PRACTICAL APPLICATION OF IN-SITU ADDITIVE MANUFACTURING TO LARGE SCALE SPACECRAFT COMPONENTS AND HABITAT FRAMEWORKS

Master's Thesis

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INTRODUCTION

https://aerospace.csis.org/data/space-launch-to-low-earth-orbit-how-much-does-it-cost/

INTRODUCTION

https://www.arianespace.com/mission-update/st29-soyuz-oneweb-ready/

INTRODUCTION

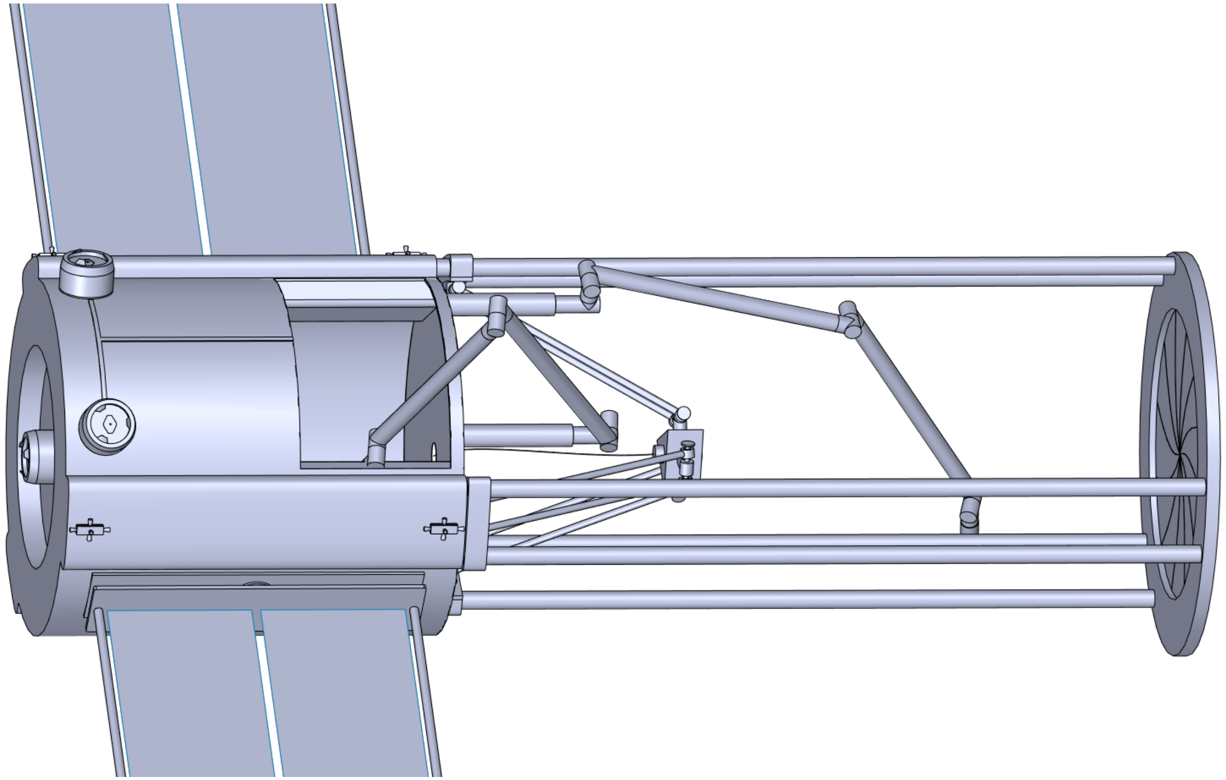
https://www.csmonitor.com/Science/2016/1102/Take-a-video-tour-of-the-International-Space-Station

PROBLEM STATEMENT

There are applications of in-situ manufacturing that have yet to be realized to drive down the cost per kg of LEO launches.

PROPOSED SOLUTION

An additive manufacturing ship capable of printing single metal variable size components.

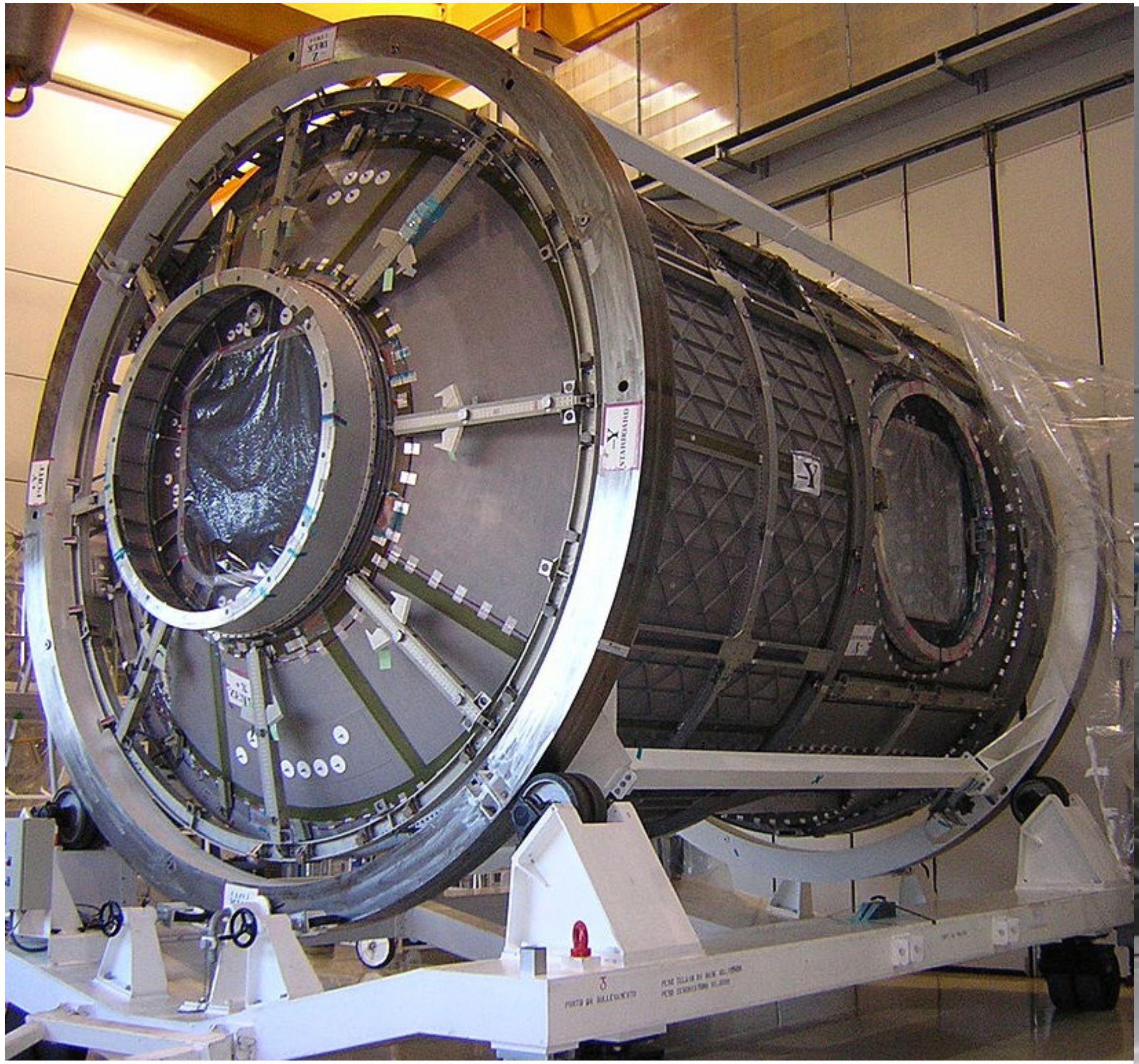


PROPOSED SOLUTION

For habitats:

- Habitat shells may be printed in orbit
- Allows for habitats of larger dimensions while retaining launch cost efficiency.
- Minimizes contamination as it is done in a clean room.
- Allows the use of highly energetically efficient electron beams for superior quality welds.

PROPOSED SOLUTION



https://commons.wikimedia.org/wiki/File:Interior_of_Harmony_Node.jpg

PROPOSED SOLUTION

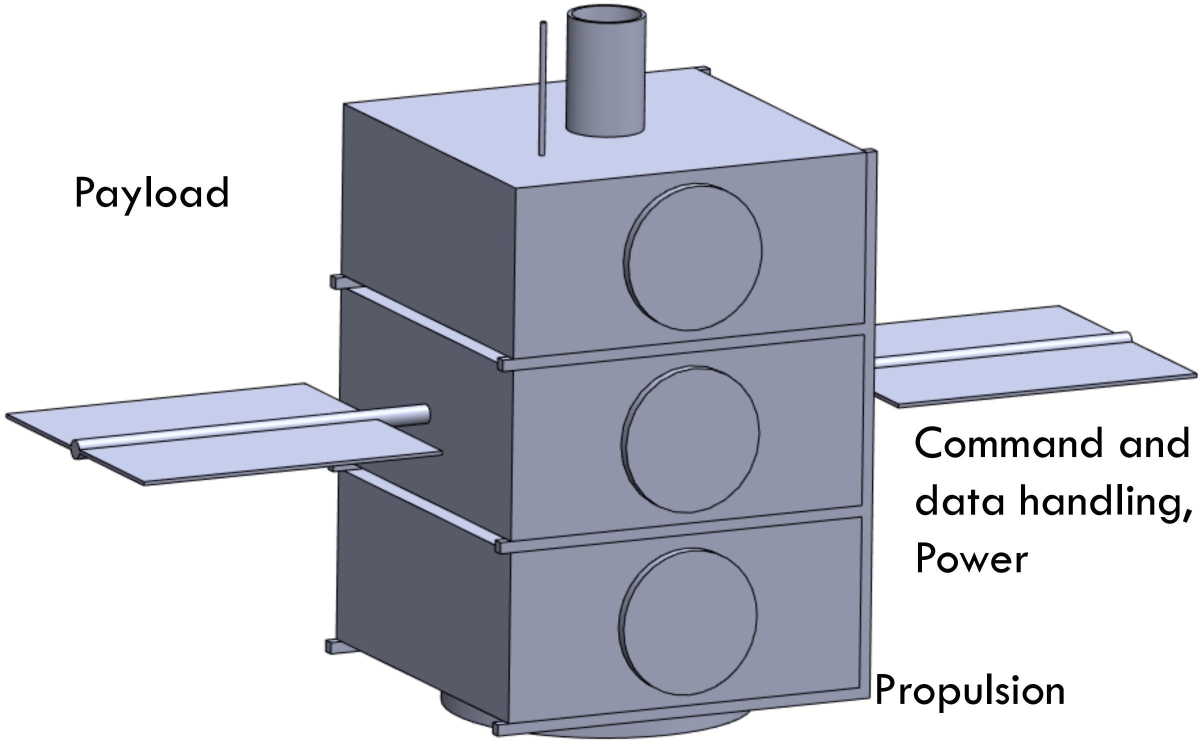
https://commons.wikimedia.org/wiki/File:Interior_of_Harmony_Node.jpg

PROPOSED SOLUTION

For satellites and spacecraft:

- Printing of structural components
- Less usage of foldable components
  - Trusses
  - Antennas
  - Solar panel supports
- Spacecraft need not to sustain launch stresses
- Less independent parts required
- More complex designs

PROPOSED SOLUTION



VISION

To advance knowledge in the field by studying applications that will contribute to a future of economic cooperation between industries operating in Low-Earth orbit in large structures.

MISSION

To provide an analysis of applications of additive manufacturing and robotics to the in-situ manufacturing of spacecraft and habitats as well as a concept study and design of a vehicle capable of performing this task.

NEEDS

LEO occupation requires large structures

For commercial and industrial applications

To generate gravity for long-term occupation

Construction of large structures in LEO must become more cost competitive

Product must take into consideration possible future ISRU resources

GOALS AND OBJECTIVES

To analyze applications of additive manufacturing and robotics in order to decrease habitat and spacecraft deployment costs.

- Analyze the best applications of additive manufacturing of medium to large scale components.

To analyze the requirements and define the functions of an additive manufacturing spacecraft capable of manufacturing medium to large scale spacecraft and habitat components.

- Define the environment, requirements, functions and assumptions necessary for the additive manufacturing spacecraft.

GOALS AND OBJECTIVES

To design a concept vehicle capable of meeting the requirements and functions.

- Define the concept of operations of the additive manufacturing spacecraft.
- Define the system architecture of the additive manufacturing spacecraft.
- Define possible future extraplanetary filament sourcing opportunities.
- Define a preliminary risk analysis for the mission.

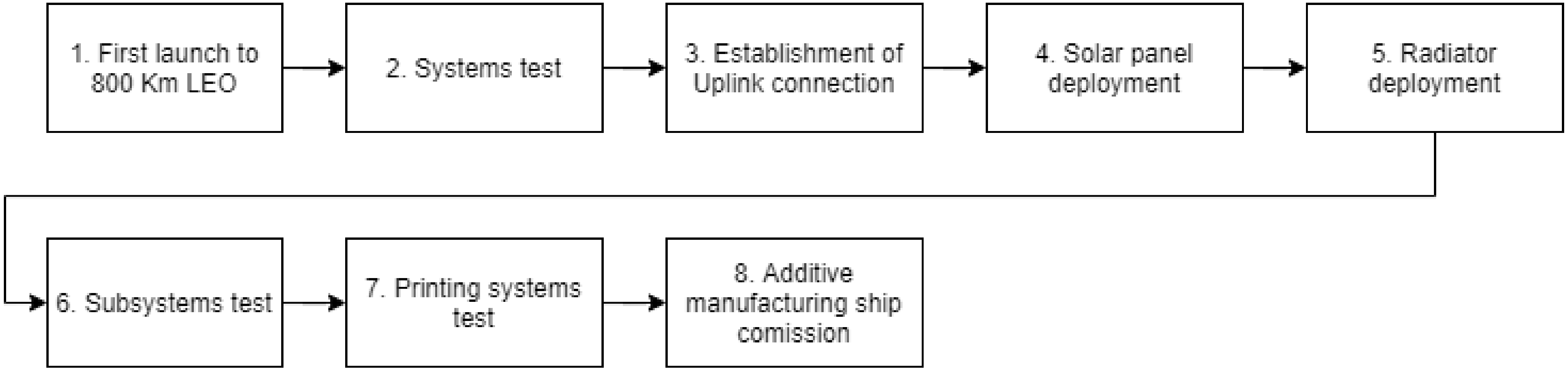
ENVIRONMENT

- Vacuum
- Radiation
- Atomic oxygen erosion at 700 km altitude
- Outgassing erosion due to vacuum exposure
- Sputtering erosion
- Electrostatic effects
- MMOD

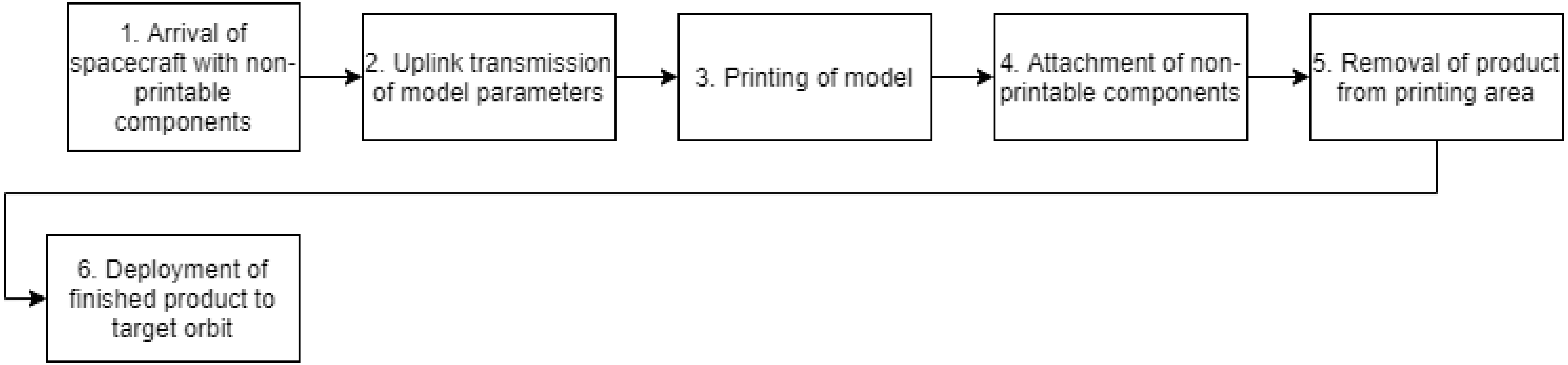
Radiation sources

- Van Allen's belt at 1000 km altitude
- SPE
- Neutron cascades from SPE
- Galactic cosmic rays

CONCEPT OF OPERATIONS – SPACECRAFT DEPLOYMENT



CONCEPT OF OPERATIONS – PRODUCT DEPLOYMENT



FUNCTIONAL REQUIREMENTS

1. Print variable scale single metal components
2. Provide power, communications and heat rejection
3. Provide station keeping
4. Provide docking to supply ships
5. Be able to manipulate products in printing area

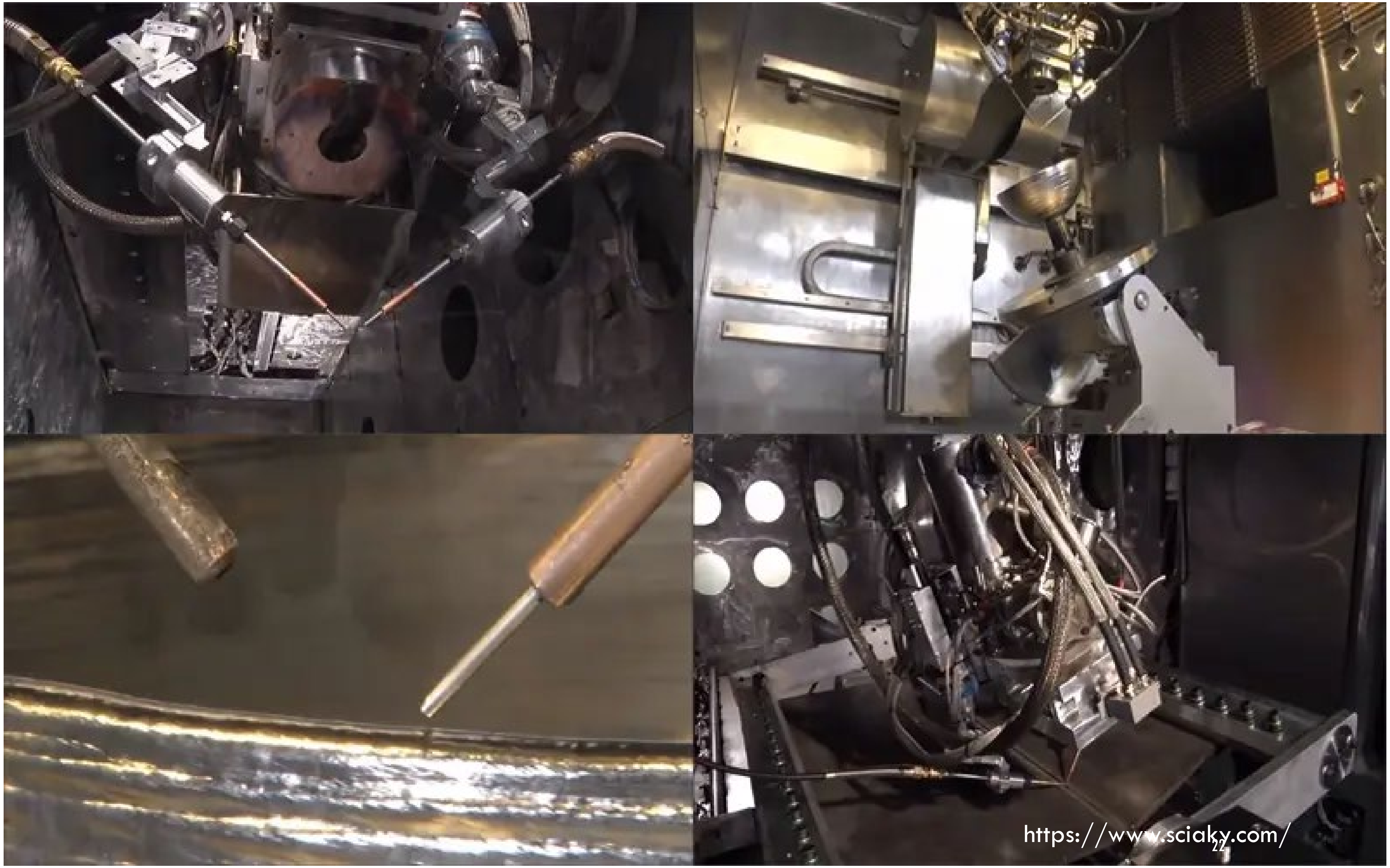
ASSUMPTIONS

- Material shall be sourced from Earth initially by supply ships.
- End-product must be able to deploy itself to orbit or have external means to be deployed
- Components must be designed to be interfaced with the robots
- In-situ deployed habitats shall be designed in order to provide for their own power, heat rejection and communication.

STATE OF THE ART

Sciaky

Launched the EBAM (Electron Beam Addictive Manufacturing) process in vacuum in 2009. Sells machines for industrial application that require up to 42 kW of power.



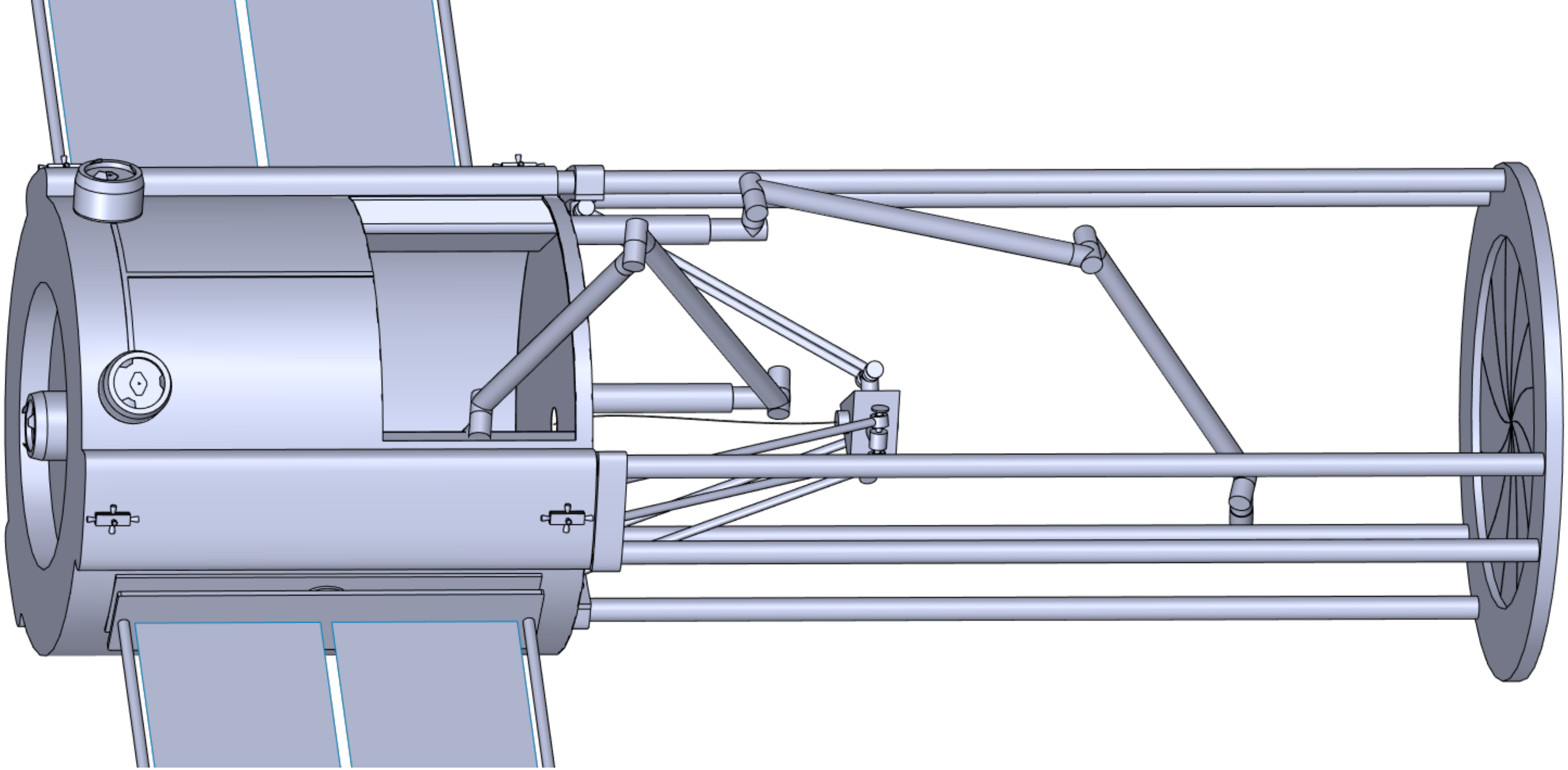
https://www.sciaky.com/

STATE OF THE ART

Relativity space

3D prints rocket components for industrial applications.

https://www.tctmagazine.com/additive-manufacturing-3d-printing-news/metal-additive-manufacturing-news/dm3d-technologies-manufactures-ten-foot-tall-rocket-nozzle-l/
https://nerdist.com/article/3d-print-orbital-rocket-relativity-space/

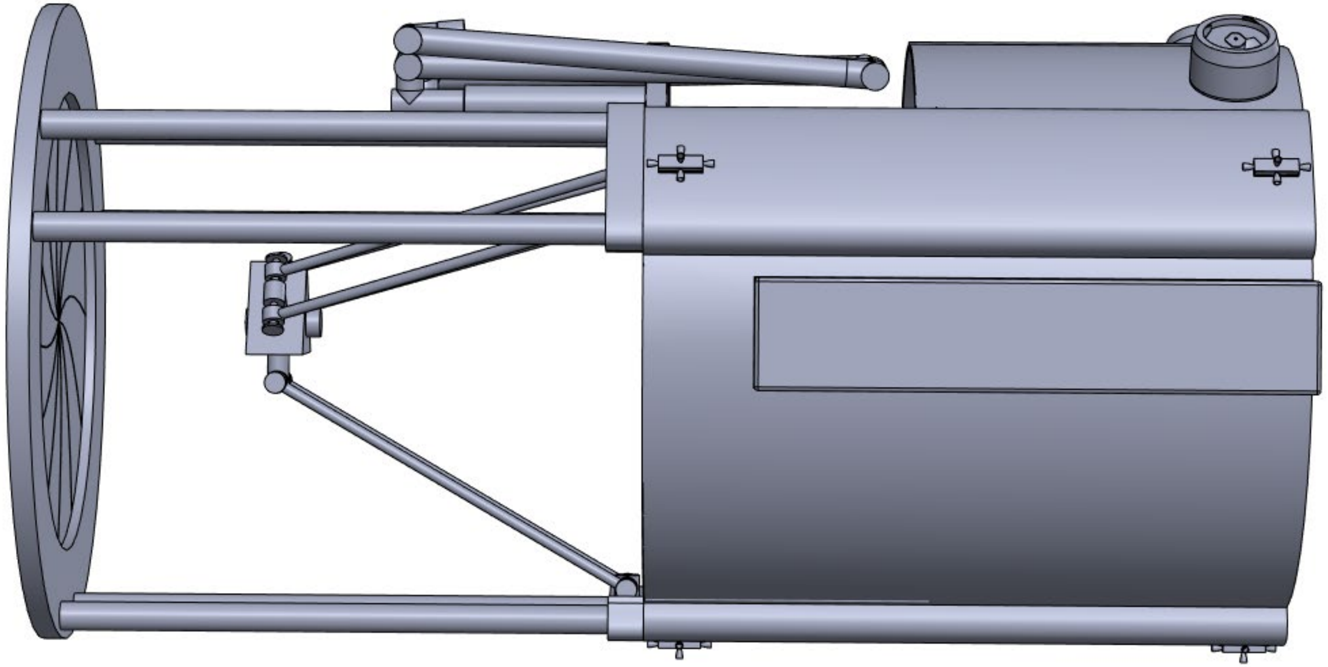


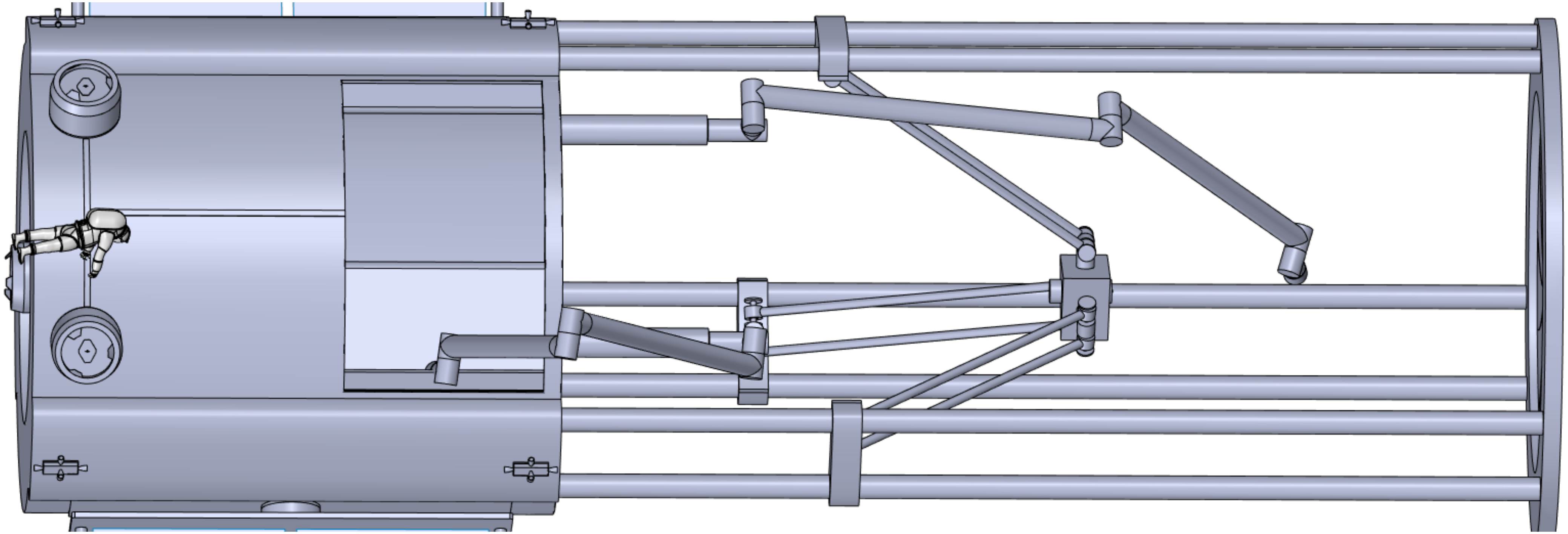
TRADE STUDIES

SCALE

9 meters diameter

17.73 m contracted, 26.23 m extended.

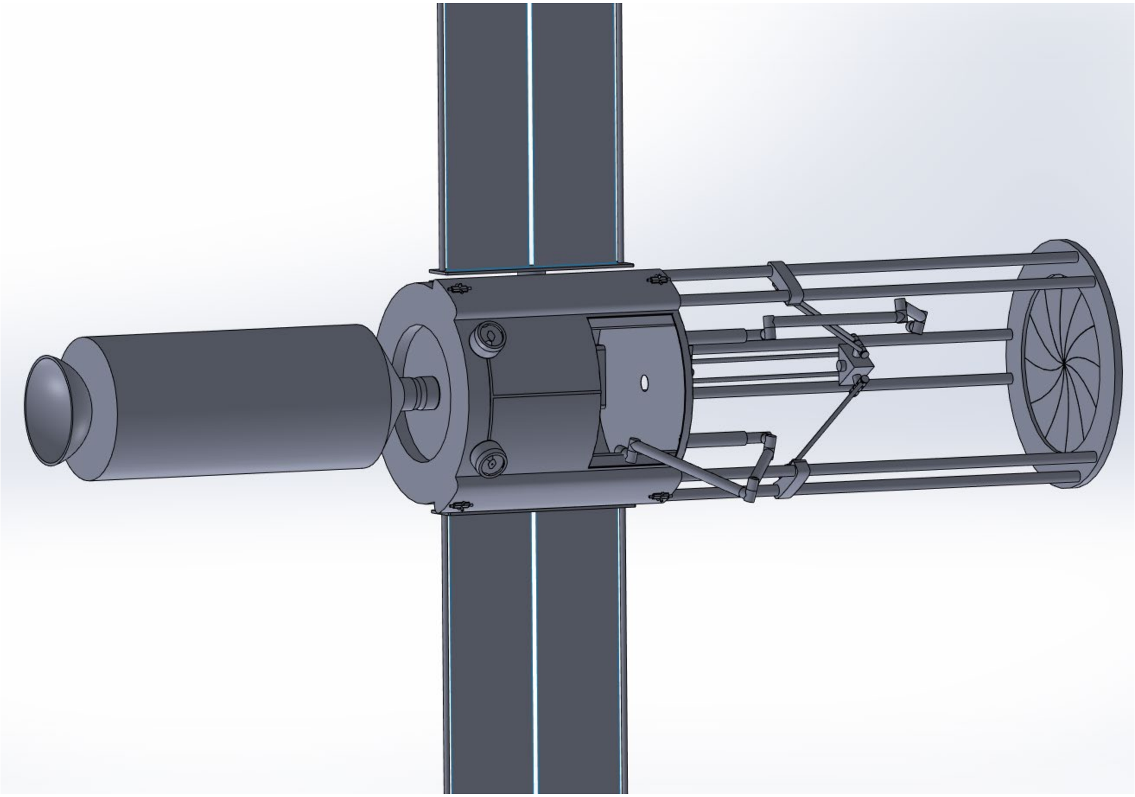




PROPULSION

- Rocket propulsion systems require igniters every time they need to turn on
- EM propulsion consumes a lot of power
- The propulsion system may fail

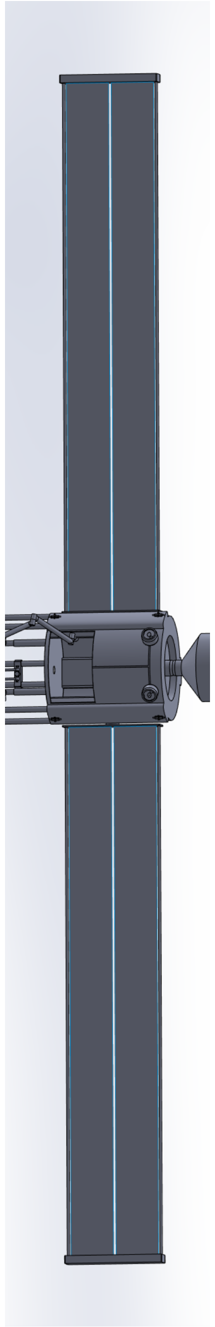
A Tug ship will perform the station keeping.



POWER

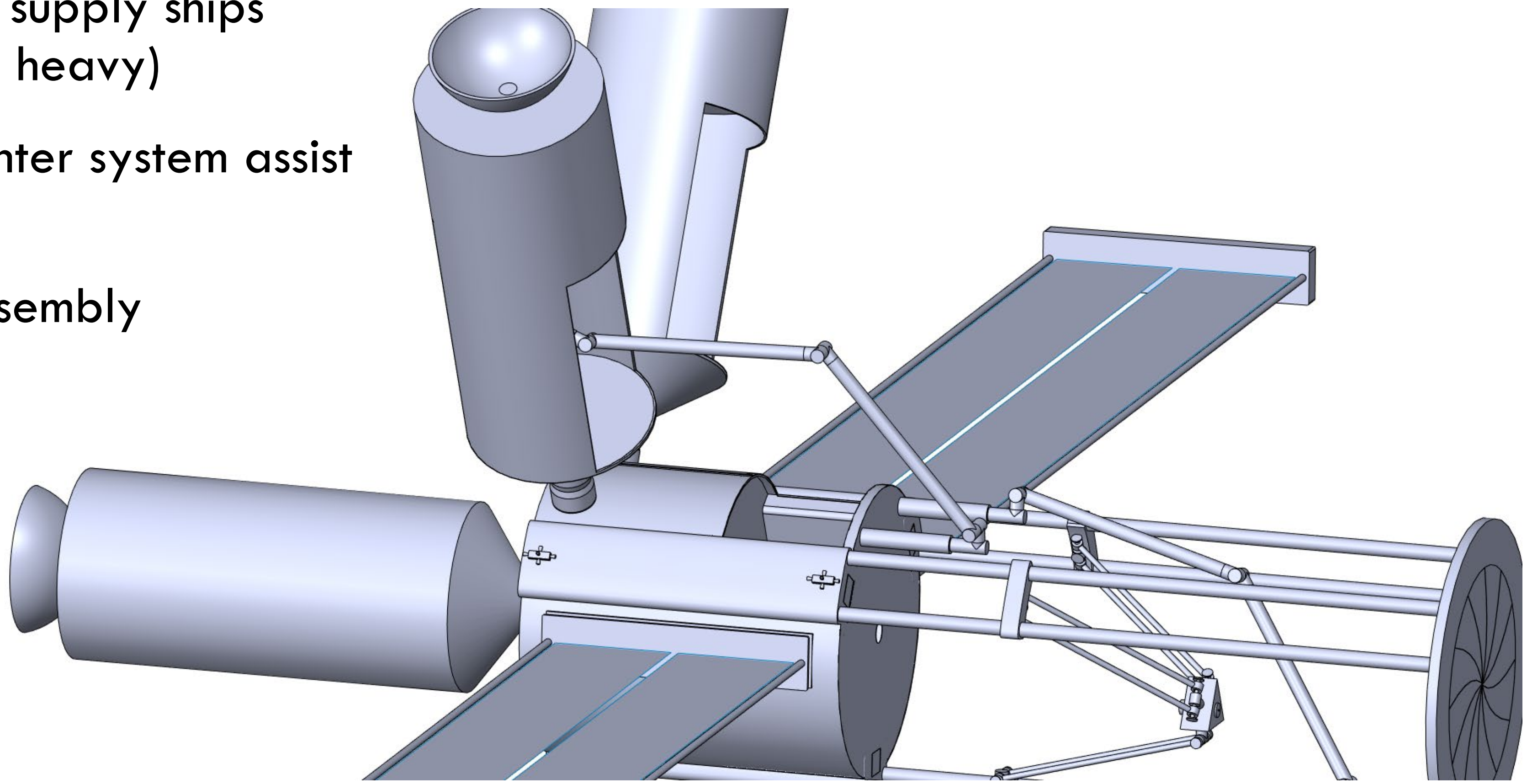
- 42 kW for the printer system + 3 kW for the remainder of the system
- 105 minutes orbit at 800 km
- Roughly 250 kg of lithium battery mass with 30% EOL degradation considered.
- 40 m x 7 m dual solar array, providing a total of 80 kW
  - EOL degradation
  - Not always in direct sunlight considered

Solar panels may be damaged. A contingency is to make them attachable to be replaced.



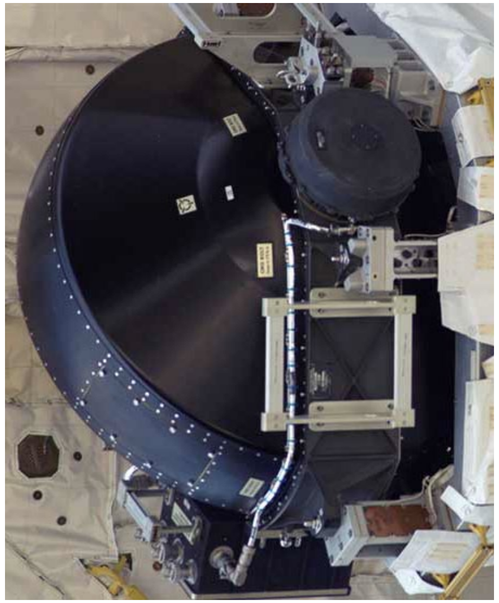
DOCKING

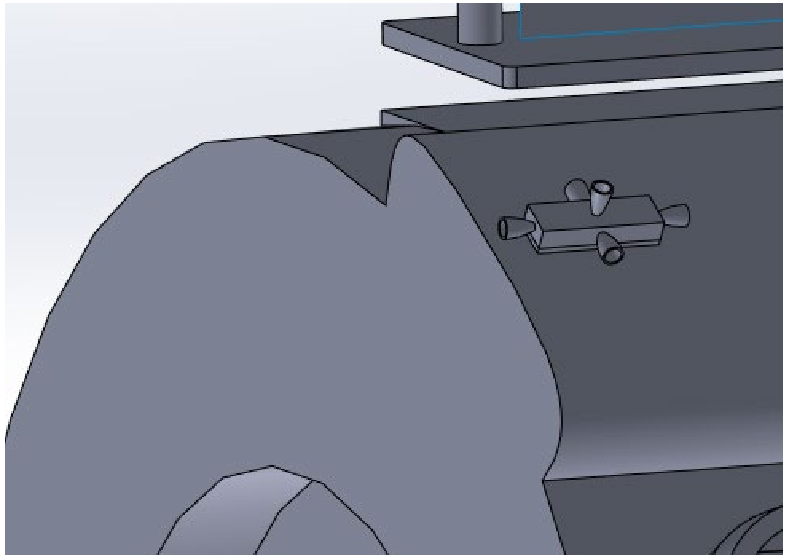
- Two docking ports for supply ships (sizing based on falcon heavy)
- Robotic arms from printer system assist on docking
- Can fit solar panel assembly



GUIDANCE, CONTROL AND NAVIGATION

- Spacecraft receives commands from Earth
- Attitude controlled primarily by large reaction masses
- The reaction masses shall be desaturated by the RCS system when necessary





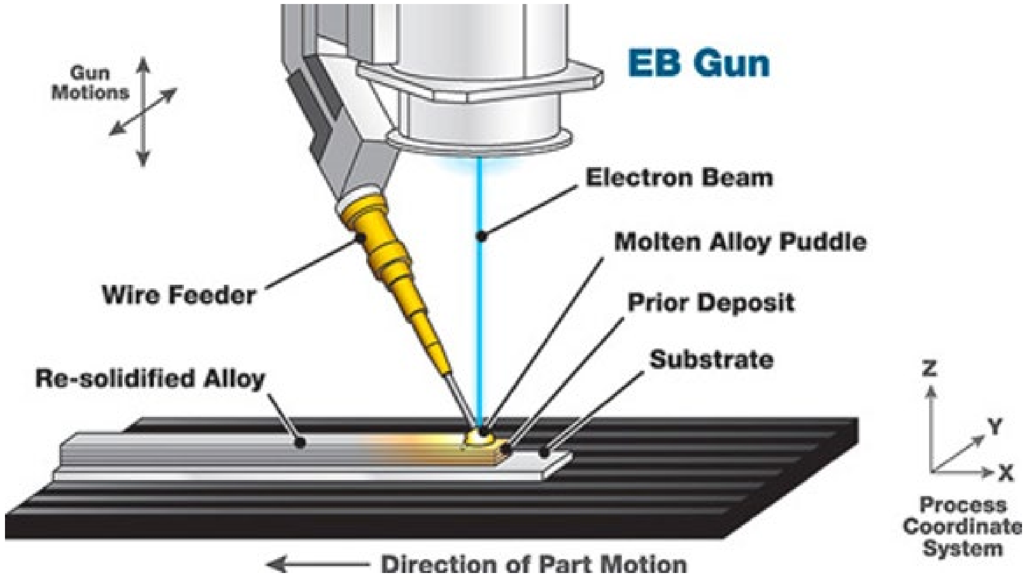
https://geekswipe.net/technology/aerospace/how-reaction-wheels-and-control-moment-gyros-work/

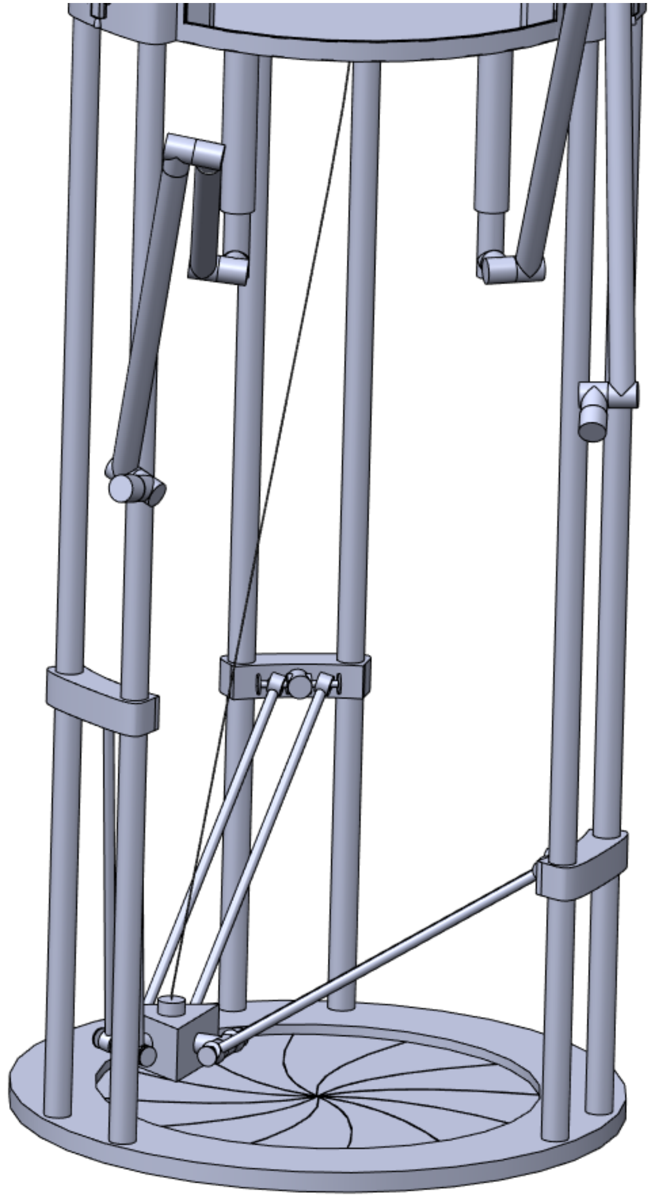
PRINTING SYSTEM

Delta 3D printer design (belts omitted)

Magnetic printing bed, adjustable bed height.

Printing limits: 11,5 m by 6,5 m diameter.

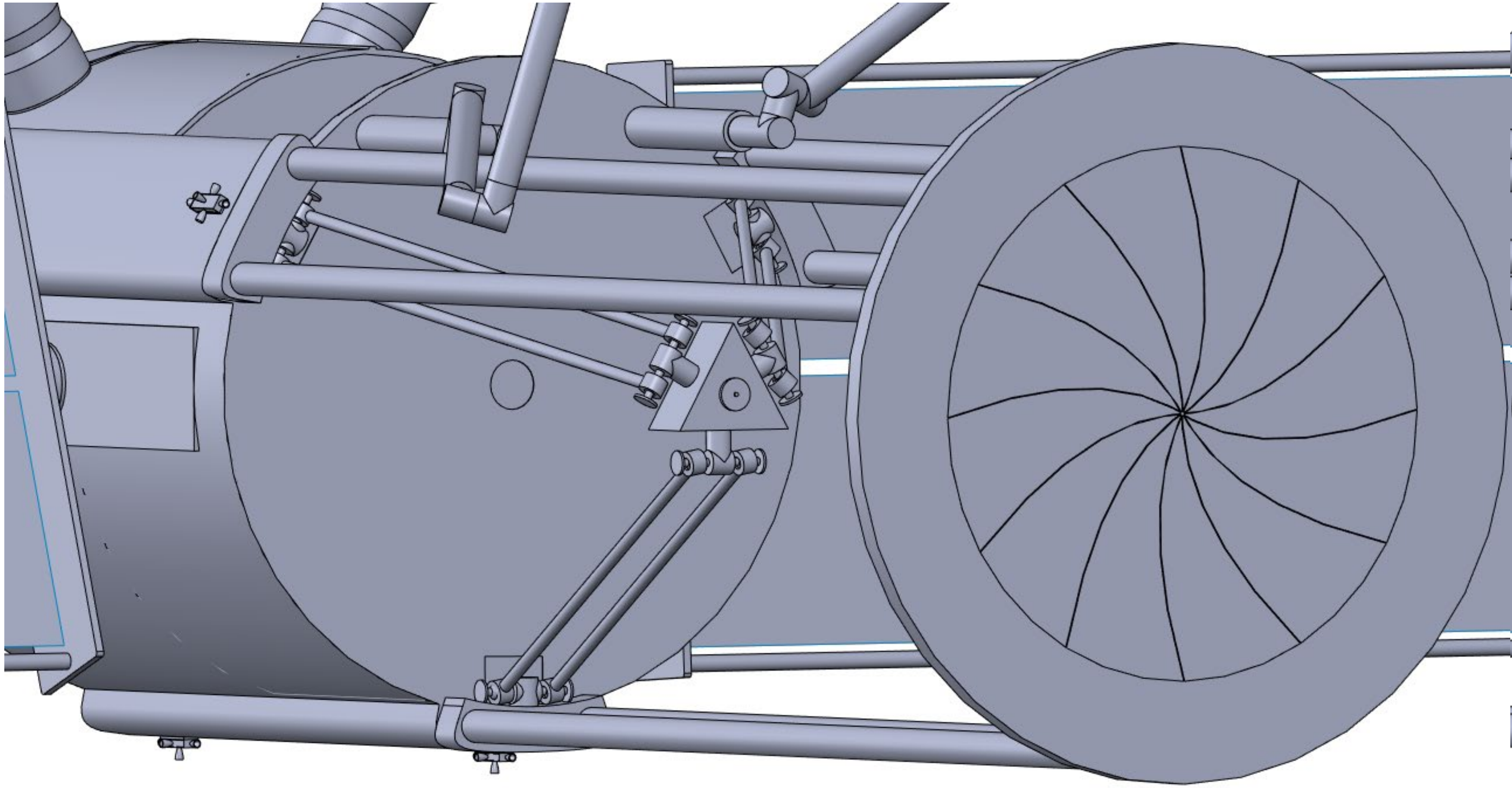


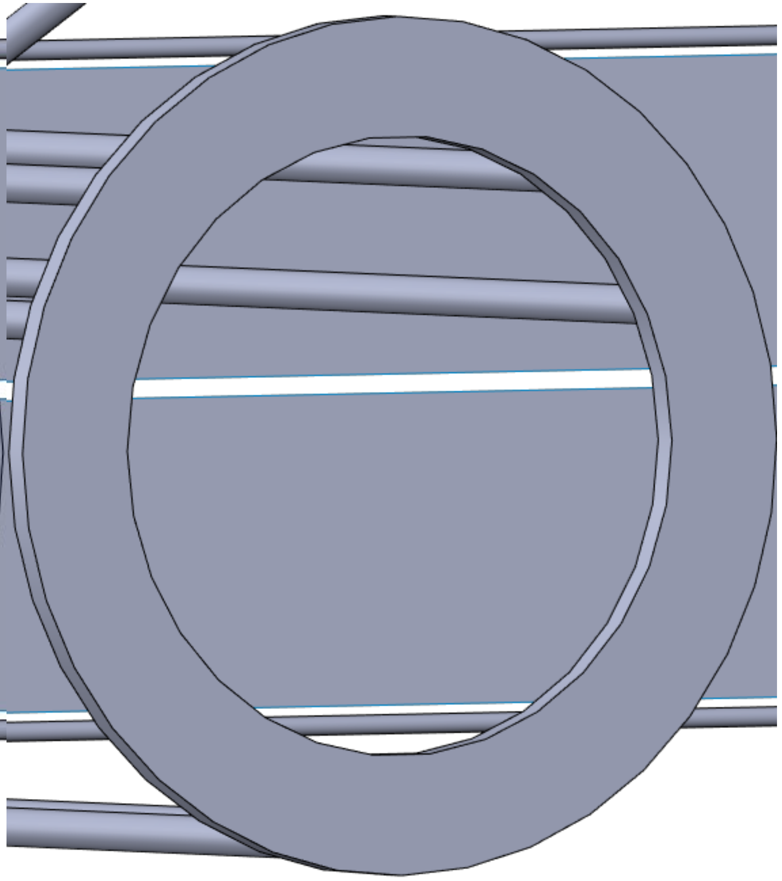


https://www.sciaky.com/additive-manufacturing/what-is-ded-3d-printing

PRINTING SYSTEM

Iris – Magnetic printing bed and exit point.





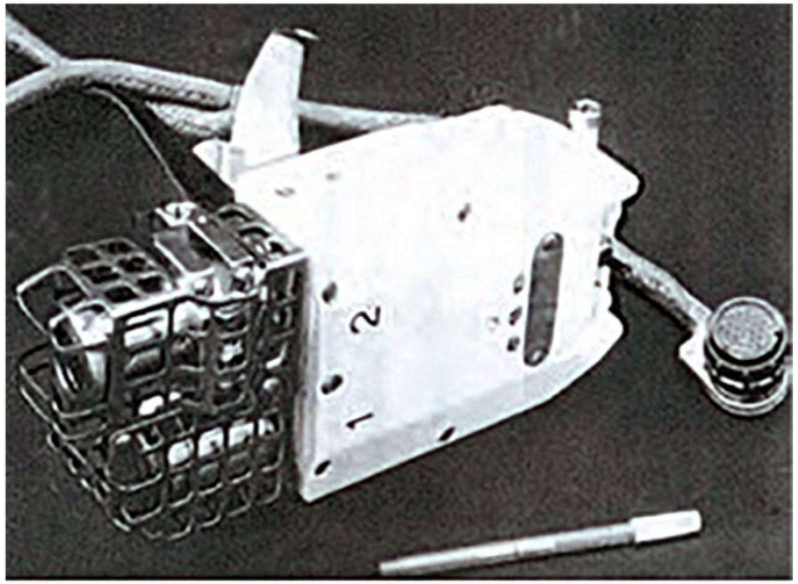
ROBOT ARMS

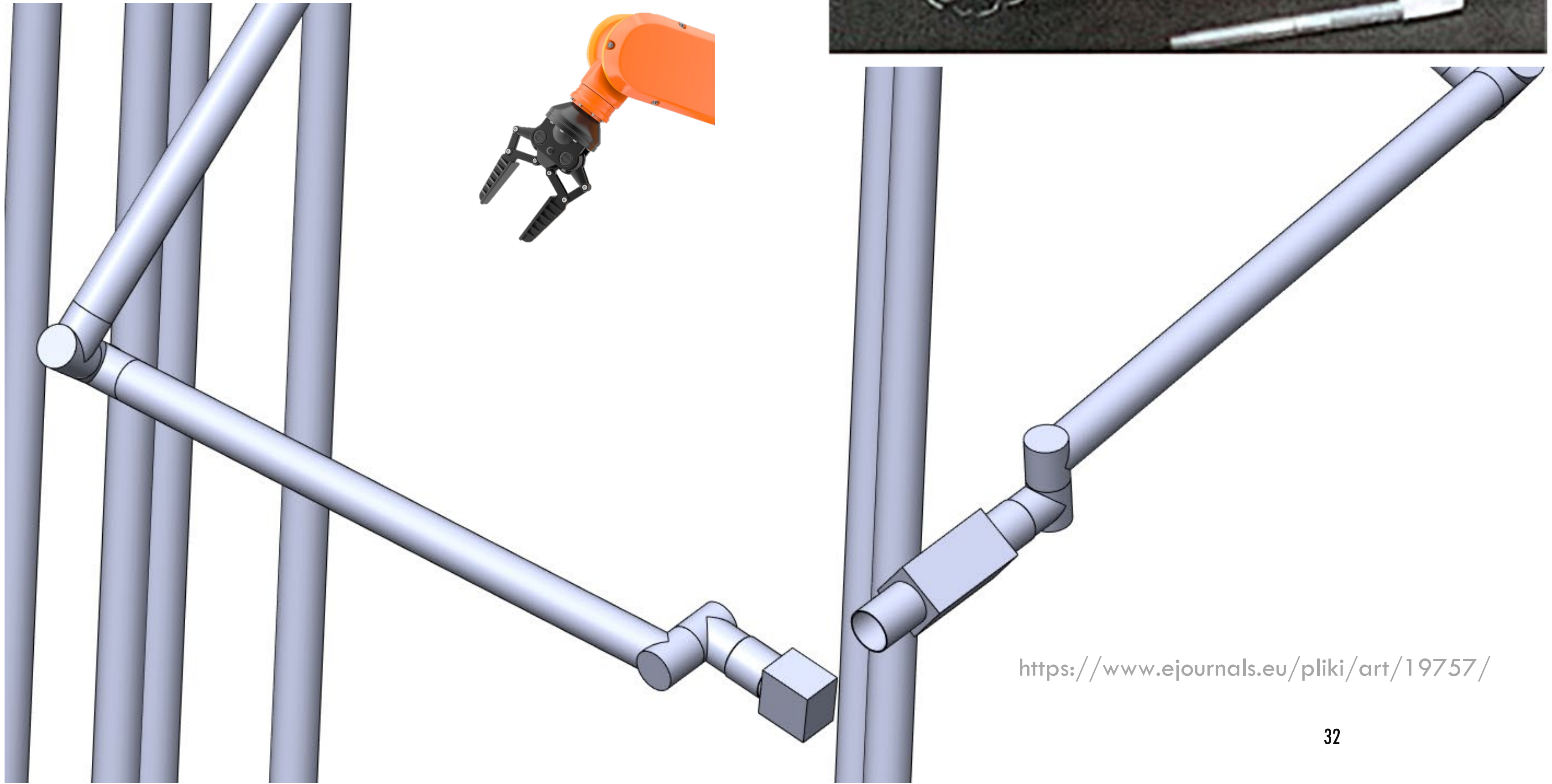
Robot arms based on Canadarm 2

Attachments:

- X-ray to verify welds
- Clamp
- Versatile electron beam

 tool





https://www.ejournals.eu/pliki/art/19757/

FUTURE FILAMENT SOURCES

- Asteroids rich in Fe and Ni.

4000 – 6500 m/s

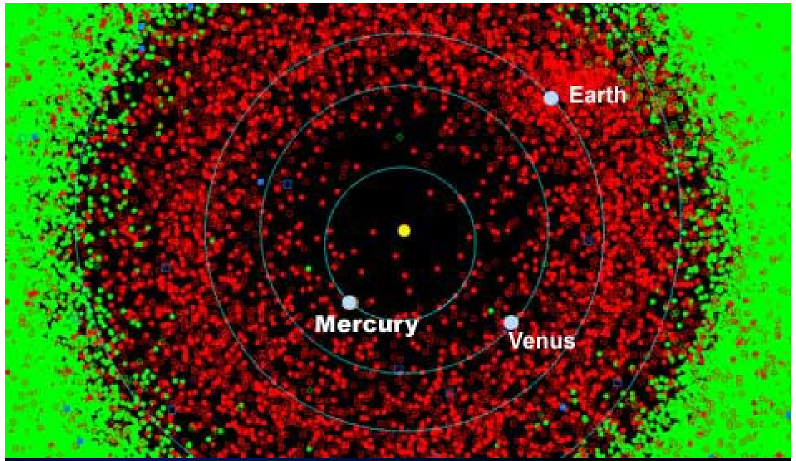
NEOs

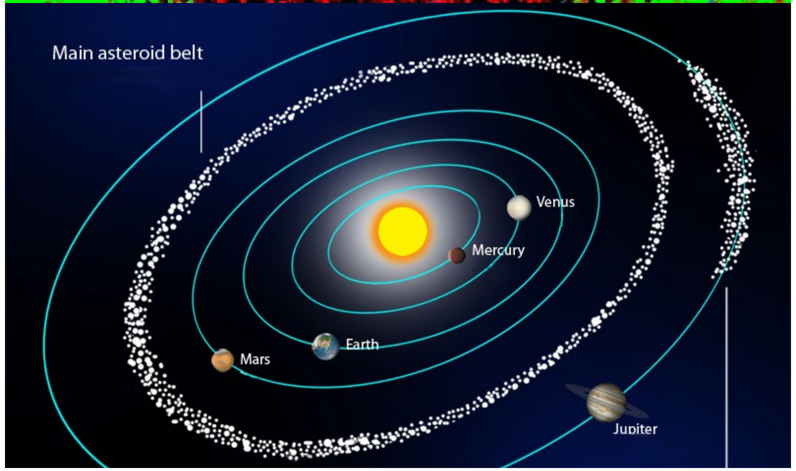
9400 m/s

9000 m/s

Δ v

Main asteroid belt





[* Approximated calculations](https://skyandtelescope.org/astronomy-news/15000-near-earth-asteroids/)
https://skyandtelescope.org/astronomy-news/15000-near-earth-asteroids/
https://app.emaze.com/@AOQWZFTL#/1

CONCLUSION

- Solutions need to be developed to drive the cost down
- Robotics and additive manufacturing present a good opportunity
- It's technologically feasible and possible to deploy
- Will create new markets
- A flight model to test the assumptions of directed energy deposition in microgravity with a magnetic bed is necessary to confirm hypothesis

RISK ANALYSIS AND CONTINGENCIES

- Filament might jam
  - Robust unjamming system with several motors
- Belt might break
  - Must be replaced by astronauts. Make replacement easier.
- Extending mechanism motors might break/printing motors might break
  - Make motors replaceable
- Head might require liquid cooling
  - Conduct breadboarding to assess
- Robotic arms might break
  - Make them replaceable