NASA SpaceApps Challenge October 2020

Let's Connect

The Challenge

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For bigger spacecraft capable of executing bigger missions, some of the assembly may be done in space. Your challenge is to design a simple approach that enables components to be assembled in space.

Background:

The future machines that humanity will build in space may be bigger than any machines on Earth, but at the same time, rockets are only so big. As we start to have bigger spacecraft and bigger missions, the ability to assemble components from multiple launches in space is a plus. In other words, structures must be put together from multiple launches like putting together building blocks in space.

The current approach to joining components in many space assembly applications involves highly capable robotic arms, with unique end effectors. However, as we look at the broad range of potential future missions, from large structures built in space to simpler missions like CubeSats, simpler solutions for in-space assembly mechanisms would be helpful. **Your challenge is to design a mechanism to facilitate in-space assembly and docking.**

Potential Considerations:

● This is a concept design/mechanism architecture challenge rather than a software challenge. How could you help build the shipyards and space hotels of tomorrow?

● What kind of mechanism will you design? Can your design roughly align and then precisely position two components relative to each other in space? Can it pull two components together, and lock them on contact? Is it possible to release the two components once connected, and if so, how? Or will your mechanism assist in-space assembly in a completely different way? These are not requirements for this challenge, but rather ideas to get you started.

For data and resources related to this challenge, refer to the Resources tab at the top of the page.

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A word from the Challenge Owner

I wanted to expand on the general questions as to what does the following challenge mean: "Your challenge is to design a mechanism to facilitate in-space assembly and docking." The keys are in the bullet points below.

But we are specifically interested in a mechanism concept which:

1) roughly aligns two components relative to each other
2) pulls them together
3) precisely positions the components
4) locks the two components to each other
5) releases at the press of a button.

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Pure Connect

A Concept Description from Team StarShipExodus2

The information resources for the document are mostly from the minds of the team members but rely on some sound elements of physics, mechanics and well known technology. The team have just been inventive in combining the principles. Where necessary, references for specific portions will be included.

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Introduction to PureConnect

The StarshipExodus2 team consider that the exploration of not only this solar system, but other solar systems will necessitate the construction of Star-Ships of truly immense proportions. The construction of such vessels on Earth become totally impractical and thus the best situation would be to construct the Star-Ships in orbit around Earth or its moon. Hence we consider that the likely vessel size will be of the order of two or three km diameter and maybe twenty to fifty km in length. Such ships are likely to be constructed as a number of sections that will be brought together once each section is completed.

It is possible that such large vessels may feature inflated sections or maybe constructed from materials that are plentiful on the moon. It would be a folly to not build such craft from many sections with appropriate use of air-locks. Considering that the construction of such large sections will lead to parts that are maybe hundreds of tonnes, there is a need to couple them in as autonomous a fashion as is possible. Making sure that any human astronaut is not in position to be in the path of any of the parts.

In addition to a secure latching system, we are also including the use of electromagnets which are considered to be more effective away from Earth's gravity and atmospheric friction. By applying appropriate control to the electromagnets we can cushion, repel, attract or even rotate the adjacent sections relative to each other. Even NASA are exploring the benefits for satellites. (3)

Scope

We are limiting the work on this challenge to the description of locating, orienting and bringing together the parts of the spaceship. The solution is modular and there is a need for many modules to be installed to complete the full system.

Vessel Aspects

This section describes the requirements for successful large multi-section space craft final assembly in space. Like any properly manufactured item, each section has a part identification and other identifying details. However, all sections must share some common features where they are to be connected. We expect our envisioned vessel to be very large (of the order of 2km diameter and at least 20km long) with a join-able hub section of some 200m. However, we feel that the techniques described are sufficiently scalable to vessel sections that are from 1m diameter to several km diameter. A stylised sketch of a section is shown in Illustration 1.

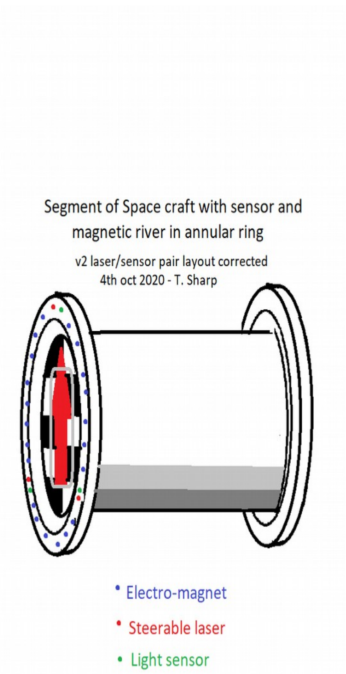

Illustration 1: Segment Sketch

Parts of the Connectors:

Identical Annular Ring on the face of each space craft segment to be connected. The annual ring is made of magnetic steel with holes in for the components and a relatively thin aluminium sheet to protect the components. The segment would also have a bulkhead with some form of door in to keep the segments airtight when not connected. Other portions of the annular ring may be devoted to achieving an air tight seal when brought together.

Equipment on the Annular Ring

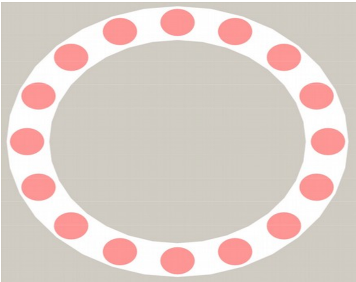

Illustration 2: Annular Ring Magnetics

- A series of electro-magnets in the joining ring which are controlled by the flight system and can be reversed and used as a magnetic river as well as initial holding when switched to attract (See Illustration 2).
- 3 modulated lasers each broadcasting a unique identification number
- Each laser is mounted on a steerable mount where the angle can be measured.
- 3 light detectors which can work out the unique number being broadcast by the lasers.

The Annular Ring does not house the Pawl Latch clamp system as this is fixed to the section structure to ensure proper flange mating.

Additional items on each connection

- Bulkhead to seal the opening of the part. These have a chequerboard pattern with a large "UP" arrow painted on and illuminated by a single light to allow a visual light camera to be able to see it.
- Mechanical clamps on anchor points around the ring with matching locating points which are designed to create a firm joint which does not need any power to maintain.
- A radar system on each part or connected to the flight system at a location that can spot both parts that need to be connected.

The spaceship parts may have their own motors or may be moved by a tug which also connects to the part temporarily using a similar coupling.

Locating the Sections

With the construction happening in space, the first thing to remember is that the distances and velocities can be quite significant. The mass of each section will likely be several thousand tonnes. Sections may be constructed several kilometres from each other, and when they are given their basic instrumentation and section power systems, they will need to be identified to each other for confirmation by radar location. Of initial interest will be whether or not items in the radar view are the correct sections to be attached to. Therefore, a coding system is required to uniquely identify each section.

Manoeuvring

Once sections to be joined are identified, they need to be moved together. A thruster system may be part of the temporary pack, a tug or maybe permanent fixtures to the section. These can be used for the general manoeuvring. Maximum approach velocity for last 5km should be no greater than 0.02m/s [*(1) and (2)*] to give time for proper orientation and alignment adjustments. Final closing velocity will need to be calculated with regards to the section masses and the kinetic or impact energy to be dissipated.

Alignment

Several systems deal with identification of the correct alignment.

Laser Targeting

Using Lasers and Detectors with unique pattern reflectances from target plates. Lasers may also be uniquely coded to ensure no improper connection.

Electromagnetic Rotational Positioning

As the electro-magnets are in a ring they can operate as a form of endless magnetic river. This means the magnets in each face can be set to repulse each other to slow and hold the segments apart. A pulse moving round the electro-magnets could be used to turn one segment in comparison to the other to orientate the two segments to zero angular difference. They can also hold the two segments together while the mechanical clamps engage.

These electro-magnets also mean that when the release sequence is initiated, the magnets can engage and hold the segments together while the mechanical clamps release and then the two sets of electro-magnets can repulse each other so the segments disengage and push away from each other.

Mechanical Guidance

From very close in, the guidance of the latching system can align for small errors by using the latch pawl as it approaches the latch bar. The side guides to the Latch Bar are angled at five degrees to form a final route into latching together.

Description of operation

We are assuming that the parts are built either on earth, in orbit or in space. The faces that are going to be connected together will have the correct size annular ring, possibly in a face of the segment or as a flange if the part is smaller than the ring.

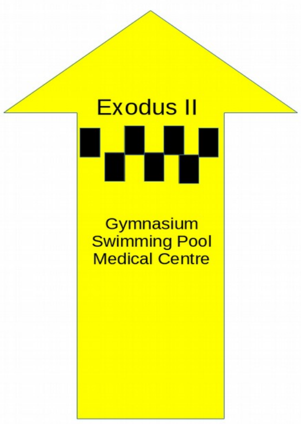

Illustration 3: Orientation Arrow

Embedded in the surface are a number of strong electro-magnets which are computer controlled to create a kind of annular magnetic river. The number of these electro-magnets depends on the diameter of ring. There will also be 3 modulated laser sources mounted on steerable mounts controlled by the control system and the 3 fixed detectors which can read them. As initial long range and as a backup system there will be at least one camera and a bulkhead with a big up arrow painted on (see Illustration 3 for example), which is illuminated by a non-shadow inducing strong light source from a ring of LEDs. These items allow either computer vision, or manual controller to see how each part is orientated compared to the other and allow the control system to bring them together if needed.

Our assumption is that each part can fly autonomously or a “tug” can move the part. Both parts to be docked have the same setup on their ring flange and both can communicate with a computer system that is co-ordinating the procedure. With the visual of the arrow, the first coarse alignment can be accomplished at a significant distance.

The laser targeting light is modulated by a unique identifying number so the detector can read the number and thus the computer will know which laser is pointing at which detector.

Initially from a number of Kilometres away the two parts find each other by radar. At that point the lasers on both parts move to point towards the other part which they are to dock with and search for a detector by scanning across the surface. The navigation systems can then move to get the lasers to point at the sensors. Once they find a sensor the guidance system works to minimise the angle that the laser mounts need to have to keep the lasers point to the sensors.

Since the lasers broadcast a unique number by the modulation in their light output the computer system knows whether there is an angular difference between the two parts. Since the parts are getting close together this angular difference can wait until the parts are close together.

The navigation system slows the two parts are they approach. At this point the navigation sets the magnetic river devices to repulse each other as a way to prevent the two hitting. Once they are close together the magnetic river on one part can modulate to turn the other part so there is zero angular difference between the parts. The motor may need to stay running gently holding the two segments together. Once the two parts are aligned then the magnetic rivers can alter to attract each other gently and when they touch together the magnets hold them in place while the mechanical clamps can engage. The magnetic rivers can de-gauss themselves by sending a decreasing sine wave of current through themselves and then power down.

Latching On

Bringing large masses together in space requires the ability to accurately align and latch onto the piece to be attached. Once captured the holding tension needs to be applied such that it does not allow joints, that may need to be air tight, to slip apart.

Hence, the latch design shown and described here is intended to enable that latching on and securely holding the parts together. The design can be considered quite scalable to the intended structure size.

The intention is that there should be many latches to assist holding aligned pieces together. There is also likely a need to separate the items, so the latch mechanism will need to be releasable.

Design Basis

The simplest mechanical latch system is the Pawl Latch. This is normally two parts. The fixed part being latch bar for the Pawl to hook onto. The other part is the Pawl itself which hooks over the latch bar. In addition to the simple mechanism a means for adding tension to the Pawl is required to ensure that sealing surfaces are able to be sealed air-tight.

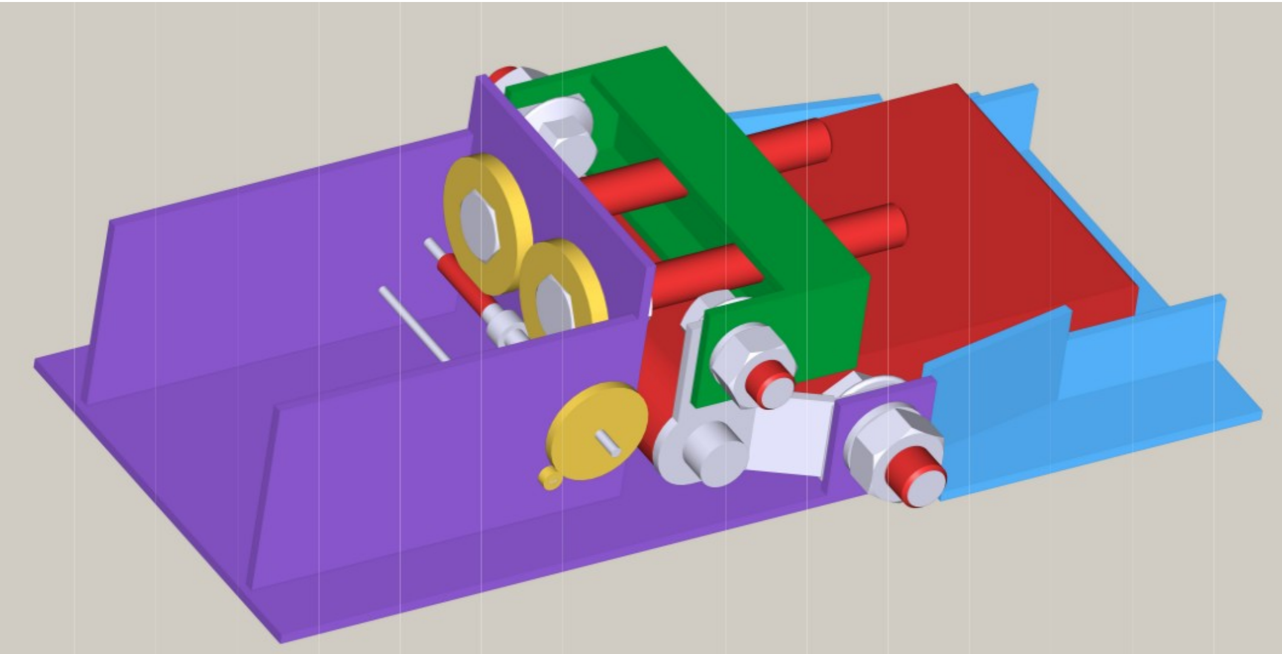

Illustration 4: Coupled Latch

The basis for the latch design is founded in the action of a Pawl Latch. The diagram in Illustration 4 shows the latch mechanism parts coupled as it would be when the parts are joined. The motor and rest of the tensioning gearbox is shown in the diagram. It is intended that the operation of the latch be as autonomous as possible. A spring (not shown) keeps the Pawl end of the latch mechanism lowe to allow auto-latching. Once latched, the motor can pull the latch Pawl back to apply the tension that will keep parts together.

The diagram in Illustration 5 shows the uncouple latch mechanism aligned but not coupled to indicate some of the Pawl Latch detail. The motor and rest of the tensioning gearbox is shown in the diagram.

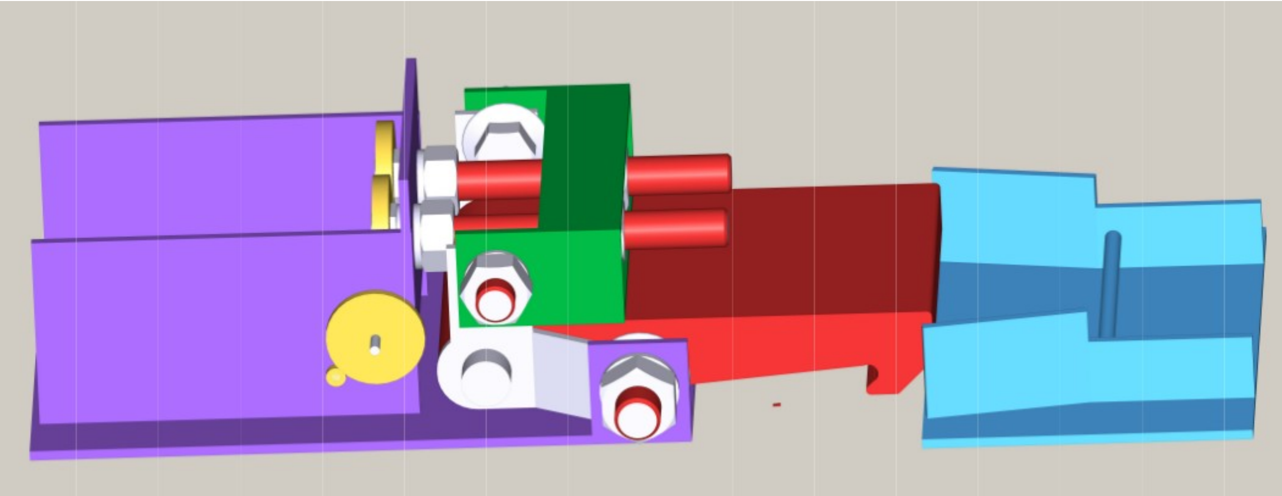

Illustration 5: Latch Uncoupled but Aligned

The Latch Bar

This consists of a base with an angled guide plate which ensures the lateral alignment of the Pawl that is to connect with the Latch Bar. A round bar crossing between the two side guides is where the Pawl rides over and is pushed down to engage by a spring at the rear of the Pawl assembly. The latch bar base-plat is affixed to the structure to be mated.

The Pawl Latch Assembly

This is affixed to the mating structure in a position that will align with the Latch Bar and its guides plates. The sprung Pawl rides over the latch bar and will drop to hook over the latch bar. Once this latch state has been achieved, the geared motor assembly is energised to rotate the screws to increase the tension that the Pawl exerts onto the latch bar, thus drawing both the craft pieces together tighter.

Release Action

To release the Pawl Latch, the tension needs to be released and the whole Pawl wound to the point it is higher all higher than the latch bar. At this point the separation system can then move the spaceship parts apart.

Pawl Release Operation Safety Consideration

That the Pawl Latch system may be used on craft that have a human population, there will be a requirement that the release actions have all the appropriate interlocks and a safe operating procedure associated to ensure that the risk of inadvertent de-pressurisation is minimised. Such a procedure may include secure tag-outs are deployed to ensure that any disconnection activity is properly authorised and that such activity follows the approved safe operating procedures.

Sealing Checks

With human occupation of the sections, there is a need to ensure that the internal atmosphere does not seep out through poor joints. It is not possible to prevent air from escaping over time, but its escape should always be minimised as far as is practical.

To aid leak checking, a series of valves that are attached to the bulkhead directly or through a pipe, shall be placed such that once coupled, the inter-space between section bulkheads can be checked prior to the section bulkheads being breached. There are a variety of techniques that can be deployed that are not the subject of this document.

The bulkhead doors or access panels for section ends are to enable large sections, already filled with an atmosphere, to retain that atmosphere. Thus, living organisms on board the section will continue to survive.

References

(1) International Docking Systems Standard [IDSS] <https://web.archive.org/web/20131216200055/http://internationaldockingstandard.com/download/IDSS_IDD_Rev_C_11_22_13_FINAL.pdf>

(2) NASA Docking System Block 1: NASA's New Direct Electric Docking System Supporting ISS and Future Human Space Exploration <https://ntrs.nasa.gov/citations/20180004167>

(3) Electromagnets Offer Tantalizing Options for Satellites <https://www.nasa.gov/feature/electromagnets-offer-tantalizing-options-for-satellites>