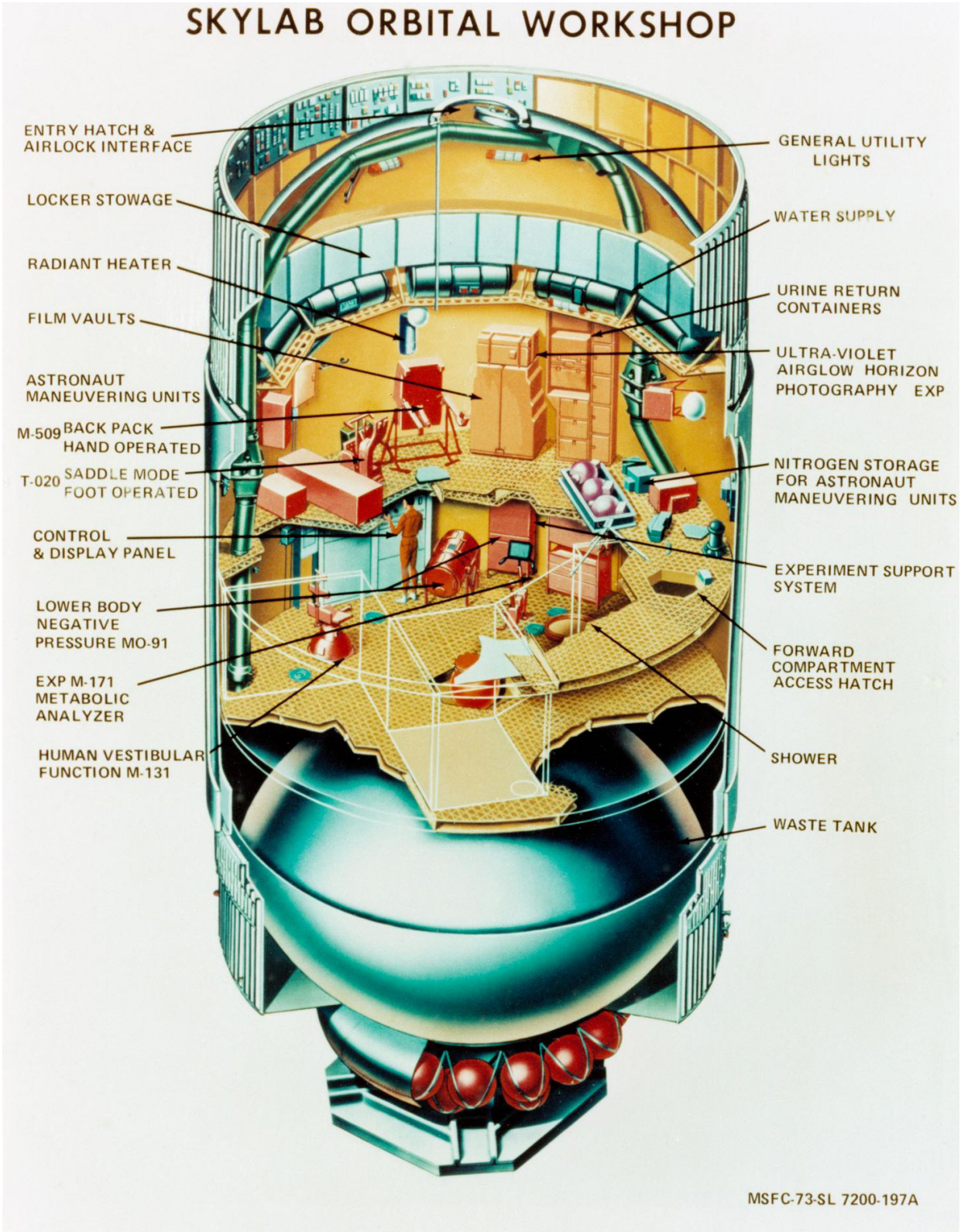


FIGURE – 2. 23 Illustration of Skylab Orbital Workshop, NASA, 1973, https://www.flickr.com/photos/nasa2explore/10840607256/in/photostream/

Understanding Living in Space

Architecturally, a home in space would be unlike any other than that on Earth for the simple fact that the parameters that ground architecture in site are absent in space. Skylab was designed to help answer one of the most pressing questions from NASA's administration - "how long can the human body and spirit endure the rigors of outer space?" Most of the data available from the Apollo missions was inconclusive regarding the effects of space on human physiology due to the short trip durations. When the Apollo 11 astronauts landed on Earth after their eight day journey, they at first appeared fine and lively with no effects of space sickness or apparent radiation issues.[9] Long-term space flight durations were needed.

Almost six years later Skylab was launched on May 14, 1973. Occupying Low Earth Orbit, the craft accommodated the rotation of three crews of three astronauts each, and in doing so subjected them to numerous biomedical tests, craft maintenance procedures, and scientific experiments in observation for durations of 28, 59 and 84 days respectively.[10] Although Skylab's mission was deemed successful, it's living conditions for the crew were less than adequate. Living and working in Skylab was a stressful strain on its astronauts and the first real test of long term habitation in space under strict time lines and scheduling. The confines of Skylab consisted of a large cylindrical volume, roughly 6.7 meters in diameter, recycled from the plentiful Saturn V rocket parts available NASA had accumulated during the Apollo Missions. The living quarters, located below the main workshop level, contained the sleeping compartments. (Figure – 2. 23) Even with the usable space inside being substantially larger, after a few weeks, the longer duration stay in space was starting to become a negative experience. Coping with the ordeals of sixteen-hour work instruction sets, micro-management and the mounting pressure and stress of crew performance reached a breaking point. Skylab IV's crew took matters into their own hands as they were in control of the ship, not Houston's mission control center, and took a

---

9 Jim Wild, "Space Radiation: The Apollo Crews Were Extremely Lucky," *The Conversation*, July 17, 2019, https://doi.org/10.64628/AB.ney9c3aw9.

10 Nicholas De Monchaux, *Spacesuit: Fashioning Apollo* (MIT Press, 2011), p 291.



FIGURE – 2. 24 The three members of the prime crew of the first manned Skylab mission dine on specially prepared Skylab space food in the wardroom of the crew quarters of the OWS trainer during training at the Johnson Space Center on March 1, 1973, NASA, https://www.flickr.com/photos/nasa2explore/11070751783/in/album-72157634791373199



FIGURE – 2. 25 Skylab crew running along the interior walls, NASA, 1973, film still retrieved from: https://youtu.be/JZNKVnDvQY4?t=253

day off from all planned activities. [11]

The design of the interior spaces also contributed to the general negativity towards life aboard the craft. From bland brown colour schemes, to wearing the same clothing outfits for days on end. Throughout the Skylab missions, some astronauts wished to modify their environment to make it more livable. Astronaut Alan Bean, lamented the failure to include a needle and thread among the station's cargo in order to modify clothing.[12] The life of an astronaut was stressful and suited only to those with years of intensive training and simulation for the specific mission. In essence, they were also part of the science experiment. What people expected space to be like due to popular science-fiction visions began to pale in comparison to reality. If space was not the promised sleek rocket ships and luxurious grand interiors, what would a permanent home in space supposed to be?

In the early 1980s, NASA began to plan for a more ambitious and permanent home in space for astronauts. Codenamed "Freedom", this new home would breathe new purpose into the study of human habitation in space, critical scientific research in microgravity and become a symbol of peaceful collaboration with nations. Reduced budgets and the rising costs of realizing these programs meant that other major space agencies, such as the European Space Agency (ESA) and the Russian Space Program needed to join forces. As such history was made with a multi-national agreement to create what we know today as the International Space Station (ISS).[13]

Meticulously planned, wildly expensive and painstakingly assembled in space over the years, the ISS transcends borders to become the world's most valuable one-of-a-kind microgravity research station. Since November 2000, the ISS over the years has accommodated 280 astronauts on board and counting.[14] Every surface of the station is cluttered and packed with delicate equipment and instrumentation to maximize the extremely limited space available on board. (Figure – 2. 28) Unlike

---

11 Ibid.

12 Nicholas De Monchaux, *Spacesuit: Fashioning Apollo* (MIT Press, 2011), p 291.

13 NASA Science, "International Space Station Cooperation," Humans in Space, *NASA Science*, n.d., accessed October 25, 2025, https://www.nasa.gov/international-space-station/space-station-international-cooperation/.

14 NASA Science, "International Space Station Visitors by Country," International Space Station (ISS), *NASA Science*, n.d., accessed October 15, 2025, https://www.nasa.gov/international-space-station/space-station-visitors-by-country/.



Figure – 2. 26 View of the earth from the Cupola Module on the International Space Station, Photograph, NASA, 2024, https://www.nasa.gov/image-detail/gmt066_15_12_jasmin-moghbeli_sn1104_cupola-photos-of-carved-dreidel-2/

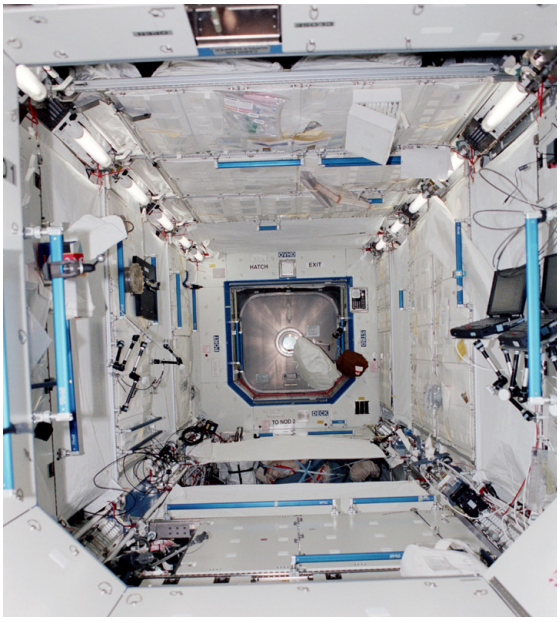


Figure – 2. 27 Freshly installed Destiny module on the International Space Station, Photograph, NASA, 2001, https://commons.wikimedia.org/wiki/File:Destiny_as_just_installed.jpg

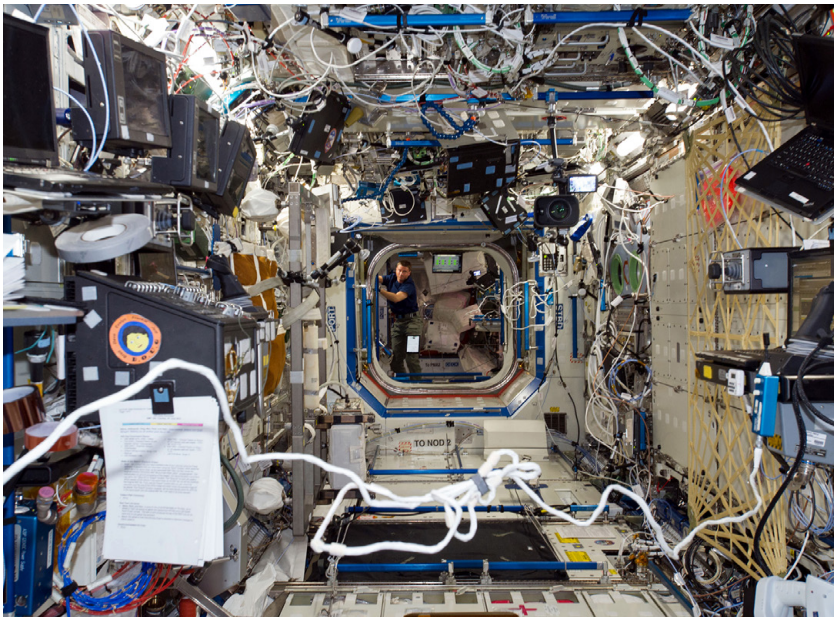


Figure – 2. 28 Destiny module over time, Photograph by NASA, 2014, https://www.esa.int/ESA_Multimedia/Images/2016/03/Destiny_module

Skylab, this scientific home required several modular, prefabricated components to be assembled over the years and extensive ground facility support across the globe. The station today spans the length of a football field (109 meters) and can accommodate up to 13 crew members at a time. This orbital laboratory has become a critical step in understanding long-term habitation in space and the Earth below (Figure – 2. 26). It has also led to significant breakthroughs and new technologies as deemed by NASA.[15] The way to truly understand living in space is to remain there and gain the valuable experience and data that can be gathered over the years in order to plan for and build better space habitats. Other nations not part of the ISS have also built or are planning their own space station operations. The China National Space Administration (CNSA) was able to build the *Tiangong*, a more refined three module space station, in just a couple of years from 2021 to 2022.[16] If this reduced construction timeline means that future space stations can be built more quickly, then aspirations for larger habitats and visionary settlements may become reality faster than anticipated.

---

15 NASA Science, *20 Breakthroughs from 20 Years of Science Aboard the International Space Station*, October 26, 2020, https://www.nasa.gov/missions/station/20-breakthroughs-from-20-years-of-science-aboard-the-international-space-station/

16 Andrew Jones, "China Completes T-Shaped Tiangong Space Station with New Mengtian Module Move," Space, November 5, 2022, https://www.space.com/china-completes-tiangong-space-station.





Figure – 2. 29 Endeavour Space Shuttle docked to the International Space Station, NASA/Paolo Nespoli, 2011, https://www.nasa.gov/image-article/international-space-station-docked-space-shuttle-endeavour-2/

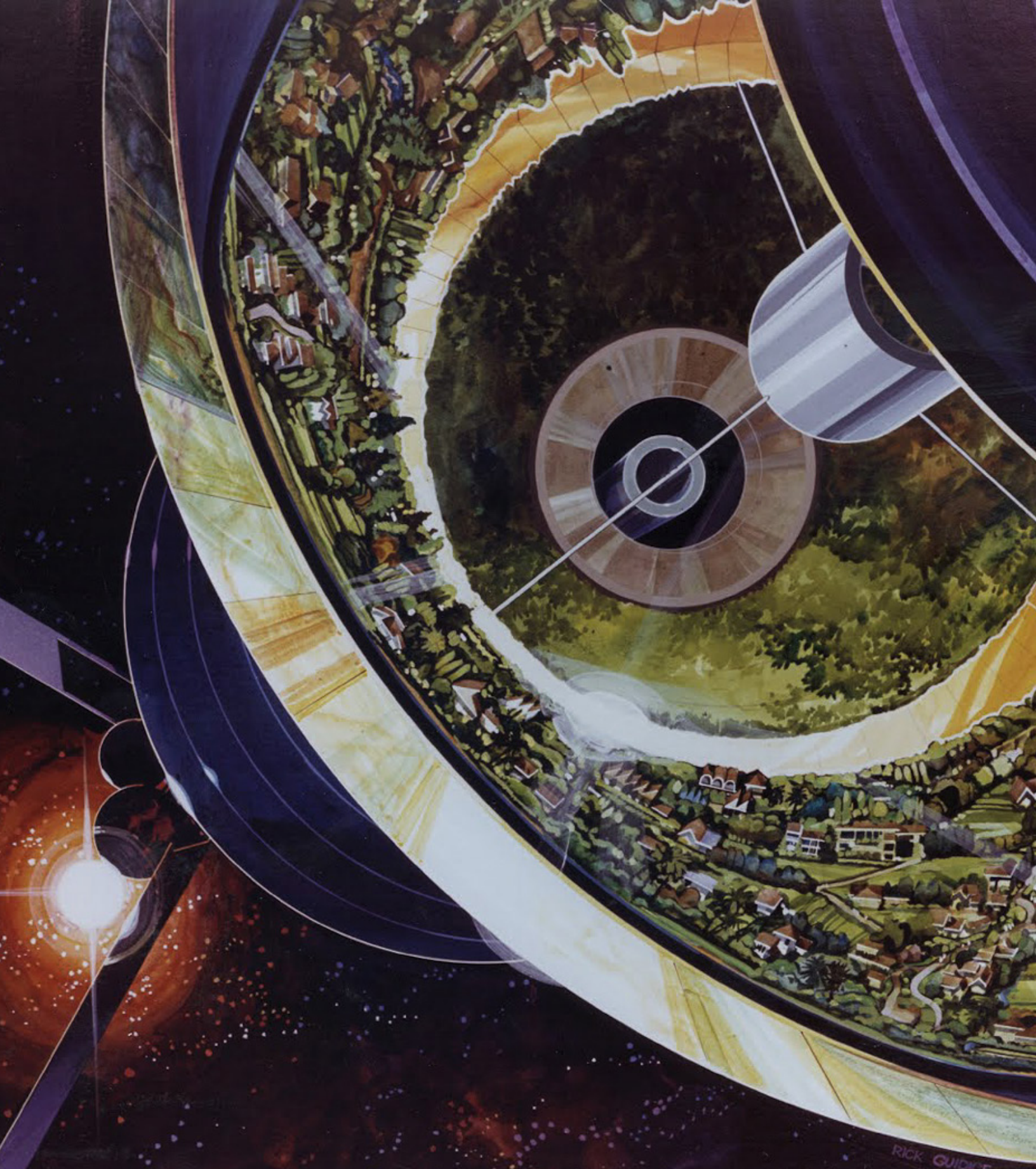


FIGURE – 2. 30 Cutaway view of Bernal Sphere, Rick Guidice, NASA Ames Research Center, 1976, https://www.flickr.com/photos/nasacommons/14052996976

We Continue to Anticipate

We continue to pretend our presence in outer space with even more grand visions. Many of the conceptual ideas of colonizing space, whether through planetary settlements or space stations remain a popular area of study and interest as they are the next step in creating a permanent home in space. (Figure – 2. 30) Even with the slow progress of technological breakthroughs and discoveries and growing restrictions of current spaceflight capabilities, humanity still continues to imagine and plan for new possibilities in space exploration.

Subsequent discoveries and achievements in spaceflight can create feedback loops as to how we continue to anticipate our presence in space. For modern society, we have imagined life in our solar system, specifically the Moon and Mars, as areas for long term beneficial permanent installations. Travel to Mars is roughly three years,[17] which is longer than any existing manned space flight mission. For architects, the challenge becomes how do we live comfortably in the extreme isolation of space where the outside is completely inhospitable and critical resources are limited? The experience of new alternate spaces and living designs are free from the norms of terrestrial architecture. Different circadian cycles, gravity, site and resources exist differently. On the moon, the sheer joy and excitement by the Apollo crew on the lunar surface at 1/3rd the gravity of Earth showed that the moon was a completely novel environment. The lower gravity and different sights of space and the Earth in the distance means that an architectural response to site is a completely different experience. How does an average person reflect and ponder gazing up on the darkness of outer space versus the sky and clouds back on Earth? If we can visualize these new found experiences into tangible data points and experiences, we may imagine living in a space in a completely different manner than initially expected. From books, and drawings to films offering a more sensory experience, to now realistic video games and virtual reality spaces, there has been a shift to be fully immersed in ideas to explore and test their validity. Because space is still such an unknown and inaccessible frontier, even with

---

17 Daisy Dobrijevic Contributions from Nola Taylor Tillman last updated, *How Long Does It Take to Get to Mars?*, Space, January 20, 2022, https://www.space.com/24701-how-long-does-it-take-to-get-to-mars.html.

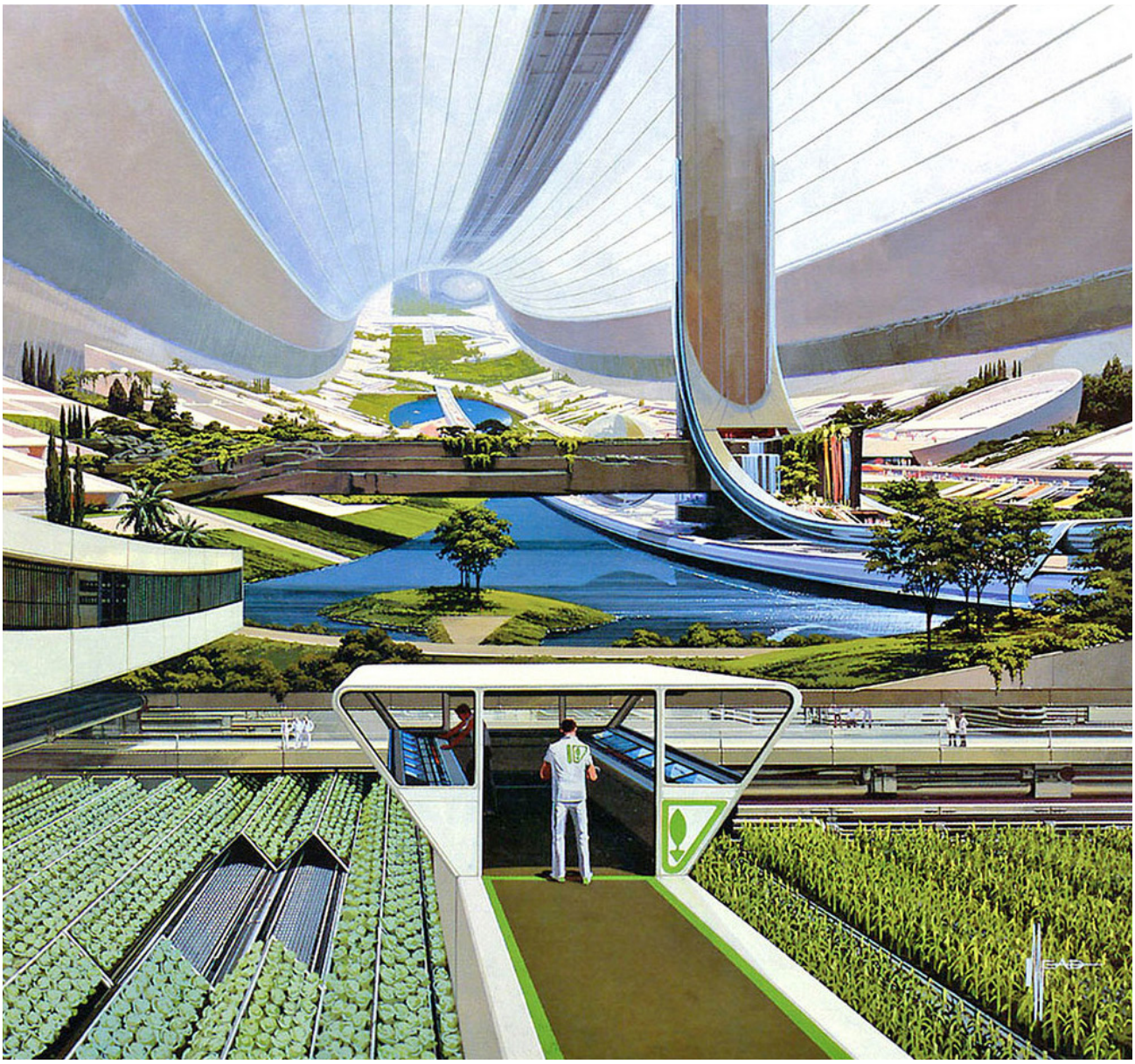


FIGURE – 2. 31 Space Wheel Interior, Gouache on panel (25 x 35), Syd Mead, 1979

our current understanding and exploration efforts, it is difficult to establish architectural precedents due to architects having limited access and input in the space industry. While space agencies and private commercial interest do employ and consult architects to help design, the finalized scope is ultimately ruled by engineering due to the science needed to mitigate risk and to keep astronauts safe. Every square inch of a spacecraft is accounted for and meticulously planned due the severe dangers and consequences of spaceflight if any faults or design flaws occur. Therefore, the actual architectural narrative mostly exists in a vacuum of conceptual and simulated designs, both in analog sites (such as the Mars missions, and Biosphere 2 buildings) and the computer, to bridge the link of what life in space could be.

When we look at visionary artists, such as Syd Mead[18], his work over the years, especially in film, is painted in an optimistic visionary future regardless of cost constraints of reality. (Figure – 2. 31) In his commissioned pieces for US. Steel, his space station design, based on the Stanford torus model, offers a glimpse of life in a settlement in space with clean lines and curvature. Much like Chesley Bonestell, art can transport one to the scenes depicted, as if you are there. In other works and contributions, such as on the movies *Blade Runner* and *Aliens*, Mead used his industrial design to develop worlds and objects with believability. When discussing the inspiration behind the cars designed for *Blade Runner*, Mead states:

> "For the vehicles' models, I used jitneys from the Philippines, stuff from Cuba, cars from the fifties and sixties. They're made to work. It was industrial design in reverse. You start with the original idea and design, then overlay it with stuff that makes it work past its design lifespan. It gives you a retro look underneath that looks rational."[19]

It is this practicality, mixed in with futuristic vision of the city and industrial cues that propelled much of Mead's movie concept work to come to life on the big screen. The artistic freedom that science fiction allows can ultimately influence creative pursuits that inspire.

---

18 Syd Mead, https://www.sydmead.com/biography

19 *Talking to Syd Mead: The Visionary Behind Elysium, Blade Runner, and 40 Years of Sci-Fi*, Vulture, August 8, 2013, https://www.vulture.com/2013/08/syd-mead-design-blade-runner-aliens-elysium.html.

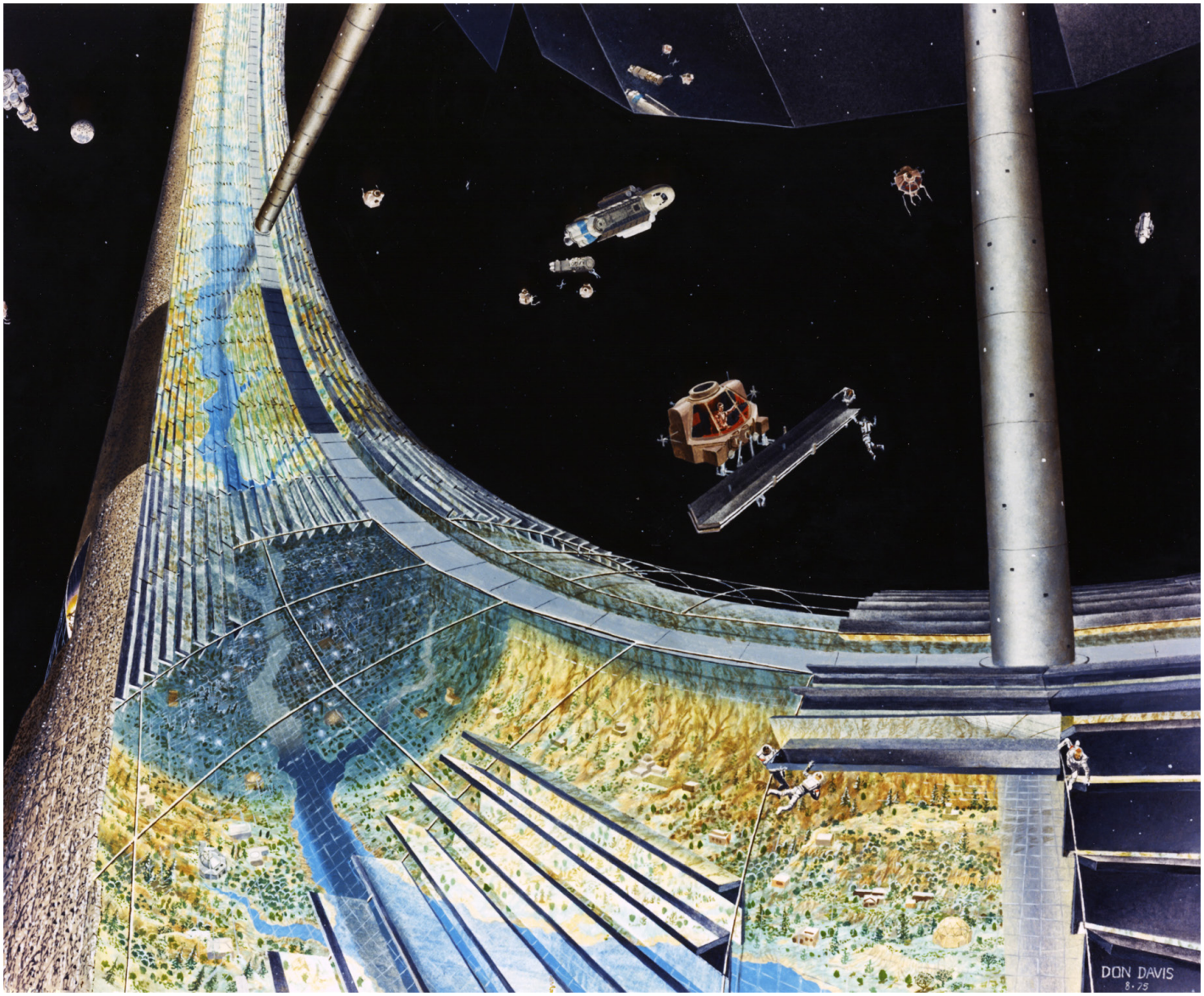


FIGURE – 2. 32 Construction along the torus rim, Don Davis, NASA, 1975, https://www.flickr.com/photos/nasacommons/14052995866/in/album-72157644439092941/

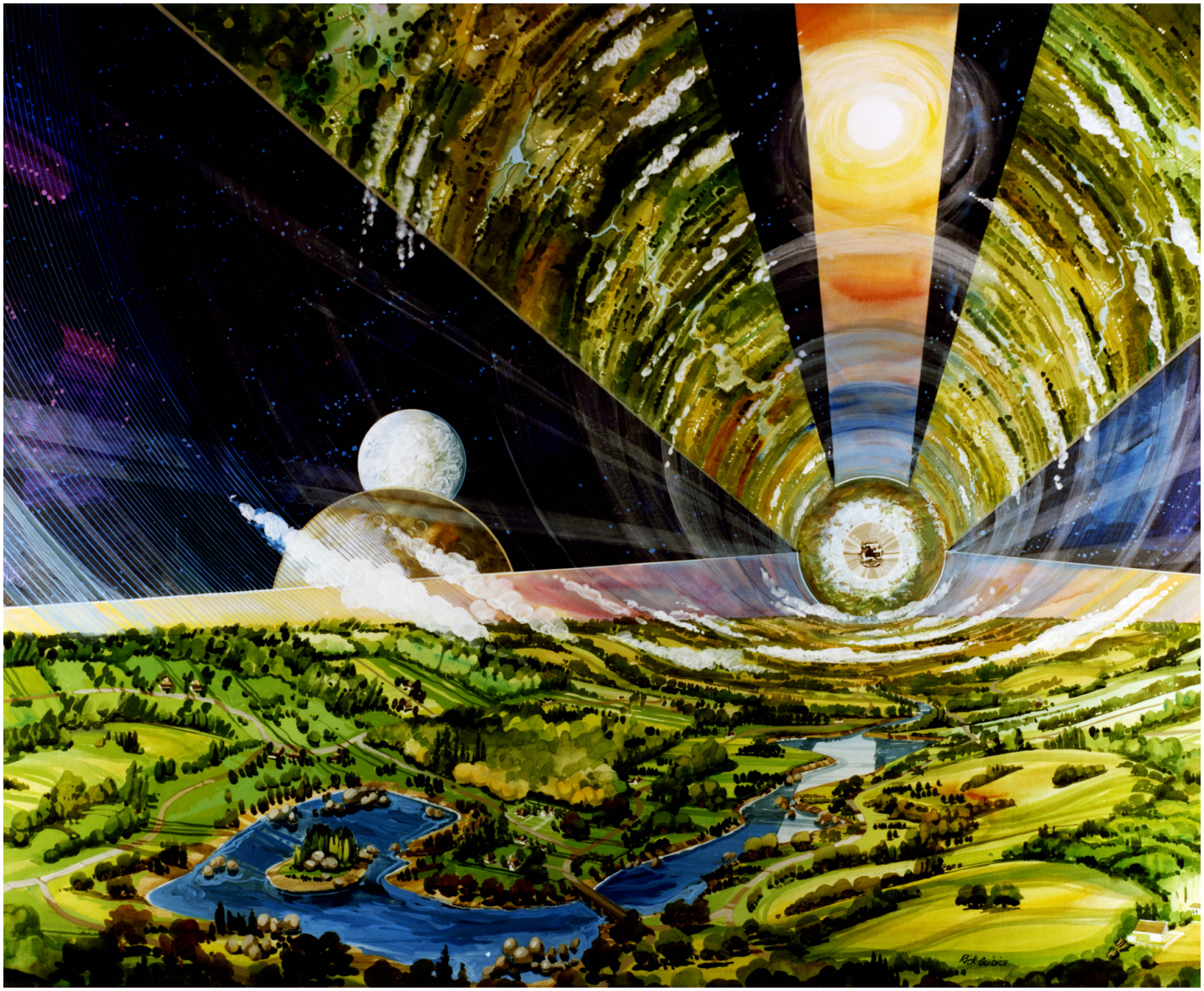


FIGURE – 2. 33 Interior view looking out through large windows, Rick Guidice, NASA, 1975, https://www.flickr.com/photos/nasacommons/14052998066/in/album-72157644439092941

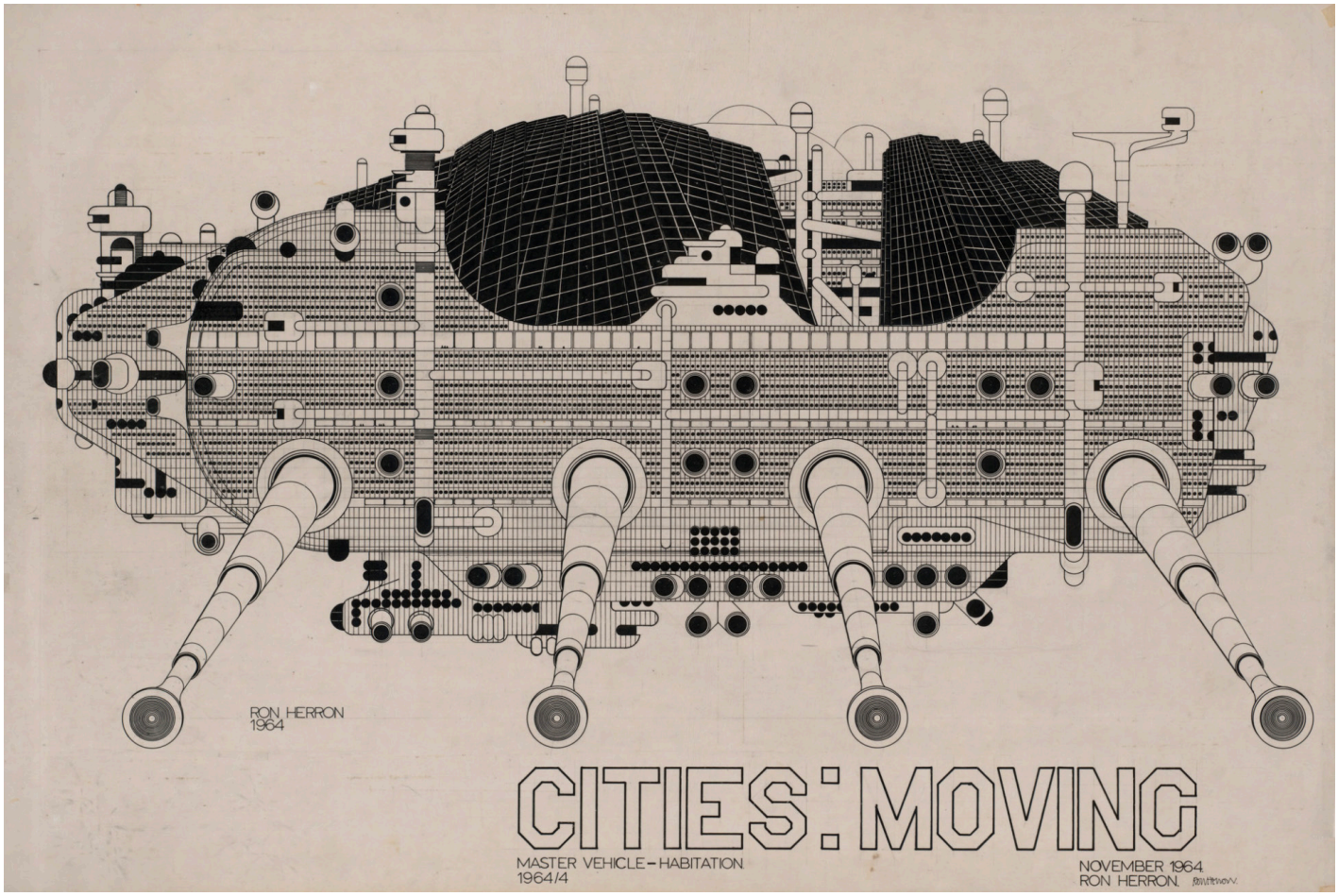


FIGURE – 2. 34 Ron Herron, Archigram, *Walking City*, 1964, https://www.moma.org/collection/works/813

Other fantastic visionary artwork comes from space feasibility studies such as NASA's *Space Settlements* of 1975. (Figure – 2. 32) - (Figure – 2. 33) The team behind the science and the proposed colony explored in detail the mathematical and scientific models required to make it plausible in order to build a sustainable colony.[20] Its architecture of prefab modules for the interior architectural modern houses, as well as the infrastructure, completely dominate and arc and extend into a curved horizon and sight line. This colossal settlement exists as credible because it is designed and presented as a government backed concept, such that its research from academics and engineers provided the necessary data to establish a base foundational model if it were to be built.

This understanding can also be applied to Archigram and other experimental and futurist architects that wished to break from traditional building norms in order to, regardless of absurdity or feasibility, pave way for newer forms to exist.

> (Archigram's) dissatisfaction with this status quo pushed the experimental architectural collective to dream of alternative urban scenarios that flied in the face of the superficial formalism and dull suburban tendencies common to British modernism of the time. The Plug-In City, along with other projects such as The Walking City or The Instant City, suggested a nomadic way of life and, more importantly, a liberation from the modernist answer of suburbia. [21]

Archigram's use of technology and the machine allowed them to think of architecture beyond normal configurations. By adopting a modular functionality as in Plug-In City, there is a correlation to the modular and prefabricated architecture that currently dominates the space industry. In Walking Cities, the idea of a nomadic moving city exists as a superstructure of a metropolis that not only moves, but adapts to the endless change of its environment (Figure – 2. 34). It's architecture is both dynamic and responsive. As noted by Simon Sadler in his book *Archigram: Architecture without Architecture*:

---

20 Richard D. Johnson and Charles Holbrow, *Space Settlements: A Design Study*, January 1, 1977, https://ntrs.nasa.gov/citations/19770014162.

21 Gili Merin. "AD Classics: The Plug-In City / Peter Cook, Archigram " 10 Jul 2013. ArchDaily. Accessed 22 Oct 2025. <https://www.archdaily.com/399329/ad-classics-the-plug-in-city-peter-cook-archigram> ISSN 0719-8884

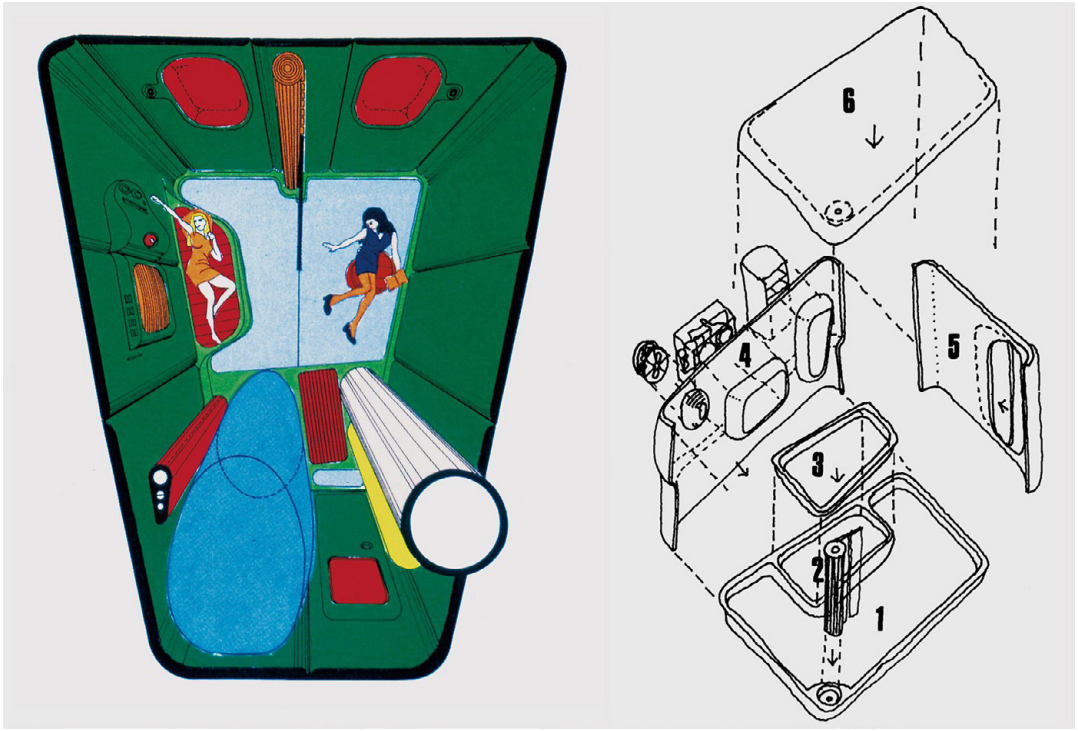


FIGURE – 2. 35 Archigram's Plug-In City concept allowed people to customise their pre-fabricated capsule homes, Archigram, 1966, https://www.dezeen.com/2020/05/12/archigram-plug-in-city-peter-cook-dennis-crompton-video-interview-vdf/

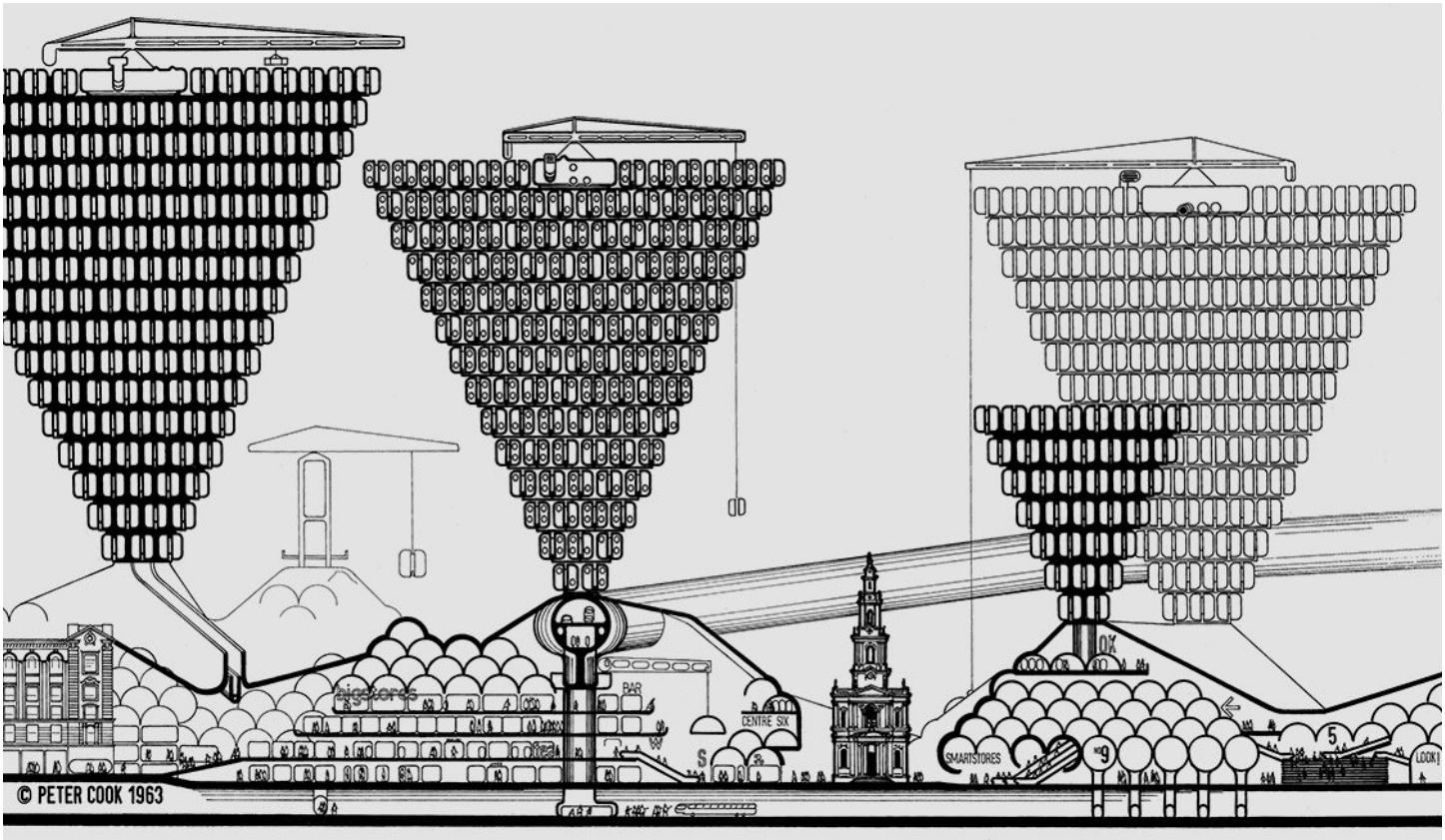


FIGURE – 2. 36 Plug in City, Peter Cook, 1963, https://www.dezeen.com/2020/05/12/archigram-plug-in-city-peter-cook-dennis-crompton-video-interview-vdf/

> Archigram's scatty presentation disguised the radicalism of its argument about architecture. Broadly, it contended that architecture should not create fixed volumes of space to be mutely inhabited, less still shaped masses of masonry, but must provide the equipment for "living," for "being." The extent to which the architectural profession was failing to design this equipment revealed to Archigram that technological modernism was an incomplete revolution, reduced to a dowdy, killjoy version of itself, colorless, hard-edged, frugal, planned rather than chosen. Architectures of serious fun provided Archigram with a way out of the modernist impasse without having to backtrack to pre-modernist "tradition."[22]

At it's core, the Archigram group and Plug-In City (Figure – 2. 35) represented a notion of pursing the ideas set out of new anti-modernist designs heavily influenced by technology and pre-fabrication.

> The merging of architecture and industrial design had been implicit since Le Corbusier had demanded a "machine for living in," which Archigram now delivered, provocatively taking the master's advice literally: "A house will no longer be this solidly built thing which sets out to defy time and decay . . . it will become a tool as the motor car is becoming a tool."[23]

Pre-built, assembled modules in outer space draws upon this same design flow, and mimics the same notion that the modular design of a space station, scales with its functionality and movement through space. This notion of the moving city also draws parallels to the many floating cities depicted in science fiction and is radical for it's time.

Examining contemporary theoretical concepts by architects El Hadi Jazairy and Rania Ghosn, their winning competition design of space station *Laika*, which is named after the ill-fated dog the Soviets sent to space to die, is tethered to the planet Earth as a space elevator.[24] Designed to collect the ever growing defunct space satellites and debris in Earth's orbit, the collection of space junk forms a symbiotic transfer of solar energy back to Earth. (Figure – 1. 37) Although the notion and capabilities of a space tether is still presently science fiction, the architecture behind linking the Earth to the

---

22 Simon Sadler, *Archigram: Architecture without Architecture* (MIT press, 2005), 5-6

23 Simon Sadler, *Archigram: Architecture without Architecture* (MIT press, 2005), 100

24 Rania Ghosn and El Hadi Jazairy, *Geostories: Another Architecture for the Environment*, 137

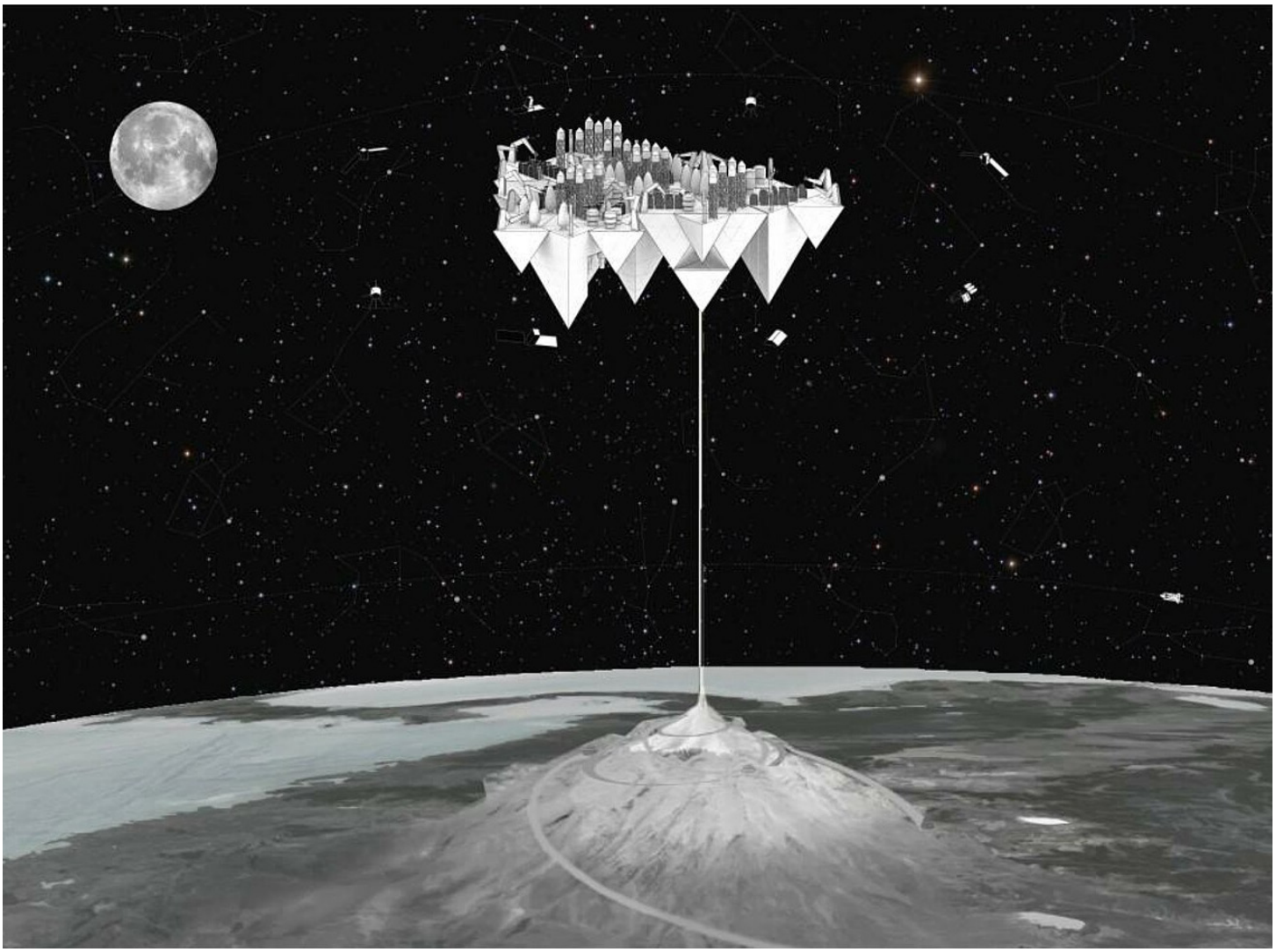


FIGURE – 2. 37 *Design Earth*, Neck of the Moon, 2015, image retrieved https://www.jacquesrougeriedatabase.com/project/neck-of-the-moon

cosmos to contain and collect the growing debris orbiting our planet touches on the realization that architectural forms will need to one day respond to the manufactured world of space parts littered above us.

The small sample of ideas presented here is just a fraction of the many that exist. Much like the growth of several architectural movements defining new architectural styles, space architecture concepts continually evolve. Early futurist space concepts and stories ultimately reshaped how society thought and expected space architecture to look like even if they did not align with reality. After spaceflight was achieved, many of these countless romanticized concepts became irrelevant and outdated. The multitude of existing constructs and layers all exist in some capacity to draw ideas and lessons from, but many exist as entertainment forms rather than carefully investigated portrayals. Showcasing realistic space architecture narratives started to become even more influential with immersive media such as film to present impressive visual and auditory experiences.

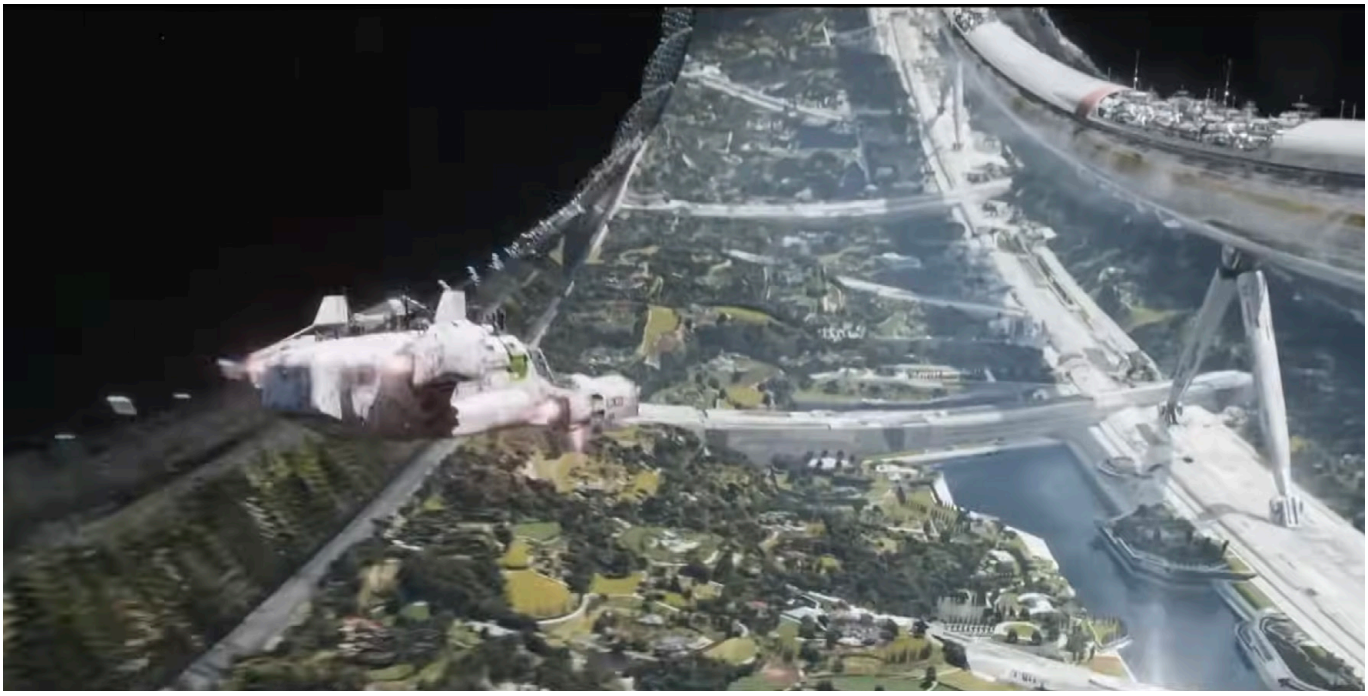


FIGURE – 2. 38 Spacecraft entering Elysium's atmosphere, frame capture, *Elysium*, 2013

The Evolution of the Medium

The portrayal of how we visualize outer space has become increasingly more prolific over time with the emergence of new technologies and techniques. Science fiction motion pictures have become embedded into the social fabric of modern society for over a century now. Today many people know of, or have at least heard of, the *Star Wars* and *Star Trek* franchises with works spanning generations since their introduction in the 60s and 70s, respectively. The creative transformation of print and artwork material into elaborate and believable science fiction set pieces is part of the *magic* of filmmaking. Along with practical and computer-generated visual effects (VFX), the once impossible becomes possible on screen.

Films and television have long served as the standard of not only showcasing dramatic stories set in space, but also visually crafting immersive experiences as if you are there with the characters. Stanley Kubricks' *2001: A Space Odyssey* was the first-of-its-kind to realistically take the viewer on a realistic and visionary journey of what our future space-faring civilization may look like. From the first discovery of a tool by our primordial ape ancestors to the larger than life spaceships as a means to explore and conquer space. The opening sequence is in itself a powerful showcase of human evolution and a nod to our discovery of fashioning the tools with which have allowed us to survive and flourish as a species over time. Developed and filmed during one of the most important times in human history - the space race, Kubrick achieved cinematic greatness even when audiences did not initially understand what they were viewing. Some early audiences found the movie baffling with reportedly 241 walkouts from the April 2, 1968, world premiere at the Uptown Theater in Washington, D.C.[25]

The film was intentionally made abstract and avoided a straightforward plot in order allow for thought-provoking reflection. The elaborate set designs were a combined effort of several engineers, aerospace experts and scientists to ensure the illusion felt real. Their efforts were monumental with the ever changing discovery of new data and science gathered during the era of the space race. Every new fact and discovery affected the reality Kubrick and Arthur C. Clarke set out to envision for the film.

---

25 Peter Howell, *2001: A Space Odyssey - 50 Facts for 50 Years*, thestar.com, December 13, 2018, https://projects.thestar.com/2001-space-odyssey-stanley-kubrick/.

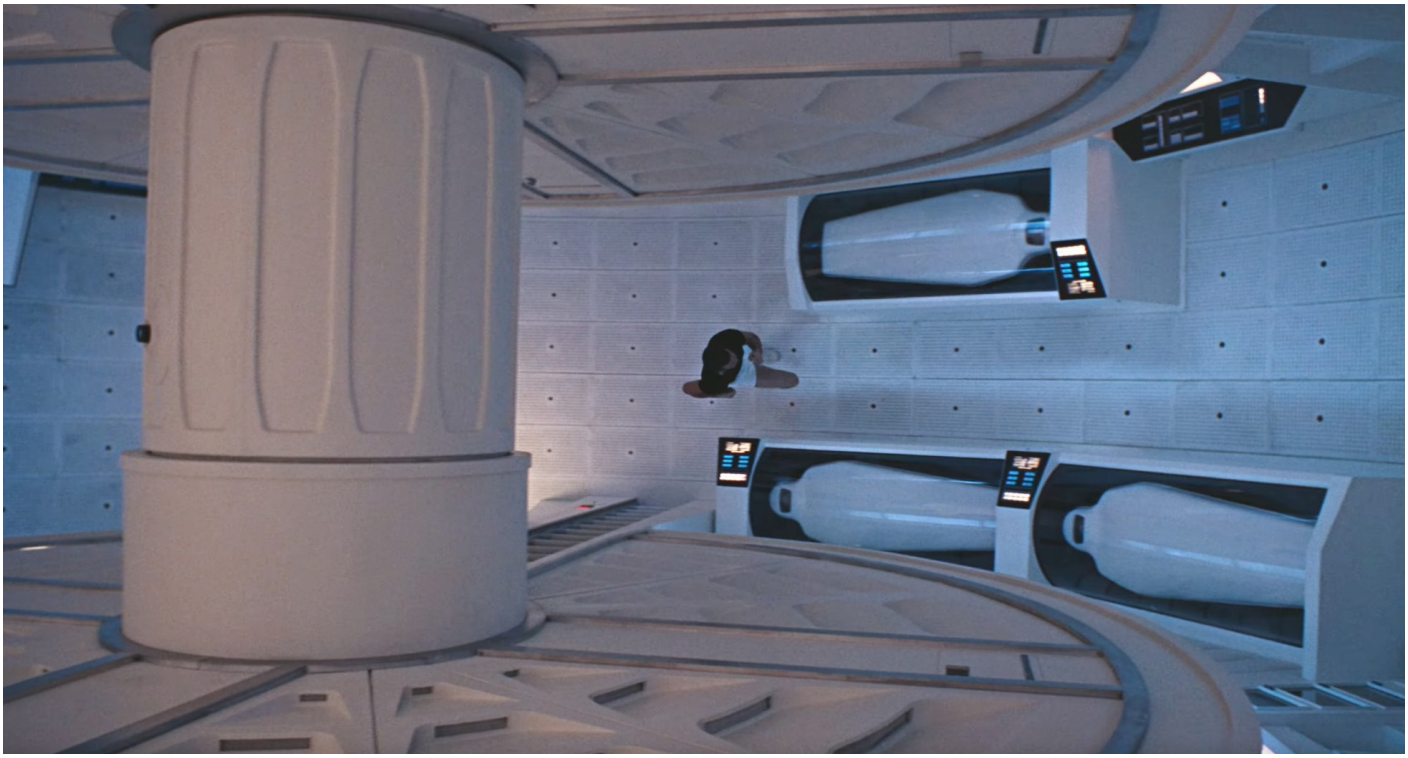


FIGURE – 2. 39 Interior of the Jupiter One's centrifuge, 2001: A Space Odyssey, 1968

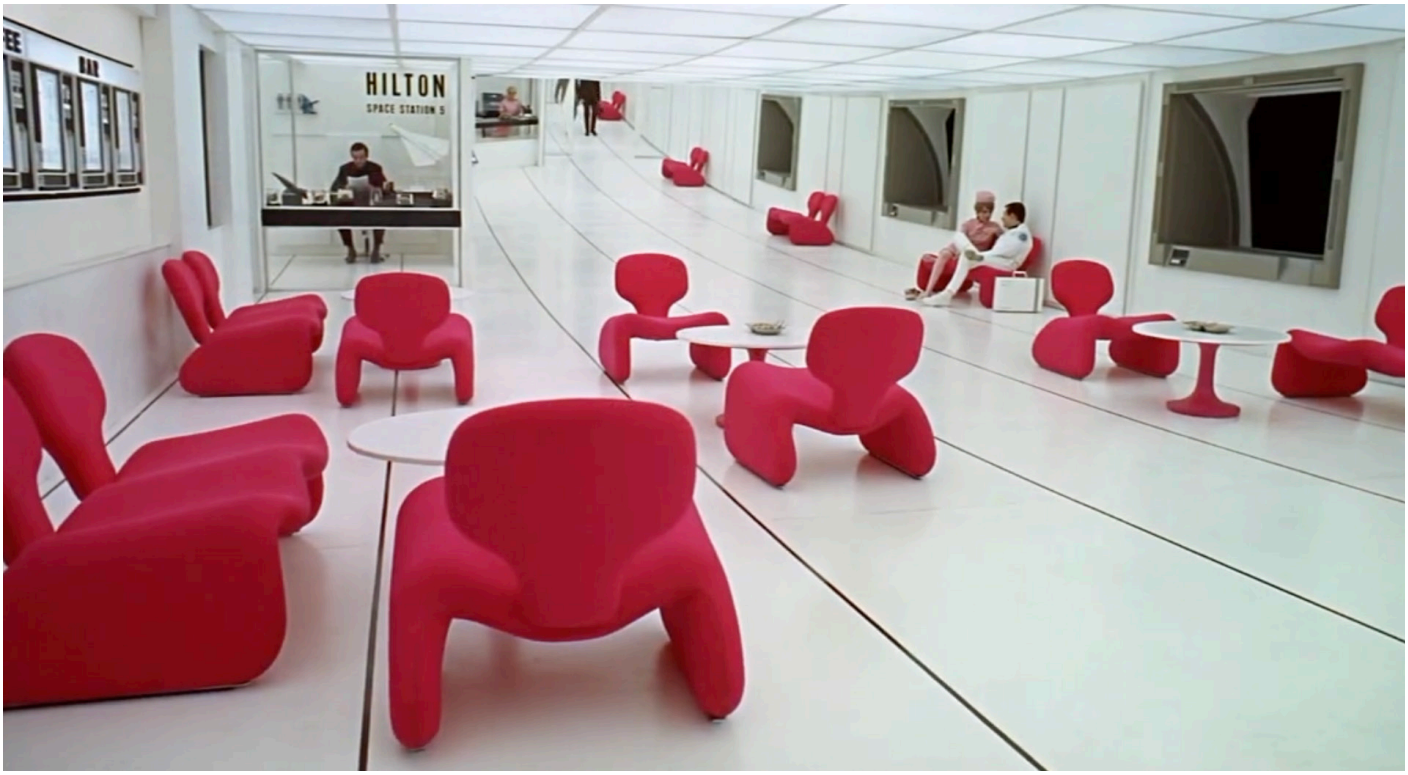


FIGURE – 2. 40 The curved floors and ceiling interior of the Hilton Space Station V, *2001: A Space Odyssey*, 1968

The Discovery One, the ship transporting Dave Bowman and crew to Jupiter, tackled the very real problem of micro-gravity in space and the harmful effects to the human body which were largely unknown at the time. Artificial gravity through centrifugal force was already presented as a viable solution to introduce gravity, theorized already by NASA scientist Werner Von Braun's own rotating space station design in 1952.[26] Due to the cylindrical geometry of the station, the floors warped into the ceiling and vice versa depending on the astronauts location. (Figure – 2. 39) Bowman and the crew existed in that smaller centrifuge being able to see the entirety of the volume while experiencing gravity perpendicular to their location. For the audience, the camera shots and movements have been meticulously planned, along with the set pieces, to create the illusion of realism. Such a surreal architectural experience is perhaps the most important aspect of the film as it relates to envisioning future geometries in space needing to exist in an extra-terrestrial manner for it to work for human occupation. Imagining and being able to see people directly above you in such a small space completely breaks the rules of traditional architecture known at the time for the average viewer and mimics a surreal, almost M. C. Escher like experience.[27]

This accurate depiction of artificial gravity is again explored in larger capacity with the orbital Hilton space station (Figure – 2. 40). On board, the viewer is taken along for the journey within. The larger hallway loop, the diffuse ceiling lighting, stark white walls and colourful modernist furniture offer a new mind-bending perspective. However, the most profound element of the architecture of the station becomes the Earth hypnotically spinning visibly in the window. The film enacts a profound representation of what living in space could be in 1968, one year before astronauts successfully land on the Moon. This critical first-of-its-kind portrayal for a reality-based visionary future allowed for film to become an artistic and thought-provoking medium. Though these spaces do not exist in reality, their set design and construction cues make them feel completely authentic to its time and still to this day. These space concepts being realistically portrayed and recorded in film, now establish an illusionary record that such spaces are true.

---

26 Nasa Science, *Von Braun's Early Wheel Space Station Concept*, n.d., accessed October 26, 2025, https://www.nasa.gov/image-article/von-brauns-early-wheel-space-station-concept/.

27 "Relativity" by Maurits Cornelis Escher is a famous artwork depicting gravity wells, 1949

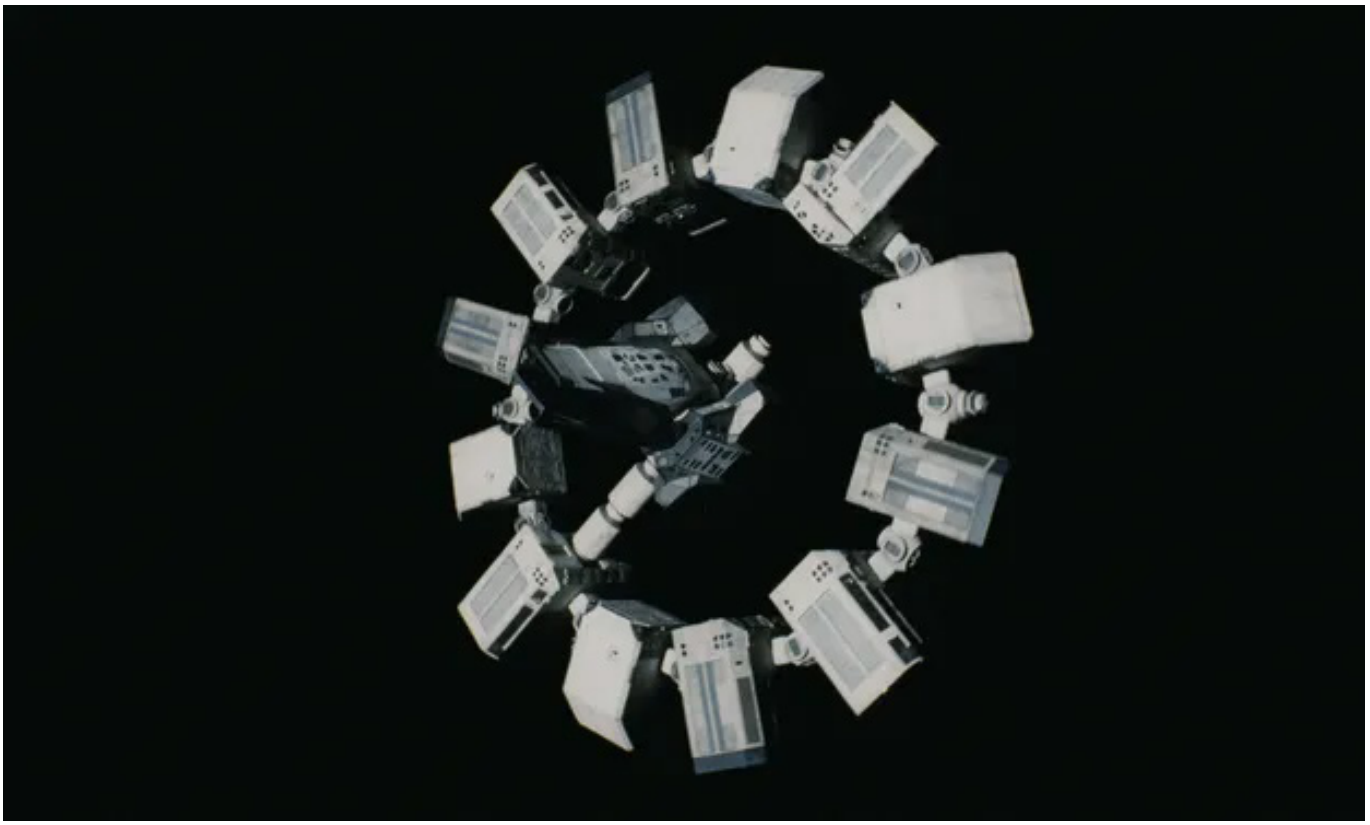


Figure – 2. 41 The Endurance, *Interstellar*, 2014

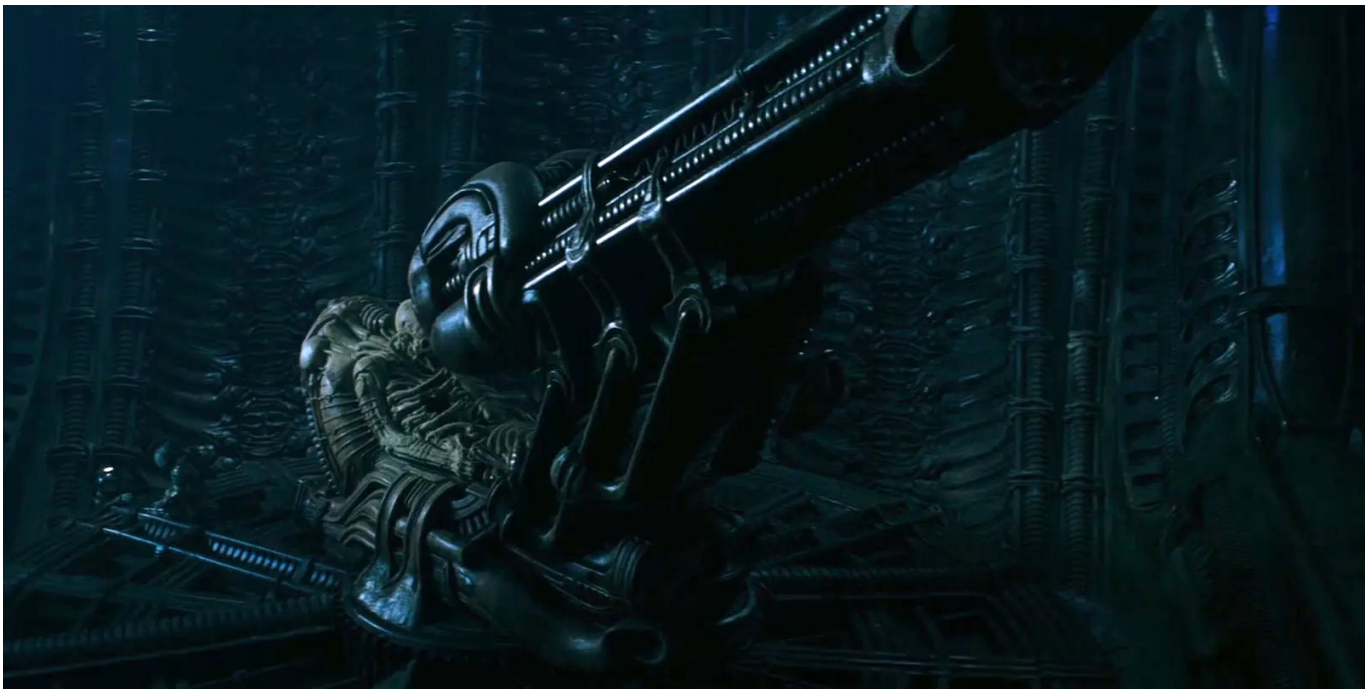


Figure – 2. 42 Interior of the derelict space ship and Space Jockey, *Alien*, 1979, screen capture, https://movie-screencaps.com/alien-1979/page/19

Leading up to the 1960s, most works shared a utopian ideal of space, where pushing humanity to the stars would lead to the betterment for all of humanity through technological innovation. In the 70s and 80s, entertaining movies set in the backdrop of space were presenting dystopia and darker ruminations of space travel. Peter Hyams' 1981 film *Outland*, was one of the first to depict a space economy in a darker, gritty experience of space mining on Jupiter's moon - Io. There is nothing glamorous depicted about space in the film, and themes of corruption, drug use, and violence are explored heavily. Space mining is depicted as a hard, stressful job, and the disparity between the living quarters of the workers in kennel like cages versus the lavish modern suites for the higher ranking officers is contrasted heavily.

Alien (1979), directed by Ridley Scott, is another highly influential film that also touches on similar themes of a dark and gritty space architecture representation, while encountering the nightmarish alien life form known as the Xenomorph. Designed by famed artist Hans Ruedi Giger,[28] the stylistic skeletal, biomechanical form of the creature, as well as the alien *Derelict* ship, instill fear and mystery. The extraterrestrial organic forms differ completely from the steel and glass architectural design of the human spaceship. The contrast of alien forms with the film's darker tone and styling is a departure from the optimistic perspective of space travel. The mystery of space itself should be feared and that the journey into the unknown can be highly dangerous. Films such as *Aliens* present themselves to the viewers as a warning to the enthusiasm of utopian space-faring expectations: space can ultimately be cruel and unforgiving.

More modern films such as *Interstellar* and *The Martian,* tackle space travel issues with hard-science and NASA-inspired aesthetics for their authenticity. Simply, the suspension of disbelief is held in place through the realism of real world data in conjunction with a plausible narrative. Joseph "Coop" Cooper piloting the *Endurance* into Gargantua is not only a visually impressive and breathtaking shot, it is also one of the most highly believable representations of how a black hole may behave in reality based on the direct involvement of physicist Kip Thorne.[29] The computer simulation, led by a team at

---

28 H. R. Giger and Mia Bonzanigo, *Giger's Alien: Film Design,* 2006

29 Kip S. Thorne and Christopher Nolan, *The Science of Interstellar*, First edition (W.W. Norton & Company, 2014).

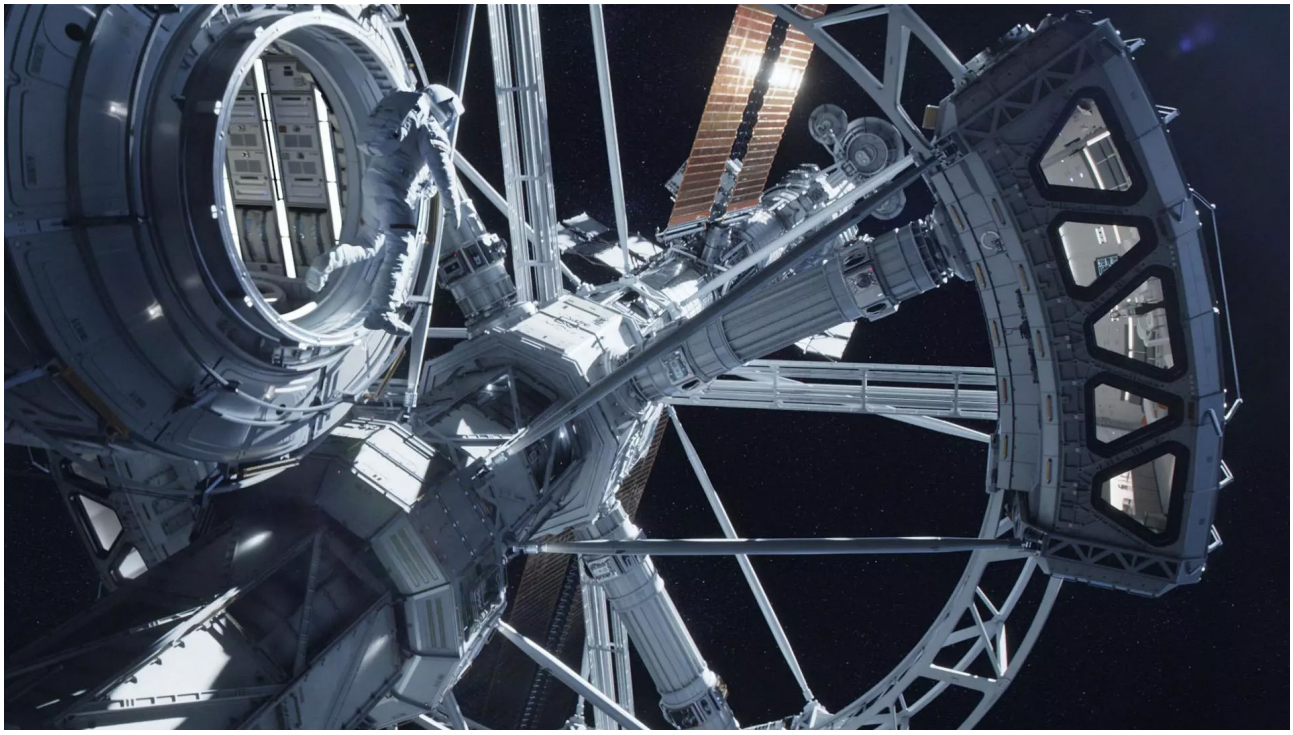


FIGURE – 2. 43 The Hermes spacecraft, *The Martian*, 2015

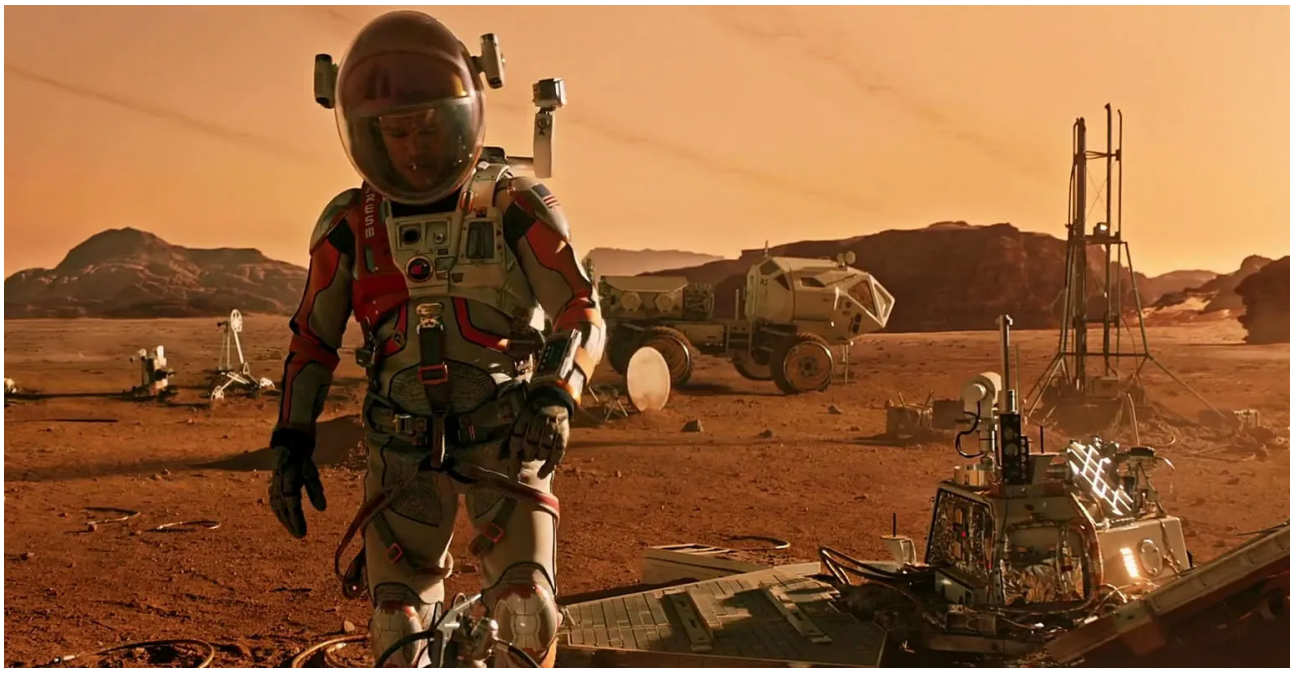


FIGURE – 2. 44 Interacting with the Mars *Pathfinder* Lander to communicate with NASA, *The Martian*, 2015

Double Negative Visual Effects (DNEG), was able to create a "completely new renderer that simulates the path of light through gravitationally warped space–time – including gravitational lensing effects and other physical phenomena that take place around a black hole."[30] But the real architectural treat of the space stations depicted in both films have artificial gravity designed in a more constrained and rational manner. In the *Hermes* space craft, (Figure – 2. 43) the radius is roughly 350 meters and the rate of spin fast enough to generate 1 g. The *Endurance* from *Interstellar*, was made available online for the public to explore as a virtual model and know more about each module function.[31] Both of these ship designs are passed off as practical and utilitarian as much as possible.

In *The Martian*, Matt Damon's character is left stranded on Mars with the bleakest hope of a rescue and as such, must use his wits and the limited shelter and resources available to survive. The geometry of the ships, rovers and space stations all have distinct believable aesthetics that look and clinically feel as if these already had been built by NASA as they collaborated on the designs. In fact, the film featured the Mars Pathfinder and its small, six-wheeled Sojourner rover which touched down on Mars on July 4, 1997.[32] The enormous efforts of films to instill credibility can alter public perception to be familiarized and influenced from the architectural designs presented. The decades of space travel advances as they exist today can directly influence filmmakers to hire technical and scientific advisors to help craft the immersion needed for their audience. In turn, films and literature have profoundly inspired people to pursue technological advancements over time: smart phones, satellite communications, robots, and artificial intelligence to name just a few. In essence these pretend spaces depicted in film, due to the visual and artistic narrative, allow the viewer to be inspired, contemplate and think beyond the realm of what is normal - or even refute what is presented. Such methods can be used in architecture to further advocate convincing design solutions and testing how the public

---

30 "Building Gargantua," *CERN Courier,* November 12, 2019, https://cerncourier.com/a/building-gargantua/.

31 Bryan Alexander, "'Interstellar': Tour The Endurance Ship Online," *USA Today*, accessed July 20, 2025, https://www.usatoday.com/story/life/movies/2014/11/03/interstellar-online-tour-endurance/18370715/.

32 "NASA's First Mars Lander Makes a Cameo in 'The Martian,'" *Christian Science Monitor*, accessed July 3, 2025, https://www.csmonitor.com/Science/2015/1004/NASA-s-first-Mars-lander-makes-a-cameo-in-The-Martian.

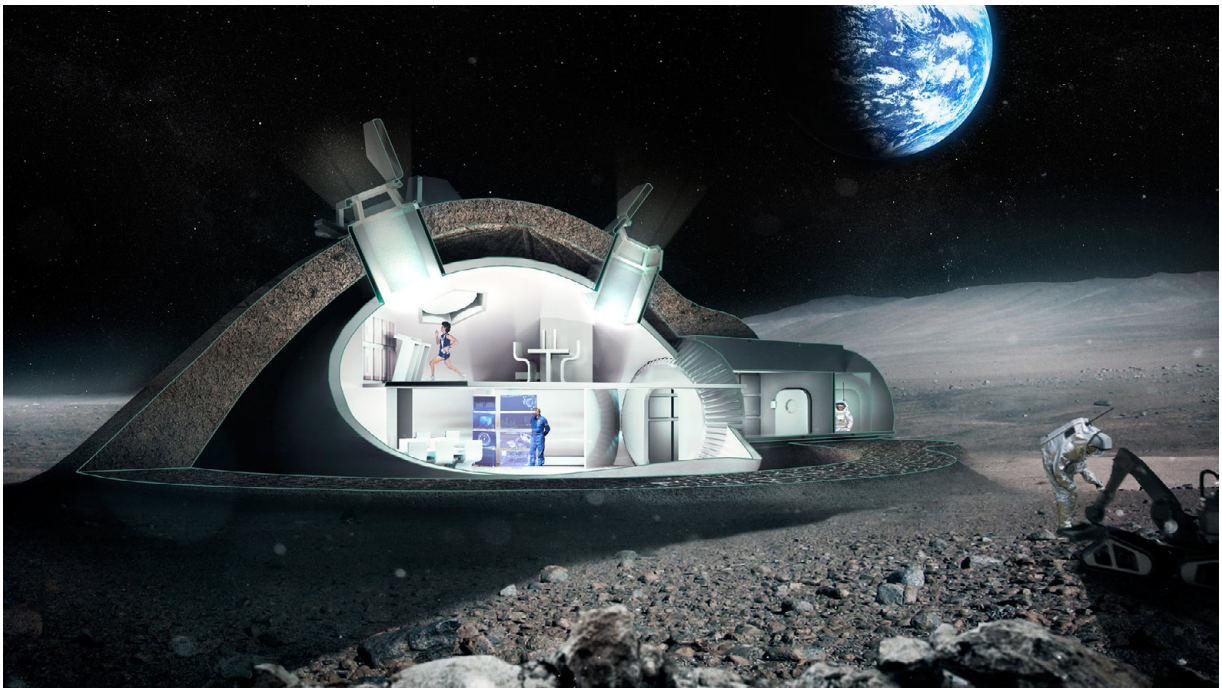


FIGURE – 2. 45 Sectional view of a four-person moon base using lunar regolith, Foster and Partners, 2016



FIGURE – 2. 46 Mars base illustration, Foster and Partners, 2016

perceives a possible design solution.

When we look at modern day developments in space architecture, the design problems for human space flight is in constant engagement with plausible Lunar and Martian architectural visions being developed. *The Martian* helped completely renewed public interest in future manned spaceflight to Mars. And with multi-billionaire Elon Musk's ambitious plans to build a Mars colony with SpaceX, more exposure and efforts have been undertaken by agencies and companies to explore the next logical step for manned spaceflight missions. As such, the concepts and designs of Mars habitats and future space settlements and vessels all followed closely this "hard-science" to make them authentic projects.

With long-term manned space missions, the inclusion of human comfort to be present in such architectural designs in order to mitigate the effects of isolation and confinement of which architects are needed. It is well known the stress and negative mental health effects of crew in long-term isolation as well as the damaging physiological effects the body endures in space from ISS data. The numerous experiments and space missions carried out through the years can be defined through NASA's acronym RIDGE which is short for (Space Radiation, Isolation and Confinement, Distance from Earth, Gravity fields, and Hostile/Closed Environments).[33] The most notable being that there exists both modern programs and emerging educational avenues to lead the design and thought of architecture in space. The University of Houston's Sasakawa International Center for Space Architecture (SICSA) program has for over a decade now, allowed students to learn and design within the parameters of current space technologies while having their work evaluated by aerospace engineers and NASA scientists.[34] This educational approach incorporates real-world mission constraints and engineering challenges while opening architectural narratives and design strategies towards viable space habitats.

The enormous research undertaken on the design of suitable Mars habitats for long-term colonies also exist in virtual reality and analog simulated spaces on Earth in great degree. Design work

---

33 Nathan Cranford and Jennifer Turner, "The Human Body in Space," Humans in Space, *NASA Science,* February 2, 2021, https://www.nasa.gov/humans-in-space/the-human-body-in-space/.

34 University of Houston, "SICSA," Sasakawa International Center for Space Architecture, accessed October 9, 2025, https://sicsa.egr.uh.edu/.



FIGURE – 2. 47 Floorplan of NASA's Mars Dune Alpha habitat, designed by BIG and built by Icon in Houston, Texas



FIGURE – 2. 48 Interior room of NASA's Mars habitat, designed by BIG and built by Icon in Houston, Texas, 2023

undertaken by architectural firm KieranTimberlake[35] with the Mars City as a program uses virtual space to prototype and manage a virtual mars base model.

> The model includes small, private areas like sleeping pods and larger communal spaces dedicated to Mission Control, dining, recreation, and workshops—as well as a garage for the storage and deployment of Mars Rovers. Essential to the simulation is a robust COBie (Construction Operations Building Information Exchange) database built in conjunction with the model. Pulling from information embedded within the model, the database allows realistic simulations of pre-programmed facilities management scenarios.[36]

This need for testing potential designs of Martian habitats is a crucial step for space settlement research. NASA and other space agencies have created their own research installations in order to test long-term mission scenarios. The Crew Health and Performance Exploration Analog (CHAPEA),[37] located at the Johnson Space Center in Texas, is a fully 3D printed structure to simulate year-long stays on the surface of Mars.[38] The need for scientific data to validate long-term systems and to develop technological solutions is critical for future successful missions on Mars. The first simulated mission lasted 384 days, starting in June 2023, where the crew was involved in carrying out simulated "marswalks," robotic operations, habitat maintenance, exercise, and crop growth. Beyond the isolation, confinement and resource limitations, these types of simulations have become a staple in space architecture design in order to truly study and predict the challenges that could be faced by crew members. If designers and space architects can use the data from such missions to inform better livable designs for astronauts, then the design process can produce a potentially more successful and comprehensive design.

---

35 Lea Oxenhandler, "Modeling a Base on Mars," *Kieran Timberlake*, May 16, 2014, https://kierantimberlake.com/posts/view/264.

36 Ibid.

37 Melodie Yashar et al., *Constructing NASA's Crew Health and Performance Exploration Analog (CHAPEA): A 3D-Printed Habitat by ICON/BIG*, 2022.

38 NASA Science, "First Mars Crew Completes Yearlong Simulated Red Planet NASA Mission," *NASA Science*, July 10, 2024, https://www.nasa.gov/missions/analog-field-testing/chapea/first-mars-crew-completes-yearlong-simulated-red-planet-nasa-mission/.

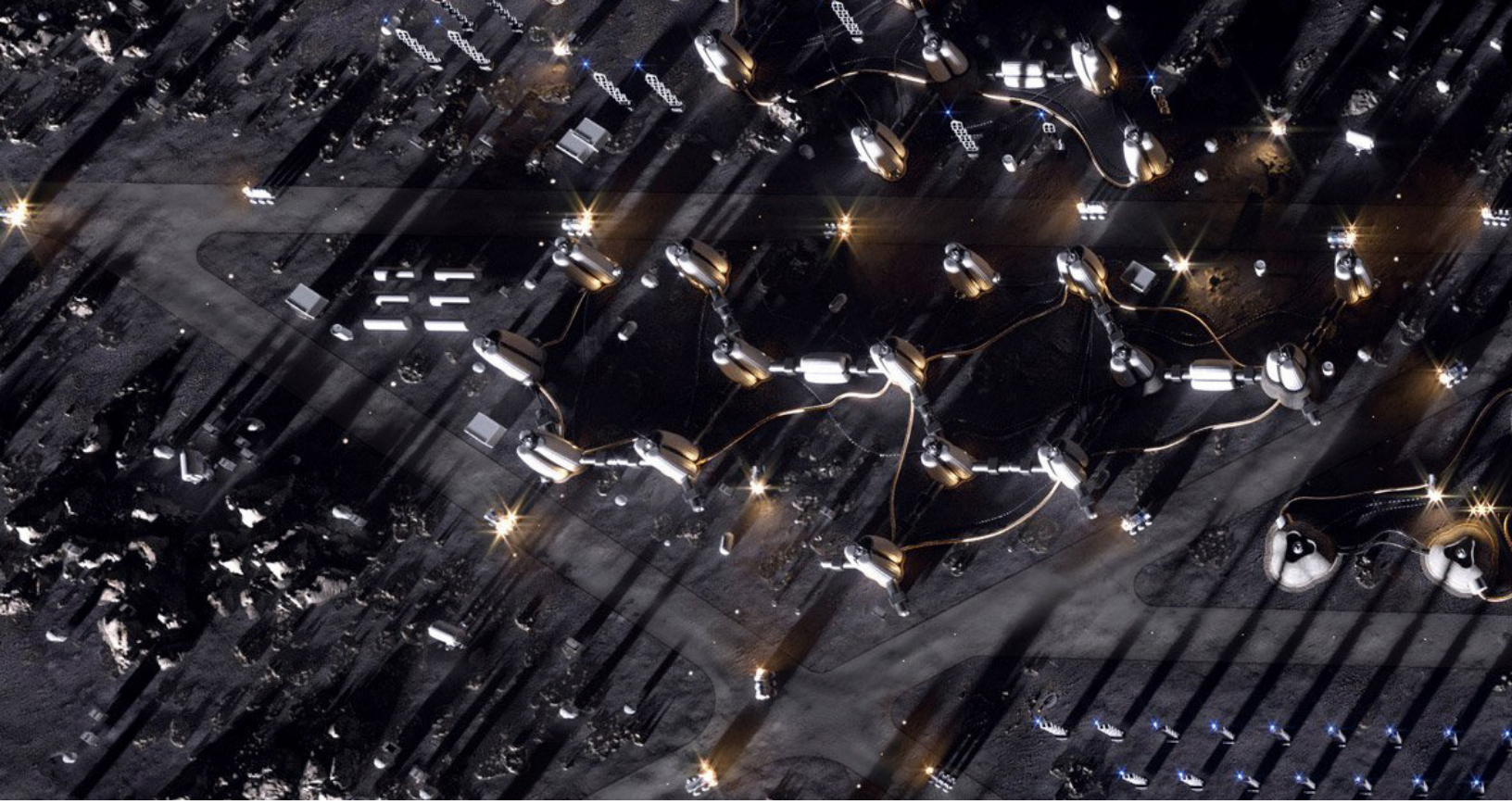


FIGURE – 2. 49 *Moon Village*, concept rendering by Skidmore, Owings & Merrill (SOM), 2019

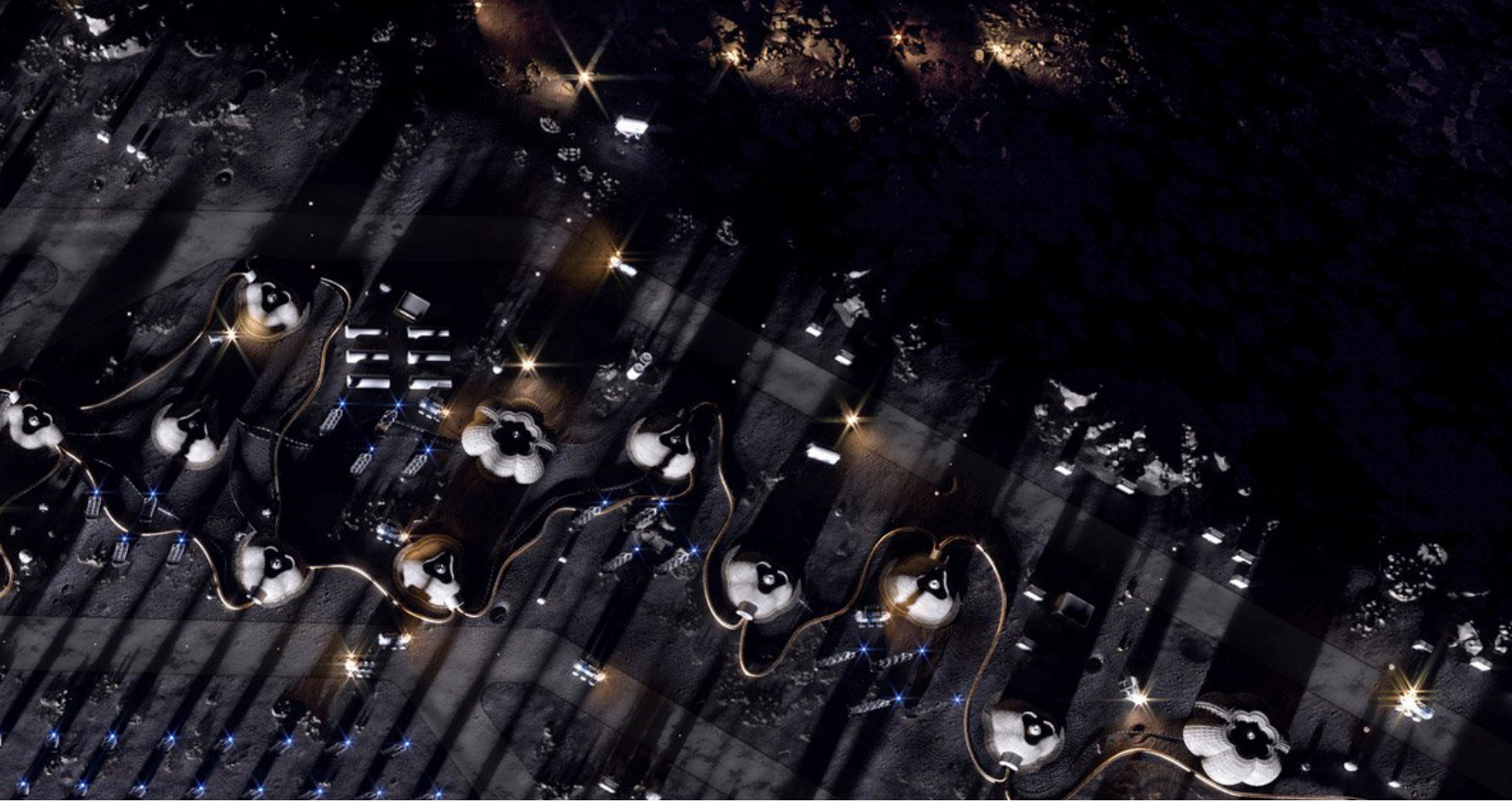
Notable architecture firms have also begun to explore and design for outer space. For Foster+Partners, they have won NASA-backed competitions for Lunar and Martian base designs. (Figure – 2. 45) – (Figure – 2. 46) The design for the habitat outlines plans for a settlement constructed by an array of pre-programmed, semi-autonomous robots prior to the eventual arrival of the astronauts.[39] Lastly, for low Earth orbit, space station ideas and concepts are still constantly being proposed, designed and developed because, as Norman Foster explains:

> Designing for space is about pushing the boundaries of innovation. The challenges we face in creating sustainable habitats on the Moon or Mars have inspired revolutionary solutions for zero-waste, zero-emission buildings on Earth. The technologies and materials developed for space exploration can revolutionise the way we build and live in harsh climates, making our planet more resilient and sustainable.[40]

---

39 Foster + Partners, "Lunar Habitation," *Foster + Partners*, accessed May 26, 2025, https://www.fosterandpartners.com/projects/lunar-habitation.

40 Annabelle Dufraigne, "Norman Foster Imagines Future Habitats on Mars and the Moon," *AD Middle East*, April 12, 2025, https://www.admiddleeast.com/story/norman-foster-imagines-future-habitats-on-mars-and-the-moon.



Foster argues that the technology and experience of designing for outer space benefits to how we build sustainable habitats today. With the growing interest and involvement of the architecture community, design for outer space is becoming a prominent, emergent field that has become more accessible with new technological insight. Skidmore, Owings & Merill (SOM) has also investigated human centric life beyond Earth with their *Moon Village* concept from 2019 using inflatable habitats.[41] The question no longer becomes if architects can design space architecture, but rather what new exciting forms can people begin to experience. For Hassell Architects, their design of a Lunar regolith base was featured as a playable mission level in the video game *Fortnite*,[42] a popular building-based first-person shooter. By blending the architectural Lunar concept with interactive user based gameplay meant that players could work together and customize different lunar base builds and scenarios within the virtual realm.

---

41 Jane Englefield, "Moon Village Could Allow People to 'Thrive over the Long Term' in Space," *Architecture, Dezeen*, July 7, 2021, https://www.dezeen.com/2021/07/07/moon-village-human-centric-inflatable-habitat-the-moon/.

42 Carter Digital, "Hassell | Lunar Horizons in Fortnite: An Immersive Reimagination of Hassell's Lunar Habitat Master Plan," *Hassell*, accessed October 1, 2025, https://www.hassellstudio.com/news-event/lunar-horizons-in-fortnite-an-immersive-reimagination-of-hassells-lunar-habitat-master-plan.

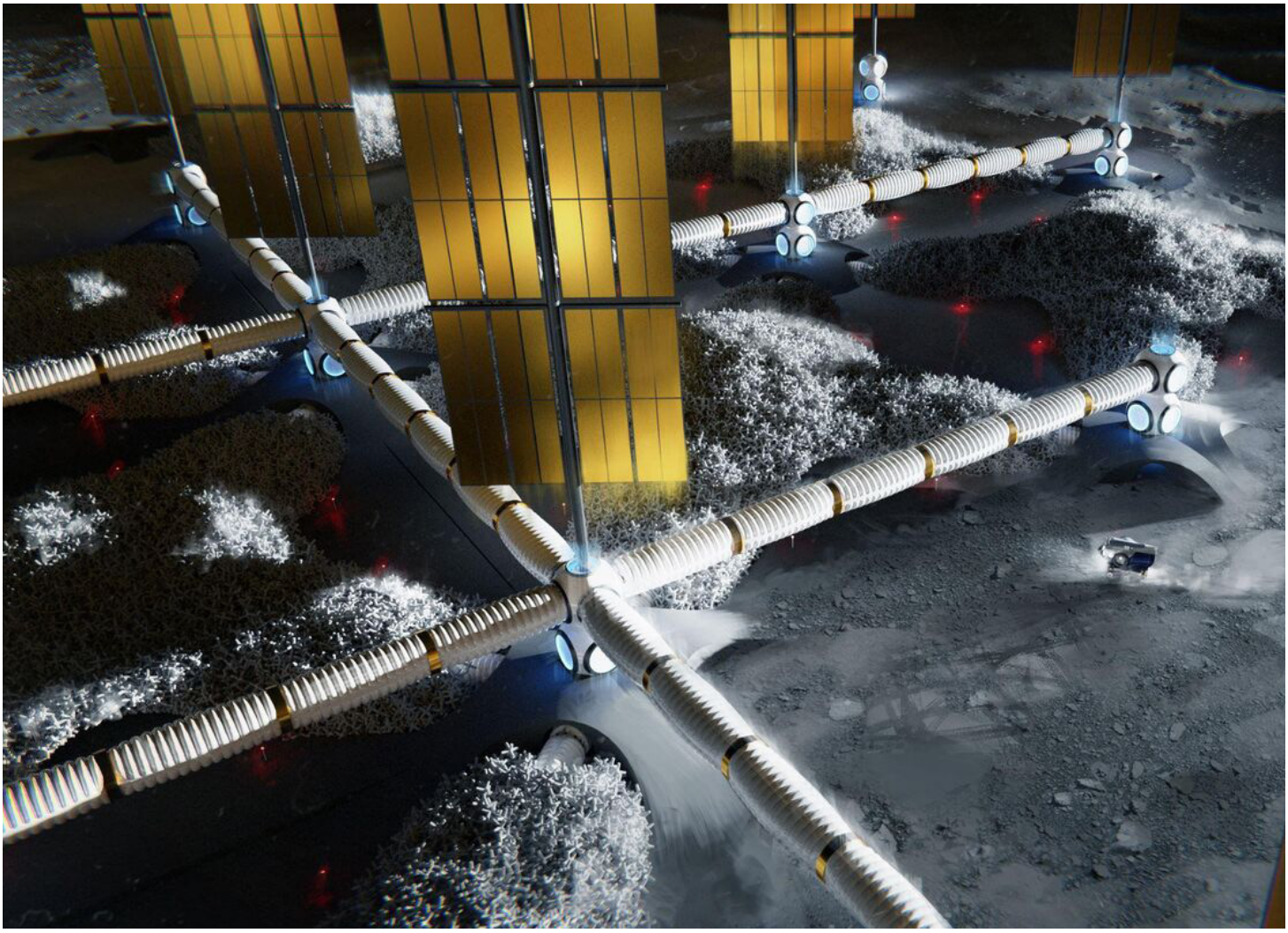


Figure – 2. 51 Aerial View - Lunar Base Illustration, Hassell Architects, 2023



Figure – 2. 50 Interior Illustration, Hassell Architects, 2023



Figure – 2. 52 Living Quarters Illustration, Hassell Architects, 2023



FIGURE – 2. 53 Frame capture, Lunar Horizons, Fortnite, 2023, https://www.youtube.com/watch?v=wLFOE9k8OUc

> Lunar Horizons is an immersive, 3D reimagination of a future European Space Agency (ESA) international lunar mission to the Moon's south pole. As a player, you must collect resources to build up the Hassell Lunar Habitat as you learn more about the wonders of space exploration.[43]

If the general public has access to these virtual simulation worlds in the form of video game entertainment, this speculative architecture can be played, configured and explored numerous times in the comfort of your home. Hassell's head of design, Xavier De Kestelier, mentions how "now everyone in the world can go in now and experience it for themselves. And not just experience the Moon base, actively build, in a mini-game, a full fledged moon habitat for a large community of astronauts."[44] Having such a theoretical base design customized with player and community driven inputs, helps cement these new learning experiences as a departure from traditional media forms.

---

43 "Discover How the Lunar Horizons Experience in Fortnite Was Made," *Epic Games' Fortnite*, accessed August 8, 2025, https://www.fortnite.com/news/the-making-of-lunar-horizons-in-fortnite-an-immersive-reimagination-of-a-mission-to-the-moon.

44 *Lunar Horizons - Created In Fortnite*, directed by FNCreate, 2024, 4:32, https://www.youtube.com/watch?v=wLFOE9k8OUc.

03 Virtual Experimentation

The best simulator for spacewalking is underwater - it allows full visuals and body movement in 3D. Virtual reality is good, too, and has some advantages, like full Station simulation, not just part. Like all simulators, they have parts that are wrong and misleading: an important thing to remember when preparing for reality.

Chris Hadfield, 2013

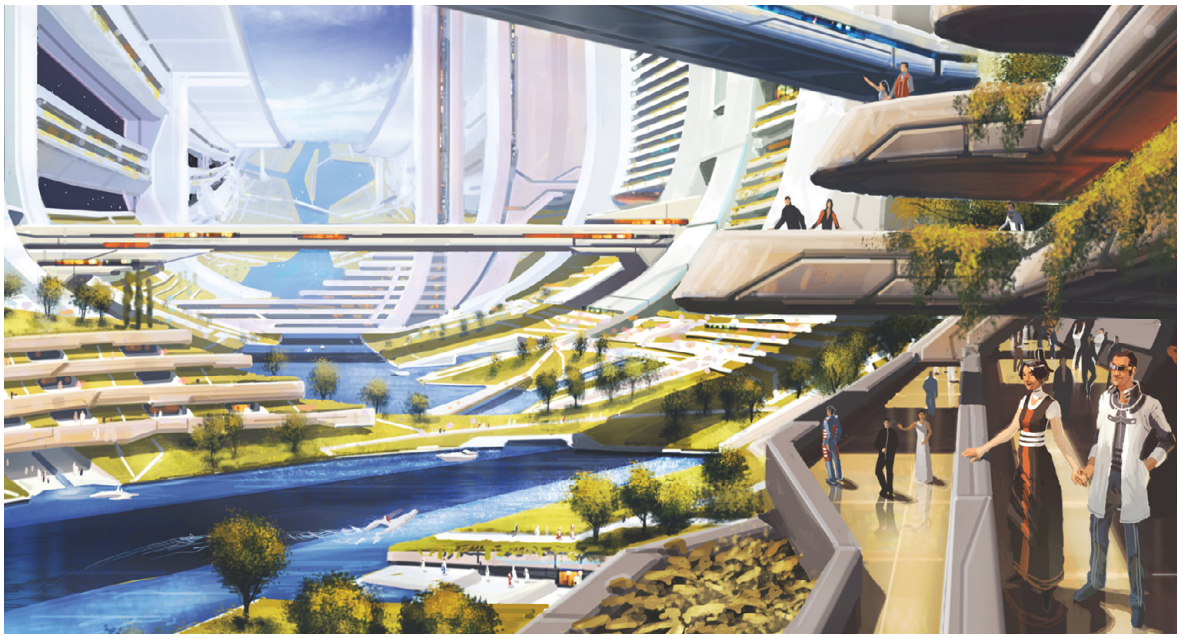


Figure – 3. 1 Concept of the Citadel for *Mass Effect*. Colored painting by Derek Watts and Matt Rhodes. 2007, https://masseffect.fandom.com/wiki/Bonus_Content_Disc/Environments:_Citadel?file=ME1_concept_citadel_1.png#Image_1

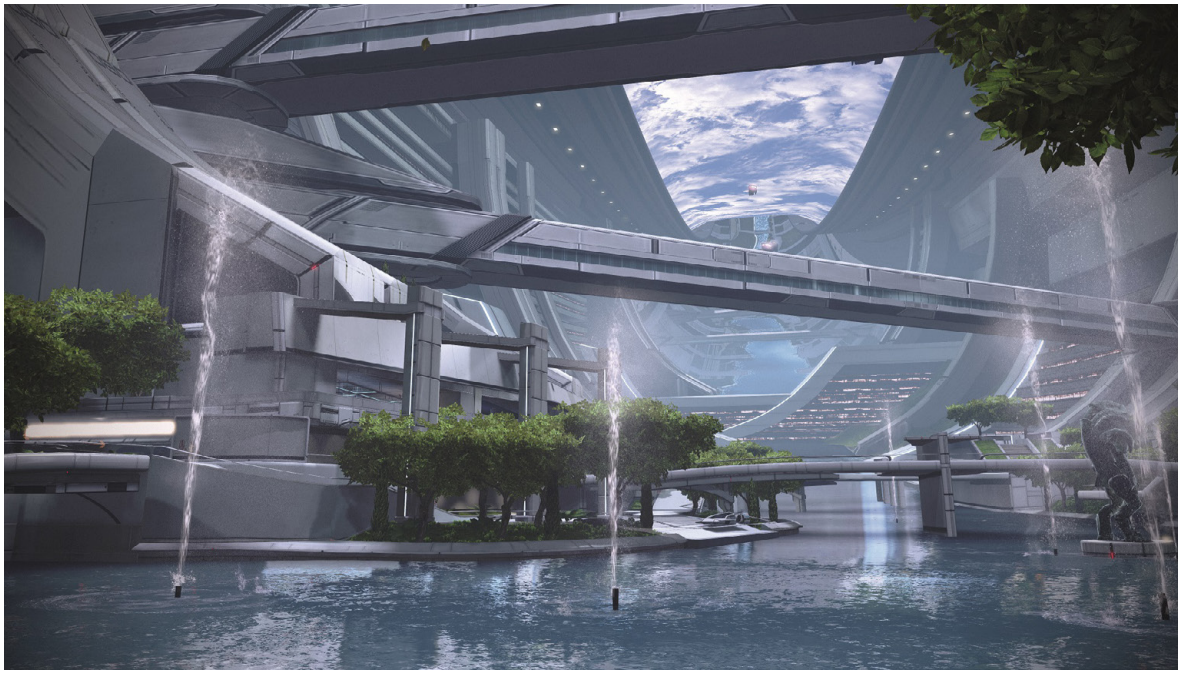


Figure – 3. 2 Citadel Interior, *Mass Effect: Legendary Edition,* Electronic Arts, 2016, digital image, https://www.pcgamer.com/mass-effects-citadel-is-one-of-the-best-virtual-cities-bioware-has-ever-created/

VIRTUAL SIMULATION

Computer technology and software have evolved dramatically in the 21st century. Advancements in hardware have allowed modern video game engines to emerge as viable, incredibly complex and interactive toolsets rather than just entertainment media forms. For architects, the benefit of conceptualizing and visualizing a design in a real-time virtual game model has only recently become mainstream in the industry. Decades ago, most applications involving real-time models were primitive and still CPU (central processing unit) compute intensive. Early professional building information modeling (BIM) and computer-aided design (CAD) software focused on model analysis to substantiate and simulate specific site, energy models (green building) and lighting conditions. Realistic real-time interactive calculations and immersion in digital models remained graphically limited due to hardware constraints. With mainstream GPU (Graphical Processing Units) of the early 2000s becoming significantly more capable, real-time photo realistic imagery was becoming more possible in large production video-games using several *faked* techniques such as light maps, cube mapping, screen-space reflections and pre-computed baked lighting.[1] More than often, these rendering techniques were crucial in allowing designers to push their digital creation to new visuals while maintaining real-time performance targets. Complex, pre-computed lighting was required to be rendered into the texture maps used in game, which required hours, if not days, to process.[2]

Today, a shift has occurred with the adoption of modern software tools such as Enscape, Twinmotion, Unreal Engine and other specialized 3D game-engine tools in order to construct *dynamic* and detailed real-time architectural models. Looking back further to the early days of primitive digital simulation tools from the space race with supercomputers from General Electric (GE)[3], the method to simulate, predict and test virtual scenarios has evolved tremendously. This digital realm holds the key to accessing and simulating unique architectural experiences and possibilities. With an accurately

1 Alex Wiltshire, "Photorealism Is Crucial To Games," *Rock Paper Shotgun*, September 3, 2015, https://www.rockpapershotgun.com/photorealism-is-crucial.

2 Dario Seyb et al., *The Design and Evolution of the UberBake Light Baking System*, ACM Transactions on Graphics 39, no. 4, 2020

3 Nicholas De Monchaux, *Spacesuit: Fashioning Apollo* (MIT Press, 2011). p 175



Figure – 3. 3 Screen capture, *Microsoft Flight Simulator 1.0*, 1982, Microsoft Windows, https://www.youtube.com/watch?v=NZLC5ekNJUY.

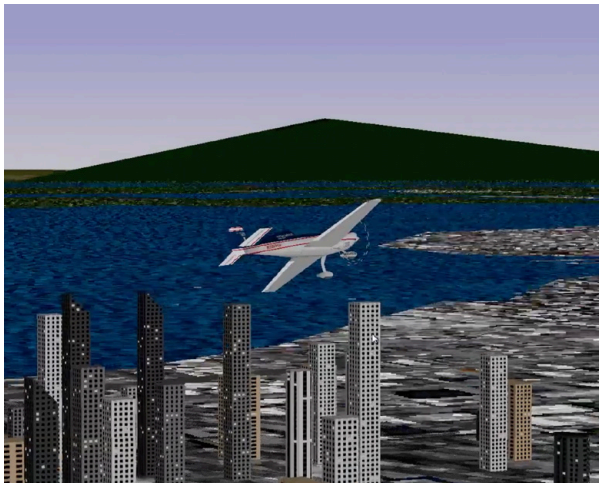


Figure – 3. 4 Screen capture, *Microsoft Flight Simulator 95*, 1996, Microsoft Windows, https://www.youtube.com/watch?v=NZLC5ekNJUY.



Figure – 3. 5 Screen capture, *Microsoft Flight Simulator* 2020, Microsoft Windows, https://www.youtube.com/watch?v=NZLC5ekNJUY.

programmed computer-generated model, physics can be simulated and mimicked. It is in this virtual realm where countless simulations can be run, analyzed and iterated upon data with relative ease. Depending on the complexity of the simulation and the computer technology hardware, visuals that took hours or even days to compute, can now be done instantaneously. (It is important to note that true to life simulation is still not capable with current technology. Most models developed and programmed are representations designed based on the hardware and compute power available able to run them smoothly.) Video games also have the benefit of being widely accessible and available to the general public, unlike most specialized space mission planning simulators. Some of the most popular simulation games today have a long history of success. *Gran Turismo* 7 for instance, faithfully recreates real-world racing tracks and automobiles to race, with full physics and weather effects.[4] Other franchises, such as *Microsoft Flight Simulator*[5] have evolved tremendously (Figure – 3. 4) - (Figure – 3. 5) in fidelity since its introduction in 1982, allowing users to pilot aircraft anywhere in the world with live, real-world weather data. It is expected that, over time, vehicle simulation games will continue to evolve and approximate the look and feel of real vehicles as closely as possible.

Simulation is an act of pretending - computer simulation, with specific productions, can roughly imitate what can exist in the real world. For space architecture, computer simulation can visually quantify hybridized gravity environments. Virtually being able to simulate and represent the physics of outer space within the confines of a game engine, has allowed game designers to imagine and create spectacular and captivating gaming experiences. Video game epics, such as *Mass Effect* and *Halo* have allowed millions of players to interactively explore notable space architecture concepts such as the Stanford torus and O'Neil Cylinder as an environment backdrop. Although it can be contested how truly effective virtual game spaces are, given their representational limitations, there remains a necessary suspension of disbelief that, along with compelling gameplay elements, allows for world immersion. Michael Nitsche argues that modern video game worlds became meaningful virtual locations due to the adoption of 3D game spaces that "allow players to crawl, jump, run, fly,

4 Polyphony Digital, *Gran Turismo 7*, Sony Computer Entertainment, released March 4, 2022, PS5.

5 *Microsoft Flight Simulator: A History*, directed by Microsoft Game Studios, 2020, https://www.youtube.com/watch?v=NZLC5ekNJUY.



FIGURE – 3. 6 Odin Gameplay level screen capture, *Call of Duty Ghosts,* Activision*, 2013*

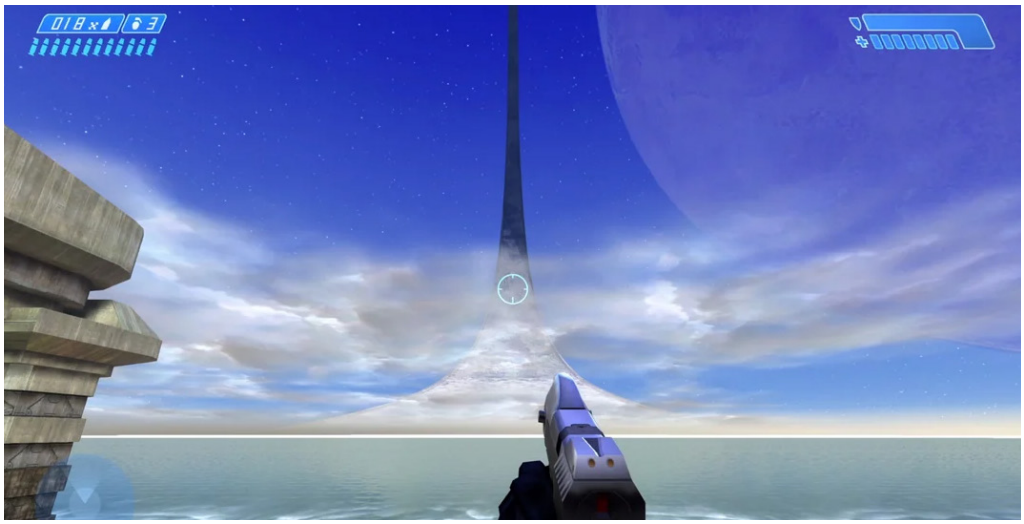


FIGURE – 3. 7 Screen capture, *Halo: Combat Evolved,* Bungie Games, 2001, source frame retrieved: *https://youtu.be/fGalf5Qv7ck?t=22*



FIGURE – 3. 8 Screen capture, *Halo: Campaign Evolved,* Halo Studios, *2025,* source frame retrieved: *https://youtu.be/fGalf5Qv7ck?t=33*

and teleport into new worlds of unheard-of form and function."[6] The spatial forms and architectural spaces that players must navigate within the stage of a 3D virtual world is ultimately unique and different in variation. Many space-themed video games, such as *Mass Effect*, *Star Citizen*, and *Starfield* are designed as massive space opera worlds with this unique freedom of user exploration. For the game *Mass Effect*, player choices in conversations over the course of the series, significantly alter which parts of the expansive game world can be explored and determine multiple different narrative outcomes.

Detailed virtual assets and environments paired with the mechanics of zero-gravity, is well-established in only a handful of video games and used sparingly as the experience can be very jarring. *The Descent* first pioneered this mechanic of 6-axis movement back in the 1995.[7] Since then, the exploration of zero-gravity environments has become common in most science-fiction games set in space. In the popular 2013 video game *Call of Duty: Ghosts* (Figure – 3. 6), a realistic scenario of space battles in Earth's orbit play out in the early game and are inspired by hard science fiction and design cues from the ISS.[8] The players experience of micro-gravity in a space combat scenario already breaks the given rules of the real world Outer Space Treaty of 1967 which prohibits weapons in space.[9] As such, the virtual exploration and experience is constrained in scope to focus on a linear narrative path with limited exploration of the space architecture present in the scene. Where computer simulation becomes incredibly useful is through access to conditions and variables, such as zero-gravity, that are not easily accessible in physical space, and are thus freer to explore in the virtual.

For real world applications, limitations with budgets in both asset and hardware resources also factor into how complex or effective virtual environments are designed. Combining both physical user movement in virtual space increases the fidelity of the simulation experience. Today, NASA's

---

6 Michael Nitsche, *Video Game Spaces: Image, Play, and Structure in 3D Worlds* (MIT Press, 2009), p. 2.

7 "Reader Picks: 15 More Classic PC Games You Should Play Again", *PCWorld*, n.d., Accessed September 1, 2025, https://www.pcworld.com/article/426841/reader-picks-15-more-classic-pc-games-you-should-play-again.html.

8 John Alexander Hitchcock, "12 Great Sci-Fi Games With Microgravity Mechanics", *Game Rant*, November 19, 2024, https://gamerant.com/sci-fi-games-microgravity-mechanics/.

9 *The Outer Space Treaty,* accessed July 30, 2025, https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/introouterspacetreaty.html.



FIGURE – 3. 9 Photograph of lunar surface simulation with VR headset and controllers, NASA, https://youtu.be/tOHYR2qanFE?t=1178

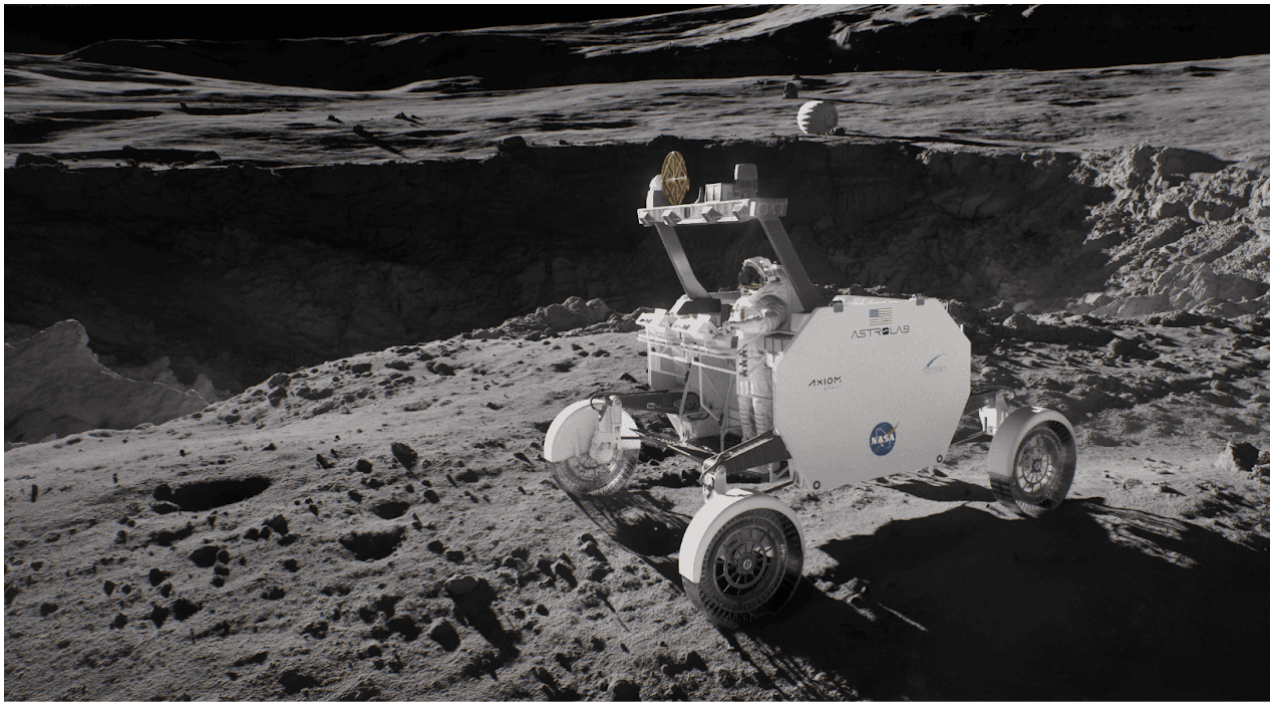


FIGURE – 3. 10 Atermis mission training DUST program, NASA, 2023

Digital Lunar Exploration Sites Unreal Simulation Tool (DUST) which uses Unreal Engine can create a digital twin of the Lunar surface with combination of Lidar and Satellite data from the Lunar Reconnaissance Orbiter (LRO).[10] As Virtual Reality Technical Lead, Eddie Paddock describes:

> It's a math model and simulation environment, and all the correct graphics that make a virtual digital twin of, you, know, whatever space systems they're training for or want to experience. So to make the user feel really immersed, we need to create the environment and for the moon, the terrain. The terrain and the lighting conditions as real as possible using real empirical data. Right? So real data from the LRO mission, height map data and real lighting data, all at the intensity of the sun, the brightness, the lumens, the size of the sun. So create that digital world and then add to that, digital twins of any subsystem that's on the moon. The suits you have, the rovers. You might have habitats in the future. You have tools, you have a tool cart. So we have the graphics models for all that so we can recreate that. And then you drive your immersive graphics environment with data from those real digital twins. So its real data. So things are moving correctly with the correct dynamics and the correct motion and kinematics and dynamics of that real system. So when you put all that together, either the astronaut that's in a training environment or if you're doing it for analysis, you get it as close to the real world as you can get.[11]

As data-driven toolsets become more robust, their application can further enhance architectural experimentation. These virtual architectural worlds are without doubt becoming even more immersive and less uncanny as development efforts, hardware and software features improve. However, user perception and expectation ultimately shape whether the immersion is sustained or breaks.[12] There still exists a profound disconnect between the physical sense of space and a suspension of disbelief is required when it is known to the user that the experience is not real. In more professional settings, with larger budgets and resources, simulation can become an authentic and finely tuned training

---

10 Saimoon Quazi, *Simulating the Moon, from the Comfort of Home*," Medium, June 25, 2023, https://space-travel.blog/ulysses-1f4342d04f66.

11 *APACHE: Spacewalking in Virtual Reality*, directed by NASA Johnson, 2025, 25:30, https://www.youtube.com/watch?v=tOHYR2qanFE.

12 Stephen B. Gilbert; *Perceived Realism of Virtual Environments Depends on Authenticity. Presence: Teleoperators and Virtual Environments* 2016; 25 (4): 322–324. doi: https://doi.org/10.1162/PRES_a_00276

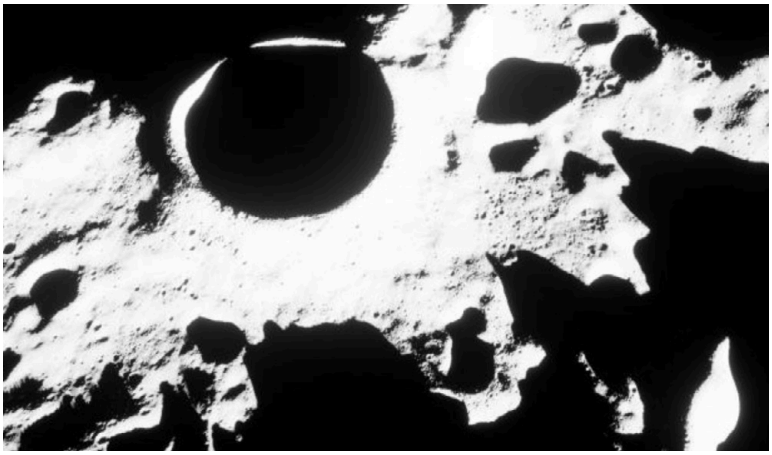


Figure – 3. 11 DUST program shadow rendering, NASA, 2023



Figure – 3. 14 DUST Generated Terrain, NASA, 2023

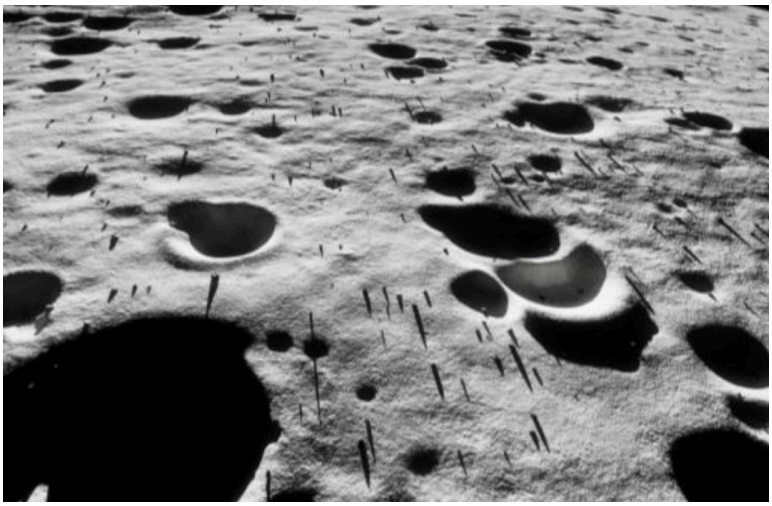


Figure – 3. 12 DUST program rocks and craters, NASA, 2023

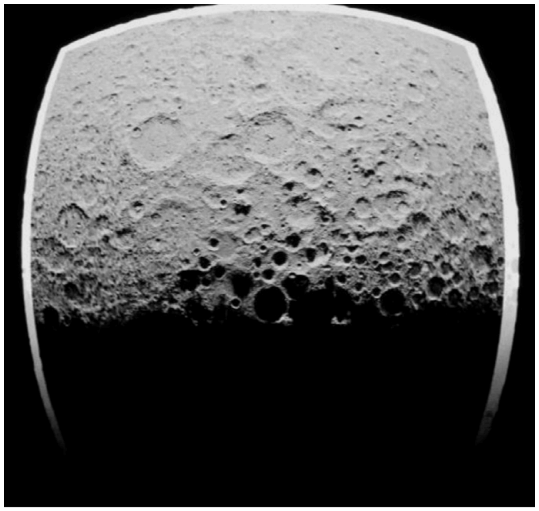


Figure – 3. 15 Lunar Curvature Representation, NASA, 2023

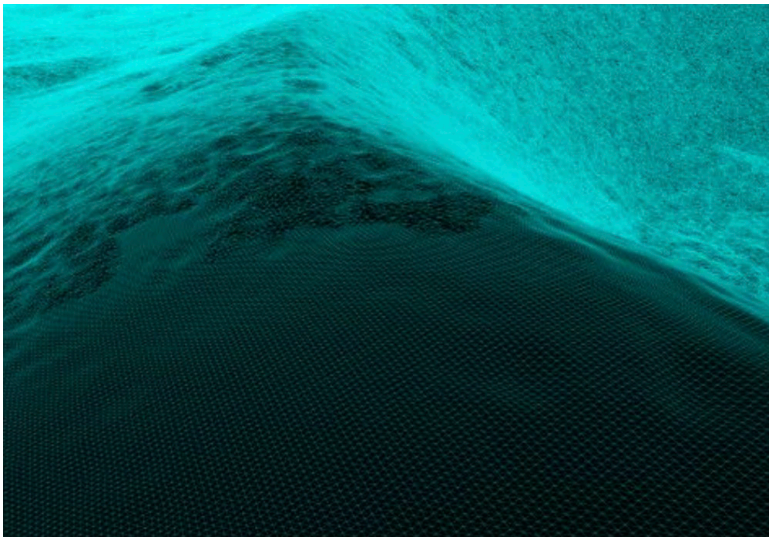


Figure – 3. 13 DUST program *Nanite* wireframe view, NASA, 2023

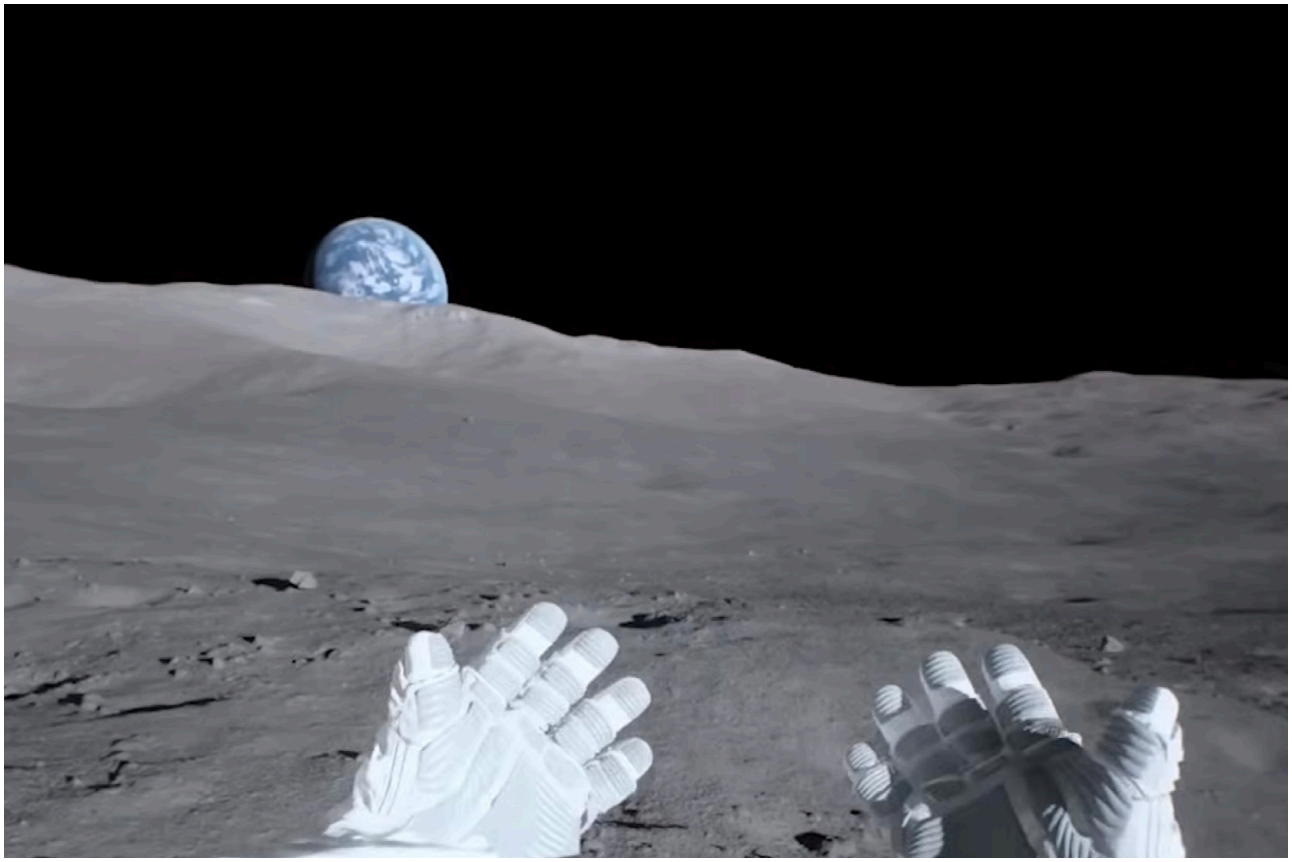


Figure – 3. 16 Atermis mission lunar surface training DUST program, NASA, 2023, https://youtu.be/tOHYR2qanFE?t=933

experience. NASA's DUST program for instance, uses physical nodes (Figure – 3. 9), mock spacesuits and actual tools to enhance and better replicate exact space mission conditions. By matching the virtual visual and audio experience to physical restraints and reality, the data acquired in the simulation is far more authentic and can be used to test infinite scenarios. The DUST program uses Unreal Engine 5 to achieve this feat. "The addition of double precision allows us to accurately position planetary bodies and incorporate engineering-based simulations with TRICK[13]. Overall, Unreal Engine 5 presents a unique feature set that indicates promising initial results in its ability to support accurate simulation development."[14] Though this application is in limited release to the public, the data set and models

13 The Trick Simulation Environment is open source simulation development software framework, NASA, https://nasa.github.io/trick/

14 Lee Bingham et al., "Digital Lunar Exploration Sites Unreal Simulation Tool (DUST)," paper presented at IEEE Aerospace Conference, Big Sky, MT, n.d., accessed October 12, 2025, https://ntrs.nasa.gov/api/citations/20220014707/downloads/DUST_IEEE2023Paper.pdf.

could serve as an excellent and photo-realistic model for lunar architecture concepts to those without the technical expertise. The technical achievement of this program is showcased in (Figure – 3. 10) — (Figure – 3. 16) where the lunar surface is accurately rendered, with proper curvature equations while maintaining a playable framerate.[15]

Simulators based on specific *programmed* variables and factors demonstrate that these complex, but simplified, representations are becoming more closer to reality over time. It is expected that one day simulating convincing true to life spatial design choices, with instantaneous feedback and control, will be a freely available reality with advanced hardware and feature-rich software.

> Simulation software, which was only decades ago the domain of specialists and highly expensive, is now freely available on the internet and fully customized to project demands. It appears that it is architects' new ability to 'compute the environment' that will reconnect the architectural design process with 'real-world' performance issues.[16]

The more accessible software and hardware devices become, the more users will be able to craft and share creative designs based on real-world constraints and data. If everyday normal people can take advantage of virtual spaces to learn and educate themselves about the peculiar nature of the Lunar surface, then new exciting designs may come forth beyond what trained engineers and designers may expect. If an advanced model could be made to truly simulate, test and fine-tune a potential habitat design, its believability and value could pave the way to the financial and societal support needed for it to be built.

---

15 Bingham et al., "Digital Lunar Exploration Sites Unreal Simulation Tool (DUST)."

16 Brady Peters and Terri Peters, *Computing the Environment: Digital Design Tools for Simulation and Visualisation of Sustainable Architecture*, AD Smart 06 (Wiley, 2018), 15

Human AR/VR Interface

The use of Augmented Reality (AR)and Virtual Reality (VR) tools and headsets has increased dramatically in the last decade. NASA extensively uses VR to train and simulate space missions in the Johnson Space Center Virtual Reality Lab. In fact, NASA was one of the first to develop a virtual reality headset back in 1985 that could display basic computer-generated imagery of what a pilot might see during flight.[17] For the time, such a device was a revolutionary first step into having a *wearable* tool that could immerse astronaut training to the machines and virtual spaces they needed to navigate and gain experience from. Forty years later, modern devices such as the Apple Vision Pro,[18] HTC Vive and MetaQuest III, showcase the decades of computing power progress to deliver engaging AR and VR experiences with higher visual fidelity and augmented controls. With future advancement in hardware capabilities, these mixed-reality spaces could one day recreate and immerse users to near identical outer space environments and conditions. For instance, a high-fidelity recreation of the view an astronaut sees on a EVA spacewalk in Earth orbit could be awe-inspiring, all without needing to physically go there. A recent study explored and found that an emotional response, similar to overview effect in VR that astronauts experience, can be triggered at a subdued level.[19] Being able to fill your entire peripheral vision, rather than just a television or computer screen, allows for a high level of immersion.

Along with continuing research in robotics and future space missions, space architecture may very well be a playground for remotely controlled robotics. Many recent space mission planning for the Artemis missions eludes to robotics becoming the extension required for establishing built lunar

17 National Air and Space Museum, "Headset, Virtual Reality, Prototype," *Smithsonian*, accessed November 5, 2025, https://airandspace.si.edu/collection-objects/headset-virtual-reality-prototype/nasm_A19970613000.

18 *Introducing Apple Vision Pro: Apple's First Spatial Computer,* Apple Newsroom (Canada), accessed October 10, 2025, https://www.apple.com/ca/newsroom/2023/06/introducing-apple-vision-pro/.

19 Laura S. Loy et al., "*A Virtually-Induced Overview Effect? How Seeing the World from above through a Simulated Space Tour Is Related to Awe, Global Identity and pro-Environmental Behaviour*," Journal of Environmental Psychology 99 (November 2024): 102428, https://doi.org/10.1016/j.jenvp.2024.102428.

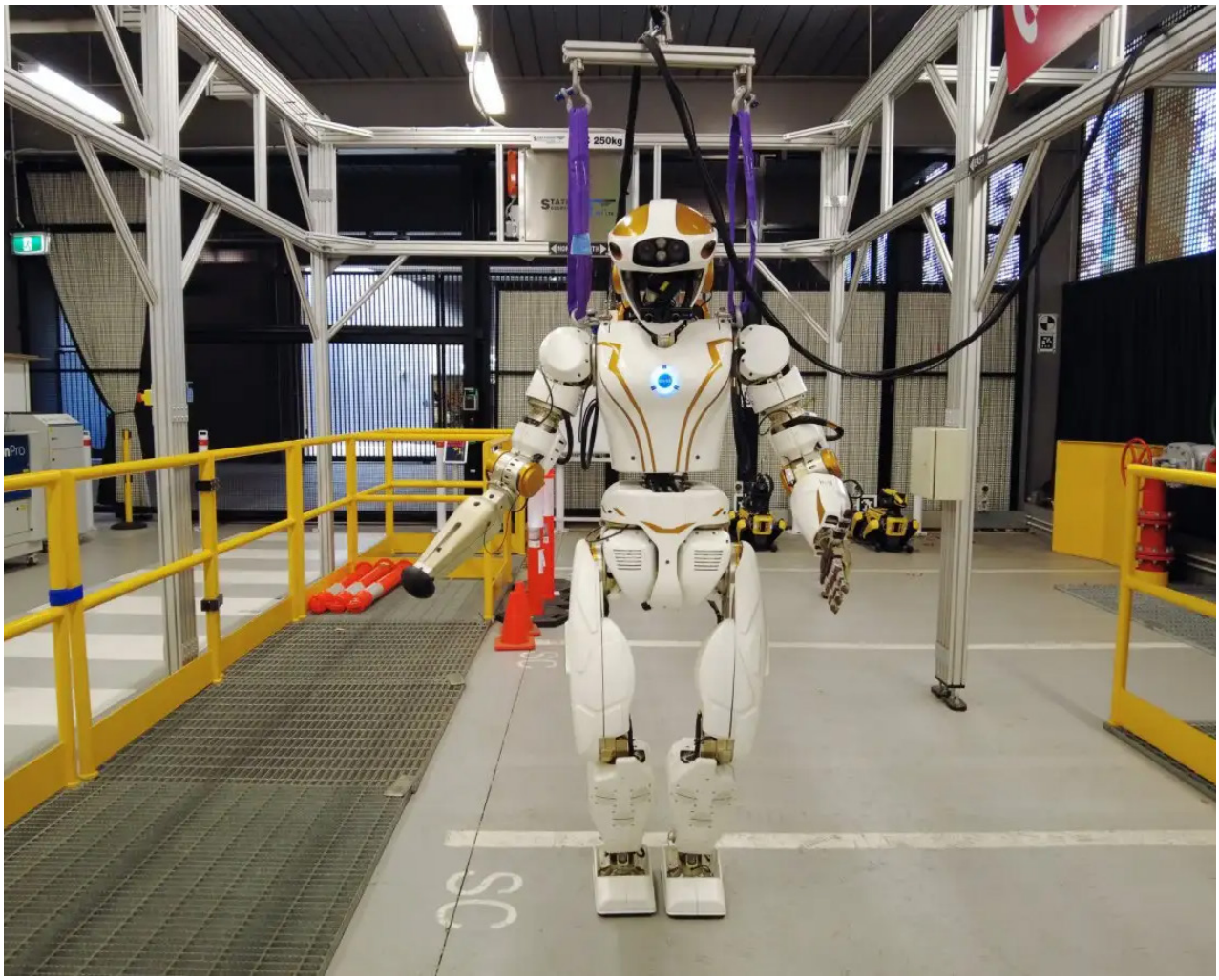


Figure – 3. 17 NASA's Valkyrie robot, ready to be inhabited through virtual reality, Photograph, James Woodford, 2024, https://www.newscientist.com/article/2446831-i-took-control-of-nasas-valkyrie-robot-and-it-blew-my-mind/

architecture. Beyond the virtual of users wearing VR headsets, they can become a controller for moving robots on the surface of the moon. The delay that occurs for this is 1.23 seconds.[20] Research is still ongoing to minimize this delay and if extrapolated, the chance of having almost instantaneous avatar control in space could be another avenue for user-centric space exploration. NASA's Valkyrie[21] robot (Figure – 3. 17) is designed to allow for users to control and use it in virtual applications. As much as one may wish to travel to space and land on the moon, it is out of reach for most people. Robotic link systems may well be a viable future for users to physically explore the moon in a controlled manner without the dangerous risks associated with spaceflight. For Verne Station, due to it's positioning between Earth and the Moon, users aboard would be able to pilot VR and AR augmented robotic devices to explore the Lunar surface and even other areas of space with an active connection.



Figure – 3. 18 NASA VR headset, 1986, NASA, Image credit Smithsonian Museum, https://www.si.edu/object/headset-virtual-reality-prototype%3Anasm_A19970613000

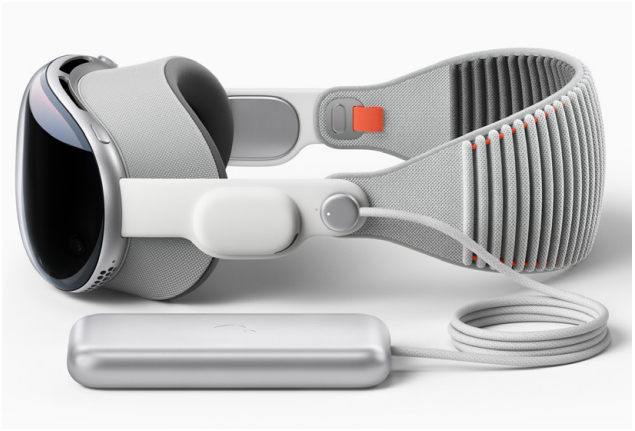


Figure – 3. 19 Apple Vision Pro AR/VR device, Apple, 2023, https://www.apple.com/ca/apple-vision-pro/

20 P. Nadrag et al., *Remote Control of a Real Robot Taking into Account Transmission Delays*, IFAC Proceedings Volumes 43, no. 13 (2010): 59–64, https://doi.org/10.3182/20100831-4-FR-2021.00012.

21 James Woodford, "I Took Control of NASA's Valkyrie Robot and It Blew My Mind," *New Scientist*, accessed October 25, 2025, https://www.newscientist.com/article/2446831-i-took-control-of-nasas-valkyrie-robot-and-it-blew-my-mind/.

Rise of the Simulator

From testing concepts, to training personnel for scenarios that are either too expensive, time-consuming or unsafe to conduct in the real world, simulation not only has proliferated, it has become a standard. Imitating the real world through a 3D virtual landscape has empowered spaceflight designers to better understand the models of which they seek answers from. For architects, the act of experiencing a building design virtually is extremely valuable. It enables the designer and client to further envision and test how building occupants will enjoy and utilize designed space. Virtual models also allow for the extraction of specific performance based building model data that would otherwise be speculated until built. With the use of a 3D model, the number of various simulation scenarios that can be executed, are only inhibited by the limitations placed by hardware and software. Multiple scenario testing with visual cues, give architects the ability to incorporate and test a wide-range of creative solutions to their design ideas. It also provides a platform that is much easier to access and distribute to consumers than that of physical simulators.

The usefulness of such digital sandbox tools allows one to have a unique freedom in the creation and testing of designs as determined by the simulation model. Parameters such as physics, weather, lighting and scripted events create the backdrop for the experience being examined. While such data strives to be as accurate, the ability to simulate the real world exists in a limited capacity. With a growing demographic and pervasiveness of people playing video games, one day people may expect an immersive and fully functional digital twin to be standard in order to visualize conceptual designs. For professional architectural rendering studios, the use of path tracing rendering clients, such as Maxwell and VRay for example, can create realistic renders with accurate lighting, but at the expense of very long render times per frame. In a video game environment, much of the processing power is off-loaded to a dedicated graphics processing unit (GPU). To produce high quality visuals, a combination of ray tracing and rasterized simulated effects and artistry is needed to achieve real-time performance targets. That said, the potential for video game environments to become truly photorealistic will continue to improve with future hardware and software developments. Coupled with VR headsets and improvements in wearable technology, the immersion that players and hopefully designers can experience will be true-to-life experiences. The game *Reentry - A Space Flight Simulator* allows users to experience piloting

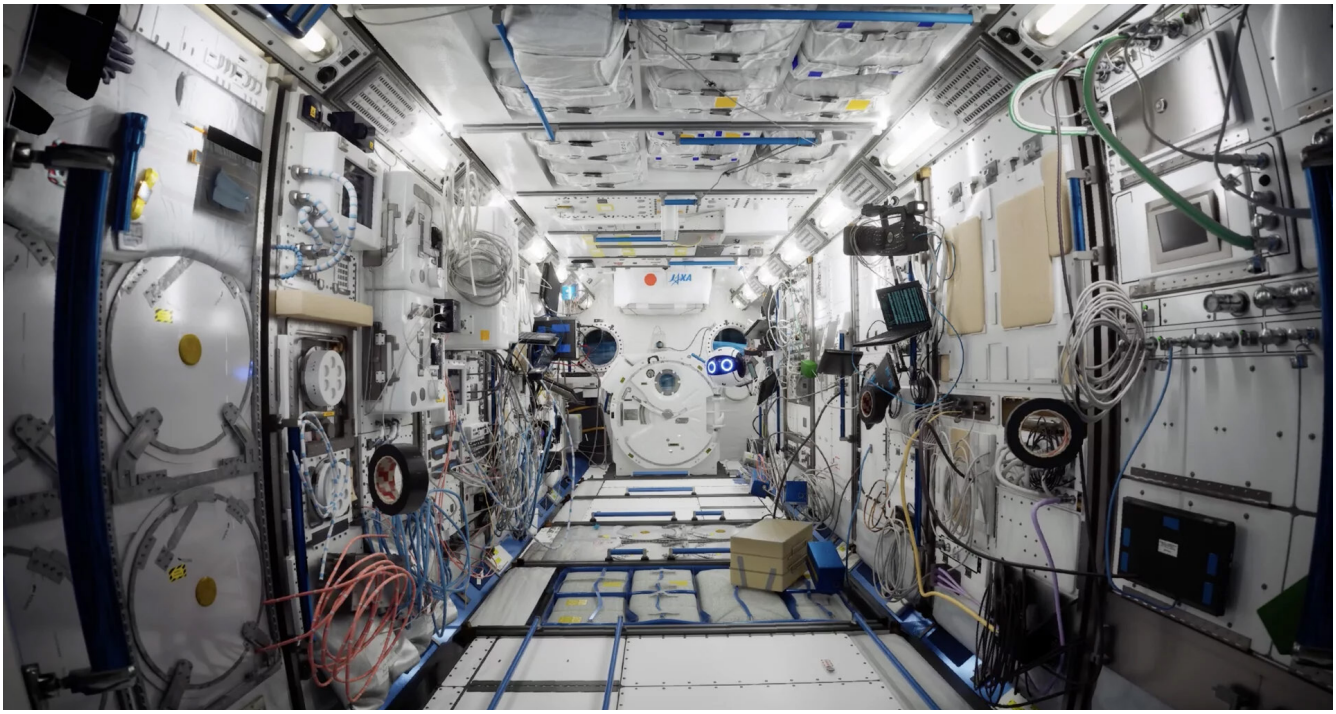


Figure – 3. 20 Detailed interior of Japan Experiment Module (Kibo) in *ISS Simulator,* SpaceData Inc. and JAXA, Screenshot, 2024, https://store.steampowered.com/app/3239970/ISS_Simulator/

historical space craft in astounding detail.[22] Microsoft *Flight Simulator* also has a DLC (Downloadable Content) add on to pilot NASA's long retired space shuttle.

There has been a shift in how computer hardware and software has progressed over the last 15 years. Better and robust graphic cards with billions of transistors are now key to delivering real-time hyper-realistic imagery with ray tracing implementations. The advancements and refinements developers have done with Unreal Engine 5 have truly set it apart in achieving large complex geometry and almost unlimited polygon counts with Nanite and realistic lighting with Lumen.[23] For instance, one of the best digital recreations of the ISS exists within Unreal engine through the efforts Japan Aerospace Exploration Agency (JAXA). *ISS simulator* (Figure – 3. 20) allows players to interact and explore a faithful and extremely detailed recreation of the famous space station. However, the most important and critical perception of these virtual environments are still hollow and pale in comparison to the real thing due to the absence of micro gravity.

22 Reentry - A Space Flight Simulator. "Reentry - A Space Flight Simulator," Reentry - A Space Flight Simulator, accessed October 3, 2025, https://reentrygame.com/.

23 https://www.unrealengine.com/en-US/unreal-engine-5



FIGURE – 3. 21 Interior ship module, *Starfield*, Bethesda, 2023, https://www.youtube.com/watch?v=I6J8n2lbAQk

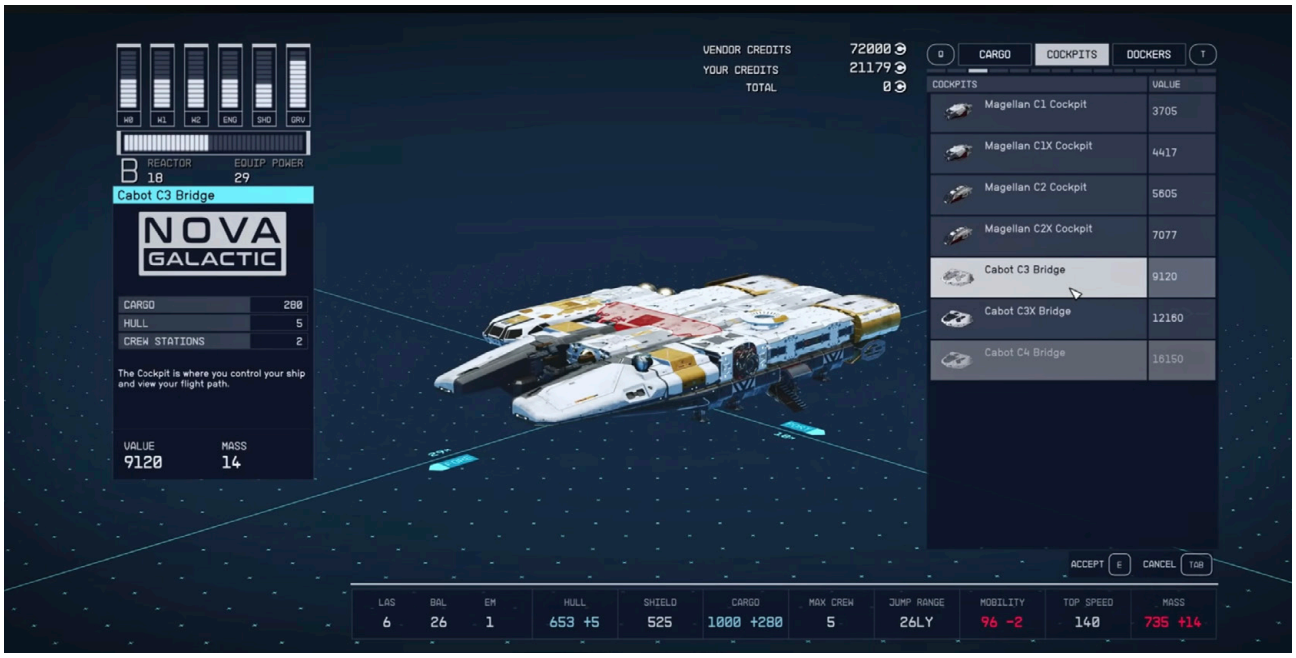


FIGURE – 3. 22 Ship Builder Editor, *Starfield,* Bethesda, 2023, https://youtu.be/I6J8n2lbAQk?t=1029

Representation of architectural spaces exist in a confined manner. In short any constructed virtual space as argued requires specific containment. As much as it is important that the look and feel of a game environment behaves, the way one traverses and explore spaces is guided by distinct prompts and geometric design choices and patterns. If we align a VR simulation to the ISS space station, what you can do onboard is severely limited and scripted. In fact, most ISS simulators that have been developed and made available to the public over the years are limited or basic in functionality due to available technology and budgets. The experience is very different from the additional spacesuit and physical devices used training astronauts versus the comfort of your home. As much as it is cheaper to build a virtual model compared to the real things, there is still a resource cost associated - albeit much lower that building the real thing. A fully interactive experience that mimics real life is out of reach and in some ways, may not even be engaging. The time to build and create these virtual digital environments is incredibly time intensive and require large teams and capital. AAA video game budgets often range in the hundreds of millions of dollars.[24]

Video game culture has grown tremendously over the last few decades. As more people play and experience video games in their everyday lives, the idea that video game engines could be useful immersive tools for space architecture design can become normalized and accepted. An example of this is the editors within popular video games. The ship building editor in *Starfield* (2023) allows users to create their unique spaceship from a wide array of modular parts for custom world building. Given the many modules and kit of parts prevalent in main science fiction lore and the basis for real-world space architecture, the end result crafted can be presented in a realistic manner. Crew quarters, medical bays, crafting and tool stations, are just some of elements that comprise the necessary modules for a complete station experience. Imagined architectural spaces can be refined and edited with each modular design piece with ease and with restriction as this is not a reality-based simulation as, in the end, the game world's primary function is to extract entertainment value over true-to-life realism. You are in command of your own space ship confined to the rules set by the game. (Figure – 3. 21) - (Figure – 3. 22) Once built, the player can explore their own ship interiors based on the kit of parts available,

24 Anastasia, "The Costs of AAA Game Development: A Financial Analysis," *EJAW*, September 25, 2023, https://ejaw.net/the-rising-costs-of-aaa-game-development/.

with the end result looking realistic and lively once the interior is populated with crew. Cat Bussell writes about the ship-building system as an engaging part of the game as it offers a lively personal connection and sense of ownership to the ship you create.

> "What really elevates any custom-built Starfield ship is how you get to walk around the environment you create, seeing your vessel's corridors, berths, and cockpit for yourself. Your creation does not exist in isolation, rather it's a thing you can touch, explore, and revel in."[25]

Furthermore, custom-modified geometric structures can be added into the game world with Bethesda's Creation Kit add-on,[26] combining the deliberate NASA-punk inspired aesthetics that the game designers used to make this futuristic world more believable and relatable.[27] As one explores their ship's zones and spaces, the relationship between designer and gamer begins to blur as the virtual space created feels more authentic and engaging.

Back in 2013, this was one of the original goals of designing Verne Station. Using a real-time virtual environment where you could, as a player, walk around and explore the design in a lively and realistic real-time simulation. In essence, the spatial form of Verne Station was bound by its primary construct – artificial gravity generation through centrifugal force. By creating a rotating ring structure, it inherently meant that the interior would exist as one bustling linear corridor, with supporting modular recreational and programmatic spaces. It is expected that by taking the general architectural design of Verne Station and combining it with *Starfield*'s art style and aesthetic within the creation kit, the immersion of the space environment would feel more visually authentic. By having this game engine work as a tool, to envision and engage in this fictional outer space setting in the comfort of your own home, is such a contrast to what architects and visionaries had to work with before computers.

---

25 Cat Bussell published, "Starfield's Ship-Builder Makes Me Feel like a Kid Again," *TechRadar*, September 25, 2023, https://www.techradar.com/gaming/consoles-pc/starfields-ship-builder-makes-me-feel-like-a-kid-again.

26 Bethesda Game Studios, "Starfield Features," *Starfield*, accessed November 11, 2025, https://bethesda.net/en/game/starfield/features.

27 "'Starfield': Todd Howard Discusses Bethesda's New Space-Based RPG," *Washington Post*, accessed July 14, 2025, https://www.washingtonpost.com/video-games/2021/06/13/starfield-bethesda/.

With the development growth of video games throughout the years increasing in realism and sophisticated game mechanics, one begins to ask: when will architects start designing virtual spaces within comprehensive video game environments that embody the principles of visionary architecture? Furthermore, how might visionary architecture of the past have been developed and tested differently by the general public if such tools had existed at the time? It would be amazing to experience, as one example, Peter Cook's *Walking City* animated and alive in the digital realm.

Crafting visionary architecture into these virtual game world spaces is still incredibly limited and tied to the confines of current technology and resources. A fully physically-based realistic simulation where players can do *everything* they wish is beyond practicality due to computational limitations, even for today. For some over ambitious video games, development time can almost have no end in sight. The game *StarCitizen*, which has been stuck in development since 2012, promises an online epic space-faring experience, full of open world gameplay and seamless interplanetary travel.[28] Yet to design and make the game mechanics work, it has taken millions of dollars and several years to create only a fraction of the content promised. The social fabric of video games today and the online presence of millions of players being able to play and engage in these open-world virtual environments is valuable data.

Having a test bed of sorts to understand how players use and occupy these spaces like Hassell and the ESA did with their content for the popular *Fortnite*[29] could very well help inform new design strategies. Architects today envision their spaces being built with complex models, but most are only tested against various energy or site environment simulations. The actual occupation and use of space may be very different than the intended design over its lifetime. If we apply this to developing space architecture, this makes the argument become, how do we begin to dynamically change the design to respond to user inputs? Because space is incredibly out of reach for the common person, these virtual

28 Alan Bradley, "$800 Million, 13 Years, and Still No Release Date — the State of Star Citizen in 2025," *Space*, June 2, 2025, https://www.space.com/entertainment/space-games/800-million-13-years-and-still-no-release-date-the-state-of-star-citizen-in-2025.

29 Carter Digital, *Hassell | Lunar Horizons in Fortnite: An Immersive Reimagination of Hassell's Lunar Habitat Master Plan,* Hassell, accessed October 1, 2025, https://www.hassellstudio.com/news-event/lunar-horizons-in-fortnite-an-immersive-reimagination-of-hassells-lunar-habitat-master-plan.



FIGURE – 3. 23 *Star Citizen,* Cloud Imperium Games, 2025, Digital Image, https://www.space.com/entertainment/space-games/800-million-13-years-and-still-no-release-date-the-state-of-star-citizen-in-2025



FIGURE – 3. 24 Screen capture, *Star Citizen,* Cloud Imperium Games, 2025, Digital Image, https://www.space.com/entertainment/space-games/800-million-13-years-and-still-no-release-date-the-state-of-star-citizen-in-2025

game engines may become powerful tools to interactively explore and test architectural visions of space architecture. Much like the visionary artists prominent in early space flight, one can wonder how their designs and aspirations may be different with the technological tools that currently exist. The virtual realm can be a compelling narrative for shaping and supporting the future design of innovative extra terrestrial spaces and modifying them as new factual data is discovered in time.

Selecting the Game Engine

By the end of my M1 studio course, I started sketching a design of my space station. I had a few options: use traditional architectural models or use a game engine to simulate the conditions of space in real-time, specifically dynamic lighting and gravity. I began to tinker with two popular video game engines, UDK (Unreal Development Kit) and CryEngine 3. Both of these programs utilize advanced rendering techniques and physics and with the right hardware setup, environments created in them could look photorealistic.

My first set of tests began with Unreal Development Kit, the popular engine behind many blockbuster game titles such as *BioShock*, *Mass Effect*, *Unreal Tournament*. In 2011, Epic Games, the company behind UDK, showcased one of its next generation game demos *The Samaritan*. This technical demo was a pure visual feast that looked better than any video game I had played. If hardware today allows a level of detail similar to high end CGI films, I was interested in making a level of my own in UDK. With the engine's large online support base, video tutorials and examples, all of which are freely available on the internet, the resources for me to learn the engine were there. My crash course in the engine began with exploring the pre-made level file examples. In the level file 'deck', I started to understand how scenes were made with prefabricated models. Lights and objects pickups had tiny icons displayed on themselves, making it easy to recognize and select each piece of the level. Overall, the environment looked great, but as I started to add in meshes from the basic library, the mesh would look strangely darker, accompanied with an in game message "lighting needs to be rebuilt". Switching to game mode, I could see that the lighting was not truly dynamic as it appeared in engine. It was *baked* (pre-rendered) to emulate global illumination and to maintain a high framerate and deliver photorealism. To make the level render correctly, I had to rebuild the lighting, a process that took either minutes or several hours based on the scene complexity. Coupled with a hard to understand user interface, I started to sway towards testing out CryEngine 3, which at the time, was shipped as the ModSDK3 for the game *Crysis 2*.

Ease of Use

From 2011-2013, this thesis explored space architecture using CryEngine developed by Crytek. From the start, the engine felt intuitive to use as it had similarities to Autodesk's 3D Studio Max, a software program I had been using extensively for digtial modelling and rendering. To my surprise, it was possible to load *Crysis 2* game level files in the editor, which revealed how the game was created by the acclaimed developer. It felt like I had my very own gaming treasure chest as several of the engine's game assets could be utilized. With the properties of the game files available for modification, I could alter some of the gameplay; create harder enemies, place objects and specific weapons, and just overall, make a mess of things and crash the program. Everything I saw on screen was almost exactly as it would appear in the game in terms of visuals, and that was immediately what I wanted when creating my space station level in terms of visual feedback.

My first test was importing a recent design studio project into one of the Crysis 2 levels. It was a detailed house model, and more than complex enough to test and understand the needed workflow from 3D Studio Max to CryEngine. A quick search online and I found myself watching my first tutorial: importing an object into CryEngine. The first step was breaking the model apart so that no single object was more than 64, 000 polygons (engine limitation). Materials and texture maps also had to be reset, with individual files being loaded into Adobe Photoshop and exported as a CryTiff format. Finally a simplified physical proximity mesh had to be created and linked appropriately to the asset for object collision. Overall, the export process was tedious for my novice skill level. The actual act of exporting my readied files became even more aggravating when issues arose. Many times, the exporter plug-in for 3D Studio Max indicated the model file had "degenerate faces" or "more than three vertex's lie on the same line". The models I had created, were improper to the engine in terms of optimization, and had to be fixed - usually by remodelling the entire object over again or by fixing polygon face normals. I now had to learn clean modelling and proper texture mapping techniques in order to import my models into the game engine without issues. With all the extra time it took to troubleshoot issues, my actual progress of the space station model stalled.

After cleaning the model as best as possible, I was still stuck. Most objects I created would not import without errors. Some of the polygons appeared disfigured and incorrect from the scene in 3DS max. I had discovered a new issue. Floating Point precision. It seems Crydev, whose best interest of making their engine as efficient as possible changed the export capabilities of the engine. Floating Point 16 vertex format was favoured over FP32 for performance, and as a result large or complex models ended up becoming distorted if they are too far away from the origin point. In short, I had to change the approach of which I made my models. Every model had to be ideally made with quads (4 vertex polygon face) without any N-gons (faces with 5 or more vertices). Clean hi-polygon modelling was something I needed to learn. After a while of soaking in some online tutorials, the models I started to export into the engine were beginning to look correct.

As I was arranging content within the engine, I could immediately see what the result would look like with dynamic light sources. Everything responded in real-time, and as I placed more objects into the scene, and more dynamic lights, my computer rig started to show its age as the scene became unresponsive and graphical errors appeared. UDK vs CryEngine 3 are both capable engines, each with their own flaws and drawbacks; every software program has them. I felt comfortable with Crytek's offering. It was now time to build a test level that focused on zero gravity.

Today, Unreal Engine has advanced even more so with path tracing and the ability to handle millions of polygons and dynamic lights. There are tech demos and video games today that match and sometimes rival the visual effects of older major motion picture films and television. Consumer Graphical Processing Units that exist today such as the Nvidia RTX 5090 with 32GB of VRAM (Video random-access memory) has 104 teraflops of processing power.[30] To contrast, the GPU I used back in 2011 was a Nvidia GTX 570 with 1.28GB VRAM and around 1.4 GFLOPS of processing power. This hardware leap demonstrates massive technological jumps can occur over time, pushing graphical capabilities to new heights. Combined with cutting edge software engines of today, modern computers could potentially render in real-time, a visually indistinguishable version of *Toy Story* (1995) - one of the first major 3D animated films. *Toy Story* took PIXAR Studio hours to render a

30 "NVIDIA GeForce RTX 5090 Graphics Cards," NVIDIA, accessed October 19, 2025, https://www.nvidia.com/en-us/geforce/graphics-cards/50-series/rtx-5090/.

single frame using several of the most cutting-edge computers at the time.[31] This is showcased (Figure – 3. 25) by the Digital Foundry from the work done in the video game *Kingdom Hearts 3*, which recreated *Toy Story* as a environment level for the PlayStation 4 (PS4) in 2019.[32] With the even more advanced modern hardware capabilities that can achieve even greater visual results, it starts to become evident just how far the industry has progressed in a few decades.

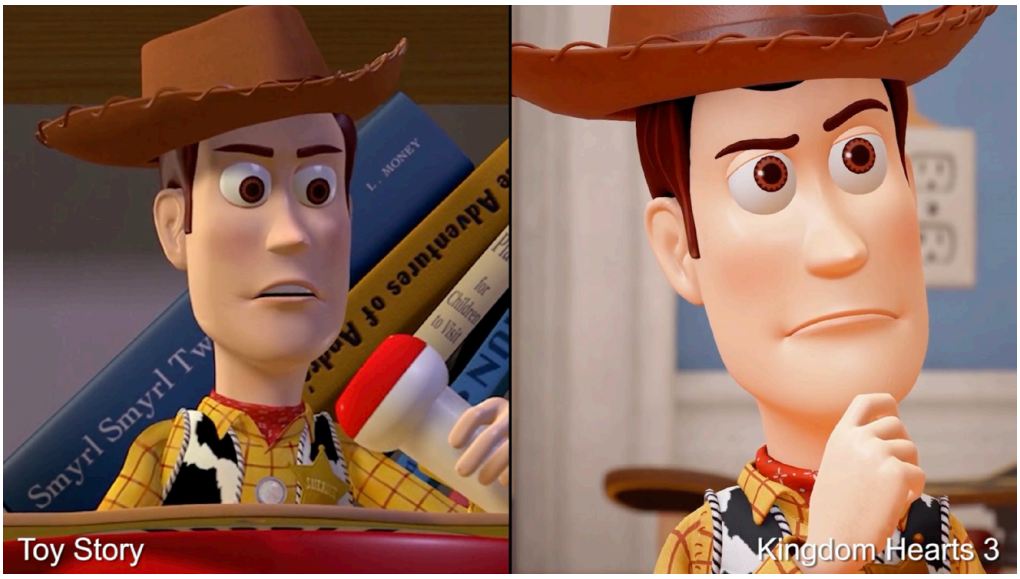
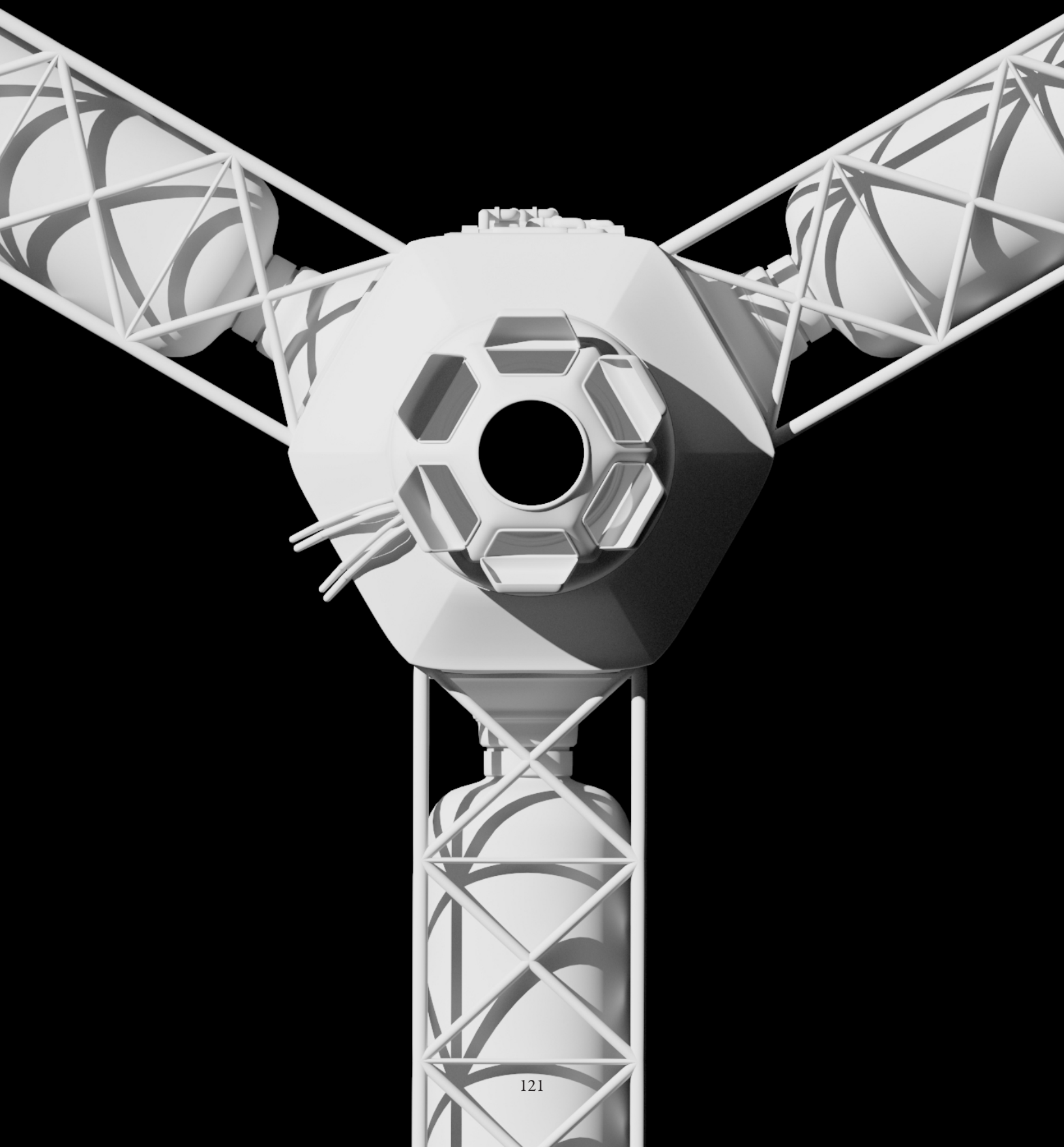


Figure – 3. 25 Toy Story (1995) frame capture compared to Kingdom Hearts 3 frame capture (2019), *Digital Foundry,* https://www.youtube.com/watch?v=tkDadVrBr1Y

31 Desire Athow published, "25 Years of Magic: A Look at How the VFX Industry Has Evolved since Toy Story Debuted," *TechRadar*, November 14, 2020, https://www.techradar.com/news/25-years-of-magic-a-look-at-how-the-vfx-industry-has-evolved-since-toy-story-debuted.

32 "Games vs CG! Kingdom Hearts 3 vs Toy Story Graphics Comparison", *Digital Foundry*, 2017, accessed October 11, 2025, https://www.youtube.com/watch?v=tkDadVrBr1Y.

FIGURE – 3. 26 Front view of Verne Station Cupola concept, Image by author, 2012



Large Centrifuge Test

Initial test mock-ups of Verne Station explored how a level file modeled after the well-known Stanford torus might function as a rotating habitat. The 250-meter diameter spacecraft was implemented within the Crytek game engine to examine how spin rate and movement could affect both spatial perception and visibility of the exterior environment. When the station's spin rate increased beyond a certain threshold, players encountered the disorienting sight of the Earth and the sunlight moving too rapidly around them. After the rotation was slowed, the resulting visual response felt noticeably calmer and more natural. Intentional viewpoints and openings were integrated into the structure to test how spatial framing and illumination might influence the sense of enclosure and the pleasure of looking outward into space. A version fully enclosed with no windows felt bleak and repetitive, as the corridor acted as an endless loop. To combat this, a strategy to include breaks in the linearity of the corridor with asymmetrical recreational zones and areas filled with vegetation were meant to be explored, but never materialized. The scale of the Stanford torus made the station seem misaligned with real world constraints. It was unreasonable to further pursue and detail this initial station design into a full fledged game level with proper effects, texturing and lighting for the thesis.

Figuring out the coding to get the player avatar to walk perpendicular along the floor surface as expected with artificial gravity generation in CryEngine (object normals) was never quite figured out by the author. The initial setup of the wheel was inefficient and involved linking several nodes within the engine in order for it to rotate with player movement. The station was rigged similar to that of a hamster wheel as a temporary solution to see the effect of walking inside the ship. Attempting to code and add in non-player character (NPC) in the scene to make them walk along the ring was unsuccessful as well. The workflow needed to create and test this video-game level was far more complex and tedious than expected and a learning experience in itself.

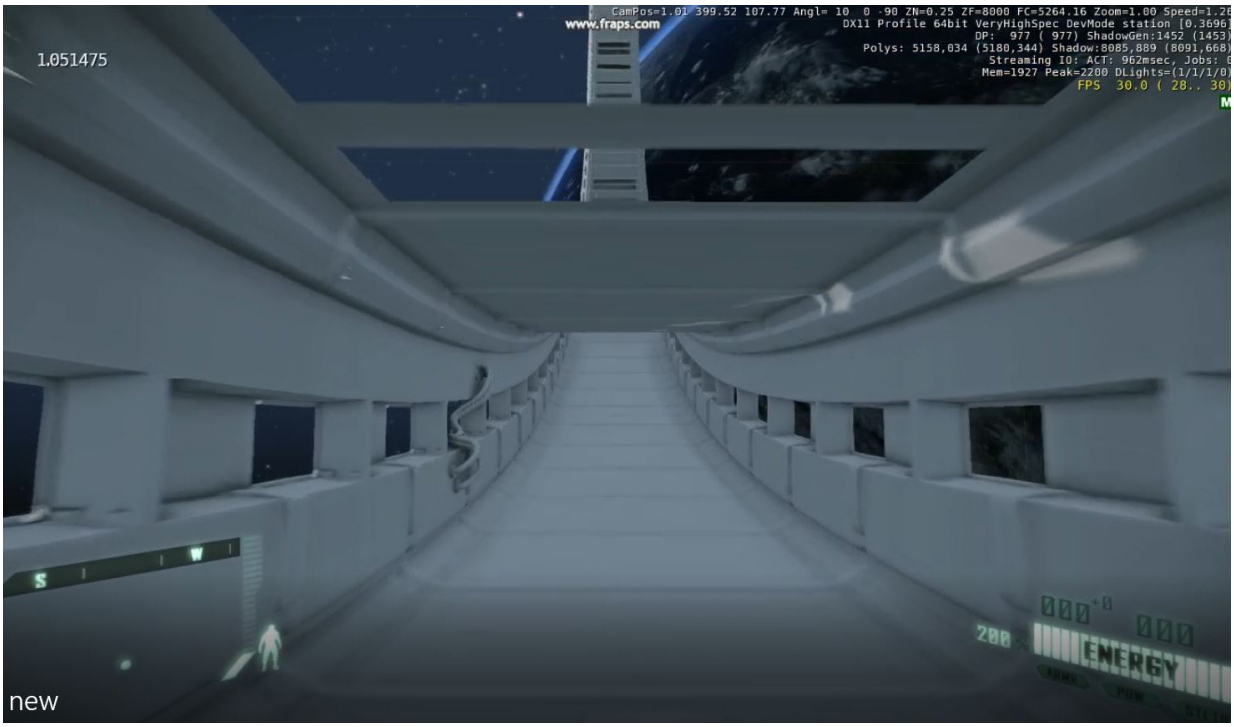


FIGURE – 3. 27 Interior Centrifuge screen capture of Space Verne Station in game CryEngine, Image by Author 2012

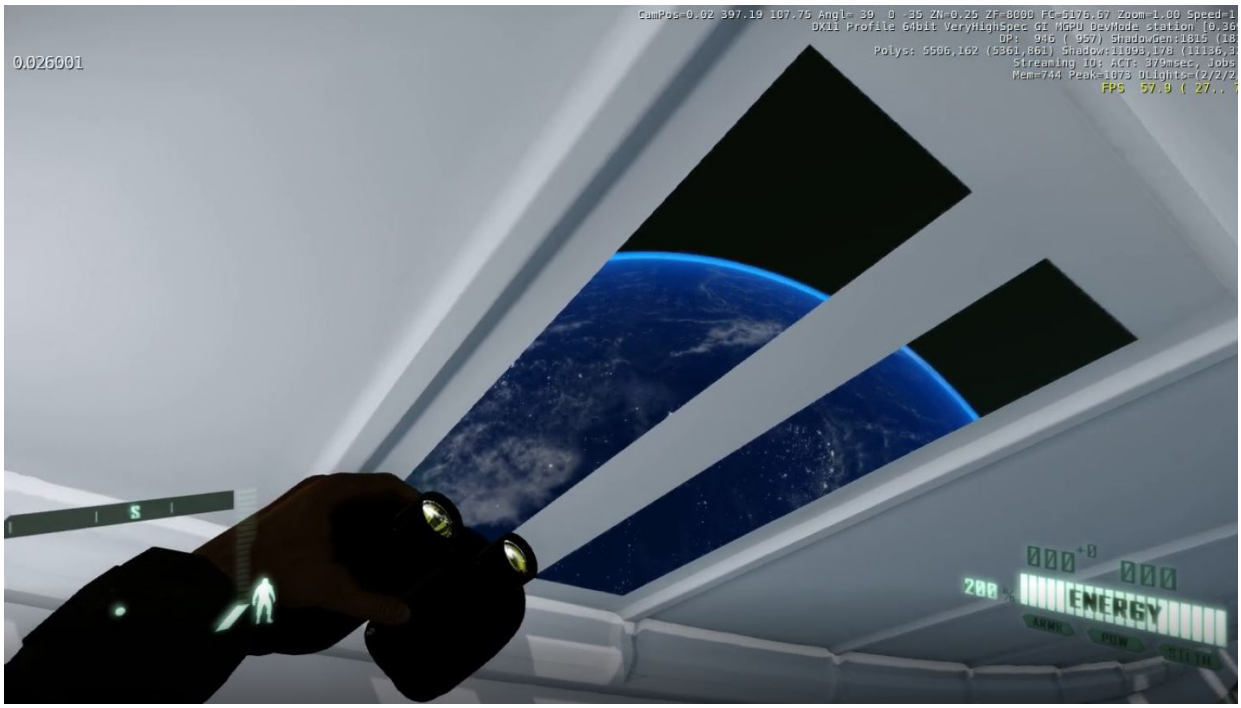


FIGURE – 3. 28 Interior Centrifuge screen capture of Verne Station in CryEngine, Image by Author 2012

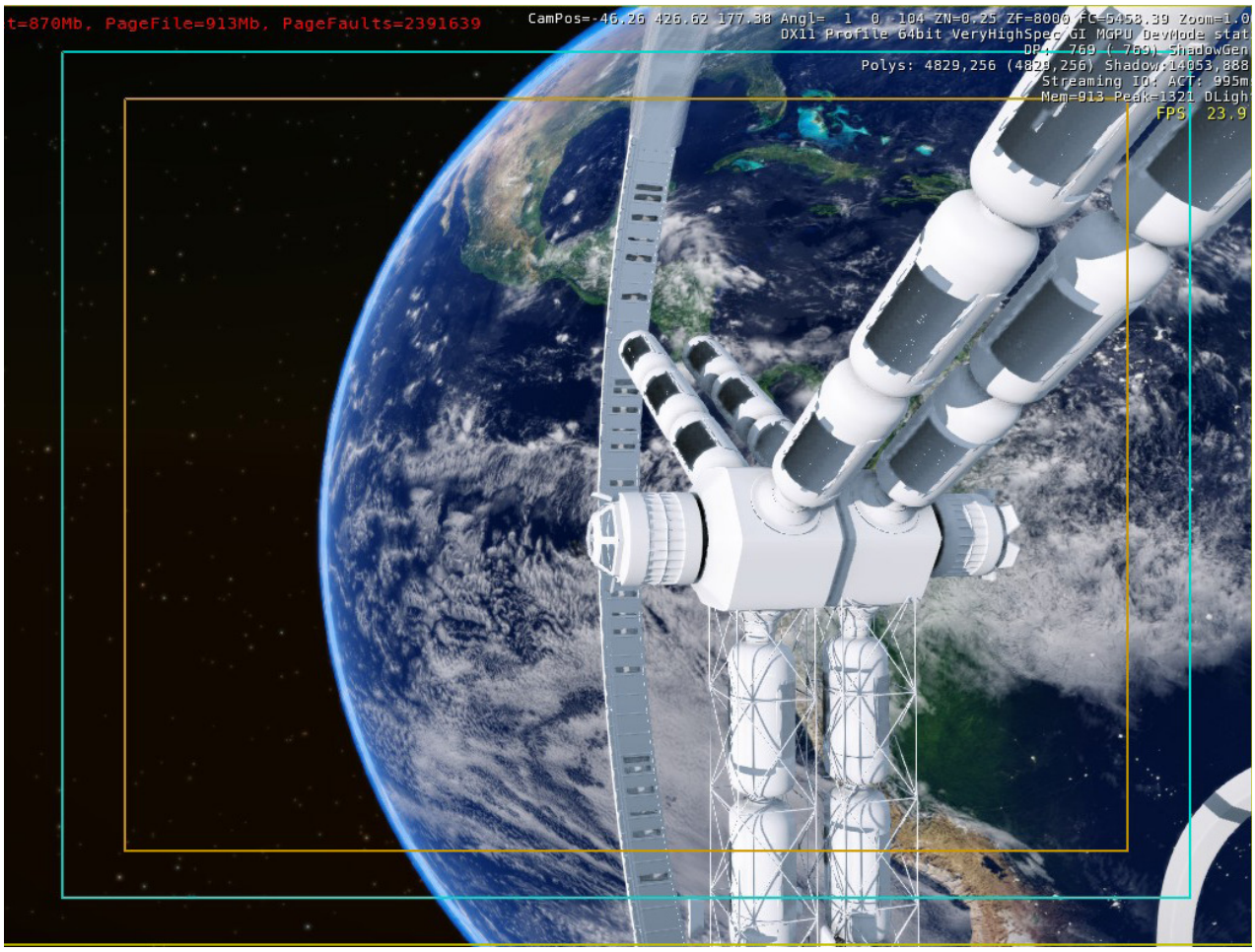


FIGURE – 3. 29 Frame capture of Verne Station concept in Earth orbit, CryEngine, Image by Author 2012.

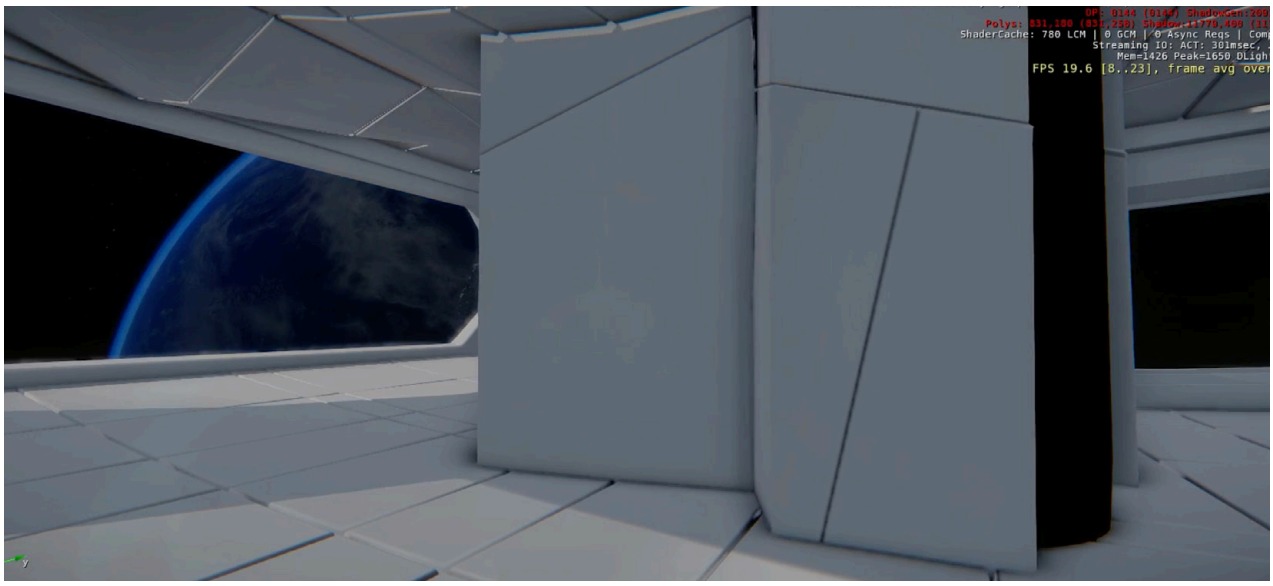


FIGURE – 3. 30 Elevator Core and Social Hub, CryEngine screen capture, Image by Author 2012

Small Gravity Test "Satellite"

Back in 2012, *Satellite*, named after the ill-fated dog in Jules Verne's *From the Earth to the Moon,* was a further test to develop how a smaller first person view of an interior centrifuge would look versus the larger Stanford torus model. Much like the Discovery in *2001: A Space Odyssey,* this smaller main ring would allow a small crew to operate in a fraction of normal Earth gravity, but at greater discomfort due to spin rate. The design goal of *Satellite* at first was to collect space debris from LEO (low Earth orbit). Abandoned satellites, space junk and small meteoroids would be collected by way of a retractable solar sail arm by matching the orbital trajectory of that object. Once an object was safely collected, it would be moved into the main storage module bays, where it could then be catalogued and then either recycled or disposed of accordingly by controlled re-entry in the Earth's atmosphere. The mission intent was intended to reduce and help prevent a Kessler Syndrome event.

Architecturally, its design is claustrophobic and essentially the same interior confinement as the ISS. As a smaller craft, it pushed the limits of safe RPM to generate artificial gravity and required astronauts on board to adapt to uncomfortable working conditions. At a diameter of roughly 25 metres, the human body would be unable to adapt properly to the Coriolis effect at 1g gravity, so the main ring achieves 0.45g instead, with the inner ring achieving 0.13g. Astronauts onboard would suffer from varying levels of gravity forces in different parts of their bodies which is not accounted for accurately in the game level.

Experiencing the design virtually in a first person perspective also posed another risk of how users would operate and move within the centrifuge with ladders only. Ultimately it would be easier to jump up and down the openings due the lower gravity. Seeing the horizon bend greatly due to low ceilings felt surreal and made the space feel claustrophobic. The validation for having artificial gravity aboard this craft became a new question to investigate. The only way to justify having such a small and uncomfortable centrifugal spin required for the design would be for more long term missions of importance. Thus, *Satellite's* mission expanded to capture and mine lucrative mineral-rich asteroids and be a space debris collector as needed. This alone would justify the requirement for a moderate crew size and artificial gravity generation to combat the physiological harm the human body endures

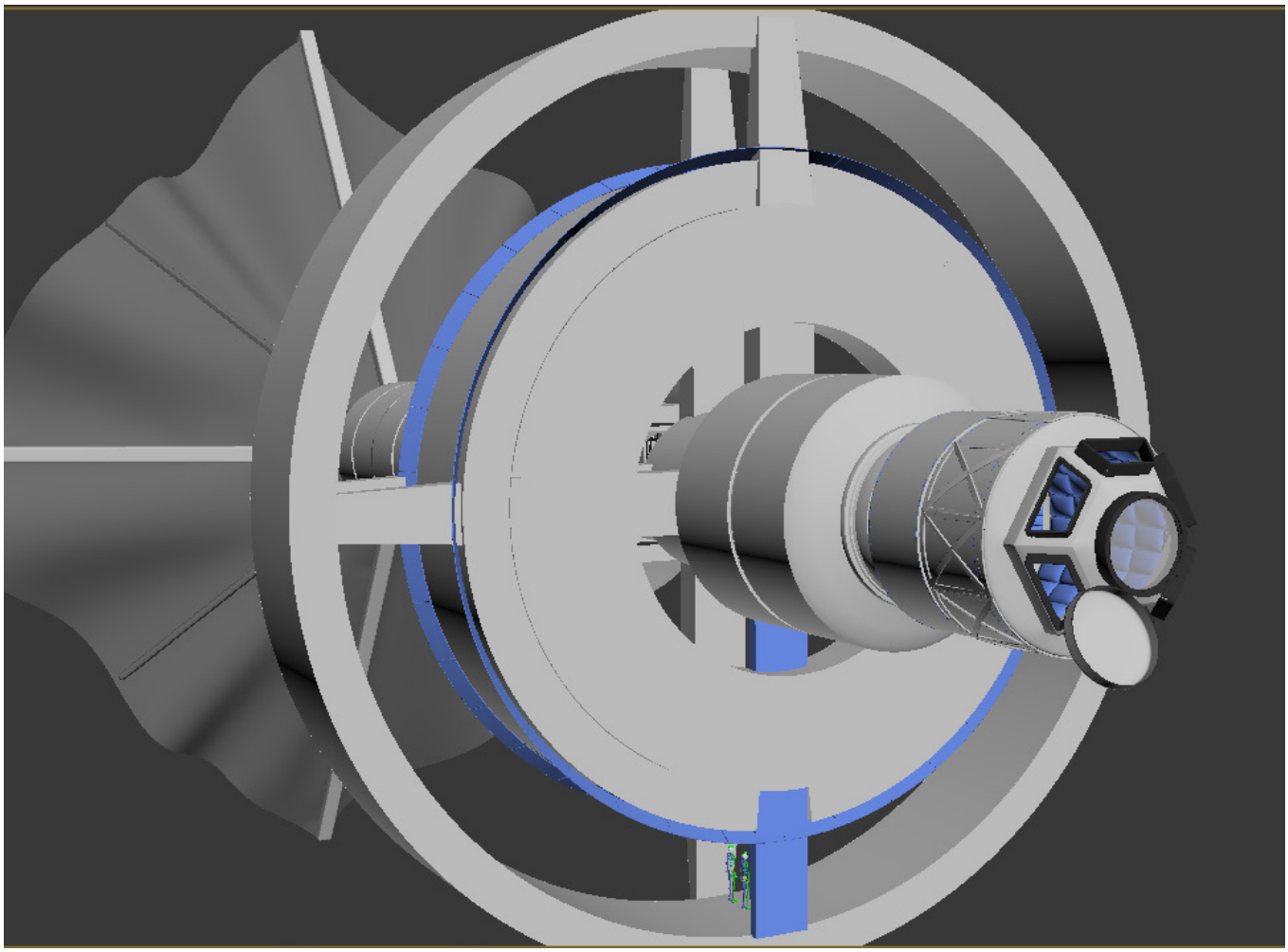


FIGURE – 3. 31 Exterior render of *Satellite*, by Author 2012

in long period durations.

The interior section (Figure – 3. 33) of the main artificial gravity wheel has zones for sleep, scientific modules, life support and various mechanical systems. Due to the small interior volume of the spacecraft, it functions without much respect to occupant comfort and recreation. The low gravity generated by the ring and the smaller ceiling height spaces, astronauts need to be fully aware of their movement. Jumping could result in severe injury and unexpected outcomes due to physics.

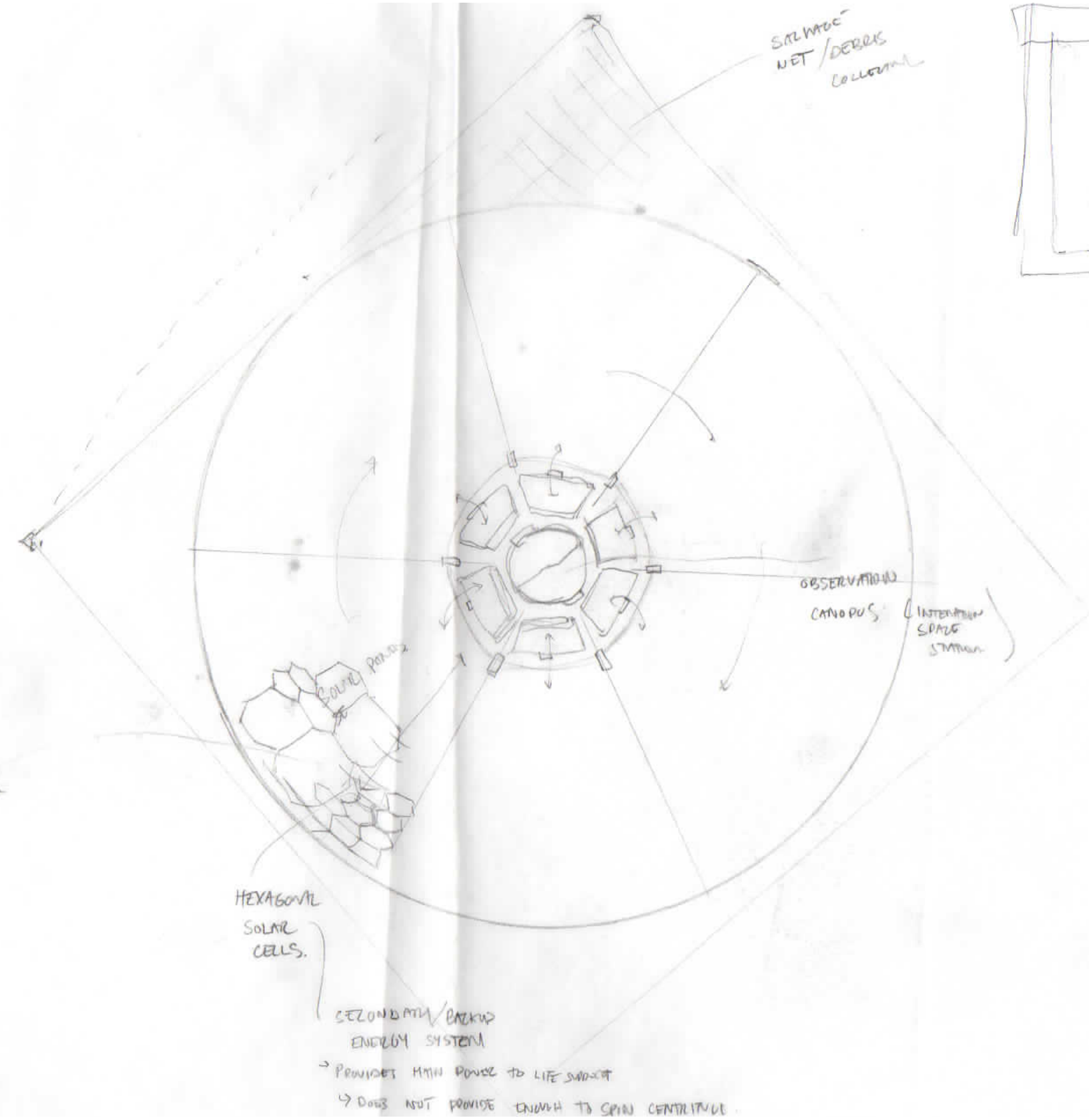


FIGURE – 3. 32 Bow of *Satellite*, Not to Scale, Drawing by Author, 2012

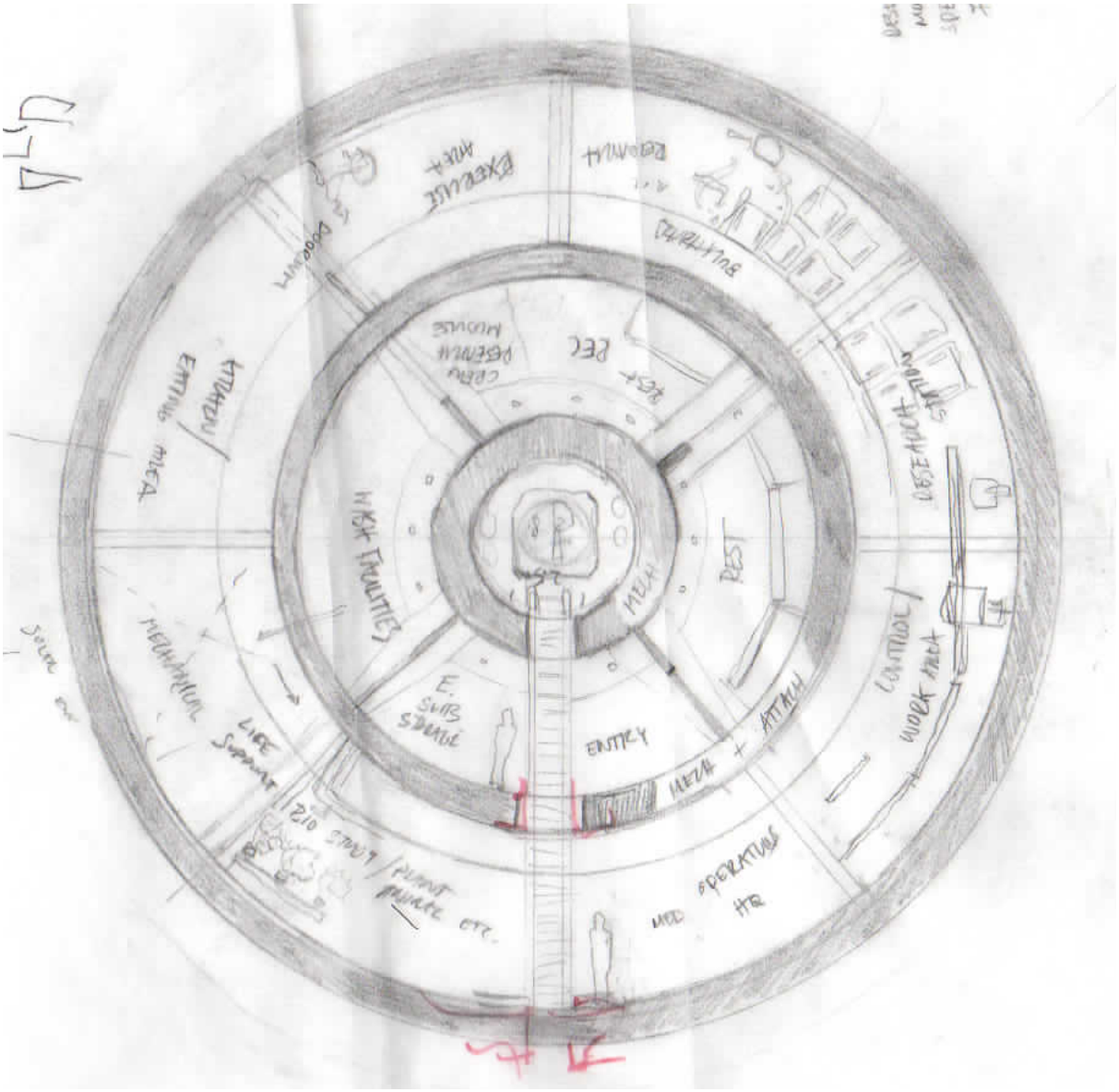


FIGURE – 3. 33 Section of *Satellite* (Aft), Not to Scale, Drawing by Author, 2012

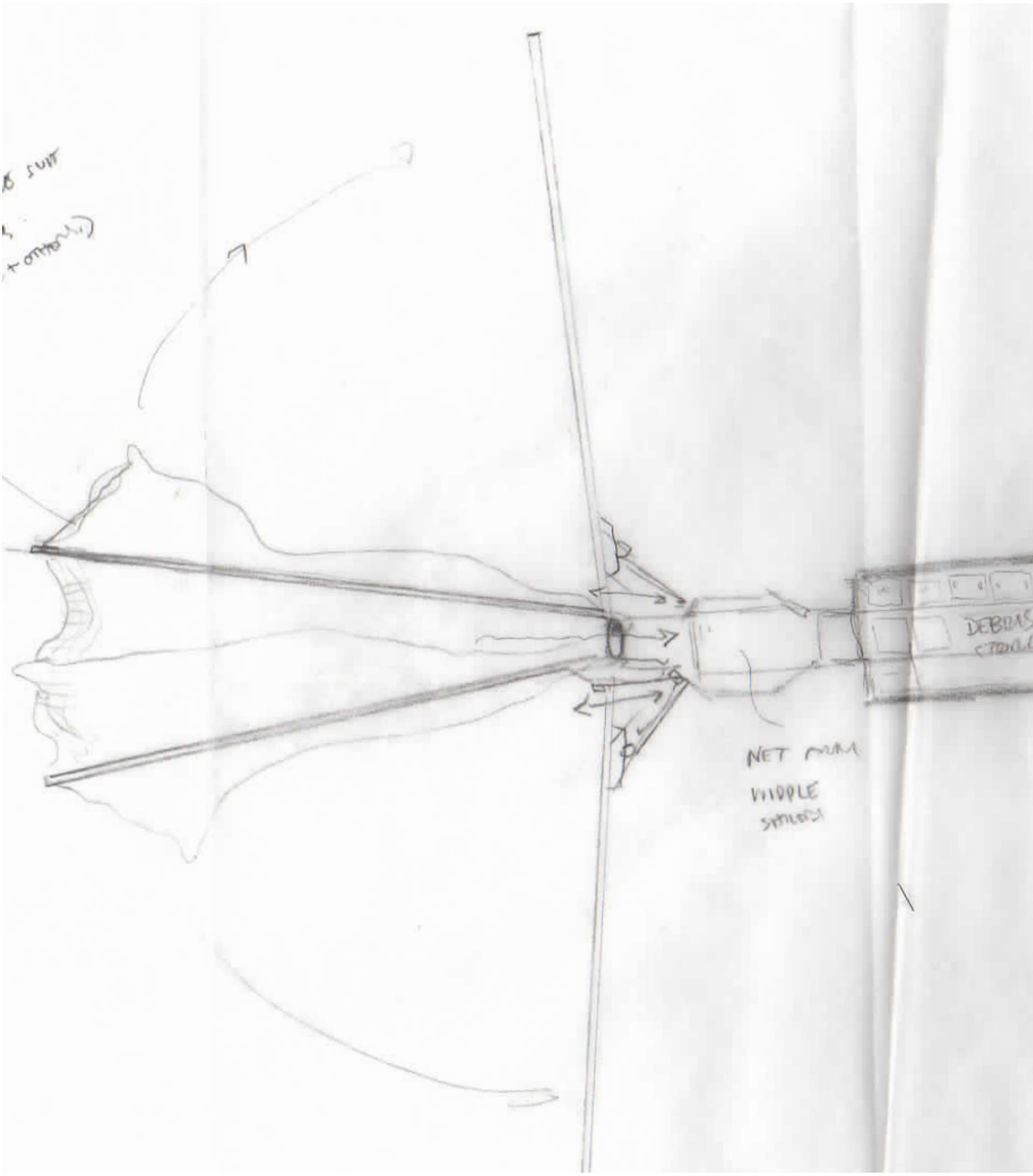
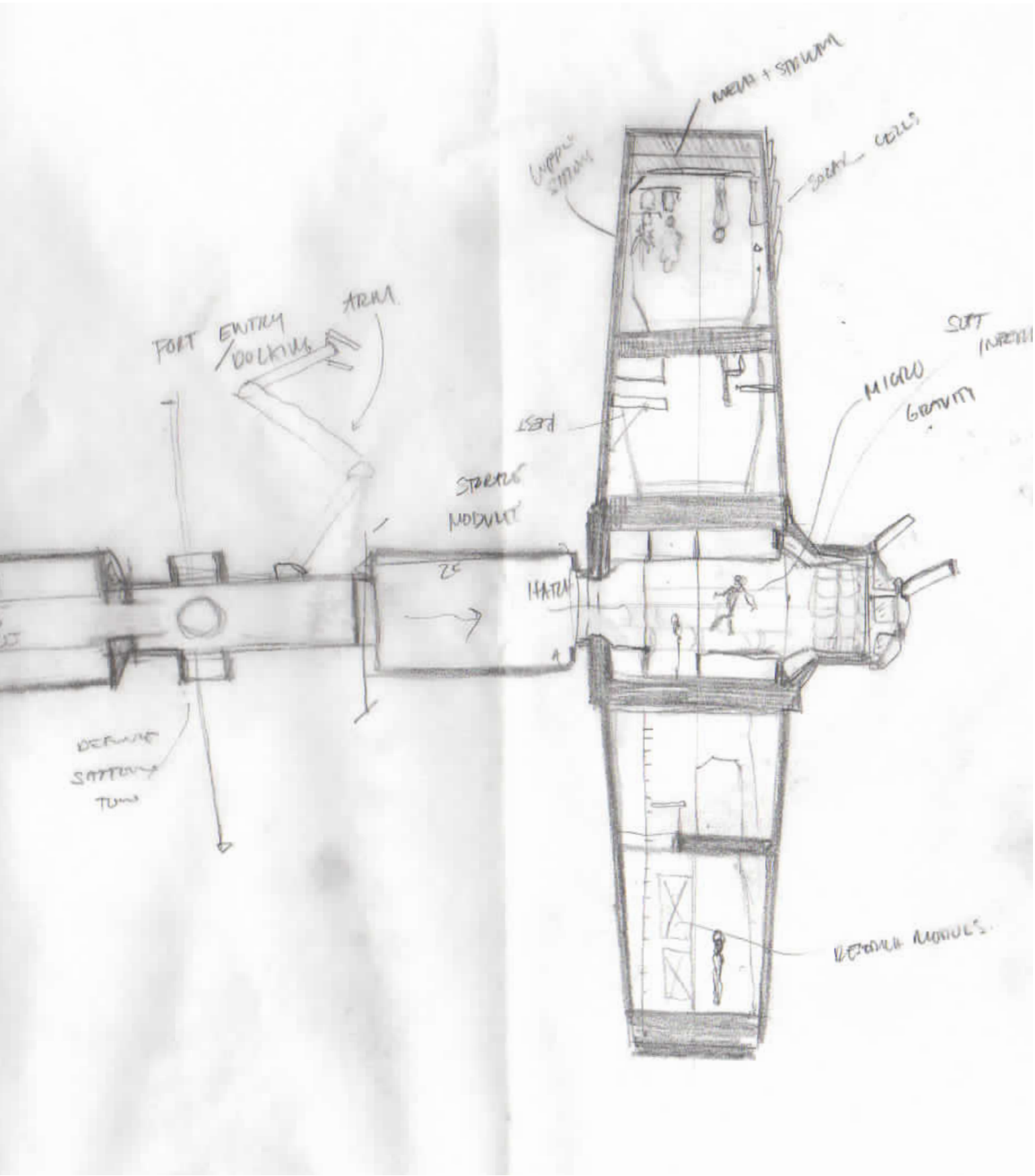


FIGURE – 3. 34 Cross Section (Port Side), *Satellite*, Not to Scale, drawing by Author, 2012


PORT
ENTRY
DOCKING
ARM
SPARE
MODULE
HATCH
MICRO
GRAVITY
SOLAR CELLS
REDUNDANT MODULES

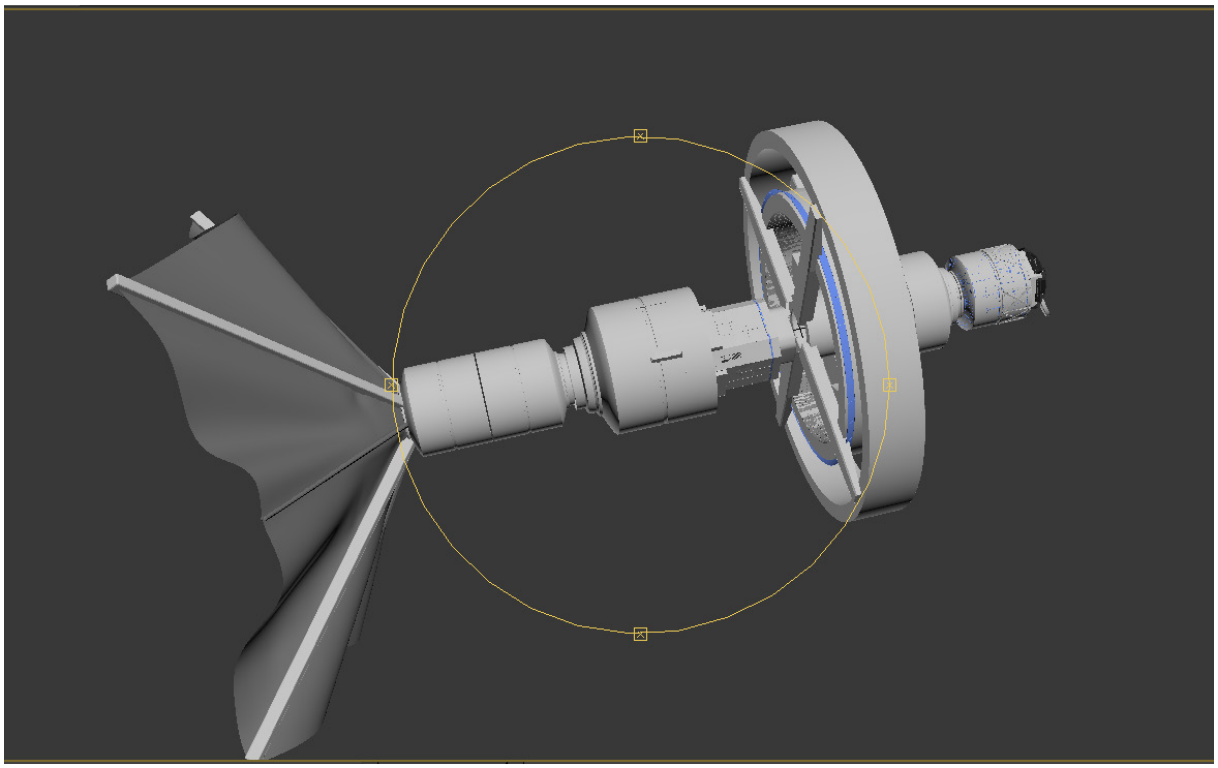


FIGURE – 3. 35 Exterior view of *Satellite*, screen capture, by Author, 2012

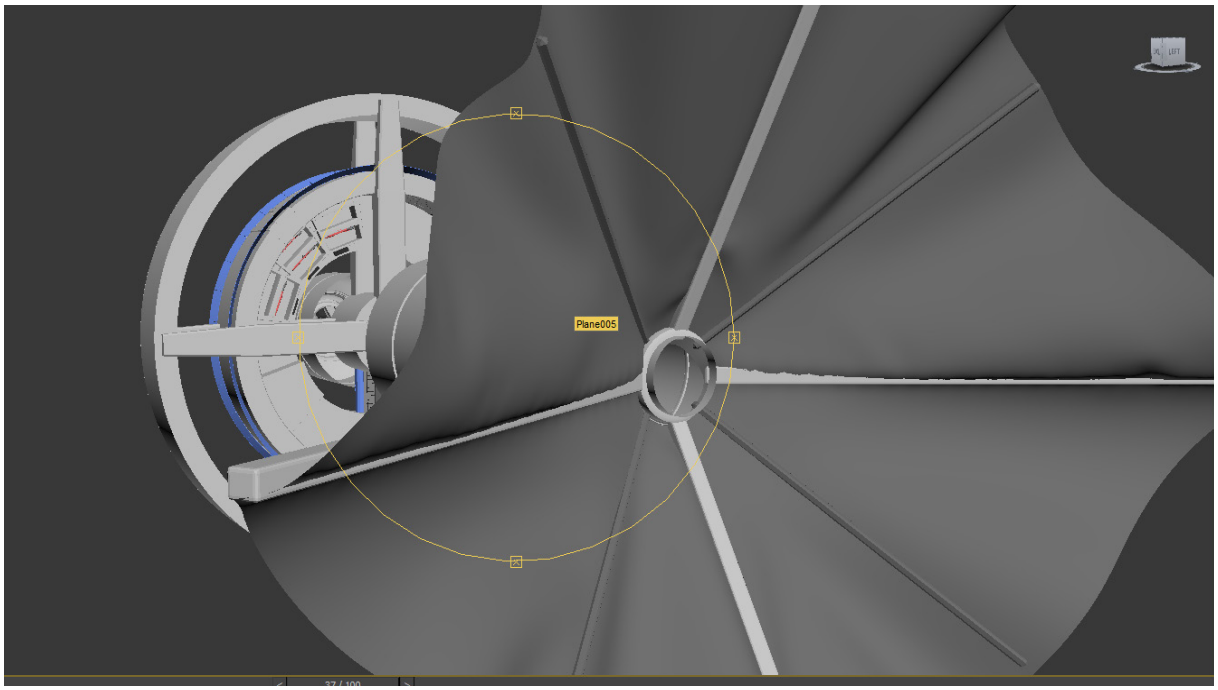


FIGURE – 3. 36 Solar sail arm and catcher for space debris objects, screen capture, by Author, 2012

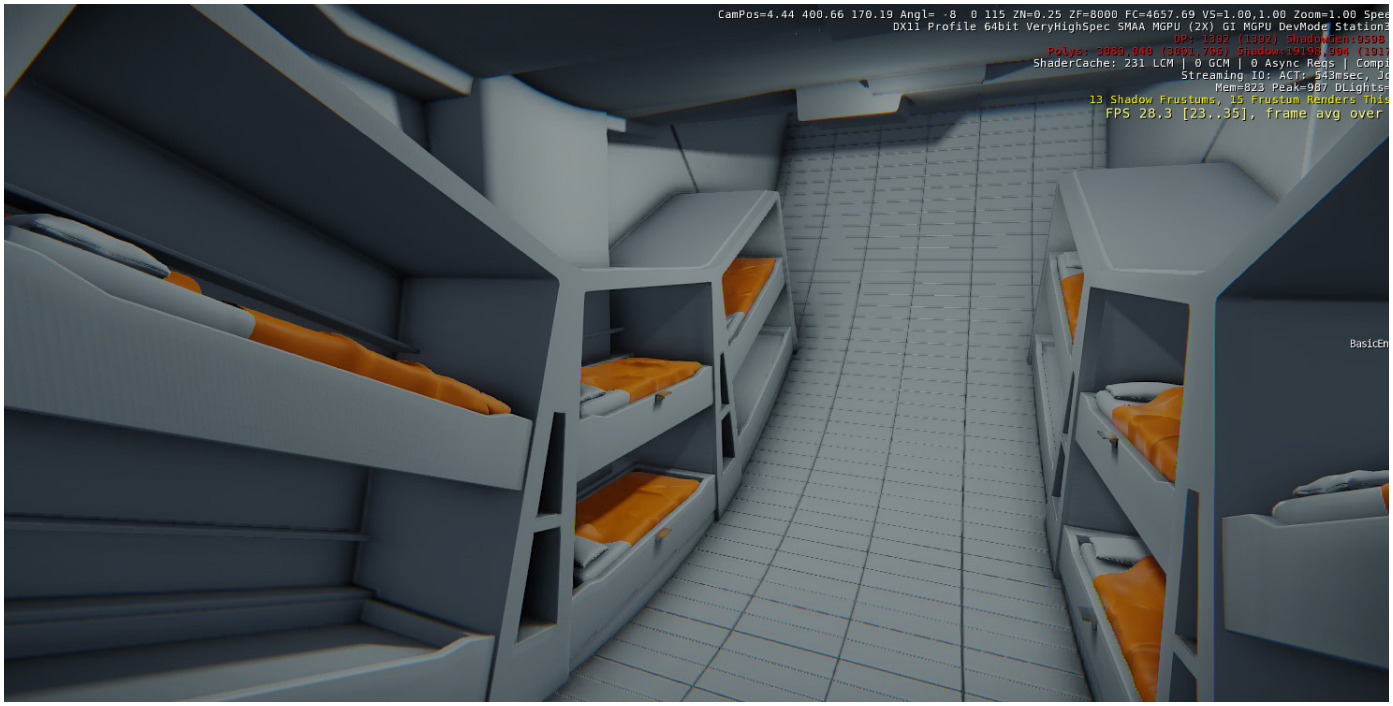


FIGURE – 3. 37 Interior Crew Quarters section of *Satellite*, CryEngine screen capture, Image by Author, 2012



FIGURE – 3. 38 Lower level ring of *Satellite*, CryEngine screen capture, Image by Author, 2012

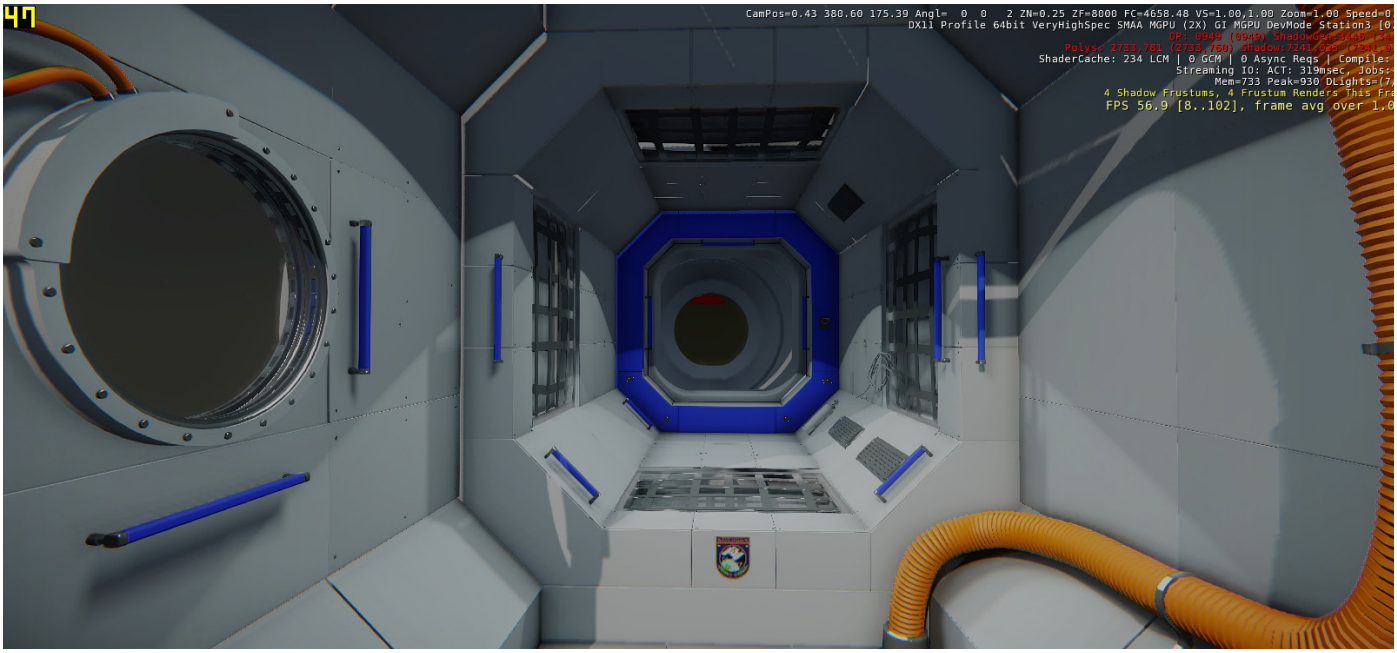


FIGURE – 3. 39 CryEngine Screen capture, main interior corridor of *Satellite*, by Author, 2012

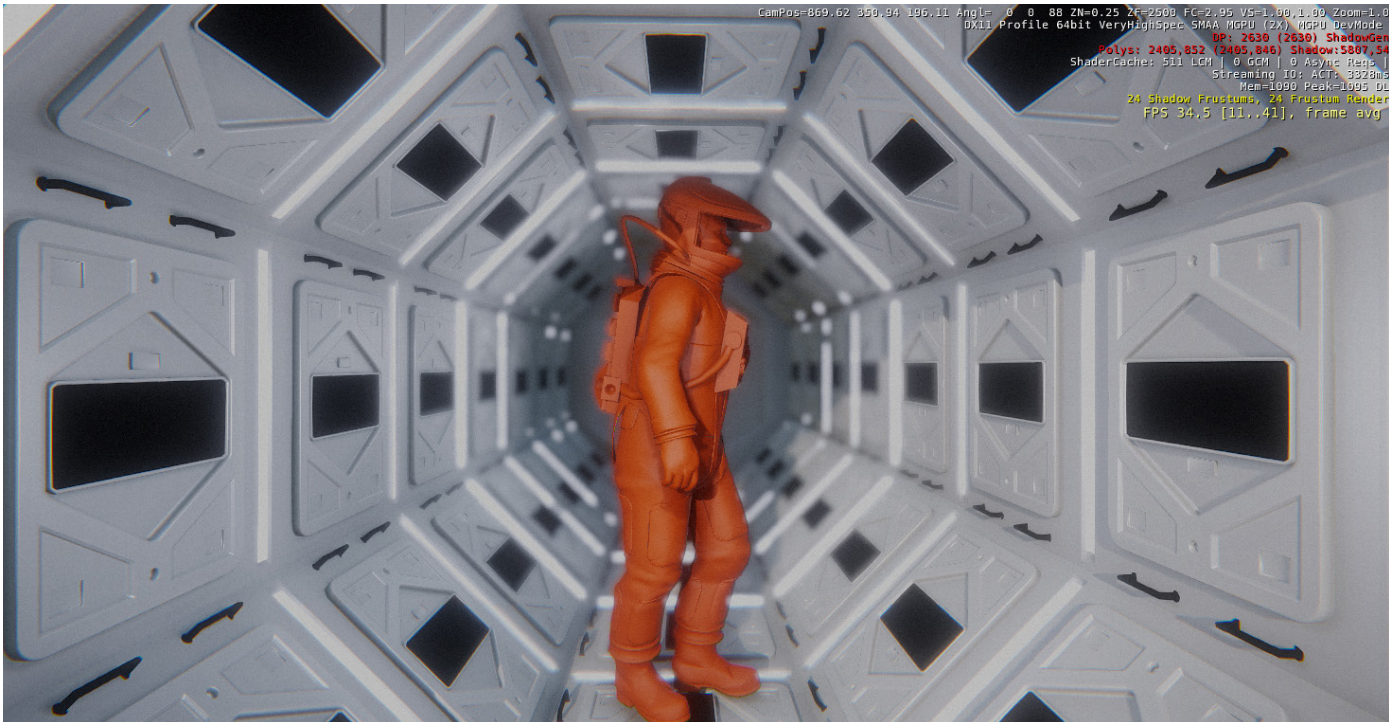


FIGURE – 3. 40 Space debris storage compartment and collection module of *Satellite*, CryEngine screen capture, Image by Author, 2012



FIGURE – 3. 41 Descending by ladder to the outer level of *Satellite*, CryEngine screen capture, Image by Author, 2012



FIGURE – 3. 42 View from interior of the Canopus module looking at the Earth, *Satellite*, CryEngine screen capture, Image by Author, 2012

04 What Might be Built

There is no such thing as a new idea. It is impossible. We simply take a lot of old ideas and put them into a sort of mental kaleidoscope. We give them a turn and they make new and curious combinations.

Mark Twain, Mark Twain's Own Autobiography



Figure – 4. 1 "The dawn of a new era in human spaceflight," photograph, Anne McClain/ NASA, 2019, https://www.nasa.gov/image-article/dawn-of-new-era-human-spaceflight/



This is usually the moment when we start to feel afraid of failing—"I'm doomed" "This project is doomed" "I shouldn't be an architect"...The despair isn't helpful because judgment is the opposite of creation. Everything gets worse because imagination cannot function when judgment is present and we lose the relaxation that is so necessary for creative work...The experience of "letting go" is often the quickest way of learning from obstacles and difficulties... Letting go connects us with the present moment and this kind of attention always brings creativity and wisdom.

Andrew Levitt , *The Inner Studio*, 2007, 151-152

Mission Objective

The primary purpose of Verne Station is to act as a tourism hub between the Earth and the Moon. Its auxiliary objectives are to support scientific research, space mining, and deep-space missions in order to make it economically viable and compatible to modern pursuits. Having this station function with just one of those mission objectives is already an incredible challenge beyond the intent of this thesis. Planning for space is tremendously complex, and any component designed exists conceptually in the realm of hard science fiction. In order to investigate what new spatial forms may occur, one must be willing to leap into a curious, futuristic mind-set. Verne Station's design is ultimately based on constructs from both reality and fiction. It is, at its core, another iteration and exploration of ideas that have persisted throughout history.

Designing for outer space requires established parameters and mission objectives in order to define its success. For the purpose of this thesis, Verne Station's scope will be more conceptually modest and practical in order to align with current technologies and known limitations. The hybrid-gravity simulations presented in the previous chapter visually demonstrate that new spatial designs can occur depending on the scale of centrifugal habitats and gravity vectors. Heavily influential colony designs like the O'Neill Cylinder and Bernal Sphere, which can comfortably house thousands, if not millions, of people are unreasonable to build today. Constructing such a mega structure in space means resources must be mined from other planets and mineral rich asteroids of which no infrastructure exists yet for. Not only that, the need to environmentally reduce the impact of resource drain from the Earth is critical.[1] As such, a more modest, but still ambitious venture would be to develop a permanent station capable of housing 400-500 hundred people with proven modular construction techniques. This population number already far exceeds any current manned space mission and immediately classifies the station as a small resort. This parameter also forces the design to require a large diameter centrifuge to ensure occupants have artificial gravity to mitigate the negative long-term affects of space travel. In fact, several commercial ventures have already put forth modern plans for rotating space stations to be built in the near future. Vast's *Haven-1*

1 Richard D. Johnson, *Space Settlements: A Design Study*, 1977, pg 1-5

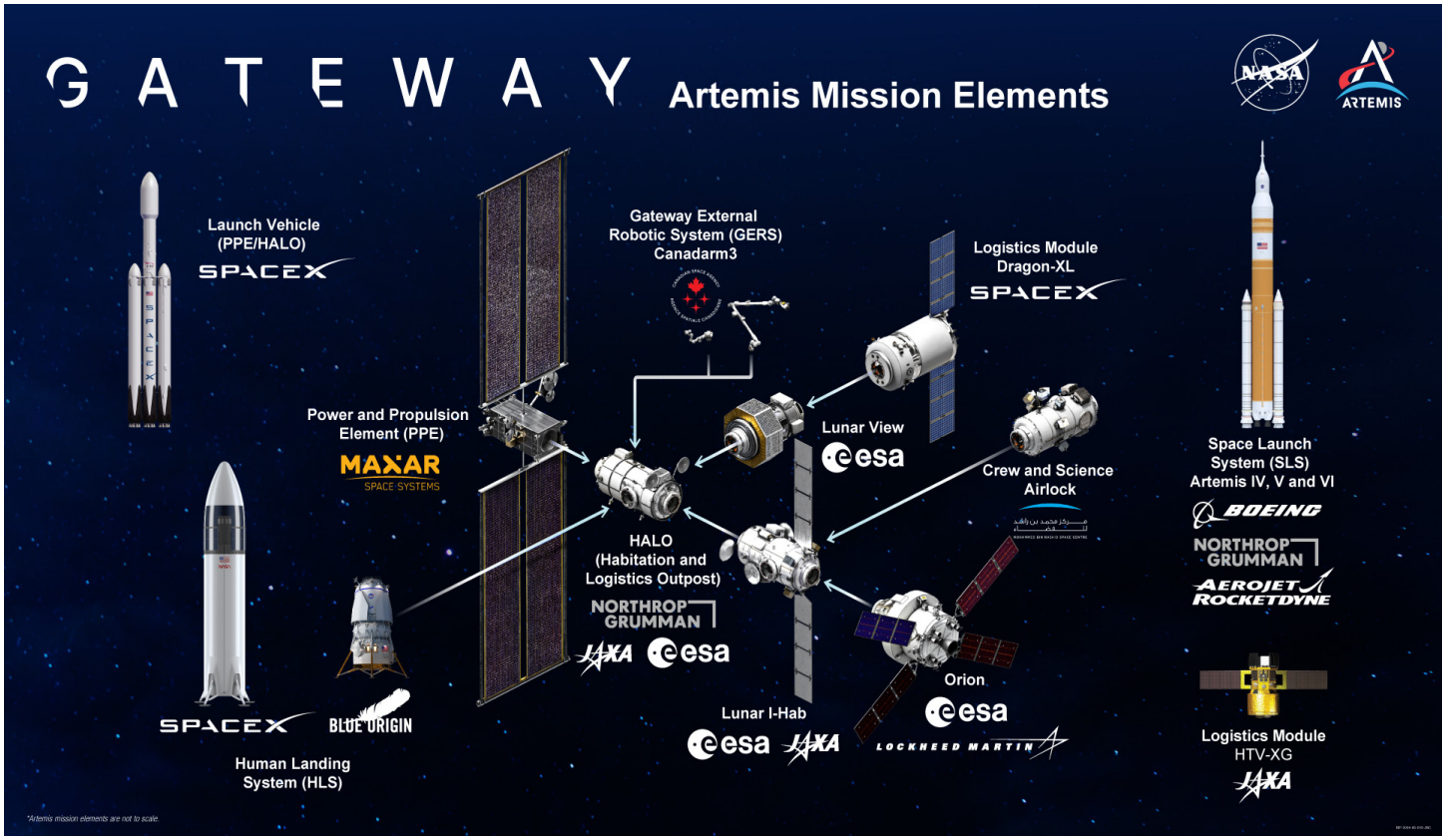


FIGURE – 4. 2 Lunar Gateway Elements, NASA, https://www.nasa.gov/reference/gateway-about/

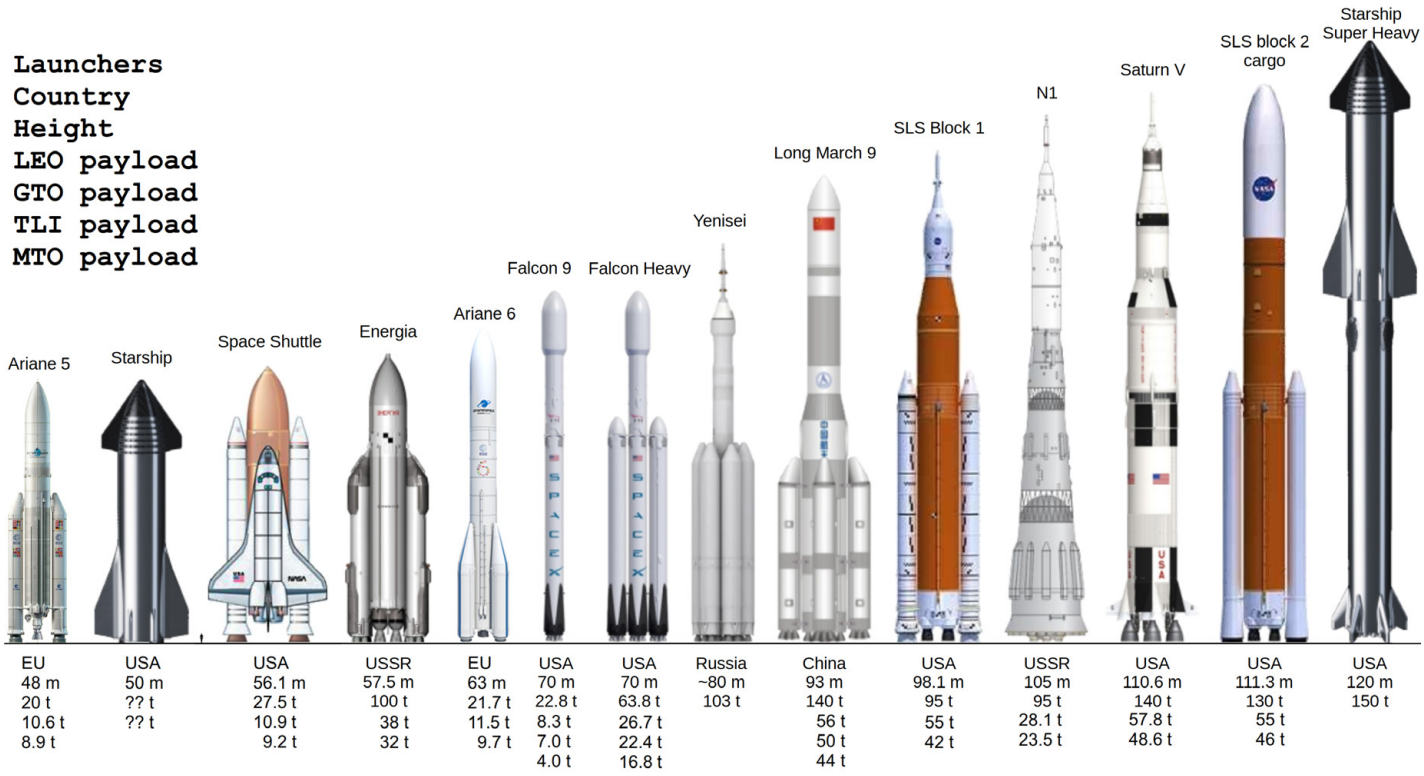


FIGURE – 4. 3 Payload mass to Low Earth Orbit, Geosynchronous Transfer Orbit, Trans Lunar Injection and Mars transfer orbit, 2021, https://commons.wikimedia.org/wiki/File:Space_Launchers.png

space station[2], *Axiom Station*[3], Blue Origin's *Orbital Reef*[4] and *Voyager Space Station*.[5] Whether such designs actually become reality and built in their planned time-frames remains hopeful. As such, the well-known science behind rotational space stations remains theoretical until built.

The Moon is an enticing destination to build a base of operations around as it is the next logical step for future long-term space missions. Sending astronauts to the Moon is within reach of commercial and government space agencies efforts and several missions are already in preparation. By comparison, a trip to Mars, which has an average distance of 140 million miles from Earth, would take around nine months, but up to three years to return due to changing planetary orbits based on our current propulsion technology.[6] While interest in Mars colonization and landing humans on its surface is at all time high, it is still out of reach and brings into question what an economy for tourism versus planetary colonization may be in the distant future.

Living and working in outer space is an incredibly daunting and stressful challenge for astronauts. In the NASA Space Settlements study from 1975, Richard Johnson states "it is the task of the architectural and environmental designer to reduce such stresses by shaping and interrelating structures and surroundings to meet the psychological, social, cultural and esthetic needs of the colony's inhabitants while also satisfying their vital physiological needs."[7] Most current NASA manned space missions are anything short of elegant solutions for occupant comfort. They remain rightfully utilitarian as possible in order to prioritize mission success and safety due to the tremendous cost of sending payloads into space. Crafting meaningful architectural spaces and experiences in outer space will need to be extrapolated on

---

2 VastSpace, *Haven-2 — Vast*, accessed October 24, 2025, https://www.vastspace.com/roadmap.

3 Axiom Space, "Axiom Space — World's First Commercial Space Station," accessed October 24, 2025, https://www.axiomspace.com/.

4 Sierra Space, *Orbital Reef | The New Space Station*, Sierra Space, n.d., accessed October 24, 2025, https://www.sierraspace.com/commercial-space-stations/orbital-reef-space-station/.

5 Above Space, *ABOVE - Providing More Space in Space*, Above, accessed October 24, 2025, https://abovespace.com/the_future.

6 Daisy Dobrijevic, *How Long Does It Take to Get to Mars?*, Space, January 20, 2022, https://www.space.com/24701-how-long-does-it-take-to-get-to-mars.html.

7 Richard D. Johnson, et all, *Space Settlements: A Design Study*, January 1, 1977, https://ntrs.nasa.gov/citations/19770014162, pg 24.

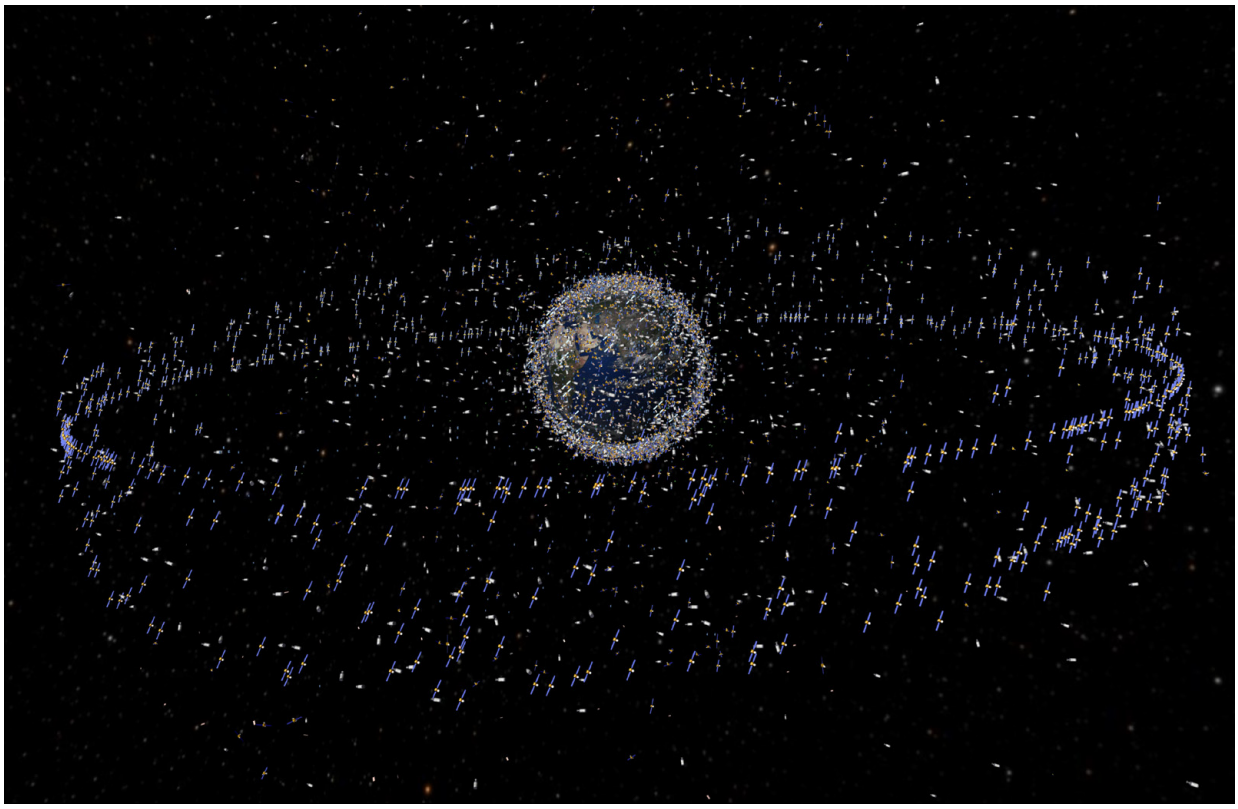


FIGURE – 4. 4 Tracked Satellites in Earth Orbit, 2008, ESA, https://www.esa.int/ESA_Multimedia/Images/2008/03/Trackable_objects_in_orbit_around_Earth

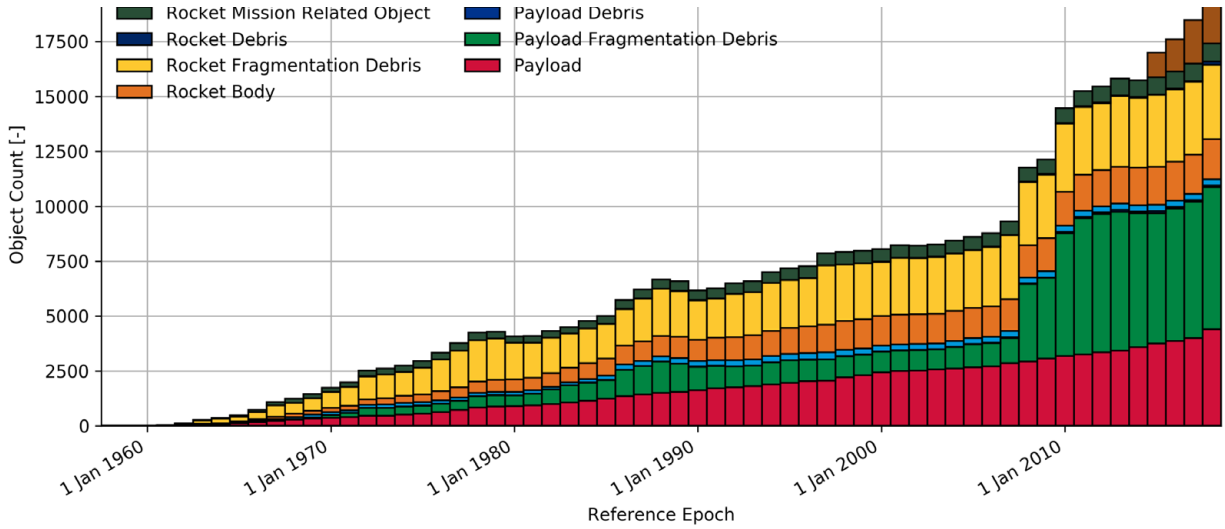


FIGURE – 4. 5 Tracked Satellites Chart, 2017, ESA, https://sdup.esoc.esa.int/discosweb/statistics/

the promising future of re-usable rocket technology. SpaceX's Falcon 9 Heavy and Starship[8], Rocket Lab's Neutron[9] are already proving they can operate at a fraction of the cost of NASA's now retired space shuttle program and are expected to reliably further lower the cost of payloads in the near future as the technology matures. Therefore, Verne Station is proposed for the year 2069 – far enough into the future to acknowledge a maturation of current space technologies and constructs in research, but not too far that the realm of this design component exists in complete fantasy. It is expected that larger payload capabilities, inflatable habitats, robotic automation in construction, and international collaboration efforts will strengthen and mitigate the exorbitant cost feasibility of space habitats.

It important to note that for this thesis, every new data point and construct researched simply magnifies how quickly space exploration discoveries can dynamically shift and constantly morph the design process, and also how slowly progress occurs. Simply put, technological revolution can change everything. Hypothetically, if the technology to make a functional and safe space elevator became a reality today it would become the most efficient way to travel into outer space and most likely render rocket propelled craft obsolete. What is imagined today could completely differ over time. For example, if a revolutionary space propulsion system was invented that could make space travel to Mars days instead of years, would generating gravity to combat physiological dangers still be relevant? The purpose of this design is not to demonstrate a fully engineered solution that will offer the needed protection protocols and safety in outer space. It is to explore and touch upon the idea that unknown possibilities of space are yet to be fully known. By using accessible and realistic game-engine tools to generate simulations, we can be better prepared for the architectural experience of how space-station habitats with hybrid gravity could function. Understanding these spatial changes and forces in response to human comfort and occupancy may be key to successful future space architecture designs and even to terrestrial applications. SpaceArchitect.org chair from 2010-2014, Theodore W. Hall remarks "Space architecture is not for the technically timid. To play this game, one needs to educate oneself about the harsh realities of life beyond Earth, and the science and technology for

8 John Uri, *5 Years Ago: First Flight of the Falcon Heavy Rocket*, NASA, 2023, https://www.nasa.gov/history/5-years-ago-first-flight-of-the-falcon-heavy-rocket/.

9 Rocket Lab, *Rocket Lab:The Space Company*, accessed October 24, 2025, https://rocketlabcorp.com/home/.

fashioning habitable bubbles in deadly environments."[10] Simulating in the safety of virtual and analog environments is not only a proven way of testing various experimental design choices, it is the most economical way to iterate and experiment different scenarios.

Almost everything we know about outer space and the universe today is built on a collective of research and innovation. Anything built for space requires years of planning and numerous specialized industries to make it viable. The International Space Station is a testament to the decades of research failures and successes of worldwide national space programs. The problem of designing for space in such extreme and unique environment conditions is that a multitude of new problems and questions arise in the pursuit of creative solutions.

> Architecture responds to specific differences in environmental characteristics such as temperature, access to resources, topography, and geological formation. When we cross the atmospheric limit, we access a virtually infinite number of unforeseen combinations of environmental characteristics with extremely low compatibility with human life. To design for space, we need to start with defining the goal of our travel because a short explorative trip or a self-sustainable surface colony requires very different design approaches.[11]

Sound design principles that work for us on Earth may no longer be viable in space. Almost everything regarding space requires a new rationale and research to account for specific conditions.

> A slightly different gravity level forces space architects to rethink those elements to fit the new conditions. The moon's gravity, which is around one-sixth of the earth's, may make it impractical to use the same ratio of tread to the riser in stairs as it is on Earth. Those conditions can pose serious design constraints but also open new capabilities.[12]

This also means that new spatial developments can be freed from traditional terrestrial norms. Micro-gravity alone allows us to float and move freely in six axis directions and forces one to re-orient the

---

10 SpaceArchitect.org, *How to Become A Space Architect*, February 28, 2021, https://spacearchitect.org/how-to-become-a-space-architect/.

11 Vittorio Netti and Olga Bannova, *Space Architecture: Designing Beyond the Sky V,* 2021, p 76–91.

12 Ibid

cardinal axis of up and down. The role of the space architect is to extrapolate based on theoretical environmental factors, and existing knowledge of current space architecture installations. This leads one to a very open-ended question: what will Lunar and Martian architecture be like in 50 years, 100 years or more?

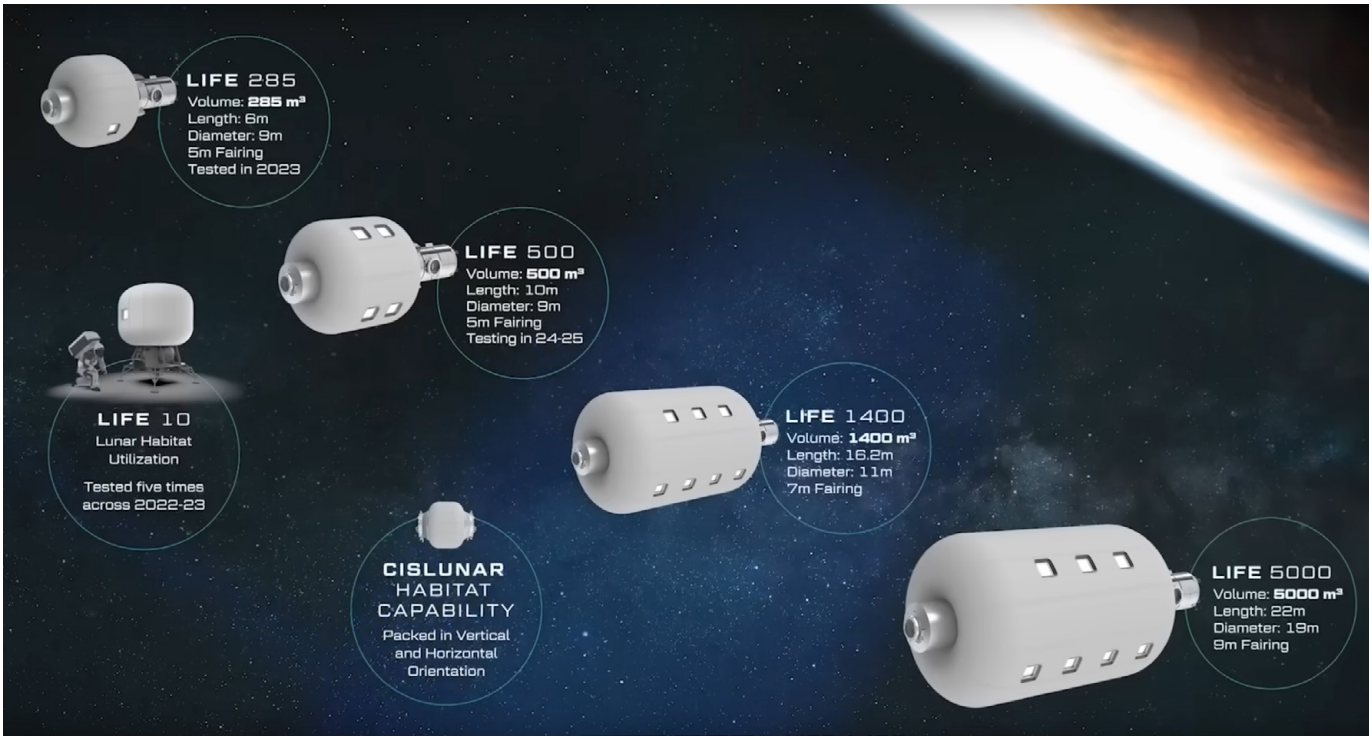


FIGURE – 4. 6 LIFE module roadmap, Sierra Space Corporation. 2025, https://www.sierraspace.com/commercial-space-stations/life-space-habitat/



FIGURE – 4. 7 Inflated LIFE module prototype, Sierra Space Corporation, 2023. https://www.sierraspace.com/press-releases/sierra-space-sets-the-stage-for-pioneering-full-scale-burst-test-of-expandable-space-station-module/

Modular Construction

Much like the ISS, as well as the future Lunar Gateway, building in space currently requires a phased modular approach for large structures. The distance from the Earth to the L2 Lagrange point is around 1,500,000 kilometers.[13] The distance from the Earth to the Moon is 384,400 kilometers. Quite simply, the use of Lagrange points, though they provided stable points in space, are not useful for this particular station in it's initial phases. Even though near-rectilinear halo orbit is the intended destination, operations will have to be completed closer to Low Earth Orbit. If the station were to be designed as a massive permanent colony, the Lagrange L5 location would offer better stability and fewer resources to maintain it's bearing. Using the International Space Station and Lunar Gateway Station as case studies of how architecture in space is built and phased, it can be roughly estimated the length of time, energy and launches needed to construct a large scale space station. Once core components of the space station is formed, its programming and capability can be further expanded. Adding the wealth of research available from government agencies is also crucial to the design and operation of Verne Station. It is expected that every module needed to form such a station would involve several agencies, specialized companies and vast resources to realize.

Including the time to launch and assemble, Verne Station could take several years to a decade to build. For reference, it took 13 years for the ISS main construction to be completed (1998-2011) using the space shuttle program. Many of the pieces were painstakingly assembled in space by astronauts on EVA walks, robotic arms and continuous systems monitoring by ground control crews. For comparison the newer, but smaller Tiangong space station was constructed in a much more streamlined manner in just a couple years from 2021-2022.[14] In the distant future, it is expected

13 Keith Cooper, *Lagrange Points: Parking Places in Space*, Space, August 22, 2017, https://www.space.com/30302-lagrange-points.html.

14 Andrew Jones, *China Completes T-Shaped Tiangong Space Station with New Mengtian Module Move*, Space, November 5, 2022, https://www.space.com/china-completes-tiangong-space-station.

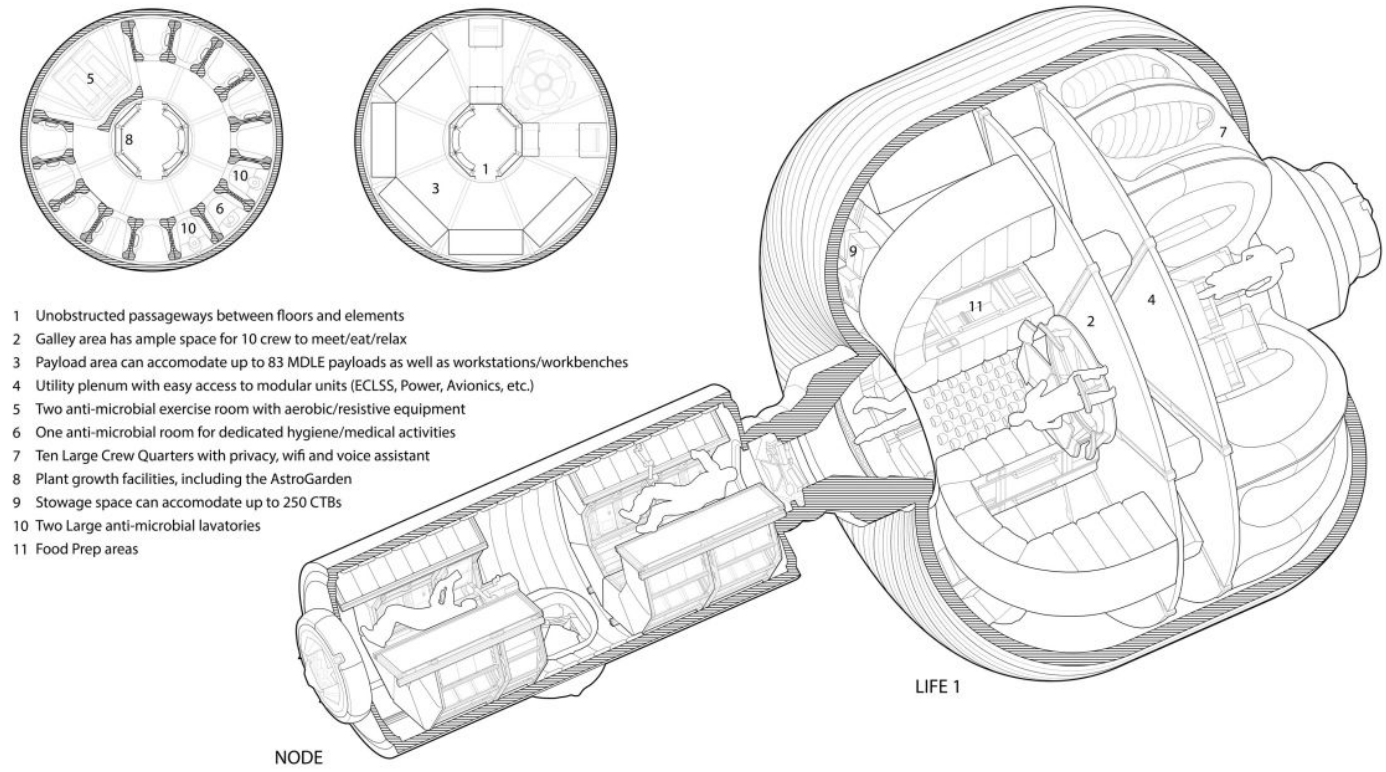


Figure – 4. 8 Habitat diagram LIFE 1 module of Orbital Reef, Hassell Architects, 2023. https://www.hassellstudio.com/project/orbital-reef-space-station



Figure – 4. 9 Interior render of LIFE module for Orbital Reef, Hassell Architects, 2023. https://www.hassellstudio.com/project/orbital-reef-space-station

that more robotic automation and teleoperated robotic free-flyer programs[15] could help alleviate construction and assembly times while reducing human risk.

Advances have occurred considerably the last few years for space-faring inflatable structures. Sierra Space's LIFE (Large Integrated Flexible Environment) module, fabricated from high-strength webbings and multi-layer fabric, shows tremendous promise.[16] In 2024, at the NASA Marshall Space Flight Center in a burst pressure test, the structure exceeded NASA's recommended four times the normal safety levels by 27% with a final rating of 75 PSI.[17] This advancement of inflatable technology compared to the smaller BEAM (Bigelow Expandable Activity Module) installed on the ISS, shows significance for human habitats (Figure – 4. 8). The cramped and constricted corridors that exist on current space craft can now be imagined with larger volumes and capacity (Figure – 4. 9). Extrapolating the LIFE 5000 habitat module that is designed for a 9 metre payload fairing, offers roughly five times the volume of the International Space Station in just one launch. This means that it will take considerably fewer launches to construct a large diameter spacecraft, making it a viable technology for Verne Station.

15 Vittorio Netti, *Design of an Autonomous and Teleoperated Modular Robotic Free-Flyer for EVA Operations*, paper presented at ASCEND 2020, Virtual Event, ASCEND 2020, American Institute of Aeronautics and Astronautics, November 16, 2020, https://doi.org/10.2514/6.2020-4257.

16 Vittorio Netti, *Life 1 | Sierra Space Commercial Space Station*, accessed May 26, 2025, https://www.vittorionetti.com/projects/life-1-sierra-space-commercial-space-station.

17 Shay Saldana, *Sierra Space Advances Its Revolutionary Commercial Space Station Technology*, Sierra Space, January 22, 2024, https://www.sierraspace.com/press-releases/sierra-space-advances-its-revolutionary-commercial-space-station-technology/.

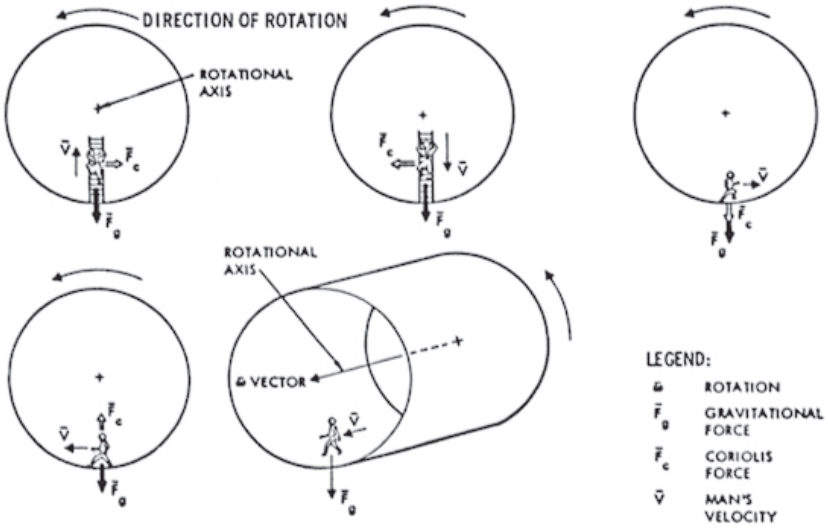


FIGURE – 4. 10 Artificial gravity and tangential velocity forces, Peter H. Diamandis, https://ssi.org/programs/ssi-g-lab-project/artificial-gravity-peter-diamandis-1987/

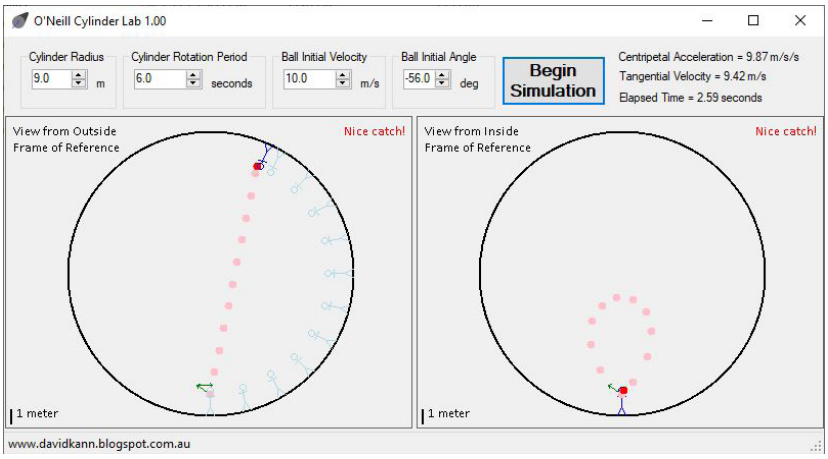


FIGURE – 4. 11 Passing a ball to yourself in an O'Neill Cylinder, Screen capture, David Kann, http://www.davidkann.blogspot.com.au

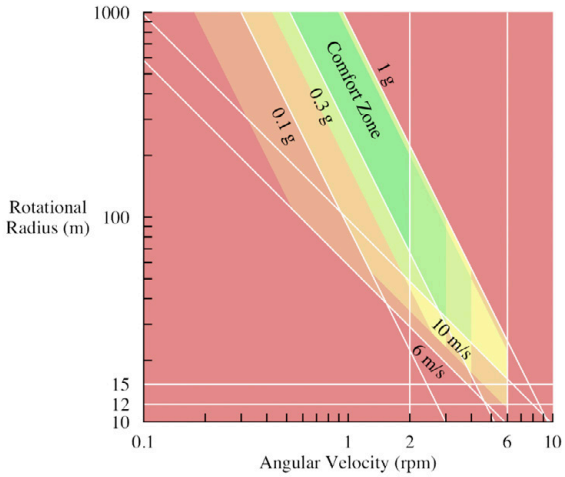


FIGURE – 4. 12 Comfort range chart for artificial gravity. Figure in Hall, Theodore W. "Artifical Gravity in Theory and Practice." http://www.artifical-gravity.com/sw/SpinCalc/SpinCal.htm#comfort

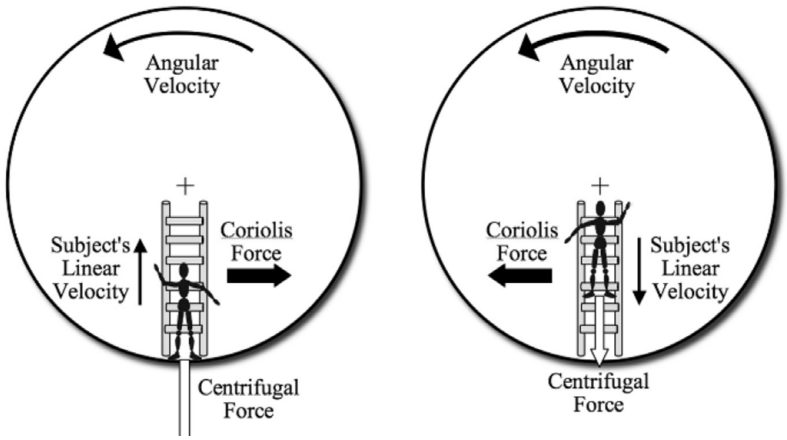


FIGURE – 4. 13 Coriolis and centrifugal forces exerted on a passenger climbing a ladder up (left) or down (right) in a rotating environment., Figure by Gilles Clément and Angie Bukley, eds., *Artificial Gravity,* The Space Technology Library 20 (Springer New York, 2007), p 44

Artificial Gravity

The human body reacts negatively in microgravity, including alterations to muscles, bones, cardiovascular system and the eyes. Many scientific investigations are trying to characterize how severe and permanent the changes are to the body, and whether they can be reversed. For any long-term space mission, astronauts are forced to exercise for at least two hours per day with specialized zero-g fitness equipment. However, even with rigorous preventative exercise, astronauts still return to Earth weaker than when they left, proving that exercise alone has not prevented muscle loss during spaceflight.[18] The ideal microgravity exercise program, remains to be defined. For space tourists, it is expected that they will not wish to undergo the same level of rigorous training required of astronauts. Even more concerning is that most passengers will need to be fully screened beforehand to determine whether they are sufficiently healthy—both mentally and physically—to endure space travel. Implementing artificial gravity would address these issues and allow for passengers to mitigate the negative effects of weightlessness.

Featured prominently in numerous science fiction works, most notably by Arthur C. Clarke in *2001 A Space Odyssey*, the idea of a rotating space station is nothing new and has been constantly referenced as a solution for generating gravity by scientists well before space flight was achieved. To live in space, our bodies need to respond to an environment similar to that of the Earth, and as such gravity is a vital component to reduce long term damage to the human body. The only real world space test was the Gemini 11 mission, where the ship was tethered to a 36 meter cable to simulate rotational gravity to 0.0001g.[19] The quirks surrounding artificial gravity can vary user experiences greatly. The Earth's diameter is large and its spin-rate is slow enough that it makes the Coriolis effect negligible to our perception. In rotational spacecraft, spin-rate and diameter play a crucial factor in determining the g-forces that can impact an astronaut's body. For short diameter spins to achieve 1g of gravity on a person's center of mass, the upper body will experience a fraction of that, while the lower body will experience gravity greater than that of Earth. Coupled with an increased Coriolis effect, the angular velocity and momentum can induce severe disorientation, discomfort, and nausea as one moves within the rotating environment. Perception is also impacted as a simple act of throwing a ball would behave

18 Gilles Clément, et al, eds., *Artificial Gravity*, The Space Technology Library, 30

19 Clément, Gilles; Bukley, Angie, eds. *Artificial Gravity. Space Technology Library,* 2007

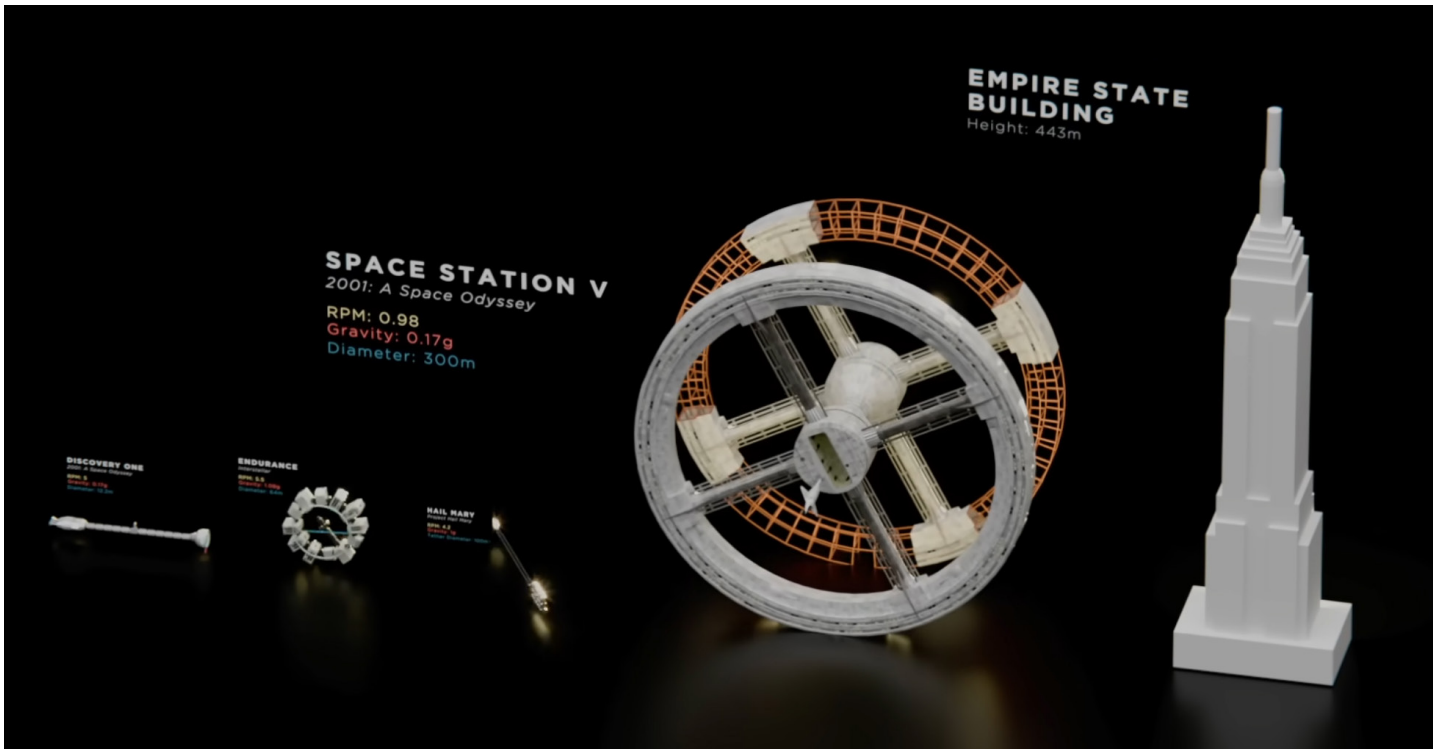


FIGURE – 4. 14 *Spin Gravity Compared*, directed by The Overview Effekt, 2024, 12:11, https://www.youtube.com/watch?v=C41gKfiihiM.

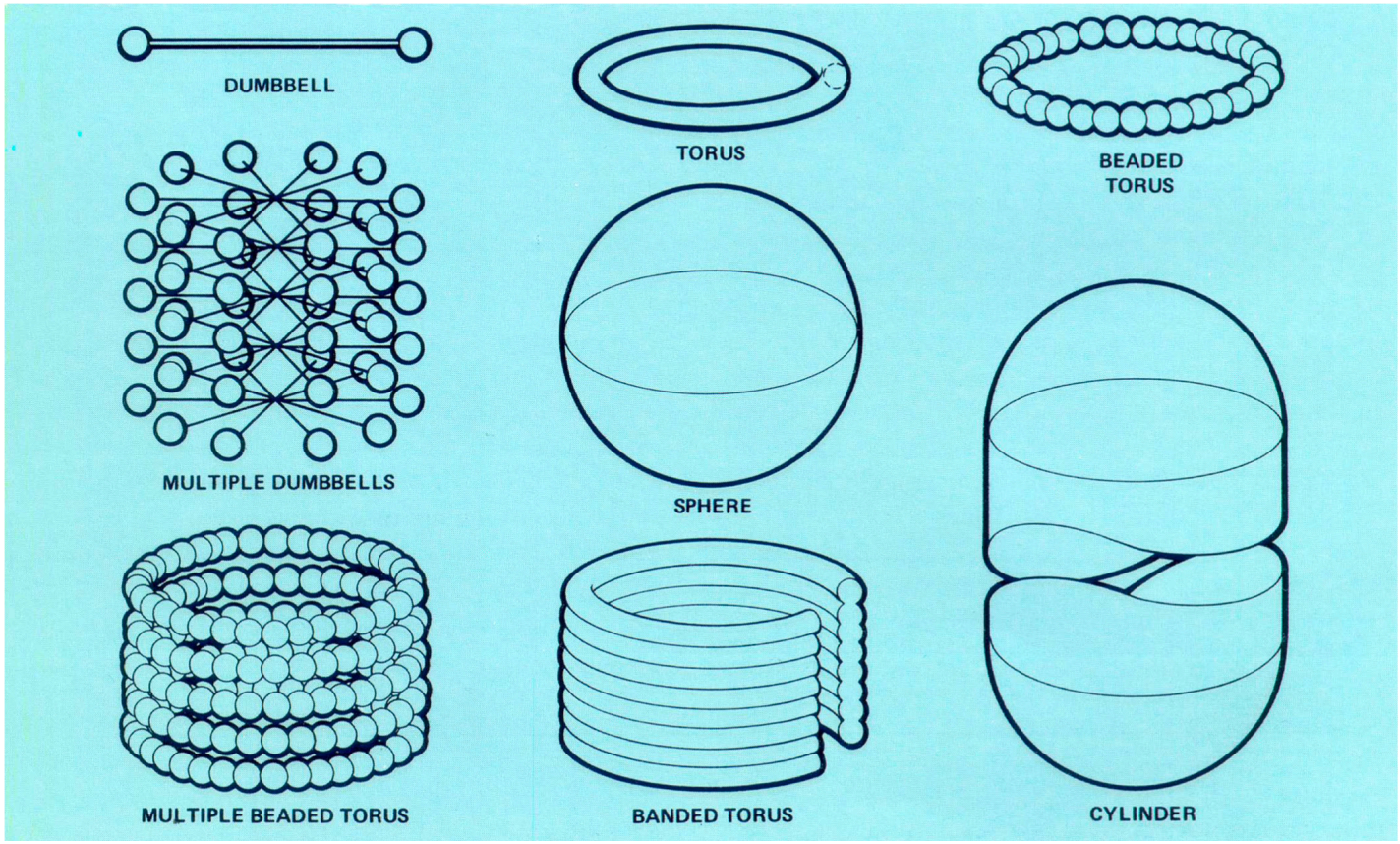


FIGURE – 4. 15 Basic and composite shapes of artificial gravity forms as identified in *Space Settlements: A Design Study*, NASA, 1977

very differently than expected as best illustrated below using a software program developed by David Kann[20] (Figure – 4. 11). The smaller the radius and greater the speed, the more adverse the ball trajectory behaves. With a larger radius and slower rotation speed, the ball has less severe trajectory drops. Using this data, the station design must have a diameter comfortable for its occupants and visitors. The following chart, (Figure – 4. 12) the green zone demonstrates the acceptable theorized range for human comfort in artificial gravity. The angular velocity of ideally 2 rpm and the diameter of 250 meters would minimize the negative effects of Coriolis. The 1975 Space Settlements study by NASA, provides insight into the creation and data of a feasible self-sustaining large scale space colony. It suggests five kilometers for ideal gravity generation and space needs within the proposed space colony, to feel open and less restrictive.[21] The smaller scale can be a disadvantage to human psychology as Johnson states:

> In a habitat rotating at several rpm, there can be disconcerting effects. Simple movements become complex and the eyes play tricks: turning the head can make stationary objects appear to gyrate and continue to move once the head has stopped turning. This is because Coriolis forces not only influence locomotion but also create cross-coupled angular accelerations in the semicircular canals of the ear when the head is turned out of the plane of rotation. Consequently motion sickness can result even at low rotation rates although people can eventually adapt to rates below 3 rpm after prolonged exposure.[22]

This means that building a more economically reasonable space station is reliant on human tolerance to the increased negative effect of Coriolis. The need for artificial gravity also inherently restricts the geometric shape of the station to a limited number of forms[23] of basic and composite shapes shown in (Figure – 4. 15).

---

20 https://davidkann.blogspot.com/2014/06/oneill-cylinder-simulator-projectile.html

21 Richard D. Johnson and Charles Holbrow, "*Space Settlements: A Design Study,*" January 1, 1977, https://ntrs.nasa.gov/citations/19770014162. p 41

22 Ibid, p 26

23 Ibid, p 40

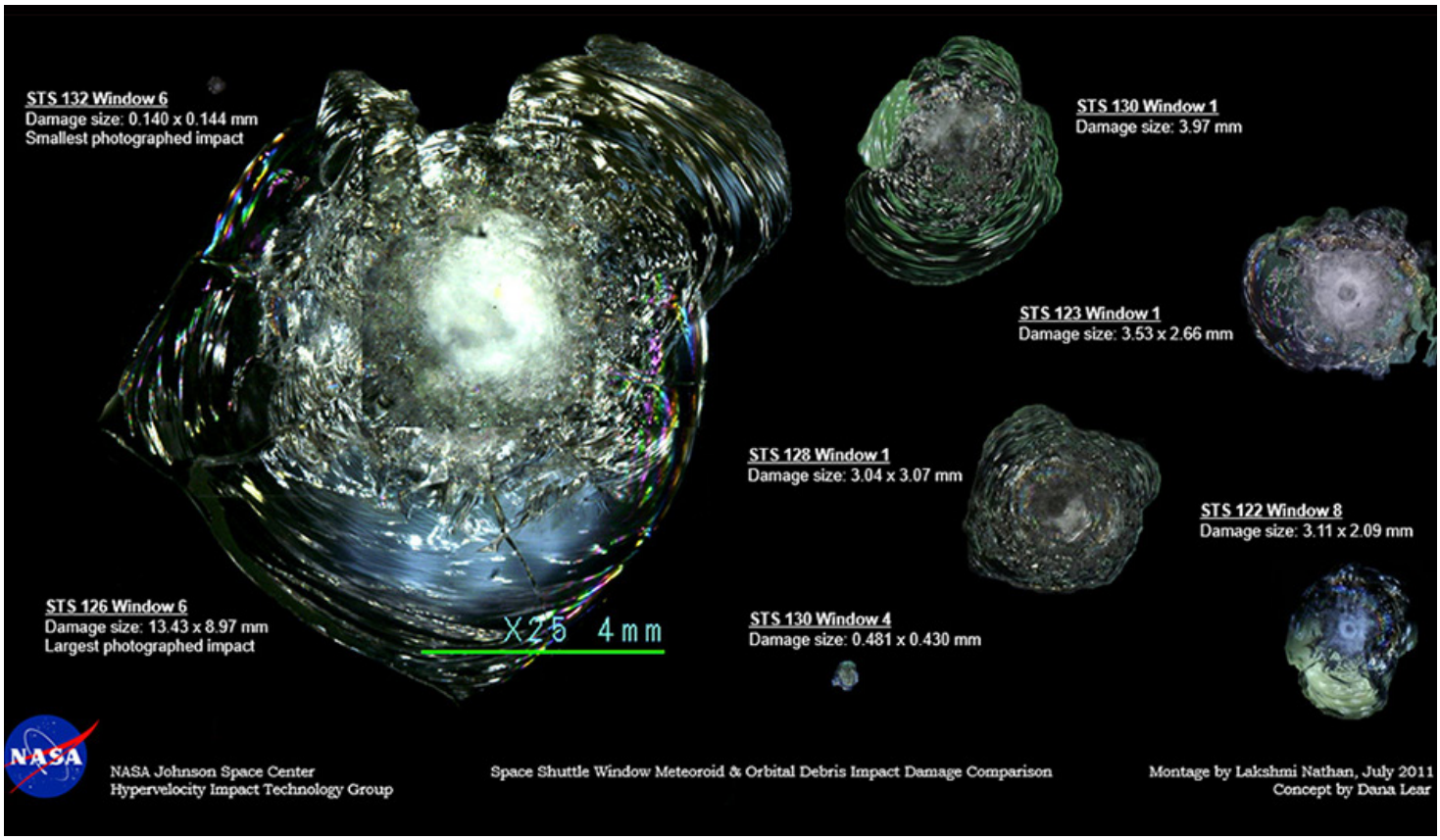


FIGURE – 4. 16 Impact damage to spacecraft windows from meteoroids and orbital debris, "ARES | HyperVelocity Impact Technology | Impact Images | Space Shuttle," accessed October 6, 2025, https://hvit.jsc.nasa.gov/impact-images/space-shuttle.cfm.

Failure Points

The construction and maintenance of space crafts is a large challenge to any operation. Machines break down and fail, and when they do, the end results can be catastrophic. Many astronauts have lost their lives in the pursuit of reaching outer space. The Mercury 1 pilots all succumbed to a grim fate of being burned alive in their module because the oxygen tank ruptured. Others, such as the *Challenger* Space Shuttle exploded shortly after liftoff in 1986 due to O-Ring failures.[24] The numerous incidents that have occurred throughout the history of spaceflight, even with safety as an utmost priority, prove that there is no safety guarantee, just mitigation. It was truly an amazing feat that we were able to land safely on the moon almost sixty years ago. The reliance on a sound life support system as well a proper mechanically working sub-systems with redundancies have become the utmost importance for manned missions and essentially balloons budgets to accommodate safety measures.

For Verne Station, the very scale and constant traffic of both crew and tourists poses a significant risk to operational safety. Any small system failure could potentially cripple the station and lead to passenger injury or death. Emergency pods and shuttles will need to be accessible in the event of an emergency, which further adds to the design scope. Habitats and systems would need redundancy and backup systems in the event of system failure. There is an enormous and complex list of unforeseen challenges, risks and hurdles to face. Construction delays, political issues, funding challenges and human error are just a few examples of things that could jeopardize the space missions. Yet despite the danger, there are still volunteers willing to go the extra few thousand miles to endure an extreme expedition with no hope of return. The now rightfully dissolved Mars One firm that planned to land colonists on Mars by 2023, ended up selecting 100 volunteers from over 200,000 applications.[25] This spirit of adventure has been evident throughout human history. The famous Shackleton expedition,

24 NASA Communications, "The Crew of the Space Shuttle Challenger STS-51L Mission," *NASA Science*, February 3, 2003, https://www.nasa.gov/history/the-crew-of-the-space-shuttle-challenger-sts-51l-mission/.

25 Jonathan O'Callaghan, "Goodbye Mars One, The Fake Mission To Mars That Fooled The World," *Forbes*, accessed October 23, 2025, https://www.forbes.com/sites/jonathanocallaghan/2019/02/11/goodbye-mars-one-the-fake-mission-to-mars-that-fooled-the-world/.

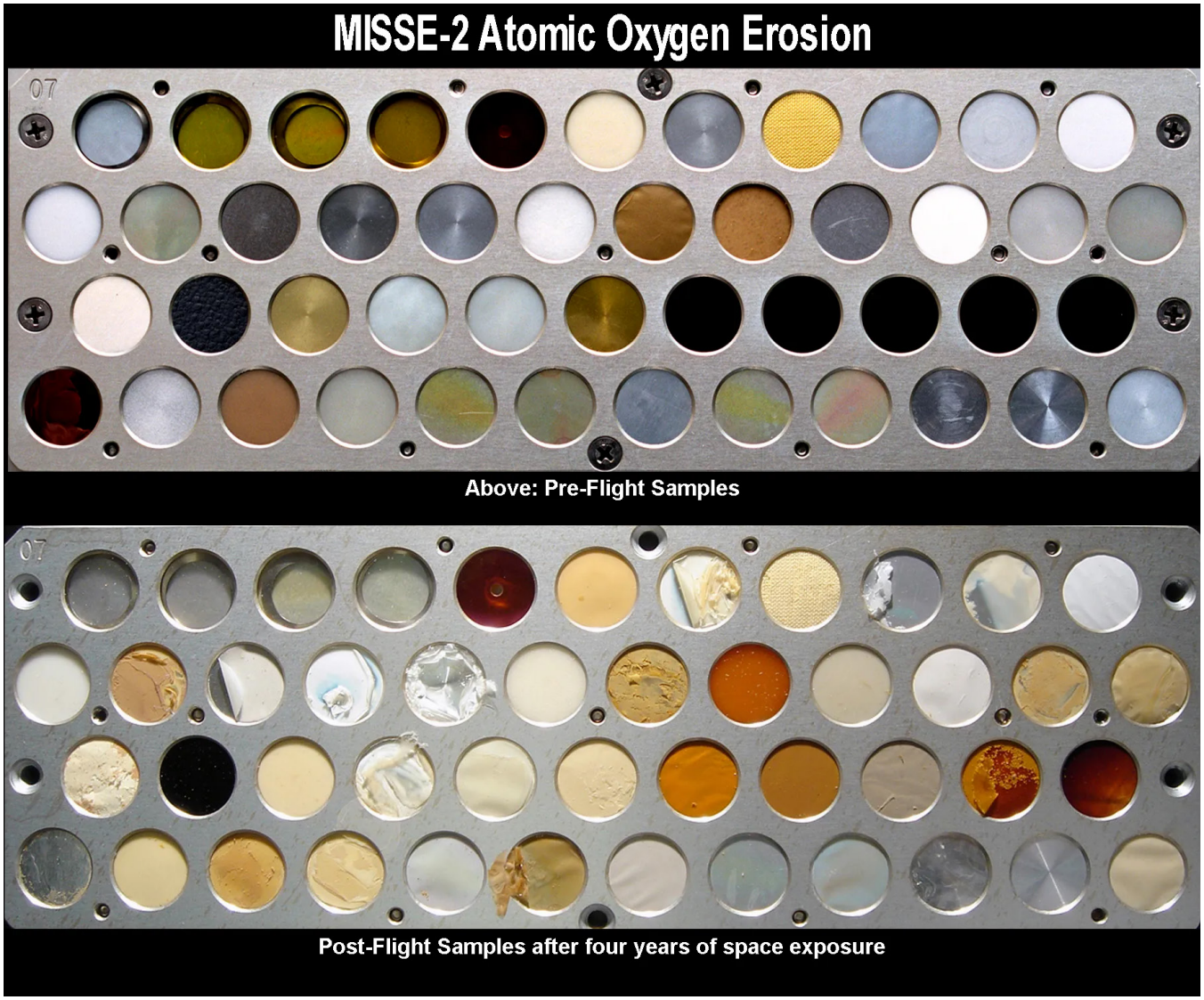


FIGURE – 4. 17 MISSE 2 Atomic oxygen erosion samples, NASA, https://www.nasa.gov/materials-international-space-station-experiment-x-misse-x/

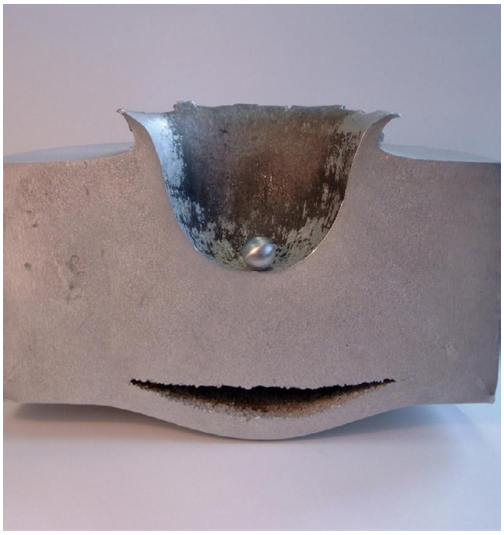


FIGURE – 4. 18 Hypervelocity Impact, NASA, https://www.esa.int/Space_Safety/Space_Debris/Hypervelocity_impacts_and_protecting_spacecraft

known formerly as the Imperial Trans-Antarctic Expedition (1914–1917), where the ship's crew were stranded and trapped in ice, found a way to navigate the unknown icy landscape to beat the odds and all survive.[26] What the stranded crew had to endure and face was unprecedented. Space travel is ultimately the pursuit of the unknown and unexplored, driven by curiosity and determination.

Every piece of machinery and technical system designed for outer space takes thousands of hours of planning, resources, testing and certification to ensure the risk for failure is immensely mitigated. The tight engineering tolerances required are mission critical and must be scrutinized well in advance in order to green-light human use. Adding the required rotational section to Verne Station to generate artificial gravity incredibly increases the engineering complexity and challenge. Having a portion rotate, instead of the entire ship, poses immense stability challenges. Sustained rotational spin loads and stresses on the craft's structural components need to be accounted for. Having the entire space station spin would offer a far more efficient engineering threshold than multiple moving parts. In addition, in order to maintain course correction and object avoidance, being able to move and adjust position to the craft also requires substantial energy and power. The ISS in orbit performs several maneuvering techniques to avoid micro-meteorites and space debris, as well as to maintain its orbit.[27] And with the number of active satellites growing from roughly 1,000 in 2014 to about 10,000 in 2024, this figure is expected to grow to several tens of thousands in the next decade.[28] Having the station travel to Near-Rectilinear Halo Orbit (NRHO) would allow for safe operation by the Moon, which is a more valuable point of interest. With Verne Station far from the increasing space debris presence in Earth's orbit, the chance of a fatal space debris collision if a Kessler Syndrome event were to occur is drastically lowered.

Beyond the risk of space debris interference, material fatigue in outer space is another important factor. Selecting proper material components is crucial to lengthen the lifespan and safety of the

---

26 Alfred Lansing, *Endurance: Shackleton's Incredible Voyage* (Basic Books, 2015).

27 NASA Science, "Station Maneuvers to Avoid Orbital Debris - NASA," Expedition 73, *NASA Science*, April 30, 2025, https://www.nasa.gov/blogs/spacestation/2025/04/30/station-maneuvers-to-avoid-orbital-debris/.

28 *Space | Stanford Emerging Technology Review*, accessed July 25, 2025, https://setr.stanford.edu/technology/space/2025.

spacecraft. Most materials exposed in space, and specifically in LOE (Low Earth Orbit) wear and degrade. Material samples on the ISS that have been exposed over the course of four years, show significant changes and deterioration due to atomic oxygen, ultraviolet radiation, and extreme temperature cycling.[29] (Figure – 4. 17) For the ISS, which primarily uses space-grade aluminum and titanium alloys, the material stresses and cracks reported over the years raise questions about how long objects in space can truly endure. Because of the inherent hazards of outer space, the station will require constant maintenance and automated computer monitoring to ensure continued operation. After almost thirty years in orbit, the deterioration of the ISS has increased over the years, such that it must be decommissioned and destroyed in a controlled re-entry to Earth.[30] If the expected lifespan for a permanent station only lasts for a few decades, then Verne Station, regardless of how well designed or proposed it could be, will eventually become derelict and unfit for human occupation faster than anticipated. Future advances in material science and spacecraft durability will be necessary for more stable and permanent structures in space to exist.

29 *Materials International Space Station Experiment-X (MISSE-X)* - NASA, Technology Demonstration Missions Program, n.d., 190, accessed August 8, 2025, https://www.nasa.gov/materials-international-space-station-experiment-x-misse-x/.

30 Corey S. Powell, *The ISS Was Never Supposed to End like This*, NBC News, February 22, 2018, https://www.nbcnews.com/mach/science/iss-was-never-supposed-end-ncna848771.

Life Support Systems

The general life support systems of the station must supply practically everything within a near closed looped system to keep occupants on board safe. (Figure – 4. 19) The necessary breathable atmosphere conditions of 14 kPa need to be maintained, filtered and recycled to conserve resources. The reliance of machinery brought into space working as intended is paramount to keeping astronauts alive.

> International Space Station uses an absorption method to remove carbon dioxide (CO_2) from the air. The absorption is accomplished in a chemical reaction using a sorbent called lithium hydroxide (LiOH). This method relies on the exothermic reaction of lithium hydroxide with carbon dioxide to create lithium carbonate ($Li2CO_3$)(s) and water (H_2O). Lithium hydroxide is an attractive choice for space flight because of its high absorption capacity for carbon dioxide and the small amount of heat produced by the reaction.[31]

Water, storage, oxygen, CO_2 scrubbers to filter air, power; in short, an incredible amount of systems and building science are required to keep astronauts safe. For Verne Station, redundancy will play a crucial factor to maintain station safety and operations. By design, every node will need to have backup systems and additional parts in the case of primary function failure. The best way to achieve this is to outfit each modular component with its own life support filtration system regardless of cost. Depending on the size of the volume, backup systems can be installed. On the ISS, and the now decommissioned Space Shuttle, the Environmental Control and Life Support system (ECLSS) operates three components: Water Recovery System, the Air Revitalization System and the Oxygen Generation System (Figure – 4. 19). In short, the necessity to plan for and accommodate failure of primary systems with robust and redundant systems is the key to maintaining large scale operations in a space station. It is hypothesized that in some near future, a fully closed system would become

31 *The Air Up There Making Space Breathable*, NASA Jet Propulsion Laboratory (JPL), accessed August 3, 2025, https://www.jpl.nasa.gov/edu/resources/lesson-plan/the-air-up-there-making-space-breathable/.

reality.[32] This could ensure self-sufficiency in space and allow for settlements to be establish.

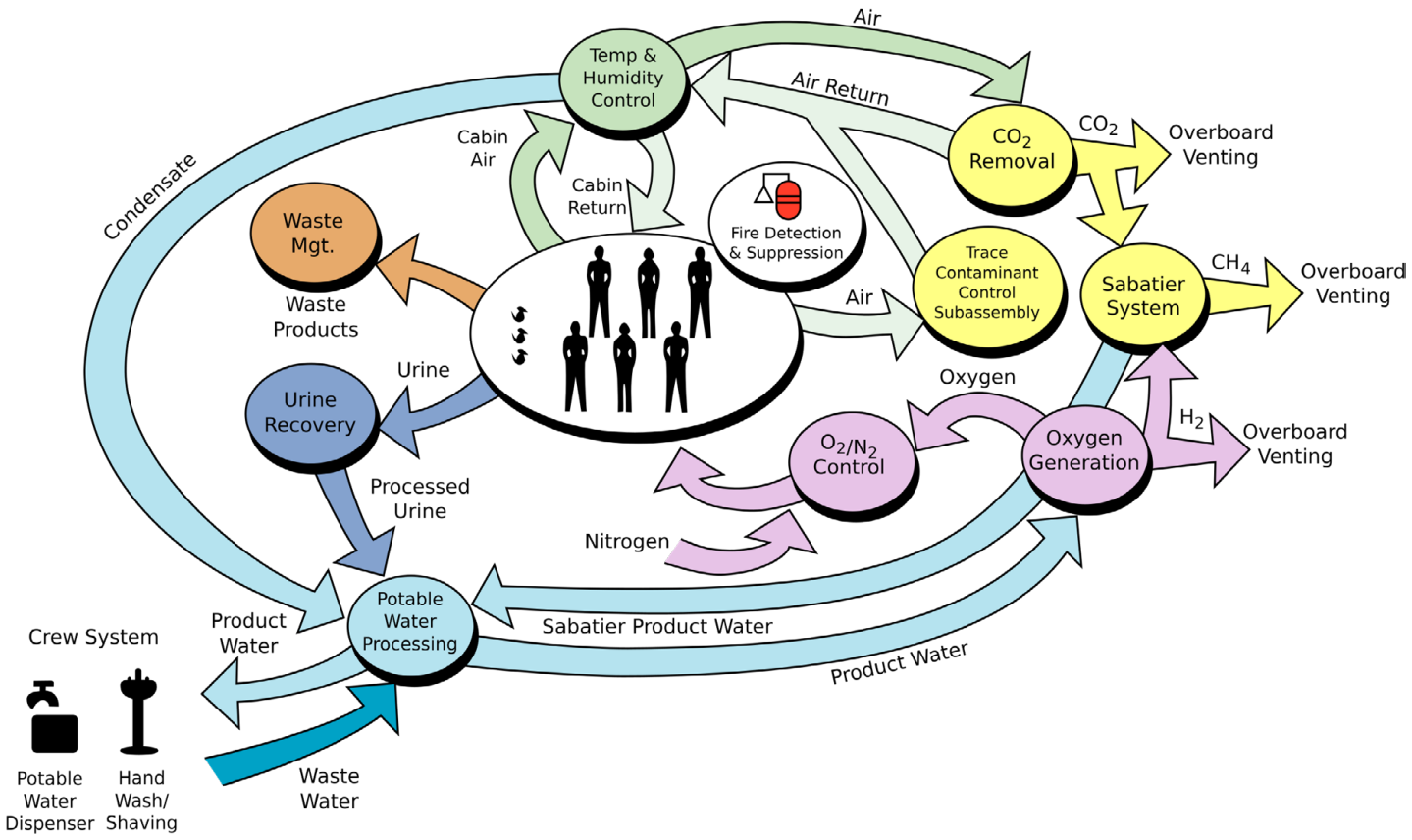


FIGURE – 4. 19 The interactions between the components of the ISS Environmental Control and Life Support System (ECLSS), NASA, https://commons.wikimedia.org/wiki/File:SpaceStationCycle.svg

32 Erik Seedhouse, "International Space Station Life Support System," in Life Support Systems for Humans in Space, ed. Erik Seedhouse (Springer International Publishing, 2020), https://doi.org/10.1007/978-3-030-52859-1_5.

Combating Isolation

One of the largest factors in the planning and design of long-term space missions is the detrimental effects of isolation in enclosed places. The absence of large spaces in current spacecraft forces close-quarter confinement amongst crew members, with little to no privacy and personal space. This often leads to tensions among crew members from increased levels of stress, fatigue, strict schedules and space sickness. Astronauts have often digressed isolation from family members and life back home on Earth as the more severe factor causing stress. Many studies have been done to simulate anticipated long-term space missions. One of the earliest studies to simulate travel to Mars, was through the ESA's MARS500 program which consisted of locking a six astronaut crew for 520 days - the estimated duration of a round trip to Mars.[33] The data from that study revealed that four of the six crew had endured a disrupted circadian rhythm, resulting in considerable problems with sleep.[34] Learning to live in space also requires intense mental training. The Canadian Space Agency (CSA) notes that when training, "(astronauts) learn self-reflection, conflict resolution and accountability, and build team cohesion and trust. Understanding themselves, their individual roles, and the team dynamics are crucial to maintain a healthy living space"[35] The crew onboard Verne Station would be required to work in unison and as a capable team to ensure safe operations.

For Verne Station, the trip durations can be short enough that the most isolating experience is the space flight to the station and the journey back in the space shuttle. On board the station, larger recreational and public spaces, mixed with generous private quarters would ideally provide the needed space requirements for healthy living. The increase global communications and connectivity world-wide help make it easier to talk and see family and friends. On board the ISS, several astronauts have

33 *Mars500: Study Overview*, accessed June 24, 2025, https://www.esa.int/Science_Exploration/Human_and_Robotic_Exploration/Mars500/Mars500_study_overview.

34 Mathias Basner et al., "Mars 520-D Mission Simulation Reveals Protracted Crew Hypokinesis and Alterations of Sleep Duration and Timing," *Proceedings of the National Academy of Sciences 110,* no. 7 (2013): 2635–40, https://doi.org/10.1073/pnas.1212646110.

35 Canadian Space agency, *How to Stay Mentally Healthy in Space*, October 7, 2022, https://www.asc-csa.gc.ca/eng/multimedia/search/image/17398.

publicly posted considerable social media content and videos. Passengers without doubt would wish to document and share their travels with the world using live video feeds and social media posts. With the growing high-speed connectivity options, it is expected that almost all aspects of the journey will also be in a constant state of real-time monitoring with tremendous levels of ground support.

Virtual reality devices could also be used to help alleviate stress and from the environment of space. As it is unknown just how well passengers could react and behave in space, tolerance to a facility where there is no immediate exit or sense of going "outside" may very well cause psychological issues. Being able to see a high definition place back on Earth such as a panoramic vista with a clear blue sky or old memories enjoyable space could be required when "stuck" in space during downtime. Significant new technologies regarding 2D to 3D image generation using Gaussian Splatting techniques show promise such as Nvidia's 3D Gaussian Unscented Transform.[36] Additional techniques of Triangle Splatting for Real-Time Neural Radiance Field Rendering (NeRF)[37] or even Nvidia's research development of new camera perspective generation.[38] are able to increase fidelity while maintaining performance.

36 Qi Wu et al., "3DGUT: Enabling Distorted Cameras and Secondary Rays in Gaussian Splatting," version 2, preprint, 2024, https://research.nvidia.com/labs/toronto-ai/3DGUT/.

37 Jan Held et al., "Triangle Splatting for Real-Time Radiance Field Rendering," version 1, preprint, arXiv, 2025, https://doi.org/10.48550/ARXIV.2505.19175.

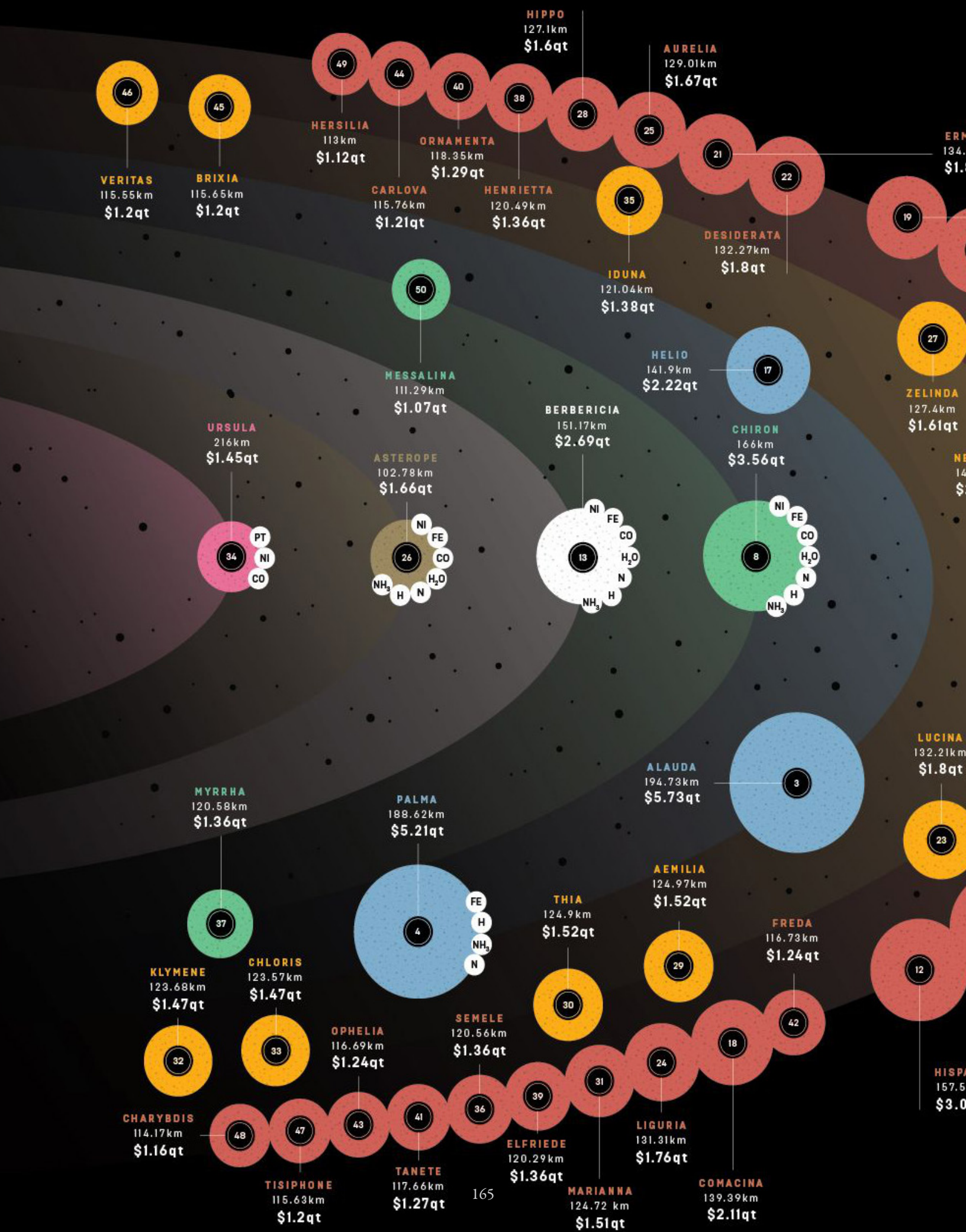
38 Xuanchi Ren et al., "GEN3C: 3D-Informed World-Consistent Video Generation with Precise Camera Control," version 1, preprint, arXiv, 2025, https://doi.org/10.48550/ARXIV.2503.03751.

Economic Reasoning

The beneficial economic parameters for the construction and utility of the station must also be taken into account. Due to cost, building for space needs justification, as government budgets are limited and held accountable. Any large space hotel cost would be in the hundreds of billions, and more realistically in the trillions of dollars accounting for future inflation. Social and political concerns and controversy also play a significant role in shaping which space projects are developed. The funds and means to focus efforts on problems here on Earth seem to take a back seat to progress. However politically, culturally, and scientifically controversial it may seem, going to space can lead to tremendous overall benefit for humanity. Beyond the immediate employment opportunities and infrastructure to support such projects on Earth, many fail to realize how space technologies completely dominate life today with satellite communications and global communications. Many habitable space crafts develop technology for sustainable closed loop systems for inhospitable environments. The Earth itself may one day become inhospitable due to us as a species. Building designs may need to be designed much like space craft to adapt to hostile environments and perhaps ensure our survival beyond Earth.

The cost of the ISS over the past few decades, is an estimated $150 billion dollars, making it the most expensive laboratory structure ever built. Achievable only through international cooperation, with budgets mired with red tape and constraints from government bodies, it's existence is an incredible feat. For the ISS, it's operational cost is roughly three billion per year and higher if indexed to inflation. As one of the only long-term micro gravity facility in existence, the ISS has facilitated more than 3,600 researchers to conduct more than 2,500 experiments to date.[39] The ISS as a platform for long-term research on human health in space differs significantly from unmanned missions, particularly in terms of maintenance, operational costs, and human risk factors. For instance, the Mars Curiosity Rover has been mapping and studying the surface of Mars since 2011 to the tune of 3.2 billion dollars

39 *International Space Station: Facts, History & Tracking*, Space, August 24, 2022, https://www.space.com/16748-international-space-station.html.


HIPPO
127.1km
$1.6qt
AURELIA
129.01km
$1.67qt
HERSILIA
113km
$1.12qt
ORNAMENTA
118.35km
$1.29qt
CARLOVA
115.76km
$1.21qt
HENRIETTA
120.49km
$1.36qt
VERITAS
115.55km
$1.2qt
BRIXIA
115.65km
$1.2qt
IDUNA
121.04km
$1.38qt
DESIDERATA
132.27km
$1.8qt
MESSALINA
111.29km
$1.07qt
HELIO
141.9km
$2.22qt
ZELINDA
127.4km
$1.61qt
URSULA
216km
$1.45qt
ASTEROPE
102.78km
$1.66qt
BERBERICIA
151.17km
$2.69qt
CHIRON
166km
$3.56qt
LUCINA
132.21km
$1.8qt
ALAUDA
194.73km
$5.73qt
MYRRHA
120.58km
$1.36qt
PALMA
188.62km
$5.21qt
AEMILIA
124.97km
$1.52qt
THIA
124.9km
$1.52qt
FREDA
116.73km
$1.24qt
KLYMENE
123.68km
$1.47qt
CHLORIS
123.57km
$1.47qt
OPHELIA
116.69km
$1.24qt
SEMELE
120.56km
$1.36qt
CHARYBDIS
114.17km
$1.16qt
TISIPHONE
115.63km
$1.2qt
TANETE
117.66km
$1.27qt
ELFRIEDE
120.29km
$1.36qt
MARIANNA
124.72 km
$1.51qt
LIGURIA
131.31km
$1.76qt
COMACINA
139.39km
$2.11qt

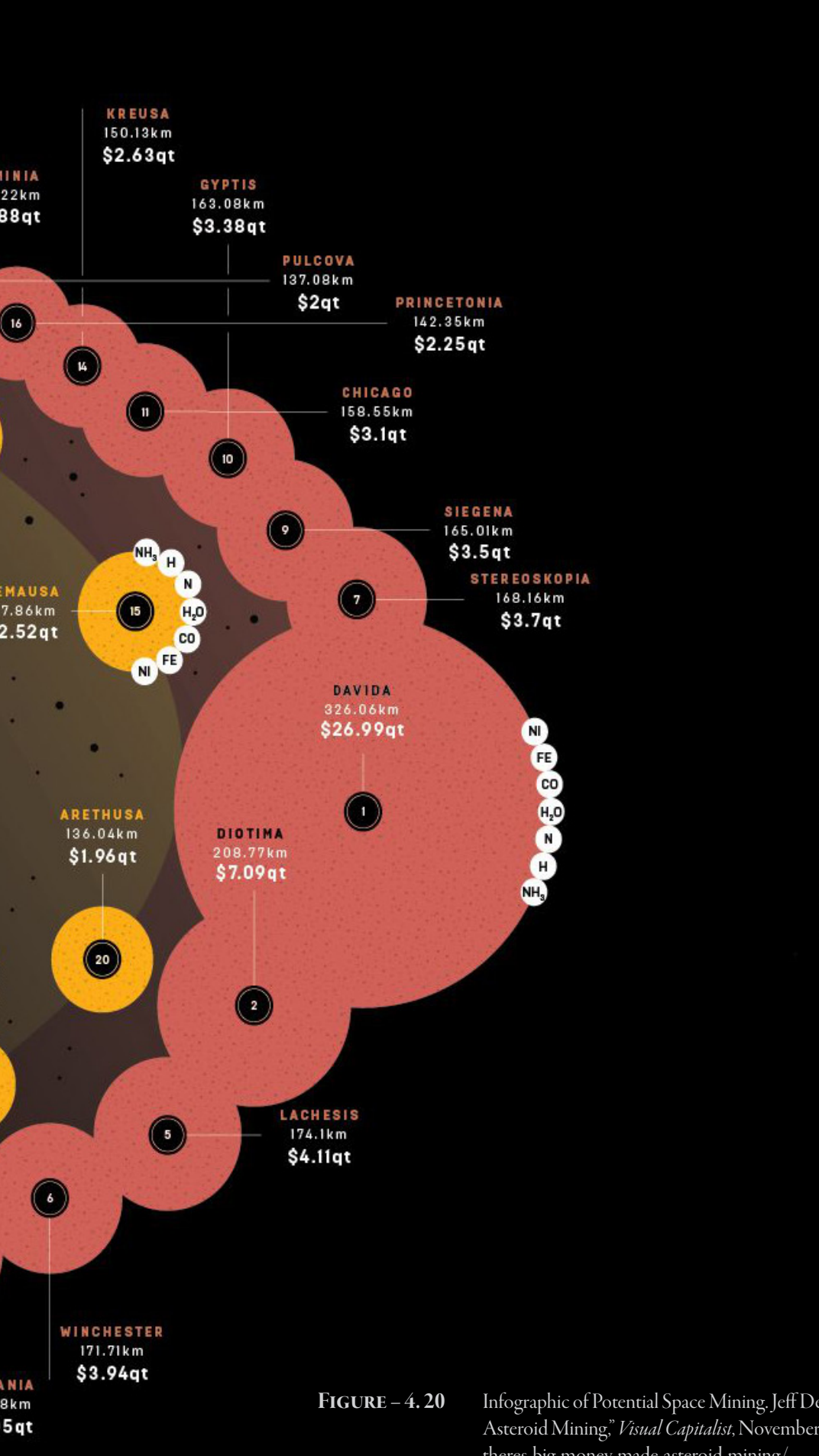


FIGURE – 4. 20 Infographic of Potential Space Mining. Jeff Desjardins, "There's Big Money to Be Made in Asteroid Mining," *Visual Capitalist*, November 2, 2016, https://www.visualcapitalist.com/theres-big-money-made-asteroid-mining/.

over the years.[40] The data and discoveries scientists have been able to retrieve so far, specifically water deposits, have been invaluable and at a significantly lesser cost to discover than if a manned space flight mission were to take place instead. Unmanned space craft are still the undisputed way to discovering the cosmos and collecting vital mission data for planning where to focus limited resources.

The average cost per pound in 2011 of sending a payload into space with the space shuttle program was, roughly $54,000/kg.[41] This figure has come down significantly over the past decade with commercial space craft leading the charge for payload efficiency with the Falcon 9 heavy rocket at $1500/kg.[42] This technological advancement and direct improvement that has occurred is significant for space travel as larger volumes and structures can be created. It can be expected the role and voice of a future space architect becomes stronger as long as newer technologies and efficiencies can become viable for the added luxuries and comforts we as a species are already used to in our day-to-day lives. The necessity to bring the operational cost down of $10,000 per pound, to $100 per pound would allow space agencies and companies to develop and plan larger, more comfortable establishments in space which could be visited by hundreds, if not thousands of people per year. If the technology reaches maturity in some distant future, then space becomes more accessible to many more people. With larger crafts, sending people and resources to future established space destination in an efficient and reliable manner, would ensure that space exploration to the masses becomes as a reality, much like airline travel is today. The ticket price per passenger is more affordable if shared with a greater number of passengers. For future spaceflight, SpaceX Starship launch cost is expected to be $100 million per launch and eventually $2 to $3 million.[43] If this number is spread between a hundred people, then a ticket price to fly onboard is $30, 000 per person instead of millions. Such a figure opens spaceflight

---

40 Casey Dreier, "The Cost of Perseverance, in Context," The Planetary Society, accessed October 26, 2025, https://www.planetary.org/articles/cost-of-perseverance-in-context.

41 *The Recent Large Reduction in Space Launch Cos*t, Jones, Harry W. (NASA Ames Research Center Moffett Field, CA, United States).

42 Thomas Roberts, "Cost for Space Launch to Low Earth Orbit- Aerospace Security Project," Aerospace Security, September 1, 2022, https://aerospace.csis.org/data/space-launch-to-low-earth-orbit-how-much-does-it-cost/.

43 Malcolm Davis, "The Starship Revolution in Space," The Strategist, October 16, 2024, https://www.aspistrategist.org.au/the-starship-revolution-in-space/.

to many more people that would have the means to afford a once in a lifetime trip to space.

In the later parts of this thesis, the construction phases alone, of which Verne Station is proposed to be built, in a time frame of several years, will rely on the effective transporting of the building components, resources and personnel to accommodate the design program. Although the cost to get to outer space is still vastly expensive, privatization has started to push reusable rockets as a more affordable solution. Recent reductions in launch costs, coupled with renewed interest in establishing Martian and Lunar colonies and bases, have stimulated significant investment from both government contracts and the private-sector.

Space mining of critical minerals and resources will most likely drive commercial pursuits beyond tourism. With an estimated quintillions worth of precious metals waiting to be mined, the ability to build and construct larger space settlements will rely upon sources beyond the Earth. (Figure – 4. 20) The valuable resources in space eclipse that of what is available on Earth in terms of raw material.



Figure – 4. 21 Emily Calandrelli on board Blue Origin flight 28, Blue Origin, accessed October 16, 2025, https://www.blueorigin.com.

Tourism

Tourism is expected to be a major industry for future space exploration. The most significant experiences of space travel in LEO (Low Earth Orbit) as described by astronauts, is the ability to gaze back in awe at the grandeur of Earth.[44] The photographs astronauts and space agencies have published showcase breathtaking discoveries and insights of life in space and our planet. For Verne Station, tourism is an essential part of its directive - to appreciate outer space.

Space tourism today is reserved mostly for the super wealthy for the time being. Many private sub-orbital spaceflights that are in operation today, such as Blue Origin's New Shepard[45] and Virgin Galactic's VSS Unity[46] have ferried only a handful of passengers to the edge of space. Tickets prices for these shorts flights have reached staggering multi-million dollar figures. For the even more daring, Axiom's price tag to send a person to the ISS is a staggering 55 million dollars.[47] And besides the millions of dollars, other ventures consider who to select based on the exclusivity of social and cultural impacts of the person applying.

> It's not about money; it's about who you are, your social capital, whether you align with their launch purposes. It's kind of a package deal," said Roman Chiporukha, cofounder of SpaceVIP, a platform that helps the wealthy book space trips, including Blue Origin's.[48]

How would an average person ever get to experience space? It is simply not possible without sponsorship from a wealthy benefactor or government agency. As such, being able to experience space today is a coveted and exclusive experience that is currently gate kept from the general population. For

---

44 Frank White, *The Overview Effect: Space Exploration and Human Evolution*, Third edition, Library of Flight (American Institute of Aeronautics and Astronautics, Inc, 2014).

45 "New Shepard," Blue Origin, accessed October 23, 2025, https://www.blueorigin.com/new-shepard.

46 "Virgin Galactic," accessed October 23, 2025, https://www.virgingalactic.com/spacecraft-fleet.

47 Sissi Cao, "What You Pay For Blue Origin's Spaceflight Depends On Who You Are," *Observer*, accessed April 20, 2025, https://observer.com/2022/06/blue-origin-space-tourism-pricing-marketing/.

48 Ibid.

Blue Origin, their sub-orbital flight travels the Kármán line, which is a widely recognized boundary that marks the edge of space. The flight itself lasts fifteen minutes and is entirely automated. Presently any venture into outer space is marketed to very wealthy or prominent public figures. Outer space is an exclusive destination and as such the recent interest in space travel today is spearheaded by efforts of billionaires.

While there is significant interest and forward-thinking vision towards commercializing space tourism; it may not be for everyone. The financial cost as well as the safety risk is hard even for those with extreme wealth to justify. Famous celebrity and actor Tom Hanks, was approached by Blue Origin for a flight, but turned it downed due to the staggering ticket price of 28 million at the time.[49] Whereas other notable figures such as William Shatner, flew for free in order to generate hype and public interest in space tourism.[50] The immediate early stages of space tourism exist beyond just monetary aspirations and instead of that of the perception of individual value. For most of society, the cost-benefit or even importance of space tourism and colonization may not be economically feasible for several decades. In the reports conducted by PEW Research Center, most Americans view space tourism as a possibility in 50 years, but 65% would not have the desire to venture into space, and 35% say they would be interested in orbiting Earth in a spacecraft.[51] Traveling to space today is an extremely limited experience, stripped of the common amenities and functions most people enjoy at home. In microgravity, washrooms and showers operate differently due to the change in fluid dynamics. Fresh food is limited and most food is dehydrated ration packs to save on transportation costs. The extensive water filtration systems on board the ISS effectively recycle urine and sweat from fellow crew back to drinkable water - less than ideal for space tourists to endure. Life onboard a space station requires a constant state of adapting to new environment conditions.

---

49 Ibid.

50 Marina Koren, "The Cost of William Shatner's 'Most Profound Experience,'" *The Atlantic*, October 13, 2021, https://www.theatlantic.com/science/archive/2021/10/william-shatner-blue-origin/620370/.

51 Brian Kennedy and Alec Tyson, "Americans' Views of Space: U.S. Role, NASA Priorities and Impact of Private Companies," *Pew Research Center*, July 20, 2023, https://www.pewresearch.org/science/2023/07/20/americans-views-of-space-u-s-role-nasa-priorities-and-impact-of-private-companies/.

Day and Night Cycle

Shadows in space exist differently than on the Earth, as they are stronger and sharper due to the lack of atmospheric scattering. Without air and clouds to scatter light, shadows in space appear starkly black, with no partial illumination (penumbra). Exploring how light interacts with the interior space architecture is another key advantage of using real-time game engines and its importance to designing for human comfort. Within the engine, examining how light behaves onboard a space craft can be controlled and simulated with decent accuracy. Windows on spacecraft are perhaps the most important element of human spaceflight to allow one to look out at the stars and see the backdrop of the Earth and Moon. For the ISS, the Cupola is the greatest module installed due to it allowing astronauts to a grand view of the Earth. Astronauts and crew have spent countless hours photographing and studying the Earth in orbit. Glass however has a higher structural failure point in space craft design that must be mitigated with shielding.

Depending on your location in space, the access to sunlight can vary tremendously compared to a normal day cycle we experience on Earth. The ISS, orbits the Earth at 27,600 km/h and as such experiences a full day and night cycle in 90 minutes.[52] This means that astronauts who are used to a regular 24 hour day and night cycle, will now experience seeing a typical Earth cycle several times in a day. With this altered circadian rhythm in space, the human body must adapt. The European Space Agency (ESA) had 10 astronauts measure circadian rhythm in 2017. In order to synchronize the body's natural rhythms to eat, metabolize and sleep, the body was found to works and run warmer in order to adapt.[53]

52 NASA Science, "20 Breakthroughs from 20 Years of Science Aboard the International Space Station," *NASA Science*, October 26, 2020, https://www.nasa.gov/missions/station/20-breakthroughs-from-20-years-of-science-aboard-the-international-space-station/.

53 European Space Agency, "Keeping the Rhythm in Space," *The European Space Agency*, June 15, 2017, https://www.esa.int/Science_Exploration/Human_and_Robotic_Exploration/Research/Keeping_the_rhythm_in_space.

Vegetation

Cultivating plants in space is highly beneficial for sustainable long-term space habitats. Not only do plants provide renewable nutrients for human consumption, they act as supplementary life-support filtration systems as they cycle carbon dioxide and produce oxygen. Beyond the physical sustenance of plant life, plants are key to our psychological wellbeing and a connection to our natural world (Figure – 4. 23). The presence of small plants are proven to immensely contribute to astronaut mental health. Beyond having food production, flowering and small tree species can be effective in the creation of memorable green spaces.

Growing plants in space has been heavily researched on the ISS as they are vital to support long-term human spaceflight. NASA's Advanced Plant Habitat (Figure – 4. 22) can successfully grow plants from seeds in micro gravity[54] and VEGGIE has also successfully grown plants with controlled nutrient, light and monitoring. Plant roots, which are free to grow uncontested, need to be contained in packets instead of soil. When compared to ground control samples, the research indicates that leafy vegetable crops can produce safe, edible, fresh food to supplement astronaut diet.[55] These studies which were done in small experiment batches, can be extrapolated into larger greenhouse applications as supported notably in science fiction. Scaling these systems to meet a more robust and automated harvesting system will be key for sustaining human life far away from Earth and future colonization efforts.

Plant life also brings aboard aesthetic and sensory experiences in what is ultimately a sterile laboratory interior. For Verne Station, extrapolation of current garden designs and capabilities into a larger greenhouse with biodiversity would become a larger recreational and leisure area for those on board. The symbiosis of plant and human life act in tandem to another for life support and this relationship is crucial to replicate living in space where there is no access to "outside."

---

54 NASA Science, "Growing Plants in Space," *NASA Science*, n.d., accessed July 20, 2025, https://www.nasa.gov/exploration-research-and-technology/growing-plants-in-space/.

55 Christina L. M. Khodadad et al., "Microbiological and Nutritional Analysis of Lettuce Crops Grown on the International Space Station," *Frontiers in Plant Science 11* (March 2020): 199, https://doi.org/10.3389/fpls.2020.00199.

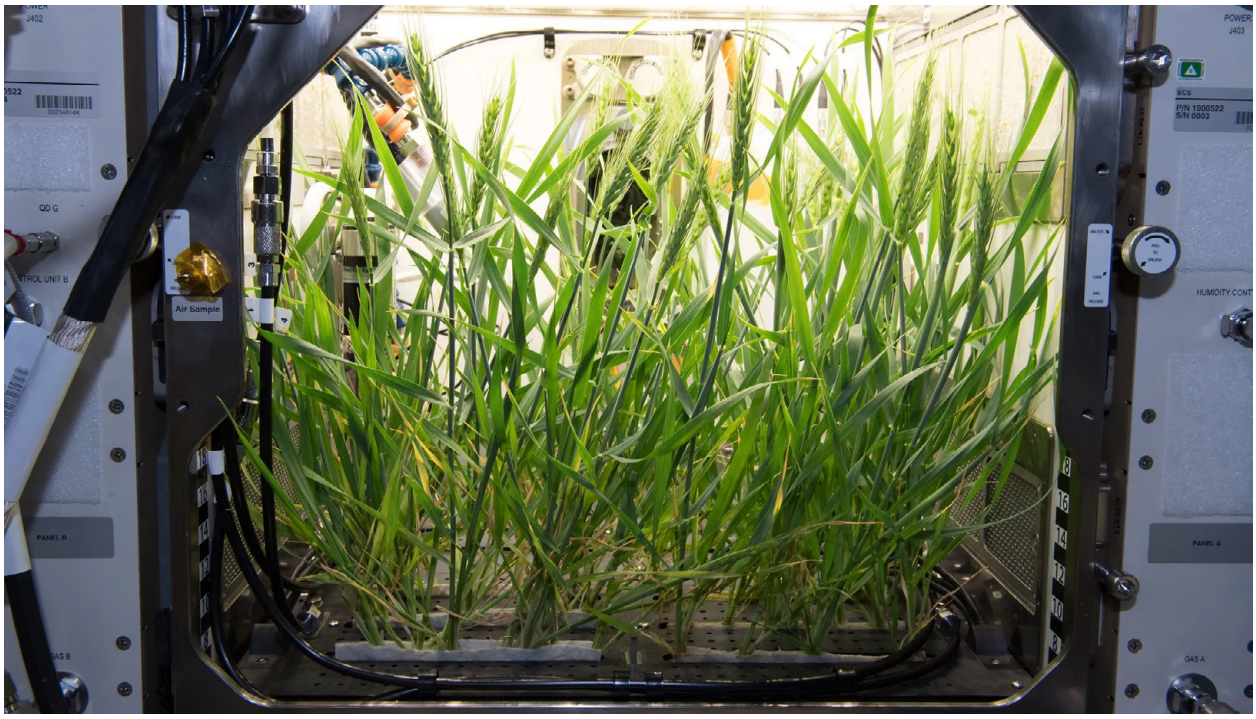


FIGURE – 4. 22 The first growth test of crops in the Advanced Plant Habitat aboard the International Space Station, NASA, 2018, https://www.flickr.com/photos/nasakennedy/26940469668/



FIGURE – 4. 23 A Zinnia flower grown inside the VEGGIE facility onboard the International Space Station, Photograph, NASA, 2016, https://www.flickr.com/photos/nasa2explore/24460739396/in/photostream/

SCHEMATICS

With the layers and constructs as defined in the preceding pages, the following pages outline the proposed basic design of Verne Station. Drawing upon the known technologies and restraints of space flight, while remaining open to future technologies and visionary aspirations, are what ultimately make Verne Station pretend architecture. The design cannot account for everything as there is simply too much to comprehensively detail and include, but the foundational components can inform the overall picture of how this concept continues the idea of a home in space.

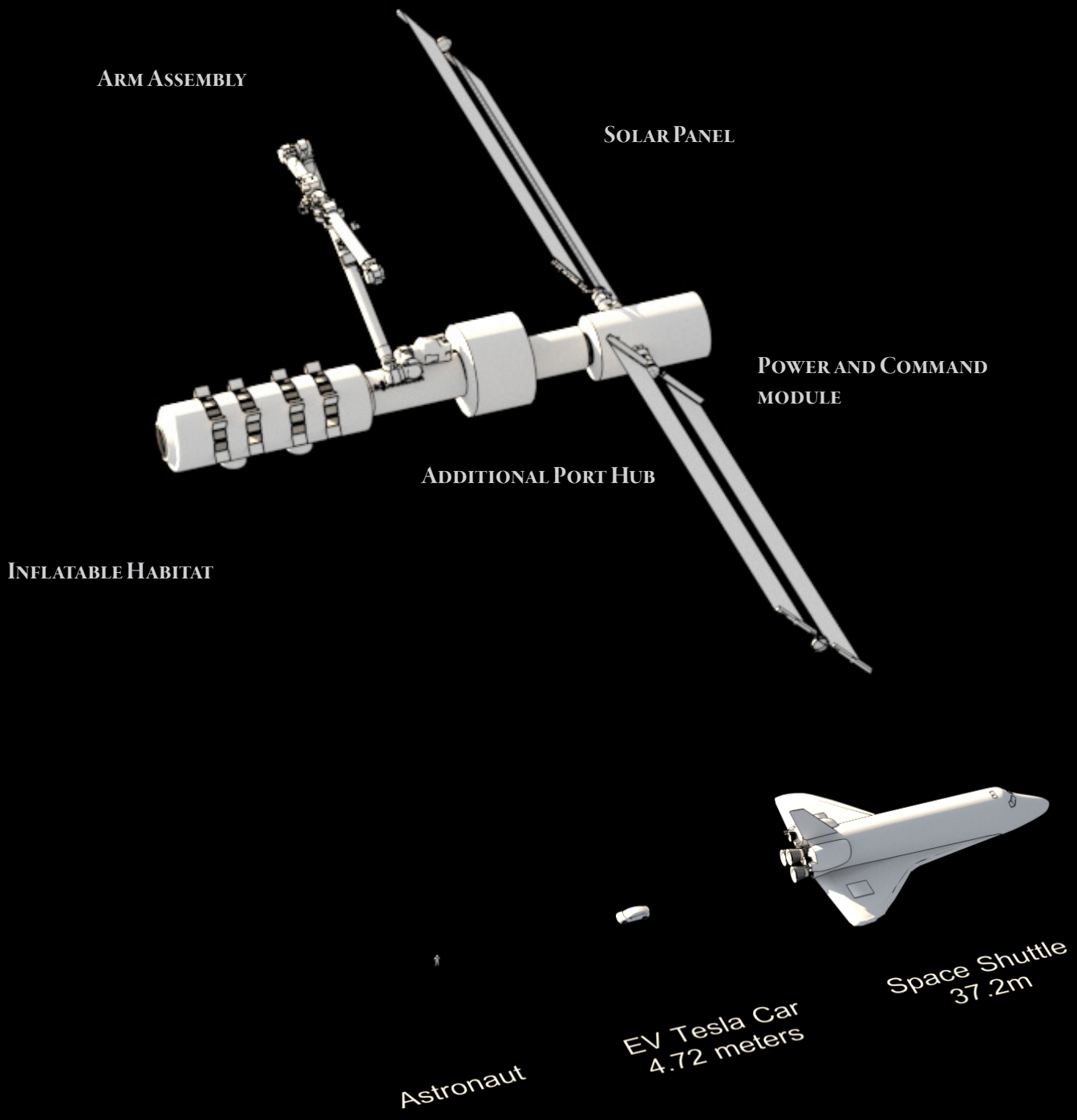


Figure – 4. 24 Orthographic view of Verne Station, Phase 1, Image by Author 2025

Phase 1: Command Module

The first phase accommodates the initial setup and core operations of Verne Station. Two assembled node modules are launched together into space using one large payload rocket. A secondary, smaller rocket payload with supplies and cargo is launched after mission success. By being situated in Low Earth Orbit, its construction follows a similar journey of the ISS where each piece of the station is built in stages. The main core power and life support modules would be able to sustain life for up to five astronauts. Multiple re-supply missions can occur with lower cost rocket launches as long as the station is in closer proximity to existing support facilities. Once all systems are active and operational, the crew module will be inflated to its maximum volume. Fully expanded, the crew will fit out the needed tech and payloads required to complete the programming of the habitat module. Based on payload capacity, the module size is 20 meters x 6 meters in it's initial state. When expanded, the diameter is 18 meters and the main central aluminum structural core provides the framework for constructing usable living spaces.

The command module will also house the gear and equipment needed for Extravehicular Activity (EVA) spacewalks, and supporting solar array panels. A small machine bay is needed for the deployment of an autonomous drone and robotic craft similar to the Mars Ingenuity helicopter.[1] Robotics, along with a Shuttle Remote Manipulator System (SRMS), often known as Canadarm, will provide the heavy lifting for future module installation. The center port module hub will have two expansion openings that will serve as airlocks and docking ports for the early artificial gravity tests.

1 NASA Science, "Ingenuity Mars Helicopter," *NASA Science*, April 8, 2024, https://science.nasa.gov/mission/mars-2020-perseverance/ingenuity-mars-helicopter/.

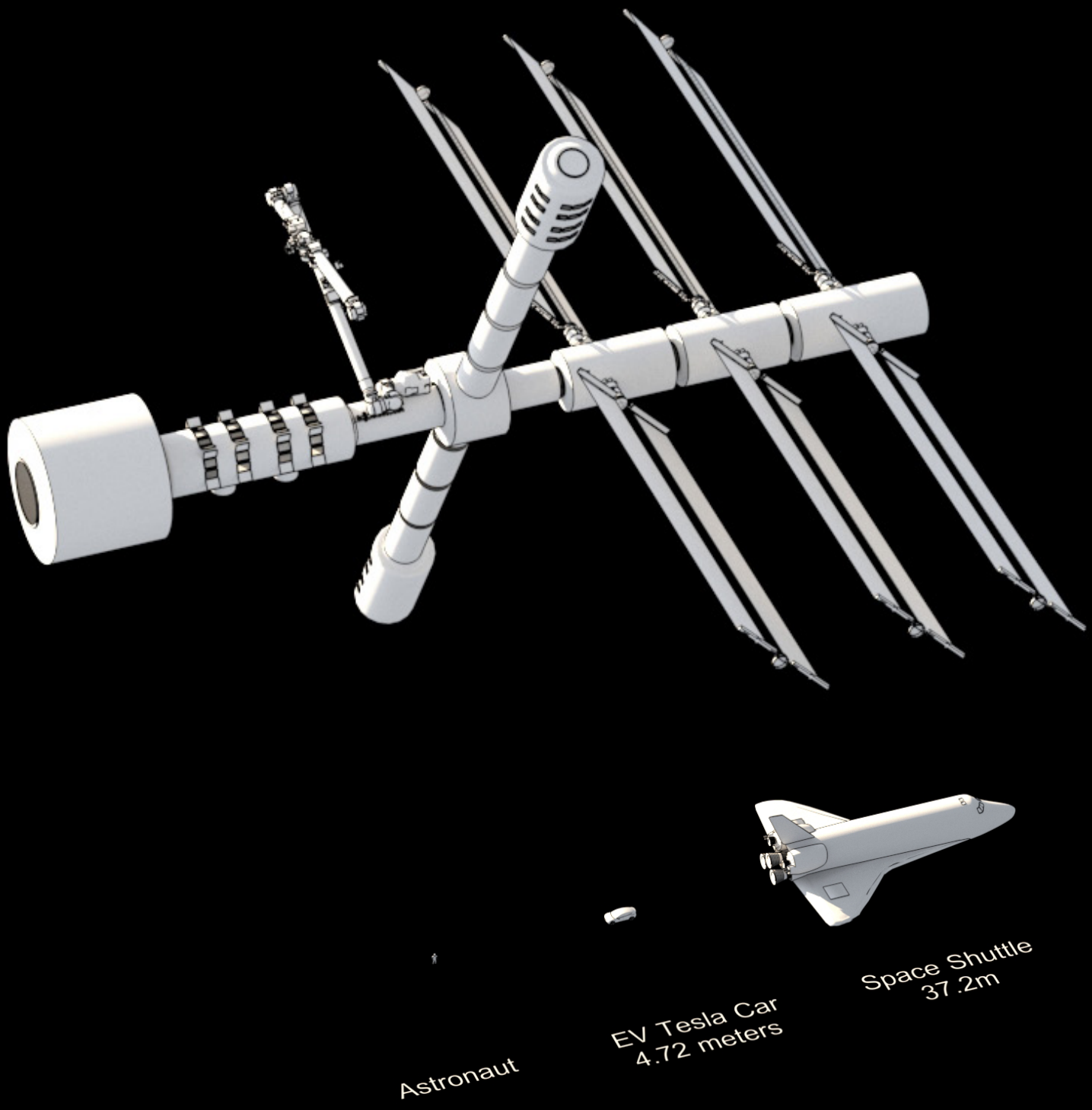


Figure – 4. 25 Orthographic view of Verne Station, Phase 1, Image by Author 2025

Phase 2: Tethered Habitats

Due to the requirements for artificial gravity to support long-term research and operations of crews and tourists beyond six months, the diameter of the structure will need to be 200 metres and spin at roughly three RPM (rotations per minute) to match the Moon's gravity level of 0.166 g; subsequent tests for Mars and Earth gravity will occur after. By combining these two non-inflatable modules, they will serve as temporary experimental nodes to study rotational spin rates. The Atlus and Titan modules will use a retractable tether system using theoretical high strength nano-carbon tubing which support extreme lengths.[2] The retractable modules will be linked with the necessary life support systems, tubings and power systems of the command module in docked mode. When needed by astronauts, each module is retracted to the same desired length and mechanically spun. With each module having its own separate life support systems, controlled long-term living in space can occur as the artificial gravity generated will recoup muscle and bone loss density that occurs in microgravity. Data from this phase would be crucial for when the main habitat ring is constructed. With the station able to generate and control specific artificial gravity levels, including more than 1g, the adoption rate and effects on the human body can be more strategically studied and observed. Crews could offset training and testing schedules for specific planetary space missions with staggered hybrid gravity implementations.

Another function of the craft will be to deploy drones to mitigate and collect space debris that place current and future space missions at risk.[3] This may be a viable early revenue source in addition to scientific payloads until a tourism economy can be established in the later phases.

2 Adrian Nixon et al., "Space Elevator Tether Materials: An Overview of the Current Candidates," Acta Astronautica 210 (September 2023): 483–87, https://doi.org/10.1016/j.actaastro.2023.04.008.

3 "Spacecraft to Remove Orbital Debris | T2 Portal," accessed July 25, 2025, https://technology.nasa.gov/patent/MSC-TOPS-90.

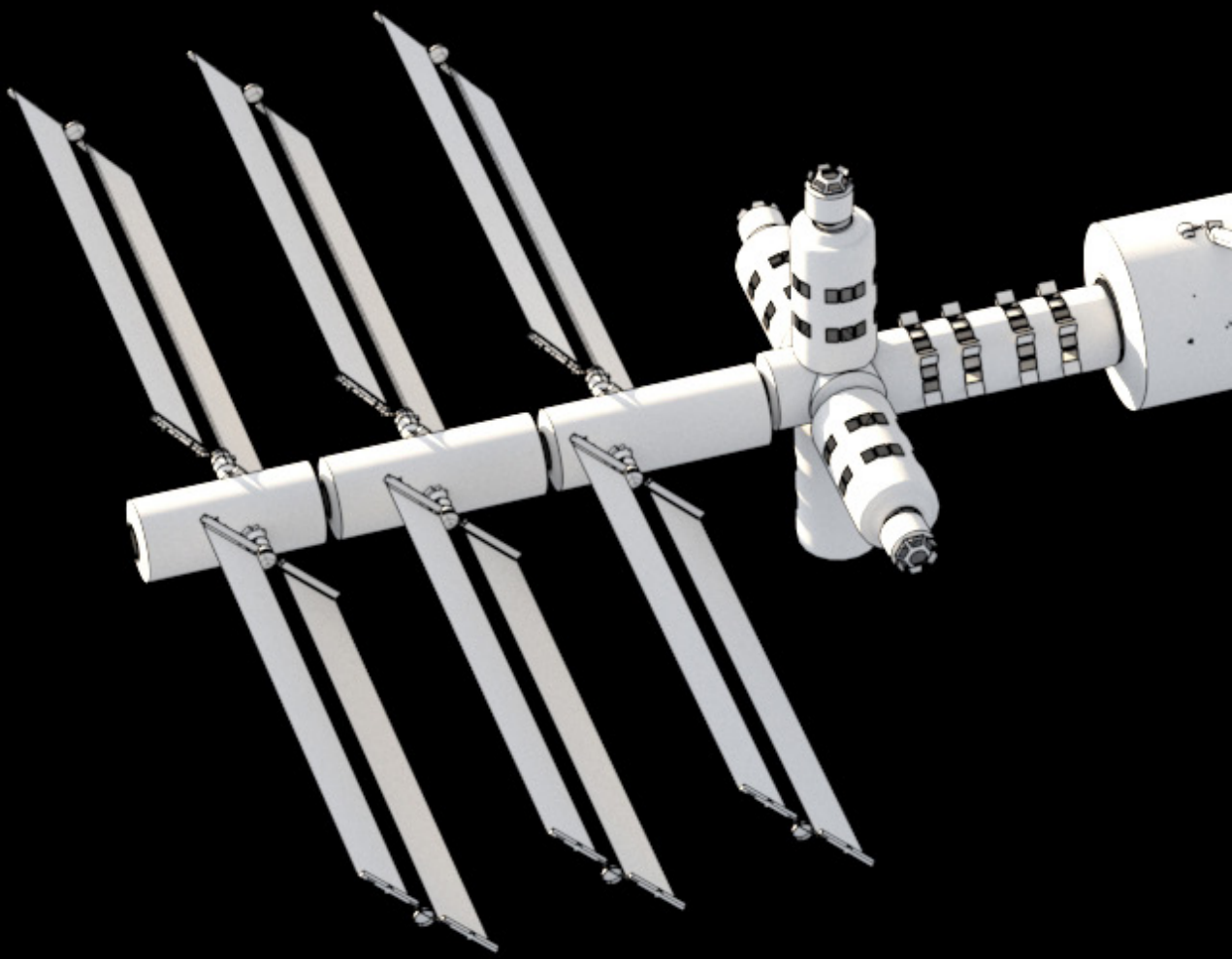
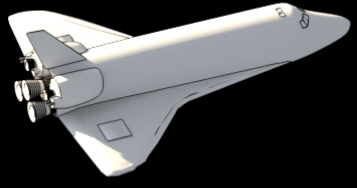


FIGURE – 4. 26 Orthographic view of Verne Station during Phase 3, Image by Author 2025







Astronaut

EV Tesla Car
4.72 meters

Space Shuttle
37.2m

Phase 3: Main Axis Expansion

Phase three construction involves expanding the necessary structural trusses and modules to form the main axis of the ship. To sustain the large future 250 metre diameter ring, the main rotational hub must be installed and tested. With a larger diameter (40 metres) than most modules and payload limits, this component requires a heavy rocket launch vehicle to get it into space. Using slip rings[4] to supply power and oxygen, this central hub module will be critical for operation.

Four additional inflatable habitats are connected to house future amenity functions and serve as the primary microgravity communal areas. Each section has several windows to space, each with operable shutters designed to shield occupants from radiation and space debris. Inside the chord ends are biodiverse green walls and lush plant life. The well-being of passengers and crew, both physically and mentally, is enhanced by vegetation throughout the station. In spacecraft, where everything feels confined and clinical, flowers and vegetables provide a vital connection to Earth's natural environment. Their dual purpose—providing the ecological framework for recyclable systems of oxygen production, carbon dioxide filtration, and sustainable crop cultivation—is essential for closed-loop scientific research and self-sustainability. Long-term space colonies will need to replicate Earth's natural systems in order to sustain life in outer space and minimize resupply dependence.

Additional solar panel arrays are installed to increase power generation output to aid in the station's increased power consumption. These panels operate in similar fashion to the ones installed on the ISS, and auto-rotate to the best angle for maximum solar efficiency. Additional docking modules are installed to allow for increased ship and cargo capture support.

4 J. Batista et al., "Roll Ring Assemblies for the Space Station," May 1, 1994, https://ntrs.nasa.gov/citations/19940028788.

Phase 4: Main Pathway Chords

Phase four requires twelve modules to construct the needed structural pathway chords that support the main ring. Passengers and crew can now enjoy longer space missions by using this area for sleep and rest and to reduce the negative health risks of micro gravity environments. Depending on the length of stay, it is expected at minimum, one would have a week long journey, and at maximum, as long as possible. These chords provide additional surface area for mounting external scientific payloads and integrating telemetry systems essential to station functionality. The distance, however, between the outermost point and the central origin is essentially that of a high-rise building. Elevator systems will allow passengers to move efficiently throughout the large structure, while emergency ladders and deployable stairs provide alternative routes in case of any system failure. Each chord also houses energy storage units and infrastructure from the main command module systems, ensuring that life-support functions remain operational.

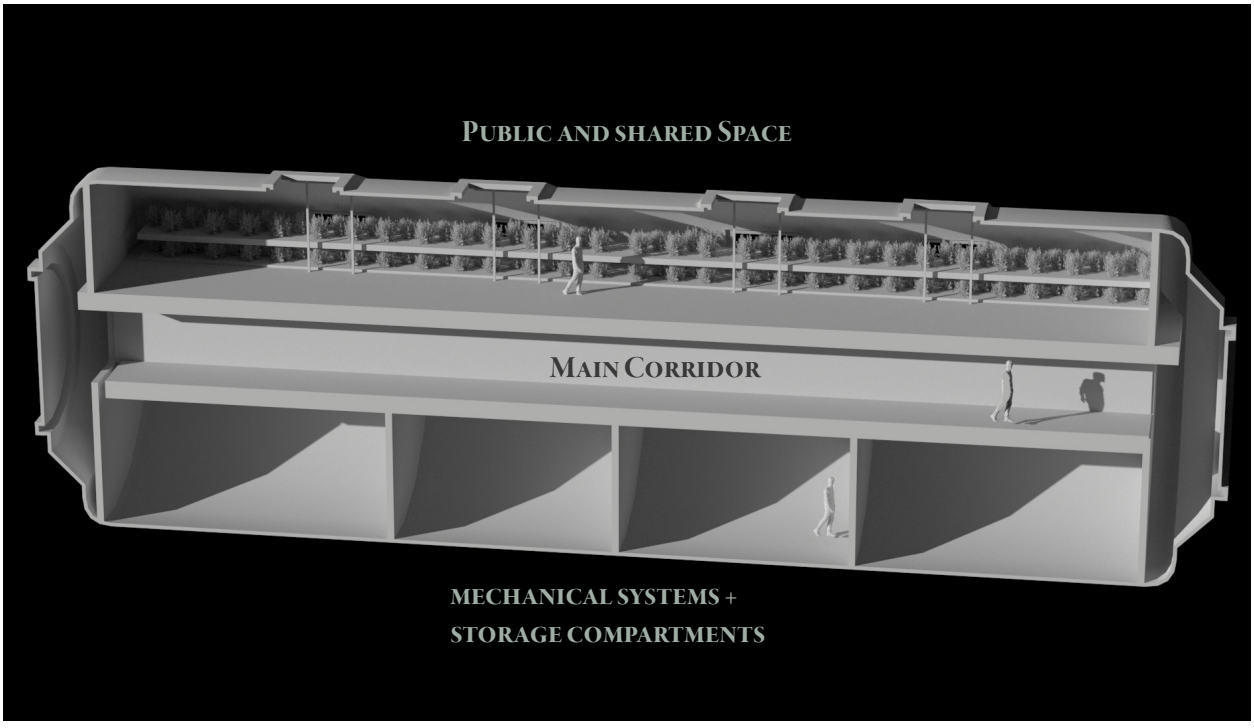


FIGURE – 4. 27 Sectional View of module showcasing structural inner core surrounding by programming and the lower level mechanical and systems storage, Image by Author 2025

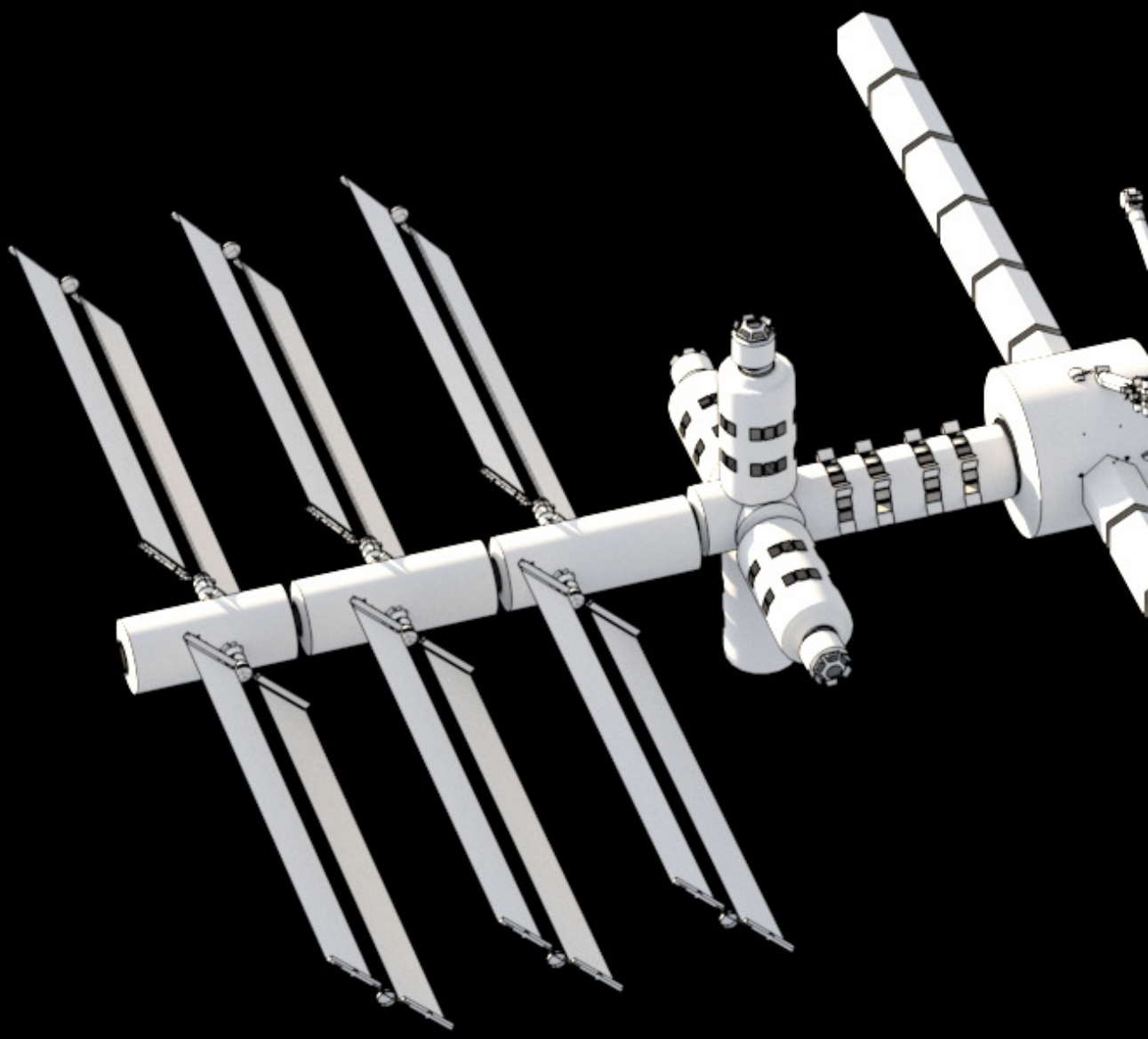
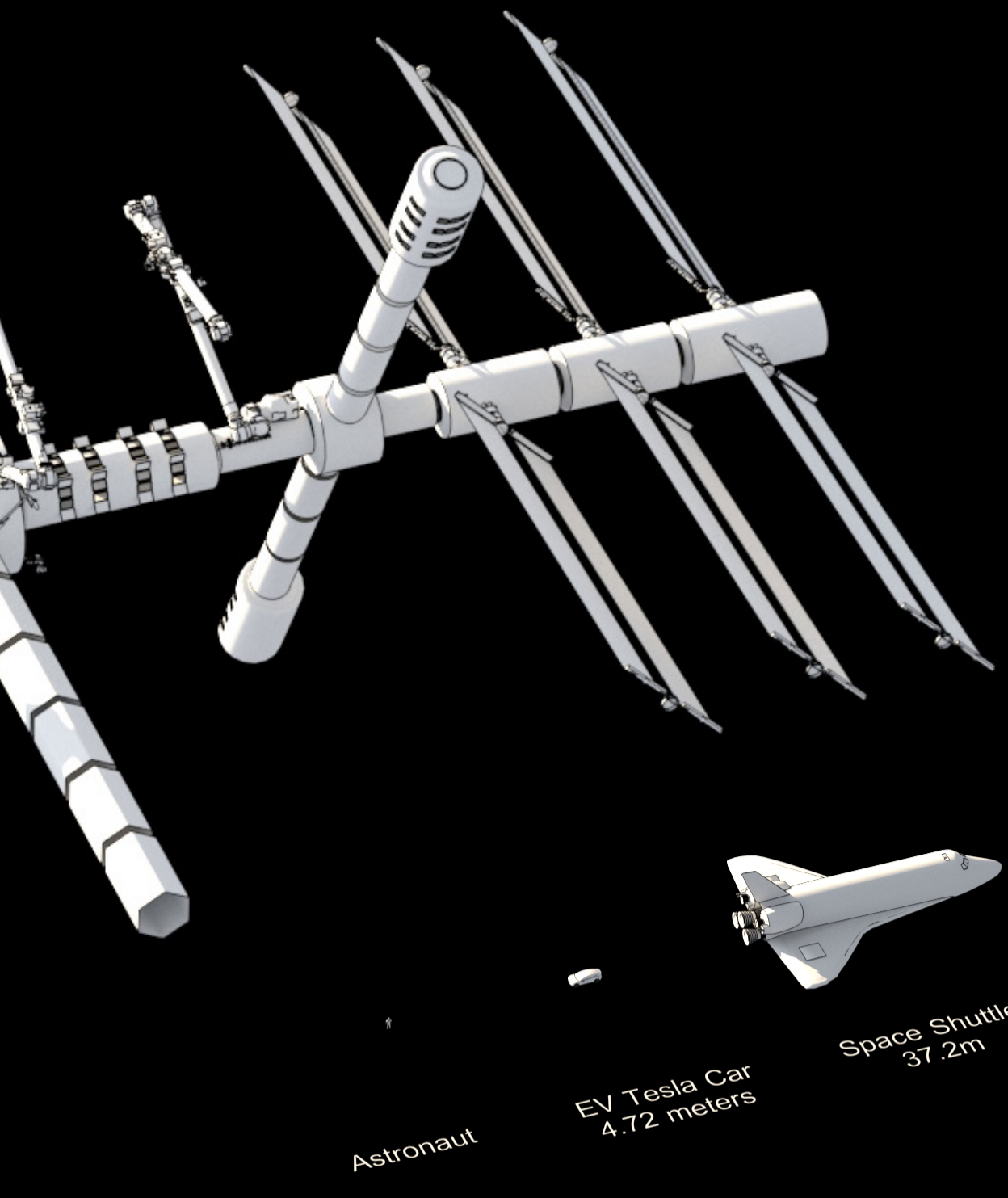


Figure – 4. 28 Phase 4 - Verne Space Station, Image by Author, 2025


Astronaut
EV Tesla Car
4.72 meters
Space Shuttle
37.2m

Phase 5: Main Ring Array

The station now undergoes its transformation to become a direct tourism hub with thousands of travellers per year with the long and arduous task of assembling the main ring. Twelve modules and twelve structural pathway modules will need to be assembled to form the main ring array. This will require significant payload launches into space and be the most arduous construction task. Multiple Canadarms installed on the structural chords will provide support for joining together module pieces safely. As the modules are connected, separate crews will build the necessary pre-fabricated internal compartments. Once all modules are assembled and completed, the ring will form an enclosed continuous corridor with multiple airlock safety points.

Floor and ceiling components are all constructed with modular and interchangeable accessible panel systems to allow for complete maintenance access and flexibility. By having compartmentalized nodes (12 sectors) the construction and design of spaces can be unique in regards to their function and styling over time as many of these spaces will end up being privatized or change ownership. Due to the luxury of space (even with inflatable technology) the double loaded corridor is completely basic except for smaller way-finding markings (direction of rotation indicated.) The architectural strategy extrapolated from the research by Theodore W. Hall's dissertation paper from 1994 explains:

> The architecture of artificial gravity has been conceived as an idealization of Earth, rather than a departure from it. Prak's views, on the relationship between architectural aesthetics and prevailing social conditions, seem relevant: "A person who knows that the road to a certain highly desirable goal is blocked, turns to wish-fulfillment in dreams. Analogously, the architecture of a society divided against itself becomes a dreamland, an image of the state desired" [64]. However, the persistence of Earth-normal concepts in space colony design need not be cast in such a negative light. The architecture derives from a global technological civilization that transcends national and cultural boundaries. It is the only architecture that most of us have ever known, and it is difficult for us to conceive of anything else.[5]

5 Hall, Theodore W. *The Architecture of Artificial-Gravity Environments for Long-Duration Space Habitation*. Doctoral dissertation (Arch.D.), The University of Michigan, 1994

This may be true regarding space architecture. People may expect some form of traditional architecture in order to comfortably navigate and enjoy space stations. Implementing small visual cues and way finding techniques, that indicate the direction of spin and travel could help with familiarization. With the ship having hybrid gravity zones, occupants can select or decompress from the novel experience of microgravity.

It is also expected that as space-faring capabilities increase and construction technology improves over time in a way that more desirable materials can be used such as wood veneers and vinyls to create enjoyable interiors rather than the aluminum plastic NASA aesthetic. Better fire retardation properties and advanced monitoring systems would be needed to ensure safety onboard and to mitigate risk to the fullest extent. Security crew and astronaut commanders onboard would need to intervene and respond to any internal conflict and maintain order to ensure safety.

Once the thrust boosters are fired to maintain a spin rate of 1 rpm, the lower levels will produce 0.75 of gravity. Water systems and storage will exist on the outermost levels to naturally accommodate water flow as well as stability in the ring structure. Depending on the expected weight mass, additional spokes and or cable tethers will need to be added to for structural stability. With the ship almost complete it can now take in tourists at a larger scale.

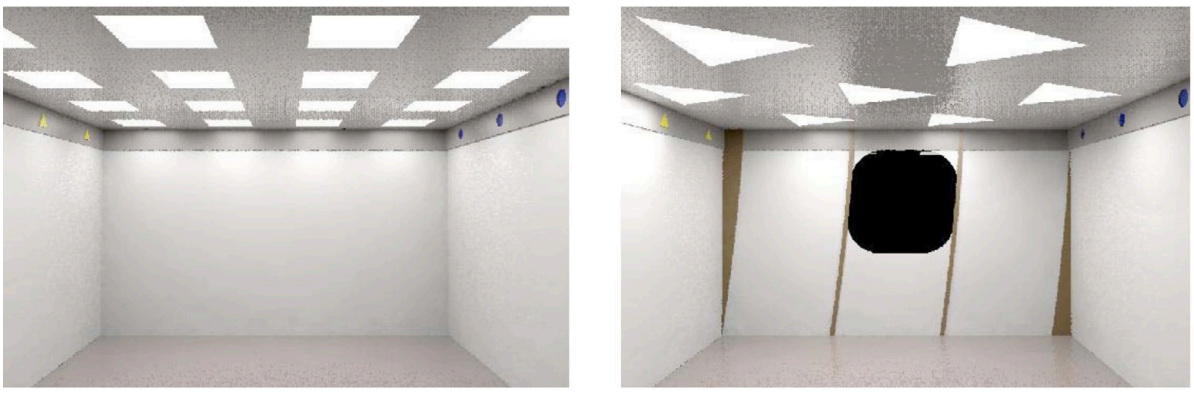


Figure – 4. 29 Experiments in the formal expression of rotation in an artificial-gravity environment, Theodore W. Hall, 1999

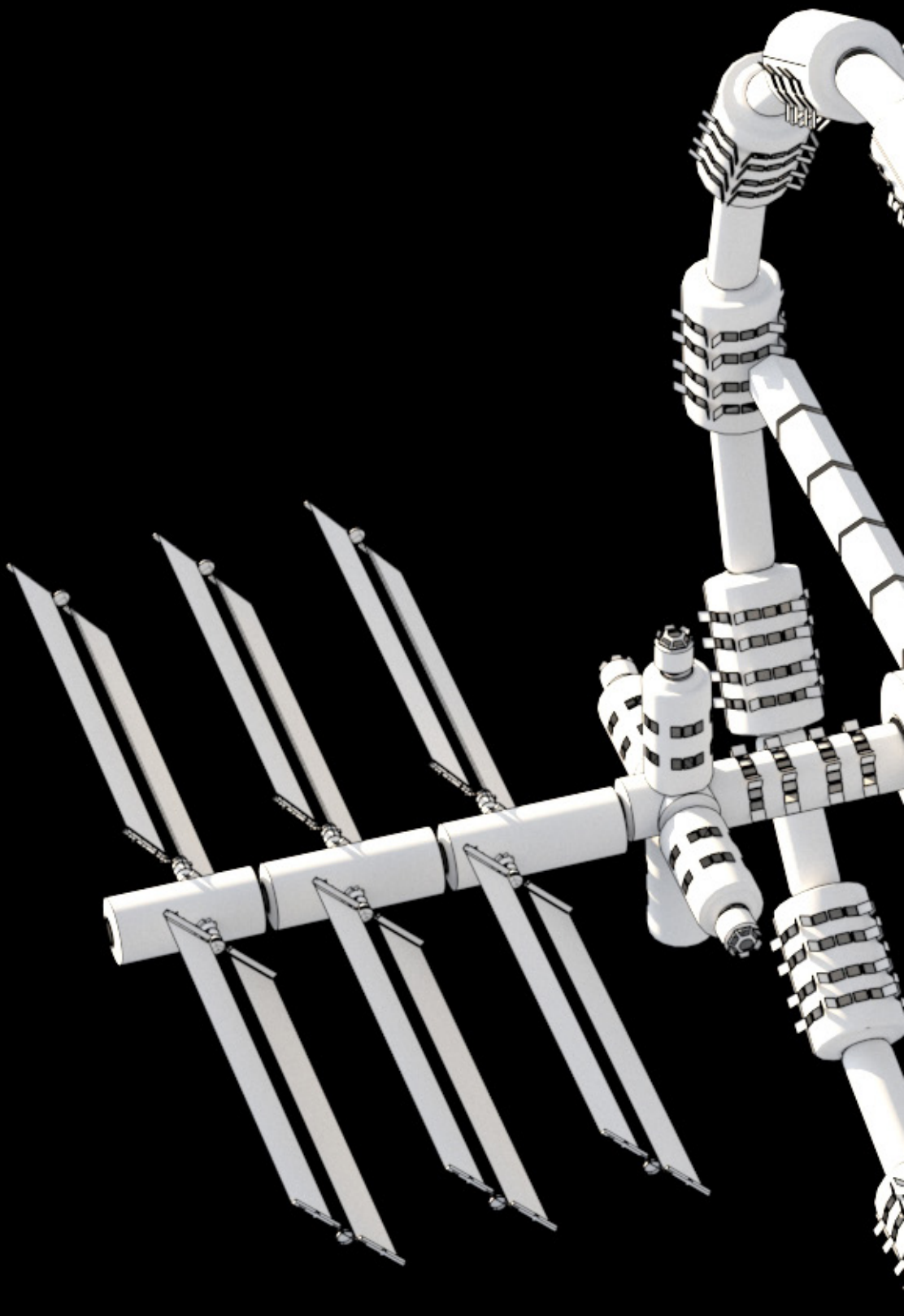


Figure – 4. 30 Phase 6 - Verne Space Station, Image by Author, 2025

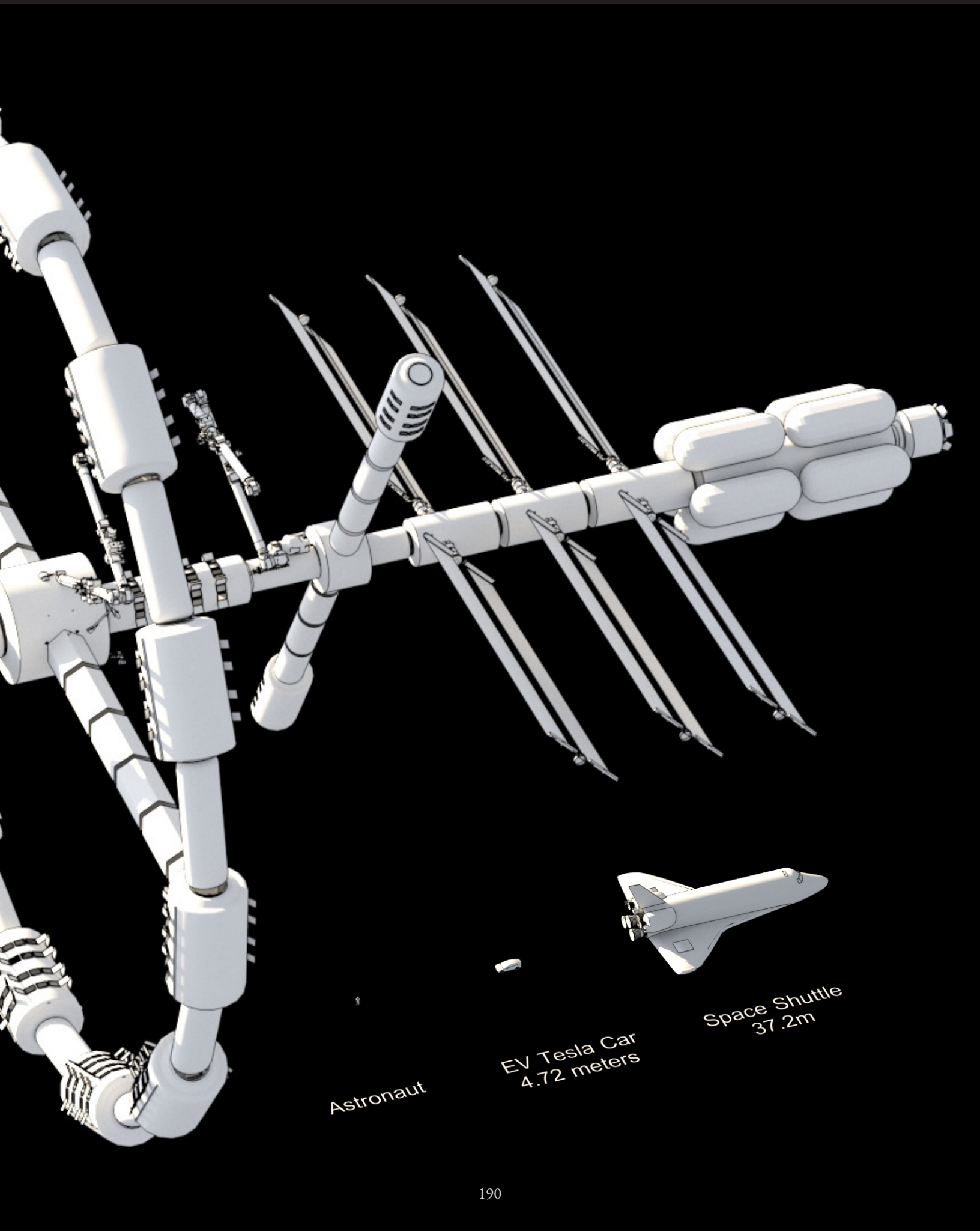

Astronaut
EV Tesla Car
4.72 meters
Space Shuttle
37 .2m



FIGURE – 4. 31 Lighting Study of Ring Module, by Author, 2025

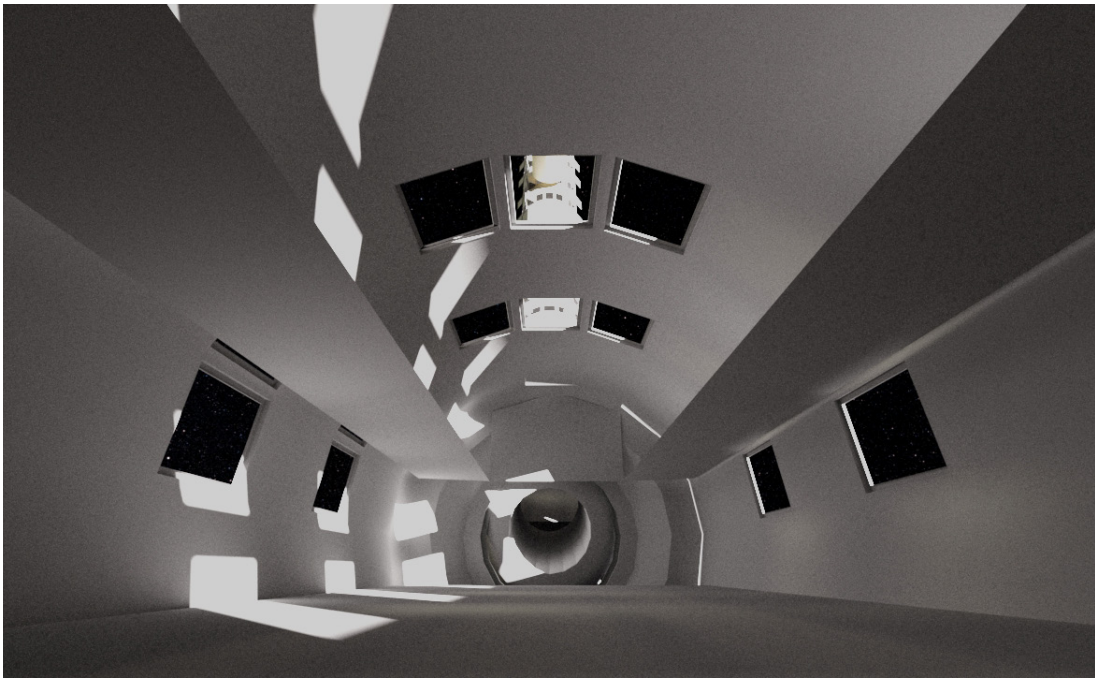


FIGURE – 4. 32 Lighting Study of Ring Module, by Author, 2025

Phase 6: Microgravity Bio-Dome

With the station now almost complete and fully taking in tourists, additional programming regarding recreation and business ventures can be implemented and further developed. Beyond the initial scientific research goals implemented in earlier phases, the recreational hubs and social spaces on board the craft are anticipated to be adapted to the needs of the passengers and crew organically over time. As such, these large volume modules act as a container to the unknown future experiences passengers and crew may need and wish for in microgravity. Recreational sport activities unique to space may also begin to emerge and tested. There is work being advocated by the Space Games Federation for possible sports in zero and micro-gravity environments.[6] Space dodgeball for instance could be wildly chaotic fun.[7] By making standardized modules configurable to accommodate a wide array of programming changes, many more design forms can be experimented with and altered, based on occupant needs.

As the years go by, it is expected that even larger rocket payloads will be possible, making the larger inflatable custom module of the Cupola viable to send into space. Attached to the back (Stern) of the ship, This space will be one of the main hubs on board the station for people to enjoy and take in sights of space, the moon, and the Earth and draws inspiration from the greenhouse-like geodesic domes of the *Valley Forge* depicted in the film *Silent Running* (1972).[8] The main floor surface area populated with small plants and trees would be interconnected with the installation of an additional six pods to house water filtration systems and act as additional storage. This geodesic dome module could be one of the most important places on the ship for food growth and production.

Navigating the Cupola in terms of safety, passengers and crew would be able to tether support hooks and grab bars scattered within the geodesic dome. Passengers would also carry an emergency propellant device to facilitate user movement in case one got stuck *floating*.

---

6 Space Games Federation, n.d., Accessed October 26, 2025, https://spacegamesfederation.com/about/.

7 Leonard David, *Let the Space Games Begin! Ideas for off-Earth Sports Move to Center Court*, Space, January 5, 2022, https://www.space.com/space-sports-ideas-microgravity-games.

8 *Silent Running*, directed by Douglas Trumbull (Universal Pictures, Trumbull/Gruskoff Productions, 1972), 1h29m.

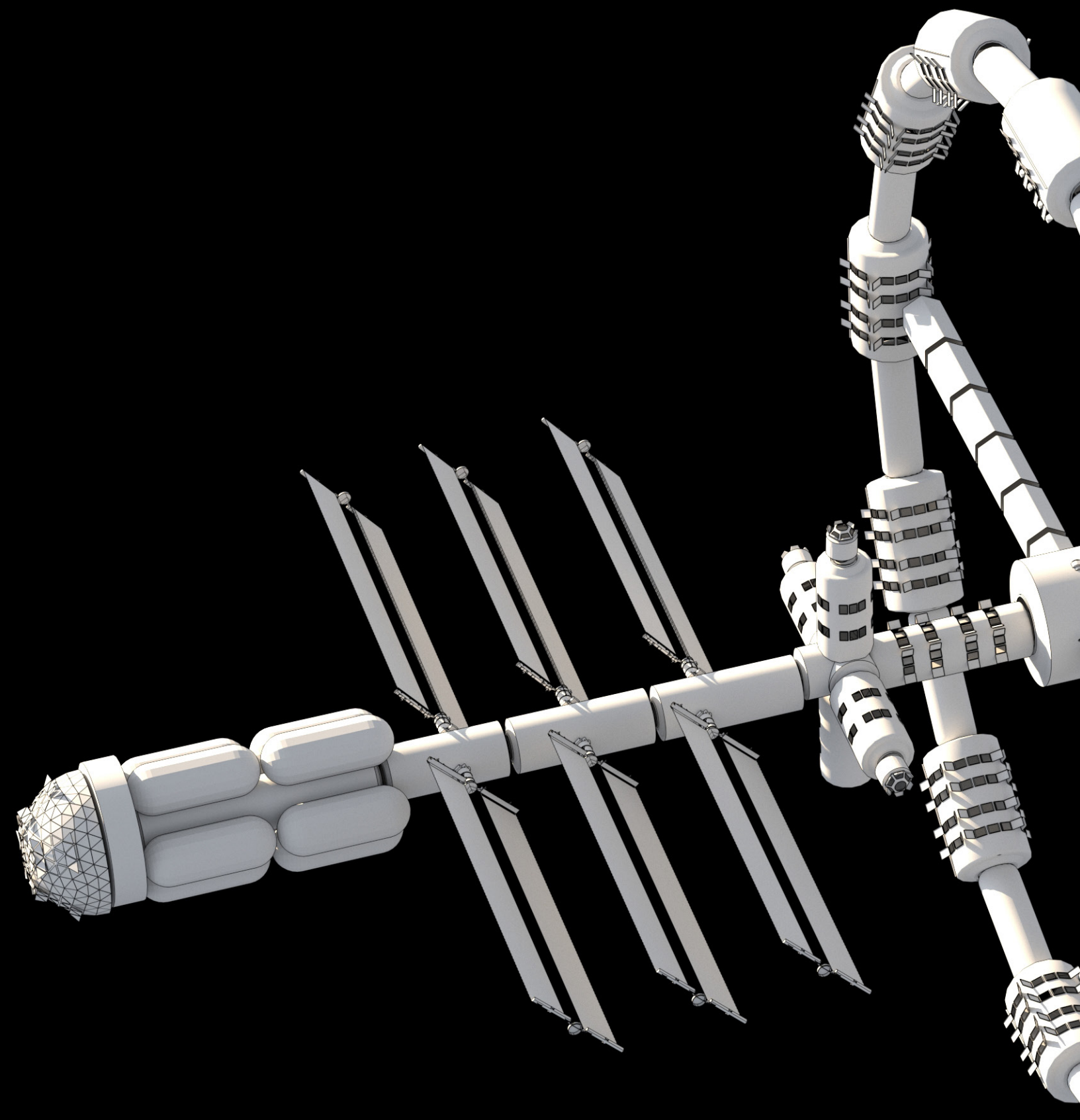
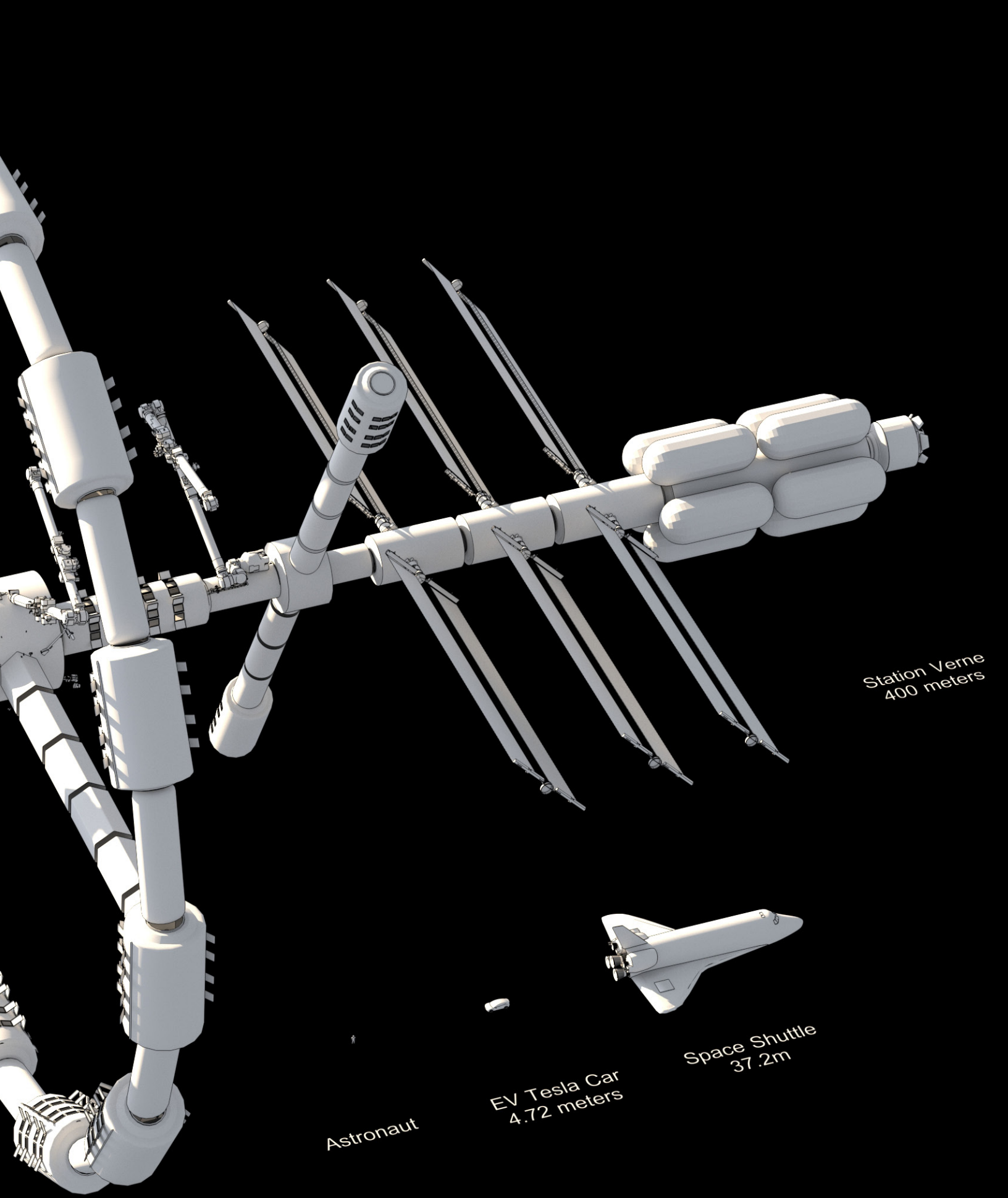


Figure – 4. 33 Final Phase of Space Verne Station, Image by Author, 2025


Station Verne
400 meters
Space Shuttle
37.2m
EV Tesla Car
4.72 meters
Astronaut

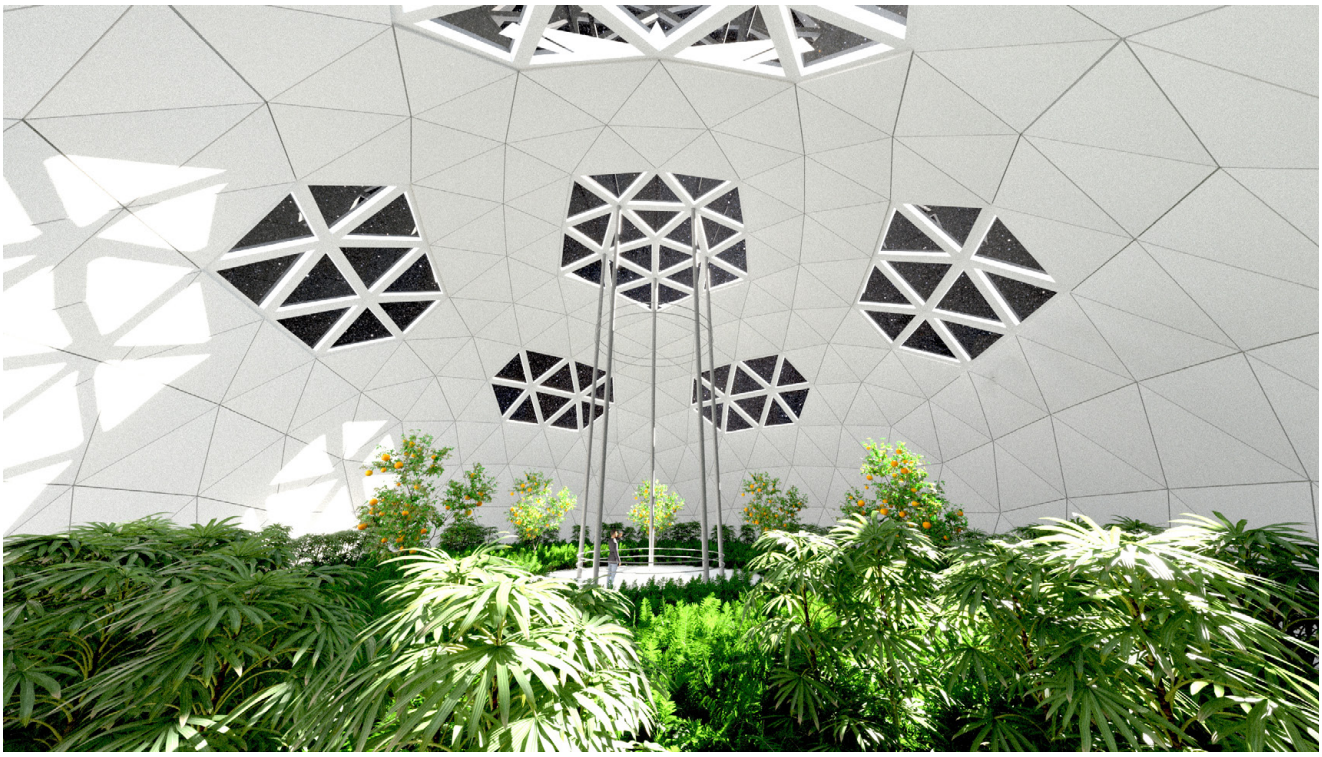


Figure – 4. 34 Interior rendering of Cupola Bio-Dome, Image by Author, 2025

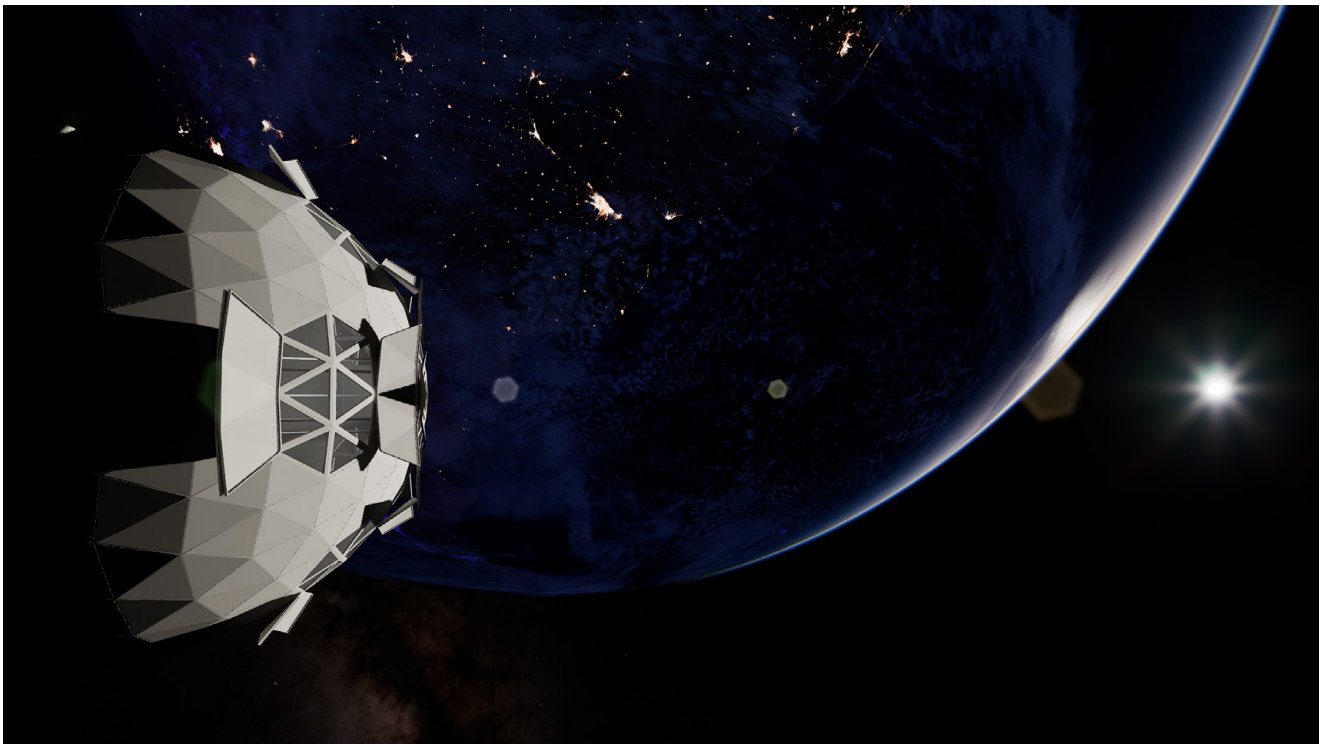


Figure – 4. 35 Exterior view of Bio-dome Module, Unreal Engine screen capture, Image by Author, 2025

With a field of high growth vegetables and fruits below the large windows, the experience will feel surreal floating within the microgravity environment. The interior triangular panel walls are equipped with sensors and ultraviolet (UV) (Light-Emitting Diode) LED modules to facilitate constant plant growth. The shutters that allow sunlight into the volume will automatically close when any micro-meteorites, debris and solar radiation storms are detected. (Figure – 4. 34) Both crew and passengers can be involved in harvesting, cultivating and monitoring the vegetation.

Having spectacular views of space is a critical part of the experience. A smaller cupola located on the front of the craft will have a larger direct view to space. Windows will be standard on all non-rotational parts of the ship. For the main ring, windows would need to be placed strategically to avoid discomfort and disorientation. It is hoped that once Verne Station travels and orbits the Moon, the Lunar surface could facilitate a similar "overview effect" that astronauts have experienced with the Earth. The greater cultural and historical importance of the Moon in our history makes this destination a strategic area to support future Lunar installations. As an end destination hotel in space, leisure activities and planned surface expeditions to the moon would eventually become focal points for tourism. Because of the dangers and risks associated, most ventures will be done by way of teleoperated machines to ensure control and safety. For space tourists with the necessary physical and mental training clearance, actual excursions to the lunar surface could become a possibility alongside other private ventures and space agency facilities.

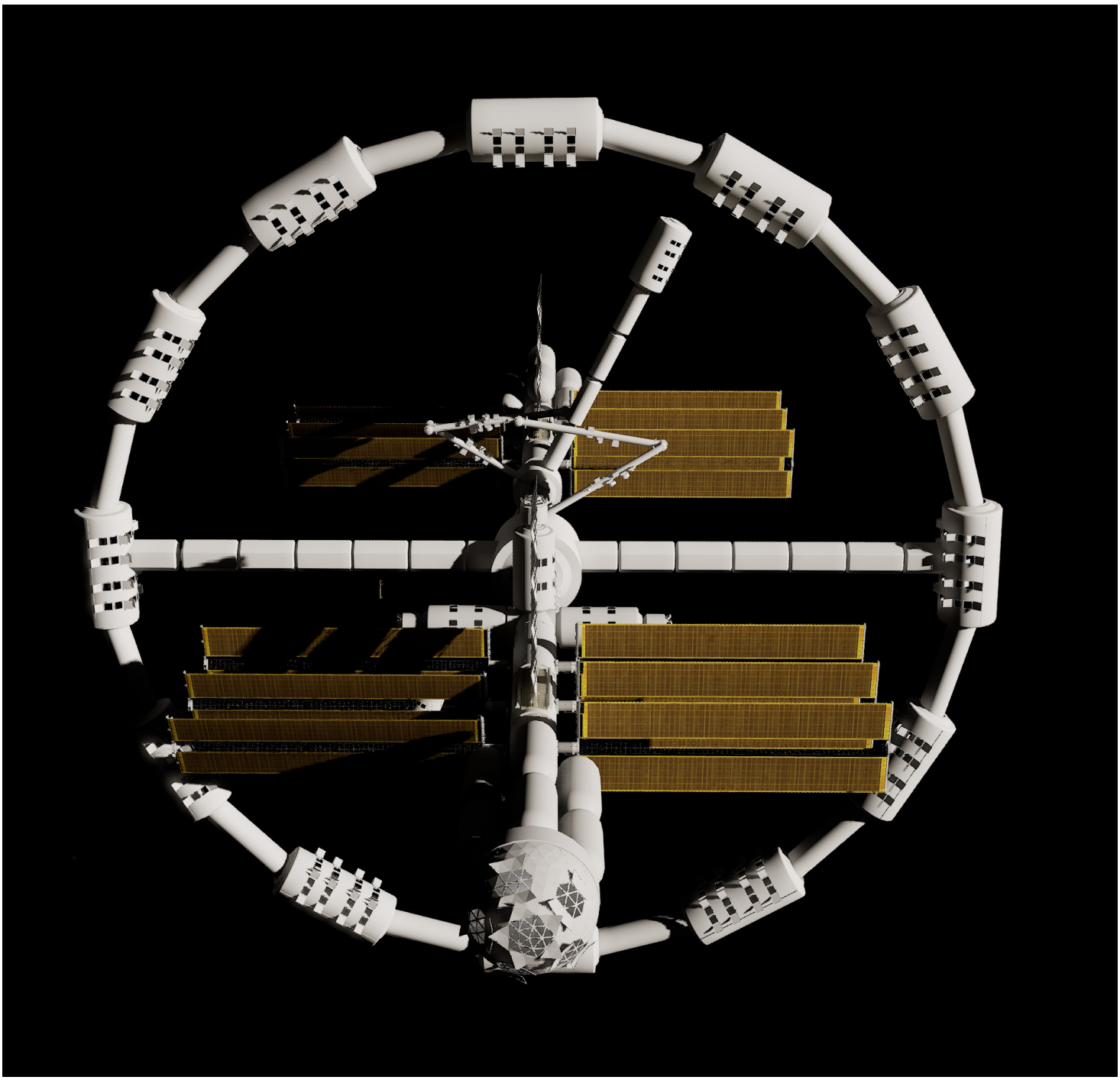


Figure – 4. 36 Exterior view of Verne Station, Unreal Engine screen capture, Image by Author 2025

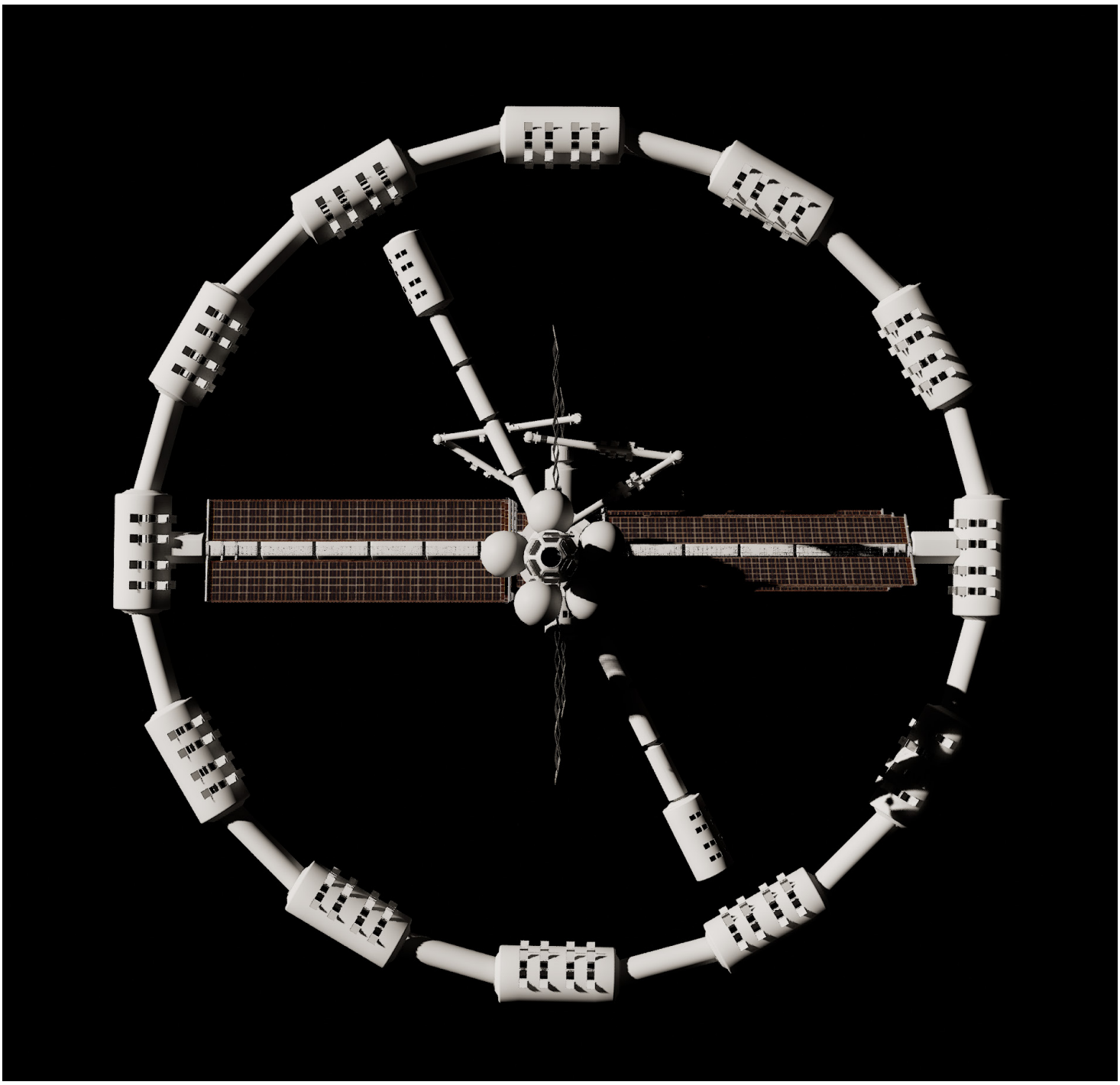


Figure – 4. 37 Elevation, Front of Verne Station, Unreal Engine screen capture, Image by Author, 2025

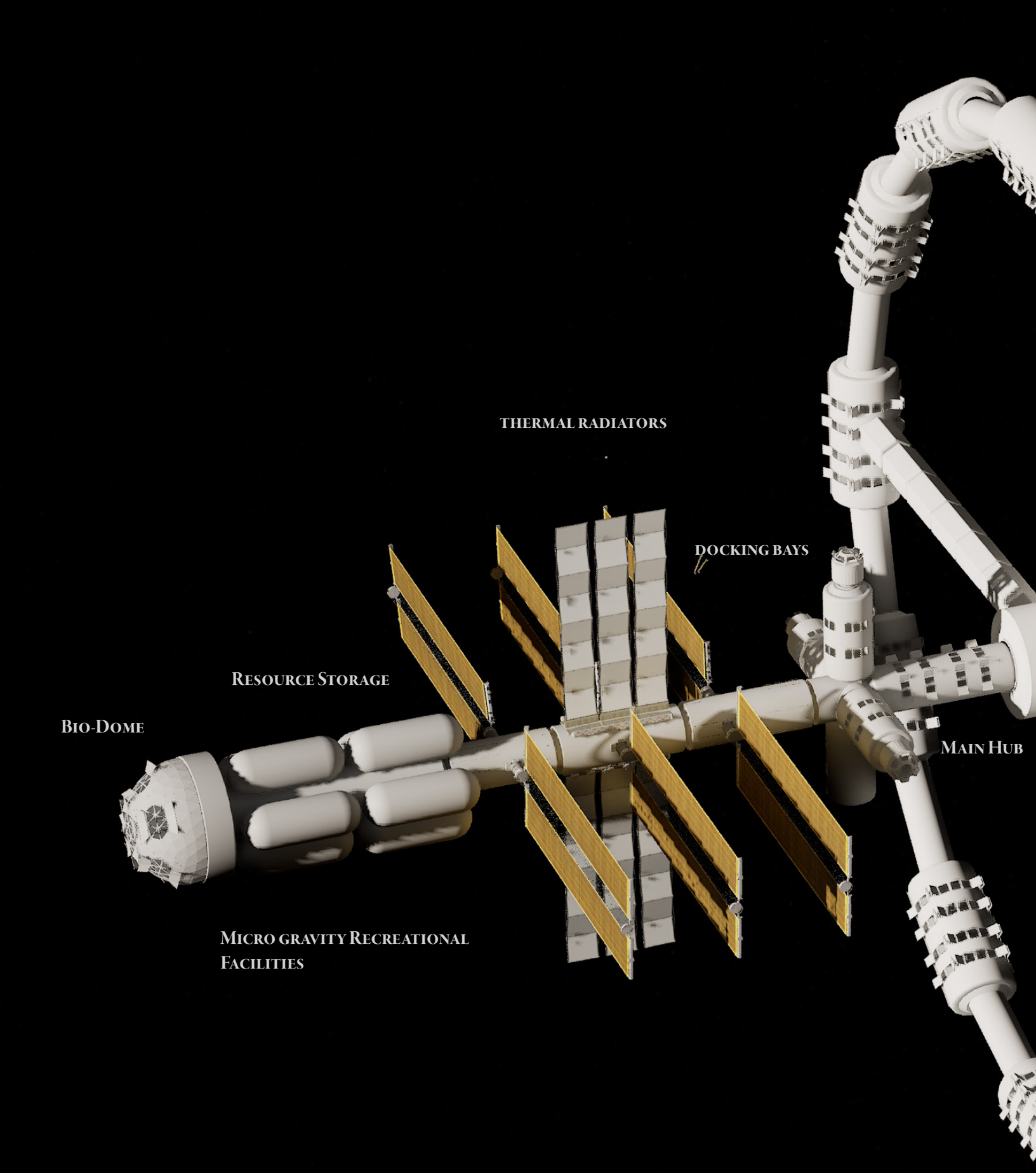


FIGURE – 4. 38 Verne Station diagram, Unreal Engine screen capture, Image by Author, 2025

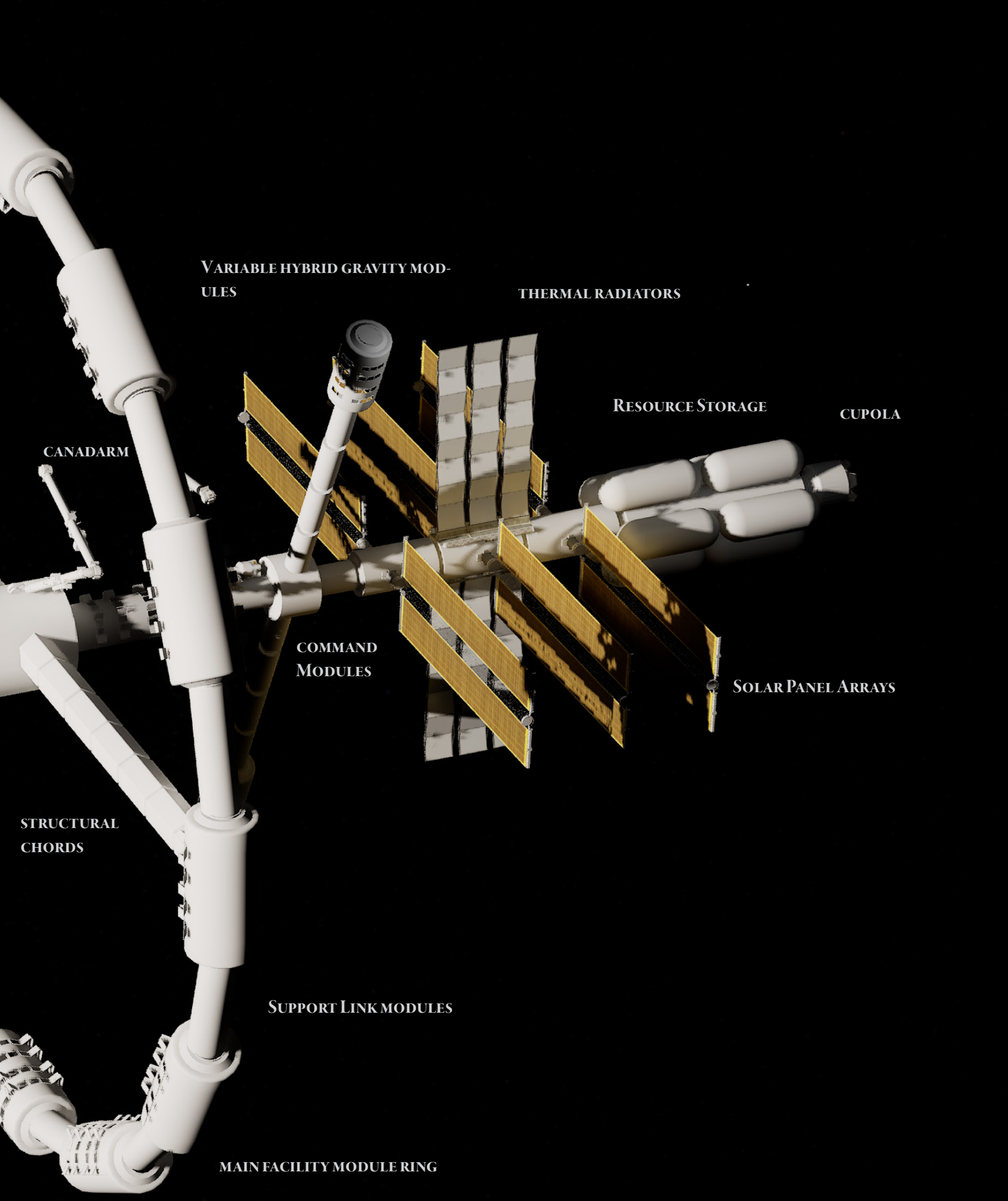

Variable hybrid gravity mod-
ules
thermal radiators
Resource Storage
cupola
canadarm
command
Modules
Solar Panel Arrays
structural
chords
Support Link modules
main facility module ring



FIGURE – 4. 39 Elevation view of Verne Station, Unreal Engine screen capture, Image by Author, 2025

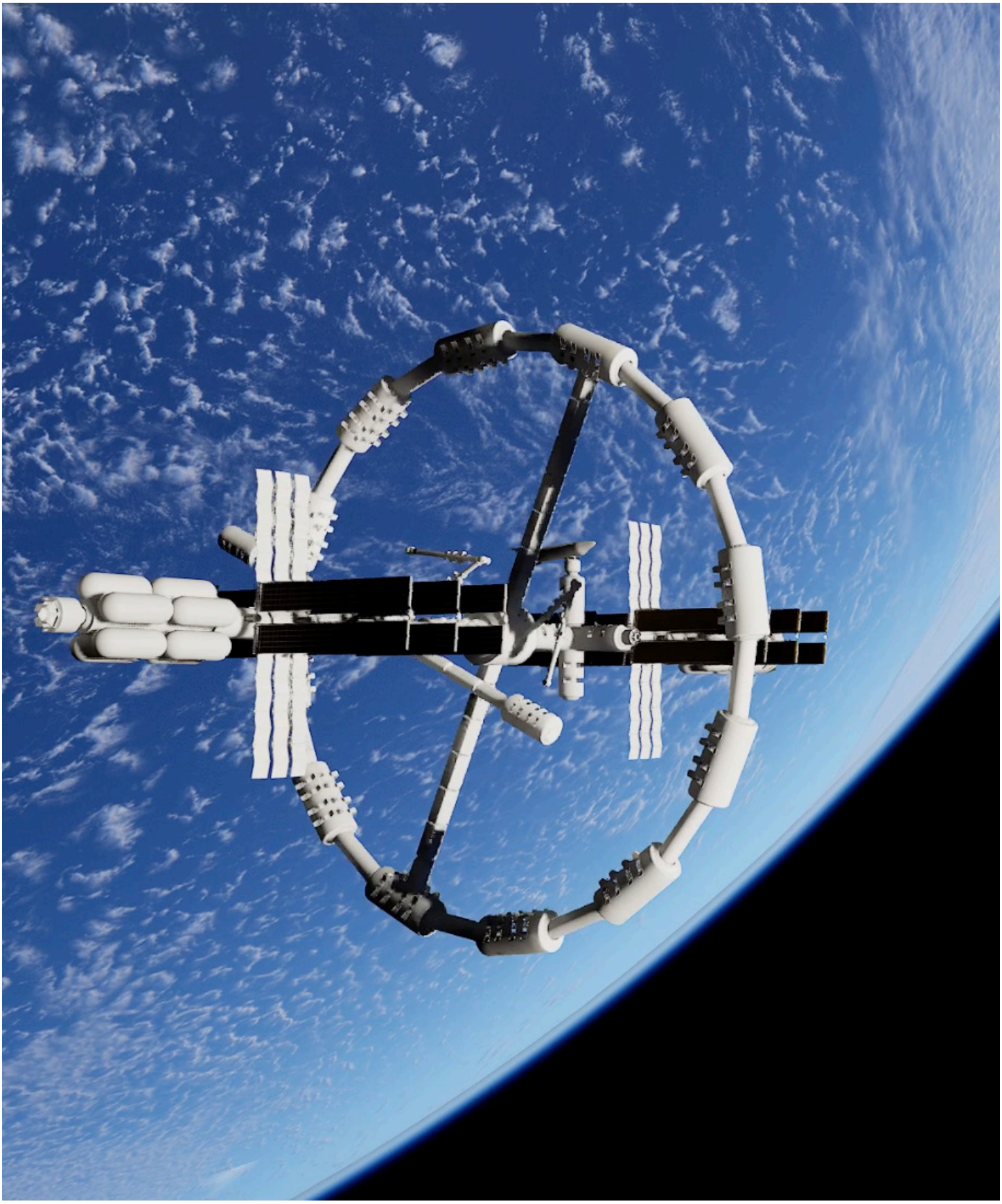


FIGURE – 4. 40 Exterior view of Verne Station, Unreal Engine screen capture, Image by Author, 2025

Phase 7: Existence

Tourism is the life of the station. Unlike earlier phases where only a small number of space-faring tourists can visit the station, the full 500-person capacity of the station is reached with the main ring completed. The numerous module and cargo supply launches, along with the years of construction and maintenance support, easily makes Verne Station a trillion dollar plus endeavour. If the station can maintain long-term safe operation for several years without any critical issues, then its capacity can scale in accordance with tourist expectations of new extraterrestrial experiences, such as landing on the surface of the Moon for instance. As a result, Verne Station, with it's high niche cost to access space, is comparable to that of cruise ships, which operate as decadent floating cities filled with excessive onboard accommodations and amenities such as theatres, swimming pools, ice rinks, food buffets, casinos, etc. With outer space, many of these amenities could be tailored to specific interesting peculiarities to the hybridized gravity environments present. With inflatable technology improvements, it is hoped more refined successors will eventually replace and fix any shortcomings of the original nodes. The difference to obtaining more efficient and functional spaces is understanding the reality of how they exist and how they are used. The novelty of microgravity and artificial gravity in space architecture is the key to making such spaces engaging for sustained appeal and growth.

Building in space is a challenging and daunting feat with several unforeseen events and criteria. The immense benefit of modular architecture means that the construction phases of the ship could be built upon further as long as the main core axis of the ship remains functionally strong. New discoveries, technologies that occur over time can significantly effect how Verne Station operates and is shaped. The rigors of outer space, however, prove that over time, materials face degradation in LEO and that machines eventually fail and prone to human error. Once Verne Station is deemed unfit or obsolete for human occupation, it will eventually become abandoned and left to slowly decay in the vastness of space.

Figure – 4. 41 Exterior view of Verne Station, Unreal Engine screen capture, Image by Author, 2025



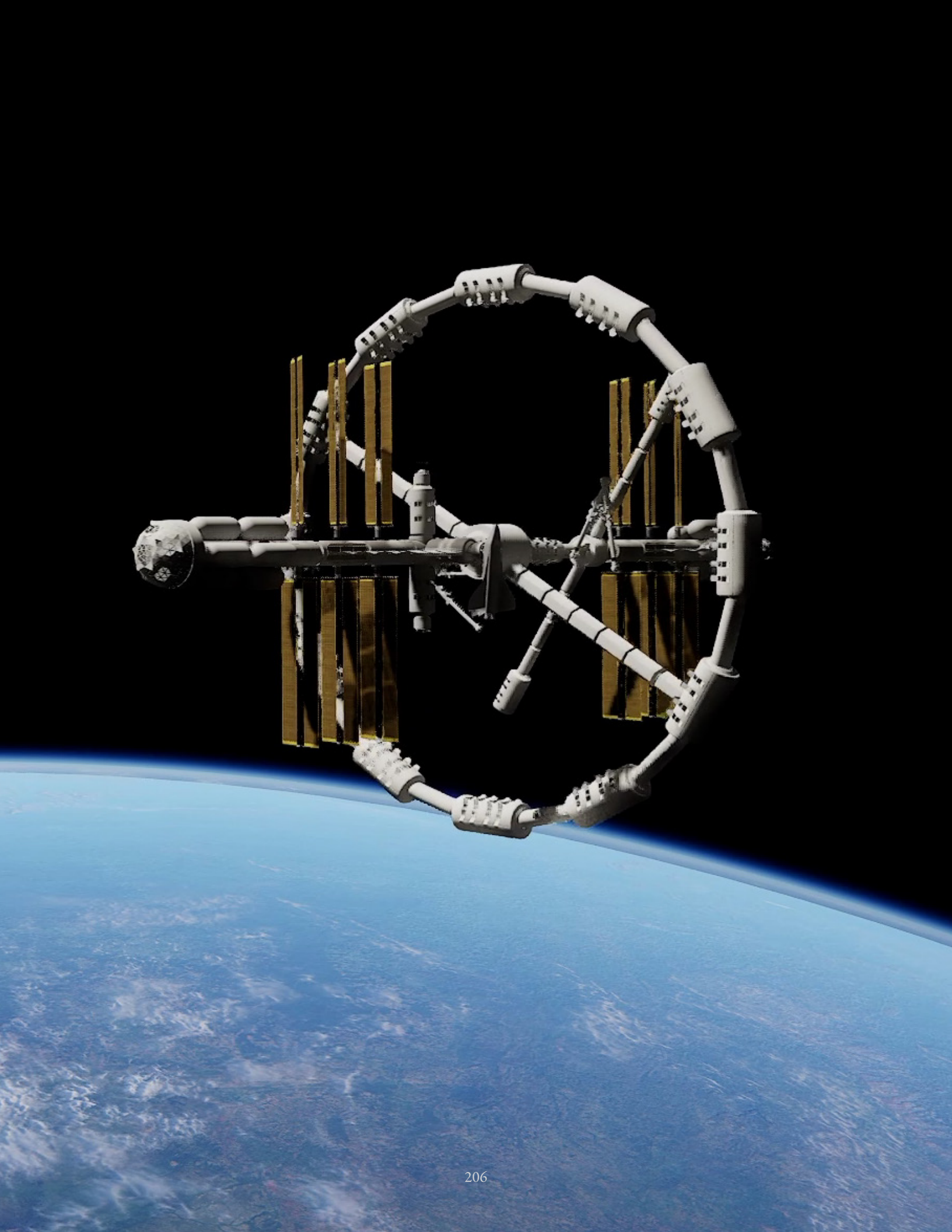
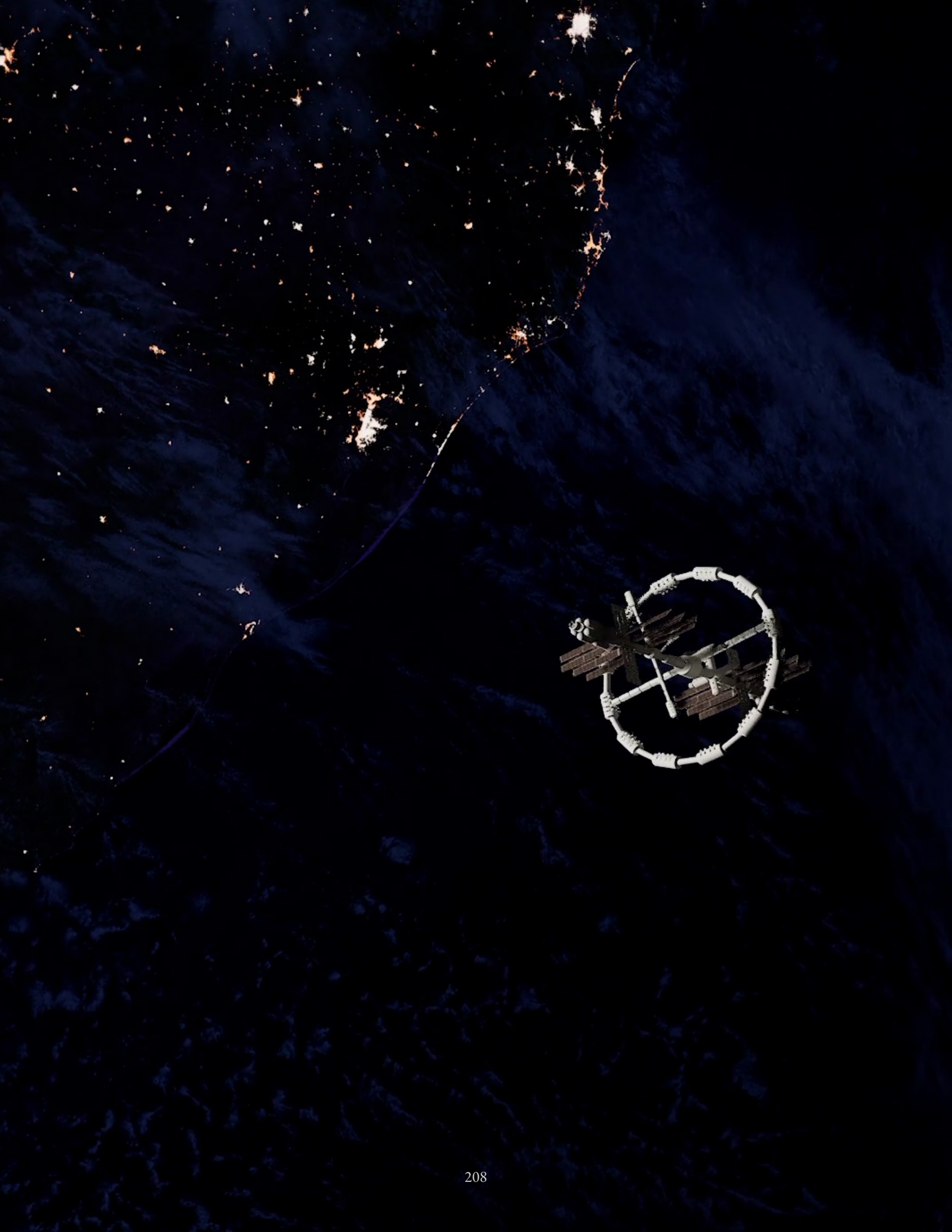




Figure – 4. 42 Exterior night view of Verne Station, Unreal Engine screen capture, Image by Author, 2025



05

Conclusion

Dare to be naïve.

- Richard Buckminster Fuller, Critical Path, 1981

END REMARKS

Architects and designers conceptualize "pretend architecture" through scientific, historical, and creative constructs. Regardless of how absurd or seemingly illogical these visions may appear, the idea that first emerges continues to evolve in response to the constructs, parameters, and limitations imposed upon it. In its infancy, an idea is emboldened and inspirational, animated by the highest aspirations until it must ultimately withstand the brutality of reality.

Designing a space station within a virtual environment provides a powerful means of visualizing and experiencing spatial forms that could not easily exist in the physical world without extraordinary cost. Ultimately, the pursuit of authenticity leads to the striking realization that creating such digital models is an inherently demanding endeavor. The ways in which pretend architecture varies according to perception and environmental parameters invites further examination. For the author, a fundamental question arises: where should one draw the line and define the limits of scope? Once realities and constructs are intertwined and reconciled, the resulting design inevitably challenges that initial, inspiring rationale that first set the creative process in motion.

The illusion of rendering a design that looks, feels, and appears authentic and real, also transforms the design experience in profound ways. There is little doubt that architects will one day play a more substantial role in space architecture-particularly when the constraints of engineering efficiency become less prohibitive. However, that future remains distant. As human-led space missions continue, ensuring that environments are comfortable and accommodating for long-term habitation will remain central to fostering new architectural forms beyond terrestrial boundaries. Although space architecture will likely continue to be defined by the rigors of precision engineering and the substantial costs associated with constructing meaningful spatial experiences, this frontier remains limitless, much as it has long been imagined in works of science fiction.

In short, something like Verne Station should never be actually taken seriously from a practicality standpoint as a viable space station. It is at its core, another act of pretending what life in space could be in some distant future. What it does offer is another version of a concept built from several constructs, in order to critique and ponder the question, what can architecture in space truly look like if we can be immersed in the visualized idea? Much like the designs of older science fiction work and cultural relics

of space travel concepts, once things become a reality, one finds it is harder to go back to outdated and obsolete constructs and viewpoints. The ship being launched by the giant cannon, the *Columbiad* in Jules Verne's *From The Earth To The Moon*, no longer presents itself today as a realistic and believable method today due to our spaceflight achievements. But it did something better over 100 years ago - it helped spur and inspire in some way or another, those responsible for the version of space flight that does exist today.

The romanticized dreams and promises of the early spaceflight days, where space could be accessible to the masses, is still yet to materialize. Today, the space tourism industry exists in its infancy with billionaires leading the charge and those with pockets deep enough to truly afford spaceflight. For government agencies, being an astronaut is based on merit and intense training and qualifications to the most stringent of demands. Despite the subdued state the space industry exists today as, it has not stopped millions from pretending and understanding our existence in outer space through creative outlets such as films and video games. Along with the issues and problems regarding economies, social problems and the pressure for government budgets, there is a negativity that exists towards manned space flight. With the increase of social media, it is easier than ever to see the valid criticisms and concerns regarding who space is for and its perceived value. Public perception plays a large role towards justifying colossal space budgets.

Over the past fifteen years from when research was first done on this thesis, it was NASA's space shuttle program that was being decommissioned versus the ISS today. In the Smithsonian National Air and Space Museum, the *Discovery* Space Shuttle now lives there along with several other relics of a bygone era. Today, spaceflight efforts have shifted to private corporations in order to push for more efficient and cost effective programs and innovation. It is expected that in time, more efficient technologies will allow for future space architects to have a greater voice and role in building and shaping the next frontier in space. If space travel can be affordable and safe, than the realized designs of future space architects and designers may ignite compelling experiences and narratives beyond our dreams. Until then, the future that seems more logical is that unmanned craft will continue to have a greater presence and capability in space than humans. These unmanned craft operate continuously, exploring the cosmos as they have done for decades, with uncontested efficiency.

In conclusion, testing these spaces virtually using a game engine for real time feedback exhibits several design challenges with regard to human comfort and function. Simulations are only as good as the model they are simulating; most cannot encompass and account for everything. In conjunction with analog experimentation and more custom-programmed parameters, models may emerge that can substantiate innovative space architecture designs. NASA and the ESA are using customized game engine software today to drive rigorous astronaut training simulations. Compared to the early days of spaceflight where full scale physical simulators in restricted government spaces were a necessity to train for missions, and computers required entire rooms to house them, the core method of simulating remains the same: to push boundaries safely and efficiently. Game engine technology has evolved to be much more viable, accessible and practical enough to sandbox and explore digital twins of extra-terrestrial environments in the comfort of your home. As such, designing space architecture concepts and testing them robustly in virtual scenarios opens new opportunities to create and evaluate ideas and push boundaries.

This evolution from the earlier 2D video game realm where titles such as S*uper Mario Bros.* existed to entertain and excite players in the comfort of their living room is ultimately special. The Nintendo Entertainment System is ancient in comparison to modern and more powerful video game consoles that have emerged since. But for its time, it delivered unreal experiences to inspire and captivate its audience. And much like other systems that have come after it, the advances in hardware and graphical technology has led to more incredible experiences and much more thought and focus on architectural spaces represented within video games. If game-engine technology can be paired effectively with the right toolsets, the virtual spaces imagined and built by users in the comfort of their homes, may very well engage and inspire new generations to continue to also push design boundaries. Along with the interconnectivity of online gaming, this may be one of the key ways to mass test, simulate and support ideal solutions for future space architecture designs as the industry grows.

For architecture in general, space architecture inevitably has ramifications for sustainable building design. If the Earth was to one day become inhospitable due to pollution and climate change, the need for buildings to function and support life in a closed loop system may very well become a grave reality. In order to protect the only home we have, building settlements in space may be a requirement for us to persevere as a species far into the future.

So to all those who design and dare to dream the impossible - never give up the spirit seeking tangible solutions and realities to the unknown. Even the most absurd ideas can inspire and question generations to follow. How different would today be if Jules Verne never wrote *A Trip to the Moon*, or Tsiokovsky to rebuke it and develop the scientific foundations of space travel theory? Or if JFK never challenged the nation to successfully land astronauts on the Moon before the Soviets? Architecture and more specifically, space architecture, needs that imaginative leap for generations to be inspired. The tools and the technology that exist today can provide insight to new potential architectural designs. The journey along the way in that search for these truths of the cosmos can be spectacular and profound.

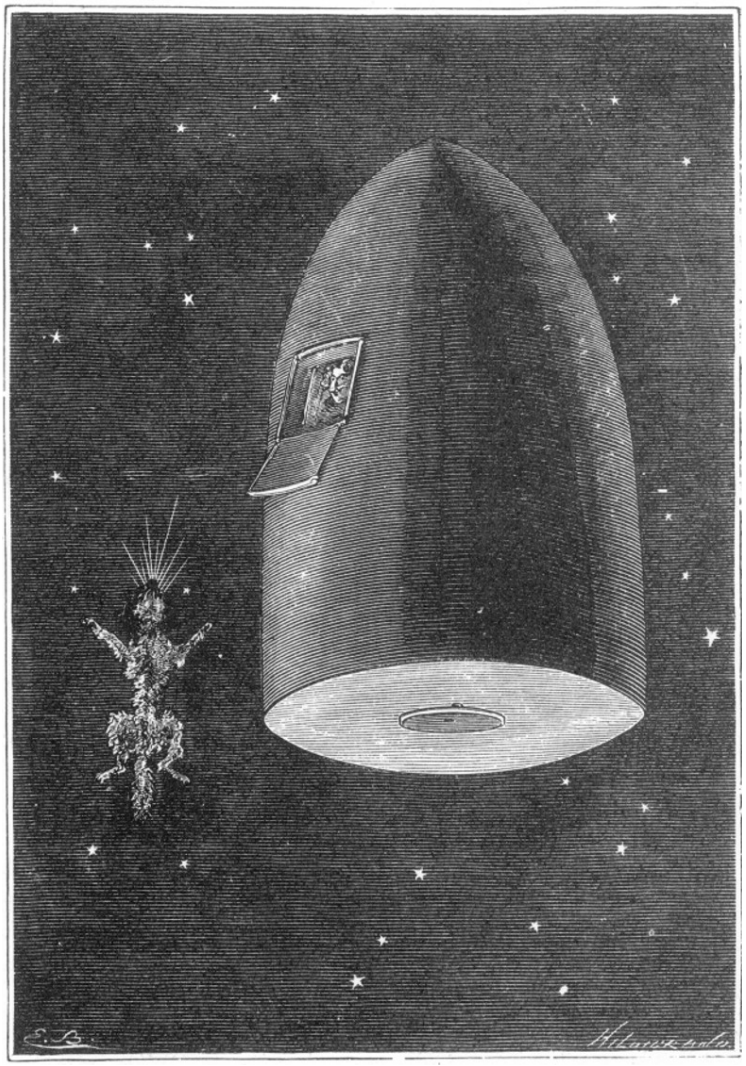


FIGURE – 5. 1 *It was the body of Satellite*, by Emile Bayard, Engraving, 1870, Jules Verne's "*Round The Moon*"

AFTERWORD

Verne Station is ultimately my white whale. Much like Captain Ahab who spent years chasing the elusive Moby-Dick, I ventured into this thesis with a similar obsession. The first couple of years I spent trying to figure out how to complete this thesis left me empty handed in failure. It took me several more years to confront that failure and return to finish what I started. With such a significant gap in time, there exist two versions of my research and writing in this thesis: one from a time when I was completely naive, and the current version, where the technology has changed and improved, and where I am a little less naive. There is beauty in this lengthy passage of time, and it is interesting for me to remember those earlier experiences. Approaching the challenge today with a different perspective and a better understanding of the task required - a complete thesis document - brought about different struggles, including time restraints and conflicting personal responsibilities I did not have years ago. Even with my professional experience, I could not fully achieve everything that I wanted to finish, which was a fully complete, immersive virtual space station environment. I had to limit the scope and be more realistic about my capabilities as I understood the end design solution can be an indefinite, endless task. From that earlier time of my initial attempt, it is clear to see now that the learning experience was the real journey. The constant push and guidance needed to keep going is how you eventually reach your milestones. Ultimately, I am the same person, with the same flaws, but with a lot more gray hairs.

Beyond the technical game engine hurdle, space architecture and spaceflight present one colossal rabbit hole of information and research to digest and understand. There is something absolutely profound, and crazy about wanting to design and test a realistic space station in a video game engine. Much of the cooler spacecraft designs from science fiction are just much more aesthetically pleasing and creatively freeing experiences than what reality dictates. Turning the design of Verne Station into something completely fantastical, rather than realistic, could have been a more interesting experimental and ephemeral design approach. There are visionary artworks by Syd Mead that I want to experience as if they were real, even if they seem entirely fantastical, such as the *Running of the Six Drgxx*. But that is part of the beauty of the process, I wanted to research a creative design of what could be a future reality based on what is currently known, even if it has no chance of being

realized. Something grounded and tangible that feels authentic enough to share. Space architecture is such a completely distinct field from traditional architecture that it encompasses new conditions and parameters different from those of Earth. In fact, space architecture draws more similarities to naval architecture, with its greater complexity and mechanical engineering reliance on a self-contained vessel. The novelty and problem-solving required for future Lunar and Martian settlements, as well as spacecraft colonies, are too interesting to pass up. It may take several decades before architects directly influence and build human settlements in space. For now, virtual and analog environments are the key for exploring what future life may be like living there and inspiring the work needed to one day reach new milestones.

The title of this thesis, *Pretending Architecture*, defines the reality that Verne Station exists as an imagined design concept as there are parts that operate on needed assumptions rather than facts. Simulating pieces of the station with a real-time game engine tests these elements further to inform a better conversation. This can help to create and validate realistic space architecture concepts because they can be more easily visualized and represented. It can reveal unique occurrences you never thought about or expected. For example, realizing how sunlight would behave in space in a much faster day and night cycle around Earth orbit made me realize most of the station windows could create moments of discomfort for occupants. The Cupola module of the ISS has several timelapse videos showcasing how fast light moves in relation. However, the ability to give astronauts spectacular views of the Earth is so crucial and important that not having windows would be a detriment. Much like the Apollo missions, there may be countless hours spent inside simulators and virtual environments to test every scenario needed before the real thing could ever be built. Simulation however, is only as good as the model constructed and what data and technology are available to create it. To maintain real-time performance on consumer grade hardware, parts of the model, such as completely accurate physics or fluid dynamics, are simplified representations. Game engines cannot do everything just yet, but for architectural design, they can provide just enough of an experience that is user friendly. For initial Verne Station designs in the beginning, it was a struggle to even get the main centrifuge working in CryEngine without any programming experience. It all paid off though when I could walk and control my character in game. The feeling of freely exploring the centrifuge space and seeing the curvature of

the ceiling and floor bend in the distance was visually powerful. Compared to the latest version of Unreal Engine, which is so robust and user friendly, with all the tutorials and documentation available online, getting a setup working was much easier. With the right setting of the Datasmith plugin, exporting the main 3D model into the engine became a near seamless experience. If there were more time, I would have developed in detail the outstanding parts of the communal and private spaces of the space station and fully populated the station with characters to animate and make everything feel alive and lived in. The amount of free high-quality assets available online would be more than enough to fully detail, texture and light Verne Station to make it look fantastic. With fully working systems, such as doors and light switches, etc, this would allow for a much better simulated experience of Verne Station as if you were actually on board. Paired with a VR headset, of which I would have to learn how to implement, exploring the ship environment in 1:1 scale would further reveal insightful data to refine the interior design. Such a task though is best suited for beyond this thesis as explained earlier. Making a high-quality video game experience is an incredibly time consuming and complex venture to do by yourself, as I had realized years ago. Designing a realistic space station is even more so.

Dreams of spaceflight and living in outer space are a significant part of our culture today, shaped and transformed over time as new milestones have been reached. Access to outer space remains extremely restricted to the public and will likely continue to be so for many decades. So instead, we imagine, as we have been doing for centuries. Answering unsolvable questions through science fiction and imagining what such experiences may be like allows us to explore possibilities beyond our physical reach. For me, creating a digital twin in a game engine was a compelling way to explore and visualize the idea beyond the initial sketch. For the time being, it may be one of the few ways to translate otherwise impossible to fund and build space architecture design ideas into tangible, visual experiences. Completing this thesis and articulating it on paper was an extremely humbling experience and a longer-than-expected undertaking. I fully expect to continue working on the virtual environment of Verne Station as a personal passion project. It is, after all, still my unignorable white whale.

BIBLIOGRAPHY

Above Space. "Providing More Space in Space." *Above*. Accessed October 24, 2025. https://abovespace.com/the_future.

Acharya, Bharagav, and Joey Roulette. "NASA Says 20% of Workforce to Depart Space Agency." *Reuters*, July 26, 2025. https://www.reuters.com/business/world-at-work/nasa-says-20-workforce-depart-space-agency-2025-07-26/.

Alderson, E. "Making Rocket Fuel From Water." *Medium*, December 19, 2020. https://medium.com/predict/making-rocket-fuel-from-water-26f2673a567f.

Alexander, Bryan. "'Interstellar': Tour The Endurance Ship Online." *USA Today*, November 3, 2014. https://www.usatoday.com/story/life/movies/2014/11/03/interstellar-online-tour-endurance/18370715/.

Allain, Rhett. "How That Spinning Spacecraft From The Martian Would Work." *WIRED*, August 25, 2015. https://www.wired.com/2015/08/spinning-spacecraft-martian-work/.

Anastasia. "The Costs of AAA Game Development: A Financial Analysis." *EJAW*, September 25, 2023. https://ejaw.net/the-rising-costs-of-aaa-game-development/.

Andrews, Bill. "If the Apollo 11 Astronauts Died, Here's the Speech Nixon Would Have Read." *Discover Magazine*, July 19, 2019. https://www.discovermagazine.com/the-sciences/if-the-apollo-11-astronauts-died-heres-the-speech-nixon-would-have-read.

Apple Inc. "Introducing Apple Vision Pro: Apple's First Spatial Computer." *Apple Newsroom (Canada)*, June 5, 2023. https://www.apple.com/ca/newsroom/2023/06/introducing-apple-vision-pro/.

Athow, Desire. "25 Years of Magic: A Look at How the VFX Industry Has Evolved Since Toy Story Debuted." *TechRadar*, November 14, 2020. https://www.techradar.com/news/25-years-of-magic-a-look-at-how-the-vfx-industry-has-evolved-since-toy-story-debuted.

Axiom Space. "World's First Commercial Space Station." Accessed October 24, 2025. https://www.axiomspace.com/.

Basner, Mathias, David F. Dinges, Daniel Mollicone, et al. "Mars 520-D Mission Simulation Reveals Protracted Crew Hypokinesis and Alterations of Sleep Duration and Timing." *Proceedings of the National Academy of Sciences* 110, no. 7 (2013): 2635–40. https://doi.org/10.1073/pnas.1212646110.

Batista, J., J. Vise, and K. Young. "Roll Ring Assemblies for the Space Station." May 1, 1994.

https://ntrs.nasa.gov/citations/19940028788.

Bingham, Lee, Jack Kincaid, Benjamin Weno, Nicholas Davis, Eddie Paddock, and Cory Foreman. "Digital Lunar Exploration Sites Unreal Simulation Tool (DUST)." Paper presented at IEEE Aerospace Conference, Big Sky, MT. n.d. Accessed October 12, 2025. https://ntrs.nasa.gov/citations/20220014707.

Blue Origin. "Fly to Space." *Blue Origin*. Accessed October 15, 2025. https://www.blueorigin.com/new-shepard/fly.

Bradley, Alan. "$800 Million, 13 Years, and Still No Release Date — The State of Star Citizen in 2025." *Space*, June 2, 2025. https://www.space.com/entertainment/space-games/800-million-13-years-and-still-no-release-date-the-state-of-star-citizen-in-2025.

Bukley, Angie, William Paloski, and Gilles Clement. "Physics of Artificial Gravity." January 1, 2006. https://ntrs.nasa.gov/citations/20070001008.

Burden, Ernest E., ed. *Visionary Architecture: Unbuilt Works of the Imagination*. 1. ed. McGraw-Hill, 2000.

Bussell, Cat. "Mass Effect's Gorgeous Sci-Fi Style Can Trace Itself Back to a Titan of the Artistic World." *TechRadar*, November 7, 2023. https://www.techradar.com/gaming/consoles-pc/mass-effects-gorgeous-sci-fi-style-can-trace-itself-back-to-a-titan-of-the-artistic-world.

Bussell, Cat. "Starfield's Ship-Builder Makes Me Feel Like a Kid Again." *TechRadar*, September 25, 2023. https://www.techradar.com/gaming/consoles-pc/starfields-ship-builder-makes-me-feel-like-a-kid-again.

Campbell, Joseph, Bill Moyers, and Betty S. Flowers. *The Power of Myth*. Anchor Books Doubleday, 1991.

Canadian Space Agency. "How to Stay Mentally Healthy in Space." October 7, 2022. https://www.asc-csa.gc.ca/eng/multimedia/search/image/17398.

Cao, Sissi. "What You Pay For Blue Origin's Spaceflight Depends On Who You Are," *Observer.* Accessed April 20, 2025. https://observer.com/2022/06/blue-origin-space-tourism-pricing-marketing/.

Carlson, Cajsa. "Blue Origin Announces Plans for Space Station Orbital Reef." *Dezeen*, October 28, 2021. https://www.dezeen.com/2021/10/28/jeff-bezos-blue-origin-space-station-orbital-reef/.

Carlson, Cajsa. "Hassell Designs Modular Moon Base for the European Space Agency." *Dezeen*, January 19, 2024. https://www.dezeen.com/2024/01/19/hassell-inflatable-moon-base-european-space-agency/.

CERN Courier. "Building Gargantua." *CERN Courier*, November 12, 2019. https://cerncourier.com/a/building-gargantua/.

Charitonidou, Marianna. *Drawing and Experiencing Architecture: The Evolving Significance of City's Inhabitants in the 20th Century*. 1st ed. Vol. 67. Architekturen. Transcript Verlag, 2022. https://doi.org/10.14361/9783839464885.

Chow, Denise. "6 Mock Mars Explorers Emerge from 520-Day Virtual Mission." *Space*, November 4, 2011. https://www.space.com/13500-mock-mars-mission-mars-500-ends.html.

Chu, Jennifer. "Mars One (and Done?)." *MIT News | Massachusetts Institute of Technology*, October 14, 2014. https://news.mit.edu/2014/technical-feasibility-mars-one-1014.

Clément, Gilles, and Angie Bukley, eds. *Artificial Gravity*. The Space Technology Library 20. Springer New York, 2007. https://doi.org/10.1007/0-387-70714-X.

Connell, Dylan, and Briana Zamora. *Through Astronaut Eyes, Virtual Reality Propels Gateway Forward - NASA*. General. April 9, 2024. 134. https://www.nasa.gov/general/through-astronaut-eyes-virtual-reality-propels-gateway-forward/.

Cooper, Keith. "Lagrange Points: Parking Places in Space." *Space*, August 22, 2017. https://www.space.com/30302-lagrange-points.html.

Cranford, Nathan, and Jennifer Turner. "The Human Body in Space" *NASA Science*. February 2, 2021. https://www.nasa.gov/humans-in-space/the-human-body-in-space/.

Crouch, Tom. "The Saga of A Lunar Landscape." *National Air and Space Museum*, January 22, 2010. https://airandspace.si.edu/stories/editorial/saga-lunar-landscape.

Davis, Malcolm. "The Starship Revolution in Space." *The Strategist*, October 16, 2024. https://www.aspistrategist.org.au/the-starship-revolution-in-space/.

De Monchaux, Nicholas. *Spacesuit: Fashioning Apollo*. MIT Press, 2011.

Desjardins, Jeff. "There's Big Money to Be Made in Asteroid Mining." *Visual Capitalist*, November 2, 2016. https://www.visualcapitalist.com/theres-big-money-made-asteroid-mining/.

Diamandis, Peter. "Reconsidering Artificial Gravity for 21st Century Space Habitats." *Space Studies Institute*, n.d. Accessed June 25, 2025. https://ssi.org/programs/ssi-g-lab-project/artificial-gravity-peter-diamandis-1987/.

Dictionary.com. "Dictionary.Com | Meanings & Definitions of English Words." Dictionary.Com, October 24, 2025. https://www.dictionary.com/browse/myth.

Digital, Carter. "Hassell | Lunar Horizons in Fortnite: An Immersive Reimagination of Hassell's

Lunar Habitat Master Plan." Hassell, April 12, 2024. https://www.hassellstudio.com/news-event/lunar-horizons-in-fortnite-an-immersive-reimagination-of-hassells-lunar-habitat-master-plan.

Dingman, Hayden. "Reader Picks: 15 More Classic PC Games You Should Play Again." *PCWorld*, n.d. Accessed September 1, 2025. https://www.pcworld.com/article/426841/reader-picks-15-more-classic-pc-games-you-should-play-again.html.

Discovery, dir. *Classic NASA Film - Skylab - #4*. 2008. 1:45. https://www.youtube.com/watch?v=S_p7LiyOUx0.

Dobrijevic, Daisy. "How Long Does It Take to Get to Mars?" *Space*, January 20, 2022. https://www.space.com/24701-how-long-does-it-take-to-get-to-mars.html.

Dreier, Casey. "The Cost of Perseverance, in Context." *The Planetary Society*. Accessed October 26, 2025. https://www.planetary.org/articles/cost-of-perseverance-in-context.

Dufraigne, Annabelle. "Norman Foster Imagines Future Habitats on Mars and the Moon." *AD Middle East*, April 12, 2025. https://www.admiddleeast.com/story/norman-foster-imagines-future-habitats-on-mars-and-the-moon.

Dunne, Anthony, and Fiona Raby. *Speculative Everything: Design, Fiction, and Social Dreaming*. The MIT Press, 2013.

Dyer, Geoff. *Zona: A Book About a Film About a Journey to a Room*. 1st Vintage books ed. Vintage Books, 2012.

Englefield, Jane. "Moon Village Could Allow People to 'Thrive Over The Long Term' in Space." Architecture. *Dezeen*, July 7, 2021. https://www.dezeen.com/2021/07/07/moon-village-human-centric-inflatable-habitat-the-moon/.

Epic Games. "Discover How the Lunar Horizons Experience in Fortnite Was Made." *Fortnite*, April 11, 2024. https://www.fortnite.com/news/the-making-of-lunar-horizons-in-fortnite-an-immersive-reimagination-of-a-mission-to-the-moon.

European Space Agency. "ESA Space Environment Report 2024." *The Euroepean Space Agency,* July 19, 2024. https://www.esa.int/Space_Safety/Space_Debris/ESA_Space_Environment_Report_2024.

European Space Agency. "Fifth European Conference on Space Debris to Address Key Issues." *The Euroepean Space Agency,* March 25, 2009. https://www.esa.int/About_Us/ESOC/Fifth_European_Conference_on_Space_Debris_to_address_key_issues.

European Space Agency. "Keeping the Rhythm in Space." *The Euroepean Space Agency*, June 15, 2017. https://www.esa.int/Science_Exploration/Human_and_Robotic_Exploration/Research/Keeping_the_rhythm_in_space.

European Space Agency. "Mars500: Study Overview." *The Euroepean Space Agency*. Accessed June 24, 2025. https://www.esa.int/Science_Exploration/Human_and_Robotic_Exploration/Mars500/Mars500_study_overview.

European Space Agency. "The Flight of Vostok 1." *The Euroepean Space Agency*. Accessed July 21, 2025. https://www.esa.int/About_Us/50_years_of_ESA/50_years_of_humans_in_space/The_flight_of_Vostok_1.

Ezra, Elizabeth. *Georges Méliès: The Birth of the Auteur*. French Film Directors. Manchester university press, 2000.

Fortin, David T. *Transcending Space: A Lunar Retreat*. University of Calgary, 2001. https://doi.org/10.11575/PRISM/17027.

Foster&Partners. "Lunar Habitation." *Foster + Partners*. Accessed May 26, 2025. https://www.fosterandpartners.com/projects/lunar-habitation.

Foust, Jeff. "Blue Origin Considers Entering Commercial Space Station Business." *SpaceNews*, September 22, 2020. https://spacenews.com/blue-origin-considers-entering-commercial-space-station-business/.

Fuller, Richard Buckminster, and Kiyoshi Kuromiya. *Critical Path*. St. Martin's Pr, 1981.

Gagarin, Yuri Alekseyevich. *Soviet Man in Space*. University Press of the Pacific, 2001.

Gerber, Andri, and Ulrich Götz, eds. *Architectonics of Game Spaces: The Spatial Logic of the Virtual and Its Meaning for the Real*. Architecture, volume 50. Transcript, 2019.

Ghosn, Rania, and El Hadi Jazairy. *Geostories: Another Architecture for the Environment*. Actar, 2018.

Giger, H. R., and Mia Bonzanigo. *Giger's Alien: Film Design, 20th Century Fox*. 7th print edition. Galerie Morpheus International, 2006.

Goldberg, Harold. "'Starfield': Todd Howard Discusses Bethesda's New Space-Based RPG." Washington Post, June 13, 2021. https://www.washingtonpost.com/video-games/2021/06/13/starfield-bethesda/.

Granath, Bob. "Lunar, Martian Greenhouses Designed to Mimic Those on Earth - NASA." NASA, April 24, 2017. https://www.nasa.gov/science-research/lunar-martian-greenhouses-designed-to-mimic-those-on-earth/.

Grojs, Boris, ed. *Russian Cosmism*. E-flux, 2018.

Gronstal, Aaron L. and Astrobio.net. "Avatars in Space." Accessed July 30, 2025. https://phys.org/news/2010-03-avatars-space.html.

Handmer, Casey. "Starship Moon Base Design Principles." *Casey Handmer's Blog*, June 28, 2021. https://caseyhandmer.wordpress.com/2021/06/28/starship-moon-base-design-principles/.

Hauplik-Meusburger, Sandra, and Olga Bannova. *Space Architecture Education for Engineers and Architects: Designing and Planning Beyond Earth*. Space and Society. Springer, 2016.

Held, Jan, Renaud Vandeghen, Adrien Deliege, et al. *Triangle Splatting for Real-Time Radiance Field Rendering.* Version 1. Preprint, arXiv, 2025. https://doi.org/10.48550/ARXIV.2505.19175.

Hesiod, and Hugh G. Evelyn-White. *Hesiod. The Homeric Hymns. and Homerica*. The Loeb Classical Library 57. Harvard University Press ; Heinemann, 1982.

Hitchcock, John Alexander. "12 Great Sci-Fi Games With Microgravity Mechanics." *Game Rant*, November 19, 2024. https://gamerant.com/sci-fi-games-microgravity-mechanics/.

Hobson, Benedict. "Archigram's Plug-In City Shows That 'Pre-Fabrication Doesn't Have to Be Boring' Says Peter Cook." *Dezeen*, May 12, 2020. https://www.dezeen.com/2020/05/12/archigram-plug-in-city-peter-cook-dennis-crompton-video-interview-vdf/.

Hoover Instituition. "Stanford Emerging Technology Review." *Stanford University*. Accessed July 25, 2025. https://setr.stanford.edu/technology/space/2025.

Horehlad, Jarett. "XR Marks the Spot: This Digital Moonscape Is Helping NASA Make Its Next Giant Leap," *Bentley Blog*. July 14, 2025. https://blog.bentley.com/insights/xr-marks-the-spot-inside-the-digital-moonscape-prepping-nasas-moon-missions/.

Howe, A. Scott, and Brent Sherwood, eds. *Out of This World: The New Field of Space Architecture*. American Institute of Aeronautics and Astronautics, 2009.

Howell, Elizabeth. "International Space Station: Facts, History & Tracking." *Space*, August 24, 2022. https://www.space.com/16748-international-space-station.html.

Howell, Elizabeth. "ISS Leaks Among 50 'Areas of Concern' for Astronaut Safety: Report." *Live Science*, October 26, 2024. https://www.livescience.com/space/space-exploration/iss-leaks-among-50-areas-of-concern-for-astronaut-safety-report.

Howell, Peter. "2001: A Space Odyssey - 50 Facts for 50 Years." *The Star*, December 13, 2018. https://projects.thestar.com/2001-space-odyssey-stanley-kubrick/.

Hunt, Katie. "ISS Gets a Rival with China's Planned Space Station." *CNN*, April 29, 2021. https://www.cnn.com/2021/04/29/world/iss-future-china-space-station-russia-us-intl-scn.

James, Oliver, Eugénie Von Tunzelmann, Paul Franklin, and Kip S. Thorne. "Visualizing *Interstellar*'s Wormhole." *American Journal of Physics* 83, no. 6 (2015): 486–99. https://doi.org/10.1119/1.4916949.

Johnson, Richard D., and Charles Holbrow. "Space Settlements: A Design Study." January 1, 1977. https://ntrs.nasa.gov/citations/19770014162.

Jones, Andrew. "China Completes T-Shaped Tiangong Space Station with New Mengtian Module Move." Space, November 5, 2022. https://www.space.com/china-completes-tiangong-space-station.

Jones, Harry W. "The Recent Large Reduction in Space Launch Cost." Paper presented at International Conference on Environmental Systems (ICES). ARC-E-DAA-TN56851. August 7, 2018, ARC-E-DAA-TN56851. https://ntrs.nasa.gov/citations/20200001093.

Khodadad, Christina L. M., Mary E. Hummerick, LaShelle E. Spencer, et al. "Microbiological and Nutritional Analysis of Lettuce Crops Grown on the International Space Station." *Frontiers in Plant Science* 11 (March 2020): 199. https://doi.org/10.3389/fpls.2020.00199.

Koren, Marina. "The Cost of William Shatner's 'Most Profound Experience.'" *The Atlantic*, October 13, 2021. https://www.theatlantic.com/science/archive/2021/10/william-shatner-blue-origin/620370/.

Krittanawong, Chayakrit, Nitin Kumar Singh, Richard A. Scheuring, et al. "Human Health during Space Travel: State-of-the-Art Review." *Cells* 12, no. 1 (2022): 40. https://doi.org/10.3390/cells12010040.

Kutsal, Melih Gürcan. *Architectural Influences in Video Games: The Sims, SimCity, Control*. Articles. August 3, 2023. https://parametric-architecture.com/a-journey-through-the-evolution-of-architectural-influences-in-video-games-the-sims-simcity-and-control/.

Landon, Lauren Blackwell, Kelley J. Slack, and Jamie D. Barrett. "Teamwork and Collaboration in Long-Duration Space Missions: Going to Extremes." *American Psychologist* 73, no. 4 (2018): 563–75. https://doi.org/10.1037/amp0000260.

Lansing, Alfred. *Endurance: Shackleton's Incredible Voyage*. Basic Books, 2015.

Leonard, David. "Let the Space Games Begin! Ideas for off-Earth Sports Move to Center Court." *Space*, January 5, 2022. https://www.space.com/space-sports-ideas-microgravity-games.

Levitt, Andrew. *The Inner Studio: A Designer's Guide to the Resources of the Psyche*. Riverside Architectural Press, 2007.

Lightman, Herb A. "Filming 2001: A Space Odyssey." The American Society of

Cinematographers, April 3, 2018. https://theasc.com/articles/filming-2001-a-space-odyssey.

Lomberg, Jon. "An Ode to Syd Mead, the Old-School Artist Who Designed Our Future." *Slate Magazine*, January 8, 2020. https://slate.com/technology/2020/01/syd-mead-blade-runner-future-obituary.html.

Loy, Laura S., Kevin Steppler, Inna Kliachko, et al. "A Virtually-Induced Overview Effect? How Seeing the World from above through a Simulated Space Tour Is Related to Awe, Global Identity and pro-Environmental Behaviour." *Journal of Environmental Psychology* 99 (November 2024): 102428. https://doi.org/10.1016/j.jenvp.2024.102428.

MacIntosh, Reggie Wade. *HORIZON*. University of Waterloo, October 22, 2010. http://hdl.handle.net/10012/5603.

Maffei, Massimo E., Raffaella Balestrini, Paolo Costantino, et al. "The Physiology of Plants in the Context of Space Exploration." *Communications Biology* 7, no. 1 (2024): 1311. https://doi.org/10.1038/s42003-024-06989-7.

Marino, Bruno D.V., Tilak Ram Mahato, John W. Druitt, et al. "The Agricultural Biome of Biosphere 2:" *Ecological Engineering* 13, nos. 1–4 (1999): 199–234. https://doi.org/10.1016/S0925-8574(98)00100-1.

McCurdy, Howard E. *Space and the American Imagination*. Smithsonian History of Aviation Series. Smithsonian Institution Press, 1997.

Mead, Syd, Craig Hodgetts, and Denis Villeneuve. *The Movie Art of Syd Mead: Visual Futurist*. First edition. Titan Books, 2017.

Melville, Herman, and Tom Quirk. *Moby-Dick, or, The Whale*. Penguin Classics. Penguin Books, 1992.

Merin, Gili. "AD Classics: The Plug-In City / Peter Cook, Archigram." *ArchDaily, July 10, 2013*. https://www.archdaily.com/399329/ad-classics-the-plug-in-city-peter-cook-archigram.

Middleton, Natalie. "Meet the Zinnias Astronaut Scott Kelly Grew in Space," *Orion Magazine*, February 6, 2023. https://orionmagazine.org/article/astronaut-scott-kelly-flower-experiment-space/.

Muhoney, Erin. *NASA Provides Updated International Space Station Transition Plan - NASA*. Humans in Space. January 31, 2022. 113. https://www.nasa.gov/humans-in-space/nasa-provides-updated-international-space-station-transition-plan/.

Nadrag, P., A. Maseda, C. Grosdemouge, et al. "Remote Control of a Real Robot Taking into Account Transmission Delays." *IFAC Proceedings Volumes* 43, no. 13 (2010): 59–64. https://doi.org/10.3182/20100831-4-FR-2021.00012.

Narici, Livio, Marco Casolino, Luca Di Fino, et al. "Performances of Kevlar and Polyethylene as Radiation Shielding On-Board the International Space Station in High Latitude Radiation Environment." *Scientific Reports* 7, no. 1 (2017): 1. https://doi.org/10.1038/s41598-017-01707-2.

Nasa Communications. "The Crew of the Space Shuttle Challenger STS-51L Mission," *NASA History*. February 3, 2003. https://www.nasa.gov/history/the-crew-of-the-space-shuttle-challenger-sts-51l-mission/.

NASA Science. "20 Breakthroughs from 20 Years of Science Aboard the International Space Station". *NASA Science,* October 26, 2020. https://www.nasa.gov/missions/station/20-breakthroughs-from-20-years-of-science-aboard-the-international-space-station/.

NASA Science. "Bigelow Expandable Activity Module (BEAM)." *NASA Science*. Accessed April 20, 2025. https://www.nasa.gov/international-space-station/bigelow-expandable-activity-module-beam/.

NASA Science. "Dr. Robert H. Goddard, American Rocketry Pioneer." *Goddard Space Flight Center.* n.d. Accessed October 24, 2025. https://www.nasa.gov/dr-robert-h-goddard-american-rocketry-pioneer/.

NASA Science. "FAQs : The International Space Station Transition Plan," *NASA Science*. July 18, 2024. https://www.nasa.gov/faqs-the-international-space-station-transition-plan/.

NASA Science. "First Flower Grown in Space Station's Veggie Facility," *NASA Science*. January 19, 2016. https://www.nasa.gov/image-article/first-flower-grown-space-stations-veggie-facility/.

NASA Science. "First Mars Crew Completes Yearlong Simulated Red Planet NASA Mission," *NASA Science*. Crew Health and Performance Exploration Analog (CHAPEA). July 10, 2024. https://www.nasa.gov/missions/analog-field-testing/chapea/first-mars-crew-completes-yearlong-simulated-red-planet-nasa-mission/.

NASA Science. "Growing Plants in Space," *NASA Science*. Kennedy Space Center. n.d. Accessed July 20, 2025. https://www.nasa.gov/exploration-research-and-technology/growing-plants-in-space/.

NASA Science. "Ingenuity Mars Helicopter," *NASA Science*. Ingenuity (Helicopter). April 8, 2024. 137. https://science.nasa.gov/mission/mars-2020-perseverance/ingenuity-mars-helicopter/.

NASA Science. "International Space Station Cooperation." *NASA Science*. n.d. Accessed October 25, 2025. https://www.nasa.gov/international-space-station/space-station-international-cooperation/.

NASA Science. "International Space Station Visitors by Country," *NASA Science*. International Space Station (ISS). n.d. Accessed October 15, 2025. https://www.nasa.gov/

international-space-station/space-station-visitors-by-country/.

NASA Science. "Materials International Space Station Experiment-X (MISSE-X)," *NASA Science*. Accessed August 8, 2025. https://www.nasa.gov/materials-international-space-station-experiment-x-misse-x/.

NASA Science. "Spacecraft to Remove Orbital Debris." *NASA Science*. Accessed July 25, 2025. https://technology.nasa.gov/patent/MSC-TOPS-90.

NASA Science. "Station Maneuvers to Avoid Orbital Debris," *NASA Science*. Accessed April 30, 2025. https://www.nasa.gov/blogs/spacestation/2025/04/30/station-maneuvers-to-avoid-orbital-debris/.

NASA Science. "The Air Up There Making Space Breathable." *NASA Jet Propulsion Laboratory (JPL)*. Accessed August 3, 2025. https://www.jpl.nasa.gov/edu/resources/lesson-plan/the-air-up-there-making-space-breathable/.

NASA Science. "Virtual Reality Training Lab," *NASA Science*. n.d. Accessed July 30, 2025. https://www.nasa.gov/virtual-reality-lab-doug/.

NASA Science. "Von Braun's Early Wheel Space Station Concept," *NASA Science*. Accessed October 26, 2025. https://www.nasa.gov/image-article/von-brauns-early-wheel-space-station-concept/.

NASA Science. "Voyager," *NASA Missions*. December 8, 2023. https://science.nasa.gov/mission/voyager/.

NASM. "Why Did We Stop Going to the Moon?" *National Air and Space Museum*, November 9, 2021. https://airandspace.si.edu/stories/editorial/why-did-we-stop-going-moon.

National Air and Space Museum. "Headset, Virtual Reality, Prototype." *Smithsonian*. Accessed November 5, 2025. https://airandspace.si.edu/collection-objects/headset-virtual-reality-prototype/nasm_A19970613000.

Netti, Vittorio. "Design of an Autonomous and Teleoperated Modular Robotic Free-Flyer for EVA Operations." Paper presented at ASCEND 2020, Virtual Event. *ASCEND 2020*, American Institute of Aeronautics and Astronautics, November 16, 2020. https://doi.org/10.2514/6.2020-4257.

Netti, Vittorio. "DMF: Deployable Modular Frame for Inflatable Space Habitats." *The International Astronautical Congress*, 2018.

Netti, Vittorio. "Life 1 | Sierra Space Commercial Space Station," *Vittorio Netti.* Accessed May 26, 2025. https://www.vittorionetti.com/projects/life-1-sierra-space-commercial-space-station.

Netti, Vittorio, and Olga Bannova. *Space Architecture: Designing Beyond the Sky*. V (November

2021): 76–91.

Neufeld, Michael. "Why Has It Been 50 Years Since Humans Went to the Moon?" *National Air and Space Museum*, December 16, 2022. https://airandspace.si.edu/stories/editorial/why-50-years-since-humans-went-moon.

NewMexicoSpaceMuseum. "Konstantin E. Tsiolkovsky." *Konstantin E. Tsiolkovsky*, n.d. Accessed August 27, 2025. https://nmspacemuseum.org/inductee/konstantin-e-tsiolkovsky/.

Nitsche, Michael. *Video Game Spaces: Image, Play, and Structure in 3D Worlds*. MIT Press, 2009.

Nixon, Adrian, John Knapman, and Dennis H. Wright. "Space Elevator Tether Materials: An Overview of the Current Candidates." *Acta Astronautica* 210 (September 2023): 483–87. https://doi.org/10.1016/j.actaastro.2023.04.008.

Nixon, David. *International Space Station: Architecture Beyond Earth*. Circa, 2016.

North, Dan. "A Trip to the Moon / Le Voyage Dans La Lune (1902)." *Spectacular Attractions*, June 10, 2010. https://drnorth.wordpress.com/2010/06/10/a-trip-to-the-moon-le-voyage-dans-la-lune/.

NVIDIA Corporation. "NVIDIA GeForce RTX 5090 Graphics Cards." *NVIDIA*. Accessed October 19, 2025. https://www.nvidia.com/en-us/geforce/graphics-cards/50-series/rtx-5090/.

O'Callaghan, Jonathan. "Goodbye Mars One, The Fake Mission To Mars That Fooled The World." *Forbes*. Accessed October 23, 2025. https://www.forbes.com/sites/jonathanocallaghan/2019/02/11/goodbye-mars-one-the-fake-mission-to-mars-that-fooled-the-world/.

Ovid, and D. A. Raeburn. *Metamorphoses: A New Verse Translation*. Penguin, 2004.

Oxenhandler, Lea. "Modeling a Base on Mars." *Kieran Timberlake*, May 16, 2014. https://kierantimberlake.com/posts/view/264.

PaleBlue. "PaleBlue Provides a VR Simulator for the ISS." *PaleBlue*, August 12, 2020. https://pale.blue/2020/08/12/paleblue-provides-a-vr-simulator-for-the-iss/.

Patches, Matt. "Talking to Syd Mead: The Visionary Behind Elysium, Blade Runner, and 40 Years of Sci-Fi." *Vulture*, August 8, 2013. https://www.vulture.com/2013/08/syd-mead-design-blade-runner-aliens-elysium.html.

Pearlman, Robert Z. "NASA's First Mars Lander Makes a Cameo in 'The Martian.'" *Christian Science Monitor*, October 4, 2015. https://www.csmonitor.com/Science/2015/1004/NASA-s-first-Mars-lander-makes-a-cameo-in-The-Martian.

Peoples, Columba. "*Sputnik* and 'Skill Thinking' Revisited: Technological Determinism in American Responses to the Soviet Missile Threat." *Cold War History* 8, no. 1 (2008): 55–75. https://doi.org/10.1080/14682740701791334.

Peters, Brady, and Terri Peters. *Computing the Environment: Digital Design Tools for Simulation and Visualisation of Sustainable Architecture*. AD Smart 06. Wiley, 2018. https://doi.org/10.1002/9781119097921.

Powell, Corey S. "The ISS Was Never Supposed to End like This." *NBC News*, February 22, 2018. https://www.nbcnews.com/mach/science/iss-was-never-supposed-end-ncna848771.

Quazi, Saimoon. "Simulating the Moon, From The Comfort of Home." *Medium*, June 25, 2023. https://space-travel.blog/ulysses-1f4342d04f66.

Rawn, Evan. "Unreal Visualizations: 3 Pros and 3 Cons of Rendering with a Video Game Engine." *ArchDaily*, March 10, 2015. https://www.archdaily.com/607849/unreal-visualizations-3-pros-and-3-cons-of-rendering-with-a-video-game-engine.

Ren, Xuanchi, Tianchang Shen, Jiahui Huang, et al. "GEN3C: 3D-Informed World-Consistent Video Generation with Precise Camera Control." Version 1. Preprint, arXiv, 2025. https://doi.org/10.48550/ARXIV.2503.03751.

Roberts, Thomas. "Cost for Space Launch to Low Earth Orbit- Aerospace Security Project." *Aerospace Security*, September 1, 2022. https://aerospace.csis.org/data/space-launch-to-low-earth-orbit-how-much-does-it-cost/.

Rocket Lab. "Rocket Lab | The Space Company." *Rocket Lab Corporation*. Accessed October 24, 2025. https://rocketlabcorp.com/home/.

Sadler, Simon. *Archigram: Architecture Without Architecture*. MIT press, 2005.

Sagan, Carl. *Pale Blue Dot: A Vision of the Human Future in Space*. 1st ed. Random House, 1994.

Saldana, Shay. "Sierra Space Advances Its Revolutionary Commercial Space Station Technology." *Sierra Space*, January 22, 2024. https://www.sierraspace.com/press-releases/sierra-space-advances-its-revolutionary-commercial-space-station-technology/.

Seedhouse, Erik. "International Space Station Life Support System." In *Life Support Systems for Humans in Space*, edited by Erik Seedhouse. Springer International Publishing, 2020. https://doi.org/10.1007/978-3-030-52859-1_5.

Seedhouse, Erik. *Tourists in Space: A Practical Guide*. 2nd ed. 2014. Tourists in Space. Springer, 2014.

Seyb, Dario, Peter-Pike Sloan, Ari Silvennoinen, Michał Iwanicki, and Wojciech Jarosz. "The

Design and Evolution of the UberBake Light Baking System." *ACM Transactions on Graphics* 39, no. 4 (2020). https://doi.org/10.1145/3386569.3392394.

Sierra Space. "Orbital Reef | The New Space Station." *Sierra Space*, n.d. Accessed October 24, 2025. https://www.sierraspace.com/commercial-space-stations/orbital-reef-space-station/.

Snorri Sturluson, and Jesse L. Byock. *Norse Mythology*. Penguin, 2005.

Solo, Elon. "Syd Mead Is Not Science Fiction." *Den of Geek*, May 13, 2025. https://www.denofgeek.com/movies/syd-mead-is-not-science-fiction/.

SpaceArchitect.org. *How To Become A Space Architect*. February 28, 2021. https://spacearchitect.org/how-to-become-a-space-architect/.

SpaceGamesFederation. "Space Games Federation." Accessed October 26, 2025. https://spacegamesfederation.com/about/.

Spiller, Neil. *Visionary Architecture: Blueprints of the Modern Imagination*. Thames & Hudson, 2006.

Staff, Guardian. "Live Webchat: Chris Hadfield." *The Guardian*, October 24, 2013. http://www.theguardian.com/science/2013/oct/24/live-webchat-chris-hadfield.

Stansbery, Eileen. "ARES | HyperVelocity Impact Technology | Impact Images | Space Shuttle." NASA. Accessed October 6, 2025. https://hvit.jsc.nasa.gov/impact-images/space-shuttle.cfm.

Statista. "Users in the Video Games Segment Worldwide 2017-2030." *Statista*. Accessed August 5, 2025. https://www.statista.com/forecasts/748044/number-video-gamers-world.

Sutter, Paul M. "Sending People to Mars Now Would Cost Trillions and Can't Work." *Scientific American*. Accessed October 23, 2025. https://www.scientificamerican.com/article/trump-wants-to-go-to-mars-thats-not-happening/.

Swayne, Matt. "Space Race 2.0: Stanford Emerging Tech Review Shows Power Shift Toward Private Sector, Lunar Mining and Orbital Infrastructure." *Space Insider*, May 1, 2025. https://spaceinsider.tech/2025/05/01/space-race-2-0-stanford-emerging-tech-review-shows-power-shift-toward-private-sector-lunar-mining-and-orbital-infrastructure/.

Thorne, Kip S., and Christopher Nolan. *The Science of Interstellar*. First edition. W.W. Norton & Company, 2014.

Thurber, James, and Louis Slobodkin. *Many Moons*. Voyager Books. Harcourt Brace Jovanovich, 1971.

Tsiolkovsky, K. *The Science Fiction of Konstantin Tsiolkovsky*. University Press of the Pacific ;

Distributed by International Scholarly Book Service, 1979.

Twain, Mark, and Michael J. Kiskis. *Mark Twain's Own Autobiography: The Chapters from the North American Review*. 2nd ed. Wisconsin Studies in Autobiography. University of Wisconsin Press, 2009.

Tyson, Brian Kennedy and Alec. "Americans' Views of Space: U.S. Role, NASA Priorities and Impact of Private Companies." *Pew Research Center*, July 20, 2023. https://www.pewresearch.org/science/2023/07/20/americans-views-of-space-u-s-role-nasa-priorities-and-impact-of-private-companies/.

UNOOSA. "The Outer Space Treaty." *United Nations Office For Outer Space Affairs*. Accessed July 30, 2025. https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/introouterspacetreaty.html.

Uri, John. "5 Years Ago: First Flight of the Falcon Heavy Rocket." *NASA History*. *NASA*, February 6, 2023. https://www.nasa.gov/history/5-years-ago-first-flight-of-the-falcon-heavy-rocket/.

Uri, John. "50 Years Ago: The Lunar Landing Training Vehicle." *NASA History*. *NASA*, December 7, 2017. https://www.nasa.gov/history/50-years-ago-the-lunar-landing-training-vehicle/.

Uri, John. "55 Years Ago: Astronaut Armstrong Survives LLRV Crash." *NASA History*. *NASA*, May 4, 2023. https://www.nasa.gov/history/55-years-ago-astronaut-armstrong-survives-llrv-crash/.

Uri, John. "65 Years Ago: Sputnik Ushers in the Space Age." *NASA History*. October 4, 2022. https://www.nasa.gov/history/65-years-ago-sputnik-ushers-in-the-space-age/.

Uri, John. "65 Years Ago: The National Aeronautics and Space Act of 1958 Creates NASA." *NASA History*, July 26, 2023. https://www.nasa.gov/history/65-years-ago-the-national-aeronautics-and-space-act-of-1958-creates-nasa/.

Uri, John. "95 Years Ago: Goddard's First Liquid-Fueled Rocket," *NASA History*. March 17, 2021. https://www.nasa.gov/history/95-years-ago-goddards-first-liquid-fueled-rocket/.

VastSpace. "Haven-2 — Vast." Accessed October 24, 2025. https://www.vastspace.com/roadmap.

Verne, Jules. *From the Earth to the Moon*. Extraordinary Voyages Series. Random House Publishing Group, 2011.

VirginGalactic. "Virgin Galactic." Accessed October 23, 2025. https://www.virgingalactic.com/spacecraft-fleet.

Wachhorst, Wyn. "The Dream of Spaceflight: Nostalgia for a Bygone Future." *The Massachusetts*

Review (Amherst) 36, no. 1 (1995): 7–32.

Wagner, Andrew. *20 Years on Station Lead to Advances on Earth*. NASA. Expedition 64. November 2, 2020. https://www.nasa.gov/missions/station/20-years-on-station-lead-to-advances-on-earth/.

Wall, Mike. "Mock Mars Explorers Say Farewell to Virtual Red Planet." *Space*, March 2, 2011. https://www.space.com/11011-mock-mars-mission-leaves-red-planet.html.

Wall, Mike. "Trip to Mars Would Turn Astronauts Into Weaklings." *Space*, August 19, 2010. https://www.space.com/8978-trip-mars-turn-astronauts-weaklings.html.

Watercutter, Angela. "Elysium's World Is Even Grittier, Prettier in This Cool Concept Art." Tags. *Wired*, August 7, 2013. https://www.wired.com/2013/08/elysium-concept-drawings/.

Weir, Andy. *The Martian*. First edition. Crown Publishers, 2014.

White, Frank. *The Overview Effect: Space Exploration and Human Evolution*. Third edition. Library of Flight. American Institute of Aeronautics and Astronautics, Inc, 2014.

Wild, Jim. "Space Radiation: The Apollo Crews Were Extremely Lucky." The Conversation, July 17, 2019. https://doi.org/10.64628/AB.ney9c3aw9.

Williams, Stuart. "2050 Inflation Prediction | Future Canada Inflation Calculator." April 7, 2011. https://www.in2013dollars.com/predict-inflation.

Williams, Stuart. "Russia Marks 50 Years since Gagarin Triumph." *Science X*. Accessed October 14, 2025. https://phys.org/news/2011-04-russia-years-gagarin-triumph.html.

Wiltshire, Alex. "Photorealism Is Crucial To Games." *Rock Paper Shotgun*, September 3, 2015. https://www.rockpapershotgun.com/photorealism-is-crucial.

Wolfe, James W., and John D. Rummel. "Long-Term Effects of Microgravity and Possible Countermeasures." *Advances in Space Research* 12, no. 1 (1992): 281–84. https://doi.org/10.1016/0273-1177(92)90296-A.

Wolfe, Tom. *The Right Stuff*. Farrar Straus and Giroux, 1979.

Woodford, James. "I Took Control of NASA's Valkyrie Robot and It Blew My Mind." New Scientist. Accessed October 25, 2025. https://www.newscientist.com/article/2446831-i-took-control-of-nasas-valkyrie-robot-and-it-blew-my-mind/.

Wu, Qi, Janick Martinez Esturo, Ashkan Mirzaei, Nicolas Moenne-Loccoz, and Zan Gojcic. "3DGUT: Enabling Distorted Cameras and Secondary Rays in Gaussian Splatting." Version 2. Preprint, 2024. https://research.nvidia.com/labs/toronto-ai/3DGUT/.

Yaragadda, Shriya. "Economics of the Stars: The Future of Asteroid Mining and the Global Economy." *Harvard International Review*, January 8, 2022. https://hir.harvard.edu/economics-of-the-stars/.

Yashar, Melodie, Calvin Glasgow, Bungane Mehlomakulu, Jason Ballard, and Sam Covey. *Constructing NASA's Crew Health and Performance Exploration Analog (CHAPEA): A 3D-Printed Habitat by ICON/BIG*. 2022.

Young, Amanda Joan. *Spacesuits: The Smithsonian National Air and Space Museum Collection*. With National Air and Space Museum. PowerHouse Books, 2009.

Young, George M. *Nikolai F. Fedorov, An Introduction*. Nordland Pub. Co., 1979.

Film/Movies

"4 LLRV Apollo Conference Conversion.Mov - YouTube." Accessed October 24, 2025. https://www.youtube.com/.

ALETROSPACE, dir. *4 LLRV Apollo Conference Conversion.Mov*. 2011. 1:22:18. https://www.youtube.com/watch?v=x2gerZtStJQ.

Blomkamp, Neill, dir. *Elysium*. TriStar Pictures, Media Rights Capital (MRC), QED International, 2013. 1h49m.

Blue Origin, dir. *Meet CrewMember 7*. 2024. 2:22. https://www.youtube.com/watch?v=ZCGurpvnr_g.

Cameron, James, dir. *Aliens*. Twentieth Century Fox, Brandywine Productions, Pinewood Studios, 1986. 2h17m.

Digital Foundry, dir. *Games vs CG! Kingdom Hearts 3 vs Toy Story Graphics Comparison*. 2017. 10:25. https://www.youtube.com/watch?v=tkDadVrBr1Y.

Discovery, dir. *Classic NASA Film - Skylab - #4*. 2008. 1:45. https://www.youtube.com/watch?v=S_p7LiyOUx0.

FNCreate, dir. *Lunar Horizons - Created In Fortnite*. 2024. 4:32. https://www.youtube.com/watch?v=wLFOE9k8OUc.

Halo: CE vs Campaign Evolved - Graphics Comparison (Exclusive Gameplay). n.d. Accessed October 25, 2025. https://www.youtube.com/watch?v=fGalf5Qv7ck.

Howard, Ron, dir. *Apollo 13*. Imagine Entertainment, Universal City Studios, 1995. 2h20m.

Hyams, Peter, dir. *Outland*. The Ladd Company, 1981. 1h49m.

Jared Owen, dir. *How Did They Build the ISS? (International Space Station)*. 2023. 15:30. https://www.youtube.com/watch?v=FhKOuxhGlmI.

Jones, Duncan, dir. *Moon*. Sony Pictures Classics, Stage 6 Films, Liberty Films Entertainment, 2009. 1h37m.

Kubrick, Stanley, dir. *2001: A Space Odyssey*. Metro-Goldwyn-Mayer (MGM), Stanley Kubrick Productions, 1968. 2h29m.

Méliès, Georges, dir. *Le Voyage Dans La Lune*. Star-Film, 1909. 13m.

NASA Johnson, dir. *APACHE: Spacewalking in Virtual Reality*. 2025. 25:30. https://www.youtube.com/watch?v=tOHYR2qanFE.

Nolan, Christopher, dir. *Interstellar*. Paramount Pictures, Warner Bros., Legendary Entertainment, 2014. 2h49m.

Rocket Science Gallery, dir. *Is Call of Duty: Ghosts "Realistic"? - A Space Engineer's Review*. 2024. 30:21. https://www.youtube.com/watch?v=lZzyxPMKGq0.

Scott, Ridley, dir. *Alien*. Twentieth Century Fox, Brandywine Productions, Scott Free Productions, 1979. 1h57m.

Scott, Ridley, dir. *The Martian*. Twentieth Century Fox, TSG Entertainment, Scott Free Productions, 2015. 2h24m.

Stanton, Andrew, dir. *WALL·E*. Walt Disney Pictures, Pixar Animation Studios, FortyFour Studios, 2008. 1h38m.

The Overview Effekt, dir. *Spin Gravity Compared*. 2024. 12:11. https://www.youtube.com/watch?v=C41gKfiihiM.

Trumbull, Douglas, dir. *Silent Running*. Universal Pictures, 1972. 1h29m.

Video Game Software

Asobo Studio. *Microsoft Flight Simulator 2024*. Released November 19, 2024. PC.

Bethesda Game Studios. *Starfield*. Bethesda Softworks, released September 6, 2023. PC.

Bioware. *Mass Effect*. Electronic Arts, released November 20, 2007. PC.

Bioware. *Mass Effect 2*. Electronic Arts, released January 26, 2010. PC.

Bioware. *Mass Effect 3*. Electronic Arts, released March 6, 2012. PC.

Bungie. *Halo: Combat Evolved*. Microsoft Game Studios, released 2001. Xbox.

Crytek Studios. *Crysis 2*. Crytek Studios, released March 22, 2011.

Microsoft. *Microsoft Flight Simulator for Windows 95*. Microsoft, released October 24, 1996. PC

Miyamoto, Shigeru. *Super Mario 64*. Nintendo Entertainment Analysis & Development (EAD), Nintendo, released June 23, 1996. N64.

Miyamoto, Shigeru. *Super Mario Bros*. Nintendo Entertainment Analysis & Development (EAD), released 1985. NES.

Polyphony Digital. *Gran Turismo 7*. Sony Computer Entertainment, released March 4, 2022. PS5.

Roberts, Chris. *Star Citizen*. V. Early Access. Cloud Imperium Games, released 2017. PC.

subLOGIC. *Microsoft Flight Simulator*. Microsoft, released 1982. PC.

Wilhelmsen, Petri. *Reentry - A Space Flight Simulator*. Lyra Creative, released November 27, 2025. https://reentrygame.com/. PC.

Model Assets

Model files of the International Space Station and other space assets available from NASA Science, was downloaded, used, or referenced in the creation of Verne Station. Satellite imagery of the Earth and Moon were also downloaded from NASA and used for creating the virtual environment levels in this thesis.

NASA Science. "3D Resources". *NASA Science*. February 21, 2025. https://science.nasa.gov/3d-resources/.

Wright, Ernie. "NASA Scientific Visualization Studio | CGI Moon Kit." NASA Scientific Visualization Studio, September 6, 2019. https://svs.gsfc.nasa.gov/4720.

NASA Science, "Blue Marble," *NASA Science*, https://science.nasa.gov/earth/earth-observatory/collections/blue-marble/