Orbital Space Settlement Design Project Questions

Orbital Space Settlement Design Group
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High Level Questions

Q0: What is the settlement's primary purpose/use-case model?

Category: High level question

- For a given use case, there might be various options for economic models or locations.
- Thus, the use case must be answered first.

Depends on

- Terms of Reference (TOR)

Q1: What is the target reliability/safety standard?

Category: High level question

- Aviation-like? nuclear-like?
- “ISS-like”?
- Telecom?
- Chip?
- Automotive?
- Defines redundancy, inspection cadence, acceptable risk to children.
- Safety vs uptime trade-off: space habitats can’t have downtime.
- Need to consider the reliability model used.
- What parts of the habitat are held to what standards?

Depends on

- Terms of Reference (TOR)

Q2: What are the core services provided to residents?

Category: High level question

- Housing space per person, privacy, recreation, food variety, internet latency, governance/rights baseline.
- Might want to put in Earthly context – “services a small town on the Earth provides.”
- Need to avoid the tragedy of the commons for “free goods.”
- What are the limits of what the planners/designers should do?

Depends on

- Terms of Reference (TOR)

Q3: What is the economic model?

Category: High level question

- How will the settlers add economic value?
- How is the settlement economically sustainable?

Depends on

- Q0 (Primary use case)
- Q4 (Location)

Q4: Where in cislunar space, exactly?

Category: High level question

- NRHO? distant retrograde?
- EML1/EML2 halo? high lunar orbit?
- Impacts eclipses, station-keeping, communications, debris, thermal, and economic model.

Depends on

- Q0 (Primary use case)
- Q3 (Economic model)

Q5: What is the logistics doctrine with Earth?

Category: High level question

- Cadence for spares, consumables; allowed lead times; acceptable downtime.
- What items do we “top off” and how often?
- Define trace elements, pharmaceuticals, replacement electronics, specialty foods, nitrogen/argon, etc.
- Spares/consumables may be an outcome of the economic model

Depends on

- Q0 (Primary use case)
- Q1 (Reliability Standard)
- Q3 (Economic model)
- Q4 (Location)

Q6: What population size and target demographics are required for social stability?

Category: High level question

- Includes sex ratio, age, etc.
- Includes consideration of percentage of the population not engaged in reproduction and the implications for social stability
- Gene flow is expected within the Earth-Moon system, so we need not consider whether the settlement can “stand alone” genetically; this is not a generation ship

Depends on

- Terms of Reference (TOR)

Q7: What population size is required for operational stability?

Category: High level question

- Include skill sets and trades, degree of automation.
- The nature of the core services impacts the number of people needed for operational stability

Depends on

- Q2 (Core services)

Q8: What population size is required for economic viability?

Category: High level question

- Export/service revenue vs labor needs; specialization; downtime tolerance; training pipeline.
- Exclude a small population of the very rich as a model.

Depends on

- Q0 (Primary use case)
- Q3 (Economic model)

Q9: What population size, including pets, is required for mental health?

Category: High level question

- Note that 1 in 20 people who stay over the winter in Antarctica develop serious mental health issues.
- This suggests a population of 200 may be too small, or that aspects of the Antarctic station model need correction.

Depends on

- Terms of Reference (TOR)

Q10: Therefore: what is the minimum viable steady-state population?

Category: High level question

- Pick the minimum that satisfies the related questions, with ≥100 as a floor.

Depends on

- Q6 (Minimum for social stability)
- Q7 (Minimum for operational stability)
- Q8 (Minimum for economic viability)
- Q9 (Minimum for mental health)

Q11: What governance model applies?

Category: High level question

- As stated in the Terms of Reference (TOR), the settlement is assumed to be under the legal jurisdiction of the launching state.
- What issues will arise from applying the laws of the launching state to the settlement, and how can those issues be resolved?

Depends on

- Q13 (International legal regime)

Q12: What ownership model applies?

Category: High level question

- Strong relationship to the economic purpose of the settlement.
- Should cover corporate ownership/company town, co-ops, condominiums, employee-owned corporations, and others.

Depends on

- Q0 (Primary use case)
- Q3 (Economic model)
- Q11 (Governance model)

Q13: What international legal regime is required to allow the first settlement to be funded and built?

Category: High level question

- Focuses on what interpretation of the Outer Space Treaty is required to allow a settlement to be constructed in orbital space.

Depends on

- Terms of Reference (TOR) only

Q38: What is the commissioning process?

Category: High-level question

- Pressure testing
- Atmosphere validation
- Fire testing
- Radiation verification
- Agriculture/life-support commissioning
- Emergency drills
- Phased occupancy
- Independent safety review
- Overall, depends on the settlement being designed, constructed, and assembled

Depends on

- Q1 (Safety standard)
- Q11 (Governance model)
- Q12 (Ownership model)
- Q31 (Fault tolerant operations)
- Q32 (Design basis accidents)

Q40: What kinds of scientific and technological benefits to humanity can be expected from this project?

Category: High-level question

- The OSSD Project is a laboratory for learning how to support a high standard of living using significantly less water, energy, land, and raw material per person. That makes the Earth benefit much broader than "space technology spinoffs." It turns the project into a research initiative in how to build more sustainable human communities with limited resources.
- The answer to this question supports the fundamental rationalization for this project.

Depends on

- All Questions

Q41: What kinds of scientific advances will the OSSD Project enable?

Category: High-level question

- The science needed to make the settlement possible
- The science that can be done on the settlement during its construction and once it is operational
- The answer to this question supports the fundamental rationalization for this project.

Depends on

- All Questions

Q42: What level of vibration is tolerable in the settlement?

Category: High-Level question

- A space settlement will have many sources of vibration
- Consideration is needed of how much vibration can be tolerated over the long term.
- Experience from long submarine voyages and the ISS is relevant

Depends on

- Terms of Reference

Q44: What level of odor is tolerable in the settlement?

Category: High-Level question

- A space settlement will have many sources of odor
- Consideration is needed of how much and what kinds of odors can be tolerated over the long term.
- Is there a cultural element in terms of what odors are acceptable?
- Will personal differences in odor perception and toleration create issues?
- Does toleration of odors increase over time such that some odor is not an issue?
- Some odors signal danger; we don't want to over-control odor to remove signals of danger

Depends on

- Terms of reference

Q46: What level of noise is tolerable in the settlement?

Category: High-Level question

- A space settlement will have many sources of noise, including vibration
- Consideration is needed of how much and what kinds of noises can be tolerated over the long term.

Depends on

- Terms of reference

Q48: What level of privacy is required for long-term thriving in the settlement?

Category: High-level question

- ISS and submarine experience is relevant
- The presence of families makes this more complex
- Need to consider size of private spaces
- Need to consider role of public spaces
- Need to consider sound-proofing requirements

Depends on

- Terms of reference

Physical Questions

Q14: What maximum rotation rate (rpm) is acceptable for a multi-generation population?

Category: Physical question

- Sets radius, since g is fixed at about one, which then drives structural mass and construction approach.
- Mainly a medical/biological question

Depends on

- Terms of Reference (TOR) only

Q15: What radius/geometry follows from g and rpm?

Category: Physical question

- Torus vs cylinder vs multi-ring vs hammerhead; habitable deck layout; zoning.
- Includes consideration of Coriolis force and width of inner ear impacts arising from the choice of rpm and radius
- Includes consideration of windows both for mental health and to allow the entry of sunlight; includes desirability of sun-alignment of the settlement
- Includes consideration of internal line-of-sight aspects

Depends on

- Q2 (Core services)
- Q10 (Minimum population)
- Q14 (Maximum rpm)
- Q18 (Shielding approach)
- Q26 (Power source)

Q16: What is the docking/visiting vehicle strategy relative to rotation?

Category: Physical question

- Spin-down? non-rotating hub? rotating-to-nonrotating transfer?

Depends on

- Q15 (Radius/geometry)

Q18: What shielding approach meets Q17 at minimum mass/cost?

Category: Physical question

- Bulk shielding, such as water/regolith, plus storm shelter; uniformity of protection needed; shielding-as-storage; consider active shields, layered shields, etc.
- Includes connection between rotating settlement and non-rotating shield

Depends on

- Q4 (Location)
- Q17 (Radiation standard)
- Q19 (Source of shielding) [circular dependency]

Q19: Where does shielding mass come from?

Category: Physical question

- Earth-launched vs lunar-derived vs asteroid; initial vs growth.

Depends on

- Q4 (Location)
- Q18 (Shielding approach)

Q20: What closure level is required to be “permanent” with imports allowed?

Category: Physical question

- Define what must be closed (water? oxygen? nitrogen?) vs what can be imported.

Depends on

- Q2 (Core services)
- Q3 (Economic model)
- Q4 (Location)
- Q5 (Logistics doctrine)
- Q10 (Minimum population)

Q25: What total power level is required (steady and peak)?

Category: Physical question

- Habitat + agriculture + industry + station keeping + reserves.

Depends on

- Q1 (Target safety standard)
- Q3 (Economic model)
- Q21 (Food system)
- Q22 (Atmosphere model)
- Q23 (Water/waste architecture)
- Q27 (Thermal rejection)
- Q28 (Local repair capability)
- Q34 (Station keeping)

Q26: What power source architecture is optimal in cislunar space?

Category: Physical question

- Solar vs nuclear vs hybrid; storage; safety case; maintenance.

Depends on

- Q1 (Target safety standard)
- Q4 (Location)

Q27: What thermal rejection system is required?

Category: Physical question

- Radiators, loops, heat reuse, zoning, orientation constraints.

Depends on

- Q15 (Radius/geometry)
- Q21 (Food system)
- Q22 (Atmosphere model)
- Q23 (Water/waste architecture)
- Q25 (Power level required)
- Q26 (Power architecture)

Q28: What minimum local manufacturing/repair capability is required?

Category: Physical question

- Spare parts, seals/filters, machining, electronics repair, additive manufacturing, QA.
- List of dependencies is long since each habitat sub-system may need repair

Depends on

- Q1 (Target safety standard)
- Q5 (Logistic doctrine)
- Q10 (Minimum population)
- Q31 (Fault tolerant operations concept)

Q29: What structural concept meets loads + micrometeoroids + pressure + rotation at minimum mass?
Category: Physical question

• Materials, compartmentalization, Whipple shielding, pressure hull segmentation.

Depends on

- Q1 (Target safety standard)
- Q4 (Location)
- Q15 (Radius/geometry)
- Q18 (Shielding approach)
- Q22 (Atmosphere model)
- Q26 (Power architecture)
- Q27 (Thermal rejection system)

Q30: What is the assembly and spin-up strategy?

Category: Physical question

• Preassembled modules vs on-orbit build; robotic vs crew; when shielding is added; how to maintain balance.

Depends on

- Q4 (Location)
- Q15 (Radius/geometry)
- Q18 (Shielding approach)
- Q29 (Structural concept)

Q31: What is the fault-tolerant operations concept?

Category: Physical question

- Staffing, training, emergency response, maintenance cycles, inspection, spares policy, cross-training
- Could have many dependencies; need to consider further
- Fail-safe operation is required
- Do we want to expose operational equipment both to remind users of their existence and for ease of repairs?
- Example of the Pompidou center in France with all service equipment external and color coded by function to create a practical example

Depends on

- Q1 (Reliability Standard)
- Q28 (Repair capability)

Q32: What are the top “design basis accidents” and how are they handled?

Category: Physical question

• Fire, depressurization, toxic release, collision, loss of rotation control, loss of power.

Depends on

- Q1 (Reliability Standard)
- Q16 (Docking strategy)
- Q22 (Atmosphere model)
- Q23 (Water/waste architecture)
- Q26 (Power source architecture)
- Q27 (Thermal rejection)
- Q29 (Structural concept)
- Q31 (Fault tolerant operations concept)

Q33: What is the growth path from the minimum system to a larger one?

Category: Physical question

- When to add rings/modules, how to avoid redesign.
- *May not be a good question, or the right question*

Depends on

- Q15 (Radius/geometry)
- Q18 (Shielding approach)
- Q29 (Structural concept)
- Q30 (Assembly strategy)

Q34: What station keeping system is required?

Category: Physical question

- What capabilities are needed to oriented the habitat?
- What capabilities are needed to maintain a proper orbit?

Depends on

- Q4 (Location)
- Q5 (Logistics doctrine)
- Q15 (Radius/geometry)
- Q18 (Shielding approach)
- Q29 (Structural concept)

Q35: What communications, navigation, timing, and cybersecurity system is required?

Category: Physical question

- Earth communications
- Local network
- Command/control
- Cybersecurity
- Navigation around the settlement
- Timing synchronization
- Emergency communications
- Autonomy during outages

Depends on

- Q2 (Core services)
- Q4 (Location)
- Q5 (Logistics doctrine)
- Q31 (Fault tolerant operations)
- Q32 (Design basis accidents)

Q37: What orbital debris/space traffic management system is required?

Category: Physical question

- Conjunction assessment
- Collision avoidance vs active mitigation of debris
- Debris environment by location
- Keep-out zones
- Visiting vehicle traffic rules
- Liability
- Disposal of construction debris
- Tracking and monitoring

Depends on

- Q1 (Safety standard)
- Q4 (Location)
- Q13 (International legal regime)
- Q16 (Docking strategy)
- Q29 (Structural concept)
- Q31 (Fault tolerant operations)
- Q32 (Design basis accidents)

Q39: What is the habitat life cycle?

Category: Physical question

- The goal as per the TOR is for permanent occupation with maintenance and repairs
- The realism of this approach requires evaluation
- If it is not realistic, an end-of-life disposal/reuse plan that does not involve entry is required; reentry is unrealistic for such a large construct.
- If the economic model is no longer viable, there needs to be a “ghost town mode” in which the settlement maintain such that it is not dangerous

Depends on

- Q1 (Safety standard)
- Q3 (Economic model)
- Q4 (Location)
- Q11 (Governance model)
- Q12 (Ownership model)
- Q29 (Structural concept) [especially with regard to thermal fatigue]
- Q31 (Fault tolerant operations)
- Q32 (Design basis accidents)
- Q34 (Station keeping system)
- Q37 (Orbital debris/space traffic management)

Q43: How can vibration be controlled to tolerable levels?

Category: Physical question

- An extensive knowledge base derived from the need to create quiet submarines is relevant

Depends on

- Q0 (Primary use case)
- Q14 (Rotation rate)
- Q16 (Docking strategy)
- Q18 (Shielding approach)
- Q28 (Local manufacturing)
- Q34 (Station keeping)
- Q42 (Tolerable vibration)

Q47: How can noise be controlled in the settlement?

Category: Physical question

- The ISS has shown that noise control is a significant issue
- Long-term habitats require a greater degree of noise control than a base with rotating crews
- Submarine and cruise ship experience is relevant
- Note that some noises warn of danger, notably leaks

Depends on

- Q0 (Primary use case)
- Q3 (Economic model)
- Q10 (Population size)
- Q21 (Food system)
- Q22 (Atmosphere)
- Q23 (Water/waste architecture)
- Q28 (Manufacturing)
- Q43 (Vibration control)

Q49: How can a desirable level of privacy be achieved?

Category: Physical question

- Need to consider design of public spaces vs private spaces
- Private spaces need to accommodate families.
- Consideration needs to be given to sound control; the honycomnb aluminum apartment walls in the Ames 1975 Summer Study seem inadequate
- Mobile home design experience is highly relevant

Depends on

- Q48 (Privacy requirements)

Biological Questions

Q17: What radiation standard do we design to for families/children?

Category: Biological question

- Annual dose targets, pregnancy limits, SPE shelter requirements.
- Regulatory and legal liability issues must be considered

Depends on

- Q1 (Target safety standard)
- Q11 (Governance model)

Q21: What food system meets nutrition, variety, and psychology at minimum mass/power?

Category: Biological question

- Hydroponics/vertical farming mix, lighting strategy, protein plan, storage buffers.
- Needs to fully consider recycling and ecological balance.

Depends on

- Q10 (Minimum population)
- Q20 (Closure level)

Q22: What atmosphere model and fire safety regime?

Category: Biological question

- Total pressure, O_2 fraction, diluents (N_2/Ar), toxin control, fire suppression doctrine.

Depends on

- Terms of Reference (TOR)
- Q1 (Target reliability)
- Q10 (Minimum population)
- Q20 (Closure level)
- Q23 (Water/waste architecture)

Q23: What water/waste architecture achieves Q20 with acceptable failure modes?

Category: Biological question

- Water recovery, sanitation, pathogen control, waste processing, “what if” contingencies.

Depends on

- Q1 (Target reliability)
- Q2 (Core services)
- Q10 (Minimum population)
- Q20 (Closure level)
- Q21 (Food system)

Q24: How can healthy immune systems be maintained?

Category: Biological question

- Children who grow on farms have very low allergy rates. We want to make sure kids in the settlement are exposed to appropriate stimuli so that their immune systems develop.
- Vaccination policy
- Healthy microbial exposure
- Pathogen exclusion
- Quarantine for arrivals
- Pets and domestic animals
- Plant/agricultural microbiomes
- Allergy/autoimmune risk
- Medical surveillance
- Food-system contamination
- Wastewater pathogen control

Depends on

- Q10 (Minimum population)
- Q20 (Closure level)
- Q21 (Food system)
- Q22 (Atmosphere model)
- Q23 (Water/waste architecture)

Q36: What medical system is required?

Category: Biological question

- Emergency medicine
- Surgery
- Obstetrics
- Pediatrics
- Dentistry
- Pharmacy
- Telemedicine
- Quarantine
- Long-term chronic care vs medical evacuation
- Medical evacuation assumptions
- Death and mortuary handling

Depends on

- Q1 (Safety standard)
- Q2 (Core services)
- Q4 (Location)
- Q5 (Logistics doctrine)
- Q10 (Minimum population)
- Q24 (Healthy immune systems)
- Q32 (Design basis accidents)

Q45: How can odor be controlled in the settlement?

Category: Biological question

- The ISS has shown that odor control is a significant issue
- Long-term habitats require a greater degree of odor control than a base with rotating crews
- The presence of agriculture and waste processing raises challenges
- Off-gassing from everything needs to be considered.

Depends on

- Q0 (Primary use case)
- Q3 (Economic model)
- Q10 (Population size)
- Q21 (Food system)
- Q22 (Atmosphere)
- Q23 (Water/waste architecture)
- Q28 (Manufacturing)
- Q44 (Tolerable odor)