KOiOS

Creating an Intellect Hub around Saturn's Moons

KOIOS Mission Scope

KOIOS Mission Concept

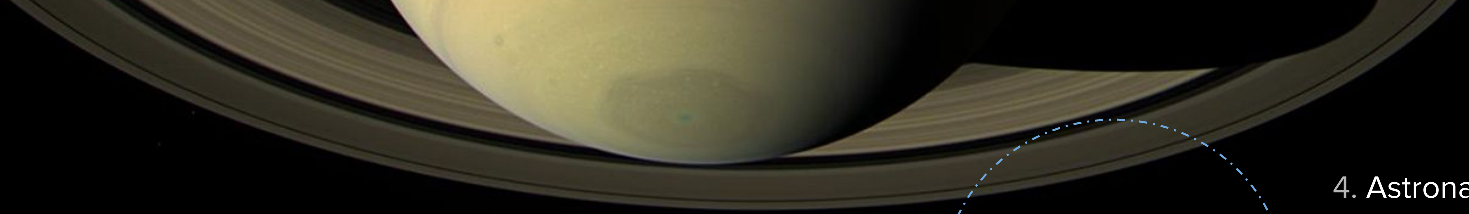
- **Need:** Expansion of human knowledge and exploration
- **Goal:** To place a scientific/fuel hub in orbit with Saturn's Moon Titan. This hub will be a premier destination for scientific studies of Saturn's unique topology, and be a future option from which to launch deep space operations.
- **Objective:** Launch hub into parking orbit of Saturn's Moon Titan
- **Mission or business case:** Transport people to Titan either as a scientific stop or a midway fueling point to further destinations
- **Operational Concept:** Launch crew, hub and return vehicle on a rocket into the parking orbit of Saturn's Moon Titan.. Crew will perform groundbreaking discoveries and return in return vehicle to Earth. Hub will stay in orbit and will get occasionally visited by space vehicle for either refueling or science.
- **Assumptions:** Everything is achievable and money is unlimited.
- **Constraints:** Keep people alive for an extended living duration in space.
- **Authority and Responsibility:** USA Space Force and NASA

Agenda

KOIOS Mission Overview

- Orbit *System Summary, Calculations & Requirements*
- Propulsion *System Summary, Calculations & Requirements*
- Reactor Design *System Summary, Calculations & Requirements*
- Thermal & Electrical Systems *System Summary, Calculations & Requirements*
- Life Support *System Summary, Calculations & Requirements*
- Radiation Shielding *System Summary, Calculations & Requirements*

CONOPS



Crew: *All are trained in piloting and are scientists.*

- Mechanical (Mech, Orbit, EVA)
- Electrical (Elec., Therm., Nuclear)
- Medicine (Human, Biochemistry)

4. Astronauts complete mini science missions.

5 years

3. Spacecraft SOI

Remains in orbit for ∞ yrs

Approx. 6 years

2. Spacecraft makes Hohmann transfer burn.

1 day

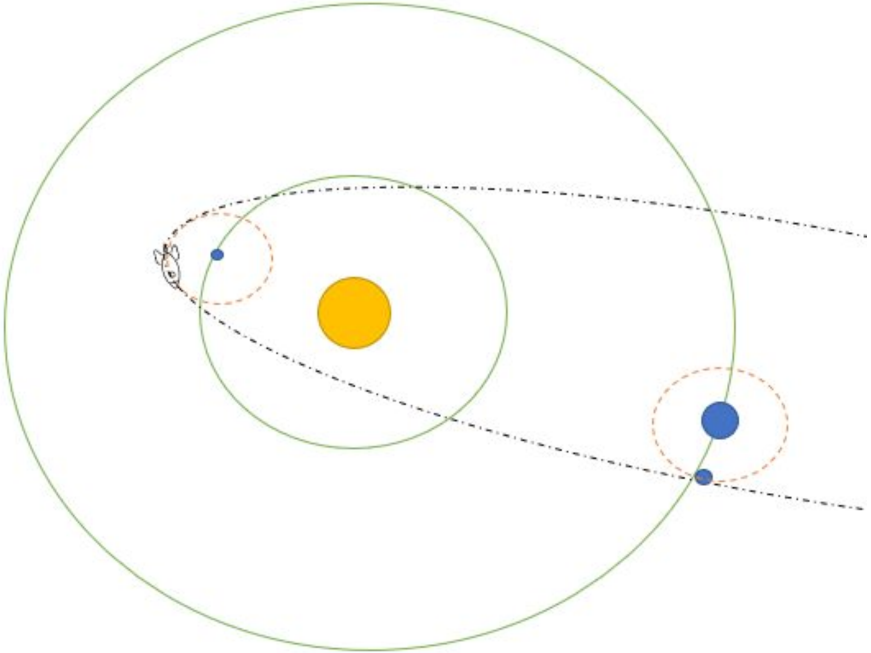
1. Spacecraft is constructed in Earth's Parking Orbit

3 months

Orbit

Travel to Planet: Hyperbolic Hohmann Planet Transfer

Analytical Calculations *Part 1*

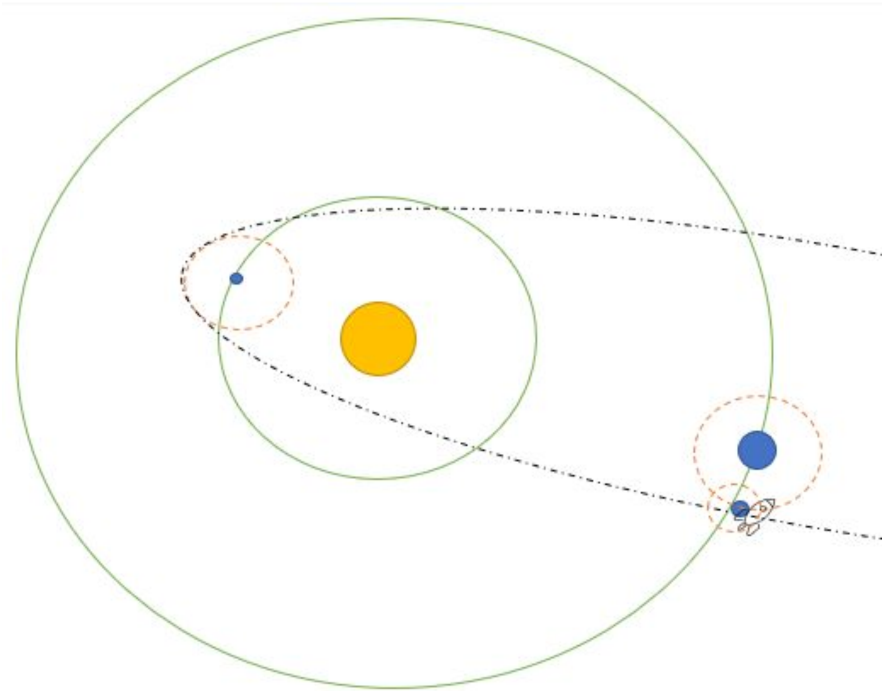


Departing Earth

$V_E = \sqrt{\frac{\mu_{sun}}{R_E}}$	29.7 km/s
$V_{transE} = \frac{1}{R_E}\sqrt{\frac{2\mu_{sun}R_E R_S}{R_E + R_S}}$	40.0
$V_{infE} = \lvert V_{transE} - V_E \rvert$	10.3
$V_{parkE} = \sqrt{\frac{\mu_E}{R_E + r_{pE}}}$	7.4
$V_{burnE} = \sqrt{V_{infE}^2 + 2V_{parkE}^2}$	14.6
$\Delta V_{dep} = \lvert V_{burnE} - V_{parkE} \rvert$	7.3

Travel to Planet: Hyperbolic Hohmann Planet Transfer

Analytical Calculations *Part 2*

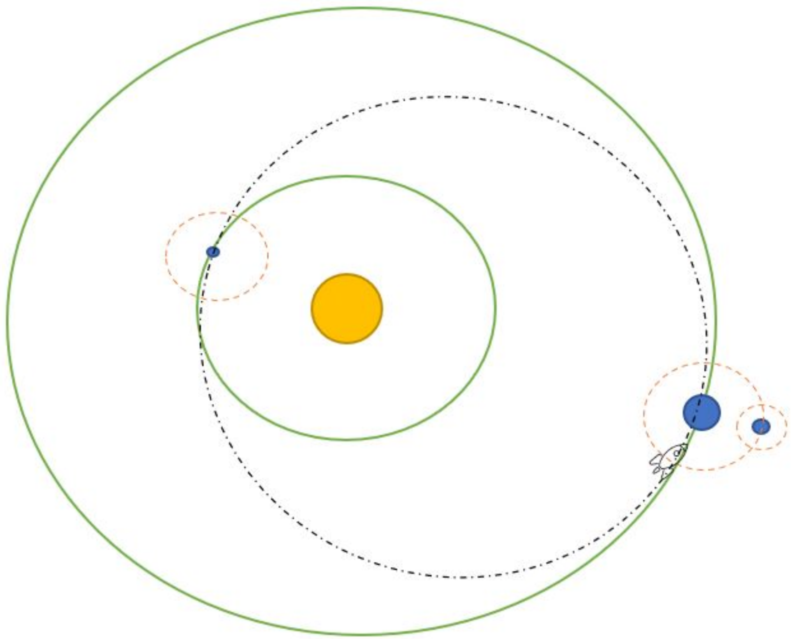


Arriving at Saturn

$V_S = \sqrt{\frac{\mu_{sun}}{R_S}}$	9.6 km/s
$V_{transS} = \frac{1}{R_S}\sqrt{\frac{2\mu_{sun}R_E R_S}{R_E + R_S}}$	4.2
$V_{infS} = \lvert V_{trans} - V_S \rvert$	5.4
$V_{parkS} = \sqrt{\frac{\mu_S}{R_S + r_{pS}}}$	5.5
$V_{burnS} = \sqrt{V_{infS}^2 + 2V_{parkS}^2}$	9.5
$\Delta V_{arv} = \lvert V_{parkS} - V_{burn_S} \rvert$	3.98

Travel to Planet: Hyperbolic vs Normal Hohmann Transfer

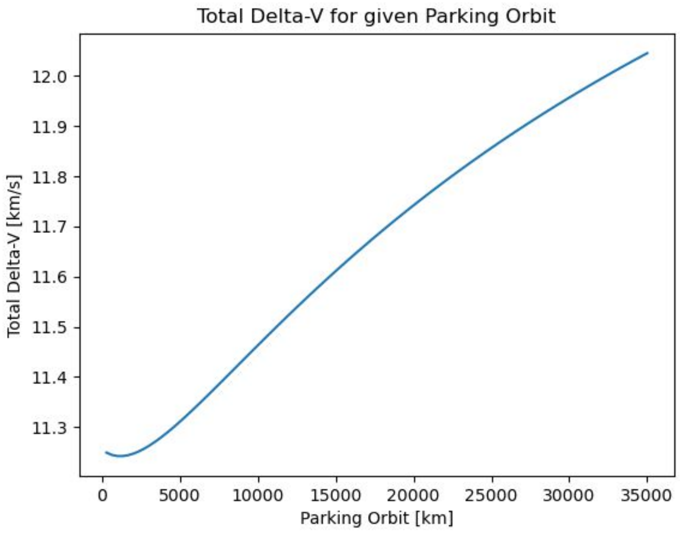
Analytical Calculations *Part 3*

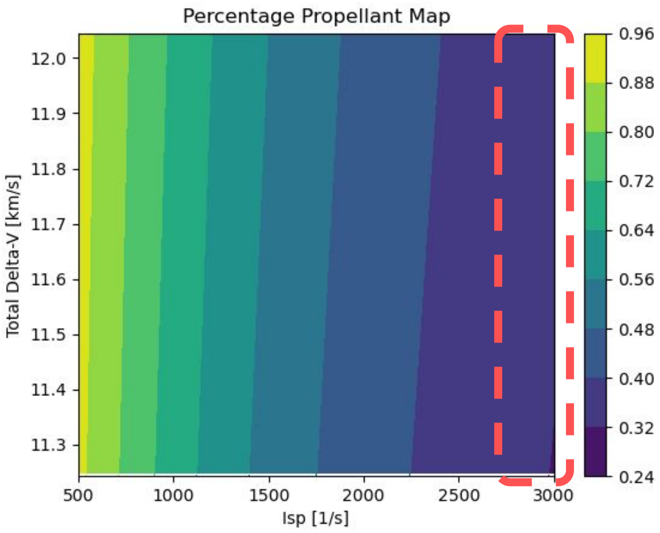


	From Parking	From Earth Orbit
Departure Delta-V	7.3 km/s	10.3 km/s
Arrival Delta-V	3.98 km/s	5.44 km/s
Total Delta-V	11.28 km/s	15.74 km/s

$$\tau = \frac{\pi}{\sqrt{\mu_{sun}}}\left(\frac{(R_E + r_{parkE}) + (R_S + r_{parkS})}{2}\right)^{\frac{3}{2}} \approx 6.04\ years$$

Total Delta-V, Percentage Propellant





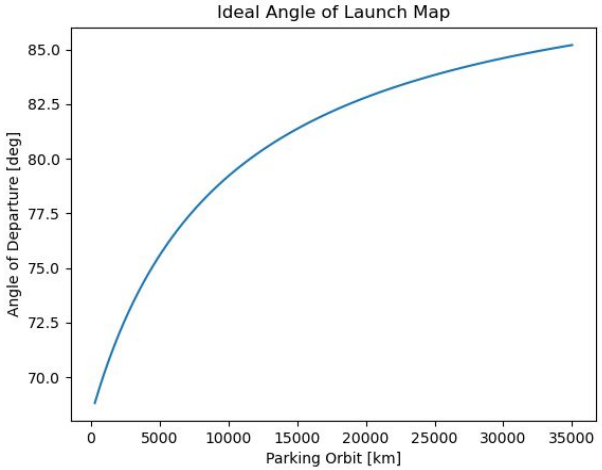
Minimum Delta-V at ~ 1000 km at Earth's Parking Orbit

Other Trajectory Parameters

Periapse Angle

$$\beta_{dep} = \cos^{-1}\frac{1}{1+\frac{(R_E + R_{parkE})V_{infE}^2}{\mu_E}}$$

$$\beta_{arv} = \cos^{-1}\frac{1}{1+\frac{(R_S + R_{parkS})V_{infS}^2}{\mu_S}} = 59.65\ deg$$



Eccentricity

$$e_1[r_{park} = 1000km] = 3.04$$

$$e_2 = 1.9$$

Phase angle

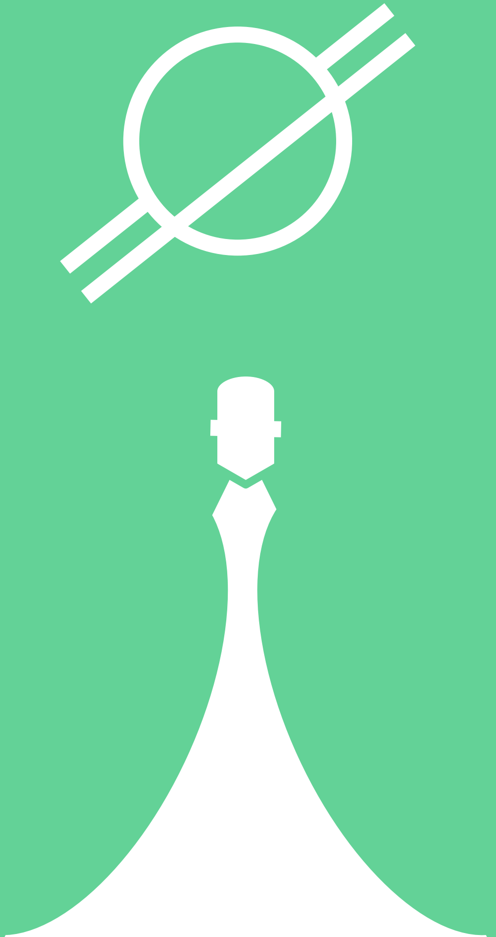
$$\theta = \pi - \sqrt{\frac{\mu_{Sun}}{R_S^3}}\tau = 106\ deg$$

Wait Time

$$t_{wait} = \frac{-2\theta - 2\pi N}{\sqrt{\mu_{sun}}\tau(\frac{1}{R_S^3} - \frac{1}{R_E^3})} = 1.65\ years$$

Synodic Period = 377 days

Propulsion



Propulsion

CD Nozzle attached to a gas core nuclear reactor

Isentropic flow was assumed

Reactor chamber gas Temperature T_0= 33800 K

Maximum Pressure P_0= 667 atm (67.6 MPa)

Propellant : H_2

Calculated I_{sp} = 2964 s

A / A_t = 29.58

A_{ex} = 1.04 m^2

Exhaust Diameter = 1.15 m

Divergent part Length = 1.76 m (15% cone half angle)

Hohmann transfer:
Departure ΔV = 7.3 km/s
Arrival ΔV = 3.98 km/s

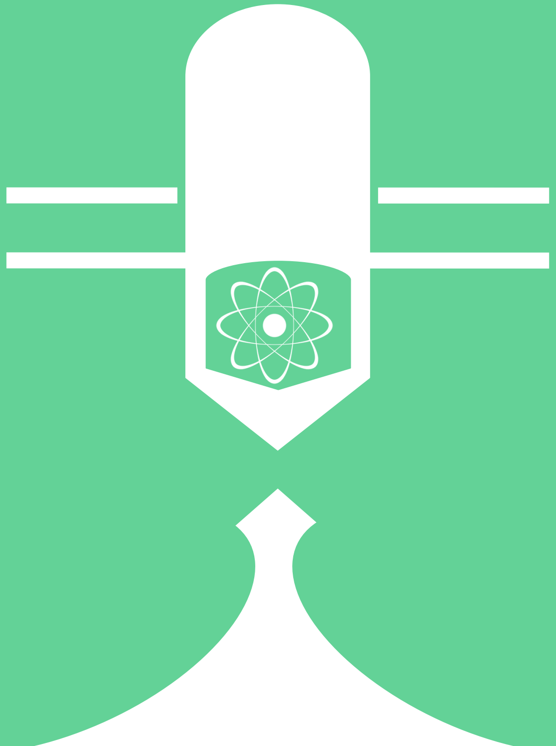
Mass ratio: M_i / M_f = 1.47

Initial Mass = 213790 kg
Final Mass = 145000 kg
Total Propellant Mass = 68790 kg

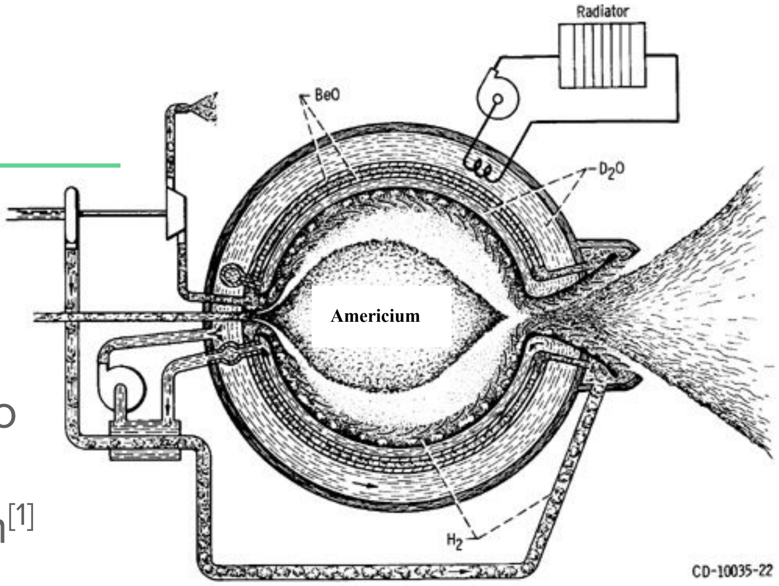
Burn 1 Propellant Mass = 47501 kg
Burn 1 final Mass = 166289 kg

Burn 2 Propellant Mass = 21289 kg
Burn 2 final Mass = 145000 kg

Reactor Design



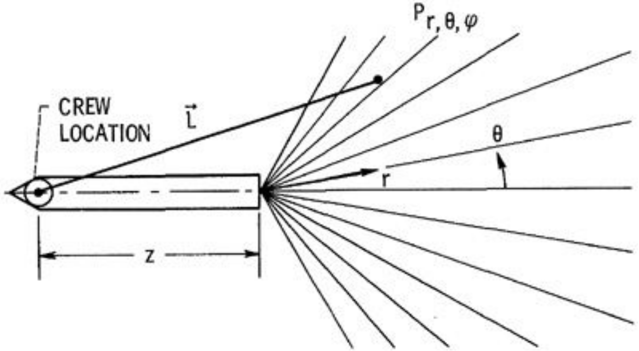
Nuclear Reactor



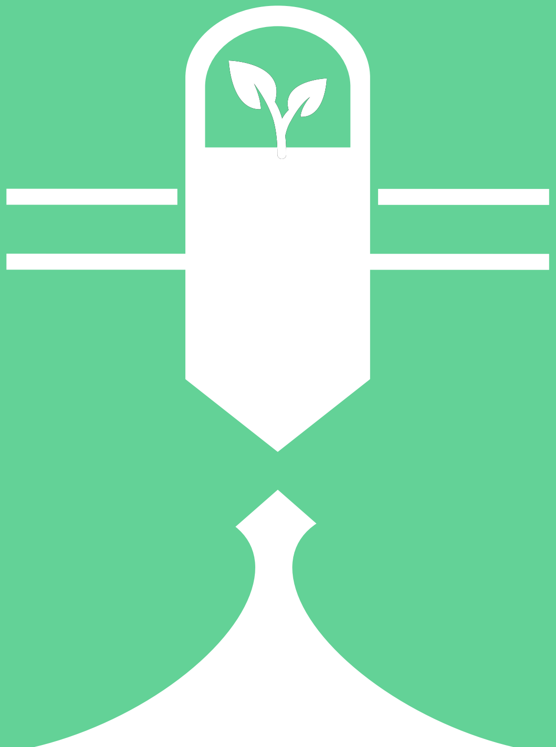
- The limit on a solid-NTR is limited to its chambers melting point
- Americium-242m is the main source of fuel to heat up the propellant (liquid hydrogen)
- The drawback is Am-241 is $1,500 USD/gram[1]
- The reaction is maintained in a vortex tailored to minimize loss of fuel out the nozzle[2]
- Reaction chamber can withstand waste heat up to 100 MW/m^2 before the chamber is destroyed[2]

Nuclear Reactor

- The chamber core is moderated via Beryllium oxide gas and a heavy water as coolant[2]
- The trouble with Open-Cycle GCR is radioactive fuel is exhausted with the propellant (neutron flux of 10^{16} [$1/m^3$])
- The cavity walls receive only about 1 or 0.5 % of the thermal radiation from the fireball[3]
- Wall protection is accomplished by introducing about 1 % by weight of a seeding material such as graphite or tungsten particles into the hydrogen[3]



Life Support

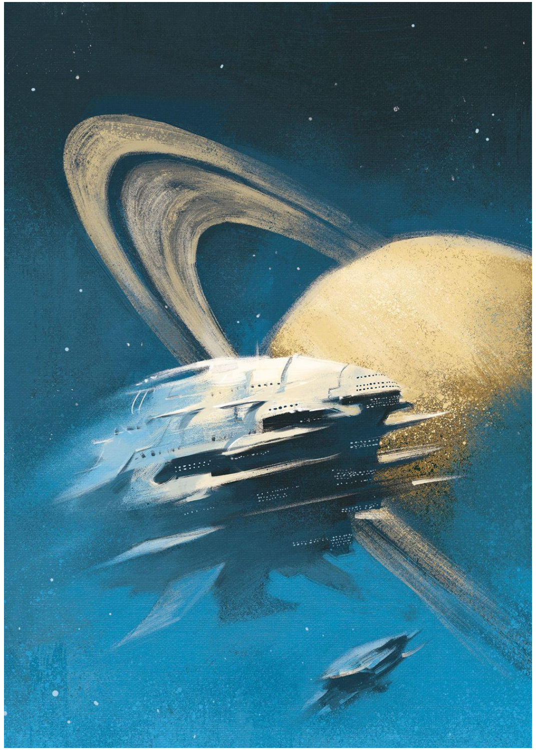


Current Life Support Technologies

https://www.space.com/60-years-human-spaceflight-changes

https://www.nasa.gov/centers/marshall/news/releases/2021/marshall-ships-next-generation-air-filtration-hardware-for-flight-to-iss.html

https://www.nasa.gov/aeroresearch/resources/artifact-opportunities/space-food/



https://www.artstation.com/artwork/VJxl5

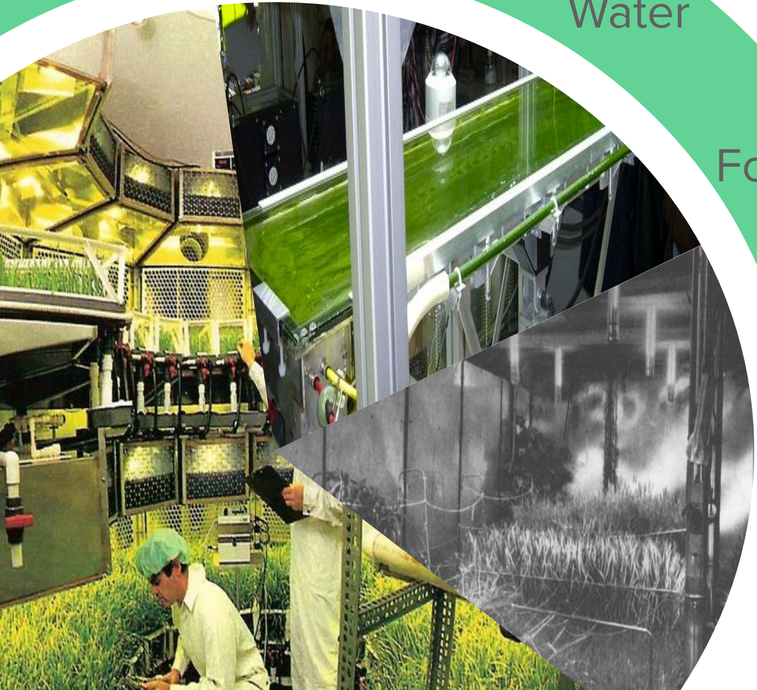
Requirements for life support

Air

Water

Food

Waste Management



BIOS -3,
MELISSA algae bioreactor,
Biomass Production Chamber

Algae based
life support system

https://commons.wikimedia.org/wiki/File:Photobioreactor_PBR_4000_G_IGV_Biotech.jpg

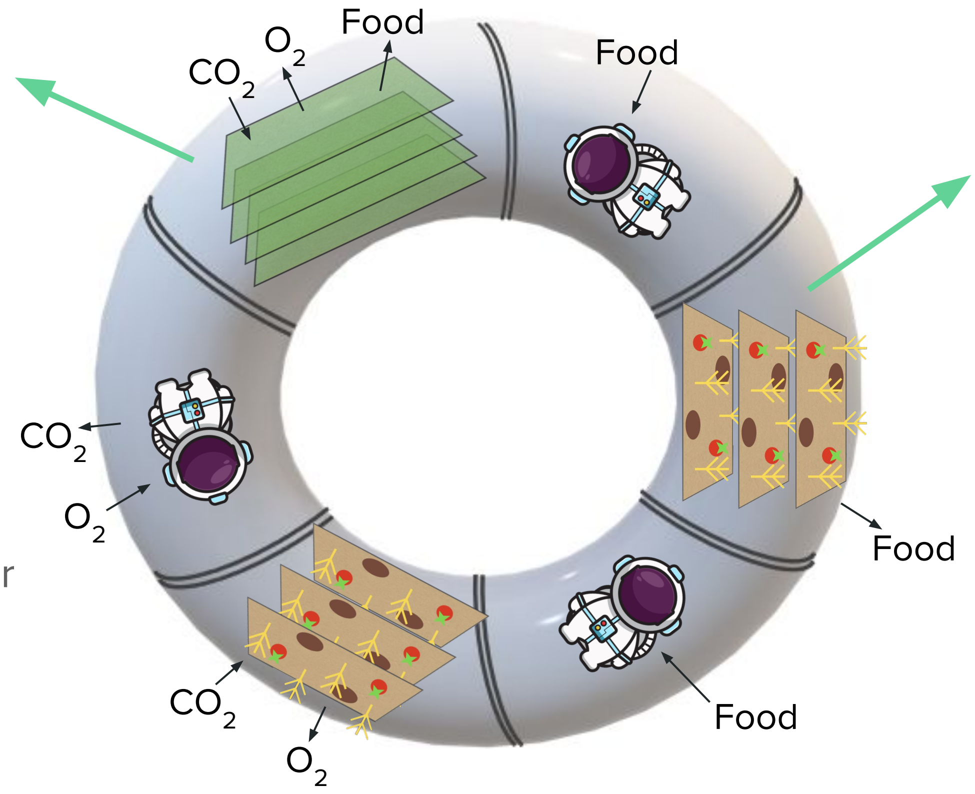
https://spinoff.nasa.gov/indoor-farming
https://www.melissafoundation.org/page/photobioreactor
https://academic.oup.com/bioscience/article/47/9/575/222647?login=true

Life support design

Algae oxygen regeneration

Per person:

- ~20 kg of water and algae[1]
- 8 m^2 of algae area[1]
- 800 W needed for LED lighting[2]



Food

Daily caloric requirement:

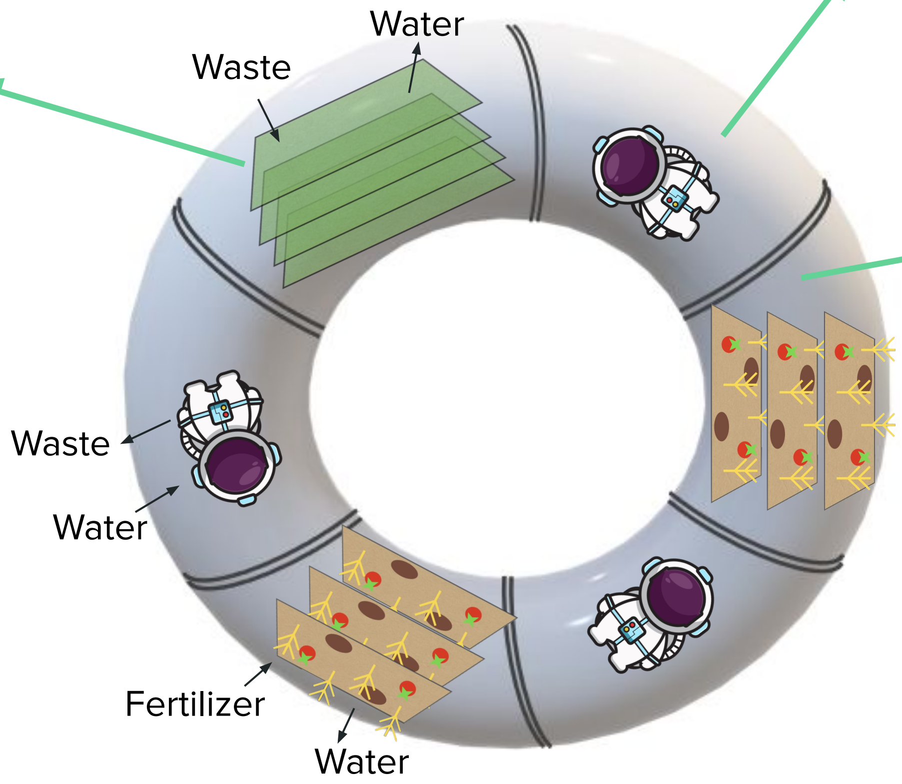
- 150 calories of Spirulina[3]
- Food from 30 m^2 of growing area[4]

https://www.vecteezy.com/vector-art/2084192-cute-astronaut-mascot-character-cartoon-vector-icon-illustration

Life support design

Water and waste recycling[1]

- Urine and solid waste added to algae tanks
- Moist air in growing chambers condensed for water



Crew area

- Need 17 m^3 per person[5]

Modeled after BEAM module on ISS[6]

- Inflatable
- 1360 kg
- 16 m^3

Total parameters

- Mass: 8500 kg
- Power: 8.7 kW

Gravity

- Creating artificial gravity using centrifugal force
    - Prevents damage to humans from microgravity effects
- Rotation tolerance from humans is up to 4 rpm[7]
- Flywheel have a radius of 55.9 m to provide 1g of artificial gravity

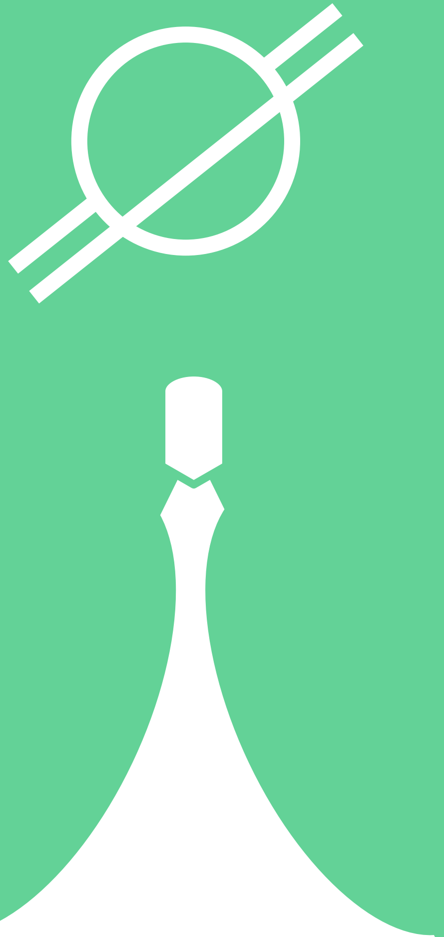
https://70sscifiart.tumblr.com/post/136401183201

$$a = \omega_{rad}^2 r = (\frac{2\pi}{60}\omega_{rpm})^2 r = 0.011\omega_{rpm}^2 r$$

$$r = \frac{a}{0.011\omega_{rpm}} = \frac{9.81m/s}{0.011 * (4rpm)^2} = 55.9m$$

[a] = centripetal acceleration in meters per second
[r] = rotation radius in meters
[ω_{rad}]= rotation rate in radians per second
[ω_{rpm}]= rotation rate in rotations per minute

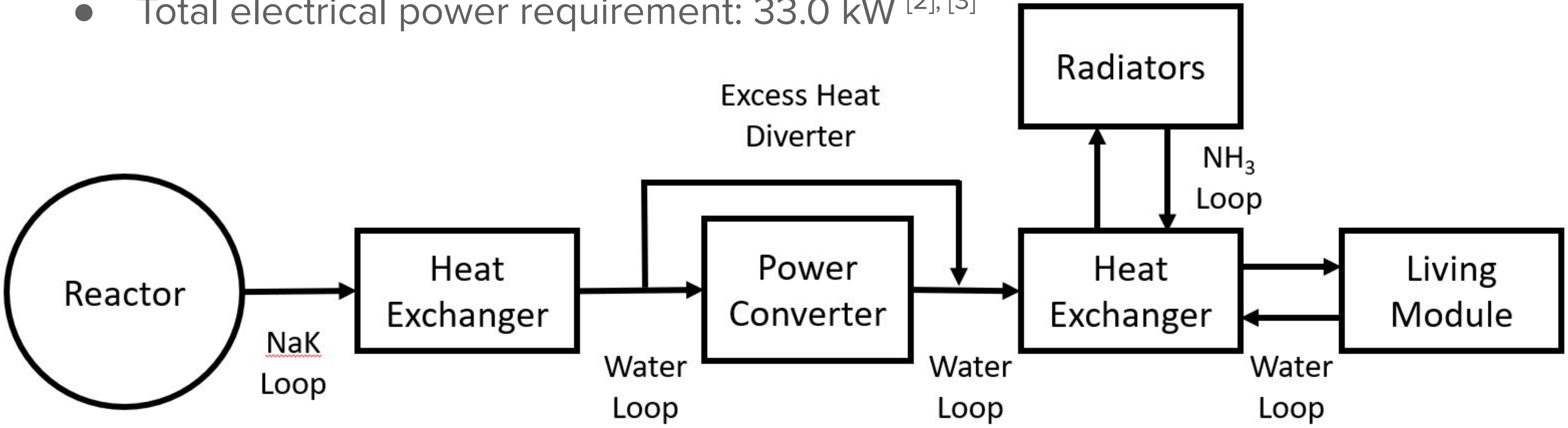
Thermal & Power Systems



Thermal and Power Systems

System removes reactor heat via thermionic power conversion and radiators for heat rejection (ATCS model).[1]

- Reactor heat: 5 MW
- Living module waste heat: 5.17 kW [2], [3], [4]
- Total electrical power requirement: 33.0 kW [2], [3]



Thermal and Power Systems

Type	Efficiency	Weight (kg)	Radiator Area (m^2)	Radiator Weight (kg)
Thermionic	60%	446	460.9	9745
Thermovoltaic	40%	3300	460.9	9745
Thermoelectric	15%	1205	460.9	9745
Gas dynamic	30%	1980	461.0	9756

References: [5]-[10]

- Radiators would be aluminum vapor fin-tube because of their superior specific weight. [10]
  - E.g. central fin-tube 2.15 kg/kW
  - E.g. vapor fin-tube 1.31 kg/kW
- Radiator weight does not change between static power converters due to similar heat removed.

Radiation Shielding

Radiation Environment

- Space Environment [1]
  - Near-Earth IRB, ORB, SEP, GCR

    You can model at CCMC NAIRAS model
  - Interplanetary SEP, GCR
  - Near- Saturn RB, SEP, GCR
- Reactor
  - Calculated assuming: 1% leak [2]
  - Allowing for 15 year mission to account for 12.5% of Astronaut career limit

Largest source is from Interplanetary Space

$$\left(62.5\,\frac{cSv}{yr}\right)_{GCR} + \left(42.5\,\frac{cSv}{yr}\right)_{SEP} = 105\,\frac{cSv}{yr} = 2.87\,\frac{mSv}{d}$$

~ 26 times career limit of Astronaut

$$\left(1.2\cdot 10^{3}\frac{n}{m^{2}}\cdot 2\ MeV\ in\ J\cdot\frac{0.75\ m^{2}}{45\ kg}\cdot 1\ day\ in\ s\right)_{n} + \left(1.2\cdot 10^{4}\frac{y}{m^{2}}\cdot 1\ MeV\ in\ J\cdot\frac{0.75\ m^{2}}{45\ kg}\cdot 1\ day\ in\ s\right)_{n} \approx 13.68\,\frac{\mu Sv}{d}$$

Shielding

Passive

Shields near-Earth & reactor

Overestimate, does not include free-space loss

- Calculated with assumptions:
  - Graphite B=2.2[3], Σ_R=0.1 cm^{-1}
  - 1% n flux leak, 2 MeV
  - +1 OOM y flux leak, 1 MeV
- 260 cm of Graphite for n shielding
- Scale 5.5 m of Graphite for y shielding
- 5.5 m^3 Carbon/Graphene/Graphite compound weighs 12463 kg

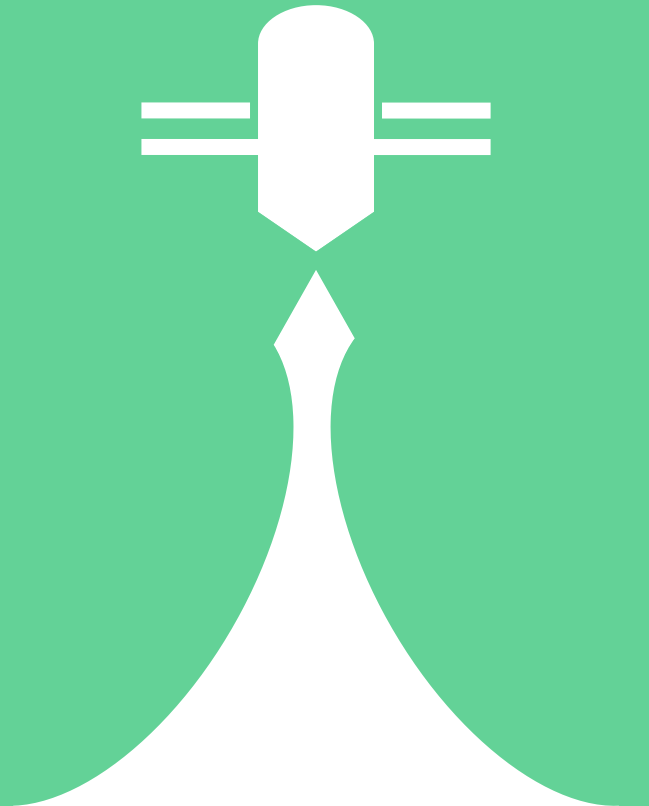
Active

Shields interplanetary travel

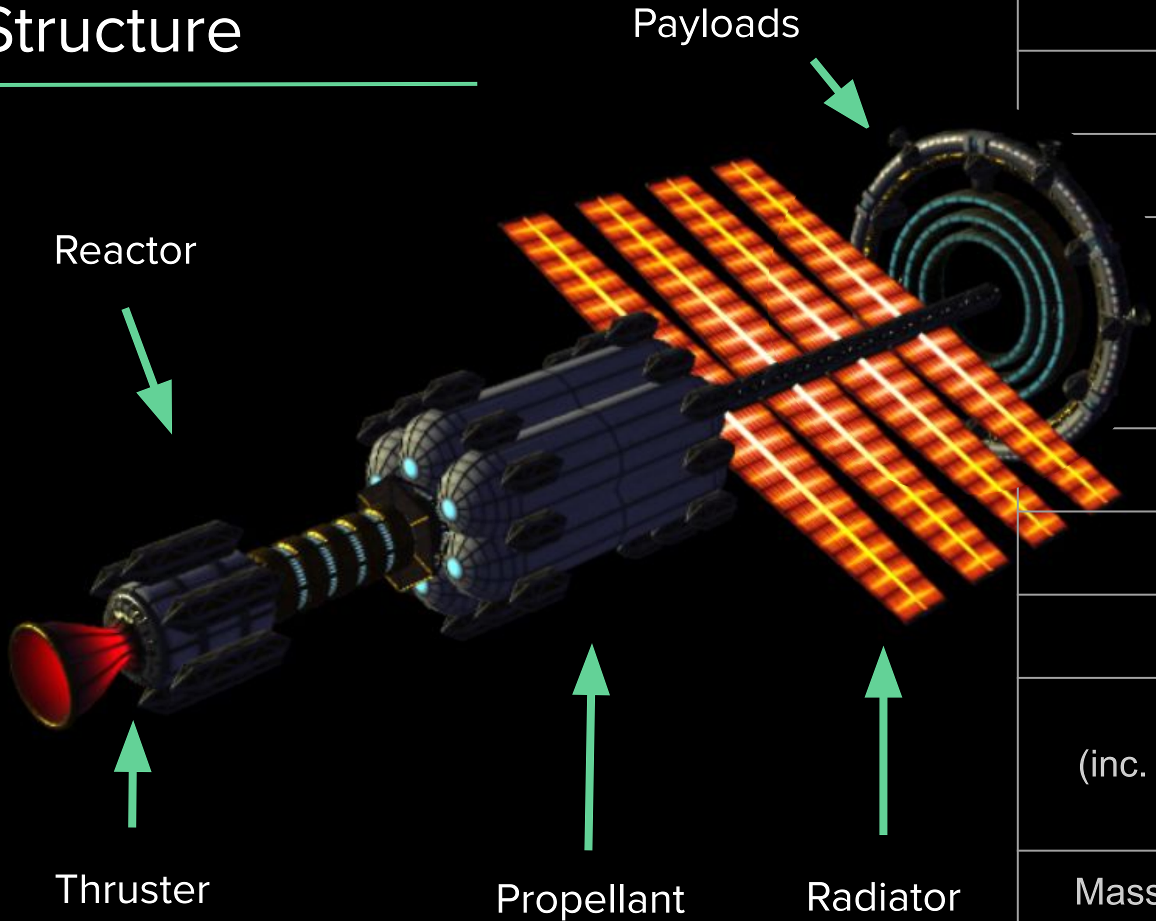
M2P2 System[4] is theoretical, will be available.

- Magnetic shielding similar to Earth shields against GeV cosmic rays
- Smaller generated EM field is expanded using injected plasma and solar wind
- 32 kW extends out 100 km
- Several kg for 10^1 cm supermagnet

Structure



Structure



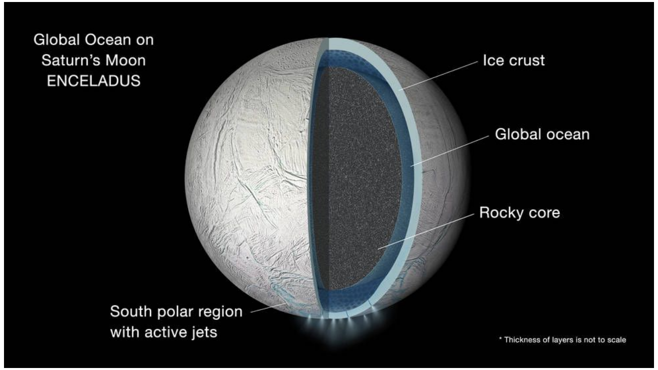
Systems Table

Delta- V	7.3 + 3.98 (km/s)
ISP	2964 (s)
Thrust	96.8 (kN)
Propulsion Type	Nuclear Gas Core Reactor
Propellant Fuel	Liquid Hydrogen
Exhaust Velocity	29077 (m/s)
Mass Flow Rate	3.33 (kg/s)
Wet Mass (total)	214150 kg
Dry Mass (inc. mini spacecraft / Lander)	145000 kg
Mass Ratio (Wet/Dry)	1.47

Mini-Explorer Craft

Space hub as refuelling station

Once in Saturn's orbit, the space hub can be used as an "gas station" for different missions to Saturn's Moons



From where can we get more fuel/propellant?

- **Enceladus** has an **ice ice shell** about 19 to 25 miles (30 to 40 kilometers) thick on its surface at ~ -200 °C

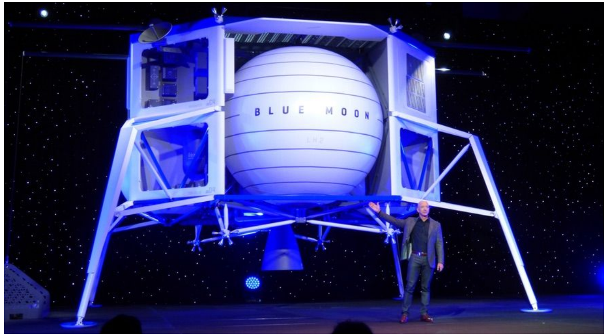
- It has a small surface gravity! only 0.113 m/s2 (0.0113 g)

➔ **Small Escape Velocity : 0.239 km/s**

- A "mini spacecraft" could travel to Enceladus from the space hub, cut a piece of ice, grab it and transport it to the station where it can be liquified and separated onto LOx and LH_2 through electrolysis.
- This can help to expand the number of possible missions once in Saturn's orbit and reduce the amount of propellant to transport to the final destination.

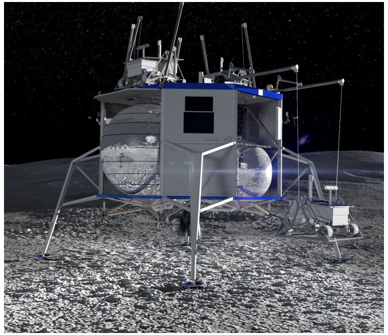
Mini Spacecraft

The “mini” spacecraft is based on private contractor designs for Moon missions where the payload is modified:



Blue Origin, Blue Moon Lunar Lander

Original specifications
- Dry mass = 10850 kg
- Propellant mass = 5550 kg
- Payload mass = 4500 kg
- BE-3U engine (710 kN vacuum thrust)
- LOx + LH_2



Proposed Modifications:

- Addition of robotic arms with a laser at the end of one of them to cut the ice
- Grab the cutted ice with two robotic arms and locate it in the payload bay

Mini Spacecraft - Laser and Robotic Arms

Laser Ice Cutting

CO_2 laser at 10.6 µm (wavelength at which ice strongly absorbs)

Drilling speed ~ 0.8 mm/s for solid ice

Laser intensity ~ 50 W/cm^2

AL50 CO_2 laser 10 W power consumption, 11 kg

Robotic arms

Private contractor: REDWIRE

STAARK robotic arm

Modular robotic system designed for various on-orbit robotics applications

32 kg max weight per robotic arm

Expanded Li-ion Battery
10 kWh
(414 Wh/kg)

→ 24 kg

Mini Spacecraft

BE-3U engine uses ($LOx + LH_2$) → Isp = 450 s

Mass Analysis

Dry mass before landing = 7759 kg
Landing propellant mass = 409 kg

→ M_{Ice} = 10000 →

Departure propellant mass = 915 kg
Mass before Departure = 17350 kg

$\boxed{M_{Ice} / M_{Propellant} = 7.55}$

$M_{Propellant}$ = 1324 kg

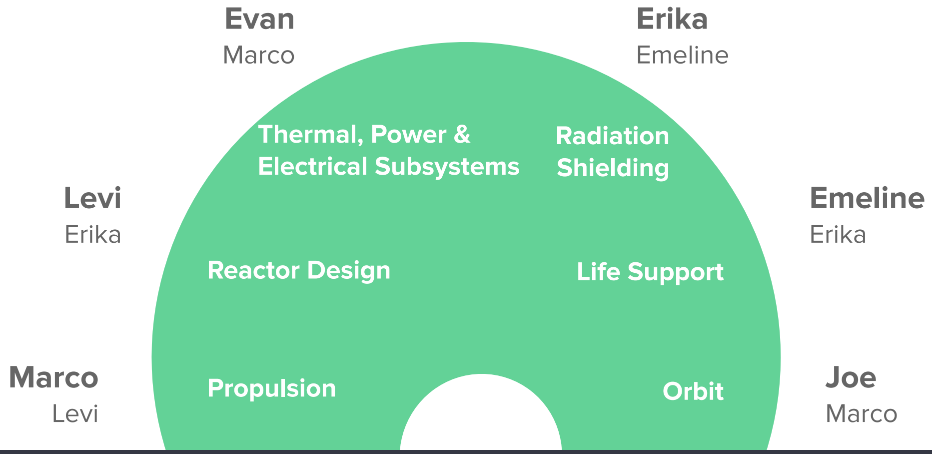
The 10 tons of ice can then be liquified and converted to LOx and LH_2 using a heater and the electrolysis module on board of the space hub

Extra Resources

Want to know more?

- Our KOIOS Team
- KOIOS Mission Scope
- Refueling Station
- Mini Spacecraft
- Electrolysis Module
- Potential Gravity Assist
- Scientific Instrumentation on Mini Spacecrafts
- Crew Specifications
- BIOS-3 Algae Experiment (Life Support)
- Requirements
- References

The Team & Our Mission



The Koios Mission

We aim to travel to Saturn, stay and establish a central deep-space hub from which we can explore Kronian moons and conduct science experiments.

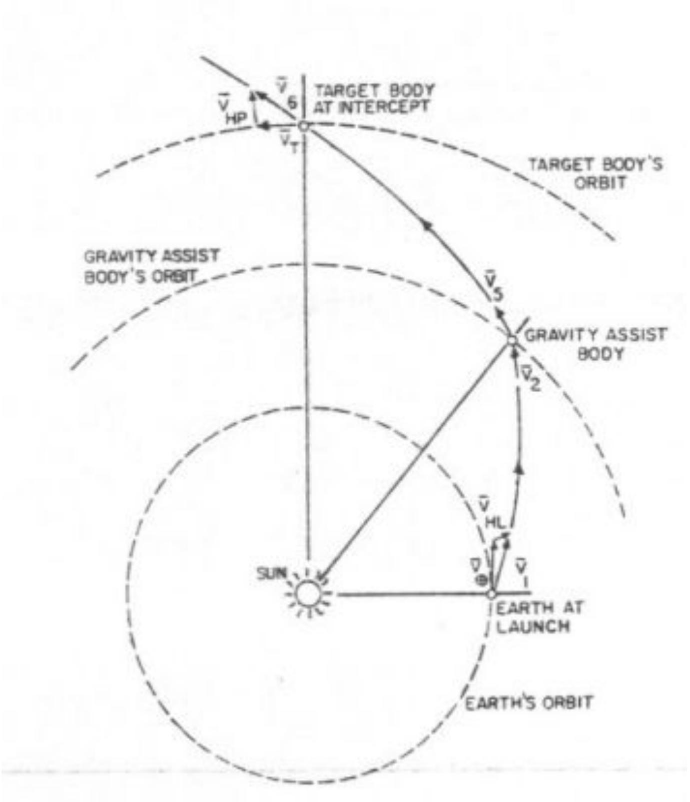
Electrolysis Module

- Wasted heat from Nuclear reactor can be used to liquify the ice
- Based on Elektron electrolysis module at ISS
- 20 units, each one 150 kg, 860 Watts of power
- ~ 1900 l per day per unit, ~ 54 kg per day in total
- 7.2 kW total power required

Scientific Instrumentation

Composite Infared Spectrometer	Measures IR thermal radiation to infer temperature
High Resolution Imaging System	UV-Visible-IR camera
UV-Visible-IR Spectrometer	-Identifying element compositions -Measure of plasma density, flow, velocity, temperature, magnetic field, electric field
Ion and Neutral Mass Spectrometer	Identifying element composition
Gamma and Neutron Spectrometer	Radiation Measurement
Cosmic Particle Analyzer	Detect dust particles to determine composition
Magnetometer	Detects Magnetic field vectors
Langmuir Probe	Ion and Electron Temp., Ion and Electron Density

Optimal Simple Single Gravity Assist



$$\Delta V_{ga\_max} = \sqrt{\frac{\mu_{ga}}{r_{ga}}}$$

$$V^{+} = Velocity\ needed\ from\ gravity\ assist\ to\ next\ planet$$

$$V_{ga} = Velocity\ of\ gravity\ assist\ planet$$

$$\Delta V_{ga} = Delta\ V\ gain\ from\ gravity\ assist\ planet$$

$$V^{+} = V_{ga} + \Delta V_{ga} + \Delta V_{arrv}$$

$$V^{+}_{min} = \sqrt{\frac{2\mu_S}{R_{ga}} - \frac{2\mu_S}{R_{ga} + R_{des}}}$$

$$\Delta V_{tot} = \Delta V_{dep\_to\_ga} + \Delta V_{arrv\_min}$$

Gravity Assist Planet	ΔV_{ga_max}	ΔV^{+}_{min}	V_{ga}	ΔV_{arrv_min}	$\Delta V^{**}{}_{dep\_to\_ga}$
Venus	7.3	47.6	35	5.3	2.47
Mars	3.6	31.7	24.1	4	2.95
Jupiter	42.6	14.8	13.1	0*	8.79

*Potentially requires no fuel burn into arriving planet

**BIG ASSUMPTION – Assume Hohmann transfer to gravity assist planet arrives at the correct angle to take all potential energy of assist planet

Crew specifications

Role:	**Pilot and mechanical/ aerospace specialist**	**Copilot and electrical/power specialist**	**Science expert and nutritionist/medical specialist**
Main responsibilities:	Mechanical systems, Flight controller, Orbit tracking, EVA activities	Electrical systems, Delegated tasks, Nuclear reactor systems	Astrobiological sciences, Biochemical testing, Life-support systems, Health care activities

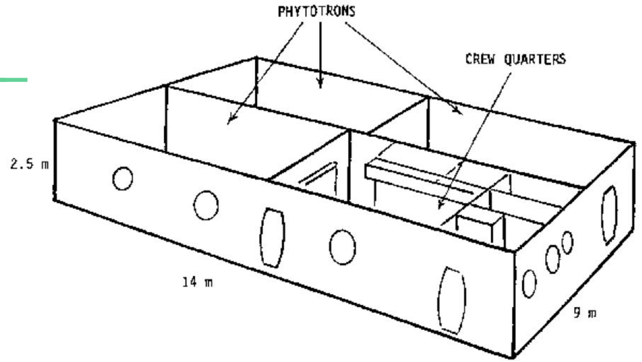
Past algae experiment: BIOS-3

Soviet controlled ecological life support system (CELSS) built in 1972

- 315 m^2 of space
- Used 400 kW of electricity

Results:

- 70% of caloric requirement satisfied by two phytotrons
- Each phyltron provided 1000 L of oxygen a day
- ~ 8 m^2 of algal culture needed per for one person
- Closed water and gas exchanges



Mission Level Requirements

Requirements

ML-1 KOIOS shall be survivable for the duration of travel to Saturn and for the duration of the scientific exploration mission.

ML-1-a Survivability is defined by the life of astronauts, including electronic and hardware, spacecraft subsystems.

ML-1-b The spacecraft should be operable at maximum capacity for at least 50% of the mission life.

ML-2 KOIOS shall be equipped with separable and independent ‘mini-spacecraft’ for individual scientific mission use.

ML-2-a The ‘mini-spacecraft’, would be self-sufficient, only requiring minor refueling.

ML-2-b The ‘mini-spacecraft’ when on but attached to the main KOIOS bus, shall take up to 15% of the main mission SWaP.

System Level Requirements

Requirements

Propulsion, Reactor Design

SL-PRD-1 Spacecraft will have enough thrust to leave Earth and change orbits using a Hohmann transfer.

SL-PRD-1-a Spacecraft shall have nuclear thermal rocket that supports propulsion and electrical power requirements.

SL-PRD-2 Propulsion system and reactor will account for 15% of spacecraft mass.

Thermal, Power, & Electrical Systems

SL-TPE-1 Power subsystem will be connected to the reactor with the thermal subsystem connected via cooling with thermoelectric energy backup support.

SL-TPE-2 Thermal subsystem will be modelled after the Active Thermal Control System (ATCS) from the ISS to regulate interior and equipment temperatures to an Earth-like temperature of 25 °C.

SL-TPE-3 Thermal, Power, & Electrical Subsystems will account for no more than 15% of spacecraft mass.

System Level Requirements cont.

	Requirements
Shielding	
SL-SH-1	Radiation shielding shall protect astronauts from radiation (from ambient environment and reactor) to keep yearly dosage to less than the radiation received by an astronaut on the ISS.
SL-SH-2	Shielding will account for 15% of spacecraft mass.
Life Support	
SL-LS-1	Enough air must be provided for astronauts to survive in a closed system for 150% of the mission length.
SL-LS-2	Each astronaut must eat three meals a day containing daily required nutrients.

System Level Requirements cont.

	Requirements
Orbit	
SL-ORB-1	Spacecraft must make it to the orbit of Saturn in under 7 years.
SL-ORB-2	Data must be constantly sent to-and-from Earth.
Design and Build	
SL-DB-1	The mass of the spaceship must be under 850 MT.
SL-DB-2	The size of the spaceship will be around 100 m^3, about the size of four school buses.
SL-DB-3	Spaceship will be launched in stages and assembled in space in under 3 months.
SL-DB-3-a	Spacecraft will have a gravitational flywheel to improve astronaut heath and plant growth.
SL-DB-4	Spacecraft must have smaller subsystems for smaller science missions within the Kronian environment (drone, blimp, air-sampling, etc.).

References

Life Support

1. F. B. Salisbury, J. I . Gitelson, G. M. Lisovsky, https://academic.oup.com/bioscience/article/47/9/575/222647?login=true
2. Amazon, https://www.amazon.com/Efficiency-Spectrum-Gardening-Aeroponic-Hydroponics/dp/B00LSGL0Q8
3. S. C. Lama, https://www.livestrong.com/article/382754-how-much-spirulina-should-i-consume/
4. R.M. Wheeler, https://doi.org/10.1016/0273-1177(95)00880-N
5. B. K. Joosten, https://ntrs.nasa.gov/citations/20070023306
6. NASA, https://www.nasa.gov/sites/default/files/atoms/files/2016-march-beam-factsheet-508.pdf
7. A. Globus and T. Hall, http://space.alglobus.net/papers/RotationPaper.pdf

References

Thermal & Power Systems

1. Boeing, https://www.nasa.gov/pdf/473486main_iss_atcs_overview.pdf
2. M. Kuzlu, https://onlinelibrary.wiley.com/doi/10.1002/2050-7038.12980
3. NASA, ISS: https://mobile.arc.nasa.gov/public/iexplore/missions/pages/solarsystem/iss.html
4. M. Stevens, http://large.stanford.edu/courses/2016/ph240/stevens1/
5. M. F. Campbell, https://onlinelibrary.wiley.com/doi/full/10.1002/advs.202003812
6. W. R. Chan, https://www.pnas.org/doi/full/10.1073/pnas.1301004110
7. A. Datas, https://oa.upm.es/50077/2/INVE_MEM_2017_264242.pdf
8. L. L. Begg, https://ieeexplore.ieee.org/abstract/document/1391964?casa_token=EMJ6jAr7VQIAAAAA:64bw-X9IV5vidgQgD-gxjVquVzKe25vMZpmx3kX-vi7ADOSAbyestsKcLqVZysChPffplzkg-A
9. NASA, TE: https://mars.nasa.gov/internal_resources/788/
10. H. C. Haller, https://ntrs.nasa.gov/api/citations/19680006855/downloads/19680006855.pdf

References

Propulsion and Mini Spacecraft (Lander)

1. Nozzle design: https://www.grc.nasa.gov/www/k-12/rocket/nozzle.html
2. Enceladus data: https://en.wikipedia.org/wiki/Enceladus
3. Blue Moon Lander data: https://es.wikipedia.org/wiki/Blue_Moon_(Nave_espacial)
4. Ice Cutting Laser paper: Cold Regions Science and Technology Volume 121, January 2016, Pages 11-15
5. Ice Cutting Laser datasheet: https://www.accesslaser.com/product/al50/
6. Robotic arms: https://redwirespace.com/products/staark/?rdws=nnn.xffxcv.tfd&rdwj=43938
7. Electrolysis module: http://www.jamesoberg.com/elektron2_tec.html

References

Gaseous Core Reactor:

1. Fuel Choice: https://deepblue.lib.umich.edu/bitstream/handle/2027.42/87734/585_1.pdf?sequence=2&isAllowed=y
2. Core Mechanics: http://www.projectrho.com/public_html/rocket/enginelist2.php#basicgcr
3. Chamber Heat: https://ntrs.nasa.gov/api/citations/19710010425/downloads/19710010425.pdf

References

Radiation Shielding

1. Radiation Sources:
    a. Schombert, Jim, University of Oregon, Astronomy 121: The Solar System Lecture 19, 2019
    b. Atwell, W., et al., “A Comparison of the Radiation Environments in Deep Space”, Journal of Aerospace, 2007
    c. Jun, I., et al., “Trapped Particle Environments of the Outer Planets”, IEEE Transactions on Plasma Science, 2019
    d. Dachev, T.P., et al., “Overview of the ISS radiation environment obserfved during the ESA EXPOSE-R2 mission in 2014-2016”, Space Weather 2017
2. Reactor Radiation calculation: Professor Foster’s HW 1 #3
3. Passive Shielding Build-up factor: Calculation for gamma ray buildup factor for aluminium, graphite and lead | International Journal of Nuclear Energy Science and Technology (inderscienceonline.com)
4. M2P2 Active Shielding: Mini-Magnetospheric Plasma Propulsion (washington.edu)

References

Structure Mass

1. Tank mass: https://spacecraft.ssl.umd.edu/academics/791S16/791S16L08.MERsx.pdf

Travel to Planet: Hohmann Planet Transfer

Simulation *Part 1*

Departure:

Planet: Earth
Year : 2040
Month : January
Day : 13

Planet position vector (km):
[-5.47233e+07 1.36573e+08 -10857.9]
Magnitude = 1.47128e+08

Planet velocity (km/s):
[-28.1361 -11.1923 0.0015663]
Magnitude = 30.2805

Spacecraft velocity (km/s):
[-40.2787 -4.05132 1.74893]
Magnitude = 40.5197

v-infinity at departure (km/s):
[-12.1426 7.14096 1.74736]
Magnitude = 14.1947

Arrival:

Planet: Saturn
Year : 2046
Month : January
Day : 27

Planet position vector (km):
[-3.85713e+08 -1.44872e+09 4.04355e+07]
Magnitude = 1.47128e+08

Planet velocity (km/s):
[8.80595 -2.51198 -0.306979]
Magnitude = 9.16237

Spacecraft Velocity (km/s):
[3.57168 -1.42159 -0.125165]
Magnitude = 3.84623

v-infinity at arrival (km/s):
[-5.23428 1.09039 0.181813]
Magnitude = 5.34973

Travel to Planet: Hohmann Planet Transfer

Simulation *Part 2*

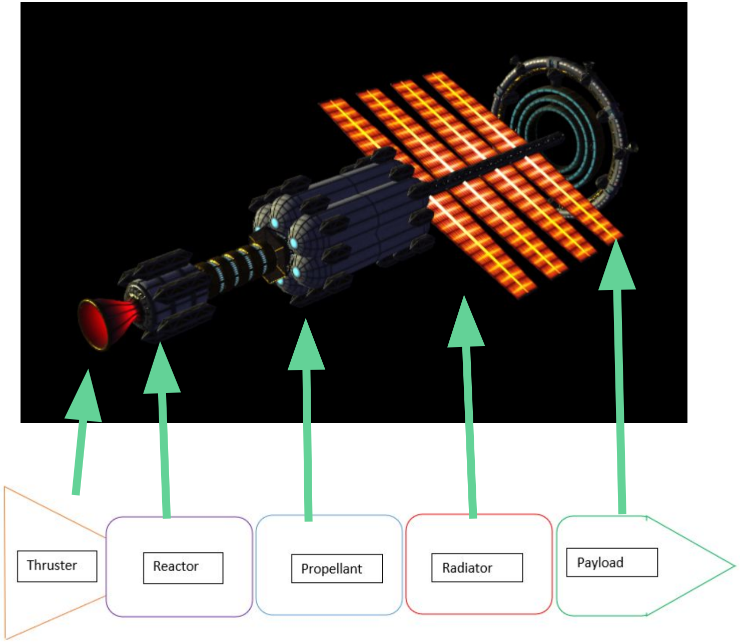
Time of flight = 2206 days

Orbital elements of flight trajectory:

- Angular momentum (km^2/s) = 5.72847e+09
- Eccentricity = 0.835353
- Right ascension of the ascending node (deg) = 111.929
- Inclination to the ecliptic (deg) = 2.57576
- Argument of perihelion (deg) = 324.47
- True anomaly at departure (deg) = 35.4358
- True anomaly at arrival (deg) = 178.664

Semimajor axis (km) = 8.18263e+08
Period (days) = 4672.5

Structure



Systems Table

Delta- V	7.3 + 3.98 (km/s)
ISP	2964 (s)
Thrust	96.8 (kN)
Propulsion Type	Nuclear Gas Core Reactor
Propellant Fuel	Liquid Hydrogen
Exhaust Velocity	29077 (m/s)
Mass Flow Rate	3.33 (kg/s)
Wet Mass (total)	214150 kg
Dry Mass (including mini spacecraft / Lander)	145000 kg
Mass Ratio (Wet/Dry)	1.68