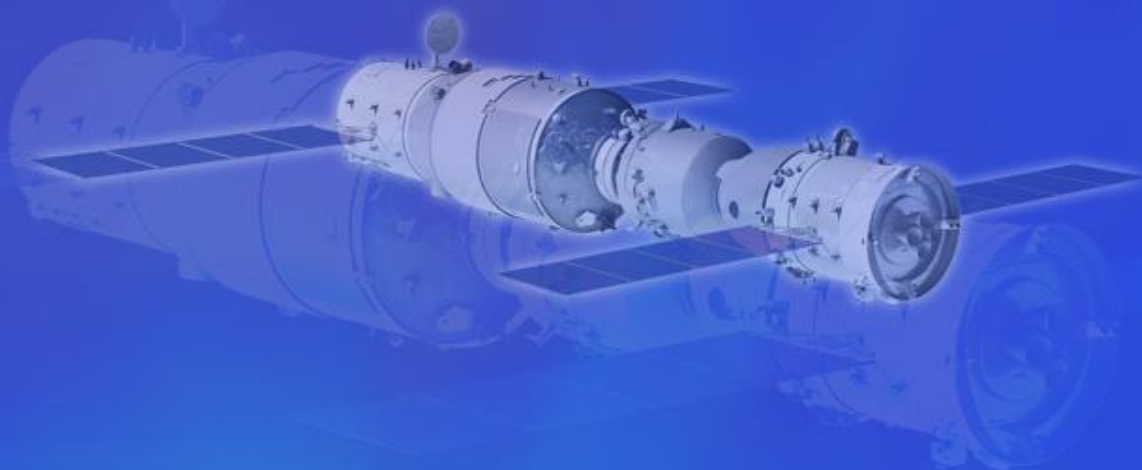

The Maintainability and Supportability of Manned Spacecrafts in Deep Space

（IAA SG3.25）

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Introduction

Human footsteps from the near-Earth space toward the Moon, Mars and deep space extension is inevitable for the future development of human being, however road is difficult for manned space exploring. Complex space environment and long mission cycle put forward higher requirements and greater challenges to assurance of success of flight mission and safety of spacecraft and astronauts

Introduction

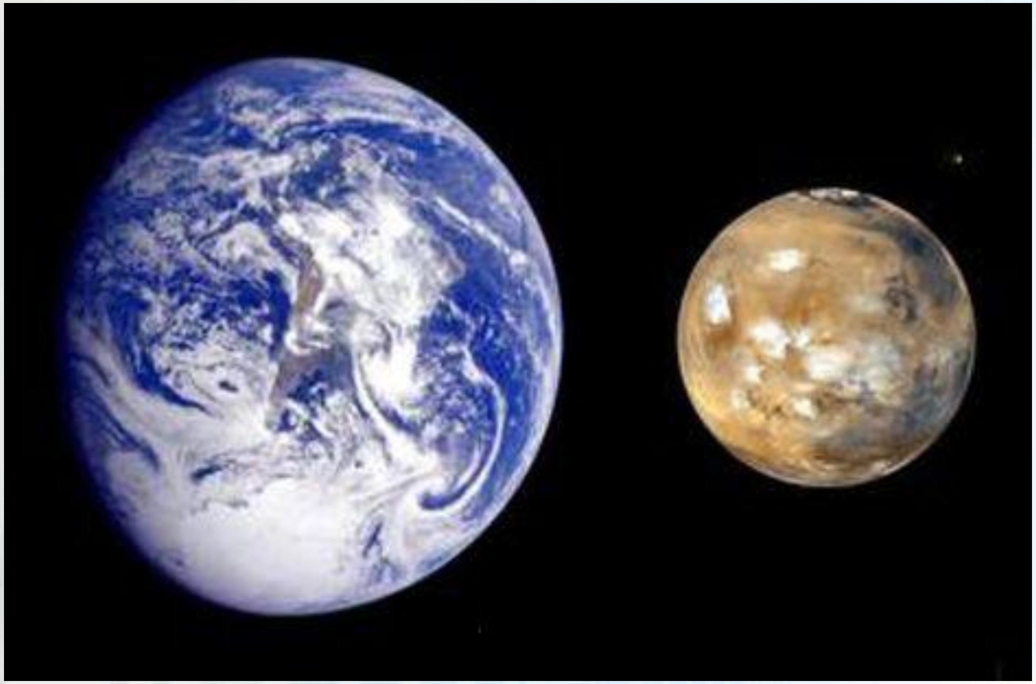
The Manned deep space exploration mission includes orbital transportation from the earth，landing on the target star， inhabitation and exploration， and returning to the earth. Throughout the mission， large quantities of propellant，cabin pressure maintenance gasses，and maintenance spares are required. Since the spacecraft can only carry limited supplies and cannot obtain regular supplies，the research on **supportability** technology becomes an urgent task in the research of manned deep space exploration.

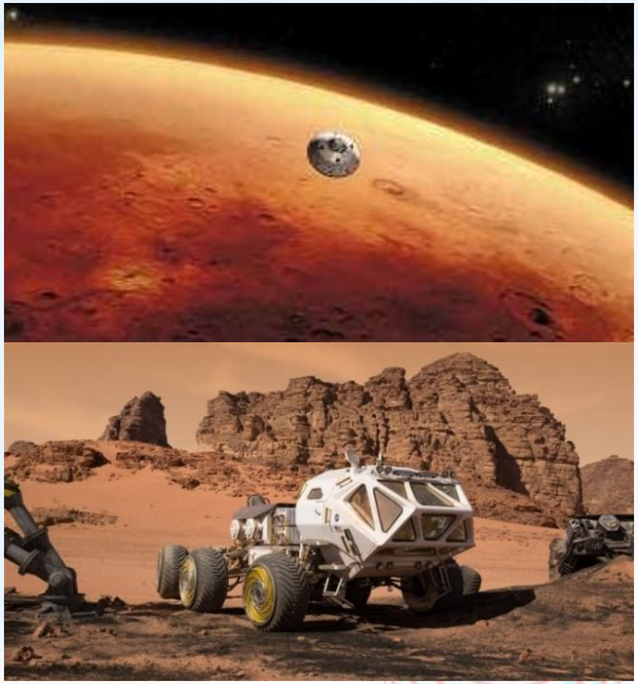
Introduction

Due to the complex and harsh environment of deep space， as well as the weak links in the design of space craft systems， there may be a variety of failures in the process of flight mission. Some failures have a small impact on the mission， while others can cause the entire mission to fail. Maintenance is a necessary means of troubleshooting， maintaining the health of the spacecraft system and extending the service life of the system. Therefore， **maintainability** research is also a key research to ensure the success of manned deep space exploration mission.

Introduction

Taking the mission of manned Mars exploration as the object, our study group researches this subject with two aspects - Maintainability and Supportability.





Supportability

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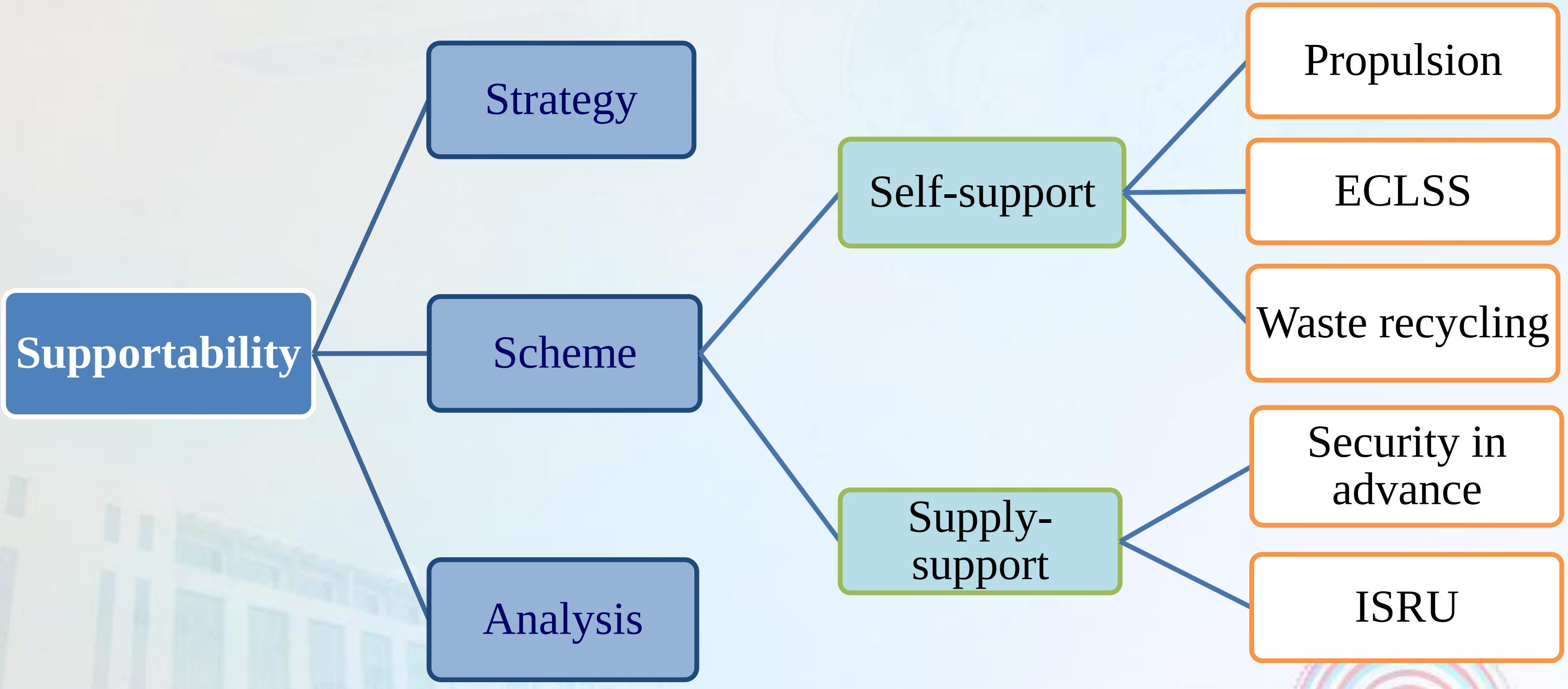

Supportability

Support strategy on the manned Mars exploration

The support demand for manned Mars exploration mission is analyzed, and the support strategy from the aspects of reducing support demand by using advanced technology, in-situ resource supplement and resource recycling is studied.

Self-support

Supply-support

Supportability

Scheme Research of Supportability

- Self-support
  - Research of propulsion technology
    - Chemical propulsion
    - Nuclear thermal propulsion
    - Nuclear power propulsion
    - Solar electric propulsion

	comparative analysis
Chemical propulsion	has the highest maturity, but provides limited thrust
Nuclear thermal propulsion	Provides high specific impulse and large thrust. Safety and radiation protection is difficult to ensure
Nuclear power propulsion	Provides high specific impulse, and works continuously Safety and radiation protection is difficult to ensure
Solar electric propulsion	No limit to impulse in theory， but a large area of solar array is needed. Capacity decreases As the distance from the sun increases

Supportability

Scheme Research of Supportability

– Chemical propulsion with high specific impulse

Considering high specific impulse, environmental requirement, and safety of the astronauts, liquid propulsion systems, using LH_2/LOX, LOX/methane, LOX/kerosene and H2O2/kerosene were studied .

Performance parameter	LH_2/LOX	LOX/methane	LOX/kerosene	H2O2/kerosene
Mixratio	6.0	3.5	2.74	7.393
Specific impulse（s）	445	355	343	322
Relative density	0.3610	0.8276	1.024	1.319
Density Specific impulse（s）	161	294	352	425

LH_2/LOX propulsion system offers the largest specific impulse, but the smallest Density Specific impulse. LOX/methane propulsion system offers specific impulse much less than LH_2/LOX, but only 12s higher than LOX/kerosene propulsion system, while it offers Density Specific impulse much less than LOX/kerosene propulsion system.

Supportability

Scheme Research of Supportability

– Nuclear thermal propulsion

The nuclear rocket engine heats the propellant with the heat released by the nuclear reaction. Then the propellant gushes out of the nozzle to produce thrust. Compared with chemical propulsion, thermonuclear propulsion provides higher specific thrust, enabling large thrust in small amounts of propellant and meeting the requirements of velocity increment.

a. Thermonuclear propulsion of Solid reactor
b. Thermonuclear propulsion of gas reactor
c. Thermonuclear propulsion based upon nuclear fuel explosion
d. Thermonuclear propulsion of dust nuclear fission reaction based on magnetically confined plasma

	specific impulse(s)
1	910
2	3000~5000
3	10000
4	10^6

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Scheme Research of Supportability

– **Electric propulsion**

Electric propulsion is divided into nuclear power propulsion and solar electric propulsion according to different energy sources:

✧ Nuclear power propulsion is a system that uses nuclear energy to drive electrical propulsion by means of thermoelectric conversion;

✧ Solar electric propulsion is a system that uses solar panels to convert solar energy into electrical energy to drive electrical propulsion.

Major electrical propulsion systems:

1. Electrostatic ion propulsion
2. Hall electric propulsion
3. Electromagnetic propulsion

	specific impulse(s)	power(W)	efficiency
1	2500～15000	10～30k	60～80%
2	1500～3500	100～50k	45～60%
3	2000～10000	>100k	35～50%

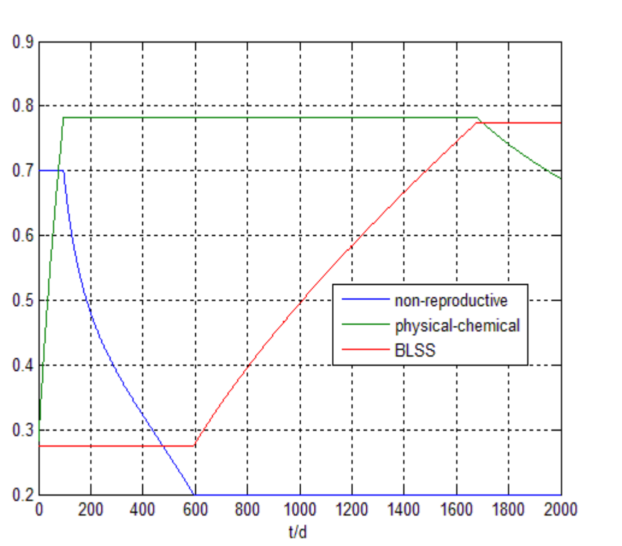
Supportability

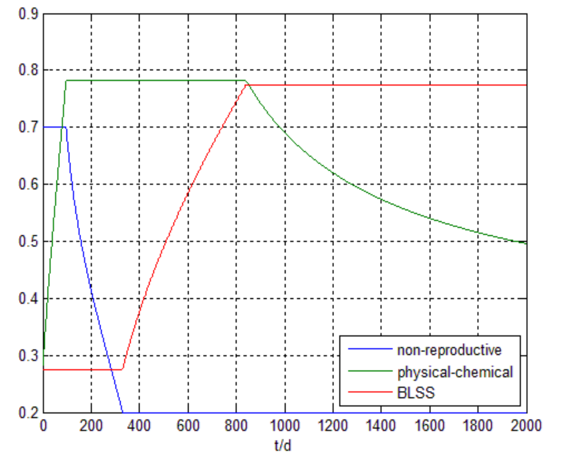
Scheme Research of Supportability

- Self-support
  - Research of the ECLSS
    - Non-reproductive ECLSS
    - physical and chemical regeneration ECLSS
    - BLSS

The three systems are evaluated based on Integrated mass degree of system closure and technology maturity.

- For medium and long term deep space exploration missions, the comprehensive index of the physical and chemical regeneration ECLSS are more than the other two life support systems. With the increase of the mission cycle, the comprehensive index of the BLSS increases and Gradually become the maximum.
- With the continuous development of technology of BLSS and space module design, BLSS will become a necessary technical means.





Scheme Research of Supportability

– **Non-reproductive ECLSS**

The non-reproductive ECLSS is where food, oxygen, and water are brought into space with the aircraft from the ground. The astronaut-generated waste is stored on the aircraft and brought back to the ground on a regular basis or at the end of the mission.

Supportability

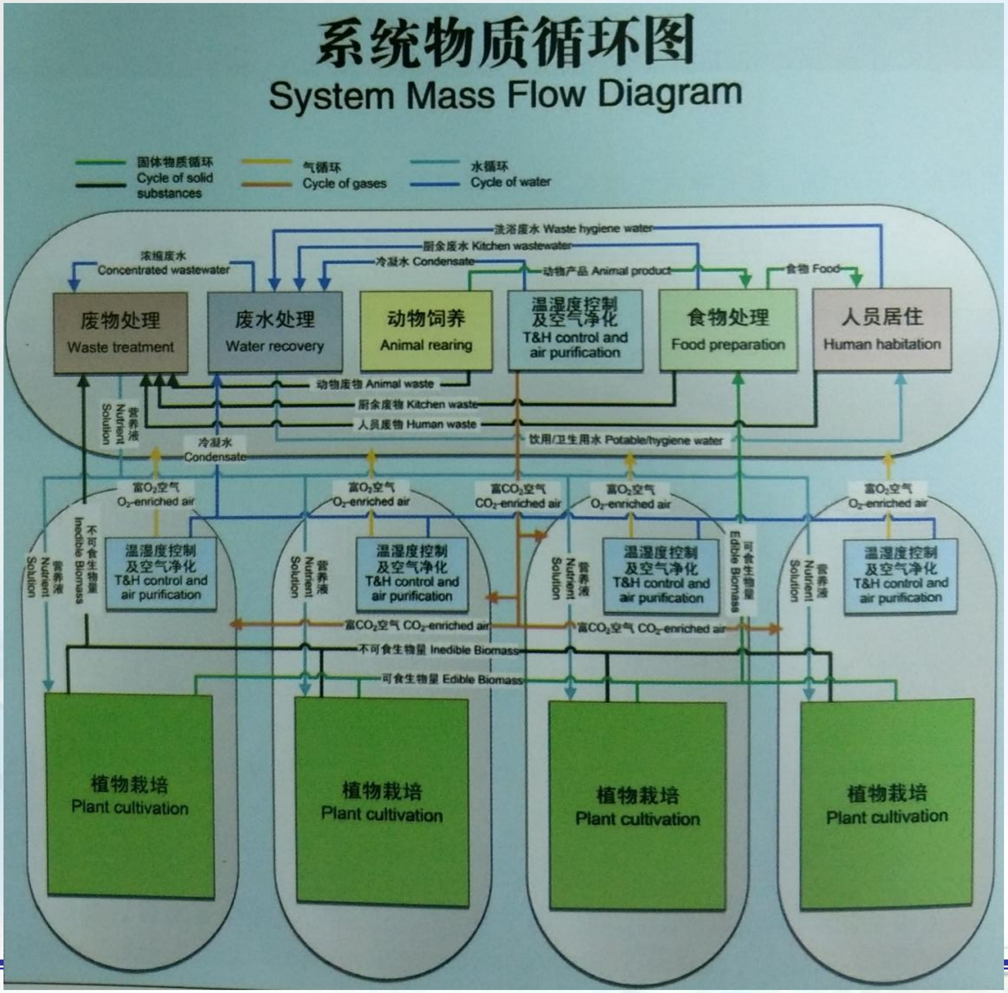
Scheme Research of Supportability

– **The physical and chemical regeneration ECLSS design**

The physical and chemical regeneration ECLSS is designed by using physical and chemical theory to realize material recycling. This system mainly realizes the regeneration and recycling of gas and water, but food needs recharge. Astronaut life waste is stored on the spacecraft and eventually brought back to the ground.

Scheme Research of Supportability

– **The BLSS design**



Supportability

Scheme Research of Supportability

– **Comprehensive assessment and analysis**

Evaluation criteria

- Integrated mass
- The degree of system closure
- The technical maturity

Supportability

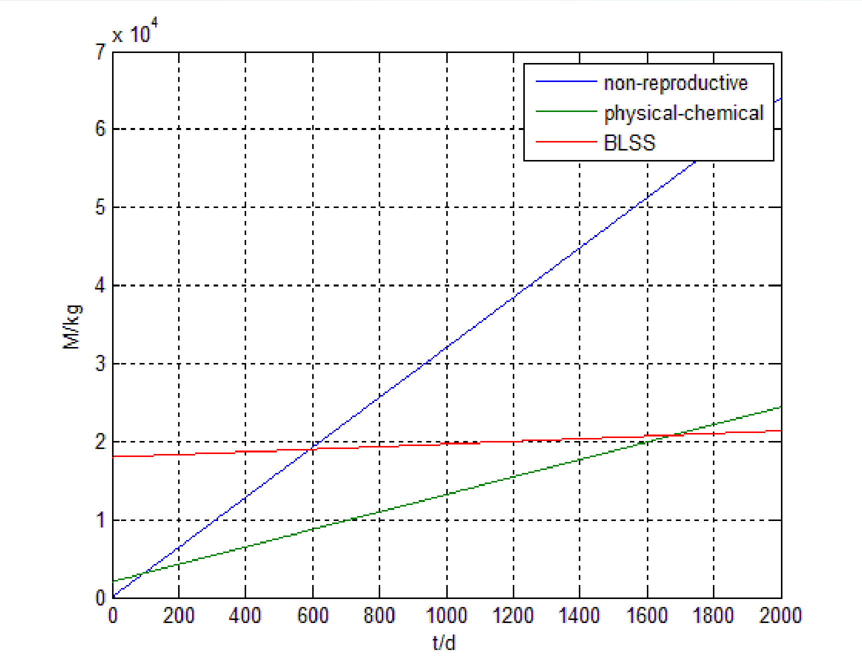
Scheme Research of Supportability

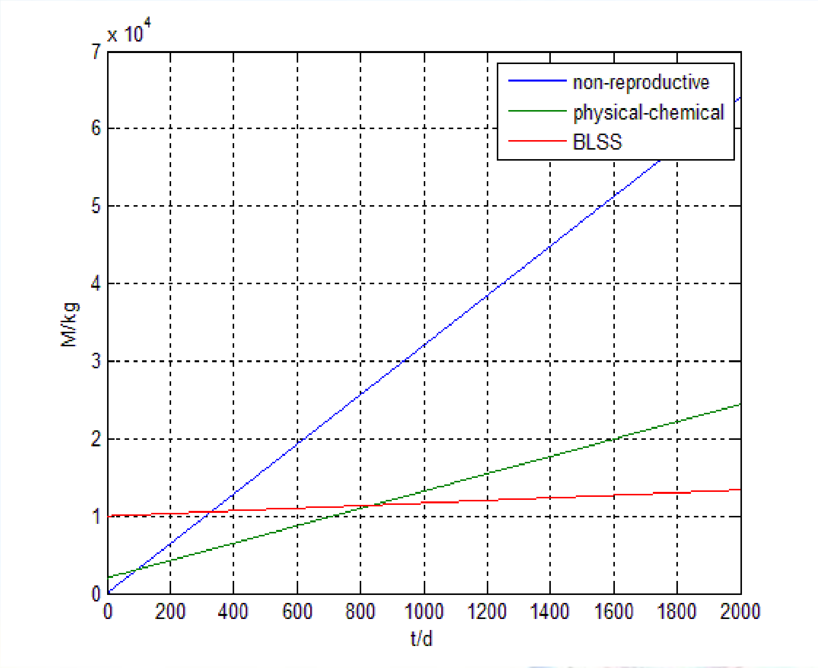
– **Comprehensive assessment and analysis**

Assessment of the Integrated mass

Set the number of astronauts is set to 4, integrated mass of the BLSS Set to 18t,considering the space and power requirements of BLSS .

Set the number of astronauts is set to 4, integrated mass of the BLSS Set to 10t, considering the development of technology of the space module.





Supportability

Scheme Research of Supportability

– Comprehensive assessment and analysis

Assessment of the system closure degree

closure coefficient of non-regeneration ECLSS is 0
closure coefficient of the physical-chemical ECLSS is 44%
closure coefficient of the BLSS is 91.6%

Assessment of the technical maturity

The technology maturity of non-regeneration ECLSS can be rated as TRL9
The technology maturity of the physical-chemical ECLSS be rated as TRL8
The technology maturity of the BLSS can be rated as TRL5

Supportability

Scheme Research of Supportability

– **Comprehensive assessment and analysis**

S1: non- regeneration ECLSS
S2: physical and chemical regeneration ECLSS
S3: BLSS

three evaluation indexes of system:
x_1: comprehensive quality
x_2: closures
x_3: technology
X: comprehensive evaluation index

the mission-time of manned Mars exploration is about 500 days
the initial weight of BLSS is set to 18t

S1: $x'_{11} = 0.12, \quad x'_{21} = 1, \quad x'_{31} = 0$

S2: $x_{12} = 0, \quad x_{22} = 0.44, \quad x_{32} = 0.916$

S3: $x_{13} = 1, \quad x_{23} = 0.75, \quad x_{33} = 0$

Weighting: $S1 = 0.5, \quad S2 = 0.3, \quad S3 = 0.2$

$X_1 = 0.26, \quad X_2 = 0.78, \quad X_3 = 0.27$

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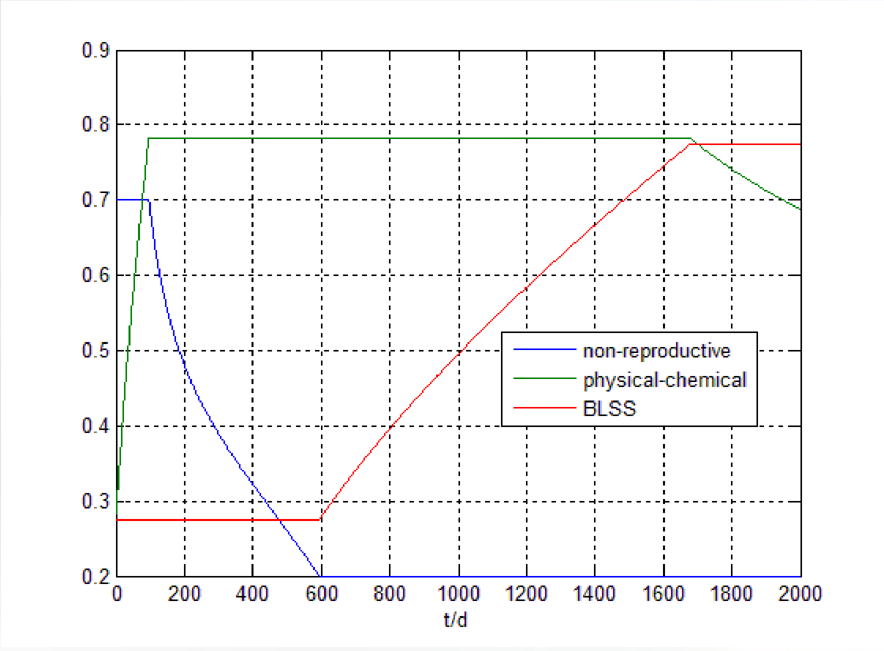
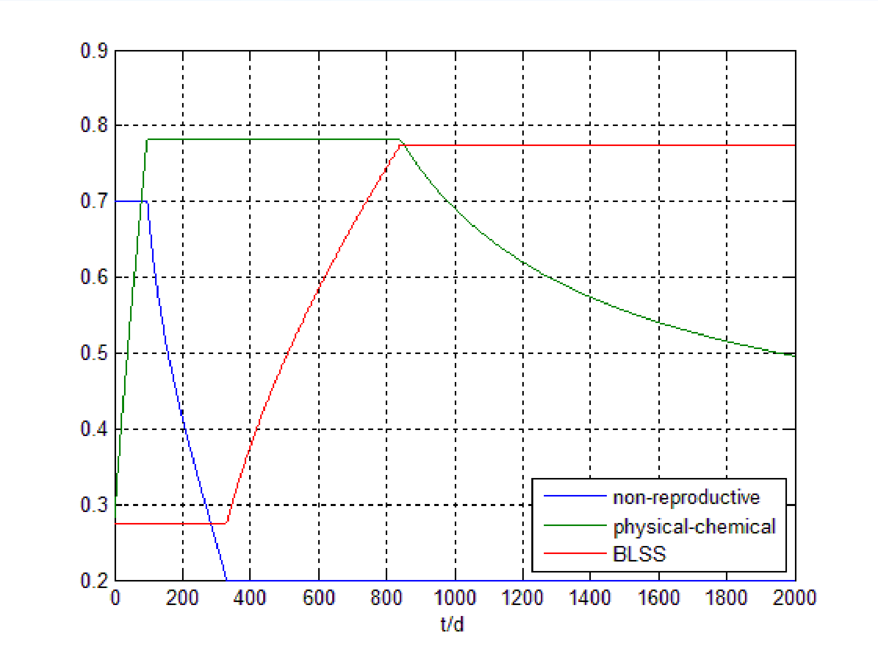
Scheme Research of Supportability

– **Comprehensive assessment and analysis**

If the mission time is set to be a variable, the changes of the comprehensive index of the three systems are as follows

For more, set the initial weight of BLSS to 10t, the results change as follows





Supportability

Scheme Research of Supportability

- Supply-support
  - Research on support by Unmanned space crafts
    - Analysis of types of materials that can be carried by unmanned spacecraft
      - Propellant
      - Maintenance and repair parts
      - Gas and water
      - Crew lander
    - Planning unmanned cargo launch mission
      - Prior to manned missions, multiple Unmanned space craft launches were launched. Unmanned space crafts fly to Mars with the smallest energy orbit. When manned spacecraft arrive at Mars, it dock with Unmanned space crafts which provide supply

Supportability

Scheme Research of Supportability

- Self-support
  - Research on recycling technology of waste on orbit
    - Analysis of waste types
      - Astronaut's clothes
      - Product packaging
      - Containers for water and gas
      - The accident product
    - Analysis of recycling technology
      - Biodegradation
      - 3D printing

Supportability

Scheme Research of Supportability

– **Recycling of waste on orbit**

- Astronaut’s clothes
- Product packaging
- Containers for water and gas
- The accident product

The recycling technology for these wastes such as Biodegradation, 3D printing is being studied and the feasibility of them on orbit will be analyzed in the future research work.

Supportability

Scheme Research of Supportability

- Supply-support
  - Research on in situ resource utilization of Mars
    - Research on technology using the Mars atmosphere to decelerate
      - In order to make better use of the Mars atmosphere to slow down the lander, a landing scheme based on "lifting body & retro-rocket & drag chute" is proposed.
    - Research on propulsion technology based on Mars atmosphere
      - Analysis of rarefied gas propulsion technology
        - ✓ atmosphere collection technology
        - ✓ Propulsion Technology Based on Mars Atmosphere
      - Aspirating propulsion scheme analysis and comparison
        - ✓ CO_2/metal propulsion system
        - ✓ CO_2 electro-thermal propulsion system

Scheme Research of Supportability

– **ISRU of Mars**

The Martian environment

Parameter	Mars	Earth	Ratio
Quality/ 10^{24} kg	0.64185	5.9736	0.107
Volume/ 10^{12} km^3	0.16318	1.0832	0.151
Equatorial radius /km	3397	6378.1	0.533
Polar radius /km	3375	6356.8	0.531
Surface gravity / m/s^2	3.69	9.78	0.379
Angular velocity /rad/s	7.0882e-5	7.2921e-5	0.972

$$\rho_M = \frac{P}{188.95110711075 \cdot T}$$

$$G = \frac{\mu}{r^2}$$

Supportability

Scheme Research of Supportability

– ISRU of Mars atmosphere

The surface of Mars is covered by atmosphere, which is mainly composed of 95% CO2 and a few of other gases. It is a very promising resource for propulsion.

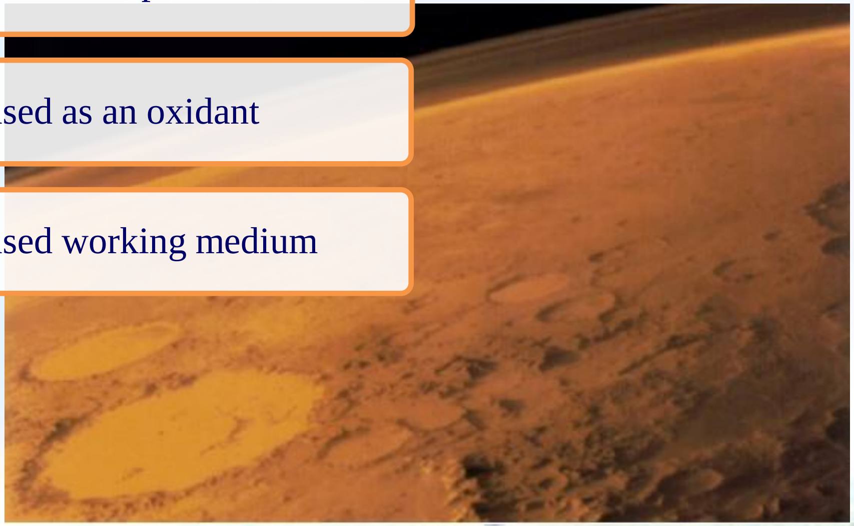
Analysis of rarefied gas propulsion technology

Atmosphere Collection Technology

- Absorption apture method
- Adsorption capture method
- Mechanical capture method
- Cryogenic refrigeration capture method

Propulsion Based on Mars Atmosphere

- CO2 ionized to produce O2
- CO2 used as an oxidant
- CO2 used working medium



Supportability

Scheme Research of Supportability

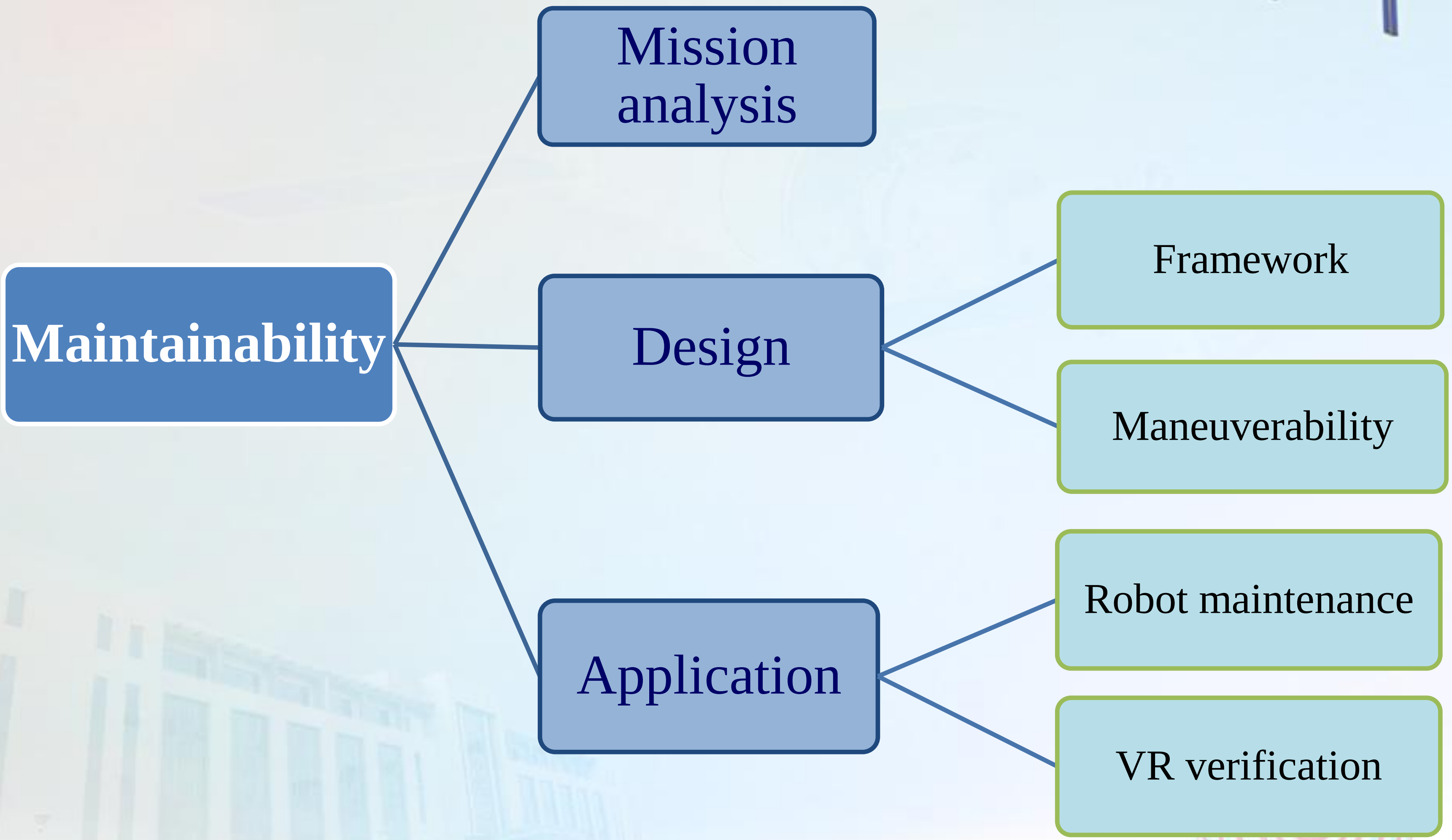
– ISRU of Mars atmosphere

Aspirating propulsion scheme analysis and comparison

Based on Mars's atmospheric environment, there are two types of propulsion schemes that can be used: CO2/metal propulsion system, and CO2 electro-thermal propulsion system

For the Mars CO2/metal propulsion system, metal fuels can only be provided by the earth. Further more, there are a lot of key technical difficulties such as supply of metal fuel, difficulty in ignition, and easy-to-plug combustion for practical application. Mars CO2 electro-thermal propulsion system does not have the technical difficulties the CO2/metal rocket propulsion system has, has a simple structure, and can use existing mature technologies. It is a new propulsion system that can be developed for Mars exploration mission in a short time.

Maintainability



Analysis of the maintenance tasks of manned Mars mission

The mission cycle of manned deep space exploration varies from several years to more than ten years.

The system of the spacecraft is complex, including the launch vehicle, the orbit transfer vehicle, and the landing vehicle and so on.

the space environment is complex ,abominable and ever-changing.

On-orbit maintenance has become a very essential means to ensure the success of the mission.

In order to ensure the smooth operation of the maintenance task, the spacecraft needs to carry out maintenance spare parts for repair. However, the weight and space of the spacecraft can be limited, so we need to select some important products from the products with maintenance needs .

Analysis of the maintenance tasks of manned Mars mission

- Device type on the manned Mars mission aircraft is analyzed based upon the method combine FTA and FMEA. According to the analysis results, and taking the severity of the failure mode and the order of the minimum cut set as the evaluation index, the evaluation matrix of the importance of products can be built. Sorting by the importance of device devices, spare parts that need to be carried are ultimately determined

No.	name
1	Power supply and distribution equipment
2	Energy management computers
3	Control moment gyroscopes
4	Attitude control computers
5	TT& C equipment
6	Propulsion system management computers
7	Thrusters
8	Heat control management computers
9	Heat control pump units
10	Core computers
11	Data storage device
12	Mechanical arm
13	Environmental control equipment
14	Life support equipment

Maintainability

Manned Mars maintainability design

- Design of maintainability framework for deep space manned spacecraft
  - Reliability Centered Maintenance Strategy
    - Ensuring the reliability of equipment with the least resources
  - Design of power and information isolation
    - The maintainable products can be independently powered off
    - Information interface supports power operation
  - Maintenance work mode design
    - Ensure that when the product cuts out the system and the new product joins the system, it has no or less influence on the system function and guarantees the platform security.
  - Visual and accessible design for ORU
    - Space instrument board structure
    - Reversible cabinet
    - Drawer type cabinet

Maintainability

Manned Mars maintainability design

- Maneuverability design of deep space manned spacecraft maintenance

  - The mechanical interface shall be easy to operate by astronauts on the basis of ensuring connection and precision, and will not be separated from the product.
  - The electrical interface can guarantee communication and power supply. The electrical connector can be hot plugged not easy to be wrongly connected.
  - The thermal interface should ensure the working temperature of the product.

Maintainability

Utilizing robot to assist astronauts to accomplish simple and repetitive operations can reduce the workload of astronauts and make them accomplish more scientific tasks.

The robot can complete the maintenance in the dangerous area instead of the astronaut, thus greatly ensuring the safety of the astronauts.

Key technology

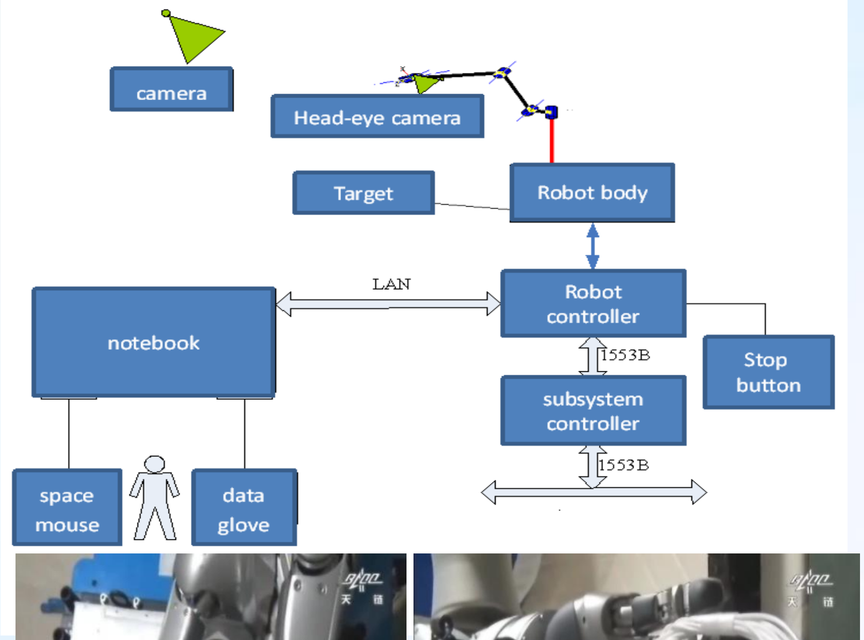
- Dexterous mechanism design technology for maintenance
- Humanoid robot technology
- Measurement and recognition technology
- Task planning technology

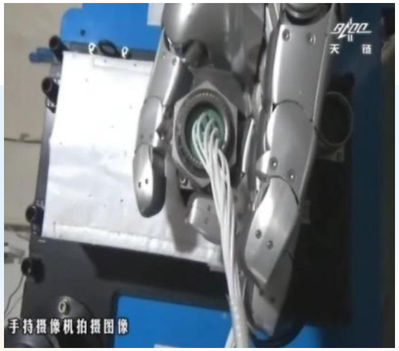
3.3 Application Research of maintainability Technology

Research of on-orbit maintenance technology based on Robot

- To assist astronauts to accomplish simple and repetitive operations
- To complete the maintenance in the dangerous area instead of the astronaut

- The on-orbit maintenance system based on robots consists of on-orbit robot and astronaut is built and verified



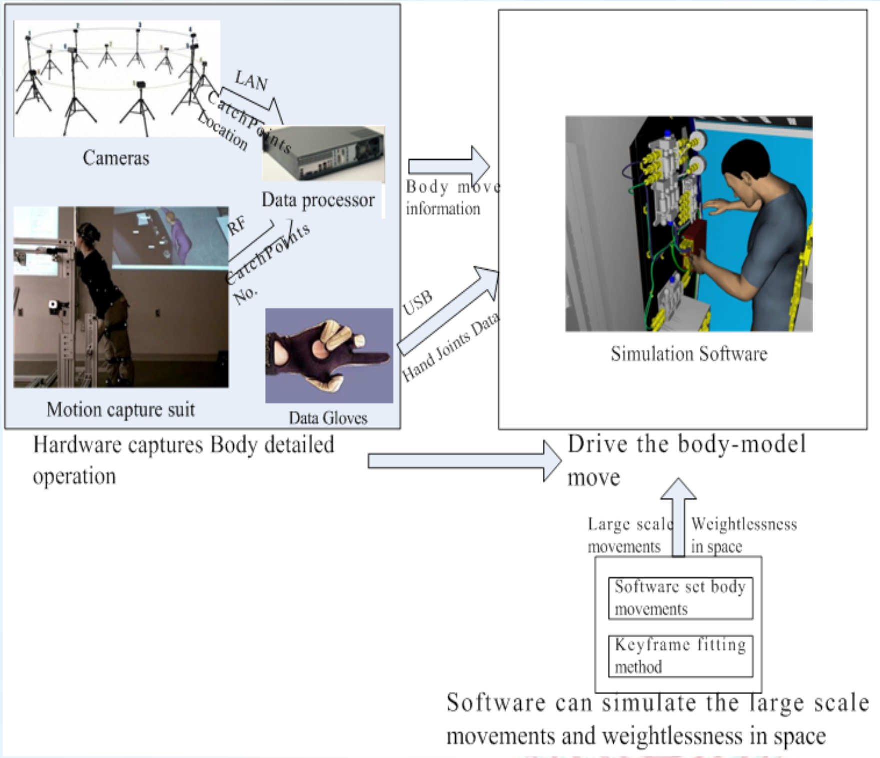


3.3 Application Research of maintainability Technology

Application of VR technology in on-orbit maintenance

Hybrid simulation platform have been built by combining the Motion Capture System and 3D virtual simulation system based upon VR technology.
The simulation of detailed operation is realized through that motion capture device and data gloves collect participants' motion. The movements of human and things can be controlled by the algorithm. The activities of 3D model of maintenance equipment can be controlled by simulation software.

- To verify maintainability design
- To plan the path in space
- To train astronauts to complete on orbit maintenance tasks



Conclusions

- Maintainability and Supportability of Manned Space crafts in Deep Space are key-factors affecting mission success or failure and issues that need urgent research.
- To research the supportability of manned spacecraft, we should research from two aspects of Self-support and supply-support.
- We should make use of in situ resources as an important guarantee for manned deep space exploration.
- With the continuous development of technology of BLSS and space module design, the deep-space exploration missions will take longer and longer, and BLSS will become a necessary technical means for Manned Deep Space Exploration.
- Maintainability design should ensure the reliability of the spacecraft system with the least resources,such as spare parts, astronaut working time and so on.
- On-orbit maintenance based on Robot technology and VR technology, can improve the autonomy of on orbit maintenance and reduce the demand for ground support.

Thanks for your Attention!

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