Inspection of Cooperative Target: ODIN

Optical Detection & INspection

NAVIGATION & SYSTEM ENGINEERING

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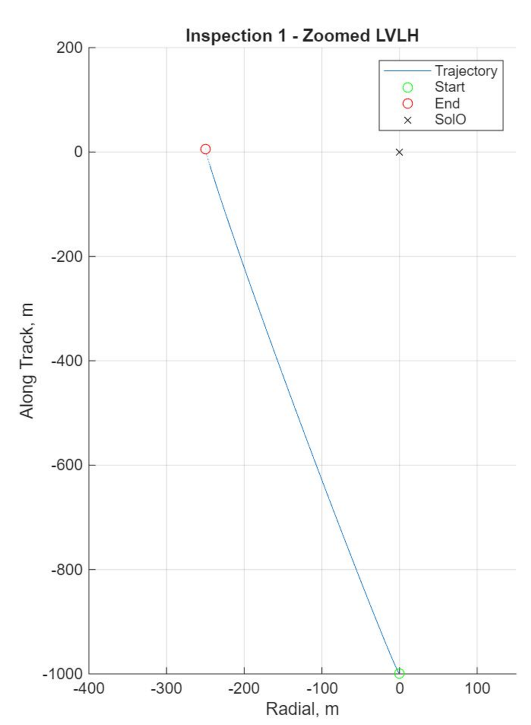
Spacecraft Properties

Launcher: SpaceX Falcon 9
Length: 8 m (3.4 m with solar panels stowed)
Width: 3.7 m (3.2 m with antenna stowed)
Height: 4.7 m (3.6 m with antenna stowed)
Wet Mass: 1517 kg
Propellant Mass: 480 kg
ΔV Capability: 12 km/s
Payload: Cameras (acquisition and feature identification), laser altimeter
Mission Duration: 4 years

Guidance, Navigation, and Control

Inspection trajectories were designed using Clohessy-Wiltshire (CW) relative motion equations, with orbital parameters derived from FreeFlyer simulations using JPL Horizons ephemeris data.



ORBITAL PARAMETERS

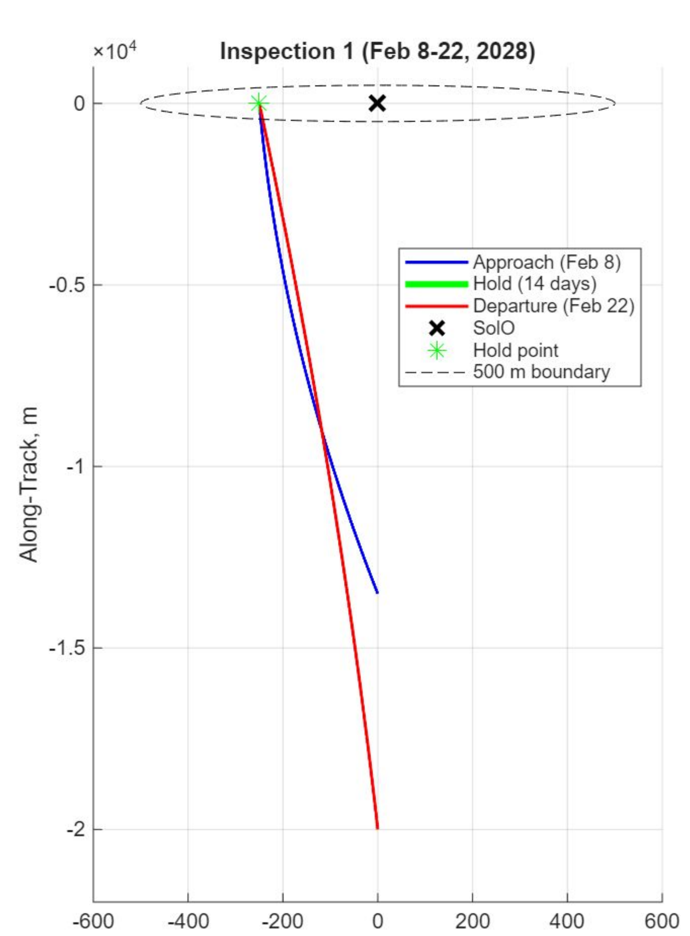
	Insp 1	Insp 2
a (km)	82,576,684	77,616,374
e	0.49125	0.50266
Along-track (km)	−13.51	−25,454
Aphelion (AU)	0.823	0.780

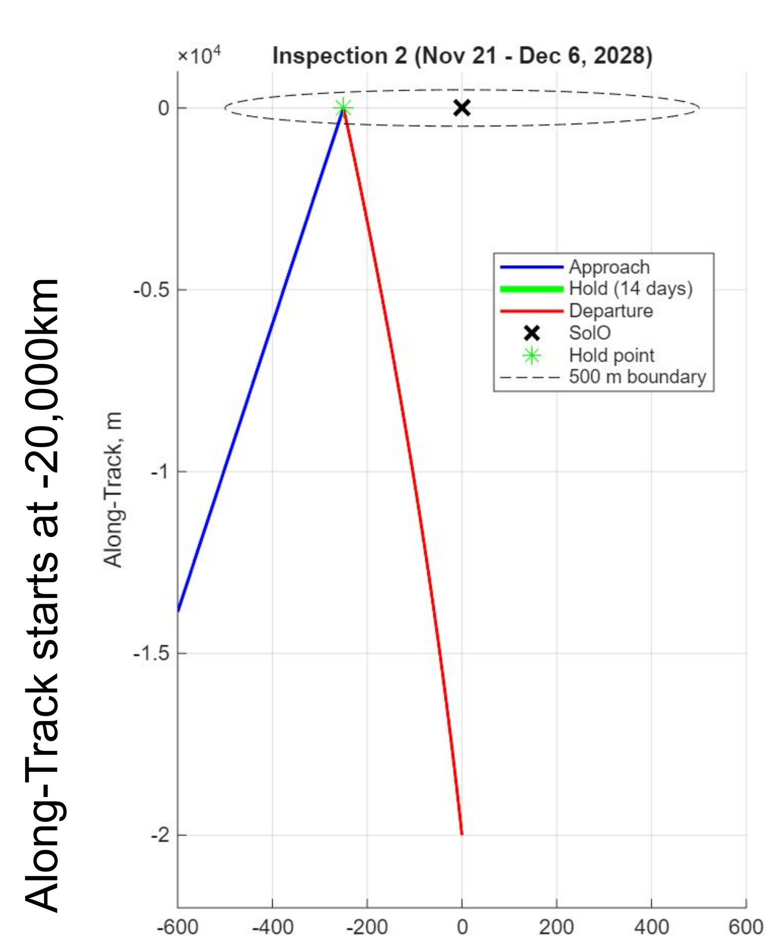
MISSION PARAMETERS

Hold point	250 m radial
Max distance	500 m
Duration	14 days
Departure target	20 km lag
Insp 1 transfer	12 hr / 4 hr
Insp 2 transfer	24 hr / 4 hr

ΔV BUDGET (PROX. OPS)

	Insp 1	Insp 2
Approach	0.63	589.3
S/K (14 d)	0.016	0.016
Departure	2.78	2.78
Total (m/s)	**3.43**	**592.1**





Mission Overview

The Optical Detection and Inspection Satellite (ODIN), is a spacecraft dedicated to the approach and inspection of Solar Orbiter (SolO). ODIN aims detect any signs of exterior degradation or damage to assess SolO's health. With this data, SolO can modify and adapt its operation to potentially extend its its mission past its planned conclusion in late 2026.

ODIN will perform two inspections. The first inspection collects initial data of images that will be analyzed on Earth for flags of damage or degradation. The second inspection occurs one orbital period later and collects secondary data that emphasizes on the flags produced from the first inspection.

Concept of Operations

March 2025 — **1. Departure**: Leave Earth on Falcon 9 into transfer orbit

March 2026 — **2. First Venus Flyby**: Reduce orbital energy in the first Venus flyby

December 2026 — **3. Second Venus Flyby**: Further reduce orbital energy and perform an inclination change with the second Venus flyby

December 2026 — **4. Inclination Change Burn**: To further increase the inclination, ODIN will perform an inclination change burn

January 2027 — **5. Rendezvous**: Rendezvous with Solar Orbiter and maintain a distance of 20km

January 2027 — **6. Hibernation**: Point solar shield towards sun and hibernate

February 16, 2028 — **7. Pre-Inspection Check**: Upon reaching 0.85 AU, get within 250 m of Solar Orbiter and being pre-inspection checks for inspection go-ahead from Earth

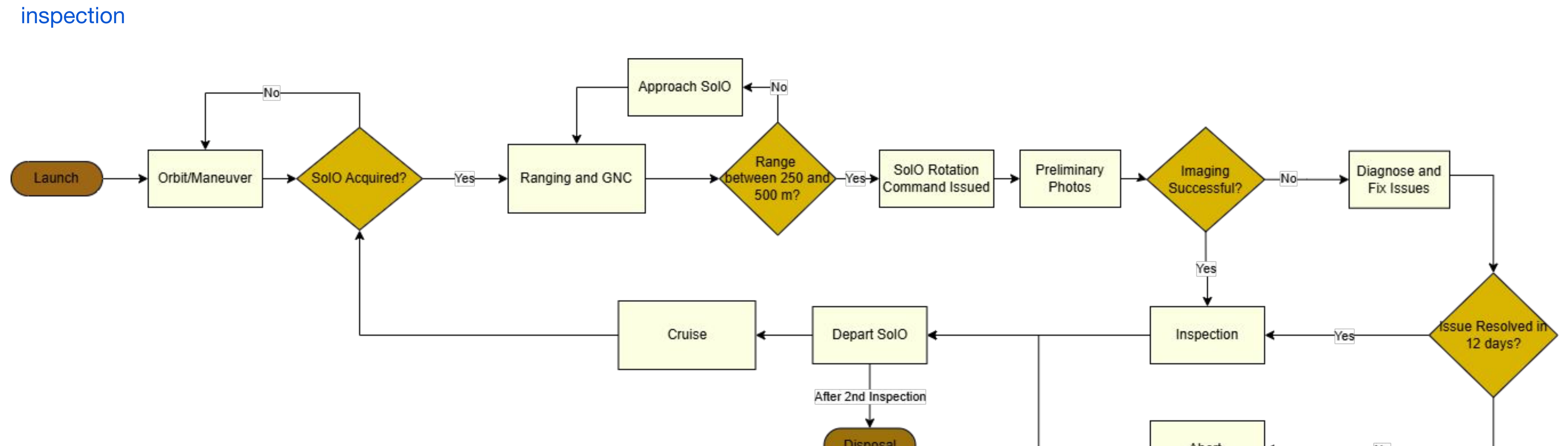
February 20, 2028 — **8. First Inspection and Downlink**: Capture imagery data and downlink them to Earth

March 2, 2028 — **9. Hibernation and Ground Analysis**: Back up to 20 km distance from Solar Orbiter and hibernate for another orbit. Ground analyzes data and create flags for secondary inspection

November 19, 2028 — **10. Pre-Inspection Check**: At 0.85 AU, reach within 250m of Solar Orbiter and perform pre-inspection check

November 23, 2028 — **11. Second Inspection and Downlink**: Capture imagery data on flags analyzed by ground and downlink

December 5, 2028 — **12. Disposal**: Perform burn to slightly change orbital elements to minimize collision risk



Mission Requirements

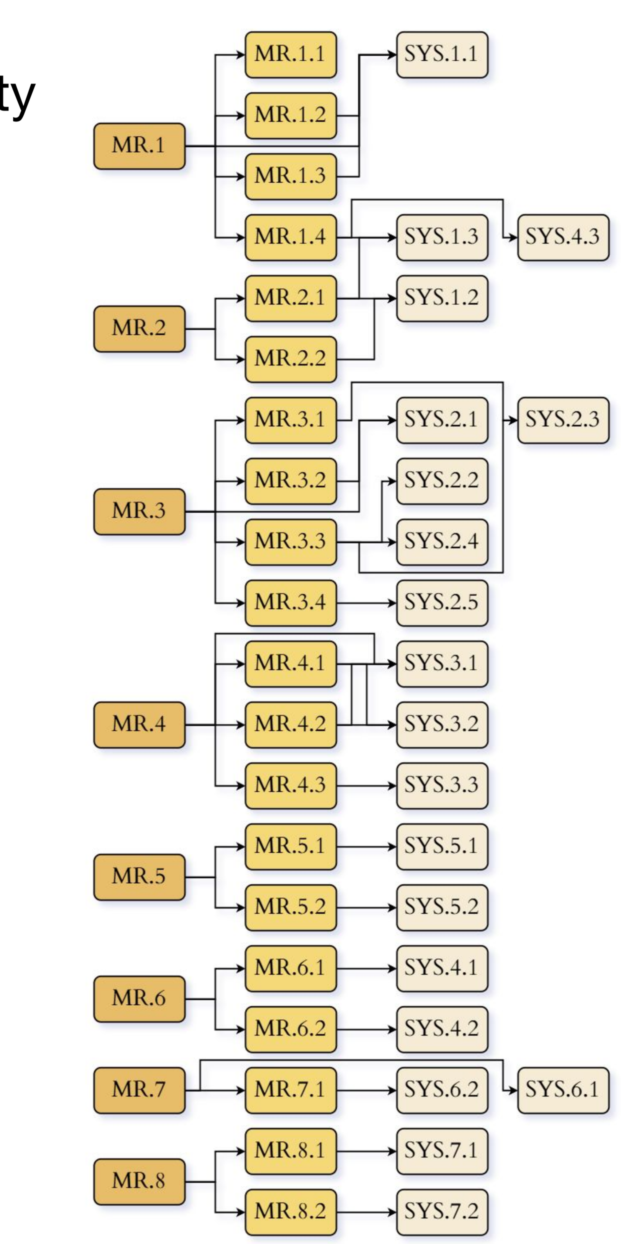
The top-level mission requirements were provided by the stakeholders as follows:

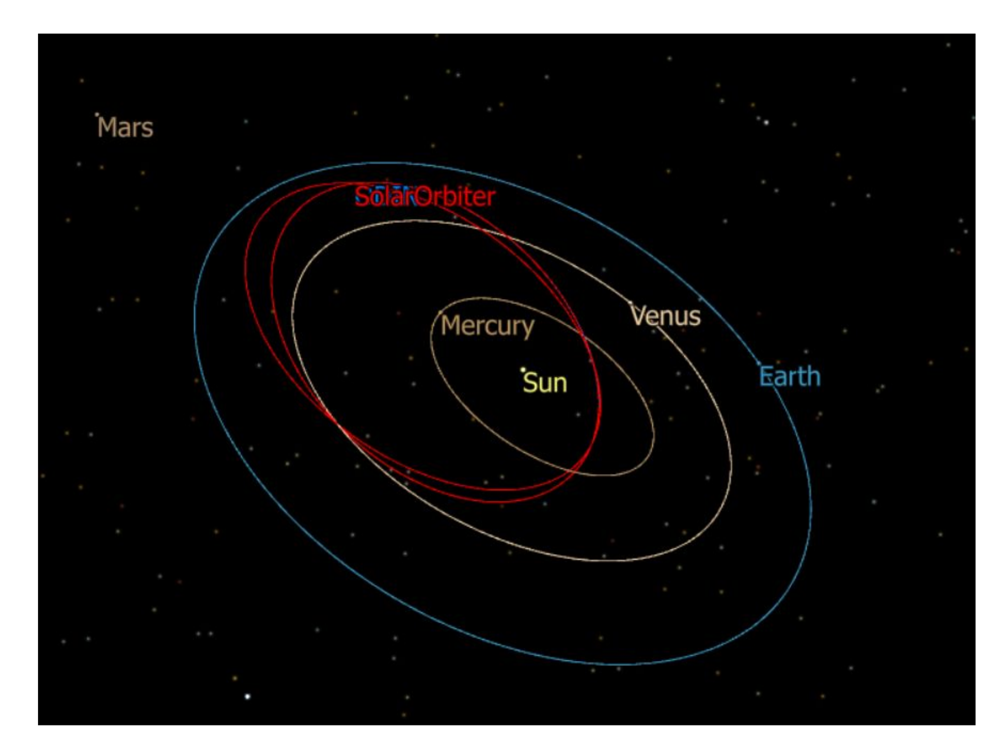
1. The mission shall inspect one cooperative space object operating outside Earth orbit within 3 years of initial on-mission operations
2. The mission shall perform close-range inspection of the selected target without physical contact
3. The mission shall operate safely in proximity to the target spacecraft
4. The mission shall be capable of reaching and operating in the vicinity of the selected target using onboard propulsion
5. The mission shall be compatible with a single-launch architecture
6. The mission shall support data return to Earth sufficient to enable post-inspection analysis
7. The mission shall have a minimum operational lifetime sufficient to complete rendezvous, inspection operations, and data return for the selected target
8. The mission shall comply with end-of-life disposal or passivation requirements appropriate to the selected operational environment

System Requirements

The system requirements are derived from and traceable to the mission requirements. Each requirement quantifies or narrows at least one mission requirement. They are grouped based on functionality they define:

1. Target Interaction and Inspection Capability
2. ProxOps and Safety
3. Propulsion
4. Comms and Data Return
5. Physical Constraints
6. Operations
7. End-Of-Life





Acknowledgements

We would like to thank Dr. Rich Whittle, Dr. Stephen Robinson, and Adam Zufall for their support and instruction.

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THERMAL, STRUCTURES, & PROPULSION

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Overview

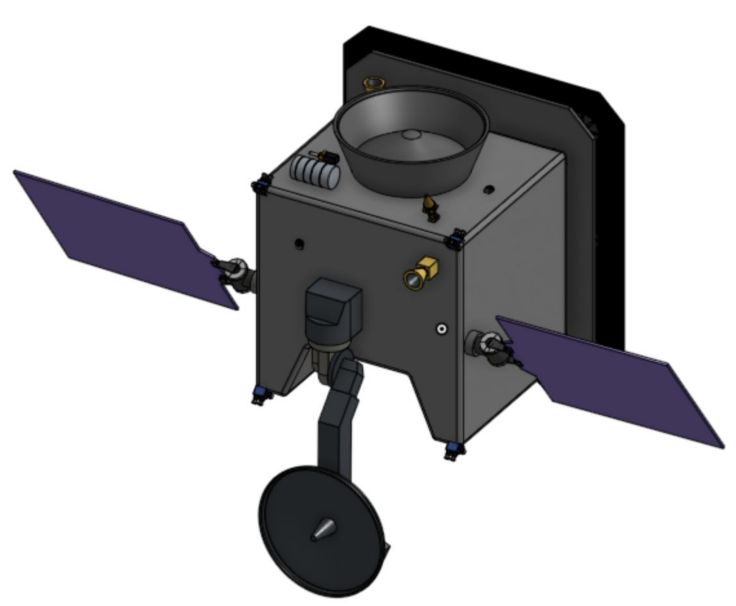
The thermal subsystem maintains spacecraft operational temperatures between 0.28 AU and 0.90 AU, where solar flux ranges from over 17,500 W/m² to approximately 1,680 W/m². The Thermal Control System (TCS) uses passive and active thermal management, while the Thermal Protection System (TPS) incorporates a Solar Orbiter-derived heat shield and SolarBlack coating to protect sun-facing surfaces.

The structures subsystem focuses on the spacecraft bus, which houses the internal payload and provides mounting surfaces for external components. The design ensures ODIN can withstand launch loads, vibrations, and potential thermal deformation throughout the mission.

The propulsion subsystem enables heliocentric transfer maneuvers and close-range inspection operations near Solar Orbiter. ODIN uses a dual-regime hypergolic propulsion architecture with a high-thrust main engine for major ΔV maneuvers and precision thrusters for station keeping and proximity operations.

Spacecraft Structure

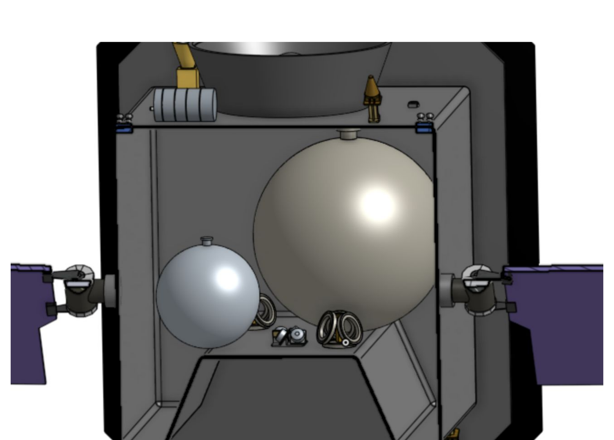
ODIN has 3 inspection cameras located on the fairing face). The spacecraft also consists of an high gain antenna that can be folded into the bus during launch and deployed periods of the mission where it is not needed. This makes sure the antenna can survive the harsh temperature environment as it is only exposed for short durations. The internal components seen in Figure 2 consist of the propellant tanks, ADCS components, and satellite computers.

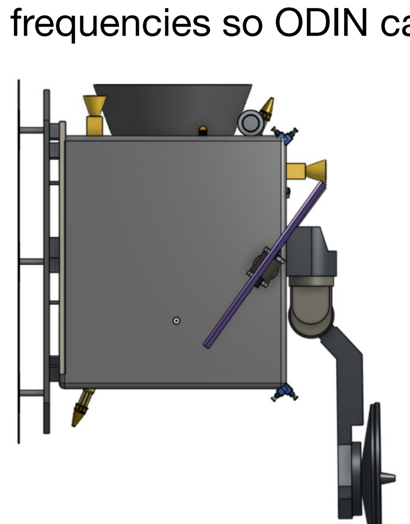


ODIN's two solar panels gimbal for efficiency and survival. The two panels will be folded in and stored during launch and eventually deployed during the mission. The main thermal structural element of the spacecraft is the heat shield which will block the majority of the sun on ODIN. The heat shield ensures the major operational elements are protected including the star trackers and the inspection cameras. The primary material of the spacecraft bus will be a Graphite-Aluminium honeycomb composite that maximizes strength and weight. Calculations have been completed to ensure this material can withstand the maximum quasi static loads that occur during the mission.

The spacecraft was modeled in OnShape with all the components created to scale in order to visualize the best layout for all the systems. This program also allows for the calculation of important spacecraft properties such as total mass, center of mass, and moment of inertia.

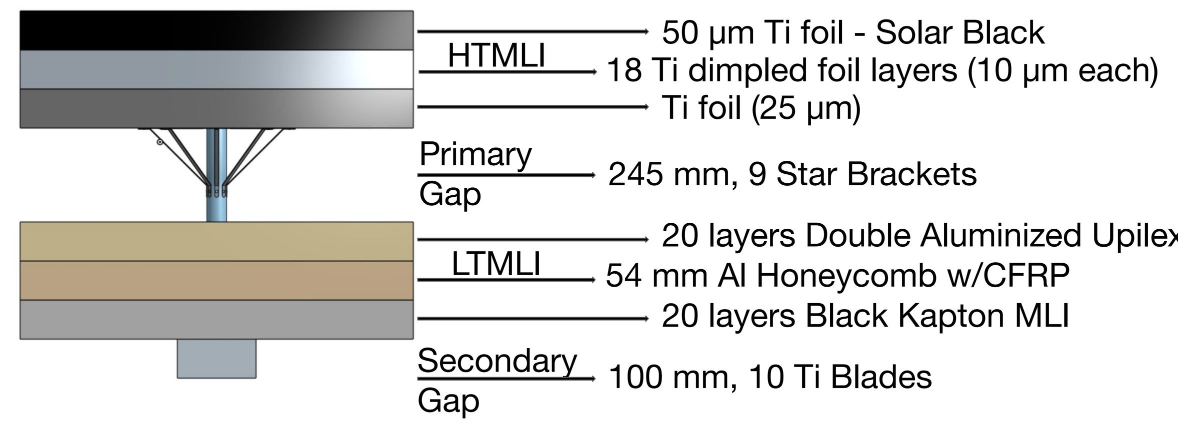
The spacecraft must survive the vibrations that occur during launch and analysis will be run to ensure that ODIN complies to the Falcon 9's requirements. Modal analysis will be conducted in Patran to determine the system's natural frequencies so ODIN can launch.

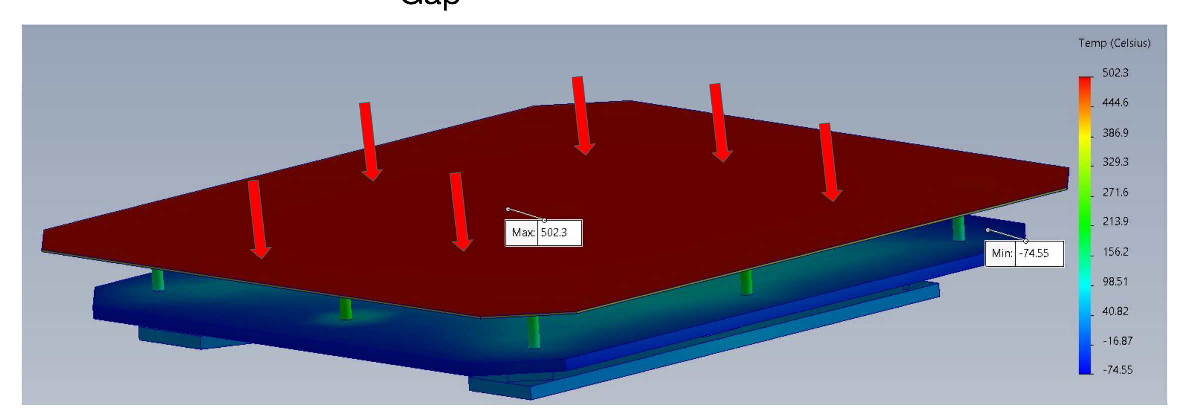




Thermal

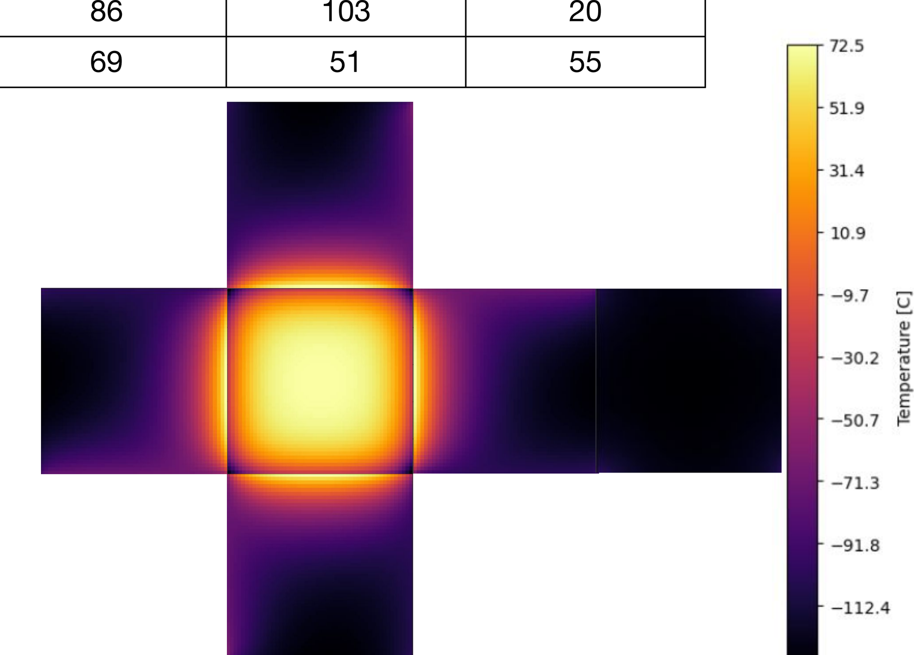
Thermal analysis of the heat shield was done in SolidWorks and a mathematical model was created with Python to evaluate the heat transfer from the shield's outermost surface to ODIN's bus.



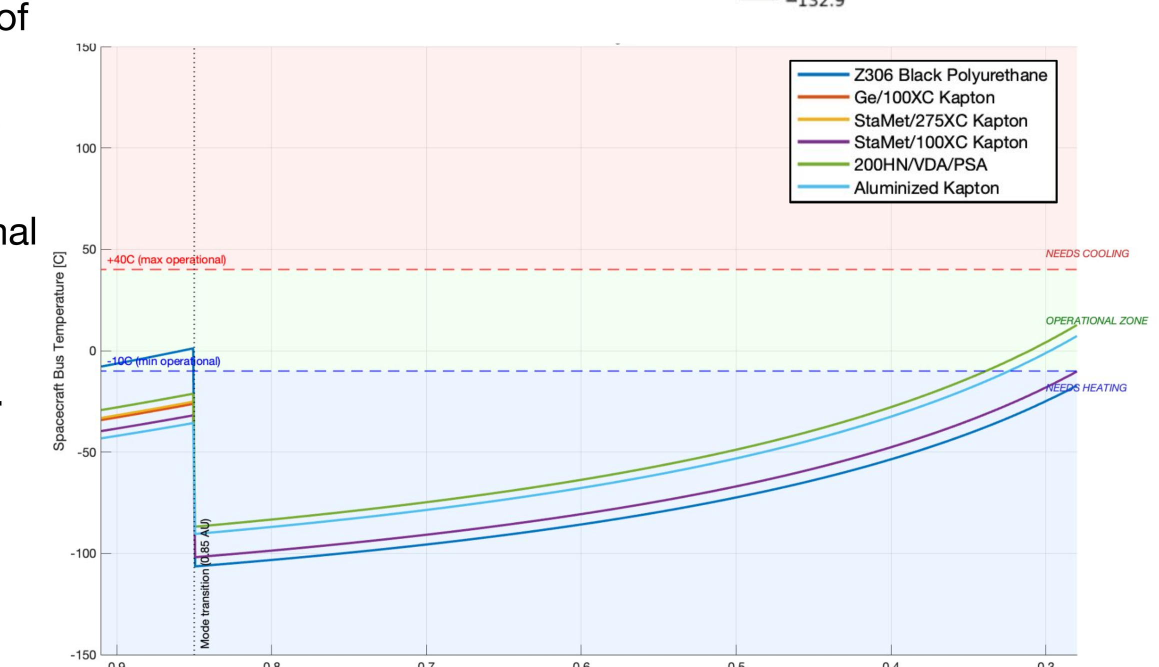


Surface	ODIN Temp °C SolidWorks	ODIN Temp °C Python	SolO Temp °C
HTMLI Top	502	510	505
HTMLI Bottom	389	292	280
SP Top	116	140	200
SP Bottom	86	103	20
SC MLI	69	51	55

A finite-difference nodal model was developed to predict spacecraft bus thermal gradients. The results are used to support localized thermal analysis, component placement, and TCS design.



Passive thermal control of the spacecraft bus is governed by the surface coating. A steady-state lumped parameter thermal model was used to evaluated six coatings across the mission orbit. Aluminized Kapton maintained the warmest bus temperature and is selected as the baseline bus surface finish.



A net 56 W of additional heating is required throughout the orbit. Passive heating is achieved through thermal straps connecting high-temperature structural elements to cold-running components, improving conductive heat distribution within the bus. Where passive measures are insufficient, flexible foil heaters are applied at the component level, providing targeted active thermal control and autonomous temperature regulation for individual instruments.

SolarBlack

SolarBlack is a high-temperature black coating used by ESA on Solar Orbiter's heat shield, also applied to ODIN's shield. The coating is designed to withstand solar flux greater than the max experienced during the mission. This is possible because it is carbon-rich and stable at very high temperatures, has high emissivity to reradiate absorbed heat, and is bonded to the titanium surface through CoBlast, a process that removes the oxide layer of the metal while simultaneously applying SolarBlack.

Produced by ENBIO.

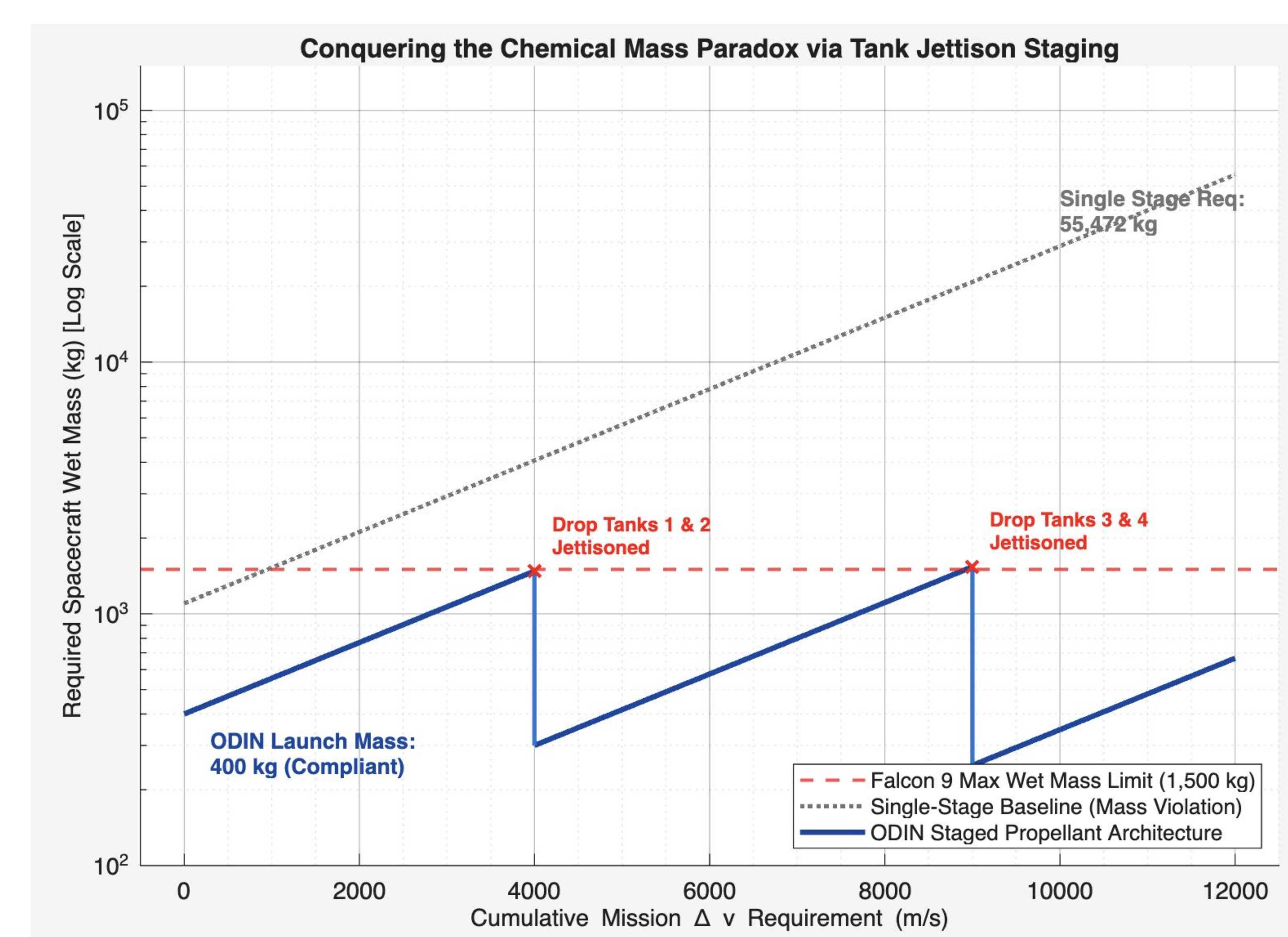
Absorptivity (α)	0.96 BOL-EOL
Emissivity (ε)	0.78 BOL-EOL

Propulsion

This propulsion subsystem features an entirely chemical, dual-regime hypergolic architecture engineering to overcome the 8 km/s heliocentric navigation bourbon imposed by a Falcon 9 launch configuration. By abandoning low-thrust electric options to guarantee a strict, sub-3-year intercept window at Solar Orbiter, the system addresses the 12 km.s cumulative delta-v profile through a staged multi-tank drop network.

Primary heliocentric transfers and large orbital-plane changes are executed via a space-proven, 490 N Aerojet Rocketdyne R-4D-11 bipropellant main engine operating at an I_{sp} of 312 seconds. Precise close-range, 6-DOF proximity operations and surgical station-keeping at a punishing 0.28 AU perihelion are delegated to an integrated cluster of 16 fast-acting, 22 N Aerojet Rocketdyne MR-106L bipropellant thrusters delivering minimum pulse widths down to 22 milliseconds.

By jettisoning empty structural tank pairs immediately following major orbital insertion burns, the design reshapes the classical exponential mass-fraction curve. This all-chemical staging minimizes deadweight throughout the transit timeline, forcing a high-thrust trajectory to close cleanly within the rigid 1500 kg Falcon 9 launch vehicle payload envelope.



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ADCS, PAYLOAD, POWER, & COMMUNICATIONS

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Overview

ODIN's Comms and C&DH subsystems manage command, telemetry, payload data processing, storage, and Earth return. Images is compressed, packetized, stored in the SSMM, and downlinked through the X-band HGA, while LGAs support low-rate TT&C and safe-mode coverage.

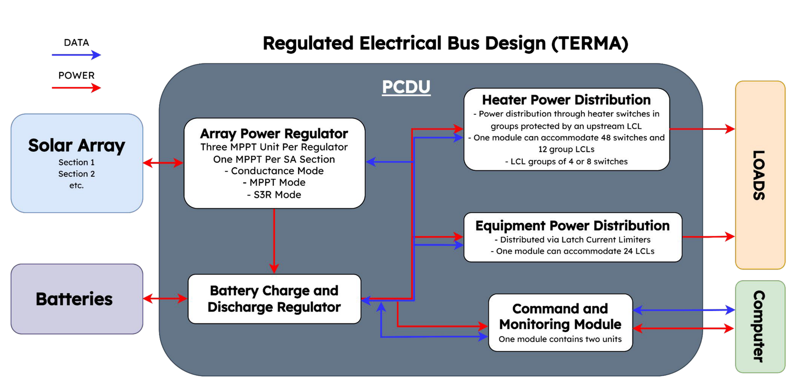
The Payload is responsible for giving ODIN its primary inspection capability. In order to inspect Solar Orbiter, the payload employs the use of several cameras and laser components to correctly determine range, acquire, and image the Solar Orbiter in both visible light and infrared.

ODIN's Power systems focuses on supplying the power for all components while managing the constant excess solar energy that comes with persistent illumination, as well as the extreme thermal fluctuations that occur during its orbits following the Solar Orbiter. Its only battery requirements stem from the lack of consistent solar illumination during inspection.

Power

Power Control & Distribution Center:

With industry standards for PCDU's shifting towards contracted manufacturing, our PCDU design takes after the BepiColombo mission in contracting with TERMA, a Danish Aerospace manufacturing company with a long heritage in PCDU manufacturing. Our design utilizes their modular systems as seen in the figure with a bus voltage of 28V.



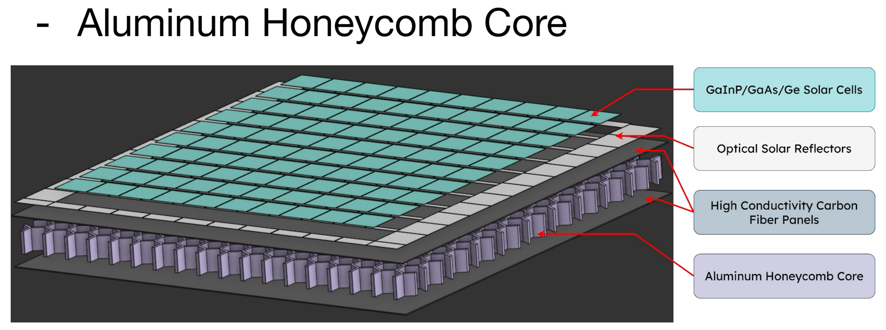
Batteries:

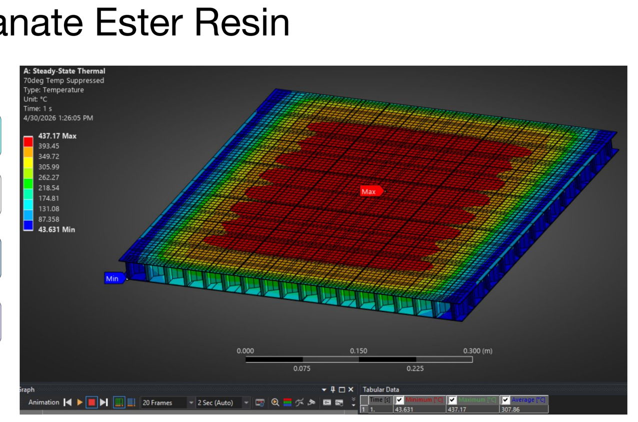
The industry standard lithium ion batteries were chosen, with the 18650 EnerSys ABSL batteries being picked due to their heritage with the BepiColombo and Parker Solar Probe missions under high radiation/heat environments. Accounting for 20% degradation and assuming the solar arrays are at a max incidence angle of 80° during inspection, ODIN will require ~3593 Wh and ~23kg of battery based off the time spent in each mode during inspection.

Solar Arrays:

With ODIN experiencing extreme solar/temperature fluctuations as it travels from 1.0 AU to 0.28 AU in its pursuit of the Solar Orbiter, its solar panel design shifts from orbital/eclipse cycles to mitigating excess heat under constant illumination. Our design follows the same principles as the ESA BepiColombo and ESA Solar Orbiter missions;

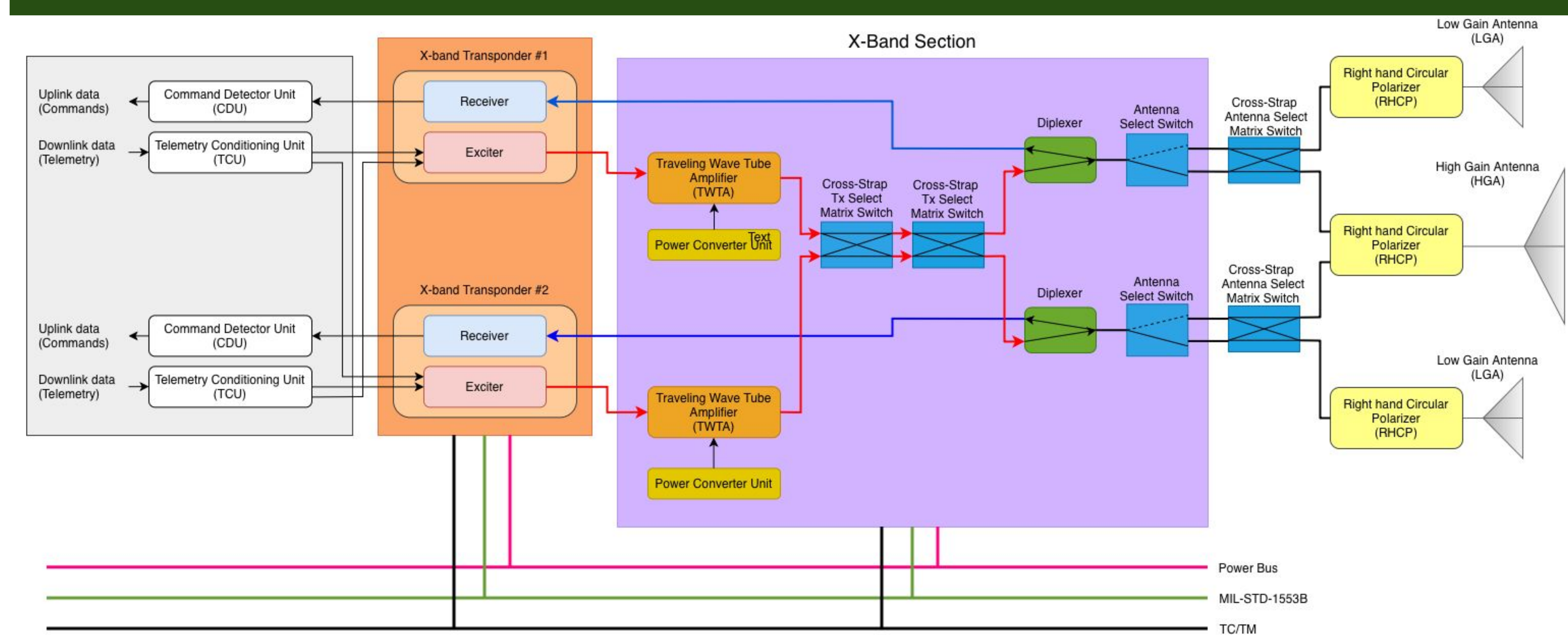
- ~60% InGaP/GaAs/Ge Triple-Junction Solar Cells
- ~40% Metalized Quartz Optical Solar Reflectors
- High Conductivity Carbon Fiber Panels w/ Cyanate Ester Resin
- Aluminum Honeycomb Core





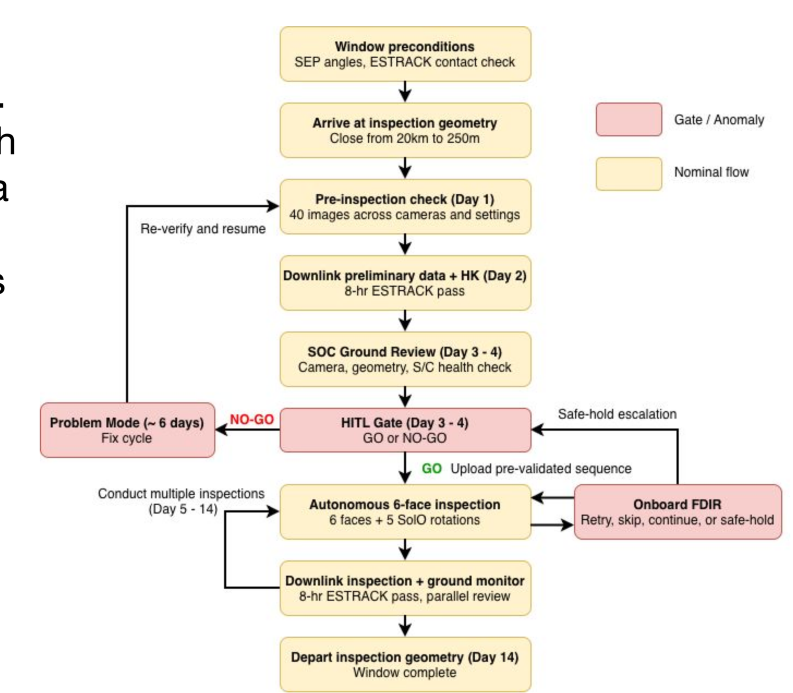
Based off power generation at 1AU and the power requirements for Safe Mode, and assuming a degradation of -32% from original effectiveness, the solar orbiter will require ~1.25 m^2 of solar cell area or ~1.75 m^2 total (including OSRs) minimum.

Communications

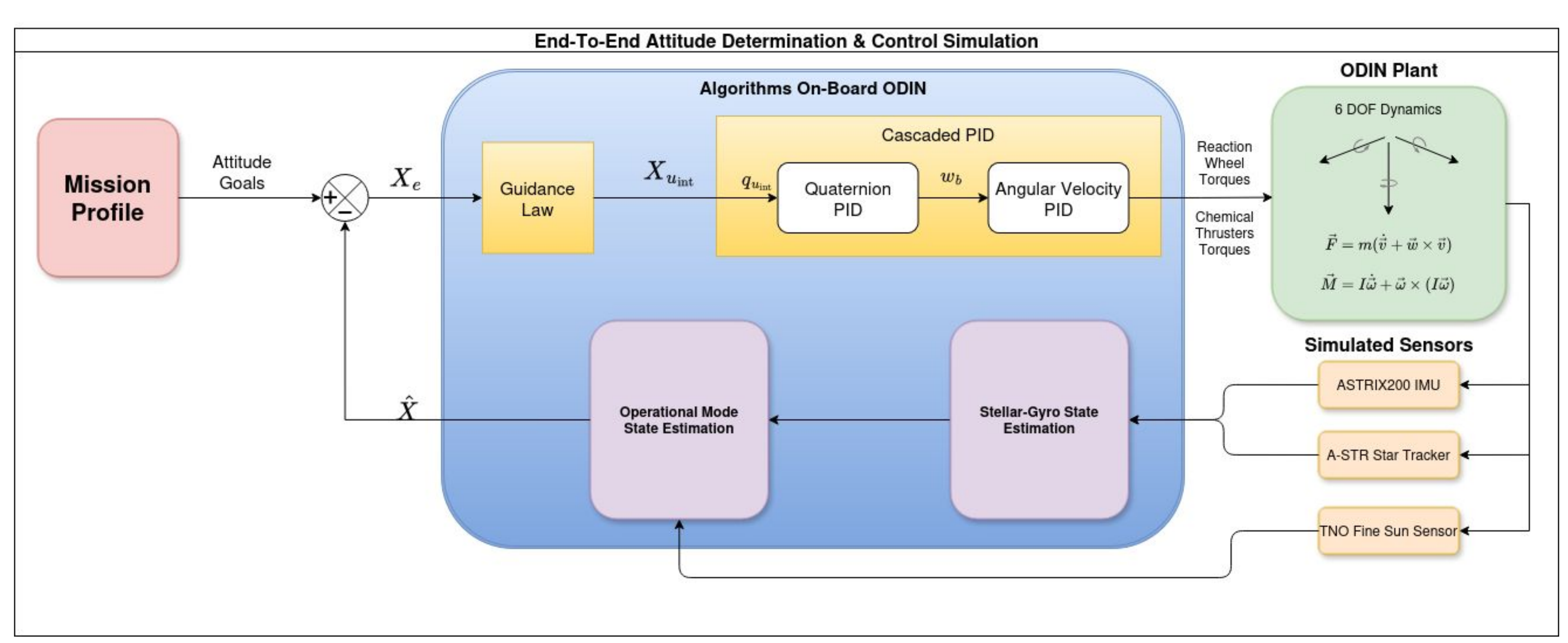


Redundant X-band architecture provides HGA science downlink and LGA TT&C/safe-mode coverage. Inspection data is stored onboard and returned through scheduled ESTRACK contacts; undumped SSMM data carries over to the next pass. Inspection 1 supports 85 kbps at 0.696 AU, while Inspection 2 supports 89 kbps at 0.456 AU.

ODIN follows a verify window conditions, arrive at inspection geometry, perform a Day 1 camera checkout, downlink preliminary data on Day 2, complete SOC review and HITL GO/NO-GO on Days 3–4, then conduct autonomous six-face inspections during Days 5–14. Stored inspection data is returned through scheduled 8-hour ESTRACK contacts.



Attitude Determination & Control System

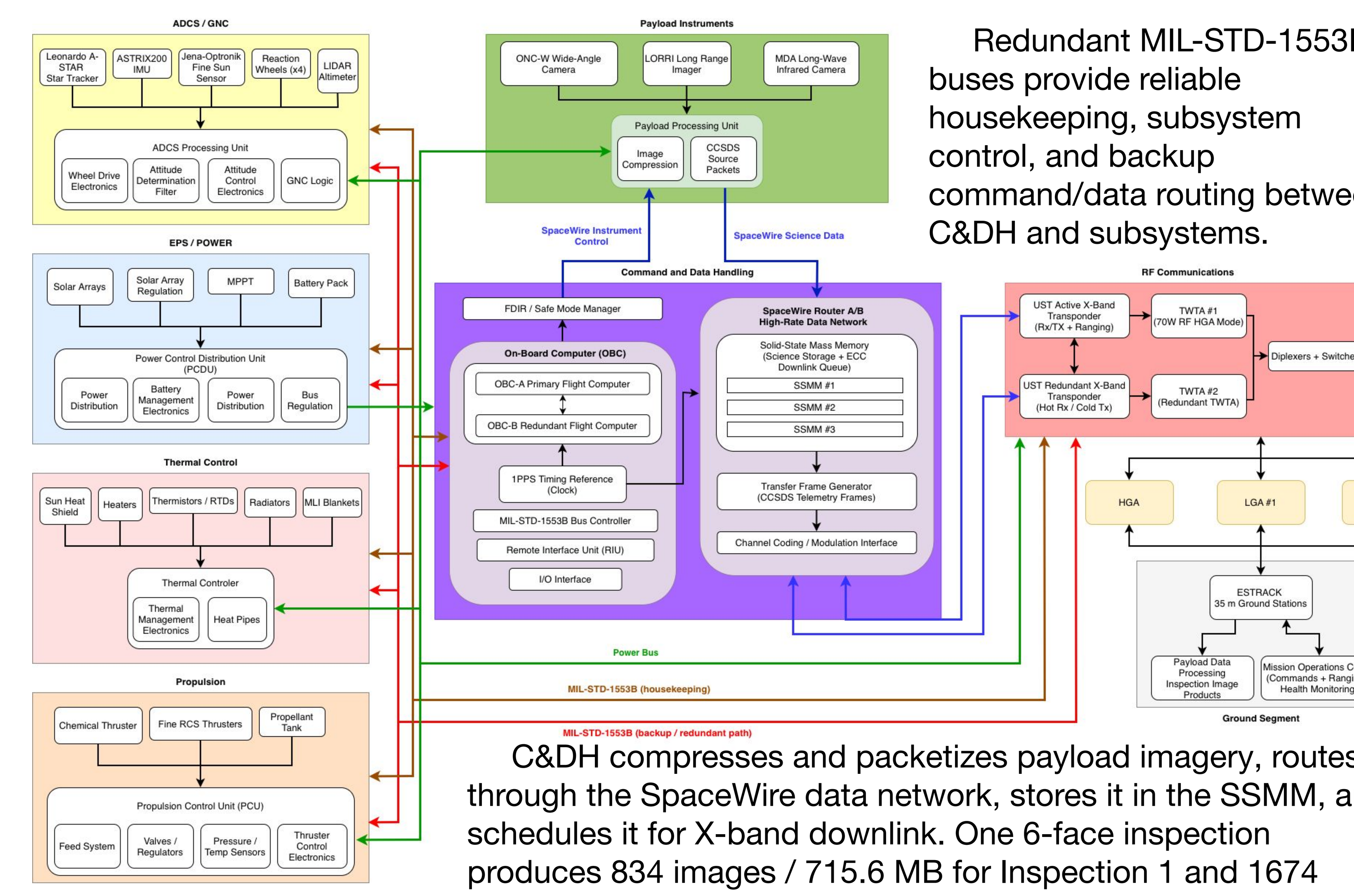


End-To-End Simulation:

The goal of ODIN's ADCS system is to meet all of the strict pointing requirements throughout the mission lifespan of ODIN. The pointing requirements change during different operational modes and as such will have a state estimation that is informe by those operational modes. The End-To-End simulation is informed by the ConOps and the simulated orbit of ODIN. This is achieved through FreeFlyer and MATLAB integration with our controller operating in tandem with the FreeFlyer simulation.

ODIN's ADCS system is actuated by 4 reaction wheels and a Chemical Propulstion system. State estimation is handled through a Gyro-Stellar Extended kalman filter and a Fine Sun Sensor informs our attitude in sun safe operational modes.

Command & Data Handling



Redundant MIL-STD-1553B buses provide reliable housekeeping, subsystem control, and backup command/data routing between C&DH and subsystems.

C&DH compresses and packetizes payload imagery, routes it through the SpaceWire data network, stores it in the SSMM, and schedules it for X-band downlink. One 6-face inspection produces 834 images / 715.6 MB for Inspection 1 and 1674 images / 1436.3 MB for Inspection 2.

Payload

The Payload is designed to support inspection of Solar Orbited by combining wide angle imaging, narrow angle feature identification, narrow angle feature identification, thermal imaging, and laser based rangefinding. Each payload component serves a different role in the inspection sequence, allowing the spacecraft to first locate the target, approach safely, identify visible surface damage, identify thermal anomalies, and measure distance during proximity operations.

The Wide Optical Navigation Camera (ONC-W) is included as the wide angle acquisition camera. Its main purpose is to allow ODIN to locate Solar Orbiter and maintain visual awareness during approach. The Long Range Reconnaissance Imager (LORRI) is included as the narrow angle feature identification camera. Its role is to capture detailed visible light images of Solar Orbiter and identify surface features like impact marks, delamination, cracks, or discolorations as small as 5 millimeters once ODIN achieves an adequate effective standoff distance. The MDA Long Wave Infrared Camera adds thermal inspection capability to the payload. Thermal imaging can identify hot spots, insulation damage, exposed surfaces, or irregular heat patterns caused by degradation in the solar environment.

The selected payload components were chosen because they support the system requirements derived from the mission requirements, as well as having relevant mission heritage, reducing design risk by relying on technologies that have already been developed or flown in demanding space environments.

To round off the payload, a laser altimeter is included to provide direct range measurements between ODIN and Solar Orbiter during proximity operations, helping the spacecraft confirm standoff distance, support safe approach control, and relieve the reliance on camera data alone for distance estimation.