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COSMIC Capstone Challenge: Final Briefing

The Weldinator
California State University, Los Angeles: Outbrief Template & Guidelines

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Outbrief 04/14/2025

Executive Summary

The Weldinator

- Problem identified
  - Need for infrastructure in space which will lead to longer missions rather than short parabolic flights
  - Maintain/repair spacecraft for longer duration of flights
- What is the capability we're proposing?
  - Weld quarter-inch wire for infrastructure purposes
- How does it solve the problem?
  - Help fortify infrastructure in space without needing to pre-build systems on Earth
  - Ability to repair damages on current systems in space
  - Reduce cost in launching infrastructure into space
- What is the status
  - Welding in space is very promising with successful testing of "ThinkOrbital" and "ESA" using Electric Beam Welding
  - Will be able to construct habitats, maintain spacecraft and assemble infrastructure

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1.1 Impact

Why this is beneficial

- Construction of structures
- Fortifies already existing structures in-space
- Ability to repair and maintain space craft with limited human involvement

1.2 Feasibility

Is it do-able?

Technical Feasibility:

- Welder: Impulse Laser Welder
- Stabilization Mechanism
- Sensors: Mapping and Quality Control/Feedback
- Communication Systems

Technical Challenges:

- Energy Constraints
- Thermal Management
- Miniaturization
- Autonomy

Mitigation:

- Power Optimization,
- Thermal Control Systems
- Sensor redundancy

1.3 Innovation – Auto-Welder in Space

Innovative System

- The welder could operate remotely, limiting human involvement while construction for infrastructure is being carried out in space.
- Will have the ability to repair or assemble structures in space, reducing the number of materials and tools that need to be transported from Earth to space
- The welder could be integrated with other space technologies like rovers enabling it to work collaboratively constructing various parts of a space station.
- This will enhance the long-term cost-effectiveness of Space Missions.

1.4 Completion of Required Elements

Welding ¼ in 316 stainless steel

Constraints:

- Payload Volume: 17" x 16.4" x 27"
- Energy Storage: 10.2 Amp-Hour
- Mass: 70kg/ 154 lbs
- Primarily Autonomous

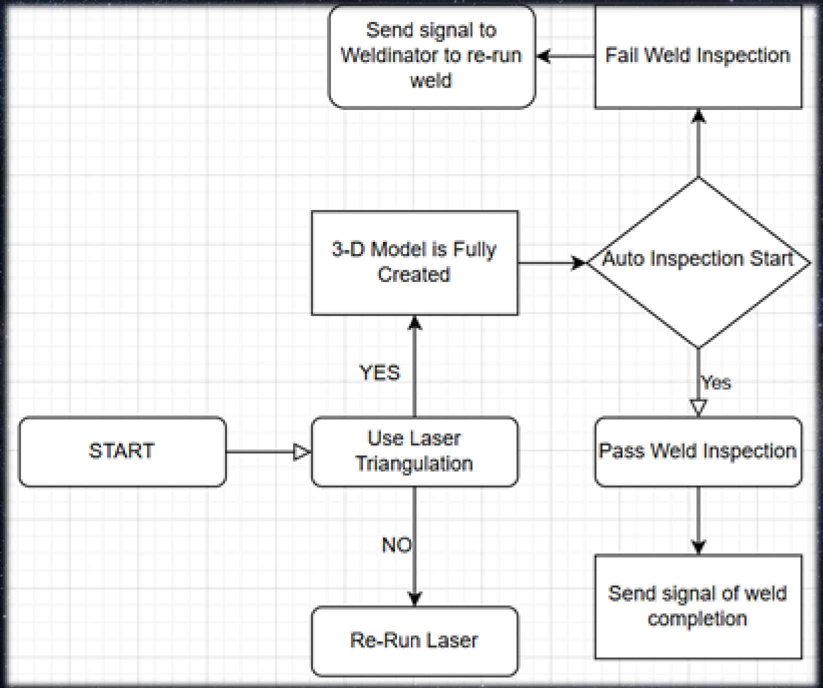
Enviromental/material factor:

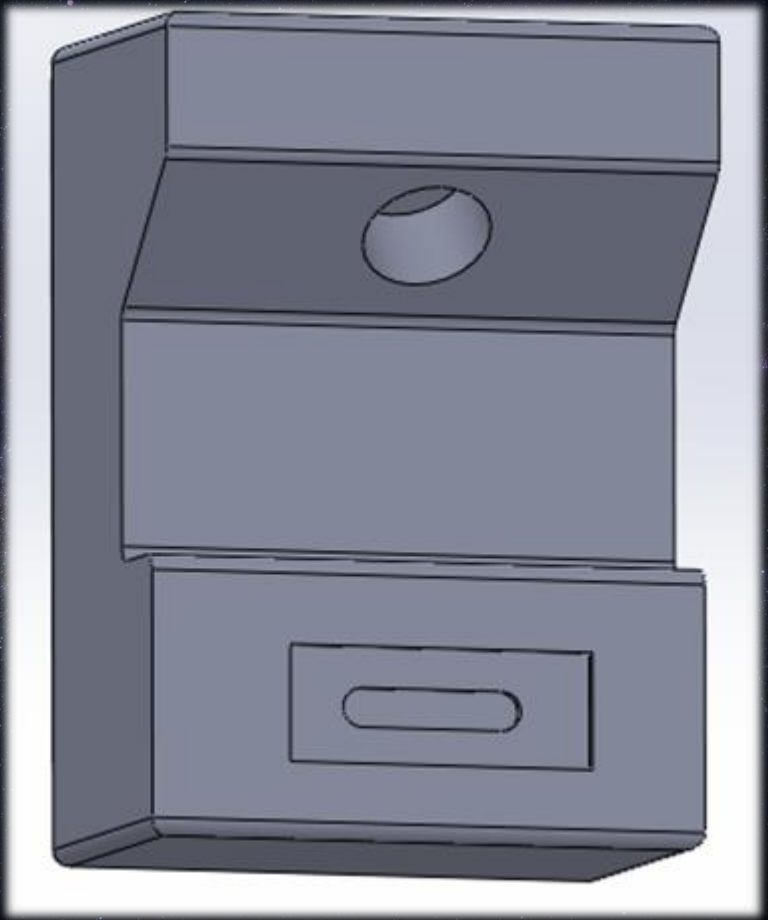
- Micro gravity
- Vacuum
- Temperature range (-157 -121C)
- Melting point: 1645-1673 K
- Density: 7980 Kg/m^3
- Surface temp:
  - Away from sun: -270C
  - Towards sun: 120C

1.4.1 Sensor Information

SmartRay ECCO X 100 Vision Sensor

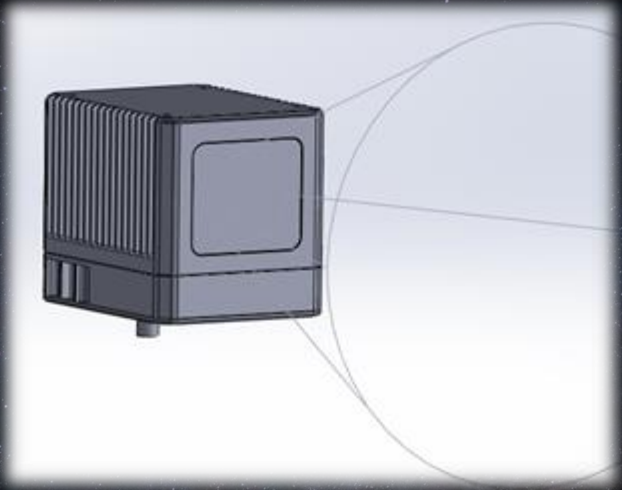
- Mid field of view (100 mm)
- Measurement range: 100 mm
- Stand off distance 190mm
- Weight: 850 g
- Scan rate: 20 kHz
- Power: 10 W
- Temp range: -20 to 70 degrees Celsius



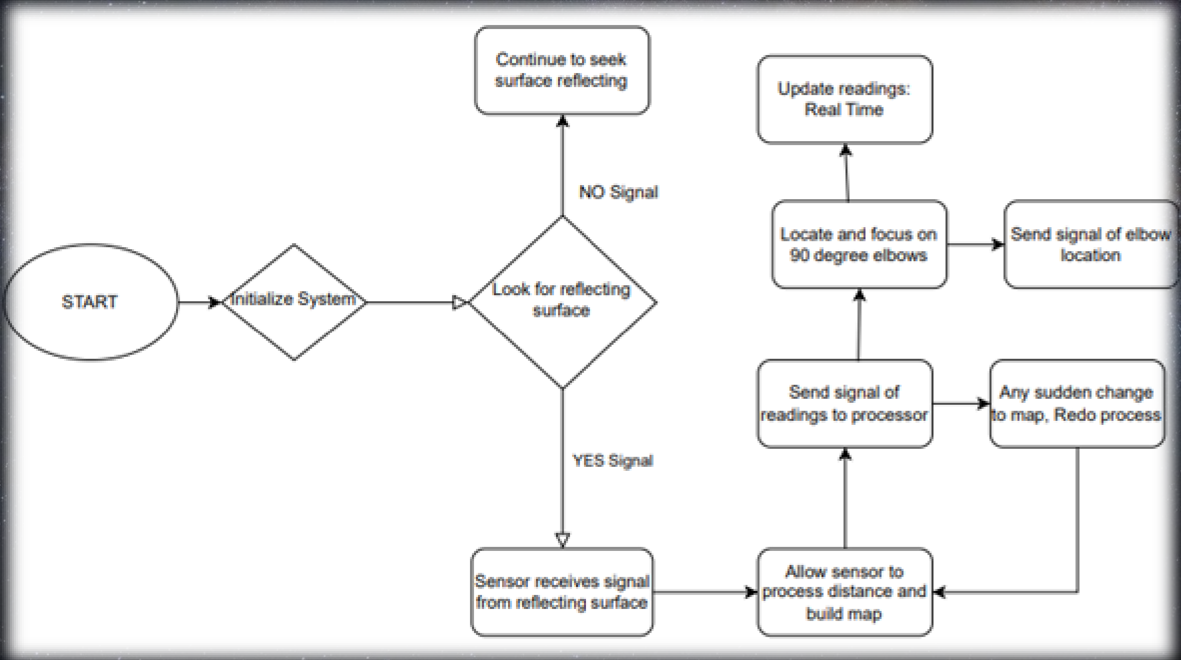


1.4.2 Sensor Information

Livox mid-40 LiDAR Sensor



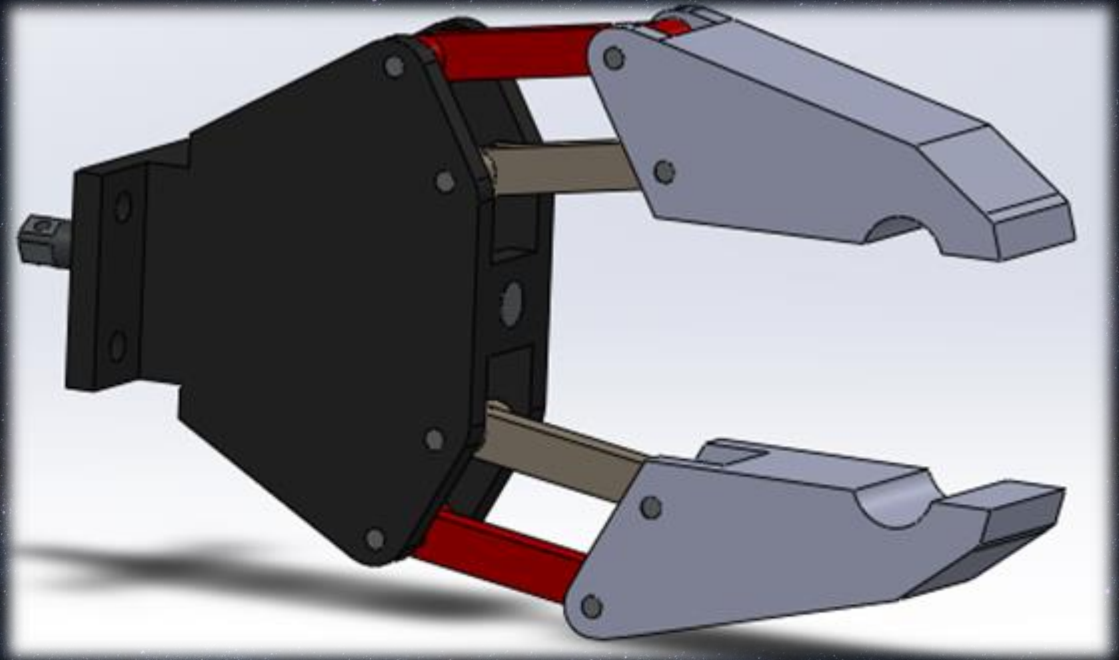
- 100K pts/sec
- Angular Accuracy of 0.1 degrees(Precision)
- FOV at 38.4 degrees circular view
- Operating Temp from -20C to 65C
- Range precision of 2cm
- Weight 760 g
- Power: 10 W



1.4.3 Material Stabilization Specifications

Information on Stabilization Clamps

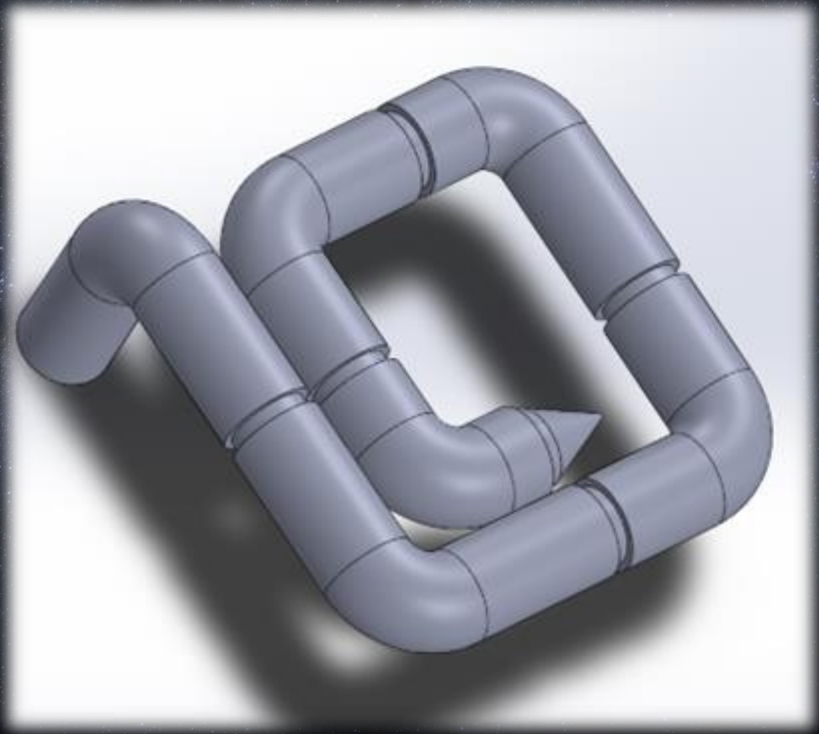
- Mass: 12 kg total (6 kg each)
- Power Consumption: 1-5 Watts
- Stability clamps will be made of T6 6061-Aluminum will withstand harsh temperatures of space
- Gears driving the clamps will be lubricated using a Solid-based Lubricant “Teflon”

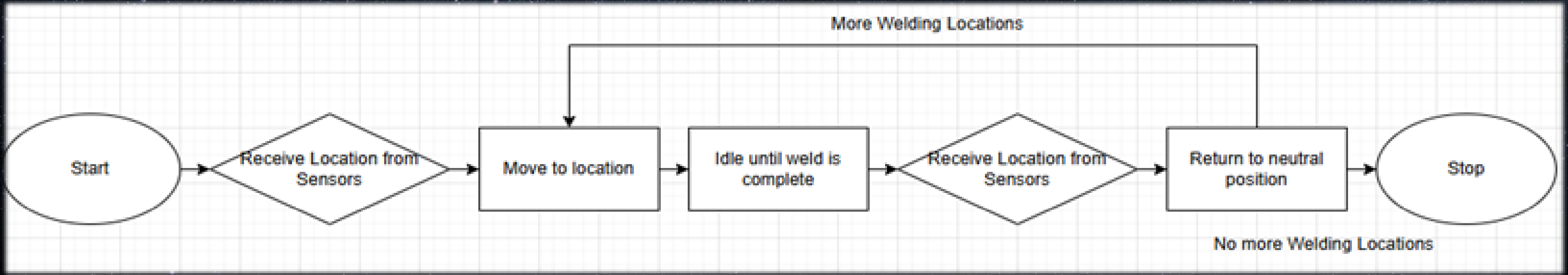


1.4.4 Robotic Arm Specifications

Information on the Robotic Arm

- 6 Degrees of Freedom
- Mass: 22kg
- Power Consumption: 125-150 W
- When fully extended is 35.93 in height





Key Takeaway - Arm can rotate inward making it more compact

1.5.1 Risks – Environmental

Risks / Potential Damage / Mitigation

- **Risk:** Solar Radiation
  - **Effects:** Electronics malfunction / Degradation of Materials
  - **Mitigation:** Multi-Layer Insulation / Shielding / Rad-Hard Chips
- **Risk:** Unwanted Heat
  - **Effects:** Thermal Expansions / Material Deformation / Overheating of Circuits
  - **Mitigation:** Multi-Layer Insulation
- **Risk:** Space Debris
  - **Effects:** Hull Penetration / Damaged Internals
  - **Mitigation:** Shielding / hull material is strong enough to protect against minimal space debris

Key Takeaway: Multi-Layer insulation will be best to protect against unwanted heat & solar radiation, space debris is neglected

1.5.2 Risks – Sensors & Communications

Risks / Potential Damage / Mitigation

- **Risk: Micrometeroids and Orbital Debris damage**
  - **Effect:** Loss of Functionality / Inaccuracy
  - **Mitigation:** Space qualified components(Rad-hard components)
- **Risk: Extreme Temperature Fluctuations**
  - **Effect: Performance effects**
  - **Mitigation: Space qualified Components/materials**
- **Risk:** Failure to communicate to Communication systems
  - **Effect:** Inability to transmit Data / Synchronization with other systems
  - **Mitigation:** Redundant comms systems / Autonomous data storage
- **Risk:** Corrupted Data
  - **Effect:** Loss of Communications
  - **Mitigation:** redundant Channels
- **Risk:** Signal Noise
  - **Effect:** Degraded signal quality
  - **Mitigation:** Signal Filtering

Key Takeaway – Key electrical components will be space grade and qualified for exposure to harsh environments

1.5.3 Risks – Stabilization Clamps

Risks / Potential Damage / Mitigation

- **Risk:** Continuous Motion
  - **Effect:** Continuous Performance / Wear / Fatigue
  - **Mitigation:** Include Variable Speed Drives (VSDs) to avoid sudden motions / control speed for stablilization engagement and de-engagement
- **Risk:** Friction between Gears
  - **Effect:** Increased Energy Consumption / System lifespan decreased
  - **Mitigation:** Space Grade Lubricants (Teflon) / Low friction coefficient material for gears

Key Takeaway – Include (VSDs) & Space Grade Lubricants to avoid frictional heat

1.5.4 Risks - Welder

Risks / Potential Damage / Mitigation

- **Risk:** Failure in Capacitors
  - **Effect:** Limits Power Output / Ineffective Welds
  - **Mitigation:** Space- Back-up Power systems
- **Risk:** Overdraw of Repetitive Power
  - **Effect:** Heating of Critical Components / Electrical System Failure
  - **Mitigation:** Power management / Load Shielding

Key Takeaway – Confirm capacitors are space-qualified and load shielding is included

1.5.5 Risks – Robotic Arm

Risks / Potential Damage / Mitigation

- **Risk:** Wear / Fatigue
  - **Effect:** Failure of joints & actuators / Loss of lubrication
  - **Mitigation:** Low friction coatings / lubrication
- **Risk:** Loss of Power to Actuators
  - **Effect:** Loss of Synchronization with other systems
  - **Mitigation:** Backup Power Systems / Redundant Actuators

Key Takeaway – Include backup power systems & verify high friction components are properly lubricated

1.6 Vision Sensor Trade Studies

Specifying sensor size

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Vision Sensor(Camera)	Small	Mid-Size	Large
Precision(Angular)	0.5 - 1	0.2 - 0.5	0.05 - 0.2
Space Environment	Fair Tolerance	High Tolerance	High Tolerance
Output Signal(MB/sec)	10 to 50	50 - 200	200 - 500
Compatibility	High	Moderate	Poor
Size(cm, diameter)	3 to 8	8 to 15	15 to 30
Energy Usage(Watts)	1 to 5	8 to 15	15 to 50
Cost (Dollars)	500 to 3K	3K to 10K	10k to over 50k
Life-Span(Years)	2 to 4	4 to 7	7 to 10+
Range(Meters)	1 to 10	10 to 50	50 to 200+
Speed(FPS)	15 to 30	30 to 60	60 to 120+
Reliability	Moderate	High	High
Resolution(Pixels)	640x480x1280x720	1280x720x1920x1080	1920x1080-4K+
Autonomous	Limited	Moderate	High
		Chosen	

Key Takeaway – Chose Mid-Sized Vision Sensor

1.6.1 LiDAR Sensor Trade Study

Specifying sensor size

LiDAR Sensor	Small	Mid-Size	Large
Precision(Angular)	0.2 - 0.5	0.1 - 0.2	0.05 - 0.1
Space Environment	Moderate Tolerance	High Tolerance	High tolerance
Output Signal(pts/sec)	200k to 400k	500k to 1M	1M to 3M
Compatibility	High	Moderate	Poor
Size(cm, diameter)	5 to 10	10 to 20	20 to 40
Energy Usage(Watts)	5 to 15	20 to 40	50 to 100+
Cost (Dollars)	2k to 5k	5k to 15k	15k to 50k+
Life-Span(Years)	3 to 5	5 to 7	7 to 10
Range(Meters)	20 to 50	50 to 200	200 to 500
Speed(Hertz)	10 to 15	15 to 20	20 to 30
Reliability	Moderate	High	High
Resolution(Channels)	16 to 32	32 to 64	64 to 128+
Autonomous	Limited	Moderate	High
	CHOSEN		

Key Takeaway – Chose Small-Size LiDAR sensor

1.6.2 Welding Trade Studies

What system will be performing welding operations

	TIG/MIG	Electron Beam	Continuous Laser	Impulse Laser
Longevity	MIG-consumable electrode Filler metal is consumed	No known consumptio n of materials	No consumption of any known material	No consumption of known material
Power consumption	Only powers the	High power consumption for electron emitter	Variable power consumption de pendent on # of passes	Generally, around 25-100 watts peak power output of 5- Kw
Heat	Heating of more than local welding	Super local in targeting area	Depending on exposure and # of passes. Heat could weaken overall structure	Local heating lasting in the milliseconds
Environment	Operates better in a vacuum due to no noble gas required	Normally operates in a vacuum	Operates optimally in a vacuum	Operates optimally in a vacuum
Weight	MIG: 5-10 lbs TIG: 1-3lbs	A few pounds	The gun portion ~ 2-3 lbs Extra components for functionality could be addition 30-60 lbs	could also be around a couple pounds with extra weight for functionality

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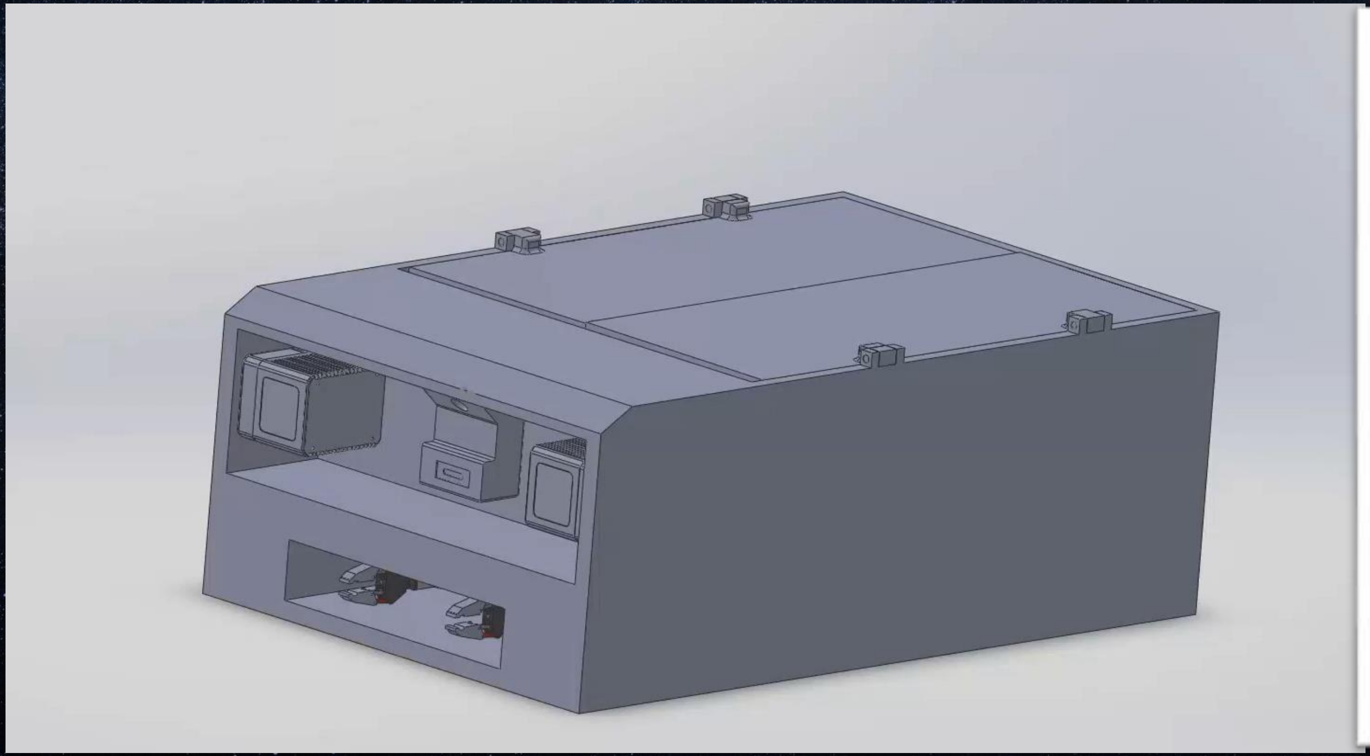
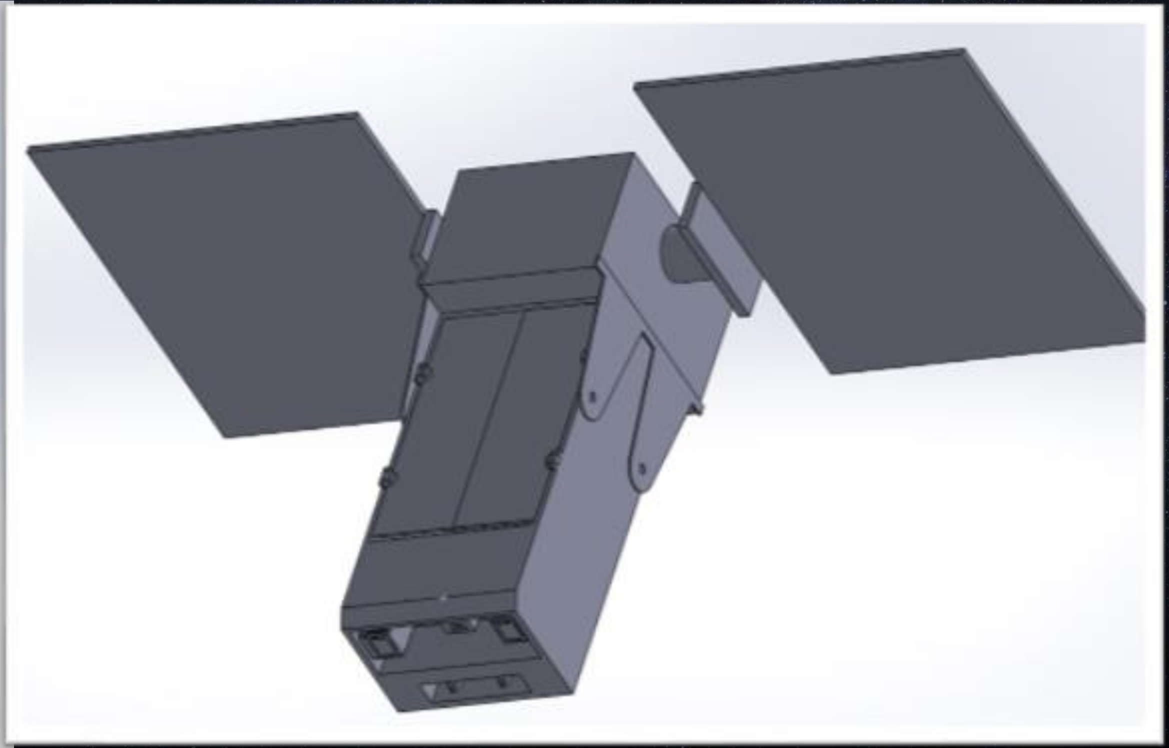
2.1 Animation of Key Operating Sequence





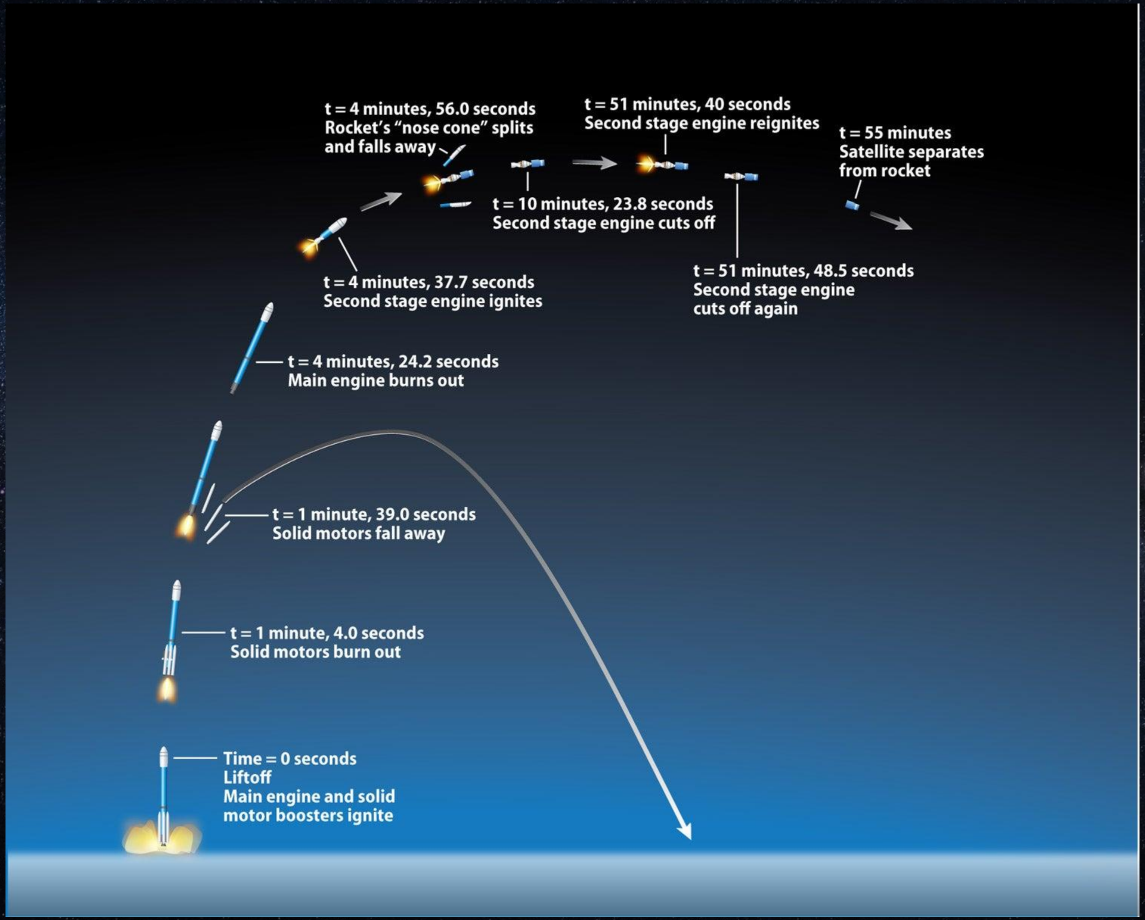
2.2 Storyboard of Complete Operation

Pre-Launch

- Satellite designed with optical terminals, LiDAR, vision sensors, robotic arm, clamps, and communication units.
- Undergoes full environmental testing: thermal, vibration, and vacuum conditions.
- Integrated into Atlas V 401 rocket and folded down and enclosed in payload fairing.
- Vehicle transported to launch pad; system power-up and checks completed.
- Weather clearance confirmed; propellant loading and final readiness poll conducted.

2.2.1 Storyboard of Complete Operation

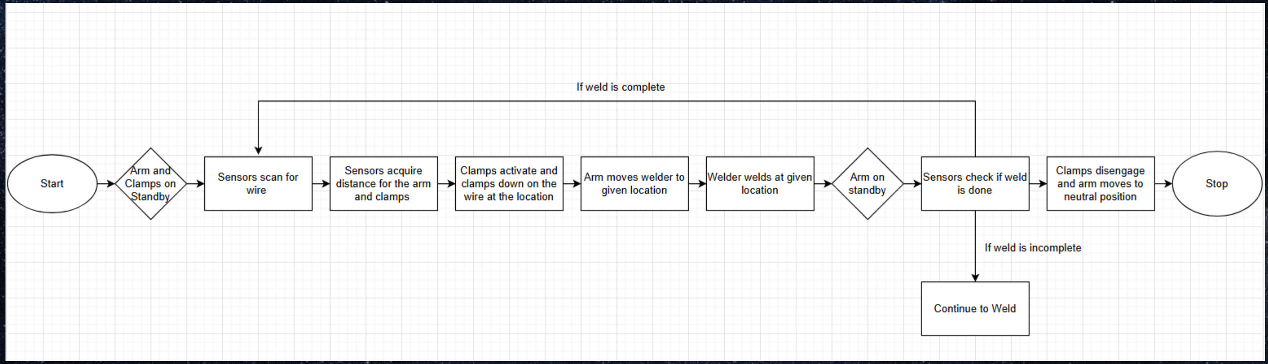
Launch



- Liftoff via Atlas V 401; rocket performs pitch and roll maneuvers.
- First stage separation → Centaur upper stage ignites.
- Fairing separation exposes payload; final upper stage burn to GTO.
- Satellite deployed with spin/push for safe distancing.
- Ground stations establish contact; solar arrays and terminals deployed.
- Orbit corrections made; systems initialized and checked.

2.2.2 Storyboard of Complete Operation

Operations



- Sensors lock onto the target environment; robotic components engage.
- Welding system engaged
- Sensor and vision data are routed via 922-420 and 922-FOM for processing to monitor the weld
- Data was transmitted optically using a 922-SFP transceiver and laser terminal.
- Relay satellite sends data to Earth-based ground stations.
- Real-time feedback from the ground adjusts welding parameters.
- If the weld is satisfactory, the welding system disengages
- Sensor system disengaged and External comms system disengaged
- Failure Recovery: Auto-switch to RF backup if the laser link fails.

2.3 Safety Plan

If the demonstration fails in operation?

- **Potential Incidents:** Incidental failures are electrical risks, performance failures, failures in capacitors or overdraw of repetitive power for the welder.
- **Recovery Effort:** System will send failure reports and will shut down. Service the main components or any sub-component that will need to be replaced to continue use of the welder.
- **Outcome:** Continued function over several more years.
- **Worst Case Scenario:** If deemed unserviceable, then process to deorbit will take place.

Key Point – Mitigation plans will be implemented for any potential incidents

2.4.1 Data Handling and Comms

System Requirements

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- **Real-Time Downlinks:** The system requires real-time downlinks to transmit live 3D sensor data, telemetry, and system feedback to the ground station for continuous monitoring.
- **Observer Requirement:** A dedicated observer is not required, but mission operators must be available to respond to alerts and make critical decisions during welding operations.
- **Operator Requirement:** Human oversight is necessary to initiate tasks, adjust parameters, and intervene in error scenarios, while the system handles autonomous execution.
- **Required Bitrate**

  - 3D Vision Data (SmartRay ECCO X 100): Up to 1 Gbit/sec (GigE interface, high-speed scan rates)

  - LiDAR Data: ~10–20 Mbps depending on resolution and sweep frequency

  - Telemetry and Sensor Feedback: ~1–2 Mbps (continuous)

  - Control Commands and Acknowledgments: <1 Mbps

  - Total Average Bitrate Required: ~100–200 Mbps (with potential peaks up to 1 Gbit/sec)

2.4.2 Data Handling and Comms

How the system should perform

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- **Achieved Requirements for Communications System:**

  - Duplex Capability: Full bidirectional communication to support data uplink and downlink.

  - Redundant Transmission Paths: Primary optical communication (SFP + laser terminal) and backup RF transmission (via DSL modem).

  - Environmental Resilience: Must function in vacuum, high-radiation, and wide-temperature environments typical of LEO.

  - **Power Efficiency:** Should operate within the 20–25W system power budget.

  - Low Latency: Critical for responsive control loops during welding operations.

- **Supporting Devices:**

  - Model 922-420 (SIIS Gateway): Converts analog sensor input to Ethernet.

  - Model 922-FOM (Ethernet Switch): Routes all communication and command data.

  - Model 922-SFP (Optical Transceiver): Converts Ethernet to an optical signal for primary transmission.

  - Model 922-DSL (Hybrid Modem): Provides RF communication fallback for data continuity.

2.5 Systems Engineering

- Select program manager
  - August 30th, 2024
- Chose operations/ capability
  - January 31st, 2025
- Defined system requirements
  - February 7th, 2025
- Completed trade studies
  - February 14th, 2025
- Finalized conceptual design
  - February 28th, 2025
- Developed a path to Preliminary Design review
  - April 1st, 2025

3.1 Most Innovative Concepts Considered

Choosing a Movement Mechanism

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	Spider-bot	Track Based	Robotic arm	Snake/Worm	Cable Drawn	Free-flying system
Power Consumption	The number of legs increase the power needed	track design, number of motors, and surface interaction	More complex movement will require more power	surface interaction, movement complexity, actuators	Number of motors, cable length, and friction change power	Depending on the propulsion type the power can increase
Size	The size overall of the spider-bot will be less than a lot of the other options	The tracks will need to be preplaced or built while moving	Being able to retract will make more space for our system	The size would be smaller than a lot of the other options	the cable system would make this option larger as it adds more to the system	Wouldn't be a big system. Envisioned to be like the astrobee
longevity	wear on the legs	Wear from track and friction	depends on usage frequency and joint wear	Wear on all the moving parts with complex movement	Cable wear and motor strain	Thruster wear and power usage
Design	The spider design will add complicity as the number of legs matters	The track makes it more complex	extend/retract will add complexity but its doab le	More complex movement to mimic a snake or worm	The cable system makes it complex	The propulsion system is the entirety of the movement
TRL/Feasibility	TRL 5-6	TRL 1-3	TRL 7-9	TRL 3-5	TRL 5-6	TRL 5-7

Key Takeaway – Chosen technology Robotic arm

3.2 Most Important Technology Gaps

High level overview

- Biggest challenge: Energy storage and available Wattage to be used
  - Longer Lasting energy storage units
- Radiation protection
  - Materials to increase protection and longevity of systems
  - Lightweight materials with higher performance to withstand radiation
- Space grade welding machine
  - Limited Welding in space has been done, little research available
  - Most Welding machines are not compact in size
  - The amount of wattage used by welding machines are high

3.3 Biggest Challenges Encountered

- Handling the data of the welds and deciding whether a weld is sufficient to remain
  - If the welds are not sufficient then a repass of the welder would be mandatory

- Power consumption of the payload
  - Making sure the payload does not surpass the 444W constraint with all the elements in the system proved challenging

- Designing the capabilities of the payload
  - Understanding the restraints of the payload and the enviroment to create something that is plausable and useful in orbit

Path to PDR

Next steps to reach a complete design

- Mechanical:
  - Construct system prototype
  - Ensure environmental proofing, thermal management, and maintainability
- Electrical:
  - Draw up harness design and routing
- Software Integration:
  - Interfaces to vehicle control; status reporting, steering
  - Localization, Path planning, perception, control
- Simulation and Bench Testing
  - Validate control logic before vehicle testing
- Vehicle Integration and Testing
  - Connect and calibrate all hardware on host vehicle
  - Validate safety systems

Key Takeaway – Validate all system components are connected and calibrated after iterations and refinements have been completed

4.1 Paper

- The paper is a journey through the process of the project
- It is more on the technical paper going in depth about each element and its function
- There is an abstract and it is 198 words
- There are 22 pages in total (1 cover page, 1 reference page, 1 appendix page, and 19 pages of content)
- 15 references were included
- A place the paper can be published is AIAA SciTech Abstracts

Summary / Conclusion / Highlights

Highlights of the project

- Autonomous precision welding in space
  - Using impulse laser welding, capable of performing high precision structural welds with minimal human involvment
- Enhancing long term space mission viability
  - System can fortify and repair spacecraft on orbit, reducing the need for help from Earth and making spacecraft last longer
- Compact, efficient, and space ready design
  - Using constraints from the X-Sat Venus Class Bus, system is compact and energy efficient

Questions?