Analysis of Operational Scenarios for Moon Related Space Flight Activities

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Summary

This paper presents an overview on a possible ground infrastructure for a moon base on one of the poles of the moon. The flight and ground control for a moon base including the transfer of crew and cargo from and to the moon base could be performed by 2 control centres, a moon base control centre (MBCC) for the moon base itself and the excursions on the moon as well as a Moon Transfer Control Centre (MTCC) for all transfer flights. The analysis showed that 3 suitably distributed ground stations are sufficient for nearly continuous communication with the moon base. For the moon communication network a two-stage approach is envisaged. In phase 1 the excursion teams could communicate directly to the moon base or via a radio tower nearby the moon base is used while in phase 2 a set of relay satellites allowing also communication on the far side of the moon is envisaged.

1. Introduction

Sending astronauts to and from the Moon is a special challenge not only for the astronauts themselves and space vehicle development but also for the establishment of new operational concepts for ground support. The Columbus module, the first European manned spacecraft to be monitored and controlled in orbit for a lengthy period of time, clearly demonstrates the necessity for a control centre. The complexity of a space station does not allow the astronaut to be an expert of everything residing on the station. As such, specific expertise and operational support from the ground is needed. Compared to the ISS a possible moon base offers the advantages that no orbit control has to be performed. Nevertheless new or increased hazards like higher radiation and moon dust, higher and more elaborate transportation needs as well as medium and long-term excursion planning with an increased number of EVA’s compared to ISS will offer additional challenges compared to the ISS.

2. Overall Scenario

As a starting point of the analysis a possible mission scenario has been developed as a baseline. This scenario will be used as a guideline for the development of an operations concept and communications setups. Based on various scenarios described in literature a very promising one has been chosen which is described briefly below:

- A Moon base for about 6 people at one of the poles of the Moon to look for ice in permanent crater shadows and to have nearly permanent sunlight
- Short and long distance excursions using dedicated vehicles
- Crew exchange by means of a manned vehicle every six months. Assuming an exchange of 3 crew members per flight leads to at least 4 flights per year.
- Unmanned, supply vehicle for food, water, air and spare parts every 3 months, adding up to 4 flights per year.

A preliminary analysis of this mission scenarios showed that ground support of a Moon crew will be needed for all the activities on, or in support of, a permanent Moon base. Assuming a high autonomy of all elements of the system, 2 mission control centres seemed to be sufficient to support the complete programme.

- 1 Moon Base Control Centre (MBCC) responsible for the base itself and for outside excursions. The tasks would include monitoring and control of the base, of the distributed autonomous support equipment, scientific experiments as well as excursion teams and vehicles.
- 1 Moon Transfer Control Centre (MTCC) responsible for manned and unmanned flights to and from the Moon base. It would coordinate the flight to and from the Moon base (maybe in conjunction with a LEO station), crew exchange and contingency resolution.

Each of the two mission control centre has its dedicated role with a reasonable task distribution as well as clear and simple interfaces to the other, e.g. the landing or launch of manned or unmanned vehicle at the moon base. Therefore it is possible to describe the tasks of the Moon Base Control Centre alone, which will be done in the frame of this paper.

3. Tasks of the Moon Base Control Centre

The moon Base Control Centre will be focal point of all activities related to the moon base, especially it will be responsible for:

- Assembly, checkout and commissioning of the moon habitat and all related facilities
- Monitoring and control of the Moon Base, the distributed support equipment and scientific experiments in routine operations

- Monitoring, control and support of excursion teams and their vehicles
- Contingency resolution for the whole moon base including EST support provision and telemedicine support
- Provision of early warning of the moon base in case of solar flares or other hazardous events
- Interface to the Moon Transfer Control Centre

The work of the Moon Base Control Centre starts with the setup of the ground communication system and the infrastructure, the preparation of the operational products, the training simulation and certification of the ground team. This has to be performed in close cooperation with the designer of the moon base hard- and software to avoid any lack of information. With the launch of the first element of the moon base the real-time operations of the MBCC begins. Due to the expected high autonomy of the moon base full 24 hour real-time operation of the unmanned first elements of the habitat will not be necessary.

The next step will be marked by the start of the permanent or intermittent manning of the moon base. From this time on a core team shall be available for 24 hours in the MBCC to ensure immediate crew support for a manned moon base and to provide permanent contact of the moon base crew to the ground. This is especially necessary for the commissioning phase of each new element, which will be critical events for the whole base. In this phase the core team will be augmented by additional flight controllers for dedicated activities and by an Engineering Support Team for immediate resolving of any contingencies.

When the first stage of expansion of the moon base is successfully achieved, the team can be reduced again to the core team for routine operations. The EST will be available offline for possible contingencies while the rest of the team will prepare themselves for the next steps like support equipment installation, experiment setup and moon excursions. Support equipment will include e.g. a radio tower for longer excursion or solar power arrays in permanent sunlight. Scientific experiments like optical and radio telescopes, moon surface and space environmental surveillance.

The monitoring and control of the moon excursion will be one of the major tasks of the MBCC because it is assumed that the moon base itself will not be able to perform the task by there own. Hence, each excursion will be planned, coordinated and supported from the MBCC. Possible goals of the excursions first by foot and later by vehicles are the moon geology, search for moon ice as well as installation and maintenance of scientific equipment.

Beside routine operations contingency support and resolution for the crew is the most important task of the MBCC. Therefore, offline support teams have to be holding ready to allow a fast response in case of an onboard failure, an accident or a crew injury or illness. A special case of contingencies are hazardous environmental events like solar flares, which necessitates immediate return of an excursion team and retraction of the whole crew to special shielded areas in the moon base. This requires permanent monitoring of the environment, especially the sun for solar flares, but also the whole sky for other threats like space debris.

For an intermediate step in the preparation of a moon mission, the lack of scientific data with respect to the above-described potential hazardous environmental effects could be the mission goal for an unmanned satellite pre-cursor mission to the moon. Here it could be technically demonstrated to send a small orbiter or lander to the moon that collects these environmental data at a possible moon base location.

During moon base operations these permanent tasks would afford an effective and reliable ground and space communication network for voice, video and data transfer to assure an excellent crew support and the highest possible safety standards for the flight crew.

4. Ground Communications Network

Monitoring and control of a moon base would require a permanent down and uplink path to the base as it is now nearly established for monitoring the ISS. Reason for that is to give the ground grew the chance for failure analysis and correction in real time. The near distance to the moon (and resulting up and downlink transmission times) makes this also possible for a moon base.

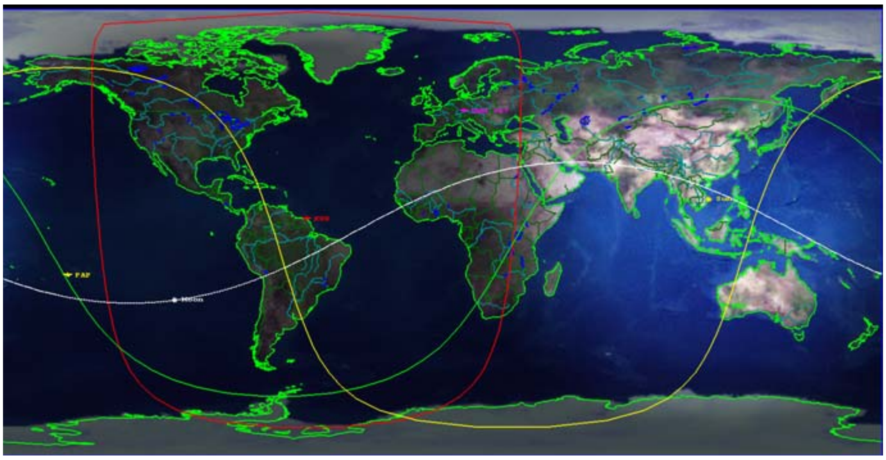

Fig. 1: Chosen Ground stations with areas of visibility

To ensure a short signal turn-around time from earth to moon a direct communication by ground station is preferred. During a possible first unmanned assembly phase a partly coverage from earth could be accepted but has to be analysed closely. The advantage of a later setup of the full ground station network has to be traded against the disadvantages of possible communication outages restricting the assembly timeline.

Assuming to permanent visibility of the moon base (or at least its antenna) from earth, a set of 3 equally distributed ground stations nearby the equator is sufficient for the communication (see Fig. 1). Due to the inclination of the Moon with respect to the Earth, ground stations located near the equator have better link visibility budgets than others. Here the pass duration is more stable and not changing according to the season moon position (see Fig. 1 to Fig. 4). As examples for this investigation the already existing ground station in Papeete, Kourou and New Norcia are chosen.

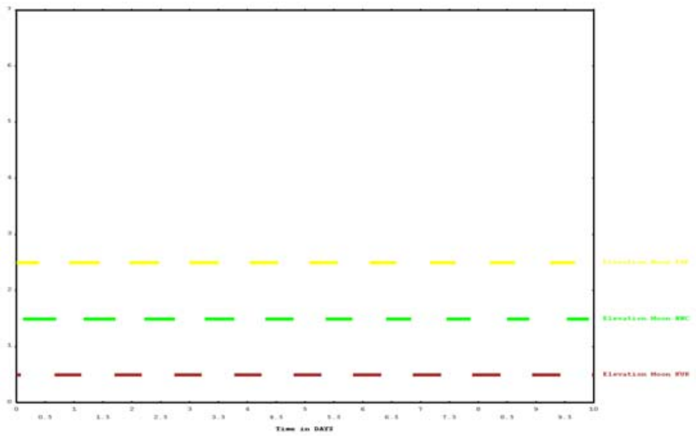

Fig. 2: Effective contact time of the 3 chosen ground stations

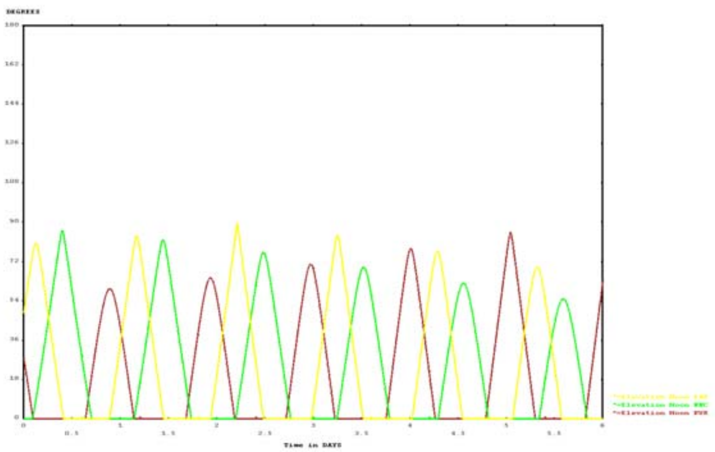

Fig. 3: Elevations of the 3 chosen ground stations over 6 days

These three ground stations offer a nearly permanent coverage of the moon with small gaps due to unevenly distribution around the earth. Additionally these 3 grounds station can provide partly hot redundancy for increased reliability. Fig. 2 to Fig. 4 show the coverage of the moon base from the 3 ground stations considering the effective contact time, the elevations and the coverage areas, respectively.

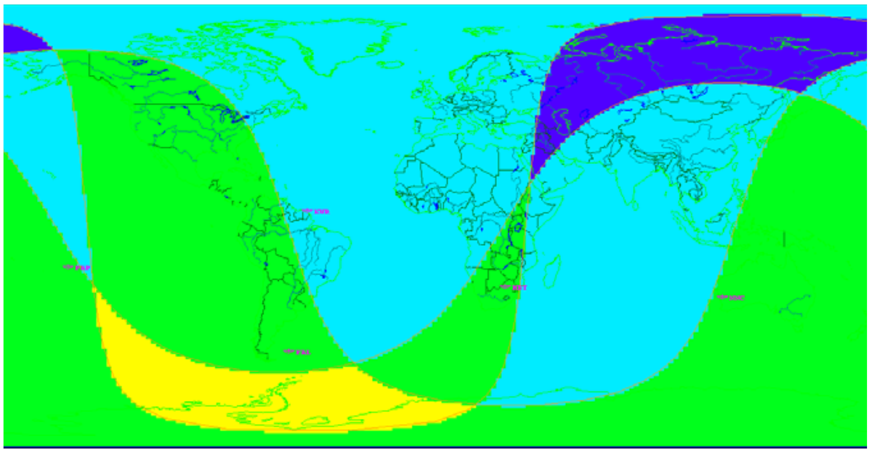

Fig. 4: Areas of coverage of the 3 chosen ground stations

To avoid any shortcoming in communication a bandwidth of about 10 times the maximum ISS bandwidth is envisaged, i.e. about 500 MBit/s. For redundancy reason a set of additional ground stations providing permanent coverage with reduced bandwidth shall be taken into account. Both sets of ground stations shall be used for the moon base in first priority, i.e. they can be used for other tasks if they are not needed for earth moon communications.

As already proven in the ISS/Columbus setup, the ground station will be connected by standard ground communications lines to the MBCC in a redundant way. Usage of Earth orbit communication satellite is not foreseen in this scenario, but they could be necessary for the operations of the Moon Transfer Control Center (MTCC).

5. Communication Network on the Moon

The activities at the moon base will first concentrate on the assembly, checkout and commission of the core elements of the habitat. Hence, a large communication infrastructure is not needed for this phase, because no large excursion will be performed in this period. When the essential modules and support equipment of the habitat are installed and running, the focus will be shifted towards excursion on the moon and to the installation and maintenance of scientific equipment. In this scenario relatively short excursions in the beginning could be followed by significantly longer excursions reaching greater distance at a later stage, e.g. when pressurized excursion vehicles are available. Therefore, a two-phase approach for the establishment of the moon communication network is envisaged

5.1. Phase 1

In the first phase of operations of a permanent moon base short time excursion (< 1 day) are expected, only. Hence, the distance from the moon base would be relatively small. This will allow a direct communication with the moon base within the line of sight (comparable to Apollo excursions from the lunar lander). This very restricted capability could be enhanced by a radio tower erected nearby the moon base. Such a tower would allow increasing the distance of the excursion and would avoid a loss of communication during the examination of at least shallow craters and rifts nearby the base. According to the dependency of the topography around the moon base, the range of such a tower cannot be specified in this stage of investigation. Due to the moon topography and the potential research goals (e.g. deep craters to search for water-ice) pre-planned and unexpected short communication losses have to be taken into account. For the visible side of the moon direct communication with the Earth ground station could be foreseen as a backup. Nevertheless excursions to the far side of the moon are very limited in this phase, because no communication link outside the radio beacon of the moon base or its radio tower will exist during this phase.

5.2. Phase 2

In a second phase of a permanent moon base long time excursion (> 1 day) with suitable vehicles are envisaged. This will include pressurized vehicles providing a suitable environment for the astronauts for medium and long-term excursion. Additionally the maintenance of scientific equipment on the far side of the moon like radio telescopes could be taken into account. To provide permanent coverage with the excursion team especially on the far side of the moon, a set of moon relay satellites have to be launched.

The following requirements shall be met:

- Permanent coverage in the vicinity of the pole where the moon base is located
- Communication via the relay satellites with moon base and MCBB

This network can also be used for data relay from scientific equipment on the far side of the moon. Due to the moon topography a 100% coverage especially in deep craters or rifts cannot be guaranteed and have to be taken into account during excursion planning and positioning of scientific equipment.

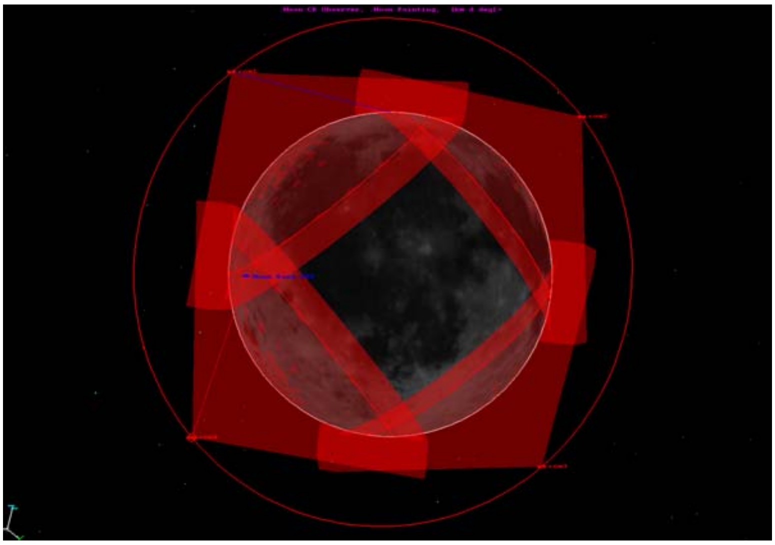

Fig. 5: Set of 4 relay satellites on a nearly polar orbit around the moon

The preliminary analysis of an envisaged moon relay satellite system shows that at least 4 relay satellites in nearly polar orbit (89° inclination) at about 700 km altitude are needed to provide the necessary coverage. In Fig. 5 the configuration and the coverage of 4 equally distributed satellites with the possible coverage are described. A set of 4 satellites offers only small overlapping areas as shown in Fig. 6. Therefore a configuration of 5 or 6 satellites would be better suited for this task and should be followed in further investigations which should also include more detailed analysis of the orbit dynamics and the stability of such a constellation.

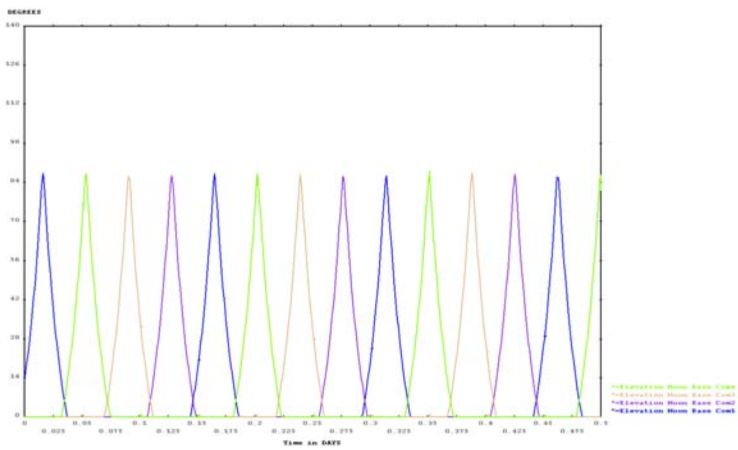

Fig. 6: Elevation of a set of 4 relay satellites

This envisaged constellation of this second phase would afford a higher need for ground support because the satellites have to be controlled from earth, i.e. from the MBCC. Nevertheless the improvement in communication especially on the far side of the moon – the main area of interest of the scientists – will offer new possibilities for the exploration of the moon and exploiting its scientific opportunities.

6. Conclusion

The next logical step for manned space flight after the International Space Station in Low Earth Orbit would be a manned base on the Moon. The Moon offers a lot of new goals for exploration, e.g. moon geology or the use of the far side of the moon for scientific equipment like radio telescopes. One of the best locations of a moon base would be nearby one of poles of the moon offering nearly permanent sunlight and short access to the far side of the moon.

The tasks of control centre for such a moon base like habitat surveillance, excursion support and contingency resolution affords a reliable and effective ground communication network. It is proposed in this paper to use 3 equally distributed ground stations on earth connected to the MCBB for nearly permanent coverage. The communication network on the moon could be set up in two phases. In the first phase the communication would be restricted to the vicinity of the moon base, maybe enhanced by a radio tower. The second phase could consist of a set of relay satellites covering a broader area of the moon including parts of the far side of the moon.

For the near future the focus should be to support and perform so called small pre-cursor satellite missions to the moon to improve the knowledge of the environmental conditions, to demonstrate and test future technology.

7. References

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