ASCEND™

16-18 November 2020 | Online

HABITAT SIZING TOOL

David Smitherman

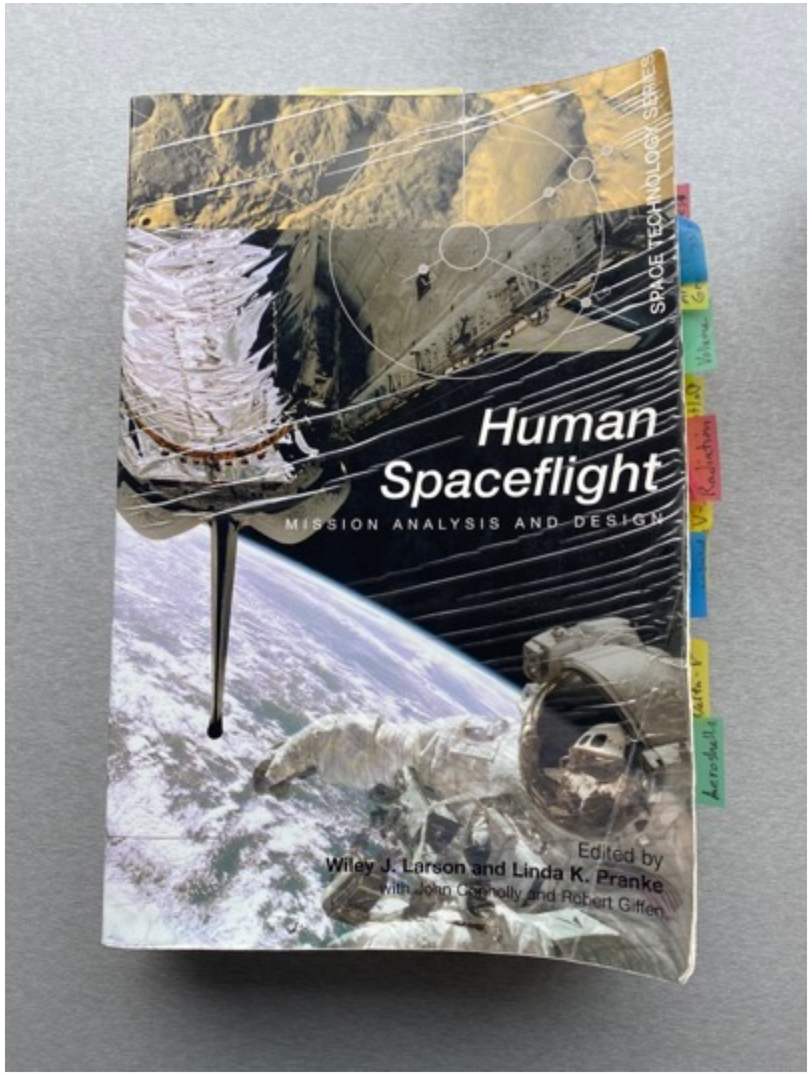
Justin Rowe

ED04 / Advanced Concepts Office

NASA Marshall Space Flight Center

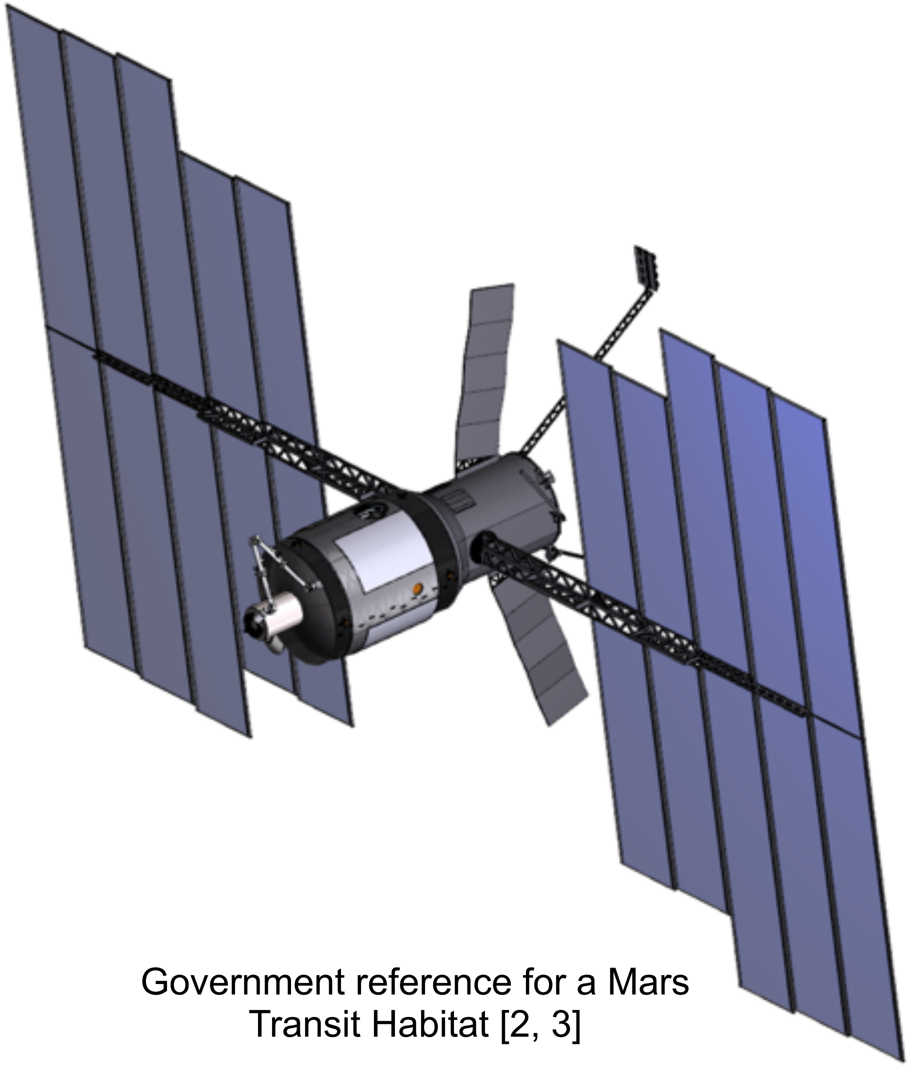
www.ascend.events

Habitat Sizing Tool

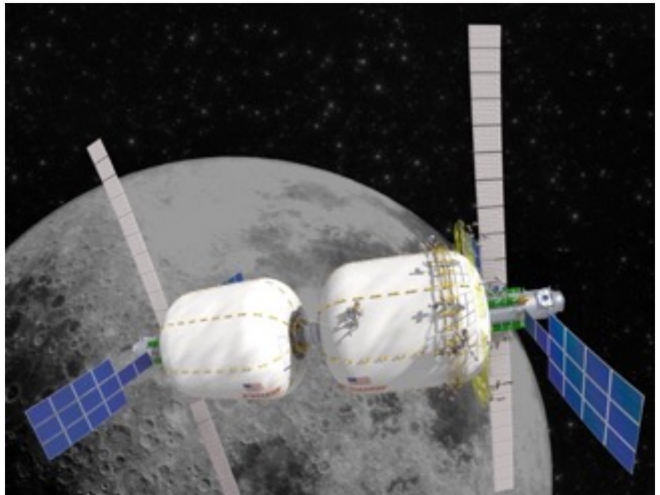


- The habitat sizing tool began in 2007 with reference material found in the book “Human Spaceflight: Mission Analysis and Design” [1] and has since expanded to include integrated sizing methods for every major discipline.
- Key attributes include the ability to size the outfitting for any mission using the most common pressure vessels.
- Key variables include instant output from crew size and mission length.
- Examples:
  1. Mars transit habitat configurations
  2. Lunar base module configurations

Example 1: Mars Transit Habitat concepts



Government reference for a Mars Transit Habitat [2, 3]



Gateway concept by Bigelow Aerospace [4]

Gateway concept by Sierra Nevada [4]

Agency team estimate & Tool Calibration

TRANSIT HABITAT REFINEMENT — HYBRID 2018

DESCRIPTION

Habitat with Hybrid Propulsion

The Mars Transit Habitat is the primary crew vessel for transportation to Mars. The habitat will be launched independent of the propulsive element needed for interplanetary travel, requiring element docking, as well as logisitics upload. For attachment to the hybrid propulsion element, the habitat requires solar panels and batteries for keep alive power and a small transfer propulsion stage to reach the cis-lunar orbit where it will be assembled to the hybrid propulsion element.

ID	FUNCTIONAL CATEGORY	Operation Mass (kg)
1.0	BODY STRUCTURES	10,625
2.0	CONNECTION & SEPARATION SYSTEMS	958
3.0	LAUNCH/TAKEOFF & LANDING SUPPORT SYSTEMS	
4.0	NATURAL & INDUCED ENVIRONMENTAL PROTECTION SYSTEMS	653
5.0	PROPULSION SYSTEMS	469
6.0	POWER SYSTEMS	692
7.0	COMMAND & DATA HANDLING (C&DH) SYSTEMS	895
8.0	GUIDANCE, NAVIGATION & CONTROL (GN&C) SYSTEMS	173
9.0	COMMUNICATIONS & TRACKING (C&T) SYSTEMS	340
10.0	CREW DISPLAYS & CONTROLS	213
11.0	THERMAL CONTROL SYSTEMS (TCS)	2,086
12.0	ENVIRONMENTAL CONTROL SYSTEMS (ECS)	1,538
13.0	CREW/HABITATION SUPPORT SYSTEMS	3,937
14.0	EXTRAVEHICULAR ACTIVITY (EVA) SUPPORT SYSTEMS	1,317
15.0	IN-SITU RESOURCE ACQUISITION & CONSUMABLES PRODUCTION SYSTEMS	0
16.0	IN-SPACE MANUFACTURING & ASSEMBLY SYSTEMS	0
17.0	MANIPULATION & MAINTENANCE SYSTEMS	1,988
18.0	PAYLOAD PROVISIONS (OPERATIONAL MASS)	0
19.0	PAYLOADS & RESEARCH (OPERATIONAL MASS)	1,500
	MANUFACTURER'S EMPTY MASS	27,385
A-H	*OPERATIONAL ITEMS - CREW ITEMS*	21,223
I-J	*OPERATIONAL ITEMS - EQUIP SPARES & MAINT ITEMS*	6,764
K-L	*OPERATIONAL ITEMS - CONSUMABLES (INCLUDING RESIDUALS)*	64
M	*OPERATIONAL ITEMS - CLOSED SYSTEM FLUIDS (REPLENISHABLE)*	0
N-P	*OPERATIONAL ITEMS - PYROTECHNIC/ORDNANCE ITEMS & BALLAST*	0
	OPERATIONAL ITEMS - MULTI-PURPOSE CONTAINERS & CARRIERS	0
Q-S	*OPERATIONAL ITEMS - PROPELLANT*	0
T-V	*OPERATIONAL ITEMS - PROPULSION CONSUMABLES*	0
	OPERATIONAL EMPTY MASS	*28,050*
	GROSS MASS	55,435

Government Reference Design [2] from Agency wide Subject Matter Experts

Description

Mars Tranist Habitat w/ Hybrid Propulsion

Description

The Mars Transit Habitat is the primary crew vessel for transportation to Mars. It is designed to support a crew of 4 for up to 1200 days. The habitat will be launched independent of the propulsive element needed for interplanetary travel, requiring element docking, as well as logisitics upload. This assembly is assumed to occur at the Gateway station in cis-lunar space where it will be configured and refurbished for multiple missions.

Design Constraints / Parameters		
Maximum Crew Size	4	
Max Crewed Mission Duration	1,200	days
Destination	Mars 1 Sol Orbit	
Pressurized Volume	316.85	m^3
Systems Volume	132.90	m^3
Stowage Volume	99.13	m^3
Habitable Volume	84.81	m^3
Operating Pressure	101.30	kPa
Oxygen Fraction	21.00	%
Life Support Closure - Water	Closed	
Life Support Closure - Air	Closed	
Habitat Structure	Aluminum	
Habitat Overall Length	11.50	m
Habitat Diameter	7.20	m
Radiation Protection	0.00	kg
EVA Capability	10	
Crew per EVA	2	
RCS Engine Type	440, 90, 30	N
RCS Propellant	Hydrazine, N2O4	
Power Generation	26.64	kW
Energy Storage	5.93	kW
Keep Alive Power (uncrewed)	5.93	kW
Solar array area	242.89	m^2
Thermal Radiator Area	100.33	m^2
Actual Estimated Loss of Mission	2.25%	
Average TRL	7.87	
Mass Growth Allowance (MGA)	15.54%	
Project Management Reserve (PMR)	0%	

Mass Breakdown		Launch Mass	Outfitted Mass
System		(kg)	(kg)
1.1	Structures	9,225	9,225
2.0	Propulsion	1,573	1,573
3.0	Power	874	874
4.0	Avionics	1,621	1,621
5.0	Thermal	2,165	2,165
6.0	Radiation Protection	-	-
7.0	ECLSS	4,142	4,142
8.0	Crew Systems	3,254	3,254
9.0	EVA	1,116	1,116
10.0	Research	764	764
11.0	Robotics	943	943
Dry Mass		**25,676**	**25,676**
12.0	Stowed Provisions	-	12,935
13.0	Consumables	-	15,319
14.0	Nonpropellant Fluids	70	70
Inert Mass		**70**	**28,324**
Subtotal		**25,746**	**54,001**
	Attached Payloads		
	Propulsion Stage		
15.0	Propellant	1,396	300
16.0	Payload Launch Adapter	1,772	
17.0	In-Space Stage Adapter	1,249	1,249
0.0%	Project Mgt. Reserve	-	-
Total Gross Mass		**30,163**	**55,550**

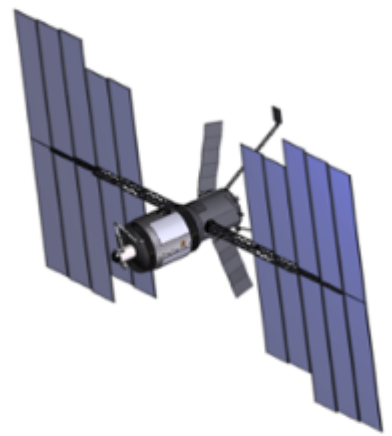
Government Reference Design [5] from Habitat Sizing Tool

Dry mass and operational mass comparison

Recent updates have aligned the ID numbers with AES / NextSTEP standards

TRANSIT HABITAT REFINEMENT		HYBRID 2018
ID	**FUNCTIONAL CATEGORY**	**Operation Mass (kg)**
1.0	BODY STRUCTURES	10,625
2.0	CONNECTION & SEPARATION SYSTEMS	958
3.0	LAUNCH/TAKEOFF & LANDING SUPPORT SYSTEMS	
4.0	NATURAL & INDUCED ENVIRONMENTAL PROTECTION SYSTEMS	653
5.0	PROPULSION SYSTEMS	469
6.0	POWER SYSTEMS	692
7.0	COMMAND & DATA HANDLING (C&DH) SYSTEMS	895
8.0	GUIDANCE, NAVIGATION & CONTROL (GN&C) SYSTEMS	173
9.0	COMMUNICATIONS & TRACKING (C&T) SYSTEMS	340
10.0	CREW DISPLAYS & CONTROLS	213
11.0	THERMAL CONTROL SYSTEMS (TCS)	2,086
12.0	ENVIRONMENTAL CONTROL SYSTEMS (ECS)	1,538
13.0	CREW/HABITATION SUPPORT SYSTEMS	3,937
14.0	EXTRAVEHICULAR ACTIVITY (EVA) SUPPORT SYSTEMS	1,317
15.0	IN-SITU RESOURCE ACQUISITION & CONSUMABLES PRODUCTION SYSTEMS	0
16.0	IN-SPACE MANUFACTURING & ASSEMBLY SYSTEMS	0
17.0	MANIPULATION & MAINTENANCE SYSTEMS	1,988
18.0	PAYLOAD PROVISIONS (OPERATIONAL MASS)	0
19.0	PAYLOADS & RESEARCH (OPERATIONAL MASS)	1,500
	MANUFACTURER'S EMPTY MASS	**27,385**
A-H	*OPERATIONAL ITEMS - CREW ITEMS*	21,223
I-J	*OPERATIONAL ITEMS - EQUIP SPARES & MAINT ITEMS*	6,764
K-L	*OPERATIONAL ITEMS - CONSUMABLES (INCLUDING RESIDUALS)*	64
M	*OPERATIONAL ITEMS - CLOSED SYSTEM FLUIDS (REPLENISHABLE)*	0
N-P	*OPERATIONAL ITEMS - PYROTECHNIC/ORDNANCE ITEMS & BALLAST*	0
	OPERATIONAL ITEMS - MULTI-PURPOSE CONTAINERS & CARRIERS	0
Q-S	*OPERATIONAL ITEMS - PROPELLANT*	0
T-V	*OPERATIONAL ITEMS - PROPULSION CONSUMABLES*	0
	OPERATIONAL EMPTY MASS	***28,050***
	GROSS MASS	**55,435**

DESCRIPTION



Habitat with Hybrid Propulsion

The Mars Transit Habitat is the primary crew vessel for transportation to Mars. The habitat will be launched independent of the propulsive element needed for interplanetary travel, requiring element docking, as well as logisitics upload. For attachment to the hybrid propulsion element, the habitat requires solar panels and batteries for keep alive power and a small transfer propulsion stage to reach the cis-lunar orbit where it will be assembled to the hybrid propulsion element.

	Mass Breakdown	Launch Mass	Outfitted Mass
System		(kg)	(kg)
1.1	Structures	9,225	9,225
2.0	Propulsion	1,573	1,573
3.0	Power	874	874
4.0	Avionics	1,621	1,621
5.0	Thermal	2,165	2,165
6.0	Radiation Protection	-	-
7.0	ECLSS	4,142	4,142
8.0	Crew Systems	3,254	3,254
9.0	EVA	1,116	1,116
10.0	Research	764	764
11.0	Robotics	943	943
Dry Mass		**25,676**	**25,676**
12.0	Stowed Provisions	-	12,935
13.0	Consumables	-	15,319
14.0	Nonpropellant Fluids	70	70
Inert Mass		**70**	**28,324**
Subtotal		**25,746**	**54,001**
	Attached Payloads		
	Propulsion Stage		
15.0	Propellant	1,396	300
16.0	Payload Launch Adapter	1,772	
17.0	In-Space Stage Adapter	1,249	1,249
0.0%	Project Mgt. Reserve	-	-
Total Gross Mass		**30,163**	**55,550**

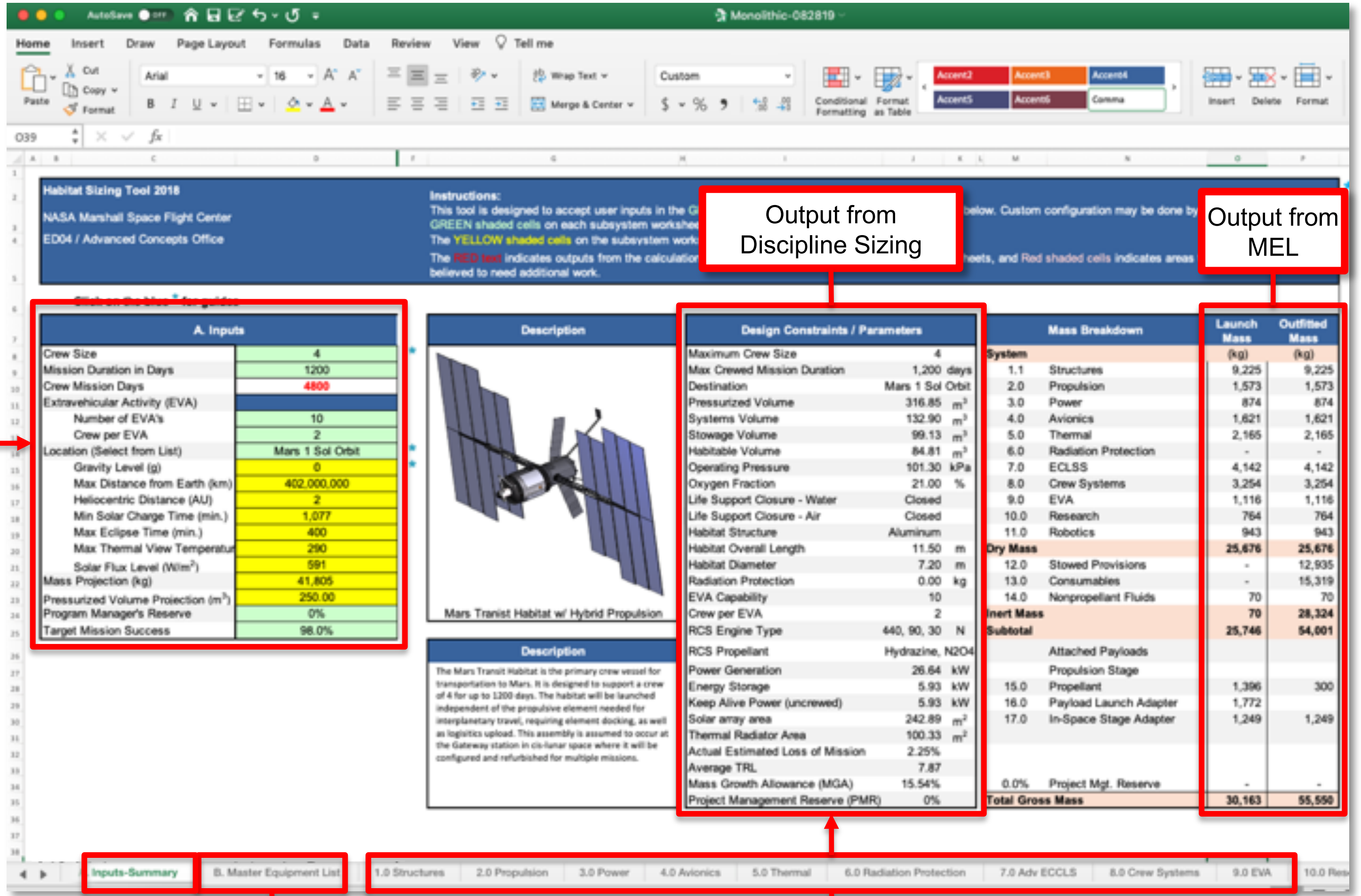
Initial Inputs and Summary Output

A. Inputs	
Crew Size	4
Mission Duration in Days	1200
Crew Mission Days	4800
Extravehicular Activity (EVA)	
Number of EVA's	10
Crew per EVA	2
Location (Select from List)	Mars 1 Sol Orbit
Gravity Level (g)	0
Max Distance from Earth (km)	402,000,000
Heliocentric Distance (AU)	2
Min Solar Charge Time (min.)	1,077
Max Eclipse Time (min.)	400
Max Thermal View Temperature	290
Solar Flux Level (W/m^2)	591
Mass Projection (kg)	41,805
Pressurized Volume Projection (m^3)	250.00
Program Manager's Reserve	0%
Target Mission Success	98.0%

Habitat mass projection curve

Input impacts Spares mass

- **User Input**
  - Number of crew
  - Mission duration
  - EVA activity
  - Primary location



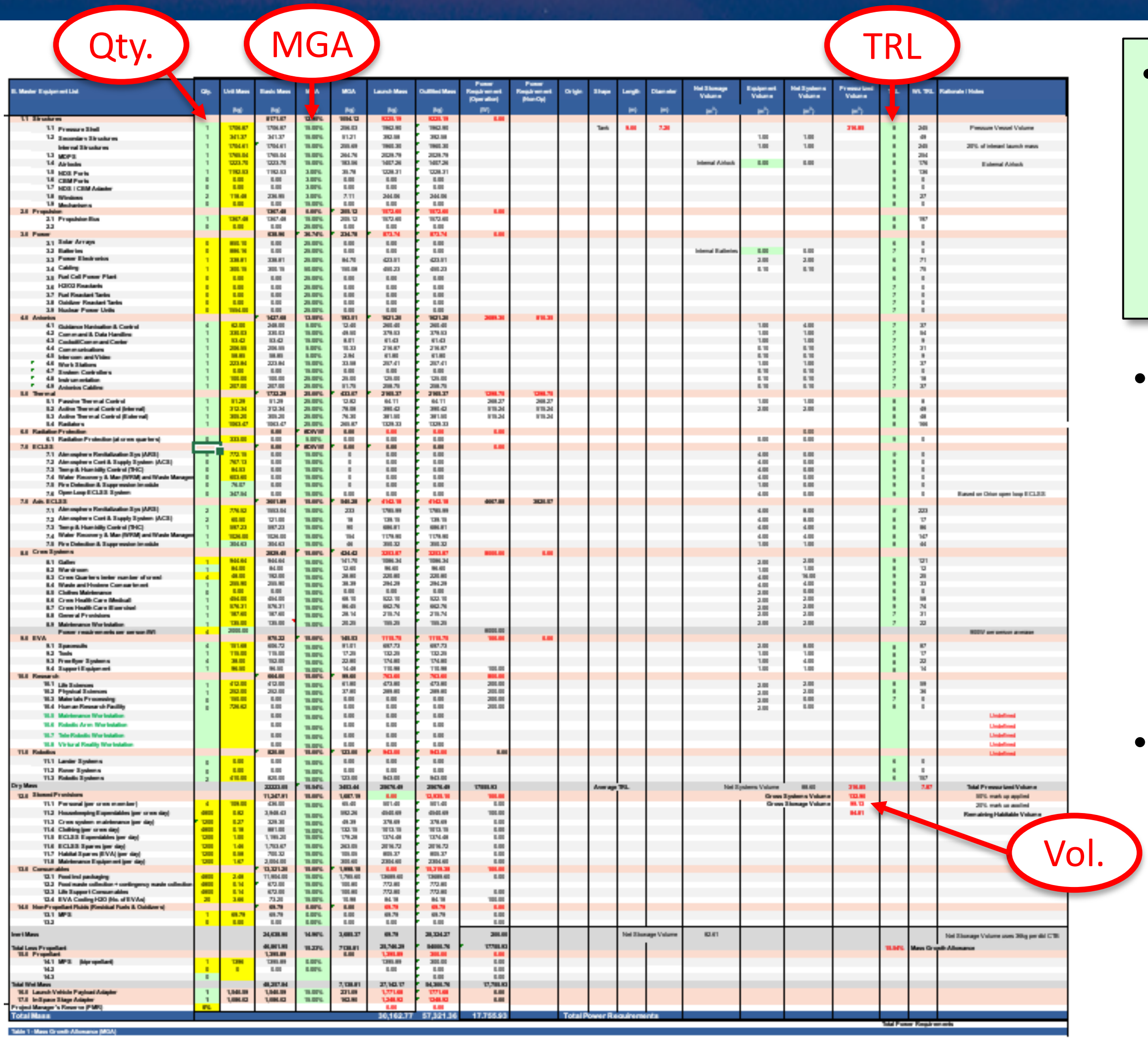
Output from Discipline Sizing

Output from MEL

MEL input from Disciplines

Discipline Worksheets

Master Equipment List (MEL)



- **User Input**
  - Automatic input from all discipline tabs
  - Quantity adjustments
  - Technology Readiness Level (TRL) estimate
  - Mass Growth Allowance (MGA) estimate

- Outputs to Summary Tab
  - Systems mass
  - Stowage mass
  - Vehicle mass
  - Average TRL
  - Average MGA
  - Equipment, Stowage, and Habitable Volumes
- Capabilities
  - Equipment and stowage volumes based on average mass density estimates for each system
  - Launch mass adjustments available for payload limits
  - Outfitted mass provided for mission requirements

0.0 Mission Analysis

- **User Input**
  - None
    - Automatic calculations based on destination input.
    - Automatic input to discipline worksheets

0.0 Mission Analysis								
	Orbital Body	Gravity Level	Max Distance from Earth	Heliocentric Distance	Min. Solar Charge Time	Max Eclipse Time	Max Thermal View Temperature	Solar Flux Level
Location		(g)	(km)	(AU)	(minutes)	(min.)	(K)	(W/m^2)
Earth's Surface	Sun	1.00	0	1	0	1440	295	1000
Lunar Surface	Earth	0.166	384,400	1	19,670	19,670	375	1366.1
Mars Surface	Sun	0.378	402,000,000	1.52	0	1477	290	591
Phobos Surface	Mars	0.0006	402,000,000	1.52	230	230	290	591
Deimos Surface	Mars	0.0003	402,000,000	1.52	909	909	290	591
Space Station Orbit	Earth	0	426	1	56	37	290	1366
Earth-Moon L1	Earth	0	322,000	1	99,999	240	290	1366
Earth-Moon L2	Earth	0	444,000	1	99,999	240	375	1366
Lunar DRO	Moon	0	444,000	1	99,999	240	375	1366
100km Lunar Equatorial	Moon	0	384,400	1	71	47	375	375
Sun Earth L2	Sun	0	1,500,000	1.01	99,999	0	375	1339
1.2 AU Typical NEA	Sun	0	332,000,000	1.2	99,999	0	375	949
500 km Mars Equatorial	Mars	0	402,000,000	1.52	80	43	290	591
Mars Phobos	Mars	0	402,000,000	1.52	339	65	290	591
Mars Deimos	Mars	0	402,000,000	1.52	369	70	290	591
Mars 1 Sol Orbit	Mars	0	402,000,000	1.52	1077	400	290	591

- Locations include:
  - Earth Surface
  - Lunar Surface
  - Mars Surface
  - Phobos Surface
  - Deimos Surface
  - Space Station Orbit
  - Earth-Moon L1
  - Earth-Moon L2
  - Lunar DRO*
  - 100 km Lunar Equatorial Orbit*
  - Sun Earth L2
  - 1.2 AU Typical NEA
  - 500 km Mars Equatorial
  - Mars Phobos Orbit
  - Mars Deimos Orbit
  - Mars 1 Sol Orbit

- Data provided includes:
  - Gravity Level (g)
  - Max. Distance from Earth (km)
  - Max. Heliocentric Distance (AU)
  - Min. Solar Charge Time (min.)
  - Maximum Eclipse Time (min.)
  - Max. Thermal View Temperature (K)
  - Solar Flux Level (W/m^2)

*Update needed to include NRO

1.0 Structures

- **User Input**
  - Pressure vessel length, diameter and end dome shape, or…
  - Standard pressure vessels from available tooling
  - Number of Airlocks and type
  - Number of Docking Ports and type
  - Number of Windows and type

- Outputs
  - 1.0 Pressure vessel mass
  - Volume, surface area, and radiator cylindrical area provided for input into other disciplines
- Capabilities
  - Lengthy menu of over 75 pressure vessel and attachment options
  - Generic rigid pressure shell masses are estimated from a database of finite element models which are mass-optimized using the HyperSizer FEA program.
  - Generic inflatable pressure shells are estimated using areal densities developed by ACO.

Custom sized rigid and inflatable pressure vessels

Numerous ISS, ISS derived, and Russian module pressure vessels

Rigid and inflatable airlocks

NDS and CBM docking systems

Windows and cupolas

1.0 Structures			Qty.	Length (m)	Overall Length	Outside Diameter / Width (m)	Diameter (m)
Generic Rigid Pressure Shell	Aluminum Isogrid Shell	Truncated 8.4m	1	9	9.00	7.20	7.20
Generic Inflatable Pressure Shell	Elliptical Ends (Define Dome Height)	With Mid-Deck	0	13.70	0.00	6.70	0.00
EAM Docking Module (0 rack bays)			0	4.70	0.00	4.30	0.00
Node 1 (1 rack bay)			0	5.50	0.00	4.30	0.00
ISS Node 1 fully outfitted			0	5.50	0.00	4.30	0.00
Nodes 2 & 3 (2 rack bays)			0	6.70	0.00	4.30	0.00
STS Airlock			1	2.50	2.50	1.50	1.50
ISS Airlock			0	5.50		4.00	
Inflatable Airlock			1				
Russian Docking Compartment on ISS			0	4.90		2.55	
Russian Mini-Research Module 2 (MRM2 with airlock capabilities)			0	4.90		2.55	
1.4 Airlock Totals			2		2.50		
NDS Active			3				
NDS Passive			0				
1.5 NDS Ports			3				
Window			1	0.61		0.50	
Window Observational Research Facility (WORF)	See also Research Systems worksheet		0	1.00		0.40	
Cupola			0	2.96		3.00	
1.8 Windows			1				

2.0 Propulsion

2.0 Propulsion		Unit Mass (kg)	Basic Mass (kg)	MGA (%)	MGA (kg)	Predicted Mass (kg)	TRL	Rationale / Notes
2.0 Propulsion			1,367.48	20.00%	273.50	1,640.98		
2.1 MPS		1,367.48	1,367.48	20.00%	273.50	1,640.98	8	
2.2 Reaction Control System (RCS)			0.00	20.00%	0.00	0.00	8	
14.0 Propellant			1,395.89			1,395.89		
14.1 MPS	(bipropellant)	1,395.89	1,395.89			1,395.89		
14.2 RCS			0.00			0.00		
14.0 Non-Propellant Fluids			69.79			69.79		
14.1 MPS	(bipropellant)	69.79	69.79			69.79		
14.2 RCS			0.00			0.00		

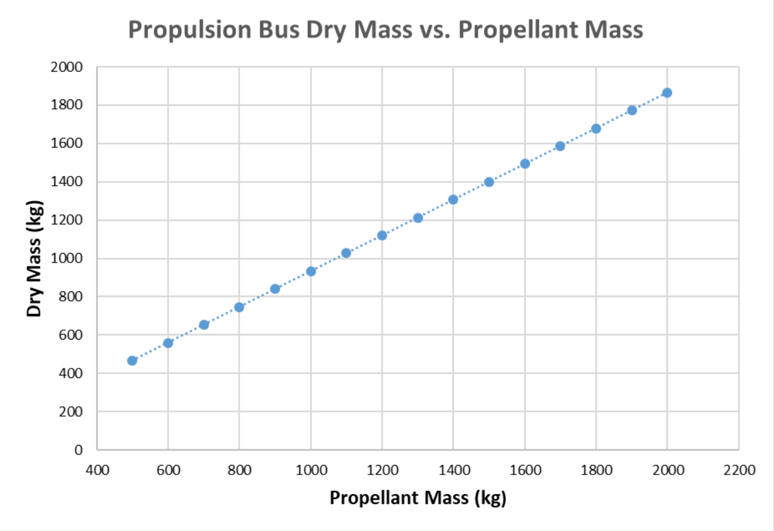
From Inputs Summary

Initial Mass 28,391.09 93.6 310 MPS Isp 326 s

Propulsion System Sizing - *Mars Vicinity*		End:						
Mars System Point-2-Point DVs, Dincl = 5 deg		500 km Mars; i = 0 deg	500 km Mars; i = 5 deg	Mars Phobos	Mars Deimos	Mars 1-Sol orbit; i = 0 deg	Mars 1-Sol orbit; i = 5 deg	User Defined
Start:		1	2	3	4	5	6	7
500 km Mars, i = 0 deg	1		289	1127	1662	1159	5673	
500 km Mars, i > 0 deg	2	289		1151	1662	5673	2066	
Mars Phobos	3	1127	1151		748	791	3521	
Mars Deimos	4	1662	1662	748		635	2023	
Mars 1-Sol orbit, i = 0 deg	5	1159	5673	791	635		287	
Mars 1-Sol orbit, i > 0 deg	6	5673	2066	3521	2023	287		
User Defined	7							3

		RCS		MPS	
Mono Prop Hydrazine Isp	:	225	sec	225	sec
Biprop NTO/MMH Isp	:	310	sec	340	sec
LOx/LCH4 Isp	:	335	sec	360	sec

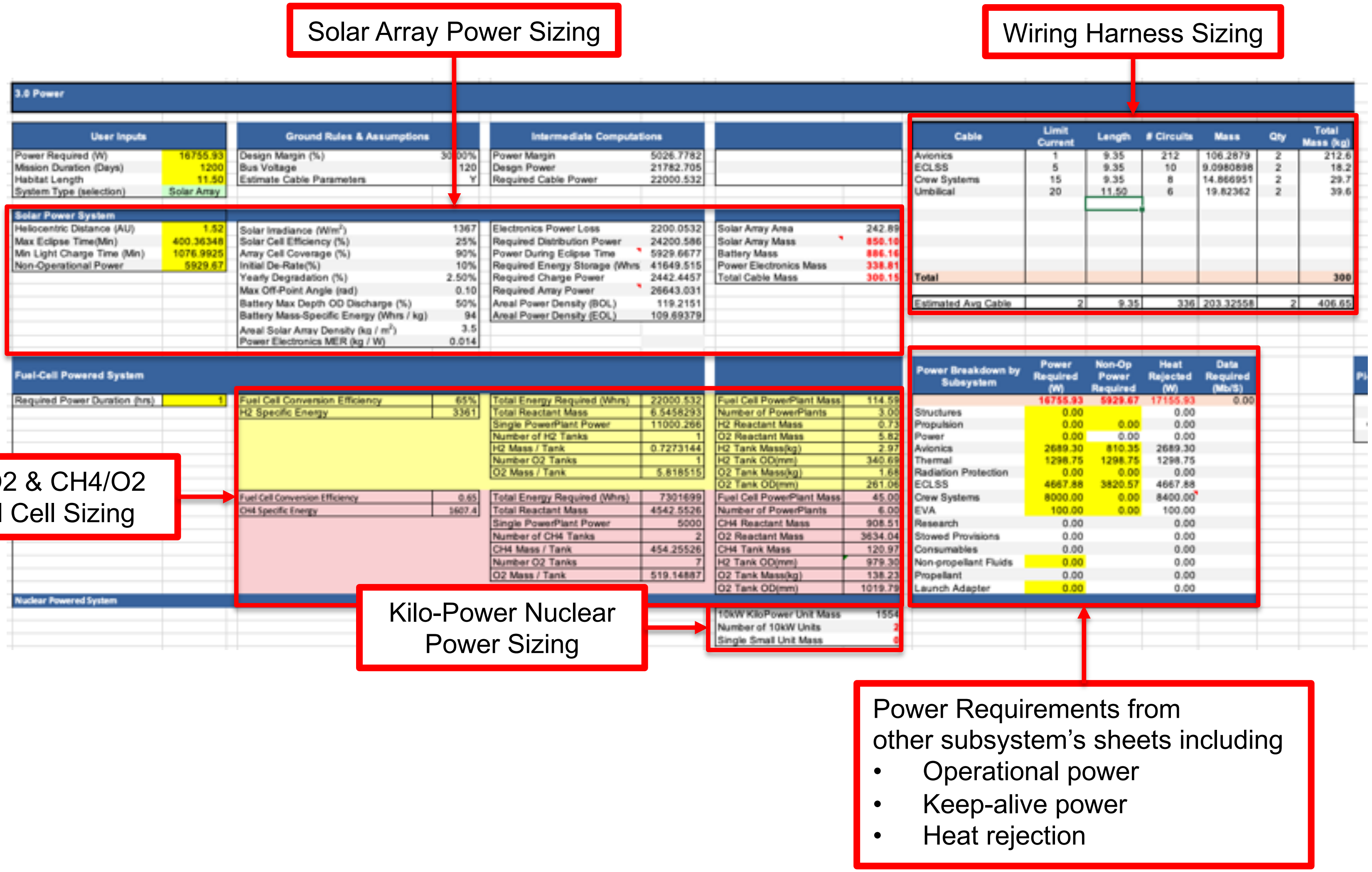
- **User Input**
  - Orbital transfer requirements
    - TLI to NRO
    - Mars 500 km orbit to Mars 1 Sol orbit
- Outputs
  - 2.0 Propulsion hardware mass
  - 14.0 Propellant mass
- Capabilities
  - Designed for low delta-v orbital transfers within Earth, Lunar and Mars orbits



3.0 Power

- **User Input**
  - Solar Arrays
  - Options
    - Solar Arrays
    - Fuel Cells
    - Nuclear
  - Automatic power requirements from other disciplines

- Outputs
  - 3.0 Power mass including…
  - Automatic output to other disciplines
- Capabilities
  - Solar array area
  - Operational power requirements
  - Keep-alive power requirements
    - Power hardware mass
    - Wiring harness mass
    - Solar array mass
    - Fuel cell fluid mass



4.0 Avionics Inputs

4.0 Avionics Equipment List

	Component	#Units	Unit Mass (kg)	Total Mass (kg)	Unit Power(w)	Standby Mode 120 daysTLI keep alive: Duty cycle(%)	Standby Mode 120 daysTLI keep alive: Total Power(w)
4.1 ACS - LowerDeck				62.00			0.00
4.1 ACS - UpperDeck				0.00			0.00
				62.00			0.00
	ACS-LowerDeck			0.00			
	Sun Sensors	0	0.03	0.00	0.13	10%	
	Sun Sensor Electronics	0	0.50	0.00	5.50	10%	
	Horizon Sensors	0	1.10	0.00	5.00	10%	
	Star Tracker	0	1.66	0.00	8.50	10%	
	IMU	0	0.75	0.00	12.00	10%	
	ACS-UpperDeck			0.00			
	Sun Sensors	0	0.03	0.00	0.13	10%	
	Sun Sensor Electronics	0	0.50	0.00	5.50	10%	
	Star Tracker	0	1.66	0.00	5.50	10%	
	IMU	0	0.75	0.00	12.00	10%	
	ACS-actuators-Service Module			0.00			
	CMG	0	65.00	0.00	350.00	25%	
	Electronic Control Unit (ECU)	0	15.00	0.00	100.00	50%	
	Mounting and Isolation system	0	32.50	0.00	0.00	100%	
	AR&D - LowerDeck			62.00			
	Passive reflector	6	0.50	3.00	0.00	0%	
	Target	2	2.50	5.00	0.00	0%	
	Floodlights	2	3.00	6.00	83.00	0%	
	Lidar Avionics System	1	10.00	10.00	40.00	0%	
	Short Range Lidar	1	16.00	16.00	72.00	0%	
	Long Range Lidar	0	16.00	0.00	72.00	0%	
	Optical Avionics System	1	10.00	10.00	40.00	0%	
	Short Range Optical/IR Camera	2	6.00	12.00	12.00	0%	
	Long Range Optical Cameras	0	6.00	0.00	11.00	0%	
	AR&D -UpperDeck			0.00			
	Passive reflector	0	0.50	0.00	0.00	0%	
	Target	0	2.50	0.00	0.00	0%	
	Floodlights	0	3.00	0.00	83.00	0%	0.00
	Lidar Avionics System	0	10.00	0.00	40.00	0%	0.00
	Short Range Lidar	0	16.00	0.00	72.00	0%	0.00
	Long Range Lidar	0	16.00	0.00	72.00	0%	0.00
	Optical Avionics System	0	10.00	0.00	40.00	0%	0.00
	Short Range Optical/IR Camera	0	6.00	0.00	12.00	0%	0.00
	Long Range Optical Cameras	0	6.00	0.00	11.00	0%	0.00
4.2 C&DH - LowerDeck							
4.2 C&DH - UpperDeck							
	C&DH-LowerDeck						
	Vehicle Management Computer	3	23.75				
	RIU-Data Acquisition Unit	4	2.68				
	Data Recorder	3	2.99				
	Data Bus Repeater	4	2.99				
	PDU-C1	0	28.16				
	PDU-C3	16	14.20				
	PDU-C5	0	32.83				
	PDU-S1	0	27.57				

Key Variables		Unit
	Crew size	4
	Maximum distance from Earth	444000
	Habitat Location	Earth-Moon L2
	MPS	1
	RCS	1
	Habitat Volume	496
	Number of docking ports	2
	Additional Deck Levels	0
	Additional Safe Haven Decks	0
	Number of Science workstations	1
	Maintenance workstation	1
	Robotic-Arm workstation	0
	Tele-Robotic workstation	0
	Virtual Presence workstation	0

Habitat Function			
	Transit	Lunar	Mars
	Orbital	DRO	Mars
	Taxi		
	Lander	Lunar	Mars
	Surface Habitat	Lunar	Mars
	Surface Rover	Lunar	Mars
	Surface Elements		

			Main Deck Mass (kg)	Number of additional decks including Safe Haven decks	Additional Deck Mass (kg)	Basic Mass Total (kg)	Power (w)
4.0	Avionics					1013.01	2724.88
	4.1	Guidance Navigation & Control	100.78	0	0.00	100.78	
		Power (w)	59.28	0	0.00		59.28
	4.2	Command & Data Handling	178.93	0	53.11	178.93	
		Power (w)	745.10	0	147.70		745.10
	4.3	Cockpit/Command Center	65.89	0	0.00	65.89	
		Power (w)	220.50	0	0.00		220.50
	4.4	Communications	135.60	0	0.00	135.60	
		Power (w)	658.90	0	0.00		658.90
	4.5	Intercom and Video	32.06	0	32.06	32.06	
		Power (w)	166.10	0	166.10		166.10
	4.8	Instrumentation	27.21	0	15.00	27.21	
		Power (w)	50.00	0	50.00		50.00
	4.9	Avionics Cabling	227.61	0	82.00	227.61	
		Power (w)	0.00	0	0.00		0.00

- **User Input**
  - Select from menu of subsystem components for…
    - Guidance Navigation & Control (GN&C)
    - Command & Data Handling (C&DH)
    - Communications & Tracking (C&T)
    - Crew Displays and Controls
  - Number of internal deck levels

- Output
  - 4.0 Avionics mass
  - Power requirements
- Capabilities
  - Mass derived from Orion, ISS, and Shuttle heritage systems
  - Quantity and type of components depends on mission definitions
    - Some quantities are automatic based on input table
    - Others are selected manually
    - Number of decks selected adds additional mass
  - Power profiling of avionics components based on major mission phases

5. Thermal

Sizing of Active TCS (Internal and External)

Method 1
Scale existing thermal control system MEL by power. Existing MEL from Ref. 1.

Input power	4100.00	W
Reference input power	6000.00	W
Active TCS (internal) basic mass	82.85	kg
Active TCS (external) basic mass	80.95	kg
Active TCS (internal) basic power	136.67	W
Active TCS (external) basic power	136.67	W

Reference MEL

	Quantity	Unit Mass kg
Active Thermal Control (Internal)		
H2O/PG Pumps	2	6.75
H2O/PG Accumulators	2	9.45
H2O/PG Lines with Coolant	1	16.70
Flow Control Valves	2	4.00
Survival Heater	1	3.00
Coldplates (SS)	8	4.00
Temperature Sensors	4	0.10
Flow Sensors	1	0.60
Liquid Level Sensors	2	0.25
Pressure Sensors	3	0.10
Filters	3	0.40
Liquid to Liquid Heat Exchanger	1	8.00
Isolation Valves	2	0.24
Check Valves	2	1.73
Fill Ports	2	0.60
Avionics Fan	1	2.00
Avionics Heat Exchanger	1	11.00
Active Thermal Control (External)		
HFE 7200 Coolant Pumps	2	6.75
HFE 7200 Primary Accumulator	1	30.30
HFE 7200 Backup Accumulator	1	10.10
HFE 7200 Lines with Coolant	1	14.20
Coldplates	8	1.31
Temperature Sensors	2	0.10
Flow Sensor	1	0.60
Liquid Level Sensors	2	0.25
Pressure Sensors	3	0.10
Filters	4	0.40
Regenerator	1	6.75
Radiator Flow Split Valve	1	2.00
Regenerator Flow Control Valve	2	4.00
Isolation Valves	10	1.73
Check Valves	6	0.24
Fill Ports	2	0.60

Sizing of Radiators

Method 1
Use empirical equations based on estimated areal heat rejection and density

Heat rejected	4418.40	W
Habitat lateral surface area	240.70	m²

Radiator type	One-sided fixed	Two-sided deployable	
Use	Yes	No	-
Areal heat rejection	171	171	W/m²
Areal density	10.6	8.5	kg/m²
Knock-down factor	0.85	n/a	-
Available area	204.60	n/a	m²
Radiator area	**25.84**	**25.84**	m²
Area margin	178.76	n/a	m²
Area margin (%)	87%	n/a	%
Additional deployable area	Not Required	n/a	m²
Total radiator area	**25.84**	**0.00**	m²
Total radiator mass	**273.89**	**0.00**	kg

Radiator Areal Heat Rejection Based on Radiatior Temperature (Ref. 2)

Radiator application and type	Average Radiator Temp K	Approx. Heat Rejection W/m²
Near Earth orbit - stationnary radiator	270	50
	290	131
Near Earth orbit - tracking radiator	270	104
	290	185
Moon - low latitude (vert. relative to surf.)	270	Need heat pump or shade
	290	
Moon - low latitude (horiz. relative to surf.)	270	106
	290	187
Moon - in orbit or near poles (vert. or horiz.)	270	171
	290	251
Mars - surface (vert. or horiz.)	270	81
	290	162
Mars - transit	270	171
	290	251

Radiator areal density (Ref. 2)

Fixed radiator, 1-sided (e.g. surface mount)	10.6	kg/m²
Fixed radiator, 2-sided	5.3	kg/m²
Deployable radiator, 1-sided	17.0	kg/m²
Deployable radiator, 2-sided	8.5	kg/m²

- **User Input**
  - In-Space or Surface System
  - One-sided fixed or Two-sided deployable radiators

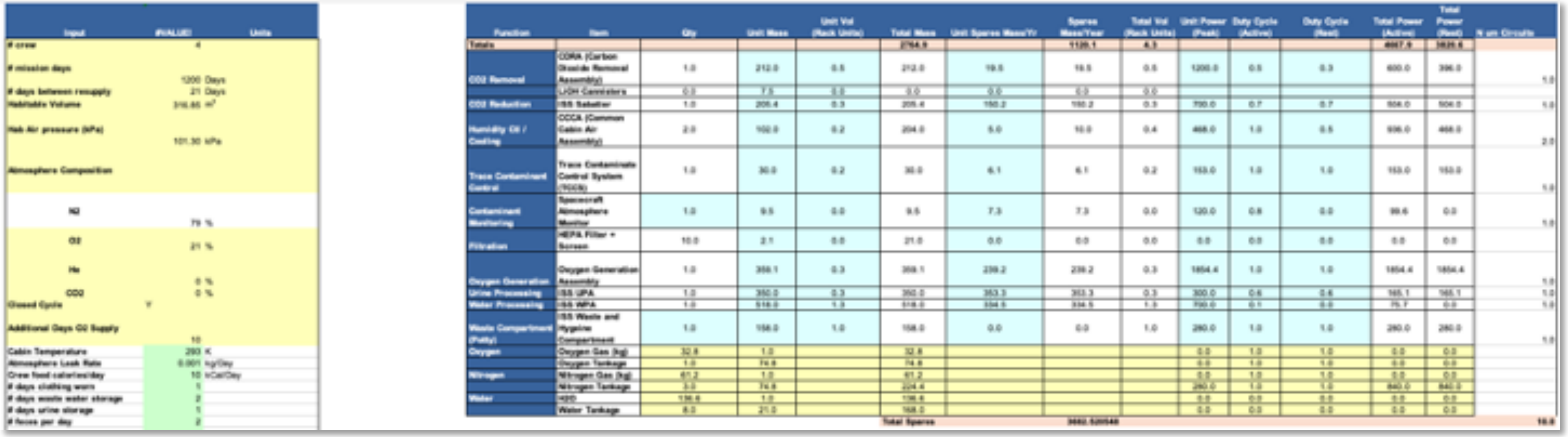
- Outputs
  - 5.0 Thermal system mass
  - Power requirements
  - Radiator area
- Capabilities
  - Active TCS based on dual pumped fluid loops (internal/external)
    - Mass and Power sizing of internal and external TCS achieved via power scaling of a reference MEL.
    - Reference MEL taken from previous NASA MSFC ACO study, "Habitat Safe Haven Configurations Study", 2017, with mass and power numbers for loop components based on Orion TCS.
    - Quantities for specific components can be adjusted.
  - Passive TCS (insulation, heaters)
    - Mass and Power sizing of passive TCS achieved via module surface area scaling of the above-mentioned reference MEL.
  - Radiators
    - Emitting area calculated from average Areal Heat Rejection values (W/m^2) based on typical thermal environment (e.g. NEO, Lunar surface, Mars surface).
    - Mass calculation based on radiator effective areal density, which depends of radiator type: fixed or deployable, single- or dual-sided.

6.0 Radiation Protection

6.0 Radiation Protection									
Radiation Protection	Rule	Provide Protection?	Number of Crew	Mass per Crew Member (kg)	Total Mass Required				Notes
SPE protection rule of thumb	333 kg / crew member		4	333	1332				TM-2012-217361 "Evaluating Shielding Approaches to Reduce Space Radiation Cancer Risks," by Francis A. Cucinotta, et al.
Radiation Protection	Rule	Depth of Material Required (m)	Density of Covering (kg/m^3)	Volume to be Covered (m^3)	Derived Width / Length / Height (m)	Volume of Material Required (m^3)	Mass of Material Required (kg)	Mass of Material Required (mt)	Notes
GCR protection rule of thumb	3m coverage in regolith for surface habitats	3	1600	316.85	6.82	1,296.00	2,073,596	2,073.60	Surface provides half of protection. Mass is usually derived from in situ materials.
	5m coverage in regolith in for space habitats	5	1600	316.85	6.82	3,025.39	4,840,616	4,840.62	
					82	11,777.72	11,777,717	11,777.72	Usually provided as water or asteroid materials.

- **User Input**
  - Automatic calculation based on number of crew quarters to be protected
  - Optional GCR protection available
- Output
  - 6.0 Radiation Protection mass
- Capabilities
  - Solar Proton Events (SPE) assumes a polyethylene panel mass wrapped around ISS like crew quarters
  - Galactic Cosmic Rays (GCR) assumes mass of water or regolith required for either in-space or surface habitat

7.0 Environmental Control and Life Support System



- **User Input**
  - Automatic inputs from number of crew and mission days
  - Open vs closed loop systems are selected automatically but selection can be toggled manually
  - ISS ECLSS and Advanced ECLSS options available from ES62 collaborations
- Outputs
  - 7.0 ECLSS hardware mass
  - 12.0 Stowed Provisions mass
  - 13.0 Consumables mass
- Capabilities
  - Includes water, air, food, and waste balance calculated from crew needs and habitat inputs

8.0 Crew Systems

- **User Input**
  - Shopping list of items based primarily on ISS systems experience including specific equipment for the…
    - Galley
    - Wardroom
    - Crew Quarters
    - Personal Hygiene Compartment
    - Crew Health Care for Medical and Exercise
    - Maintenance

- Output
  - 8.0 Crew Systems mass
- Capabilities
  - Washer / Dryer system
  - Shower
  - Custom exercise equipment

No.	Item	Qty	Unit Mass (kg)	Basic Mass (kg)
8.0	Crew Systems			
8.1	Galley			944.64
8.1.1	Support structure and enclosures	1	157.44	157.44
8.1.2	Food warmer / microwave	2	59.10	118.20
8.1.3	Water dispenser system	1	15.00	15.00
8.1.4	Trash compactor	1	150.00	150.00
8.1.5	Misc. food prep equipment	1	10.00	10.00
8.1.6	Freezer	1	496.00	496.00
8.2	Wardroom			84.00
8.2.1	Support struct and enclosure	1	14.00	14.00
8.2.2	Meeting/dining table	1	40.00	40.00
8.2.3	Crew Restraints (table)	4	2.50	10.00
8.2.4	Lights and Utilities	1	20.00	20.00
8.3	Crew Quarters			48.00
8.3.1	Support Structure, enclosure, acoustic insulation	1	30.00	30.00
8.3.2	Lights and Utilities	1	10.00	10.00
8.3.3	0-g Sleep Restraint (structure and restraint)	1	8.00	8.00
8.3.4	Bunk (planetary)	0	15.00	0.00
8.4	Personal Waste and Hygiene Compartment			256.00
8.4.1	Support struct and enclosure	2	50.00	100.00
8.4.2	Urine collection (collection device)	1	9.40	9.40
8.4.3	Waste Management System (commode)	1	75.60	75.60
8.4.4	Restraints	1	11.00	11.00
8.4.5	Lighting/ventilation fixtures	2	15.00	30.00
8.4.6	Hand/face wash	2	15.00	30.00
8.4.7	Shower			0.00
8.4.7.1	Support struct and enclosure	0	50.00	0.00
8.4.7.2	Lighting/ventilation fixtures	0	15.00	0.00
8.4.7.3	Shower head and controls	0	3.00	0.00
8.5	Clothes Maintenance			0.00
8.5.1	Washer	0	100.00	0.00
8.5.2	Dryer	0	60.00	0.00
8.5.3	Supplies for washer	0	0.02	0.00
8.6	Crew Health Care (Medical)			454.00
8.6.1	Medical/surgical/dental	1	250.00	250.00
8.6.2	Healthcare consumables	1	108.00	108.00
8.6.3	Emergency Breathing Apparatus	4	4.00	16.00
8.6.4	Survival Kit	4	20.00	80.00
8.6.5	Convenience Medication Pack	1	2.50	2.50
8.6.6	Oral Medication Pack	1	2.70	2.70
8.6.7	Topical / Injectable Medication Pack	1	3.40	3.40
8.6.8	Medical Supply Pack	1	2.90	2.90
8.6.9	Minor Treatment Pack	1	3.90	3.90
8.6.10	Medical Diagnostic Pack	1	4.00	4.00
8.6.11	IV Supply Pack	1	6.20	6.20
8.6.12	Physician Equipment Pack	1	2.60	2.60
8.6.13	Emergency Medical Treatment Pack	1	2.80	2.80
8.7	Crew Health Care (Exercise)			576.31
8.7.1	TVIS Treadmill with active loading (0-10 mph)	0	382.87	0.00
8.7.2	T2 Treadmill with bungee (0-12 mph)	0	1087.78	0.00
8.7.3	CEVIS Bicycle Ergometer	0	102.96	0.00
8.7.4	ARED Resistive	1	544.31	544.31

9.0 Extra-Vehicular Activity (EVA)

9.0 Extravehicular Activity (EVA)		Qty	Unit Mass (kg)	Basic Mass (kg)	MGA (%)	MGA (kg)	Predicted Mass (kg)	TRL	Rationale / Notes
9.0 EVA				[illegible]		[illegible]	[illegible]		
9.1 Spacesuits				[illegible]		[illegible]	[illegible]		
9.1.1	ISS Suit (weightless ops)	1	123.00	123.00	3%	3.69	126.69	9	ISS EMU
9.1.2	Apollo Lunar EVA suit	0	96.20	0.00	10%	0.00	0.00	6	Apollo 15-17
9.1.3	[illegible]	0	[illegible]	0.00	10%	0.00	0.00	[illegible]	[illegible]
9.1.4	Shuttle Advanced Crew Escape Suit (IVA)	0	12.70	0.00	10%	0.00	0.00	9	
9.1.5	[illegible]	1	[illegible]	[illegible]	3%	[illegible]	[illegible]	9	[illegible]
9.1.6	Exploration EVA Suits	0	[illegible]	0.00	10%	0.00	0.00	[illegible]	
9.1.7	LCVG	1	7.00	7.00	3%	0.21	7.21	9	LaRC Logistics Model (Email from Lindsay Aitchison 2/26/12 regarding LCVG "For a 'dry' LCVG, assume 7lbs for a large size.") General rule: [illegible] uses until too dirty
9.2 Tools				115.00		8.70	123.70		
9.2.1	EVA tools and work restraints	1	75.00	75.00	10%	7.50	82.50	9	Mission specific (estimate)
9.2.2	Flight installed handrails	10	4.00	40.00	3%	1.20	41.20	9	Spacecraft configuration specific (estimate)
9.3 Free-flyer Systems				[illegible]		[illegible]	[illegible]		
9.3.1	Manned Maneuvering Unit (MMU)	0	141.00	0.00	10%	0.00	0.00	6	MMU mass from Shuttle Program (add EVA suit and 12kg propellant mass)
9.3.2	Safer (ISS system)	1	38.00	38.00	3%	1.14	39.14	9	Current ISS system includes propellants
9.3.2	[illegible]	0	[illegible]	0.00	30%	0.00	0.00	[illegible]	[illegible]
9.3.3	Recharge propellants (enter prop. Needed)	0	1.00	0.00		0.00	0.00		Input propellants needed in kilograms
9.4 Support Equipment				[illegible]		[illegible]	[illegible]		
9.4.1	Suit maintenance and sizing	1	40.00	40.00	10%	4.00	44.00	[illegible]	Estimate
9.4.2	Umbilical ([illegible])	1	7.00	7.00	3%	[illegible]	7.21	9	
9.4.3	Umbilical Service Sta ([illegible])	1	15.00	15.00	3%	0.45	15.45	9	
9.4.4	Umbilical Panel and Controls (airlock)	1	[illegible]	[illegible]	3%	[illegible]	[illegible]	9	
9.4.5	[illegible] valve	1	[illegible]	[illegible]	3%	[illegible]	[illegible]	9	
9.4.6	Battery charger and charge station	1	25.00	25.00		[illegible]	[illegible]	[illegible]	One required. Battery charger ISS LIB ([illegible] kg) and power supply ISS PSA ([illegible] kg)
12.4 EVA Cooling			[illegible]	[illegible]		[illegible]	[illegible]		
12.4.1	Cooling water	20	[illegible]	[illegible]		[illegible]	[illegible]		LaRC Logistics Model
12.4.2	[illegible]	20	[illegible]	[illegible]		[illegible]	[illegible]		[illegible]

- **User Input**
  - Number and type of EVA suit
  - EVA equipment options include…
    - Tools
    - Free-flyer systems

- Outputs
  - 9.0 Extra-Vehicular Activity (EVA) mass
  - 13.0 EVA consumable mass
- Capabilities
  - Shopping list or primarily heritage ISS, Apollo, and Russian systems, and Orion systems
  - Automatic consumables calculation based on number of EVAs anticipated
- Airlocks included in 1.0 Structures section
  - Options include ISS, Shuttle, and custom inflatable airlocks

10.0 Research

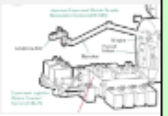
10.0 Research		
Space Habitat Science and Maintenance Workstations		Qty
Mass Breakdown Structure		
10.0 Research		
10.1 Life Sciences		
10.1.1	Microscope	1
10.1.2	Molecular Analyzer (Mass Spec TOF)	1
10.1.3	Molecular Analyzer (Gas Chromatogrpah)	1
10.1.4	Freezer	1
10.1.5	Refrigerator	1
10.1.6	Mass Measurement Device	1
10.1.7	Specimen Centrifuge	1
10.1.8	Interface for Gas Analysis	1
10.1.9	Cell Culture System	1
10.1.10	Small Animal Research Facility (AEM Vivarium Glove Box)	1
10.1.11	Botany/Plant Biology Research	1
10.1.12	Consummables (Media; Hydroponic Nutrient Fluid; Feed; Gasses; etc)	1
10.1.13	Microbial Detection (Medical microbiology and Astrobiology)	1
10.2 Physical Sciences		
10.2.1	Heavy Ion Tracker	1
10.2.2	Materials and Environment	2
10.2.3	Relativistic Gravity Experiment	4
10.3 3-D Printer workstation		
10.3.1	3-D printer	1
10.3.2	Feed stock	1
10.3.3	Recycler	1
10.3.4	Verification Station (structured light scanning box)	1
10.3.5	Glove Box	1

- **User Input**
  - Select from shopping list of research equipment

- Output
  - 10.0 Research Equipment mass
- Capabilities
  - Based primarily on ISS research systems

11.0 Robotic Systems

- **User Input**
  - Custom Shuttle derived robotic arm selected
- Output
  - 11.0 Robotic systems mass
- Capabilities
  - Shuttle, ISS, and surface robotic systems options available
  - Mobility systems included for various surface mobility options

11.3 Robotic Systems		Qty	1.1 Dry Mass (kg)	1.1 Total (kg)	Collapsed Width (m)	Deployed Width (m)	Length / Reach (m)	Height (m)	Extended Height (m)	Martian Payload Capacity (kg)	Lunar Payload Capacity (kg)	Total Capacity (kg)	Primary Fuel Type
Mars Exploration Rovers (MER)		0	180	0		2.30	1.60	1.50		6.80		0	RTG
Robotic Methane Scavenger		0		0								0	FuelCells
Curiosity Rover		0	899	0		2.70	2.90	2.20		80.00		0	RTG
Robonaut 2		0	160	0	0.97		1.22	0.74		54.00		0	Battery
Robotic Manipulator Arm		0	102	0	0.20	0.20	1.64	0.91	1.66	500.00		0	Battery
Stereoscopic Computer Vision		0	0.43	0	0.28		0.06	0.04				0	Battery
Spherical ("3D") Camera		0	0.65	0	0.11		0.11	0.11				0	Battery
Fuel Transfer Boom		0	300	0								0	Methane
HPCL, Habitat Personnel and Cargo Lift		0	454.00	0	1.50	1.50	1.50	8.00	8.00	250.00	250	0	Battery
ISS Space Station Remote Manipulator System (SSRMS)		0	1,497	0		0.36	17.60						Battery
ISS Mobile Base System (MBS)		0	1,450	0		4.50	5.70						Battery
ISS Special Purpose Dexterous Manipulator (SPDM)		0	1,662	0		0.88	3.50						Battery
Shuttle Robotic Arm		0		0									Battery
ISS JEM Remote Manipulator (main arm)		0		0			9.90						Battery
ISS JEM Remote Manipulator small arm)		0		0			1.90						Battery
Robotic Arm	Custom. Shuttle derived.	1	410	410			17.60						Battery
Total Dry Mass		1		410									

12.0 Stowed Provisions

- **User Input**
  - Automatic input based on number of crew and mission days
- Output
  - 12.0 Stowed Provisions mass
- Capabilities
  - Additional options available from selection menu
  - Provisions based on ISS experience, but custom selections are available

	12.0 Stowed Provisions	ISS w/ Packaging	Unit Mass (kg)	Basic Mass (kg)	MGA (%)	MGA (kg)
12.0	Stowed Provisions			11,248		
12.1	Personal (per crew member)		109.00	436.00		
12.1.1	I/VA - OPERATIONAL SUPPLIES		29.00			
12.1.1.1		OPERATIONAL SUPPLIES	25.00			
12.1.1.2		LAPTOP	2.00			
12.1.1.3		PRINTER	2.00			
12.1.2	I/VA - PHOTOGRAPHIC EQUIPMENT		30.00			
12.1.2.1		EQUIPMENT (STILL & VIDEO CAMERAS, LENSES,	30.00			
12.1.3	I/VA - RECREATIONAL EQUIPMENT		50.00			
12.1.3.1		RECREATION & PERSONAL STOWAGE	50.00			
12.2	Housekeeping Expendables (per crew day)		0.82	3346.43		
12.2.1	I/VA - CREW HYGIENE, WASTE MGMT., AND HOUSEKEEPING SUPPLIES		0.82			
12.2.1.1		PERSONAL HYGIENE KIT	0.04			
12.2.1.2		HYGIENE CONSUMABLES / WCS WIPES	0.21			
12.2.1.3		TOWELS	0.10			
12.2.1.4		COMMUNITY HYGIENE KIT	0.00			
12.2.1.5		WASTE COLLECTION - FECAL CANISTERS	0.24			
12.2.1.6		WASTE COLLECTION - URINE PREFILTER	0.06			
12.2.1.7		FECAL/URINE COLLECTION BAGS (CONTINGENCY	0.00			
12.2.1.8		TRASH BAGS	0.03			
12.2.1.9		HEALTH CARE CONSUMABLES	0.11			
12.2.1.10		WIPES (HOUSEKEEPING)	0.05			
12.2.1.11		VACUUM (PRIME + 2 SPARES)	0.01			
12.3	Crew system maintenance (per day)		0.27	328.38		
12.3.1	I/VA - MAINTENANCE AND REPAIR TOOLS/KITS		0.27			
12.3.1.1		ELCTRMECHANICAL TOOL SET	0.00			
12.3.1.2		HATCH UNJAMMING TOOL SET	0.00			
12.3.1.3		SOLDERING KIT	0.01			
12.3.1.4		DRILLING KIT	0.04			
12.3.1.5		METAL CUTTING AND BENDING KIT	0.06			
12.3.1.6		METALLURGICAL ANALYSIS KIT	0.01			
12.3.1.7		SURFACE BONDING KIT	0.02			
12.3.1.8		ELECTRONICS ANALYSIS AND REPAIR KIT	0.01			
12.3.1.9		COMPUTER INSPECTION, TESTING, AND REPAIR	0.00			
12.3.1.10		CAD AND SOFTWARE WORKSTATION	0.00			
12.3.1.11		MATERIAL HANDLING KIT	0.02			
12.3.1.12		PRECISION MAINTENANCE KIT	0.00			
12.3.1.13		3D PRINTING KIT	0.02			
12.3.1.14		SOFT GOODS KIT	0.02			
12.3.1.15		THERMOPLASTICS KIT	0.05			
12.3.1.16		DUST MITIGATION KIT	0.01			
12.3.1.17		SPARES	0.01			
12.3.1.18		RAW MATERIALS	0.00			
12.4	Clothing (per crew day)		0.184	881.08		
12.5	ECLSS Expendables (per day)		1.00	1195.20		
12.6	ECLSS Spares (per day)		1.46	1763.67		
12.7	Habitat Spares (EVA) (per day)		0.58	701.32		
12.8	Maintenance Equipment (per day)		1.67	2004.00		
12.9	Cargo Transfer Bag Mass (total)			0.00		

SOURCES
JSC CAT/FAT - Pedro Lopez (2013) [illegible]
Old Deep Space Habitat (2012) As referenced in [illegible]
EMC BELL
MSC Refinement Study - Ural (2016) See ALD/Studies/MSC Refinement Study. "Ural includes the CBM mass in his calculations"

13.0 Consumables

- **User Input**
  - Automatic input based on number of crew and mission days

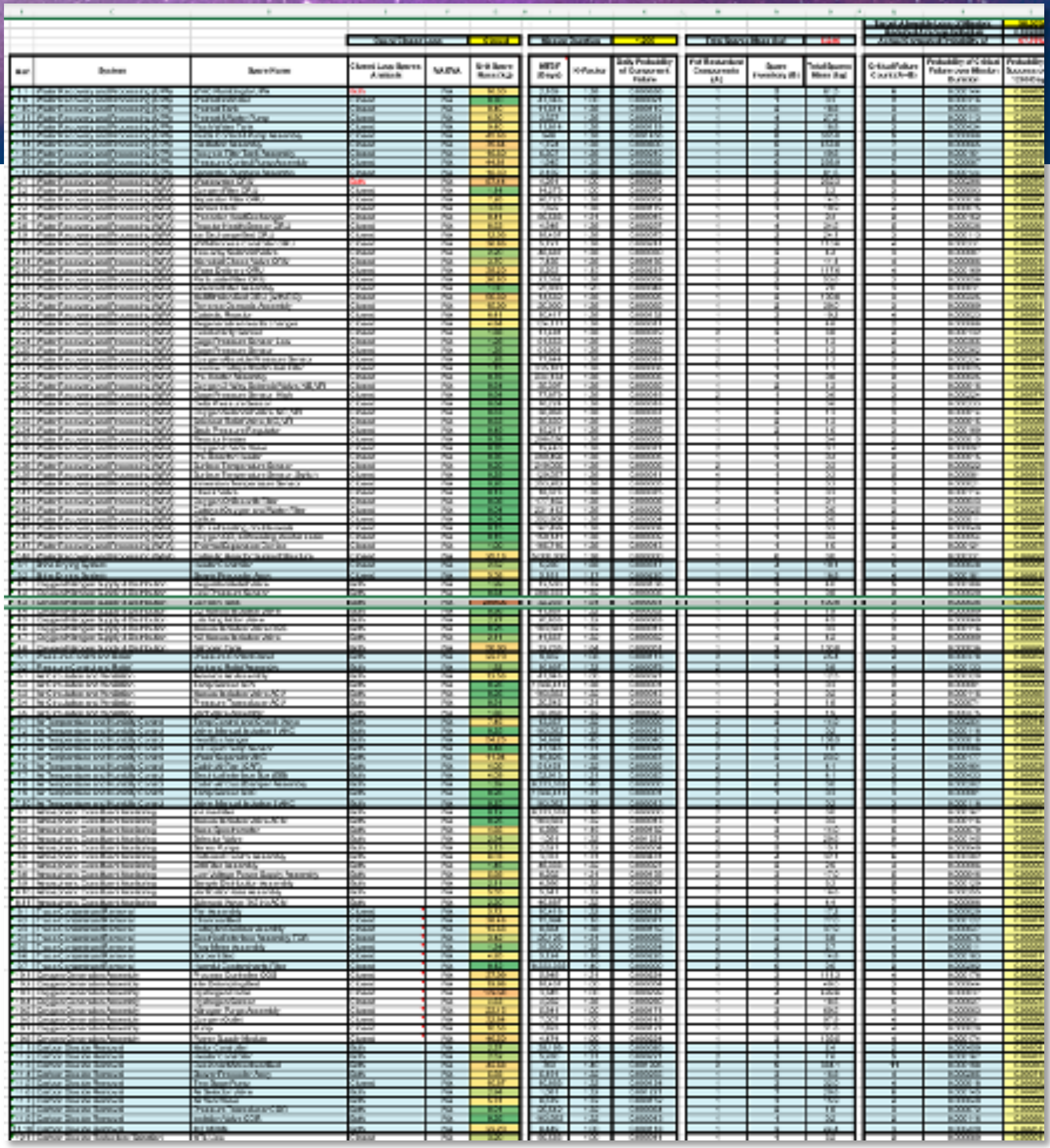
- Output
  - 13.0 Consumables mass
- Capabilities
  - Estimates based on ISS experience and outputs from 7.0 ECLSS section

	13.0 Consumables	ISS w/ Packaging (Per Chel 6/18)	Uni
13.0	**Consumables**		
13.1	Food including packaging (crew days)		
13.2	Food waste collection system (per day)		
13.3	Life Support Consumables (per day)		
13.3.1	LIFE SUPPORT ITEMS AND CONSUMABLES		
13.3.1.1		COOKING/EATING SUPPLIES	
13.3.1.2		H_2O	
13.3.1.3		O_2	
13.3.1.4		N_2	
13.3.1.5		LIOH CANISTERS (30 DAYS)	

14.0 Spares

- **User Input**
  - Automatic input based on number of crew and mission days
  - User input on Summary tab for Target Mission Success

- Output
  - 14.0 Spares mass
- Capabilities (Work in progress)
  - Higher Mission Success rates will increase number of spares and associate mass
  - Mass will vary according to number of crew, mission duration, mean time between failures, and hardware repair capabilities
  - Data is based on LaRC model from ISS experience



Example 1: Mars Transit Habitat

Description

Mars Tranist Habitat w/ Hybrid Propulsion

Description
The Mars Transit Habitat is the primary crew vessel for transportation to Mars. It is designed to support a crew of 4 for up to 1200 days. The habitat will be launched independent of the propulsive element needed for interplanetary travel, requiring element docking, as well as logistics upload. This assembly is assumed to occur at the Gateway station in cis-lunar space where it will be configured and refurbished for multiple missions.

Design Constraints / Parameters		
Maximum Crew Size	4	
Max Crewed Mission Duration	1,200	days
Destination	Mars 1 Sol Orbit	
Pressurized Volume	316.85	m^3
Systems Volume	132.90	m^3
Stowage Volume	99.13	m^3
Habitable Volume	84.81	m^3
Operating Pressure	101.30	kPa
Oxygen Fraction	21.00	%
Life Support Closure - Water	Closed	
Life Support Closure - Air	Closed	
Habitat Structure	Aluminum	
Habitat Overall Length	11.50	m
Habitat Diameter	7.20	m
Radiation Protection	0.00	kg
EVA Capability	10	
Crew per EVA	2	
RCS Engine Type	440, 90, 30	N
RCS Propellant	Hydrazine, N2O4	
Power Generation	26.64	kW
Energy Storage	5.93	kW
Keep Alive Power (uncrewed)	5.93	kW
Solar array area	242.89	m^2
Thermal Radiator Area	100.33	m^2
Actual Estimated Loss of Mission	2.25%	
Average TRL	7.87	
Mass Growth Allowance (MGA)	15.54%	
Project Management Reserve (PMR)	0%	

Mass Breakdown		Launch Mass	Outfitted Mass
System		(kg)	(kg)
1.1	Structures	9,225	9,225
2.0	Propulsion	1,573	1,573
3.0	Power	874	874
4.0	Avionics	1,621	1,621
5.0	Thermal	2,165	2,165
6.0	Radiation Protection	-	-
7.0	ECLSS	4,142	4,142
8.0	Crew Systems	3,254	3,254
9.0	EVA	1,116	1,116
10.0	Research	764	764
11.0	Robotics	943	943
Dry Mass		**25,676**	**25,676**
12.0	Stowed Provisions	-	12,935
13.0	Consumables	-	15,319
14.0	Nonpropellant Fluids	70	70
Inert Mass		**70**	**28,324**
Subtotal		**25,746**	**54,001**
	Attached Payloads		
	Propulsion Stage		
15.0	Propellant	1,396	300
16.0	Payload Launch Adapter	1,772	
17.0	In-Space Stage Adapter	1,249	1,249
0.0%	Project Mgt. Reserve	-	-
Total Gross Mass		**30,163**	**55,550**

- Transit habitat configuration options [5]
  - Government reference
  - Bigelow configuration option
  - Sierra Nevada configuration option
  - (3 other cases were run using ISS derived module)

Description

Bigelow Module w/ Hybrid Propulsion

Description
The Mars Transit Habitat is the primary crew vessel for transportation to Mars. It is designed to support a crew of 4 for up to 1200 days. The habitat will be launched independent of the propulsive element needed for interplanetary travel, requiring element docking, as well as logistics upload. This assembly is assumed to occur at the Gateway station in cis-lunar space where it will be configured and refurbished for multiple missions.

Design Constraints / Parameters		
Maximum Crew Size	4	
Max Crewed Mission Duration	1,200	days
Destination	Mars 1 Sol Orbit	
Pressurized Volume	330.00	m^3
Systems Volume	129.30	m^3
Stowage Volume	99.18	m^3
Habitable Volume	101.52	m^3
Operating Pressure	101.30	kPa
Oxygen Fraction	21.00	%
Life Support Closure - Water	Closed	
Life Support Closure - Air	Closed	
Habitat Structure	Inflatable	
Habitat Length	13.70	m
Habitat Diameter	6.70	m
Radiation Protection	0.00	kg
EVA Capability	10	
Crew per EVA	2	
RCS Engine Type	440, 90, 30	N
RCS Propellant	Hydrazine, N2O4	
Power Generation	26.70	kW
Energy Storage	5.96	kW
Keep Alive Power (uncrewed)	5.96	kW
Solar array area	243.41	m^2
Thermal Radiator Area	100.51	m^2
Actual Estimated Loss of Mission	2.25%	
Average TRL	8.39	
Mass Growth Allowance (MGA)	18.49%	
Project Management Reserve (PMR)	0.00%	

Mass Breakdown		Launch Mass	Outfitted Mass
System		(kg)	(kg)
1.1	Structures	10,992	10,992
2.0	Propulsion Bus	1,875	1,875
3.0	Power	1,207	1,207
4.0	Avionics	1,621	1,621
5.0	Thermal	1,911	1,911
6.0	Radiation Protection	-	-
7.0	ECLSS	4,393	4,393
8.0	Crew Systems	3,254	3,254
9.0	EVA	1,116	1,116
10.0	Research	764	764
11.0	Robotics	943	943
Dry Mass		**28,076**	**28,076**
12.0	Stowed Provisions	-	12,935
13.0	Consumables	-	15,319
14.0	Nonpropellant Fluids	83	83
Inert Mass		**83**	**28,338**
Subtotal		**28,159**	**56,413**
	Attached Payloads		
	Propulsion Stage		
15.0	Propellant	1,664	300
16.0	Payload Launch Adapter	1,937	
17.0	In-Space Stage Adapter	1,304	1,304
0.0%	Project Mgt. Reserve	-	-
Total Gross Mass		**33,065**	**58,018**

Description

Sierra Nevada Module w/ Hybrid Propulsion

Description
The Mars Transit Habitat is the primary crew vessel for transportation to Mars. It is designed to support a crew of 4 for up to 1200 days. The habitat will be launched independent of the propulsive element needed for interplanetary travel, requiring element docking, as well as logistics upload. This assembly is assumed to occur at the Gateway station in cis-lunar space where it will be configured and refurbished for multiple missions.

Design Constraints / Parameters		
Maximum Crew Size	4	
Max Crewed Mission Duration	1,200	days
Destination	Mars 1 Sol Orbit	
Pressurized Volume	324.00	m^3
Systems Volume	135.98	m^3
Stowage Volume	100.72	m^3
Habitable Volume	87.30	m^3
Operating Pressure	101.30	kPa
Oxygen Fraction	21.00	%
Life Support Closure - Water	Closed	
Life Support Closure - Air	Closed	
Habitat Structure	Inflatable	
Habitat Overall Length	15.30	m
Habitat Diameter	6.20	m
Radiation Protection	0.00	kg
EVA Capability	10	
Crew per EVA	2	
RCS Engine Type	440, 90, 30	N
RCS Propellant	Hydrazine, N2O4	
Power Generation	26.82	kW
Energy Storage	6.02	kW
Keep Alive Power (uncrewed)	6.02	kW
Solar array area	244.46	m^2
Thermal Radiator Area	100.87	m^2
Actual Estimated Loss of Mission	2.25%	
Average TRL	8.39	
Mass Growth Allowance (MGA)	15.25%	
Project Management Reserve (PMR)	0.00%	

Mass Breakdown		Launch Mass	Outfitted Mass
System		(kg)	(kg)
1.1	Structures	14,843	14,843
2.0	Propulsion	1,178	1,178
3.0	Power	998	998
4.0	Avionics	1,782	1,782
5.0	Thermal	1,930	1,930
6.0	Radiation Protection	-	-
7.0	ECLSS	4,144	4,144
8.0	Crew Systems	3,254	3,254
9.0	EVA	1,116	1,116
10.0	Research	764	764
11.0	Robotics	943	943
Dry Mass		**30,951**	**30,951**
12.0	Stowed Provisions	-	12,935
13.0	Consumables	-	15,319
14.0	Nonpropellant Fluids	52	52
Inert Mass		**52**	**28,307**
Subtotal		**31,003**	**59,258**
	Attached Payloads		
	Propulsion Stage		
15.0	Propellant	1,045	300
16.0	Payload Launch Adapter	2,136	
17.0	In-Space Stage Adapter	1,370	1,370
0.0%	Project Mgt. Reserve	-	-
Total Gross Mass		**35,554**	**60,927**

Mass Comparison

Government Reference

	Mass Breakdown	Launch Mass	Outfitted Mass
System		(kg)	(kg)
1.1	Structures	9,225	9,225
2.0	Propulsion	1,573	1,573
3.0	Power	874	874
4.0	Avionics	1,621	1,621
5.0	Thermal	2,165	2,165
6.0	Radiation Protection	-	-
7.0	ECLSS	4,142	4,142
8.0	Crew Systems	3,254	3,254
9.0	EVA	1,116	1,116
10.0	Research	764	764
11.0	Robotics	943	943
Dry Mass		**25,676**	**25,676**
12.0	Stowed Provisions	-	12,935
13.0	Consumables	-	15,319
14.0	Nonpropellant Fluids	70	70
Inert Mass		**70**	**28,324**
Subtotal		**25,746**	**54,001**
	Attached Payloads		
	Propulsion Stage		
15.0	Propellant	1,396	300
16.0	Payload Launch Adapter	1,772	
17.0	In-Space Stage Adapter	1,249	1,249
0.0%	Project Mgt. Reserve	-	-
Total Gross Mass		**30,163**	**55,550**

Bigelow Derived Concept

	Mass Breakdown	Launch Mass	Outfitted Mass
System		(kg)	(kg)
1.1	Structures	10,992	10,992
2.0	Propulsion Bus	1,875	1,875
3.0	Power	1,207	1,207
4.0	Avionics	1,621	1,621
5.0	Thermal	1,911	1,911
6.0	Radiation Protection	-	-
7.0	ECLSS	4,393	4,393
8.0	Crew Systems	3,254	3,254
9.0	EVA	1,116	1,116
10.0	Research	764	764
11.0	Robotics	943	943
Dry Mass		**28,076**	**28,076**
12.0	Stowed Provisions	-	12,935
13.0	Consumables	-	15,319
14.0	Nonpropellant Fluids	83	83
Inert Mass		**83**	**28,338**
Subtotal		**28,159**	**56,413**
	Attached Payloads		
	Propulsion Stage		
15.0	Propellant	1,664	300
16.0	Payload Launch Adapter	1,937	
17.0	In-Space Stage Adapter	1,304	1,304
0.0%	Project Mgt. Reserve	-	-
Total Gross Mass		**33,065**	**58,018**

Sierra Nevada Derived Concept

	Mass Breakdown	Launch Mass	Outfitted Mass
System		(kg)	(kg)
1.1	Structures	14,843	14,843
2.0	Propulsion	1,178	1,178
3.0	Power	998	998
4.0	Avionics	1,782	1,782
5.0	Thermal	1,930	1,930
6.0	Radiation Protection	-	-
7.0	ECLSS	4,144	4,144
8.0	Crew Systems	3,254	3,254
9.0	EVA	1,116	1,116
10.0	Research	764	764
11.0	Robotics	943	943
Dry Mass		**30,951**	**30,951**
12.0	Stowed Provisions	-	12,935
13.0	Consumables	-	15,319
14.0	Nonpropellant Fluids	52	52
Inert Mass		**52**	**28,307**
Subtotal		**31,003**	**59,258**
	Attached Payloads		
	Propulsion Stage		
15.0	Propellant	1,045	300
16.0	Payload Launch Adapter	2,136	
17.0	In-Space Stage Adapter	1,370	1,370
0.0%	Project Mgt. Reserve	-	-
Total Gross Mass		**35,554**	**60,927**

Comparisons to Government Reference

- Primary difference was in 1.0 Structures for use of different pressure vessels

- Structures mass for inflatables went up
  - In general inflatable systems do not decrease the mass in comparison to rigid pressure vessels due to the multiple layers required for micrometeoroid shielding, deployment systems, and inflation systems

- Power mass went up due primarily to larger thermal load from larger surface area for the inflatable module

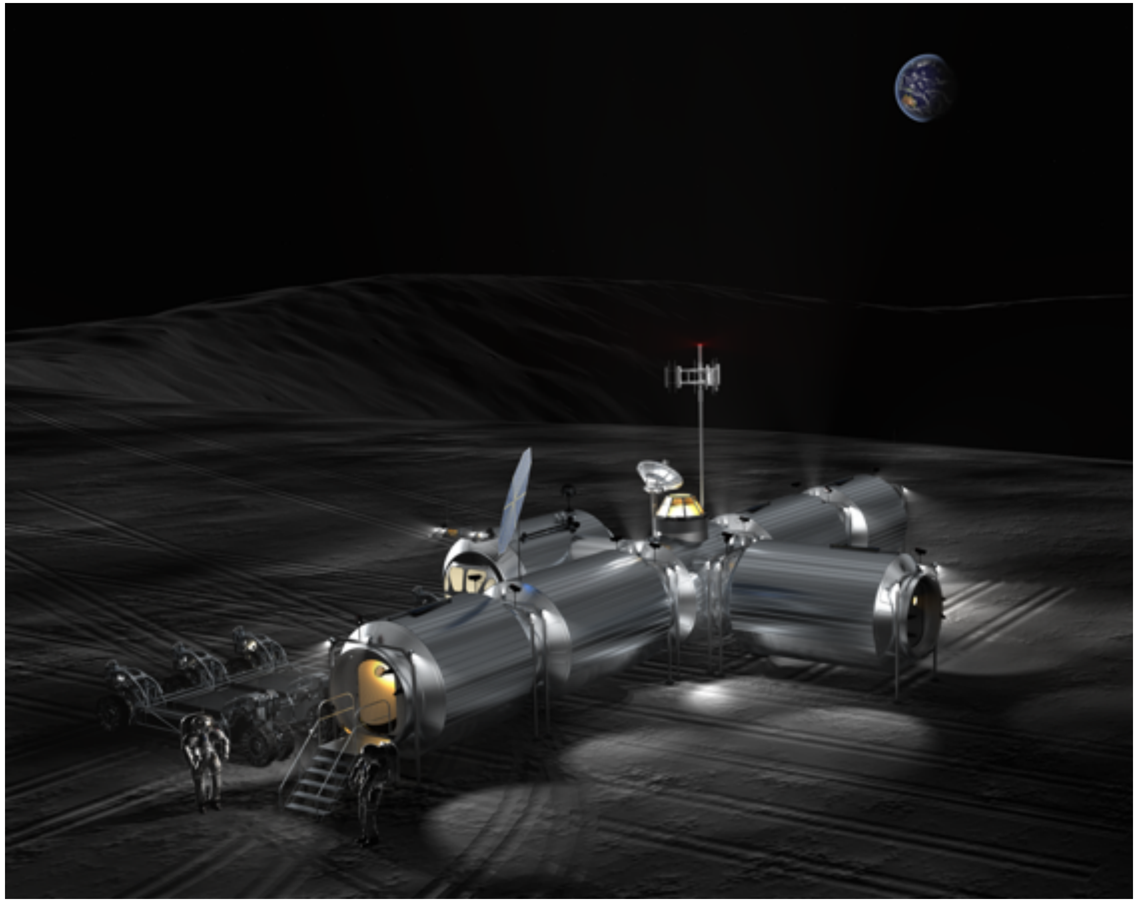
- Thermal mass went down on inflatables
  - Government reference used surface mounted radiator panels that doubled as micrometeoroid shielding which increased the thermal mass and decreased the structures mass
  - Inflatable systems used 2-sided deployable radiator panels which decreased the thermal mass

Example 2: Lunar Surface Base

- AIAA ASCEND 2020: “Concepts for Phased Development of a Lunar Surface Base” by D. Smitherman, S. Canerday, J. Perry, D. Howard

- Initial Sizing with Tool utilized to create
  - 2-crew Operations module
  - 2-crew Laboratory module
  - Closed loop ECLSS module
  - Mobile lab (by adding mobility base)
  - Airlock module
  - Logistics module
  - Node (by adding radial ports and cupola)

- Primary differences in each module
  - Two module lengths utilized
  - Internal outfitting based on function



Lunar Surface Base Government Reference Design [6]

Credits / References

Advanced Concepts Office Team

- David Smitherman: *A. Summary & B. MEL and overall team coordination, 6.0 Environmental Protection*
- Larry Kos, Leo Fabisinski, Adam Irvine: *0.0 Mission Analysis*
- Jay Garcia, Justin Rowe, Mark Ibekwe: *1.0 Structures, 16.0 Payload Adapter*
- Jack Chapman, Larry Kos, Quincy Beam: *2.0 Propulsion, 14.0 Non-Propellant Fluids, 15.0 Propellant*
- Leo Fabisinski: *3.0 Power*
- Pete Capizzo: *4.0 Avionics*
- Andrew Schnell, Steven Sutherlin, Olivier Demaneuf: *5.0 Thermal*
- David Tabb, Brittany Brown, Leo Fabisinski: *7.0 ECLSS & Advanced ECLSS*
- Brand Griffin, David Smitherman: *8.0 Crew Systems, 9.0 EVA, 10.0 Research*
- Justin Rowe, David Smitherman: *11.0 Robotic & Mechanical Systems*
- Brand Griffin, David Tabb, Justin Rowe: *12.0 Stowed Provisions*
- Justin Rowe, LaRC/Chel Stromgren: *13.0 Spares*

References

1. Larson, W., ed., et al., "Human Spaceflight: Mission Analysis and Design" Space Technology Series, McGraw-Hill, New York, 2000.
2. Polsgrove, T., J. Waggoner, D. Smitherman, T. Percy, R. Howard, "Transit Habitat Design for Mars Exploration", Paper No. AIAA-2018-5143, AIAA Space and Astronautics Forum and Exposition, Orlando FL, September 2018.
3. Simon, M., D. Smitherman, et al, "NASA's Advanced Exploration Systems Mars Transit Habitat Refinement Point of Departure Design," IEEE Aerospace 2017.
4. NASA.gov website: "Moon to Mars, NASA Begins Testing Habitation Prototypes", https://www.nasa.gov/ feature/nasa-begins-testing-habitation-prototypes, visited September 24, 2019.
5. Smitherman, D., A. Schnell, "Gateway Lunar Habitat Modules as the Basis for a Modular Mars Transit Habitat," IEEE
6. Smitherman, D., S. Canerday, J. Perry, D. Howard, "Concepts for Phased Development of a Lunar Surface Base," AIAA paper No. , AIAA ASCEND 2020, online publication.