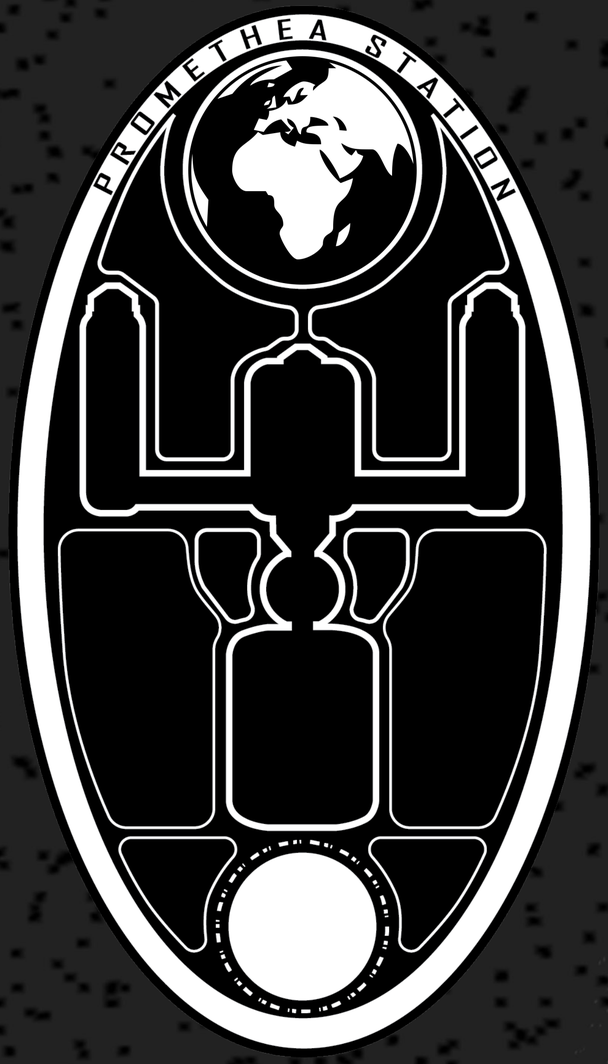
HB2

TECHNISCHE UNIVERSITÄT WIEN

PROMETHEA STATION

TESTBED FOR BETTERING HUMAN HEALTH



BSc Luka Pejic, BSc Christopher Egg, Senior Lecturer Dipl. Ing. Dr. Ing. Sandra Häuplik-Meusburger
„24th IAA Humans In Space Symposium“, Montecatini, IT

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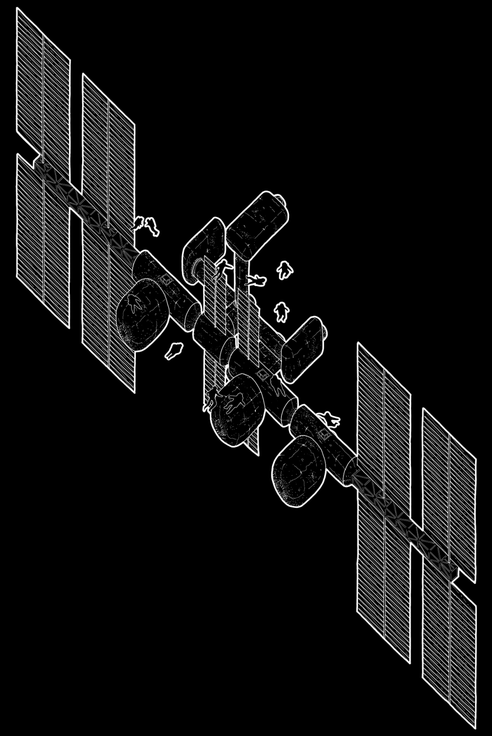
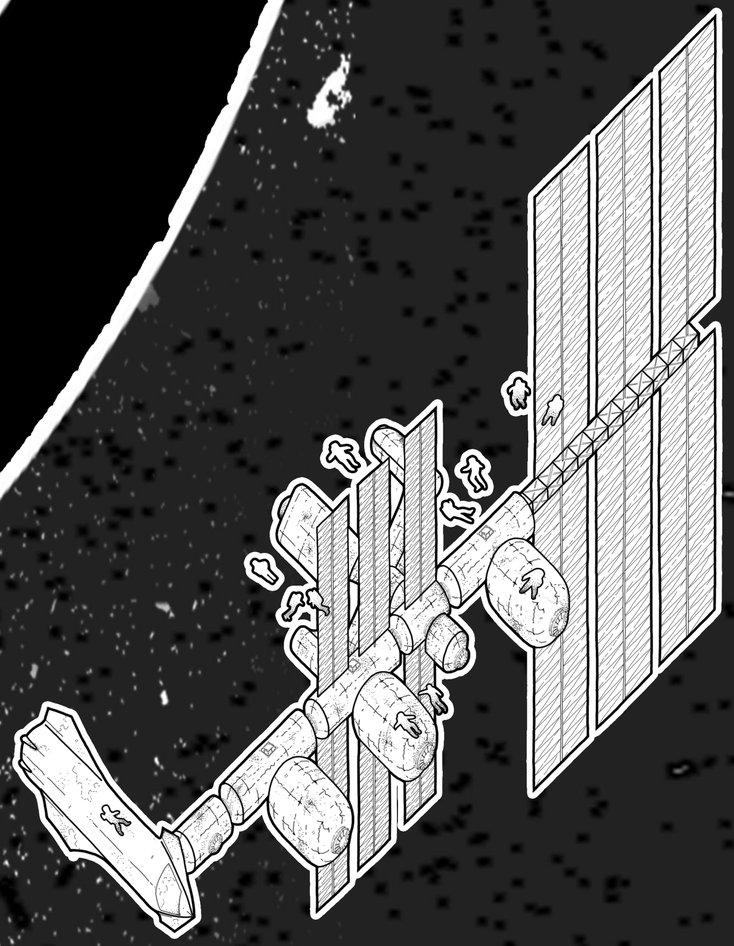


PURPOSE



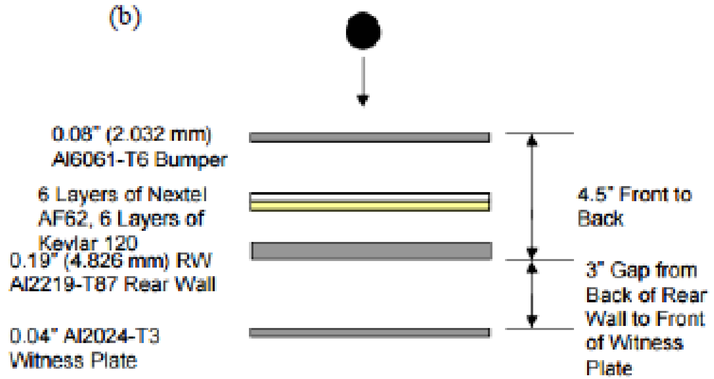
- **Low Earth Orbit (LEO)**
- **Microgravity + Martian gravity**

- **Primary objective** - modern successor to the International Space Station (ISS)
  - Future, long missions will require reliable, self-sustaining systems
    - ie. an **ecological life support system and artificial gravity**
  - Long-term testing of new systems to ensure their dependability for future space travel

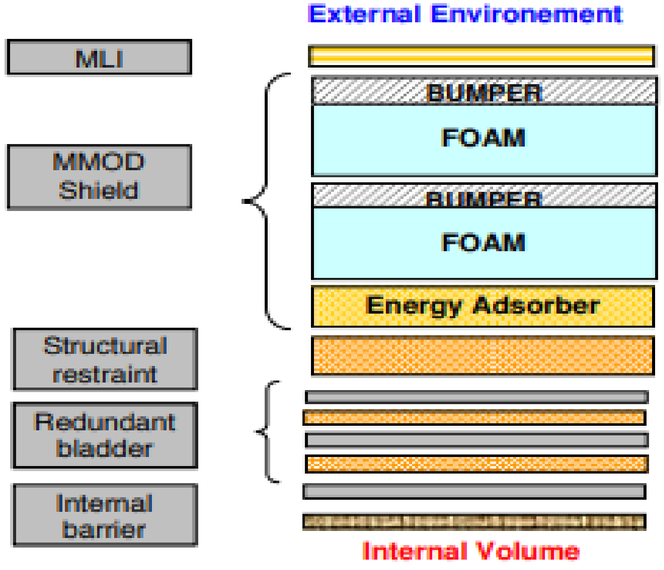
- **Secondary objective** - introduce **space tourism**

CONCEPT DEVELOPMENT

SCIENTIFIC FIDELITY

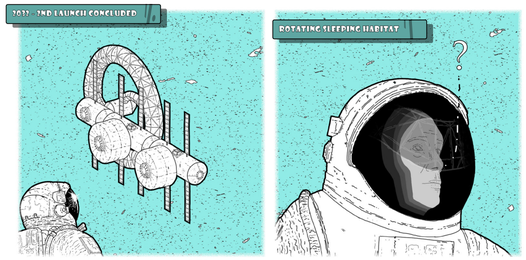


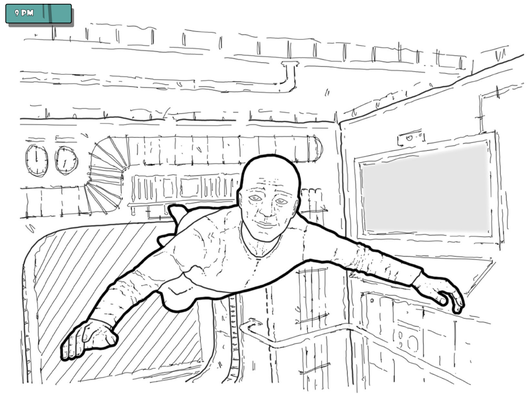
Stuffed whipple shield (Falk et al., 2021)

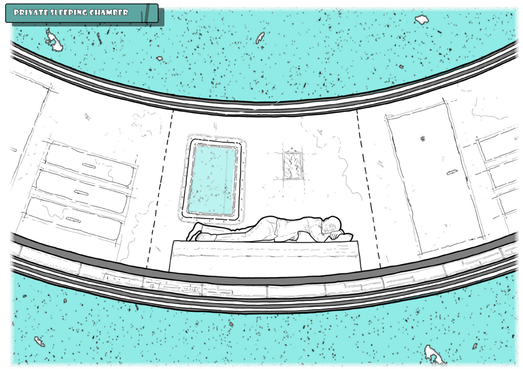


Layers of an inflatable module (Destefanis et al., 2006)

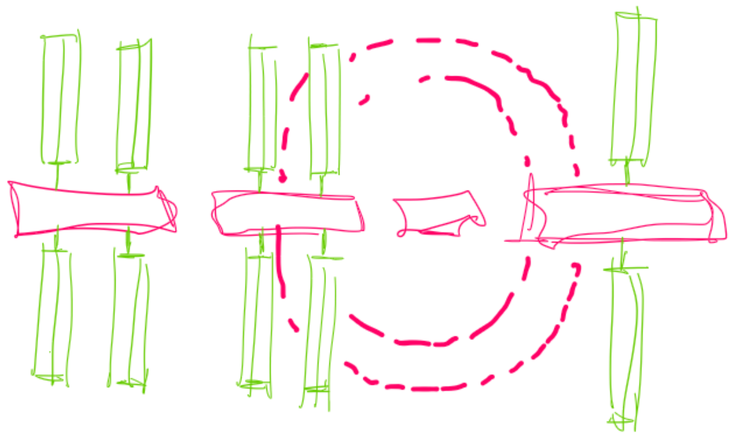
ITERATIONS

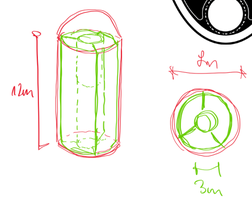


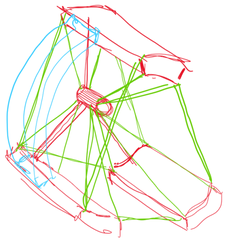


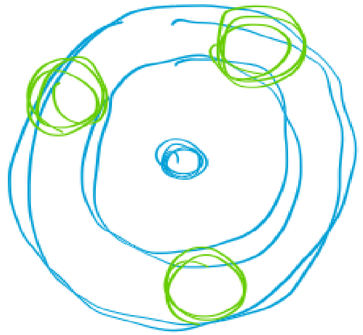


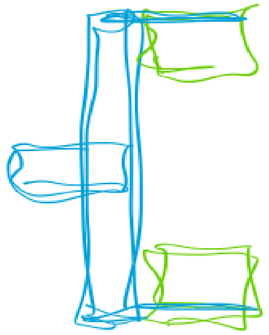
CONCEPTS FOR KEY FEATURES

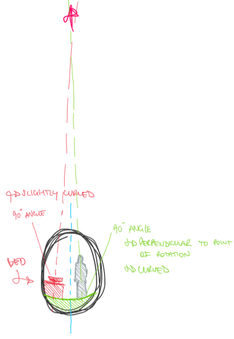


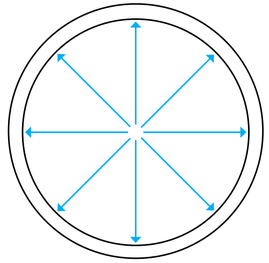




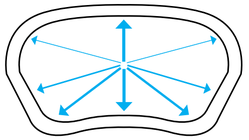




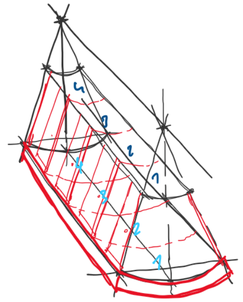




Cross-section of rigid and inflatable modules



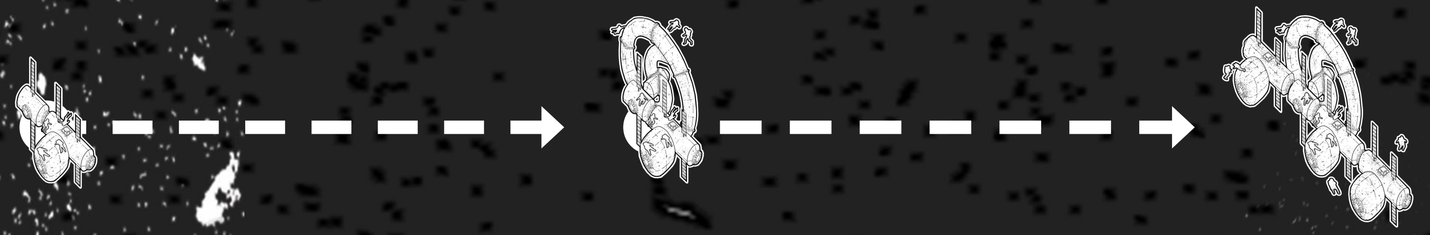
Cross-section of space crusader habitable modules



OVERVIEW OF ITERATIONS (V1)

I. PHASE → **II.** PHASE → **III.** PHASE

V1

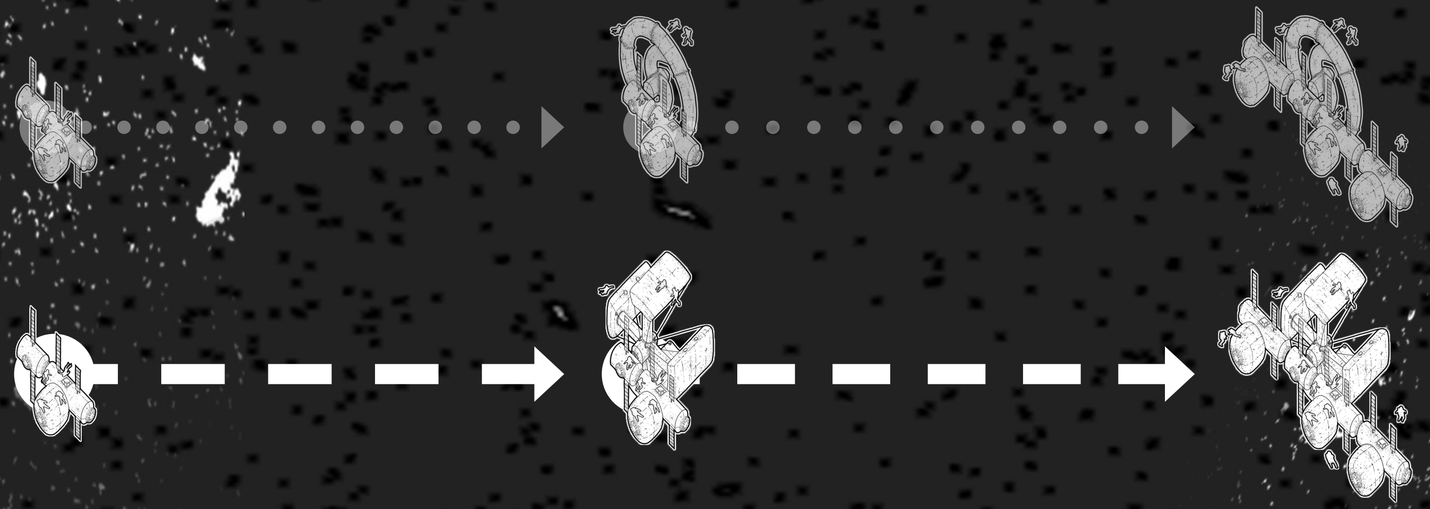


OVERVIEW OF ITERATIONS (V2)

I. PHASE → **II.** PHASE → **III.** PHASE

V1

V2



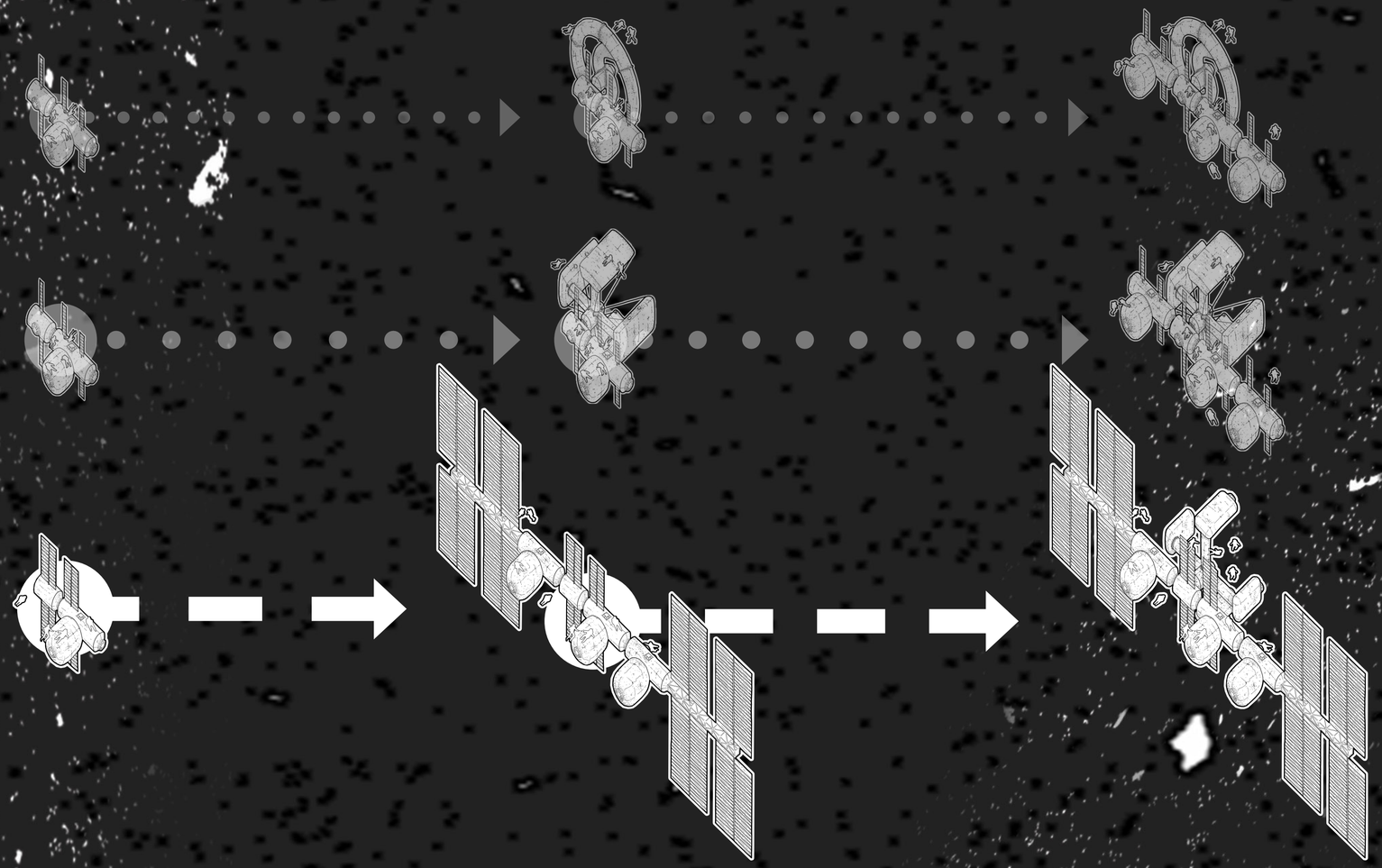
OVERVIEW OF ITERATIONS (V3)

I. PHASE → **II.** PHASE → **III.** PHASE

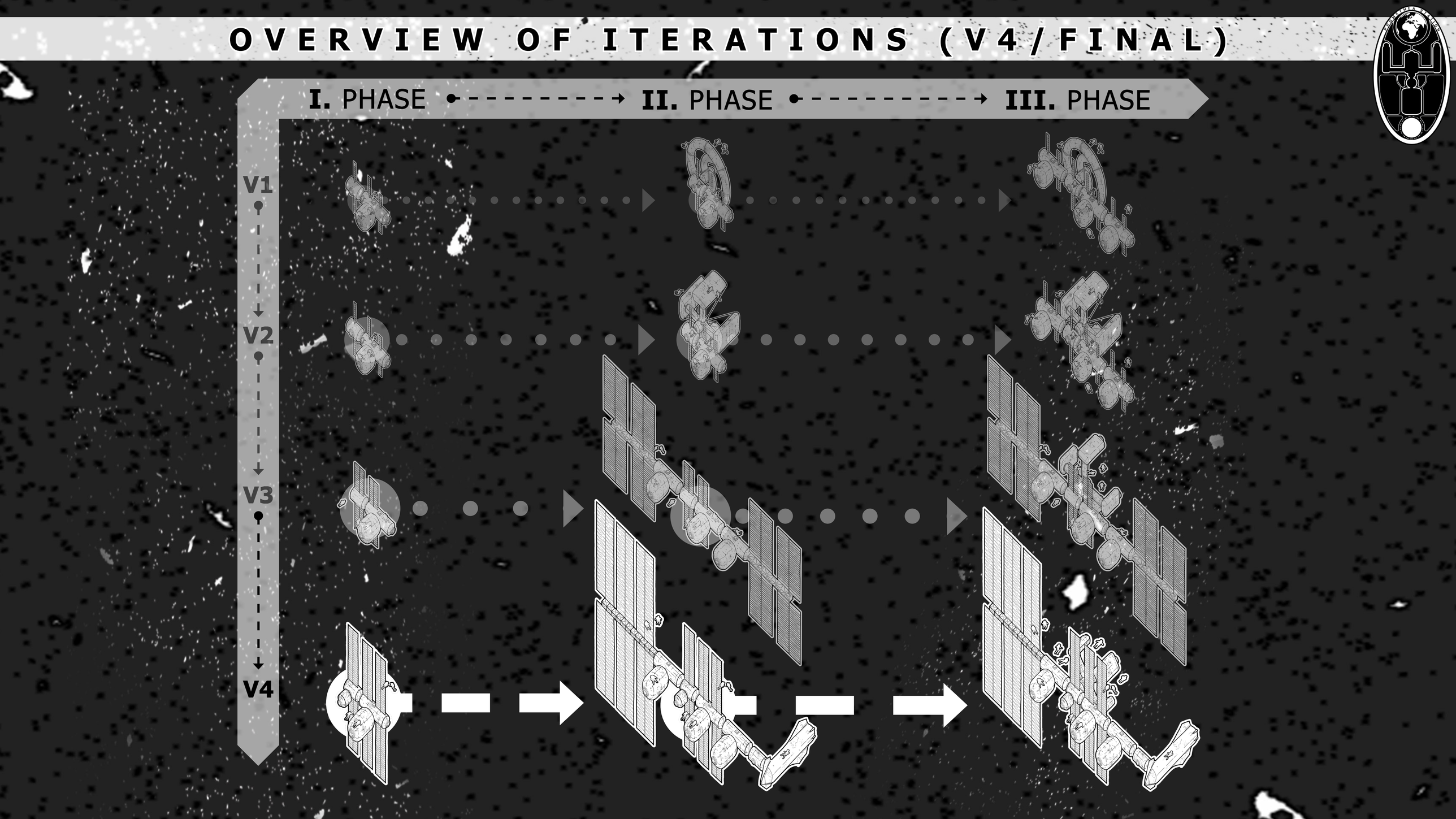
V1

V2

V3



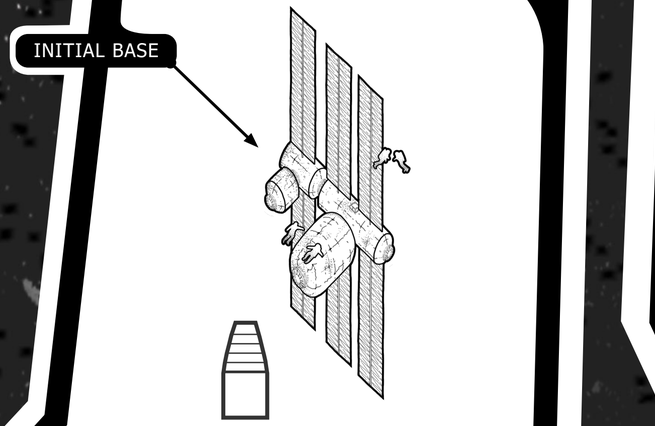
OVERVIEW OF ITERATIONS (V4/FINAL)



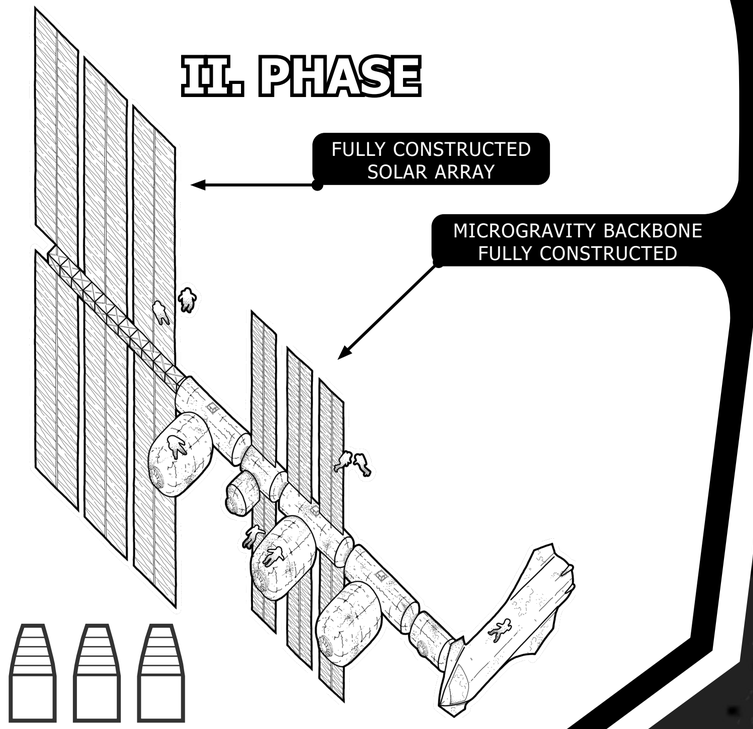
LAUNCH PHASES

I. PHASE

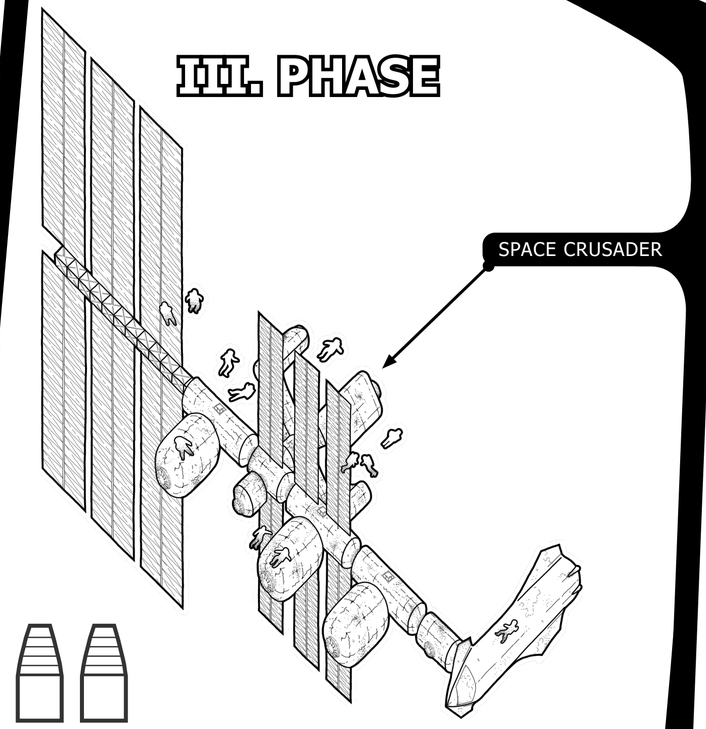
SpaceX Starship payload size
8m (circular base) x 17,24m (height)



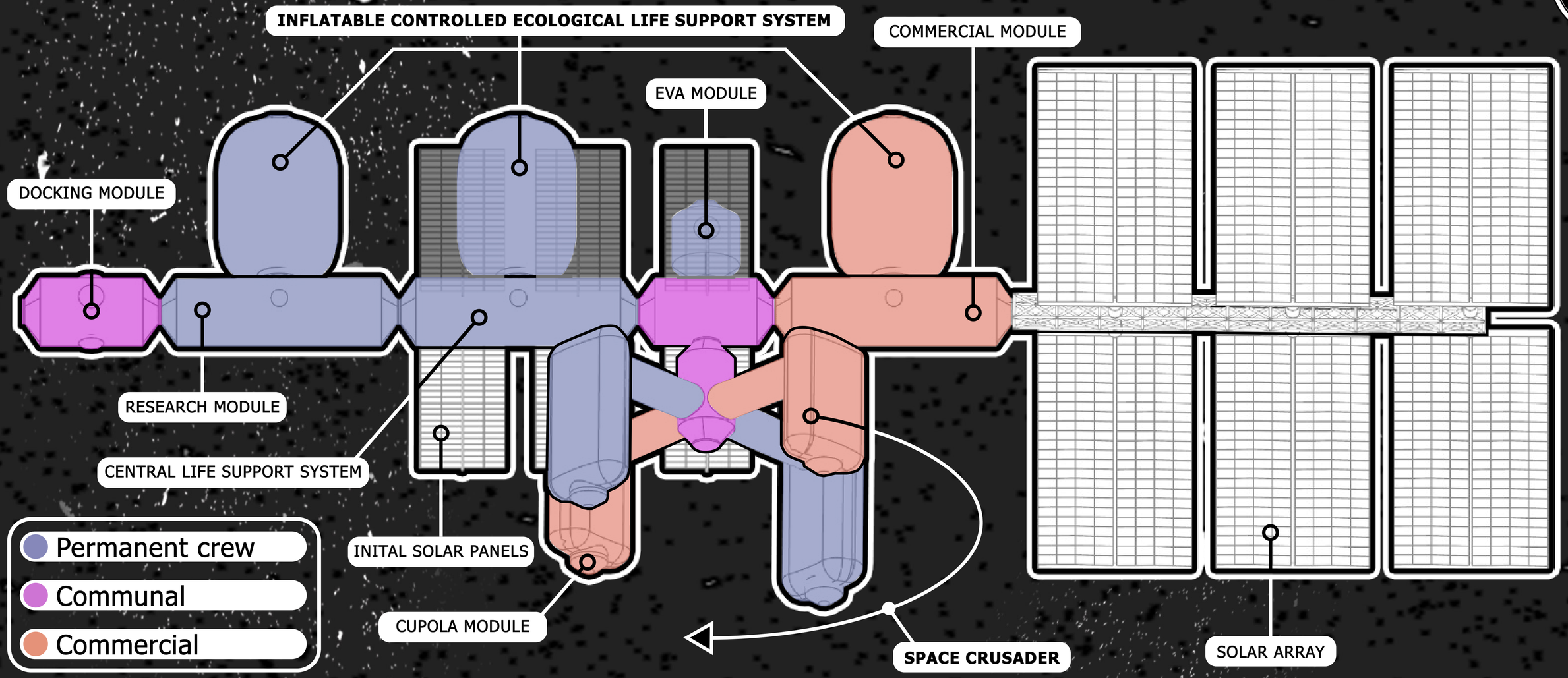
II. PHASE



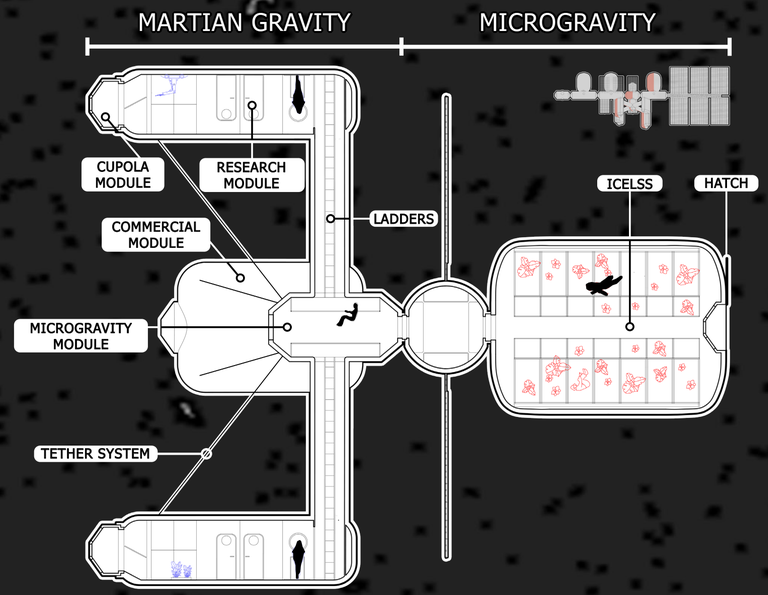
III. PHASE



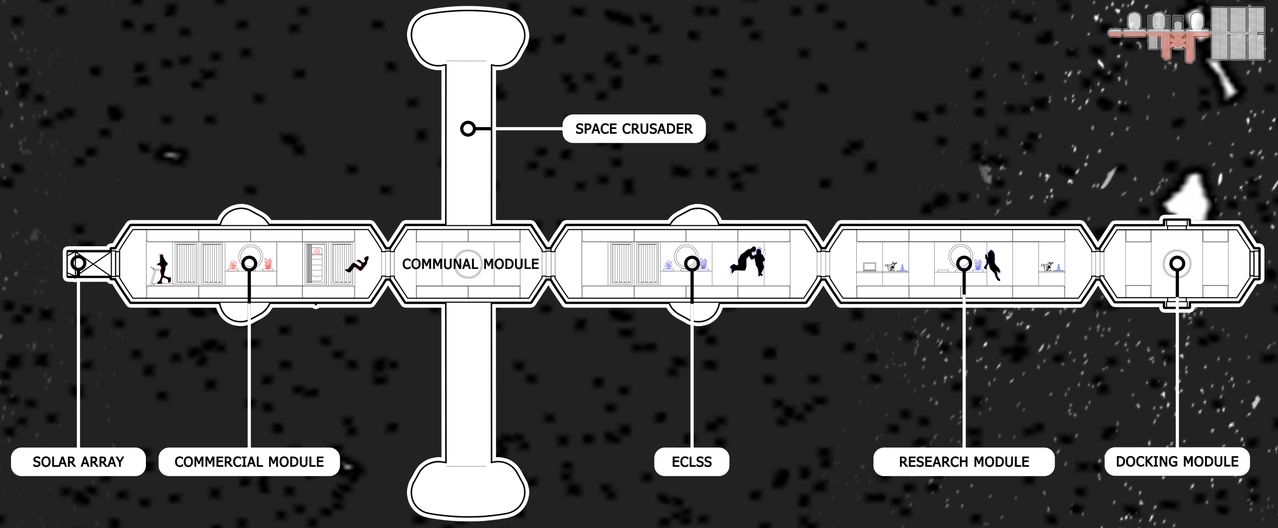
FUNCTIONS DIAGRAM



SECTIONS



EARTH — SUN



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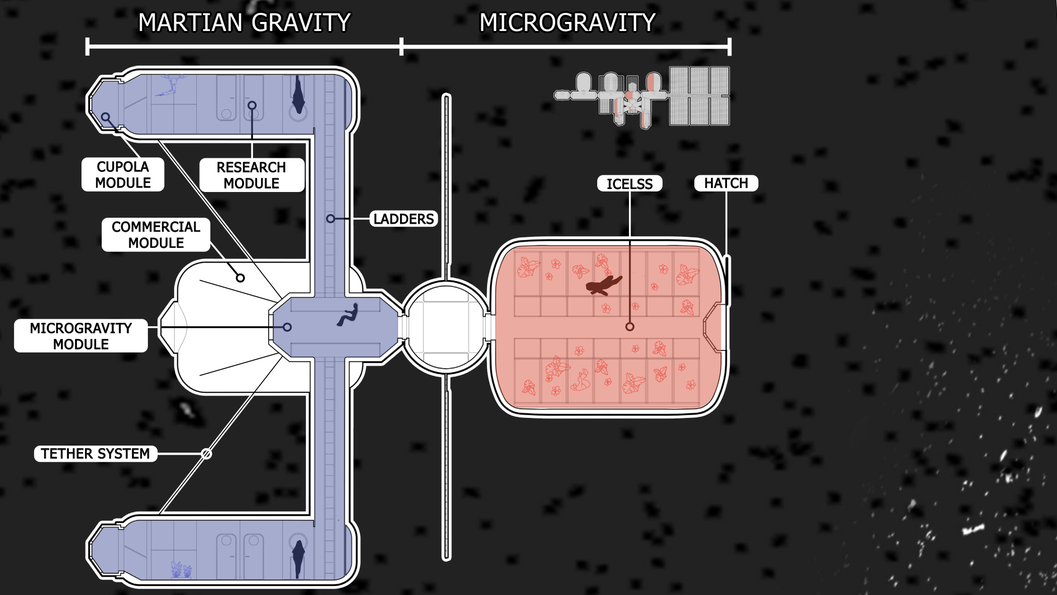
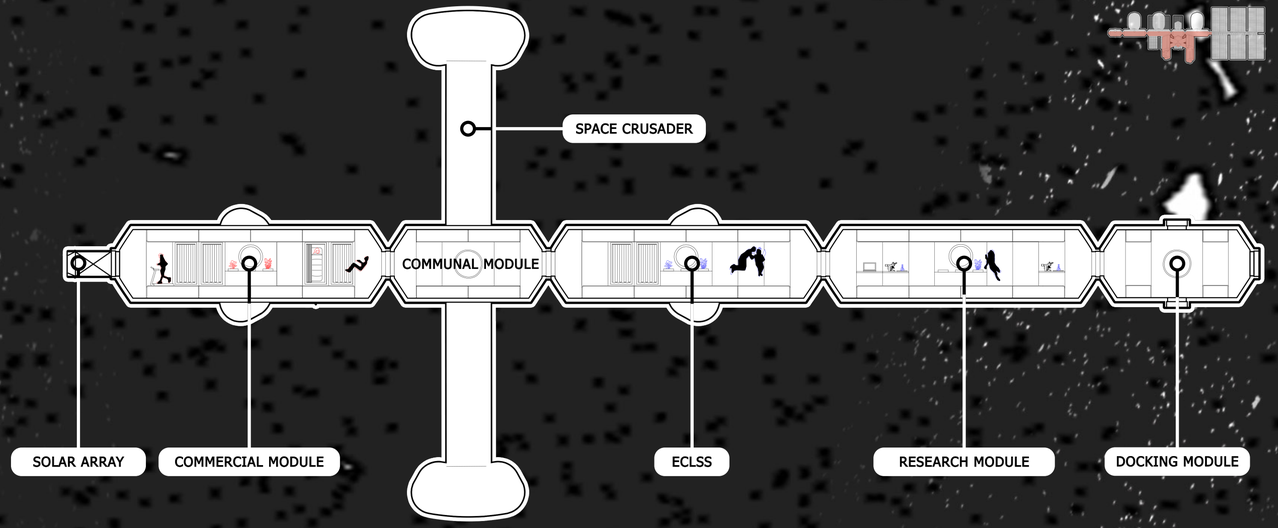
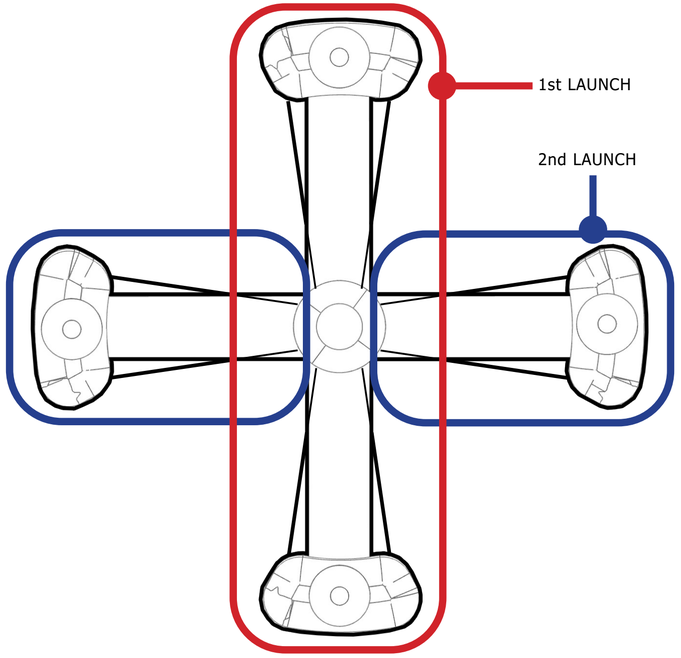


EARTH

SUN

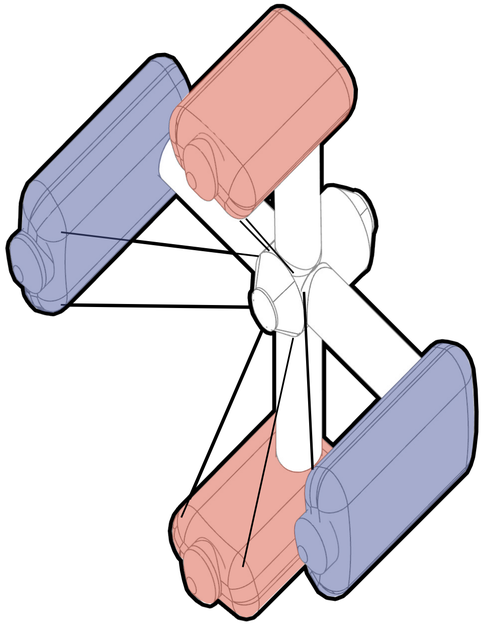


KEY FEATURE #1 - ARTIFICIAL GRAVITY

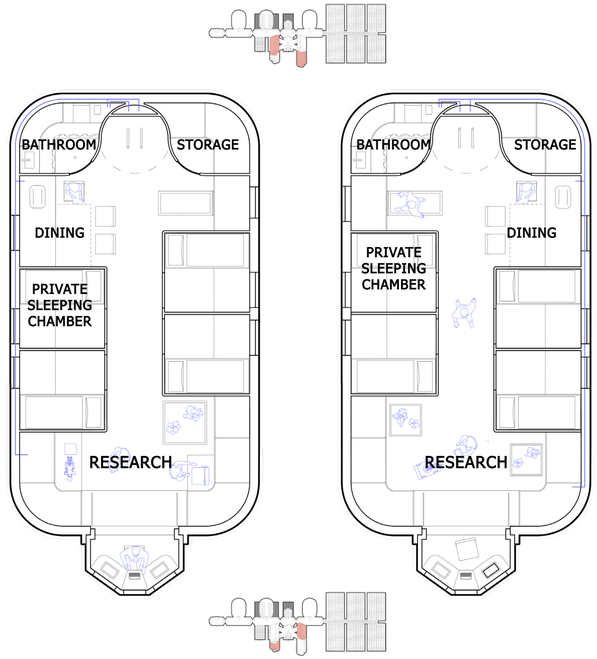


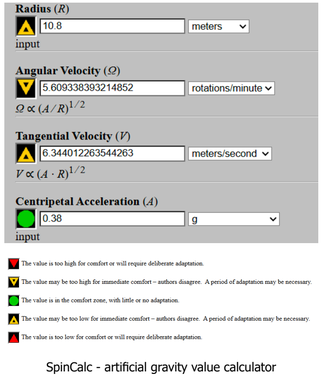
Space Crusader frontal view

Commercial Permanent crew



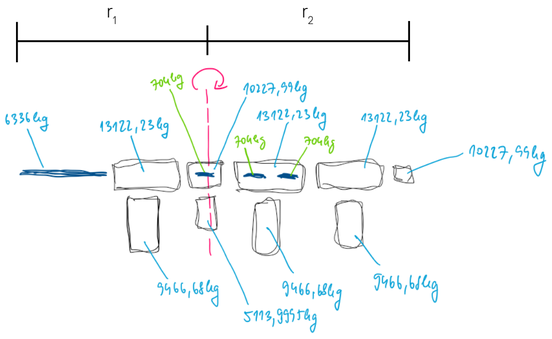
Space Crusader axonometric view





SpinCalc - artificial gravity value calculator

Momentum and torque simplified illustration



Angular momentum and torque

$r_1 = 49{,}27\ m$

$r_2 = 40\ m$

$m_1 = 36947{,}91\ kg$

$m_2 = 64836{,}81\ kg$

$L = I * \omega$

$I = \frac{1}{3} * m * r^2$

$L = \frac{1}{3} * m * \omega * r^2$

$$\boldsymbol{L_1 = -3130857{,}65\ Nms}$$
$$\boldsymbol{L_2 = -3621178{,}78\ Nms}$$
$$\boldsymbol{L_{total} = -6752036{,}43\ Nms}$$

$\tau = \frac{L_{total}}{t}$

$t = 1\ day = 24h = 86400s$

$\tau = \frac{L_{total}}{t}$

$\tau = \frac{6752036{,}43 Nms}{86400s}$

$$\boldsymbol{\tau = 78{,}15\ Nm}$$

Coriolis : centripetal

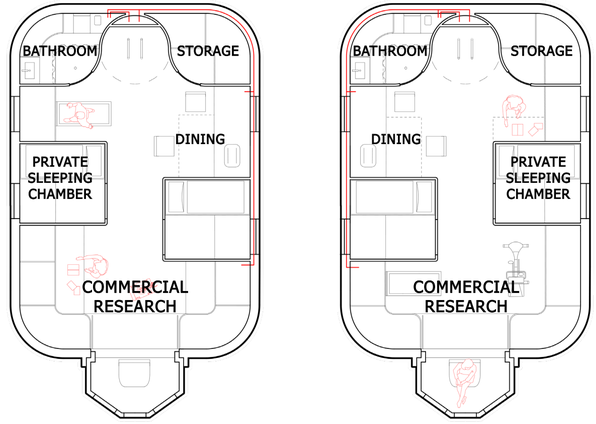
$a_{coriolis} = 2 * \Omega * v_{rim}$

$a_{coriolis} = 2 * 0{,}10472 * 6{,}03$

$a_{coriolis} = 1{,}263 m/s^2$

$$\boldsymbol{\frac{a_{coriolis}}{a_{centripetal}} = \frac{1{,}263}{3{,}73} = \frac{1}{2{,}95} \approx \frac{1}{3} = \frac{0{,}13g}{0{,}38g}}$$

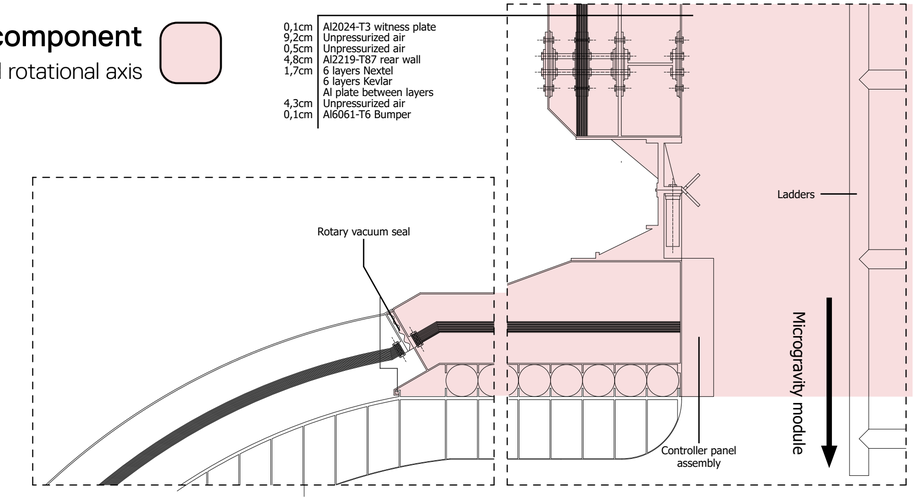
The calculation above indicates that within the Space Crusader there is a constant Coriolis force approximately equivalent to that of **lunar gravity**.

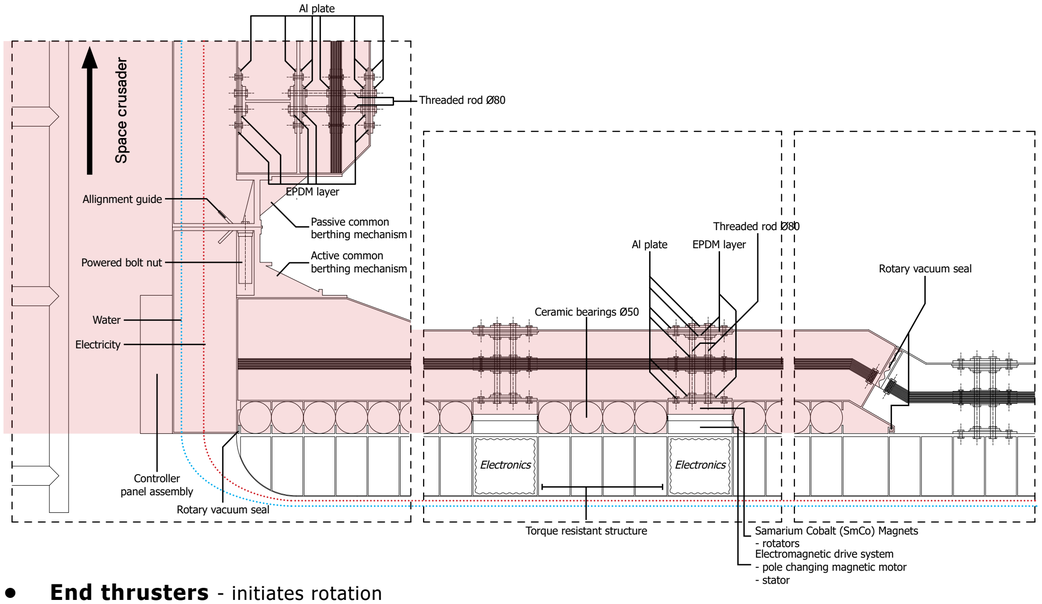


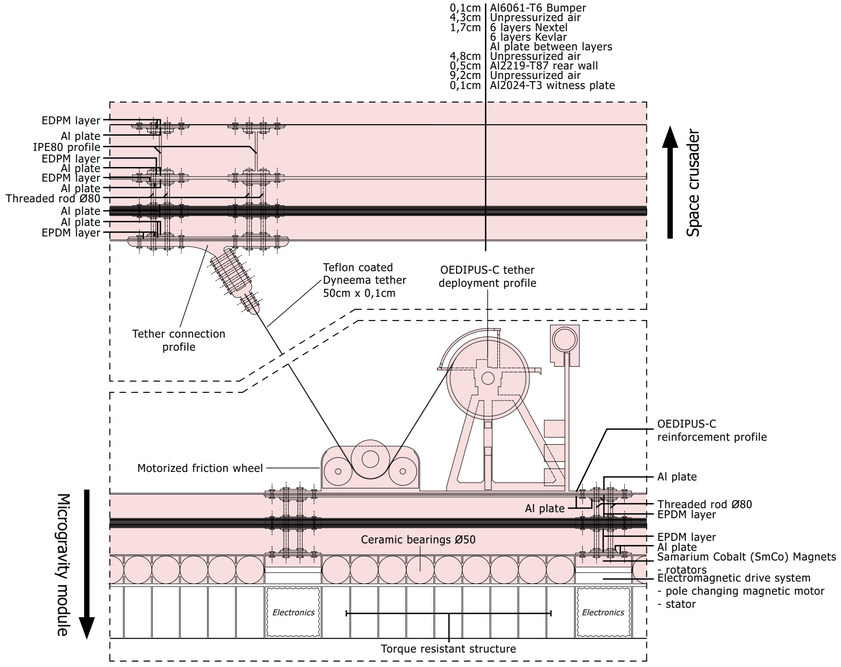
Space Crusader research and commercial modules

SPACE CRUSADER DETAILS

Rotating component
around rotational axis

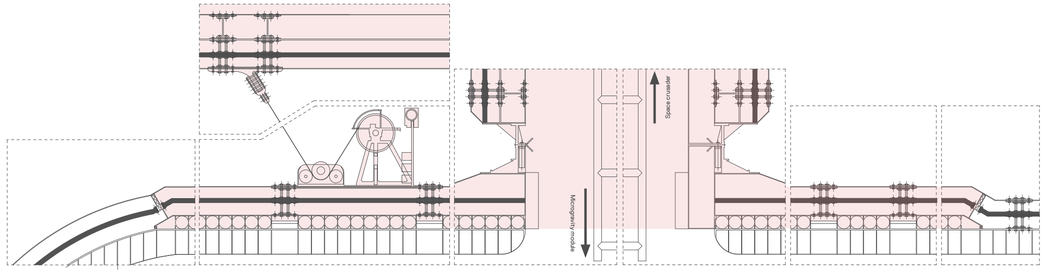






- **End thrusters** - initiates rotation
- **Solar-powered electromagnetic pole-switching motors** - sustains rotation
- **Samarium Cobalt magnets** - forms the rotators around the stators
- **Multi-ring ceraming bearing system** - supports radial and axial loads without magnetic interference
- **Torque-resistant frame** - links rotating and static sections, housing cabling and drive systems
- **Rotary vacuum seals** - maintains pressure integrity
- **Tether stabilisation system** - balances rotation and prevent floor misalignment

Full detail



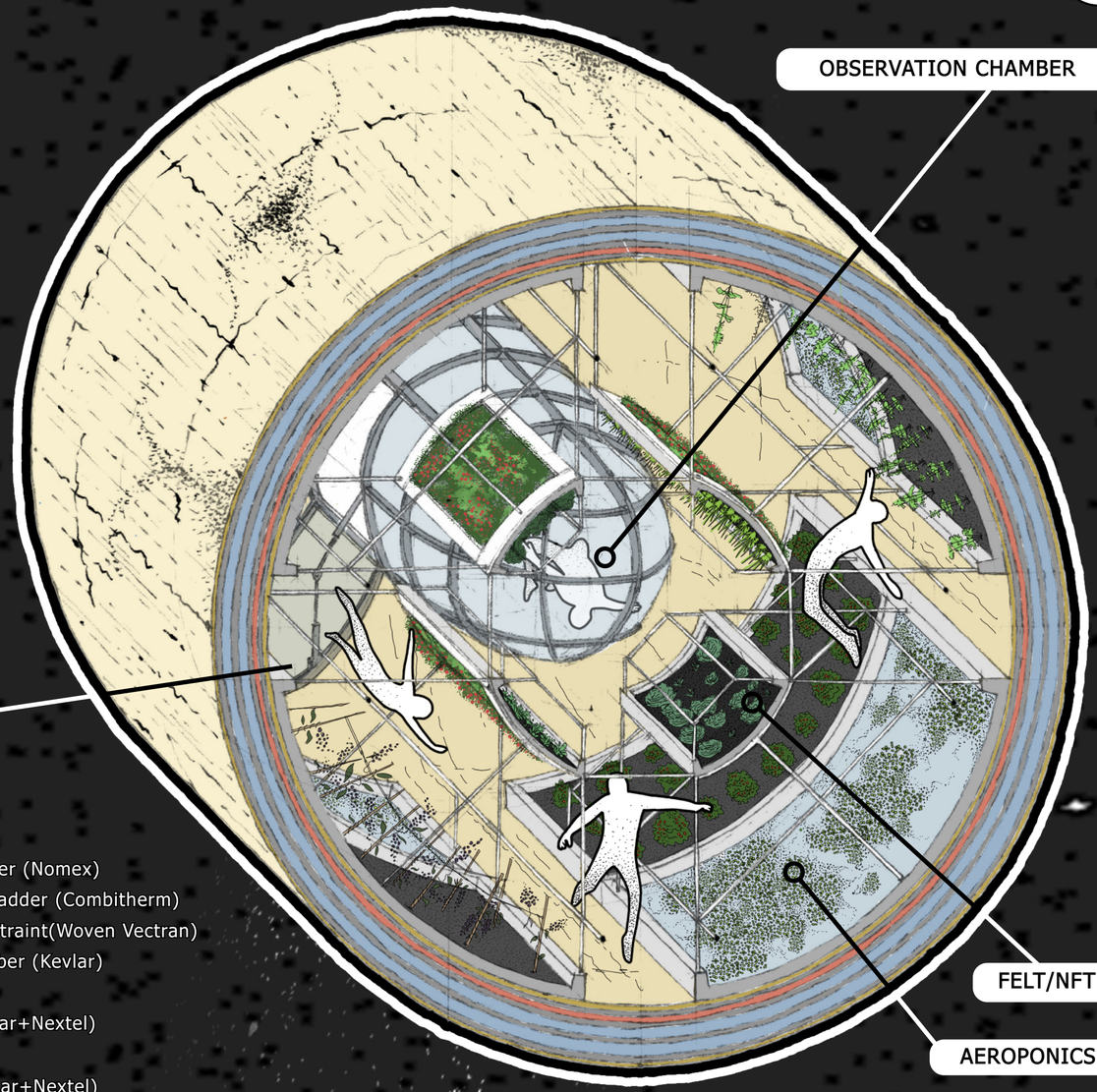
References and theoretical framework, used to draw the two details and design the Space Crusader:

Cosmo et al., 1997
Ding et al., 2024
Hall, 2006
Hall, 2020
Hall, 1999
Hall, 1993
Hall, 2002
Lackner et al., 2003
Lansdorp et al., 2012
Liu et al., 2023
Liu et al., 2021
Wang et al., 2006

KEY FEATURE #2 - LIFE SUPPORT

First iteration of ICELSS (Inflatable Controlled Ecological Life Support)

Final Iteration of ICELSS



I. Internal barrier (Nomex)
II. Redundant bladder (Combitherm)
III. Structural restraint(Woven Vectran)
IV. Energy absorber (Kevlar)
V. Foam (PU)
VI. Bumper (Kevlar+Nextel)
VII. Foam (PU)
VIII. Bumper (Kevlar+Nextel)
IX. MLI (Mylar)

CELSS - CROP CHARTS

KEY INFORMATION

- features two types of cultivation methods: **aeroponics and felt/NFT** (Nutrient Film Technique)
- each inflatable accommodates the life support needs of **4 individuals**
- total surface area required per individual - **40m²** (Wheeler, 2003)
- 40 -> 14 cultivation areas
- 7 aeroponics-based (**4,421m²** each)
- 7 felt/NFT-based (**1,341m²** each)
- 28 aeroponics units per module
- 28 felt/NFT units per module
- emphasis on providing plants rich in **antioxidants** (ie. luthein and zeaxanthin)

Literature, used to gather crops from:

Coughlan et al., 2022
Escobar et al., 2017
Ewert et al., 2022
Hava et al., 2019
Meinen et al., 2018
Mitrea et al., 2024
Nelson et al., 2009
Olson et al., 1984
Polutchko et al., 2022
Romano et al., 2021
Salisbury et al., 1996
Salisbury et al., 1997
Schwartzkopf, 1922
Skoog, 1984
Ushakov et al., 2011
Wheeler, 2003
Wheeler, 2021
Wheeler et al., 2003
Wilks, 1962
Yuan et al., 2016
Zabel et al., 2016

AEROPONICS

CATEGORY	Name (EN)	Name (LA)	Key nutrients	plant density/m²	CO_2 absorption g/m2d	O_2 production g/m2d	days to maturity	harvest cycle (days)	Spread harvesting	Notes regarding harvest
Leafy greens										
X	Cabbage	*Brassica oleracea*	Vit C, Vit K, Fiber, Folate	4	9,88	7,19	70-100	Single harvest		
X	Chard	*Beta vulgaris cicla*	Vit A, Vit C, Vit K, Mg, K	4	15,79	11,49	70-100	Single harvest		
	Chinese cabbage	*Brassica rapa*	Vit A, Vit C, Ca, Fe	6	14,68	10,67	50-80	10-14	X	
	Collards	*Brassica oleracea var. acephala*	Vit A, Vit C, Vit K, Ca, Fiber	6	6,36	4,62	60-85	7-14	X	
X	Celery	*Apium graveolens*	Vit A, Vit C, Vit K, Fiber	6	16,83	12,24	100-130	Single harvest		
	Dandelion	*Taraxacum officinale*	Vit A, Vit C, Vit K, Ca, Fe	10	3,53	2,57	40-50	10-15	X	
	Endive	*Cichorium endivia*	Vit A, Vit C, Vit K, Fiber	10	8,15	5,93	45-95	10-15	X	
	Kale	*Brassica oleracea Acephala*	Vit A, Vit C, Vit K, Antioxidants	8	7,83	5,69	55-75	7-14	X	
X	Lettuce	*Lactuca*	Vit A, Vit K	10	10,70	7,78	30-55	5-10	X	
	New Zealand spinach	*Tetragonia tetragonioides*	Vit A, Vit C, Ca, Fe	6	2,65	1,93	55-70	7-10		
	Red mustard	*Brassica juncea*	Vit A, Vit C, Vit K, Antioxidants	15	35,87	26,08	30-50	7-10	X	
X	Spinach	*Spinacia oleraceae*	Vit A, Vit C, Vit K, Fe, Folate	20	10,70	7,78	35-50	7-10*	X	*regrows once or twice*
	Swiss chard	*Beta vulgaris cicla*	Vit A, Vit C, Vit K, Mg, K	40	4,82	3,50	50-65	7-14	X	
	Turnip greens	*Brassica rapa*	Vit A, Vit C, Vit K, Ca	4	4,54	3,30	30-40	7-10	X	
Herbs/spices										
	Chives	*Allium schoenoprasum*	Vit A, Vit C, Antioxidants	25	2,65	1,93	60-90	14-21	X	
	Dill	*Anethum graveolens*	Vit C, Mn	20	1,41	1,03	60-90	7-14	X	
	Fennel	*Foeniculum vulgare*	Vit C, Fiber, K	10	28,27	20,55	60-90	14-21	X	
	Oregano	*Origanum vulgare*	Vit K, Vit E, Antioxidants	8	0,94	0,68	80-100	14-28	X	
	Parsley	*Petroselinum crispum*	Vit A, Vit C, Vit K	20	4,24	3,08	40-60	14	X	
	Saffron	*Safranum*	Vit C, Mn, Antioxidants	100	3,18	2,31	40-60	90	X	
	Sage	*Salvia officinalis*	Vit K, Antioxdiants	8	2,65	1,93	75-90	28-42	X	
	Thyme	*Thymus vulgaris*	Vit A, Vit C, Antioxidants	8	5,30	3,85	70-90	21-28	X	
Grains										
	Barley	*Hordeum vulgare*	Vit B, Se, Fiber	250	0,88	0,64	80-100	Single harvest		
	Flax	*Linum usitatissimum*	Omega-3 acids, Fiber, Lignans	2000	0,36	0,26	90-120	Single harvest		
	Millets	*Milium*	Vit B, Mn, P	200	0,28	0,20	60-90	Single harvest		
	Oats	*Avena sativa*	Vit B, Fe, Fiber	250	0,46	0,33	90-120	Single harvest		
	Quinoa	*Chenopodium quinoa*	Mg, Fe, Protein	10	0,15	0,11	90-120	Single harvest		
X	Rice	*Oryza*	Vit B, Fiber	50	36,55	26,57	100-150	Single harvest		
	Sorghum	*Syrucum*	Vit B, Fe, Antioxidants	80	0,76	0,55	100-120	Single harvest		

FELT/NFT

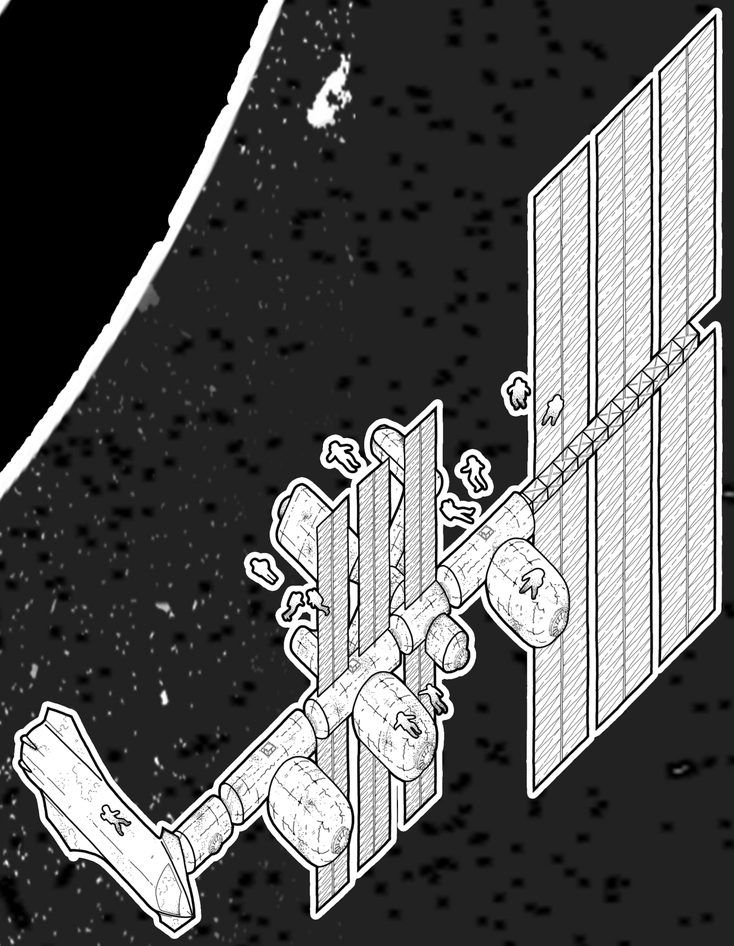
CATEGORY	Name (EN)	Name (LA)	Key nutrients	plant density/m²	CO_2 absorption g/m2d	O_2 production g/m2d	days to maturity	harvest cycle (days)	Spread harvesting	*notes*
Tubers & roots										
X	Beet	*Beta vulgaris*	Mn, Nitrates, Folate	25	9,77	7,10	50-70	Single harvest		
X	Carrot	*Daucus carota subsp. sativus*	Beta-Carotene	40	22,50	16,36	60-80	Single harvest		
	Garlic	*Allium sativum*	Vit C, Vit B6, Allicin	25	0,28	0,20	240-270	Single harvest		
	Ginger	*Zingiber officinale*	Gingerol, Anti-inflammatory properties	10	2,01	1,46	240-300	Single harvest		
X	Green onion	*Allium fistulosum*	Vit B, Vit C, Quercetin	20	14,67	10,67	60-75	Single harvest		
	Horseradish	*Armoracia rusticana*	Vit C, Glucosinolates	10	0,99	0,72	140-180	Single harvest		
	Kohlrabi	*Brassica oleracea var. gongylodes*	Vit C, K, Fiber	10	1,27	0,92	45-60	Single harvest		
	Nut sedge	*Cyperus rotundus*	Fiber, Starch	40	0,91	0,66	90-120	Single harvest		
X	Onion	*Allium cepa*	Vit C, Vit B6, Quercetin	25	16,50	12,00	90-120	Single harvest		
X	Radish	*Raphanus sativus*	Vit C, Antioxidants	50	16,31	11,86	25-40	Single harvest		
X	Sweet potato	*Ipomoea batatas*	Beta-Carotene, K, Fiber	6	56,54	41,12	90-150	Single harvest		
	Taro	*Colocasia esculenta*	Vit E, Fiber, Starch	4	2,12	1,54	150-200	Single harvest		
	Turnip	*Brassica rapa subsp. rapa*	Vit C, Fiber	25	1,33	0,97	40-60	7-10		
X	White potato	*Solanum tuberosum*	Vit B6, Vit C, K	6	45,23	32,23	90-120	Single harvest		
	Young potato	*Solanum tuberosum*	Vit B6, Vit C, K	8	2,73	1,98	60-80	Single harvest		
Fruiting crops										
	Butternut squash	*Cucurbita moschata*	Vit A, Vit C, K, Mg, Fiber, Antioxidants	2	10,60	7,71	90-110	Single harvest		
	Cucumber	*Cucumis sativus*	Vit C, Vit K, K, Antioxidants	6	53,00	38,53	50-70	3-5	X	
	Gac	*Momordica cochinchinensis*	Vit A, Vit C, K, Fe, Fiber, Antioxidants	2	5,62	4,09	180-210	7-14		
X	Pepper	*Capsicum annum*	Vit C, Capsaicin	6	33,98	24,71	60-90	Single harvest	X	*2-3 weeks of continous harvest*
	Pumpkin	*Cucurbita pepo*	Vit C, Vit K, Fe, Mn, Fiber, Folate, Protein	1	7,95	5,78	85-125	Single harvest		
Ultra dwarf fruit trees										
	Banana	*Musa × paradisiaca*	Vit B6, Vit C, K	2	8,83	6,42	270-450	Single harvest		
	Grape	*Vitis vinifera*	Vit K, Antioxidants	1	0,29	0,21	730-1095	90		
	Melon	*Cucumis melo*	Vit C	1	3,74	2,72	70-100	Single harvest		
	Papaya	*Carica papaya*	Vit A, Vit C, Digestive enzymes	1	3,79	2,76	275-425	7-14		
	Spicy peppers	*Capsicum annuum*	Vit C, Capsaicin	4	6,63	4,82	60-100	7-10*		*for 4-8 weeks*
X	Strawberry	*Fragaria × ananassa*	Vit C, Antioxidants	20	34,82	25,32	90-120	3-5*	X	*for 2-6 weeks*
	Tomatillo	*Physalis philadelphica*	Vit C, Niacin	2	3,18	2,31	70-100	5-7*	X	*for 2-4 weeks*
X	Tomato	*Solanum lycopersicum*	Vit C, K, Lycopene	2	26,36	26,36	60-85	5-7*	X	*for 4-8 weeks*
Legumes										
	Chickpea	*Cicer arietinum*	Fe, Folate, Fiber, Protein	30	0,16	0,12	90-110	Single harvest		
	Cowpea	*Vigna unguiculata*	Fe, Folate, Protein	85	0,26	0,19	60-100	7-10		
X	Dry Bean	*Phaseolus vulgaris*	Fe, Folate, Fiber, Protein	15	42,17	30,67	60-90	Single harvest		
	Graden pea	*Pisum sativum*	Vit A, Vit C, Vit K, Fiber, Protein	75	0,40	0,29	55-75	3-5*	X	*for 2-3 weeks*
	Green bean	*Phaseolus vulgaris*		25	0,24	0,17	50-70	2-4*	X	*for 2-4 weeks*
	Lentil	*Lens culinaris*	Fe, Folate, Fiber, Protein	150	1,15	0,84	80-110	Single harvest		
X	Pea	*Pisum sativum*	Vit A, Vit C, Vit K, Fiber, Protein	10	45,26	32,92	60-90	Single harvest		
	Pinto bean	*Phaseolus vulgaris*	Fe, Folate, Fiber, Protein	25	1,01	0,73	90-120	Single harvest		
X	Snap bean	*Phaseolus vulgaris*	Fe, Folate, Fiber, Protein	15	50,09	36,43	50-70	Single harvest		
	Snow pea	*Pisum sativum var. saccharatum*	Vit C, Fiber	15	0,49	0,36	60-70	3-5*	X	*for 2-3 weeks*
X	Soybean	*Glycine max*	Fe, Ca, Protein	20	19,13	13,91	80-120	Single harvest		
	Winged bean	*Psophocarpus tetragonolobus*	Vit A, Vit C, Protein	4	0,18	0,13	80-100	3-7	X	
Oil-storing crops										
	Canola	*Brassica napus*	Omega-3 acids	80	0,40	0,29	90-120	Single harvest		
	Flax (oil)	*Linum usitatissimum*	Omega-3 acids, Lignans	30	0,10	0,07	90-120	Single harvest		
X	Peanut	*Arachis hypogaea*	Folate, Niacin, Protein, Healthy fats	15	49,28	35,84	100-140	Single harvest		
	Sunflower	*Helianthus annuus*	Vit E, Healthy fats	6	0,61	0,44	90-120	Single harvest		
X	Wheat	*Triticum*	Vit B, proteins	300	77,00	56,00	100-130	Single harvest		
Special crops										
	Green tea extract	*Camellia sinensis*	Catechins, Antioxidants	10000	2,65	1,93	300	7-14		
	Duckweed	*Lemna*	Protein, Antioxidants, Amino acids	whole gu	145,75	105,96	7-14	3-5		

Ewert et al., 2022

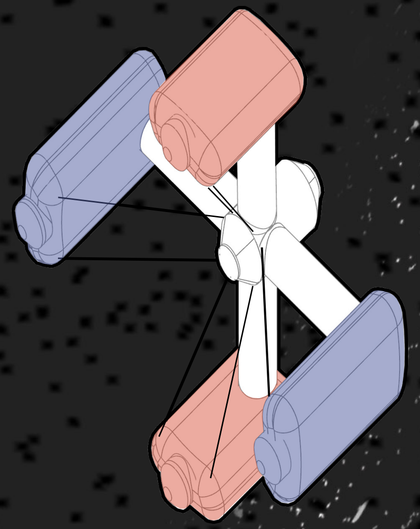
"Life Support Baseline Values and Assumptions Document"

RÉSUMÉ

- **Low Earth Orbit (LEO)**
- **12 crewmembers (8 crew + 4 tourists)**
- **Microgravity + Martian gravity**
- **3 phases, 6 launches**
- **Primary objective** - Long-term testing of new systems
- **Secondary objective** - introduce space tourism

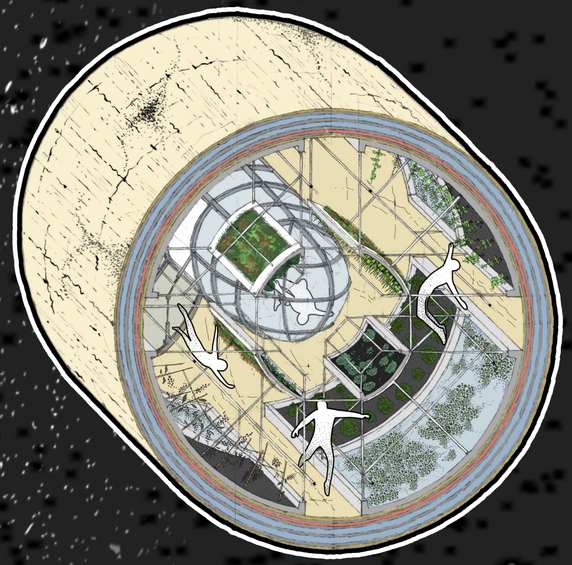


SPACE CRUSADER



- 10,8m radius
- 2 launches
- 2 permanent crew modules, 2 tourist modules
- electromagnetic-pole switching motors
- tether stabilisation system
- $F_{coriolis}$ = lunar gravity

ICELSS



- 3 modules
- 40m² per individual (160m² per module)
- aeroponics and felt/NFT
- focus on crops advised by literature and rich in antioxidants
- automated harvesting

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