Conceptual Design Review for SPAMM

Space Printer for Autonomous Manufacture of Mega-Structures

UNITED STATES AIR FORCE ACADEMY

<u>USAFA Astro</u>

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Advisor: Major Miller
Mentor: Monty Greer

Team Overview

- Stephen Timperley (PM)
- Grant Stec
- Giorgio Simoncioni
- Nicholas Realuyo
- John Fredette
- Gavin Ehrich
- Ashley Spear
- Benjamin Yan

- Dr. Monty Greer (Mentor)
- Major Daniel Miller (Advisor)

Outline

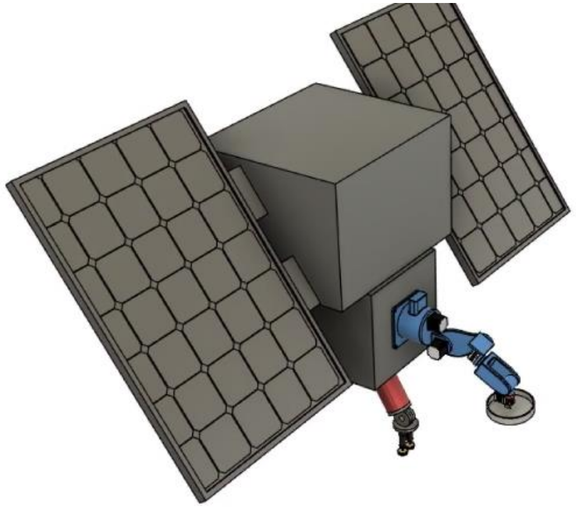
- Main Body
  - System Engineering Milestones
  - Executive Summary
  - Description / Payload Overview
  - Business Case + Impact
  - Launch / Orbit
  - OV1
  - Trade Study
  - Animation
  - CONOPS
  - Feasibility
    - Payload
    - Environment
    - Operations
  - Risks
  - Prototype
  - Innovation + Impact
  - Tech Gap
  - Biggest Challenges Encountered
  - Innovative Ideas
  - Paper
  - Path to PDR
- Conclusion
- Backup / Work Cited

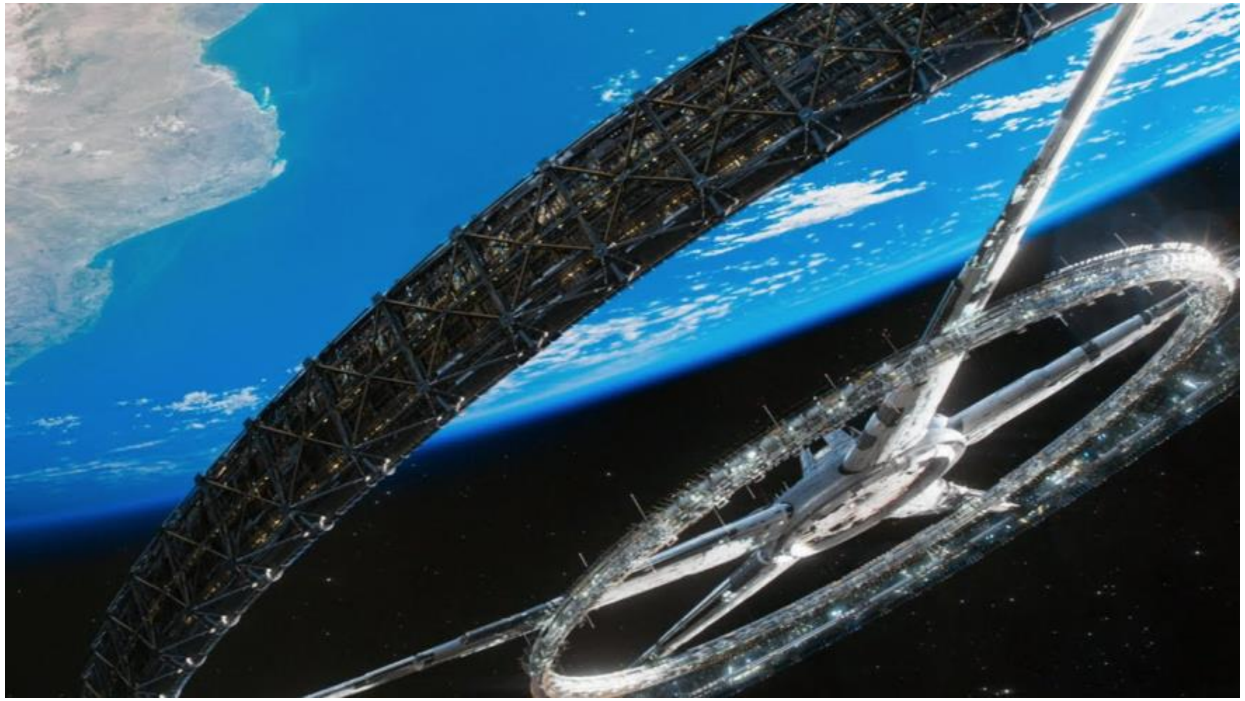
System Engineering Milestones (2.4)

- Identify PM: 8/13/24
- Select Operations: 9/10/24
- Present SRR: 11/22/24
- Complete Trade Studies: 1/28/25
- Present Conceptual Design Review: 4/1/25
- Develop a plan to reach Preliminary Design Review: 4/7/25
- Present at C3 Final Showcase: 4/14/25
- Submit paper to technical conferences: 5/30/25

Executive Summary

- What does the future of space look like?
  - Mega-Structures in Space
- Space Printer for Autonomous Manufacture of Mega-Structures (SPAMM)





Elysium

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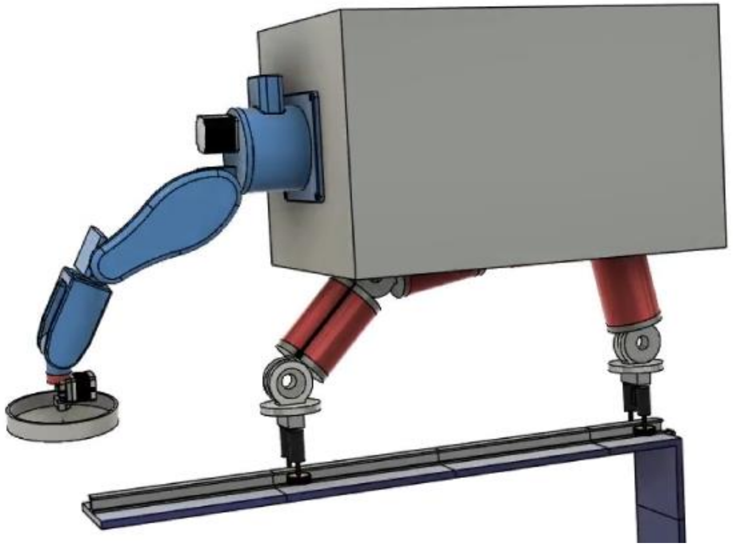
Description / Payload Overview (1.4)

SPAMM 3 Operations

- FDM 3D Printing (utilizing robotic arm)
  - Heating
  - Extrusion
  - Printer head movement
- Mobility Across Manufactured Parts
  - Moving along tracks
  - Switching tracks
- Leveling/Location Estimation
  - Determining part location accurately to enable mobility and continued printing

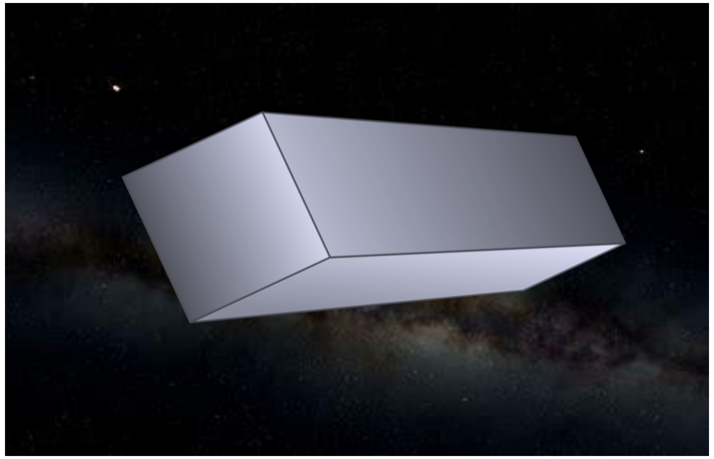


Important Note:

- Reload Serviceable

Business Case + Impact (1.1)

- Tech Demo w/ Real Capability
  - Can print any unique structure in the vacuum of space
  - 10-by-10 cm beam at 10% infill at rate of 1 km/year
    (assuming 2 mm nozzle and 41.6 mm^3/s flow rate)(1)

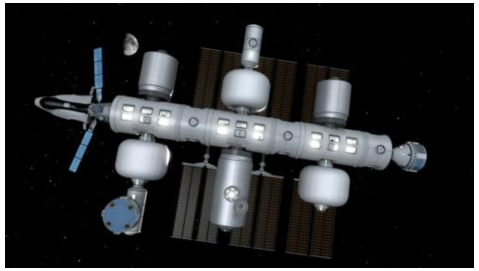


SeekPNG

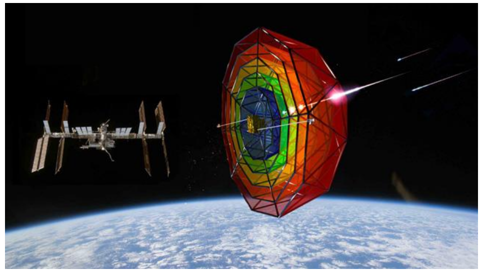
Applications

- Deployables
  - Antennas / Dishes
  - Trusses
- Pressurized Volumes
  - Fuel tanks
  - Space Station / Habitats
- Unpressurized Volumes
  - Storage
  - Shielding
- Space Craft
  - Repair
  - Capability Extension
  - Creation

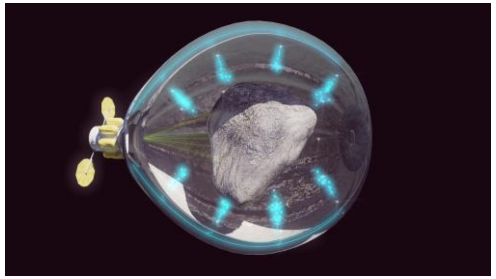
Redwire Space



Procommun



SpaceNews



DigitalSpace

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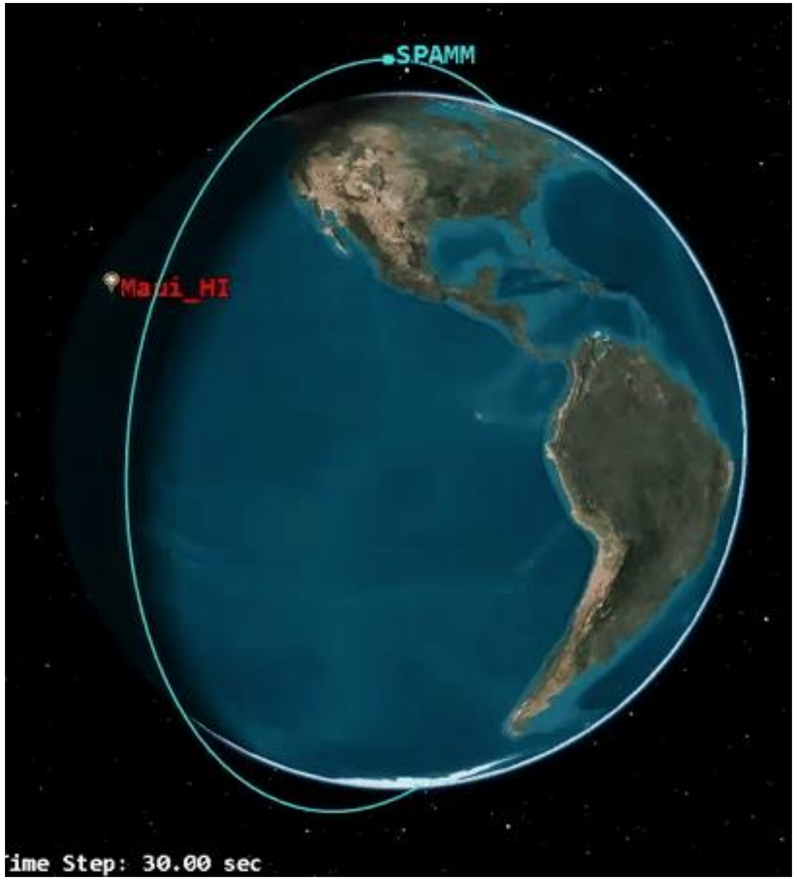
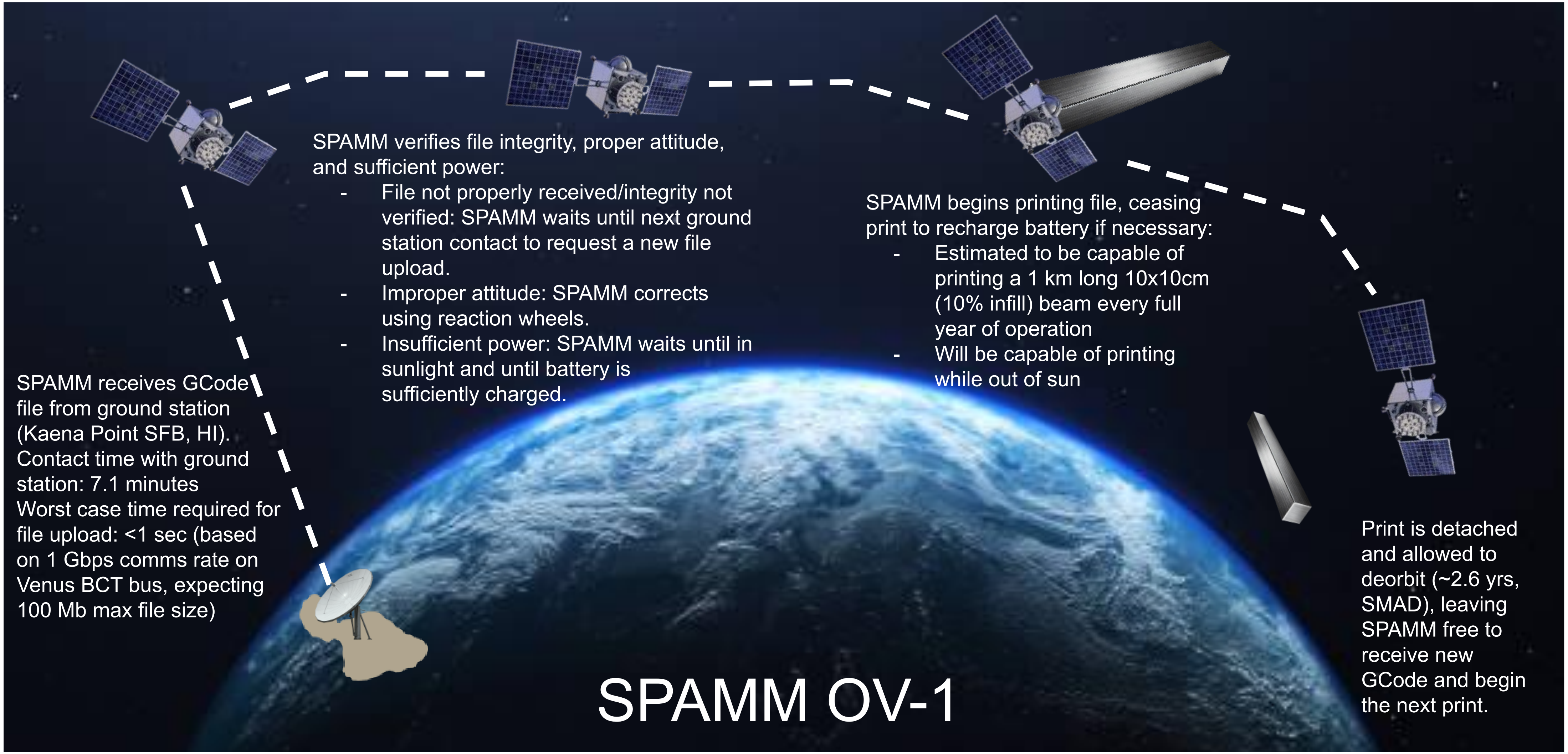
Launch / Orbit (1.4)

- Launch Parameters:
  - Launching out of Vandenberg Space Force Base due to highly inclined orbit (i = 98 deg)
  - Falcon 9 rideshare to LEO (altitude 600 km) using ESPA ring
- Orbit Parameters:
  - Sun Time
    - Sun-synchronous 600 km altitude circular orbit, i = 98 deg
    - Minimum sun time per orbit of 1.2 hours (continuous sun Aug-Feb)
    - Maximum in-shadow time per orbit of 18.42 minutes
  - Comms with Kaena Point SFB, HI (arbitrarily selected ground station)
    - 7.1-minute minimum window each contact, 4-5 passes/day
  - Deorbiting
    - Due to low altitude, all printed parts and satellite are expected to deorbit no later than 2.6 years after mission EOL (SMAD) (2)



OV1 (2.2)



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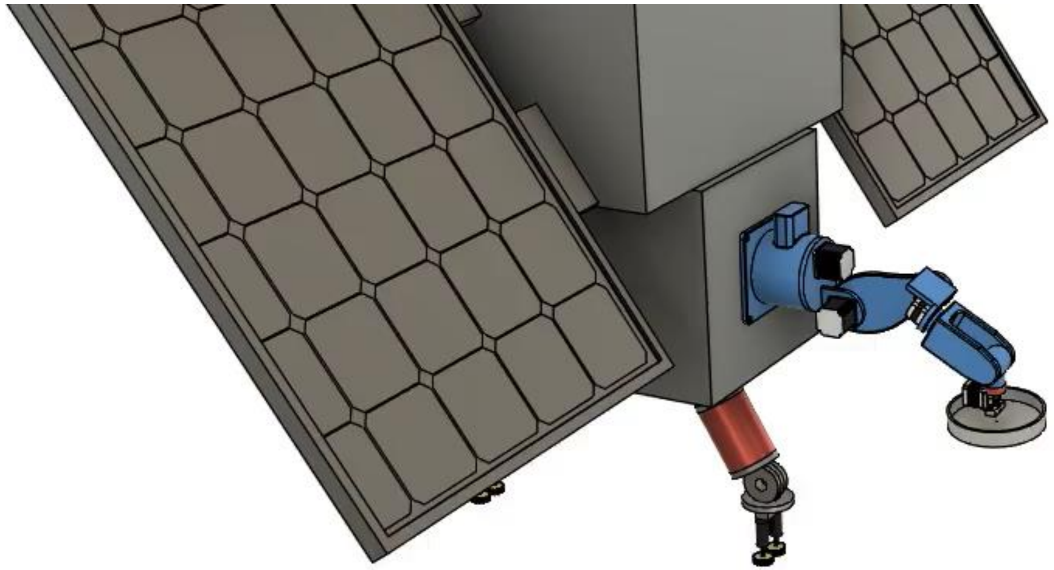
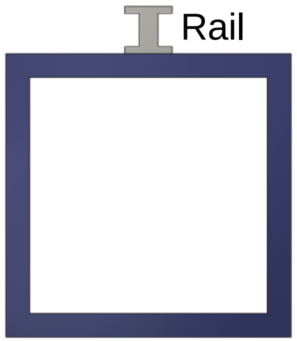
Trade Study (1.7)

3D Printing Mechanisms & Methods

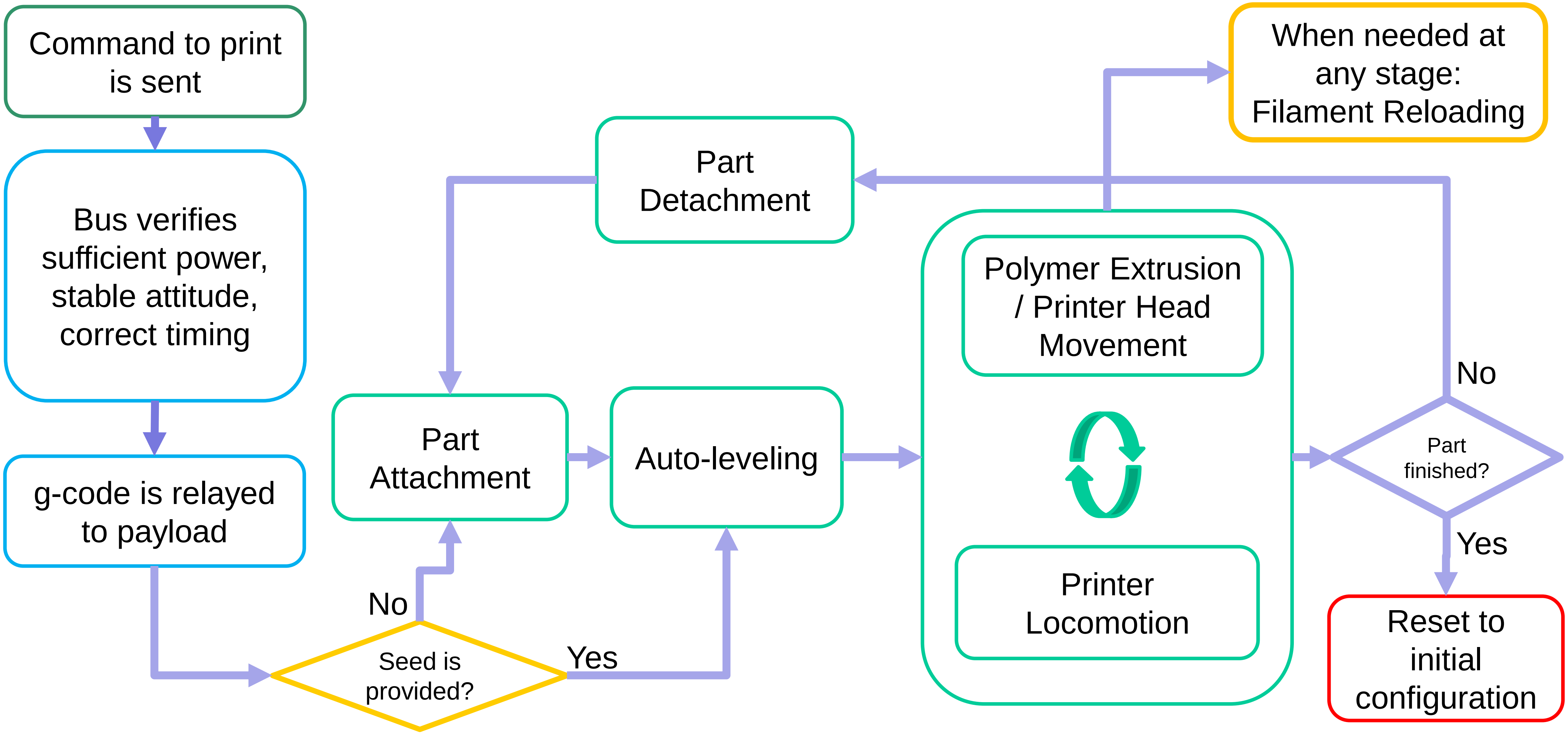
Criteria	Climbot (Bipedal Climbing)	Roller Bot (Wheeled System)	Hybrid (Climb + Wheels)	Thruster-Based Printer
Structure & Design Complexity	Two complex articulated arms, modular links	Uses wheels on printed surfaces	Combines arms + wheels	Uses thrusters for movement and requires excessive power
Degrees of Freedom (DoF)	Climbs in any direction(up to 6 DoF)	Limited to very wide turns (6 DoF)	Uses both climbing and rolling modes (6 DoF)	Fully unrestricted (6 DoF)
Ease of Reorientation	Reorients by pivoting around attachment points	Must follow paths and change orientation via turning	Adapts dynamically between climbing and wheeled motion	Can rotate freely in any direction
Gripping Stability	Continuously regripping for movement	Never requires regripping	Requires occasional regripping for certain turns	Needs precise thrust control and stabilization

Animation (2.1)





Payload Function CONOPs (2.3)



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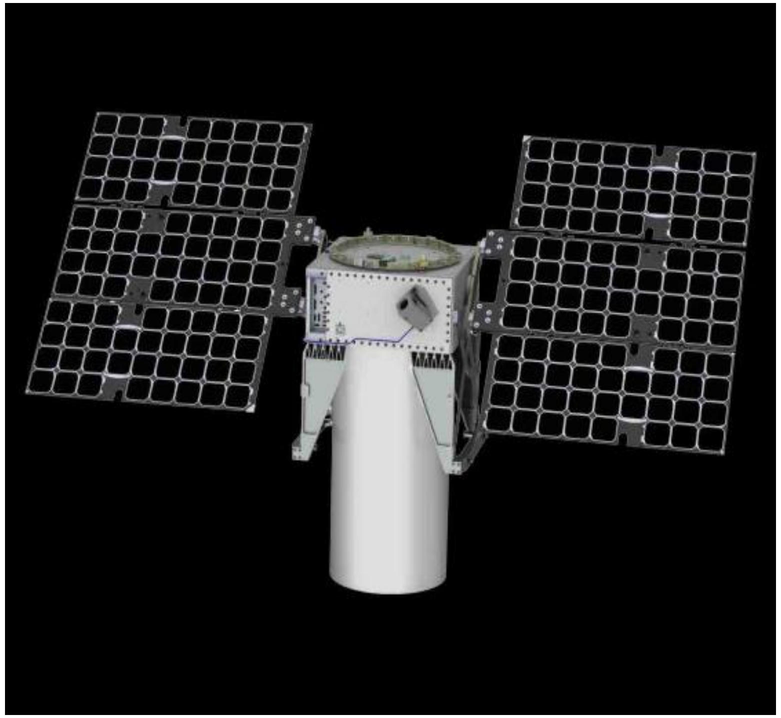
BUS Compatibility: BCT X-Sat Venus Class (1.4)

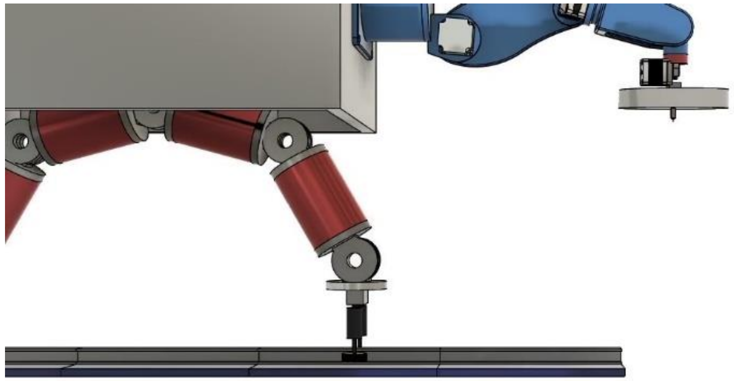
- Power
  - In Sunlight: ~220 W Total Payload Power In Operation (444W Available)
    - ~150 W needed for continuous printer operation
      - ~70 W for filament heating (3)
      - ~80 W for other printer operations (electronics, printer head movement, extrusion, etc)
    - ~50 W needed for motor operation to move across printed objects
  - In Eclipse: ~70 W Total Idle Power to maintain Thermal Environment
    - ~70 W for filament heating (3)
- Volume
  - Printer + Spools + Arms fit inside the 17” × 16.4” × 27” payload volume
- Mass
  - Printer + Filament + Arms mass estimate: 60Kg (Meets the 70Kg requirement)
- Data
  - Between Bus and Payload: Ethernet
  - Between Bus and Ground Station: capable of 1 Gbps with a 7.033 Minute pass



Blue Canyon Technologies - Spacecraft solutions

Leveling / Location Estimation (1.2)

- Auto-leveling / location estimation required for mobility and continued printing
- Location Sensing
  - General Movement: 0.5 mm precision (4)
    - Known motor characteristics
    - Stereoscopic cameras for depth and edge detection
  - Auto-leveling: 0.01 mm accuracy (5)
    - IR sensors
- Frequency of re-estimation
  - Only required during and after printer locomotion (once every print section)
- Camera for monitoring print progress and failures
  - Camera & computer vision for detection



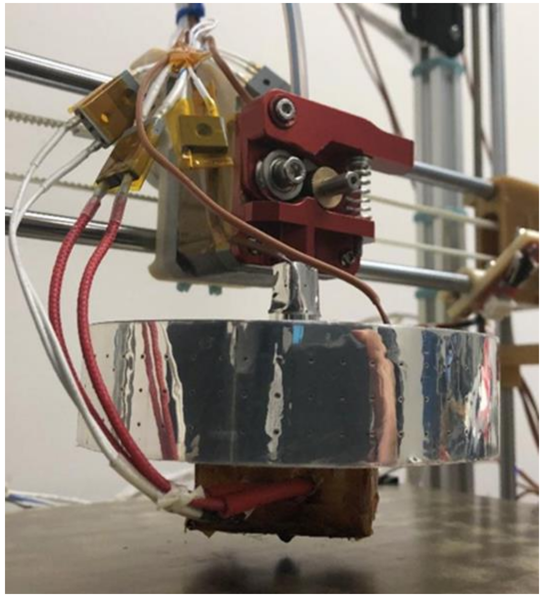
Trade Study (1.7)

- **PEEK: Outgassing PEEK vs ULTEM (6):**

Filament	Temperature range (°C)	Applications	Outgassing (%TML, %CVCM)
Unfilled PEEK	-50 - 250	Used in aerospace, medical, and industrial applications	%TML = 0.14% %CVCM = 0%
Bearing Grade PEEK	-50 - 250	Slide and bearings exposed to temperatures	
Conductive PEEK	-50 - 250	Semiconductor and electronics applications that require static dissipation	
ULTEM	-40 - 217	Excellent dimensional stability, high tensile strength, low outgassing	%TML = 0.55% %CVCM = 0.02%

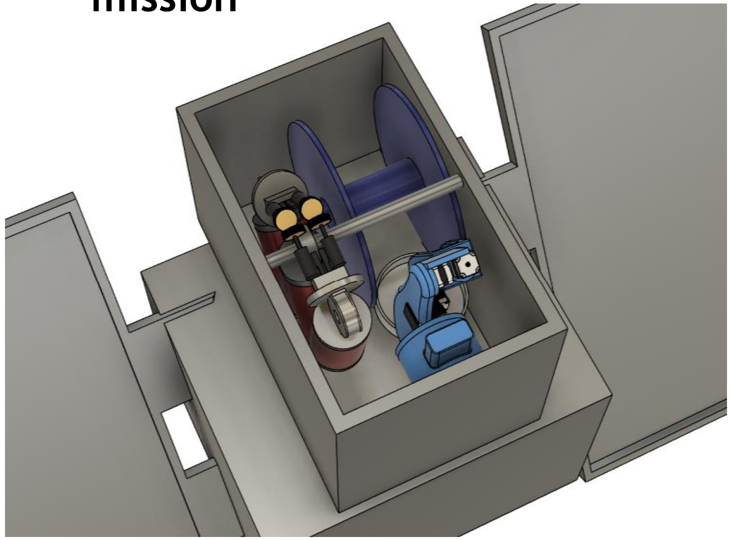
Filament (1.2)

- PEEK (Polyether Ether Ketone)
- Filament Feed
  - Direct drive
    - Higher flow rate than Bowden (7)
    - Aids heat dissipation and reduces clogging
    - Less powerful motor required
  - Larger Idler wheel
    - Higher pressure
    - Less damaging (less dust) => less clogs
- Cooling path to Hot-end
  - Unique radiative hot-end to prevent premature melting (8)
  - Extruder must maintain 360-450 C
  - MLI to reduce power draw, maintain heat, and separate from the rest of the system



[Development of a 3D Printer Capable of Operation in a Vacuum]

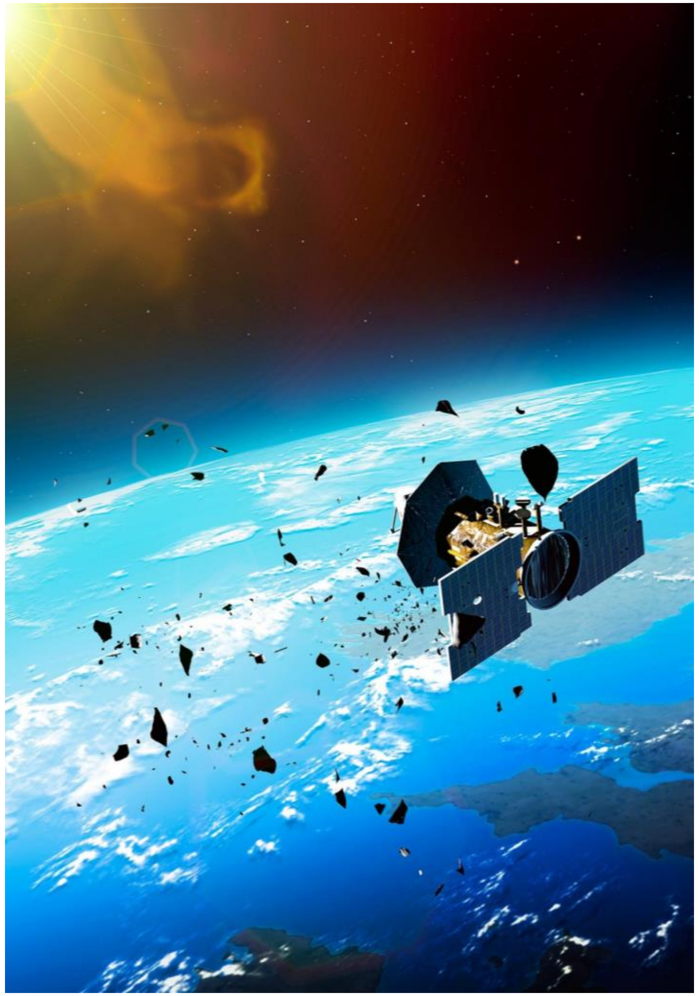
- Filament Storage & Reload
  - Store spools of 20kg of PEEK (28% of total payload mass)
  - Design payload for reload feasibility
  - Servicing is not the focus of this mission



20kg spool in payload
38cm outer diameter, 8cm bore for roller, 17.7cm width, assuming 80% packing density (error) for 2.85mm dia. filament

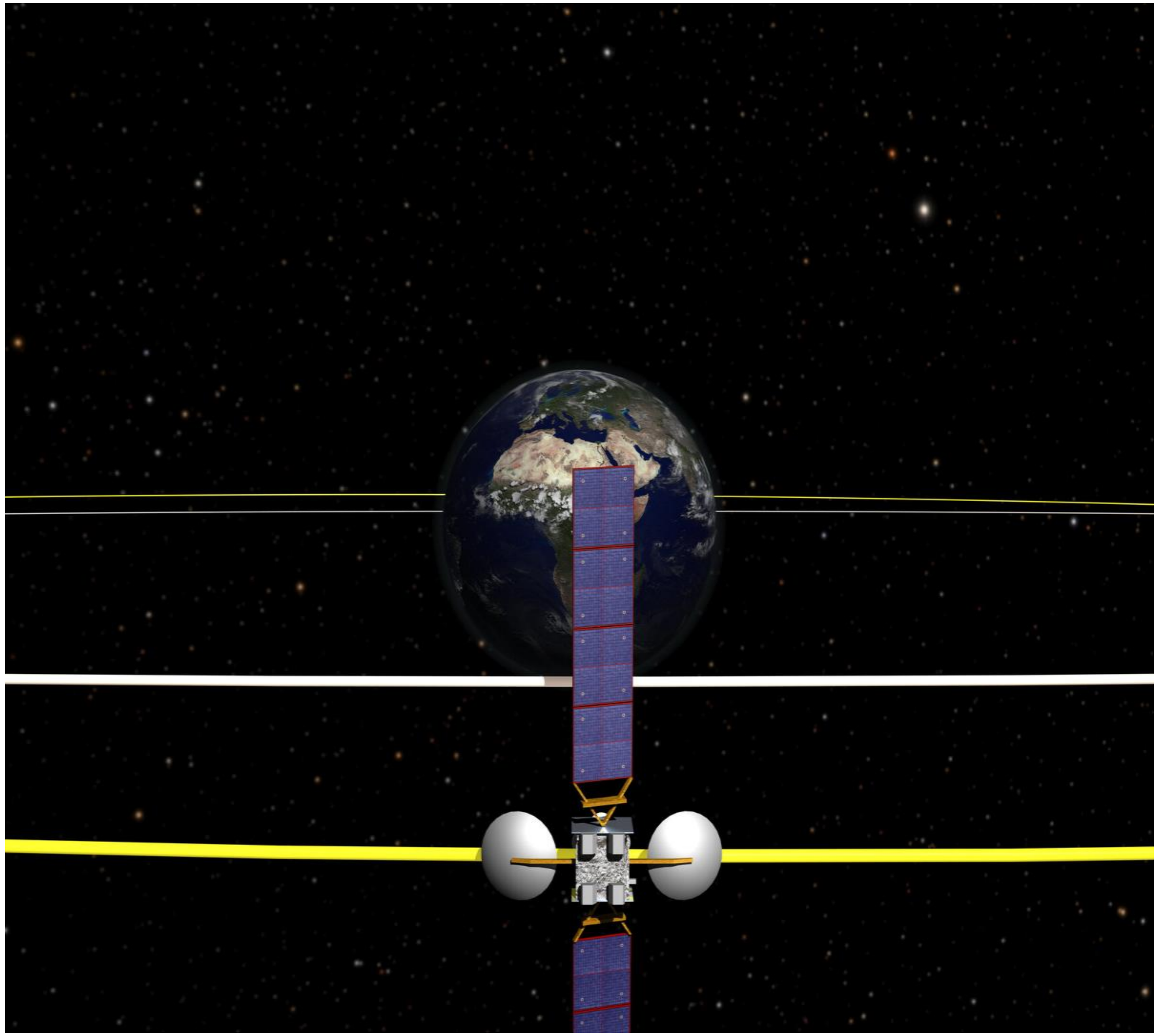
Environmental Feasibility (1.2)

- Outgassing
- Requirements: %TML < 1.0% & %CVCM < 0.1% (9)
  - PEEK - solid and molten
    - Solid State - $\%TML = 0.14\%, \%CVCM = 0.0\%$
- Cold Welding (10)- avoid metal-on-metal, use lubricant
- Thermal: Expected range: -40° to 71° C
  - PEEK: -50 ° to 250°C Operating range
- Radiation: Mission placement reduces radiation
  - Must survive a total dose of $0.6\ kRad$ over a $5\ year$ mission (11)
  - Must survive about $10,000\ charged\ particle/(cm^2 s)$ at orbit of 600km (12)
- 3D printing in microgravity
  - Proven possible by REDWIRE (formally MadeInSpace) mission to ISS
  - Regular 3D printers can print upside down
- Atmospheric Oxygen: Structures / External Electronics - avoid use of polymers
  - Otherwise surface erosion and the creation of CO and CO2
  - Mitigation – additives such as BTO or aluminum acetylacetonate (13)



Operations Feasibility (1.2 & 2.3)

- Station Keeping
  - Bus has total ΔV of 7000 m/s
  - 50.5 m/s for 5 years (13)
  - Estimated orbit lifetime of ~2.6 years after EOL (13)
- Attitude Control
  - Excess ΔV used for attitude control
  - 0.005 Nm on reaction wheels (disturbance torques: ~0.0012 Nm)
- Ground Station
  - Data rate: 1 Gbps
  - Eb/N0: ~52 Uplink/~66 Downlink



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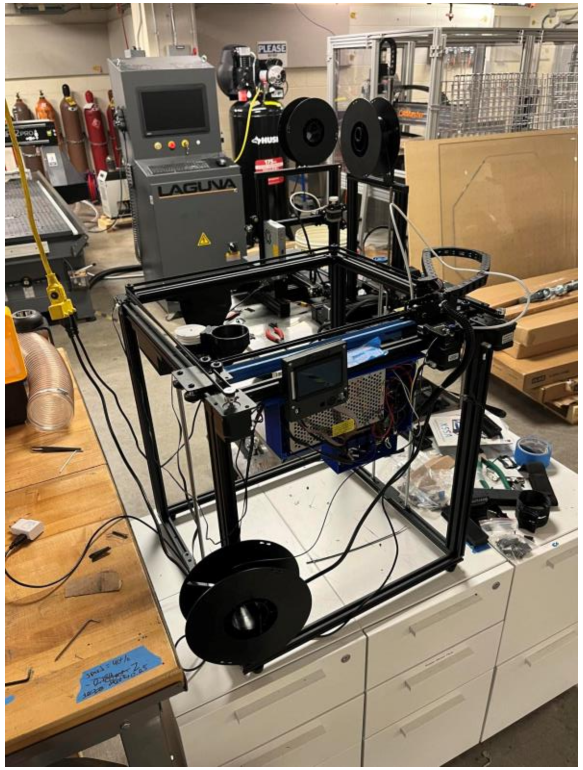
FMEA Risk Analysis Diagram (1.5)

	Negligible	Minor	Moderate	Significant	Severe
Very Likely (75-100%)			4	1	
Likely (50-75%)					2
Possible (30%-50%)			5		3
Unlikely (15-30%)					
Very Unlikely (0-15%)					

1. 3D Printer Failure
2. Extended Structural Failure
3. Climbing Bot Grip Failure
4. Attitude Disturbance
5. Climbing Bot Motor Failure

Prototype (1.1)

- Demonstrated movement along + continuous printing/extension of 3D printed part
- Lesson Learned: Importance of accuracy, precision, and vibration minimization / control



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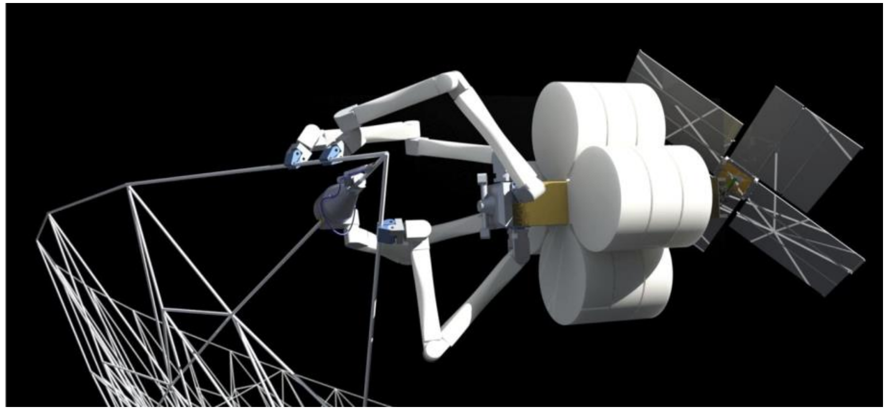
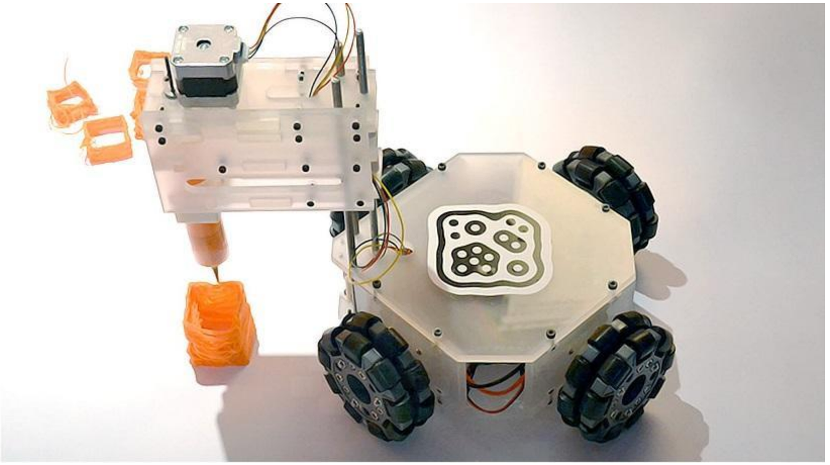
Innovation + Impact (1.1 & 1.3)

- "First" 3D Printer Operating in Vacuum of Space
- Printer Mobility Across Manufactured Part
  - Mega Structures!
- Step Towards Von Neuman Machines?



SpiderFab



PUC-rio's 3D printing process

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Biggest Challenges + Tech Gap (3.2 & 3.3)

Biggest Challenges

- Orbital Dynamics to Maintain Comms and Power
- Estimating Realistic Power Draws for Temperature Maintenance
- Filament Selection
- Prototype

Tech Gap

- Demonstration of 3D printer Operation in Vacuum of Space
- Material Science - Filament
  - Reduce effect of atomic oxygen
  - Metal?
- Reload
  - Filament servicing in space

Innovative Ideas (3.1)

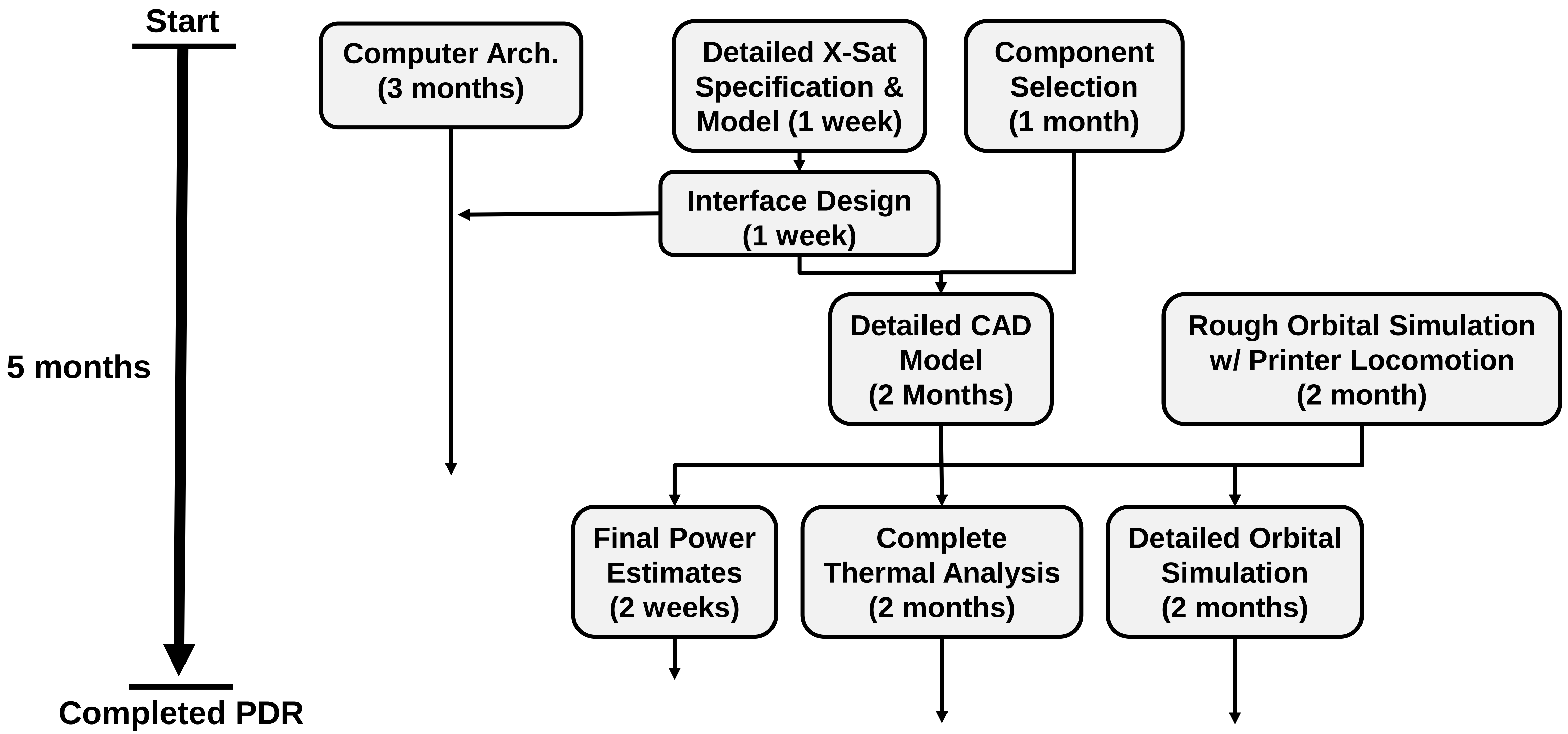
1. Growing GaAs
   - To replenish photovoltaic materials for solar panels, synthesize Gallium Arsenide in space
2. Laser-Created Structures
   - Laser cut sheets of material and weld back together using the same laser into a stable structure
3. Bioprinting Structures
   - Maintain a culture of E-coli to harden/reinforce concrete material in a specified shape
4. Molten Metal Manipulation using Magnets
   - Use magnets to manipulate molten metal into useful shapes in the microgravity environment

Paper (4.2)

- **Abstract:**

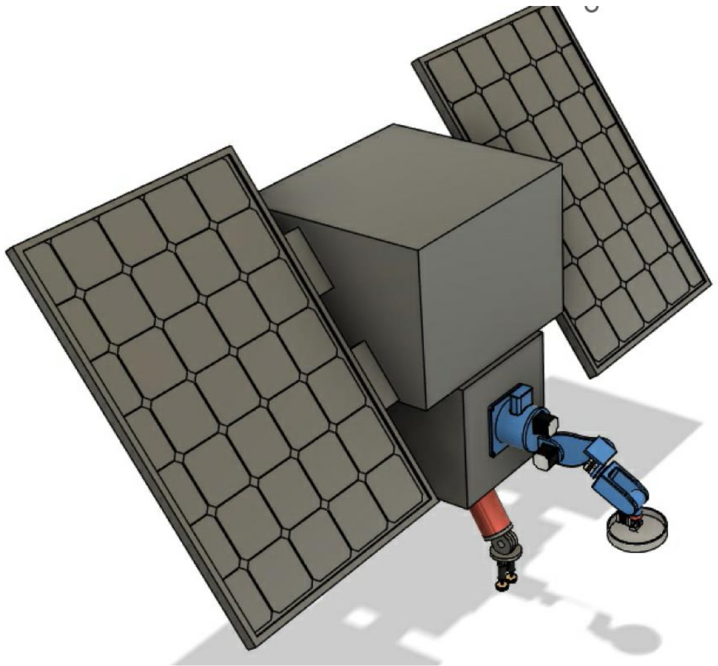
  This paper presents the conceptual design and mission architecture for the Space Printer for Autonomous Manufacture of Mega-Structures (SPAMM), a self-reliant, in-space manufacturing payload integrated onto the Blue Canyon Technologies X-Sat Venus-Class Bus. SPAMM leverages fused deposition modeling (FDM) to autonomously construct large-scale structures in low Earth orbit (LEO), targeting future applications in deployable apertures, structural trusses, space habitats, and infrastructure repair. Unlike traditional static additive manufacturing systems, SPAMM features a mobile printer head capable of locomotion across the structures it builds, enabling prints significantly larger than the satellite itself. This work addresses challenges in creating scalable in-space fabrication systems critical to ISAM (In-Space Assembly and Manufacturing) missions as part of the COSMIC Capstone Challenge. In addition, a prototype locomotive 3D printer demonstrated the feasibility of the core function of movement along manufactured parts and the continued extension of those parts. Future work involves continuing the design process towards a Preliminary Design Review.

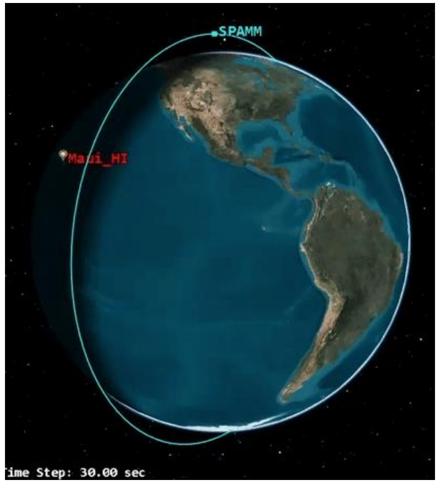
Path to PDR (1.6)



Conclusion

- Space Printer for Autonomous Manufacture of Mega-Structures (SPAMM)
  - Unique Locomotive Design
  - Broad Application
    - Deployables, Habitats, Storage, Space Craft Manufacture, Capability Extension, Repair
- Prototype Proving Feasibility





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Questions?

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Example PEAK capable printer

FUNMAT HT
Desktop High-performance 3D Printer

Multi-material printing capability
Can print high-performance materials such as PEEK, PEEK-CF, PEEK-GF, PEKK and other materials such as PA-CF, PA, PC, ABS.

Maximized build volume ratio
Build volume can be up to 260 x 260 x 260 mm.

Advanced Thermal Design
90 °C (194 °F) heated chamber, 160 °C (320 °F) build plate and 450 °C (842 °F) nozzle.

Intelligent Design
Auto-leveling, filament runout warning, remote video monitoring.

Technical Parameters

Printing

Technology	FFF (Fused Filament Fabrication)	Leveling	Auto Leveling, Manual Leveling
Build Volume	260 x 260 x 260 mm (10.2 x10.2 x 10.2 in)	Materials*	PEEK, PEEK-CF, PEEK-GF, PEKK, PPS, PC, PC-ABS, PA6/66, PA6-CF, PA12, PA12-CF, ABS, ASA, HIPS, PVA, Carbon Fiber-Filled, Glass Fiber-Filled, ESD-safe, etc.
Layer Thickness	0.1-0.5 mm		
Number of Nozzles	1		
Number of Spools	1 (Max 1 Kg/pc)		
Filament Diameter	1.75 mm	Nozzle Temperature	Max. 450 °C (842 °F)
Print Speed	Max. 120 mm/s	Build Plate Temperature	Max. 160 °C (320 °F)
Nozzle Diameter	Default: 0.4 mm (Optional: 0.25/0.6/0.8 mm)	Chamber Temperature	Max. 90 °C (194 °F)
		Functions	Filament Runout Warning, Remote Monitor

Machine

Voltage	100 ~ 132 V/15 A or 200 ~ 240 V/7 A. 50/60 Hz	Build Chamber	Fully Enclosed Printing Chamber
		Motor System	High Performance Standalone Driver
Max. Power	1200 W	Cooling	Fan
Connectivity	USB, SD Card	Travel Speed	Max. XY 200 mm/s
Screen	3.2" Touch Screen	Resolution	XY: 15.6 μm; Z: 1.56 μm
Build Plate	Ceramic Glass Plate, with Magnetic Fixations	Printer Size	543 x 501 x 645 mm (21.3 x 19.7 x 25.4 in)
		Printer Weight	63 Kg (139 lb)

Safety

Safety Design	Overload Protection, Closed Chamber, Warning Labels
Safety Standards	EN60204
Certification	CE, FCC, SGS

Slicing

Slicing Software	INTAMSUITE™
Supported File Types	.stl/.obj/.x3d/.3mf/.stp/.iges
Operating System	Windows

Operating Environment

Working Temperature	15 °C ~ 32 °C (59 ~ 89.6 °F)
Working Humidity	30 ~ 70 %
Storage Temperature	0 °C ~ 54 °C (32 ~ 129.2 °F)
Storage Humidity	10 ~ 85 %

*Printing materials are not limited to this table, recommended printing materials are fully validated on the printer.

Matlab Calculations: Disturbance Torques

```
Cd= 2.2; % coeff of drag estimation
A=0.35709606; % estimated worst case cross sectional area (m)
pdrag=7.17*10^-11; % atmospheric density at altitude of 275 km (kg/m^3)
V=7740; % circular velocity at altitude of 275km (m/s)
d=0.6858; % worst case distance between center of gravity and drag (m)
Tdrag=(1/2)*Cd*A*pdrag*(V^2)*(d); % torque from atmospheric drag (Nm)

psrp=4.527*10^-6; % solar radiation pressure (N/m^2)
Cr=2; % max coefficient of reflectivity
Tsrp=psrp*A*Cr*(d); % torque from solar radiation pressure (Nm)

mu=398600.5; % gravitational parameter of Earth (km/s^2)
R=275+6378.137; % magnitude of R vector (km)
Ipitch=(1/2)*70*0.6858; % moment of inertia about pitch (kg/m^2)
Iyaw=(1/2)*70*0.41656; % moment of inertia (yaw kg/m^2)
Tgrav=((3*mu)/(2*R^3))*(Ipitch-Iyaw); %torque from gravity gradient (Nm)

Ttotal = Tdrag+Tsrp+Tgrav % Estimated total of significant disturbance torques (Nm)
```

```
Ttotal =          0.0011784635667899
```

Operations Feasibility

Matlab Calculations: Uplink Eb/N0

```
%% Satellite Uplink
% For a satellite at 600 km altitude with 1 Gbps data rate

%% Calculate Space Loss
% Space loss calculation at typical satellite frequency (e.g., Ka-band at 26 GHz)
freq = 26e9;  % Frequency in Hz (26 GHz - typical Ka-band)
c = 3e8;      % Speed of light in m/s
d = 600e3;    % Distance in meters (600 km)
lambda = c/freq;

% Free space path loss in dB
FSPL = 20*log10(4*pi*d/lambda);
%% Set Realistic Parameters
Pt = 40;          % Transmit power in dB (typical satellite power ~10W = 40dBm)
Gt = 35;          % Transmit antenna gain in dB (typical satellite antenna)
Lt = -2;          % Transmit system losses in dB
Ls = -FSPL;       % Space loss in dB (calculated from distance)
Lm = -3;          % Miscellaneous losses (rain fade, atmospheric loss, etc.)
Gr = 45;          % Ground station receive antenna gain in dB (large dish)
Tr = 290;         % System noise temperature in Kelvin (room temperature)
R = 1e9;          % Data rate in bits/second (1 Gbps)

EbN0 = Pt + Gt + Lt + Ls + Lm + Gr + 228.6 - 10*log10(Tr) - 10*log10(R)
```

```
EbN0 = 52.6718
```

Matlab Calculations: Downlink Eb/N0

```
%Satellite downlink
%% Satellite Link Calculator
% For a satellite at 600 km altitude with 1 Gbps data rate
% Ground station transmitting to satellite receiver

%% Calculate Space Loss
% Space loss calculation at typical satellite frequency (e.g., Ka-band at 26 GHz)
freq = 26e9;  % Frequency in Hz (26 GHz - typical Ka-band)
c = 3e8;      % Speed of light in m/s
d = 600e3;    % Distance in meters (600 km)
lambda = c/freq;
% Free space path loss in dB
FSPL = 20*log10(4*pi*d/lambda);
%% Set Realistic Parameters
Pt = 50;          % Transmit power in dB (ground station power ~100W = 50dBm)
Gt = 45;          % Transmit antenna gain in dB (large ground station dish)
Lt = -1;          % Transmit system losses in dB (better for ground station)
Ls = -FSPL;       % Space loss in dB (calculated from distance)
Lm = -3;          % Miscellaneous losses (rain fade, atmospheric loss, etc.)
Gr = 35;          % Satellite receive antenna gain in dB (typical satellite antenna)
Tr = 150;         % System noise temperature in Kelvin (colder in space)
R = 1e9;          % Data rate in bits/second (1 Gbps)

% Calculate Eb/N0 ratio
EbN0 = Pt + Gt + Lt + Ls + Lm + Gr + 228.6 - 10*log10(Tr) - 10*log10(R)
```

```
EbN0 = 52.6718

EbN0 = 66.5348
```

Severe Risk Item 1

FEMA Risk Analysis

Risk:	Impact:

3D Printing Failure	▪ Fragile rail
	  ▪ Potential issues supporting megastructure
	▪ Segment floats away
	  ▪ Misalignment
	  ▪ Construction paused
	  ▪ Wasted filament
	▪ Print Repeat
	  ▪ Wasted time

Cause:	**Action:**

▪ Inadequate adhesion
  ▪ Poor bonding
▪ Solidification issues
  ▪ Vacuum
  ▪ Rapid Temperature Variation
▪ Segment release
  ▪ Jammed feeder
  ▪ Climbing bot failure
	▪ Test and Validate print
	  ▪ Test all temperature ranges/variations
	▪ Bonding Sensors
	  ▪ Verify bonding
	  ▪ Abort below threshold
	  ▪ Camera
	▪ Specialized Models
	  ▪ Larger files with specialized parameters for printing

Severe Risk Item 2

FEMA Risk Analysis

Risk:	Impact:

Extended Structural Failure	▪ Loss of structural integrity
	  ▪ In extended rail or printed object
	▪ Segment Break-away
	  ▪ Essential parts fall off
	  ▪ Print falls apart; becomes debris
	▪ Sudden Moment change
	  ▪ Messes up ADCS
	  ▪ Uncontrollable spin
	▪ Mission compromised

Cause:	**Action:**

▪ Mechanical Overstress
  ▪ Excessive forces/torque
  ▪ Unplanned acceleration
▪ Cumulating Fatigue
  ▪ Over mission period
  ▪ Continuous usage of printer
▪ Thermal Cycling
▪ Defects
  ▪ Damage during launch
  ▪ Pre-existing defects
	▪ Conservative Margins
	  ▪ Account for worst case loads + fatigue
	▪ Space Grade Materials
	  ▪ Test Print Quality
	  ▪ Low out-gassing
	▪ Design for Wear
	  ▪ Plan for degradation
	  ▪ Emergency jettison
	  ▪ Extensive testing in Lab
	▪ Thermal Conditioning
	  ▪ Material testing/Insulation

Severe Risk Item 3

Risk:	Impact:

Climbing Bot/Extruder Grip Failure	▪ Printing Operation Failure
	  ▪ Print head attached to robot out of position
	▪ Climbing Bot failure
	  ▪ No more printing mechanism
	  ▪ Bot detaches from satellite
	▪ Mission Failure

Cause:	**Action:**

▪ Clamp/Gear Failure
  ▪ Gear locking
  ▪ Cold welding
  ▪ Gear wear
▪ Unexpected Shocks
  ▪ From Launch > Orbit
  ▪ Satellite Maneuvers
▪ Rail Contamination
  ▪ Reduced Friction
	▪ Fail-safe Strategy
	  ▪ At least one module firmly locked all times
	▪ Grip sensors
	  ▪ Verifies secure grip/next position.
	▪ Design for contamination
	  ▪ Materials that resist contamination in space
	  ▪ Microgravity tests
	▪ Back-up Tether system
	  ▪ Emergency Tether system to satellite

Severe Risk Item 4

FEMA Risk Analysis

Risk:	Impact:

Attitude Failure	▪ Pointing Error increases
	  ▪ ACDS becomes more complex + more torque needed
	▪ Oscillations
	  ▪ ACDS Overcompensation
	▪ Attitude Lock failure
	  ▪ Sat enters safe mode/no more printing
	  ▪ Tumbling
	▪ Precision tasks unable to be executed

Cause:	**Action:**

▪ Center of Mass Shift
  ▪ Object causes torques beyond ACDS compensation
  ▪ Axial shift, ACDS fails
▪ Large inertia “arm”
  ▪ Motion of Satellite printer
▪ Dynamic Movement
  ▪ Impulsive torques from boom/robot
▪ Uneven Solar radiation/drag pressure
  ▪ Especially prevalent on large surface areas
	▪ Calculate CoM and Moment of Inertia
	  ▪ Prior to print
	▪ High Margins
	  ▪ Use powerful ACDS systems
	▪ Counterweights
	  ▪ Deployable masses
	  ▪ Rate gyroscopes

Severe Risk Item 5

Risk:	Impact:

Climbing Bot Motor Failure	▪ Robot stuck
	  ▪ Print unable to continue
	▪ Excess Strain
	  ▪ Robot uses excess force to move as needed
	▪ Mission Delay
	  ▪ Until maintenance period is over

Cause:	**Action:**

▪ Gear wear/jamming
  ▪ Obstructions
  ▪ Debris/Residue from print
▪ Lubricant Failure
  ▪ Freezing
  ▪ Cold Welding
  ▪ Increased/decreased Friction from extreme temperatures
▪ Motor Burnout/Failure
  ▪ Overheating/Overcurrent
  ▪ Hardware failure
	▪ Reliable Actuators
	  ▪ Torque limiters
	  ▪ Current limiters
	  ▪ High F.S. chips/systems
	▪ Launch Environment Testing
	  ▪ Design rail with margins to allow for thermal changes
	  ▪ Space grade Lubricants
	▪ Debris clearing system
	  ▪ Wiper/brush
	  ▪ Motor telemetry sensors
	▪ Early Detection Systems
	  ▪ Detect excessive values

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