

Lunar and Mars Mission Analysis and Design Using Commercial Launch Systems and the International Space Station

ARCH 7610: Master's Project – Space Architecture ARCH 6398: Special Projects

David Smitherman Sasakawa International Center for Space Architecture University of Houston, Houston, TX

> Summer Semester 2008 August 12, 2008

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only. NASA Marshall Space Flight Center / Full Time Study Program

1



Course Objectives

- ARCH 6398: Special Projects
 - Detailed Spreadsheet analysis for sizing of launch vehicles, lunar test mission vehicles and systems, Mars mission vehicles and systems, and program planning
- ARCH 7610: Master's Project Space Architecture
 - Mission concept to promote economic growth and infrastructure development in space, at the moon, and Mars
 - Emphasis on using existing and near-term space systems and technologies
 - Design development of compatible Lunar and Mars architectures
 - Design studies using 3D computer modeling, animations, and computer generated plastic models

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Presentation Contents

- Lunar and Mars Missions
 - Mission Concept
 - Objectives
 - Use of Existing Space Systems
 - Derived Launch Systems
- Mission Analysis and Design
 - Vehicle Sizing and Design
 - Lander Design and Deployment
 - Outpost Assembly
 - Habitat Design
- Program Planning
 - Launch Requirements
 - Cost & Schedule
 - Summary of Findings and Issues

- Credits
- Acronyms and Abbreviations
- Reference Materials
- Spreadsheet Analysis List
- Design Animations List
- Appendices
 - A. Mission Assumptions
 - B. Mars Mission Elements
 - C. Habitat Design Drawings
 - D. Habitat Module Model
 - E. Future Launch and Propulsion Systems
 - F. Mars Mission Story Board
 - G. ISS Components Utilized in the Design

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Lunar and Mars Mission Scenario

Following the completion of the International Space Station (ISS) mission, the International Partners agree to pursue human exploration missions to Mars that include a development path for commercial space development and lunar exploration. The missions will provide for continued exploration and development in space through the utilization of in-situ resources and support for the expansion of commercial operations and enterprises.



David Smitherman / ED04 Advanced Concepts Office

All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.

NASA Marshall Space Flight Center / Full Time Study Program



Lunar and Mars Mission Concept

A Mars Ship is developed at the ISS in increments over 8 to 10 years as the ISS has been developed. It then flies a test mission to the Moon before being refurbished for a mission to Mars. The mission scenario includes:

- 1. Build Mars Ship attached to the ISS.
- 2. Launch Mars Ship to the Moon to test all systems and mission operations.
- 3. Return Mars Ship to Earth orbit.

- 4. Rebuild or refurbish the Mars Ship for the mission to Mars.
- 5. Launch Mars Ship to Mars and conduct full operational mission.
- 6. Return Mars Ship to Earth orbit and refurbish for next mission.





Lunar and Mars Mission Profiles

Mars Mission Profile

- Earth to Mars transfer time of 6 months, and surface time of 18 months
- Propellant production depot established in Mars orbit and on surface to service reusable Landers and return vehicles
- Total mission = 30 months or 900 days



Lunar Test Mission Profile

- Earth to Luna transfer time of 6 months, and surface time of 18 months to duplicate Mars mission operations
- Propellant storage depot established in lunar orbit to service reusable Landers
- Total mission = 30 months or 900 days

Luna Transient time options

- 6 month Lunar Orbit stay
- 6 month elliptical orbit around the Earth & moon

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Mars Science and Exploration Objectives

- Transport a human exploration crew to Mars and its' two moons, Phobos and Deimos, and return them safely to Earth
- Search for aqueous environments and for signs of past and present life
- Increase our knowledge about the solar system's origin and history
- Return selected samples of Martian material to Earth for detailed analysis



Mars today.



Mars as it may have looked when water was on the surface.

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Lunar Science and Exploration Objectives

- Conduct a full scale Mars mission simulation to test systems and operations
- Land a human crew on the moon and return them safely to Earth
- Search for life forms and unique resources in the permanently shadowed craters at the poles
- Return samples of lunar water-ice and other resources to Earth for detailed analysis





David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



International Partnership Objectives

- Explore the feasibility of sustaining human expansion into space utilizing space resources from the Moon, Mars, Martian Moons and Near Earth Asteroids
 - Continue and strengthen cooperation between the International Space Station partners and expand the Partnership to include other interested Nations
 - Utilize commercial resources and operations to the greatest extent possible
 - Support the development of new space enterprises by establishing needed infrastructures and removing the risk involved with new ventures
 - Create a tax infrastructure that funnels tax revenues from profitable space ventures into the development of new space enterprises and space launch infrastructures

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Commercial Objectives

- Develop an economically viable and self-sustaining space-based economy
 - Develop an in-space propellant refueling and servicing capability to support earth orbit satellite systems and new explorations systems
 - Support the development of a transportation infrastructure that will make it possible to return resources from the Moon, Mars and asteroids for exploration and profit
 - Extract oxygen from the moon and confirm the existence of water-ice resources at the moon and Mars to support exploration and commercial development
 - Begin construction of an infrastructure for permanent human settlements in space, on the Moon, and on Mars

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Satellite Servicing

- The satellite servicing industry capabilities would include:
 - Ability to capture and relocate existing satellites and debris
 - Refueling of new serviceable satellites
 - Storage of cryogenic oxygen and hydrogen propellants at a servicing platform on orbit
 - Satellite servicing and replacement of parts on orbit via remote operations or crew operations from an advanced crew transfer vehicle
- The new satellite servicing systems would be utilized to construct and maintain the new Mars Ship and prolong the operations of the International Space Station.



Transfer vehicle launched from a servicing platform.

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Propellant Production and Storage

- Propellant production and storage would support the satellite servicing industry and would include:
 - Long-term storage of cryogenic hydrogen and oxygen propellants
 - Accumulation of water and conversion to propellants for space systems and future Lunar and Mars missions
 - Development of a propellant production system for use on the surface of Mars and in Mars orbit



Propellant production depot.



Propellant storage depot.

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Asteroid Exploration and Mining

- Asteroid exploration and mining capabilities would include:
 - Crew transfer vehicle to the moons of Mars and other asteroidlike bodies
 - Extraction and return of asteroid materials
 - Processing of asteroid materials on orbit to support commercial and exploration systems
 - Asteroid orbit manipulation for mining and defense



Asteroid mining could support other industries and exploration goals



Asteroid defense is needed

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Space Tourism

- Space tourism capabilities include:
 - Development of commercial passenger launch systems for suborbital, orbital, and lunar orbit tours
 - Development of commercial space stations and space hotels as commercial research facilities and tourist destinations
 - New industries supporting entertainment such as 0-g televised sporting events and 0-g movie production stages
 - Objective is to build the infrastructure that will support development of large permanent settlements in space on the Moon and Mars



Space hotel and multiuse facility.



Tourism out to the moon and back.

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Lunar and Mars Exploration and Development

- Lunar and Mars exploration and development capabilities include:
 - Crew transfer vehicle to the surface of the Moon and Mars
 - Extraction and return of surface and subsurface materials
 - Processing of materials on the surface to support commercial and exploration systems
 - Return resources from the Moon and Mars for a profit



Surface and subsurface exploration will be done at the Moon and Mars to extract resources, and to test operational concepts human exploration and settlement

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Crew Launch Systems

- Crew launch systems include the existing Russian Soyuz vehicle, and the US Ares I vehicle now under development. The Space Shuttle is assumed to be no longer available.
- Soyuz
 - 3 crew capacity to ISS
 - Return capsule
 - Expendable
 - 7,000-8,000 kg to LEO
 - Payload Fairing (dia. x ht.)
 - Outside: 3m x 9m
- Ares I (Under Development)
 - 6 crew capacity to ISS
 - Return capsule
 - Expendable
 - Payload Fairing
 - Outside: 5m diameter capsule



Russia's Soyuz Launch Vehicle United States' Ares I Vehicle (under development)

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Cargo Launch Systems

Cargo launch systems include existing systems plus additional expansion of the Delta IV vehicle to include the author's version of a new Delta V vehicle

- Delta IV Heavy
 - 25,000 kg to LEO
 - Payload Fairing
 - Outside: 5.1m x 23m
 - Inside: 4.572m x 14.884m

- Proton M
 - 21,000 kg to LEO
 - Payload Fairing
 - Outside: 4.1m x 15m
 - Inside:
- Ariane 5
 - 18,000 kg to LEO
 - Payload Fairing
 - Outside: 5.4m x 17m
 - Inside: 4.570m x 10.350m



United States' Delta Launch Vehicles



Russia's Proton M Launch Vehicle



ESA's Ariane 5 Launch Vehicle

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Delta IV Derived Launch Systems

Lauristi	ence Sale-Earlt to US								Noles Gren holizate printecultur, veri tegit		Launch Vehicle Options		New Modes of Leaster of red									
10	activated acts the candad Deta building for a Ceta (Lant Ceta (L	N REAVISION	niim te sco	ng calulatons	and then use	s he land ne	tot trisce tex	•	Red reaction process of the underseases Data instead of the worksneets All other cells are from reference calls or intermediate coput data.		This worksheet provides a fixed sciences and	l inaffecteriti	united the s		here, salard, or	- Reclands V	dik ik Sama w	-			Esta simed to after anticidents Al other cells are lock withour or data or elementate colorit data	
		Planetary	OHM V		Mates. Possillers	Sam Dat	Propellant	Wer Mann									_					
Statu // P	NEW	Sate	1000	de.	(millio)-	Mass list!	1001 000	90	Nobe .	Seferance	Likuech Vehicle Options								the property.	_	Sister	Fafatances
573 C01	icard stage 1 plus two stage 0 fouration				1				2	International Guide to Space Laurich Systems		Dry Marce	Propeiber	So. Units (Stopes 2	Ver Nate	Capacity	Tool Mass					
Ext			1				1.000		" Rocket equation formula monod - mito a le* (petaV) as a p(-1)	Formula 12-2:0404		1 194	Water Polit	49671	84_	140	940	Buges 0, 1	Page 2	Patron	9	-
15	1208	El0	5 950	420	0.192	139.378	\$89,864	729,742	Propellant mass may not existed lans capacity of 597,000 kg		Carlos IV Danier											
20	State	Earth	2.758	452	0.545	30,650	25.608	139.878	Propellant mass may not exceed tank capacity of 25,700 kg		State 6	28.300	100-528		30.740		20.04				Spani 1.2	
100	percent from Earth (pros multiple reen 9.3 and 10 (use 9.55)	1018 DEGEV	9.85	-		Proceiprt +	615.472	30.650	EUFOLI MASS ALISS • Payload + 2nd stage by mass + 2% resilual prosaliant		and a second sec					-						
-							-	-											-			
_			_	_	_	_	-	_			Delta III Hervy	26,300	100-538				1.1			_	Singe C I	
		-	-		Maxz		-	in the second			25,300 kp pagilikad deliving to ISG	26,700	199,558	3	30,7%	2.00	72,411				Shipr E.2, payland	
Carlle V at	a sector	Property lies	1.000		Concession of the	Man out	Wight dat	THE BASE	and a second sec	Balarance.		20,000	80,008								Elser (2	
522	vient state 1 plus four state 0 confi	na atom					-		Delta /V Heavy + 2 more State 6 // e. States 0 3 8 0 41											-		
Ear	h	-										26.200	100-008								Shame () in the stational	
18	Stable (4 Stable 05)	1200	2 610	420	0.387	454.474	123 803	1,278,377	Properties make may not exceed the capacity of 191 400 40		Delle Y	28,700	10.00								Rige C2 Lavie president	
111	State (Lander)	Fatt.	2 375	410	0.935	41.653	84.315	(48,793	Propertiest mass needed in taken (3nd state) 34 600 km max		Loder Jelsen 1: Rid	26 300	100-010	4	26.630	96.423	1 204 144		_		State 1 Male 21 Ander bestellant geduat	
100	Delta-v from Earth to ISS must be	Total delta-v							Burnout mass at ISS + 2nd Stage dry mass (Lander)+ 5% residual			28,300	100-528			15,790	Lander dry m		-	_	Suge C.3. Lexis populari.	
beh	wen 9.3 and 10 (use 9.55)		9.550		_	Propeilant -	1,247,888	95,659	ercevitant.			26,300	100-025			52,636	Lander gaulo	el			Stopy C.4. Lancer paylow!	
																15,800	Residual prop	elat				
		-			Mass	-		1								90,435	354 6366-36	Lysed to ISB				
		Planetary.	Diff. U		Frantiers	Ours Dail	Propetters	Wel Mass														
Certa VI		Both	Ame	10	(mfmo)	Mana Regi-	1000 0005	0.0	KOW	Reference		-	-						_			
D01	ble stage i tara sel pus four stage 3	contoured to	261/61/2002	E 1206 540 10 10	3 000	-	-	-	Deta V - Stape Z luent stape 1 as stape 21		factor 2	20.00	56/308								Stop C1	
112	State	Earth	3.630	420	0.4%	100 563	790 663	1.349.121	Propelant mass may not exceed their capacity of 795400 ep		Patter N land as analyzed to 15% only	28,000	100,000		110.000	27.870	1413-000				Trans 1. Stars 7 a south of compliant	
255	State	Earth	5.000	420	0.297	-06.400	2755	203 444	Propelant mass may not exceed amount available in cell 859		Contraction of the behavior in 197 and	28,300	100.000		C PROMPT	10.70	de mint.				Rive C3	
700	Delta-vittom Earth to ISS must be	Total Getta-V	1.000		12.2		1	10000				26.300	105-528			50,300	pagelari na				State C.4	
020	een eus and to (une e so)		9.550		Max avail	1.591.000	1.132.401	125,422	Europit mass at this other + policie tank set + resignal properation							82.76	Total wants de	when the list of	el la			
		-				-	-									2.11	11.1.1.1.1.1					
			1.0		Mare			1											_			
		Planetary	Celts V		Frenklen	Burn Det	Propeilant	Wel Mase				26.700	185-528								Scope C F	
100	start stars t alle fuir shas 2 seefs	number of stations	a Calls III et	man in 100 mil	100/050	Made Tat	100 100	12	Calle 11 - Chang T Luting share (as stress 7)	Asterance	Celle II	26,800	100.008		in side	-	- les ins				50P 62	
Ext	to an a subject is prove total stable a contract	T	a write it is						The second statement and the Edit at		contain tank of deevery to Site offar		-		245,680	52.43	1.24.600		-		Power Transmission of phycold + residue propriet	81 C
12	5353	Earth	5.450	420	0.265	34150	\$42,676	1,283,519	Propellant mass may not exceed tank capacity of 998,000 kp			20.00	100.000			53,400	one makes	-			Some C.A.	
24	State	Earth	4.180	482	0.454	82,700	101 815	341.543	Propelant mass may not exceed arrount available in cel 855			-1.00	100,000			114.41	Tot many in	want is the cal			2.00 S -	
100	Deta-v from Earth to IGS must be	TOTA GETE-V	0.575		diversity of	1 101 010	1.003.000	23.765	E-mod street or 107 with a Daily III has a maintening section?							10.00	the restore	and the second	-			
- 041	Heet 9.4 and 10 (056 9.55)		9.000		MILERS.	1.141.655	1.003.099	02,700	Contrast many at too once - perain/ Shit + IRBOUD Proteint:			_	_	_	_	_	_		_	_		_
		<u>.</u>	_	-				-		-												

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Delta IV Heavy

- Delta IV Heavy
 25,800 kg to LEO
- Stage 1
 - 26,700 kg dry mass
 - 199,600 kg propellant
- Stage 0 (2 boosters)
 - 26,700 kg dry mass each
 - 199,600 kg propellant each
- Stage 2 (upper stage)
 - 3,490 kg dry mass
 - 27,200 kg propellant
- Assumed Cost: \$160 M



- Payloads limited to Delta IV and Ariane 5
 - All transfer habitat modules
 - Crew Excursion Vehicle
- Payloads acceptable Delta IV, Proton M, and Ariane 5
 - Transfer habitat attachments
 - Lander attachments
 - Propellant
 - Water
 - Consumable
 - Additional racks and crew consumables
 - Power systems
 - Depot systems

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the authors interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Delta V Tanker

- Delta V Tanker
 82,700 kg to LEO
- Stage 1
 - 26,700 kg dry mass
 - 199,600 kg propellant
- Stage 0 (4 boosters)
 - 26,700 kg dry mass each
 - 199,600 kg propellant each
- Stage 2
 - 26,700 kg dry mass
 - 199,600 kg propellant



- Assumed Cost: \$300 M
 - Includes stages 0 2
- Payload
 - 26,700 kg Delta IV tank
 - 56,000 kg residual propellant in second stage
 - 82,700 kg total delivered mass

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the authors interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Delta V Double Tanker

- Delta V Tanker
 - 106,400 kg to LEO
- Stage 1 (double tank set)
 - 53,400 kg dry mass
 - 398,000 kg propellant
- Stage 0 (4 boosters)
 - 26,700 kg dry mass each
 - 199,600 kg propellant each



- Payload
 - 26,700 kg Delta IV tank
 - 53,000 kg residual propellant in second stage
 - 106,400 kg total delivered mass

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the authors interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Delta V Lander

- Delta V Lander
 90,400 kg to LEO
- Stage 1
 - 26,700 kg dry mass
 - 199,600 kg propellant
- Stage 0 (4 boosters)
 - 26,700 kg dry mass each
 - 199,600 kg propellant each
- Stage 2 (Lander)
 - 16,800 kg dry mass
 - 64,400 kg propellant



- Assumed Cost: \$250 M
 - Includes stages 0 1
 - Stage 2 / Lander cost not included
- Payload
 - 16,800 kg Lander
 - 58,600 kg payload on Lander
 - 15,000 kg residual propellant in Lander
 - 90,400 kg total delivered mass

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the authors interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



International Space Station Utilization

- The International Space Station has a 10 year mission beyond final assembly in 2010. After completion of this mission, in the 2020 time frame, it is proposed in this scenario to be used as a space port for the assembly of the Mars Ship.
- Possible Scenarios:
 - ISS becomes part of an International Consortium to facilitate commercial space development.
 - Primary support is provided through International Government development of Lunar and Mars missions.
 - Option: ISS is gradually moved to a lower inclination with each re-boost operation to facilitate more efficient payload delivery



David Smitherman / ED04 Advanced Concepts Office

All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



ISS Design Compatibility

- The ISS and all existing space systems are used as the starting point for the Mars Ship design.
 - ISS Pressurized Modules
 - Existing launch vehicles are capable of launching ISS sized modules, so a modified space station module is used in the design
 - ISS hatch and docking systems
 - ISS internal racks
 - ISS robotic systems for assembly
 - ISS derived power and thermal systems





David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Mission Analysis and Design

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only. NASA Marshall Space Flight Center / Full Time Study Program

25



System Sizing

- All major systems were sized based on the formulas, historical data, and rules of thumb from the text, "Human Space Flight: Mission Analysis and Design," editied by Larson and Pranke. Excel spreadsheets were developed and used for the sizing the following items:
 - Propellant calculations for each vehicle and each phase of the mission
 - Propellant tank sizing for each vehicle
 - Habitat mass and volume sizing for crew size and mission duration
 - Habitat systems sizing for volumetric layout
 - Historical data and "Rules of Thumb" on other items for approximate mass requirements and program plans



David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Lunar and Mars Vehicle Sizing



Numerator security of the secu										No. of Concession, Name	An man cannot have The contract of both 14 business properties of the set bornes from electric theory both 100 boxes 14297 or the descent average and the contract performance on an								en okulta du sum vid hu o duces du samme de sub a tor inne de sub as melan up da	Alles with Operations 1 (Villian system) (Villian System)		100 A		Service of the servic									
Consideration	Per	Vance in		tester	Nam Out Singert			THE MALE	Seta Vi Seta Seta			Care Banchas			1				-	ten l			East Marchair	Financia	Cire 1	100	Der 1	Ant Cill Daget	Louis Vegamor	I Particl	Head Blance Dates	in Taret Mi	
Theorem is a subscript of the subscript		2 June	-	where:	Basic (10) 11,584	a Lance	Mat ingl	M	Regired	VIII	Conternal	Transfer income Annual and	-		-	-	-	All and a second	-	10.0	Contract called to carriers and	Laure lines lines on	BURGE WORK HIDE	and an and an	- CRA			B-1 (14) 1 2	In some	Pine Die	20	200 Progetant caracto der tank per	Lawton vehicle lights lads
and there was				-		-	-		42.435	Tank riskt	His Remult 102 pilot 2+5 cf/38	dura.		-						0.40	CTR (CORE)	ins have be set of any	Eat .		1	_			_	-		Call Call	HB REPORT (25.2454-344-245)
	-	-				- P.				Rocket equation formula increp + neo a le" certa	No.				1.000					- 2	COM MULTIPLICE FORD - FORE CF	and the second										Rapide establish formula monto + muc i ven	int then (3.2 company)
	-	-				-	-			32 A E - E			740. 10		1.747	1700-02	· 1.00 m	1.70.00	A 178 Part 1	- 72	5 B 15 1	20 Tel 21 2010	51	Eat.	2.005	447 1.7	10. 1	106.117 7			1348.157 8	m	HE 308 01 529 011
10	- 10		40	110	Augure at	151.87	133102	1001-001	1.10		NO 1004 102 5210211	216	Sami Lin	3 4	2265	612 82	 1 108-20 	100.00	\$102.415 I	(2			24	540	1.000	42 10	22 1	108.217 2	1.1	1 1	2.385.577	2	
TU complete	1174	12 200	462	2.507	1 873 362 53	-	10 107	1 201 12*	0.05			- No	600 1	- <u>- 2</u> k - 18	660	188.02	1. 1.00 Mar	1.000.205	182-01	2.22			Di	140	6416	482 62	72 - 1	265.752 5	1785.007	2 1 1 111 117	J 199 237 5.	2	
1.2	MS	n 0.820	417	0.3%	103.454 1.5	209,200	241.816	11026	0.86			To peeper	1 1 1 1 1	2	- 2.944	100000	1 1 1 1 1 1	10.473	Table 1 a	100			THE DESIRES	0.00	1 100			300 1	-++-	1 1000	1 (2) 541 5	18	
Secondary Terry Secure	4	1.02		-	_		20101	1471254	100	1 Shit with the Denil	-	50	Net 11	10	124	378.94	1 20.00	201716	2108-001	-	10 m 10 m 2 m 2		142	9.85	2.563	452 54	0	IDA.312 J	1338.25	121.429	1 123 541	D I fait immers a genti	
		104140	Distant.				010			a management of the				100			2	1,80%0	1.80.516					-	1424	1.00	-	12	1 1982.007	2 1 116 726	027.882		
		-	1.00				CITE AT DO	816 522		Propulsion segment mass							-	-		-				100	70.0	and a				and the second second			
Esture Vehicle Vehicle I	Propulsion	-					10.000	-					1.5	free 12 per la rest				100	COASE .	-	CALLER COMPANY AND IN COMPANY			-	(Chatter's	and the second	_		_	and a	81.800	Transietori anneret han	
TE coracione	100	A 2472	447	1.424	542 AV	199.000	7474	10100	A.11			Antal Letter Provider		-	-		-	-		-			Refuer Vehicle Prozves	EM .			-		-				
Prevent Ca.	La	1.04	412	1.812	344,008 1.0	3110 200	340382	581.5%	2.86			1 12	ATT 14	6	1.10	46.00	- 33	31.21	100.000	-	the leads have		To constitute	1000	142			221 - 1		1 1 1 1 1 1 1 1	7.891.824	12 PORTER IN CONTRACTOR	-
Property Tanks Reacher	2	_					000,172	201.612	100	11							-			-	DOUGH STREET AND ADDREET						-					Manufale Maturia sales to hund 44,000 kg L008-Lin	1
		1.000	and in the	_		-		· · · · · · · · · · · · · · · · · · ·	-	-	-	140 million	800 -10	E	1.96	4275	2 2	10.05	- artes	225	6		1020000318	241	1100	140 D.0	35	154.712 2	731.45	748.822	1.121.252	() (est)	
		1.000					and the second second	+120						-				10.21	41.000	-	TOP AT 1941 2	Comment.		-	-				1000.007	A ADD	10.10	Contrast out man (2)	State-4
Lovel Test Removing Heat Lovenery Transfer Velloye Mass	-	1	VOLDER FOR T	B0280	no. or same long	terit tingar Tak Massi	faul tocom	Toto Almon Ref.		-	1000			-					-h-dic	-				Street of	e Lengin	10070 814			+-	Tell Total	RUED This Asso	the second se	-
Bappy story which	1 12	22.00		-C 182	1			(23)2		Proceitant in Electrotettor Vehicle anti-	Exception listice Fights lipitated		and the second		_			344	-				August .				-			444	-		
Carportandes	. 162	¢.		121,084	1			36,148				Tanaha Intona Moan		-			_			_			THE OW LENGTH MASS		10.14	-	-		_	-			
Descent Device	1.13	14.90	-	Dis mary		-		200 BAC	-	And they prove an used out some	ANT THE CASE ANT	Land and	-111	-	20.02		_		201120	-		CORP. AND DOG	Proteint	1.00		-	10.012	1	_	-		Property for Landen and Exception (195)	Marcuarder Table
Ametes	-			1.375	14.1	-	-	1.772		TARKAT Part SID	Notific Extern Cella softward	Dres Jacket	129-						294,485	_		The Local Party	Patrate	1.44	-12.55		10.000	4	_	1	32,000	Augustus results and available of	times under Filling
PERSONAL AVE	12	16.30		10.024	1			21.643		32.3 10 660	Fixed Production Figure Date admitteet	Provide Sect.	10 1	22	10.00		_	-	20100	-		Transmission fairs simpler	Projelan Terri	1.17	-125		1100	0	_				Provident Clenck Station and Alternation
faters	- 12	112	-	14.121		_	-	- 36726	4			Poess.	100 10	-				+ +	4.796	- +	With Ter. Dil	April Andre 20 annor	Patrice Area	2.97	12.54		10.000	2	_	+			Resource Respond Cora apresived
Cette 1/ tertes		11.12		31.77		20.00	-	-	-	CTRICKED CONTACT	CALCULATION OF A DATA	ACCESSION AND			1.00				1.122		CONTRACT OF THE PARTY OF THE PA		(h2003h4 1412/ h1	114	_		1111	1	_	-		ATTACATES & GALLES TO WAS SURVEY	
Teta Trateller ve	504					-						Ratition	12 3	22			_		34.05	_			Lander	5.53	34.63		14,124	\$	_	-			
Mess	-	-		-		-	-	_	_			Sela y las at	1 2 2 2	-			_	-	_		COLUMN CONCEPT	AND HER SPECIFIC	Total Transfer Ver	1.0	100	_	11.44	_	_	-		ESTRATE STATE & PARTS HOLE	Cherch rance party solution
AND ADD ADD		10.00				-	-	31 AV.	-	Second and	Parameter and a first instance	first .		-				1	and the second s				9164				-		-	1		-	
an Vindung	12	12.00		12.00	4			88,263		Includes \$200 to water per module	+0. "Size 11-54, 2357	Pattan Inticia Minu					_	-		_			Sature Vehicle Bland			-		-	_	+	11.00		
Voce Mooses	10	-2.50		23.367	1.			46,714	-	Includes \$500 kg water per mobule	H1. Tage 17-14, g287	La gibes		-	and the second			+ +	Martin	-	CARD COLL OF HIM DO LIVER	Ph. 200 214 200	Barrie United	1.04	30			-	_	+	10.000	Provide Link of Kill of State	ALL THE THE ALL AND
Science Pachaoes		1 100		- 200	-	-	+	- 1000			AAIAEIAI Sur	Thomas furname		-	1.80		-		1921		CONTRACTOR OF THE PARTY	outs first the	Digente Packagen	1		-	1000	100 11		-	1.000	Constant of Social Party of	INDIA SLAT SER.
Correl DR/ Batting	- 47	40		100		-	-		-			Curse.	200 2	22	3.60				10.000	_			Europa	2.52	223		2622	4	_	-	142 000		
10070120	20	2.00		303	1	-		1,000		1		CRI Betring	10 10	= 1		1 1			- 199				24/30919	13.52	1.25		422	2		1	1,000		
America	-					-		1.000		2030/0 \$24 (0)	Rooptic Bystems Cate worksheet	- Second		-			_	+ +		-	and the fill	Name Association	Durte	-	-	_	1712	10		+	1.755	CORPORATION AND ADDRESS OF ADDRESS ADDRES	failures Burrana Data partitient
CRI Carrier		1 522		143		-	-		-		MALA EIAL SUDI	CAU Cashed	10 5	-	1.00	- X - 1			54,000			LINEA COLD THAT	Chi Calale	1.07	1.25		* 11*	2	_	-	112.576		Maila good Shidy
TASH	- 12	2.00	2.70	ALC: THE		1	1 1	2 470	-	Traine per new memory a trainer.	Full Turning Tana John Trans	Denice Motore	12 3	2	14.0		_	-	2.0	_			Eldwice Mahre	10	12.00		No. of Lot	1	_	-	200	and the second second	
gun 7500	-			121				201		Contraction of the later		States	1 23 3	-	-			+ + +	7.03	-	ADD DE CONTRACTOR CONTRACTOR	A Lines in white	- <u>89894</u>	0.99	1 22 1	_	100	2		-	4 528	P SALE OF DRY DECISI - DURB	ALANDERIC CHARTINE
EAMINERING	Unit .			8			1												-	_			E A Manual Anton	100			- 10		_		78		
		1.00			-	-	-		-	Making and	Annual States and Party States and Party	Contracting of			-	_	_			-			and a second second	10-11		_		-	_	-			
Paters	12	12		14.124	1			54 (24			Contraction of the second	Continue are and	1 10 1 3	-	111			+ +	1400		the start is a success for light home of	Contraction of the case in a second	CASELINA MAL	1107	1 200	_	100	7		+	7,621	Arts and a manni for these colores	The second second second
Deta 11 tara seta	. 61	72.00		12.655	4 100	-		_		20 minute and a state and	Lauron vehicle (tang portsheet	Departure	1 3	12					14.124	- 1			Calgin	1.22	18.22	1 1	14.144	T			19.028		
Total fullen Veta Total Faluen Veta	N#	142		2.2		2.00		24		-		Date of Section University	12 2	-	8.4				-		o mani addeci i inaliti i dano-K	CART OF DE LE COLLEGE	Total Febrar Vetal Maga	10 1.C	.7152		8.0			-	-	Errindra attert in starrid atter	Lainto liette Tata Antore

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Lunar and Mars Vehicle Configuration

3

Lunar Test Mission Configuration

- 1. 3 single & 4 dbl tank stages for TLI + 1 dbl tank stage for LOI
- 2. 2 Crew Landers and 2 Cargo Landers attached to Propellant Depot
- 3. 2 Solar Power Units
- 4. 1 dbl tank and 2 single tank stages for TEI
- 5. 2 Solar Power Units + 1 radiator unit
- 6. Transfer Habitat (6 modules)
- 7. 2-Crew Return Vehicles
- 8. 1-Exploration / Crew Transfer Vehicle

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only. NASA Marshall Space Flight Center / Full Time Study Program

Mars Ship Configuration

- 1. 15 dbl tank stages for TMI + 5 dbl tank stages for MOI
- 2. 2 Crew Landers and 2 Cargo Landers attached to Propellant Depot
- 3. 2 Solar Power Units w/ twice the array area as the Lunar vehicle
- 4. 1 dbl tank and 2 single tank stages for TEI
- 5. 2 Solar Power Units with twice the array area as at earth orbit + 1 radiator unit
- 6. Transfer Habitat (6 modules)
- 7. 2-Crew Return Vehicles
- 8. 1-Crew Excursion Vehicle

5



8



Vehicle Size Comparisons



International Space Station

- Mass: 232,693 kg
- Length:58.2 m along truss
- Width: 44.5 m from Destiny to Zvezda
- Height:27.4 m
- Living volume: 424.75 m³
- Crew Size: 6



Lunar Test Vehicle

- Mass: 4,295,684 kg wet mass
 247,932 kg Transfer Habitat mass
- Length: 335 m
- Width: 76 m (span of solar arrays)
- Height: 39 m
- Living volume: 826 m³
- Crew Size: 8

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Vehicle Size Comparisons



Mars Ship

- Mass: 10,128,544 kg wet mass
 - 247,932 kg Transfer Habitat mass
- Length: 505 m
- Width: 76 m (span of solar arrays)
- Height: 39 m
- Living volume: 826 m³
- Crew Size: 8



Mars Ship after 3rd Mission

- Mass: 3,396,637 kg wet mass
 - 247,932 kg Transfer Habitat mass
- Length: 230 m
- Width: 76 m (span of solar arrays)
- Height: 39 m
- Living volume: 826 m³
- Crew Size: 8

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Transfer Habitat and Lander Assembly Operations at ISS

- Mass attached to ISS
 - Habitat: 245,000 kg
 - 4 Landers: ~80,000 kg each
 - Includes 15,000 kg residual propellant in each Lander
 - Total: ~565,000 kg

- Total Mass including ISS: ~800,000 kg
 - Attached mass will be greater than total ISS mass
 - ISS re-boost will be by Exploration vehicle at lower end of Transfer Habitat

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the authors interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Tethered Assembly Concept

Lunar Test Mission Vehicle

- Transfer Vehicle:
 - Dry Mass: 945,623 kg
 - Propellant 2,475,520 kg
- Return Vehicle
 - Dry Mass: 370,768 kg
 - Propellant: 503,772 kg
- TLI Mass: 4,295,684 kg

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the authors interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only. NASA Marshall Space Flight Center / Full Time Study Program

Mars Mission Vehicle

- Transfer Vehicle:
 - Dry Mass: 1,692,037 kg
 - Propellant 7,397,550 kg
- Return Vehicle
 - Dry Mass: 354,732 kg
 - Propellant: 684,226 kg
- <u>TMI Mass:</u> 10,128,544 kg



Lunar and Mars Ship Staging Trans-Mars Injection (TMI)



Lunar Test Mission Vehicle Staging

- TLI: 5.5 tanks
- LOI: 1 tank
- TEI: 0.5 tank
- LEO capture: 1 tank (The transfer habitat is brought into LEO orbit for refurbishment at the ISS)

Mars Mission Vehicle Staging

- TMI: 15 tanks
- MOI: 5 tanks
- TEI: 2 tanks
- LEO: 2 CRV vehicles deorbit (The transfer habitat cannot be saved until depot capability is in place in Mars orbit)

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the authors interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Variable Gravity Configuration



David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Artificial Gravity Phase

Lunar Mission

- Transfer Vehicle:
 - 1/6 g = 1 rpm
- Return Vehicle
 - 2 rpm = 1/4 g

Mars Mission

- Transfer Vehicle:
 - 1/3 g = 1.3 rpm
 - Animation is at 1.5 rpm
- Return Vehicle
 - 2 rpm = 1/4 g

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the authors interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Lunar and Mars Orbit Operations

- Habitat Segment:
 - Dry Mass: 370,768 kg
 - Propellant: 503,772 kg
 - 2 Crew Landers: 254,485 kg
 - Total: 1,129,015 kg

- Propellant Depot Segment:
 - Propellant Depot: ~135,000 kg
 - Residual Propellant: ~
 - 2 Cargo Landers: 248,149 kg
 - Total: ~383,000 kg

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the authors interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.


Reusable Lunar and Mars Lander Sizing

Lanie Lettler Biptig This worksheet is used to calculate the too coolide exception fragments including Payloads Mass Summery worksheet. In a calculated kang the Cargo Lander cascula resizance Creak Lander	a gross of Re propellant tan non-reveable Note: Note IN	ucalaine Cango A alaota : Rayka catrifigueration al life critisi an	Lancers and and data to in the extention role! Mas & Ch	Revatole Crea out automatical occule becomes ou motive (32)	w Lancers, sm Ny from the Sk Is poyleted and CC kg) Mache	no lo Lufaco Loari br Si Billine	04.8	iches reen Process constraines into constraines into inked to other wo il other cells are from itermediate output da	routing add front Orbout attac Interests reference Gata or Ia.					Mare La	New Nong This worksheet is used to capculate the tota received recomments including processor formings worksheet, in a non-muscale con large Lancer capculations. Note that the or	i gross of Reus tark sizes. Pa riguration the s ew ander has t	isole Cargo Lan Voise dels la ric subert module i s crew matike i	Sers and Re M automati ecumes pitu ROOD kgi ett	eusable Crew I Cally from the pload and can fached to the r	Landers, and Surface Pay be calculate evidable Cre	to calculate case (Asis i using the v Lander,		Notes Green rd Red wood Cata Inte Al other o intermedia	cates cells reg lies pormally on d to other work els are from re te output data.	Naimg user input our other sheets ference data or		
	Fantian	Della V	11	Mass. Frailine	Dry Mass	Propertient 1	Nei Marce									Planetary	DetaV	-	Mass Prectice	Ory Maks	Propettant	Wet Mac					
Researche Caroli Lander	Both	OTHER.	iet:	intrici	Jacob .	Mass (Rel	(Rel IN	ides .		Reterens				Beugap	e Cardo Lander	Body	Rmisi	HED.	infinci	(ka)	Mass (kg)	tkol	Notes			Fisterers	68
LDO	Moon	0.019	390	0.554	130,435	860	ID BE C	intes cargo lander ma	105	HS Table	10-2.0275				Mars Landing	Mars	2,10	160	1 000	120,523	3.661	120.521	Gross Car	to anotr mass		HS TADIS	10-2.0277-278
Lunar rouencown	Veen	1282	175	9.554	52,123	10.28/	B0.138 In	+ seem tuo mus +	ander cavloads	_					Mars Touchdown	Mars	2630	360	0.815	102.210	18,314	120,523	-			-	
Lunar accent	5600	1.215	350	0.622	14.214	5.054	23,978								Second Sectors Lander	100		1/1		10.000	-	102,210	input purn	out mass + iar	nder pavloads	-	
Circularization	Mpon	0.019	350	0.995	Total procelant -	ED DES	14.514 14.540 B	um out mass al orbit	al depot						Steadin Pariolic Lander			724	4.427	Total proceitant -	52.325	15.650	Burnout	tass al orbital (cenat		
Englishie Crow Lander	Paretary Body	Deta V Ansisi		Mass Frastice (mitmo)	Dry Mass-	Propeliant N	vel stass	iotes		Relateratio				Baugan	n Crew Lander	Planetary Body	Detta V Bimst	ko	Masic Presilion Intitrici	Ory Maks	Propertant Mass (kg)	Wet Mac	Notes			Pateron	ce
LDO	Moon	0.019	390	0.954	121,515	606	111 22 0	ross crew lander mar	10	HS Table	10-2 0275				Mars Landing	Mars .	2,11	390	1,000	123,601	3.642	123,600	Gross crea	d mass on par	artules	10 305	192.0277-278
Lunar Touchdown	Meen	1362	390	0.552	74.719	40.095	74,719	+ seem too mud fuor	anded payloads	-	-				Mars Touchdown	Mars	2.630	350	0.815	104,520	18,751	123.501	-				
Lunar accent	Mean	1.215	350	0.622	20,944	12,729	33.573	and the second second second	a set of the set of the						Seurable Crew Lander	1000	4.945	160	0.367	21 692	40 10*	104,820	inout ourn	cut mass + lat	nced obviceds	-	
Unevanization	Mage Edu	No Recuired	Sur	This wo	oade Mai orksheet i Sizing w	es Summa is used to a orksheets.	iry isouate	the total lande	d payload ma	is. Add and (modify as nee	ded. Celis are	linked to the	6	Notes Green indicates cells regul Fies indicates primary sub Data Inixed to other worksh All other cells are from refe intermediate output data.	ing user i di sata teets rence data	npud a or					1	1		Sha franzifer habitat Dibalance laads	Beferer	
Node Modules	23.960																									HS. 303	21-5 0898
aurface Equipment	-							and the second second		100.00		Anna A	Total	-							_	_				-	
Science Packages	1,000	- 1						Diameter of	Length (m)	volume	Mass (ko)	No. of Units	Volume	Total Mas	Notes						Refer	ence				NASAE	SAS Study
Electrolysis Units	1.632	- 4		10.00				Width (m)		(m^3)	and the first		(m45)	(kg)				- 1						- 1	The state	NASA E	EAS Study
Surface Mobility Systems			Sur	Tana Hahi	tot Modu	eali							111 37	-				-	-	_	_			_	it's	Contract in	A STATE PARTY DAVITING PARTY
Fressurged Hover	18.000		301	Lab Maur	tat modu	100	-	5.00	10.00	-	20.555	-	-	00.73	linely day 2000 km water new	manue		-	O Table		127	_		_		NASAE	SAS Study
Unpressurized RovenTrailers	1,050	2		Cab Mu	Julies		_	5.00	10.00		22,000			90,73	e includes coop kg water per	mouue		n	io, laule	11-14, p	100			_	estimated at 5 times	HS DEC	21-11 0755
UPR Allachements	500	-		Node N	voquies			5.00	10.00		23,960	- 2		47,92	u includes abou kg water per	r module	_	E	is, table	11-14, p.	557				(are Drll		
EVA Tools	123		Sur	face Equi	pment	-									and the second sec				50.000						-	NASAE	SAS Study
Surface Power	-			Science	e Packag	86		-			1.000		-	1,00	0 Can be broken up into sma	aller payloa	305.	N	ASA ES/	4S Study	1					-	
Mars Nuclear Power Unit or Lunar	10,000	2		ISRU P	ackages.	· · · · · · · · · · · · · · · · · · ·					500		· · · · ·	50	Can be broken up into sma	aller pavloa	ads.	N	ASAESA	4S Study	Sec. 19	-			5	NASAE	RAS 95.0
Power Management and Data equip	2 370					-								1	Utilizes lander propellant ta	anks, and p	produces 2	5.000 B	Based on NASA / Boeing Study (5% scale per			-	NAGACI	O AS Chine			
Total Payload Macs to Surface				Electro	lysis Unit	5					1,632	14 C		6,52	ko propellant per year, each	h		13	anden								
Lander Secondry	Mary Mar	827 5	Sur	face Mob	lity Syst	ams	_							1	all property of the test		_	-			_	_	_	_	and a second state and	Pateren	005
Propulsion svs. enginesitariks	9000	- 10 725		Draceur	ritad Rou	10.1		5.00	10.00	-	18,000	1.		18.00	Includes 2000 kp of water			N	494 504	C Church				_	por approximate var	HS TOOL	31-6 0999
Ascent cabin	500	-	+	Licorer	rudend E	Auge Traile		5.00	10.00		1.000		-	0,00	a manades coop wy or water			1	HOR LOP	to black	-	_		-	1		
Cruise state power system	4	-	EH	Unpres	iounzed P	wvernals	510	0.00	10.00	-	0.090		-	4,10	Castless Ciasts Cance A	ten Patr	_	-+			_	_		-	-	105 1201	2110.0222
Pavipad structures	4.85	-		UPITA	cacheme	153	_				500			2,00	Backhoe, blade, Scoop, Co	one Unit		-						-		-	
Total integed Mass	-			EVA SU	jil			0.75	2.00	3.00	365	6	24	2,92	8 2 suits per crew member +	spares		N	ASA ES/	4S Study	1.1			-	-	-	
				EVA TO	ols			-		-	123	2		24	6			_							202		
The second second second	-	-	Sur	Tace Pow	96				J	-		-		-			_		_							-	
Franking	41 114	80		Mars N Photow	luclear Po oltaic Arra	ower Unit o av	r Lunar	5.00	5.00	-	10,000	2	<u>}</u>	20,00	o 25 kW each. Solar and Nut total mass.	clear syste	ems have s	imijar _N	ASAESA	ks Study	n z			-	t load is input here and tanks for all four	Use Tan	rk Bizing Tool" for ventication and more detailed
LOX	50253.083	ito i		Power	Manager	nent and D	ata equili				2,970	1		2.37	includes 2.5 km power cab	ies.		N	ASAESA	S Shurt					-	-	
Outside diameter				. oner		and a second sec	are adapt	-		-				2,01	and a set and participation of					- amol	1.1				-	-	
Tuess sauce.	-		Tot	al Payload	d Mass to	o Surface		1		_				154.41					-						its and domes and	and line	
Length of LOX tank	1 to			-					•															_			
Culture damater	10075 962	80	+- - -				-						-		and a second	10-10-							1.	-		-	
inside diameter	4.5	10					-								hside clameter	49			-		-		1			1	
		1					L	enoth includies half sp	sherical end domes a	nd wall													Length inc	luces half sphe	erical and domes and	wali i	
Length of each LH2 tank in a two tank	11.2				122		-	righ includes har s	denta est sores a	les tr				Length	enotin If each LH2 tank in a two tank	11.75					1	-	Length Inc	luces had some	erica end comes and	tex.	

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Reusable Lunar and Mars Lander Sizing Summary

- Lunar Crew Landers 1 & 3
 - Lander dry mass: 20,840 kg
 - Propellant: 60,000 kg
 - Descent: 47,000 kg
 - Ascent: 13,000 kg
 - Payload: 41,046 kg
 - Total Wet Mass: ~122,000 kg
- Lunar Cargo Landers 2 & 4
 - Lander dry mass: 14,840 kg
 - Propellant: 60,000 kg
 - Descent: 47,000 kg
 - Ascent: 13,000 kg
 - Payload: 56,159 kg
 - Total Wet Mass: ~131,000 kg

- Mars Crew Landers 1 & 3
 - Lander dry mass: 22,790 kg
 - Propellant: 64,000 kg
 - Descent: 22,000 kg
 - Ascent: 42,000 kg
 - Payload: 41,046 kg
 - Total Wet Mass: ~128,000 kg
- Mars Cargo Landers 2 & 4
 - Lander dry mass: 16,790 kg
 - Propellant: 52,000 kg
 - Descent: 22,000 kg
 - Ascent: 30,000 kg
 - Payload: 58,638 kg
 - Total Wet Mass: ~128,000 kg

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Primary Payloads

- Mission Operations Module
- EVA / Airlock Node
- Un-pressurized Rover

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the authors interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Lander 2 Deployment



Primary Payloads:

- Greenhouse Module
- Galley / Airlock Node
- Surface Equipment

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the authors interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Lander 3 Deployment



Primary Payloads:

- Materials Science Module
- Life Science Module
- Un-pressurized Rovers

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the authors interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only. NASA Marshall Space Flight Center / Full Time Study Program

41



Lander 4 – Lunar Power System

4



- Pressurized Rover
- Solar Power Module
- Surface Equipment

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the authors interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Lander 4 – Mars Power System

4



- Pressurized Rover
- Nuclear Power Module
- Surface Equipment

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the authors interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Transfer and Surface Habitat Sizing



David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Lunar and Mars Outpost Assembly

Surface Habitat:

- 6 pressurized modules
- Mass: 138,000 kg
- Volume: 825 m^3 (excluding water wall)
- Volume per person: 103 m^3
- Power: 56 kW
- Consumables: 21,500 kg
- Water: 48,000 kg (recycled)

Outpost Primary Payloads:

- 2 Un-pressurized Rovers
- 1 Pressurized Rover
- 56 kW Power Module
 - Solar at Moon
 - Nuclear at Mars
- 6 Habitat Modules
 - Mission Ops Module
 - Life Science Module
 - EVA / Airlock Node
 - Galley / Airlock Node
 - Materials Science Module
 - Greenhouse Module

All calculations are based on the authors interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Module Assembly Details

Module Design Concept

Standard Habitat Module based on ISS rack accommodations, ISS hatches, and subsystems

 Module size slightly larger to accommodate an interior water wall for radiation protection and align with the 5m payload diameter of the Delta IV Heavy and Ariane 5 launch vehicles

Module Elements

- Composite exterior shell and insulation for micrometeoroid and thermal protection
- Grapple fixtures for payload handling and attachment of mobility systems
- Aluminum pressure vessel
- 15 cm (6 in.) water wall filled with 5 cm (2 in.) of water initially for radiation protection
- Standard ISS wall racks
- Electrical and air systems above the ceiling
- Water and storage systems below the floor
- Aluminum or composite interior rib structure

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the authors interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Cross-Section of Habitat



David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



David Smitherman / ED04 Advanced Concepts Office

All calculations are based on the authors interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Transfer and Surface Habitat Configurations



David Smitherman / ED04 Advanced Concepts Office All calculations are based on the authors interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Propellant Depot Sizing for Recurring Mars Missions

- Propellant Production Depot
 - Production: 500,000 kg per year
 - Propellant required: 2,500,000 kg
 - 3 Depots required, producing propellant from water over a 2 year period
 - 3,000,000 kg production capacity
 - 2,500,000 kg for return vehicle
 - 500,000 kg remaining for Landers and Exploration Vehicle
 - Option: 1 Depot sized up slightly could support missions on a 4 year cycle





David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Crew Excursion Vehicle Sizing

- Excursion Vehicle
 - Designed for 2 crew members to explore Phobos and Deimos in 2 week excursions from the Mars Ship in a 500 km orbit around Mars
 - Includes 2 pressurized maneuvering units for surface exploration
 - Dry Mass: 22,071 kg
 - Wet Mass: 34,433 kg

cupio	This worksheet is used to calcon requirments including propelant the Habitat Sizing Tool. The Ma to do to an esteroid.	ale the total gro tank sizes. Pa is Mission IS sta	se (wet) mai yload data is sic for elipto	is of the Expl input automa ration of Photo	ration Venime, a toally using a st calant Detrica	ind to calculate andard hastlat The Lunar Atiss	propeliant module from ann le assumed		Green Indicates cells requiring user input. Green Indicates proved scene table Data Intest to other workshoets Al other cells are from reference data or Intermediate output data.	
	A Research and a	Planetary	Dalla v	-	Marr	Dry Mase	Propellant	Wet Mass		-
1216	Mars orbit to Deimos Transfer	DODA	(AUT/AD	-	10,00000	1000	Mana (CO)	12.00	NO128.	MENTRINE
	Orbit	Mare	0.200	390	0.935	32,677	1.755	34435		
_	Delmos Transfer Orbit to	117	0.700	300	0.000	17 000	E 165	10 577		
-	Delmos Transfer Orbiet to	04413	4.00	229	0.500	- e.e.e.	2,405	24.9/1		
-	Phobos Transfer Orbit	Mars	0.300	390	0.909	25,155	2.054	27,209		
	Phobos Transfer Orbit to Phobos Surface	Mars	0.500	390	0.853	22.071	3.084	25.155		
				-			12.352	22.071	Exploration vehicle module mass assumed to be equivalent to one lab module.	
ander	Tank Sizas	Data	Unita	_		1			Halas	
	Propellant	12 362	MQ.	-					Maximum lander properant load is input here automatically to size standard tanks for all four landers	Use 'Tank Sizing Tool' for verification and more detailed information.
-	LOX	10297.3524	k0					0.00		
	Outside diameter	5	m					-		
	Inside diameter	49	10			-	-			
ength	of LOX tank	415							Length includes half spherical end domes and wall thickness	
	LH2	2064.41519	kg			1.0				
	Outside diameter	5.00	m				1			
	Inside diameter	4.9	m					2		
Length	of LH2 tank	22		1				i	Length includes half spherical end domes and wall thickness	
	Length of LOX & LH2 tank In a stacked configuration	5 65							Length includes half spherical end domes and wall thickness	





David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Program Planning

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only. NASA Marshall Space Flight Center / Full Time Study Program

52



ISS Assembly

- The space station will be assembled in about 45 flights over 15 years and then operated for an additional 10 years.
 - 28 US Assembly Flights
 - 7 US Utilization Flights
 - 10 Russian Flights





David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Lunar and Mars Vehicle Assembly Launches

Loter Test Minister Loverth Coll.						leres .	_	Muris	Meston Launch Coll						NODE	
						Green indicates only required she's type:									Green indicates cells regaring user input:	
						Data linkes to other workplayers					-				Data linked to other worksheets	
The excepted is used to derive the pa	apitals to be prove that	the second them the Law	och lience Coltras Activities	Contraction (1997)		All other cells are from reference data or Intermediate output data			The environment is used to definition the post- of technology resourced for each version, and can	India to the proper taurus	the cost for march	INCO VERICIA OCTORE MOREIRA	a circula de co	CODA-	All other cells are from reference data or internied are output data	
						The weed are copie used.					and the part of					
	-	1 1	-	These of Case							-		F Delta Vi	Datale		
	Bars Dail An.	Della Transfer 1	Dette V-Laware Dette V-1	Line Tax	Bernat					Mari Sala In.	Dellá IV Heavy	Deta V-Lander Deta S	-Tankar 7a	ek Realman		
Surface Faithful Modules	THE PHONE H	L Allen Pollan	CHOMICH CHOM	CHOMEN	Prosecurity	90M	ADDENION	5urtac	ce Habitat Modurea	act negated	Science / Proton	Configuration Confi	pareton Contig	aration Properati	2. (40544	(telerences
Lao Modules	21,585 4		20.739						Lab Mobiles	22.555 4	-	90.735				-
Surface Egylproetf	20.000		4 322	-	-			Surface	ce Equipment	4.64		AL.122				-
Science Packages	1.000 1		1 000		-				Coence Packages	1000 1	-	1.000	_		-	-
Eactovilla Unita	1.622		8.555						Electrolysis Units	1.522 4		6.824		_		
Surface Mobility Systems	10.000		10.784				_	Surface	Ce Mobility Systems Dressurged Rover	18.000	-	18,000	-	-		-
Ungress and the Power Trailers	V.090 2		1.160						Unpressurged Roven Trailers	1,090 2		2,160		1		
P/A full	500 <u>4</u> 366 B		2 000	_	-		-		EVA Dut	365 4	-	2,000	_		-	-
E/A Toos	123 2		246						EVA Tools	123 2		245		1		-
Man Nuclear Power Unit or Linter	-	-	_	-			-	and a second s	Mars Nuclear Power Unit or Lunar	10000 0						
Photovataic Array	1000 2	-	20.000						Photoyottaic Artax Dever Massagement and Data en in	2320 1	-	20.000		_	-	-
Landers	120		A. STV		1			Lander	K3	area -		60.3			1	
Cargo Lander	16342 2		22.651		20.10				Cargo Lander Résidual Procétant	16,790 2	-	33,581	_	30	0	-
Creat Lative	20342 2		41.661						Crew Lander	22,790 2	-	45,581				
(Residual Propelant Transfer Vehicle Mass	1500 2				8.00			Transf	Inteligual Plotelant far Vehicle Mass	12.000 1				30		
Exploration Vehicle propettant	EMI NA				-				Exporation Vehicle	22.071 1				_	-	
Carbo Landers	100.251 NA	1		-					Crex Landers	127.345 NA				_		
Propelant Depot	2020 1		32.007						Propelant Depti Robotes	12,007	1 75	32,007			-	
Protocitat Array	1.770 I 18424 2	1,775							Photovoltaic Artay	15.534 2	31.64					-
Rasialors	12,024 1.	14:124					_		Additional array area Registers	3.710 2	14 19		-			
Residual Propelant	10.00			124.6	318,000				Delta Vi tana set	53,400 20		· · · · · · ·		1.058.000		-
Della // briss	26.700			21.722	-				Deta IV tarks	26 700 0			0	1,990	60	-
Return Vehicle Mass	1 202.02		-	-	30.00		-		Residual Propertant	56.000 0	-				9	
Exploration Vehicle	22671 1	22.071						Return	n Vehicle Mans	20 071 4	84.24	-	_	-	-	-
Note Modules	21,357 2	45,714							Note Modules	21.367 2	41.71					-
Science Packages	1.000 1	1,005			-		_		Cuppla	2,000 3	10.000					
CRV Bething Mechaniam	22 2	1,000							CRV Berthing Mechanism.	500 2	100				-	
62053 CRV C20018	100	3,770			-				CRV Capture	1 2	0/18					
Senice Module	1 2	1							Denice Module	1 2	205		_		-	-
EVA Sut	35 8	2,829			-				EVA Tools	12 2	34					
EVA Manusvering Unit	35 1	35							EVA Manueverno Unit Protosotalo Array	15.824 2	31.64		_		-	-
Photo-cities Artas Ballalors	10.014 1	31,648			-				Additional array area	3.712 2	7.42					
Defa VI tank sets	51,400	53,400							Delta Vi taria sec	53,400 2	106.600					-
Presidual Propellant Deta fy betas	50,000 1			100	53,100		-		Residual Propellant	53,000 2				195	50	-
Residual Projetant	5.000 1				56,00					00 0					0	
Exploration Vehicle propellant	12.92	-			-		1						_	_		-
Lander cropellant	253.425					and the second s				25					-	
Return vehicle propertient	503.772									550					-	
Retai propelaris realized	3,251,079			_	641.000	- 34	6 J			562					_	_
Remaining propertant required	2,707,075		2.7	01,075	-		1920			562	-			1,226.00	-	
Eguivatent water required	3303435	And in case of		-	-		7.00			083		1	9.502,053	-		-
Laurenti lassiciae		Data II Heavy	Delle V Lander Delle V T	Gene Dets U							Delta IV Heavy	Delta V Lander Delta	V Tank Det	W D		
Propetant lanches regulated		2.00	10 10	2.02			1				25.800	30,428 52	700 106	40.		
Equivalent ealer taumnet required			44	-				and a state of the			_		115	_		-
Latercies regares					Total Laureb									Total Lists		
Ceta N	Col (146) Units	525			CHI MI		-			(SM) Usie				Cost (\$4	Noise	Association
Loser stage	14 1	14			-	10 ST 10				14 1	26					
Deta V Lander	80 5 80 6		4(0)	450		16.00				80 5		420	244		5 Deta IV units 6 Deta IV units	
Dela VI dal tanta	<u>80</u> 5			4	0	is pa		Contraction of the second s		80 6	1		Pre-	450	6 Deta /V units all merged core tanks	
Cost per vehicle (SM)	4 1	254	200	45 4	4			State of the second		14 1	25	420	442	16	-	
Total Lutar Test Mission laurich cost (\$M)		3,158	1,317	16.932 1,4	8 21,985						3.53	1.352	55.151	4.555 65.001		
		-			-										1	
										1.1						
								a 🕂 da 🖉 👘 👘 👘 👘 👘								
									100							
									and the second se							
									The second second							
						A CONTRACTOR OF		A DECKER OF THE REAL PROPERTY								
						100			CONTRACTOR OF THE OWNER							
						and the second second	1.5		N							
						Constant of the local division of the local	100		Statement of the							
						and the second s										
										20.0						

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Lunar and Mars Ship Assembly Launch Summary

- The Lunar Test Mission requires about 52 launches over 8 years (6-7 launches per year)
 - 12 payload delivery flights from a Delta IV Heavy, Proton M, or Ariane 5
 - 4 Delta V Lander flights
 - 5 Delta V double tanker flights
 - 30 Delta V Tanker flights for propellant delivery, or about twice this many flights from current heavy lift vehicles

- The Mars Mission requires about 142 launches over 13 years (11 launches per year)
 - 10 payload delivery flights from a Delta IV Heavy, Proton M, or Ariane 5
 - 4 Delta V Lander flights
 - 115 Delta V Tanker flights for water deliver, or 86 flights for propellant deliver, or twice this many flights from current heavy lift vehicles



Lunar Test Mission Vehicle



Mars Mission Vehicle

David Smitherman / ED04 Advanced Concepts Office

All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Recurring Mars Missions

- After the 3rd mission to Mars, a propellant production capability is put in place for the reusable Landers and reusable transfer vehicle.
- Recurring missions would require 44 launches over 4 years (11 flights per year)
 - 1 payload delivery flight from a Delta IV Heavy, Proton M, or Ariane 5
 - 0 Delta V Lander flights
 - 10 Delta V double tanker flights
 - 33 Delta V Tanker flights for water deliver, or 24 flights for propellant deliver, or twice this many flights from current heavy lift vehicles



Propellant Production Depot



Recurring Mars Mission Vehicles

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Lunar and Mars Program Cost & Schedule



David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



David Smitherman / ED04

Advanced Concepts Office

ISS Mission Program Summary

- The following program calculations do not include ongoing crew flights to the ISS for support of the ISS, Lunar and Mars programs
- ISS Program
 - Ongoing crew flights to ISS per year
 - 4 Ares 1
 - 2 Soyuz
 - 2 Proton M
- Launch Cost:
 - Assume equivalent of 8 Delta IV

/ launches: \$1.3 B



All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Lunar Missions Program Summary

- Vehicle Development
 - 2009-2010 Pre-Phase A studies
 - 2010-2013 Phase A designs
 - 2012-2017 Phase B designs
 - 2014-2023 Phase C build
 - 2012-2023 launch & assembly
 - 52 launches
 - Launch Cost: \$13.8 B
- Lunar Test Mission
 - 2024 transfer to lunar orbit
 - 2025 lunar surface mission
 - 2026 return to earth orbit
- Program Cost: \$43 B
- \$4.5 B peak in annual cost

- Recurring Lunar Crew Missions
 after 2026
 - 9 launches
 - 1 Delta IV Heavy
 - 4 Delta V Tankers
 - 1 Delta V Dbl Tanker
 - Launch Cost: \$1.7 B
- Recurring Lunar Cargo Missions (1 Cargo Mission will support Reusable Landers for 3 to 4 Crew Missions)
 - 9 launches
 - 4 Delta IV Heavy
 - 4 Delta V Tankers
 - 1 Delta V Dbl Tanker
 - Launch Cost: \$1.9 B

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Mars Missions Program Summary

- Vehicle Development
 - 2021-2030 Phase C build
 - 2018-2030 launch & assembly
 - 139 launches
 - Launch Cost: \$40.3 B
- Mars Mission
 - 2031 transfer to Mars orbit
 - 2032 Mars surface mission
 - 2033 return to earth orbit
- Program Cost: \$54 B
- \$6 B peak in annual cost
- \$7 B peak in annual cost when overlapped with Lunar Test Mission phasing

- Recurring Mars Missions
 - After the 3rd Mars Mission a propellant depot capability is established to provide propellant for reusable Landers and return and reuse of the Transfer Habitat
 - 44 launches
 - 1 Delta IV Heavy
 - 33 Delta V Tankers
 - 10 Delta V Dbl Tankers
 - Launch Cost: \$13.1 B

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Program Summary

- Development Cost: \$34.6 B
 - Lunar Test Mission: \$16 B
 - Mars Mission: \$10 B
 - Nuclear Power: \$8.6 B
 - Schedule: 2014-2030 (16 years)
 - \$1 B to \$2.5 B per year
- Launch Cost: \$54.1 B
 - Lunar Test Mission: \$13.8 B
 - 52 launches
 - Mars Mission: \$40.3 B
 - 139 launches
 - Schedule: 2016-2030 (14 years)
 - 191 launches total
 - About 8 to 20 launches per year from all International Partners

- ISS Program Cost: \$36.8 B
 - Phase C Support: \$16 B
 - Launch Cost: \$20.8 B
 - Schedule: 2014-2030 (16 years)
 - 128 launches
 - About 8 launches per year from all International Partners
- Total Lunar and Mars Program Cost: \$133.8 B
 - Lunar Test Mission: \$43 B
 - Mars Mission: \$54 B
 - ISS Support: 36.8 B

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Findings

- Transportation
 - Large propellant requirements supports logic for large heavy lift launch vehicles
 - Saturn V
 - Ares V
 - Launch cost of all elements for the Lunar and Mars missions is \$54.1
 B, of which \$49 B is for the propellant and propellant stages.
 - What is the development cost for the Ares V?
 - How many Ares V launchers can be produced for \$50 B?
 - Use of existing launch systems supports growth of commercial markets

- Lunar Missions with in-space assembly appears feasible with current launch systems, (i.e., Delta-IV Heavy, Proton M, and Ariane 5)
- Saving the return habitat does not appear feasible for initial Mars missions due to large propellant requirements

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Findings

- Mission Design
 - One design for both lunar and Mars missions saves program development time and cost
 - Reusable Lunar Landers and Reusable Mars Landers can be about the same size and mass
 - Propellant production at Mars for return missions reduces vehicle size and makes saving the return habitat more feasible
 - Propellant Storage depots look more attractive in Earth – Moon neighborhood, whereas Propellant Production depots look attractive at Mars

- Nuclear Systems
 - Nuclear surface power is included for Mars development due to difficulty solar systems would have on the surface
 - Nuclear propulsion was not selected because the large hydrogen tank mass negated the advantages of the high engine efficiency

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Technology Issues

- In-space alignment and docking of large mass vehicles
- Water resource acquisition on Mars
- Propellant production in space and on the surface of Mars
- Long term storage of propellants in space
- Delta V vehicle configuration feasibility
- Reuse of engines for Lander and propellant stages
- Surface nuclear power on Mars

- Precision Landing, especially on Mars where the landing system is dependant on parachutes
- ISS operations
 - Re-boost operations as center of mass shifts
 - Additional power requirements for attached elements
 - Support vehicle and payload delivery docking and berthing operations

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



... and a special thanks to all that encouraged, inspired, and supported this effort ...

- NASA Marshall management, and the Full Time Study Program
- University of Houston, Sasakawa International Center for Space Architecture
- Prof. Larry Bell, Assist. Prof. Olga Bennova, Harmon Everett, Prof. Peter Noldt
- Kriss Kennedy, Joe Howell, Jim Talbot, Larry Toups, Reggie Alexander
- Rachel Smitherman, Ana Mari Cadilla, Margaret Smitherman



David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Acronyms and Abbreviations

В	Billion
dbl doub	le
dia.	Diameter
ESA	European Space Agency
EVA	Extra-Vehicular Activity
g	gravity
ht.	height
in.	inches
ISS	International Space Station
kg	kilograms
kW	kilowatts

LEO	Low-Earth-Orbit
m	meters
Μ	Million
TLI	Trans Lunar Injection
TMI	Trans Mars Injection
US	United States

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Reference Materials

A Comparison of Transportation Systems for Human Missions to Mars, by Griffin, B., et al, AIAA Technical Paper

Encyclopedia Astronautica website, http://www.astronautix.com

Human Space Flight: Mission Analysis and Design, edited by Willey J. Larson and Linda K. Pranke, Space Technology Series, McGraw-Hill Companies, Inc.

International Space Reference Guide to Space Launch Systems, Third Edition, Steven J. Isakowitz, Joseph P. Hopkins Jr., Joshua B. Hopkins, AIAA, 1999

National Aeronautics and Space Administration website: <u>http://www.nasa.gov</u>

Sasakawa International Center for Space Architecture (SICSA) website: http://www.sicsa.uh.edu

Space Solar Power and Platform Technologies for In-Space Propellant Depots, Final Report, November 14, 2000, Boeing Company in cooperation with NASA Marshall Space Flight Center, NAS8-99140, Mod.2, Task 3

AIAA Technical Papers by Smitherman, D. et al

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Spreadsheet Analysis

- ARCH 6398: Special Projects
 - Detailed Spreadsheet analysis of launch vehicles, lunar test mission, and Mars mission
 - Surface Base Sizing Tool
 - Habitat Sizing Tool
 - Crew Accommodations Sizing
 - Surface Habitat Outfitting
 - Transfer Habitat Outfitting
 - Crew Consumables Data
 - Surface Payloads Mass Summary
 - Lunar Lander Sizing
 - Mars Lander Sizing
 - Excursion Vehicle Sizing
 - Lunar Vehicle Chemical Staging
 - Lunar Cargo Missions
 - Lunar Crew Missions

- Recurring Lunar Cargo Missions
- Recurring Lunar Crew Missions
- Mars Vehicle Chemical Staging
- Mars Crew & Cargo Missions
- Mars with Operational Depot
- Recurring Mars Missions
- Mars Transfer Habitat Mass
- Crew Return Vehicle Sizing
- Propellant Depot Sizing
- Vehicle Configurations
- Launch Vehicle Sizing
- Launch Vehicle Options
- Lunar Test Launch Cost
- Mars Mission Launch Cost
- Program Plans
- Tanks Sizing Tool (Continued)

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Spreadsheet Analysis

(Continued)

- Water Wall Sizing Tool
- EVA Systems Data
- Lander Ref. Data
- Power Production Sizing Data
- Power Requirements Data
- Robotic Systems Data
- Ref. Mars Habitat Lander
- Artificial Gravity Data
- Greenhouse Sizing Tool
- Delta-v Data
- Engine ISP Data
- Systems Sizing Data

- 41 Excel Spreadsheets were generated to size everything from launch vehicles to crew accommodations. All formulas, data and rules of thumb are based on the text "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke
- File Name: LunarMarsSizing081208.xls contains the 41 workbooks listed. Many workbooks are linked where indicated.

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Design Animations

ARCH 7610: Master's Project – Space Architecture

- Conceptual Design and Animations using 3-D computer modeling; AutoDesk 3D Studio Max, Versions 9 and 2008
 - Delta IV Heavy Launch
 - Delta V Tank Launch
 - Delta V Double Tank Launch
 - Delta V Lander Launch
 - Assembly Operation At ISS
 - Transfer Vehicle Tether Assembly
 - Transfer Vehicle TMI
 - Artificial Gravity Phase

- Lunar and Mars Orbit Operations
- Lander 1 Deployment
- Lander 2 Deployment
- Lander 3 Deployment
- Lander 4 Lunar Solar Power
- Lander 4 Mars Nuclear Power
- Surface Habitat Assembly
- Module Assembly Details
- Habitat Tour
- Habitat Configurations
- Electromagnetic Water Launcher

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Moon to Mars Mission Assumptions

Appendix A

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



ISS Utilization

Assumptions	Notes
Design to make innovative use of exiting space technology (including ISS) where practical.	Modules, racks, docking devices, power systems, etc., to be compatible with ISS systems.
The ISS is to be transferred to a lower inclination and used as the Mars Ship assembly platform after its current mission. (Optional)	Attachment will be made through the Node 1 (nadir / zenith) port.
ISS to be operated as a port authority for both commercial and government activities.	Commercial activities at space station to be permitted.
Assembly will be done one module or component at a time as done with space station.	Assume about 4 crew flights per year (Ares I and/or Soyuz), 2 servicing flights per year (Progress or others), and 8 cargo flights per year (Delta IV and others); two major assembly operations per crew rotation.

All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.


Power and Propulsion

Assumptions	Notes
Assume abundant power from nuclear systems with options and back up using solar power	Include Thermal Nuclear Generators and Radiant Thermal Generator systems. Provide adequate protection using water shielding as needed.
Existing commercial launch systems to be utilized to the greatest extent possible.	Delta IV Heavy is used as a baseline, but capable launch systems include Ariane, Proton, Titan
Delta IV Heavy to be baseline system for all propulsive stages for vehicle transfer to and from Mars	Other vehicles, Titan, Progress, and Aerean are options
Assume no heavy lift vehicle will be built.	No Saturn V or Ares V vehicles to be developed.

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Water

Assumptions	Notes
An abundant propellant option is assumed utilizing water	Propellant depot to be operational for commercial and
converted to propellants at a servicing platform at or near	exploration missions
the Mars Ship assembly area.	Mars surface water to be exploited for long term habitation
Assume mission options for use of water produced at	Options include additional EVAs, propellants to support reusable landers, and propellants to support de-
Mars	acceleration of transfer habitat into LEO
SPE and GCR radiation protection to be provided per	Design for 15cm water jacket around all habitat areas.
current knowledge with options for additional protection	Carry 5-10cm equivalent of water with remainder provided
as more is understood.	at Mars or on later missions.
Carry minimal water for habitat and nuclear power source.	Assume options for adding water to habitat and nuclear power shielding from Martian sources to increase overall radiation protection over time
All water, propellant and oxygen to be provided for entire mission. Electrolysis equipment will be provided to convert excess water to oxygen and propellants	Surface water will be utilized to provide extra EVA operations and extra propellants for transit to other exploration site options

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only. NASA Marshall Space Flight Center / Full Time Study Program

74



Reusable Systems

Assumptions	Notes
Propellant production from water to be the baseline through entire mission.	Assume water deliveries to LEO for Mars Ship propellant production. Water deliveris to Mars orbit, and Mars surface water extraction.
First mission to deliver a water based propellant production capability to Mars orbit and the surface outpost.	Required for more efficient operation of future missions.
Mars landers to be refueled at Mars orbit and surface propellant production facilities.	Assume two landers as hopers with ruse capabilities, and the other two landers used for crew ascent only at end of mission
Landers may be used as hoppers for transport to exploration sites around the planet.	Refueling to be done at surface depots or on orbit.

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Assumptions	Notes
Assume options for an EVA extensive mission design	Assume option abundant water and use of existing surface water resources to support extensive EVA operations
Design for maintenance and repair of all systems	Provide materials and equipment designed to fabricate replacement parts as needed
Provide at least two airlocks to overall habitat and two access hatches to all habitable volumes	One access hatch can be from outside with emergency pressure balls on inside for stranded crew
Provide two EVA suites for each crew member	Suits to be modular in design for repair capability

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only. NASA Marshall Space Flight Center / Full Time Study Program

76



Mobility

Assumptions	Notes
All mobile systems to accommodate two driving stations and remote driving operations from habitat	Remote operations to be possible from any crew location via laptop
Surface habitats to be movable but not necessarily a mobile habitat design	Mobility options to include relocation of habitats, pressurized rovers, un-pressurized rovers, pressurized hoppers, and EVA
All mobile systems carry 8 crew in an emergency and at least 2 crew under normal operations	Provide vehicle accommodation for injured crew
Douid Smitherman / ED04 All coloudations are based on the outbar's int	

David Smitherman / ED04 Advanced Concepts Office Il calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.

NASA Marshall Space Flight Center / Full Time Study Program

77



Design / Operation

Assumptions	Notes
Full duration test mission will be run to the Moon and back prior to Mars mission	Mars Ship will be refurbished or new ship constructed during lunar test mission
Lunar Test Mission will leave similar assets in place to support future science and commercial operations.	(Reusable landers and propellant production and storage systems.)
Assume dust problems on Mars may be similar to lunar dust problems	Mars should not be as bad, but same precautions are needed
Distribute supplies in all habitable volumes for emergency access and use	Provide EVA access to all habitable volumes for emergency access
Some systems and supplies may be sent ahead of time prior to crew arrival	Extra water, propellants, supplies, and habitable volumes may be sent ahead of time if mission scenario seems practical
Habitat has near 100% water, closed loop system	Human waste products my be used in greenhouse systems
Create redundant habitable volumes that can accommodate all crew in emergency situations	Design life support supplies for rescue time required in the event system failure occurs at the return phase. (3 years?)

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Mars Mission Elements

Appendix B

A breakdown of all the major vehicle and infrastructure elements required to create and support the Mars Ship.

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only. NASA Marshall Space Flight Center / Full Time Study Program

79



Mars Mission Elements

- Mars Ship Elements
- Mars Transfer Vehicle
 - Transfer Habitat w/ Science Facilities
 - Propulsion Systems
 - Propellant production
 - Exploration vehicle (Phobos / Deimos)
 - Crew return vehicles
- Mars Surface Vehicles
 - Landing vehicles
 - Habitat w/ Science Facilities
 - Surface Mobility
 - Surface / Sub-surface exploration
 - Propellant production

- Infrastructure Elements
- ISS
 - Supports 6 crew
 - Growth to 12 crew as Mars Ship habitats are added
 - Gradually moved to lower inclination orbit with each re-boost operation
 - Operated as a port authority for government and commercial operations
- Propellant Production
 - Attached to ISS, Mars Ship, or free-flyer
 - Water storage
 - Propellant production and storage
 - Transfer and servicing vehicles, crew and remote operated
 - All commercial operations
- Orbital Systems
 - Global communications, navigation, mapping, weather satellites

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Crew

- 8 Crew Members
 - 2 Pilots / Systems Specialists
 - 2 Medical Doctors / Life Sciences Specialists
 - 2 Geologists / Materials Sciences Specialists
 - 2 Astrophysicists / Space Science Specialists

- Mission scenario
 - 6 crew members will go to surface in two landers
 - Two landers will be landed autonomously, or by remote operations
 - 2 crew members will explore Phobos and Deimos with options to go to surface later using a reusable lander
- Lunar mission will be a test run for long duration, mixed gender crew, single and married couples.

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Mars Transfer Vehicle Habitats

- Habitable Areas
- Habitat
 - Mission Control Center
 - Vehicle guidance, navigation & control center
 - Communications
 - Remote operations control center
 - Galley
 - Food storage
 - Meal preparation
 - Dining
 - Crew quarters
 - Sleeping bunk
 - Work desk
 - Personal storage
 - Restroom Facilities
 - Toilet
 - Shower
 - Sink
 - Laundry

- Science Facilities
 - Life Sciences Facility
 - Medical equipment
 - Exercise equipment
 - Greenhouse
 - Food production
 - Waste recycling
 - Oxygen generation
 - Geo Sciences Facility
 - Materials research
 - Materials storage
 - Fabrication equipment
 - Space Sciences Facility
 - Telescopes and detectors
 - Environmental detection equipment
 - Extravehicular Activity (EVA) Facility
 - Pressure suit maintenance
 - Storage
 - Airlock

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Mars Transfer Vehicle Systems

- Non-Habitable Systems
- Environmental Control & Life Support
 - Air quality control
 - Temperature control
 - Water reclamation & purification
- Communications
 - Voice, video, and data handling
 - Data storage
- Guidance, Navigation & Control
 - Star trackers
 - Control moment gyros
 - Thrusters
- Power
 - Nuclear Thermal Generators
 - Solar Arrays
 - Radiators
- Propulsion Systems
 - Propellant storage
 - Engines

- Propellant Production
 - Water storage
 - Electrolysis system
 - Propellant storage
 - Transfer systems
- Structures
 - Habitat pressure vessels
 - Propellant pressure vessels
 - Primary structures
 - Movable structures
- Thermal Control
 - Insulation systems
 - Heaters
 - Radiators
- Environmental Protection
 - Micrometeoroid debris shield
 - Solar Particle Event (SPE) protection
 - Galactic Cosmic Ray (GCR) protection

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Mars Surface Vehicles

- Landing Vehicles
- Descent/Accent Vehicle Control Center
 - Vehicle guidance, navigation & control center
 - Communications
 - Remote operations control center
- Crew Accommodations
- Environmental Control & Life Support
 - Air quality control
 - Temperature control
 - Water storage
- Communications
 - Voice, video, and data handling
 - Data storage
- Guidance, Navigation & Control
 - Star trackers
 - Thrusters
- Power
 - Nuclear Thermal Generators
 - Radiators

- Propulsion Systems
 - Propellant storage
 - Thrusters
 - Main engines
- Environmental Protection
 - Micrometeoroid debris shield
 - Solar Particle Event (SPE) protection
- Structures
 - Assent/Descent module pressure vessels
 - Propellant pressure vessels
 - Primary structures
 - Movable structures
- Thermal Control
 - Insulation systems
 - Heaters
 - Radiators

All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Mars Surface Habitat

- Habitable Areas
- Habitat
 - Mission Control Center
 - Vehicle guidance, navigation & control center
 - Communications
 - Remote operations control center
 - Galley
 - Food storage
 - Meal preparation
 - Dining
 - Crew quarters
 - Sleeping bunk
 - Work desk
 - Personal storage
 - Restroom Facilities
 - Toilet
 - Shower
 - Sink
 - Laundry

- Science Facilities
 - Life Sciences Facility
 - Medical equipment
 - Exercise equipment
 - Greenhouse
 - Food production
 - Waste recycling
 - Oxygen generation
 - Geo Sciences Facility
 - Materials storage
 - Fabrication equipment
 - Space Sciences Facility
 - Telescopes
 - Environmental detection equipment
 - Extravehicular Activity (EVA) Facility
 - Pressure suit maintenance
 - Storage
 - Airlock

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Mars Surface Vehicles & Equipment

- Pressurized Rover
 - Includes all accommodations of a surface habitat module
 - Transports 2-8 crew members
 - Tows un-pressurized rover in its flatbed trailer configuration
- Un-pressurized Rover
 - Transporting 2-8 crew members
 - Flat-bed trailer configuration for moving large habitat modules
 - Forklift and crane configuration for moving surface equipment
 - Backhoe, and blade attachments for lifting and excavating
 - Drilling rig attachment for subsurface exploration
 - Manual, autonomous, and remote operation modes

- Hopper
 - Two autonomous landers to be refueled and reused as crewed and remote operated hoppers
 - Payload bays available for large payload delivery to and from surface

David Smitherman / ED04 Advanced Concepts Office

All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Habitat Design Drawings

Appendix C

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.







Standard Module Cross-Section



- 1. Air systems equipment and distribution
- 2. Water systems equipment and distribution
- 3. Standard ISS wall racks
- 4. Standard ISS hatch turned at 45 degrees for submarine hatch scale
- 5. Lighting and air supply
- 6. Air return

Scale: 1/4"=1'-0"

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Larson & Pranke. This presentation is for educational purposes only.

Full Time Study Program



Interior Design Standards

- 1. Air systems equipment and distribution
- 2. Water systems equipment and distribution tied to perimeter water-wall system
- 3. Standard ISS wall racks
- 4. Central work counter (ISS interior corridor is about 7x7 feet. This module is slightly larger, 8x8 corridor, which allows space for a center counter where needed.)
- 5. Lighting and air supply
- 6. Open work surfaces designed to fit ISS rack standards.



David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Standard Lab Module Plan

Typical Layout for EVA, Materials Science, Life Science, And Greenhouse Modules





Standard Node Module Plan

Typical Layout Nodes with Airlocks and either Operations or Galley functions



David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Standard Node Interior Elevation



David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Materials Science Module



Scale: 1/4"=1'-0"

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Node / Airlock Modules



Scale: 1/4"=1'-0"

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



EVA Equipment Module



Scale: 1/4"=1'-0"

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Life Sciences Module



Scale: 1/4"=1'-0"

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Greenhouse Module



Scale: 1/4"=1'-0"

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Pressurized Rover



Scale: 1/4"=1'-0"

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Surface Habitat Outfitting



Crew Accommodations



David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Transfer Habitat Layouts

- Single level layout
- Advantages
 - All laboratory and crew quarters are on the same level
- Disadvantages
 - Two module are perpendicular to the plane of rotation with risk of motion disorders for the crew
- Notes
 - Exploration Vehicle port needs to be added.



- Multiple level layout
- Advantages
 - All modules are oriented along the plane of rotation
 - Module layout could be simullar to the surface habitat layout
- Disadvantages
 - More vertical circulation required with crew split on multiple levels



David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Habitat Module Model

Appendix D

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only. NASA Marshall Space Flight Center / Full Time Study Program

105



David Smitherman / ED04 Advanced Concepts Office All calculations are based on the authors interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Model Production Equipment

Equipment

- Dimension SST 1200 es 3D printer
- ABS Plastic spools
- Support material bath







David Smitherman / ED04 Advanced Concepts Office

All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Plastic Model



David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.


Future Launch and Propulsion Systems

Appendix E

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Delta IV Heavy

Various configurations of the Delta IV Heavy were explored by Boeing in the propellant depot study referenced below. This work generated the concepts for the tanker and double tanker concepts used in this design

Space Solar Power and Platform Technologies for In-Space Propellant Depots, Final Report, November 14, 2000, Boeing Company in cooperation with NASA Marshall Space Flight Center, NAS8-99140, Mod.2, Task 3







David Smitherman / ED04 Advanced Concepts Office

All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Electromagnetic Launch Systems

Coil Gun Launch Tube

- High-g launch for water, propellants, and payloads
- Launch assist for conventional rocket systems

Electromagnetic Launch Rail

- Low-g for passenger transports
- Launch assist for aircraft and future space planes



David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Coil Gun Launch Tube Animation



David Smitherman / ED04 Advanced Concepts Office All calculations are based on the authors interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Nuclear Systems

- Findings
 - Nuclear propulsion option was not selected because the large hydrogen tank mass negated the advantages of the high engine efficiency
 - Transfer Vehicle required 39 tanks
 - Staging with drop tanks, 18 tanks required
 - How do you stage a nuclear system with one nuclear engine and drop tanks?

The Activities - Nacional The Activities of the second Vehicle in the according straggif back to (.E.f.) also	potter for pro the CRV has in togetal pla	utiler nähe 4 Serves ko 5 Brougt 4 J	y tokowiatika y njek siseli ta i Gar tivrsta kilja	together failt for ing the case of rSF sector op	NAME Conservations of the operation of t					
arth-Warn-Earth Propulsion	Planetary	Delta V	lip.	Manu	Blane Diat	Propellant	Wet Mass	Delta VI Tani	1 Notes	Relevence
rantier Vehicle Propulsion					-			BR 300	LHC propellant Lapacity per tank sid	Launch Vehicle Sizing data
Eath									Rocket equation formalia: inperior = mbo x (e ^x	HS, Formula 12-2, p404, 24-2, p789
17.00	Earth	4.914	350	6 278	4,735,581	2,549,567	7,280,127	28.02	Delta VI 98,000 kg LH2 propetant	HS Table 10-2, p276-277
TMI corrections	in transf	0.156	0.50	0.984	4.765,225	26,335	4,730,561	0.26		
100	Marc	2,855	950	0.401	3.458,603	1,245,623	4,705,226	12.72		
					Propeikant =	3,821,525	3,458,603	19.00	Burn out mans in Mars relat	
	-		_			-	2,706,637		Propulsion segment mass	
sturn Vehicle Propulsion								-		
IE	An internal	3.621	350	.0.296	408,855	253,111	751,966	2.58	Delta VI 18,000 kg LH2 propellant	
TEI carrections	in traved	0.950	950	0.984	132,772	715	456 855	6.01		
LEO propulsive	Eath	5130	492	0.195	42,764	300.065	132,772	0.00	LOX7LH2 properants for CRV return	
				-	-		42.761	1.22	Concession in succession in concession of the local	Street 4
							pursuit mass			
lacs Mission Vehicle Mass	Diameter or	Length	Volume	Nens (kg)	No. of Units	Total Volume	Total Nase		Notes	Reference
tansfer Vehicle Mass										
Explanation Vehicle.	5.00	20.00		34,433	. I		34,433			Exploration Vehicle Sizing applicateet
Cargo Landers	1500			124,975	2		248,115			
Crew Landers	15.00			127 243	2		254,431	1. · · · ·		and the second sec
Propeilant Depot	5.90	15.00	_	32,007	1		32,007		inchases 6050 kg water per module	HS, Table 11-14, p357
Rubolics				1,771	. I		1,770	1	SSRMS Itam ISS	Robolic Systems Data worksheet
Photovoltax Array	5.00	15.00	_	15 104	2		31,645		32.8 kW each	Power Printiction Sizing Data wolksheet
Additional array area				3.74	2		7.421	1	Array area is disibled for Mars distance	
Radiators	5.00	15.00		14,124	1		14,124			
Delta VI tark sel	5.10	70.00		53,408	30		2,082,406	8	Dry mass of 1 Delta VI tank sid	Launch Vehicle Signg worksheet
Total Transfer Vehicle							2700-507			
eturn Vehicle Mass			-				1.1.1			
Lab Nodules	5.00	10.00		22,071	4		28,283		Inclusies 8038 kg water per module	HS, Table 11-14, pES7
Node Modules	5.00	10.00		23,357	2		.45,718	1	Includes 5000 kg water per module	HS Table 11.14, p357
Science Packages				1,000	1	_	1.000	1		NASA ESAS Study
Cupola	2.90	2.66	_	2,008	5		10 000	N.		
CRV Berthing	2.00	2.00		500	. 2		1 000	9		
Retolics				1.770	- E-	-	1,771		SSRMS from ISS	Robite Systems Data worksheet
CRV Capsule	5.00	5.00		7,33	- 2	-	11.124			NASA ESAS Study
Service Module	5.00	15.00		LL DIS	2		28.080		45,000 kg LOX/LH2 propellant capacity each	
EVA Sull	0.75	2.00		36	8	0	2.925	9	2 suls per crew member + spares	EVA Systems Data worksherd
EVA Tools				- 523	2	-	.24	-		
EVA Manusversig Unit			_	10	1	-	35	5		
Photoveitaic Array	5.00	15,00		15,529	2		31,645	5	32.8 KW each	Poeer Protection Sizing Eats worksheet
Addienal anay area				374	2		7,421	1	Array area is doubled for Mars distance	
Radiators	5.00	.15.00		14.124	1	_	12 124	1		
Delta VI tank seit	5.10	78.05		50,408	30		1/10.200	1	(Dry mass of 1 Delta VI tank set	Launch Vehicle Sizing exclusion
Total Return Vehicle			-	_	_	_				



Card Medice - Racher The anti-plant large 1 concern the CPD- has a	anter for an		-	est logation into	Driven are	reasing for 1	in which they t	a trial of	Arden		Committeente orikurguing por iguit Tata inied to gher weischens	
Techapi sina Tecar Nat	2.P where r										All offer cells are from reference data or	
	_											
anti-Marc Earth	Panetry	Detta V	100	Mate	Sum Dur	Sept.	Organizet	Prepaiant	diar Mons	Selts in Gen	s Stones	Fatarance
ranster Vehicle Propulsion	-									88,000	LH2 propertient capacity per tank set	Launch Whicke Sorro data
Earth		-								\$1,480	Cets VI tariici set mats /kg1	HS. Formula 12-2: (HDA, 24-2: (710)
1											Robit souther family many 4 mpc x (#4	
73.6	Earth	3580	9%	8.732	3525,606	÷.	392,008	391,513	3.816.820	3.99		HS. Table 10-2, p376-277
The	Earth	1.488	1950	0.622	2,823,940	5	490,000	435,169	3,312,009	4.10		H5. Table 10-2, p276-277
11.0	Earth	1.545	9/2	160	2 164 (07	4	382,008	381,204	2.5%.840	3.00		HS Table 10-2 p276-277
(TM carectors	In parist	500	92	0.954	1.540.775	- 4	2	10,450	1.961.227	0.11		the second se
3408	tian:	0.700	955	0.965	1.100.044	2.	96,000	20,732	1 940,776	0.21		
(16)	Alan	2.106	160	0.511	1,482,780	4	382,000	377,864	1.995,544	3.00		
103	Marc	000	965	0.840	t 187.500	1	96,000	87,261	1.275.180	0.01	It card consume as Direct.	-
		4.014	2.896				Fragelant -	867,321	1.134,520	2.54		
		TELS	MON 4		_				624,837		Propulsion segment rooms	
leturn Vehicle Propulsion		1				_				-	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	
08	In transit	200	961	0.629	411.80F	1	94,000	98.675	\$10,483	1.01		
	In transt	1321	160	0.560	338.855	0.	0	73,153	411.808	0.75	Add 2 Delta VI tanks, 198:000 kg properioni	
TEI convictions	th tramet	0.050	941	0.964	122.772	- 1	96,000	715	338.655	0.01	Rybum Whice Main	
(LEO propubling	Lati	5120	412	0.155	42,784			90,009	122,772	0.00	Service Mixbole spect to held 45,000 ket LOXLH2	
		3 821							42.784	1.0	CRV but out mass (2)	Siret4.
							-			-		
fore Minister Mahiria Sheer	Disease of	(I among the local states of the local states	Linkson .	Marra (Barl)	No. of Lots			Every Union	Babal Maura		- Anter	Defension
carother Vehicle Mass												
Exploration Vehicle	5.00	2010		3411	1.1				34.453			Exploration Vehicle Sizing emilisheet
Cargo Landers	15.00			124 075	2				245.149			
Orew Landers	15.00			127.243	2.				254.495			
Propellant Depict	5,99	15.00		32,007	1				12,907		It choices (CCC) kg water per introdute.	HS. Table 11-14, p251
RiteRit					11				1.770		SSBNS tran. ISS	Robotic Systems Data worksheet
		17.00		15.854	2				14.048		197 G MM month	Contraction for the Contraction of the Contraction
Pheipeitac Istar	5.00	15116									144.0 SKI DBUI	Prover Propulsion Serve Light without
Phylovitac Aray Additional aroy area	5.00	ISIN		3,7%	1 2 -				7,422	-	Army area is doubled for Marx distance	Pose Prosition Scholand without
Phylopolitac Array Actificanti array area (Raciatint)	5.00	15.00		3.7%	1	_			7,420		Arcen area is doubled for Marc distance	Prover Production Solve Data working
Phyloxiblac Artas Actificanal artag urea Raciatino Della VI tank set	5.00 5.00 5.10	15.00	_	378) 14 (14 15,40)	÷	_		-	7,420		Active area is doubled for Mars distance Devices of 1 Detta Virtank and	Laurch Vehicle Score workcheet
Phylopeitac Artav Actificani artay area Ballatiers (Della VI Jank set Total Transfer Vehicle	5.00 5.00 5.10	15.10 70.10	_	3.7% 14.124 151.482	1				7.420		Artin and a doubled for Mari Itsiance Drugson of 1 Delta VI lank ed	Liarch Wride Scon workfeet
Photocollac Artav Additional artoy area Barlasters IDetta VI tarvis set Total V tarvis set Total V tarvis et atum Vehicle Mass	5.00 5.00 5.10	15.00		3.7% 14.124 52,482	-				7,411 34,124 6		Anny ann a doorded for Mars Islams Dry types of 1 Della VI lark ad	Lands Wride Score existent
Photovoltac Antav Aculturosi antay ansa Banatimo Detta VI tarvi set Total Transfer Vehicle atam Vahicle Mass Lab Modules	5.00 5.00 5.10 5.00	15.00 70.00 10.00		3.710 14.724 152,400					7.420 7.420 14.124		Den mann al decided for Mann distance Den mann of 1 Detta VI lank ant Trokades 2020 kg watter per misuite	Haven Vehicle Score volicitient
Preispesitas Artav Astificional arteguines Barlatimis Della VI lanii set Todal Transfer Vehicle atam Vehicle Mass Lab Mokares Toda Tropoles	5.00 5.00 5.10 5.00 5.00	15.10 70.10 10.00 10.00		1710 14.724 52.400 22.001 23.567	-				7.570 14.124 6 18.265 46.714		Army and is disorted for Warn disberor Des rupps of 1 Detta VI lank of Includes 2000 Ap water per missile Includes 2000 Ap water per missile	Poset Production Science united and writing Linearch Vehicle Science workpland 185, Table 15-14, p.257 195, Table 15-14, p.257
Photovistac Artav Acathonal acou unso Batatimo Detta VI taxis set Total Transfer Vehicle starer Vehicle Mass Lab Modures Nock-Modures Science Parloages	5.00 5.00 5.10 5.00 5.00	15.00 70.00 10.00 10.00		178 14.04 12.40 20.91 20.95 1.90	4 4 4				7.620 34,124 624,125 81,265 46,714 1,500		Do monato Anna anna a disobite tor Mara Ilisianov Dei rappo nit i Delta Vi tark ed Incluses 3000 ko salter per mosile Incluses 3000 ko salter per mosile	Protect Production Scing Land without Latench Writede Scings works/best HS, Table 15-14, p257 HS, Table 15-14, p257 HS, Table 15-14, p257 HS, Table 15-14, p257
Photoesibac Artav Additional active ranks Backsteins Della VI Dani ved Tatkal Transfer Vehicle atter Vehicle Mass Lab Modales Node Modales Science Facebares Capita	5.00 5.00 5.10 5.00 5.00 2.00	15.10 15.10 70.10 10.00 10.00 10.00		17% 14.1% 12.4% 20.9% 1.9% 2.0%	-				7.620 34.124 624122 81.281 46.714 1.000 16.000		De a fin alle de la constant per final de la persona Des ingues et la Cente VI fante del Techades 3000 kg autor per ministri Techades 3000 kg autor per ministri	Free Freiden sons bai versiehen Lande Verlage Score wonighent HS, Table 11-14, p257 HS, Table 11-14, p257 NASA ESAS Sonity
Protocoltac Antor Applications area area Dela VI Jack and Tata Travelle Mass Lish Moden Jose Moden Jose Moden Carola (CP/ Detrives	5.00 5.00 5.10 5.00 5.00 2.00 2.00	15.00 70.00 10.00 10.00 10.00 10.00 10.00 10.00		1778 14 724 52,480 72,387 73,387 1,585 2,000 500					7.520 14.124 6 18.265 46.714 1.000 15.000 1.000		20 a 1979 alex a decisión for Marci desprox Alexa para a la Conta Vo Marci desprox Des spans al 1 Denta Vo taris set Vocades RODO da valtar per missula Dobales RODO da valtar per missula	Free Freichte Scrig Lau virgeleit Laurch Veligte Scrie wollicheit HS. Table 15-14, p357 HS. Table 15-14, p357 HS. Table 15-14, p357 HSA 15545 South
Pretovellac Antor. Additional action area Barlatino: Default faces set Takai francefer Websche starer Vehicle Mass Use Modern Stater Ander Sonere Pretoven Carola (Carola (Carola Bacotos)	5.00 5.00 5.10 5.00 5.00 7.00 2.00	15.00 70.00 10.00 10.00 10.00 10.00 10.00 200		1700 14.194 12.462 20.197 1.000 2.000 500 4.770					7,520 34,524 6 46,214 46,214 1,000 16,000 1,000 1,000 1,000		De a tra la la discritei fur Man distance Des insues al 1 Cente VI fante sel Inclusion (2007 Ag watter per mosale Inclusion (2007 Ag watter per mosale Inclusion (2007 Ag watter per mosale SISTRAT Accession)	Freed Production Science Law Ampulate Lawych United Science wonleybert HS, Tabler 11: M, p.157 HS, Tabler 11: M, p.157 HSAA ESAS Sould Robotic Science Data with Beet
Protocoliac Actor Acatematica and area Paratama Desis Vi Jank and Tacal Transpired Vehicle Attam Vehicle Mass Lab Moders I Jab Moders I Jab Moders I Jab Moders I Jab Moders I Soner Paratages I Carola I Directors I Carola Directors I Carola	5.00 5.00 5.10 5.00 5.00 2.00 2.00 5.00	15.00 70.00 10.00 10.00 10.00 10.00 10.00		22,001 14,000 12,400 22,001 22,567 1,000 2,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000					7,420 34,124 64,125 46,714 1,0000 1,0000 1,0000 1,000 1,000 1,000 1,000		Jacob Selan Kana Janua Kana Kalan Kalan Din Supa Jari Josha Vi Jank ad Trouanes 3000 Ag water per misuae Incluaes 3000 Ag water per misuae Incluaes 3000 Ag water per misuae Incluaes 3000 Ag water per misuae	Preservision Constraints Science under Laurch Vehicle Science under His. Rate 11-14, 2257 NASATSAK State Rocket, Repairing Data under Rocket, Repairing Data under Rocket, Science Data
Protocolitate Actas Antibroni actas una Bariston Denis Vi pars and Theat Transfer Vahide atam Vahide Mass Lab Moden Nade Moden Some Fransper Carota Carota Carota Carota Carota I Brootes Denotes Server Fundar	5.00 5.00 5.10 5.00 7.00 7.00 7.00 5.00 5.00	15.00 70.00 10.00 10.00 2.00 2.00 5.00 15.00		22,001 19,124 12,450 12,557 1,000 2,000 5,000 1,250 1,250 1,250 1,250 1,250 1,250					7,420 34,124 61,4124 61,245 46,714 1,200 1		De tropa de la contret for Mars debroy Des tepas de 1 Della VI laña et Rocales, ROD da autor por mocian Incluies, ROD da autor por mocian Incluies, ROD da autor por mocian Incluies, ROD da autor por mocian SSIRIE dona SSI	Preservices and the source sensitive of the sensitive of the source of t
Protocolina Artan Jaditsona sera ana Badatam Deta Visas set Deta Visas set Deta Visas set Itala Nostan Node Nobles Science Paragen Datola (Carr Fernina Ristona (Carr Fernina Ristona) (Carr Fernina Ristona (Carr Fernina Ristona) (Carr Fernina) (Carr Fernina Ristona) (Carr Fer	5.00 5.00 5.00 5.00 7.00 7.00 7.00 5.00 5	15.00 70.00 10.00 10.00 2.00 2.00 5.00 65.00 65.00 2.00		3,276 14 (14 12,460 20,987 1,297 1,2				0	7,420 34,124 6,244 1,245 6,274 1,265 6,274 1,265 1,225 1,225 1,225 2,225		Anny serie a doctine tor twen deproy Dos separa of 1 Entia VI lank ant Incluient 5000 da valate per movale incluient 5000 da valate per movale incluient 5000 da valate per movale SMEME terro 105 2 w/s, per crem metricer + daar en.	Preservice Sore una enterte Tainet Vehicle Screa exclution PS. Rate 11:14 (2017) INS Rate 11:14 (2017) INS RESS Soleth Rotots, Soleth Data enterte Rotots, Soleth Data enterteen
Protocolitac Actas Antiferina sease una Baladiant Deta VI Jank set Total Travaster Vehicle Lab Molde Nach Model Science Frasper Garota Carto Entite ICP Fertition Resoto ICP Centition Server Model Server Model Server Model DOR Capacit Server Model Server Model Server Model Server Model Server Model Server Model	5.00 5.00 5.00 5.00 2.00 2.00 5.00 5.00	15.00 70.00 10.00 200 200 5.00 15.00 15.00 200		22,001 14,724 12,402 22,001 1,000 2,000 1,0000 1,0000 1,000 1,000 1,000 1,0000 1,000 1,000 1,000				3	7,450 34,126 66412 66,714 1,000 1,00		Afrika Janes & disalifer for Marc Jataney Den Ingen af 1 Ontek V lank ant Probates 2000 As willing per mesuae Includes 2000 As willing per mesuae Includes 2000 As willing per mesuae Includes 2000 As will per consult Statistical Associations of the Association Statistical Associations of the Association	Preservice Centre Science understand Laurech Vehicle Science understand Hist. Basier 15-14, p.152 Hist. Tasser 15-14, p.152 Hist. Science Centre Science Restorts: Science Centre Science NetScience, Science Centre Hist. Science, Science Centre Eris, Science, Science, Science, Science Eris, Science, Science
Protocolinic Actor Additional server and Data Visional Toronal Toronal Toronal Toronal Visional Toronal Toronal Visional Instant Notalies Science Factories Care Combine Care Combine Combi	5.00 5.00 5.00 5.00 7.00 7.00 7.00 5.00 5	15.00 15.00 70.10 10.00 2.00 2.00 5.00 5.00 5.00		3,770 14,724 12,460 22,001 22,567 1,500 2,000 2,000 3,000 1,775 1,500 4,7400 4,7400 4,7400 4,7400 4,7400 4,7				a	7.520 14.124 14.124 14.124 1000 1000 1000 1000 1000 1000 1000 1		Anna seni a disclete for Stan Indone Des spass al 1 Della VI San Indone Totalano 1920 da catero per mosile robano 1920 da catero per mosile 2 seto per cate mentiler + silaeriti	Paser Prop. Carl Science were and lacenth Minde Science were added 198, Index 15, 34, 4257 1985, Science 15, 44, 4257 1985, ATE Science 2002 were added Robotic, Science 2002 were added Robotic 2002
Protocollate Area Anditroni Serge ana Paralistica Deals Villanis set Total Transfer Vehicie Inter Vehicie Mass Inter Vehicie Mass Inter Vehicie Mass Inter Vehicie Carota	500 500 510 500 500 200 500 500 500 500 500 500	15.00 15.00 10.00 10.00 10.00 200 5.00 5.00 15.00		2700 14.724 12.462 22.857 1.963 2.957 1.963 2.957 1.963 4.775 1.963 4.775 1.963 4.775 1.963 4.775 1.963 4.775 1.963 4.775 1.963 1.96				0	7,520 34,226 46,244 3,920 46,214 3,920 1,0		Anny area a deciden to Sans Inderne Den seas at 1 chill V Sans and Tracales 1900 da nette por imnolae Tracales 1900 da nette por innolae Stateel fear too Stateel fear too 2 algs per care member * daarte 10 2 algs per care member * daarte	Prover Protocher Schritt und versicher Takenty Minder Schritt versichert His, Taken 15-14, gall? His, Taken 15-14, gall? His/SLE-Schritt Rechter, Schritten Data versichert His/Schritten Data versichert Protock Total sollten. Protect Production, Schridt Data versichert Protect Production, Schridt Data versichert
Protocollate Areas Acalitonia eras anas Bandania eras anas Della Vilacia sel Toscia Vilacia sel Toscia Vilacia Massi Li Jak Modelen I Skole Modelen I Skole Modelen I Skole Modelen I Skole Modelen I Skole Modelen I Skole Skole I Skola Skole Feld Skole Potostal Acalitatia Areas anas	500 500 510 500 700 200 500 500 500 500 500 500	15.00 15.00 70.10 10.00 10.00 2.00 2.00 1.00 15.00 15.00		2700 14 704 12 460 20 00 20 167 1 000 2 000 5 00 5 00 5 00 5 00 5 00 5 00				9	7,450 14,255 46,714 1,000 1,00		Acting and a decided for Menn Bachrey Don space of 1 Polity V Steen Bachrey Versauer, Stock Steen Berg monute Inscise III V Steen Berg monute Stolliget Bachr Sto 2 setti Berg Colo 2 setti Berg	Tree Franchis Schule and Link entropy Land Mittel Schule and Mittel 18 Jane 11 4 (2017) 18 Jane 11 4 (2017) 19 Jane 11 4 (2017
Protocollate Areas Antibronic actors area Basiltania Datali Nanesket Vehicle Like Moders Robert Norders Somer Protection Garb Enforders Garb Enforders Garb Enforders (Großenstein Basiltania Somer Protection (Großenstein Basiltania Somer Protection Somer Protection Somer Protection Somer Protection Somer Protection Somer Protection Protection Areas Auffranzia Areas and Antiperty Protection	500 500 510 500 700 200 500 500 500 500 500 500	15.00 15.00 10.00 10.00 2.00 2.00 10.00 15.00 15.00		3,776 14,724 12,452 22,87 23,557 2,000 5,0000 5,000 5,000 5,0000 5,000 5,000 5,0000 5,0000 5,000				1	7,450 94,526 94,526 94,526 94,524 1,000		After anna a balante to Vien Inanne Den Ingel I. Dela V Julie al Viralan RUCA de etter por molan Tradan RUCA de etter por molan Tradan RUCA de etter por molan Dela Dela Dela Sectoria de este 2005 filman de 2005 filman de este 2005 filman de este	The Products Soft Link ended Land Michael Some anticipant His Rate 15 4 (2017) MISSI Soft Link (2017) MISSI SSS Soft MISSI SSS SOFT MISS SOFT MISSI SSS SOFT MISSI SSSS SOFT MISSI SSS SOFT MISSI SSS SOFT MISSI SSS SOFT MISSI SS
Protostilac Area Autoros area area Bastarro Dela Vitas até Tosai Trongér Velan Racé Moder Noce	5.00 5.00 5.10 5.00 2.00 2.00 5.00 5.00 5.00 5.00 5.0	15.00 15.00 10.00 10.00 200 200 15.00 15.00 15.00 70.00		27.00 14.08 12.460 20.07 1.090 2.000 5.00 5.00 5.00 5.00 5.00 5.00 5.				1	7,420 34,124 46,214 46,214 46,214 46,214 46,214 46,214 46,214 1,000 1,00		Affen einen aus Asseine für Mein, Baieren Den Insein 41 Dehlu Y Baie, auf Unseine 1921 das einer om meine Deblem, 1921 das einer per sonder Deblem, 1921 das einer per sonder Deblem, 1921 das einer Deblem Zu Berlanden und das einer Steater Zu Berlanden das einer Steater Deblem das einer Steater Deblem deblem das einer Steater Deblem deblem das einer Steater Deblem deblem das einer Steater Deblem deblem deblem deblem deblem deblem Deblem deblem deblem deblem deblem deblem Deblem deblem deblem deblem deblem deblem deblem Deblem deblem deblem deblem deblem deblem deblem deblem deblem deblem Deblem deblem deblem deblem deblem deblem deblem deblem deblem deblem deblem Deblem deblem deblem Deblem deblem deb	The Products of Lab and Lab an

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Mars Mission Story Board

Appendix F

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only. NASA Marshall Space Flight Center / Full Time Study Program

114



Assembly Concept 1

- Assemble entire vehicle from nadir port of ISS
- Issues
 - Requires mobile crane system to travel length of vehicle
 - Requires constant relocation of propulsion system for re-boost



David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Assembly Concept 2

- Assemble habitable sections at ISS and propulsion sections separately
 - Transfer habitats and propulsion module attached to nadir port
 - Landers assembled off transfer habitat ports
 - Propellant depot, power systems and propulsion stages assembled separately
- Benefits
 - Transfer habitats and Landers assembled at the ISS
 - Propulsion elements assembled safely away from ISS
 - Propulsion module or Exploration vehicle used for ISS re-boost



- Issues
 - Options for docking of large masses
 - Automated rendezvous
 - Docking using remote operated mechanical arms
 - Tether connections using winch mechanisms

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Earth Departure

- 1. Earth departure or Trans-Mars Injection (TMI)
- 2. 1 of 4 TMI stages burn out and drop off.
- 3. Remaining 3 stages burn out and outer 2 drop off. Center stage remains attached to electrolysis unit (Propellant Depot)
- 4. Side thrusters rotate habitat





David Smitherman / ED04 Advanced Concepts Office

All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Mars Arrival

- Thrusters stop rotation and last two TMI stages are used to de-accelerate and enter into Mars orbit
- 2. Vehicle separates to reconfigure
- 3. Remaining TMI stage(s) becomes a free-flying Propellant Depot
- 4. Landers dock to ports and the ends of the Transfer Habitat modules





David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.

Program

NASA Marshall Space Flight

Center / Full Time Study



Exploration Scenario

- 1. Automated Lander 2 and 4 depart first and land near the outpost site. Lander 4 contains power module and pressurized rover
- 4 crew members depart on Lander 1 to deploy power module and pressurized rover

 4 more depart on Lander 3 once deployment completed
- An option is for 2 crew members to remain on board the transfer station for the Phobos / Deimos missions
- 4. The Phobos / Deimos mission is two weeks or longer, so this can be done before during or after the surface stays
- A surface depot is set up for the two automated Landers to deliver water to the Propellant Depot for propellant production
- Rotating the Transfer Station at 3 RPM would provide 1/6-g for any long term crew stays while in orbit and during return to earth





David Smitherman / ED04 Advanced Concepts Office

All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Surface Outpost Setup

- Cargo Lander 4 is the first to land in a remote area out of the line of site from the outpost. This will be the location for the nuclear power (NP) unit. Radiation options include:
 - Operate on Lander 4 out of line of site
 - Burial of reactor unit
 - Encapsulation or reactor unit with Martian soil or water obtained from Mars in water bladders
- 2. Payloads are deployed, and checked out by the Lander 1 crew







David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Notional Outpost Site Layout



David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Mars Departure

- 1. Landers 1 and 3 have an Ascent Vehicle on top designed for 4 crew members
- 2. If surface refueling is successful then the entire Lander can be refueled and used for ascent and descent throughout the mission duration
- 3. Upon completion of their missions at Phobos and Deimos the other crew members return to the Transfer Station
- 4. Ascent Vehicles return crew to the Transfer Station
- 5. Reusable Landers and Transfer Vehicle remain at the Propellant Depot for reuse on future missions



David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Earth Return

- 1. Last two stages are used to return the Transfer Habitat to Earth, Trans-Earth Injection (TEI)
- 2. Habitat can be rotated during the return phase up to 3 rpm for 1/6 g
- Crew returns directly to surface via the capsules on the 2 Crew Return Vehicles. Each holds 4 crew members plus sample returns
- 4. Saving the Transfer Station is not possible until after the 3rd mission when an operational propellant production capability is established in Mars orbit and on the surface



David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



ISS Components Utilized in Design

Appendix G

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



ISS Statistical Data

- Mass: 232,693 kg (513,000 lb)
- Length:58.2 m (191 ft) along truss
- Width: 44.5 m (146 ft) from Destiny to Zvezda span of solar arrays
- Height:27.4 m (90 ft)
- Living volume 424.75 m³ (15,000 ft³)
- Atmospheric pressure: 101.3 kPa (29.91 inHg)
- Perigee: 339.3 km (183.2 nmi)
- Apogee: 341.8 km (184.6 nmi)
- Orbit inclination: 51.64 degrees
- Typical orbit altitude: 340.5 km (183.86 nmi)
- Average speed: 27,743.8 km/h (17,239.2 mi/h, 7706.6 m/s)
- Orbital period: 91.34 minutes
- Orbits per day: 15.76

David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.







ISS Derived Power & Thermal

28 kW Solar Power Unit

- Standard unit provides power for habitat and propellant depot systems
- Derived from ISS systems
- Includes storage batteries
- Design provides for rotational mechanisms to track sun

Thermal Radiator Unit

- Derived from ISS systems
- Thermal radiators include a fluid loop from the habitat to provide transfer of waste heat out of the habitat





David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Space & Surface Habitat Modules

ISS Destiny US Laboratory Module

- Specifications
 - Length: 8.53 m
 - Diameter: 4.27 m
 - Mass: 14,500 kg (32,000 lb)

Laboratory Module

- 4 Laboratory modules include
 - Materials
 - Mission Operations
 - Life Sciences
 - Greenhouse
- Specifications
 - Length: 10 m
 - Diameter: 5 m
 - Mass: 18,918 kg





David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Space & Surface Habitat Modules

ISS Harmony Node II

- Specifications
 - Length: 7.2 meters
 - Diameter: 4.4 meters
 - Volume: 75 cubic meters
 - Mass: 14,288 kilograms

Node Module

- 2 Node modules include a built-in airlock
 - EVA Node / Airlock
 - Galley Node / Airlock
- Specifications
 - Length: 10 m
 - Diameter: 5 m
 - Mass: 21,369 kg





David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Other Attached ISS Components

ISS Cupola

- Specifications
 - Overall height: 1.5 m
 - Maximum diameter: 2.95 m
 - Mass: 1,880 kg

ISS Quest Airlock

- Specifications
 - Material: aluminum
 - Length: 5.5 m (18 ft)
 - Diameter: 4 m (13 ft)
 - Weight: 6,064 kg (13,368 lb)
 - Volume: 34 m³ (1,200 ft³)
 - Cost: \$164 million, including tanks
- Capabilities included in Node modules





David Smitherman / ED04 Advanced Concepts Office

All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



ISS Robotic Systems

 All ISS robotic systems are used as a baseline for the assembly and maintenance systems for the Lunar Test Mission Vehicle and the Mars Ship



David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



Payload Racks

ISS International Standard Payload Rack (ISPR)

- Specifications
 - Slots available: 64
 - Volume: 1.571 m³ (5.55 ft³)
 - Rack Mass: 104 kg (230 lbs)
 - Equipment Mass: 700 kg (1540 lbs)
 - Sub-rack accommodations:
 - Spacelab drawers: 483 mm (19 in) width
 - Space Shuttle Mid-deck Locker



- Standard Payload Racks utilized in walls
- Air & power systems above Ceiling
- Water and storage systems below floor
- 7 foot floor to ceiling height
- 8 foot width to accommodate center counter



David Smitherman / ED04 Advanced Concepts Office

All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



ISS Multi-Purpose Logistics Module

 Modules like the Multi-Purpose Logistics Module (MPLM) are anticipated for all recurring missions at the Moon and Mars. The open end ports on all surface habitat modules are designed for mating of additional modules



David Smitherman / ED04 Advanced Concepts Office All calculations are based on the author's interpretation of the formulas, data, and rules of thumb found in the text, "Human Spaceflight: Mission Analysis and Design" by Larson & Pranke. This presentation is for educational purposes only.



David Smitherman / ED04 Advanced Concepts Office

All calculations are based on the authors interpretation of the formulas, data, and rules of thumb found uppe text, "Human Spaceflight: Mission Analysis and Design" by Larson & Prace. This presentation is for educational purposes only.