Crew Systems Design Project

Group A8

Chrissy Doeren
Kip Hart
Kiran Patel
Alex Slafkosky
Project Overview

• Objective: design a crewed spacecraft for a low cost lunar mission
• Crew: 3 - 95th percentile men
• Duration: 10 days + 3 contingency = 13 days
• Spacecraft Shape: Cone
• Spacecraft Max Diameter: 3.57m
• Half-Cone Angle: 25°
• Wall Thickness: 10cm
• Maximum Mass Allowed: 1500kg
Crew Composition

• Capsule designed for three astronauts
• 95th percentile males
• Height: 74.3 inches
• Weight: 225 lbs each
• Mass: 102 kg each
Mission Timeline

• Travel on lunar transfer orbit (LTO) to low lunar orbit (LLO) and descent from LLO to surface - 3 days
• Surface / EVA days - 4 to 7 days
• Ascent from surface to LLO, travel on LTO to LEO and Earth entry, descent, and landing - 3 days
• Total mission timespan: 13 days
Outline of Project – Allocated Tasks

• Perform life support system trades studies and select life support systems
• Identify power requirements
• Select atmosphere and perform denitrogenation calculations for transition to 5 psi 80% O₂ suit
• Perform interior layout of vehicle using CAD
  – Seats for launch and landing
  – Placement of life support elements and consumables
  – Stowage
  – Control station for landing with direct vision
• Analyze sight lines for landing
• Design ingress/egress for lunar surface operations
Cabin Atmospheric Conditions

- Total Pressure: 10.2 psi
- O2 content: 26.5%
- N2 content: 73.5%
1. Life Support Specifications (LTO to LLO)

• Lunar Transfer Orbit to Low Lunar Orbit:

2. External Accelerations

• G forces will be so small as to be considered negligible even though there will be a burn
• Astronauts will be seated for this portion of the mission
2. Life Support Specifications (LLO to Surface)

- Descent from Low Lunar Orbit to Lunar Surface:
  1. Atmospheric conditions
     1. Total pressure: 10.2 psi
     2. Percent $O_2$: 26.5%
     3. Percent $CO_2$: 0%
     4. Other gases: none
     5. Percent $N_2$: 73.5%
2. Life Support Specifications (LLO to Surface)

• Descent from Low Lunar Orbit to Lunar Surface:

2. External Accelerations

• Crew seats must provide support during accelerations experienced by the capsule during landing
• Assume that if the astronauts survive landing on Earth, they will survive landing on the Moon since gravity on the moon is 1/6 the value of Earth
• **Maximum value:** estimated at 1.2 g’s
• Maximum acceleration experienced by Apollo missions: 7.19 g’s (Apollo 16) multiplied by 1/6 to account for gravity on the moon, not Earth
• Used Apollo missions as a guideline because the capsule shapes are similar and thus will cause similar g forces upon reentry
3. Life Support Specifications (Moon Surface)

• Four days on the surface of the moon:

1. Atmospheric conditions
   1. Total pressure: 10.2 psi
   2. Percent O$_2$: 26.5%
   3. Percent CO$_2$: 0%
   4. Other gases: none
   5. Percent N$_2$: 73.5%

2. External Accelerations: none
4. Life Support Specifications (Surface to LLO)

- Ascent from Lunar Surface to Low Lunar Orbit:
  1. Atmospheric conditions
     1. Total pressure: 10.2 psi
     2. Percent $O_2$: 26.5%
     3. Percent $CO_2$: 0%
     4. Other gases: none
     5. Percent $N_2$: 73.5%
  2. External Accelerations: minimal
5. Life Support Specifications (LTO to LEO)

- Lunar Transfer Orbit to Low Earth Orbit:
  1. Atmospheric conditions
     1. Total pressure: 10.2 psi
     2. Percent O$_2$: 26.5%
     3. Percent CO$_2$: 0%
     4. Other gases: none
     5. Percent N$_2$: 73.5%
  2. External Accelerations: minimal
6. Life Support Specifications (Entry, Descent, Landing)

• Earth entry, descent, landing:
  1. Atmospheric conditions
     1. Total pressure: 10.2 psi
     2. Percent O$_2$: 26.5%
     3. Percent CO$_2$: 0%
     4. Other gases: none
     5. Percent N$_2$: 73.5%
  2. External Accelerations
     • Maximum value: estimated at 7.19 g’s
     • According to Apollo Missions G Levels chart
2. Life Support Specifications

Table 2
Apollo Manned Space Flight Reentry G Levels

<table>
<thead>
<tr>
<th>Flight</th>
<th>Maximum G at Reentry</th>
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<tbody>
<tr>
<td>Apollo 7</td>
<td>3.33</td>
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<tr>
<td>Apollo 8</td>
<td>6.84</td>
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<tr>
<td>Apollo 9</td>
<td>3.35</td>
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<td>Apollo 10</td>
<td>6.78</td>
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<td>Apollo 11</td>
<td>6.56</td>
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<td>Apollo 12</td>
<td>6.57</td>
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<tr>
<td>Apollo 13</td>
<td>5.56</td>
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<tr>
<td>Apollo 14</td>
<td>6.76</td>
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<tr>
<td>Apollo 15</td>
<td>6.23</td>
</tr>
<tr>
<td>Apollo 16</td>
<td>7.19</td>
</tr>
<tr>
<td>Apollo 17</td>
<td>6.49</td>
</tr>
</tbody>
</table>

Life Support Specifications Constant for all Stages of Mission

• Food and Drinking Water
  • Metabolic requirements:
    • Inputs:
      • \( O_2 \): 1.11 kg / (person*day) = 1.11*3 people * 13 days = 43.29 kg
        • \( O_2 \) stored at 5000 psi
        • temperature below deck while on moon: 200K (daytime temp of surface of the moon)
      • \( H_2O \) drink: 1.62 kg / (person*day) = 1.62 * 3 * 13 = 63.18 kg
      • \( H_2O \) food prep: 0.76 kg / (person*day) = 0.76 * 3 * 13 = 29.64 kg
      • Food: 3.4 kg / (person*day) = 3.4 * 3 * 13 = 132.6 kg
        • Mass fits in 1 CTB
      • \( H_2O \) clothes, dishes, sanitary: 2.8 kg / (person*day) = 109.2 kg
Life Support Specifications Constant for all Stages of Mission

• Food and Drinking Water
  • Metabolic requirements:
    • Outputs:
      • $\text{CO}_2$: 1 kg / (person*day)
      • $\text{H}_2\text{O}$ urine: 1.5 kg / (person*day)
      • $\text{H}_2\text{O}$ respiration / perspiration: 2.28 kg / (person*day)
      • urine solids: 0.06 kg / (person*day)
      • feces: 0.12 kg / (person*day)
Life Support Specifications Constant for all Stages of Mission

• Hygiene
  • H₂O hygiene: 2.8 kg / (person*day) = 109.2 kg

• Waste Management
  • Waste will be contained in bags and stored below deck
Life Support System Requirements

Atmosphere Regeneration

CO₂ scrubbing

LiOH: 2.09 kg / kg CO₂ = 39*2.09 = 81.51 kg

O₂ generation

Open loop, no method for generation

Bring total required amount

Water Regeneration

TIMES

68.094 Kg of H₂O Brought
44.95 Kg of TIMES System Components
0.1541 M³
1418 Watt for 13 Day Trip (Power Requirement)
Life Support System Requirements

2. Atmosphere Regeneration
   • CO$_2$ Scrubbing Trade Study **Assumptions:**
     1. Minimum volume for 3 crew members = 3 m$^3$
     2. Maximum diameter allowed = 3.57 m
     3. Density of Aluminum = 2810 kg/m$^3$
     4. Mass of crew = 3*102.58 = 307.74 kg
     5. Capsule angle = 25 degrees
     6. Specific energy of fuel cells = 186 Wh/kg
     7. Need 3*1.11 = 3.33 kg of O2 scrubbed per day
Life Support System Requirements

2. Atmosphere Regeneration
   • Reasoning for CO$_2$ Scrubbing Trade Study
     ◦ Mass of Each Component
     ◦ Mass Penalty for:
       ▪ Volume of Component
       ▪ Power Requirement of Component
     ◦ Mass Bonus for:
       ▪ Reduction of Mass in other Systems
Life Support System Requirements

2. Atmosphere Regeneration

• **CO₂ Scrubbing Trade Study Results:**
  • Mass of LIOH system (CO₂ scrubbing): **56.17 kg**
  • Mass of packing: **51.53 kg**
  • Volume of system: **0.0385 m³**
Regenerable vs Time

Mass of Regenerable CO$_2$ Filtration System versus Duration

- 4BMS
- 2BMS
- SAWD
- EDC
- BOSCH
- Sabatier coupled w/ ACRS

Duration (days)

Mass of System (kg)

$3 \times 10^4$
Non-Regenerable vs Time

Mass of NON-Regenerable CO$_2$ Filtration System versus Duration

- LIOH
- Ca(OH)$_2$
- KO$_2$
Best of Non-regenerable and Best of Regenerable vs Time

Mass of Best Non-Ren. and Ren. CO\textsubscript{2} Filtration System versus Duration

- LIOH
- EDC
Life Support System Requirements

2. Atmosphere Regeneration

- O$_2$ Trade Study **Assumptions:**
  1. Minimum volume for 3 crew members = 3 m$^3$
  2. Maximum diameter allowed = 3.57 m
  3. Density of Aluminum = 2810 kg/m$^3$
  4. Mass of crew = 3*102.58 = 307.74 kg
  5. Capsule angle = 25 degrees
  6. Specific energy of fuel cell = 186 Wh/kg
  7. Need 3*1.11 = 3.33 kg of O$_2$ scrubbed per day
  8. Wattage = 3 people*2 Watts/person
Life Support System Requirements

2. Atmosphere Regeneration
  • Reasoning for O2 Trade Study
    ◦ Mass of each Component
    ◦ Mass Penalty for:
      ◦ Volume of Component
      ◦ Power Required of Component
    ◦ Mass Bonus for:
      ◦ Reduction of Mass in Other System
Life Support System Requirements

2. Atmosphere Regeneration

• **O₂ Scrubbing Trade Study Results:**
  • Mass of O₂ (liquid) open loop: 43.29 kg
  • Mass of O₂ (liquid) open look tank: 21.65 kg
  • Volume O₂ open loop system: 0.348 m³
Open Loop (Gas and Liquid) vs Time

Mass of Open Loop O2 System vs Duration

- Open/Gas
- Open/Liquid
Non-Regenerable vs Time

Mass of Non-Regenerable O2 System vs Duration

- H2O2
- LiO2
- KO2
- MgO4
- CaO4

Duration (Days)

Mass of System (Kg)
"Candle" vs Time

Mass of "Candle" O2 System vs Duration

- LiClO4
- KClO4
- Ca(ClO4)2
Best of all systems vs Time

Best System (Candle, Open, Non-Regenerable) Mass O2 System vs Duration

Mass of System (Kg)

Duration (Days)

- LiClO4
- Open/Liquid
- LiO2
# Batteries for Space Power

<table>
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<tr>
<th></th>
<th>PRIMARY</th>
<th></th>
<th>SECONDARY</th>
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<tr>
<td>CHEMISTRY:</td>
<td>LiCF</td>
<td>LiSOCl2</td>
<td>AgZn</td>
</tr>
<tr>
<td>Lifetime (cycles)</td>
<td>Not Applicable</td>
<td>Not Applicable</td>
<td>200³</td>
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<tr>
<td>Watt-Hours/Kilogram</td>
<td>130</td>
<td>185</td>
<td>110</td>
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<tr>
<td>Watt-Hours/Liter</td>
<td>160</td>
<td>240</td>
<td>200</td>
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<tr>
<td>Discharge Rate</td>
<td>Low Mod⁵</td>
<td>High</td>
<td>High Mod⁺</td>
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<tr>
<td>Charge Retention</td>
<td>Not Applicable</td>
<td>Not Applicable</td>
<td>High</td>
</tr>
<tr>
<td>Memory</td>
<td>Not Applicable</td>
<td>Not Applicable</td>
<td>No</td>
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<tr>
<td>Wet Shelf Life</td>
<td>Long</td>
<td>Short⁷</td>
<td>Short⁷</td>
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<tr>
<td>Failure Tolerance</td>
<td>Low⁹</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Notes:</td>
<td>Not Sensitive within limits⁹,¹⁰</td>
<td>Activation req'd at time of use; May have free Electrolyte</td>
<td>Pressure Vessel; Capacity loss concerns after storage</td>
</tr>
<tr>
<td>Operating Temp</td>
<td>0°C - 100°C</td>
<td>10°C - 50°C</td>
<td>0°C - 45°C</td>
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<tr>
<td>Venting Requirements</td>
<td>Burst vent req'd</td>
<td>Can be sealed</td>
<td>Can be sealed</td>
</tr>
<tr>
<td>Cell Voltage (Operating)</td>
<td>2.95V</td>
<td>3.1V</td>
<td>1.5V</td>
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<tr>
<td>Experience Level</td>
<td>High</td>
<td>Mod</td>
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<tr>
<td>Costs</td>
<td>Low</td>
<td>Low</td>
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</tbody>
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1. Based on MSFC applications (EB12)
2. New Technology
3. Approximately 50% depth of discharge
4. Refers to 61 minute sun and 35 minute eclipse low earth orbit cycle with approximately 5500 cycles per year at less than 20% depth of discharge
5. Can be designed for high rate use
6. Significantly improves with lower temperature (0° C)
7. Lifetime is limited to 90 - 200 days depending on construction
8. High temperature buildup on "high-rate" overcharge
9. Unstable at very high temperatures and high rate of discharge
10. Environmental concerns with constituent materials

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Life Support System Requirements

3. Water Regeneration

• Trade Study **Assumptions**:
  1. Minimum volume for 3 crew members = 3 m³
  2. Maximum diameter allowed = 3.57 m
  3. Density of Aluminum = 2810 kg/m³
  4. Mass of crew = 3*102.58 = 307.74 kg
  5. Capsule angle = 25 degrees
  6. Specific energy of fuel cell = 186 Wh/kg
  7. 80% Reclamation
Life Support System Requirements

3. Water Regeneration
   • Reasoning for Trade Study
     o Compare Savings vs Volume vs Mass
     o Mass of Each Component
     o Mass Penalty for:
       ▪ Volume of Component
       ▪ Power Requirement of Component
     o Mass Bonus for:
       ▪ Reduction of Mass of HOH Brought On
Water Distillation

Mass of Water Distillation System versus Duration

- OPEN
- OPEN/VCD
- OPEN/VAPCAR
- OPEN/TIMES

Mass (kg) vs. Duration (Days)
3. Water Regeneration

• Conclusions:
  ○ TIMES Offered the best of three competing aspects
    ▪ Volume (lowest)
    ▪ Mass (2nd Lowest)
    ▪ Power (2nd Lowest)
Radiation Shielding

• 0.5 Sv limit for radiation exposure for lifetime of crew members
• Adding shielding for SPE is unnecessary
• Adding more shield mass is ineffective for GCR protection (see charts on next slides)
• Total radiation over 1 year = 470 rem = 4.7 Sv
• Total radiation over 13 days = 0.0356 Sv
• 0.0356 Sv << 0.5 Sv - far under radiation limit
• shielding is too heavy for this mission
Radiation Shielding - SPE and GCR

Radiation Shielding - GCR

Layout and Design of Capsule

1. CAD Model: Preliminary Design
   • Cone base: diameter of 3.57m - 20cm
   • Cone height: from 25° half angle
   • Curved bottom: radius of curvature of 5m
   • Chop cone with diameter of 98.8cm

   Code:
   \[
   h = 2.167 \text{ m} \\
r_{\text{top}} = 0.5 \text{ m} \\
r_{\text{bottom}} = 1.505 \text{ m} \\
V_{\text{frustrum}} = \frac{\pi h}{3} (r_{\text{top}}^2 + r_{\text{top}} r_{\text{bottom}} + r_{\text{bottom}}^2) = 7.145 \text{ m}^3 \\
V_{\text{prism}} = 1.5 \text{ m} \times 1.7 \text{ m} \times 0.351 \text{ m} = 0.89505 \text{ m}^3 \\
V_{\text{total}} = 8.31 \text{ m}^3
   \]
Chair Design

• An effective seat would be one that spreads g forces evenly over the astronaut’s body and constrains motion to avoid the harm done to limbs or head

• Given the tight quarters, the seats would have to be compact, lightweight, and easily stored

• One problem with the existing design: the seat was flat and humans aren’t. There’s a problem of adjusting for different leg lengths to provide continuous support
Chair Design

• Controllers near the knees on the sides of the flight crews’ chairs, eliminating the complication of separate armrests for the hand controllers
• Contributions from many sources: the Lockheed Martin design team, race-car engineers, suit designers, former astronauts, and others
• The Lockheed Martin guys saw that it would be easier and better to have the leg and foot support part of the seat fold over.
• Lockheed Martin built an improved metal version of the prototype seat, while incorporating new solutions in the design and has been crash-tested
Initial Capsule Design
Initial Capsule Design

• Chairs represented in blue, CTBs (Cargo Transfer Bags) represented in red (single), orange (triple), and yellow (half)
• Hatch is light green, window in the center
• Average-sized person shown for reference
• Very cluttered, not much room without collapsible or stowable chairs
• Solution: to swivel one chair against the wall and stow the other two in the below deck compartment where EVA suits were during launch
Initial Capsule Design

- **Preliminary Design:**
  - Cone base: diameter of 3.01m
  - Cone height: from 25° half angle, 2.167m
  - Curved bottom: radius of curvature of 5m
  - Chop cone where diameter = 100cm
Optimal Spacing for Capsule Design
Configuration before EVA

Two spare chairs
Configuration at Launch

Instrumentation panel

EVA suits
Below Deck at Launch (Storage)
CBT Stacking Configuration

- CBT spacing for optimal storage
- Storage compartment shown below deck
Line of Sight

Field of View:
When astronaut standing at control panel, he/she can look down at an angle 23.3° inclined from the surface of the spacecraft and look out at an angle 106.1° from the surface of the spacecraft. This gives the standing astronaut 50.6° field of view in standing posture.
Line of Sight
Denitrogenation
Denitrogenation

- 1 ft/minute of water ascending
- Pressure corresponding to 12" of water
- To safely change pressure and avoid decompression sickness, stick to 1 ft of water per minute (12" of water)
  - Used to figure out time to go from cabin pressure to suit pressure
Denitrogenation

1. Assumptions:
   - RQ=0.85 (Healthy Diet)
   - R=% N2
   - Haldane Equation
   - $P_{HOH} \approx 0.06 \times P_{Amb}$
   - $P_{CO2} \approx 0.05 \times P_{Amb}$
   - Q= % N2 @ End
Denitrogenation

2. Data

- Chose 6 tissue half lifes
  - $T=[5,10,20,40,75,120]$  
- Chose 2 Sets of Data Points
  - $P_{Amb}=14.7$ Psi, $N_2=79\%$, and $O_2=21\%$
  - $P_{Amb}=10.2$ Psi, $N_2=73.5\%$ and $O_2=26.5\%$
- Compute Partial Pressure of $N_2$
- Find Time till 20\% Partial Pressure of $N_2$ of 40 Minute Half Life Tissue Type
3. Trade Study Conclusion:

- $P_{\text{Amb}} = 10.2 \text{ Psi}$
- $\%N_2 = 73.5\%$
- $\%O_2 = 26.5\%$
- Prebreath-229 Minutes @ 100% O2
- Plus 12 Minutes to decrease pressure from 10.2 psi to 5 psi
- Thus, 241 minutes from start to end for EVA's
Denitrogenation

3. Trade Study Conclusions (Cont.)

- From these Atmospheric Conditions Set
  - 6.16 g O2 are lost over the course of 3 EVA missions
  - 14.9618 g N2 are lost over the course of 3 EVA Missions
  - Storage for replacing this N2 is accomplished by a 30 g tank with 15 g of N2 contained
Denitrogenation

$P_{amb} = 10.2 \text{ Psi}$ $P$ tissue vs Time

- $\text{Suit \%N2}$
- K1
- K2
- K3
- K4
- K5
- K6

Partial Pressure N2 (Psi)

Time (Minutes)
Denitrogenation

Pamb=14.7 Psi P tissue vs Time

Time (Minutes)

Partial Pressure N2 (Psi)

- Suit %N2
- K1
- K2
- K3
- K4
- K5
- K6

X: 235
Y: 0.2
# Mass Budget

<table>
<thead>
<tr>
<th>Component</th>
<th>Mass Estimate</th>
<th>Percent of Budget</th>
</tr>
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<tbody>
<tr>
<td>Oxygen tank</td>
<td>21.65 kg (trade study)</td>
<td>1.45%</td>
</tr>
<tr>
<td>Oxygen</td>
<td>43 kg</td>
<td>2.87%</td>
</tr>
<tr>
<td>HOH brought</td>
<td>68.09 kg</td>
<td>4.54%</td>
</tr>
<tr>
<td>TIMES System</td>
<td>44.95 kg</td>
<td>3.00%</td>
</tr>
<tr>
<td>CO2 scrubber</td>
<td>107.7 kg</td>
<td>7.18%</td>
</tr>
<tr>
<td>3 Spacesuits</td>
<td>83.91*3 = 251.73 kg</td>
<td>16.78%</td>
</tr>
<tr>
<td>CTBs</td>
<td>30.7 kg</td>
<td>2.05%</td>
</tr>
<tr>
<td>Food</td>
<td>132.6 kg</td>
<td>8.84%</td>
</tr>
<tr>
<td>Water</td>
<td>63.18+29.64 = 92.82 kg</td>
<td>6.19%</td>
</tr>
<tr>
<td>3 Seats &amp; 3 People</td>
<td>61.23 + 306.18 = 367.41 kg</td>
<td>24.49%</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>Under Mass Budget</strong></td>
<td><strong>82.72% &lt; 100%</strong></td>
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References


• [http://upload.wikimedia.org/wikipedia/commons/a/a3/USN_Treatment_Table_6.png](http://upload.wikimedia.org/wikipedia/commons/a/a3/USN_Treatment_Table_6.png)


• [http://askmagazine.nasa.gov/issues/31/31s_new_astronaut_seat.html](http://askmagazine.nasa.gov/issues/31/31s_new_astronaut_seat.html)

• [http://spacecraft.ssl.umd.edu/design_lib/SSP50005rC.ISS_crew_integ.pdf](http://spacecraft.ssl.umd.edu/design_lib/SSP50005rC.ISS_crew_integ.pdf)