

ICON

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ISRU Centrifugal Orbital Node.

A Conceptual Design White Paper for a Crewed, Centrifugal Space Station in Lunar Orbit.

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Status: Conceptual.

Idea

The ISRU Centrifugal Orbital Node (ICON) is a conceptual design for a small, permanently crewed station in Lunar orbit. Combining a zero-g main hull for docking, logistics, refueling ports and workspace that functions with a rotating centrifuge pod that provides artificial gravity for crew habitation. The station is designed around a Near Rectilinear Halo Orbit (NRHO) for long term stability, in-situ resource utilization (ISRU) of Lunar polar ice for propellant, and consumables, and a centrifuge geometry chosen to keep rotational effects within established human comfort factor limits. This document presents the station concept, its major subsystems and the full set of governing engineering calculations used to size them.

All calculations in this document are reproducible. In the Calculations page you can find all the live formulas for every value presented here.

1. ICON

ICON is conceived as a small-crew (4-6 people) outpost in Lunar orbit. Serving as a staging point for lunar surface operations, extraterrestrial missions, a research platform for long duration partial-isolation human factors, and a technology demonstrator for ISRU-derived propellant and life support consumables.

1.1 Design Drivers

- Provide sustained 1g artificial gravity for crew health, avoiding the unknowns of long duration partial-g exposure.
- Maintain a stable, low maintenance orbit in NRHO to minimize propellant logistics.
- Reduce resupply mass through ISRU-based propellant and water from Lunar polar ice.
- Keep rotational artificial-gravity effects (Coriolis force) within crew comfort limits.
- Use mass efficient, flight realistic materials and subsystems.

1.2 Station Architecture Overview

The station consists of a zero gravity main hull housing living and/or working quarters, docking ports and solar arrays. These are connected via a central spoke to a rotating centrifuge pod beneath it. The pod provides the station's artificial gravity crew quarters. A general illustration is shown in Figure 1.

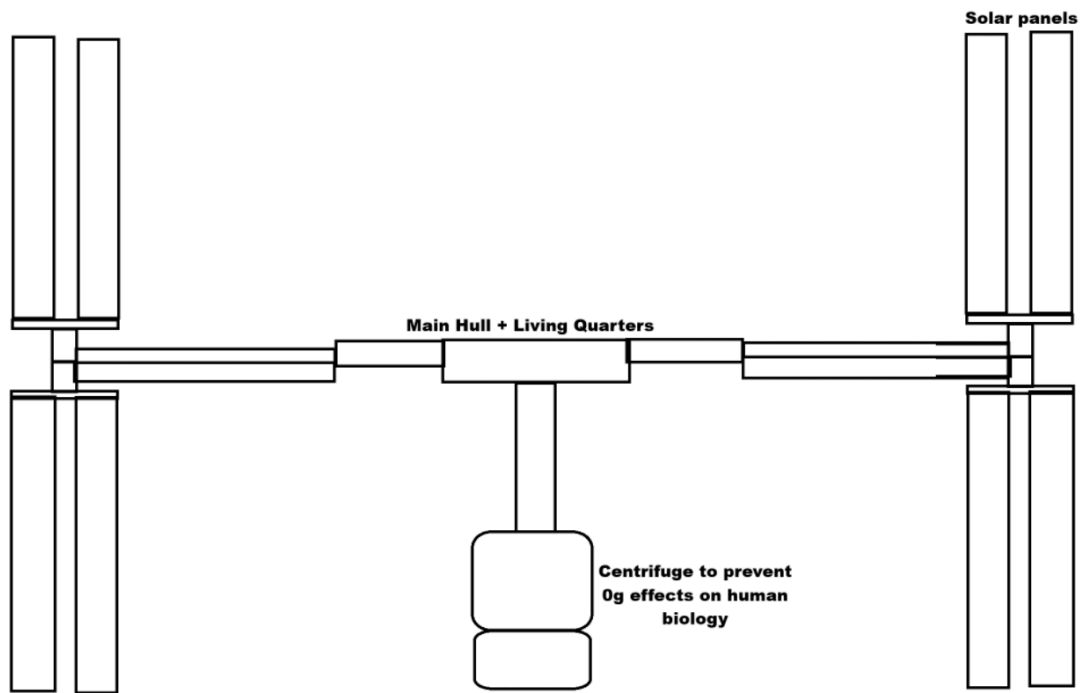


Figure 1. ICON general grouping. Main hull with docking/solar structure. Central spoke. And a centrifuge pod.

2. Artificial Gravity. Centrifuge Design

The centrifuge pod is sized to provide 1g of artificial gravity at deck level while keeping rotation within the range that is generally considered tolerable for a trained crew.

2.1 Design Inputs

Variable	Symbol	Value
Target gravity	a	9.80665 m/s ²
Centrifuge radius	r	50 m
Crew height (design)	r_head	1.7 m
Radial transit speed	v_radial	0.5 m/s
Rotating mass (pod + crew + consumables)	m	20,000 kg

2.2 Main Equations and Results

Centripetal Acceleration

$$a = \omega^2 \cdot r \rightarrow \omega = \sqrt{a / r}$$

$$\text{Result: } \omega = \sqrt{(9.80665 / 50)} = 0.442869 \text{ rad/s}$$

Rotation Rate

$$RPM = (\omega \cdot 60) / (2\pi)$$

$$\text{Result: } RPM = 4.23$$

Centripetal Force

$$F_c = m \cdot \omega^2 \cdot r$$

Coriolis Acceleration

$$a_{cor} = 2\omega \cdot v_{radial}$$

$$\text{Result: } a_{cor} = 2 \cdot 0.442869 \cdot 0.5 = 0.4429 \text{ m/s}^2$$

Conclusion: a 50 m radius spinning at 4.23 RPM delivers full 1g at the deck with both Coriolis disturbance and head-to-foot gravity gradient within widely cited human-factors comfort thresholds for trained crew.

3. Structural Design — Spoke / Tether

The spoke connects the zero-g main hull to the rotating centrifuge pod and carries the full centripetal tensile load of the pod. It is sized in tension using a carbon-fiber composite (CFRP), selected for its high strength-to-weight ratio relative to metals.

3.1 Design Inputs

Variable	Symbol	Value
Spoke material	N/A	CFRP (carbon fiber composite)
Material density	ρ	1,600 kg/m ³
Material yield strength	σ_{yield}	600 MPa
Safety factor	SF	2.2
Allowable design stress	σ_{allow}	272.73 MPa
Spoke cross-sectional area	A	0.05 m ²

3.2 Governing Equations and Results

Tensile Stress Load

$$\sigma = F_c / A$$

$$\text{Result: } \sigma = 196,133 / 0.05 = 3,922,660 \text{ Pa}$$

Stress Margin

$$\text{margin} = \sigma_{allow} - \sigma$$

$$\text{Result: } \text{margin} = 272,727,272.7 - 3,922,660 = 268,804,612.7 \text{ Pa}$$

Characteristic Velocity Parameter

$$v_c^2 = 2\sigma_{allow} / \rho$$

$$\text{Result: } v_c^2 = 2 \cdot 272,727,272.7 / 1,600 = 340,909.09 \text{ m}^2/\text{s}^2$$

Spoke Mass Ratio

$$M_{spoke} / M_{payload} = e^{(\rho \cdot \omega^2 \cdot r^2 / (2 \cdot \sigma_{allow}))} - 1$$

$$\text{Result: } \text{ratio} = e^{(1,600 \cdot 0.442869^2 \cdot 50^2 / (2 \cdot 272,727,272.7))} - 1 = 0.0014393$$

Spoke Mass

$$M_{spoke} = \text{ratio} \cdot M_{payload}$$

$$\text{Result: } M_{spoke} = 0.0014393 \cdot 20,000 = 28.79 \text{ kg}$$

Conclusion: At this radius and rotation rate, the CFRP spoke mass is negligible relative to the 20000 Kkg payload. Proving the spoke geometry and material choice are correct. The Stress Margin is large, allowing us to reduce the cross-sectional area A further if mass savings are prioritized in later design interactions.

4. Orbital Mechanics

ICON is placed in a Near Rectilinear Halo Orbit (NRHO), the same orbit selected for NASA's Lunar Gateway. NRHO's avoid the rapid decay that happens in low circular lunar orbits while requiring only a small annual stationkeeping propellant budget.

4.1 Design Inputs

Variable	Symbol	Value
Moon gravitational parameter	μ_{Moon}	$4.9048 \times 10^{12} \text{ m}^3/\text{s}^2$
Moon mean radius	R_{Moon}	1,737,400 m
Perilune altitude	h_{peri}	3,000,000 m
Apolune altitude	h_{apo}	70,000,000 m
Stationkeeping Δv (annual)	Δv_{sk}	12 m/s/yr

4.2 Governing Equations and Results

Perilune / Apolune Radius

$$r_{\text{peri}} = R_{\text{Moon}} + h_{\text{peri}} ; r_{\text{apo}} = R_{\text{Moon}} + h_{\text{apo}}$$

$$\text{Result: } r_{\text{peri}} = 4,737,400 \text{ m} ; r_{\text{apo}} = 71,737,400 \text{ m}$$

Semi-Major Axis

$$a_{\text{orb}} = (r_{\text{peri}} + r_{\text{apo}}) / 2$$

$$\text{Result: } a_{\text{orb}} = 38,237,400 \text{ m}$$

Orbital Period

$$T = 2\pi \cdot \sqrt{(a_{\text{orb}}^3 / \mu_{\text{Moon}})}$$

$$\text{Result: } T = 670,813.4 \text{ s} = 7.764 \text{ days}$$

Orbital Velocity

$$v = \sqrt{(\mu_{\text{Moon}} \cdot (2/r - 1/a_{\text{orb}}))}$$

$$\text{Result: } v_{\text{perilune}} = 1,393.70 \text{ m/s} ; v_{\text{apolune}} = 92.04 \text{ m/s}$$

Escape Velocity at Perilune

$$v_{\text{esc}} = \sqrt{(2\mu_{\text{Moon}} / r_{\text{peri}})}$$

$$\text{Result: } v_{\text{esc}} = 1,438.98 \text{ m/s}$$

10-Year Stationkeeping Δv Budget

$$\Delta v_{total} = \Delta v_{sk} \cdot years$$

$$\text{Result: } \Delta v_{total} = 12 \cdot 10 = 120 \text{ m/s}$$

Conclusion: the selected NRHO gives a ~7.76-day orbital period and a modest 120 m/s total stationkeeping budget over a 10-year station life. A major logistics advantage over low circular lunar orbits.

5. Power Systems

Electrical power is provided by deployable solar arrays sized for continuous station load, with battery storage sized to cover the maximum expected eclipse duration per orbit.

5.1 Design Inputs

Variable	Symbol	Value
Solar constant	S	1,361 W/m ²
Panel efficiency	η	30%
Station electrical load	P_load	15,000 W
Eclipse duration	t_eclipse	2,880 s
Battery depth of discharge	DoD	0.7
Area design margin	margin	1.75×

5.2 Governing Equations and Results

Required Panel Area

$$A_{panel} = P_{load} / (S \cdot \eta \cdot \cos\theta)$$

Result: $A_{panel} = 15,000 / (1,361 \cdot 0.3) = 36.74 \text{ m}^2$

Recommended Panel Area (with margin)

$$A_{design} = A_{panel} \cdot margin$$

Result: $A_{design} = 36.74 \cdot 1.75 = 64.29 \text{ m}^2$

Power Output Check

$$P = S \cdot A_{panel} \cdot \eta \cdot \cos\theta$$

Result: $P = 1,361 \cdot 36.74 \cdot 0.3 = 15,000 \text{ W}$ (matches load — sanity check passes)

Required Battery Energy Capacity

$$E_{battery} = P_{load} \cdot t_{eclipse} / DoD$$

Result: $E_{battery} = 15,000 \cdot 2,880 / 0.7 = 61,714,285.7 \text{ J} = 17,142.86 \text{ Wh}$

6. Thermal Control

Waste heat from electronics, life support, and crew metabolism is sent out into space via deployable radiator panels sized using the Stefan-Boltzmann law.

6.1 Design Inputs

Variable	Symbol	Value
Stefan-Boltzmann constant	σ_{SB}	$5.670 \times 10^{-8} \text{ W/m}^2\text{K}^4$
Radiator emissivity	ϵ	0.88
Radiator operating temperature	T	290 K
Heat load to reject	Q	17,000 W

6.2 Governing Equations and Results

Required Radiator Area

$$A_{rad} = Q / (\epsilon \cdot \sigma_{SB} \cdot T^4)$$

$$\text{Result: } A_{rad} = 17,000 / (0.88 \cdot 5.670 \times 10^{-8} \cdot 290^4) = 48.17 \text{ m}^2$$

Two-Sided Radiator Area

$$A_{panel} = A_{rad} / 2$$

$$\text{Result: } A_{panel} = 24.09 \text{ m}^2$$

7. Radiation Shielding

Crew quarters use water as primary shielding mass. Hydrogen rich materials block galactic cosmic rays (GCR) more effectively per kilogram than metals, and water doubles as a stored consumable.

7.1 Design Inputs

Variable	Symbol	Value
Shielding material	N/A	Water
Material density	ρ_{shield}	1.0 g/cm ³
Target areal density (general)	AD_general	20 g/cm ²
Target areal density (storm shelter)	AD_storm	40 g/cm ²

7.2 Governing Equations and Results

Required Shield Thickness

$$t = AD / \rho_{shield}$$

Result: $t_{general} = 20/1.0 = 20 \text{ cm}$; $t_{storm} = 40/1.0 = 40 \text{ cm}$

8. Propulsion and ISRU

Stationkeeping propellant is derived from electrolyzed water ice mined at the lunar poles (ISRU), consistent with the station's namesake. Propellant mass is sized using the Tsiolkovsky rocket equation against the orbital stationkeeping Δv budget.

8.1 Design Inputs

Variable	Symbol	Value
Standard gravity	g_0	9.80665 m/s ²
Propellant	N/A	LOX/LH2 (ISRU-derived)
Specific impulse	I_{sp}	450 s
Required Δv	Δv	120 m/s
Dry mass (stationkeeping tug)	m_f	2,000 kg

8.2 Governing Equations and Results

Exhaust Velocity

$$v_e = I_{sp} \cdot g_0$$

Result: $v_e = 450 \cdot 9.80665 = 4,412.99$ m/s

Initial (Wet) Mass — Tsiolkovsky Rocket Equation

$$m_0 = m_f \cdot e^{(\Delta v / v_e)}$$

Result: $m_0 = 2,000 \cdot e^{(120/4,412.99)} = 2,055.13$ kg

Propellant Mass

$$m_{prop} = m_0 - m_f$$

Result: $m_{prop} = 2,055.13 - 2,000 = 55.13$ kg

Propellant Mass Fraction

$$MF = m_{prop} / m_0$$

Result: $MF = 55.13 / 2,055.13 = 2.68\%$

9. Life Support and Consumables

Resupply mass is calculated per crew rotation, accounting for ISS-realistic environmental control and life support system (ECLSS) recycling rates. Food cannot be recycled and is supplied in full.

9.1 Design Inputs

Variable	Symbol	Value
Crew size	n_{crew}	6 people
Mission duration	$t_{mission}$	270 days
O ₂ consumption rate	$rate_{O2}$	0.84 kg/day
Water consumption rate	$rate_{H2O}$	4.0 kg/day
Food consumption rate	$rate_{food}$	0.62 kg/day
Water recycling efficiency	η_{H2O}	92%
O ₂ recycling efficiency	η_{O2}	78%

9.2 Governing Equations and Results

Total O₂ Resupply Mass

$$M_{O2} = n_{crew} \cdot rate_{O2} \cdot t_{mission} \cdot (1 - \eta_{O2})$$

$$\text{Result: } M_{O2} = 6 \cdot 0.84 \cdot 270 \cdot (1 - 0.78) = 299.38 \text{ kg}$$

Total Water Resupply Mass

$$M_{H2O} = n_{crew} \cdot rate_{H2O} \cdot t_{mission} \cdot (1 - \eta_{H2O})$$

$$\text{Result: } M_{H2O} = 6 \cdot 4 \cdot 270 \cdot (1 - 0.92) = 518.40 \text{ kg}$$

Total Food Resupply Mass

$$M_{food} = n_{crew} \cdot rate_{food} \cdot t_{mission}$$

$$\text{Result: } M_{food} = 6 \cdot 0.62 \cdot 270 = 1,004.40 \text{ kg}$$

Total Consumables Resupply Mass

$$M_{total} = M_{O2} + M_{H2O} + M_{food}$$

$$\text{Result: } M_{total} = 299.38 + 518.40 + 1,004.40 = 1,822.18 \text{ kg per 270 day rotation.}$$

10. Summary of Key Results

Subsystem	Key Result
Centrifuge	4.23 RPM at $r = 50$ m gives us 1g. Coriolis 0.44 m/s^2 ; gradient ratio 1.035
Structural (spoke)	$\sigma = 3.92 \text{ MPa}$ vs. $\sigma_{\text{allow}} = 272.7 \text{ MPa}$. PASS. spoke mass $\approx 28.8 \text{ kg}$
Orbital mechanics	9:2 NRHO; period 7.76 days; $120 \text{ m/s } \Delta v$ over 10 years
Power	64.3 m^2 panel area (with margin); 17.14 kWh battery capacity
Thermal	24.1 m^2 two sided radiator area for 17 kW heat load
Radiation shielding	20 cm water (general) / 40 cm water (storm shelter)
Propulsion / ISRU	55.1 kg ISRU-derived LOX/LH2 propellant per 10 year stationkeeping budget
Life support	$1,822.2 \text{ kg}$ consumables resupply per 270-day, 6-crew rotation

11. Assumptions, Open Items, and Future Work

- The pod mass (20000 kg) and station electrical load (15000 W) are first pass estimates pending detailed equipment and subsystem mass budgets.
- Spoke sizing assumes static tensile loading only. A full structural pass should add fatigue and dynamic spin up or spin down bending analysis.
- Eclipse duration assumes a worst case 48-minute shadow. Actual NRHO eclipse geometry should be modeled in mission design software (NASA's GMAT, for example.) and may be substantially shorter or near zero depending on orbit phasing.
- ECLSS recycling rates are based on current ISS class hardware, closed-loop performance may improve with future life support technology.
- This document does not yet address micrometeoroid/orbital debris (MMOD) shielding, docking system design, EVA operations, or crew transfer vehicle interfaces. This is recommended as the next design iteration.
- All figures should be treated as conceptual or Pre-Phase A estimates. Suitable for early trade studies rather than flight hardware specification.

12. Conclusion

The ICON concept demonstrates that a 50 m radius, 4.23 RPM centrifugal station in a lunar NRHO is physically and structurally feasible using current materials and propulsion technology. Rotational comfort metrics, structural margins, power and thermal budgets, radiation shielding requirements, and consumables logistics all land within established or reasonably projected engineering limits. The next design phase should focus on detailed subsystem mass closure, dynamic structural analysis of the spin-up sequence, and integration of the ISRU propellant and water production chain with the station's resupply logistics chain.

Calculations

Centripetal Acceleration

$$a = \omega^2 \cdot r$$

$$\sqrt{\frac{9.80665}{50}} = 0.44286905513$$

$$(0.44286905513 \cdot 60) \div (2 \cdot \pi) = 4.22908795598$$

Centrifuge \approx 4.23 RPM

Centripetal Force

$$F_c = m \cdot \omega^2 \cdot r$$

$$F_c = 20,000 \cdot 0.44286905513^2 \cdot 50 = 196132.999992 \text{ N}$$

Coriolis Acceleration

$$a_{cor} = 2\omega v_{radial}$$

$$a_{cor} = 2 \cdot 0.44286905513 \cdot 0.5 = 0.442869055 \text{ m/s}^2$$

Gravity Radiant

$$\Delta a = \omega^2(r - r_{head})$$

$$\Delta a = \omega^2(50 - 1.7)$$

$$\Delta a = 0.44286905513^2 \cdot 48.3 = 9.47322389969 \text{ m/s}^2$$

Tensile Stress Load

$$\sigma = \frac{F_c}{A}$$

$$\sigma = \frac{196133}{0.05} = 3922660 \text{ Pa}$$

Stress Margin

$$\sigma_{allow} - \sigma$$

$$272727272.7 - 3922660 = 268804612.7 \text{ Pa}$$

Velocity Parameters

$$V_c^2 = 2\sigma_{allow}/\rho$$

$$V_c^2 = 2 \cdot 272727272.7/1600 = 340909.0909 \text{ m}^2/\text{s}^2$$

Spoke Mass Ratio

$$M_{spoke}/M_{payload} = m^{(\rho \cdot \omega^2 \cdot r^2 (2 \cdot \sigma_{allow}))^{-1}}$$

$$M_{spoke}/M_{payload} = m^{(1600 \cdot 0.44286905513^2 \cdot 50^2 (2 \cdot 272727272.7))^{-1}} = 0.001439344$$

Spoke Mass

$$M_{spoke} = ratio \cdot M_{payload}$$

$$M_{spoke} = 0.001439344 \cdot 20000 = 28.78687057$$

Perilune Radius

$$r_{peri} = R_{moon} + h_{peri}$$

$$r_{peri} = 1737400 + 3000000 = 4737400 \text{ m}$$

Apolune Radius

$$r_{apo} = R_{moon} + h_{apo}$$

$$r_{apo} = 1737400 + 70000000 = 71737400 \text{ m}$$

Semi Major Axis

$$a_{orb} = (r_{peri} + r_{apol})/2$$

$$a_{orb} = (4737400 + 71737400)/2 = 38237400 \text{ m}$$

Orbital Period

$$T = 2\pi \cdot \sqrt{\frac{a_{orb}^3}{\mu_{moon}}}$$

$$T = 2\pi \cdot \sqrt{\frac{38237400}{4904800000000}} = 670813.4289 \text{ s}$$

$$T/86400$$

$$670813.4289/86400 = 7.764044316 \text{ days}$$

Orbital Velocity Perilune

$$v = \sqrt{\mu_{moon} \left(\frac{2}{r_{peri}} - \frac{1}{a_{orb}} \right)}$$

$$v = \sqrt{4904800000000 \left(\frac{2}{4737400} - \frac{1}{38237400} \right)} = 1393.69988 \text{ m/s}$$

Orbital Velocity Apolune

$$v = \sqrt{\mu_{moon} \left(\frac{2}{r_{apo}} - \frac{1}{a_{orb}} \right)}$$

$$v = \sqrt{4904800000000 \left(\frac{2}{71737400} - \frac{1}{38237400} \right)} = 92.03726109 \text{ m/s}$$

Escape Velocity Perilune

$$v_{esc} = \sqrt{\frac{2 \cdot \mu_{moon}}{r_{peri}}}$$

$$v_{esc} = \sqrt{\frac{2 \cdot 4904800000000}{4737400}} = 1438.982862 \text{ m/s}$$

Station Keeping Delta-V

$$\Delta v_{sk} = (\text{estimate}) 12 \text{ m/s/yr}$$

10 Year Station Keeping Delta-V

$$\Delta v_{total} = \Delta v_{sk} \cdot \text{years}$$

$$\Delta v_{total} = 12 \cdot 10 = 120 \text{ m/s}$$

Required Panel Area

$$A_{panel} = \frac{P_{load}}{(S \cdot \eta \cdot \cos \theta)}$$

$$A_{panel} = \frac{15000}{(1361 \cdot 0.3 \cdot \cos \theta)} = 36.73769287$$

Recommended Panel Area

$A_{panel} \cdot margin$

$$36.73769287 \cdot 1.75 = 64.29096253 \text{ m}^2$$

Power Output

$$P = S \cdot a_{\text{panel}} \cdot \eta \cdot \cos \theta$$

$$P = 1361 \cdot 36.73769287 \cdot 0.3 \cdot \cos \theta = 15000 \text{ W}$$

Required Battery Energy Cap.

$$A_{energy} = P_{load} \cdot T_{eclipse} \div DoD$$

$$A_{energy} = 15000 \cdot 2880 \div 0.7 = 61714285.71 J$$

$$61714285.71 \div 3600 = 17142.85714 Wh$$

Required Radiator Area

$$A_{rad} = \frac{Q}{(\epsilon \cdot \sigma_{SB} \cdot T^4)}$$

$$A_{rad} = \frac{17000}{(0.88 \cdot 0.0000000567 \cdot T^4)} = 48.17161412 \text{ m}^2$$

Two Sided Radiator Area

$$A_{rad} \div 2 = 24.08580706 \text{ m}^2$$

Req. Shield Thickness Gen.

$$t = \frac{AD}{\rho_{shield}}$$

$$t = \frac{20}{1} = 20 \text{ cm}$$

Req. Shield Thickness Storm

$$t = \frac{AD}{\rho_{shield}}$$

$$t = \frac{40}{1} = 40 \text{ cm}$$

Exhaust Velocity

$$V_e = I_{sp} \cdot g_0$$

$$V_e = 450 \cdot g_0 = 4412.9925 \text{ n/s}$$

Initial Mass

$$m_0 = m_f \cdot e^{\left(\frac{\Delta v}{v_e}\right)}$$

$$m_0 = 2000 \cdot e^{\left(\frac{\Delta v}{v_e}\right)} = 2055.131041 \text{ kg}$$

Propellant Mass

$$m_{prop} = m_0 - m_f$$

$$m_{prop} = 2055.131041 - 2000 = 55.13104117 \text{ kg}$$

Total O2 Resupply Mass

$$M_{O_2} = n_{crew} \cdot rate_{O_2} \cdot t_{mission} \cdot (1 - \eta_{O_2})$$

$$M_{O_2} = 6 \cdot 0.84 \cdot 270 \cdot (1 - 0.78) = 299.376 \text{ kg}$$

Total Water Resupply Mass

$$M_{H_2O} = n_{crew} \cdot rate_{H_2O} \cdot t_{mission} \cdot (1 - \eta_{H_2O})$$

$$M_{H_2O} = 6 \cdot 4 \cdot 270 \cdot (1 - 0.92) = 518.4 \text{ kg}$$

Total Food Resupply Mass

$$M_{food} = n_{crew} \cdot rate_{food} \cdot t_{mission}$$

$$M_{food} = 6 \cdot 0.62 \cdot 270 = 1004.4 \text{ kg}$$

Total Consumables Mass

$$M_{total} = M_{O_2} + M_{H_2O} + M_{food}$$

$$M_{total} = 299.376 + 518.4 + 1004.4 = 1822.176 \text{ kg}$$