Space Architecture

Master’s Thesis Project

Jain, Abhishek  Dec. 2nd, 2013
## Medium Lift Launch Vehicles Study

<table>
<thead>
<tr>
<th>Funding</th>
<th>Status</th>
<th>Producer</th>
<th>Country</th>
<th>Vehicle name</th>
<th>Payload to LEO (mT)</th>
<th>Fairing diameter (m)</th>
<th>Successes rate</th>
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<tbody>
<tr>
<td>Private</td>
<td>Under dev</td>
<td>Space-X</td>
<td>US</td>
<td>Falcon Heavy</td>
<td>53.00</td>
<td>5.2</td>
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<td>EU</td>
<td>Ariane 5</td>
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<tr>
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<td>CALT</td>
<td>China</td>
<td>Long March 3B</td>
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<td>Delta II</td>
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<td>Yuzhnoye Design Bureau</td>
<td>Ukraine</td>
<td>Zenit 2</td>
<td>13.74</td>
<td>3.3</td>
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Medium Lift Launch Vehicles Comparison

- Falcon Heavy
- H-IIA
- Falcon 9
- Soyuz-FG
- Delta IV Heavy
- Ariane 5
- Long March 3B
- Atlas V
- Delta II
- Zenit 2

- Successes rate
- Fairing diameter (m)
- Payload to LEO (mT)
## LV Selection Criteria

- Capable of human crew transfer
- Maximum payload carrying capacity to LEO < 55,000 Kg
- Preference given to currently active Launch Vehicles
- In order of decreasing fairing diameter
- Success rate

<table>
<thead>
<tr>
<th>Funding</th>
<th>Status</th>
<th>Producer</th>
<th>Country</th>
<th>Vehicle name</th>
<th>Payload to LEO (kg)</th>
<th>Payload to GTO (kg)</th>
<th>Fairing diameter</th>
<th>Successes rate</th>
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<tr>
<td>Private</td>
<td>Active</td>
<td>Space-X</td>
<td>US</td>
<td>Falcon 9</td>
<td>11,500</td>
<td>7,000</td>
<td>5.2</td>
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<td>Active</td>
<td>United Launch Alliance</td>
<td>US</td>
<td>Atlas V</td>
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<td>13,000</td>
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<tr>
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<td>Mitsubishi Heavy</td>
<td>Japan</td>
<td>H-IIB</td>
<td>19,000</td>
<td>8,000</td>
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<td>100%</td>
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<tr>
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<td>Ariane 5</td>
<td>21,000</td>
<td>6,950</td>
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Sasakawa International Center for Space Architecture
University of Houston College of Architecture
Launch Vehicle - Falcon 9/Heavy
Country - United States

Propellant Tanks

Type- A
Vol = 18 m³
Ø = 1.6 m
L = 9 m

Type- B
Vol = 30 m³
Ø = 2.3 m
L = 8 m

Type- C
Vol = 15 m³
Ø = 1.6 m
L = 8 m

Type- D
Vol = 35 m³
Ø = 2.3 m
L = 9 m

Type- E
Vol = 23 m³
Ø = 1.9 m
L = 9 m

Falcon Heavy/Falcon 9
Fairing Volume = 166 m³
Payload Mass= 53 mT/13.2 mT

LOX/LH₂
Mass= 34mT/2.1mT
Vol.= 60 m³

LH₂
Mass= 4.2mT
Vol.= 60 m³

LOX/LH₂
Mass= 40mT/3.3mT
Vol.= 81 m³

LOX/LH₂
Mass= 51mT/2mT
Vol.= 81 m³

LH₂
Mass= 5.8mT
Vol.= 81 m³
Launch Vehicle - Atlas V  
Country - United States

Propellant Tanks

<table>
<thead>
<tr>
<th>Type</th>
<th>Vol</th>
<th>Ø</th>
<th>L</th>
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<tr>
<td>Type-A</td>
<td>24 m³</td>
<td>1.7 m</td>
<td>10.5 m</td>
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<tr>
<td>Type-B</td>
<td>15 m³</td>
<td>1.5 m</td>
<td>10  m</td>
</tr>
<tr>
<td>Type-C</td>
<td>38 m³</td>
<td>2.3 m</td>
<td>10  m</td>
</tr>
<tr>
<td>Type-D</td>
<td>40 m³</td>
<td>2.4 m</td>
<td>10.5 m</td>
</tr>
<tr>
<td>Type-E</td>
<td>28 m³</td>
<td>2   m</td>
<td>10.5 m</td>
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Atlas V  
Fairing Volume = 227 m³  
Payload mass = 29.4 mT

LH₂  
Mass = 7 mT  
Vol. = 96 m³
Launch Vehicle - H II- B
Country - Japan

H II- B
Fairing Volume = 230 m³
Payload mass = 19 mT

Propellant Tanks

<table>
<thead>
<tr>
<th>Type</th>
<th>Volume</th>
<th>Diameter</th>
<th>Length</th>
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<tbody>
<tr>
<td>A</td>
<td>24 m³</td>
<td>1.8 m</td>
<td>9 m</td>
</tr>
<tr>
<td>B</td>
<td>15 m³</td>
<td>1.5 m</td>
<td>9 m</td>
</tr>
<tr>
<td>C</td>
<td>33 m³</td>
<td>2.3 m</td>
<td>9 m</td>
</tr>
<tr>
<td>D</td>
<td>35 m³</td>
<td>2.3 m</td>
<td>9.3 m</td>
</tr>
<tr>
<td>E</td>
<td>25 m³</td>
<td>1.9 m</td>
<td>9.3 m</td>
</tr>
</tbody>
</table>

LH₂
Mass = 10 mT
Vol. = 140 m³

LOX/LH₂
Mass = 17 mT/3.4 mT
Vol. = 63 m³

LH₂
Mass = 6.8 mT
Vol. = 96 m³

LH₂
Mass = 5.8 mT
Vol. = 81 m³

LOX/LH₂
Mass = 17 mT/4.5 mT
Vol. = 81 m³
Launch Vehicle - H II- B
Country - Japan

Propellant Tanks

- **Type- A**
  - Vol = 24 m³
  - Ø = 1.8 m
  - L = 9 m

- **Type- B**
  - Vol = 15 m³
  - Ø = 1.5 m
  - L = 9 m

- **Type- C**
  - Vol = 33 m³
  - Ø = 2.3 m
  - L = 9 m

- **Type- D**
  - Vol = 35 m³
  - Ø = 2.3 m
  - L = 9.3 m

- **Type- E**
  - Vol = 25 m³
  - Ø = 1.9 m
  - L = 9.3 m

H II- B
Fairing Volume = 230 m³
Payload mass = 19 mT

LH₂
Mass = 5 mT
Vol. = 70 m³

LH₂
Mass = 6 mT
Vol. = 85 m³
Launch Vehicle - Ariane 5
Country - Europe

Ariane 5
Fairing volume = 205 m³
Payload mass = 21 mT

Propellant Tanks

Type-A
Vol = 24 m³
Ø = 1.7 m
L = 10.5 m

Type-B
Vol = 15 m³
Ø = 1.5 m
L = 10 m

Type-C
Vol = 38 m³
Ø = 2.3 m
L = 10 m

Type-D
Vol = 40 m³
Ø = 2.4 m
L = 10.5 m

Type-E
Vol = 28 m³
Ø = 2 m
L = 10.5 m

LH₂
Mass = 10 mT
Vol = 140 m³

LOX/LH₂
Mass = 17 mT
Vol = 106 m³

University of Houston College of Architecture
Sasakawa International Center for Space Architecture
Launch Vehicle - Ariane 5
Country - Europe

Ariane 5
Fairing volume = 205 m³
Payload mass = 21 mT

LH₂
Mass = 5.5 mT
Vol. = 76 m³

LH₂
Mass = 7 mT
Vol. = 96 m³

Propellant Tanks

Type A
Vol = 24 m³
Ø = 1.7 m
L = 10.5 m

Type B
Vol = 15 m³
Ø = 1.5 m
L = 10 m

Type C
Vol = 38 m³
Ø = 2.3 m
L = 10 m

Type D
Vol = 40 m³
Ø = 2.4 m
L = 10.5 m

Type E
Vol = 28 m³
Ø = 2 m
L = 10.5 m
Launch Vehicle - Falcon 9/Heavy
Country - United States

Mission Components

<table>
<thead>
<tr>
<th>Component</th>
<th>Mass</th>
<th>Volume</th>
<th>Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>HAB</td>
<td>4mT</td>
<td>42 m3</td>
<td>0.8mT</td>
</tr>
<tr>
<td>Cargo</td>
<td>4mT</td>
<td>42 m3</td>
<td>0.8mT</td>
</tr>
<tr>
<td>HAB</td>
<td>7mT</td>
<td>73 m3</td>
<td>1.5mT</td>
</tr>
<tr>
<td>Cargo</td>
<td>7mT</td>
<td>73 m3</td>
<td>1.5mT</td>
</tr>
<tr>
<td>HAB</td>
<td>10mT</td>
<td>103 m3</td>
<td>2mT</td>
</tr>
<tr>
<td>Cargo</td>
<td>10mT</td>
<td>103 m3</td>
<td>2mT</td>
</tr>
<tr>
<td>Lunar Lander</td>
<td>3mT</td>
<td>35 m3</td>
<td>1mT</td>
</tr>
<tr>
<td>Dragon/ERV/Science LAB</td>
<td>5mT</td>
<td>34 m3</td>
<td>1mT</td>
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</tbody>
</table>

Falcon 9/Falcon Heavy

Payload Mass: 53 mT/13.2 mT

Fairing Volume: 166 m3

Sasakawa International Center for Space Architecture
University of Houston College of Architecture
Launch Vehicle - Falcon 9/Heavy
Country - United States

Mission Components

Falcon Heavy/Falcon 9
- Mass: 4mT
- Vol: 42 m3
- Structure: 0.8mT

HAB
- Mass: 7mT
- Vol: 73 m3
- Structure: 1.5mT

Cargo
- Mass: 7mT
- Vol: 73 m3
- Structure: 1.5mT

HAB
- Mass: 10mT
- Vol: 103 m3
- Structure: 2mT

Cargo
- Mass: 10mT
- Vol: 103 m3
- Structure: 2mT

Lunar Lander
- Mass: 3mT
- Vol: 35 m3
- Structure: 1mT

Dragon/ERV/Science
- Mass: 5mT
- Vol: 34 m3
- Structure: 1mT

Node
- Mass: 1mT
- Vol: 8 m3
- Structure: 1mT

Falcon 9/Falcon Heavy
- Mass: 53 mT/13.2 mT
- Vol: 166 m3
Launch Vehicle - Ariane 5
Country - Europe

Mission Components

- **HAB**
  - Mass: 4mT
  - Vol: 42 m³
  - Structure: 0.8mT

- **Cargo**
  - Mass: 4mT
  - Vol: 42 m³
  - Structure: 0.8mT

- **Module 1**
  - Mass: 4mT
  - Vol: 42 m³
  - Structure: 0.8mT

- **Cargo**
  - Mass: 7mT
  - Vol: 73 m³
  - Structure: 1.5mT

- **Cargo**
  - Mass: 10mT
  - Vol: 103 m³
  - Structure: 2mT

- **Lunar Lander**
  - Mass: 3mT
  - Vol: 35 m³
  - Structure: 1mT

- **Node**
  - Mass: 1mT
  - Vol: 8 m³
  - Structure: 1mT

**Ariane 5**
- Fairing volume: 205 m³
- Payload mass: 21 mT
Launch Vehicle - Ariane 5
Country - Europe

Mission Components

Ariane 5
Fairing volume = 205 m³
Payload mass = 21 mT

HAB
Mass = 4 mT
Vol. = 42 m³
Structure = 0.8 mT

Cargo
Mass = 4 mT
Vol. = 42 m³
Structure = 0.8 mT

Module 1
Mass = 7 mT
Vol. = 73 m³
Structure = 1.5 mT

Lunar Lander
Mass = 10 mT
Vol. = 103 m³
Structure = 2 mT

Node
Mass = 1 mT
Vol. = 8 m³
Structure = 1 mT

HAB/Lander
Mass = 9 mT
Vol. = 77 m³
Structure = 1.8 mT

HAB/Cargo/Lander
Mass = 13 mT
Vol. = 119 m³
Structure = 2.6 mT

HAB/Lander
Mass = 12 mT
Vol. = 108 m³
Structure = 2.5 mT

HAB/Lander
Mass = 16 mT
Vol. = 138 m³
Structure = 3 mT

HAB/Node
Mass = 5 mT
Vol. = 50 m³
Structure = 1.8 mT

HAB/Cargo/Node
Mass = 9 mT
Vol. = 92 m³
Structure = 2.6 mT

HAB/Cargo/Module 1/Node
Mass = 13 mT
Vol. = 134 m³
Structure = 3.4 mT
Launch Vehicle - Ariane 5
Country - Europe

Ariane 5
Fairing volume = 205 m3
Payload mass = 21 mT

Mission Components

- HAB: Mass = 4 mT, Vol. = 42 m3, Structure = 0.8 mT
- Cargo: Mass = 4 mT, Vol. = 42 m3, Structure = 0.8 mT
- Module 1: Mass = 4 mT, Vol. = 42 m3, Structure = 0.8 mT
- HAB: Mass = 7 mT, Vol. = 73 m3, Structure = 1.5 mT
- Cargo: Mass = 7 mT, Vol. = 73 m3, Structure = 1.5 mT
- HAB: Mass = 10 mT, Vol. = 103 m3, Structure = 2 mT
- Cargo: Mass = 10 mT, Vol. = 103 m3, Structure = 2 mT
- Lunar Lander: Mass = 3 mT, Vol. = 35 m3, Structure = 1 mT
- Node: Mass = 1 mT, Vol. = 8 m3, Structure = 1 mT

HAB/Node: Mass = 8 mT, Vol. = 81 m3, Structure = 2.5 mT
HAB/cargo/Node: Mass = 12 mT, Vol. = 123 m3, Structure = 3.3 mT
HAB/Cargo/Node: Mass = 15 mT, Vol. = 154 m3, Structure = 4 mT
HAB/Node: Mass = 12 mT, Vol. = 111 m3, Structure = 3 mT
HAB/Cargo/Node: Mass = 16 mT, Vol. = 153 m3, Structure = 3.8 mT
HAB/Node/Lander: Mass = 10 mT, Vol. = 85 m3, Structure = 2.8 mT
Launch Vehicle - Atlas V
Country - United States

Mission Components

Atlas V
Fairing Volume = 227 m³
Payload mass = 29.4 mT

HAB
Mass = 4mT
Vol. = 42 m³
Structure = 0.8mT

Cargo
Mass = 4mT
Vol. = 42 m³
Structure = 0.8mT

Module 1
Mass = 4mT
Vol. = 42 m³
Structure = 0.8mT

HAB
Mass = 7mT
Vol. = 73 m³
Structure = 1.5mT

Cargo
Mass = 7mT
Vol. = 73 m³
Structure = 1.5mT

HAB
Mass = 10mT
Vol. = 103 m³
Structure = 2mT

Cargo
Mass = 10mT
Vol. = 103 m³
Structure = 2mT

Lunar Lander
Mass = 1mT
Vol. = 8 m³
Structure = 1mT

Node
Mass = 1mT
Vol. = 8 m³
Structure = 1mT

HAB
Mass = 4mT
Vol. = 42 m³
Structure = 0.8mT

HAB/Cargo
Mass = 8mT
Vol. = 84 m³
Structure = 1.6mT

HAB/Cargo/Module
Mass = 12mT
Vol. = 126 m³
Structure = 2.4mT

HAB
Mass = 7mT
Vol. = 73 m³
Structure = 1.5mT

HAB/Cargo
Mass = 11mT
Vol. = 115 m³
Structure = 2.3mT

HAB/Cargo
Mass = 14mT
Vol. = 146 m³
Structure = 3mT

HAB
Mass = 11mT
Vol. = 103 m³
Structure = 2mT

HAB/Cargo
Mass = 15mT
Vol. = 145 m³
Structure = 2.8mT
Launch Vehicle - Atlas V
Country - United States

Mission Components

<table>
<thead>
<tr>
<th>Component</th>
<th>Mass</th>
<th>Volume</th>
<th>Structure</th>
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<tbody>
<tr>
<td>HAB</td>
<td>4mT</td>
<td>42 m3</td>
<td>0.8mT</td>
</tr>
<tr>
<td>Cargo</td>
<td>4mT</td>
<td>42 m3</td>
<td>0.8mT</td>
</tr>
<tr>
<td>Module 1</td>
<td>4mT</td>
<td>42 m3</td>
<td>0.8mT</td>
</tr>
<tr>
<td>HAB</td>
<td>7mT</td>
<td>73 m3</td>
<td>1.5mT</td>
</tr>
<tr>
<td>Cargo</td>
<td>7mT</td>
<td>73 m3</td>
<td>1.5mT</td>
</tr>
<tr>
<td>HAB</td>
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<td>103 m3</td>
<td>2mT</td>
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<tr>
<td>Cargo</td>
<td>10mT</td>
<td>103 m3</td>
<td>2mT</td>
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<tr>
<td>Lunar Lander</td>
<td>11mT</td>
<td>35 m3</td>
<td>1mT</td>
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<tr>
<td>Node</td>
<td>1mT</td>
<td>8 m3</td>
<td>1mT</td>
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Payload mass = 29.4 mT

Sasakawa International Center for Space Architecture
University of Houston College of Architecture
Launch Vehicle - Atlas V
Country - United States

Atlas V
Fairing Volume = 227 m³
Payload mass = 29.4 mT

Mission Components

HAB Mass = 4mT
Vol. = 42 m³
Structure = 0.8mT

Cargo Mass = 4mT
Vol. = 42 m³
Structure = 0.8mT

Module 1 Mass = 4mT
Vol. = 42 m³
Structure = 0.8mT

HAB Mass = 7mT
Vol. = 73 m³
Structure = 1.5mT

Cargo Mass = 7mT
Vol. = 73 m³
Structure = 1.5mT

HAB Mass = 10mT
Vol. = 103 m³
Structure = 2mT

Cargo Mass = 10mT
Vol. = 103 m³
Structure = 2mT

Lunar Lander Mass = 3mT
Vol. = 35 m³
Structure = 1mT

Node Mass = 1mT
Vol. = 8 m³
Structure = 1mT

HAB/Node Mass = 8mT
Vol. = 81 m³
Structure = 2.5mT

HAB/Cargo/Node Mass = 12mT
Vol. = 123 m³
Structure = 3.3mT

HAB/Cargo/Node Mass = 15mT
Vol. = 154 m³
Structure = 4mT

HAB/Node Mass = 12mT
Vol. = 111 m³
Structure = 3mT

HAB/Cargo/Node Mass = 16mT
Vol. = 153 m³
Structure = 3.8mT

HAB/Node/Lander Mass = 8mT
Vol. = 85 m³
Structure = 2.8mT

HAB/Node/Lander Mass = 9mT
Vol. = 93 m³
Structure = 3.8mT
Launch Vehicle - H II- B
Country - Japan

H II- B
Fairing Volume ~230 m³
Payload mass= 19mT

Mission Components

HAB
Mass= 4mT
Vol.= 42 m³
Structure = 0.8mT

Cargo
Mass= 4mT
Vol.= 42 m³
Structure = 0.8mT

HAB
Mass= 7mT
Vol.= 73 m³
Structure = 1.5mT

Cargo
Mass= 7mT
Vol.= 73 m³
Structure = 1.5mT

HAB
Mass= 10mT
Vol.= 103 m³
Structure = 2mT

Cargo
Mass= 10mT
Vol.= 103 m³
Structure = 2mT

Lunar Lander
Mass= 3mT
Vol.= 35 m³
Structure = 1mT

Node
Mass= 1mT
Vol.= 8 m³
Structure = 1mT

HAB/Lander
Mass= 9mT
Vol.= 77 m³
Structure = 1.8mT

HAB/Lander
Mass= 12mT
Vol.= 73 m³
Structure = 2.5mT

HAB/Node
Mass= 5mT
Vol.= 50 m³
Structure = 1.8mT

HAB/Cargo/Node
Mass= 9mT
Vol.= 92 m³
Structure = 2.6mT

HAB/Node
Mass= 8mT
Vol.= 81 m³
Structure = 2.5mT

HAB/Cargo/Node
Mass= 12mT
Vol.= 123 m³
Structure = 3.3mT

HAB/Node
Mass= 12mT
Vol.= 111 m³
Structure = 3mT
**Inspiration Mars Mission**

**Chemical propulsion**
- Payload: 15mT
- Delta V for Mars C3 transfer = 4.7 Km/s
- Transfer Propellant = 30 mT
  - LOX: 25mT
  - LH2: 5mT

**Mission Components**

<table>
<thead>
<tr>
<th>Component</th>
<th>Mass (mT)</th>
<th>Volume (m^3)</th>
</tr>
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<tbody>
<tr>
<td>HAB</td>
<td>7</td>
<td>67</td>
</tr>
<tr>
<td>Re-entry Capsule</td>
<td>5</td>
<td>34</td>
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<tr>
<td>Engine</td>
<td>1</td>
<td>6</td>
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</table>
Inspiration Mars Mission

LOX/LH2
Mass= 25mT/5mT
Vol.= 96 m3
Atlas V

HAB/Engine
Mass= 8mT
Vol.= 81 m3
Structure = 2mT
H II-B

Re-entry vehicle
Mass= 5 mT
Vol.= 34 m3
Falcon 9

Launch 1
Launch 2
Launch 3

Assembly in LEO
Lagrange L2 Station : Halo Orbit
Trajectory

L2 is ideal for astronomy because a spacecraft is close enough to readily communicate with Earth, can keep Sun, Earth and Moon behind the spacecraft for solar power and (with appropriate shielding) provides a clear view of deep space for our telescopes.
## Delta V’s — High thrust

<table>
<thead>
<tr>
<th>∆V km/s From \ To</th>
<th>EML-2</th>
<th>LLO</th>
<th>Moon</th>
<th>Mars Transfer Orbit</th>
<th>LEO-Ken</th>
<th>LEO-Eq</th>
<th>GEO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earth</td>
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<td></td>
<td></td>
<td></td>
<td>9.3 - 10</td>
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<tr>
<td>Low Earth Orbit (LEO-Ken)</td>
<td>3.43</td>
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<td>4.24</td>
<td>4.33</td>
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<tr>
<td>Geostationary Orbit (GEO)</td>
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<td></td>
<td></td>
<td>2.06</td>
<td>1.63</td>
<td></td>
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<td>Lagrangian point 1 (EML-1)</td>
<td>0.64</td>
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<td>0.77</td>
<td>1.38</td>
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<td>0.33</td>
<td>1.47</td>
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<tr>
<td>Low Lunar orbit (LLO)</td>
<td>0.65</td>
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<td>1.87</td>
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<tr>
<td>Moon (Moon)</td>
<td>2.53</td>
<td>1.87</td>
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<tr>
<td>EML-2</td>
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<td></td>
<td></td>
<td></td>
<td>&lt;1.0</td>
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</table>
* L2 point is unstable on a time scale of approximately 23 days, which requires satellites orbiting these positions to undergo regular course and attitude corrections.
Mission Goals

Goals

Primary

Manned Mission beyond LEO
Research and Experiments beyond orbit

Mission Tasks

- Test EVA procedures
- Test payload docking and fuel
- Moon survey mission components deployment
- Solar radiation effects on human
- Other human factors
Mission Requirements

- A Habitat
- 2 people on board
- A lander for sortie missions to moon
- Earth return vehicle
- Fuel Depot
- Ergonomic design – user friendliness
- Interior space flexibility – mobility
- Radiation protection solutions
- EVA concepts
**Mission Statistics**

<table>
<thead>
<tr>
<th>Year of study</th>
<th>2013</th>
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<tbody>
<tr>
<td>Crew</td>
<td>2</td>
</tr>
<tr>
<td>Mission duration</td>
<td>6 months - 1st Phase</td>
</tr>
<tr>
<td>Payload mass</td>
<td>≈ 40 MT</td>
</tr>
<tr>
<td>Fairing diameter</td>
<td>≈ 5m</td>
</tr>
<tr>
<td>Starts in LEO</td>
<td>Yes</td>
</tr>
<tr>
<td>Number of deployments from LEO</td>
<td>1</td>
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<tr>
<td>Propulsion</td>
<td>Chemical</td>
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<tr>
<td>H-Lift launches</td>
<td>0</td>
</tr>
<tr>
<td>M-Lift launches</td>
<td>4</td>
</tr>
<tr>
<td>International cooperation</td>
<td>May be</td>
</tr>
<tr>
<td>Coop. with private companies</td>
<td>May be</td>
</tr>
<tr>
<td>HAB parking position</td>
<td>L2-HALO Orbit</td>
</tr>
<tr>
<td>Stay at Moon</td>
<td>Sortie missions to moon</td>
</tr>
<tr>
<td>Assembly in LEO</td>
<td>Yes</td>
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<tr>
<td>Total Mission duration</td>
<td>6.1 months</td>
</tr>
</tbody>
</table>
System Elements

- **HAB** – Habitation Module
- **ML** – Moon Lander (sortie missions)
- **REV** - Re-entry Vehicle
  (Use SpaceX Dragon Capsule or Orion)
- **TP** - Transfer Propellant
- **FDP** - Fuel Depot Propellant (Warehouse)
- **SL** – Scientific Laboratory
Mission Components

Station HAB
Mass: 7.5 mT
Volume: 67 m³
Structure: 1.5 mT

Lunar Lander
Mass: 3 mT
Volume: 35 m³
Structure: 1 mT

ERV/Science Lab
Mass: 5 mT
Volume: 34 m³
Structure: 2 mT

Node
Mass: 1 mT
Volume: 8 m³
Structure: 1 mT

Crew stay-6 months
Moon Sortie missions
Experiments
Contingency vehicle
Connection
EML2 Mission Design – Propulsion Selection

**Chemical propulsion (Isp- 342 s, LOX/LH2)**
From LEO to EML2-
40 mt of dry mass ~ 35 mt of propellant
Total Mission mass = 75 mt
LOX= 30mT LH2= 5 mT

**Bimodal Nuclear Thermal Reactor - BNTR (Isp – 945 s, LH2)**
From LEO to EML2-
40 mt of dry mass ~ 30mt of propellant
Total Mission mass = 70mt
LH2= 30 mT

LH2 has a very Low density as compared to LOX.
NTR propulsion requires twice the number of launches required in Chemical propulsion.

**Alternative approach**
Starting the mission from ISS.
EML2 Mission Design – Catalog application

Chemical Propulsion (LOX/LH2)
Payload = 40 mT
Transfer Propellant = 35 mT
LOX = 30 mT
LH2 = 5 mT
Depot Propellant = 21 mT
LOX = 20 mT
LH2 = 6 mT
Total LOX = 50 mT
Total LH2 = 11 mT

- LH2
  - Mass: 8 mT
  - Vol.: 112 m3
  - Falcon 9

- LOX/LH2
  - Mass: 50 mT/3 mT
  - Vol.: 90 m3

- HAB/Node/Lander
  - Mass: 9 mT
  - Vol.: 93 m3
  - Structure: 3.8 mT
  - Atlas V

- Dragon as ERV/Science LAB
  - Mass: 5 mT
  - Structure: 2 mT
  - Less payload = 46 T
  - Excess Delta V = 4.50 km/s
  - Falcon Heavy

Launch 1
Launch 2
Launch 3
Assembly in LEO
Launch 4
Direct to EML2

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L2 Mission Architecture

EML2 Halo Orbit

Low Earth Orbit

Assembly in LEO

Launch 1 (F9) = Propellant and Engine
Launch 2 (FH) = Propellant
Launch 3 (Atlas V) = Hab, lander, Node
Launch 4 (FH) = Crew in Dragon spacecraft

Dragon docks with the station and serves as Science laboratory

Dragon with crew Direct to EML2 Excess $\Delta V = 4.25$ km/s

$\Delta V = 3.4$ km/s Duration $= 6.2$ days

6 months in orbit 1st Phase

Moon

6 months in orbit

Earth return

Launch 1 = Crew in Dragon spacecraft

6 months in orbit

Earth return

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EML2 Mission Design - Catalog

At LEO

At EML2

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EML2 Station - Performing EVA
<table>
<thead>
<tr>
<th>Subsystems</th>
<th>Volume(m3)</th>
<th>Mass(Kg)</th>
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<tbody>
<tr>
<td>C.A. - Galley and Food Systems</td>
<td>13</td>
<td>1677</td>
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<tr>
<td>C.A. - Waste collection system</td>
<td>3</td>
<td>137</td>
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<tr>
<td>C.A. - Clothing</td>
<td>1</td>
<td>20</td>
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<tr>
<td>C.A. - Recreational equipment &amp; Personal Stowage</td>
<td>2</td>
<td>50</td>
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<tr>
<td>C.A. - Housekeeping</td>
<td>2</td>
<td>77</td>
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<tr>
<td>C.A. - Operational Supplies &amp; Restraints</td>
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<td>80</td>
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<tr>
<td>C.A. - Maintenance / All Repairs in Habitable Areas</td>
<td>3</td>
<td>245</td>
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<td>C.A. - Photography</td>
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<td>25</td>
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<tr>
<td>C.A. - Crew Health Care</td>
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<tr>
<td>E.S.S - Guidance, Navigation and Control</td>
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<tr>
<td>E.S.S - Electrical Power Systems</td>
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<tr>
<td>E.S.S - Thermal Control System</td>
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<td>300</td>
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<tr>
<td>E.S.S - Communications and Tracking</td>
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<tr>
<td>E.S.S - Command and Data Handling</td>
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<td>E.S.S - Avionics</td>
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<tr>
<td>E.S.S - ECLSS</td>
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<td>E.S.S - Structures and Mechanisms</td>
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<tr>
<td>E.S.S - Others(Spare margin, Hydroponics, furniture)</td>
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<td>400</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>54</strong></td>
<td><strong>8836</strong></td>
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</tbody>
</table>
Station HAB – Subsystems

- C.A. - Galley and Food Systems
- C.A. - Clothing
- C.A. - Housekeeping
- C.A. - Maintenance / All Repairs in Habitable Areas
- C.A. - Crew Health Care
- E.S.S - Electrical Power Systems
- E.S.S - Communications and Tracking
- E.S.S - Avionics
- E.S.S - Structures and Mechanisms
- C.A. - Waste collection system
- C.A. - Recreational equipment & Personal Stowage
- C.A. - Operational Supplies & Restraints
- C.A. - Photography
- E.S.S - Guidance, Navigation and Control
- E.S.S - Thermal Control System
- E.S.S - Command and Data Handling
- E.S.S - ECLSS
- E.S.S - Others(Spare margin, Hydroponics, furniture)
### Station HAB – Mass-Volume graph

<table>
<thead>
<tr>
<th>Category</th>
<th>Volume (m³)</th>
<th>Mass (mT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C.A. - Galley and Food Systems</td>
<td>1.68</td>
<td>0.14</td>
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<td>C.A. - Waste Collection System</td>
<td>0.02</td>
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<tr>
<td>C.A. - Recreational Equipment</td>
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<tr>
<td>C.A. - Housekeeping</td>
<td>1</td>
<td>0.01</td>
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<tr>
<td>C.A. - Operational Supplies &amp; All</td>
<td>0.25</td>
<td>0.03</td>
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<tr>
<td>C.A. - Maintenance / All</td>
<td>2</td>
<td>0.08</td>
</tr>
<tr>
<td>C.A. - Photography</td>
<td>2.20</td>
<td>0.35</td>
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<tr>
<td>E.S.S. - Guidance, Navigation</td>
<td>2</td>
<td>0.30</td>
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<td>E.S.S. - Electrical Power Systems</td>
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<tr>
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<td>0.10</td>
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<td>E.S.S. - Avionics</td>
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<tr>
<td>E.S.S. - Others/Spare Margin</td>
<td>33.00</td>
<td></td>
</tr>
</tbody>
</table>

**SICSA**

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Station HAB – Design Concept

- Modular structure
- Multiple usage of space saves volume
- Less structure
- Reconfigurable interiors
Station HAB – Sectional Plans

**Vertical Section**
- 1.2m
- 2.4m
- 3.5m
- 5.7m
- 1.0m

**Horizontal Section**
- 4.5m
- 2.4m

**Dimensions**
- 4.5m
Station HAB – Volume Distribution

**Upper Module**
- Circulation space = 10 m³
- Flexible space = 15 m³
- Fixed Volume = 3.5 m³
- Total volume = 28.5 m³

**Docking Hatch**
- Volume = 3 m³

**Lower Module**
- Circulation space = 8 m³
- Fixed Volume = 16 m³
- Total volume = 24 m³

**Water storage**
- Volume = 5.5 m³

Total volume = 67 m³
Mass = 9 mT
Usable volume = 61 m³
Station HAB – Interior Upper Module

- Projection screens
- Navigation and Guidance
- Health and Exercise
- Airlock
- Communication & Tracking
- Command & Control
- Temporary Partition

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Station HAB – Interior Upper Module

- Rotatable & Adjustable storage
- Command & Control
- Rotatable & Adjustable storage
View- 3D Section

Table

Contingency Storage

Water Bag Storage
View - Communication and Tracking

Access to anyone
View- Communication and Tracking

Limited access
View- Communication and Tracking
View - Personal Space - Command and Control

- Personal stowage
- Personal space
- Command and Control
View - Personal Space - Command and Control
View - Crew Quarter

Rotatable panel
View- Command and Control
View - Exercise - Navigation and Guidance

- Exercise Machine
- Airlock Door
- Navigation and Guidance
View- Exercise- Navigation and Guidance

Exercise Area

Curtain
View - Crew accessing storage
View - Limited Access Situation

Curtains

Restricted Entry

Restricted Entry

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View- From Upper Module
View - Lower Module

Kitchen & Galley

Storage
View - Lower Module

Hydroponics

Kitchen & Galley

Trash compactors
View- Radiation Protection

Safe Haven
View - Simulating Surrounding
View- Simulating Surrounding
View- Simulating Surrounding
Acknowledgement

Special gratitude to my professors Larry Bell, Olga Bannova and Bob Sauls for their patient guidance and support over the entire program.

Thanks to Larry Toups for sparing his precious time to take us around NASA and his motivation whenever required.

Thanks to Nejc for his help and support in learning new things.

Thanks a lot to the jury for being here and for their feedbacks.
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