Rotational forming of large habitable structures in orbit

CEOI-ST Grant for Exploratory Ideas

Short summary report

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Report summary

Our grant proposal outlined a technique for creating large structural shells in orbit using relatively simple mechanisms and drawing on techniques used in the additive manufacturing industry.

This grant has allowed us to explore our concept in more detail and to come to a better understanding of the challenges that come with this approach. Space is a challenging environment but it is beyond the scope of this initial exploratory research to solve some of the more complex engineering and material science questions raised by our approach. What we proposed as a project for the Grant for Exploratory Ideas was a vague and ill thought out concept. The grant has given us the time and motivation to begin the long process of converting this vague concept into a more solid idea and given us a better understanding of how to make our concept a reality.

We have introduced a conceptual approach to construction in space which we call the safe harbour principle. This is an inversion of how conventional construction where the internal framework is assembled first and clad with material to form an external hull. Instead the hull is formed first, and largely autonomously, with the primary aim of enclosing a large volume of space with a protective shell. All other tasks required to construct a working spacecraft then take place within this 'safe harbour'.

We constructed a small scale demonstrator that is currently in the final stages of testing and fine tuning. This purpose of this demonstrator is predominantly to help publicise the idea and to demonstrate the concept and process in a visceral manner but it also allowed us to look more closely at the practicalities of the design and resulted in us specifying two basic machine concepts and a third hybrid design. These designs relate to the way in which a spacecraft hull can be formed using techniques partly derived from additive manufacturing. We classified these three processes as follows:

- **Single Stage (SS)** Where multiple layers of material are formed in a single continuous process.
- **Multi Stage (MS)** Where successive layers of individual materials are laid down one after the other.
- **Hybrid Stage (HS)** Where more than one material is laid down in one pass but the process is repeated many times.

The report describes a pair of machines based on the first two methods and discusses their relative strengths. From this we were able to determine that a multi stage machine forming successive hull layers is the simplest in several ways, and is therefore the best candidate for further development. This conclusion has some qualifications though and we have also looked at the benefits of a hybrid machine, and how a single stage machine may be more suitable for very large scale construction.

We expanded on the SS design and derived a couple of variants, one where all layers are formed at the same point, and a second 'stepped' method where the outer hull layers are formed slightly in advance of the innermost ones. This method allows for alternative approaches to material deposition, such as spraying onto an already formed surface, which can only normally be achieved with the MS or HS process.

All three machine variants are designed to produce the same or similar hull structure which we elaborate on in our report. We have explored the physical properties that would be required of it, from the ability to protect from radiation and impacts, to air permeability, pressure containment and structural loading. We have concluded that all the required properties of a spacecraft hull can be achieved with our proposed process, and that some beneficial properties such as the ability to withstand impacts can be enhanced when compared to more conventional spacecraft.

This conclusion is still tentative and a large factor in the success of our approach will be in the material science and the methods of processing materials into the final structure. In order to get a better understanding of these problems we performed some crude experiments on the creation of materials that might be used to form the hull. These are not intended as solutions that would be employed in a fully working system but they have allowed us to get some insight into the problems involved in the formation of certain materials in a vacuum.

We created some test samples that consisted of alternating layers of high and low density foams. We experimented with layers seeded with conventional glass fibres and with sand as a crude analog for raw material from an asteroid and synthetic fibres like Kevlar or Nextel that might provide extra strength.

Some attempts were made to test how these materials, whose rigid foam structure is generated with a chemical blowing agent, performed when curing under a vacuum. Predictably the materials final density was dramatically lower than that produced under pressure, and some samples of the final material collapsed after pressure was restored. We noted that this may not be an issue for parts of the hull that are outside any layers designed to contain air pressure but that out gassing may be an issue. Our tentative conclusion from these crude tests was that the creation of low density reinforced rigid material in a hard vacuum was possible and could be used as part of the construction process.

We noted that our approach may also produce useful structures that are not intended to contain a pressurised atmosphere. The safe harbour concept is drawn on again and a semi enclosed space can function as a working environment for EVA activities with the shell providing protection from external factors and containment of un-tethered objects within its confines – a literal space harbour.

Our proposal for the hull structure is one where alternating layers of high density and low density material are formed, and that this layering in conjunction with the right materials can provide all the required properties for a spacecraft hull. We have noted some advantages over conventional construction techniques in relation to the performance of the hull. One element is the removal of payload volume limitations and the restrictions they consequently place on design elements such as bumper shield standoff spacing for debris protection. The multi layered hull structure we specified can function as a bumper shield but, because it is formed in situ, the spacing between bumpers can be increased beyond that practical for a prefabricated module that has to fit inside a launch vehicle.

The candidate materials required for creating the hull were discussed and these range from metal wire applied with a seam welding technique to spray coating and spray mixing of materials in a similar fashion to a glass fibre layup gun, and the use of hot and cold polymer and resin extrusions and materials sourced from asteroids. We noted that polyethylene is a good candidate for many roles within the structure due to its low mean atomic weight and consequent ability to disrupt harmful radiation, and its ability to be used in a hot extrusion system or processed into high performance fibres for structural reinforcement.

We discussed the process and methods that might be used to validate a completed structure and ensure it is fit for purpose. We identified methods of gathering data as the hull is being created in order to produce a virtual model of the completed structure and to simulate performance and compare against real test results. We also outlined how the construction mechanism can use surface penetrating techniques such as x-ray imaging to build up a detailed picture of the internal structure both during and after the main construction phase. Any validation process would have to be derived in part from a better understanding of the materials and processes used and so they would evolve as the techniques were developed. Any post construction testing would also include pressure and load tests with the possibility of some being carried out over a period of months.

At the end we outlined a few variants of the concept that can be used to create a more diverse range of structures such as a torus or a cylinder, and for producing natural lighting and viewing ports that preserve the protective properties of the hull. We also briefly looked at the idea of a self supporting machine that lacks some of the dimensional constraints of our other designs and could be developed as a way of constructing very large scale structures.

Report Conclusions

We have concluded that our approach is entirely feasible in principle but that a significant degree of research and development is required to develop and evaluate the materials that would be used, the methods for processing and applying them and of validating the final structure. We also briefly outline a 14 year development timeline that, subject to sufficient finance, would develop a series of machines and associated techniques and IP for testing in orbit with the goal of producing a fully functional 40 meter diameter shell as a commercially viable solution.

We expect to generate some technical publications from the completed report which will be submitted to relevant academic publishers. We also intend to produce material for a more general audience in the form of blog posts and media stories that expand on the concept and help promote the UK’s participation and expertise in space exploration and science.