TREKKER HULL CLASS:
ORBITAL-ASSEMBLY PRELOAD-RESTRAINED SEGMENTED RIGID PRESSURE VESSELS WITH SANDWICHED SOFT GAS BARRIERS

TECHNOLOGY PRIMER

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Contents

Illustrations

Introduction into the Invented Technology

The Trekker Hull Class technology was invented in 2007 by sole inventor, Max Leonov (b.12.4.79), as an extracurricular activity in his free night hours, at modest personal expense, and using a very old Compaq Armada 1500 laptop.

This invention is intended most of all for the large hulls of manned interplanetary spacecraft to undertake prolonged deep space missions, including to Near Earth Objects and Mars. Such heavy interplanetary spacecraft are to be designed for a lifetime of navigating deep space and orbital parking in orbits around planets and their moons.

Despite the interplanetary imperative, the invention can be equally applied to other possible directions of human spaceflight programs, such as shuttling manned spacecraft on routes Low Earth Orbit - Lunar Orbit, parts of lunar habitats, or future modules of the International Space Station or its successor, either in LEO or beyond.

When compared to thin-walled metal pressure vessel spacecraft, such as Soyuz TMA, and to soft-inflatable-shell modules, such as Genesis I, this invention represents a third major class of man-rated pressurized hulls.

This invention is also differentiated as a class on its own from both ‘monolithic’ class spacecraft, such as Salyut 6, and the follow-on ‘modular’ class of spacecraft, as represented by the Mir complex.

In the latter respect, this invention is further characterized as a class of man-rated spacecraft hulls all components of which are prefabricated and tested on the ground, and where the assembly of the hull is completed in outer space environments using simple assembly actions, such as screwing in and tightening threaded fasteners.

In order to avoid a multiple-word technology name or an abbreviation for a technology such as this that relies on simple mechanical principles and yet requires complex structures for its realization, it is proposed here to call this invented technology simply the “Trekker Hull Class.” The term “Trekker” was chosen based on the understanding that the invented technology appears to be a present-day precursor to future manned spacecraft that may coincidentally resemble such Star Trek sci-fi creations as starship Enterprise.

This invention is a non-airtight yet pressurized rigid spacecraft hull with integrated soft airtight layers that retain the air mixture inside the habitable volume of the hull. The best embodiment of this spacecraft hull structure consists of: three segmented rigid non-airtight shells that are mechanically loaded with the clamp force from threaded fastener preload/tension to serve as a pressure vessel and as the spacecraft’s primary structure in spaceflight, each shell fabricated as consisting of rigid hollow 3-dimensional blocks that are delivered to space as independent payloads and there collectively assembled with threaded fasteners to form the rigid load-bearing hollow walls of such shell; and of two air pressure systems consisting of soft airtight sacks, which are packed and sandwiched between those rigid shells to be subsequently removed and replaced at the end of each sack's lifecycle.

The backs and lids of the rigid hollow 3-dimensional blocks form the inner and outer surfaces of each shell. The three-shell hull structure also features a rigid protective skin on the outside, and also features comfort panels that cover the hull structure inside the rooms.

The soft airtight sacks, when packed between those rigid shells, are entirely encased and restrained by those rigid shells for the purpose of pressurizing such spacecraft hull and retaining the air inside the spacecraft's habitable volume.

The shells are attached to each other through the soft airtight sacks by rigid structural load bridges, which are airtightly preinstalled in the soft airtight sacks and fastened into corresponding sockets in shell blocks. The soft airtight sacks also incorporate rigid pressurized hatchway assemblies and rigid pressurized window assemblies.

In order to make this technology primer easier to follow, the term 'spacecraft' shall be used throughout as referring to all spacecraft and space stations used for spaceflight in orbits associated with Earth and other celestial bodies in the Solar System and for inter-planetary spaceflight in the Solar System, and to all habitats on other celestial bodies in the Solar System. The term 'room' shall refer to all rooms and cabins used for diverse purposes, all kinds of corridors, airlocks, and docking compartments being here referred to as 'docking rooms', that is all pressurized habitable onboard facilities that are separated between each other by airtight-boundary pressurized hatchways, which are preferably equipped with airtight hatch doors that can be locked for pressurization.

The presented examples of embodiments in the drawings, artist's impressions, and photographs, are only illustrative and are presented in order to aid in the understanding of the nature of this invention and of the correlation of described parts that constitute this invention. Thus other designs of the described parts of this invention that incorporate the functions outlined in the textual description in this technology primer fall within the scope of this invention.

All the necessary structural and thermal-control engineering calculations when designing specific embodiments of this invention are to be carried out by qualified engineers, which are skilled in the engineering arts that cover manned spacecraft and pressurized systems, according to the conventional presently-accepted engineering practices and approaches. Obviously, specific structural and thermal-control engineering calculations will vary with every particular spacecraft design that will feature the invented spacecraft hull structure. Therefore engineering calculations are omitted from this technology primer, with focus placed on the textual and visual description of this invented technology.

This technology primer only describes basic embodiments, although because this invention may be embodied in more complex spacecraft hull structures, it can be realized through a variety of embodiments that may be characterized by some unique structural and material features without departing from the scope of this invention.

The following concept of a short-term in-flight testing program for this technology as part of the ISS activities is proposed. An Experimental Airlock Module EXAM will be engineered for the ISS. The parts for this module will be delivered to the ISS using an unpressurized satellite bus or an unpressurized cargo transfer vehicle, such as the HTV. Future expeditions to the ISS will assemble the module during EVAs and from then on monitor its pressurized states on dedicated computers, while the module's internal pressurized volume will be used for storage of vacuum-certified items.

Development of this new technology continues. Currently, functional demonstration and mockup models are being built by the inventor. Several university activities to involve students in structural and operations research and testing have been drafted by the inventor. Steps are being taken to involve organizations and to initiate interest-based public collaboration projects.

Background

First instances of description and use of soft airtight bladders in pressurizing the habitable volume of manned spacecraft go back to the first years of manned space exploration in the 1960's. Alden P. Armagnac's article "Inside Our First Space Station" on page 96 of the December 1962 issue of Popular Science serves as publicly available evidence that back then NASA in cooperation with Goodyear Aircraft Corp. was working on a 30-foot-diameter prototype of an inflatable space station with a rigid hub and a soft inflatable shell of multi-layered rubberized fabric that featured a soft primary structural restraint layer for the internal air pressure. In March 1965, Soviet manned spacecraft Voskhod-2, which was successfully launched in order to conduct the first ever EVA, featured a successfully deployed and subsequently jettisoned inflatable airlock that had a soft airtight bladder, soft structural restraint for the bladder, inflatable longerons, and two rigid end rings.

It is worth noting that both just mentioned historical precedents in the USA and USSR of soft-airtight-bladder pressurized spacecraft volumes were soft-rigid hybrids, which leads to a theoretical conclusion that barring appearance of more advanced techniques in rigidizable soft pressurized structures, any soft airtight bladder pressurized spacecraft hull concept is a priori a hybrid that requires some rigid structures to make it realizable. This conclusion is upheld by the recent developments in soft airtight bladder pressurized volumes, namely the inflatable module technology developed by NASA's Lyndon B. Johnson Space Center in the TransHab project during 1997-2000 that has been since under development at Bigelow Aerospace. Although the use of a multi-layered inflatable shell in this approach resulted in a larger pressurized volume inside a module when expanded in space by gas inflation, the structural core bus and the inflatable shell's dependence on having to be folded around it for launch have imposed inherent limits on this approach's potential for increasing the size of such modules because of the payload fairing constraints that are imposed by the present generation of launch vehicles on the size of one payload.

The presently known state of art both for thin-walled metal pressure vessel spacecraft, such as Soyuz TMA, and for inflatable/expandable modules, such as Genesis I of Bigelow Aerospace, dictates that the airtight layer around the onboard habitable volume is provided by the spacecraft's permanent shell structure that is not replaceable during the spacecraft's lifetime in outer space, which in turn results in the fact that when the spacecraft's airtight layer fails, that causes the lifecycle of such entire spacecraft to end, meaning that such spacecraft is from then on rendered unusable for manned spaceflight for which it was purposely designed, manufactured, and delivered to space. Some are lifecycle-related causes, such as a certified number of an airtight hatch door's openings, other causes are accident-related, such as the depressurization accident in the Spektr module of space station Mir in 1997, when having experienced the hit by Progress M-34, Mir EO-23 crew, in order to survive, had to seal off the Spektr module's depressurized habitable facilities that became unusable for the rest of the station's lifetime. This Spektr accident highlighted the grave consequences of uncontrolled depressurization of man-rated spacecraft: life-threatening danger to, or death of, spacecraft crew as a result of decompression; financial loss in terms of the damaged spacecraft; terminated mission and cancelled all further expeditions involving the damaged spacecraft.

The grave consequences of uncontrolled depressurization are magnified in manned interplanetary flights. Given the distances to Mars as an example, the several-month-long transit time to Mars eliminates the chances of any outside help or quick return of the spacecraft's crew back to Earth as is possible with LEO space station operations. So the Spektr accident attests to the need to design man-rated spacecraft that allow the spacecraft crew to restore the pressurization of onboard habitable facilities after an instance of uncontrolled depressurization of the spacecraft hull without outside help and at any coordinate in their spaceflight.

The current man-rated spacecraft, such as Soyuz TMA, use rigid hulls that are thin-walled metal pressure vessels. The severe limitation of the thin-walled metal pressure vessel spacecraft type is that it cannot be larger than the maximum mass and size that its launch vehicle is capable of successfully delivering to orbit. For example, a Proton Launch Vehicle had Zvezda Service Module of the ISS housed in a payload fairing, and would not be capable of orbiting a fully assembled module with mass and dimensions that are greater by a factor than Zvezda. So the severe constraints on the mass and size of spacecraft that are imposed by the present generation of launch vehicles represent fundamental obstacles to increasing the size of metal pressure vessel spacecraft that are fully assembled on the ground and then delivered to space.

Given the severe limitations in terms of spacecraft mass and payload fairing's cylindrical volume that are imposed by launch vehicles, as well as the problems of pressurization of habitable facilities aboard spacecraft, a larger spacecraft or space station is by the present state of art expected to be built as a modular complex, such as done in the ISS. The predecessor of the ISS, Mir complex, consisted of such modules as Mir DOS-7, Kvant-1, Kvant-2, Kristall, Spektr, Priroda. The ISS itself consists of such modules as Zvezda FGB, Zarya, Unity Node 1, Harmony Node 2, Integrated Truss Structure, Destiny Lab, Columbus COF, Kibo JEM, Quest JAM, Pirs SO1.

Expansion of present-day human exploration and exploitation of outer space using manned spacecraft is dependent on building and operating larger spacecraft and space stations. There exists a contradictory problem of larger spacecraft manufacturing and delivery to outer space.

On the one hand, larger monolithic spacecraft are manufactured on the ground given the fact that the contemporary industrial facilities that are required for spacecraft manufacturing are located on the planetary surface of our planet in its biosphere. But such larger monolithic spacecraft that are completed on the ground cannot be delivered to outer space due to the payload mass limitations of existing launch vehicles and size limitations of each launch vehicle's payload fairing or bay.

On the other hand, existing launch vehicles have the obvious capabilities to deliver to outer space all the components and assemblies of a larger man-rated spacecraft that has such pressurized volume of its onboard habitable facilities that exceeds by a factor the volume of the payload fairing or bay of the existing launch vehicle type used to transport those spacecraft components and assemblies. In essence this means delivery of a man-rated spacecraft in its disassembled state to outer space, where it can be subsequently assembled by astronauts in the course of Extravehicular Activities. As of now, it does not appear feasible to the present state of art within reasonable funding and safe manned space operations to mechanically assemble a man-rated spacecraft from components and assemblies in outer space due to the problem of not obtaining safe and reliable airtight joints and subsequent pressurization of rigid spacecraft hulls assembled from parts in space. In addition to that, assembly work by astronauts during Extravehicular Activities in outer space imposes the requirement of simplicity of assembly tasks due to a slower rate of assembly tasks performed in the doubly complicated environment - work in cumbersome pressurized spacesuits and complication of human movements due to microgravity. There is also the requirement of a minimal amount of labor hours available for construction of a spacecraft in outer space due to the minimal number of astronauts aboard a spacecraft or space station.

The 104 EVAs totalling 653 hours, as of 2/23/08 on nasa.gov, used for assembly, installation, and repair works on the ISS, 75 EVAs totalling 361 hours that were conducted on station Mir according to history.nasa.gov, and Hubble Servicing Missions 1, 2, 3A, 3B, collectively attest to the feasibility of successfully using EVAs for extensive spacecraft assembly and repair work in outer space. The internal spacewalk/IVA in spacesuits inside the depressurized Mir module Spektr during Mir Expedition EO-24 on August 22, 1997, successfully proved the feasibility of working in EVA spacesuits inside a man-rated spacecraft, which is not pressurized at the time of such works.

Use of International Standard Payload Racks for scientific payloads and onboard hardware that constitutes the Internal Thermal Control System, Command and Data Handling System, Communication and Tracking System, Crew Health Care System, Lab Atmosphere Revitalization System, Robotics Work Station and so on, inside the modules of the ISS demonstrates the feasibility of successful installation of onboard hardware inside the pressurized volume of man-rated spacecraft by spacecraft crew in spaceflight. ISS's ISPRs can be delivered separately from the module they are prepared for, and at a different time. Furthermore, installation of ISPRs, which had been delivered separately into the ISS modules, has successfully demonstrated manual manipulation and installation by spacecraft crew of hollow block objects that are in size larger than a human body inside man-rated spacecraft in microgravity.

Removal and re-installation of Meteoroid and Debris Protection System panels prior to attachment of Columbus module to Node 2 Harmony of ISS during an STS-122 EVA successfully demonstrated manual installation and removal of rigid components of the hull structure of a man-rated spacecraft in outer space environment. The same was demonstrated on May 30-31, 2007, during an EVA conducted by ISS Expedition 15 Flight Engineer Oleg Kotov, who rode on the Strela cargo crane loaded with three bundles of 17 several-feet-large Service Module Debris Protection panels that he afterwards successfully installed onto the hull structure of DOS-8 Zvezda Service Module.

Threaded fasteners have been successfully used in aerospace engineering for decades to attach and hold together load-bearing sections of aerospace structures. An example of use of threaded fasteners in space-related hardware is the attachment of the launch escape tower to the payload fairing during integration of a Soyuz FG launch vehicle, which successfully withstands the relatively harsh launch environments. An example of the use of threaded fasteners that hold together aerospace structures for extended periods of operational life that includes routine structural loads is their use to join sections of the fuselage of military aircraft, such as US UH-1 helicopter that consists of the forward section and aft tailboom section held together by threaded fasteners.

The four decades of successful use of soft airtight materials for pressurization of Extravehicular Activity spacesuits, culminating in such designs as Russian Orlan-MK and American EMU, as well as the launch and successful performance of the Genesis I inflatable module by Bigelow Aerospace that uses a soft gas barrier for its internal pressurized volume, all indicate a potential for successful use of soft materials for pressurizing the habitable facilities inside man-rated spacecraft and space stations.

Advantages for Spacecraft Architectures and Operations

This invention offers a number of fundamental technological advantages over current thin-walled metal pressure vessel spacecraft and inflatable space modules, as described below in this section and in the description of components and assembly operations in the further sections.

This invention makes the gas barrier function in a man-rated rigid-hull spacecraft reside in a replaceable soft airtight bladder (i.e. soft airtight sack), while leaving the spacecraft's rigid hull structure (i.e. segmented rigid shells) non-airtight, which means the rigid spacecraft hull structure does not retain the air or any gas at all and allows any gas to escape into outer space. At the same time, the soft airtight bladder and the rigid non-airtight hull structure are both pressurized by the internal air pressure that is exerted on the soft airtight bladder in the direction of the rigid non-airtight hull structure. In other words, pressurization of the soft airtight bladder that is a gas barrier restrained by the rigid-non-airtight hull structure results in the gas pressure loading of the restraining rigid non-airtight hull structure. Thus the invented rigid hull structure lacks the gas barrier function, yet still remains structurally loaded throughout the applicable surface area by the internal gas pressure, which for the purposes of this technology primer is considered as a pressurized state, among other reasons also in order to differentiate among variously loaded structures.

This separation of the gas barrier function and rigid hull primary structure enables a spacecraft or space station to be assembled in outer space, any part of the rigid hull replaced while in outer space, and the entire hull completely overhauled while in outer space, where overhaul means any disassembly, from partial to a complete disassembly of the entire spacecraft in outer space back to the disassembled state in which such spacecraft was delivered to outer space by a number of launch vehicles.

Each and every block in any of the shells of the invented spacecraft hull structure is detachable and replaceable during spaceflight due to needed repair, overhaul, or irreparable accidental damage. In scenarios of damaging impacts and penetrations through shell blocks, blocks that have sustained major damage are completely replaced, while blocks with minor damage are unfastened from the shell, taken inside the pressurized habitable facilities of such spacecraft and repaired inside there by the spacecraft crew, and then installed back into their place in the shell.

The use of soft airtight sacks for pressurization inside such rigid hull structure allows such soft airtight sacks to be removed and replaced while such spacecraft remains operational and manned in outer space. Furthermore, punctures in soft airtight sacks, which have been removed from the hull, can be repaired with patches under a press equipment inside the pressurized habitable volume of the spacecraft after the removed soft airtight sacks have been brought inside the spacecraft's pressurized habitable volume for repair. Such spacecraft's continuous operation in outer space requires only replacement of specific components and assemblies that have lived their specific lifecycles, rather than having to deorbit the entire spacecraft.

One more advantage of replaceable soft airtight sacks in such rigid hull structure is their removal and replacement in the event of damage to the spacecraft hull as a result of collision with space debris and other spacecraft.

Because airtight sacks in this invention are replaced at the end of each airtight sack's lifecycle, this invention enables incorporation of newer and more reliable airtight sacks as replacements for older sack models of same dimensional specifications for a spacecraft build according to this invention, while such spacecraft remains operational in outer space.

Another fundamental advantage of this invention over the current spacecraft is the fact that since only replacement of specific components of the hull is required in order to prolong the lifetime of a spacecraft built according to this invention, those components, such as a folded airtight sack, represent much lighter and smaller-sized payloads than launch of new space station modules and entire metal pressure vessel spacecraft. That means those components can be delivered to such spacecraft that remain in outer space using freighter spacecraft that routinely bring supplies to LEO, for example such freighter series as Progress and ATV.

Since this invention features a rigid non-airtight spacecraft hull, then in order to build the architecture of such spacecraft according to desirable size, shapes, and decks layouts, the entire spacecraft hull is assembled in outer space from a plurality of custom-shaped 3-dimensional load-bearing components, 'shell blocks' as they are called here, that are smaller in size than separate ISS modules, and that are manufactured and tested on the ground and delivered to outer space by existing launch vehicles.

The use of such shell blocks to compose the rigid spacecraft hull in this invention makes it possible to manufacture man-rated spacecraft and space stations of various architectures that are not constrained by the size of a launch vehicle's payload fairing, and that are not constrained by the requirement that overall spacecraft hull cross-section be circular, as is currently the case with rigid ISS modules and inflatable/expandable modules, when the circular cross section is dictated not by the efficiency of the shape of a pressure vessel but rather by the dimensional limitations of the payload fairing of the launch vehicle used.

The combination of soft airtight sacks that are replaced in outer space, and of rigid blocks used to assemble spacecraft hulls in outer space, enables building large spacecraft and space stations that contain independently-pressurizable sections, and where each section consists of decks, and each deck features corridors and rooms, and also airlocks and docking rooms where required. The number of such sections a spacecraft or space station can consist of according to this invention is limited only by the human civilization's needs to have such large manned objects in space. Thus this invention allows building a custom-sized and custom-shaped man-rated spacecraft with one pressurized habitable hull that has such physical size that is significantly greater, by a factor if not by an order of magnitude, than the size of the payload fairing or bay of a launch vehicle type used to deliver the shell blocks and other components of such hull to outer space. This is a fundamental technical feature that intentionally bypasses an existing launch vehicle's payload fairing and mass limitations and that is not achievable using the existing monolithic, modular, and inflatable/expanding modular, spacecraft architectures.

Delivery of a plurality of separate shell blocks by launch vehicles is another advantage of this invention as opposed to delivery of large monolithic spacecraft structures such as modules in a modular spacecraft design, an example of which is the ISS, because each such shell block represents a simpler smaller structure for structural loads analysis in launch environments, as opposed to such large complex structures as a Space Shuttle orbiter. That spacecraft built according to this invention are delivered to space in a disassembled state, as a collection of shell blocks that are independent payloads sharing a launch to space on a common bus, eliminates the requirement for a custom launch vehicle, but rather offers a number of alternative launch vehicles to be used, from a greater number of medium lift launch vehicles to a smaller number of heavy lift launch vehicles.

This invention also eliminates the requirement that a large spacecraft habitation module is to be launched into LEO using a heavy lift launch vehicle, which in turn is a critical budgetary obstacle to building a reusable manned spacecraft for destinations beyond LEO. Whereas, the heavy lift launch vehicle still remains a fundamental requirement for both monolithic thin-walled metal pressure vessel habitation modules and large inflatable habitation modules for interplanetary spacecraft, or else reliance on the traditional modular 'space station' architecture is expected in the current practice. Additionally, this new technology permits to eliminate the time period that is required to develop a heavy lift launch vehicle from the program schedule, and therefore begin spacecraft design activities at an earlier date and proceed with commencing multiple launches on existing and reliable commercial medium lift launch vehicles at an earlier date, while using the ISS as an orbital assembly platform.

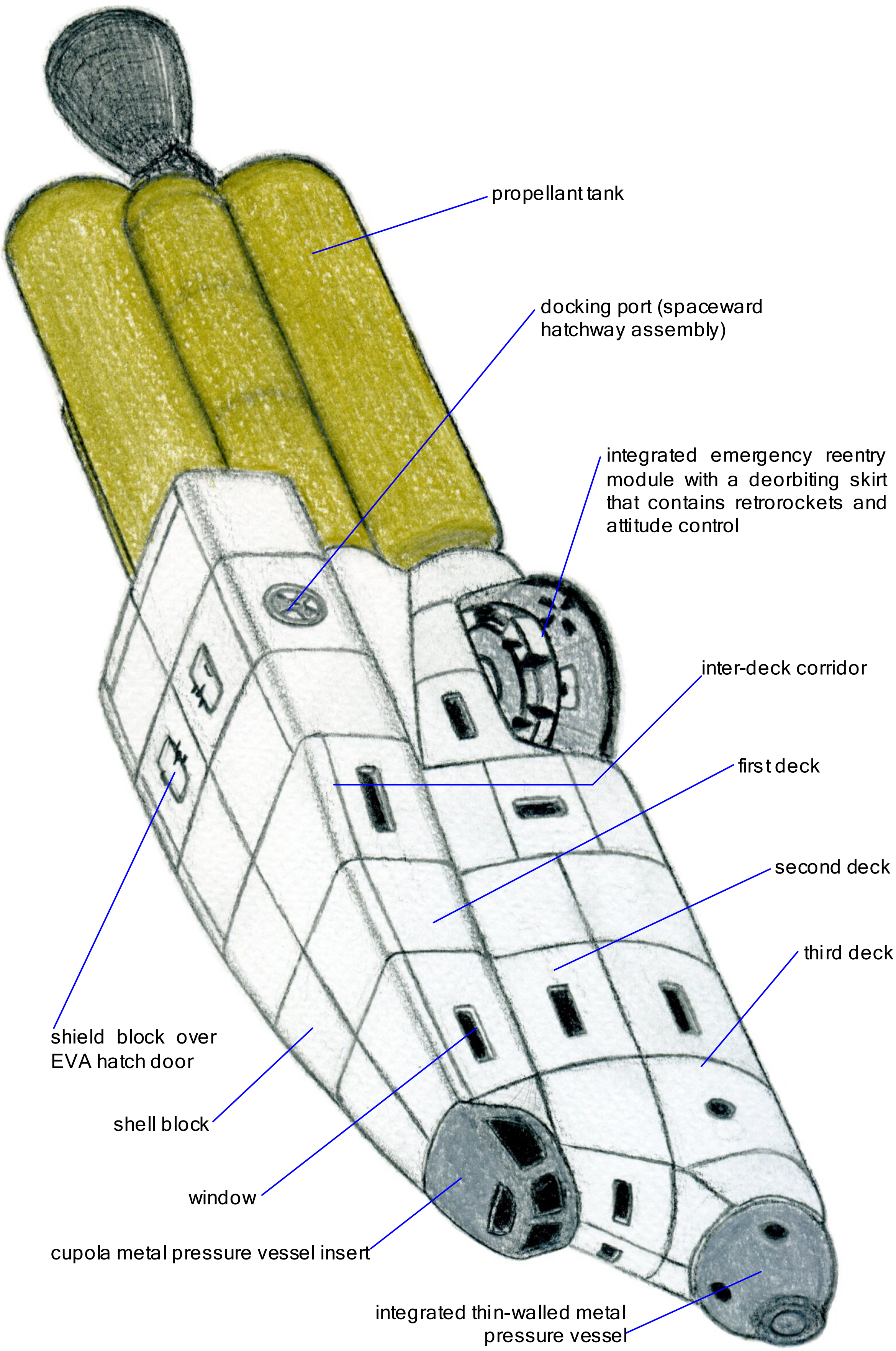
The habitable pressurized volume of the hull designed according to this technology, in contrast to the current ISS modules, is divided into a number of independently pressurizable rooms and corridors, which can be separately cut off by the crew from the air pressure system of the spacecraft in the event of their puncture/leak and depressurization, while some of the crewmembers can cut off other facilities for their immediate refuge. In combination with the replaceable airtight sacks, this results in a spacecraft hull that is repairable at any location in the Solar System, enabling a small astronaut crew to autonomously repressurize up to 100% of the habitable volume of a large interplanetary transit spacecraft at interplanetary separation from Earth. This can be considered critical for the autonomous survival of the crew and their safe return from all manned missions beyond LEO. Given the aforementioned grave consequences of uncontrolled depressurization, restoration of pressurization of man-rated spacecraft during spaceflight that this invention provides is also a method of ensuring permanent space presence. Moreover, the invented spacecraft hull structure features multilayered impact protection using several consecutive rigid structures and layers of soft materials that in conjunction with two air pressure systems give this invention a greater measure of spacecraft crew survivability and accident recovery.

One of the technical advantages brought about by this invention is that use of blocks to compose the shells of such spacecraft hull permits to replace those few blocks that are associated with specific models of onboard hardware, in other words those blocks that were designed to house or support those specific hardware models, with new blocks in their place that support installation of specific newer or alternative models of onboard hardware from other manufacturers. Thus this invention also permits, while such spacecraft remains in space, subsequent installation of new replacing onboard hardware that differs in shape, size, and onboard location, from that which was initially used in designing a specific spacecraft hull, and this is also why this invention supports production of different versions of a specific spacecraft design without significant alterations to the overall design of such spacecraft hull despite the alternative models of onboard hardware used in conjunction with a number of shell blocks designed to support them. Due to this advantage, this invention also results in more economical space presence, since only the onboard hardware in question is replaced together with shell blocks that were designed to support it on the spacecraft hull, as opposed to deorbiting the entire spacecraft.

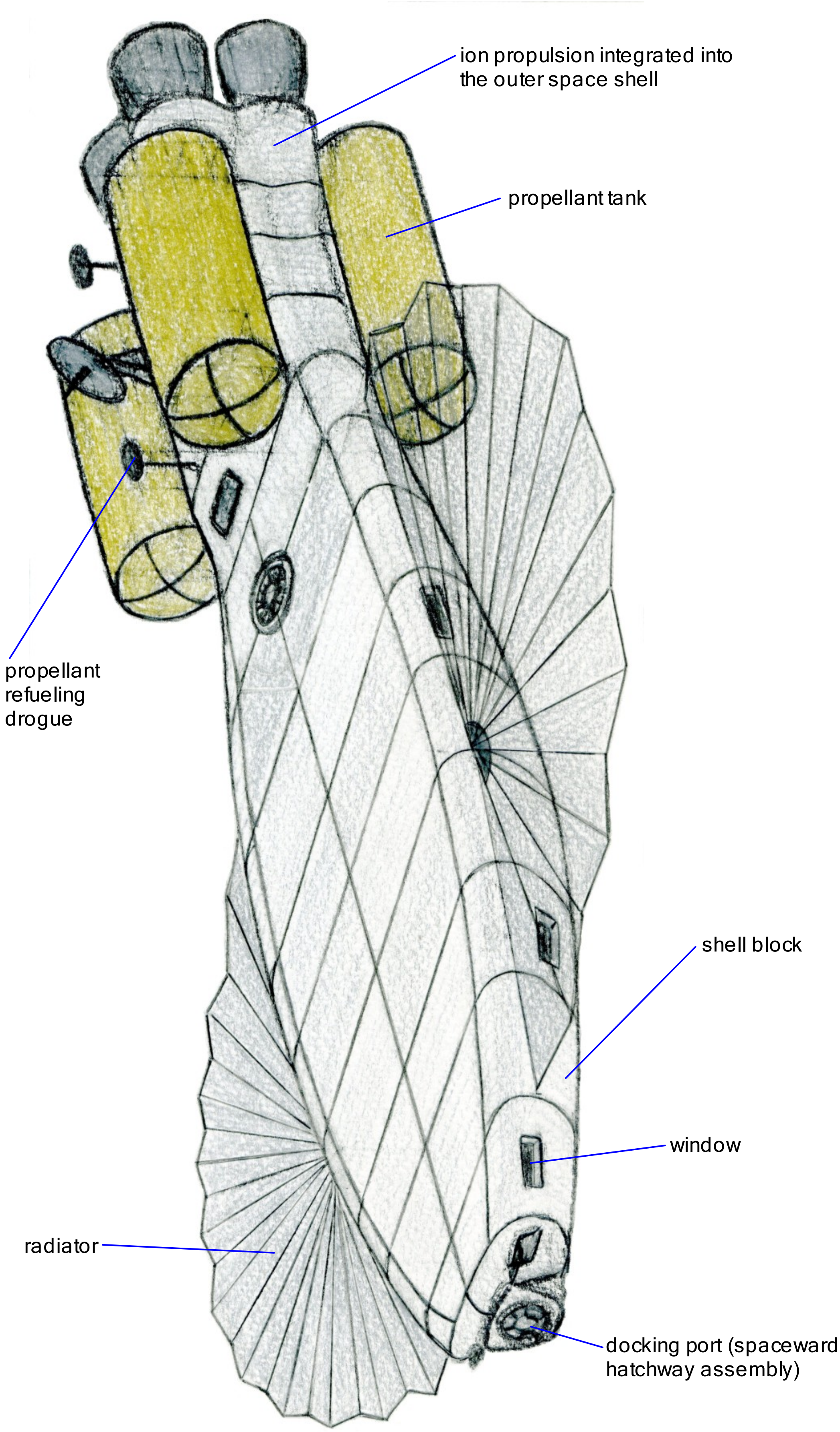
Because this invention enables its users to build spacecraft containing rooms of larger sizes than the dimensions of payload fairings or bays of contemporary launch vehicles and of manned spacecraft currently operating in LEO, such as Soyuz TMA, this invention enables its users to manufacture sections of spacecraft and space stations that contain fully-pressurized airlock docks of large-room sizes that permit arrival entry, internal storage, and departure exit, of such manned spacecraft as Soyuz TMA, thus enabling spacecraft crews to conduct in short-sleeve environment their servicing, maintenance, diagnostics, and repair of such manned spacecraft inside fully pressurized facilities within larger spacecraft and space stations that are built according to this invention. All the just mentioned advantages of such internal docking of manned spacecraft are not only vital to human spaceflight safety, but also contribute to ensuring permanent human space presence. Another use of such internal docking is in-space repair and servicing of unmanned spacecraft such as satellites, which are brought inside such room-sized airlock dock and where all the repair and servicing work is conducted by astronauts without having to wear spacesuits.

The above mentioned advantageous features of this invention clearly position the Trekker Hull Class technology as a competitor to the envisioned self-sealing airtight hulls in hull puncture scenarios, with one distinction - the Trekker Hull Class relies on a mechanical solution that incorporates (a) isolation and (b) minimization of the depressurized volume and (c) subsequent removal and (d) repair/replacement of damaged components.

Artist’s impressions 1 and 2 further below depict two concepts of manned spacecraft with Trekker class hulls.



Artist's Impression 1: Manned spacecraft concept on chemical propulsion.



Artist’s Impression 2: Deep-space manned spacecraft concept with ion propulsion.

Man-Rated Pressurized Spacecraft: the Trekker Hull Class

The preferred embodiment of this invented Trekker Hull Class technology was deliberately invented for long-duration (several months to several years) autonomous interplanetary manned missions that justify the added complexity of the hull in return for increased crew safety.

This preferred embodiment, Trekker-III (three shells), consists of three matryoshka-principle fully-encasing, rigid load-bearing shells with non-airtight rigid hollow walls that restrain the internal air pressure and serve as the primary structures of the spacecraft in flight. Each shell's non-airtight rigid hollow walls are assembled with tensioned threaded fasteners from, and thus composed of, rigid hollow 3-dimensional blocks, which are delivered to outer space as independent payloads. Inside the shells, the hull's habitable volume is pressurized with the use of two matryoshka-principle air pressure systems: a soft airtight sack that envelopes an entire section of such spacecraft hull, and inside it several soft airtight sacks of which each sack envelopes a room within the given section, with each sack also incorporating rigid airtight pressurized hatchway and window assemblies. The soft airtight sacks constitute sandwiched removable components of the rigid hull structure. The three shells are interspersed by the two air pressure systems' sacks and are held together and mutually loaded as structures by the sacks' incorporated rigid structural load bridges.

In addition to the load-bearing shells, this invention features a layer of protective skin that faces the outer space and also comfort panels inside the habitable facilities inside such hull structure.

Such spacecraft hull features one or more sections. Each section has a number of decks with rooms and corridors.

Listed from the outside inward, with some components/assemblies of the preferred embodiment that will be described further being omitted immediately below, this hull structure consists of the following layers:

1. Rigid non-airtight unpressurized protective skin 1 in FIG. 1 and 2
2. Rigid non-airtight pressurizable outer space shell 2 in FIG. 1 and 2
3. Soft airtight section sack 3 in FIG. 1 and 2
4. Rigid non-airtight pressurized deck support shell 4 in FIG. 1 and 2
5. Soft airtight room sacks 5, 27, 28, 29, 30, 31, in FIG. 1 and 2
6. Rigid non-airtight air-pressure-loaded room interior shells 6, 32, 33, 34, 35, 36, in FIG. 1 and 2
7. Rigid non-airtight unpressurized comfort panels, such as 7 in FIG. 1 and 2

Due to the large size of a spacecraft hull section in this invention, the drawn cross-section of the invented spacecraft hull structure in FIG. 1 and 2 is shown only partially. Because this invention allows for design and manufacture of a very wide range of spacecraft that will represent a wide variation of embodiments made by different spacecraft manufacturers, the parts in the said sectional views, such as spacecraft deck layouts and room architectures, that are not shown, will vary accordingly. Although most of the blocks of the three shells in FIG. 1 and 2 are relatively aligned across the shells, it is expected that in those embodiments in which the sizes of the blocks of the three shells will vary, especially due to the shapes of the hull, that shell blocks of the three shells may not be aligned in relation to the blocks of the adjacent shells. And the size of the example of a room 15 in FIG. 1 and 2 in relation to the overall thickness of the invented hull structure was intentionally chosen small for optimal scale of the drawing that would in the most feasible way show the nature of this invention.

In contrast to the just mentioned preferred embodiment for interplanetary manned missions, for such manned facilities as (a) experimental modules for Trekker Hull Class technology in LEO, (b) specialized pressurized volumes (e.g. storage of vacuum-rated supplies, artificial gravity centrifuge) of manned deep-space spacecraft, or (c) LEO space station facilities that can be evacuated on short notice using a parked or integrated lifeboat re-entry capsule, the following two embodiment categories are also possible:

Simplified Embodiment: Trekker-II (two shells):

1. Rigid unpressurized protective skin 1 in FIG. 1 and 2
2. Rigid non-airtight pressurized outer space shell 2 in FIG. 1 and 2
3. Soft airtight section sack 3 (or airtight room sacks 5, 27, 28, 29, 30, 31) in FIG. 1 and 2
4. Rigid non-airtight air-pressure-loaded room interior shells 6, 32, 33, 34, 35, 36, in FIG. 1 and 2
5. Rigid unpressurized comfort panels, such as 7 in FIG. 1 and 2

   This embodiment category (a) offers only one air pressure system, (b) leaves out from the hull design the entire deck support shell, so that the outer space shell takes on the functions of the omitted deck support shell, and (c) still offers the room interior shell as the rigid interior for mounting hardware and for rigid protection of the soft airtight sack from inside the habitable facilities. An example from the simplified embodiment category is shown in artist's impression 3.

Highly Simplified Embodiment: Trekker-I (one outer shell):

1. Rigid unpressurized protective skin 1 in FIG. 1 and 2
2. Rigid non-airtight pressurized outer space shell 2 in FIG. 1 and 2
3. Soft airtight section sack 3 (or airtight room sacks 5, 27, 28, 29, 30, 31) in FIG. 1 and 2

   This embodiment category is a further simplified embodiment: it leaves out from the hull design also the room interior shell, although as a result, very few internal attachment points are available only on structural load bridges that in turn can still be used for attachment of rigid beams or non-airtight bulkheads that form the secondary structures for attachment of soft or rigid interiors and for mounting onboard hardware. An example from the highly simplified embodiment category is shown in artist's impression 4, which depicts a one-shell module of artificial 1g gravity for daily sleep, physical exercises, and reentry conditioning. Within its habitable pressurized volume that is lined with soft padding inside, the module contains an unpressurized low-mass centrifuge construction (beam/truss structure covered with soft airtight walls and rigid-panel floors), which is assembled by astronauts after the module is pressurized. The centrifuge is mounted on a high-strength metal axle that acts as the module's central-axis internal tensile restraint beam for internal air pressure loads; at its two ends, the axle features multiple-component mounting adapters, one of them having passage holes for the crew to enter the module near the axle. The centrifuge is powered by a 24h-accessible electric motor on the axle, and contains several soft airtight depressurization-proof compartments that are fastened to the rigid lightweight centrifuge structure, each compartment accessible through an Orlan-derived airtight hatch assembly and equipped with an emergency Sokol-series spacesuit featuring umbicals that connect to a separately manufactured Orlan life support system, which in turn is enclosed inside two Orlan hatch doors joined together to form a sleek airtight pressurized suitcase in which the Sokol spacesuit is also stowed.

This invention is a compound analogue to a conventional rigid thin-walled pressure vessel with wall stiffeners, with the difference being the fact that this rigid non-airtight shell restrains the loads caused by gas pressure, while the soft airtight sack, being an airtight bladder, acts as a gas barrier that is contained and restrained by the load-bearing structures of the rigid non-airtight shell. The gas pressure loads are counteracted by the combined preload, i.e. tension, in a quantity of tightened threaded fasteners that join shell blocks by the clamp force to form one rigid non-airtight shell. An inner shell and an outer shell are jointly mechanically loaded through the structural load bridges. With respect to the shell's gas pressure vessel role, the back/lid surfaces of shell blocks act as the walls of a thin-walled pressure vessel, and the side surfaces and the blocks' structural reinforcements act as pressure vessel wall stiffeners.

With respect to such shell's role as a spacecraft's primary hull structure for the structural loads that result from the spacecraft's propulsion and attitude control subsystems, the sides of a shell block body and the structural reinforcements they feature preferably perform the structural roles of stringers and longerons, such as sides 100 in FIG. 3-7, 9-11, and 102 in FIG. 3-6, 8-11, and of frames/formers, such as sides 101 in FIG. 3-8, 10, 11, and 103 in FIG. 3-9, depending on the intended orientation of a particular block in the shell. If this terminology is not followed, spacecraft designers may alternatively call these structures of the invented Trekker Hull Class technology by a vaguer term 'bulkheads,' although this particular term is in turn reserved in this technology primer for entire walls of rigid shells within the hull volume that act as bulkheads, especially for the shell role as a pressure vessel. The shell block body's back and the shell block's lid preferably perform the structural roles of two load-bearing skins, which are spaced by the depth of such hollow block body, owing to the block body's side surfaces.

As such, this invention is clearly not an inflatable spacecraft and neither is it an expandable spacecraft structure in the sense that none of its structures are intended for expansion in space. Rather, such spacecraft is built using rigid blocks, which compose the shells, and unfolded soft airtight sacks, where pneumatic inflation is not necessary for unfolding the sacks. In contrast to space inflatables/expandables, this invention refers to a distinct type of rigid hulls for man-rated spacecraft and a distinct assembly method of such hulls in outer space environments. The airtight section sack and airtight room sacks in this invention are soft airtight multi-layered assemblies that are incorporated, by functional design and in the physical structure, within the spacecraft's fully encasing rigid hull, and as such are enveloped and pressed between the spacecraft's fully encasing rigid shell structures. All installed airtight sacks of such assembled spacecraft hull remain packed and fixed according to the shapes and sizes of the rigid shell structures of such hull in between which those airtight sacks are encased. Thus, all airtight sacks of such spacecraft hull structure remain fixed in the same shape and position irrespectively of their pressurization or depressurization.

In other words, the airtight section sack and airtight room sacks are neither expected to expand nor is there any role for their inflation in this invention, but rather all airtight sacks are installed on a replaceable removable basis in outer space environments to continuously conform to the shapes of the rigid hull structures between which they are packed, immobilized, and fully encased since installation, and to remain conforming to those rigid structures, both during pressurization and depressurization, and throughout their lifecycles. Because all airtight sacks in this invention are packed in between rigid structures, the airtight sacks are also better protected by the several layers of rigid structures from impact-caused damage, and as a result combine the advantages of not causing depressurization in the event of such rigid spacecraft hull forming a crack, as well as in the event of the said micrometeoroid impact or debris-caused damage to the rigid spacecraft hull's spaceward structures, e.g. outer space shell's block lids.

Here are some of the fundamental differences between the Trekker class hulls and inflatable/expandable modules:

1. Restraining wall structures (pressure vessel role):
    - Trekker class hulls: the restraining wall is composed of segmented rigid shell structures, such as rigid hollow 3-dimensional shell blocks
    - Inflatable modules: the restraining wall is composed of interwoven layers of soft fibers
2. Restraint mechanism (pressure vessel role):
    - Trekker class hulls: the internal air pressure loads are counteracted by the clamp force of preload tension in tightened threaded fasteners that hold together said rigid shell structures
    - Inflatable modules: the internal air pressure loads are counteracted by the tensile strength of said soft fibers under tension
3. Delivery and installation relationship (pressure vessel role):

   - Trekker class hulls: the restraining walls and the airtight bladder are launched into space as independent payloads, which makes their installation and removal from the hull possible in outer space
   - Inflatable modules: the restraining walls and the airtight bladder are launched into space already preinstalled to the rigid core elements
4. Work in outer space vacuum environment (pressure vessel role):
   - Trekker class hulls: the work of assembling the hull is performed by human and robotic movements, which permit complex tasks to be completed
   - Inflatable modules: the work of reconfiguring the module is performed by the released gas that causes the inflation, which is limited to geometry changes over a gas pressure range
5. Restraining wall structures (primary hull structure role):
   - Trekker class hulls: the rigid shells that are used as restraining walls for internal air pressure loads in the pressure vessel role also perform the primary hull structure role
   - Inflatable modules: the restraining wall and primary hull structure roles are separated. The layers of soft fibers that form the restraining wall only perform the pressure vessel role.

Moreover, this invention features rooms, such as 15-20 in FIG. 1, inside each spacecraft section, where each room is independently pressurizable and can be isolated from the air pressure systems of such spacecraft in the event of an emergency, either because it has been depressurized or because it is used as an emergency refuge for the spacecraft crew.

This invention uses existing designs of transfer hatchways for docking to other spacecraft and space stations, airlocks for Extravehicular Activities, and windows for visual observation of outer space from inside the habitable facilities inside such spacecraft hull.

The three shells are manufactured from rigid materials and are composed of hollow 3-dimensional blocks, which are finally assembled, along with the installation of all soft airtight sacks, in outer space by astronauts during Extravehicular Activities, and using mechanical EVA aids, such as robotic arms and cranes.

The three shells, in addition to performing the function of primary restraint to the internal air pressure inside the airtight sacks, and the function of keeping a specific shape of all airtight sacks from both the outer and inner surfaces of the sacks, also perform the function of thermal control.

All three shells must be manufactured to withstand during their lifetime mechanical, including structural, loads on their assembled structures, including those loads that result from independent pressurization or depressurization of the airtight section sack and of all or any airtight room sacks.

Such spacecraft hull consists of one or more sections of which each section is capable of independent pressurization and life support, and where each section of the hull is manufactured as a plurality of blocks that form a specific custom shape and size as required according to the purpose served by the specific section's interior as well as by the decks' layout. The division of a spacecraft design on sections in this invention only concerns the layout of the outer space shell and deck support shell for the purposes of encasing a airtight section sack between those two shells, and therefore this division need not be at all apparent either from the external view of such spacecraft from space or from the internal view of such spacecraft inside its pressurized habitable facilities.

All the three rigid shells, because of being connected by structural load bridges, act to a substantial extent as one restraining rigid structure in relation to the internal air pressure exerted through one or more soft airtight sacks. The structural bulkheads 8 in FIG. 1 and structural deck floors 9 in FIG. 1 of the deck support shell that through the structural load bridges of the airtight section sack join blocks of the outer space shell at its opposite ends, and room walls, floors, ceilings of shell blocks of room interior shells that are joined by structural load bridges of airtight room sacks to the said structural bulkheads of the deck support shell, altogether provide additional internal restraints that bear the tensile loads, which are caused by the internal air pressure in the airtight sacks.

In this invention, radiation shield bags, block liners, thermal insulation blankets, airtight sack layers, and space-rated transportation bags, are composed from existing thermal-control and micrometeoroid-protection materials that are used in spacecraft and spacesuits, including materials used in the conventional Multilayer Insulation MLI blankets and other types of thermal insulation and micrometeoroid protection, and other existing materials that are used for the purposes stated in this technology primer. Some examples of such materials are: Dacron, glass-fiber cloth, Kapton, Kevlar, Mylar, Nextel, Nomex, Teflon-coated Beta cloth, Twaron, Vectran. Such materials may be used on other parts of the invented spacecraft hull structure in accordance with the conventional art of spacecraft thermal control and micrometeoroid protection. Particular choice of materials and their combinations will vary with each specific spacecraft design to be manufactured according to this invention. The existing methods of attachment of those space-rated materials are also expected to be used.

FIG. 1

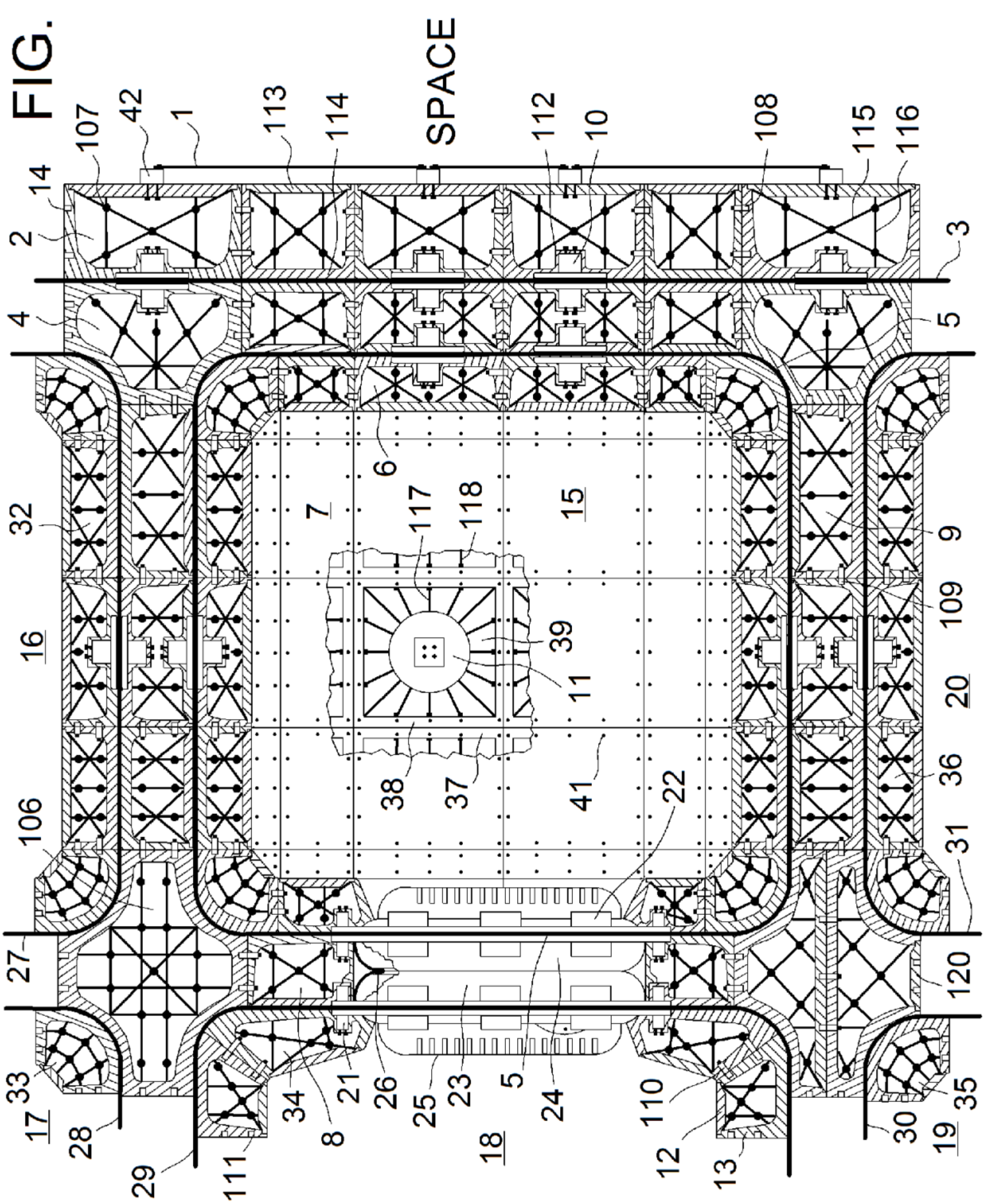


FIG. 1 Partial sectional view of the invented Trekker-III spacecraft hull structure when assembled that is sectioned at structural load bridge components.

FIG. 2

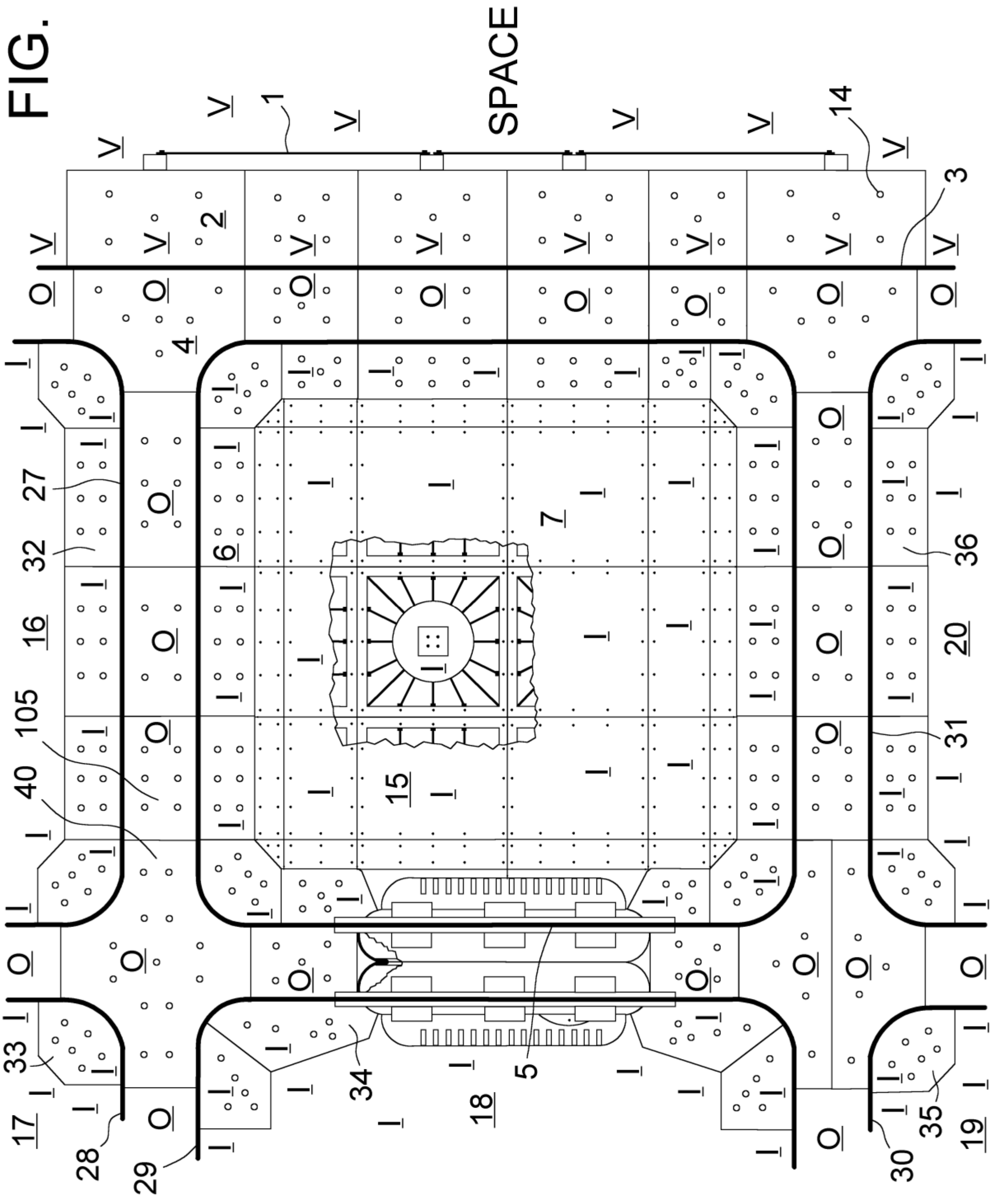
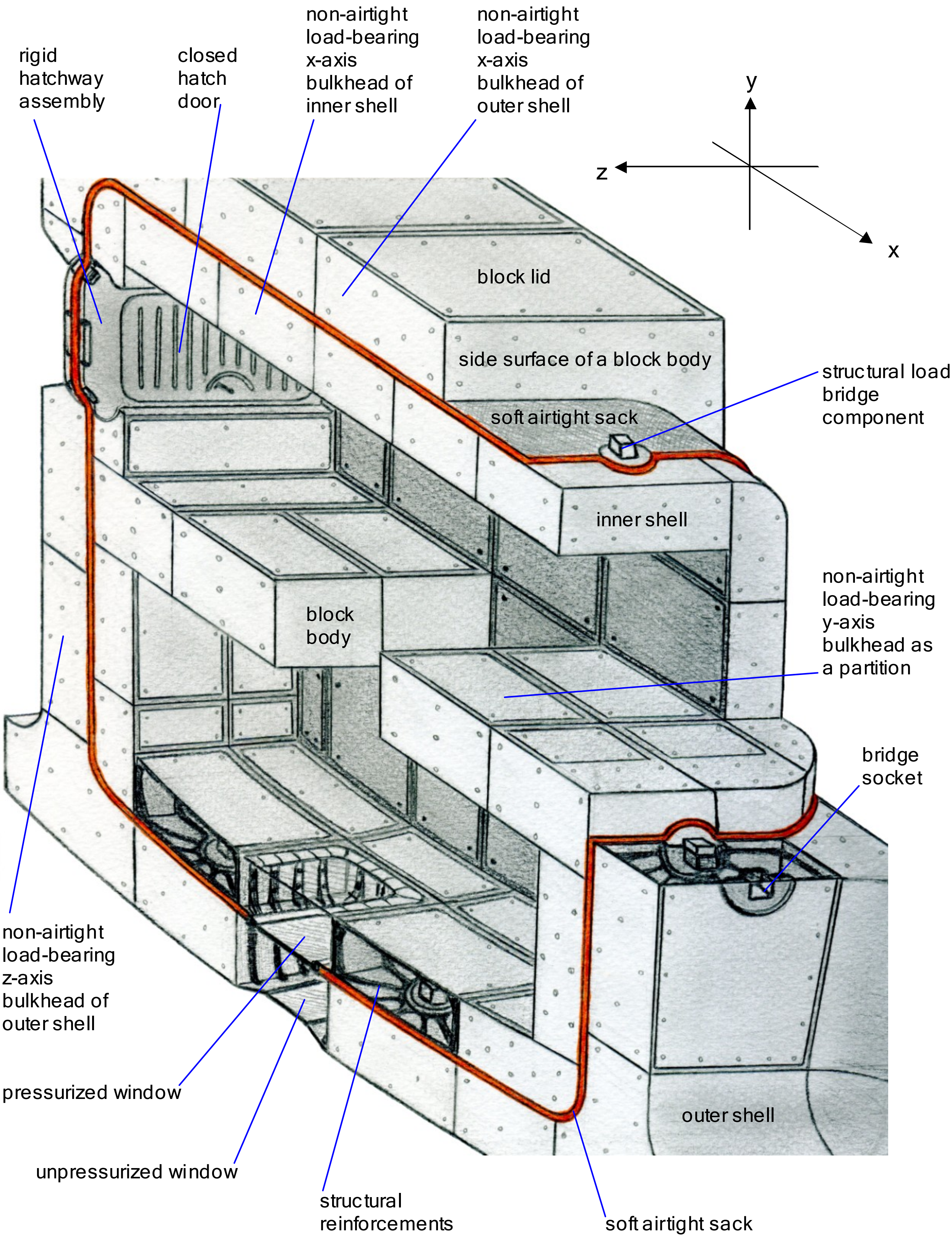
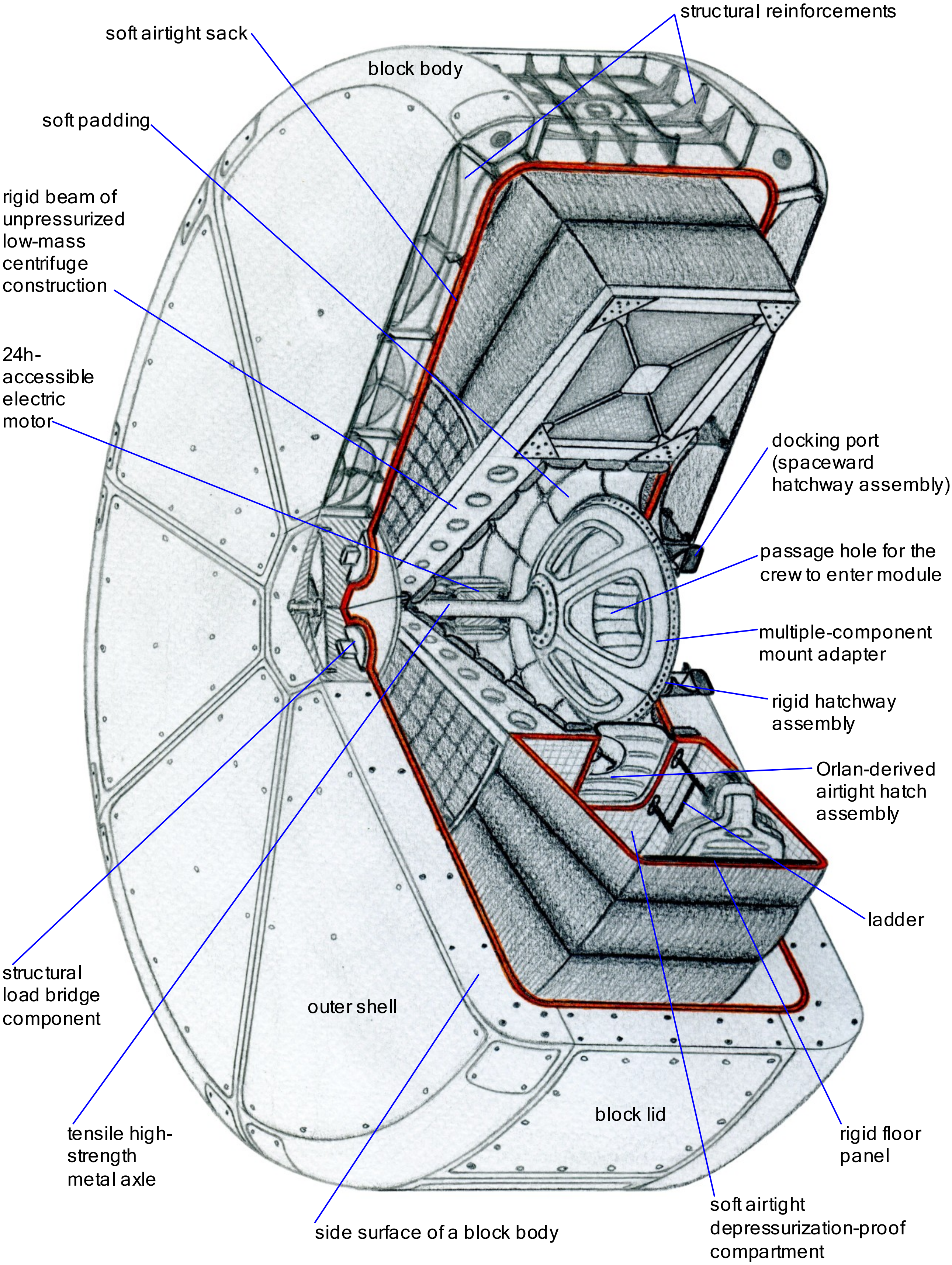


FIG. 2 Partial sectional view of the invented Trekker-III spacecraft hull structure when assembled that is sectioned at the side surfaces of shell block bodies, also showing the inner air pressure system I, outer air pressure system O, and vacuum of outer space V.



Artist's Impression 3: Partial cross sections of local hull structures that compose the two shells in the simplified embodiment/Trekker-II.



Artist's Impression 4: One-shell module of artificial 1g gravity as an example of a highly simplified embodiment/Trekker-I.

Rigid Non-Airtight Shells and Shell Blocks

Blocks that compose a shell are preferably fabricated from space-rated, either composite or metal-alloy, rigid materials with a low coefficient of thermal expansion and greatest stiffness at minimal thickness of the back, side, and lid, surfaces of a shell block. Examples of composite materials for preferred embodiments are fiber-reinforced plastics, more specifically Carbon Fiber Reinforced Plastics. Examples of metal-alloy materials for preferred embodiments are aluminium alloys used in the rigid hulls of ISS modules. Other space-rated rigid materials, such as various high-strength polymers, may be used in future embodiments of this invention.

The sizes of specific embodiments of shell blocks are determined by trade studies for each specific spacecraft design. Such trade studies must account for a number of considerations in relation to a specific spacecraft design that include, but are not limited to: overall size of the section; complexity, curvatures, and shapes of the shells; minimal achievable number of largest possible blocks that can be transported by a choice of launch vehicle in a maximally efficient packaging configuration; strength of particular shell block designs to bear the mechanical loads of such spacecraft hull when pressurized and during spaceflight, and as determined by each specific embodiment's choice of materials, fasteners, and structural reinforcement designs. A shell block may vary in size, shape, and structural design, in comparison to the shell blocks of the other shells in such spacecraft hull, and/or in comparison to other shell blocks of the same shell.

In the invented spacecraft hull class, a shell block is a hollow thin-walled 3-dimensional structure with several surfaces that conform to the shapes of the inner, outer, and cross-sectional surfaces of a shell, and that constitute the structures of such shell. One of the surfaces of the block, which also preferably constitutes either the inner or outer surface of the shell, features an opening that is framed with a load-bearing flange, or other reinforcements around its perimeter, and it must be such opening that enables access into the cavity inside the block body, and such opening is closed by a fully detachable and replaceable lid, called here 'block lid'. Examples of such flanges are 37 and 38 in FIG. 1 and 44 in FIG. 3, 4, 11. The block lid, examples of which are shown as 12 and 113 in FIG. 1 and 55 in FIG. 7-13, is preferably manufactured separately from the block body, preferably from the same materials as the block body. The block lid represents one of the surfaces of the block and follows the curvatures and shapes of the shell that the block composes. Each block body and its block lid are manufactured to the specific size, curvatures, and dimensions to fit a predetermined location in one of the three shells of a custom-shaped spacecraft hull. The block lid can be secured to the body of the block using a variety of existing fastening methods, fasteners, and devices, although the preferred method of attachment here is use of titanium screws which are put through respective holes, such as 69 in FIG. 12 and 13, which are made in the block lid, and hold the block lid attached to the body of the block when they are screwed into threaded inserts, such as 45 in FIG. 3 and 4, preferably made of titanium, that are prefabricated into the body of the block. In the preferred embodiment of this invention, the block lid's inner surface that faces the cavity inside the block body should preferably feature structural reinforcements, such as 57 in FIG. 7, 8, 10, 13, and 58 in FIG. 7, 9, 11, 13, and 61 in FIG. 8-11, 13, and 63 in FIG. 9,11, 13, preferably similar in their construction and materials to those that structurally reinforce the back, such as block backs 39 in FIG. 1 and 43 in FIG. 3, 4, 7-11, and to those that structurally reinforce the side surfaces of the block body inside the block body's cavity. The block lid is set to the block body in direction 104 in FIG. 7-11.

Although FIG. 3-13 show a block body and block lid examples with flat surfaces, block bodies and block lids for each shell are likely to feature complex 3-dimensional curvatures as required in order to conform to the design shape of the shell.

A block body embodiment that is fabricated as one piece is preferred to a block body embodiment that consists of several parts that can be disassembled and that is transported to space in such disassembled state, whether as a skeleton truss-like structure or as full-surface-area side surfaces and back, and then assembled into one block body in space, whether in outer space or inside the habitable facilities of a spacecraft. The one-piece block body embodiment is preferred, among other reasons, because it minimizes the number of parts, minimizes the duration of assembly works in space by a parent spacecraft's limited-number crew, and minimizes the number of tasks required during the assembly.

The structural reinforcements in the preferred embodiment are fabricated onto the block body/lid during the manufacture of the block body/lid. A structural reinforcement is located on each inner surface of the block body that it structurally reinforces, and jointly reinforcing two or more inner surfaces of the block body on the inside of the block's cavity. Such structural reinforcements in a block body should be preferably spaced and shaped in order not to obstruct for the assembling astronaut the screw insertion and tightening during the attachment of the block body to the adjacent blocks in outer space.

Structural reinforcements on inner back and side surfaces of such block body and the inner surface of the block lid can incorporate any of the following and their combinations: profiles fabricated as multiple layers of fiber strips, profiles fabricated as folds, and fabricated frames, of composite materials; sandwich panels with honeycomb core; open and closed isogrid; perforated panels; various metal profiles; and other existing structural reinforcements. The quantity, materials, cross-section, and positioning of structural reinforcements in shell blocks will vary for every particular embodiment of the shell block and also with every particular spacecraft design. Given the just mentioned variations in structural reinforcements, such structural reinforcements should be preferably designed uniquely for each specific block in a shell according to the load paths for that location in the shell that such block will occupy, as well as according to the load paths within each specific block. Examples of structural reinforcements are shown as 13, 114, 115, 116, 117, 118 in FIG. 1, and 48 in FIG. 3, 11, and 49 in FIG. 3, and 65 in FIG. 4 and 11, and 66 in FIG. 11, and 67 in FIG. 11.

Embodiments of block bodies in this invention may incorporate various existing mass-saving engineering solutions that are used in spacecraft engineering, in particularly for application in various embodiments of the side surfaces of block bodies. Some widely used categories of such existing conventional mass-saving engineering solutions are named as follows:

- (1) open and closed isogrid;
- (2) perforated panels;
- (3) sandwich panels with honeycomb core;
- (4) holes and openings of various shapes that are cut out in the side surfaces of block bodies;
- (5) the side surfaces of block bodies being stripped of most of the surface area to expose their structural reinforcements as a skeleton;
- (6) locally thinner cross-section of side surfaces in required areas in combination with load-path-determined optimized local topological increases in the thickness of the cross-section of the side surfaces in other required areas, either in addition to or as part of the structural reinforcements in the block bodies;

and so forth. The said mass-saving solutions can be combined with soft screens (e.g. cut out pieces of airtight sacks or other fabric combinations) manufactured to cover the holes, openings, or the skeleton of structural reinforcements, in order to prevent free uncontrolled movement of objects and fluid blobs inside a fully assembled shell across the hollow blocks that are assembled together to form the shell. Such free movement cannot be reasonably controlled or halted inside a normally-inaccessible deck support shell or outer space shell of a fully assembled section of a spacecraft that is built according to this invention, thus normally requiring an extensive disassembly of one or more shells of the spacecraft section, and also removal of one or more airtight sacks as a necessary intermediate step in such disassembly.

The blocks of each shell feature soft block liner, such as 53 in FIG. 5-11, 54 in FIG. 6 and 11, which is a multilayer liner of existing soft thermal insulation materials that are used in spacecraft thermal control applications.

One of the purposes of block liner is to thermally insulate the soft airtight sacks from the rigid shell structures. Another purpose of block liner is to provide a smooth soft liner for each airtight sack during its pressurization and throughout its operational lifetime of being pressed between two fully-encasing rigid shells. The block liners of all specific blocks, when all those blocks are attached to one another to form one assembled shell, must form a smooth flowing surface against which the airtight sack is to be packed.

Such block liner is preinstalled during the blocks’ manufacture, on those surfaces of shell blocks that constitute the outer and inner surfaces of the shells and face the soft airtight sacks. For the majority of shell blocks in a shell those surfaces are the outer surfaces of the backs of the block bodies of the outer space shell, outer surfaces of block lids and of backs of the block bodies of the deck support shell, and outer surfaces of backs of the block bodies of the room interior shell. Some blocks, especially of the deck support shell may feature block liner also on the outer surfaces of their block lids, such as 56 in FIG. 7-13. Block liner that is installed on block lids of shell blocks may feature partially cut out flaps, such as 105 in FIG. 12, in order to hide screw heads under the liner material for the purpose of avoiding physical contact between a airtight sack and the screw head of a screw that fastens a block lid to the corresponding block body.

Although the block liner is preinstalled during blocks' manufacture, it is still important that its method of attachment to the block body/lid provides for repairs in outer space and/or inside the habitable facilities of the spacecraft, especially in extended, long-duration interplanetary spaceflight.

Preferred is the use of materials, such as Nextel, that provide not only thermal insulation, but also micrometeoroid protection and act as layers providing additional mitigation of hull penetrations by space debris and of impacts during collisions with nearby spacecraft.

The block liner is also of use during in-space assembly, overhaul, or repairs, of such spacecraft hull, when each block irrespectively of its shell can be fully exposed to the effects of outer space environments.

The exact quantity, as well as the order of layers from inside out, of thermal insulation fabrics and micrometeoroid protection fabrics, will vary for every particular embodiment of the block liner and with every spacecraft manufacturer depending on the properties of particular materials selected and on the achievable optimal performance of a combination of those materials. The micrometeoroid protection fabrics that can be used for the layers of the block liner are preferably Nextel and Kevlar, which are known and used by NASA for their Stuffed Whipple Shield use.

Block liner can be attached to block bodies and lids using a variety of existing fastening methods, although preferred is the method that uses high-strength, space-rated threads, such as Vectran, 47 in FIG. 3-6, 12, 13, by which the block liner is attached to the block body/lid. A grid pattern, or any other pattern or irregular layout of holes as appropriate, for example 46 in FIG. 3-6, 12, 13, is made in the block body/lid throughout that surface of the block body/lid on which the block liner is to be attached. The block liner is then attached to the block body/lid by pulling the thread through with a needle and stitching the block liner to the block body/lid with the thread put through the said holes on the surface of the block body/lid.

Shell blocks have to be fabricated using tight-tolerance manufacturing processes: in addition to nominally preloading the assembled shell, also for the purpose that when assembled into the shell, blocks must provide smooth-flowing even surfaces with nominal separation between the two shells for the airtight sack to be encased in between. Irregular surface rise among blocks may lead to occurrences of areas of irregular and uneven, if not abrupt, restraint of the airtight sack during its pressurization, as well as greater and uncontrolled compression of the airtight sack between the two shells when the screws of a nearby structural load bridge in its socket are tightened. If necessary according to nominal design considerations, the mating side surfaces of shell blocks may feature mechanical alignment guides for more precise attachment of such blocks to respectively adjacent blocks by threaded fasteners.

Shell blocks can be attached to one another using a variety of fasteners, although use of self-locking threaded fasteners is preferred, screws in particular. A shell block, such as featured in FIG. 3-11, is attached to adjacent shell blocks at its side surfaces 100-103 in FIG. 3-11 as shown. The preferred method of attachment of shell blocks to each other in the shell is as follows and as appropriate for each embodiment. Preferably titanium-made, non-threaded inserts and threaded inserts with internal female thread are preferably permanently joined to the structural reinforcements in block bodies during the fabrication of the block bodies. By inserts in this invention are understood any inserts, either with no thread or with internal female thread, that can consist of any combination of shape or gussets, and that are imbedded in, implanted in, driven into, or otherwise permanently attached to, an embodiment of the block body in this invention preferably during, or after, the fabrication of the block body, to be positioned as for example 14 in FIG. 1, 2, and 107-111 in FIG. 1, 64 in FIG. 10, 11, inside structural reinforcements such as 68 in FIG. 11. The quantity and locations of threaded and non-threaded inserts on the side surfaces of shell block bodies will vary for every particular embodiment of the shell block and also with every particular spacecraft design, among other reasons because of the load paths at each unique location in the shell that each block to be attached using such inserts will occupy. Although floating fasteners, such as nuts and bolts, can also be used in place of the above fixed fasteners, such as female thread inserts, the latter fastener type, that is female thread inserts, is preferred because it substantially simplifies shell assembly during EVAs, and requires manipulation with a significantly smaller quantity of free-floating parts in microgravity during EVA assembly, that is only screws as opposed to bolts and an equal quantity of nuts.

The blocks in this invention are attached to each other by putting a preferably titanium threaded fastener, which features a male thread, through the hole in a non-threaded insert, such as 60 in FIG. 8 or 62 in FIG. 9, or a preferably titanium washer or gusset plate embedded in the inner surface of one block body, and screwing the threaded fastener into the threaded insert, such as 59 in FIG. 7 and 64 in FIG. 10 and 11, which is correspondingly located in a second block body and accessed through a hole in the second block body’s corresponding surface that is mated to the first block. Other means of block attachment can be used, such as locks of various designs. It is preferred that all inserts in block bodies are located on structural reinforcements, so that preferably each insert involved in attaching two adjacent blocks together is manufactured to be permanently installed in/on a structural reinforcement. The reason for such preference is because structural reinforcements span a number of surfaces of a 3-dimensional block body, and hence joining two adjacent block bodies by screws at inserts that are in the structural reinforcements ensures greater strength of the shell as a fully encasing 3-dimensional rigid construction consisting of such blocks. The number, locations, and distribution of fasteners by which shell blocks are fastened together, may vary with every particular block in every shell and in every particular spacecraft design, and will depend, among other considerations, on the strength of those fasteners, size and structural design of shell blocks, load paths, and the mechanical loads of a particular spacecraft design.

Where necessary due to higher structural loads in the shell, a block can feature gussets at which it is fastened to another block, where such gussets can be either extensions of the block's innate material structure in any direction or they can be preferably titanium gusset plates that are attached to threaded inserts in both blocks that those gussets attach to each other. Use of such gussets can be made in mating two already assembled spacecraft hull sections, where such spacecraft sections are not assembled together or where the foundational blocks of the outer space shell of an adjacent section at two sections' meeting plane are not installed during the outer space assembly of the first of those two sections of such spacecraft hull to be assembled.

The plurality of blocks of each shell can have one or combination of the following layouts of blocks on either inner or outer surface area of the shell: axial, radial, or diagonal brick wall patterns, and grid patterns, such as the pattern of the blocks of the room interior shell in FIG. 1 that are covered with comfort panels, one of those panels being 7 in FIG. 1; regular patterns of blocks of same geometric figures; load-paths-aligned layouts, such as a spiderweb pattern; and unique layouts of blocks where each block is manufactured in a unique polygon shape or other geometric figure dictated by a combination of design factors, such as the overall shape of the section, ease of assembly in outer space, and layout of rooms within the section, as well as location of any onboard systems. The just mentioned examples of block layouts in a shell, when applicable, may be considered as perpendicular, parallel, diagonal, and so forth, in relation to an axis of such spacecraft hull.

Specific embodiments of rigid shell blocks, in particular their fastening methods, block liners, block lids, sockets for structural load bridges, should preferably be designed such that, when assembled together to form one rigid non-airtight shell, slow the rate of air leak as effectively as possible in instances of depressurization of airtight sacks from lifecycle-related causes. Slowing the rate of air leak in said instance gives the spacecraft crew more time to undertake survival actions, such as closing airtight hatch doors or donning pressure suits.

The outer space shell of the invented spacecraft hull structure is one of the rigid shells that bear the mechanical loads of such spacecraft hull. Among its other purposes, the outer space shell provides radiation protection, impact protection, and thermal insulation of the airtight section sack and of the deck support shell, and acts as a fully-enveloping restraint to the airtight section sack by keeping it completely encased inside this shell and thus preventing the airtight section sack from expanding and bursting due to the internal air pressure in the outer air pressure system. The side surfaces of a block body may feature holes for placement of sensor wiring, cables, and hoses, across blocks, as required.

The upper limit on the size of one shell block of the outer space shell is the length and width of the payload fairing of the launch vehicle used. It may be better for outer space shell's blocks, especially for those that are relatively flat, to be engineered as large as possible in order to shorten the duration of shell assembly EVA works as a consequence of a smaller quantity of blocks to fasten to one another. Thus one block of the outer space shell may be as long and as wide as such module of the ISS as Zvezda FGB or Zarya.

The block lid of each block in the outer space shell preferably faces the spaceward side in the assembled outer space shell, and on the spaceward side is covered with a thermal-insulation blanket/MLI. Although it is possible to have the outer space shell blocks designed and assembled with their block lids inwards into the spacecraft hull and facing the airtight section sack, it is preferred that the block lids of outer space shell blocks face the spaceward side. One reason for such preference is that the sockets for structural load bridges in the cavities of the outer space shell's blocks are accessible from the outer space side and allow secured fastening of the bridges in the sockets with threaded fasteners, that is maximum use of two-shell attachment bridges as described further. Another reason is because of the block lids of the outer space shell being used as replaceable and sacrificial intermediate members in the invented hull's damage mitigation against space debris and accidental spacecraft collisions. The backs of the blocks in the outer space shell feature the aforementioned thermal-insulation block liners on the outside in order to insulate the airtight section sack from the outer space shell.

For the blocks of the outer space shell, the block lid, which is shown in FIG. 13, and which closes the cavity inside the block body when the block lid is fastened to the block's body, is preferably manufactured from the same materials as the block body, thus forming a removable part of the shell block. Same applies to the block lids of the other shells.

The blocks of the outer space shell carry in their cavities removable radiation shield bags, of which each bag is sized and visually numbered to fit inside a specific block body in a specific shell of a specific spacecraft design. Such bags are sewn from space-rated abrasion-resistant soft materials that provide micrometeoroid protection and thermal insulation from the outer space thermal environments to the bags' filling material that protects the spacecraft hull's interior from radiation. The currently preferred embodiment of the bags' filling materials is in the form of precut polyethylene mats or plates, shaped to correspond to the cavity inside each particular shell block, and interspersed by S-cross-sectioned folds of one uncut roll of a hypervelocity-impact-protection fabric, such as Kevlar or Nextel, so that the bags represent an additional layer of protection against impacting debris. The bags are closed permanently by sewing and feature venting holes. The bags are preferably attached to the inner surfaces of either the block body backs or the block lids of the outer space shell and of the deck support shell, by use of existing hook-and-pile fasteners that are used in spacecraft applications and widely referred to as Velcro. The shapes of the bags must accommodate the structural reinforcements inside the block cavities, so that the bags can be inserted into the cavities of the blocks to a fuller extent notwithstanding the structural reinforcements. Where a shell block features a socket for a structural load bridge inside the block body's cavity, the bag must be shaped respectively to accommodate the socket. Each such bag should preferably feature a strip of soft material sewn at its both ends onto the bag in order to enable astronauts in spacesuits to grab the bag at the sewn-on strip by a hand wearing a spacesuit glove and pull the bag off the Velcro by which it is attached to the rigid block structures. Because the shell blocks in this invention enable repeated access into their cavities during spacecraft overhauls and repairs, bags filled with older radiation shield material can be replaced during the spacecraft's operational life by new bags filled with newer and more effective radiation shield materials as such become available.

This invention permits installation of conventional spacecraft components, which are used in man-rated spacecraft, on the outer space shell in a variety of positions, ranging from recessed positions inside block body cavities to protruding positions over the protective skin. Examples of such components and assemblies are propellant and pressurant tanks, docking targets, booms, remote manipulators, trusses, thrusters, rocket engine modules, radiators, louvers, Sun/Earth/start sensors, TV cameras, antennas, gimbals, floodlights, and other components and assemblies that are currently used on the modules of the ISS and in past and present manned spacecraft.

A variety of existing designs of mountings and interfaces of spacecraft hardware can be used to attach the just mentioned components to the outer space shell in this invention. Larger assemblies of spacecraft components may be attached to the outer space shell at several points that are spread out over several block bodies on the shell, thus providing attachment for wider platforms.

Such spacecraft components can be attached to an outer space shell block body's structural reinforcements that are partly shaped as mounts with threaded or non-threaded inserts for attaching such components. The spacecraft component is then mounted on and attached either to a thermal spacer or directly onto the structural reinforcement inside the cavity of the block body. The mounting points for the spacecraft component on the block body's structural reinforcement can be located at any area of such structural reinforcement, as dictated by the component's dimensions, for example on a segment of such structural reinforcement that is joined with a side surface of the block body, or as another example on a segment of such reinforcement that is joined with the back of the block body.

Spacecraft components can also be mounted to the outer space shell on a plate, which is made of for example a sandwich panel with honeycomb core or made of other known spacecraft materials, that is fastened onto the block body with threaded fasteners in place of a block lid.

The inner surfaces of the cavity inside a block body of the outer space shell and all structural reinforcements, including those structural reinforcements that are shaped as mounts for the spacecraft component, and that is in the block bodies of those blocks to which such spacecraft components are attached in a configuration that has the cavity inside the block body at least partially exposed to the environment of outer space, are preferably covered with existing methods of thermal insulation, such as MLI or thermal blankets, and micrometeoroid protection materials.

The block lid in some cases can be designed recessed halfway inside the block body cavity in order not to expose the back of the outer space shell that protects the airtight section sack to outer space environments. In those cases where the block lid design is recessed inside the block body cavity, the block lid may also be divided into smaller parts covering smaller compartments inside the block body's cavity.

Block lids of the outer space shell and protective skin panels that are positioned over the said spacecraft components can be either or both:

(a) shaped to follow the protrusion, or recessed to feature an impression, that is necessary in order to accommodate such spacecraft component, or
(b) feature an opening for the spacecraft component, where such opening is additionally covered by existing spacecraft thermal insulation methods and existing micrometeoroid protection materials

Such block lids of the outer space shell or protective skin panels can also be shaped and fabricated as a part of the said spacecraft component.

Such components, as for example thrusters' propellant and pressurant feed lines and electric cables, can be placed either between the outer space shell and protective skin or inside block bodies of the outer space shell in conjunction with holes in the side surfaces of those block bodies.

By spaceward hatchway assembly in this invention is understood any hatchway assembly that is mated to a pressurized hatchway assembly of an airtight section sack from the spaceward side. A spaceward hatchway assembly can be embodied in a variety of designs and two types: EVA and transfer for pressurized docking of two spacecraft.

This invention uses existing docking systems as transfer hatchways for airtight docking of two man-rated spacecraft, that is such docking systems as APAS, APDS, SSVP, iLIDS.

The preferred embodiment in the invented hull structure of androgynous-docking-system transfer hatchways and EVA hatchways, both mated to a airtight section sack's pressurized hatchway assembly that is in turn mated to a airtight room sack's pressurized hatchway assembly, is that such transfer hatchway or EVA hatchway has only one airtight hatch door, which is the airtight hatch door of the pressurized hatchway assembly of the airtight room sack of the docking room or EVA airlock. Transfer hatchways of probe-and-drogue docking systems should preferably feature fully detachable and unpressurized structures in lieu of presently used forward-mounted airtight hatch doors that are constituent assemblies of such docking systems, in conjunction with the just mentioned preferred embodiment for androgynous docking systems.

In order to protect the pressurized habitable volume of docking rooms and airlocks from the effects of space environments, such as radiation, when the spaceward hatchway assembly is not in use, the spaceward hatchway assembly is preferably covered with a correspondingly shaped shield block assembly, which is attached to adjacent blocks in the outer space shell or protective skin via an opening/closing mechanism. The preferred embodiment of the blocks used in the shield block assembly is that such blocks have the materials and fabrication methods of the blocks of the outer space shell. Using an opening/closing mechanism for use in outer space environment of a design driven by electric and/or manual power, the shield block assembly opens outward into space away from the spacecraft hull. Such shield block assembly of a spaceward hatchway preferably has conical side surfaces, so that the perimeter of its outer surface, which faces outer space when the shield block assembly is closed, is greater than the perimeter of its inner surface that faces the spacecraft interior when the shield block assembly is closed. Such shield block assembly can consist of one or more blocks attached together, depending on the shield block assembly's required size and the size of each block in the shield block assembly. The use of a shield block assembly that consists of both the outer space shell blocks and the protective skin panels is preferred, because this option offers better impact protection as well as permits use of radiation shield bags inside the cavities of the outer space shell blocks of the shield block assembly. During outer space assembly of the invented spacecraft hull structure, the shield block assembly will have to protect the interior of the outer space shell and of the deck support shell until the airtight room sack of each airlock or docking room is installed that features an airtight hatch door. Similar shield block assemblies, either internal or external, can also be designed for the windows that are described further. A shield block assembly to be used for various docking systems that protrude from the surface of the outer space shell, such as SSVP-M, is preferably designed in a corresponding shape to fully accommodate inside itself such protruding docking system.

The outer space shell can also physically cover with unpressurized shell blocks such spacecraft's propulsion subsystem and various pressurized tanks when intended in a particular spacecraft design. Additional existing thermal insulation methods may be used in the areas of propulsion units in order to prevent heat transfer from those areas of the spacecraft to the hull shells. In those locations of such spacecraft hull, the shell blocks may also be manufactured from materials that are different from the materials used in the shell blocks throughout the outer space shell elsewhere in the hull, and the blocks in those locations may be attached to one another through insulating thermal spacers that are shaped and sized to correspond to the side surfaces of the blocks. In those coverage areas, depending on a specific propulsion design, use of thermal blankets or even ceramic tiles on the backs or block lids of shell blocks may be required.

Where necessary according to spacecraft design considerations, the cavities of specific blocks of the outer space shell can be designed to be unpressurized storage racks or contain onboard hardware that is necessary for the operation of the spacecraft.

The outer space shell, in various particular spacecraft designs as embodiments of this invention, may also locally incorporate collections of shell blocks that are assembled for use in those spacecraft-related activities in the spirit of this invention that are conducted in outer space environments, such as unpressurized cabins for grapple by remote manipulators that offer micrometeoroid and radiation protection for conducting EVA assembly and repair works that involve shell blocks.

The blocks of the deck support shell are preferably similar in their structural design and material composition to the blocks of the outer space shell. The functions of the deck support shell are, among others: to carry and transfer the mechanical loads of the spacecraft hull, to structurally reinforce the outer space shell from inside, to provide a load-bearing rigid enveloping construction for the load-bearing room interior shells assembled within it, to act as a fully encasing restraint to airtight room sacks, and to encase the airtight section sack on its inner surface. The deck support shell also serves as an additional layer of kinetic protection against impact penetration by space debris, where this function is namely resident in the block lids and backs of this shell's block bodies being reinforced by the side surfaces of the block bodies, and in the layers of block liner on those block lids and backs of this shell's block bodies. The side surfaces of a block body of the deck support shell may feature vent holes for pressurization of the outer air pressure system, and holes for the placement of state-of-health monitoring sensor wiring and other cabling, as required. Some blocks of the deck support shell, for example those blocks that are located adjacent to the pressurized hatchway assemblies that transverse the deck support shell, may feature their block lids and their block bodies' backs located in the side surfaces of those block bodies when considered in relation to the shell's surfaces. Same applies to use of deck support shell's blocks in structural bulkheads and structural floors of decks, so that for example surface 40 in FIG. 2 is in fact the back of the block, and surface 106 in FIG. 1 is that block's lid, whereas the adjacent block is positioned as a majority of deck support shell's blocks with its surface 105 in FIG. 2 being a side surface of its block body. Another example is block lid 120 in FIG. 1. Same can also apply to the blocks of the outer space shell and room interior shells in unique spacecraft designs' shell block positioning options.

Deck support shell blocks contain the same radiation shield bags that are sized, fabricated, transported, and secured in exactly the same manner as for the blocks of the outer space shell.

Shell blocks of the deck support shell's structural bulkheads and structural deck floors may feature a second removable/detachable block lid instead of the block body's back in those instances where one shell block has to accommodate two sockets of structural load bridges of adjacent rooms, whether on the same deck or on adjacent decks.

The outer space shell and deck support shell when assembled to be held together through the structural load bridges of a airtight section sack, and when the room interior shells are not yet assembled, must be capable of withstanding mechanical loads that result from the airtight section sack being pressurized to at least the air pressure value of spacesuits or pressure suits used in intravehicular assembly of room interior shells.

The blocks of the room interior shell encase the airtight room sack of each room in a packed position from inside, within the airtight room sack, thus packing the airtight room sack against the deck support shell, and represent an internallyenveloping load-bearing rigid construction, which supports all installations inside the room, the room's walls, ceiling, floor, the airtight room sack's pressurized hatchway assemblies and pressurized and unpressurized window assemblies. The blocks of the room interior shell are used as hardware racks and supplies-storage racks. Thus the room interior shell carries in the cavities of its block bodies and attached, preferably by threaded fasteners, to those block bodies' structural reinforcements and internal surfaces, such items as gas pressure vessels and onboard electronic, life-support, and other electric and mechanical hardware required for the operation of the spacecraft, as well as mission-determined payloads and supplies. Onboard hardware to be mounted to the room interior shell structures inside the rooms of such spacecraft hull also includes electronic components in metal radiation-shielding boxes and control moment gyroscopes CMG, reaction wheels, momentum wheels, and similar devices, where such mounting allows continuous monitoring, servicing, diagnostics, repair, and replacement of such hardware by spacecraft crew in short-sleeve environment. Room interior shell block bodies that contain heat-generating hardware should preferably be covered inside their cavities with passive thermal control materials, should use thermal spacers for attachment of such hardware to the block body, or should use active thermal control.

Whereas the cross-sectional width of the blocks of the outer space shell and deck support shell is determined by the mechanical loads those blocks are expected to carry on their sides that act similarly to stringers and longerons, and frames/formers, the cross-sectional width of the blocks of the room interior shell is in addition to that also dependent on the useful volume of cavities that is required for a specific room. For spacecraft, among those according to this invention, that are expected to be used beyond LEO, as well as depending on the effectiveness of the materials used in such spacecraft's radiation shield bags, the cavities of room interior shells, especially of crew sleeping rooms and/or airtight sleeping berths as described further, can also carry radiation shield bags, such as described to be used in the outer space shell, in order to provide increased radiation shielding for those habitable facilities inside such spacecraft hull structure.

The onboard hardware that is installed in the cavities of block bodies of the room interior shell should preferably either allow unimpeded access inside the block body cavity to the fasteners by which such block is attached to adjacent blocks in the room interior shell, and/or permit quick and easy detachment and removal of such hardware from the block body in order to allow access to the said fasteners.

The side surfaces of block bodies in the room interior shell may feature larger holes and openings of various figures for the placement of cabling, hoses, pipes, and assemblies of onboard systems that are housed jointly in the cavities of two or more adjacent blocks of the room interior shell.

The backs of some blocks of the room interior shell feature sockets for attachment of the structural load bridges of the airtight room sack. Block bodies of the room interior shell feature inside their cavities threaded inserts for fastening the onboard hardware.

The lids of the blocks in the room interior shell are referred to here as ‘comfort panels’. Comfort panels’ main functions are to cover and shield the hardware and supplies that the blocks of the room interior shell carry in their cavities, and to provide a comfortable surface for physical contact by spacecraft crew and where necessary also sound insulation.

The comfort panels, such as 7 in FIG. 1 and 2, are manufactured using known designs and devices used to manufacture cabin interior panels and upholstery in manned spacecraft, passenger aircraft, and in other means of transport. These comfort panels are attached, either by screws, such as 41 in FIG. 1, or hinges, to the room interior shell’s block bodies in order to cover the cavities in the blocks. The comfort panels can be manufactured in sizes that cover more than one block but have such sufficiently small sizes that permit them to pass through the hatchways of airtight room sacks.

The comfort panels represent the walls, ceilings, and floors of rooms, corridors, docking rooms and airlocks, as well as some comfort panels function as doors of hardware racks and storage racks that are located inside the cavities of the room interior shell’s blocks. Where the onboard hardware requires so, the comfort panels feature, either directly attached to the panel or through an opening or glass, controls and monitoring interfaces, such as keyboards and computer displays, switchboards and dials. Where the hull features windows, the comfort panels may also feature unpressurized windows, e.g. from polycarbonate, in order to protect the pressurized window assemblies of airtight room sacks and provide an additional barrier against ultraviolet radiation for the habitable facilities inside the rooms of such spacecraft hull.

The comfort panels are preferably fabricated using fiber-reinforced plastics, such as Carbon Fiber Reinforced Plastics, or lightweight metal alloy sheets. The panels can also be manufactured from other space-rated lightweight rigid materials, such as other fiber laminates, or polymers, as well as a variety of existing padding and cover materials can be used.

Comfort panels which may also feature structural reinforcements, which are a major feature of the preferred embodiment of all shell blocks as described in this technology primer, on those panel surfaces that face the cavities inside the block bodies of the room interior shell.

The surface of a comfort panel that faces the room interior preferably features padding, which is preferably vacuum-rated and covered with leather-like soft non-flammable materials to provide a measure of cushioning comfort during accidental contact for crew floating in microgravity. Where padding with cover can be omitted, comfort panels preferably feature smooth polished surface that faces the room interior and that is finished with thermal control paints or coatings.

Either depressions in the comfort panels or the cavities of the room interior shell blocks feature recessed lamps to provide artificial lighting inside the rooms and corridors.

Where necessary, the comfort panels can be manufactured as molded according to the shapes of the items of hardware, such as crew seats, that protrude from the cavities of the block bodies of the room interior shell into the room interior.

FIG. 3

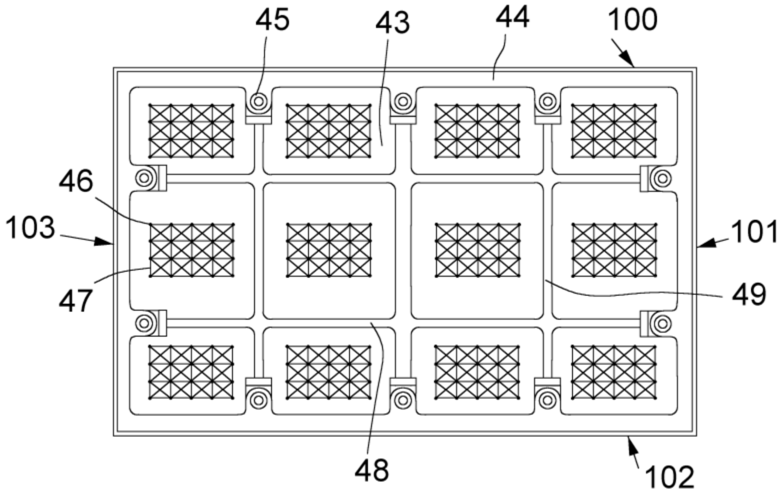


FIG. 3 Front view of a shell block body that does not feature a socket, and where the block lid is detached and not shown.

FIG. 4

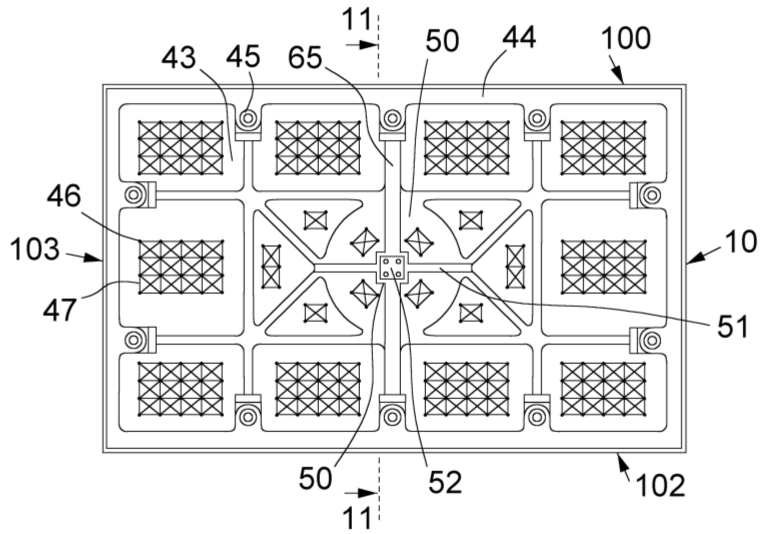


FIG. 4 Front view of a version of a shell block body that features a socket, and where the block lid is detached and not shown.

FIG. 5

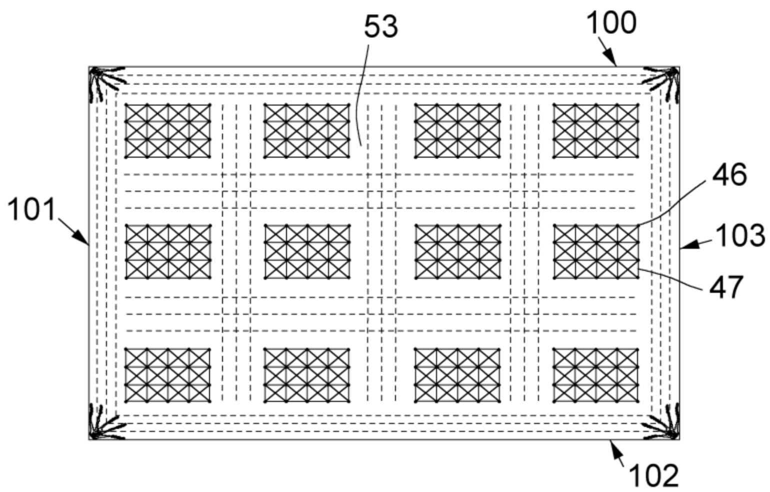


FIG. 5 Back view of a shell block body that does not feature a socket.

FIG. 6

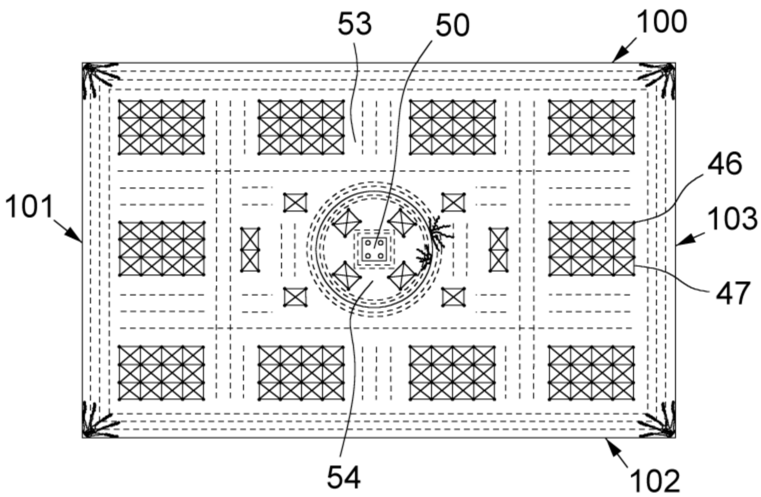


FIG. 6 Back view of a version of a shell block body that features a socket.

FIG. 7

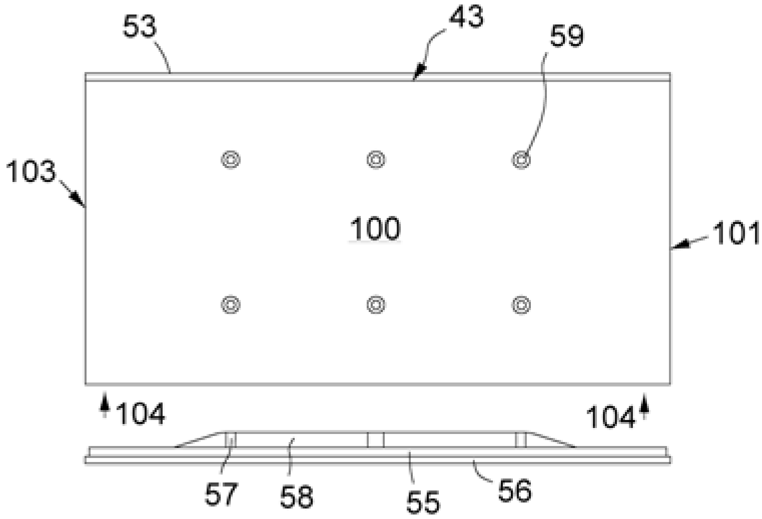


FIG. 7 Top view of a shell block body with a detached block lid.

FIG. 8

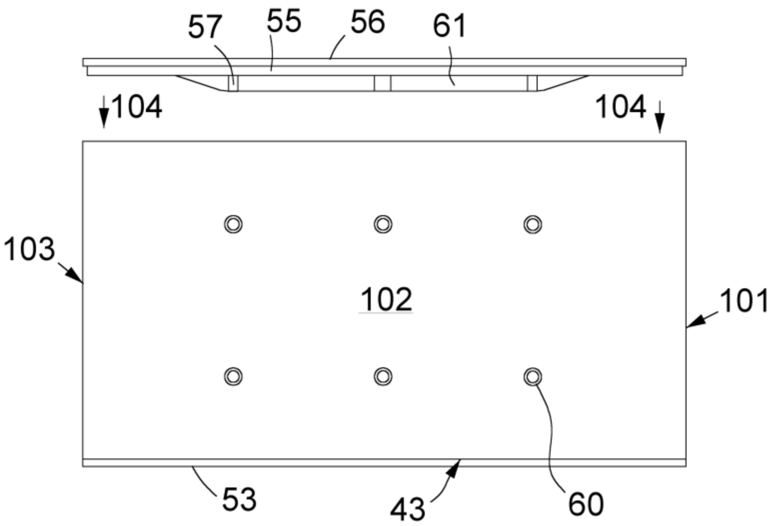


FIG. 8 Bottom view of a shell block body with a detached block lid.

FIG. 9

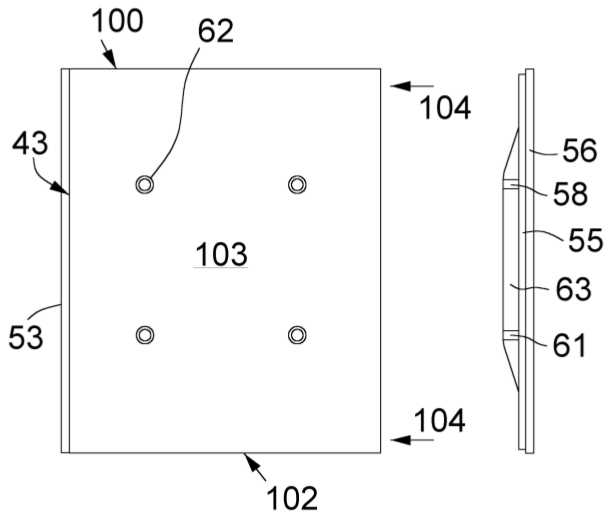


FIG. 9 Left view of a shell block body with a detached block lid.

FIG. 10

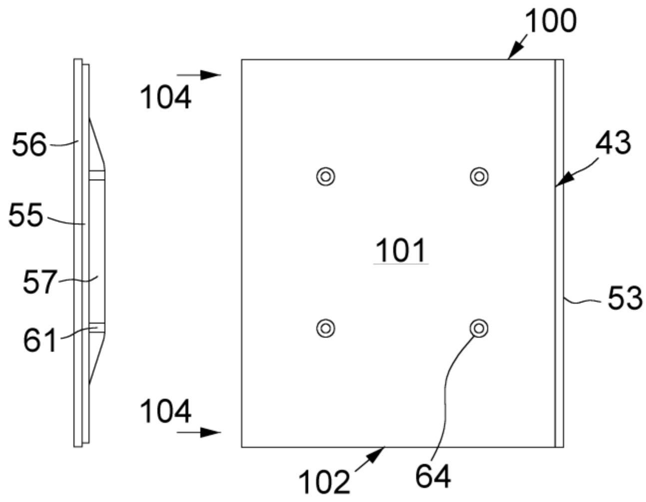


FIG. 10 Right view of a shell block body with a detached block lid.

FIG. 11

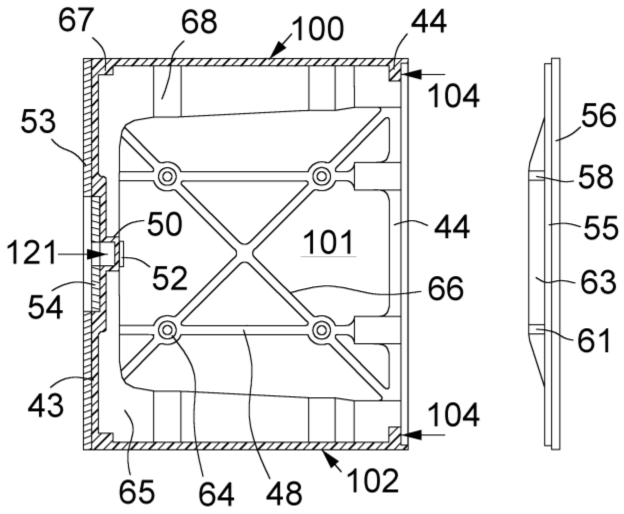


FIG. 11 Sectional view of a shell block body that features a socket, also showing here the detached block lid.

FIG. 12

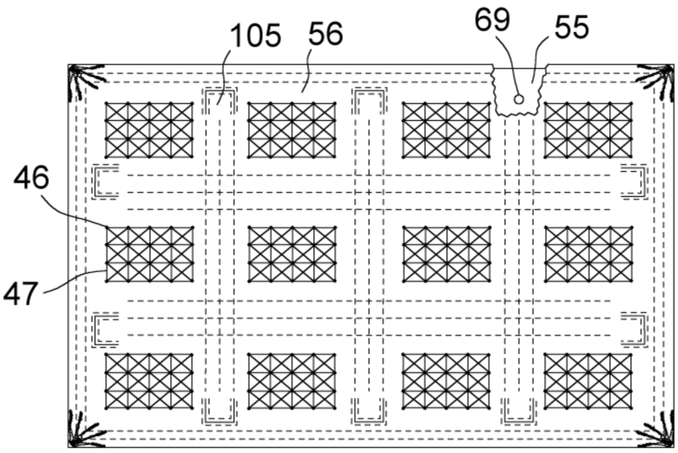


FIG. 12 Front view of a detached block lid.

FIG. 13

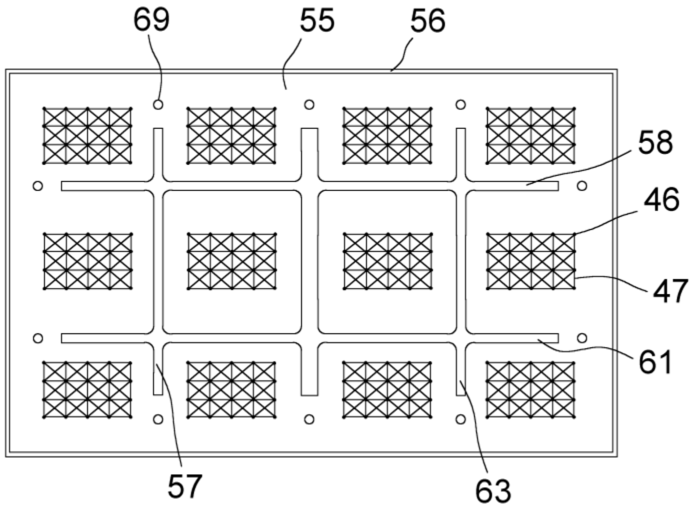


FIG. 13 Back view of a detached block lid.

Soft Airtight Sacks

This invention features airtight sacks that are manufactured from soft materials. Each soft airtight sack is a constituent of the invented rigid hull structure of a spacecraft build in accordance with this invention. Every soft airtight sack that is featured in this invention is mechanically replaceable in the rigid hull structure after the expiration of its lifecycle or due to accidental damage.

It is worth noting that although the section sack is referred to below as ‘pressurizable’ and room sacks are referred to as ‘pressurized,’ both terms have identical meaning and can be used interchangeably. These two terms are used below to emphasize the state of each sack under nominal conditions.

The airtight section sack and airtight room sacks are all soft multiple-layered sacks that contain internal layers of soft sheet materials, which provide: a pressurizable airtight bladder that acts as a gas barrier, tensile strength of a fabric/webbing for the interaction of the gas-pressurized soft airtight bladder with a rigid shell’s restraining surface, thermal insulation, micrometeoroid protection, and abrasion resistance. The multiple-layer composition of all soft sacks’ layers needs to be such that when a sack is sandwiched between two shells, the materials of the multiple layers protect the airtight bladder layer in the sack from both sides and serve as additional liners to it. The exact choice of specific soft materials and the choice of a specific number of layers will vary for every particular embodiment of this invention and for every specific spacecraft design, to be selected and decided by the given spacecraft manufacturer. The layers of soft materials that comprise an airtight sack are joined together using existing methods, such as adhesives, seams of threads, and fabric laminating.

A number of existing space-rated soft materials as presently used in space applications that include spacesuits, thermal insulation blankets, micrometeoroid protection blankets, and those materials that are currently limited to inflatable module applications, may be used in the fabrication of airtight sacks. Examples of such soft sheet materials include Combitherm, Kevlar, Nextel, Vectran, Twaron, Teflon-coated Beta cloth, rubberized kapron, neoprene/urethane-coated nylon, and other materials that satisfy material properties requirements. The external layer of every sack should feature informative text, symbols, numbers, and various other visual markings, especially around structural load bridges, rigid window assemblies, and rigid hatchway assemblies, for orientation during assembly EVA that involves work with the sack, and for onboard storage of spare sacks that are kept for replacement.

Every sack is fabricated to fit a specific section or room in a specific spacecraft design. That is each airtight sack is prefabricated to fit the exact shape and dimensions of those shell surfaces between which it will be packed during its installation in the spacecraft hull, where the shape of the sack is dictated by each particular spacecraft design and can be any complex 3-dimentional figure, including substantially rectangular with curved or two-obtuse-angled corners, that permits fabrication of a reliable airtight sack. The airtight section sack is evenly and tightly packed between the outer space shell and deck support shell. An airtight room sack is evenly and tightly packed between the deck support shell and room interior shell.

The airtight section sack envelopes an entire section of such spacecraft hull, whose overall pressurized volume consists of a number of sections. Each section features inside it a number of airtight room sacks, where each airtight room sack envelopes only one room of a deck inside the section, as shown in artist's impression 5. A section of the invented spacecraft hull has to contain at least one or more decks and at least one or more rooms per deck.

Both the airtight section sacks and all airtight room sacks must be designed to withstand exposure to outer space environments, during assembly works in outer space on spacecraft, hull overhaul or repairs, and when passed through outer space into the hull of a spacecraft being built in space, or in the event of deep and extensive damage to the spacecraft's hull that would result in a degree of exposure to outer space environments.

The airtight section sack is installed during the spacecraft assembly in outer space to be tightly packed between the outer space shell and deck support shell. Airtight room sacks are installed during the spacecraft assembly in outer space to be tightly packed between the deck support shell and room interior shells. All airtight sacks, i.e. the airtight section sack and airtight room sacks, are attached to at least one or preferably both shells between which each sack is encased.

A soft airtight sack is attached to a rigid shell using rigid structural load bridge components that are preinstalled in the sack in order to secure the airtight sack in a mechanically removable and replaceable, wear-reducing stationary state in relation to the two shells that encase the airtight sack from within and from outside during its lifecycle. In other words, the rigid shell blocks facing the inner and outer surfaces of each soft airtight sack form the rigid and smoothly flowing, fully encasing shells of the hull as rigid restraints to each airtight sack. The soft airtight sack is thus packed between two rigid shells and is attached by the airtight sack's structural load bridges at multiple points to at least one and preferably both of those two shells in order to prevent any uncontrolled movement of such soft sack in relation to either of the two rigid shells as a result of pressurization and depressurization of the air pressure system the sack belongs to throughout the installed sack's lifecycle.

The preferred embodiment of this invention is a spacecraft hull that features two air pressure systems, one inside the other, where the gas barrier of each system is one or more soft airtight sacks. The gas barrier of the outer air pressure system, such as the areas marked as O in FIG. 2, is one airtight section sack, whereas the gas barrier of the inner air pressure system is a number of airtight room sacks that are airtightly mated. Outside the airtight section sack is the vacuum environment of outer space, which is marked as V in FIG. 2.

All airtight room sacks in a section are mated and interconnected by pressurized hatchway assemblies to form the inner air pressure system, such as the areas marked as I in FIG. 2, that is independent of the airtight section sack and that can reliably remain pressurized even if the airtight section sack is depressurized to the outer space pressure. Thus the inner air pressure system consists of a number of independent airtight room sacks, where each airtight room sack, by enveloping the corresponding room, and by being airtightly connected to other airtight room sacks through pressurized hatchways can be, by locking an airtight hatch door leading to it, isolated from the inner air pressure system, that is from the rest of airtight room sacks in the section.

The inner air pressure system is pressurized to a habitable air pressure value that is used inside existing human-rated pressurized spacecraft. The airtight section sack is preferably kept depressurized to the outer space pressure but still remains a closed pressure system in order to provide an escape vessel for the air if it escapes from the inner air pressure system, that is from the inhabitable facilities of the spacecraft, such as in the event of a lifecycle-related failure of a airtight room sack, as opposed to accidental damage caused from outer space. The purpose of this two-system pressurization is multi-fold:

1. The airtight section sack represents a backup system against failure of the inner air pressure system due to lifecycle-related causes. It is preferred to keep the airtight section sack as a passive backup pressure system, because it is encased around an entire section of the spacecraft hull, whereas airtight room sacks are easier to replace than the section sack, and therefore the room sacks can be replaced more frequently than the section sack.
2. In the event of accidental depressurization of the outer air pressure system, that is of the airtight section sack, either due to accidental damage from outer space or due to lifecycle-related causes, to ensure safe pressurization of all inhabited facilities inside such spacecraft by the inner air pressure system, i.e. by the airtight room sacks.
3. In the event of accidental depressurization of a airtight room sack due to its lifecycle-related causes, the two-system pressurization ensures that such accidental depressurization of a single room does not result in accidental depressurization of the entire spacecraft, and provides sufficient time for the crew to detect, locate, and isolate the leak by locking the airtight hatch door leading to the room, whose airtight room sack has been depressurized.
4. In the event of accidental depressurization of both the airtight section sack and a airtight room sack, such as in the case of a deep penetration of the spacecraft hull by space debris, the spacecraft crew isolate themselves in those airtight room sacks within which they are present at that instant, done emergency pressure suits, seal off the damaged airtight room sack by locking the airtight hatch door leading to the room with the damaged airtight room sack, and re-pressurize the inner air pressure system, that is the rest of the intact airtight room sacks. Then the spacecraft crew must conduct work to replace the damaged airtight room sack(s), and shell blocks if any were damaged, and airtightly mate the new airtight room sack’s pressurized hatchway assembly, after which work the room is restored to the inner air pressure system. A subsequent replacement of the damaged airtight section sack can be conducted at a later time in controlled conditions.

5. The two-system pressurization permits continuous monitoring of the pressure in the inner air pressure system, and enables users of this invention to detect the depressurization of the inner air pressure system due to lifecycle-related causes, without endangering the spacecraft crew. Such depressurization is detected by a drop in the pressure of the inner air pressure system and/or rise in the pressure of the outer air pressure system.
6. The two-system pressurization enables users of this invention to regularly test the health of the airtight room sack of each room in each section by controlled raising and lowering the internal air pressure in one or more rooms of the inner air pressure system without endangering the spacecraft crew.
7. The two-system pressurization also enables users of this invention to regularly test the health of the airtight section sack by controlled raising and lowering the internal air pressure in the outer air pressure system, and thus allows detection of depressurization of the outer air pressure system due to either lifecycle-related causes or accidental damage from outer space, without endangering the spacecraft crew.

Although use of even only one airtight sack is sufficient to pressurize the habitable facilities inside the invented spacecraft hull structure, as opposed to having the outer and inner air pressure systems that consist of the airtight section sack and the airtight room sacks respectively, use of the airtight section sack and the airtight room sacks within it are the preferred embodiment, because it offers increased spacecraft crew safety for long-term space presence, especially in spaceflight beyond LEO. For the scenarios of air leaks from the inner air pressure system, also is preferred use of this embodiment with existing pressurization hardware for man-rated spacecraft that in conjunction with the backup outer air pressure system permits by compensating for a detected air pressure decrease during the leak to equally increase the air pressure and in this manner to retain the nominal pressure value during an air leak from the inner air pressure system to the outer air pressure system, and that is when no leak is detected from the outer air pressure system to outer space.

Although the preferred embodiment is that one airtight room sack envelopes one room in the inner air pressure system, still the layout of so enveloped room can be divided into smaller cubicles separated by bulkheads or floors that are structures assembled from either or both the blocks of the room interior shell and comfort panels, if the design of onboard inhabitable facilities and the purpose served by the room so requires. In those cases, the bulkheads/floors that are assembled inside a room interior shell, such as in artist’s impression 3, and are attached to it may be designed as also bearing the structural loads of the invented spacecraft hull structure, in addition to the three load-bearing rigid shells. In contrast, the use of additional airtight room sacks within a room’s airtight room sack may be necessary for such purposes as an airtight sleeping berth for a spacecraft crew member that contains independent life support systems and an auxiliary spacesuit for evacuation in the event of depressurization of the inner air pressure system.

An airtight room sack is replaced by removing comfort panels and disassembling the interior shell, then moving and storing the comfort panels, onboard hardware, and blocks of the room's interior shell in other rooms of the section. If the airtight section sack exhibits reliable pressurization performance, and the outer space shell together with the deck support shell as well as other intact room interior shells altogether reliably perform as structural restraints at the spacecraft's nominal internal air pressure or the crew spacesuits' air pressure value, then the airtight section sack can be pressurized to the spacecraft's nominal internal air pressure value or the crew spacesuits' air pressure value during the removal of the old airtight room sack and installation of the new airtight room sack, thus permitting the spacecraft crew to conduct such work without having their pressure suits pressurized all the time.

The preferred embodiment is such spacecraft hull featuring at least two sections and more, each section with its independently pressurizable airtight section sack. Each such section has its airtight section sack sealed off, from an adjacent section's airtight sack, around the perimeter of pressurized hatchway assemblies of this section's airtight room sacks of corridors that lead to that adjacent section. In a spacecraft hull that has two or more sections, such independent pressurization of each section's airtight section sack thus forms a number of independent soft pressure vessels, which represent nominally independent outer air pressure systems of such spacecraft hull, as well as forming one inner air pressure system that transcends all sections to comprise all habitable facilities aboard such spacecraft hull.

In order to provide self-sufficiency of such spacecraft during the replacement of each section's airtight section sack, at least two sections, and preferably three or more, should compose one such spacecraft hull, each section with its independent airtight section sack. Spacecraft built according to this invention that feature one section, and in some cases also spacecraft with two sections, may require external storage of shell blocks for the duration of airtight section sack replacement works. By external storage of shell blocks is understood removal of shell blocks outside the hull, for those blocks to be secured in bags, nets, netting, or bundles to the panels of protective skin that remain on the assembled intact outer space shell of the section, or to a docked additional spacecraft bus or space station. For spacecraft with two and more sections, having an additional adjacent section, which is independently pressurizable and offers useful volume for storage, may reduce the need to put removed shell blocks in external storage, and retain at least one section of such spacecraft in operational and habitable state during such hull overhaul that is required in order to replace a airtight section sack. The airtight section sack is replaced by removing comfort panels in the section, disconnecting onboard hardware that is spread over more than one block in room interior shells, disassembling room interior shells, removing airtight room sacks, disassembling the deck support shell of that section and removing protective skin panels and outer space shell block lids in order to gain access to the bridge sockets in block cavities of the outer space shell, all of which are moved to and stored, during the airtight section sack's replacement works, in the rooms of an adjacent section of the same spacecraft, where the adjacent section remains at least partly pressurized and habitable. Temporary depressurization of some rooms and corridors of the adjacent section may be necessary during relocation to it of shell blocks and onboard hardware from the section being disassembled.

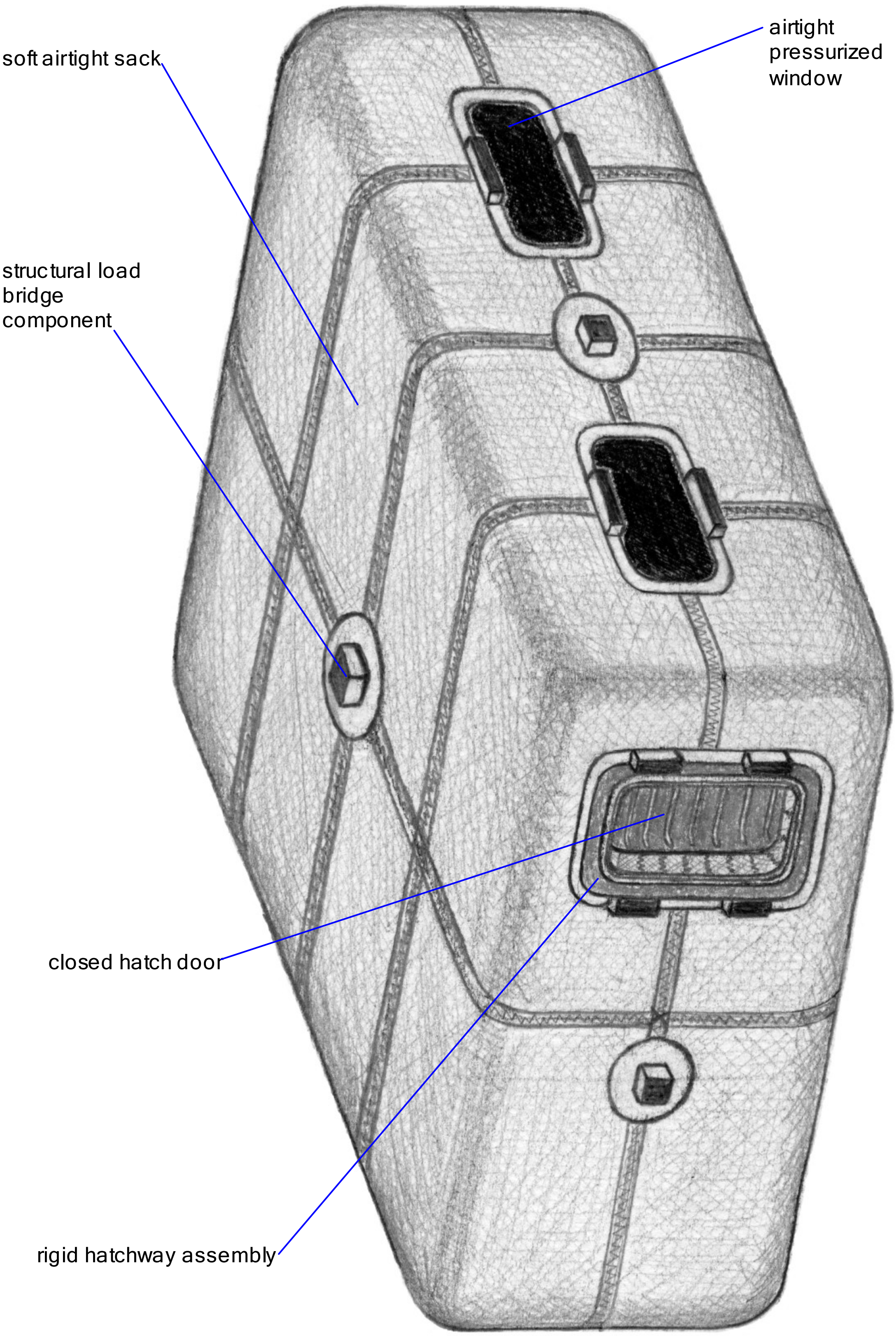
The said self-sufficiency of such spacecraft in replacing its airtight sacks, together with the onboard storage of airtight sack replacements, increases crew safety in long-duration interplanetary missions.

Unlike spacesuits, and yet like inflatable modules and thin-walled metal pressure vessels, a airtight sack in this invention must be capable of pressurized state for extended periods of time and is itself enveloped and sandwiched between two rigid shells of the spacecraft hull, with the rigid shells performing as primary structural restraints of internal air pressure for each sack. All airtight sacks must be fabricated to withstand prolonged pressurization to the atmospheric pressure at sea level, which is the nominal operating pressure of airtight room sacks as well as the operating pressure of the airtight section sack in the event of the inner air pressure system's depressurization. All airtight sacks, when packed between shells, must exhibit sufficient strength to withstand pressure rises and drops that are characteristic of a list of scenarios, including among others:

1. Airtight sack health tests conducted by varying the internal air pressure in either pressure system or in any specific room of the inner air pressure system
2. The sack's pressurization to a nominal air pressure value following the airtight sack's installation between the shells
3. Accidental or controlled depressurization of the inner air pressure system to a vacuum pressure value when the outer air pressure system is pressurized to an air pressure value
4. Accidental or controlled pressurization of the outer air pressure system to an air pressure value as a result of a leak from, or venting of, the inner air pressure system
5. Routine use of airtight room sacks installed in airlocks and docking rooms

Both the airtight section sack and airtight room sacks should feature the following airtight pressurized assemblies:

1. Structural load bridges, such as 10 in FIG. 1
2. Hatchway assemblies, such as 23 and 24 in FIG. 1
3. Window assemblies, such as existing spacecraft window designs



Artist's Impression 5: Airtight room sack with a room interior shell assembled inside.

Airtight Structural Load Bridge Components

Structural load bridge components, or simply 'structural load bridges,' that are featured in this invention are rigid components that transfer structural loads between shells while providing a gas boundary with rigid solid faceplates and such airtight seals as o-rings, and are thermal insulators for the soft airtight sack into which they are airtightly installed during the fabrication of the sack. Such bridges represent a combination of high tensile and compressive strengths that enable them to bear the static and dynamic loads of the spacecraft hull. In addition to providing load paths, mechanical/structural loads transfer between shells, soft gas barrier integrity, and thermal insulation, these bridges also immobilize the airtight sack that features them in relation to the two shells that encase the sack.

Structural load bridges are shaped to be mated to respective sockets, such as 11 and 112 in FIG. 1 and 50 in FIG. 4, 6, 11, preferably in the backs and lids of blocks of the three shells. A socket may feature structural reinforcements, such as 51 in FIG. 4, which are similar to those used in the cavity of a shell block body.

The preferred embodiment of structural load bridges is to have a cross-section featuring flat side surfaces with corners, such as is the shape of towers 70 in FIG. 14, 16, and 71 in FIG. 15, 16, that culminates in a flat face, which is mated to the bottom of the corresponding socket in a specific shell block. The preferred shapes of such bridges should incorporate prisms, such as a triangular, square, pentagonal, or hexagonal prism. A prism-incorporating embodiment of a bridge is preferred in order to prevent rotation of the bridge inside the corresponding socket during the tightening of a threaded fastener into the bridge from the corresponding socket inside the cavity of a block in the shell. A structural load bridge is preferably attached to a shell block using two or more threaded fasteners, rather than one.

A structural load bridge in this invention may take a number of various embodiments within the spirit of this invention, although the following embodiment is preferred. This embodiment consists of two bases, 72 in FIG. 14 and 16 and 73 in FIG. 15 and 16, that are circular faceplates with each of them featuring a flat mating face, and that are preferably manufactured from lightweight and preferably high-strength metal, such as a titanium alloy or aluminium alloy. The two bases are airtightly joined by tensioned threaded fasteners, such as 83 in FIG. 16, through one or more holes in the airtight layer of the given airtight sack. The tensioned threaded fasteners, which join the two bases, provide the clamp force to counteract the air-pressure-caused tensile structural loads between the two shells. When fastened together, the two bases are partly in direct surface contact at their flat mating surfaces and partly through the sack's pressurizable airtight layer, 74 in FIG. 16.

Onto each base a part called 'tower' is attached, such as 70 in FIG. 14, 16, and 71 in FIG. 15, 16, by tensioned threaded fasteners, such as 81 and 82 in FIG. 16, that provide the clamp force to counteract the air-pressure-caused tensile structural loads between the two shells. For the threaded fasteners that attach a tower to a base, preferred is use of threaded and non-threaded inserts, such as 80 in FIG. 16, for the towers. Those threaded fasteners, which have their heads recessed in holes inside a tower when tightened, are preferably covered by threaded thermal-insulation plugs, such as 79 in FIG. 14 and 84 in FIG. 15 and 16, that are made of the same material as the tower, feature a screw drive type, and are screwed into female-threaded holes in the tower to conceal the said threaded fasteners. Such thermal-insulation plugs are for example used in Soyuz TMA spacecraft, namely in the heat shield of its reentry capsule. Each tower is fabricated to fit into a socket in one of the two shells, which encase the given airtight sack that features this bridge installed into it. Towers are the preferred parts of structural load bridges for the aforementioned incorporation of prisms. The height of a tower is influenced by the length of the tower's female threads. The size of each bridge tower and its overall physical shape are determined by the strength and related properties of the material from which the tower is to be manufactured, and by the load paths and mechanical loads that a particular bridge tower is to withstand at its unique location in a specific spacecraft design. Each tower preferably features a flat outer face that meets the bottom of the corresponding socket in a shell block. On its outermost flat face, a tower features threaded inserts, 77 in FIG. 14, 16, and 78 in FIG. 15, 16, for the screws with which the tower, and hence the whole bridge, will be attached to a corresponding socket in a shell block. Thus each bridge is inserted at its two towers to two sockets located in two different shells. Towers, such as 70 in FIG. 14, 16, and 71 in FIG. 15, 16, and soft bridge washers, such as 88 in FIG. 14, 16, and 89 in FIG. 15, provide thermal insulation to the base onto which they are installed, thus insulating it from the shell block that features the corresponding socket. The towers are fabricated from thermally insulating and high-strength structural materials, such as partially stabilized zirconia or fiberglass-reinforced plastics, and possibly covered with additional thermally insulating coatings, in order for the towers and bases to be capable of serving as load paths of such spacecraft hull between each two shells without resulting in thermal bridges that would affect the performance of the airtight seals pressed in between the two bases.

Bases of the said structural load bridge can be made lighter in terms of mass using the existing conventional mass-saving engineering solutions, such as machined holes in machined bases, and molded cavities in molded bases. Similar mass-saving engineering solutions can also be applied to bridge towers.

Prior to fastening the second base to the first base, a preferably metal fixation washer, such as 76 in FIG. 16, featuring a row of holes for screws, 95 in FIG. 16, is installed on the mating face of the first base around the area where the holes are located for the screws by which the second base will be attached to the first base. The purpose of the fixation washer is to securely attach the airtight layer of the given sack to the first base.

Between the mating faces of the two bases, gaskets such as 93 in FIG. 16, and airtight seals, such as o-rings 94 in FIG. 16, are installed in the respective grooves in each of the two bases. Those groves are located between the fixation washer and the outer edge of the base.

Although a variety of clamping solutions can be used employing threaded fasteners to securely clamp the soft sack's non-airtight layers to the rigid base, currently suggested by the inventor is the following method to immobilize those non-airtight layers of the sack in relation to the bridge base and in the preferred embodiment to compensate the fabric strength of the sack layers, especially of the tensile-strength sack layer, for the cut out hole that those sack layers feature in the middle of the bridge base. This is the same method as for the attachment of the soft block liner with thread to the back of a shell block body in this invention. This attachment method was tested on a flattened aluminium sieve inside a rig shown in photographs 1, 2, and 3. The preferred embodiment of a bridge base is such bridge base design that features a plurality of holes that are located in such preferred layout: along the circumferences of a number of circles whose center point is at the center of the base, and diameters/chords separated by equal angles that pass through the center point of the base and cross said number of circles. The holes are used in stitching with a space-rated thread all the sack layers on the base's side of the sack, except for the airtight sack layer, together and to the rigid base. The thread is preferably made of a high-strength material, such as Vectran or Kevlar. The stitches are made along the said circumferences of the circles, along the diameters/chords that cross the center point of the base and the circles, and in diagonal to form crosses among adjacent holes. Fabric areas of the layers of the sack layers to be stitched to the rigid base are treated with non-fray coating or laminating.

Thread, such as 91 in FIG. 14, 16, and 92 in FIG. 15 and 16, must be stitched through holes, such as 85 in FIG. 16, in each base, so as to provide a tight grip to all the layers of the sack, 75 in FIG. 14, 16 and 99 in FIG. 15, 16, other than the sack's airtight layer, throughout the hole-dotted surface area of the base that covers those sack layers when the bridge is fully assembled.

Prior to stitching the sack layers to the base, those sack layers are, during the airtight sack's fabrication, stitched together in a plurality of stitches in order to reinforce the airtight sack throughout the area to be stitched to the base. Those stitched together sack layers can also be reinforced by stitching over them additional layers or other soft high-strength materials.

Although in FIG. 14 and 15, the bridge base features a circular outermost edge, the shape of the outermost edge of the base may vary, and will among other factors depend on the producibility of the socket, and on materials and fabrication methods used in each specific embodiment of a shell block body, as well as on the producibility of each specific embodiment of the base itself. Hence the outer edge of such base may be circular, square, hexagonal, octagonal, and so on.

For the thermal-insulation washer on the base around the tower, preferred is use of soft materials, such as fabrics and non-woven mats, including those fabrics that compose the block liner used on shell blocks in this invention and thermal-insulation blankets used elsewhere in space applications. Such soft thermal-insulation washer consists of two parts:

(1) the outer part, such as 88 in FIG. 14, 16 and 89 in FIG. 15, that offers entire area coverage for the bridge base starting from the bridge tower and to the outer edges of the bridge base, and
(2) the inner part, such as 90 in FIG. 16, that offers protection to the edge of the base where the base meets the airtight sack.

Both the outer part and inner part are cut out as rings of the said soft materials, where the outer part is significantly wider ring, whose inner diameter is significantly lesser than of the inner part, which features greater inner diameter. Both soft washer parts feature same outer diameter. Both soft washer parts, at their outer circumference are stitched together directly to each other at least in two rows of stitches 97 in FIG. 15 and 16, that extend beyond the diameter of the base. The inner soft washer part is stitched to the rigid base through holes, 86 in FIG. 14 and 87 in FIG. 15, in the rigid base, using thread 98 in FIG. 16, near the outer edge of the base in order to tightly secure both soft washer parts to the rigid base. The edges of both soft washer parts are covered with a strip, such as strip 95 in FIG. 14, 16, and strip 96 in FIG. 15, 16, of same soft material or an alternative soft material selected for this purpose. The strip is then bent to cover the stitched-together edges of both washer parts from both the upper and lower sides, and the strip is secured over both soft washer parts by stitches to the both soft washer parts in order to seal them off thermally. The outer part of such soft washer features around its inner diameter a number of stitches, such as 119 in FIG. 16, which are covered by the tower, thus immobilizing with the tower the outer part of the soft washer in relation to the base, and additionally adhesives or Velcro may be used for this purpose.

In order to facilitate packing and prevent packing-caused hazards arising from the rigid bridge towers to the soft materials of an airtight sack, the towers of its bridges may feature rounded edges on the towers' outermost flat faces. For the same purpose, use of soft caps featuring cushioning pads that are made of known space-rated soft materials to cover bridge towers is preferred during the packing of airtight sacks.

Structural load bridges are airtightly installed into an airtight sack during its fabrication to correspond in each bridge's location to the correspondingly located sockets in the blocks of both shells that encase the airtight sack on either side. So installed in the sack, such bridge is inserted into a corresponding shell block's socket and is attached to the block structure of the socket preferably by use of screws. The screws are put through holes in the socket that preferably features embedded or attached washers or gussets, such as 52 in FIG. 4 and 11, and the screws are driven into the threaded inserts that feature internal female thread in the corresponding bridge tower. Although use of such threaded fasteners as screws is preferred to attach a bridge to its socket, a variety of other fasteners and locking mechanisms can be used for this purpose.

The number, locations, and distribution of structural load bridges over the hull shells must be such as to ensure that mechanical loads in such spacecraft hull are carried by all three shells irrespectively of whether the airtight room sacks and airtight section sacks are pressurized or depressurized, so that the entire three-shell hull acts as one structure that bears mechanical loads.

The airtight section sack preferably features as many two-shell attachment bridges as are required according to the structural design of a specific spacecraft section, that is of a specific embodiment of such spacecraft hull section.

A airtight room sack features as many two-shell attachment bridges as can be practically installed into the deck support shell inside a specific room cavity of the deck support shell in such manner as to enable either the astronaut in a spacesuit/pressure suit, or a remote manipulator responsible for such installation, to exit the room cavity of the assembled deck support shell after the secure installation of all two-shell attachment bridges of that room into the deck support shell, and before mating a pressurized hatchway assembly of so installed airtight sack to the corresponding pressurized hatchway assembly of an adjacent room. The preferred embodiment is such that the two-shell attachment bridges of airtight room sacks are sufficiently robust to carry all the required structural loads at a minimal number of such bridges, and provide more stability and structural load paths for the room interior shell in more directions in order to minimize the number of such bridges per each specific room interior shell. Depending on the particular design and materials of such bridge embodiments in airtight room sacks, as well as depending on the design of the blocks of the deck support shell, it may be preferable to first attach a two-shell attachment bridge to the socket-featuring block lid of the corresponding block of the deck support shell prior to installation of that block lid into the corresponding block body in the deck support shell, and only after that install that block lid into the deck support shell.

Firstly the bridges of an airtight sack are installed in the outer shell that encases the sack from outside, and any pressurized hatchway assemblies and window assemblies that the airtight sack features are installed and mated to the outer shell.

Secondly the inner shell, which encases the sack from within it, is assembled to completely cover the sack from within, and those blocks of the inner shell that feature the sockets for bridges are attached to their specific bridges concurrently or prior those socket-equipped blocks' attachment to adjacent blocks in the inner shell. A bridge is inserted into a socket in direction 121 in FIG. 11.

There are two embodiments of structural load bridges that can be preinstalled into each airtight sack, as applicable:

1. Two-shell attachment bridge – a bridge, which is attached preferably by screws to the sockets of both shells that encase the airtight sack. This attachment of the bridge to both shells permits to transfer structural loads between the two shells on either side of the sack, and provides a load path and secure structural attachment of the two shells through the bridge.
2. One-shell attachment bridge – a bridge, which is only attached, preferably by screws, to only one shell of the two shells that encase the airtight sack of such bridge. An example of a one-shell attachment bridge in the context of the assembled hull structure is 21 in FIG. 1, which is a bridge incorporated into a pressurized hatchway assembly of a airtight room sack. Such bridge

embodiment provides a permanent structural stop to the inner shell against the outer shell, so that the inner shell does not move toward the outer shell and exert uncontrollable pressure on the airtight sack encased between them. Given that such one-shell attachment bridge embodiments are present on all surfaces of a 3-dimensional construction, such as a room interior shell, but same can also apply to the deck support shell, such bridges provide multidirectional outward static structural preloads from all surfaces of the room interior shell against the sockets in the outer encasing shell, and hence fix such room interior shell being a 3-dimensional construction in a stationary position in relation to the cavity of the outer body within which it is assembled, such as for room interior shells in relation to the deck support shell, and for the deck support shell in relation to the outer space shell. One of other purposes of one-shell attachment bridge embodiment is to ensure even spread, distribution, and secured positioning of the soft airtight sack material across the respective surfaces of the two shells. One-shell attachment bridges are similar to two-shell attachment bridges except for the fact that one-shell attachment bridges need not feature threaded inserts on the tower that is not fastened to the corresponding shell.

Bridge embodiments may feature a narrowing cross-section with the bottom of tower at the base being widest and the tower’s flat face that faces the bottom of the socket in the corresponding shell block being narrowest. Bridge embodiments may also feature existing types of alignment guides in order to mechanically aid in their installation into the corresponding sockets and in order to keep such bridge embodiments nominally positioned after the installation.

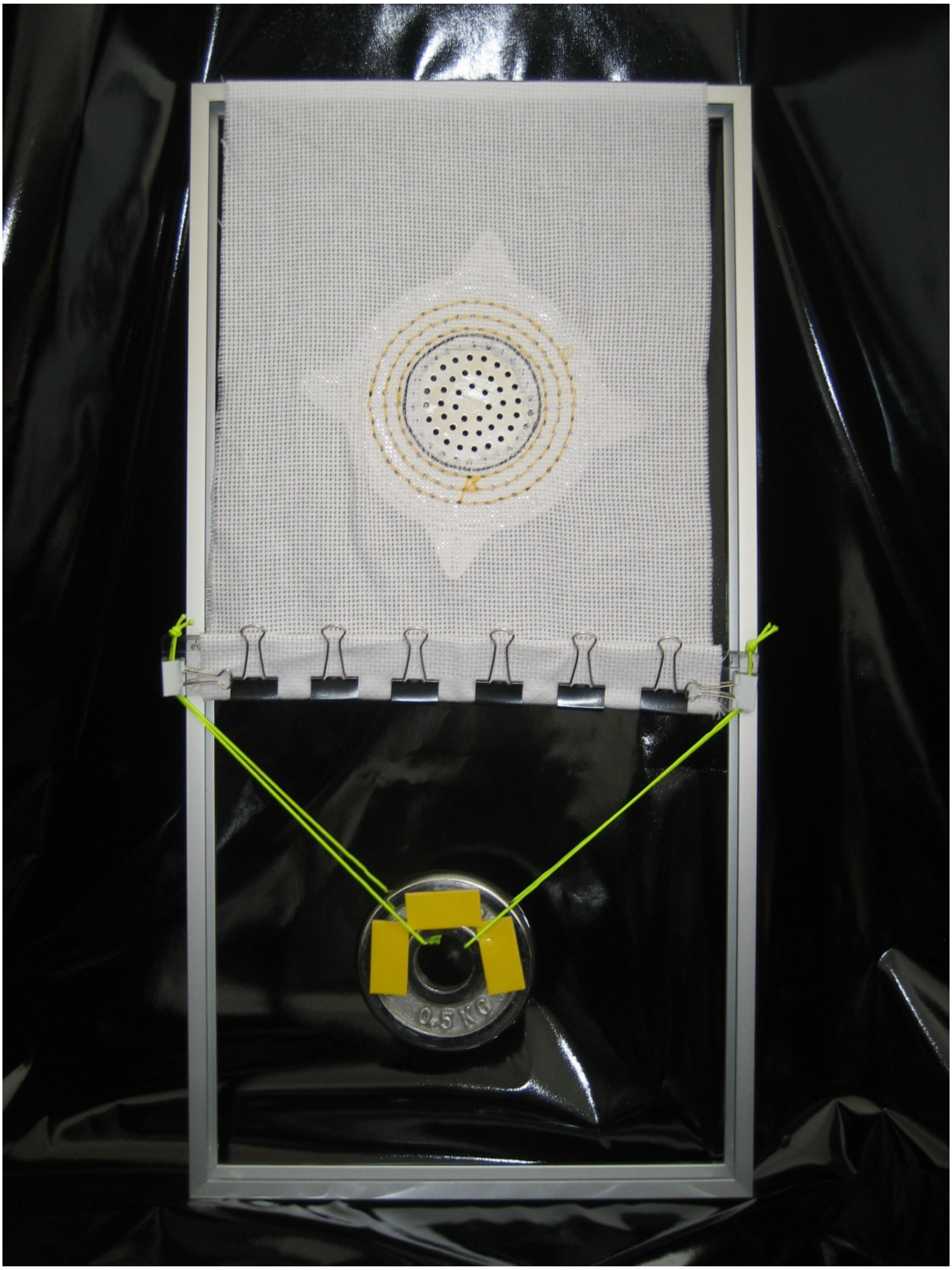
Although it is possible to attach pressurized window assemblies and pressurized hatchway assemblies of both the airtight section sack and airtight room sacks directly to the two shells that encase each sack, the preferred embodiment is that the pressurized window assemblies and pressurized hatchway assemblies that are installed in the airtight sacks also incorporate load-bearing structural load bridges of required shapes in order to attach the window frame assembly or hatchway assembly to respectively shaped sockets in the shells through structural load bridges.

Where the frames of rigid pressurized hatchway and window assemblies incorporate structural load bridges, the rigid frames’ airtight components along the outer perimeters of those frames serve as the bases in this preferred embodiment of the structural load bridges.

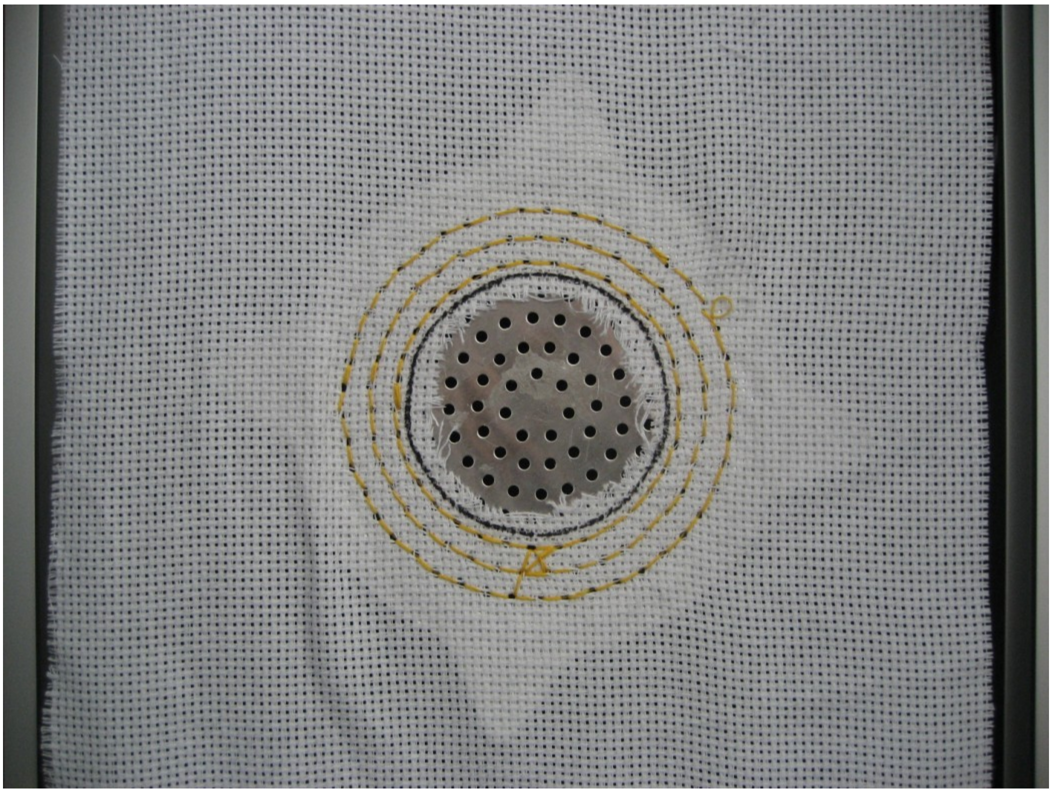
The towers of those structural load bridges, such as 22 in FIG. 1, that are used to attach to a shell a pressurized hatchway assembly or a pressurized window assembly may be preferred to be fabricated in a shape that is substantially that of a triangular prism, rectangular prism, elongated rectangular prism, shaped as a flange along the perimeter of the rigid hatchway or window assembly, or any other custom shape as required in any specific spacecraft design.

Structural load bridge towers in the shape of rectangular and elongated rectangular prisms may also be used in attaching to the shells a airtight section sack or airtight room sacks in those shell locations where the structural load paths of the invented spacecraft hull structure so require. In those instances where the structural load paths of the invented spacecraft hull structure require so, structural load bridge towers can be manufactured in other and more complex 3-dimensional shapes or in those shapes that fit the curvatures and block layout patterns of the hull structure. Spaceward hatchway assemblies are also preferably fastened to the outer space shell using incorporated structural load bridge towers as described.

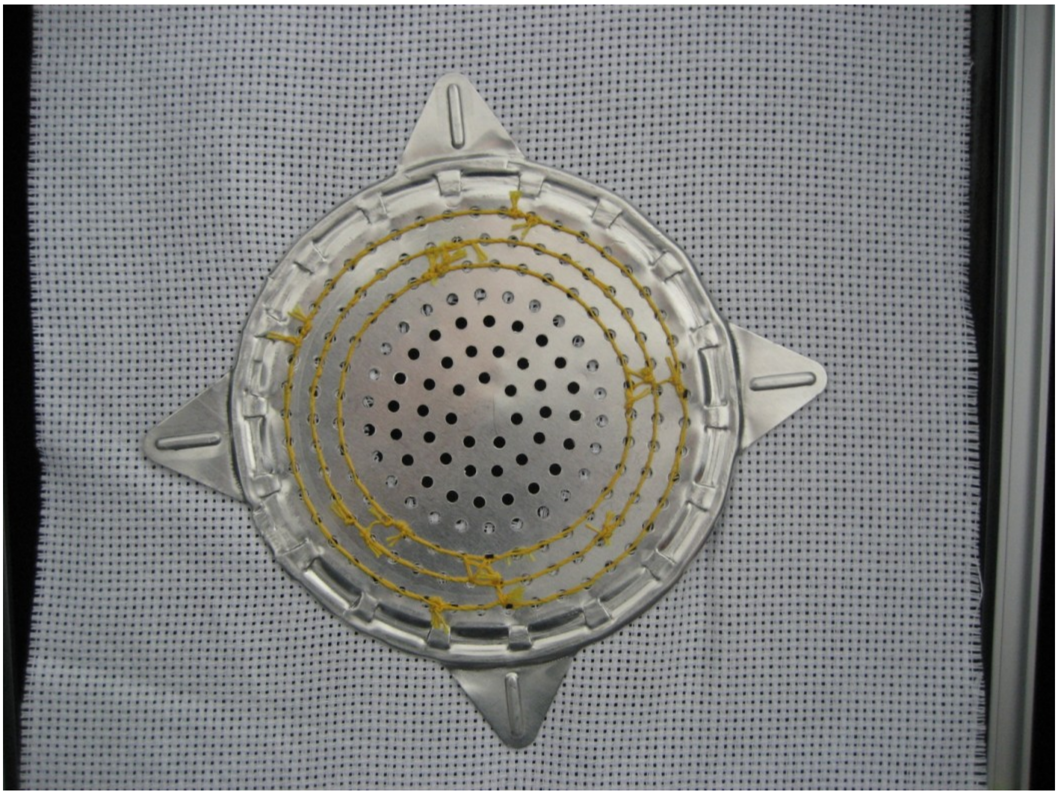
A model of such structural load bridge component, displayed already installed into a soft airtight sack, is shown in photographs 4 and 5.



Photograph 1: The rig used to prove the concept using a flattened aluminium sieve that had been bought at Tesco for less than 2 Euros for this purpose.



Photograph 2: Front view of the flattened aluminium sieve as proof of concept.



Photograph 3: Back view of the flattened aluminium sieve as proof of concept.

FIG. 14

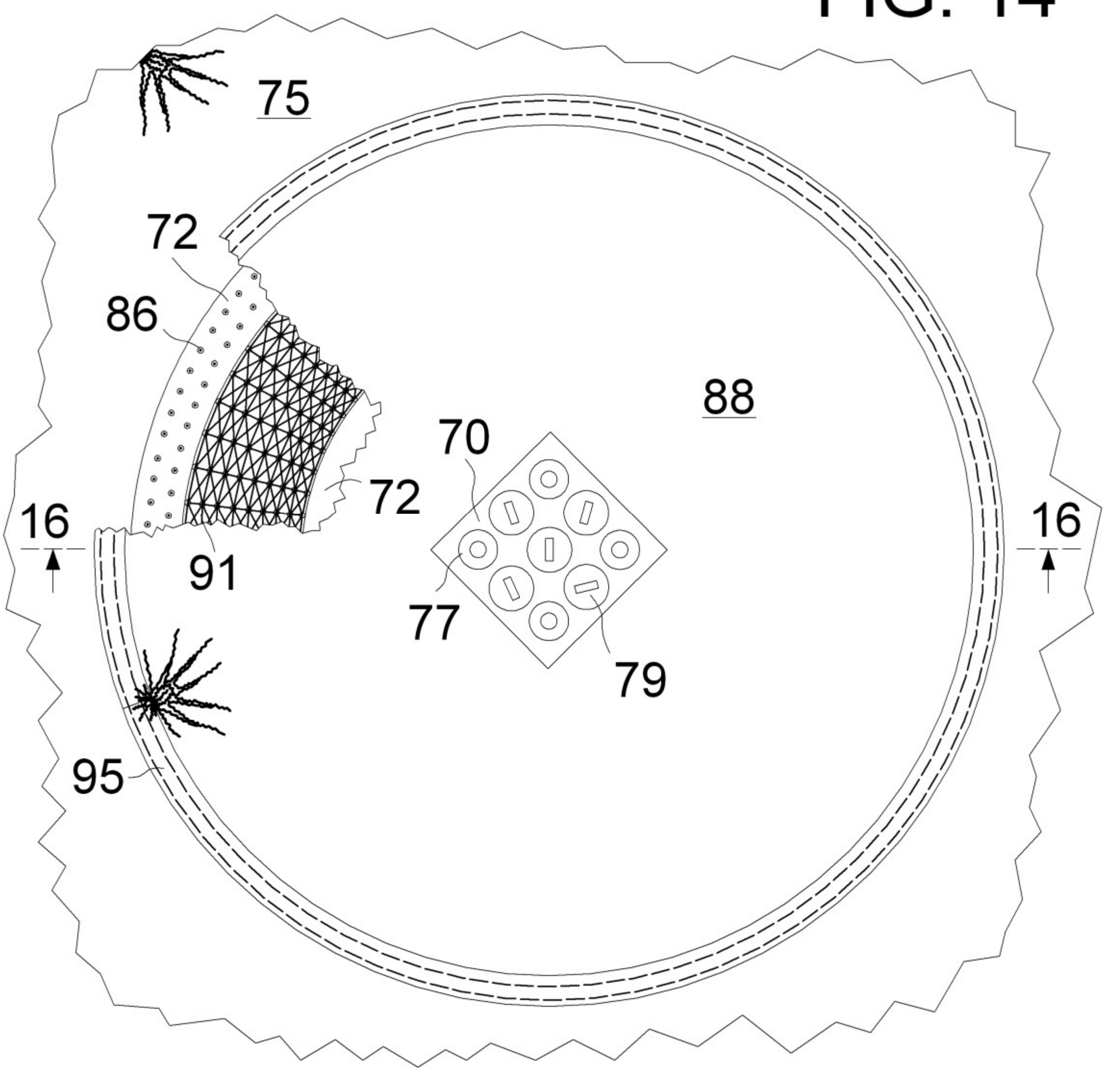


FIG. 14 Top view of a structural load bridge component installed into a soft airtight sack.

FIG. 15

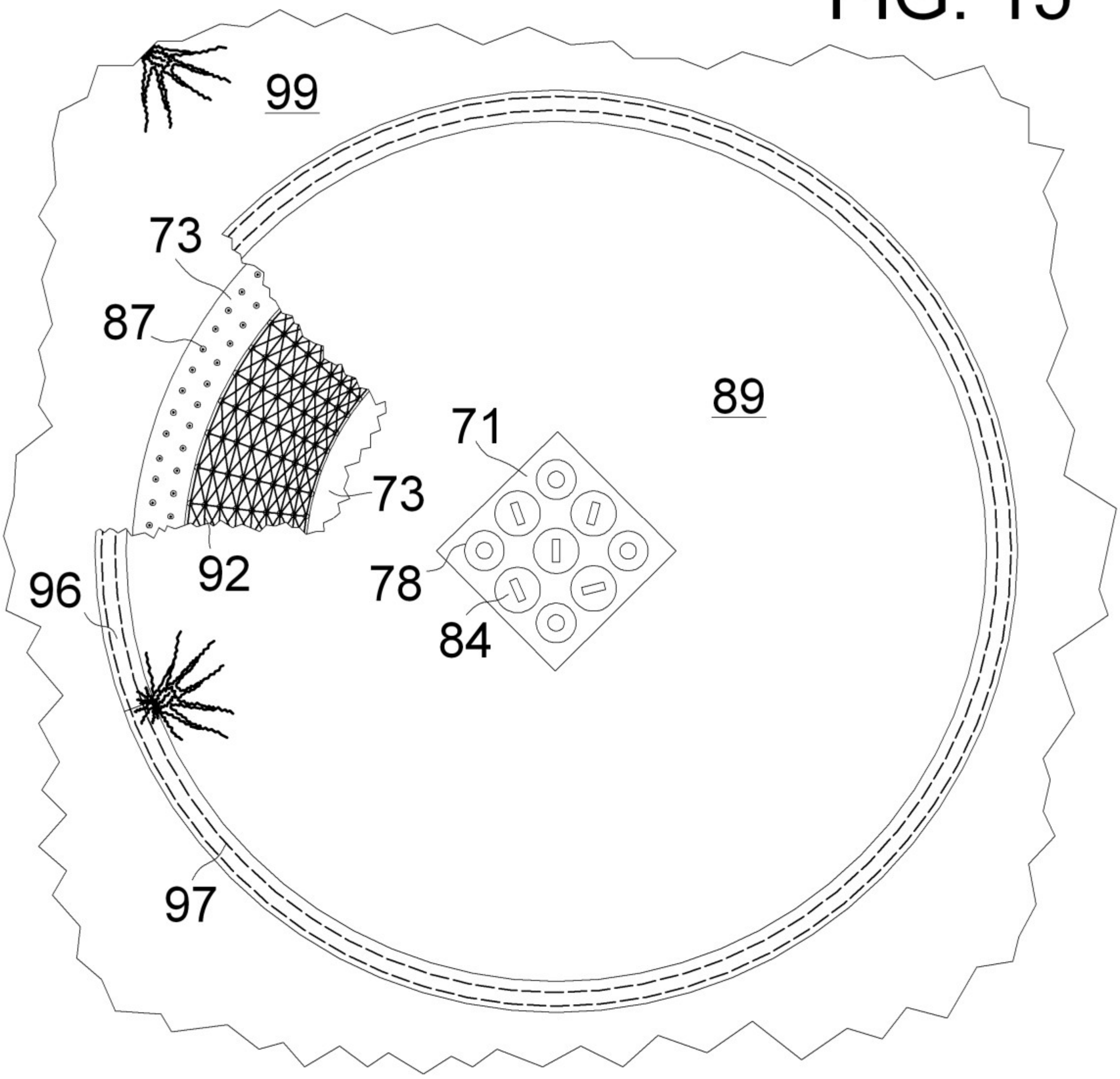


FIG. 15 Bottom view of a structural load bridge component installed into a soft airtight sack.

FIG. 16

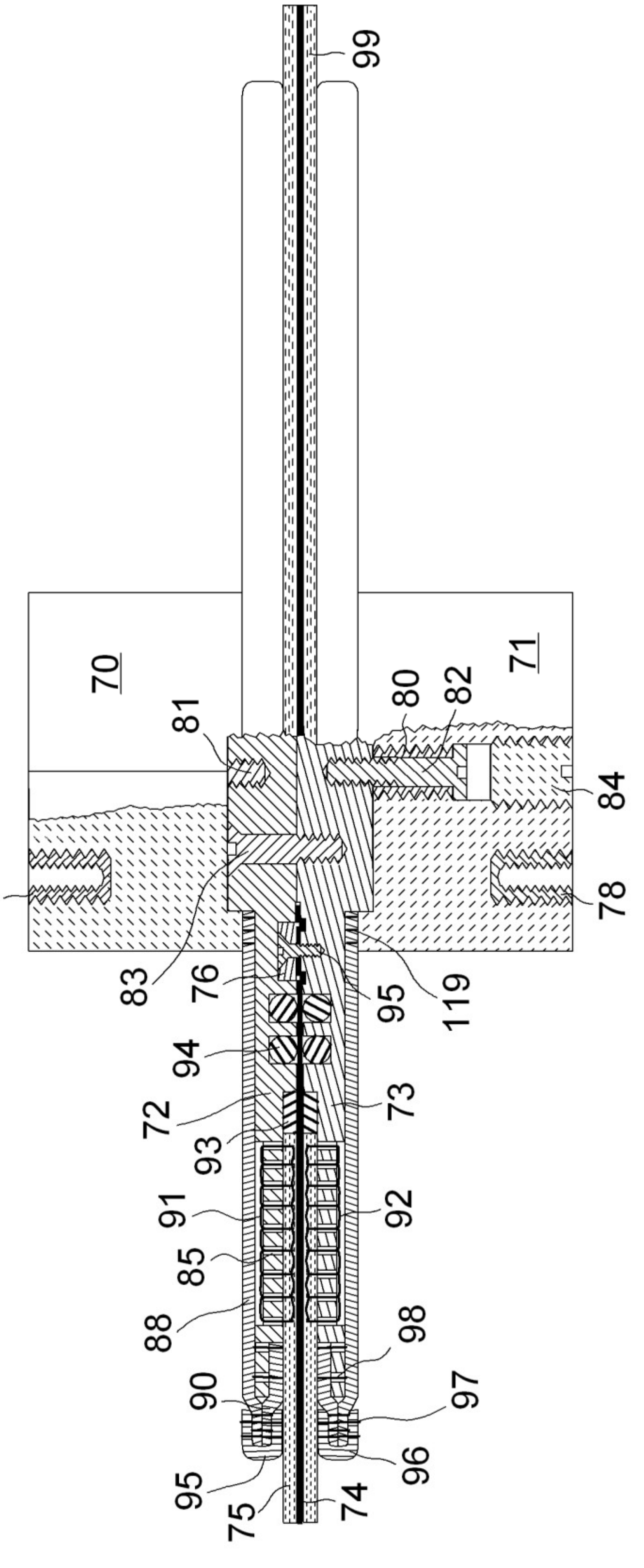
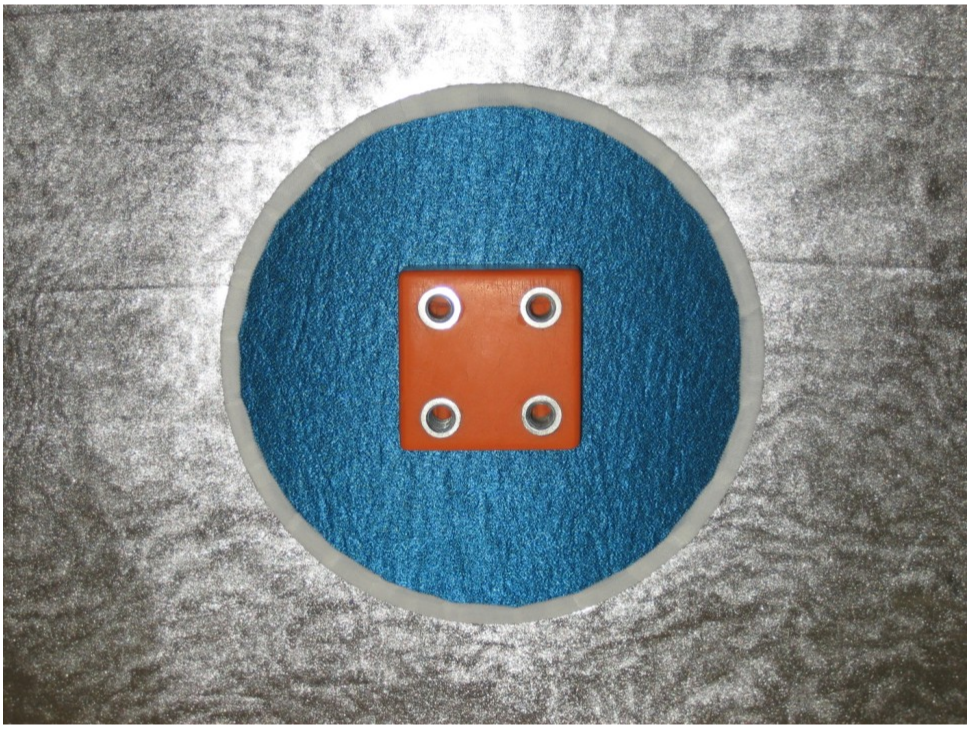
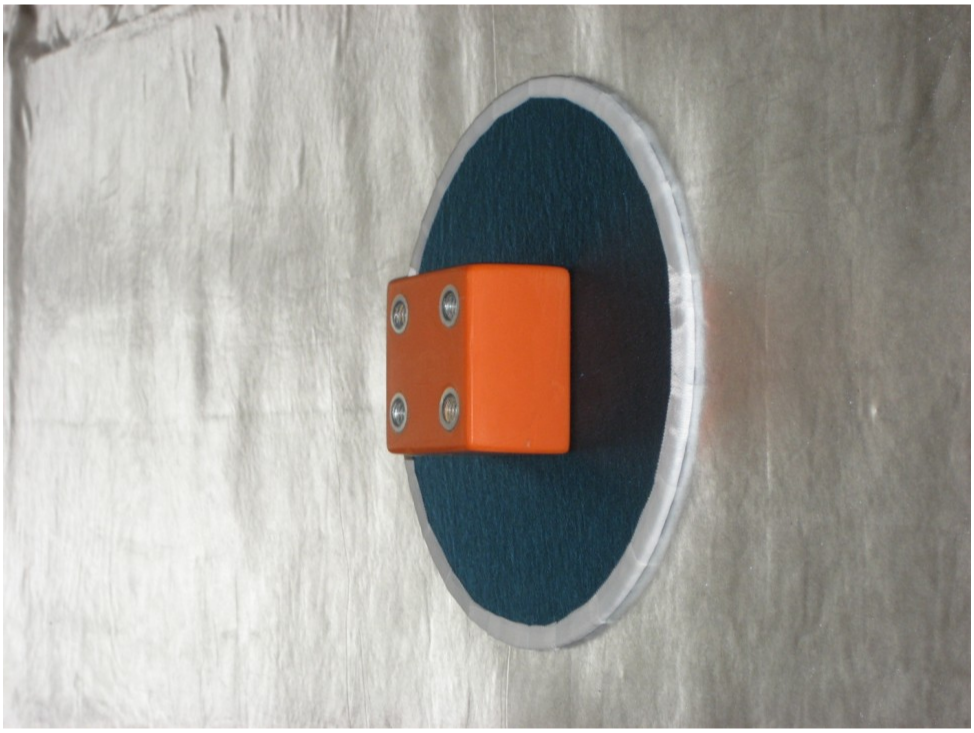


FIG. 16 Side view of a structural load bridge component installed into a soft airtight sack.



Photograph 4: Front view of a model of a structural load bridge component that has been installed into a soft airtight sack, showing the bridge component’s one visible half, the other half is behind the soft airtight sack.



Photograph 5: Perspective view of the model of a structural load bridge component that has been installed into a soft airtight sack, showing the bridge component’s one visible half, the other half is behind the soft airtight sack.

Pressurized Hatchway Assemblies and Windows

The term ‘hatchway’ is used in this technology primer to mean a connecting passage way for the crew between two pressurized rooms/corridors inside a spacecraft hull, and the term ‘hatch door’ is used rather than only ‘hatch.’ The purpose of such distinct terminology is to make it clear which hardware is specifically being mentioned and to emphasize the fact that not every pressurized passage way needs a door, as well as the function of a passage way for the spacecraft crew is primarily the movement of the crew, supplies, and hardware through the hull, as opposed to the limited use of the closed position of the airtight door that is installed inside such passage way.

Existing pressurized hatchway designs found in contemporary space applications can satisfy the requirements of this invention as pressurized hatchway assemblies of airtight sacks, such as the rear-entry hatchway of Russian EVA spacesuit Orlan-M, more specifically as consisting of the rigid airtight pressurizable hatch door that can be airtightly locked to the rigid hatch frame that is incorporated in a rigid metal-alloy pressure vessel that is pressurized during nominal operation, as can be seen in photograph 6.

The rigid pressurized hatchway assemblies are preferably thin-walled pressure vessels, preferably fabricated from a metal alloy. The depth of a pressurized hatchway assembly may depend on the thickness of the shells that it is designed to span in conjunction with a pressurized hatchway assembly to which it is intended to be airtightly mated. The rigid pressurized hatchway assemblies are mated to each other with an airtight seal, in such mutual positioning as 26 in FIG. 1, using known airtight pressurized mating methods.

A rigid pressurized hatchway assembly is attached to a soft airtight sack by either of two preferred methods:

1. by the method of airtight pressurized attachment of the preferred embodiment of the rigid structural load bridge in this invention as described in this technology primer and shown in FIG. 16, where the soft airtight sack is attached to the described rigid structural load bridge; or
2. by the method used to attach the airtight pressurizable soft garment to the rigid aluminium-alloy torso cuirass in the Russian Orlan-M spacesuit.

Using said first method, the rigid pressurized hatchway assembly along its entire outer perimeter incorporates the structures of the structural load bridge that are described further and shown in FIG. 16. And in other embodiments of this invention, other known airtight pressurized attachment methods can be used. Manufactured rigid pressurized hatchway assemblies are installed into their airtight sacks during the fabrication of those sacks.

The pressurized hatchway assemblies of airtight section sacks do not feature hatch doors. These pressurized hatchway assemblies incorporate two-shell attachment structural load bridges, by which these pressurized hatchway assemblies are attached to both the deck support shell and the outer space shell.

The pressurized hatchway assemblies of airtight room sacks are attached to the blocks of the room interior shells by use of incorporated structural load bridges. Both two-shell attachment bridges and one-shell attachment bridges may be used for attachment of the pressurized hatchway assemblies of airtight room sacks.

Substantially rectangle-shaped hatchways with rounded corners, such as the rear-entry hatchway of Russian EVA spacesuit Orlan-M, are preferred for installation in airtight room sacks as the pressurized hatchway assemblies for airtight mating of airtight room sacks in the inner air pressure system. Substantially rectangle-shaped pressurized hatchway assemblies are preferred over circular hatchway assemblies for this purpose, because the rectangular geometry of rigid hatchway frames of such pressurized hatchway assemblies permits such rigid hatchway assemblies to be passed through other rectangle-shaped hatchways of the same specifications due to the height of a rectangle-shaped hatchway assembly being greater than its width. Same applies to square-shaped hatchways with rounded corners due to the fact that the diagonal of a square-shaped hatchway assembly is greater than its width/height, although some square-shaped hatchways may be prevented from being used in this invention due to a depth limit of such rigid hatchway frame that would negate this geometrical advantage. Due to this geometry consideration, rectangle-shaped hatchways are more preferred than square-shaped hatchways, because the former offer more clearance than the latter; and circular hatchways should preferably be associated only with spaceward hatchways.

The above advantages of rectangle-shaped and square-shaped hatchway assemblies translate into the following significant advantages of so shaped hatchway assemblies for extended, long-duration, interplanetary spaceflight:

1. Auxiliary airtight room sacks for replacement to be stored inside the inner air pressure system - for example, stored folded in a storage room for airtight sacks.
2. Replacement of an airtight room sack requires only disassembly of that particular room’s room interior shell and comfort panels.

The preferred embodiment of this invention is that every room’s airtight room sack contains at least one rigid pressurized hatchway assembly, such as 23 in FIG. 1, with its own airtight hatch door, such as 25 in FIG. 1. This means that a hatchway passage between two rooms, that is for example between a corridor and a room, or between an airlock and a corridor, has two airtight hatch doors, one hatch door closing from inside each room. Two airtight hatch doors per hatchway passage are preferred, because in the event of the airtight room sack failure in one room, that room can be sealed off from the inner air pressure system by closing and locking the airtight hatch door of the adjacent room, which leads to the room with failed airtight room sack. And in the event of accidental depressurization of the inner air pressure system, a member of spacecraft crew can isolate themselves by closing the airtight hatch door of the room in which they are located at the instant of depressurization. Once they isolate themselves in their room, they must done emergency pressure suits and seal off the room with the failed airtight room sack from the inner air pressure system. Another advantage of using a separate airtight hatch door per each room per hatchway is that it serves as a safety feature in the event of failure of the airtight pressurized mating of two rigid pressurized hatchway assemblies of two rooms' airtight room sacks, i.e. depressurization of the inner air pressure system at a juncture of two airtight room sacks, or depressurization at a juncture between a airtight room sack's pressurized hatchway assembly and a airtight section sack's corresponding pressurized hatchway assembly, or between a airtight section sack's pressurized hatchway assembly and a corresponding pressurized spaceward hatchway assembly.

Two mated pressurized hatchway assemblies form what is known as a pressurized 'vestibule' and are lined inside with soft thermal insulation blankets, and in the cases of hatchway assemblies of docking rooms and airlocks also with micrometeoroid protection blankets.

Although two respective rigid pressurized hatchway assemblies of two airtight room sacks, or of two airtight section sacks, or a spaceward hatchway assembly and a corresponding pressurized hatchway assembly of a airtight section sack, or a pressurized hatchway assembly installed in a airtight section sack and a pressurized hatchway assembly of the airtight room sack of the corresponding docking room or airlock, can be mated using a variety of known space-rated attachment methods and fasteners to provide an airtight seal, preferred is use of a plurality of screws/bolts around the inner perimeter of the rigid pressurized hatchway assembly, where such use of screws/bolts permits attachment that is accessible inside the rigid pressurized hatchway's inner perimeter from within a airtight room sack, and with mating and screw-tightening work conducted within such rigid hatchway's inner perimeter. It is preferred that all screws/bolts are tightened using a space-rated power tool that permits registration of force applied to tighten each screw, such as the Pistol Grip Tool (PGT). The plurality of screws/bolts around the inner perimeter of a pressurized hatchway assembly can feature one or more parallel rows of screws/bolts, and depending on the airtight mating surfaces of the two pressurized hatchway assemblies to be attached to each other can feature various conventional airtight mechanical seals around the perimeter of two mated pressurized hatchway assemblies, such as gaskets and o-rings.

A rigid pressurized hatchway assembly of the airtight section sack is same as a rigid pressurized hatchway assembly of a airtight room sack, and can be substantially rectangle-shaped with rounded corners, substantially square-shaped with rounded corners, or circular, but featuring airtight mating surfaces on its both sides, that is one additional identical airtight mating surface instead of the hatch door flange as is the case with the pressurized hatchway assembly of a airtight room sack, so that such pressurized hatchway assembly can be airtightly mated at its one airtight mating surface either to a spaceward hatchway assembly as described in this invention or to an identical pressurized hatchway assembly of an adjacent airtight section sack, and at its second airtight mating surface to be airtightly mated to an identical but airtight-hatch-door-equipped pressurized hatchway assembly of a airtight room sack, such as of a corridor within the airtight section sack.

A rigid pressurized hatchway assembly of the airtight section sack does not have an airtight hatch door of its own as noted above, but is airtightly mated to a pressurized hatchway assembly of a airtight room sack during spacecraft assembly in space, identically to how each two airtight room sacks' pressurized hatchway assemblies are airtightly mated to each other as for example 23 and 24 in FIG. 1, and where the airtight room sack's corresponding pressurized hatchway assembly features an airtight hatch door that leads to the said pressurized hatchway assembly of the airtight section sack. In such manner, each pressurized hatchway assembly of the airtight section sack provides an airtight barrier to both the outer air pressure system, as represented by the airtight section sack, and the inner air pressure system, as represented by all the airtight room sacks inside the section. The outer air pressure system is thus airtight both in relation to outer space and to the inner air pressure system, and the inner air pressure system is thus airtight both in relation to outer space and to the outer air pressure system.

Two sections of such spacecraft hull structure are preferably joined by having a common load-bearing bulkhead or floor on their outer space shells, where the two outer space shells meet at such common load-bearing bulkhead or floor that is associated with both sections' outer space shells when the sections are joined. This joining method can be used in simultaneous assembly of two sections, in sequential section assembly when a next section is assembled after completion of each section, and in nearly-simultaneous section assembly in which assembly of a next adjacent section is started after the common load-bearing bulkhead or floor has been assembled in the section that is already being assembled. Although that is the preferred embodiment, depending on a particular spacecraft design, two sections may be joined in such manner as for both sections to feature their own load-bearing bulkheads or floors of their outer space shell at the joining plane, in which case a pressurized adapter assembly may be airtightly mated, preferably with threaded fasteners, in between the two pressurized hatchway assemblies of the airtight section sack; otherwise, each of the two pressurized hatchway assemblies of the airtight section sacks must be of such depth that will fully match the thickness of the outer space shell of the section. An alternative method of airtightly mating two sections of such spacecraft hull is to use existing docking systems and mating adapters that are presently used for long-term pressurized connection of the ISS modules.

A rigid pressurized hatchway assembly of the airtight section sack of one section is airtightly mated to a corresponding pressurized hatchway assembly of the airtight section sack of an adjacent section at a location, where the corridors of the two sections meet to compose one inner air pressure system of such habitable spacecraft that consists of two or more sections. Two mated pressurized hatchway assemblies of two adjacent airtight section sacks are also airtightly mated on their inward (facing the inside of the section sack) mating surfaces to the two respective airtight-hatch-door-equipped pressurized hatchway assemblies of airtight room sacks located in their respective sections. Such pressurized airtight connection of two sections involving pressurized hatchway assemblies of airtight section sacks mated to their respective corridors' pressurized hatchway assemblies installed into airtight room sacks, provides separate independent pressurization of each section' outer air pressure system within such spacecraft, and does so irrespectively of whether either of the two airtight hatch doors of the respective two airtight room sacks is open or airtightly closed to seal off the inner air pressure system of one of the two sections from the inner air pressure system of the other section so airtightly joined.

Blocks of the deck support shell and folded airtight room sacks with their preinstalled rigid structural load bridges, pressurized hatchway assemblies, and pressurized window assemblies, must have sufficiently small physical dimensions in order to pass through the pressurized hatchway assemblies of the airtight section sack during spacecraft assembly, repairs, and overhauls. Blocks of all room interior shells, all rooms' comfort panels, and all onboard hardware to be installed inside the inner air pressure system of such spacecraft, are preferably manufactured with such physical dimensions as to pass through each and every pressurized hatchway assembly of the inner air pressure system of such spacecraft, meaning the pressurized hatchway assemblies of all airtight room sacks inside each section of such spacecraft hull. The onboard hardware may be made to pass through the said hatchway assemblies either in its assembled state or in a disassembled state with the assembly and disassembly performed by spacecraft crew inside a room of the section.

It is preferred that all vents, transfer pipes, hoses, and cabling, that transcend shells from the inner air pressure system, through the outer air pressure system, and to the vacuum of outer space or into another spacecraft when docked, are incorporated in the rigid pressurized hatchway assemblies of the airtight room sacks of docking rooms or airlocks, and in the corresponding rigid pressurized hatchway assemblies of the airtight section sack. Such incorporation simplifies such vents', pipes', hoses', and cables' repairs and replacement, as opposed to their being buried into the invented hull's encasing rigid shells that are interspersed with two airtight sacks without sufficient access for most of the spacecraft's lifetime in space.

Preferred are removable and replaceable hatchway assembly parts, including each airtight hatch door, each hatch door's airtight seals, and each hatchway frame's airtight seals, that in order to be replaced do not require removal of the entire hatchway assembly and its airtight sack.

This invention uses existing methods of airtight attachment of window glass to a rigid metal frame in a pressurized window assembly, such as the cockpit window assembly design in the Russian Buran orbiter that uses tempered glass in a titanium-alloy frame, as seen in photograph 7. A window in the invented spacecraft hull structure consists of a number of aligned unpressurized and pressurized window assemblies constituting one window, where the window assemblies preinstalled in shell blocks are unpressurized and the window assemblies preinstalled in the airtight sacks are pressurized. The rigid metal frames of the pressurized window assemblies incorporate structural load bridges by which they are attached to the shells on either side of each airtight sack. The unpressurized window assemblies in the corresponding blocks of the shells are attached in accordance with existing thermal control methods and using existing methods of attachment, such as threaded fasteners, to the block's back or lid that is fabricated with an indentation inward into the block's cavity in order to permit the pressurized window's rigid metal frame assembly that is installed in the sack to fit between the two shells without coming into physical contact with any unpressurized window assembly of the two shells encasing the sack. The unpressurized window assemblies, which may use among other materials also for example polycarbonate, serve the purposes of thermal control, UV filter, and protection of the pressurized windows from impacts, whereas the pressurized window assemblies are constituents of the two air pressure systems. The block bodies through which such multi-layer window structure is positioned should preferably feature their inner surfaces protected with existing thermal control methods, such as MLI or thermal surface finishes. Manufactured pressurized window assemblies are installed during the fabrication of the respective airtight sacks. Unpressurized window assemblies are installed during the fabrication of their shell blocks. The preferred embodiment of such distinct window structure may consist of the following, listed from outside inward:

1. Non-airtight unpressurized window assembly attached to a panel of the protective skin
2. Non-airtight unpressurized window assembly attached to the indented block lid of a block in the outer space shell
3. Non-airtight unpressurized window assembly attached to the indented back of the block body of the said block in the outer space shell
4. Airtight pressurized window assembly installed in the airtight section sack
5. Non-airtight unpressurized window assembly attached to the indented back of the block body of a block in the deck support shell
6. Non-airtight unpressurized window assembly attached to the indented block lid of the said block in the deck support shell
7. Airtight pressurized window assembly installed in the airtight room sack
8. Non-airtight unpressurized window assembly attached to the indented back of the block body of a block in the room interior shell
9. Non-airtight unpressurized window assembly on the comfort panel, which is attached to the said block in the room interior shell

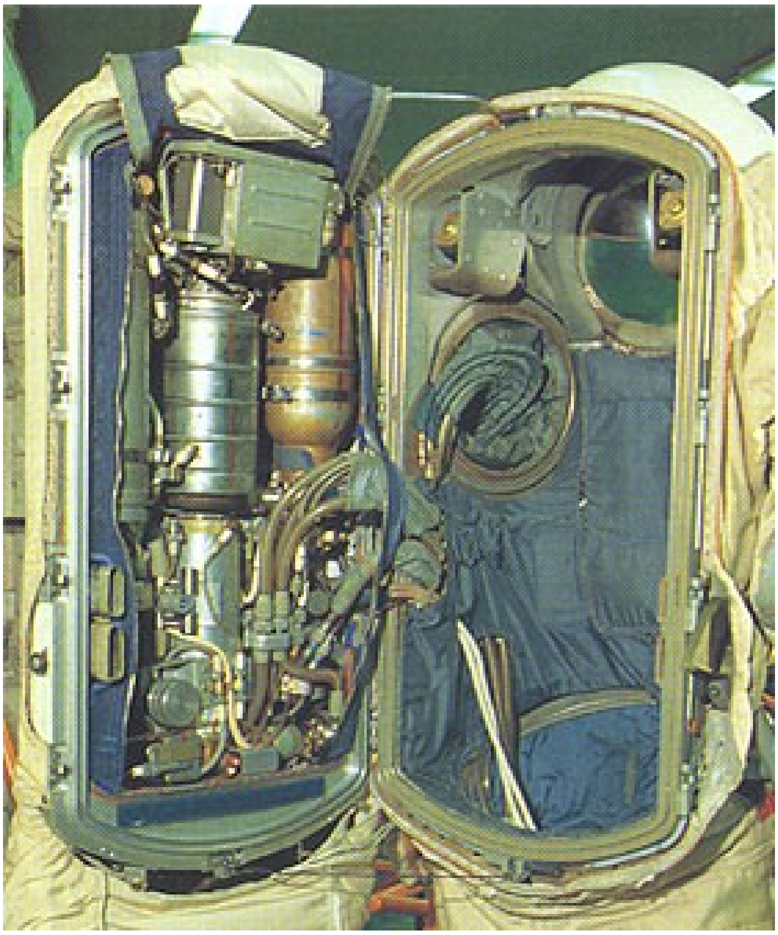
Such distinct window structure can also be installed inside the invented spacecraft hull structure between two rooms within one section or between two sections, for observation of one room from inside another room, such as between a room and a corridor, a room and an airlock, and between rooms comprising the flight control facilities or laboratories of such spacecraft.

It is preferable that the rigid window frames of unpressurized window assemblies permit their detachment, replacement, and reuse from damaged blocks, either as entire assemblies or their parts, by spacecraft crew inside the habitable facilities of such spacecraft during its lifetime in space in order to minimize the subsequent payloads to be transported to space from the ground to keep the spacecraft operating in outer space.

A pressurized window assembly that is installed in its airtight sack is attached to both shells, which encase the airtight sack, using incorporated structural load bridges. The rigid window frame of such pressurized window assembly must be packed tightly along its entire perimeter against the block liners of both encasing shells in order to contain within such rigid frame and the block cavity any fragments of shattered glass that can originate from a window assembly during an impact of e.g. space debris, thus preventing such free-floating glass fragments from coming into contact with any soft portion of the airtight sack. Each airtight sack should preferably feature such abrasion-resistant sack layer that provides sufficient protection against lodging and cuts by smaller glass fragments as well as larger shards of a window glass.

The rigid structural load bridges, pressurized hatchway assemblies, and pressurized window assemblies, of failed or damaged airtight sacks, can be returned to Earth as part of the payload of a routine pressurized cargo reentry capsule, such as the publicized Soyuz-TMA-based Progress version. After that the structural load bridges, pressurized hatchway assemblies, and pressurized window assemblies, are assessed for health, and, if possible, recycled in the production of replacement airtight sacks. For such recycling to be technically permitted, the used airtight sack's pressurized hatchway assemblies and window assemblies must be small enough to pass through the transfer hatchway of the reentry vehicle. Moreover, such failed or damaged airtight sacks that are returned to planet Earth can undergo a technical investigation on the ground into the causes of their inoperability.

Due to microgravity in space, designation of a geometric deck plane for a spacecraft that is built according to this invention is arbitrary, and can allow for such irregular deck layouts where one deck will adhere to different floor planes throughout its corridors and rooms, as well as where one deck will be positioned in a different floor plane than its immediately adjacent deck, or where different rooms on one deck adhere to different floor planes. Same arbitrary use applies to the distinction between structural bulkheads and deck floors. Hence, for the purposes of defining a deck in this invention, a deck is considered here any grouping of rooms and corridors that connect those rooms. Therefore, use of the term 'deck' in this invention is only for the convenience of describing the location of, as well as locating, rooms and corridors within a section of the invented spacecraft hull structure. Decks can be connected by pressurized hatchways of corridors or rooms, where the airtight room sacks of two rooms/corridors belonging to immediately adjacent decks are airtightly mated at their pressurized hatchway assemblies. Decks can also be connected by corridors that transcend two or more decks.



Photograph 6: Orlan's airtight hatch door and hatch frame from the website of NPP Zvezda. Photograph credit: OAO NPP Zvezda.

Photograph 7: Airtight pressurized window assembly from the cabin of Buran orbiter. Photograph credit: Weltraumladen.de.

Protective Skin

This invention is best used in conjunction with a layer of protective skin that is assembled from a plurality of rigid impact-mitigation panels that follow the curvatures and shape of the outer space shell. The protective skin completely encases and shields the invented spacecraft hull structure from outer space, and is fastened to the outer space shell at a plurality of locations. Panels of the protective skin may also cover those spacecraft components that are installed on the outer space shell, such as various pressurized tanks or propulsion subsystem.

The preferred type of the protective skin is that of rigid panels that function according to the concepts of Whipple Shield, Enhanced Whipple Shield, or other existing concepts of spacecraft shielding for the same purposes. Examples of existing panel designs for these purposes are the Service Module Debris Protection panels for Zvezda FGB of the ISS and Meteoroid and Debris Protection System panels for Columbus COF of the ISS.

The protective skin is responsible for impact protection of the invented spacecraft hull structure in the events of micrometeoroid hits, collisions with space debris, and accidental collisions with other spacecraft during rendezvous and docking. These functions reside in the protective skin in order to provide a sacrificial layer of such hull structure, which will absorb impact energy during collisions and minimize damage to the outer space shell, which carries the structural loads of the hull. Thus the purpose of the protective skin is to provide an easier replaceable layer of the spacecraft hull and ensure that replacement of blocks of the outer space shell and the rest of the inward hull structures is only required in those rarer instances of more severe damage.

Although the protective skin is a layer of such hull structure that is directly responsible for protecting the invented spacecraft hull from micrometeoroids and space debris, it must be emphasized here that the entire spacecraft hull structure in this invention was deliberately invented to serve as one complex multiple-layered protection mechanism that acts as a multiple Whipple Shield, which in this invention consists of layers of various spacecraft hull structures.

During nearby spacecraft collisions or hypervelocity impacts and penetrations by pieces of space debris, the protective skin transfers a fraction of the impact energy, through such skin attachment parts as 42 in FIG. 1, into the lids of the blocks of the outer space shell. The panels of the protective skin are attached preferably with threaded fasteners through the mentioned skin attachment parts, such as 42 in FIG. 1, to the block lids of the outer space shell, so that a cavity is arranged between the panels of the assembled protective skin and the blocks of the assembled outer space shell. The skin attachment parts are attached to the block lids of the outer space shell, so that the block lids of the outer space shell can act as an intermediate member in the transfer and absorption of impact energy into the spacecraft hull, rather than permitting that energy to be transferred directly into the load-bearing side surfaces of the block bodies of the outer space shell and inwards. Thus the structural failures of the skin attachment parts and of block lids of the outer space shell in order to absorb the impact energy are considered less threatening to such spacecraft hull than the structural failures of the back and side surfaces of the outer space shell's block bodies that act similarly to stringers and longerons, and frames/formers in the shell structure, even if the block bodies of the outer space shell also sustain minor damage and require replacement in the aftermath of the impact. The radiation shield bags carried inside the cavities of the blocks of the outer space shell and deck support shell also absorb a fraction of impact energy in hypervelocity penetrations.

Other functions of the protective skin are:

1. The fully encasing protective skin that is covered with existing thermal surface finishes or MLI is utilized for passive thermal control of the spacecraft hull.
2. Attachment of conventional body-mounted solar cells and radiators on the panels, or incorporated into the panels, of such protective skin
3. Installation of conventional EVA handrails on the panels of such protective skin

Any panel of the protective skin can be replaced independently of adjacent panels in the event of damage and for scheduled replacement of a given protective skin model for a new protective skin model of improved performance of the said functions. Replacement of the given protective skin model is therefore permitted in this invention to be conducted during the spacecraft's lifetime in spaceflight without any need to disassemble any portion of the outer space shell, i.e. without having to overhaul the spacecraft's load-bearing hull structure, as well as permitting replacement of the entire protective skin using the local panel-by-panel method, in which only one panel in the protective skin of the given model is replaced by one panel of a new model at a time, until all panels of the protective skin have been replaced. This local panel-by-panel replacement method permits all the other remaining panels of the protective skin of the older model to remain installed and provide continuous protection to such spacecraft hull against impacts and thermal environment of outer space. Hence this local panel-by-panel replacement method enables the invented spacecraft hull structure to remain fully operational, safe, and habitable, during the process of replacing its protective skin.

Unpressurized Cargo Delivery to Low Earth Orbit

Such spacecraft hull structure is manufactured and tested on the ground, launched to LEO in its disassembled state in the payload fairings/bays of several launch vehicles, and assembled during repeating routinized EVA procedures in outer space environments.

It is preferred that the blocks of the outer space shell, deck support shell, room interior shell, airtight section sack, airtight room sacks, onboard hardware to be installed inside the onboard habitable facilities, components for installation on the outer space shell and protective skin, comfort panels and protective skin panels, are packed into soft space-rated cargo bags, called here 'space transportation bags,' on the ground in order during spacecraft assembly in outer space to facilitate assembly and reduce the number of trips by astronauts moving blocks and hardware toward and inside the invented spacecraft hull structure that is in the process of being assembled. Such space-rated transportation bags are preferably sewn from high-strength, abrasion-resistant soft materials, such as fabrics, films, and fibers used in spacecraft applications. Such bags should preferably provide thermal insulation and micrometeoroid protection to their contents in outer space environments. Such bags can be produced by conventional manufacturing methods in a variety of designs as determined by the launch vehicle used to deliver them to outer space, and by the shapes of the parts they will contain. In order to eliminate arbitrary floating that may result in hitting astronauts, such space-rated transportation bags must feature fasteners or locking devices by which a bag is fastened, if necessary using harnesses or tethers, to the blocks of an already assembled shell structure for the duration of EVA works that involve installation and attachment of parts that represent the contents of the bag.

A multideck-multipallet bus is proposed below for this new hull technology as an initial solution to the problem of delivering shell blocks and other hull components by launch vehicles to LEO. This is an initial solution that is expected to serve as a starting point and to evolve in order to result in smooth and safe implementation.

The proposed solution employs such existing methods for transporting shell blocks and other spacecraft components by launch vehicles to space that use softgoods for securing payloads to spacecraft bus structures, such as used in Russian Soyuz series spacecraft:

1. Kazbek-U seats that feature a metal support structure, profiled liner, and harnesses.
2. Soft strapped packs located inside the Descent Module SA on the walls of the parachute containers.

The preferred method of attachment of payloads that is described here permits the shell blocks that are packed inside space transportation bags to avoid those structural loads that arise in launch environments when a block is fastened to the bus directly using rigid attachment methods, such as threaded fasteners.

This in turn offers an opportunity to make the design process of shell blocks more economical in terms of structural analysis.

This method also avoids, for astronauts in EVA spacesuits, the time-demanding and complex tasks of unscrewing shell blocks from the bus if the blocks were attached to the bus using threaded fasteners.

Each shell block during its delivery to space by a launch vehicle must only carry structural loads experienced by its own mass, meaning it must not have other blocks stacked directly on top of it, nor can it be fastened by threaded or other rigid fasteners to the bus on which it is secured. Especially, such shell block must not be attached to the bus by threaded fasteners through the inserts in the block body through which threaded fasteners are normally put and tightened to attach the block to adjacent blocks in the shell during outer space assembly of the given spacecraft according to this invention.

Space transportation bags that are secured on the profiled liner-covered cradle trays, as in FIG. 17 and as described further, by soft fastening methods, such as harnesses, straps, webbing, cargo nets, tethers, and so on, are preferred in order to distribute evenly launch environments' loads over the surface area of that block surface on which the block is secured inside the space transportation bag on the cradle tray, and same applies to the block's inner reinforcements that have been fabricated onto that surface. Furthermore, the soft liner on the cradle tray and the soft materials of the space transportation bag in which the shell block is packed, together ensure a greater surface area of that block surface being supported by the cradle tray in launch environments.

One advantage of this invention that supports the use of softgoods as methods of securing shell blocks packed in space transportation bags to the bus structure is the light mass of shell blocks.

Hence shell blocks are to be packaged in space transportation bags, and the bags are to be secured to the cradle trays of the bus, in such a position as to obtain the maximal achievable alignment of the structural loads occurring in launch environment with the shell's structural loads caused by pressurization and depressurization of airtight sacks, as well as with the dynamic loads experienced by the spacecraft hull in space during its spaceflight life. For example, a shell block packaged in a space transportation bag is strapped to the bag's deck-mounting cradle tray with the block's back facing the cradle tray.

Each bag containing shell blocks must be packed as a horizontal row of shell blocks, so that no shell block is transported aboard the bus as sitting directly on another shell block in launch environments. When several shell blocks are packed inside one bag, the bags feature spacers between every two blocks, where the spacers are preferably vertical vibration-dampening inserts from softgoods, possibly featuring flexible vibration isolators. When one or more shell blocks inside a bag do not permit close horizontal packaging due to complex shapes, the blocks inside the bag are separated by a gap that is strapped by a harness, strap, webbing, or tether, to immobilize both blocks in the bag on either side of the gap.

The number of blocks inside space transportation bags will vary depending on the sizes of those blocks as determined by a specific spacecraft design, as well as depending on the bus deck dimensions. Very large shell blocks, such as the outer space shell in some spacecraft designs, are packed separately, one shell block per space transportation bag. In order to fully utilize the deck area of every pallet as described further, some blocks and assemblies may be packed separately. Space transportation bags should also be used to deliver other spacecraft components that are cleared for the unpressurized mode of space transportation.

The functions of the cradle tray, which acts similarly to the metal shell of Kazbek-U seats in Soyuz series spacecraft, and of securing softgoods, are to:

- support the secured space transportation bag in launch environments
- immobilize the secured space transportation bag on the pallet structure
- minimize the mass of the bag's support structure on the pallet
- isolate vibrations and control responses of packed items to launch environments

Cradle trays can be mounted atop the deck, on the bottom of the deck in order to suspend the space transportation bag under the deck; or a cradle tray can be recessed into a respectively sized opening in the deck.

Cradle trays can also be integrated into the deck structure, so that the bottom of the cradle tray is then in fact the very deck structure, leaving the cradle tray structure to be a frame within which the space transportation bag is secured on the deck. Such cradle tray in the form of a frame is then attached to the deck structure, and the soft liner is secured within it on the deck.

Profiling to evenly fit each space transportation bag into its cradle tray can be engineered through either or both depending on the selected bottom surface of each shell block that is packed in a space transportation bag:

- Profiling of the liner by thickness and relief variations in the liner over the liner area that supports the space transportation bag
- Profiling of the cradle tray's rigid structure under the liner

Each respective cradle tray and space transportation bag must carry unique alphanumeric identification of the space transportation bag that is identifiable by astronauts in outer space during spacecraft assembly EVAs.

Because such types of payload as shell blocks and other spacecraft components do not yet constitute a final spacecraft when the launch vehicle reaches its destination in outer space, space transportation bags must have been mounted on the bus using such methods that permit easy and quick removal of the bags from the bus in order to streamline the spacecraft assembly process in outer space.

The preferred method of fastening the securing softgoods is to use buckles or other release methods that ensure quick and easy release when operated by astronaut's hands in EVA spacesuit gloves.

The securing softgoods can be either used as stand alone, or they can be sewed on or otherwise permanently attached, or temporarily fastened using buckles, to the space transportation bag for reuse aboard the partially completed spacecraft during its assembly (when a bag needs to be temporarily secured to a shell). Another alternative is to permanently attach the securing softgoods to bus structures. The securing softgoods may feature fabric gussets, fabric blankets, or padding, sewn onto them.

When stand-alone tether is used to secure a space transportation bag, the tether best holds the bag in place by being fastened in a zigzag or spider web pattern over the bag.

Space transportation bags can be moved from the bus to the spacecraft being built using a streamlining system of tethers moving on pulleys.

This invention permits the use of a variety of existing launch vehicles. Preferred are launch vehicles with payload fairings/bays of larger volume due to the fact that shell blocks are lightweight and thus efficiency of a launch vehicle in delivering this kind of payloads will depend more on the largest possible size of a bus that can be delivered.

A spacecraft bus that delivers space transportation bags to the parent spacecraft preferably features a docking mechanism, such as SSVP, APAS, or iLIDS, at the front, by which it docks to the parent spacecraft, and a space tug, upper rocket stage, inter-orbital tug, or an integrated satellite propulsion subsystem, at the rear, such as Russian Fregat space tug, with which the bus attains the orbit of the parent spacecraft and performs the rendezvous and docking maneuvers.

Mainly preferred are closed-architecture configurations of the satellite bus, although this closed architecture may feature elements of open architecture, such as absence of side panels, presence of frame structures that constitute a deck, or space transportation bags being secured externally on the side panels. The cross section of the bus body architecture is preferably octagonal, circular (cylindrical), or hexagonal, in order to use the largest possible deck area of the bus per a given launch vehicle fairing diameter.

Deck mounting of space transportation bags is preferred, although panel mounting is an option that may be used in some bus designs, especially for such narrow-cross-section items as the panels of the protective skin, panels of room interior shells, and in some cases also blocks of room interior shells, block lids, and other parts.

In order to efficiently pack more space transportation bags into a bus of a given volume that is significantly larger in size than a space transportation bag, and in order to provide access to every space transportation bag on every deck, it is necessary for the bus to be composed of a number of deployable pallets, of which each pallet is a frame structure. Pallet deployment mechanisms can feature a variety of drives, including electric motor-driven, EVA astronaut-driven using tethers and pulleys, or manually deployed by astronauts using handles during EVA.

Deployment mechanisms, such as hinges and latches/locks, on the pallets perform the functions of keeping all pallets securely attached for launch and orbital spaceflight, and of transferring the pallets into deployed positions for the purpose of emptying the bus of the space transportation bags during outer space assembly EVAs. Thus the preferred bus configurations for delivery of space transportation bags are characterized by featuring a number of hinged pallets and a number of decks, where during spacecraft assembly EVAs each of those decks is accessible to astronauts in EVA spacesuits. Here, this overall category of configurations is termed “multideck-multipallet bus”.

The reason why the pallets are linked together with hinges and locking mechanisms is in order to keep all pallets fastened together, meaning the emptied pallets still remain fastened together with those pallets that are still carrying space transportation bags during spacecraft assembly, as well as when all pallets have been emptied of their space transportation bags. The purpose of keeping all pallets fastened together is because such bus must not be deorbited separately and the pallets must not be expended into space one by one after the space transportation bags are removed from them, but all pallets on the bus must remain a series hinged together, so that the bus will be deorbited as one whole by the propulsion available to the bus as described above. This design is preferred in order to prevent orbital debris formation as a result of spacecraft assembly in outer space. Moreover, in some scenarios, especially for smaller, one-section spacecraft designs that fall under this invention, a wholly retained bus in orbit may serve as a temporary storage structure for shell blocks and other spacecraft assemblies during repairs or a major overhaul.

A selected configuration and a specific design of a multideck-multipallet bus will vary depending on a specific launch vehicle used and depending on the shell blocks’ shapes and sizes as determined by a specific spacecraft design that is to be assembled in space.

Two deck-mounting configurations of a multideck-multipallet bus are proposed:

<u>Single-Deck Pallet Configuration:</u>

In this pallet configuration, each pallet is the size of the bus deck and represents one deck of the bus, so that the bus in this case is a stack of hinged and locked single-deck pallets between the docking mechanism of the bus at the front and the propulsion of the bus at the rear, as in FIG. 18.

In order to decrease the number of pallets per bus volume, and hence of pallet deployments during spacecraft assembly EVAs, the following solution can be used given the light mass of shell blocks: cradle trays can be mounted on both sides of the single-deck pallet: on top of the deck and under the bottom of the deck at launch, so that in effect the space transportation bags secured to the bottom of the pallet have their mass supported by the securing softgoods.

The layout of space transportation bags and their cradle trays on a deck of a single-deck pallet can be any of the following: regular, such as in FIG. 19, where each bag on the deck is longitudinally and independently aligned with either of two axes on the deck plane (e.g. axes x and z); center-oriented, where the bags are aligned as spokes toward the center/hub of the deck; irregular layout where the bags are not aligned with respect to one another or to any reference on the deck plane.

The deployment process of a single-deck pallet is shown in FIG. 20.

Petal-Panel Pallet Configuration:

In this configuration, the bus consists of a small number (two and more) of pallets that in their stowed positions represent the panels of the bus and where each pallet is a multideck structure, as in FIG. 21. This type of pallets is deployed in FIG. 22 in a petal fashion from the rear of the bus. As seen in FIG. 23, one of the pallets is non-deployable, although still carrying space transportation bags, and its front end features the docking mechanism on a support structure by which the bus is docked to the parent spacecraft. Instead of the non-deployable pallet, a centrally located, closed or open rigid structure, e.g. a boom or truss, can span the length of the bus from the propulsion subsystem/tug to the docking mechanism, thus permitting all the petal-panel pallets to be designed as deployable.

Petal-panel pallet configuration requires extra clearance between decks in order for an unfastened space transportation bag to clear the cradle tray. If significant, the clearance means loss of efficient packaging within bus volume.

Which configuration will be used for a specific bus will depend on the physical dimensions of space transportation bags for each specific spacecraft design, as well depend on centre of mass calculations that will determine compatibility of space transportation bags for mounting on the same pallet in conjunction with the sequence in which the bags must be unbuckled from the bus for use during spacecraft assembly EVAs.

Every deck of every pallet must be designed for the most efficient mounting layout of cradle trays for space transportation bags per bus volume. Each pallet's layout of cradle trays is either custom designed for a specific set of space transportation bags carrying specific shell blocks and other spacecraft components for a specific spacecraft design, or versatile adjustable pallet cradle tray designs can be used to accommodate different sets of space transportation bags for several spacecraft designs.

The bus structure, pallets, and cradle trays, can be manufactured from conventional, rigid, spacecraft structure materials, such as metal alloys and composites. The designs of the bus and its pallets' latching/locking and deployment mechanisms, and of the pallet cradle trays, like the securing softgoods and their buckles, must ensure ease of removal of space transportation bags from the pallets during EVAs and minimal actions to be taken by astronauts in order to remove space transportation bags during EVAs.

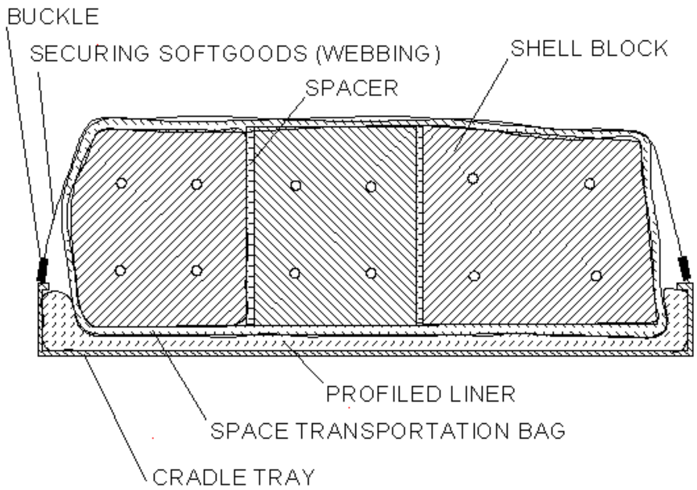


FIG. 17 A space transportation bag secured onto a cradle tray, hatching showing separate blocks.

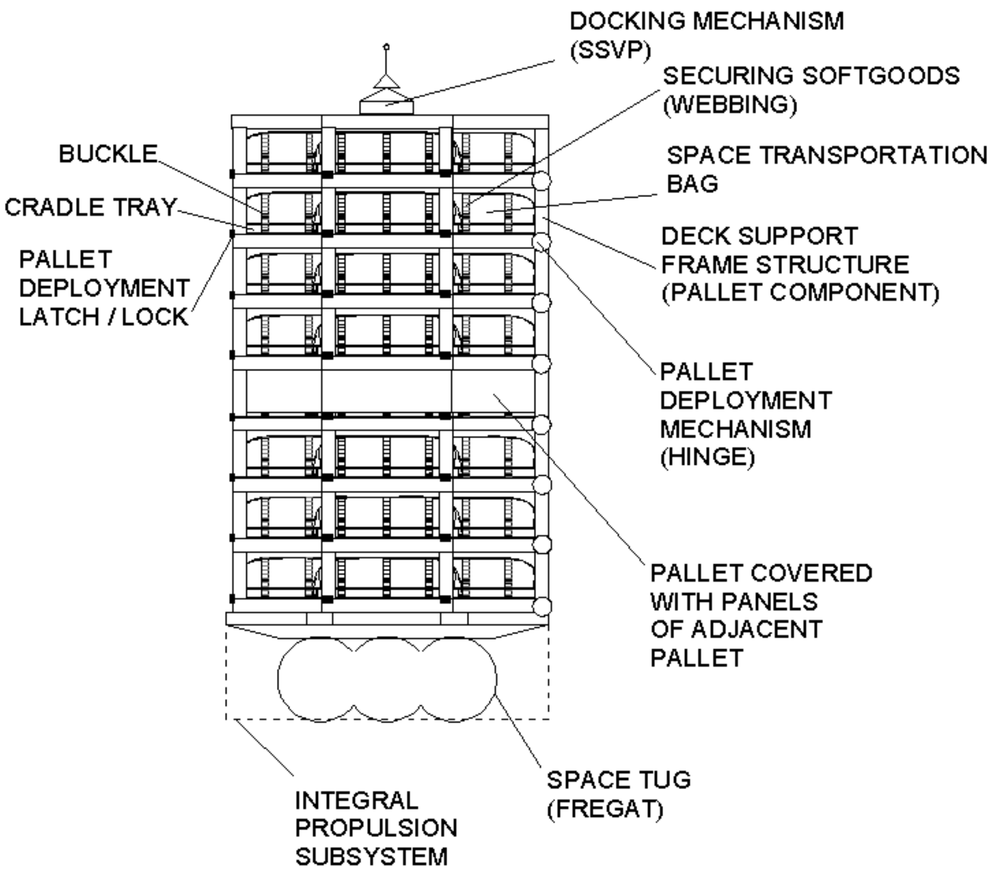


FIG. 18 Side view of a single-deck pallet bus in launch vehicle orientation.

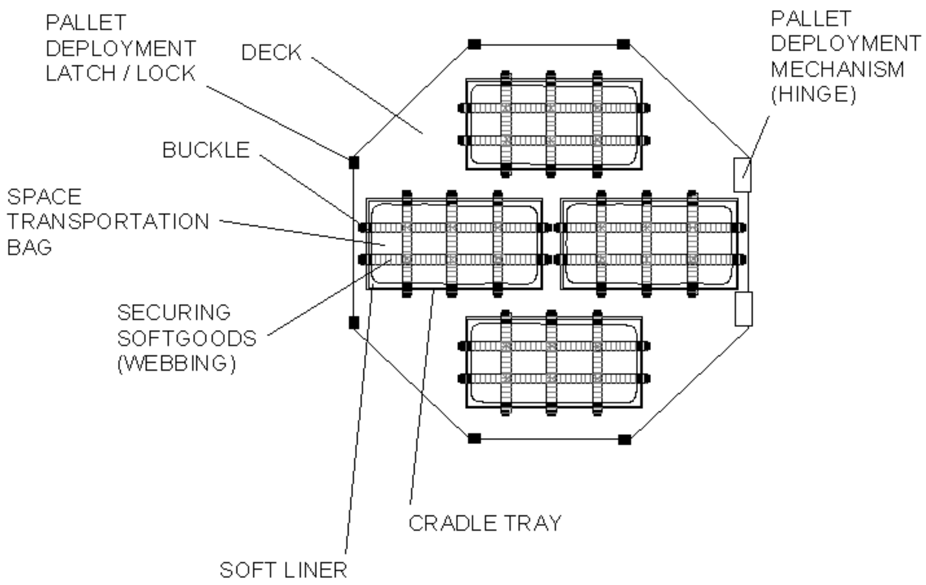


FIG. 19 Top view of a single-deck pallet in launch vehicle orientation.

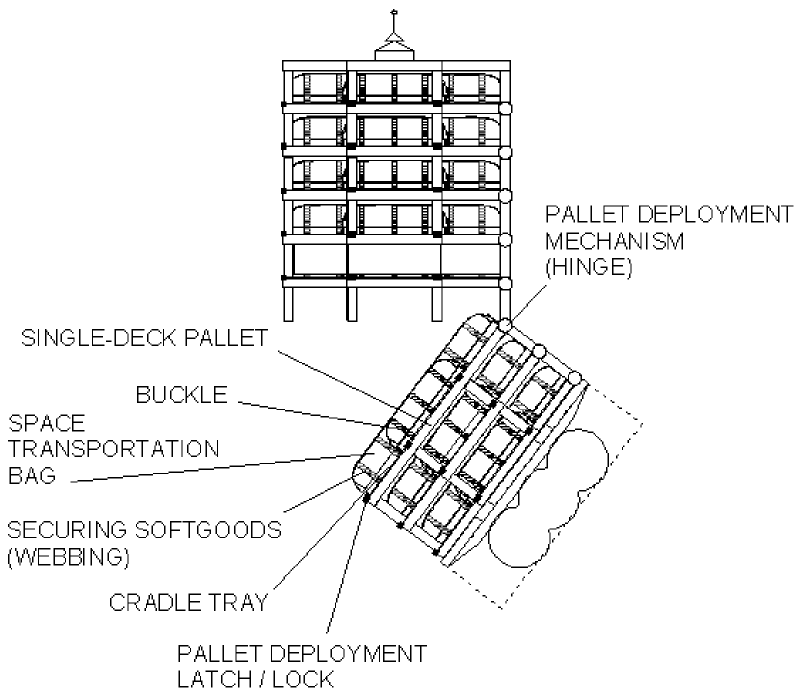


FIG. 20 Single-deck pallet bus during deployment of a pallet.

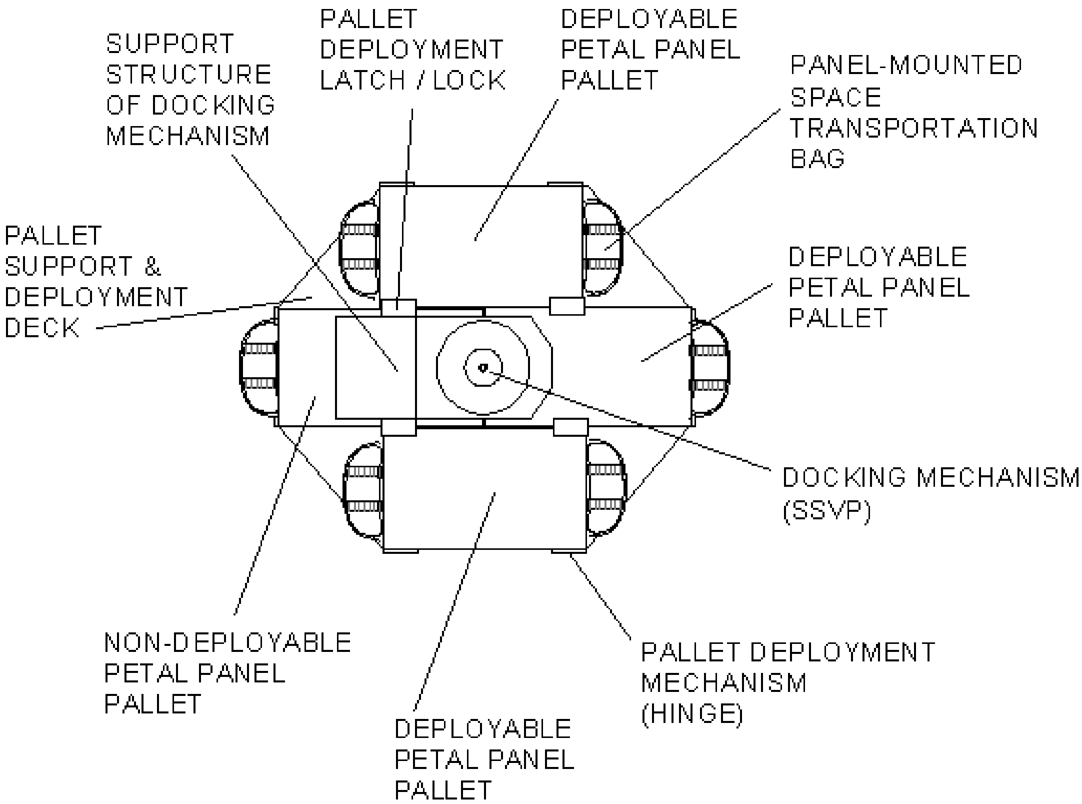


FIG. 21 Top view of a petal-panel pallet bus when not deployed, shown in launch vehicle orientation.

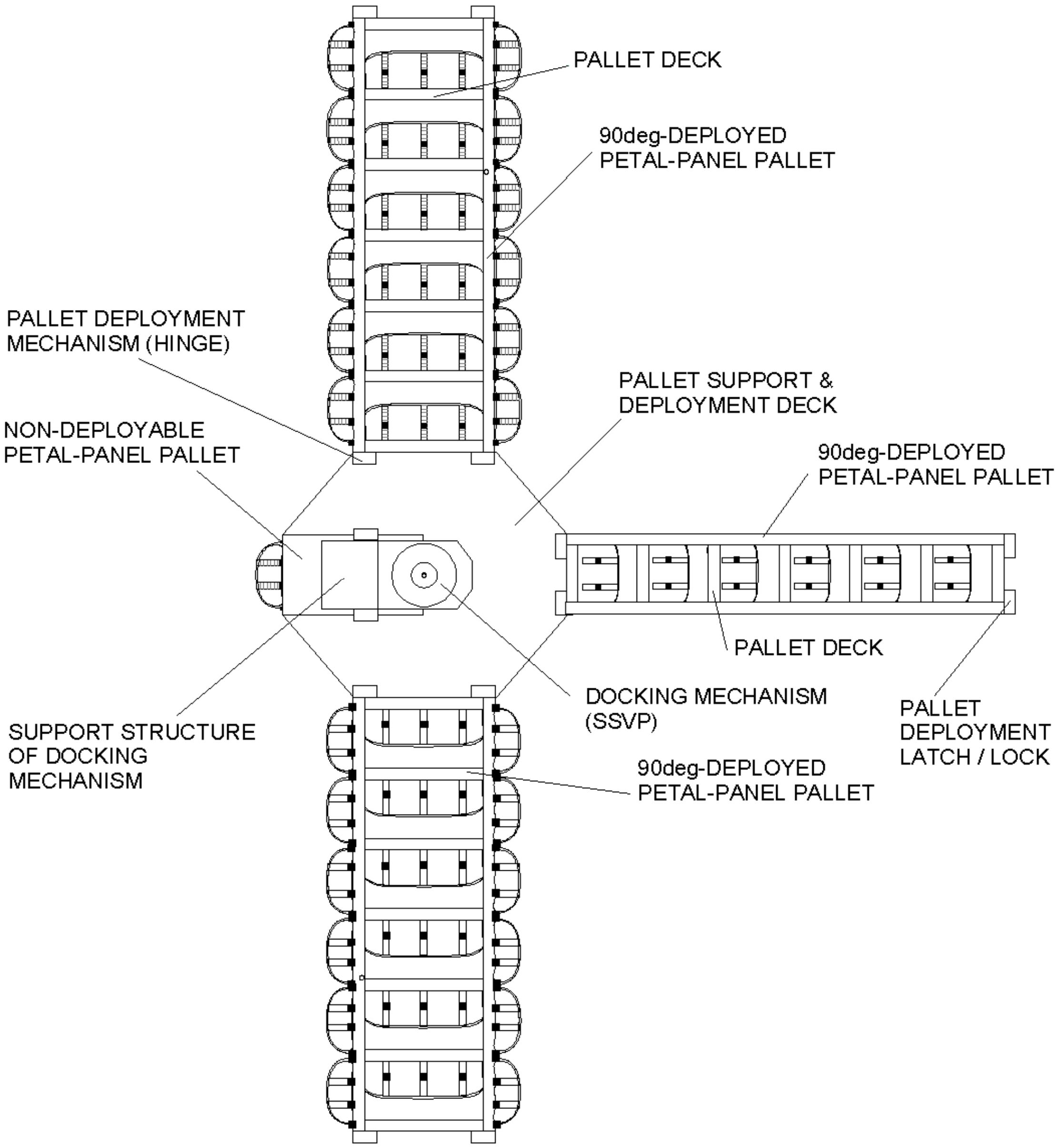


FIG. 22 Top view of a petal-panel pallet bus when deployed to 90deg, shown in launch vehicle orientation.

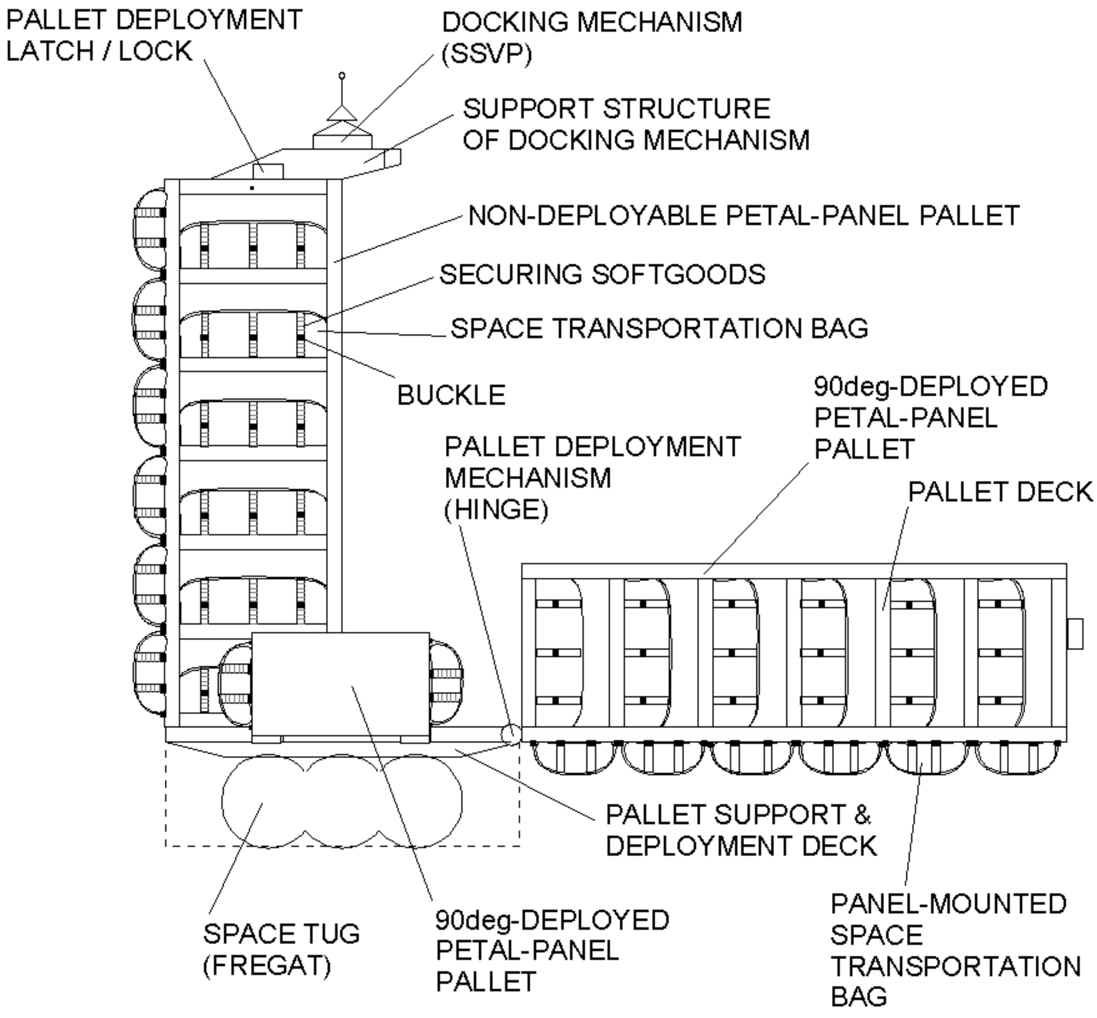


FIG. 23 Side view of a petal-panel pallet bus when deployed to 90deg, shown in launch vehicle orientation.

EVA Hull Assembly in Outer Space

Such hull is assembled during a series of EVAs, in other words a dedicated EVA campaign. Existing EVA spacesuits are used to assemble such spacecraft hull in outer space, for example in LEO. Astronauts performing the assembly works on such spacecraft hull are to use power tools, such as the Pistol Grip Tool (PGT) used for Extravehicular Activities on the ISS. Spacecraft hulls in this invention are assembled in outer space using existing EVA-support equipment that is at present successfully used on the ISS, such as Strela cargo crane, and telemanipulators, such as Space Station Remote Manipulator System (SSRMS), Special Purpose Dexterous Manipulator (SPDM), Japanese Remote Manipulator System (JEMRMS), and European Robotic Arm (ERA).

In conjunction with such robot freighters as Progress, ATV, and HTV, the use of remote manipulators, despite the seemingly slow pace of such remotely controlled work, is preferred to accomplish the majority of orbital assembly tasks, in particular the routine tasks of joining shell blocks to one another with threaded fasteners, because in theory remote manipulators may be employed 8 hours a day 365 days a year, which offers roughly 3,000 working hours on a one-shift working day and 7-day working week for the ground-based operators that can continuously control the remote manipulators from Earth, rather than astronauts aboard the ISS. At the same time, more complex and delicate tasks, such as installation of a soft airtight sack, would be best left to astronaut spacewalks in EVA spacesuits.

During assembly works inside an assembled outer space shell, that is prior to and during the installation of the airtight section sack, use of the following aids may be resorted to in order to permit spacesuit-clad astronaut movement inside large hull volumes: brightly colored equidistantly spaced squares or strips of hook-and-pile Velcro fasteners' pile fabric that is sewn on block liners to be used by astronauts in possession of hook fabric as they conduct their assembly works inside the outer space shell; and astronaut maneuvering equipment, such as Russian Orlan SPK and NASA's MMU.

Structural load bridges, hatchway assemblies, pressurized window assemblies, sockets in block bodies, block bodies, block lids, and other spacecraft components, should preferably bear unique alphanumeric or other markings and symbols that are painted, sewn on, or otherwise applied, for part identification purposes and in order to clearly show the correct shell location and spatial orientation of the structural load bridges and blocks in order to assist EVA astronauts or remote manipulator operators to correctly align each bridge and block during its installation.

The following sequence contains essential assembly steps and only describes assembly of one section, whereas assemblies of other sections can be either done concurrently or in a section-by-section sequence. In the below sequence, a spacecraft or space station, which serves as the space base for astronauts, who in outer space assemble a new spacecraft that was manufactured according to this invention, is called ‘parent spacecraft’. This is a spacecraft hull assembly process that is unique to this invention.

Unpressurized Payloads Delivery to Parent Spacecraft:

1. Deliver the payloads constituting the disassembled outer space shell including all shell blocks and airtight section sack to outer space, and fasten/dock them to the parent spacecraft.
2. Deliver the payloads constituting the disassembled protective skin to outer space, and fasten/dock them to the parent spacecraft. These payloads can be delivered after the completion of the outer space shell assembly.
3. Deliver the payloads constituting the disassembled deck support shell to space, and fasten/dock them to the parent spacecraft. These payloads can be delivered after the installation of the airtight section sack.
4. Deliver the payloads constituting the disassembled room interior shell including all shell blocks, airtight room sacks, comfort panels, and onboard hardware, to space, and fasten/dock them to the parent spacecraft. These payloads can be delivered after the deck support shell assembly.

Outer Space Shell Assembly:

1. If having uniform shell block layouts, assemble the outer space shell using the ring-by-ring assembly method: first fasten a block to either a point on the parent spacecraft or to a robotic arm of the parent spacecraft, then attach to it an adjacent block after block to form a ring of the spacecraft hull. The outer space shell being assembled is preferably attached to the parent spacecraft at one or more points from the start, and for the duration, of such spacecraft hull assembly works in outer space. When the first ring is completed, attach a block to it and assemble a second ring by attaching each subsequent block to each outermost block of the ring of blocks being currently assembled and to the previously completed ring. Where the block pattern is not uniform, progress according to the logical block layout to produce outer space shell area growth. These methods minimize astronaut movements and manipulation during Extravehicular Activity. Fasten the corresponding block lid to each attached block body with the exception of those block bodies that feature a socket for a structural load bridge. Install each shield block assembly immediately after the blocks of the outer space shell that in the particular spacecraft design surround the shield block assembly in its closed position have been attached to the outer space shell. Keep all installed shield block assemblies on the outer space shell locked closed, except when required for access inside the assembled outer space shell.
2. Stop assembly of the outer space shell leaving uncompleted the designated area around the intended location in the spacecraft hull of a spaceward hatchway assembly of the airtight section sack in order to permit passage of the folded airtight section sack into the assembled outer space shell.

3. Move the airtight section sack inside the outer space shell, the assembly of which has been stopped, through the uncompleted designated area of the outer space shell.
4. Complete outer space shell assembly at the said designated area.
5. Scan all inner surfaces of the assembled outer space shell for micrometeoroid damage, for presence of space debris, and for any anomalies in block surfaces that constitute the inner surfaces of the outer space shell.
6. Gradually unfold the airtight section sack; attach its rigid pressurized hatchway assemblies of spaceward hatchways to their respective holes in the outer space shell; attach its rigid pressurized window assemblies to their respective holes in the outer space shell; attach its structural load bridges to their respective sockets on the outer space shell. Progress in attaching each next bridge into its socket, where each next bridge is preferably a bridge located immediately next to the recently attached bridge on the surface of the airtight section sack. Grow the area of attached structural load bridges of the airtight section sack on the inner surface of the outer space shell until all the bridges are attached to their respective sockets of the outer space shell. If the unfolded airtight section sack presents a large obstruction to astronauts working to attach it to the outer space shell inside this assembled shell, attach one of the structural load bridges at the other end of the sack to its corresponding socket in the outer space shell.
7. Fasten the block lids of those outer space shell blocks that feature sockets to their corresponding block bodies. Install the protective skin on the outward surface of the outer space shell. Progress using either the ring growth method or the area growth method, as used in assembly of the outer space shell. Prior to installing each protective skin panel, conduct visual/optical inspection of the outer space shell block lids located under it.
8. Scan all inner surfaces of the installed airtight section sack for micrometeoroid damage, for presence of debris, and for any irregularities in the attachment of the structural load bridges, rigid pressurized hatchway assemblies, and rigid pressurized window assemblies, especially in relation to the soft sack materials.

<u>Deck Support Shell Assembly:</u>

1. Move blocks of the deck support shell in their respective space-rated transportation bags through a hole in the outer space shell that is designed for a spaceward hatchway assembly.
2. Attach the blocks of the deck support shell that feature sockets for the structural load bridges of the airtight section sack to those structural load bridges. Bring each such block’s socket onto the corresponding structural load bridge of the installed airtight section sack and screw the bridge to the socket in the block to a low tension value of the screws that fasten the bridges to the sockets. Progress in attaching all other blocks of the deck support shell that feature a socket for a structural load bridge of the airtight section sack.

3. Attach the rest of the blocks of the deck support shell using either the ring growth method or the area growth method, as used in the assembly of the outer space shell. When the entire deck support shell is assembled, tighten all screws, both those screws that fasten bridges to sockets and screws that fasten each two adjacent blocks of the deck support shell together, to a higher, nominal screw tension value.

Room Interior Shell Assembly:
Portable pressurizing and life-support equipment is preferably used to provide a nearby standby emergency airlock for the astronauts conducting the installation work on airtight room sacks and respective room interior shells, where each successive completed room that is in the condition of readiness to be airtight will, in combination with such portable pressurizing and life-support equipment, act as a standby emergency airlock.

1. Move the respective space-rated transportation bags containing packed room interior shell blocks, folded airtight room sacks, and onboard hardware for each room into the deck support cavity of each specific room. Fasten each space-rated transportation bag to the blocks of the deck support shell cavity of the room to which the contents of the bag belong. Progress in moving and fastening space-rated transportation bags on a room-after-room basis according to the logical layout of corridors and rooms on decks: when all the space-rated transportation bags have been brought inside one said room cavity of the assembled deck support shell, and have been fastened to the blocks of the said room cavity, then all respective space-rated transportation bags are brought to an adjacent room cavity of the deck support shell, and so forth.
2. Install the airtight room sack and assemble the room interior shell inside the docking room designated to be used to dock the spacecraft being assembled to the parent spacecraft.
3. Install pressurization hardware and life-support systems into the room interior shell cavities inside the docking room.
4. Test full pressurization of the airtight room sack of the docking room and retain the internal air pressure on a nominal value.
5. Dock the spacecraft being assembled at the assembled docking room to the parent spacecraft.
6. Progress on a room-by-room basis in airtight room sack installation followed by airtight attachment of the airtight room sack's pressurized hatchway assembly, and assembly of room interior shell - one room at a time - first all docking rooms and airlocks, then all other rooms according to the logical deck layouts of corridors. When the installation of airtight room sacks and assembly of room interior shells of all docking rooms and airlocks of the section has been completed, bring portable pressurizing and life-support equipment inside the section and pressurize the section sack to the operating pressure of pressure suits worn by astronauts during these intravehicular assembly works in order to provide a breathing environment during assembly of airtight room sacks and room interior shells in all other rooms in the section. Use each successive

completed room at such stage of spacecraft assembly as a backup emergency airlock.

7. Install pressurization hardware and life support systems in the room interior shell blocks' cavities in those rooms as provided according to the particular life support architecture of the spacecraft being assembled.

Spacecraft hull components and vacuum-rated onboard hardware to be used inside the pressurized volume of the section, including room interior shell blocks, is first brought inside the not-yet-pressurized section being assembled, and only then the entire section is pressurized. This method does not require the sequence of first bringing in a quantity of spacecraft components inside an airlock, pressurizing the airlock, then astronauts going out on EVA to bring in a next quantity of components from outer space, and the process repeated many times. This method equally eliminates the requirement for costly pressurized man-rated spacecraft to deliver all the spacecraft components. This advantage equally applies in reverse sequence to overhauls of this spacecraft hull structure in outer space.

<u>Pressure Testing of Inner and Outer Air Pressure Systems:</u>

1. When the installation of all room interior shells in all the rooms, corridors, docking rooms and airlocks is completed, and all airtight room sacks' rigid pressurized hatchway assemblies are airtightly attached to form the inner air pressure system, test pressurization of the inner air pressure system to a range of pressure values combined with a vacuum pressure value set in the outer air pressure system, and retain the pressure in the inner air pressure system on the nominal operating value.
2. Test pressurization of the airtight section sack to the nominal operating air pressure value of the inner air pressure system, and to a range of pressure values, including a vacuum pressure value set in all docking rooms and airlocks combined with the nominal operating pressure value of the inner air pressure system maintained in the outer air pressure system.

<u>Completion of Installation Works in Room Interior Shells:</u>

1. Ingress without spacesuits or pressure suits on into all rooms of the completed section.
2. Complete installation of onboard hardware into the room interior shell in each completed room, corridor, airlock, and docking room of the spacecraft section.
3. Install the comfort panels that cover all the onboard hardware in the room interior shells' cavities in all rooms.

It is preferable that parent spacecraft crew, on a mission to install onboard hardware to pressurized rooms of a section, wear emergency pressure suits folded in backpacks in order to have access to an emergency pressure suit if an astronaut has to opt for self isolation in a room in the event of accidental depressurization of the inner air pressure system. Because it cannot be predicted in which room an astronaut will be during such accidental depressurization, it is important that the emergency pressure suit remains with the astronaut at all times during intravehicular hardware-installation works in the pressurized habitable facilities of a spacecraft hull that is built according to this invention. The Russian Sokol-KR pressure suit, which is compatible with regenerative life support, or such suit's derivatives are preferable, providing they are equipped to provide autonomous pressurization and breathing support that will be sufficient to permit the astronaut to reach the nearest airlock.

The above sequence describes only the essential steps required during the assembly in outer space of a spacecraft hull built according to this invention. Depending on a particular spacecraft design, as well as in complex spacecraft architectures, some of the above steps may be completed prior or after the location in the sequence that a step has been assigned above. Each of the steps in the above sequence constitutes, or requires, performance of a number of smaller tasks that will depend on particular settings and hardware used on a specific space mission.

Theoretical Summary of Predominantly-Rigid Hybrid Sandwich Hull Structure 'Shell-Bladder-Shell'

The fundamental theory of this new pressurized habitable hull class for a space vacuum environment is a structural sandwich shell-bladder-shell that is realized here as a combination of:

1. A segmented non-airtight pressurized rigid outer shell that is:

    (a) assembled in a space vacuum environment from a number of separate non-airtight load-bearing rigid hollow block bodies that feature side surfaces, back, lid, and internal load-bearing structures, in such arrangement that said non-airtight pressurized rigid shell's thickness, as the overall thickness of the shell's hollow wall, is formed by the side surfaces of said rigid hollow block bodies, and that said non-airtight pressurized rigid shell's solid surface that restrains at least one soft airtight bladder from point 2 is combined of either the backs or lids of said rigid hollow block bodies;

    (b) assembled into one body shape for its nominal use in a space vacuum environment only after the delivery of said rigid hollow block bodies as independent payloads to a space vacuum environment, where said rigid hollow block bodies are joined with their adjacent counterparts by threaded fasteners;

    (c) a body shape featuring at least one combined solid surface that restrains said soft airtight bladder under internal air pressure throughout the corresponding surface area of said bladder;

    (d) the primary load-bearing structure for structural restraint of internal air pressure loads, whereby the internal air pressure is restrained and counteracted by the clamp force from combined preload of the threaded fasteners that join all said load-bearing rigid hollow block bodies that form said non-airtight pressurized rigid shell, as an alternative to a thin-walled metal pressure vessel with wall stiffeners;

    (e) the primary load-bearing structure for structural loads associated with said hull structure's motion or with gravitational force in a space vacuum environment, and for mounting secondary and tertiary structures and onboard subsystems;

    (f) constituting the structural load-bearing bulkheads outside said soft airtight bladder.

2. At least one airtight bladder assembly that is delivered to a space vacuum environment as an independent payload, that is pressurizable when restrained by said rigid outer shell of point 1, and that comprises:

(a) at least one layer of said soft airtight bladder that acts as a soft gas barrier for internal air pressure;

(b) airtight rigid elements, which are pressurized when the airtight bladder assembly is pressurized, and at which said airtight bladder assembly is non-sealingly and non-airtightly fastened to said non-airtight pressurized rigid outer shell from point 1 and to a non-airtight air-pressure-loaded rigid inner shell from point 3, wherein said rigid elements are sealingly and airtightly preinstalled in said soft airtight bladder and wherein said rigid elements comprise:

(b.1) at least one rigid airtight hatchway assembly of a non-circular shape, which can be pressurized/depressurized separately if the hatch door is locked;

(b.2) at least one airtight structural load bridge component that is present on both interior and exterior surfaces of said soft airtight bladder as a means of fastening said airtight bladder assembly to at least one shell;

(b.3) one or more optional rigid airtight window assembly.

3. An additional segmented non-airtight air-pressure-loaded rigid inner shell inside said fastened soft airtight bladder assembly from point 2 and said non-airtight pressurized rigid outer shell from point 1, wherein said additional non-airtight air-pressure-loaded rigid inner shell is:

(a) a body shape assembled in a space vacuum environment from a number of separate non-airtight load-bearing rigid hollow block bodies that feature side surfaces, back, lid, and internal load-bearing structures, in such arrangement that the overall thickness of the hollow wall of said non-airtight rigid inner shell is formed by the side surfaces of said rigid hollow block bodies;

(b) assembled into one body shape for its nominal use in said hull structure only after the delivery of said rigid hollow block bodies as independent payloads to a space vacuum environment, and only after the assembly of said non-airtight pressurized rigid outer shell from point 1 and after the fastening of said airtight bladder assembly from point 2 to said non-airtight pressurized rigid outer shell from point 1;

(c) a load-bearing structure for structural loads of said rigid outer shell from point 1 that are caused by the internal air pressure acting on said rigid outer shell, whereby said structural loads pass through said structural load bridge component of said airtight bladder assembly, and are counteracted by the clamp force from combined preload of the threaded fasteners that join all said rigid hollow block bodies that form said non-airtight air-pressure-loaded rigid inner shell;

(d) a load-bearing structure for structural loads associated with said hull structure's motion or with gravitational force in a space vacuum environment, for mounting secondary and tertiary structures and onboard subsystems;

(e) featuring at least one combined solid surface that encases said soft airtight bladder throughout the corresponding surface area of said bladder, where said solid surface is combined of either the backs or lids of said rigid hollow block bodies;

(f) fastened to said airtight rigid elements of said airtight bladder assembly;

(g) constituting the structural load-bearing bulkheads and structural load-bearing floors and ceilings inside said soft airtight bladder;

(h) providing shape retention to said soft airtight bladder on its inner side when said bladder is depressurized.

4. The structural sandwich in points 1-3, as most evident in the simplified embodiment Trekker-II, such as in artist's impression 3, whereas:

(a) in the cross section of the preferred embodiment Trekker-III, the structural sandwich in points 1-3 is repeated to result in three shells interspersed by two soft airtight bladders, with the outer shell according to point 1, the intermediate shell according to both points 1 and 3, the inner shell according to point 3, and two soft gas barriers of separate airtight bladder assemblies according to point 2;

(b) in the highly simplified embodiment Trekker-I, said rigid inner shell in point 3 is substituted by rigid load-bearing beams or stand-alone bulkheads, which are composed of shell blocks according to point 3 without a complete shell.

5. A set of further vital defining characteristics:

(a) no dedicated launch vehicle is required, and the length, width, height, cross section area, and pressurized volume, of said hull structure are not constrained by the payload fairing dimensions of the launch vehicle used;

(b) any of said rigid hollow block bodies is removable and replaceable while said hull structure remains in a space vacuum environment;

(c) at least one said airtight bladder assembly can be stored as a spare inside said hull structure's pressurized volume while said hull structure remains in a space vacuum environment;

(d) said airtight bladder assembly is removable from said non-airtight rigid outer and inner shells and is replaceable by another airtight bladder assembly that meets the specifications while said hull structure remains in a space vacuum environment;

(e) in the preferred embodiment Trekker-III, said rigid outer shell and said rigid inner shell may reverse the above roles due to the spacecraft hull having three matryoshka-positioned shells and two matryoshka-positioned air pressure systems.

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