SMAP Proposal:

“Wet-Workshop” Heavy Lift Launch Craft

Overview

The Heavy Lift Launch Craft (HLLC) is an application of the Standardised Modular Systems Technologies (SMST) design philosophy. In technical terms, assets are configured around technologies that leverage reiterative systems using interchangeable modular components that follow a common interface. Breaking this down into more friendly terms, each project is designed from conception to realisation to be able to integrate with all other individual components and/or sets of components.

This Modular Heavy Lift Rocket proposal returns us to the “wet workshop” concept first studied for NASA’s Skylab, and takes that concept a step further. Instead of using a traditional (usually expendable) staged heavy lift launch vehicle (“booster rocket”) to place a single propellant stage into orbit, *<u>all</u>* of the standardised “stages” used as propellant tanks would be lifted into orbit. On the one hand, this would mean that a Saturn V sized rocket, instead of bringing a payload to trans-lunar insertion, would only be able to bring that “payload” to low Earth orbit, which might appear to be a waste of propellant and structure. On the other hand, this means that the rocket can be effectively 100% reused. More accurately, virtually 100% of the structural mass *becomes* useful payload, as habitable volume for a productive space station. Furthermore, advances in solar electric propulsion would allow these modules to be transferred to much higher orbits, using less propellant. Such a transfer could be conducted well after any original servicing missions, reducing overall operations costs. The entire assemblies could even be transferred to lunar orbit. Of the initial launch mass, only the thruster assemblies would be staged, with various thruster packages being jettisoned for return to Earth when the total thrust produced is no longer necessary. These packages could easily be designed for controlled return, allowing reuse in later rocket assemblies. Effectively, instead of building rockets to launch payloads, part of the payload is repurposed to serve as the rocket.

This would not be an inexpensive program. Although a dedicated effort would allow for a ten-year timeline, the requirements for establishing funding, as well as a construction infrastructure, would likely move this into a Category 3 mission timeline (20 – 30 years). However, initial trial units could serve immediately productive functions that might be “hired-out” with the first units built. This is primarily intended for the Operations Demonstration Mission domain

Function & Characteristics

The HLLC is a multi-modular craft designed to lift large loads to low Earth orbit (LEO). Importantly, the propellant containment modules for the liquid hydrogen (LH) and liquid oxygen supplies shall themselves serve as important “payload” items, utilising the “wet-workshop” launch concept studied by NASA, in consideration for the Skylab project. Following this concept, the modules would be delivered to space, where they would void or dilute their contents (normally after transferring all possible contents into dedicated storage, for later use) before being re-pressurised with atmosphere. Internal furnishings and fittings would be assembled according to the required functions of future missions. The individual modules can be undocked and re-docked according to any number of functional configurations.

The maximum load configuration for the HLLC is capable of delivering 250 tonnes of non-structural “payload” to orbit, in addition to 860 tonnes of standardised modules to be repurposed from launch propellant tanks, in a single-stage-to-orbit (SSTO) configuration. Alternatively, the non-structural “payload” can be increased to 565 tonnes, with 540 tonnes of standardised modules, following an appropriate staging strategy. These performance figures are based upon the following assumptions:

- propellant mass to total mass ratio of 90%
- propulsion mass to total mass ratio of 2%
- structural mass (less propulsion mass) to total mass ratio of approximately 7%
- propulsion system parameters consistent with RS-25 “Space Shuttle Main Engine”
- required effective delta-v (calculated delta-v plus drag penalties) of 9.5 km/s

Composition

The HLLC shall consist of the general components listed below. However, not all components would be required for all missions. Furthermore, each general component would have several possible specific variations, depending upon the operational regime and mission-determined specifications.

Each component itself would generally be composed of a selection of “plug-in” mission packages. These packages would likewise follow the principle SMST design philosophy, in that each should be designed around a common interface configuration.

- **Pressure Vessel Modules (including fuel and/or propellant)**

  Pressure vessel modules are simply containers used to store “fluids” (normal or cryogenic liquids, pressurised or ambient gases, particulate solids, etc) for later use. This might include combustive fuels (oxidants, reductants, and/or catalysts), propellants, pressurisers, pneumatic or hydraulic fluids, lubricants, water and air provisions, etc. These pressure vessel modules will plug in to standardised connectors that will distribute the contents through piping that is nominally built into the structure of the frame, with minimal extra mass.

  In the case of the HLLC, these pressure vessel modules are the single most important elements of the assembly, as they constitute the principle “payload” being delivered to space. The standardised modules will conform to 12.5m, 6.25m, and 3.125m diameter configurations, with the larger intended to serve as the primary habitation modules for space-based assemblies. The mid-sized modules would normally be used for “depot” storage, as well as docking node assemblies; and the smaller modules would primarily serve as airlocks and transfer corridors between larger modules.

The 12.5m modules intended for use as habitat modules in space will be constructed with five concentric shells. The inner shell will provide containment for the propellant, and the outermost shell will provide the structural support necessary to carry the superposed modules and perimeter core assemblies under full launch stress. The additional shells will provide additional impact and radiation protection, as well as isolation. The resulting “void” spaces will have functional inserts, and will serve as propellant feed piping during launch, while serving as tankage in space. Other modules will normally have only the inner and outer shell, with inserts in the “void” spaces.

These modules are notably “over-engineered” in terms of use as propellant tanks. However, it should be kept in mind that these will serve as primary habitation structures for space missions, and the additional structure will provide necessary protection for long-term space missions.

- **Control Module**

  As the name implies, control modules are assemblies of packages that govern the operation of an asset. This would include all systems required to permit direct operation by a (human) controller; remote operation through direct tethered (wired) and/or transmitted (wireless) command signals; automation assisted direct or remote control (“fly-by-wire”); programmed automated guidance, with or without transmitted “assignment” and/or “revision” commands; and/or, full Artificial Intelligence (AI) guidance, with or without transmitted override commands. In order to perform these tasks, the control module will integrate the following plug-in packages:

  - Guidance Package

    At its simplest, the guidance package would consist of a manual control system that allows an operator to command the unit directly, either through mechanical, electrical, and/or electronic mechanisms. Alternatively, the guidance package would consist of a control relay system that receives and acts upon command signals from an operator; a programme package that stores and acts upon pre-programmed operating instructions; and/or, an AI package that acts directly as an independent operator subject to a set of dictated mission orders and parameters.

    In addition to these control functions, the guidance package will generally include systems that provide feedback to the operator, whether control is manual or remote. At the most basic, this would include status information and/or alert systems. Other information would include visual and/or other sensory environment displays, navigational orientation and plotting information, command confirmation, performance information, etc.

Examples of such guidance packages would include the common throttle and "joystick" controls found on most aircraft, the steering wheel and dashboard displays found in most cars, or simply the handlebars and simple indicators mounted on a motorcycle.

- Inertial Navigation Package

  An inertial navigation package would include mechanical and/or electronic gyroscopes and accelerometers to track inertial rotations and displacement. This would allow for some minimal guidance information should more reliable information become unavailable.

- Navigational Sensor Suite Package

  The navigational sensor suite package includes any instrument necessary for determining orientation and location information, as well as relative guidance information. This information is especially necessary for conducting rendezvous manoeuvres. An example of such a package would be the star trackers found on most existing spacecraft and probes.

- Interactive Navigational Positioning Package

  Interactive navigational positioning packages are intended to complement the functions of navigational sensor suite packages and inertial navigation packages by allowing the reception of tracking information provided by an outside source. If necessary, these functions may replace on-board navigational functions, although this should be avoided, as exterior systems might lack the resolution necessary for close manoeuvres. Examples of these packages include GPS, fixed directional transmitters, radar relays, etc.

- Processing Hardware and Software Packages

  The processing packages are essentially computer systems that support and coordinate the functions of the other integrated packages and components.

In addition to these packages, the control module will also provide the basic shielding required to protect these integrated plug-in systems from nominal ballistic impact, radiation hazards, and any other hazard inherent to normal function.

An HLLC might be fitted with a large number of control modules, etc being reassigned to a specific task once delivered to space. Normally, these will be mounted as “nose-cone” structures capping the core stacks (described below).

- **Core Frame**

  The primary functions of the core frame are to: provide structural support for all components and assemblies; to provide standardised connections to link all components and assemblies; and, to act as a primary bus for electronics, power, and piping.

  The core frame does not include any sub-system packages, per se, as all other modular assemblies are essentially plug-in packages for the frame. However, the frame shall be designed to incorporate piping/conduit channels directly into the support structure, permitting the easy installation of bus “circuits”, integrating the functions of connected modules. These channels shall be integrally constructed into the frame structure, providing strength and reinforcement, while allowing for a lighter overall structure, in the same way that reductive machining of the shells of the Saturn V stages allowed their mass to be reduced.

  In addition to the integral channels, there shall be a number of connector “hard-points”, which shall accommodate all functional modular components and assemblies. These connector points will have a standardised configuration governing the placement of structural joints, piping joints, electrical and electronic bus conduit joints, etc.

  In the case of the HLLC, the core frame shall consist of a central core stack of “wet-workshop” propellant modules. In the heaviest HLLC configuration, this core would normally be composed of four large modules, each measuring 25 meters in length and 12.5 meters in diameter.

- **Frame Extension Modules**

  In some circumstances, the core frame module might not beef sufficient size to support all the component modules required for a given mission. In such cases, extension modules might be plugged-in, using existing connectors, to extend and reinforce the structural support provided by the frame. These extensions will be standardised components, and might themselves consist of spare core frame modules.

  In the case of the HLLC, these modules would constitute the intermodule assemblies between pressure vessel modules; but would also include the peripheral, or perimeter, core stacks. These latter core stacks would normally be smaller diameter modules than those used for the central core frame. The peripheral core stacks could be delivered to orbit in a single-stage-to-orbit (SSTO) configuration. However, they might also be jettisoned for reuse with another HLLC assembly, allowing a staging strategy that would permit a greatly expanded allowance for non-structural “payloads”.

- **Propulsion Modules**

  As the name implies, propulsion modules are responsible for producing the thrust necessary for translational and rotational displacement. For the purposes of this project, this would include otherwise “passive” control surfaces that modify the fluid flow of a surrounding environment. This function would then include the following packages:

  - Thruster Package(s)

    The thruster package provides the force necessary for motion, and would include any items required for providing, directing, and modifying that force.

  - Thrust Assembly Structure

    Thrust assembly structures serve as mounts for thruster packages, and are further responsible for distributing the force of thrust through a given structure. In addition, these structures include features to protect surrounding structures from any resulting hazards, such as thermal loads, shock/vibration loads, etc. Several thruster packages might be mounted on a single thrust assembly structure. Thrust assembly structures may also include systems necessary to eject the structure for staging or abort manoeuvres, as well as those required for assisting in the recovery of the assembly.

  - Control Surface Packages

    Control surface packages include simple surface structures, joint/hinge assemblies, and motive actuators. These packages might simply be appropriately placed to modify the fluid-dynamic flow of a surrounding media, such as water or air, or they may be placed in the exhaust stream of the thruster(s) used. Examples would include dive planes, ailerons, and rudders.

  - Auxiliary Packages

    Auxiliary packages are systems and components that allow propulsion systems to be tapped to provide for other functions, and/or to facilitate and augment the functions of propulsion systems. An example of the former function would be an auxiliary generator that produces electrical power by tapping the exhaust flow from the thruster to power a turbine. An example of the latter would be a set of pumps and valves to regulate and augment propellant flow.

  Propulsion modules will plug-in to standardised structural and functional connector points, located on the core frame. As with all such points, there will be a fixed orientation between piping joints, electrical and electronic conduit joints, etc.

On HLLC assemblies, the propulsion modules will normally be strictly reserved for the base assemblies of the central and peripheral cores. Unlike the strategy used by Saturn V, and other similar rockets, no thrust assemblies will be located between modules. First, this is because the modules themselves tend to constitute “payload”. Second, because the reservation of thrusters for later stage use means that there is an increased initial mass that detracts from the useful mass allowance for orbital delivery. Rather, every thruster will be available for use at launch, where maximum combined thrust is required. Individual propulsion modules will then be “staged” independently, when the combined thrust is no longer necessary.

- **Power Supply, Storage, and Conditioning Modules**

  All active on-board systems will require power to operate. This requirement shall be addressed by the following components.

  - Power Generator and/or Collector Package(s)

    Power generators and collectors provide power necessary for the operation of various systems. Generators produce the power themselves, often through the use of turbines that tap either ambient fluid flow or fluid flows generated by chemical or nuclear reactions. Collectors passively absorb ambient energy, generally converting that energy to electrical power.

  - Power Capacitor/Storage Package(s)

    Most simply, power capacitor/storage packages are “batteries” that store and supply power (usually electrical charge, but this might also apply to hydraulic and/or pneumatic systems) to onboard systems. These units do not actually produce any power, but allow power to be tapped when generators and/or collectors are not in operation.

  - Power Conditioning Package(s)

    Many, if not most, onboard systems require relatively precise configurations of electrical power. Power conditioning packages, then, provide for the carefully controlled supply and distribution of power (again, normally this would be electrical power, but there are other options, more mechanical in nature). Such functions might include conversion between direct and alternating current, augmenting (concentrating) or decreasing (stepping-down) current loads, augmenting or decreasing voltage, etc.

These modules will plug in to standardised connectors that will distribute electricity through wiring conduits nominally built into the structure of the frame, with minimal extra mass. Wherever possible, the modules will, themselves, fill spaces in the core frame structure, to provide additional strength reinforcement. Likewise, the distribution wiring would preferably be in the form of “printed” plates that also add to the frame strength.

- **Thermal Control Modules**

  Thermal control modules shall consist of all components and assemblies required for regulating on-board thermal conditions. This would include, for example, coolant reservoirs, flow piping, heat exchangers, and radiator arrays for a thermal rejection system. Again, this would be designed to plug-in to the core frame, or directly into a specific component requiring thermal control, via a standardised connector.

  Normally, thermal control provisions would be built directly into the outer shell of the propellant modules. Additional modules, however, might be required for deployment in space, according to specific mission requirements.

- **Standardised Structural Elements**

  Some missions might require more customised configurations than could normally be provided by standardised modules. To address this issue, there shall be a number of more basic standardised structural components. These would be provided exclusively through additive manufacturing (3-D) printers. Such component designs might include, but not necessarily be limited to:

  - Spinal Elements

    Spinal elements redesigned to support the linear stresses induced by thrust. Normally, this function is addressed by the core frame. This would be equivalent to the function of the spinal column and lower limbs of the human body

  - Framal Elements

    Framal elements are intended to support lateral loads, and distribute them through the spinal elements. This function is roughly equivalent to the ribs of the human body.

  - Stanchional Elements

    Stanchional elements are designed to distribute stresses through a larger area, thereby decreasing the loads applied to any given point.

  - Brachial Elements

    Brachial elements provide structural reinforcement and rigidity. In principle, these elements, being more easily replaceable and less vital, are designed to fail before more important elements.

  - Shells

Shells constitute the “skin” of a structure, and are designed to provide a measure of protection for underlying components. They also provide containment, and/or other forms of isolation (or protection) between environments.

Normally, these functions are built directly into the previously specified modules, where over-redundant elements may be eliminated.

For the HLLC, these standardised structural elements would be used to provide custom frames for mounting peripheral cores to the central core, especially where there might be projections from “payload” assemblies. These components might also be used to construct customised “nose-cone” fairings and intermodule assemblies.

- **Mission Specific Modules**

  Mission specific modules are those components and assemblies that are specifically designed to perform required tasks. Such modules are too numerous to itemise; however, they might include such elements as mission-dedicated sensor arrays and suites, grappling and mooring arms, manipulator arms, tooling arms, extended range transmitters, narrow beam transmitters, scientific instruments, recording equipment, analytic instruments, mini- and micro- laboratories, etc.

  On the HLLC, most mission specific modules will generally be loaded as “payload” within faring assemblies. However, in some cases, a standardised pressure vessel module might be replaced by one or more specialised modules that deviate to some degree from the normal structure.

Sample Configurations

The standard configuration of an HLLC would consist of a central core stack of four 12.5m modules, with a central thrust structure surrounded by four stageable thrust structures. Eight peripheral core stacks of four 6.25m modules (or their equivalent in overall length) each would then be appended to this assembly; as well as up to four stacks of 3.125m modules. Each peripheral core stack would be fitted with its own faring and thrust structure. The central core would normally supply LOX, while the mid-sized peripheral cores would store LH. Under normal operation, the thrust structures would be progressively staged. Where additional non-structural “payload” mass is required, The mid-sized peripheral cores would also be staged, at the expense of total mass delivered to space (due to the decreased mass ratio, in terms of propellant to total mass, at launch).

An alternative arrangement would simply have the central core, with no peripheral cores. A single module would be used to store LOX, with the remaining modules dedicated to LH supply. This configuration would serve as an SSTO craft, with only the four outer thrust assemblies being staged. The three LH modules would be a lighter design, with only two shells each, and thus would not be suitable as primary space habitat modules. They would, however, be suitable for use as surface habitat modules, either inserted into mines, or covered with regolith.

Other alternatives would follow the same basic configuration, except the central core would consist of 6.25m modules, with up to ten 3.125 module core stacks used for the peripheral assemblies.

Realisation

The HLLC project is intended for a thirty year time frame. At present Space Decentral does not have even the most basic infrastructure in place for such a proposal. However, that should not block the pursuit of such an objective.

The first, and most important, stage for this project would be the design and testing of the standardised modules. This can progress first with the development of initial “mock-up” constructions. Although unsuitable for space applications, these initial structures could be used to examine interior configurations, as living and working spaces. Early structures could be built from simple sheets of aluminium. Ideally, these structures would be mass produced, allowing for the greatest variety of interior and composite configurations. The units could then generate revenue as low-cost housing structures and test facilities. Initial models could be made available within a single year. With an internal diameter of 12 meters, a four-level module with a lateral orientation, configured for living and/or office working space, will provide over 500 m^2 of floor space with full 2.5m ceiling clearance; with an additional 125+ m^2 of reduced clearance, but useful, floor space. Configured as a three-level industrial workspace, the module will provide 200 m^2 of floorspace with a full 4m clearance, with an additional. Projected cost should fall in the $50 000 to $100 000 range for each test article.

When internal arrangements have ben studied for some time, formal structural designs and configuration can be tested for suitability with various construction methods; notably additive manufacture (3D printing). Again, the products can be sold or rented out as low-cost living units, deriving revenue for future work. These construction studies could be pursued within a five-year time frame.

Eventually, more complex shell structures would be manufactured. These would then be available for testing under extreme conditions. Units would be made available for remote stations in various climates, as well as for testing in polar and submersed aquatic environments. Once again, these could be made available for common housing, but they would also actively serve to support research operations, especially for oceanic research communities. Full service to scientific institutions should be possible within a ten-year time frame, as infrastructural elements continue to be developed and put in place for eventual space-based activities.

In the long term, research would progress with the alternative arrangements using smaller core stacks. Eventually, the infrastructure should be available for larger arrangements. Even at later stages, the most important elements for the design would be the pressure vessel modules. If necessary, propulsion modules could be assembled from existing corporate suppliers, such as Space-X; although it would ultimately be less expensive to design and produce these components in-house.

Value Proposition

State Of The Art

SMST assets are founded upon the long established precedents that are the bases for such varied transportation resources as the common tandem truck, the common locomotive, the common car or pick-up truck (with the option of trailers), and the less common Sikorsky CH-54 / S-64 Tarhe “SkyCrane” helicopter. Similar precedents from other domains include the wide range of USB (especially “plug & play”) devices in the electronics domain, Dremel tool sets (especially the current “Speed Click” attachment line) in the home projects domain, click-on hose attachments in home gardening; just to name a few. Incidentally, all of these items, in addition to the inspiration that they have provided to the conceptual design, have direct applications that SMST will draw upon.

Purpose

The fundamental purpose of all SMST assets is to create a flexible infrastructure serving the development of space based communities, with numerous Earthbound applications as well. In the same way that the US Interstate Highway System, and all the lesser highways, streets, and smaller roads are integral to the functioning of the US economy (with the support of waterways, railways, and air-travel), SMST assets are intended to provide for all the necessities of the eventual interplanetary economy. Such an economy would of course include spacecraft, space stations, and surface bases; however, development of the Earth’s own oceans and currently remote sites (not to mention the scope of existing society) would equally be part of that future industry.

Outside of such well-established, mundane roles, the SMST line would equally provide infrastructural support to more specialised operations. Scientific research would of course be a principle interest, as vehicles, craft, vessels, and other assets deploy equipment and personnel to the outermost reaches; and would likewise be directly engaged in many such activities. Colonial development and support would be another major application; as would resource location, extraction, and transport.

Benefit

SMST assets provide the multi-use flexibility that is commonly found in the products we use in our daily lives. The primary benefit is an adaptable infrastructure that can be modified to accommodate the needs of a specific entity at a specific time.

The application of standardisation means that components will be intentionally designed to function with one another with maximum ease. Modularity allows for components to be arranged in a virtually unlimited number of configurations. It also allows for worn, damaged, or faulty parts to be easily replaced; as well as providing for future upgrades, without having to “through away” otherwise functional, or even “state of the art” parts. Applying this philosophy to different level of systems, rather than just to individual components, offers a degree of recursion that allows even greater diversity in expression.

Space is a difficult domain to operate in. Common expression is “every gram counts”. Whereas a “family car” approach to transport, with one vehicle enlisted to perform every necessary task, tends to waste resources by requiring that vehicle to carry all of the other components that it needs for other tasks, SMST can greatly streamline missions by only carrying the components required for any given mission. On the other side of the equation, where dedicated spacecraft will always outperform any other configuration in any given task, such spacecraft often perform poorly when faced with unanticipated tasks, or unexpected operating conditions. Furthermore, such craft are typically useless after completing their mission, absent the intervention of exceptional mission planners who think of new ways to use the available systems. Although SMST assets can not hope to compete with such a spacecraft in its intended domain, it allows the flexibility for mission planners to reconfigure and reuse old assets endlessly, saving costs on development and assembly; and further permits “last minute” changes in mission parameters.

The HLLC offers a very high “payload” mass delivery to orbit. More importantly, much of this mass is in the form a structural containment for large habitats, which will be a requirement for any serious development of a space-based community. Since this structural mass is no longer a penalty, but a gain, this allows the use of very low density fuels, notably hydrogen, which permits a very clean propellant mix for launches from Earth.

End Users

In the same way that virtually every human in the developed world is an end-user for automobiles, SMST assets are intended to provide a broad-spectrum infrastructural service to anyone operating in space. This service would also be available for application in many domains here on Earth.

Proposal Team

At present, there is no actual team available for this project.