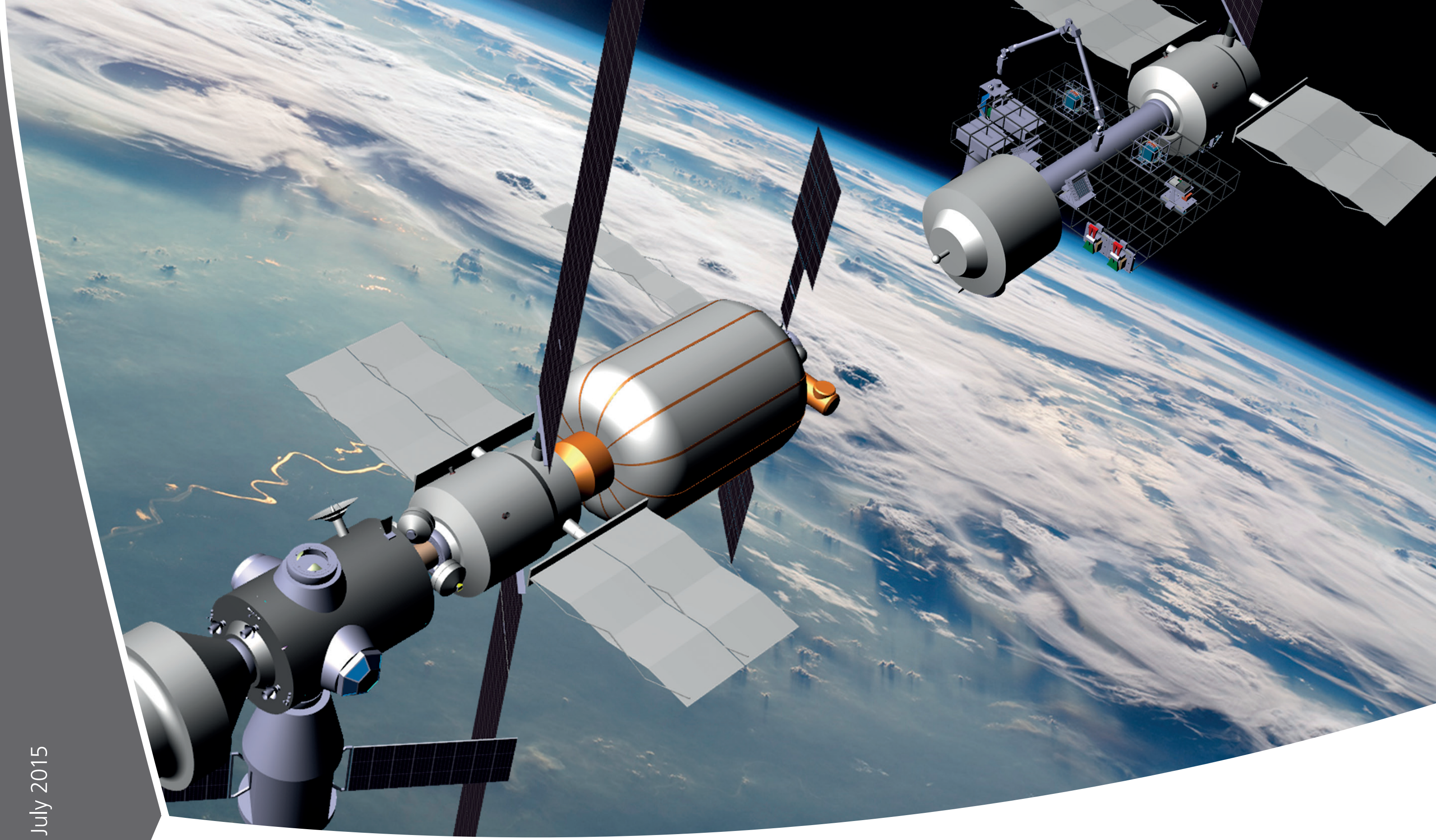
DLR, July 2015



Orbital-Hub
DLR Vision 2025

DLR Institute of Space Systems
System Analysis Space Segment

Bremen, July 2015

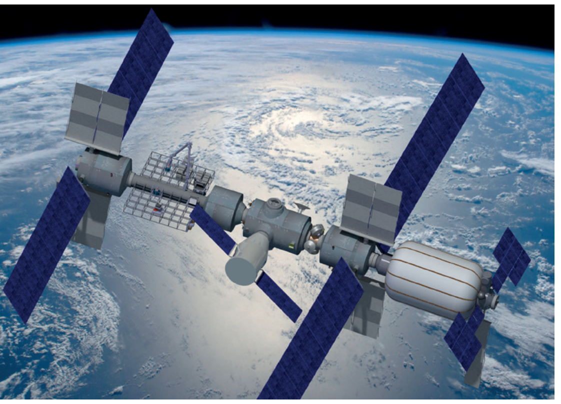


Figure 1: Illustration of DLR's Orbital-Hub concept during the docked phase for the servicing of the Free-Flyer consisting of an external science platform and a pressurized laboratory.

International Context

For decades the International Space Station ISS has demonstrated not only long-term international cooperation between 14 partner governments but also a significant engineering and programmatic achievement mostly as a compromise of budget, politics, administration and technological feasibility. Most ISS technologies are based on Mir and other previous experience. Due to high safety standards required for human spaceflight activities, these technologies are often conservative and new developments require patience and waiving 'state-of-the-art' technologies. A paradigm shift to more innovation and risk acceptance can be observed in the development of new markets by shifting responsibilities to private entities and broadening research disciplines, demanding faster access by users and including new launcher[1] and experiment facilitator companies[2].

The research part of the systems-engineering study shows that spacefaring nations are developing their individual programmes for the time after ISS: NASA shifts LEO operations and utilisation to competing U.S. commercial companies while focussing on the next preparatory steps of exploration (e.g. SLS, MPCV) of asteroids, the Moon and in the long-term, Mars. Russia plans new human-rated space infrastructures at various optional locations (e.g. OKA-T Free-Flyer) rather than committing to continue the utilisation of its dated ISS modules. In the field of human spaceflight, China proceeds to go on with its Chinese Space Station CSS and prepares its next objective: a human Moon landing. Europe's human spaceflight partners seem to tend to the consideration of new platforms in LEO or cis-lunar space while utilising ISS as long as possible and necessary for the transition expected beyond 2024. Europe itself is interested in LEO[3] and human spaceflight as discussed by the ISECG, depending on the funding commitment. [DLR-RY-Post-ISS-AP1000[4]]

DLR's Future Objectives in LEO

In line with the space strategy of the German Government, ISS follow-on activities should comprise clear scientific objectives and key technological competences (e.g. robotic, internal and external structures, module/facility and experiment operations, interface systems (ATV)).

In this way, DLR started to investigate future options by evaluating various LEO infrastructure concepts including opportunities for national realisation or international cooperation. A corresponding list of options can be found below. DLR scientists from various disciplines were asked to assess the usability of these options and design payloads based on their Mir and ISS experience and with respect to future scientific fundamental and technological research questions.

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[1] U.S. commercial launch providers currently are for example: SpaceX, Orbital Sciences.

[2] European experiment facilitators Airbus and OHB tried the commercial approach but are still awaiting success. U.S. experiment facilitators are for example: NanoRacks, Kentucky Space and the mediator foundation CASIS. The only platform provider with a commercial approach is Bigelow.

[3] See also ESA's LEO 2020.

[4] Project report: AP 1000, „ISS-Analyse & Lessons Learned".

Motivation for New LEO-Platform Considerations

All Space Station partners agree to utilise the orbital research facility until at least 2020. NASA, Roscosmos and CSA announced a desire to support the extension of the ISS until 2024. Whether this is politically, technologically and financially feasible for all partners is unknown. But still, there is a common understanding that a platform in LEO is a basic requirement for science, Earth observation and monitoring and even potentially for the next steps to the Moon or Mars. If the current ISS seems to be too expensive we have to think about ways to make it cheaper. In general, a transition to a new concept without a critical loss of know-how amounts to 10 to 15 years. Therefore, the conceptualization regarding technical layout, road mapping and development of a new outpost in LEO must be started now. The DLR project "Post-ISS" (a system analysis study) can be understood as national preparatory work for the establishment of future programmes in the field of human spaceflight and to secure long-term research and astronautical activities in LEO. Corresponding questions focus on:

- How to continue with space research and space technology development after the ISS utilisation period (≥~2024)?

Therefore, the following objectives were defined within the DLR study:

- Analysis of the pros and cons of ISS (DLR internal) and recommendations based on lessons learned
- Market research of existing technologies / techniques
- Analysis of additional user demand and utilisation opportunities by including additional scientific disciplines and technological research
- Design of infrastructure concepts that conform to crew-systems integration standards
- Analysis of the reusability of the current architecture

In a nutshell: We need to have ideas and a plan once the ISS will not – for whatever reason – be available anymore. We need to talk to our partners worldwide, exchange ideas and harmonize the required next steps in order to initiate the necessary political, conceptual and technical processes for the development of a follow-on platform in LEO. The greater goals should be: to have an agreement between all relevant agencies concerning a follow-on concept for the ISS within 2 years, and second, to have a replacement ready by the year 2025. Finally, if feasible, the future platform might use some of the existing ISS modules.

Concept Framework Conditions

- Technical-modular concept (separation of astronauts and experiments were driven by science considerations; in case single modules fail to operate: exchange of those is possible, optional autonomous operation of units (Habitat/ temporarily crewed Free-Flyer) is enabled)
- Political-modular concept (countries resp. agencies can participate according to individual budget possibilities and science interests)
- Design mainly based on available technologies with participation of private and commercial partners
- User (science) requests for multiple disciplines (see details below)
- Reasonable costs for operations

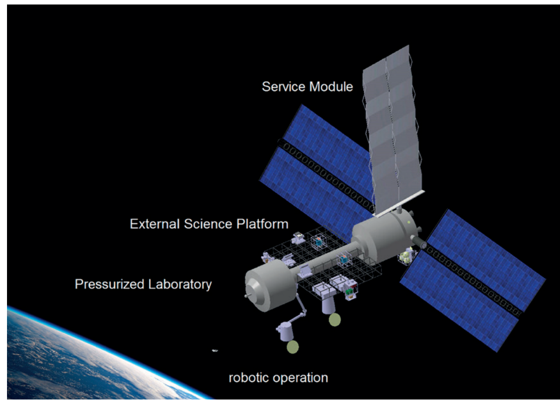


Figure 2: Orbital-Hub architecture: Dockable Free-Flyer to comply with specific science and user requirements.

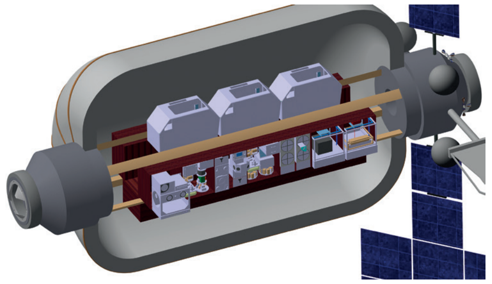


Figure 3: Expandable Habitat module of the Orbital-Hub with crew quarters and infra-structure for human physiology, biology and radiation experiments accommodated on the central structure with reference to the Bigelow Aerospace B330 module.

User Requirements for LEO-Platforms

Requirements regarding a future Mini-platform in LEO have been collected from German scientists and engineers [DLR-MP-Post-ISS-AP3000[5]] Several research disciplines participated in the one week Orbital-Hub User Concurrent Engineering study and contributed recommendations for defining payloads for the preferred option (Orbital-Hub). In addition to traditional µg-research, an extended focus was placed on Earth observation, atmospheric physics and technology demonstrations for human-rated platforms. The following overview summarises the top-level science needs based on detailed quantitative requirements:

- Observe processes in real-time (e.g. materials); on-orbit analysis opportunity to significantly reduce the return of samples
- Low vibration levels (e.g. caused by astronauts or moving structures)
- High and flexible modularity (easy access and exchange of samples or instruments)
- High data transmission possibility and storage
- Storage for instruments, spare parts, new hardware, samples
- Minimum utilisation time of ten years
- Robotic exchange of samples
- Maintenance possibilities, work bench
- Astronauts: crew exchange after approximately 20 days (resulting in higher sample rate for human physiology), implying no requirement for extensive exercise devices

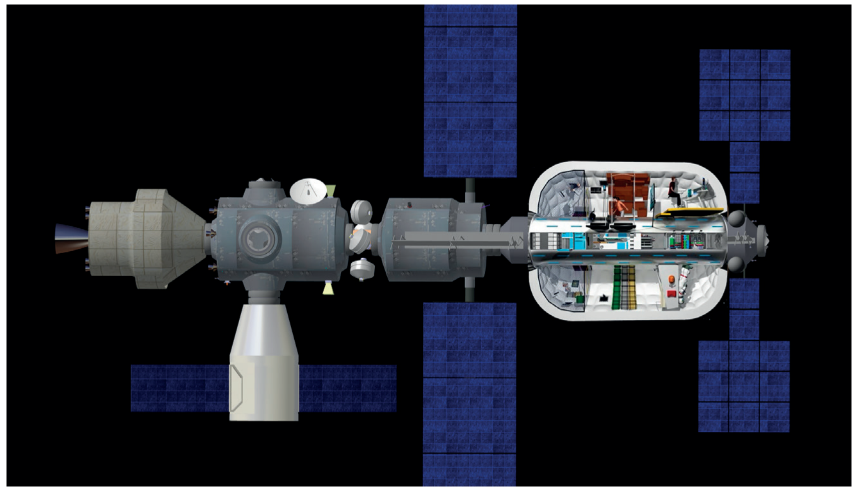


Figure 4: Base Station of the DLR Orbital-Hub architecture with a section view of the habitat module provided by Bigelow Aerospace.

[5] Project report: AP 3000, „Post-ISS: Mögliche Anwendungen & Nutzlasten“, work in progress.

Table 1: General LEO platform requirements derived by strawman payloads

Platform	Strawman Payloads	General User Requirements	Overall Architecture Requirements
Habitat (base station), pressurised	Human physiology (measurement of intracranial pressure) Radiation dosimetry and biology (e.g. Phantom) Gravitational biology (signal transduction)	Connection: high-vacuum, inert gas, cooling, power, data 12 astronauts (cumulated over time) per human experiment, with 1 hour per measurement and 10 measurements per astronaut Tele-presence Centrifuge for biological samples Freezer for samples	Power: 30 kW ISPR: approx. 24
Free-Flyer external	UV-VIS-NIR-SWIR spectrometers Bio signatures (Bio-Life) Raman spectrometer Plume simulator	Orbit between 300 and 600 km, ca. 51°inclined Connection: power, cooling, data Data rate up to 3 Tbyte/day downlink Data rate up to 1.5 Gbyte/s uplink Isolation against vibrations from (manned) station structure Angle of view: Nadir Cleanness: max. 130 Å/year (surface contamination of optics) Instrument exchange: every 2 years	Free-Flyer power total: 20 kW (depending on PL and OPS) Area: approx. 20 m²
Free-Flyer pressurised	GPoptEO Material physics (MUMS) LIDAR observation	Microgravity Level: up to 10-6g Connection: high-vacuum, inert gas, cooling, power, data Isolation from station structure	ISPR: approx. 6

Engineering Concepts for Modular LEO Platform

During a Concurrent Engineering (CE) workshop conducted by DLR several options (in total 13 including sub-options) fitting to the aforementioned concept framework conditions were identified [DLR-RY-Post-ISS-AP4000[6]]. Four of them were chosen for detailed evaluation using the Analytical Hierarchy Process (AHP) regarding political, social, technical and economic criteria. A lean multi-purpose station with dockable module/platform, which was called “Orbital-Hub”, was evaluated to be the most promising option from a European and German point of view (see Figure 1 and Figure 5). Orbital-Hub[7], stands for the basis or the core element of a space village idea: On the hub, spacecraft can dock and be serviced, or goods (e.g. propellant or experiments) can be distributed (cf. hub as distribution node of the Internet). Therefore, the Orbital-Hub concept was the baseline for further development during a CE-study regarding utilisation and science (see Table 1) and another complete CE-study to elaborate the architecture in more detail.

[6] Project report: AP 4000, “Post-ISS: Szenarienentwurf”, work in progress.
[7] Hub = central portion of a wheel, turnstile, modular logistics/distribution centre.

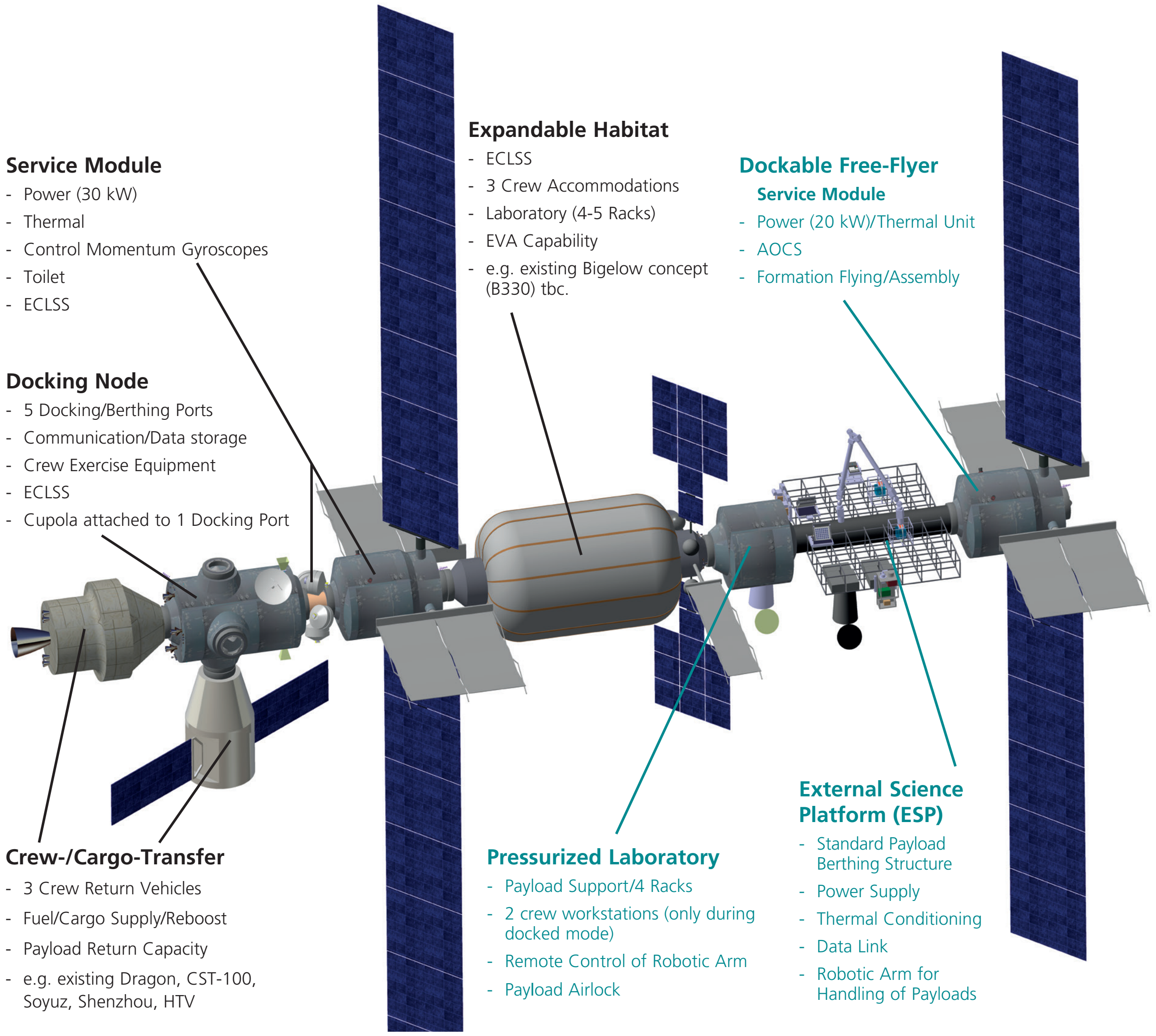


Figure 5a: Modular Orbital-Hub architecture: multi-purpose station with dockable module/platform as a European initiative.

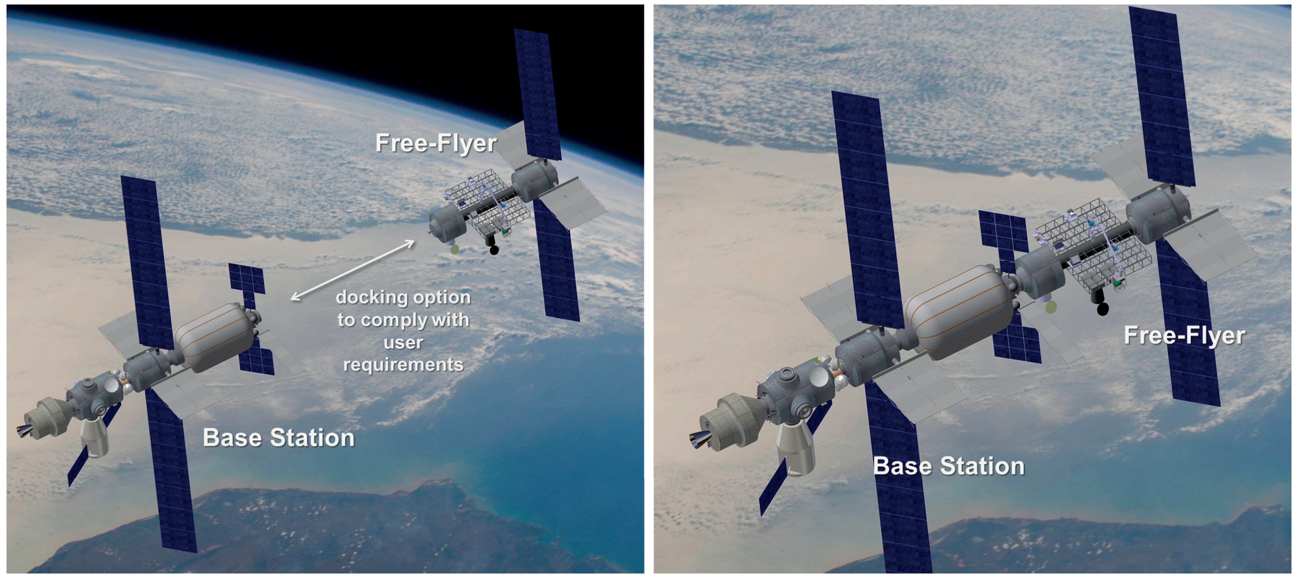


Figure 5b: Orbital-Hub architecture: multi-purpose station with dockable module/platform as a European initiative (left: detached for observation and µg-operation; right: docked for servicing)

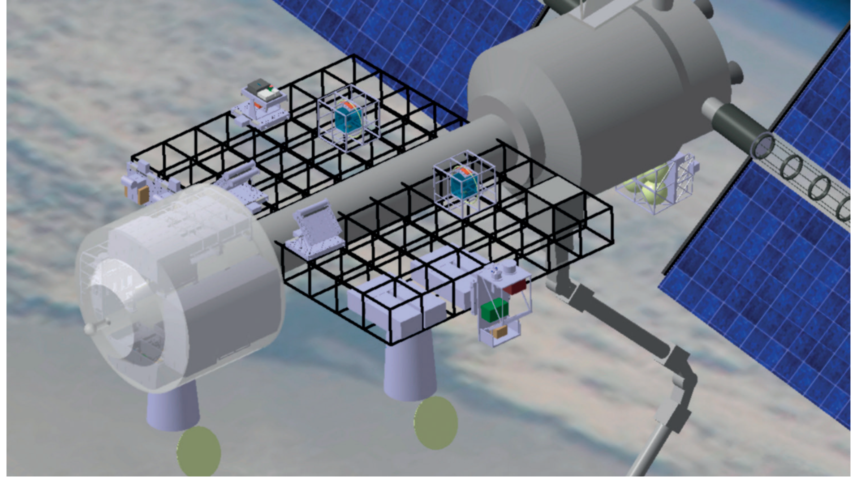


Figure 6: Dockable Free-Flyer with External Science Platform and Pressurized Laboratory as part of the Orbital-Hub concept (draft).

The selected concept strives to employ only the minimum functionality required for a scientific astronautical base station (three crew members continuously plus visitors) in LEO (see Figure 5a, left side; Figure 4 and Figure 8): At least one module is needed for science laboratories, the crew accommodation and according environmental control and life support systems (example design: expandable habitat) (see Figure 3 and Figure 4). In addition, a service module is needed to ensure attitude and orbit control and provide power and thermal control. A five-point docking node (one used by the cupola) allows for crew and cargo transfer and extension opportunities and can comprise communication and data systems or backup subsystems. Up until today, there have been 187 EVAs on the ISS. In contrast to the ISS, the Orbital-Hub concept is designed to limit the number of EVAs by avoiding items placed externally to the station. However an EVA contingency is foreseen on the Base Station and an airlock is planned for the pressurized part of the Free-Flyer in order to service the External Science Platform using a robotic arm. Since the critical requirements regarding attitude and disturbances are shifted towards the Free-Flyer, the Base Station is free to roll or yaw a certain amount. That allows for a one-axis rotatable solar panel design which does not need additional truss structures as used on the ISS (see Figure 12). The Base Station is also free to have the Habitat Module or the Docking Node point into the direction of flight. To avoid regular refuelling for orbit maintenance, the respectively docked crew or cargo vehicle will provide the required manoeuvres. Hereby electrical thrusters are a promising solution for drag compensation.

In addition to the Base Station, a Dockable Free-Flyer (see Figure 5a, right side; Figure 2 and Figure 6) is part of the Orbital-Hub concept in response to the scientific user requirements. It is intended to fly uncrewed in a safe formation to the Base Station for e.g. three-month periods until it can be maintained or reconfigured when docked to the station for short duration. Therefore in analogy to the Base Station, it also needs a service module for attitude and orbit control and also for formation flying and independent power and thermal control. It further contains a pressurised module for µg-research which can be accessed when docked to the Base Station (e.g. via the Docking Node or via the Expandable Habitat module) or to a crew vehicle (Figure 11). The external science platform is the centre of the Free-Flyer. It has a berthing structure for any external payload and provides power, data and thermal conditioning. The Free-Flyer will most likely fly with the instruments pointed nadir (see Figure 7), but in principle, is free to change attitude for certain periods depending on user requirements. The size and shape of this platform is only an example and it is intended to be deployable in order to launch the Free-Flyer in one piece. Robotic arm interfaces are foreseen to handle the payloads on the platform, which is based on the Orbital-Hub User Concurrent Engineering study, described above. The Free-Flyer is intended to support the assembly of the Base Station by being the active part of automated docking, since there is currently no similar vehicle like the U.S. Space Shuttle available.

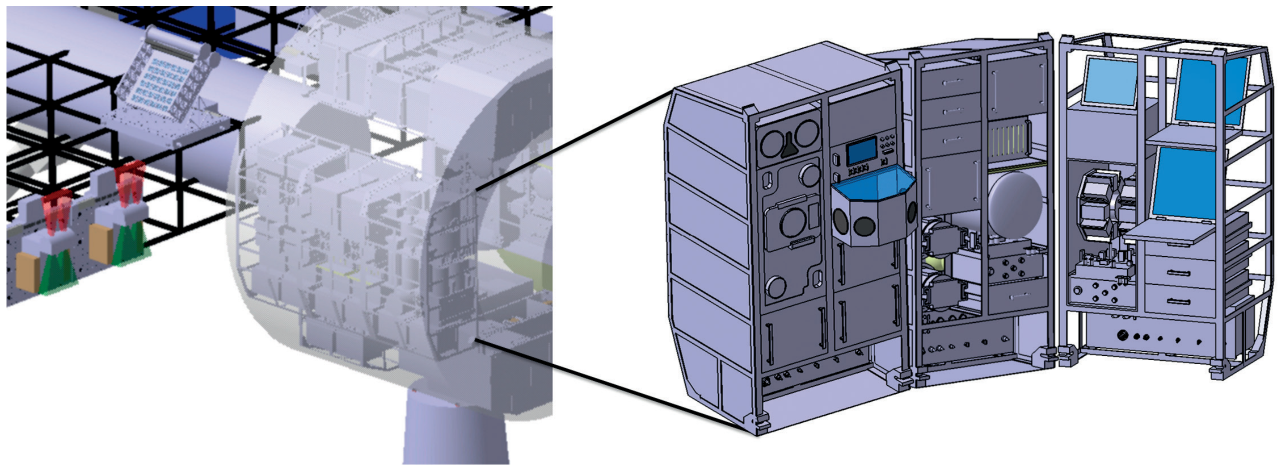


Figure 7: Section of the Dockable Free-Flyer with instruments (e.g. for observation of atmospheric chemistry) on the External Science Platform and example racks (e.g. for material physics) in the pressurized part (draft).

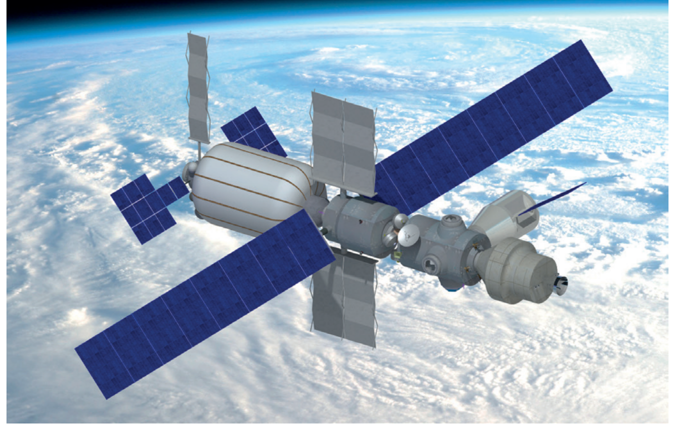


Figure 8: Orbital-Hub Base Station with a minimum number of modules to allow for the continuous residence of three astronauts.

Launch Scenario and Mass/Size Budget Estimation

Based on the described modules of the Orbital-Hub (see Figure 9 and Figure 10; Table 2) the following launch scenario could be derived:

(1) Launch **Free-Flyer**: e.g. Ariane 6-4, Proton, Atlas V, Falcon

(2) Launch **Habitat**: Autonomous Docking by Free-Flyer — e.g. Delta IV, Proton, Falcon Heavy

(3) Launch **Service Module**: Autonomous Docking by Free-Flyer + Habitat — e.g. Ariane 6-4, Proton, Atlas V

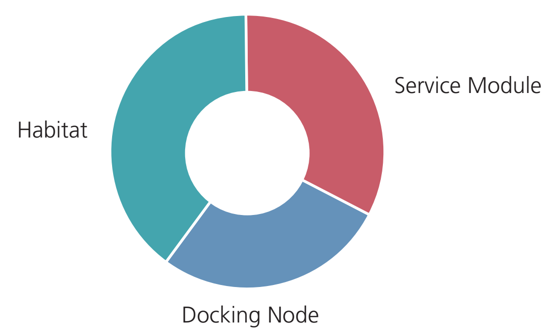
(4) Launch **Docking Node**: Autonomous Docking by Free-Flyer + Habitat + Service Module — e.g. Ariane 6-4, H-II, Atlas V

(5) 1st **Crew** to Docking Node: e.g. Dragon, CST-100, Soyuz, Dream Chaser, Shenzhou

Table 2: Mass and size budget estimation of the Orbital-Hub architecture.

Module	Size Estimate in metres	Mass Estimate in tons
Free-Flyer	launch configuration: Ø = 4.5; length = 9.8	21
External Science Platform	length = 7; width = 7; height = 1 (deployed)	3.2
Pressurized Laboratory	Ø = 4.5; length = 3.4	6.9
Service Module	Ø = 4.5; length = 5.4	10.9
Habitat + Laboratory	Ø = 7.5; length = 13.7 (expanded)	26.1
Service Module	Ø = 4.5; length = 5.4	21.8
Docking Node	Ø = 4.5; length = 6.7	17.4

Figure 9: Pie chart of the mass distribution of the Orbital-Hub Base Station's three modules (Expandable Habitat, Service Module and Docking Node) generated during the CE-study "Post-ISS Scenario-I".



	Mass w/o margin [kg]	Margin [%]	Margin [kg]	Mass with margin [kg]	% of total dry mass
AOCS	1166.60	10.21	119.09	1285.69	2.43
Communication	101.00	20.00	20.20	121.20	0.23
CrewFacilities	1310.00	10.48	137.30	1447.30	2.74
ECLSS	3150.00	17.33	546.00	3696.00	6.99
EVA	730.00	12.05	88.00	818.00	1.55
OnBoardComputer	984.00	20.00	196.80	1180.80	2.23
Power	3593.80	20.00	718.76	4312.56	8.16
Propulsion	742.90	12.40	92.11	835.01	1.58
Robotic_Mechanisms	127.00	20.00	25.40	152.40	0.29
Science_on_BaseStation	2750.80	20.00	550.16	3300.96	6.24
Structure	25312.92	18.20	4607.58	29920.50	56.60
Thermal	4830.00	20.00	966.00	5796.00	10.96

	Mass w/o margin [kg]	Margin [%]	Margin [kg]	Mass with margin [kg]	% of total dry mass
Total dry mass:	44799.02			52866.42	
System margin:		20.00		10573.28	
Total dry mass with system margin:				**63439.71**	
Propellant:				1752.40	
Adapter mass:				0.00	
Launch Mass:				**65192.11**	

Figure 10: Mass table of the Orbital-Hub Base Station generated during the CE-study "Post-ISS Scenario-I" as shown by the DLR data model "Virtual Satellite".

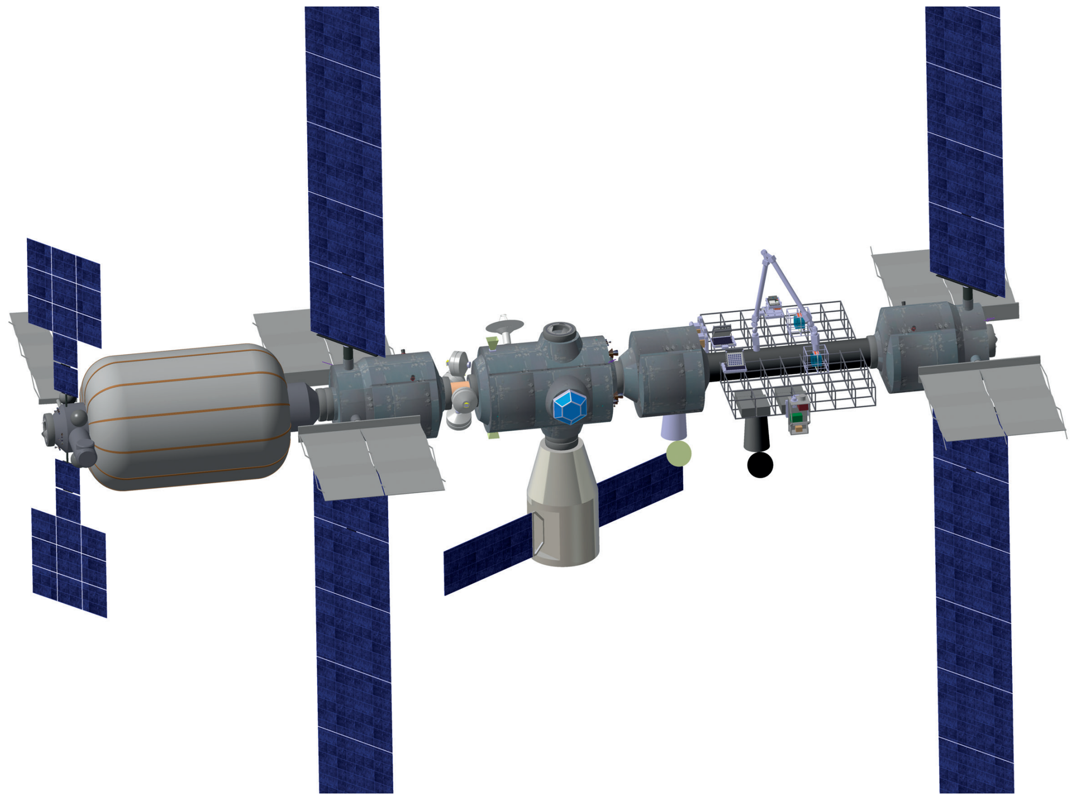


Figure 11: Alternative docking configuration of the Orbital-Hub concept with the Free-Flyer docked to the Docking Node.

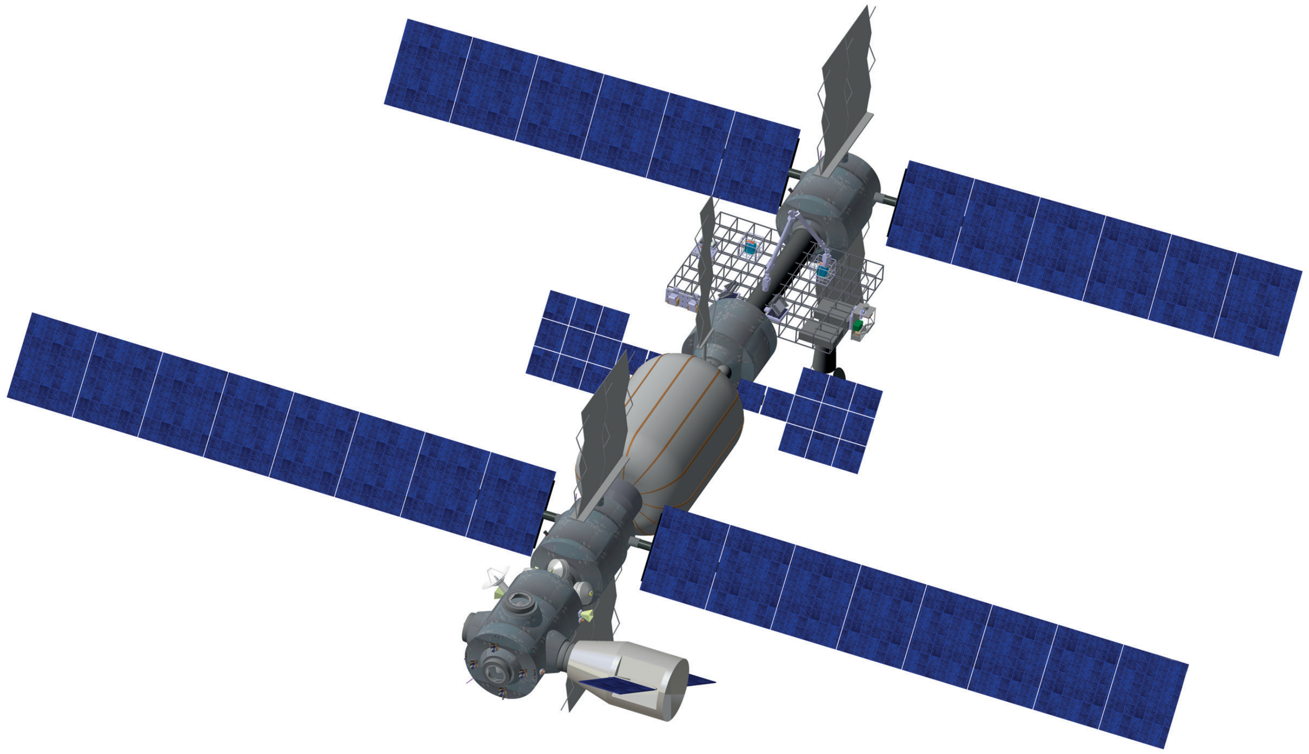


Figure 12: Modular Orbital-Hub concept with Solar Panels pointing to the Sun when beta-angle is around 0 deg.

Conclusions and Next Steps

The feedback by German scientists and engineers has shown continuous high interest in using the Low Earth Orbit on a Multi-purpose Mini-Space-Station. As explained in the “FuW Strategy 2025”[8]: a space laboratory is unique and not replaceable. Research in space complements terrestrial opportunities. Scientists also highlighted the fact that Europe/Germany has achieved a technological system competence by developing, constructing and operating research facilities in space. The option with the highest interest and flexibility currently is the modular Orbital-Hub (see above). It represents the highest degree of maturity based on current technologies, operational/logistical options, current commercial developments and financial aspects. It includes the opportunity to be realised by significant involvement of Europe with international cooperation. Alternatively, parts of the concept could be implemented e.g. the Free-Flyer only or base station parts as a contribution to an upcoming station.

[8] Programmausschuss FuW 2010.

Concept study results (at midterm) suggest further consideration of the following items for potential German key contributions:

- (Astronautical) science operation in LEO
- Ongoing requirements definition with national/international science user community
- Know-how regarding automated service modules
- Robotic technology options for internal and external use
- Advanced lowthrust propulsion[9]
- Clear interface definition –> only a few partners per module (not applicable to experiments)

The detailed design of the Free-Flyer will be part of an upcoming CE-study at the end of 2015. During the accommodation design of the interior of the Expandable Habitat module, all rigid parts have been attached to the central core structure. With this approach, the balance between rack accessibility and volume still has to be proven. One promising technology for drag compensation for LEO architectures is an electrical low-thrust engine. Independent of this proposal, a follow-on study including interested and dedicated partners and new market players is strongly recommended.

In general, we expect future LEO architectures to be smaller and more modular and flexible than the current ISS. Complementing payloads such as Earth observation will add to the scientific utilisation. The continuous interest of the science community in an outpost in LEO serves as a basis for the architecture’s design (e.g. temporary separation of human presence from µg-experiments). However, science on its own cannot serve as the main justification to build and operate human-tended infrastructures in LEO.

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DLR Institute of Space Systems
System Analysis Space Segment

[9] Reference to Space Administration H2020 EPIC, Electric Propulsion Innovation and Competitiveness project

DLR at a Glance

DLR is the national aeronautics and space research centre of the Federal Republic of Germany. Its extensive research and development work in aeronautics, space, energy, transport and security is integrated into national and international cooperative ventures. In addition to its own research, as Germany's space agency, DLR has been given responsibility by the federal government for the planning and implementation of the German space programme. DLR is also the umbrella organisation for the nation's largest project management agency.

DLR has approximately 8000 employees at 16 locations in Germany: Cologne (headquarters), Augsburg, Berlin, Bonn, Braunschweig, Bremen, Goettingen, Hamburg, Juelich, Lampoldshausen, Neustrelitz, Oberpfaffenhofen, Stade, Stuttgart, Trauen, and Weilheim. DLR also has offices in Brussels, Paris, Tokyo and Washington D.C.

DLR's mission comprises the exploration of Earth and the Solar System and research for protecting the environment. This includes the development of environment-friendly technologies for energy supply and future mobility, as well as for communications and security. DLR's research portfolio ranges from fundamental research to the development of products for tomorrow. In this way, DLR contributes the scientific and technical expertise that it has acquired to the enhancement of Germany as a location for industry and technology. DLR operates major research facilities for its own projects and as a service for clients and partners. It also fosters the development of the next generation of researchers, provides expert advisory services to government and is a driving force in the regions where its facilities are located.

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