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Logistics Rates and Assumptions

For Future Human Spaceflight Missions Beyond LEO

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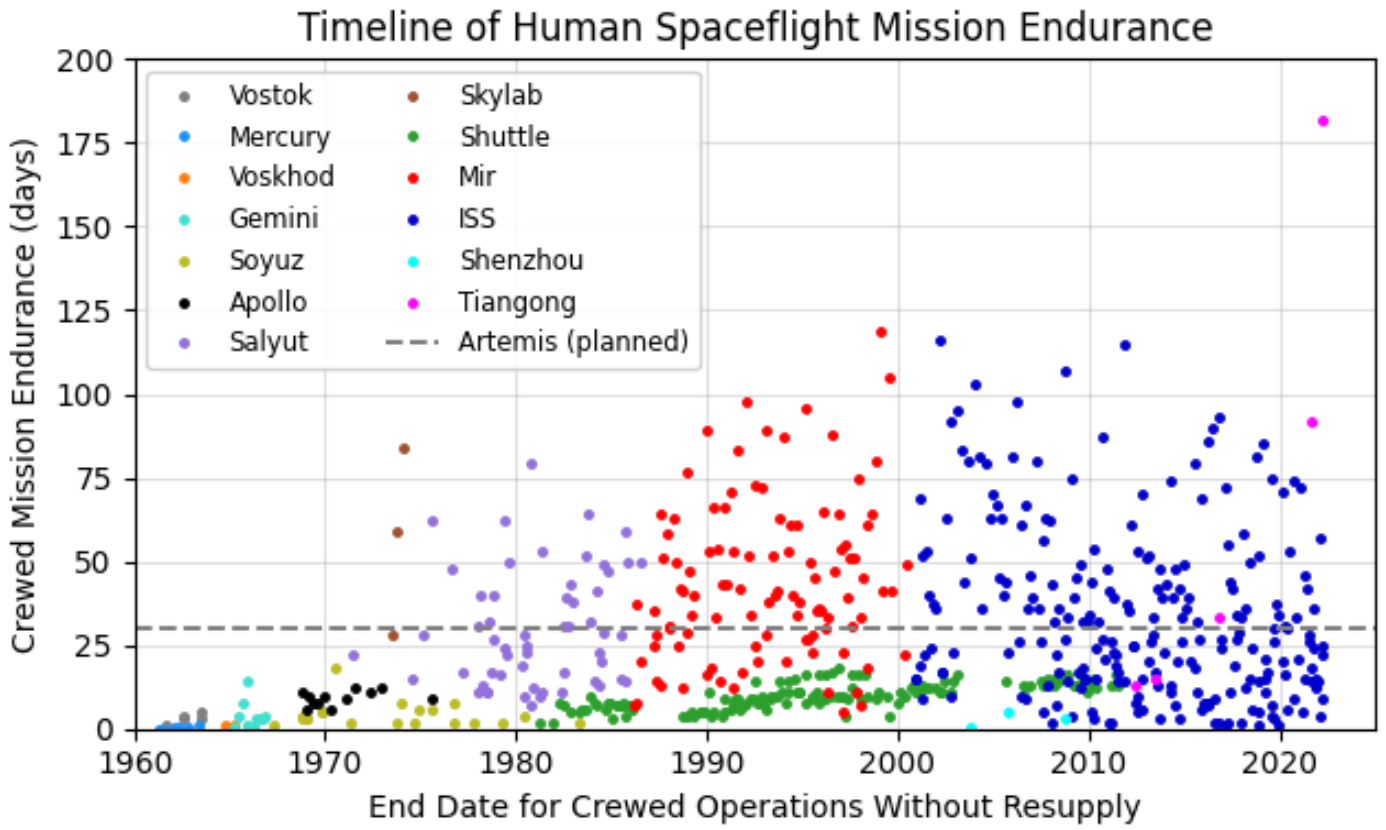
Logistics Impacts for Future Missions

- NASA is planning human spaceflight missions far-beyond what has been done before
- Endurance times are extended, and cost of delivered mass is increased

Previous Human Spaceflight Mission Endurances:



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Logistics Impacts for Future Missions

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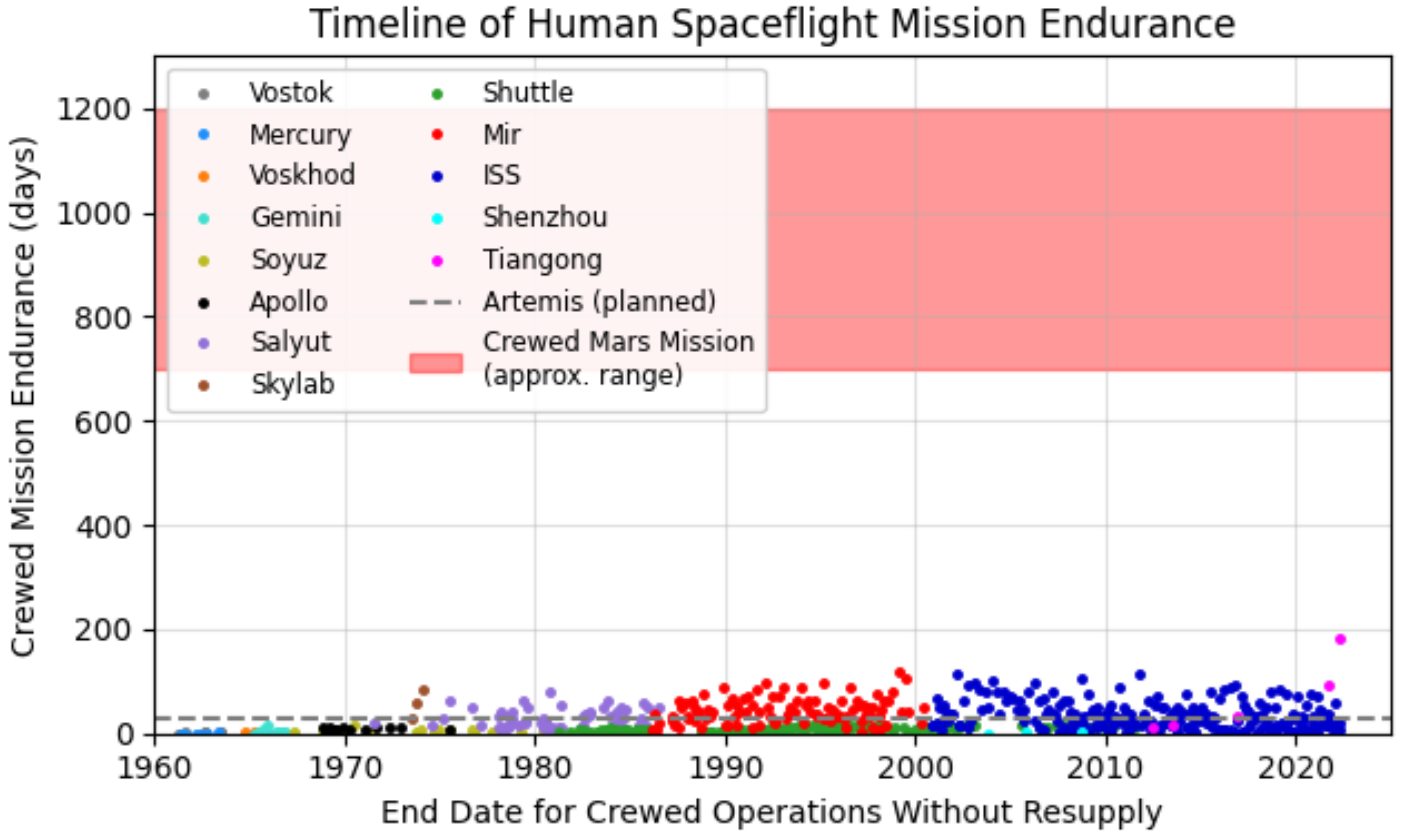
Potential Future Mission Endurances:



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Logistics Categories

Subcategory	Item
Consumables	Food
	Wipes and Gloves
	Hygiene Kits
	Recreation & Personal Stowage
	Operational Supplies
	Health Care Consumables
	Clothing
	Towels
	Waste and Hygiene
	Fecal/Urine Collection Bags
	LiOH Canisters
Maintenance	Maintenance
	Spares
Utilization	*Mission Dependent*
Outfitting	*Mission Dependent*
Packaging	*Mission/Architecture Dependent*

Food Mass

Item	Rate, Non-EVA Days	Rate, EVA Days	Units
Food Packaging	0.40	0.40	$\frac{kg}{(CM \times day)}$
Food Water Content, as Shipped	0.98	1.26	$\frac{kg}{(CM \times day)}$
Food Dry Mass, as Shipped	0.98	1.26	$\frac{kg}{(CM \times day)}$
Total Packaged Food	2.36	2.91	$\frac{kg}{(CM \times day)}$
BOBs	0.03	0.03	$\frac{kg}{(CM \times day)}$
Total, As Shipped	2.39	2.94	$\frac{kg}{(CM \times day)}$

Food Hydration %	Food Mass, as shipped kg/(CM x day)	Water Rehydration Requirement kg/(CM x day)
50%	2.36	0.50
45%	2.18	0.68
40%	2.03	0.83
35%	1.91	0.95
30%	1.80	1.06
25%	1.71	1.15

Hygiene Items

Hygiene Item	Crew & Duration Allocation
Hairbrush, Tweezers, Comb, Hair Ties, Hygiene Mirror & Assembly, Nail Clippers	Per CM
Razor (Electric)	Per Male CM
Cotton Swab Assembly, Hygiene Disposal Bags, Body Bath Pouch, Bar Soap, Razor Cartridges	Per CM Per 7 Days
Emesis Bags	2 Per CM Per 7 Days
Lip Balm, Deodorant	Per CM Per 30 Days
Feminine Hygiene Products	Per Female CM Per 30 Days
Toothbrush, Toothpaste, Floss, Lotion, Shave Cream, Shampoo, Conditioner, Hand Cream, Razor	Per CM Per 90 Days

- Smallest Mass:
  - Hair Ties – 0.01 kg/unit
- Largest Mass:
  - Feminine Hygiene Products – 0.71 kg/unit
- Smallest Mass Per Crew & Duration Allocation:
  - Hair Ties – 0.01 kg per CM mission
- Largest Mass Per Crew & Duration Allocation:
  - Emesis Bags – 0.02 kg per CM per day

Clothing Items

Hygiene Item	Crew & Duration Allocation
Underwear (Male & Female)	Per CM Per 2 Days
Exercise Shirts (Surface)	Per CM Per 5 Days
Sports Bra (Female), Socks (Surface), T-Shirts (Surface), Handkerchief (In-Space), Athletic Supporter (in-Space), Exercise Shorts (Surface), Exercise Socks (Surface)	Per CM Per 7 Days
Socks (In-Space), T-Shirts (In-Space), Exercise Shorts (In-Space), Exercise Shirts (In-Space), Exercise Socks (In-Space)	Per CM Per 14 Days
Polo Shirts	Per CM Per 15 Days
Shorts/Pants/Cargo Pants, Eye Cover, Sleepwear (Top & Bottoms), Wristband (In-Space), Athletic Band (In-Space)	Per CM Per 30 Days
Shoes, Gloves (In-Space), Polartec Socks (In-Space), Sweater (In-Space)	Per CM Per 180 Days
Belt (In-Space)	Per CM Per 360 Days

- Smallest Mass:
  - Handkerchief– 0.01 kg/unit
- Largest Mass:
  - Shoes– 0.84 kg/unit
- Smallest Mass Per Crew & Duration Allocation:
  - Polartec Socks– <0.001 kg per CM mission
- Largest Mass Per Crew & Duration Allocation:
  - Underwear– 0.15 kg per CM per day

Towels, Waste, and Other Solid Consumables

Item	Mass Rate (kg)	Allocation
~~Food~~	*Slide 5*	
Wipes and Gloves	0.20	Per CM Per Day
~~Hygiene Kits~~	*Slide 6*	
Recreation & Personal Stowage		
Operational Supplies		
Health Care Consumables	0.09	Per CM Per Day
~~Clothing~~	*Slide 7*	
Towels		
Waste and Hygiene	0.30	Per CM Per Day
Fecal/Urine Collection Bags	0.17	Per CM Per Cont. Day
LiOH Canisters	1.75	Per CM Per LiOH Day

Item	Mass Allocation (kg)	Mission Durations (Days)
Recreation & Personal Stowage	5	0-14
	10	15-60
	25	61-360
	50	361-1100
Operational Supplies	2.5	0-14
	5	15-60
	20	61-360
	25	361-1100

Item	Unit Mass (kg)	Life Limit Per CM
Towel	0.16	7
Hygiene Towel	0.14	2
Washcloth	0.05	7

Gas & Liquids

Metabolic Crew Consumption Rates

- Factor of CM size, assuming an average activity rate:
  - ***a***: 5th Percentile sized CM
  - ***b***: 82kg sized CM, considered the average
  - ***c***: 95th Percentile sized CM

Item	Long-Duration, In-Space			Surface	Units
	a	*b*	*c*	*b*	
Oxygen, Metabolic	0.89	0.89	1.08	0.84	$\frac{kg}{(CM \times day)}$
Water, Drink	1.78	2.79	3.89	2.00	$\frac{kg}{(CM \times day)}$
Oxygen, WPA Injection	0.0034				$\frac{kg\ O_2}{kg\ H_2O\ Processed}$
Water, Food Rehydration	0.50				$\frac{kg}{(CM \times day)}$
Water, Hygiene	0.40				$\frac{kg}{(CM \times day)}$
Water, Flush	0.30				$\frac{kg}{(CM \times day)}$
Water, Sampling	2.0				$\frac{kg}{mission}$

Remaining O_2/H_2O rates support systems

Maintaining Atmosphere

Item	Rate at 14.7 psia/21% Oxygen	Rate at 10.2 psia/26.5% Oxygen	Rate at 8.2 psia/34% Oxygen	Units
Cabin Air Leakage, Oxygen	0.005	0.004	0.004	$\frac{kg}{(day \times module)}$
Cabin Air Leakage, Nitrogen	0.016	0.010	0.007	$\frac{kg}{(day \times module)}$

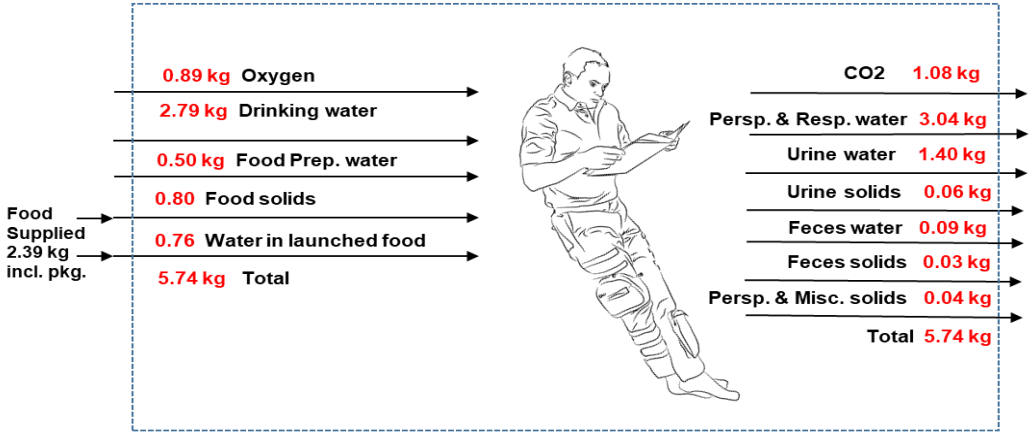
Mass Requirements for Pressurizing Volumes to Atmosphere:

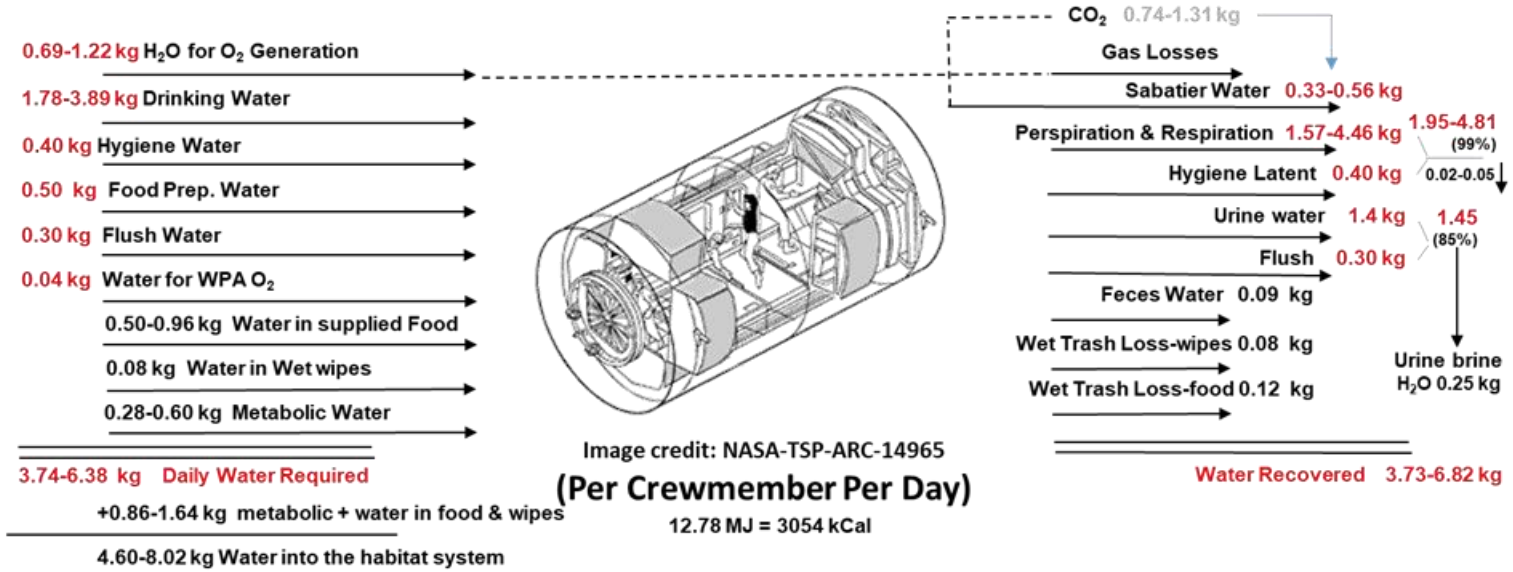
$$m_g = \frac{mp_g V P m_{a,g}}{RT}$$

m_g = Mass of gas required
mp_g = Mass percentage of gas in atmosphere
V = Pressurized Volume
P = Atmosphere Pressure
$m_{a,g}$ = Atomic Mass of Gas
R = Gas Constant
T = Temperature

Crew Outputs and ECLSS Processing

- Crew waste outputs and ECLSS capabilities affect the logistics delivered mass requirements
- CO_2, Wastewater, and Urine are capable (with current architecture assumptions) of being recycled to fresh water
- Current Regen ECLSS options include water, urine, and brine processing, and CO_2 reduction
- Oxygen Generation systems take freshwater, produce O_2 and H_2 through electrolysis

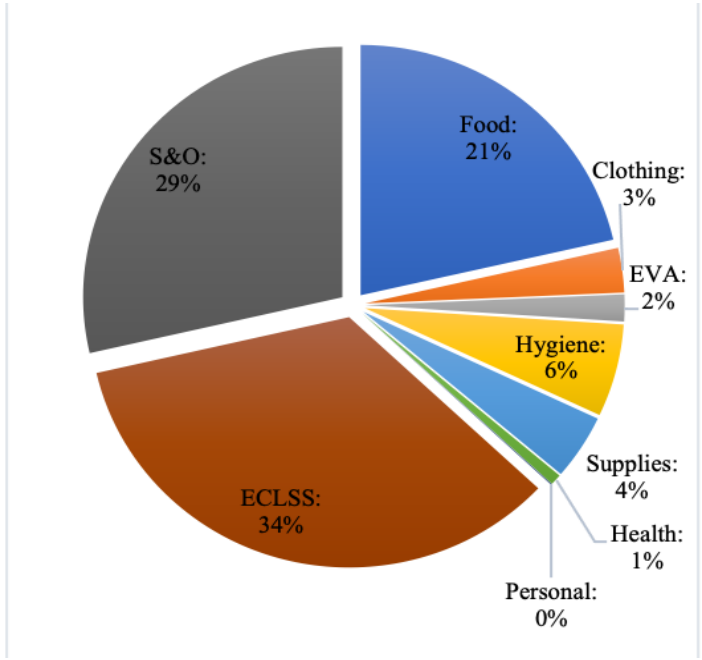




Maintenance, Utilization, and Outfitting

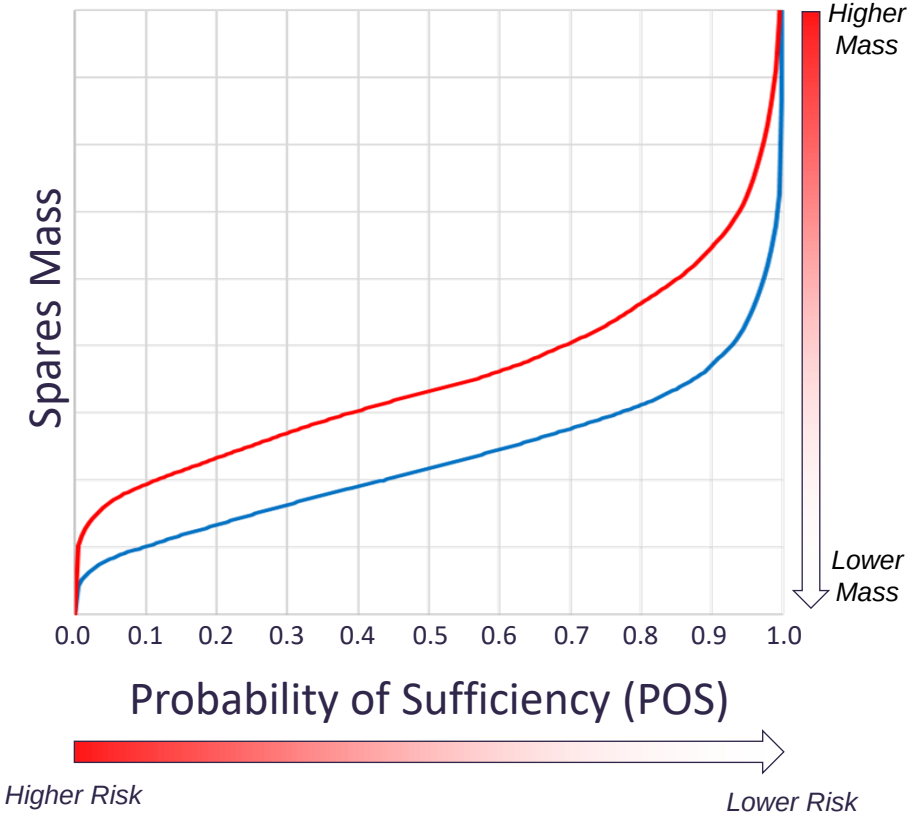
- Maintenance includes maintenance items, tools, spares and other related parts
- Outfitting supplies are subsystem hardware or components that are flown after the initial module delivery for permanent installation or use
- Utilization includes additional hardware and items that take advantage of the space-based architecture but are not required for vehicle operation
- Is allocated based on mission objectives, and accepted risk threshold in failing those objectives
- Allocations can be made for conceptual mission planning early on

Delivered cargo mass to ISS breakdown across 33 deliveries from October 2017 – February 2020



H. Leach and M. Ewert, "Analysis of Historical International Space Station Logistical Mass Delivery," 2021. doi: 10.1109/AERO50100.2021.9438212.

ECLSS spares mass as a function of mission endurance (Notional data for reference)



Packaging

- Packaging includes materials required to safely and effectively transport and store each of the logistics items
- Calculated via item density and volume

Item	Rate	Units
CTBE Mass	0.83	kg
CTBE Liner Mass	0.10	kg
CTBE Cargo Mass Limit	26.81	kg
CTBE Cargo Volume Limit	0.049 (1)	m^3 (CTBE)
CTBE External Volume	0.053	m^3

Item	Empty Mass incl. Ullage	Max Usable Content Capacity Mass	Units
Oxygen HPGC Mass	53.7	35.6	kg
Nitrogen HPGC	53.7	31.2	kg
CWC-I Water Carriers	1.22	21.7	kg

Example Mission

Mission Definition

Parameter	Value	Unit
Crew Members	2	#
Duration	14	days
Habitat Volume	20	m^3
Habitat Pressure	8.2	psi
Habitat O_2 by Volume	34	%
EVAs	4	#
Airlock Volume	10	m^3

Mass Results

Item	Mass (kg)	Volume (m^3)
Food	47.8	0.12
Food, EVA Days	23.5	0.06
Wipes and Gloves	5.6	0.03
Hygiene Kits	4.8	0.03
Recreation & Personal Stowage	10.0	0.04
Operational Supplies	5.0	0.02
Health Care Consumables	2.5	0.01
Clothing	11.4	0.07
Towels	2.7	0.01
Wastes and Hygiene	8.4	0.05
CTBs (Volume listed as # of CTBs)	8.3	10
TOTAL, Solid Goods	130.0	0.53

Item	Mass (kg)
Solid Goods	130.0
Water & Tanks	137.4
Gas & Tanks	169.4
TOTAL	436.7

Sources and Relevant Literature

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Discussion

Supporting Tables and Definitions

Logistics Definitions

- Consumables include all commodities that support the conduct of mission activities (often related to mission crew needs) that are not related to a specific payload or research activity and do not include propellant. In some cases, this category also includes consumables driven by non-crew activities (e.g., air leakage, vestibule re-pressurizations). Examples of specific consumable items include food, clothing, personal items, operational supplies, hygiene items, trash and human waste collection containers, towels, extravehicular activity (EVA) consumables, and gases & liquids.
- Maintenance items include planned replacement hardware, and associated tools, for required replaceable system components that have known limited lifetimes and have a scheduled replacement plan. Planned maintenance items are largely system dependent and are categorized as preventive.
- Spares include spare components or orbital replacement units (ORUs), and associated tools, which address corrective maintenance for unexpected or unplanned failures of systems' hardware. Spares needs are dependent on system architecture and risk acceptance levels and do not include a standard rate.
- Utilization includes additional hardware and items (e.g., science, research, capability demonstration, outreach, etc.) that take advantage of the space-based architecture but are not required for vehicle operation. For early exploration mission planning, mass and volume allocations are typically defined rather than specific utilization hardware as the latter is often mission dependent.
- Outfitting supplies are subsystem hardware or components that are flown after the initial module delivery for permanent installation or use. As items are identified for outfitting, they are expected to be tracked as part of the integrated logistics plan. Outfitting is often driven by insufficient resources to implement all the desired functions within the initial launch mass or schedule, so key systems are delivered on alternate flights. Outfitting estimates are mission dependent.
- Packaging includes materials required to safely and effectively transport and store each of the logistics items. This may include loose packaging or soft carriers, consumables stowage, or pressurized carriers that are delivered to support the mission. This category does not include any spacecraft secondary structures required to house or contain logistics.

Waste Management Rates

System/Item	Rate	Unit	Comments
Trash Bags	0.03	$\frac{kg}{(CM \times day)}$	Includes soft-sided trashcans, which are discarded after a time.
Fecal Canisters	0.23	$\frac{kg}{(CM \times day)}$	Includes fecal cans, lids, and bags.
Urine Prefilter/Pretreat	0.04	$\frac{kg}{(CM \times day)}$	Includes urine filters, funnels, hoses and pretreat.
Fecal/Urine Collection Bags	0.17	$\frac{kg}{(CM \times Cont.Day)}$	Used to inform contingency waste collection. Applies only to days of planned contingency usage.

Crew Output Rates

Item	Long-Duration, In-Space			Surface	Units	Comments
	Rate for 5th % Crew	Rate for 82 kg Crew	Rate for 95th % Crew	Rate for 82 kg Crew		
Carbon Dioxide, metabolic	0.74	1.08	1.31	1.08	$\frac{kg}{(CM \times day)}$	In-Space: 1.5 hours of Resistive exercise and Aerobic exercise per day, high fitness in the 95% case. Surface: Assumes 0.5 hours of Resistive and Aerobic Exercise per day, on average.
Water, Perspiration & Respiration	1.57	3.04	4.46	3.04	$\frac{kg}{(CM \times day)}$	In-Space: 1.5 hours of Resistive exercise and Aerobic exercise per day, high fitness in the 95% case. Surface: Assumes 0.5 hours of Resistive and Aerobic Exercise per day, on average.
Misc. Losses	0.04				$\frac{kg}{(CM \times day)}$	Includes all other human outputs: solids, hair, skin, mucus, menses, etc. [2].
Water, urine	1.4				$\frac{kg}{(CM \times day)}$	
Fecal, dry mass	0.03				$\frac{kg}{(CM \times day)}$	
Urine Solids	0.06				$\frac{kg}{(CM \times day)}$	
Water, fecal	0.09				$\frac{kg}{(CM \times day)}$	

ECLSS Processes

Item	Rate	Units	Comments
OGS Conversion Rates	0.889	$\frac{kg\ O_2\ produced}{kg\ H_2O\ converted}$	Based on molecular masses.
	0.111	$\frac{kg\ H_2\ produced}{kg\ H_2O\ converted}$	
Sabatier Conversion Rates	0.183	$\frac{kg\ H_2\ required}{kg\ CO_2\ processed}$	Based on molecular masses. Reaction limited by availability of CO_2 or availability of H_2. Excess CO_2 or H_2 remains after processing. Assumes 90% efficiency.
	0.819	$\frac{kg\ H_2O\ produced}{kg\ CO_2\ processed}$	
	0.364	$\frac{kg\ CH_4\ produced}{kg\ CO_2\ processed}$	

Assumed Densities

Item	Rate	Units
Food	388	kg/m^3
Wipes and Gloves	186	kg/m^3
Operational Supplies	235	kg/m^3
Recreation & Personal Stowage	235	kg/m^3
Health Care Consumables	186	kg/m^3
Trash Bags	186	kg/m^3
Hygiene Kits	186	kg/m^3
Clothing	170	kg/m^3
Towels	186	kg/m^3
Fecal Canisters	186	kg/m^3
Urine Prefilter	186	kg/m^3
Fecal/Urine Collection Bags	186	kg/m^3
Pressurized Spares and Maintenance	557	kg/m^3
Pressurized Utilization	557	kg/m^3

Fluid Mass Requirements from Mission Example

Item	#	Mass (kg)
Water, Drink	-	78.1
Water, Food Hydration	-	14.0
Water, Hygiene	-	11.2
Water, Flush	-	8.4
Water, Sampling	-	2.0
Water, Total	-	113.7
CWCs	6	7.3
M02 Bags	2	16.3
TOTAL, Water and Water Carriers		**137.4**

Item	#	Mass (kg)
Oxygen, Metabolic	-	24.9
Oxygen, Leakage	-	0.06
Oxygen, Airlock Represses	-	10.3
Oxygen, Total	-	35.3
Oxygen HPGCs	1	53.7
M01 Bags	1	4.8
TOTAL, Oxygen and Oxygen Carriers		**93.8**

Item	#	Mass (kg)
Nitrogen, Leakage	-	0.1
Nitrogen, Represses	-	17.0
Nitrogen, Total	-	17.1
Nitrogen HPGCs	1	53.7
M01 Bags	1	4.8
TOTAL, Nitrogen and Nitrogen Carriers		**75.6**