

# 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

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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

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#### **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

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#### **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

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#### 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.



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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

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# 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.

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# 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





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#### 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

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### **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

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#### 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.

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### **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.

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### 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

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#### **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.

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# 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

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#### **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)

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#### 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

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### Delta IV Derived Launch Systems

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| 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  |            |
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### 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

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# 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

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# 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

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### 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

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#### **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



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### **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





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### Mission Analysis and Design

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### 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



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#### 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

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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 m<sup>3</sup>
- 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 m<sup>3</sup>
- Crew Size: 8

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#### 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 m<sup>3</sup>
- Crew Size: 8



Mars Ship after 3<sup>rd</sup> 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 m<sup>3</sup>
- Crew Size: 8

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# 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

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# **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

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#### 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)

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#### Variable Gravity Configuration



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### **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<br>This worksheet is used to calculate the too<br>coolide exception fragments including<br>Payloads Mass Summery worksheet. In a<br>calculated kang the Cargo Lander cascula<br>resizance Creak Lander | a gross of Re<br>propellant tan<br>non-reveable<br>Note: Note IN | ucalaine Cango<br>A alaota : Rayka<br>catrifigueration<br>al life critisi an | Lancers and<br>and data to in<br>the extention<br>role! Mas & Ch | Revatole Crea<br>out automatical<br>occule becomes<br>ou motive (32) | w Lancers, sm<br>Ny from the Sk<br>Is poyleted and<br>CC kg) Mache | no lo<br>Lufaco<br>Loari br<br>Si Billine  | 04.8               | iches<br>reen Process constraines<br>into constraines<br>into inked to other wo<br>il other cells are from<br>itermediate output da | routing add front<br>Orbout attac<br>Interests<br>reference Gata or<br>Ia. |               |               |                |               | Mare La   | New Nong<br>This worksheet is used to capculate the tota<br>received recomments including processor<br>formings worksheet, in a non-muscale con<br>large Lancer capculations. Note that the or   | i gross of Reus<br>tark sizes. Pa<br>riguration the s<br>ew ander has t | isole Cargo Lan<br>Voise dels la ric<br>subert module i<br>s crew matike i | Sers and Re<br>M automati<br>ecumes pitu<br>ROOD kgi ett | eusable Crew I<br>Cally from the<br>pload and can<br>fached to the r | Landers, and<br>Surface Pay<br>be calculate<br>evidable Cre | to calculate<br>case (Asis<br>i using the<br>v Lander, |         | Notes<br>Green rd<br>Red wood<br>Cata Inte<br>Al other o<br>intermedia | cates cells reg<br>lies pormally on<br>d to other work<br>els are from re<br>te output data. | Naimg user input<br>our other<br>sheets<br>ference data or |             |   |
|---|--|--|--|--|--|--|--------------------|---|--|---------------|---------------|----------------|---------------|-----------|--|---|--|--|--|---|--|---------|--|--|--|-------------|---|
|   | Fantian  | Della V  | 11   | Mass.<br>Frailine  | Dry Mass   | Propertient 1  | Nei Marce          |   |  |               |               |                |               |           |  | Planetary   | DetaV  | -  | Mass<br>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<br>procelant -   | ED DES   | 14.514<br>14.540 B | um out mass al orbit  | al depot   |               |               |                |               |           | Steadin Pariolic Lander  |   |  | 724  | 4.427  | Total<br>proceitant -                                       | 52.325   | 15.650  | Burnout  | tass al orbital (  | cenat  |             |   |
| Englishie Crow Lander   | Paretary<br>Body   | Deta V<br>Ansisi   |  | Mass<br>Frastice<br>(mitmo)  | Dry Mass-  | Propeliant N   | vel stass          | iotes   |  | Relateratio   |               |                |               | Baugan    | n Crew Lander  | Planetary<br>Body   | Detta V<br>Bimst   | ko   | Masic<br>Presilion<br>Intitrici                                      | Ory Maks  | Propertant<br>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<br>Recuired   | Sur  | This wo  | oade Mai<br>orksheet i<br>Sizing w                                 | es Summa<br>is used to a<br>orksheets.   | iry<br>isouate     | the total lande   | d payload ma   | is. Add and ( | modify as nee | ded. Celis are | linked to the | 6         | Notes<br>Green indicates cells regul<br>Fies indicates primary sub<br>Data Inixed to other worksh<br>All other cells are from refe<br>intermediate output data.  | ing user i<br>di sata<br>teets<br>rence data                            | npud<br>a or   |  |  |   |  | 1       | 1  |  | Sha franzifer habitat<br>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<br>Photow   | luclear Po<br>oltaic Arra  | ower Unit o<br>av  | r Lunar            | 5.00  | 5.00   | -             | 10,000        | 2              | <u>}</u>      | 20,00     | o 25 kW each. Solar and Nut<br>total mass.   | clear syste   | ems have s   | imijar <sub>N</sub>                                      | ASAESA   | ks Study  | n z  |         |  | -  | t load is input here<br>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   | +- <b>-</b> -  |  |  |  | -                  |   |  |               |               |                | -             |           | 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<br>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

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#### **Primary Payloads**

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

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# Lander 2 Deployment



#### **Primary Payloads:**

- Greenhouse Module
- Galley / Airlock Node
- Surface Equipment

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# Lander 3 Deployment



#### Primary Payloads:

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

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## Lander 4 – Lunar Power System

4



- Pressurized Rover
- Solar Power Module
- Surface Equipment

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# Lander 4 – Mars Power System

4



- Pressurized Rover
- Nuclear Power Module
- Surface Equipment

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# Transfer and Surface Habitat Sizing



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## 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

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# 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

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#### **Cross-Section of Habitat**



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# Transfer and Surface Habitat Configurations



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# 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





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#### **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<br>requirments including propelant<br>the Habitat Sizing Tool. The Ma<br>to do to an esteroid. | ale the total gro<br>tank sizes. Pa<br>is Mission IS sta | se (wet) mai<br>yload data is<br>sic for elipto | is of the Expl<br>input automa<br>ration of Photo | ration Venime, a<br>toally using a st<br>calant Detrica | ind to calculate<br>andard hastlat<br>The Lunar Atiss | propeliant<br>module from<br>ann le assumed |          | Green Indicates cells requiring user input.<br>Green Indicates proved scene table<br>Data Intest to other workshoets<br>Al other cells are from reference data or<br>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<br>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<br>equivalent to one lab module.   |   |
| ander  | Tank Sizas  | Data   | Unita   | _   |   | 1   |   |          | Halas  |   |
|        | Propellant  | 12 362   | MQ.   | -   |   |   |   |          | Maximum lander properant load is input here<br>automatically to size standard tanks for all four<br>landers  | Use 'Tank Sizing Tool' for verification and more<br>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<br>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<br>thickness   |   |
|        | Length of LOX & LH2 tank In a<br>stacked configuration  | 5 65   |   |   |   |   |   |          | Length includes half spherical end domes and wall<br>thickness   |   |





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# Program Planning

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#### **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





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# Lunar and Mars Vehicle Assembly Launches

| Loter Test Minister Loverth Coll.            |                          |                         |                               |                    |              | leres .  | _        | Muris  | Meston Launch Coll  |                            |                    |                             |                 |                   | NODE  |             |
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|  | -                        | 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<br>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><br>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<br>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<br>Résidual Procétant  | 16,790 2                   | -                  | 33,581                      | _               | 30                | 0   | -           |
| Creat Lative                                 | 20342 2                  |                         | 41.661                        |                    |              |  |          |  | Crew Lander   | 22,790 2                   | -                  | 45,581                      |                 |                   |   |             |
| (Residual Propelant<br>Transfer Vehicle Mass | 1500 2                   |                         |                               |                    | 8.00         |  |          | Transf   | Inteligual Plotelant<br>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<br>Robotes  | 12,007                     | 1 75               | 32,007                      |                 |                   | -   |             |
| Protocitat Array                             | 1.770 I<br>18424 2       | 1,775                   |                               |                    |              |  |          |  | Photovoltaic Artay  | 15.534 2                   | 31.64              |                             |                 |                   |   | -           |
| Rasialors                                    | 12,024 1.                | 14:124                  |                               |                    |              |  | _        |  | Additional array area<br>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<br>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<br>Protosotalo Array  | 15.824 2                   | 31.64              |                             | _               |                   | -   | -           |
| Photo-cities Artas<br>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<br>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<br>80 6             |                         | 4(0)                          | 450                |              | 16.00  |          |  |   | 80 5                       |                    | 420                         | 244             |                   | 5 Deta IV units<br>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                       |                    |                             |                 |                   |   |             |
|  |                          |                         |                               |                    |              |  |          |  |   |                            |                    |                             |                 |                   |   |             |
|  |                          |                         |                               |                    |              |  |          |  |   |                            |                    |                             |                 |                   |   |             |
|  |                          |                         |                               |                    |              |  |          |  |   |                            |                    |                             |                 |                   |   |             |

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# 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

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# **Recurring Mars Missions**

- After the 3<sup>rd</sup> 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** 

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# Lunar and Mars Program Cost & Schedule



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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

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# 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 3<sup>rd</sup> 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

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## 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

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# 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

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# 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

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## **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

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## 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         |

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#### **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

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#### **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)

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#### **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

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# **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<br>and used as the Mars Ship assembly platform<br>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<br>and/or Soyuz), 2 servicing flights per year<br>(Progress or others), and 8 cargo flights per year<br>(Delta IV and others); two major assembly<br>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<br>Thermal Generator systems. Provide adequate<br>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<br>capable launch systems include Ariane, Proton,<br>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.  |

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## 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             |

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# **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.   |
|  |   |

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| 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<br>emergency pressure balls on inside for stranded<br>crew         |
| Provide two EVA suites for each crew member  | Suits to be modular in design for repair capability  |

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# 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,<br>pressurized rovers, un-pressurized rovers,<br>pressurized hoppers, and EVA |
| All mobile systems carry 8 crew in an emergency<br>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                            |   |

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# **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<br>emergency access   |
| Some systems and supplies may be sent ahead of time prior to crew arrival                                  | Extra water, propellants, supplies, and habitable volumes<br>may be sent ahead of time if mission scenario seems<br>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?)      |

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# Mars Mission Elements

#### Appendix B

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

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## 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

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## 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.

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## 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

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#### 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

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## 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

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## 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

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# Habitat Design Drawings

Appendix C

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## **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"

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

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# 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.



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# 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



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## **Standard Node Interior Elevation**



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## Materials Science Module



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

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# Node / Airlock Modules



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

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# **EVA Equipment Module**



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

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#### Life Sciences Module



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

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#### **Greenhouse Module**



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

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#### **Pressurized Rover**



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

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# Surface Habitat Outfitting



Crew Accommodations



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## **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



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# Habitat Module Model

Appendix D

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# Model Production Equipment

Equipment

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







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## Plastic Model



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# Future Launch and Propulsion Systems

Appendix E

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### 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

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# 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



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# Coil Gun Launch Tube Animation



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# **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<br>The Activities of the second<br>Vehicle in the according<br>straggif back to (.E.f.) also | potter for pro<br>the CRV has<br>in togetal pla | utiler nähe<br>4 Serves ko<br>5 Brougt 4 J | y tokowiatika y<br>njek siseli ta i<br>Gar tivrsta kilja | together failt for<br>ing the case of<br>rSF sector op | NAME<br>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 <sup>x</sup> | 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<br>The anti-plant large 1<br>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<br>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<br>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<br>Actificanti array area<br>(Raciatint)  | 5.00  | 15.00  |           | 3.7%   | 1           | _             |                 |             | 7,420  |              | Arcen area is doubled for Marc distance   | Prover Production Solve Data working   |
| Phyloxiblac Artas<br>Actificanal artag urea<br>Raciatino<br>Della VI tank set  | 5.00<br>5.00<br>5.10  | 15.00  | _         | 378)<br>14 (14<br>15,40)   | ÷           | _             |                 | -           | 7,420  |              | Active area is doubled for Mars distance<br>Devices of 1 Detta Virtank and  | Laurch Vehicle Score workcheet   |
| Phylopeitac Artav<br>Actificani artay area<br>Ballatiers<br>(Della VI Jank set<br>Total Transfer Vehicle   | 5.00<br>5.00<br>5.10  | 15.10<br>70.10   | _         | 3.7%<br>14.124<br>151.482  | 1           |               |                 |             | 7.420  |              | Artin and a doubled for Mari Itsiance<br>Drugson of 1 Delta VI lank ed  | Liarch Wride Scon workfeet   |
| Photocollac Artav<br>Additional artoy area<br>Barlasters<br>IDetta VI tarvis set<br>Total V tarvis set<br>Total V tarvis et<br>atum Vehicle Mass   | 5.00<br>5.00<br>5.10  | 15.00  |           | 3.7%<br>14.124<br>52,482   | -           |               |                 |             | 7,411<br>34,124<br>6   |              | Anny ann a doorded for Mars Islams<br>Dry types of 1 Della VI lark ad   | Lands Wride Score existent   |
| Photovoltac Antav<br>Aculturosi antay ansa<br>Banatimo<br>Detta VI tarvi set<br>Total Transfer Vehicle<br>atam Vahicle Mass<br>Lab Modules   | 5.00<br>5.00<br>5.10<br>5.00  | 15.00<br>70.00<br>10.00  |           | 3.710<br>14.724<br>152,400   |             |               |                 |             | 7.420<br>7.420<br>14.124   |              | Den mann al decided for Mann distance<br>Den mann of 1 Detta VI lank ant<br>Trokades 2020 kg watter per misuite   | Haven Vehicle Score volicitient  |
| Preispesitas Artav<br>Astificional arteguines<br>Barlatimis<br>Della VI lanii set<br>Todal Transfer Vehicle<br>atam Vehicle Mass<br>Lab Mokares<br>Toda Tropoles   | 5.00<br>5.00<br>5.10<br>5.00<br>5.00  | 15.10<br>70.10<br>10.00<br>10.00   |           | 1710<br>14.724<br>52.400<br>22.001<br>23.567   | -           |               |                 |             | 7.570<br>14.124<br>6<br>18.265<br>46.714   |              | Army and is disorted for Warn disberor<br>Des rupps of 1 Detta VI lank of<br>Includes 2000 Ap water per missile<br>Includes 2000 Ap water per missile   | Poset Production Science united and writing<br>Linearch Vehicle Science workpland<br>185, Table 15-14, p.257<br>195, Table 15-14, p.257  |
| Photovistac Artav<br>Acathonal acou unso<br>Batatimo<br>Detta VI taxis set<br>Total Transfer Vehicle<br>starer Vehicle Mass<br>Lab Modures<br>Nock-Modures<br>Science Parloages  | 5.00<br>5.00<br>5.10<br>5.00<br>5.00  | 15.00<br>70.00<br>10.00<br>10.00   |           | 178<br>14.04<br>12.40<br>20.91<br>20.95<br>1.90  | 4 4 4       |               |                 |             | 7.620<br>34,124<br>624,125<br>81,265<br>46,714<br>1,500  |              | Do monato<br>Anna anna a disobite tor Mara Ilisianov<br>Dei rappo nit i Delta Vi tark ed<br>Incluses 3000 ko salter per mosile<br>Incluses 3000 ko salter per mosile  | Protect Production Scing Land without<br>Latench Writede Scings works/best<br>HS, Table 15-14, p257<br>HS, Table 15-14, p257<br>HS, Table 15-14, p257<br>HS, Table 15-14, p257   |
| Photoesibac Artav<br>Additional active ranks<br>Backsteins<br>Della VI Dani ved<br>Tatkal Transfer Vehicle<br>atter Vehicle Mass<br>Lab Modales<br>Node Modales<br>Science Facebares<br>Capita   | 5.00<br>5.00<br>5.10<br>5.00<br>5.00<br>2.00  | 15.10<br>15.10<br>70.10<br>10.00<br>10.00<br>10.00   |           | 17%<br>14.1%<br>12.4%<br>20.9%<br>1.9%<br>2.0%   | -           |               |                 |             | 7.620<br>34.124<br>624122<br>81.281<br>46.714<br>1.000<br>16.000   |              | De a fin alle de la constant per final de la persona<br>Des ingues et la Cente VI fante del<br>Techades 3000 kg autor per ministri<br>Techades 3000 kg autor per ministri   | Free Freiden sons bai versiehen<br>Lande Verlage Score wonighent<br>HS, Table 11-14, p257<br>HS, Table 11-14, p257<br>NASA ESAS Sonity   |
| Protocoltac Antor<br>Applications area area<br>Dela VI Jack and<br>Tata Travelle Mass<br>Lish Moden<br>Jose Moden<br>Jose Moden<br>Carola<br>(CP/ Detrives   | 5.00<br>5.00<br>5.10<br>5.00<br>5.00<br>2.00<br>2.00                                | 15.00<br>70.00<br>10.00<br>10.00<br>10.00<br>10.00<br>10.00<br>10.00   |           | 1778<br>14 724<br>52,480<br>72,387<br>73,387<br>1,585<br>2,000<br>500  |             |               |                 |             | 7.520<br>14.124<br>6<br>18.265<br>46.714<br>1.000<br>15.000<br>1.000   |              | 20 a 1979 alex a decisión for Marci desprox<br>Alexa para a la Conta Vo Marci desprox<br>Des spans al 1 Denta Vo taris set<br>Vocades RODO da valtar per missula<br>Dobales RODO da valtar per missula  | Free Freichte Scrig Lau virgeleit<br>Laurch Veligte Scrie wollicheit<br>HS. Table 15-14, p357<br>HS. Table 15-14, p357<br>HS. Table 15-14, p357<br>HSA 15545 South   |
| Pretovellac Antor.<br>Additional action area<br>Barlatino:<br>Default faces set<br>Takai francefer Websche<br>starer Vehicle Mass<br>Use Modern<br>Stater Ander<br>Sonere Pretoven<br>Carola<br>(Carola<br>(Carola<br>Bacotos)   | 5.00<br>5.00<br>5.10<br>5.00<br>5.00<br>7.00<br>2.00                                | 15.00<br>70.00<br>10.00<br>10.00<br>10.00<br>10.00<br>10.00<br>200   |           | 1700<br>14.194<br>12.462<br>20.197<br>1.000<br>2.000<br>500<br>4.770   |             |               |                 |             | 7,520<br>34,524<br>6<br>46,214<br>46,214<br>1,000<br>16,000<br>1,000<br>1,000<br>1,000   |              | De a tra la la discritei fur Man distance<br>Des insues al 1 Cente VI fante sel<br>Inclusion (2007 Ag watter per mosale<br>Inclusion (2007 Ag watter per mosale<br>Inclusion (2007 Ag watter per mosale<br>SISTRAT Accession)   | Freed Production Science Law Ampulate<br>Lawych United Science wonleybert<br>HS, Tabler 11: M, p.157<br>HS, Tabler 11: M, p.157<br>HSAA ESAS Sould<br>Robotic Science Data with Beet   |
| Protocoliac Actor<br>Acatematica and area<br>Paratama<br>Desis Vi Jank and<br>Tacal Transpired Vehicle<br>Attam Vehicle Mass<br>Lab Moders<br>I Jab Moders<br>I Jab Moders<br>I Jab Moders<br>I Jab Moders<br>I Soner Paratages<br>I Carola<br>I Directors<br>I Carola<br>Directors<br>I Carola  | 5.00<br>5.00<br>5.10<br>5.00<br>5.00<br>2.00<br>2.00<br>5.00                        | 15.00<br>70.00<br>10.00<br>10.00<br>10.00<br>10.00<br>10.00  |           | 22,001<br>14,000<br>12,400<br>22,001<br>22,567<br>1,000<br>2,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000  |             |               |                 |             | 7,420<br>34,124<br>64,125<br>46,714<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,0000<br>1,0000<br>1,0000<br>1,000<br>1,000<br>1,000<br>1,000     |              | Jacob Selan<br>Kana Janua Kana Kalan Kalan<br>Din Supa Jari Josha Vi Jank ad<br>Trouanes 3000 Ag water per misuae<br>Incluaes 3000 Ag water per misuae<br>Incluaes 3000 Ag water per misuae<br>Incluaes 3000 Ag water per misuae  | Preservision Constraints Science under<br>Laurch Vehicle Science under<br>His. Rate 11-14, 2257<br>NASATSAK State<br>Rocket, Repairing Data under<br>Rocket, Repairing Data under<br>Rocket, Science Data  |
| Protocolitate Actas<br>Antibroni actas una<br>Bariston<br>Denis Vi pars and<br>Theat Transfer Vahide<br>atam Vahide Mass<br>Lab Moden<br>Nade Moden<br>Some Fransper<br>Carota<br>Carota<br>Carota<br>Carota<br>Carota<br>I Brootes<br>Denotes<br>Server Fundar  | 5.00<br>5.00<br>5.10<br>5.00<br>7.00<br>7.00<br>7.00<br>5.00<br>5.00                | 15.00<br>70.00<br>10.00<br>10.00<br>2.00<br>2.00<br>5.00<br>15.00  |           | 22,001<br>19,124<br>12,450<br>12,557<br>1,000<br>2,000<br>5,000<br>1,250<br>1,250<br>1,250<br>1,250<br>1,250<br>1,250  |             |               |                 |             | 7,420<br>34,124<br>61,4124<br>61,245<br>46,714<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1,200<br>1 |              | De tropa de la contret for Mars debroy<br>Des tepas de 1 Della VI laña et<br>Rocales, ROD da autor por mocian<br>Incluies, ROD da autor por mocian<br>Incluies, ROD da autor por mocian<br>Incluies, ROD da autor por mocian<br>SSIRIE dona SSI   | Preservices and the source sensitive of the sensitive of the source of t   |
| Protocolina Artan<br>Jaditsona sera ana<br>Badatam<br>Deta Visas set<br>Deta Visas set<br>Deta Visas set<br>Itala Nostan<br>Node Nobles<br>Science Paragen<br>Datola<br>(Carr Fernina<br>Ristona<br>(Carr Fernina<br>Ristona)<br>(Carr Fernina<br>Ristona<br>(Carr Fernina<br>Ristona)<br>(Carr Fernina)<br>(Carr Fernina<br>Ristona)<br>(Carr Fer  | 5.00<br>5.00<br>5.00<br>5.00<br>7.00<br>7.00<br>7.00<br>5.00<br>5                   | 15.00<br>70.00<br>10.00<br>10.00<br>2.00<br>2.00<br>5.00<br>65.00<br>65.00<br>2.00   |           | 3,276<br>14 (14<br>12,460<br>20,987<br>1,287<br>1,287<br>1,287<br>1,287<br>1,287<br>1,287<br>1,287<br>1,287<br>1,287<br>1,287<br>1,287<br>1,287<br>1,287<br>1,287<br>1,287<br>1,287<br>1,287<br>1,287<br>1,287<br>1,287<br>1,287<br>1,287<br>1,287<br>1,287<br>1,287<br>1,287<br>1,287<br>1,287<br>1,287<br>1,287<br>1,287<br>1,287<br>1,287<br>1,287<br>1,287<br>1,287<br>1,287<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,297<br>1,2 |             |               |                 | 0           | 7,420<br>34,124<br>6,244<br>1,245<br>6,274<br>1,265<br>6,274<br>1,265<br>1,225<br>1,225<br>1,225<br>2,225  |              | Anny serie a doctine tor twen deproy<br>Dos separa of 1 Entia VI lank ant<br>Incluient 5000 da valate per movale<br>incluient 5000 da valate per movale<br>incluient 5000 da valate per movale<br>SMEME terro 105<br>2 w/s, per crem metricer + daar en.  | Preservice Sore una enterte<br>Tainet Vehicle Screa exclution<br>PS. Rate 11:14 (2017)<br>INS Rate 11:14 (2017)<br>INS RESS Soleth<br>Rotots, Soleth Data enterte<br>Rotots, Soleth Data enterteen   |
| Protocolitac Actas<br>Antiferina sease una<br>Baladiant<br>Deta VI Jank set<br>Total Travaster Vehicle<br>Lab Molde<br>Nach Model<br>Science Frasper<br>Garota<br>Carto Entite<br>ICP Fertition<br>Resoto<br>ICP Centition<br>Server Model<br>Server Model<br>Server Model<br>DOR Capacit<br>Server Model<br>Server Model<br>Server Model<br>Server Model<br>Server Model<br>Server Model  | 5.00<br>5.00<br>5.00<br>5.00<br>2.00<br>2.00<br>5.00<br>5.00                        | 15.00<br>70.00<br>10.00<br>200<br>200<br>5.00<br>15.00<br>15.00<br>200   |           | 22,001<br>14,724<br>12,402<br>22,001<br>1,000<br>2,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,0000<br>1,0000<br>1,000<br>1,000<br>1,000<br>1,0000<br>1,000<br>1,000<br>1,000 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7,450<br>34,126<br>66412<br>66,714<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,00 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Basier 15-14, p.152<br>Hist. Tasser 15-14, p.152<br>Hist. Science Centre Science<br>Restorts: Science Centre Science<br>NetScience, Science Centre<br>Hist. Science, Science Centre<br>Eris, Science, Science, Science, Science<br>Eris, Science, Science  |
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| Protocollate Areas<br>Acalitonia eras anas<br>Bandania eras anas<br>Della Vilacia sel<br>Toscia Vilacia sel<br>Toscia Vilacia Massi<br>Li Jak Modelen<br>I Skole Modelen<br>I Skole Modelen<br>I Skole Modelen<br>I Skole Modelen<br>I Skole Modelen<br>I Skole Skole<br>I Skola Skole<br>Feld Skole<br>Potostal<br>Acalitatia Areas anas  | 500<br>500<br>510<br>500<br>700<br>200<br>500<br>500<br>500<br>500<br>500<br>500    | 15.00<br>15.00<br>70.10<br>10.00<br>10.00<br>2.00<br>2.00<br>1.00<br>15.00<br>15.00  |           | 2700<br>14 704<br>12 460<br>20 00<br>20 167<br>1 000<br>2 000<br>5 00<br>5 00<br>5 00<br>5 00<br>5 00<br>5 00  |             |               |                 | 9           | 7,450<br>14,255<br>46,714<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,00 |              | Acting and a decided for Menn Bachrey<br>Don space of 1 Polity V Steen Bachrey<br>Versauer, Stock Steen Berg monute<br>Inscise III V Steen Berg monute<br>Stolliget Bachr Sto<br>2 setti Berg Colo<br>2 setti Berg | Tree Franchis Schule and Link entropy<br>Land Mittel Schule and Mittel<br>18 Jane 11 4 (2017)<br>18 Jane 11 4 (2017)<br>19 Jane 11 4 (2017 |
| Protocollate Areas<br>Antibronic actors area<br>Basiltania<br>Datali Nanesket Vehicle<br>Like Moders<br>Robert Norders<br>Somer Protection<br>Garb Enforders<br>Garb Enforders<br>Garb Enforders<br>(Großenstein<br>Basiltania<br>Somer Protection<br>(Großenstein<br>Basiltania<br>Somer Protection<br>Somer Protection<br>Somer Protection<br>Somer Protection<br>Somer Protection<br>Somer Protection<br>Protection Areas<br>Auffranzia Areas and<br>Antiperty Protection   | 500<br>500<br>510<br>500<br>700<br>200<br>500<br>500<br>500<br>500<br>500<br>500    | 15.00<br>15.00<br>10.00<br>10.00<br>2.00<br>2.00<br>10.00<br>15.00<br>15.00  |           | 3,776<br>14,724<br>12,452<br>22,87<br>23,557<br>2,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,000<br>5,0000<br>5,000<br>5,000<br>5,0000<br>5,000<br>5,000<br>5,0000<br>5,0000<br>5,000 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7,450<br>94,526<br>94,526<br>94,526<br>94,524<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000<br>1,000 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# Mars Mission Story Board

Appendix F

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# 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



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# 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

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### 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





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### 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





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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





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### 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







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# Notional Outpost Site Layout



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# 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



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# 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 3<sup>rd</sup> mission when an operational propellant production capability is established in Mars orbit and on the surface



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# **ISS** Components Utilized in Design

Appendix G

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### **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 m<sup>3</sup> (15,000 ft<sup>3</sup>)
- 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

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### **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





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### 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





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### 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





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### **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 m<sup>3</sup> (1,200 ft<sup>3</sup>)
  - Cost: \$164 million, including tanks
- Capabilities included in Node modules





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# **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



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### **Payload Racks**

#### ISS International Standard Payload Rack (ISPR)

- Specifications
  - Slots available: 64
  - Volume: 1.571 m<sup>3</sup> (5.55 ft<sup>3</sup>)
  - 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



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# **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



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