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# Inflatable Land Shelter Demonstrator

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**This paper presents a concept for a rapidly deployable Inflatable Land Shelter Demonstrator that can be dropped from the air and deploys independently of an external power grid. This architecture concept is intended to be used as an analog for future space missions using a self-deployable techniques for the habitat construction on another celestial body as well as for increasing the technology readiness level of critical components of the design as a technology demonstrator. The first analog ILSD is designed to be used in moderate conditions on Earth as a precursor to future revisions for increasingly harsh terrestrial environments and application. Options for deployment of the habitat are studied and optimal architecture for the habitat demonstrator is proposed while interdisciplinary approach is kept in mind. The architecture takes into account three primary operating modes: delivery, deployment, and habitability, and the tradeoffs in the design for an integrated architecture concept for the ILSD. The delivery possibilities are considered from a ground and air-borne, deployment possibilities include fully and partially autonomous as well as one time use versus the ability to reuse or refurbish the habitat, and internal habitability aspects such as HVAC, power generation, lighting, etc. Pre-integration of utilities is also studied.**

## Nomenclature

| | | |
|---|---|---|
| *FEM* | = | Finite Element Analyses |
| *ILSD* | = | Inflatable Land Shelter Demonstrator |
| *HVAC* | = | Heating, Ventilation, and Air Circulation |
| *BXL* | = | Badger eXploration Loft |
| *HDU* | = | Habitat Demonstration Unit |

## I. Introduction

CURRENT long-term space exploration goals for various countries converge on a single idea, planetary body extended habitation. Whether this is the Moon, Mars, or some other planetary body, the use of inflatable structures can increase the launch efficiency of these missions by having a low stowed to deployed volume ratio. This reduced stow volume leads to either more payload on a large launch vehicle, or the ability to use a smaller launch vehicle reducing overall mission costs.

Inflatables have been used for both terrestrial and space applications. Terrestrial applications include air ships, hazmat suits, shelters for polar environments, and space analog demonstrators such as the Badger Exploration Loft[1]. Space applications of inflatable structures include spacesuits, Mars Lander airbags, antennae, airlocks, as well as concepts like Transhab and Bigelow aerospace orbital hotels under development. The use of inflatables as a space

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habitat are still in the testing phases, so terrestrial analog habitats can aide in progressing the maturity of technology used in space applications[2].

For both terrestrial and space based inflatables the design requirements can be derived from the mission concept of operations. The most important scenarios in these design requirements are structural stability, life support systems, habitability, work, simplicity of deployment, and emergency situations. These space mission and design requirements can be directly correlated to design decisions for an analog habitat. This can be seen from the X-Hab competition where the requirements were directly related to the categories of structural integrity, habitability, and utility.

The Inflatable Land Shelter Demonstrator (ILSD) will follow similar design requirements to that of the X-Hab competition due to the similar use scenarios. Additionally it will incorporate additional features such as power generation, and the ability to be air dropped into remote and extreme conditions.

Air dropping of shelters is not a new concept. Patents by Moss[3] and Bixler[4] show concepts of simple shelters that can be air dropped to provide shelter for a couple of days. The ILSD concept expands on that by adding rapid deployment capability, compactness and basic habitability systems to extend the habitation timeframe to weeks.

## II. Relevant Technology – Inflatable Habitats Summary (Space, Earth)

The following examples show the use of inflatables both on Earth and in Space. The examples are chosen to provide a broad overview of inflatable technology, but should not be assumed to be a total review of current uses for inflatables.

### A. Terrestrial Inflatable Shelters

Terrestrial inflatables are a well-defined field with many examples. These inflatable structures range from small shelters e.g., used by military as seen in Fig. 1 to large-scale structures like the ArchiExpo inflatable Hangar seen in Fig. 2. These structures are used for the same reason inflatables are used in space, ease of transportation and packing. There is also a current trend of using rigidizable inflatable structures for semi-permanent structures.

**Figure 1. Military inflatable structure.**


**Figure 2. ArchiExpo inflatable hangar.**

B. **Transhab**

Transhab was a NASA program out of the Johnson Space Center. The aim of the projects was to develop a transit habitat for a trip to Mars[5]. The project evolved into a plan to attach an inflatable module to the International Space Station. This proposed module had dimensions of 12.19 m in length with a 7.28 m diameter, making it a larger volume than any of the hard shell modules in the ISS architecture. The space was designed with four functional areas in mind. The first level was a galley and store room, the second level was crew living quarters, the third was a medical operations area, and the fourth was a transit tunnel to the rest of the space station. Transhab used a bladder and restraints system as seen in Fig. 3, using Kevlar similar to the ILSD inflatable rib system.

Although Transhab never flew due to budget cuts, the ground testing of a prototype model provided valuable data on inflatables as well as insight on manufacturing techniques. Much of the work performed on Transhab has now been carried on by the Bigelow Aerospace Company who are developing inflatable space hotel. Bigelow has flown two models in space, Genesis I and II, and up until recent layoffs were working on a third model called Sundancer.

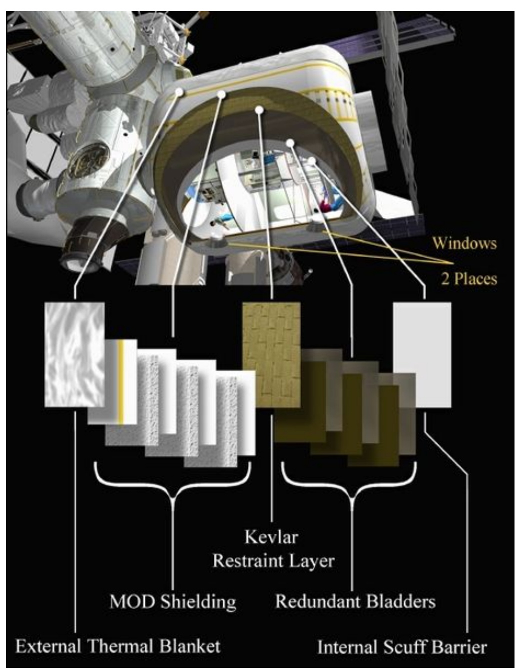



**Figure 3. NASA Transhab material layering.**

C. **Inflex – Intelligent Flexible Structures**

Intelligent flexible structure for rapid space-borne deployment called Inflex is being developed by American ILC Dover[6]. Some of the design concepts for this structure can be used to guide design choices and requirements for other inflatable structures. There are seven objectives of Inflex structure that can be integrated also in the ILSD design:

- Health monitoring sensors
- Self-healing material
- Low permeation materials
- Anti-microbial materials
- Radiation protective materials
- Flexible power generation and storage.

A summary of these parameters can be seen in Table 1.

**Table 1. How can Inflex technology be used in the ILSD Design.**

| **Technology** | **Description** | **Application to ILSD** |
|---|---|---|
| ***Health Monitoring Sensors*** | Identify penetration and quantify damage over time for disturbances larger than 2mm diameter | N/A |
| ***Self-Healing Materials*** | Flexible membrane that can passively seal penetrations smaller than 2mm diameter | Self-healing materials could be used to protect from environmental abrasions |
| ***Low Permeation Materials*** | Reduce the permeation of the pressure retention layer | Materials with low permeability will be used for inflatable ribs |
| ***Anti-Microbial Materials*** | Create a material to enhance crew health through inclusion of anti-microbial and anti-viral capabilities | N/A |
| ***Radiation Protective Materials*** | Embedded shielding to reduce radiation by 5-15% | N/A |
| ***Flexible Power Generation and Storage*** | Harness solar energy and store it | ILSD will utilize photovoltaic blankets to provide power generation for inhabitants |

D. **Badger exploration loft**

In 2010 NASA and the National Space Gran Consortium announced the X-Hab Academic Innovation Challenge. The purpose of this challenge was to get university teams to design and build an analog inflatable habitat to attach to the NASA hard shell Habitat Demonstration Unit (HDU). The University of Wisconsin designed and built the winning entry called the Badger Exploration Loft (BXL). The BXL had four subsystem teams: soft goods, hard goods, electrical lighting, inflation and air circulation, and interior design. Design decisions made for BXL specifically in the soft goods can be directly applied to the design of the ILSD. Design choices of the other subsystems can be indirectly looked at when designing the ILSD.

The BXL used a set of 6 inflatable ribs and 1 inflatable arch with a 25 centimeter diameter inflated to approximately 15 psi. A diagram of this layout can be seen in Fig. 4.

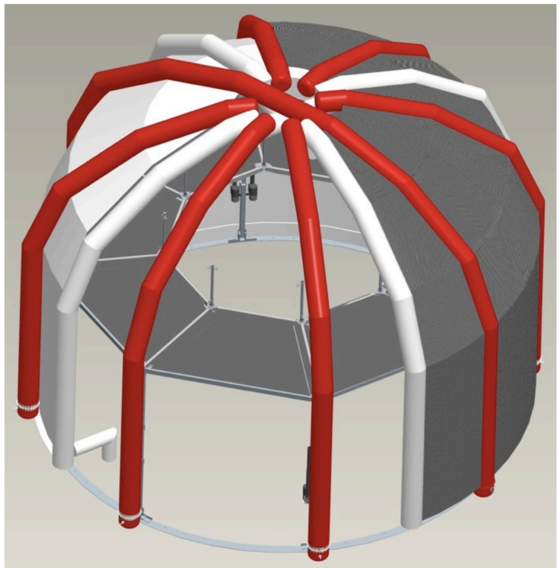


**Figure 4. University of Wisconsin BXL inflatable rib layout.**

These ribs were fully incased in the fabric of the shell to constrain motion and define shape. The ribs were accessible from either the inside or outside via zippers. Fig. 5 shows the placement and installation of the ribs. Due to manufacturing inconsistencies the ribs were not all exactly uniform. In order to compensate for this a keystone structure was assembled so that all of the beams appexed at the appropriate point. This allowed the structure to maintain stability and shape.

**Figure 5. BXL ribs outside of shell (Left), Fully Deployed BXL (Right).**

**Table 2. Material selection for the BXL.**

| Layer | Material |
|---|---|
| Inner Wall | Nylon Ripstop |
| 5 cm Insulation Gap | Air |
| Insulation Layer | Aluminized Polyethylene Film |
| 5 cm Insulation Gap | Air |
| Insulation Layer | Aluminized Polyethylene Film |
| 15 cm Insulation Gap | Air |
| Outer Wall | Acrylic Coated Polyester |

E. **Airdrop Inflatables**

During a review of air dropped shelters, two US patents show some of the ideas that are being looked at. The first is US Patent 4607655[4] which demonstrates a small shelter than can be carried aboard small aircraft and used in case of accidents. This shelter is also designed to be airdropped by small aircraft should the need arise. The second is US Patent 3724473[3] which shows a portable shelter that can be dropped from an aircraft and automatically deploys and locks itself into shape that also functions as a parachute to deliver the structure to the ground. Fig. 6 shows the proposed deployment procedure for US patent 3724473.

Current forms of air-deployed structures are often military based. Specific information on these shelters is difficult to find from a reliable or peer reviewed source.

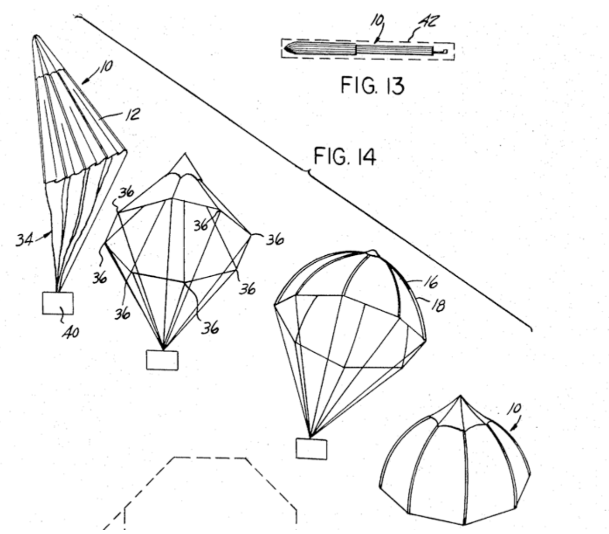



**Figure 6. Airborne Deployment procedure of US patent 3724473.**

F. **Life rafts – Marine Emergency as an Extreme Environment**

Another reason for extreme environment survival habitat in terrestrial conditions is in the marine domain. In case of collision, explosion, fire, or toxic contamination of the mother vessel or platform in the open seas, there may be a need to abandon it. The surrounding ocean or sea waters are thus perceived as extreme environments in which lifeboats or life rafts need to be deployed and enable crew safety in this environment for days to weeks. Although the environment in the high seas is different compared to land emergencies, the hardware in form of deployable life rafts can be perceived as one of the inspirations for concept of the Inflatable Land Shelter Demonstrator.

The life raft system exist in various sizes and shapes with inflatable floating floor, inflatable walls and some versions are also equipped with fabric, tent-like, waterproof roof (canopy) that is supported by inflatable beams as seen in Fig. 7 and 8. The roof should provide thermal insulation, and interior color should have positive psychological effect. The roof should allow air circulation even in case of full closure, it should have one viewing port as minimum, and it should enable collecting rainwater by its geometry and enable the mounting of necessary hardware (antennae) on the exterior of the inflatable structure. The rafts are designed in sizes to accommodate 6 to 46 crew members[7].

**Figure 7. Inflatable rafts for 15, 10 and 6 persons manufactured by Viking.**

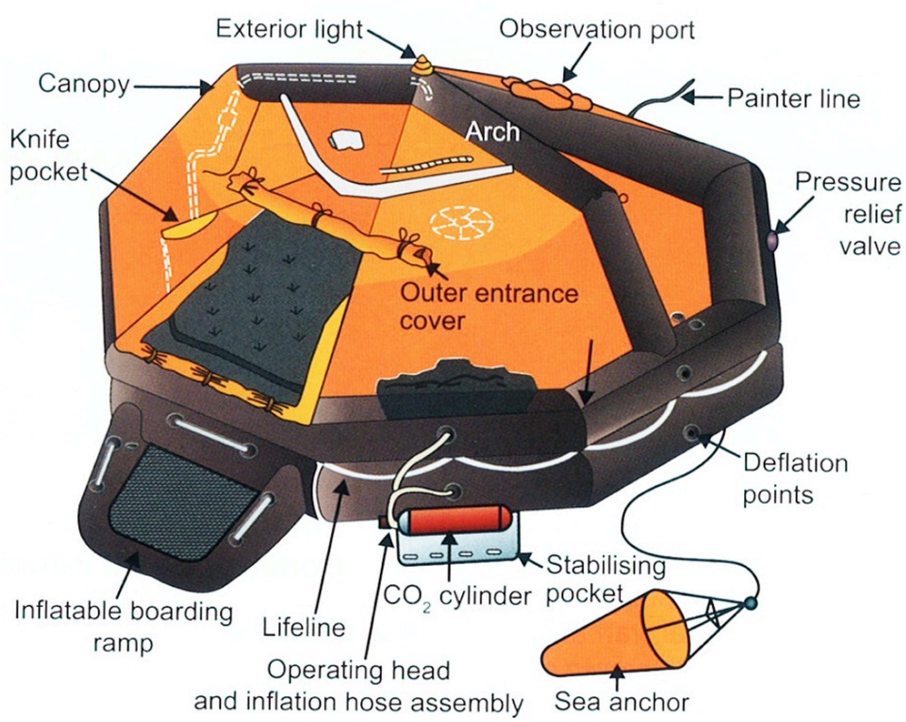



**Figure 8. Life raft systems scheme[7].**

Deployable life rafts can be deployed on the embarkation deck level while hanging from the crane. The crew climbs directly into the life raft. The second option is deployment in the water where the crew uses inflatable or net slide for raft access as seen in Fig. 9.

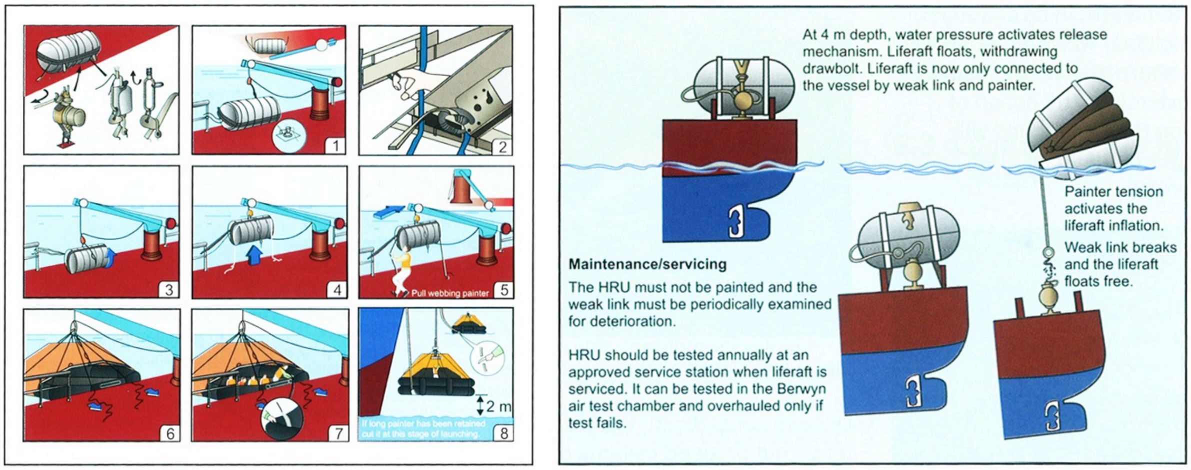



**Figure 9. Life raft deployment schemes on embarkation level (left) and deployment in the water (right)[7].**

The folded structure is compacted in cylindrical shell and a standard raft should be robust enough in structure to withstand impact on water surface from 18 meters. When inflated by $CO_2$ gas stored in the bottle inside the raft package, and fully deployed, the raft has to withstand impacts from crew jumps to its surface from 4.5 m height.

## G. Inflatable Temporary Structures for Terrestrial Use

Producers of inflatable shelters for nominal temporary environment and activities offering large variety of inflatables are e.g., Pneumocell in Fig. 10, Inflate in Fig. 11 and 12, and Lindstrandt in Fig. 13. These structures require significant time for deployment and hardware for maintenance. Nevertheless the geometries of these inflatables may be inspirational for the ILSD and other self-deployable concepts as well as for space and space analog applications.


**Figure 10. Pneumocell dome deployment (top left), structure testing (top right), simulation of the dome utilization in extreme scenario.**


**Figure 11. Light open inflatable components for mild climate or interior use by Inflate.**


**Figure 12. Inflatable domes geometries by Inflate.**

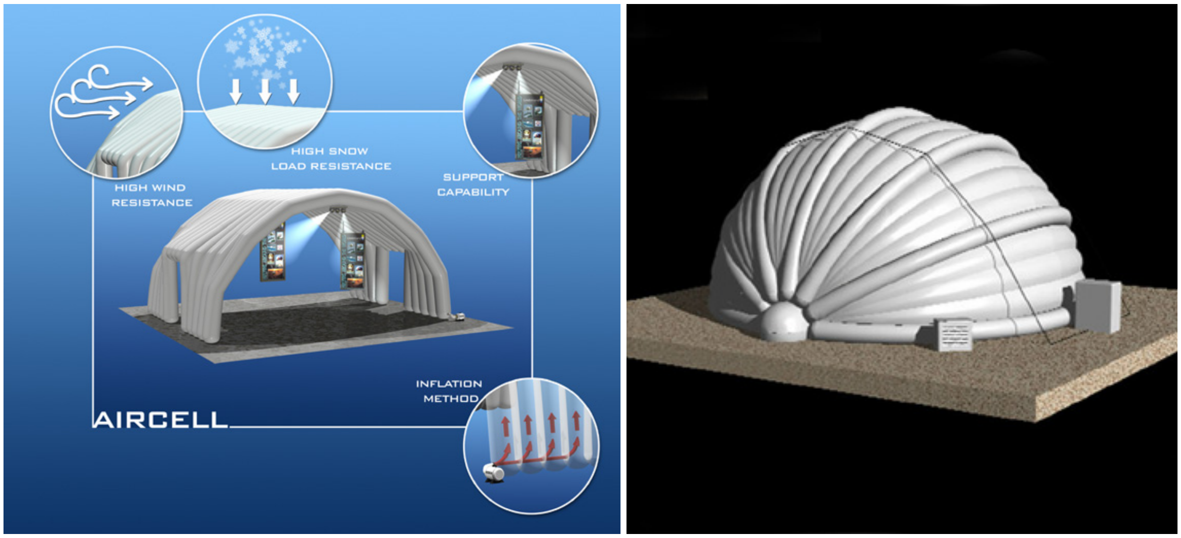



**Figure 13. Inflatable habitats Aircell (left) and Inflatable Telescope Dome (right) for terrestrial extreme environments by Lindstrand Technologies.**

### H. **Deployable tents**

Although not inflatable, these structures are temporary habitats designed as light and transportable while enduring extreme temperatures and high speed winds. Weather Haven company produces these tents for any on land use with the possibility of additional furnishing as seen in Fig. 14.

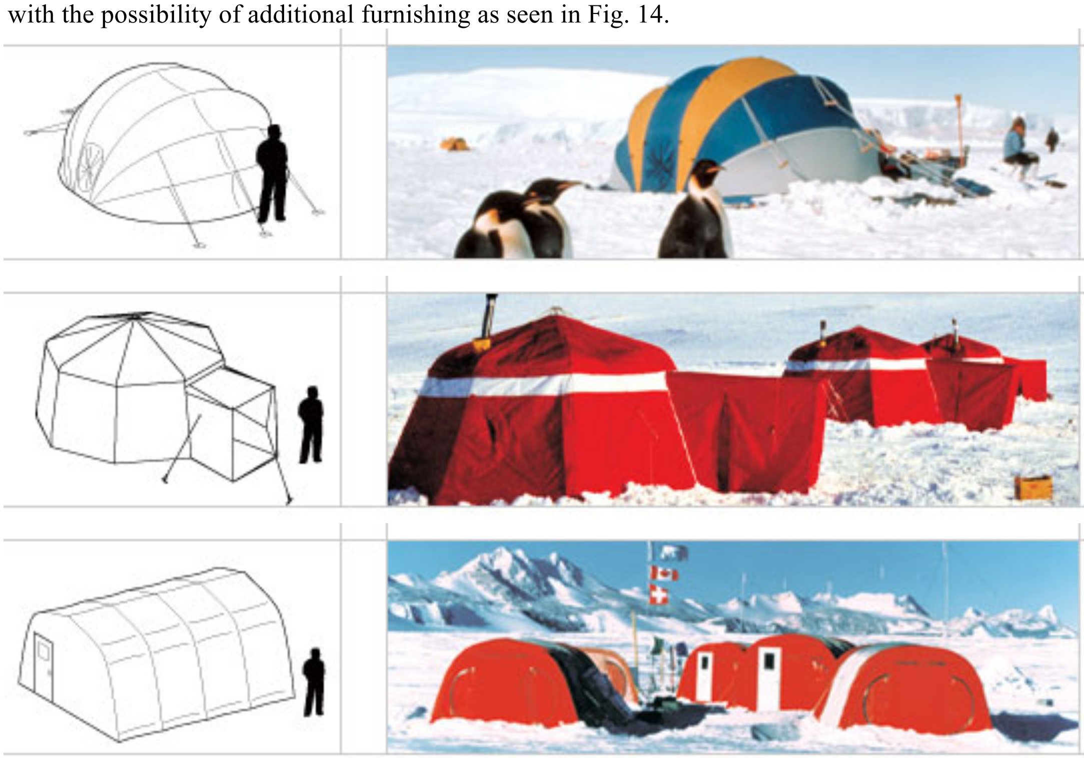


**Figure 14. Light deployable shelters by Wheather Haven.**

## III. The ILSD Concept

### A. Architecture

The ILSD can use many of the lessons learned in the inflatables and shelters explored in this review, but ultimately the design will incorporate a combination of features that have not been looked at in combination before. Initial design ideas for the ILSD call for an inflatable rib structure similar to the BXL but without the hard goods to support the soft goods or attach to another structure. The ILSD will also have basic habitability systems including ventilation and power in order to support up to two people for an extended period of time. The ILSD design will be applicable for space simulation in operations only, and will not be an adequate materials analog. When looking at space mission design, specifically for planetary exploration, it is useful to consult the Constellation Architecture 12.1,[8] which the Habitat Demonstration Unit is designed for. This scenario calls for a permanent structure, and mobile structures to support exploration such as the Chariot Rovers being designed at the NASA Johnson Space Center.

One use for the ILSD in this scenario would be to attach it to the Chariot rover as a stowable habitability module. In this situation, the life support and inflation could come from the rover module. Another situation where small habitats could be useful is in emergency. Numerous portable shelters could be placed on the planetary surface to provide refuge for stranded astronauts. In both of these cases, the ILSD design that will be proposed would not be suitable, especially in terms of thermal and radiation protection, but can provide a basis for future design.

The material and structural design proposed for the ILSD will be more like survival tents currently used today. One can imagine a scenario where an easily transportable structure providing basic habitability systems can be useful. The ILSD has a usable floor area of approximately 12 $m^2$, assuming a person needs a minimum of 3 $m^2$ the ILSD could potentially supply shelter for 4 people. The inflatable beam structure of the ILSD can withstand a heavier wind load as compared to standard pole based tents. A pole structure is suitable for tents with a small cross sectional area, but the ILSD has a maximum cross sectional area of approximately 11 $m^2$.

In the design of the ILSD self-deployment will be a key requirement for driving the design. In order to accommodate this requirement the packaging of inflatables and soft goods as well as subsystem components will need to be looked at. Additionally a preliminary geometry and layout have been proposed as can be seen in Fig. 15 and 16.

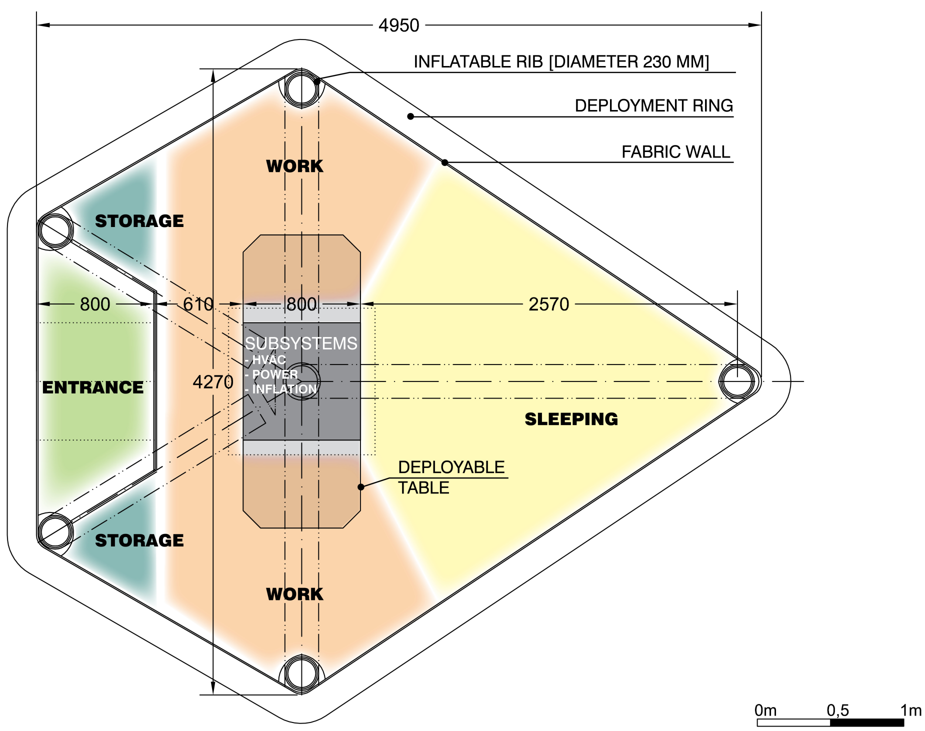



**Figure 15. Floor plan of the ILSD.**

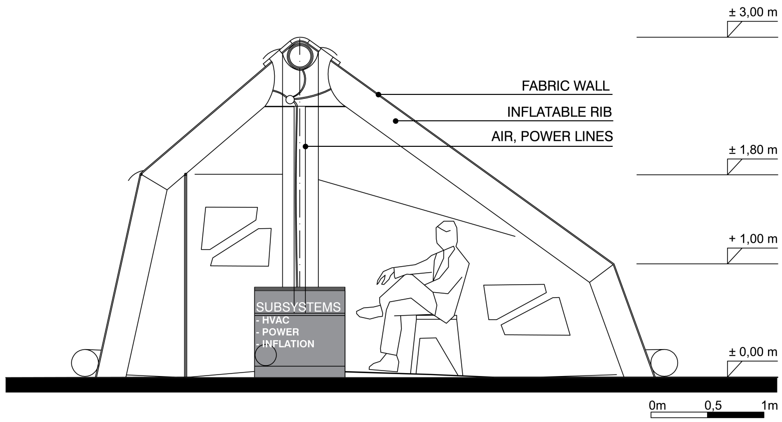



**Figure 16. Profile of the ILSD.**

## IV. Materials, Structure and Testing

The inflatable structure will have to be a composite of multiple layers and more advanced systems will also comprise of intelligent sensors network integrated into the structure. As an optimal benchmark in the inflatable structure design for the ILSD concept is considered inflatable space habitat structure Inflex.

### B. **Materials of the Inflatable Structures**

For the ILSD design, a bladder and restraint system is used. For this system, a gas retention bladder is oversized with respect to the restraint layer in order to transfer the forces due to internal pressure. The restraint layer is chosen based on the internal pressure and pressure geometries, as well as for durability. Material choices looked at include nylon, glass fiber (Kevlar 29), and Kevlar 49. The analysis of this can be seen in the upcoming section on structural analysis. An illustration of the bladder and restrain system as used in the ILSD can be seen in Fig. 17.

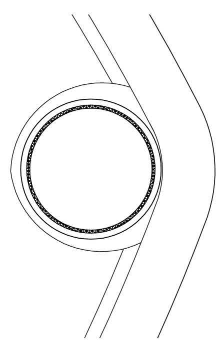


**Figure 17. Cross section of the bladder and restraint used for the inflatable beams in the ILSD.**

The ILSD utilizes a pressurized beam for support versus a total volume pressurization due to the terrestrial usage of the ILSD. If a total volume pressurization were to be used a high operating pressure with respect to the outside environment would need to be kept as well as an airlock component. A space based design of the ILSD would probably utilize a total volume pressurization due to the added stability and relatively low operating pressure.

## C. **Inflatable Beam Structural Behavior**

The inflatable structure chosen for the ILSD is based on Beam – Membrane structural elements. The inflatable beam members can be approximately evaluated as traditional static beam elements and as pressure vessels although the unique differences between these objects must be kept in mind. An inflatable beam is made of material that cannot support a compressive loading to any substantial amount. Some small compressive force due to bending can be accommodated because of the preload applied to the fabric from the axial force from the pressure differential.

Additionally the fabric properties are weave dependent and cannot be assumed to be linear or isotropic. Hand calculations can be used to find first approximations of size and pressure, but computational analysis is needed to fully understand the loading and deflections of inflatable beams[9].

### *1. Inflatable Beam Analysis*

<u>Assumptions:</u>

- Inflatable tubes are beam elements and act accordingly
- They are made of materials that do not support compression
- They are made of materials that are anisotropic and non linear (ignored for these basic calculations)

### *2. Inflatable Beams as Pressure Vessels*

Inflatable beams in simple analysis can be treated as pressure vessels. Especially when looking at the maximum pressure of the beam. Traditionally inflatable beams are made of two fabric layers. The inner most layer is an airtight membrane layer that is oversized with respect to the outer layer to transfer the internal pressure forces. The second layer is a stronger restraint layer that has the ability to carry much more load. In aerospace applications, this fabric is usually Kevlar or Vectran due to the high load carrying capability and low creep (ability to resist strain through time with a given load applied). Ultimate load for fabrics can vary greatly depending on weave pattern, and most fabrics can withstand pressure vessel loading needed for the ILSD.

### *3. Bending Moments in Inflatable Beams*

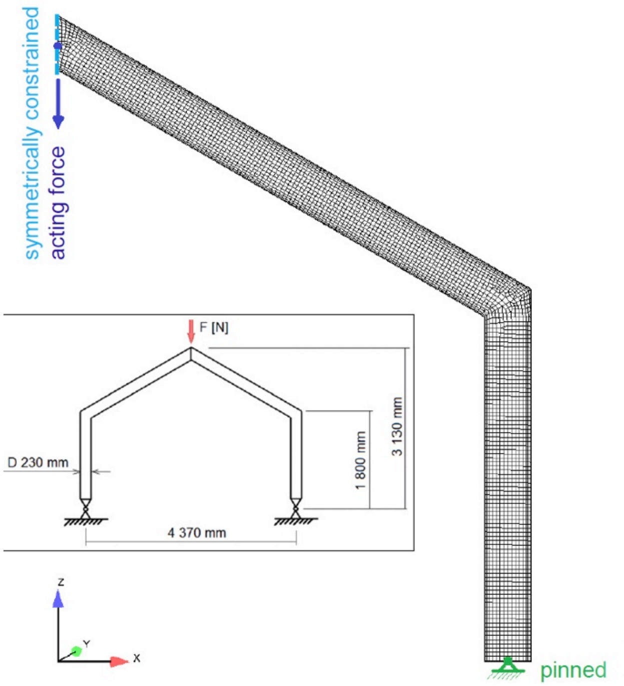
Looking at assumption two, beams are made of materials that do not support compression; a likely mode of failure will be bending. In bending of a beam member, one side goes into tension, while the other goes into compression. The beams can support some amount of compression from bending due to the preloaded tension from inflation. By setting the stress from the applied moment equal to the inflation pressure, you can calculate the onset of wrinkling moment. As can be seen in Eq(1) where $P$ is the internal pressure and $r$ is the radius of the inflatable beam.

$$M_{wr} = \frac{\pi P r^3}{2} \tag{1}$$

It should be noted that experimental results show that this value is conservative and the onset of wrinkling can happen as much a 1.6 times the calculated force due to the breakdown of assumption two. Softgoods can support some localized compression. Some additional force can be carried after the onset of wrinkle, but before collapse.

### *4. Simulations*

More in depth computational calculations for the ILSD concept structures were done for Nylon 66, E-Glass/ Kevlar 29 and Kevlar 49. The goal is to analyze the behavior of these materials and analyze influence of Young's modulus and inflatable pressure on the capability to bear a point load. For the computational calculations a finite element method code MSC.NASTRAN R2004 has been used. A nonlinear static solver SOL106 was utilized. Behavior of the inflatable beam structure after reaching a bifurcation point of stability was investigated by ARC length method; see Fig. 18.




- A symmetrical quarter of the real 3D geometry model was used.
- A linerly elastic material model was used.
- Young's modulus for bending properties of the shell elements were set to 1/1000 of the membrane properties (simulation of a fabric behaviour)
- FEM model consists of :
  4074 CQUAD4 elements
  9 CTRIA3 elements
  2 RBE2 elements
  4364 nodes (6 DOF)
- A constant fabric thickness
  0,1 mm was used at the whole model
- Forces from the pinned constraint and the acting force are transfered to the shell model through rigid elements (RBE2).

**Figure 18. FEM Model Description.**

The results of simulation summarized in Table 3 has led the authors to choose Kevlar 49 material inflated to a pressure of 14kPa that is capable to bear a higher maximum acting force 1.2kN than other materials. Under this load the structure reaches the displacement value of 42 mm. The lower pressure structure is safer from user point of view and also from inflation requirement viewpoint. A Low power compressor will be required for the Kevlar beam inflation compared to Nylon 66 and Kevlar 29 structures. The Kevlar 49 material and its required internal over pressure should be sufficient for self-carrying of the structure including redundancy for accidental load or climate change load from exterior. Fig. 19 depicts the displacement for a given pressure under varying load. Forces were chosen to show the significant events in the beam failure, onset of wrinkling, deep wrinkles, and finally buckling.

**Table 3. Various Young's modulus and Internal overpressure combinations.**

| | | Young's modulus [Gpa] | | | | | |
|---|---|---|---|---|---|---|---|
| | | 6 | | 70 | | 112 | |
| | | NYLON 66 | | E-Glass / Kevlar 29 | | Kevlar 49 | |
| Internal overpressure | | acting force | displacement | acting force | displacement | acting force | displacement |
| [kPa] | [psi] | [N] | [mm] | [N] | [mm] | [N] | [mm] |
| 14 | 2 | 175 | 61 | 944 | 48 | 1275 | 42 |
| 34 | 5 | 339 | 129 | 1181 | 51 | 1703 | 50 |
| 69 | 10 | 590 | 219 | 1426 | 53 | 2003 | 51 |
| 103 | 15 | 809 | 298 | 1680 | 57 | 2235 | 52 |

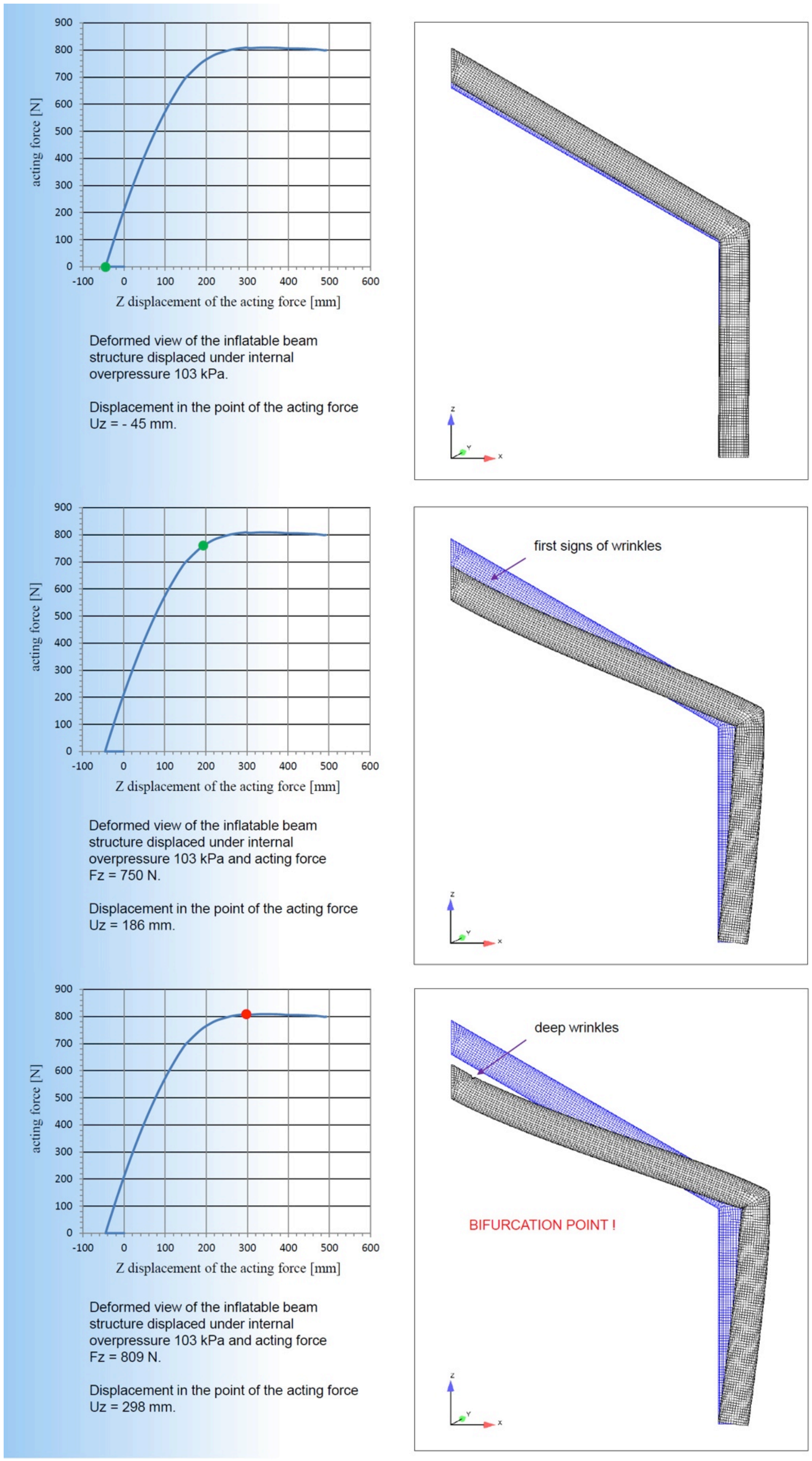



**Figure 19. Computational calculations of behavior of the inflatable beam structure after reaching a bifurcation point of stability.**

## D. **Material Selection**

As identified in the previous section, it is recommended the beams be made out of a material with a high Young's modulus. This material is not ideal for the wall fabric, mostly due to weight concerns. A weather resistant polyethylene can be used such as the Odyssey III fabric. This fabric weighs 0.22 kg/m$^2$ for a total weight of 8.5 kg. A double walled approach can be taken such as that used in arctic tents and the BXL to provide a passive thermal protection. An air gap space of approximately 2 cm is ideal for thermal insulation[10]. Air gaps larger generate heat transfer via convection from air buoyancy. The inner layer of this double wall tent can be a lighter fabric such as the A5764 nylon ripstop from Stern and Stern weighing 0.07 kg/m$^2$ for a total weight of 2.7 kg.

## E. **Testing of Softgoods**

In order to verify the structural integrity of inflatable beams a number of standard tests can be employed. A summary of those tests can be seen in Table 4.

**Table 4. Standard testing procedures for softgoods.**

| Performance Characteristic | Standard/Test Method |
|---|---|
| Finished Bladder Fabric | |
| Weight (oz/yd2) | ASTM D 3776 (Fed-Std-191, TM 5400) |
| Tensile Break Strength (lbs/in) warp x fill | ASTM D 5035 (Fed-Std-191, TM 5102) |
| Tear Strength (lbs) warp x fill | MIL-C-21189, TM 10.24 |
| Peel Adhesion | ASTM D 751 (Fed-Std-191, TM 5970) |
| Seam Constructions | ASTM D 5034 |
| Flame Resistance, Vertical | ASTM D 6413-99 (Fed-Std-191) |
| Webbings | |
| Width/Thickness (inches) | ASTM D 3774/ASTM D 1777 |
| Weight (oz/yd2) | ASTM D 3776 |
| Min Tensile Break Strength (lbs/in) | ASTM D 5035 |
| Seamed Strength | ASTM D 5035 |

## F. **Subsystems**

For the ILSD design, the subsystems will be concentrated into one central package that will perform the following roles: inflation, HVAC, and power distribution. The subsystem box and components are chosen in such a way so that transportation of the ILSD provides a minimal risk to damaging the individual components. This can be done by a passive damping and crushable material. The entire ILSD system should be kept under 100kg so that transportation can be accomplished without extra equipment. The following list of subsystems includes preliminary components that could provide functionality, but do not represent an optimization on size or weight.

### *1. Inflation subsystem*

The inflation subsystem expands the inflatable portions of the ILSD design. Concepts looked at include the Badger eXploration Loft (BXL) and inflatable life rafts. The main difference between these two is the type of inflation system used, and the differences are based off of the functional requirements. The BXL was designed to be repeatedly deployed and retracted in a short duration (15 minutes) while maintaining structural integrity for extended periods of time. Inflatable life rafts are single use structures that must be inflated rapidly. From these requirements the inflation system used by the BXL is a compressor that can provide pressure maintenance, and inflatable life rafts use compressed gas cylinders that provide rapid inflation.

When comparing these two systems it is also important to look at the inflation volume. BXL uses an inflation volume of approximately 1.5 meters cubed at 15 psi and a seven man inflatable life raft from Life Support International uses a volume of 0.6 meters cubed at 2 psi. The proposed volume of the ILSD is 0.882 meters cubed. The ILSD also more closely mimics the functional requirements of the BXL. One way of incorporating advantages from both of these systems would be to first deploy a rapidly inflatable ring to provide the perimeter shape of the habitat. This would place the load supporting ribs in the correct position before a compressor inflates them and is able to provide pressure maintenance. The volume of such a ring would be equal to or less than the volume of the inflatable life raft with similar pressure requirements. One compressor that could perform the inflation is the Gast 75R. It has a small volume of 90 x 240 x 194mm and a power draw of 250 watts, weighing eight kilograms.

*2. Heating cooling and Air Circulation*

Deployment of the ILSD may not happen in comfortable temperature zones. For cases such as these a heating and air conditioning unit would provide thermal control for the inhabitants. Additionally the system can draw fresh air from the outside environment and remove air from inside the habitat making for a more comfortable living area. One heating and air conditioning unit that would be able to perform the required functions is the Climate Right CR-2500 Mini. This subsystem would require the most weight, space, and power. The CR-2500 for example would weigh 22 kg, take up a volume of 431 x 356 x 330 mm and have a maximum power draw of 500W at startup. This system would supplement the passive cooling techniques described in the material selection section, especially in the case of extreme temperature environments.

*3. Electrical Subsystems*

In order to power the ILSD flexible photovoltaic will be used to generate power. Taking into account the subsystems that need power as well as adding in power for habitation uses such as lighting and laptops with a 25% margin for losses and additional load on the system. The photovoltaics will need to produce approximately 1125 W of power. Typical photovoltaics produce about 34 W/kg so a total mass of 33kg of solar panels will be needed. This also translates to approximately 7.5 $m^2$ of area. In order to store this power, batteries will need to be used. Battery sizing would be dependent on ILSD deployment location. In order to regulate the voltage from the solar cell to the battery a buck converter would need to be used. Finally a DC to AC converter would be needed to power the AC systems such as the HVAC, Inflation, and personal power outlets.

## G. **ILSD in Operation**

In Fig. 20 the proposed deployment sequence for the ILSD is shown for an airdrop scenario. The ILSD deployment package would be approximately 1m x 1m so that it can be handled by humans in transportation and should an automatic deployment system fail and a manual deployment be needed.

A) The ILSD is air dropped
B) Laser altimeter triggers release of parachute near ground.
C) Landing triggers the box sides to fall
D) The base ring is deployed to provide initial shape
E) Support beams deploys
F) Support beams inflate
G) ILSD inflation is complete

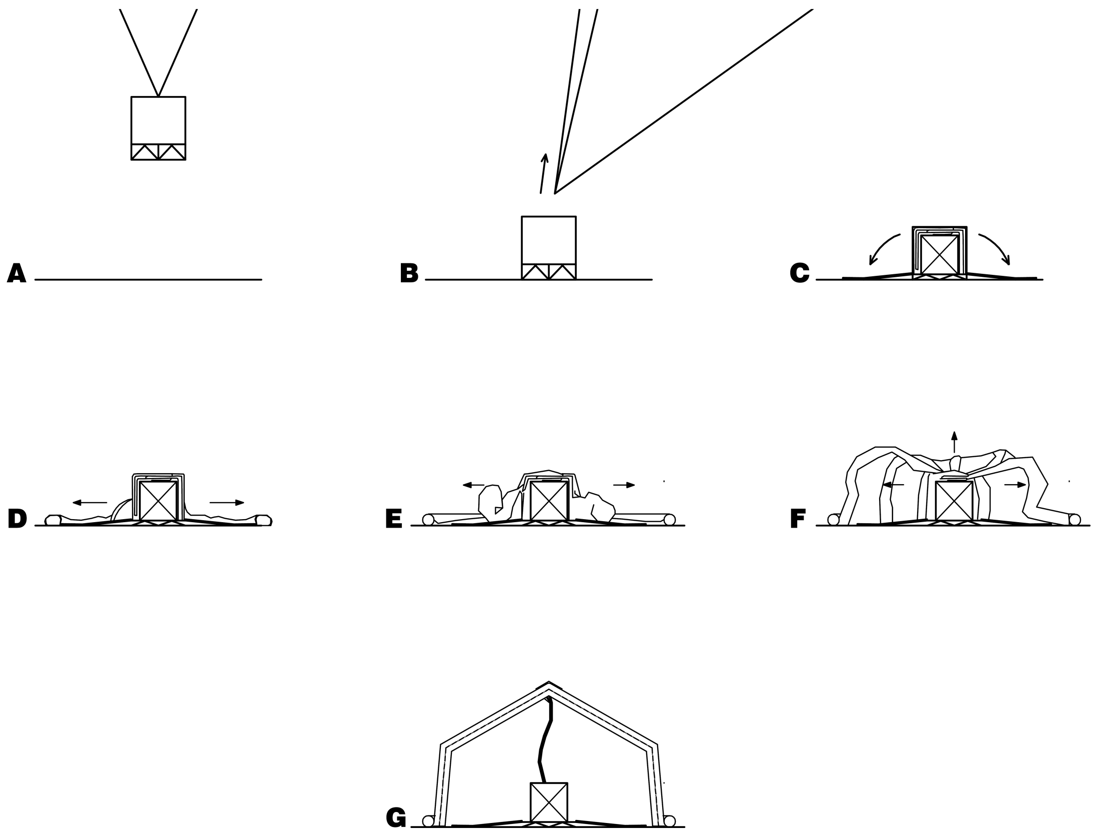



**Figure 20. Deployment concept for the ILSD.**

## V. Conclusion

This work aimed to address the architecture and development of a rapidly deployable inflatable land shelter demonstrator. Both historical and present day examples of inflatables and shelters were used as inspiration for the ILSD. The ILSD was designed to perform as both a space shelter analog and as an emergency shelter on Earth to demonstrate a self deployable habitat which will serve to further designs of habitats for nominal terrestrial uses. A structural analysis was performed on the inflatable load bearing members in order to determine a correct operating pressure as well as providing a recommendation on material choice. In order to provide extended habitation, a subsystem layout was explored. Finally an autonomous deployment sequence was identified.

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