Space Transportation Systems – The Perspective of the DGLR Working Group

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1. INTRODUCTION

DGLR-WORKING GROUP "SPACE TRANSPORTATION"

The DGLR S4.1 Working Group on Space Transportation Systems (Fachausschuss S4.1 Raumtransportsysteme) is a forum for members from agencies, institutions, industry and universities, having regular sessions on the subject of space transportation. Gathering and analysing information and argumentation on space transportation systems' past, present and future is the objective of the group. Analysis and documentation are coordinated around the topics: Demand & Market, System Concepts & Subsets, Propulsion, Structures & Subsystems (System related aspects), Missions & Operations (incl. Ground infrastructure), Cost (Development, Production & Operation) and Projects & Political Objectives (Development & Demonstration). On behalf of the DGLR/CEAS-conference in 2007, the working group has prepared six position papers on these subjects. Major results are summarized in the following paragraphs:

Demand / Market [4]

The space launch demand or market is analysed according to four major categories defined by customers (commercial and institutional ones) and target orbits (GTO and Non-GTO). The GTO market is mainly commercial and is expected at 20-25 sats/year. Arianespace has the potential to get 40-60%, i.e. some 4-7 launches/ year (Ar5 & Soyuz). Predictions for the mass increase rate of GTO sats show uncertainties. The return of Chinese launchers in the commercial market is regarded the major uncertainty for launch price evolution. The European institutional market will ask for 1 to 2 Ariane 5, 1 to 2 Soyuz (launched from CSG starting 2009) and 2 to 3 Vega class (Vega, Rockot, Cosmos, Dnepr, PSLV) launches. The space launch market share accessible to the European launcher portfolio sums up to roughly 800M€/year (500M€ comm., 300M€ inst.). Ariane 5 is most important for the European institutional launch market, covering roughly 60% of the demand. Europe has not yet developed a common (political) vision for space exploration. Mid- to long-term launch demand including potential increase of launcher performance requirements and entry into manned flight capability is not yet defined. A suborbital space tourism market is under preparation by commercial ventures. New space applications (orbital tourism, power from space, etc.) are still blocked by the vicious circle of high transportation cost and low flight rates.

System Concepts & Subsets [5]

With Ariane, Vega and Soyuz, Europe has a LV family covering a broad range of different missions and performances, especially suited for the current commercial and institutional market. Some flexibility maybe added w.r.t missions requiring re-ignition capability (e.g. direct MEO and GEO). The interest in RLV as a means for reducing recurring cost for classical unmanned space transportation missions is once more declining. However, the interest in reusability technology maybe revived by non-classical approaches such as space tourism. A "Next Generation Launcher" will not be operational before the 2020 – 2025 timeframe, therefore key industrial competences need to be maintained. Space Exploration may become a strong driver for design requirements of future launchers.

Propulsion, Structures & Subsystems (System related aspects) [6]

A survey of ongoing developments concerning propul-sion, structures and subsystems of space transportation systems is based on propellants: they determine to a high degree the properties of propulsion systems, their categories being essentially defined by the state of aggregation of the propellants (liquid-, solid- and hybrid-propulsion), the number of their components (mono- and bipropellants) and the energy release as measured by specific impulse (Isp). Current propellant R&D focuses on solid high energy additives to liquids, which in turn requires stabilization by gelling. Special hydrocarbons and nitrogen compounds are promising candidates for new High Energy Density propellants. Conventional propellants may be greatly improved by introduction of solids in the form of frozen liquids: Hydrogen (improved density as slush) and also conventional liquid bipropellants that are frozen to yield cryogenic hybrid (USAF) or solid bipropellants (AI/FhG Germany and SNPE, France). Environmentally benign ("green") propellants are mainly of interest, due to their capability to reduce handling costs. In terms of reducing the environmental load of rocket launches, the present launch rate is tiny compared with other anthropogenic emissions. A depiction of the state of the art in liquid propulsion shows European Aestus 1 and 2 as pressure and turbine fed Ariane upper stage engines with storable propellants, Vulcain 2 and Vinci as gas-generator and expander cycle cryogenic propellant engines. Staged combustion engines exist in USA (the venerable SSME), Russia (RD0120) and Japan (LE-7A). Current developments in liquid propulsion include LOX/CH4 as a new cryogenic bipropellant and full flow staged combustion. The same description for solid propulsion has to consider small motors of orbital stages, where metallic steel and titanium as well as fibre wound cases are being used. A performance factor with the dimension energy over force (=length) reveals recent improvements in solid motor design. Where older designs such as the Ariane 4 PAP had values between 2.5 and 4.5kms, the younger

ATK Orion motors obtained, in 2004, 7 to 8kms with high strength steel. Most modern designs reach 15kms with filament wound cases. The present VEGA development in Europe is an example of monolithic carbon composite case design. Hybrid propulsion remains an all time favourite of experiments by university students, but has also seen major advances by the successful suborbital flight of “Space-Ship1” and the introduction of fast-burning paraffin in NASA sponsored research. A glance at non-rocket or non-chemical high thrust propulsion reveals the total absence of any replacement for chemical rocket propulsion in all foreseeable future.
Propulsive structures have fully turned towards mature compact design with a minimum of hollow spaces as they are used with storable propellants (e.g. Ariane 5 EPS upper stage formed by the Gore-panel technique) or cryogenic ones (Ariane 5 ESC-A). Ariane 5 EPC is also a typical example of a modern load carrying structure. Re-entry structures need either complete thermal protection, or must be “hot” structures.

Missions, Operations and Ground Infrastructure [7]

Overall space missions, their operations and their enabling infrastructure are analysed from a European perspective. These subjects are of specific importance, since they contribute a significant share to the overall cost of a space mission. Historically, orbits of spacecraft around Earth, namely GEOs, LEOs and MEOs in that sequence, were of main importance for European space transportation systems. These orbits are characterised by the utilisation for spacecraft that provide specific services for users on Earth, such as tele-communication, Earth observations and weather services or navigation. European logistic missions to the ISS in LEO have also started to materialise. A number of launch service providers in Europe offers their launch services for these orbits, presently using about five different launch vehicles. Only Ariane 5 and, in the near-term future, Vega are European-built launch vehicles, whereas the others are manufactured in Russia but operated by a European launch service provider. The only European launch site presently in use is the CSG in Kourou, which is especially suitable for launch into GTO/GEO. From Kourou, beside Ariane 5, two new launch vehicles (Soyuz and Vega) are going to be operated in the near-term future. Currently, Europe has no vehicle and also no launch site supporting access to space with humans. Nevertheless, Europe can serve a broad range of missions with the available launch vehicles and ground infrastructure, covering missions ranging from small to heavy spacecraft in a variety of orbits, even including interplanetary missions. This situation will actually be improved, when new launch vehicles come into service in the near future, providing additional services and/or capabilities.

Cost [8]

In this paper, the evolution of cost for space transportation is analysed. The cost per flight and the specific transportation cost for various orbits and their historical trend show a tremendous cost reduction in the early days of space transportation. But then the specific transportation cost decreased only slightly or remained nearly constant. Clearly, factors initially reducing specific cost were the increasing size and performance of launch vehicles. A deeper analysis of the composition of the cost-per-flight shows, that the small number of launches per year is one of the key factors preventing further substantial cost reductions for both, the cost of vehicle manufacturing as well as the cost which are independent of launch rate (Indirect Operations Cost, IOC). It was concluded, that the main factors dominating the cost of expendable launch vehicles (ELV) are the vehicle production cost, followed by the IOC. For re-usable launch vehicles (RLV), the share of the IOC on the overall cost is even larger. A comparison of the specific transportation cost for ELVs and RLVs shows the dramatic influence of the number of flights per year for both vehicle types. An analysis of future cost reduction potential concludes, that a real break-through may only be achieved by the development of a “simple” re-usable space transportation system with small development cost and frequent flights per year.

Projects / Programmatic aims and matters [9]

This paper gives a worldwide overview of the overall budgets for space programmes in general and the launcher sector in particular. Clearly, in the US most space money is spent for civil and military programmes. Although Europe spends second-most money worldwide, the ESA-budget is smaller by a factor of ten than that in the US. In the field of space transportation, the lion's budget share is spent for various programmes related to Ariane 5, followed by the budgets for Vega development and Soyuz operation from GSC. Today, only a small share is spent for preparing the mid-term future and developing new future transportation systems. A major objective of the present European launcher policy is the consolidation and evolution of the present European launcher workhorse Ariane 5. In various programmes like ACEP and Ariane 5-ME the present Ariane 5 is going to be improved with regard to performance, reliability, availability and cost. The present objective is to operate this launch vehicle far into the next decade. A next generation launch vehicle is prepared in ESA’s Future Launcher Preparatory Programme FLPP. Presently this programme focuses on systems and technologies for a future expendable launch vehicle, the decision to be made at the beginning of the next decade. Only a minor share is related to systems and technologies for re-entry or re-usability.

DGLR S4.1 areas of interest

The 2007 status quo of DGLR S4.1 analysis and position shown in the precedent paragraphs is mainly oriented towards present markets, missions and systems. Beyond that there is great interest to have this analysis extended towards emerging and new areas of utilization, which will generate additional transportation demand and eventually will require improved transportation capabilities and systems. For that purpose, present and future areas of space utilization are identified and grouped into four “horizons” (FIG. 1). A matrix of present and future space activities can be formed, using these utilization horizons and combining them with the mission elements required. This matrix provides a means for the systematic identification of DGLR S4.1 areas of interest (FIG. 2).

The DGLR S4.1 core interest comprises the mission elements: Launch from Earth, Earth Reentry and Landing, Transfer (to moon, mars, …and optionally back) and Landing & Ascent (on moon, mars, … surface). Partial interest is given for the mission elements Suborbital/ Near Space and Surface Infrastructure & Transport.

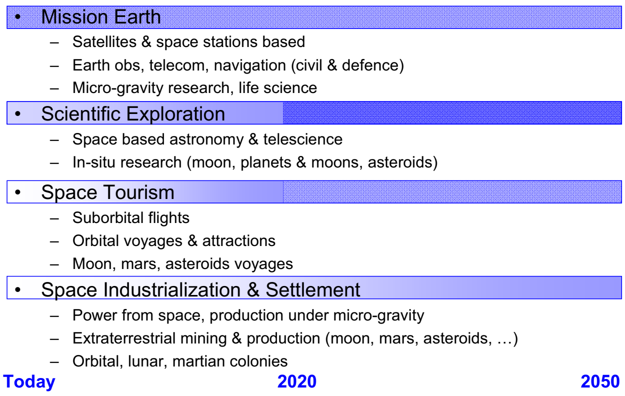


FIG 1. Space Utilization Horizons

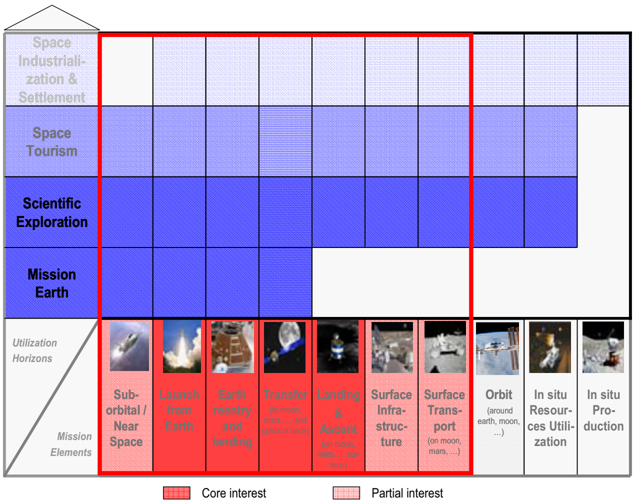


FIG 2. Areas of interest of DGLR S4.1

As shown in Fig. 1, the threshold for stepping into the 4th space utilization horizon, Space Industrialization and Settlement, may appear between 2020 and 2050 following scientific exploration activities mainly at the moon. This threshold is taken as a logical limitation of future evolutions of space utilization as far as they can presently be previewed and analysed. As a consequence, this analysis is roughly limited today to the 2030 time frame.

Concerning 2008-activities, the DGLR S4.1 has identified two major areas of emerging applications and corresponding space transportation demand:

- Lunar exploration (within the Scientific Exploration Horizon)
- Space militarization (within the Mission Earth Horizon)

Their discussion is put into the context of the S4.1 matrix of interest.

2. SPACE UTILIZATION HORIZONS

The four kinds of existing and future space utilization are here called horizons. This indicates on one hand (top down) the chronological sequence and on the other the significance of the title for a wider area of applications. The sequence of the four horizons of application also indicates the sequence of occurring space launch or market demand. Mission Earth and Scientific Exploration are existing applications. Space Tourism is at the threshold of coming into existence. Space Industrialization and Settlement will take some more time for preparation. These applications are existing or will exist in parallel and the discussion of the necessary mission elements has to be integrated when concluding about the present and future demand of transportation means.

2.1. Mission Earth

The Mission Earth Horizon comprises missions and applications based on satellites & space stations. There are earth observation, telecom and navigation both by civil and military customers. In addition it comprises micro-gravity research and life sciences. Today and for the near-term future (5 years) the majority of European institutional missions / payloads are oriented for "Mission Earth". The update of the table of European institutional missions with those related to "Mission Earth" (in bold) provides the information in more detail (FIG. 3).

	2008	2009	2010	2011	2012
ESA	**·ATV 1** (J. Verne) **·GIOVE B / GSTB V2B** (ESA/EU) **·SMOS** **·Proba 2** **·Goce**	·Herschel ·Planck **·ADM-Aeolus** ·LISA Pathfinder **·SWARM** **·Cryosat 2**	**·ATV 2** **·MSG 3** ·IXV	**·Sentinel 1A** **·Metop 2** ·GAIA	**·ATV 3** **·Sentinel 2A** **·Sentinel 3A** ·LISA 1-3 **·Galileo 1** **·Galileo 2** **·Galileo 3** **·Galileo 4**
CNES/ DGA		**·Helios 2B (DGA)** **·Megha-Tropiques**	**·Pleiades1 (DGA)**	**·Pleiades2 (DGA)**	
DLR/ BWB	**·SAR-Lupe 4** **·SAR-Lupe 5**	**·SatcomBW 1** **·SatcomBW 2** **·TanDEM-X**			**·EnMAP**
ASI/ SITAB	**·COSMO SkyMed 3**	**·COSMO SkyMed 4** **·Sicral 1B** (SITAB) ·LARES		**·Sicral 2 (SITAB)**	**·Athena-Fidus**
BNSC/ Paradigm	**·Skynet 5B** **·Skynet 5C**				**·Skynet 5D**
INTA/ Hisdesat				**·Seosat**	

FIG 3. European institutional missions 2008-12, Mission Earth related missions in bold

Galileo still remains as the major uncertainty, although the political will is there and the decision is fostered. Earth observation and related sciences are stabilized via the GMES program and a cadence of one new satellite per year comprises roughly 10% of the launch demand. While long-term evolution (2030) is not fixed in detail, it is expected that earth observation, communication and navigation activities will continue at today's level.

Future military systems

It is not believed within the 2030 time-frame that completely new applications will materialise in the field of military space use or that weapons will be installed in space. Nevertheless, it is expected that the present military application satellites, mainly reconnaissance & communication-spacecraft, will evolve in the following directions:

- Installation of constellations & swarms of smaller reconnaissance satellites, that increase redundancy and inherently reduce vulnerability of the

reconnaissance capability
- Implementation of the capability to rapidly launch a new military spacecraft, either to replace a failed or destroyed one or to increase a specific military capability ("orbit on demand")
- Implementation of the capability to communicate any time and world-wide to ground-based systems for global network-centric operations, using MEOs to install a network of military communication satellites. The spacecraft-trajectories in these orbits are less predictable, respectively might easily be changed and provide a better antenna gain compared to communication satellites in GEO.

Although this expected evolvement does not require completely new space transportation capabilities, some new requirements have to be implemented. These are discussed in section 3.2.

2.2. Scientific Exploration

Scientific space exploration comprises a wide-spread area of activities, although the locations for in-situ research and especially human rated missions are rather limited. Space transportation is the enabling but also limiting factor especially when looking for the long-term evolution.

One subject becoming more and more important for the space transportation sector in Europe is the exploration of celestial bodies in our solar system. The early phase of exploration with missions performing fly-bys of small probes is now finished. Europe has started to develop highly sophisticated spacecraft orbiting around the body of interest, observing it with a variety of instruments for many years. Examples of this type of exploration are Smart-1, which orbited around Earth's moon, and Mars-Express still operational in a Martian orbit. A first successful landing on a celestial body was performed with the Huygens-probe on Saturn's moon Titan and a lander is also on its way to an asteroid within the Rosetta-mission. Another major milestone for Europe will also be the landing of a large rover to explore the Martian surface and to search for traces of life within the Exomars-mission, which is currently under preparation. All these missions rely either on existing European launch vehicles like Ariane 5 or make use of those of other nations, e.g. the Russian Soyuz-launcher. Exomars is going to be launched with a vehicle of the Ariane 5/Proton-class.

An overview of the European objectives and interests in space exploration is shown in FIG 4. The present focus of European interests in the future is the utilisation of ISS in low Earth orbit, along with going on to Moon and Mars.

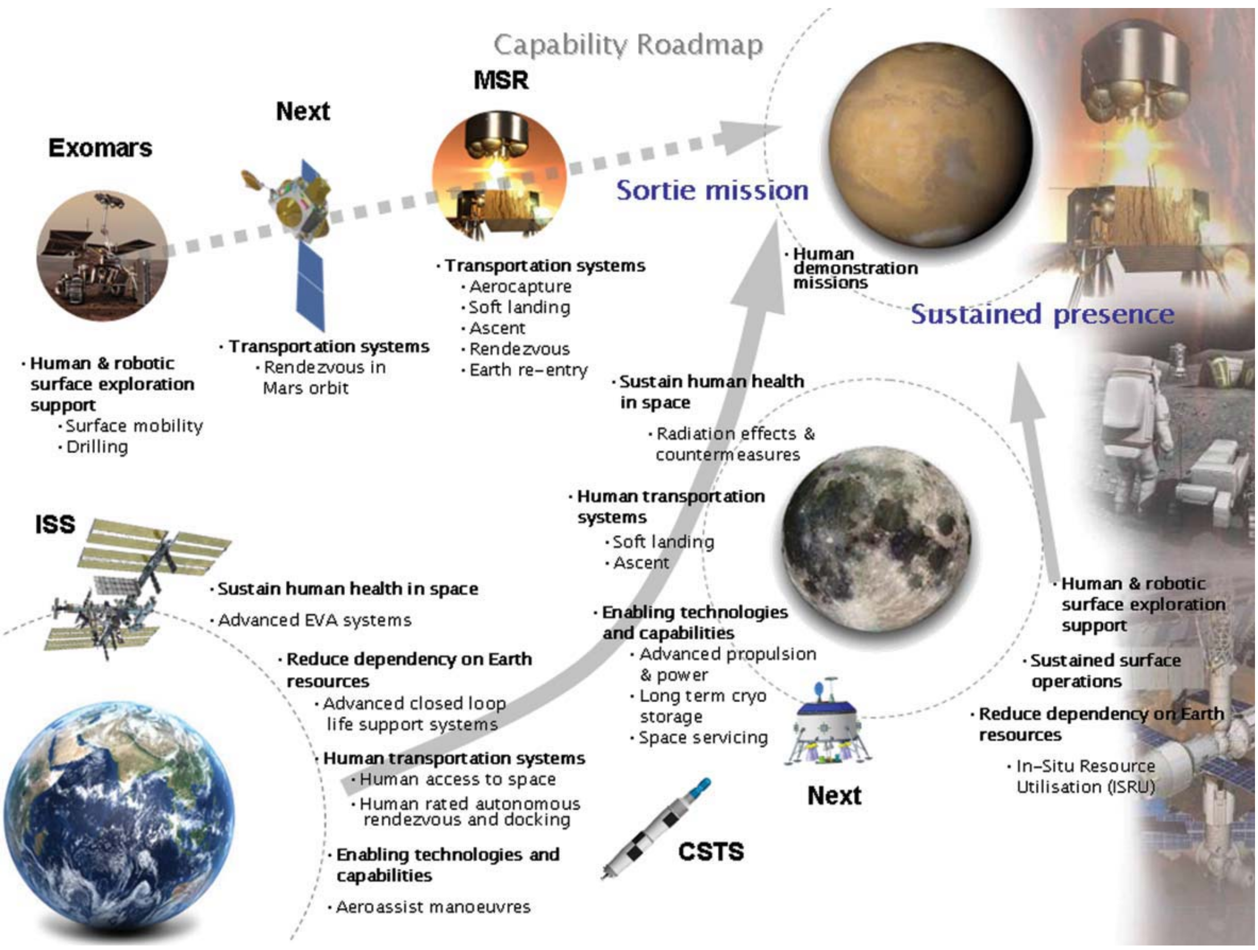


FIG 4. European objectives and interests in space exploration [1]

Basically, ISS is being used to prepare for prolonged human operations by demonstrating new technologies relevant for exploration, as for example studies of the effects of radiation, microgravity and psychological environment, and the demonstration of advanced life support systems, all pre-requisites for future human missions to Moon and later to Mars.

Presently, Europe prepares missions to the Moon, starting with a robotic lunar landing around 2016, commercial lunar orbital flights around 2018 and building of a first infrastructure on the Moon around 2020. Subsequently, sustained human missions to the lunar surface are foreseen. To support these objectives, studies are presently ongoing to develop a Crew Space Transportation System (CSTS) and an unmanned lunar lander to demonstrate the technology of soft precision landing and to provide initial science on the lunar surface within ESA. Following to this Phase 1 of early robotics a Phase 2 is studied that will start around 2020 with extended surface robotics, a station orbiting around the Moon, human sorties to the lunar surface and technology demonstrations for extended human missions (EVA, ISRU, Life Support). A Phase 3 of lunar exploration, starting around 2030, foresees advanced robotics, a manned lunar space station as well as a permanently occupied lunar surface base along with the extended use of reusable vehicles for transportation. A sketch of the scenarios on the lunar surface in Phase 1 is shown in FIG 5.

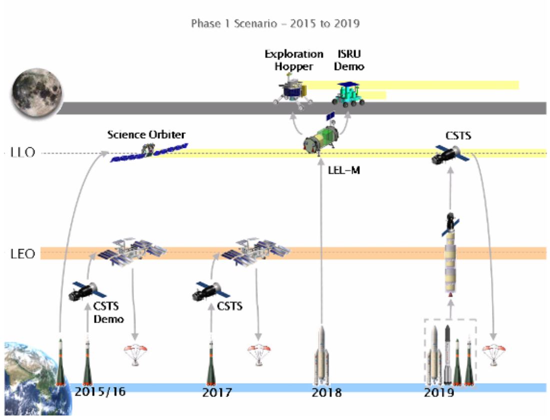


FIG 5. Phase 1 of lunar surface exploration [2]

Existing launch vehicles like Soyuz with a Fregat upper stage or Ariane 5 provide the performance for placing about 100 kg respectively 1700 kg of useful payload to the lunar surface (1000 kg respectively 3000 kg including the lander vehicles). These payload masses may be sufficient to land scientific instruments or to support logistic missions, but they are not sufficient for landing larger habitats or crewed vehicles on the lunar surface. The Apollo Lunar Module for example had a mass of approximately 15 tons. It was designed for transporting two astronauts to the lunar surface and back to a low lunar orbit.

Following to the Exomars mission, which is in development, present plans foresee to perform a rendez-vous and docking demonstration mission in the Martian orbit, combined with the landing of some surface probes. These are key technologies to contribute to an international Mars Sample Return (MSR-) mission, presently scheduled for the time around 2020. A human mission to Mars may take place not earlier than 2035+ (FIG 6).

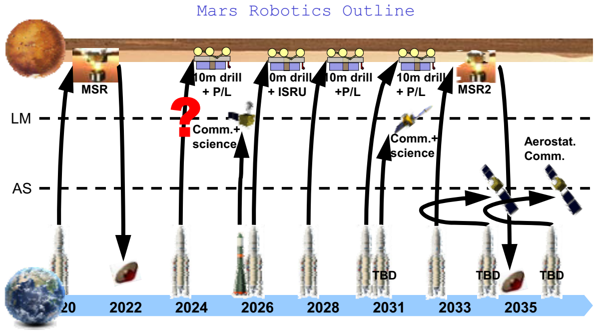


FIG 6. Mars robotics outline [2]

A human Mars mission for example, that carries into a Martian orbit a crew of four including resources, along with a transfer habitat and an Earth-return capsule, requires in LEO a spaceship having a mass of approximately 500 tons, assuming all-cryogenic transfer stages and aero-braking in Mars-atmosphere. In order to carry to the Martian orbit the Crew landing vehicles, a surface habitat and surface resources, two cargo-spacecraft have to be assembled in LEO, having a mass of about 700 t in total. In case braking in Mars-orbit is performed by propulsive means, the LEO-fly-off masses increase even further by some 40%.

Thus, considering exploration missions exceeding the requirements of robotic exploration missions requires the development of new systems, like cargo and crew landers, transfer stages and, at least for the crews, Earth return vehicles. An alternative solution is to bring into orbit smaller modules compatible to the existing launch vehicles and to build the entire spacecraft there. However, this would require a large amount of launches.

2.3. Space Tourism

Space Tourism started at the beginning of this decade, with D. Tito's mission to ISS and is a rapidly growing branch of applied space technology, that – in terms of space transportation categories - evolves along several morphological lines: vertical or horizontal take-off and/or landing, sub-orbital or fully orbital capability, winged re-entry (as US-Space Shuttle) or ballistic one (as Russian Soyuz), return to launch site (pleasure rides) or elsewhere (passenger transportation with intermediate space experience). Orbital tourism comes in two categories. The first uses the transportation vehicle as orbital craft and of course also for return, the second uses it only for transportation to some orbital infrastructure, which could be a visit to ISS or to an orbital hotel. An individual concept for the latter is shown in FIG 7. It uses inflatable modules that are not diameter-limited by transportation requirements.

FIG 7. Bigelow Aerospace Space Tourist Lodging [14]

Low Earth orbit (LEO) is the natural beginning of space tourism, but of course one can consider any other target for tourism, such as geostationary orbits, the Moon or planets. However, all this will be limited by risk considerations and finally by financial feasibility. Among the many evident risks one should mention space radiation, which admittedly cuts down the life expectancy of interplanetary astronauts, while LEO tourism can take advantage from the Earth magnetic field.

Up to today about ten tourists have been in space. In 2007, some 25 companies have announced projects related to space tourism. Most of them intend to start their commercial business at the beginning of the next decade. Virgin Galactic, SpaceAdventures, A&K Space and Bigelow Aerospace may be taken as representative examples. Most companies propose suborbital missions, but some of them are also developing concepts for either visiting ISS or a space hotel, and some even offer a trip around the Moon. Thus, the ticket-prices vary significantly, beginning at about 200.000 US$ per passenger for a sub-orbital flight to 100 Mio-US$ for circling the Moon. The market predictions are rapidly increasing, with a forecast number at the end of the next decade of 15000 passengers [3] per year for sub-orbital flights (FIG 8).

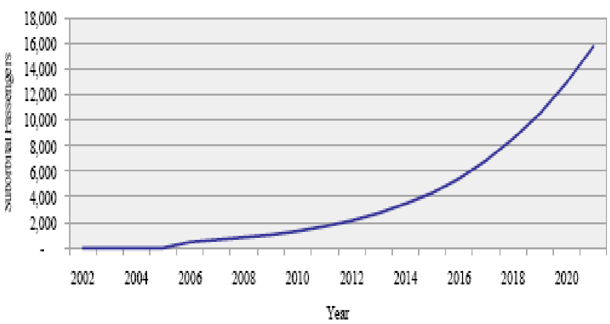


FIG 8. Forecast of annual number of sub-orbital passengers [3]

Due to the different target missions, the transportation systems vary significantly. Whereas a sub-orbital vehicle does not need much more than Mach=3, the propulsive energy of an orbital flight is 64 times higher than that of a sub-orbital mission, that of a lunar orbital mission approximately 120 times. This influences not only the required fuel and type of propulsion system, but also suitable structural and thermal protection concepts. The vehicles used for space tourism will hence be very different, depending on their mission. This is discussed exemplarily in section 3.

2.4. Space Industrialisation & Settlement

Today, three areas of activities and space utilization can be considered nuclei for extension towards space industrialization & settlement to materialize in a 2030 time frame:

- Evolution of space station(s) towards an orbital colony for space tourism and settlement
- Power from space provided by large-scale orbital infrastructures
- Lunar mining & production as basis for on-going missions and/or tourism

After a long period of slow progress and regular set-backs the ISS has now reached nearly fully operational capability. Public attention will grow together with the crew and its activities. While as a consequence the short-term possibility for orbital tourism will decline, the orbital infrastructure necessary for long-term evolution will be demonstrated and refined. This includes the phase-out of the human space transportation “dinosaur”, the space shuttle and the introduction of new US systems and -sooner or later- also European ones.

Within a new wave of awareness of fossil fuel limitations and pollutions a new wave of alternatives in exploration and development is running up. Power from space is an exotic option, but has particular potential for “island solutions”. A characteristic concept is shown in FIG 9. Optical laws of electromagnetic wave propagation imply that conversion from light to electric power be made in space, even if this needs low efficiency microwave transfer to Earth-side. Simple mirrors produce divergent beams and could only be used for illumination purposes. While they could be built in a very light way (foils), they would still require considerable propulsion effort for orientation and station keeping against light pressure.

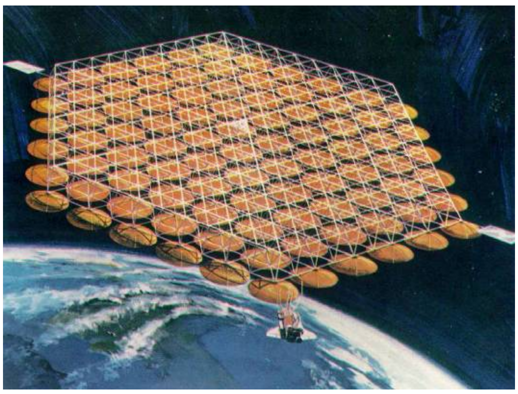


FIG 9. Concept for “Power from Space”

The political US orientation for returning to the moon with infrastructure building missions should be fostered by the competition with China. In addition Russia, Europe and Japan will play their roles in cooperation agreements and hence contribute to a variety of activities and corresponding infrastructure. As this will materialize around 2020, 10 years are left for identification and implementation of activities beyond mere scientific research to arrive at a 2030 entry into the “Space industrialization & settlement” horizon.
FIG 10 shows a NASA scenario comprising advanced Lunar activities in the course of Lunar mining. Oxygen for use as propellant and human life support is produced by reduction of regolith at an eastern Mare Serenitatis site. It is as yet not sure, whether or not water for hydrogen production is present on the Moon.

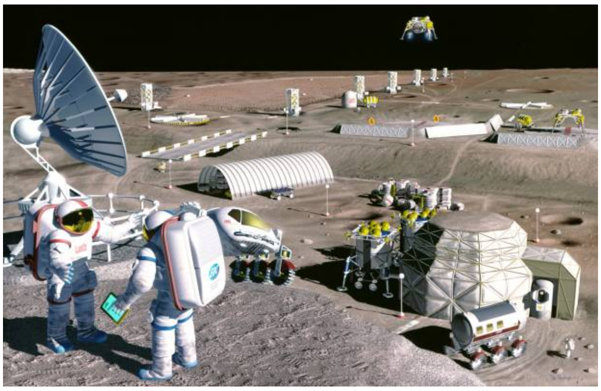


FIG 10. NASA concept of Lunar spaceport for mining and other activities (Image: NASA [16])

3. MISSION ELEMENTS

3.1. Sub-orbital/near Space Transportation Systems

Space Tourism

Vehicles used for sub-orbital space tourism are characterised by the following main features:

- Re-usability, to limit cost of operations
- Simple structural design, due to limited g-loads of about 3 g and low thermal loads
- Low complexity to increase reliability and safety

FIG 11. Myasishchev Design Bureau (MDB) air launched sub-orbital space tourism vehicle [10]

One- and two stage-concepts are studied, using an aircraft as the lower stage for a rocket-propelled upper stage, like the air-launched concept for a suborbital tourism vehicle in FIG 11, the result of a feasibility study by the Rusian V.M.Myasishchev Experimental Design Bureau ("AKS M-91", air launched with 2 pilots, 14 passengers 27000kg mass on Myasishev VM-T Atlant as carrier aircraft). Small single stage (SSTO) concepts use air-breathing turbojet engines, as for example (see FIG 12) the Astrium concept, that would carry 4 passengers to 100kms altitude, providing about 3 minutes of zero-g experience.

FIG 12. EADS Astrium single stage suborbital space tourism vehicle [11]

FIG 13. Kankoh Maru SSTO Passenger Carrier (50 passengers, 550t GLOW, 50t dry weight) [12]

Full fledged orbital space tourism concepts are most advanced in Japan, where by now they have a long tradition, seriously beginning in the early 1990s with the Kankoh Maru space craft (FIG 13) by Kohki Isozaki of the Japanese Space Society. It was a category1 concept: comparable with a sight-seeing bus, a vehicle carries tourists into orbit (for $15.000 / 1995 per ticket), circles the Earth for a while, then re-enters and carries them back to the launch site.

Kankoh Maru has been followed recently by more practical concepts such as the Russian one, also with ballistic re-entry, shown in FIG 14. In a precursor version, the vehicle will be used for vertical, suborbital flights of 3 minutes zero-g duration.

FIG 14. Yuzhnoye Tourist Spacecraft

It carries 8 passengers, features rocket engine controlled landing on un-folded landing gear with large shock absorber travel, and can land on a field of only 100x100m [13].

3.2. Launch from Earth

Mission Earth

The present launch demand related to “Mission Earth” is dominated by GEO communication satellites, mainly to be launched into GTO. The majority of operational launch vehicles is oriented for this task including: Ariane 5, Proton, Sea Launch, Atlas 5, Delta 4, H2, Long March 3, Land Launch. Depending on the launch site latitude, the possibility of variation of upper stages and boosters along with the strategy of multi-payloads launch capability results in a wide-spread portfolio of launch performance to various orbits. In addition, the portfolio is enlarged by smaller launchers mainly oriented to LEO missions. This portfolio of expendable chemical rocket based launch vehicles satisfies fully the present and forseeable performance oriented launch demand for “Mission Earth”. Of course attempts will go on to improve cost and reliability characteristics. Reusability and the use of airbreathing propulsion for the first phase of ascent will remain the major ideas for improvement. Technology and demonstration programmes will be necessary to achieve the basis for future developments.

Systems for military applications

Following the scenario expected for future military applications as described in §2.1, the typical mission performance to the target orbits LEO, MEO and GEO of existing launch vehicles is also adequate for the requirements in the next decades. Nevertheless, military applications have the following new demands on their transportation systems:

- Orbit-on-demand capability
- Payload deployment flexibility

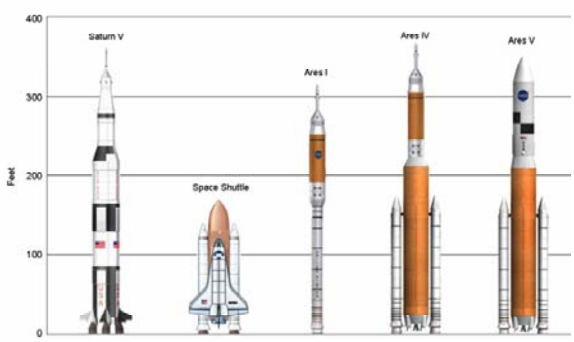
The first point is derived from the need to quickly react in case of a crisis, such as a failure or destruction of a military spacecraft. The deployment of a new spacecraft requires a time for preparation of the launch vehicle of about less than 72 hours. This requirement is already implemented since the beginning of the space age within the ballistic rockets, using solid or storable propellants for that reason. It is not yet realised in the more powerful vehicles serving high-energy orbits. The second requirement is to support the deployment into different orbital heights or planes of swarms or constellations of military satellites used for communication or Earth observation purposes. This needs the capability of re-ignition of the propulsion system for plane changes or altitude manoeuvres, even after long-duration coast phases.

Exploration

For exploration missions to Moon, Mars and beyond launch vehicles with the following, exemplaric performances are required:

- Soyuz/Fregat-class launcher for a small lunar lander with approx. 100 kg payload on lunar surface (approx. 2.5 t in lunar transfer orbit)
- Ariane 5 class launcher for a medium lunar lander with approx. 1700 kg payload on lunar surface (approx. 9.2 t in lunar transfer orbit)
- Approx. 60 t in LEO (transfer stages and crew module) for crew delivery at LLO (Crew module and transfer stage, 14 t in LLO)
- Approx. 85 t in LEO (transfer stages and crew lander) for a manned lunar lander (23 t in LLO)

In case that existing launch vehicles are going to be used for missions involving humans or heavy cargo, a huge number of launches of various launch systems (unmanned & manned) with rendez-vous&docking operations would be required. In order to avoid this, a heavy-lift launch vehicle in the Saturn V-class is required. The US have decided to go that way and to develop in their constellation programme a new family of launch vehicles, making use of building blocks and



existing technologies (FIG 15).

FIG 15. US launchers size comparison

The Ares-family consists of three new launch vehicles for transportation of crew and cargo. The most powerful ARES-V vehicle for example has a capability of approximately 130 t to LEO, similar to the capacity of the earlier Saturn V. For large exploration missions it remains to be decided whether a more capable launch vehicle ought to be developed in Europe too, or the existing ones are used for the transportation of modules, which are then assembled in an orbit, or Europe decides to co-operate with other nations, making use of their heavy-lift launch vehicle developments.

Space Industrialization & Settlement

Based on the three evolution lines described in chapter 2.4., the "Space Industrialization & Settlement" might be touched within the time frame of 2030. No additional space transportation capability will be necessary and available beyond the evolution required for those lines.

At that level of space utilization the core options of launch vehicle evolution will be in a demand and market driven competition. There is the option of serial production of expendable launch vehicles, perhaps in combination with modularity, for arriving at lower cost and higher reliability. In competition there might evolve reusable systems with a sufficiently high rate of reuses and very high reliability supported by abort capabilities. As discussed in the 2007 paper on cost, heavy launch systems with low reusability rate might be an (interim) option.

3.3. Earth Re-entry and Landing

Mission Earth

Today's "Mission Earth" demand for re-entry and landing is rather limited compared to the planning some 20 years ago. ISS crews and limited mass samples of processed materials and bio-experiments are the core demand. The retrieval of infrastructure elements for repair, refurbishment or new mission adaptation has not materialized. This situation is not expected to change and the retirement of the shuttle and its unique retrieval capability will not be a set-back for mission options.

Exploration

For exploration missions crew and sample/cargo Earth return vehicles are required. They have to be safe, with limited crew loads for the sake of non-trained passengers and ill or de-conditioned crews. In case they are also used for crew transfer, they have to provide sufficient habitable volume. Acceptable limits are dependent on transfer duration. For a trip to Mars a volume of approximately 15-20 m^3 per crew member is to be seen as a minimum. Depending from where the vehicle returns, the atmospheric entry velocity varies between about 8 km/s for return from a circular LEO to 11 km/s for return from a Moon- or interplanetary mission. With regard to the heat loads, that means a factor of more than 2 ½ . As concepts simple re-entry capsules may be used, which are robust, reliable and provide good volumetric efficiencies, but they have only a poor L/D, limiting the size of the re-entry windows. They also have only minimal control capability and high deceleration loads. At the other end of the spectrum are winged re-entry vehicles, providing large cross- and downrange, aerodynamic manoeuvring capability and low g-loads, but they are much more complex. Land-landing is today the preferred solution, in order to avoid the large operational effort for recovery at sea. The Orion-concept of the US follows the capsule-type approach. This decision was strongly influenced by the objective to reduce development cost.

Space tourism

The description of elements as given for the exploration missions may also be applied in case of return vehicles for space tourists, on their way back from an Earth-orbital or Lunar mission. Important issues are again the comfort of the passengers, which means acceptable habitable volume per passenger, low g-loads during re-entry and fast recovery operations. Thus, the re-entry vehicles used for space tourists might be similar to the ones applied in exploration missions.

Space Industrialization & Settlement

The download demand resulting from the three evolution lines discussed in chapter 2.4 is quite different. Orbital colony and lunar infrastructure will be dominating this demand. As already mentioned in the discussions above, the driver concerning system concepts will be the higher re-entry energy of lunar return missions. In addition, near earth orbits will allow for - more comfortably landing - winged vehicles, whereas exploration missions will enforce more efficient vehicles in terms of the mass that has to be transported to the exploration goal afore. As an option there is the possibility to use a LEO space station with space port function. This would separate the (lunar) transfer and the re-entry and landing mission elements and the related transportation vehicles.

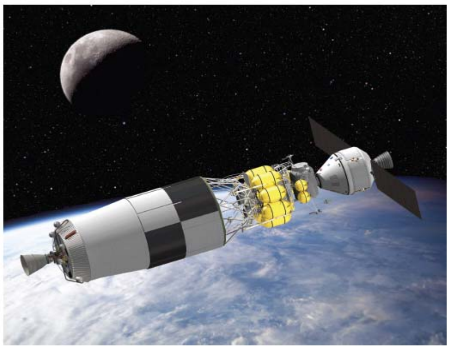
3.4. Transfer-Systems

Mission Earth

Today the orbital transfer (LEO, MEO, GTO/GEO, HEO) function is combined with the launch vehicle and/or the re-entry and landing system. Additional need may arise from space station evolution including separated "free-flying" platforms. System concepts should be derived from existing upper stages. Depending on performance demand and mission duration, storable and cryogenic chemical propulsion can be applied. Further evolution might turn to the use of solar energy for solar thermal or solar electric propulsion. Within this context the application of tethers is an option. Unfortunately, up to now the attempts to demonstrate the capabilities of tether technology have resulted in very limited progress only.

Exploration

Due to the enormous masses to be transferred to Moon, Mars or other destinations in case of large-size robotic or human missions, transfer stages will be important elements of future transportation architectures. It will no longer be possible to implement the transfer function into one vehicle and to launch it as a whole. The transfer stages will be docked in a suitable orbit with their payload or vehicle and perform the impulsive manoeuvres to send these into the interplanetary or lunar trajectory. Once their fuel is consumed, they are jettisoned, increasing the overall mission efficiency by applying the staging principle. They will also be used for orbit insertion at the target destination and if applicable also for Earth return manoeuvres. These stages will be similar to classical rocket stages, consisting mainly of fuel, a propulsion system and a structure. But they have to be compatible for a rendez-vous and docking manoeuvre with their payload/vehicle and for a longer period in orbit until these elements arrive. Thus, the decision whether to use highly efficient cryogenic propulsion systems or less efficient storable propellants has to be traded also from a boil-off/thermal insulation concept point of view. The size of the transfer stages is off course dependent on the ΔV, the propulsion system and the mass transported. It is also limited by the capability of the launch vehicle used. For very heavy payloads or large ΔV-requirements eventually several transfer stages have thus to be used. As an example, the transfer stage presently envisaged in the US-constellation program is shown in FIG16.



Concept image of the Ares V earth departure stage in orbit. (NASA/MSFC)

FIG 16. Concept of Earth-departure stage in Orbit [NASA/MSFC]

Space Industrialization & Settlement

The lunar mining & production evolution line of the three evolution options discussed in chapter 2.4 will clearly be the most demanding for the transfer systems. Several options of system concepts development can be imagined for such a scenario:

- Transfer systems remaining in space with fuel stations in LEO and/or lunar orbit
- Solar thermal and solar electric propulsion
- Aerobraking in earth atmosphere for deceleration and/or orbital plane change
- Tethers for acceleration and/or deceleration

The preparation of technologies and their demonstration will take considerable time and hence the choices for the initial US lunar return programme will already fix major directions. Europe should carefully regard and analyse these choices and look for complementary system options that would offer interesting development lines in terms of technology and European identification within cooperation programmes.

3.5. Planetary Landing & Ascent

Exploration

For exploration missions, crew and cargo lander and ascent vehicles will be required, vehicles perform the transfer from a low orbit to the surface of the celestial body. The presence or absence of an atmosphere is decisive for the vehicle design. In the first case, the landing vehicle might use the atmosphere to decelerate and dissipate a large portion of its kinetic energy, whereas in the latter case the whole descent and braking has to be performed by propulsive means. If a heavy payload is to be landed, a propulsion system for the final deceleration can not be avoided, even on bodies having an atmosphere. Depending on the mission concept, the landing vehicle does not only carry the payload, but also the ascent stage for the return of a crew or cargo. This ascent consists either of the entire landing vehicle, or makes use of the staging principle, leaving empty tanks and structures on the surface. This however limits re-usability of the concept. Further, the requirement to return larger payload masses or crews requires the implementation of a rendezvous and docking capability, in order to combine the ascent vehicle with an Earth return stage in the orbit. As an example, the newly to be developed vehicle “Altair” in NASA’s lunar programme is shown in FIG 17.

FIG 17. Nasa’s lunar landing and ascent vehicle “Altair”

Space Industrialization & Settlement

3.6. Surface Infrastructure & Transportation

Exploration

The use of a “hopping vehicle” might be a means of surface transportation for crew and cargo, especially over long distances of some 10 to hundreds of kms. Such vehicles perform a rocket-propelled ascent, a ballistic flight and a rocket-propelled landing. Most of their functionalities are identical or similar to that of landing vehicles as used for atmosphere-less bodies. Thus, a strong similarity is to be expected between landing & ascent vehicles and hopping vehicles used for surface transportation (such as the one shown in FIG 18).

FIG 18. Large crewed Moon Hopper similar to a Soviet Moonbus pre 2001 concept (artist conception by M.Tim [17])

Much smaller unmanned hoppers could be used for landing site testing, long time data collection or other activities that enhance work of astronauts.

Space Industrialization & Settlement

Understanding "industrialisation" as the development of the local infrastructure required for the manufacture and provision of goods, merchandise and services, and settlement as the development of permanent human presence accompanying these and other space activities, the distinctive system parameters are means of production, provenience of the raw materials and consumables (either local "in situ" or from Earth-side) and location of customer (same). In terms of transportation requirements the course of events is likely to begin with the installation of the proper infrastructure for transportation, accommodation & housing, power supply and communication, followed by the installation of imported machinery. The installation will require building materials. Operations will require a steady supply with consumables and replacements. While consumables include all life support of astronauts (5340kg per astronaut per year [20]), their demand is towered by propellant requirements for local transportation (e.g. hoppers) and return missions. Given the tremendous costs of all lunar transportation it is hence no wonder, that the use of local materials, "in situ resources utilization, ISRU", is an item of prime interest for the phase of steady state lunar operations. In terms of propellants, fuels will have to be imported with the possible exception of hydrogen, if the presence of water could be confirmed. This would be near the lunar poles and require transportation to other lunar sites. Concerning oxidizers, oxygen is the only candidate for ISRU application, as there is no nitrogen for the synthesis of "storable" N_2O_4. (Which would be of questionable storability under Lunar conditions anyway, as these are characterized by the monthly cycle of average temperatures of 107C (max. 123C) in daytime, and -153C (Min. typical -181C, at poles -233C) in the night). FIG 19 shows one of several NASA concepts that were studied in the NASA JSC Lunar Lander Concept Studies since 2006. The "lunar freighter" could be launched from earth by a heavy-lift launch vehicle similar to the Russian Energia (Image: NASA/JSC image #S94-027636)[18].

FIG 19. NASA Automated Cargo Lander delivers an ISRU plant for oxygen production to the surface of the moon.

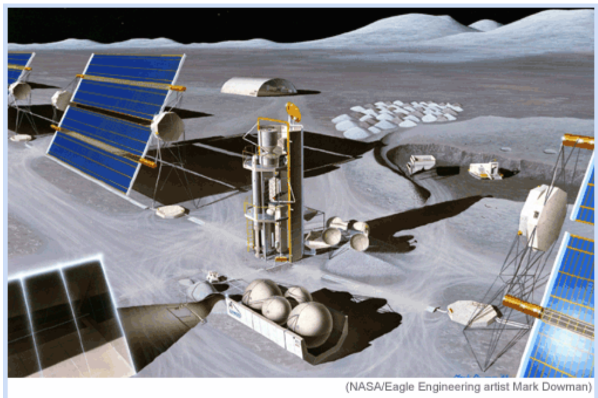


FIG 20. NASA Oxygen plant on the Moon [19]]

In FIG 20 is shown an operational oxygen production pilot facility. (Mass 800kg, 15kW solar power, 1.14 kg Ox/hr, mass of liquefaction equipment 200kg, 1.25 kW power). There are several schemes for producing oxygen out of Lunar surface materials, of which most are based on reduction with hydrogen obtained from recycled water.

4. WORKING GROUP – STATUS & PERSPECTIVE

Within the DGLR S4.1 (Space Transportation Systems) working group's areas of interest current missions have been regarded with priority. As a consequence, the "Mission Earth – Launch from Earth" area of interest has mainly been analysed. This paper shows a first systematic discussion of all identified areas of interest, of course at a limited level of detail (FIG 21).

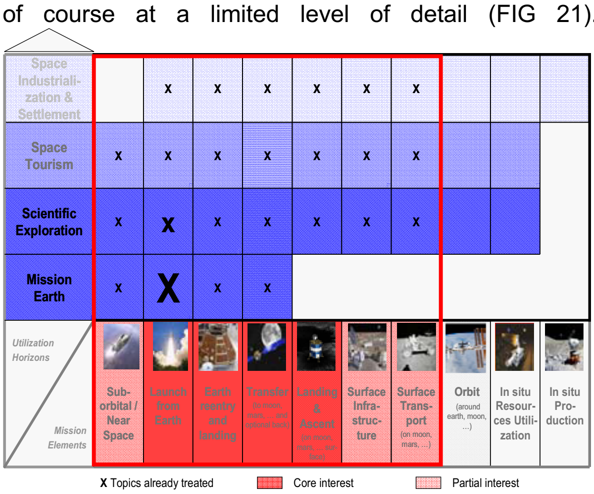


FIG 21. Level of discussion of DGLR S4.1 areas of interest

Further activities of the DGLR S4.1 will add more detailed elements of discussion. There will be again the need to make use of the six sub-topics of space transportation systems shown and used in the introduction:

- Demand / Market
- System Concepts & Subsets
- Propulsion, Structures & Subsystems (System related aspects)
- Missions & Operations (incl. Ground infrastructure)
- Cost (Development, Production & Operation)
- Projects / Programmatic Development & Demonstration

For a next step of discussion a two-days working meeting will be organized in early 2009 in Bremen. Any contribution and/or participation to the working group and the working meeting are welcome. Further information concerning the working group and the next meeting will be available on the DGLR home-page (**www.DGLR.de**) or from the working group chairmen:

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