DLR, August 2017

Orbital Hub
DLR Vision 2025

DLR Institute of Space Systems
System Analysis Space Segment

SARA

Bremen, August 2017

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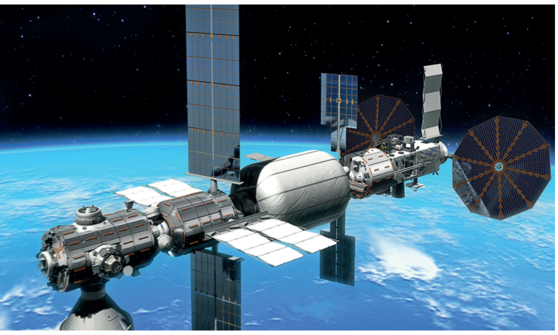

Figure 1: Illustration of DLR's Orbital Hub concept during the docked phase for servicing of the Free Flyer consisting of an external platform and a pressurised laboratory.

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. 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 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 in space (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 continues with its Chinese Space Station CSS and prepares its next objective: a human Moon landing. Europe's human spaceflight partners tend to consider new platforms in LEO or cis-lunar space and utilise ISS as long as possible and necessary for the transition expected beyond 2024. Europe itself is interested in continuing research in LEO in particular within the human spaceflight area[3] as discussed by the ISECG[4], depending on the funding commitment[5].

DLR's Future Objectives in LEO

ISS follow-on activities should comprise clear scientific and technological objectives combined with the long-term view on space exploration (e.g. robotics, internal and external structures, module/facility, crew training and experiment operations, supply systems (ATV)).

Therefore, DLR started to investigate future options by evaluating various LEO infrastructure concepts including opportunities for national realisation or international cooperation. DLR scientists from various disciplines assessed the usability of these options and designed payloads based on their Mir and ISS experience 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 ATK.

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. Exemplary providers with a commercial approach for complete platforms are for example: Bigelow Aerospace, Axiom Space.

3 See also ESA's LEO 2020.

4 International Space Exploration Coordination Group (ISECG) Global Exploration Roadmap 2013.

5 Project report: AP 1000, „ISS-Analyse & Lessons Learned".

Motivation for New LEO-Platform Considerations

All International Space Station partners agree to utilise the orbital research facility until at least 2024. Whether this is politically, technologically and financially feasible for all partners is unknown. However, there is a common understanding that a platform in LEO is crucial for continuous research, technology demonstration, Earth observation and monitoring and potentially for preparing the next steps for going to Moon or even Mars. With the presented lean concept a significant cost reduction compared to ISS can be achieved.

In general, a transition to a new concept without a critical loss of know-how takes up to 10 to 15 years. Therefore, the conceptualisation regarding technical layout, creating a road map and development of a follow on 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. The engineering concept study focussed 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 based on realistic German / European budgets
- Analysis of the reusability of the current architecture

In a nutshell: We need to have ideas and a plan once the ISS is not available anymore. Recent coordinating efforts with our partners worldwide are part of the necessary political, conceptual and technical processes for the development of a follow-on platform in LEO. The greater goals ought to be: invest into a new agreement between potential partner agencies concerning a follow-on concept for the ISS within two years, and second, to have a feasible, affordable and useful replacement ready within 8 - 10 years. Finally, the future platform might even re-use some of the existing ISS modules and technologies.

Figure 2: Dockable Free Flyer to comply with specific science and user requirements.

Concept Framework Conditions

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

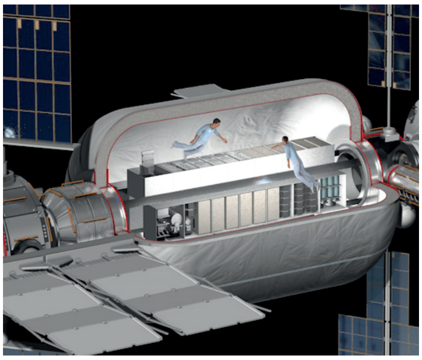


Figure 3: Expandable Habitat module of the Orbital Hub with crew quarters and infrastructure for human physiology, biology and radiation experiments accommodated on the central structure with reference to the Bigelow Aerospace B330 module.

User Requirements for LEO-Platforms

Requirements regarding a future Mini-platform in LEO have been collected from German scientists and engineers[6]. Several research disciplines participated in the Orbital Hub User Concurrent Engineering study and contributed recommendations for payload definitions 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 driven expectations 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
- Long-term utilisation time (e.g. min. 10 years)
- Robotic exchange of samples
- Maintenance possibilities, work bench
- Astronauts: short term crew exchange for extended terrestrial research, long-term mission for preparation of exploration activity aspects

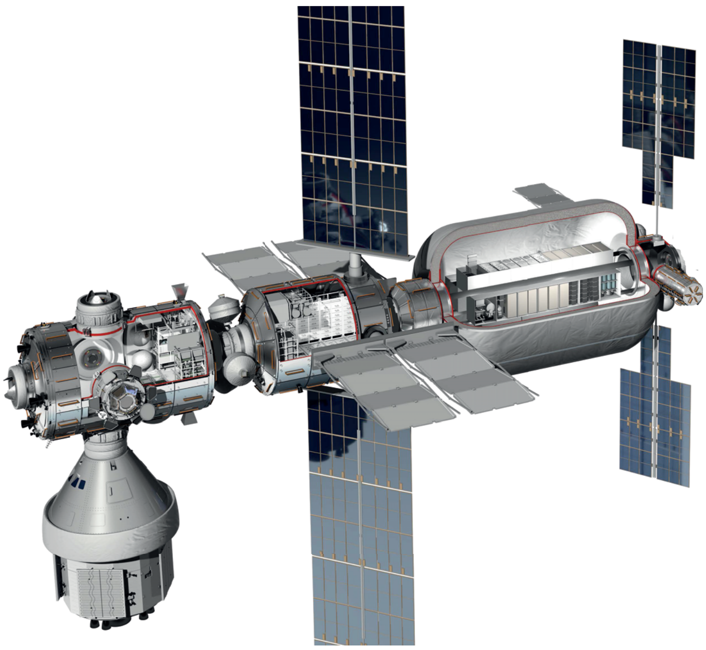


Figure 4: Sectional view of the DLR Orbital Hub Base Platform architecture

[6] 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
Habitat (Base Platform), pressurised	Human physiology (measurement of intracranial pressure/general health research) Radiation dosimetry and biology (e.g. Phantom) Gravitational biology (signal transduction/ FLUMIAS) Robotic experiments (robot-assistant, NanoSatFreeflyers) Tech-demo (e.g. additive manufacturing)	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 Incubator, Refrigerator, Glovebox
Free Flyer external	UV-VIS-NIR-SWIR spectrometers LIDAR observation GPoptEO Bio signatures (Bio-Life) Raman spectrometer Plume simulator Tech-demo (electric propulsion) EOB with pointing platform (e.g. MUSES) Sky-/Solar observation	Orbit between 300 and 600 km, ca. 51° inclined Connection: power, cooling, data Data rate up to 3.3 Tbyte/day downlink Data rate up to 1.5 Gbyte/s uplink Isolation against vibrations from (manned) platform structure Angle of view: Nadir Cleanness: max. 130 Å/year (surface contamination of optics) Instrument exchange: every 2 years
Free Flyer, pressurised	Material physics (MUMS) Payload airlock Work bench/storage	Microgravity Level: up to 10^{-6}g Connection: high-vacuum, inert gas, cooling, power, data Downlink about 100 GByte/day Isolation from platform structure

Engineering Concepts for Modular LEO Platform

During a Concurrent Engineering (CE) study conducted by DLR several options (in total 13 including sub-options) fitting to the aforementioned concept framework conditions were identified[7]. 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 platform 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[8], stands for the basis or the core element of a space village idea: on the hub, spacecrafts can dock and be serviced, or goods (e.g. propellant or experiments) can be distributed (cf. hub as distribution node of the Internet).

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

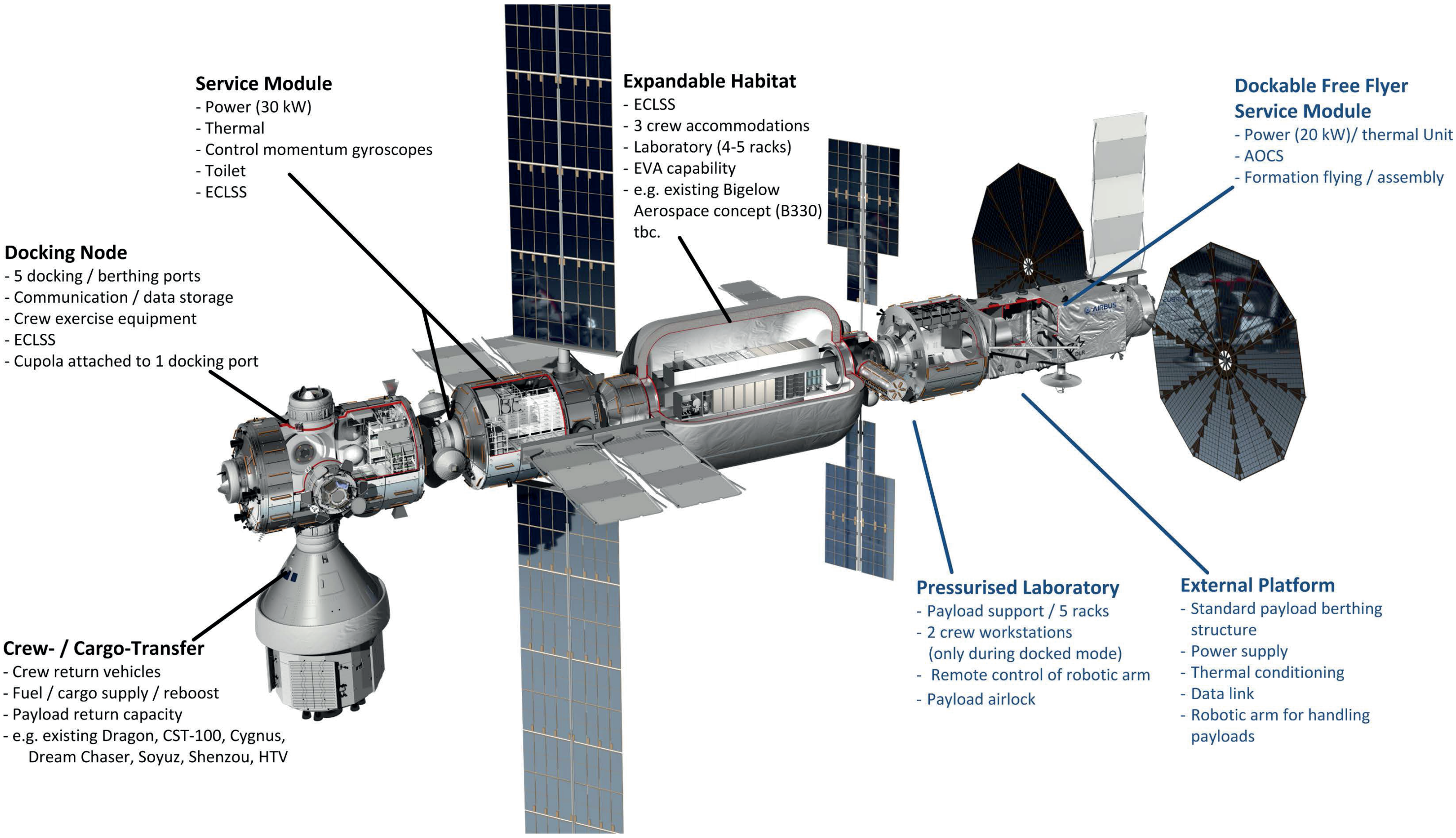


Figure 5a: Modular Orbital Hub architecture comprised of a crewed multi-purpose platform with dockable free-flying module as a European initiative.

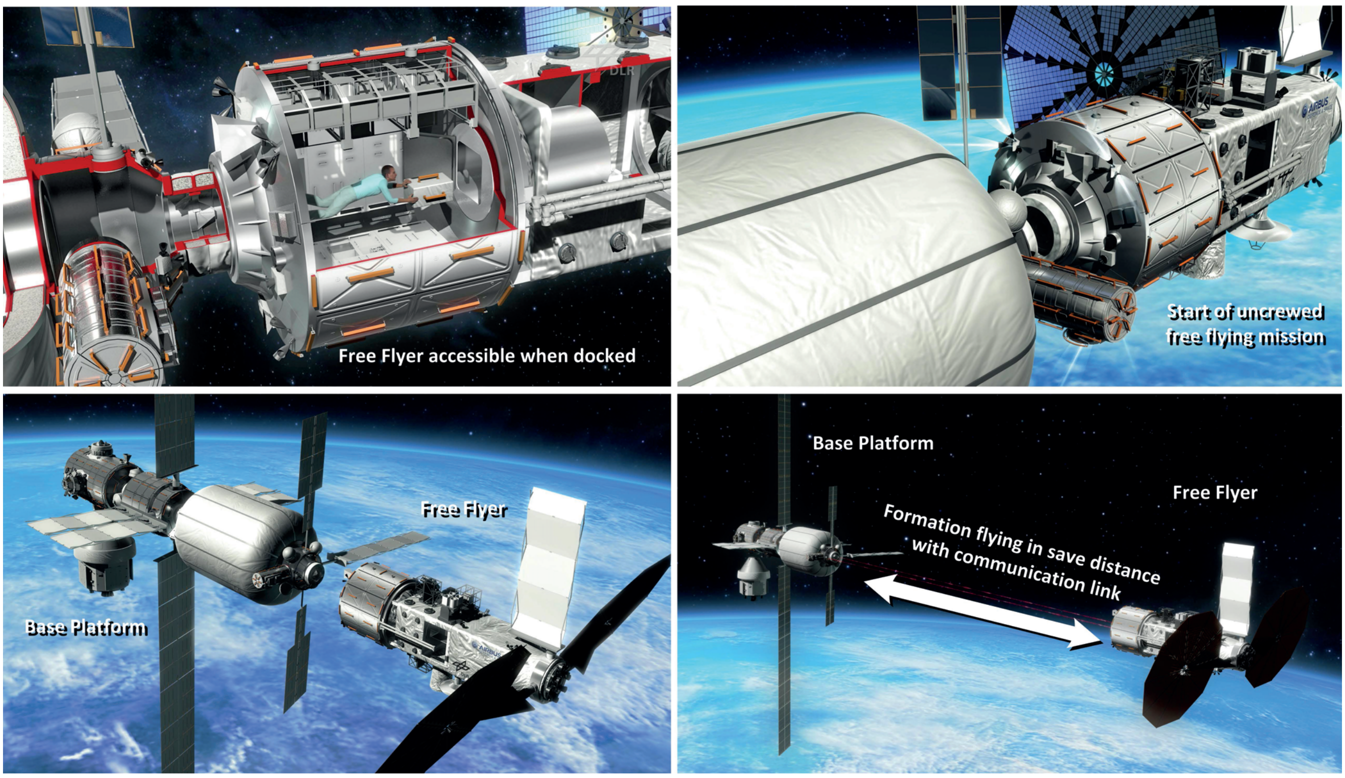


Figure 5b: Free Flyer docking to Base Platform for servicing, maintenance and reconfiguration by crew; detached formation flying for undisturbed observation and μg operation.

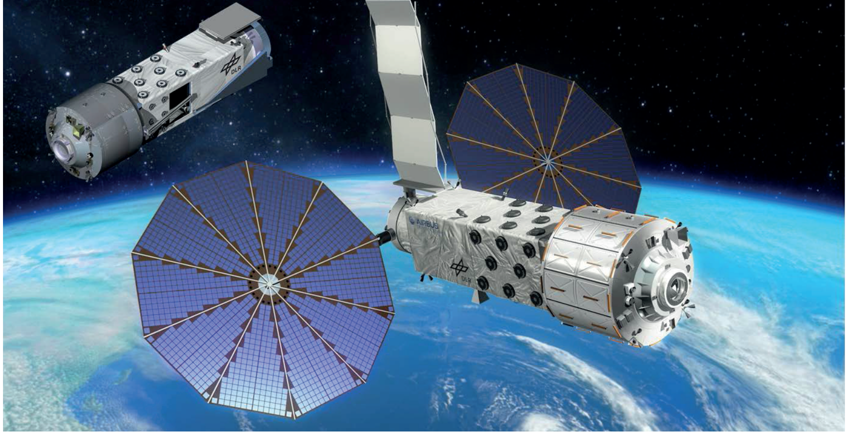


Figure 6: Dockable Free Flyer with External Platform and Pressurised Laboratory as part of the Orbital Hub concept in stowed and deployed configuration.

The selected concept aims to employ only the minimum functionality required for a scientific astronautical base platform (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 201 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 platform. However an EVA contingency is foreseen on the Base Platform and a payload airlock is included between the pressurised and unpressurised parts of the Free Flyer in order to service the External Platform using a robotic arm. Since the critical requirements regarding attitude and disturbances are shifted towards the Free Flyer, the Base Platform 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. The Base Platform 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 Platform, 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 Platform for e.g. three months periods until it can be maintained or reconfigured when docked to the base for short duration (see Figure 5b). In analogy to the Base Platform, it also requires a service module for attitude and orbit control and also for formation flying and independent power and thermal control. Furthermore, it contains a pressurised module for µg-research which can be accessed when docked to the Base Platform (e.g. via the Docking Node or via the Expandable Habitat module) or to a crew vehicle. The external 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. As one result of the Free Flyer's CE study, which has been conducted in close cooperation with AIRBUS DS, the External Platform is designed as a rigid rectangular truss structure covered with MLI. The main volume of the payload airlock is located inside this structure and can be reached through a cut-out by the robotic arm. This manipulator is moving along a rail around the structure to place different payloads onto the four sides of the platform with respect to their desired viewing direction. As the Free Flyer's Service Module does not need to be pressurised, it has been redesigned using the same truss approach as the External Platform and by this facilitating the mechanical design for stiffness and launch load transfer through the overall structure. 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. Furthermore, the Free Flyer is intended to support the assembly of the Base Platform by being the active part of automated docking, since there is currently no similar vehicle like the U.S. Space Shuttle available. The overall dimensions of the Free Flyer in stowed configuration (retracted photovoltaics and radiator wings) have been optimised to be in line with the launch scenario using a single ARIANE 64
(see Figure 6).

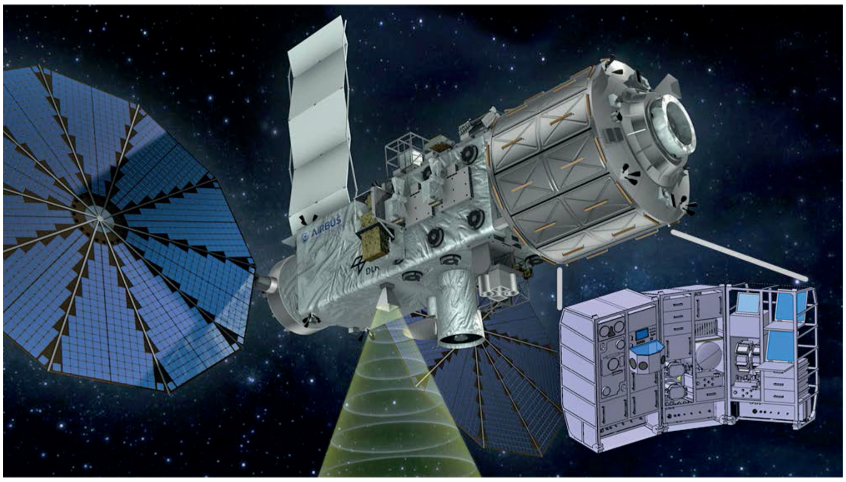


Figure 7: Dockable Free Flyer with instruments (e.g. for observation of atmospheric chemistry) on the External Platform and example racks (e.g. for material physics) in the pressurised part.

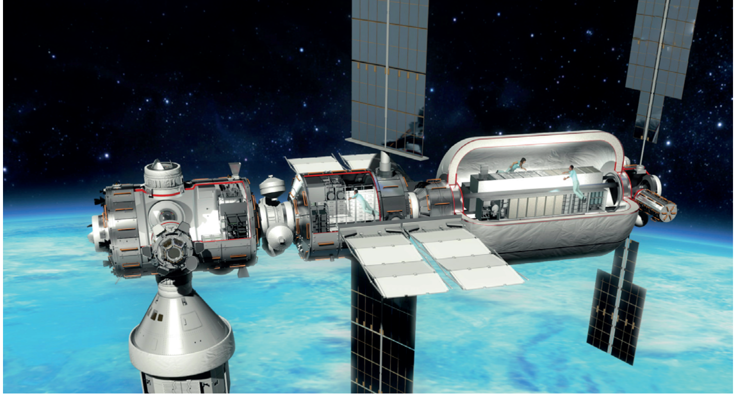


Figure 8: Orbital Hub Base Platform with a minimum number of modules to allow for the continuous residence of three astronauts.

Launch Scenario and Mass/Size Budget Estimation

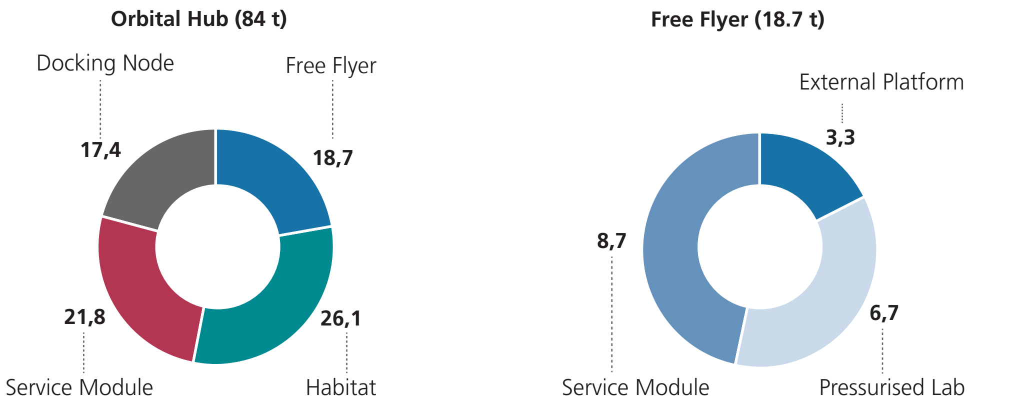
Based on the described modules of the Orbital Hub (see Figure 9 and Figure 10a,b; Table 2) the following launch scenario could be derived:

(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 m	Mass Estimate in t
Free Flyer	launch configuration: Ø = 4.5; length = 15.4	18.7[9]
Pressurised Laboratory	Ø = 4.5; length = 4.5	6.7
External Platform	length = 4; width = 3.2; height = 3.2	3.3
Service Module	length = 6.4; width = 3.2; height = 3.2	8.7
Habitat/Laboratory	Ø = 7.5 (expanded); length = 13.7	26.1
Service Module	Ø = 4.5; length = 5.4	21.8
Docking Node	Ø = 4.5; length = 6.7	17.4

Figure 9: Mass distribution of Orbital Hub Base Platform and Free Flyer and their modules resulting from the CE studies.



[9] Only part of the considered strawman payloads is accommodated on the launch configuration (further payloads are planned to be installed later via servicing).

	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:				125.00	
Launch Mass:				**65317.11**	

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

	Mass w/o margin [kg]	Margin [%]	Margin [kg]	Mass with margin [kg]	% of total dry mass
AOCS	733.51	19.13	140.30	873.81	6.00
Communication	311.00	15.87	49.35	360.35	2.47
Crew_Workstation	30.00	20.00	6.00	36.00	0.25
DHS	141.00	8.40	11.85	152.85	1.05
ECLSS	156.40	9.49	14.84	171.24	1.18
Harness	367.48	10.00	36.75	404.23	2.78
Payload_Science	1130.00	20.00	226.00	1356.00	9.31
Power	2271.14	9.61	218.36	2489.50	17.09
Propulsion	352.23	12.51	44.06	396.28	2.72
Robotic_Automation	267.00	13.75	36.70	303.70	2.09
Structure_Debris_Rad_Protection	5110.00	19.37	990.00	6100.00	41.88
Thermal	1666.00	12.40	206.60	1872.60	12.86
Venting_Systems	40.80	16.03	6.54	47.34	0.33

	Mass w/o margin [kg]	Margin [%]	Margin [kg]	Mass with margin [kg]	% of total dry mass
Total dry mass:	12576.56			14563.91	
System margin:		20.00		2912.78	
Total dry mass with system margin:				**17476.69**	
Propellant:				1100.00	
Adapter mass:				125.00	
Launch Mass:				**18701.69**	

Figure 10b: Mass table of the Orbital Hub Free Flyer generated during the CE-study "Post-ISS Scenario-II" as shown by the DLR data model "Virtual Satellite"[9]

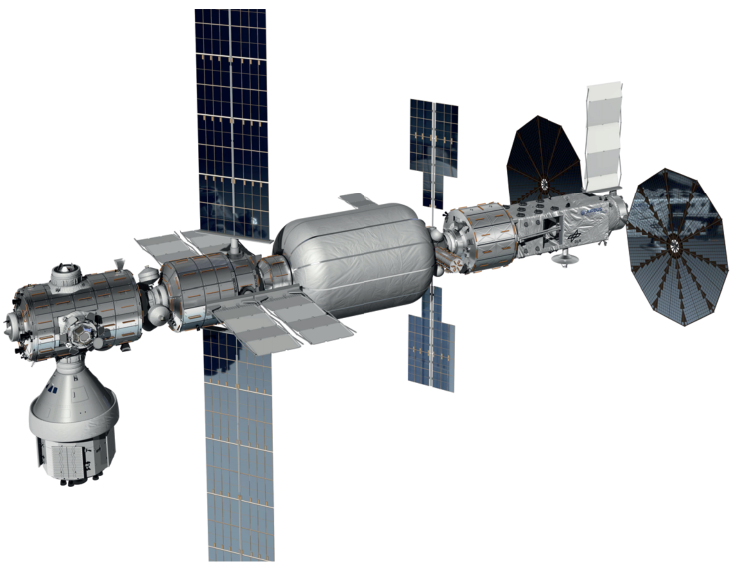


Figure 11: Final result of the Post-ISS Scenario CE studies: "Orbital Hub" with crewed Base Platform and autonomous Free Flyer

Figure 12: Free Flyer docking to current ISS during one of its first missions.

Conclusions and Next Steps

The feedback from many scientists and engineers has shown continuous high interest in using the Low Earth Orbit on a multi-purpose mini-platform. As explained in the "FuW Strategy 2025"[10]: 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 is the modular Orbital Hub (see above). It represents the highest degree of maturity based on current technologies, operational/logistical systems, current commercial developments and financial aspects. The modular Orbital Hub is a realistic opportunity, however, only with a significant involvement of Europe and international (commercial) partners. Alternatively, parts of the concept could be implemented separately e.g. the Free Flyer only or Base Platform parts as a contribution to an upcoming architecture.

[10] Programmausschuss FuW 2010.

Concept study results 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 low thrust propulsion; electric low thrust engine as promising technology for drag compensation for LEO architectures[11]
- Clear technical and programmatic interface definition –> only a few partners per module (not applicable to experiments)

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. 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, more modular and flexible than the current ISS. Complementing payloads such as Earth observation, technology demonstration, commercial application as well as opportunities for preparation of human planetary exploration will add to the conventional scientific utilisation. The interest of the user community in a research laboratory and an observation platform in LEO serves as a basis for the architecture's design open for future commercial involvement. The first flying hardware components, i.e. the Free Flyer operating with still existing ISS (c.f. Fig 12), could be realised in the frame of moderate budgets in the next eight years.

The Orbital Hub would guarantee a smooth transition between ISS and future human space activities in LEO and would represent an affordable step regarding long-term human space exploration beyond LEO.

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[11] 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 20 locations in Germany: Cologne (headquarters), Augsburg, Berlin, Bonn, Braunschweig, Bremen, Bremerhaven, Dresden, Goettingen, Hamburg, Jena, Juelich, Lampoldshausen, Neustrelitz, Oberpfaffenhofen, Oldenburg, 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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