

Concurrent Engineering of an Infrared Telescope System



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Introduction

Space-borne Electro-Optical (EO) sensor systems may be designed by small, interdisciplinary teams of engineers using concurrent engineering techniques.

An Infrared telescope payload is provided as a design example.

Aspects of the design:

- Optical design

- Initial CAD design

- Structural model

- Integration of structures and CAD for refinement of CAD design

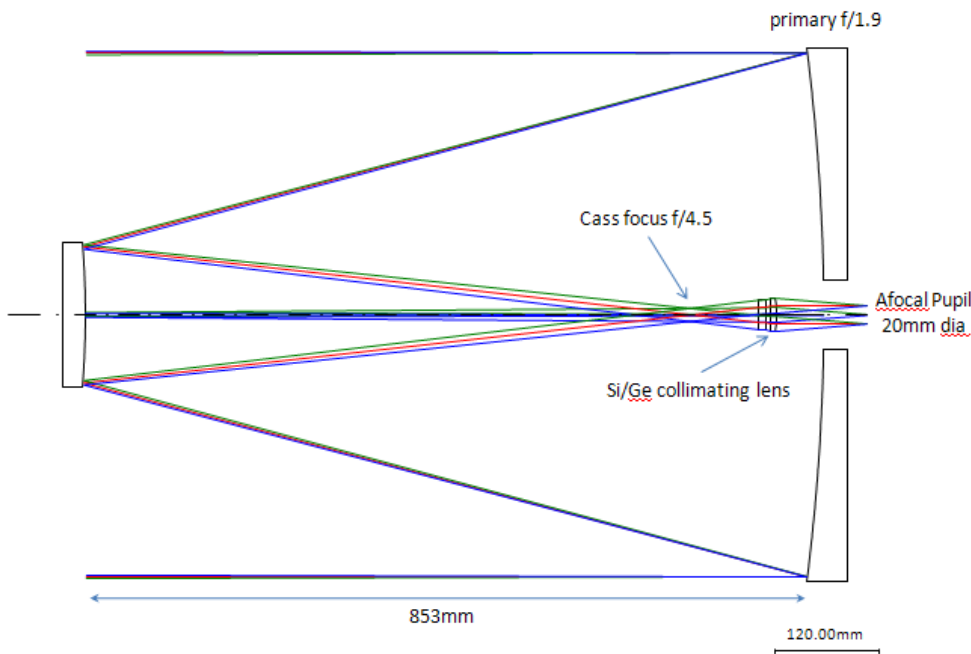
- Conceptual design of space segment

- Thermal design for payload

- Evaluation of optical performance for on-orbit thermal environments

- Integrated Structural/Thermal/Optical (STOP) analysis

IR Telescope Optical Design



Afocal telescope with exit pupil suitable for use as a cold stop with interchangeable MWIR instruments

Cassegrain with refractive doublet that can be refocused to maintain collimation over environments

Compatible with Minotaur I launch vehicle

$F/No = 4.5$

EPD = 60 cm

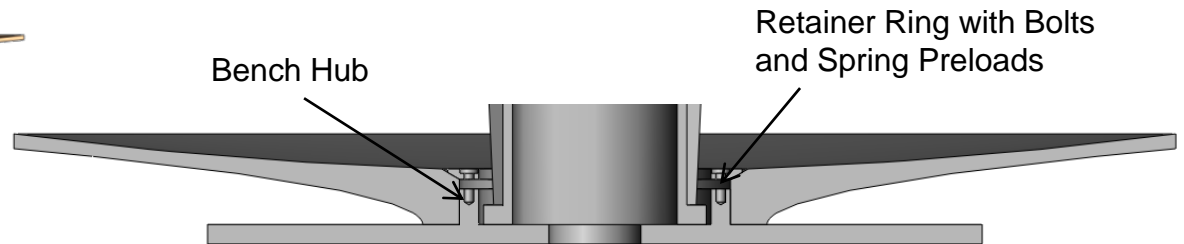
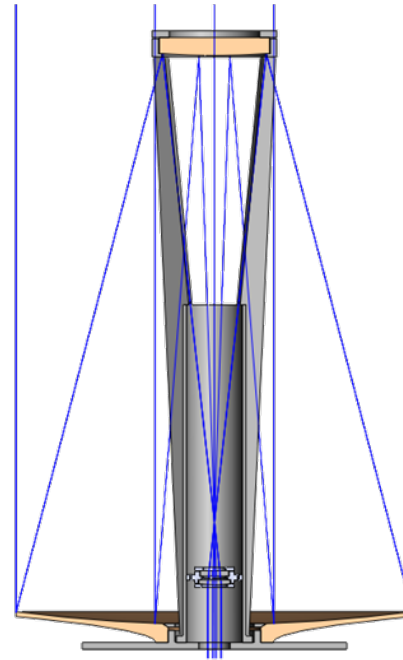
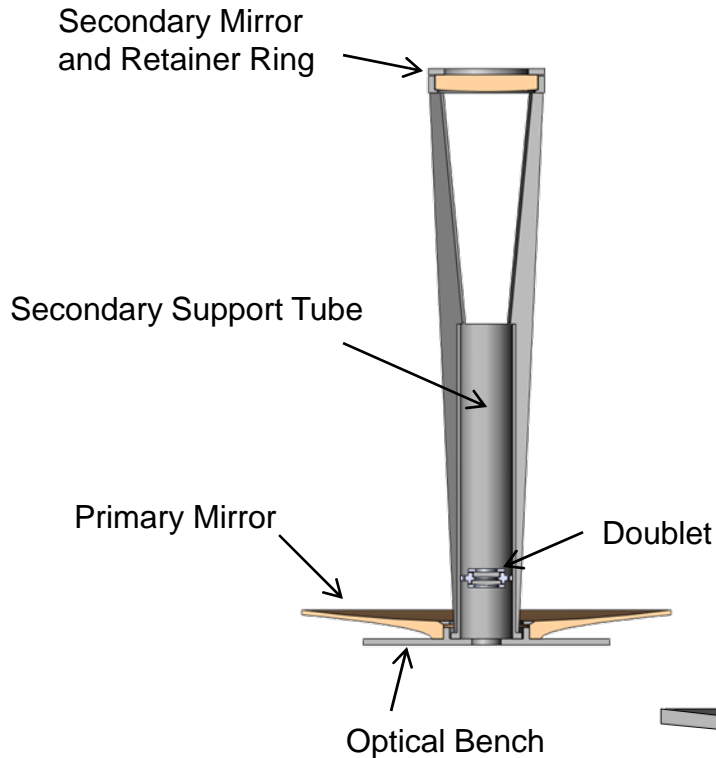
FOV diameter = 0.25 deg

Wavelength band = 3 to 5 microns

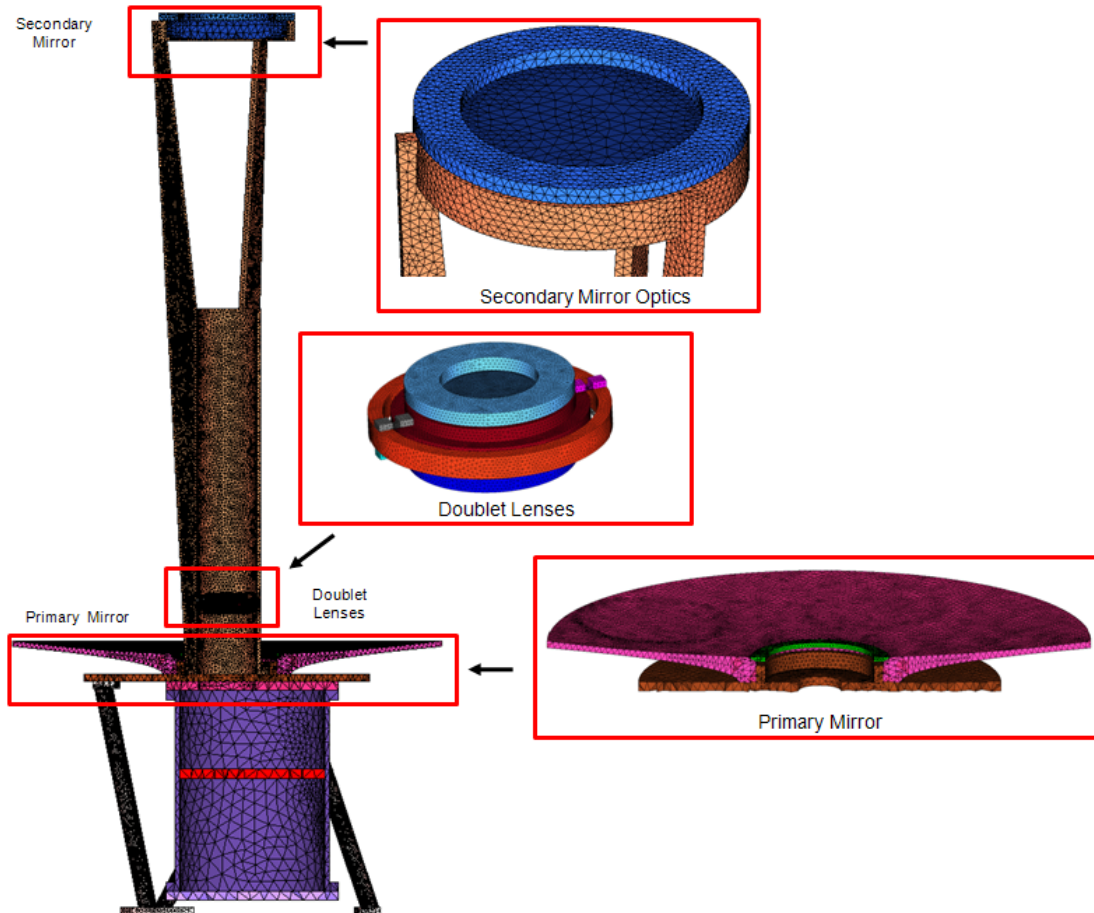
Baseline design is diffraction limited over the field of view

IR Telescope CAD Design

STEP files of optical components and rays are inputs for development of initial CAD model.



IR Telescope Structures Model



Initial CAD model is used for development of structures mesh.

Meshes are optimized at the component level, then combined into an integrated mesh for the payload.

Mechanical and Structural Design of IR Telescope

CAD and structures models are integrated to aid optimization of CAD design for launch loads. CAD engineer evaluates changes in fundamental mode frequency and maximum stress levels as CAD design is modified using Simulation Process developed by CAD and structures engineers.

The screenshot displays a simulation software interface for the structural analysis of an IR telescope. The interface is divided into several key sections:

- Project Tree:** Located on the left, it shows a hierarchical view of the project, including 'Telescope Assembly', 'Structures', and various CAD templates (CAD 10-13).
- Process Schematic: Structural Analysis FINAL:** This central diagram illustrates the simulation workflow. It starts with a 'Telescope Assembly' block, which branches into four parallel simulation paths: three for '+ y gravity (20G)' and one for '+ x gravity (20G)'. Each path involves an 'MSC' (MSC Nastran) solver block, followed by an 'Output' block. A central 'Extract Results' block then feeds into 'Frequency' and 'Displacement' output blocks.
- CAD Model:** A 3D rendering of the telescope structure, showing its cylindrical body and tripod-like base.
- Structures Mesh:** A visualization of the finite element mesh applied to the CAD model.
- Fundamental Mode:** A visualization showing the first mode of vibration, with the structure colored by stress or displacement levels.
- Project Dashboard:** Located at the bottom, it contains several data tables:
 - Constant Value:** Empty table.
 - Variable Value:** Empty table.
 - Requirement Value:** Shows a requirement for 'Frequency Req' at 45,9325 Hz.
 - Metric Value:** A table of simulation results:

Metric	Value
CM [X]	1.5833 e-09 m
CM [Y]	-1.268783e-02 m
CM [Z]	-1.347626e-01 m
First Mode Frequency	45.9325 Hz
First Mode Max Displacement	21.7821 in
I [xx]	6.0637 m ² *kg
I [yy]	6.0530 m ² *kg
I [zz]	9.190154e-02 m ² *kg
Mass	36.8772 kn

Spacecraft Conceptual Design

A conceptual design of the mission space segment is conducted using the payload CAD design as input.

Generates top-level designs for:

Systems

Attitude determination and control

Astrodynamics (orbit)

Command and data handling

Ground segment

Communications (payload to ground)

Power and data processing

Propulsion

Software

Telemetry and tracking

Overall mass and power

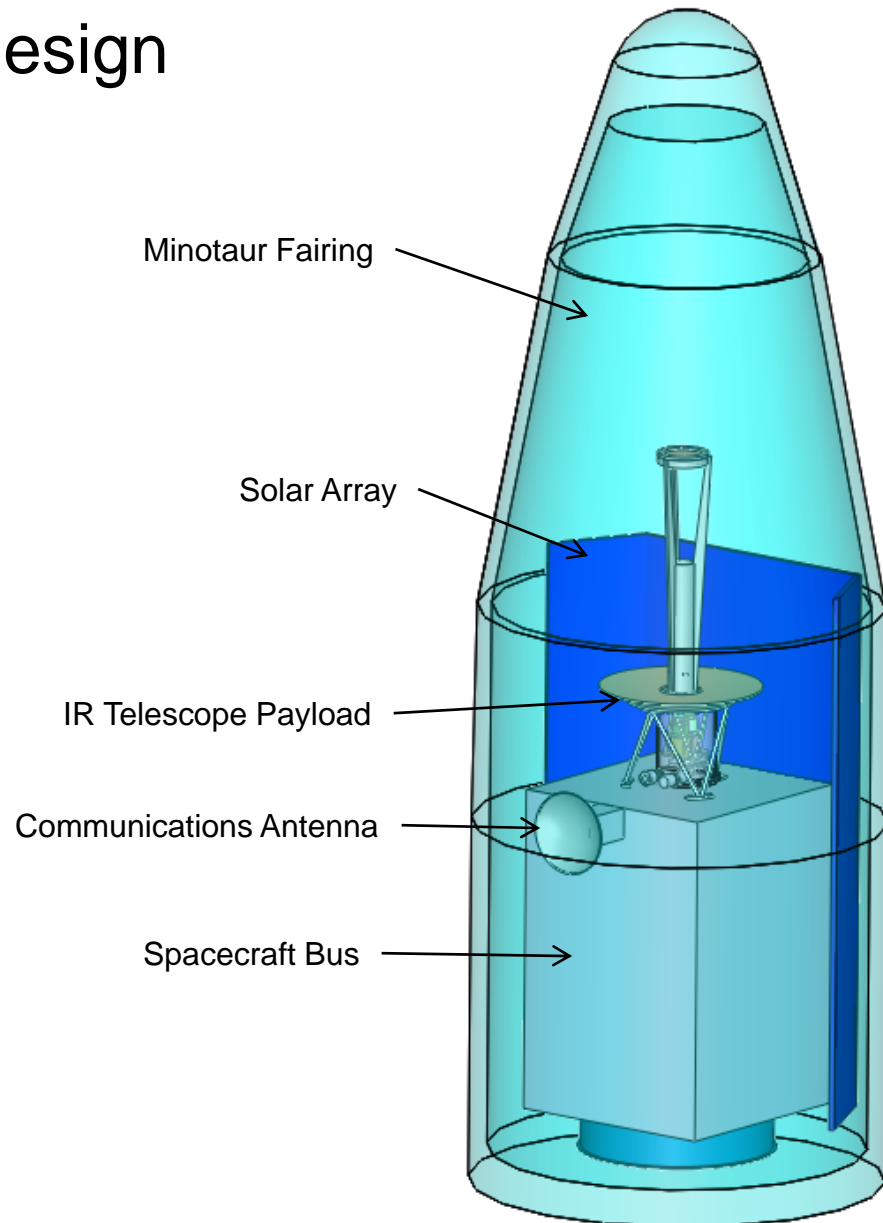
Conceptual CAD designs for:

Spacecraft

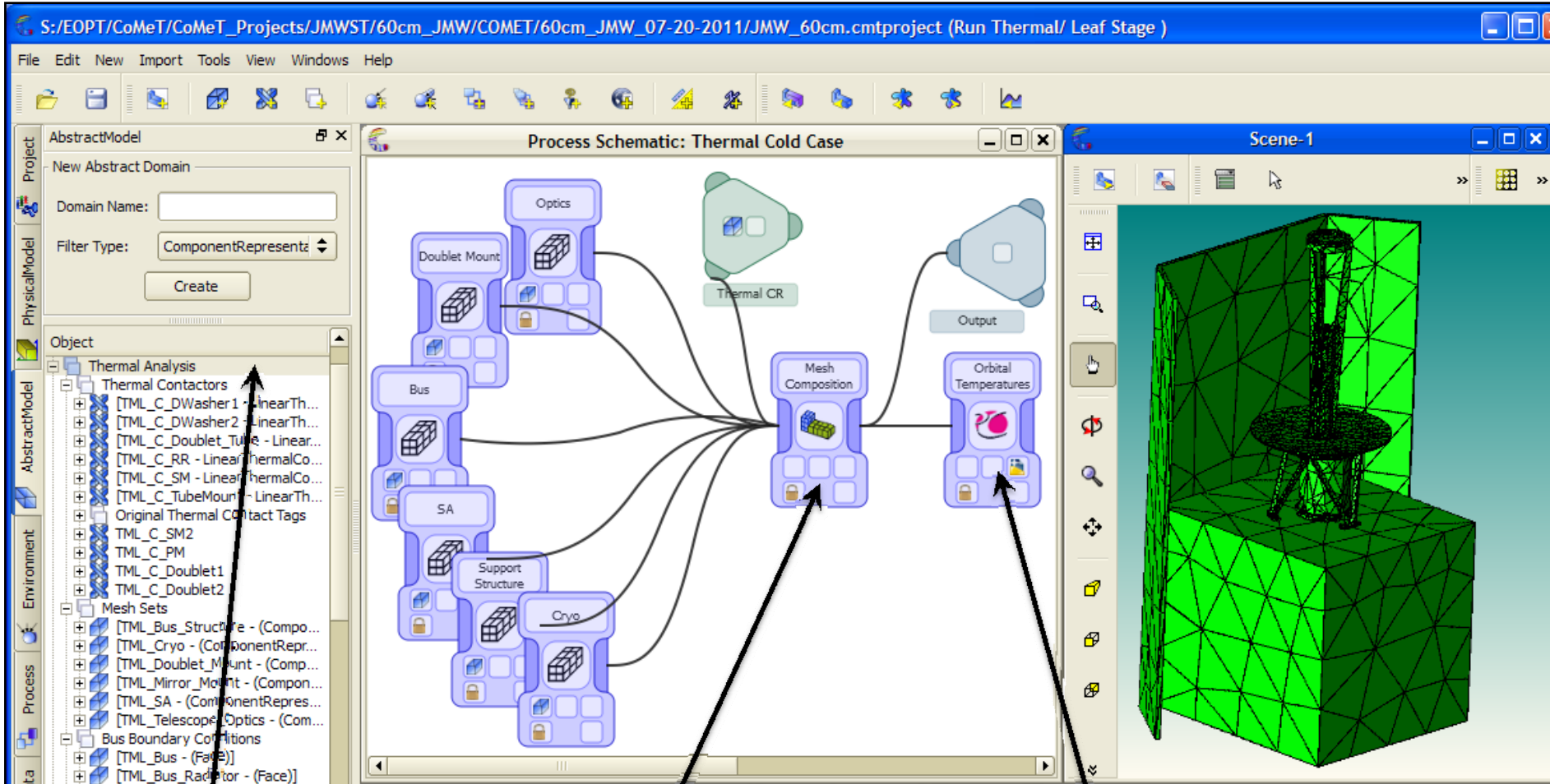
Bus

Solar arrays

Provides inputs for thermal design of payload



Thermal Design of IR Telescope

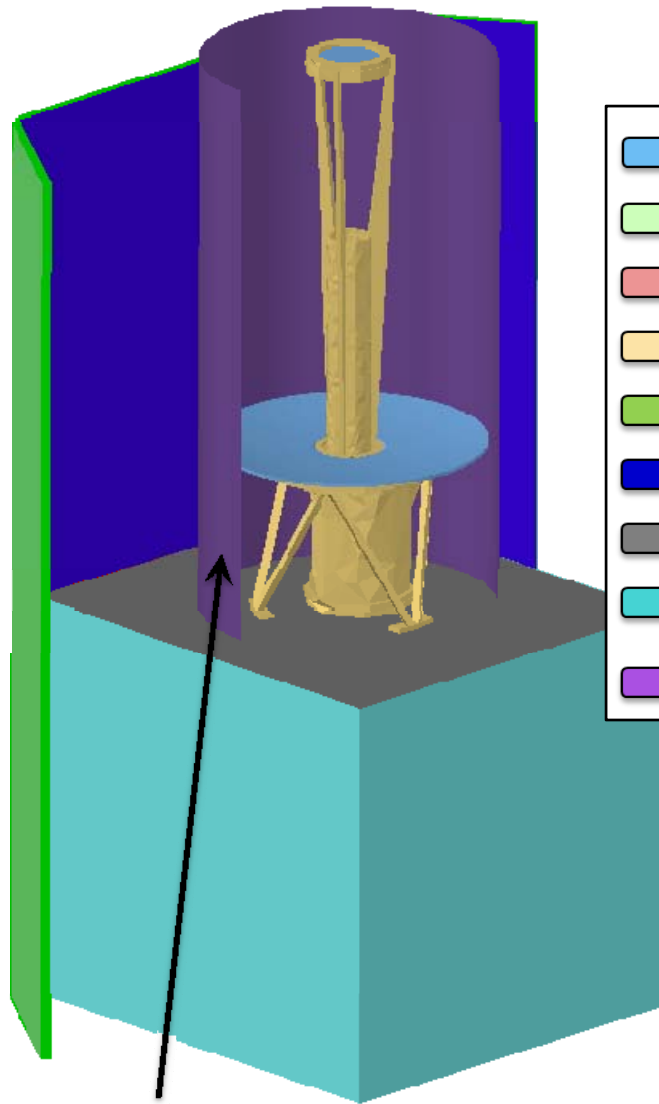


The thermal abstract model contains boundary conditions, meshing parameters and thermal contactors

Several thermal meshing tasks are combined to form a composite mesh with less detail on the bus and more detail on the telescope optics

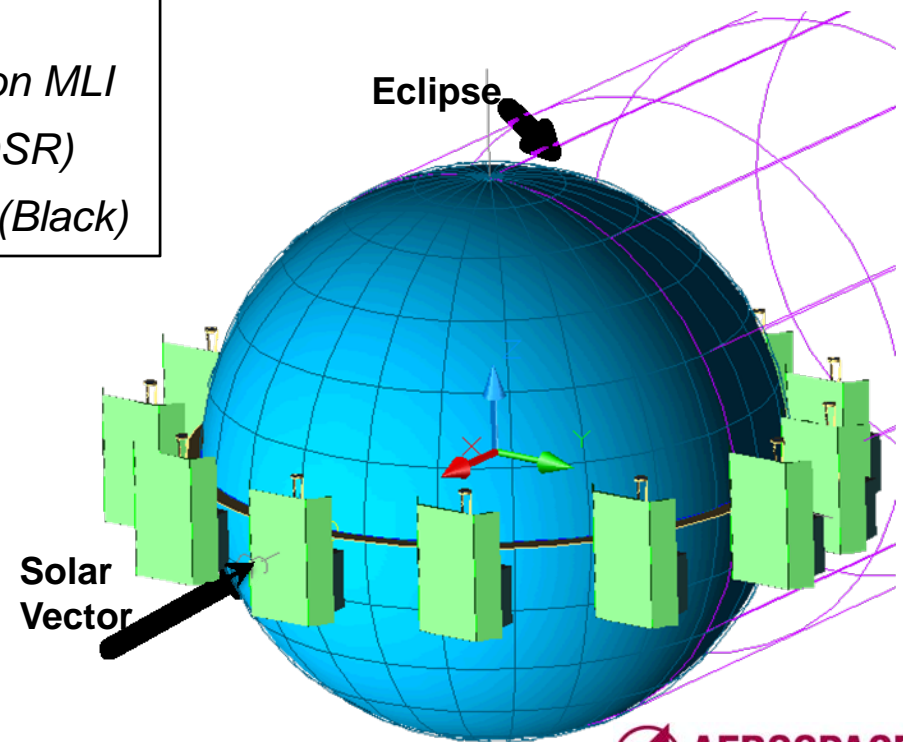
The thermal desktop task generates radiation view factors, orbital heat rates and orbital temperatures, then maps these temperatures to the structures mesh

Surface Treatments and Cold Case Orbit Parameters



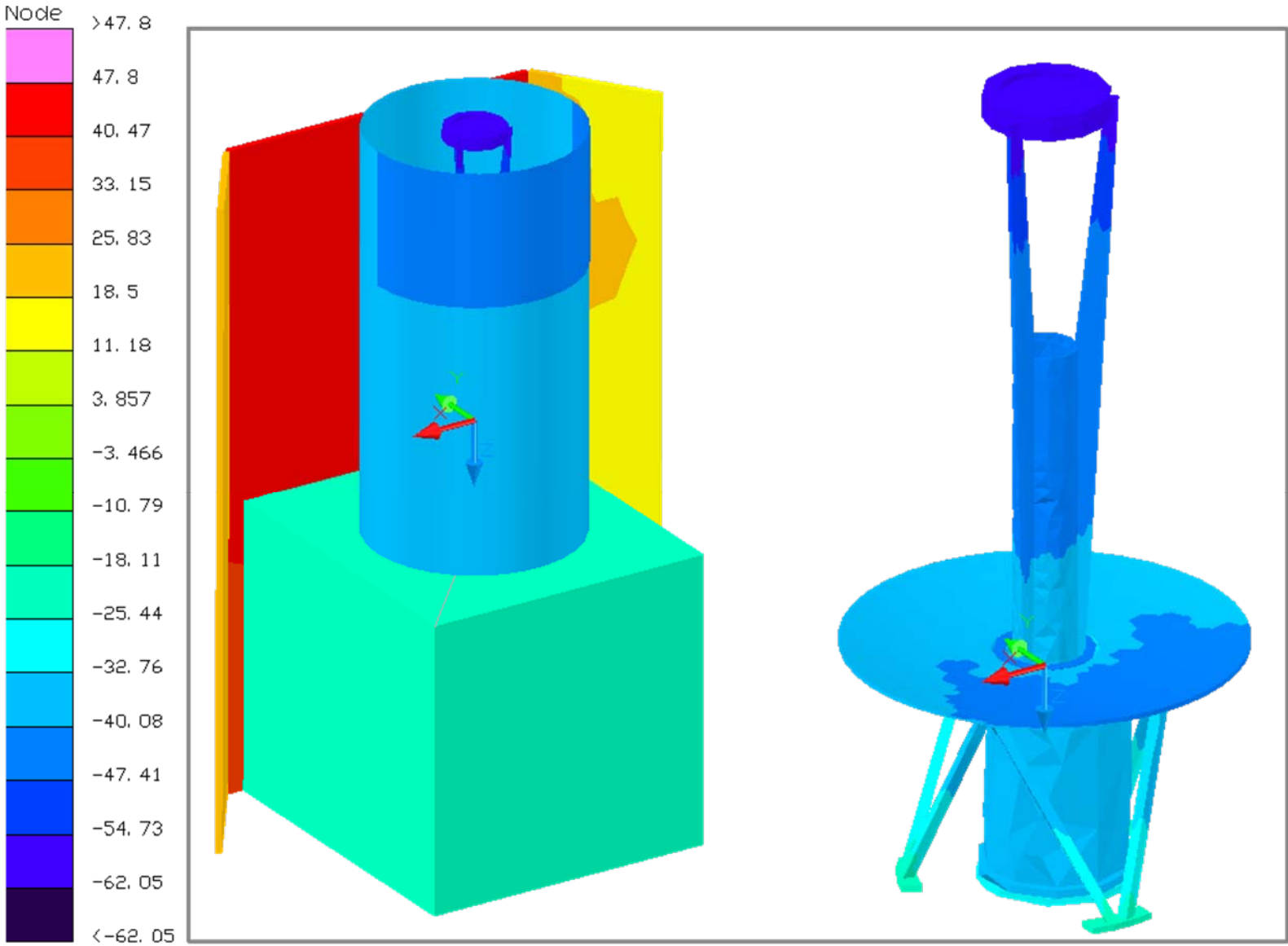
- | | |
|---|--------------------------|
|  | <i>Borosilicate</i> |
|  | <i>Germanium</i> |
|  | <i>Silicon</i> |
|  | <i>Titanium</i> |
|  | <i>Solar Cells</i> |
|  | <i>Black Paint</i> |
|  | <i>Black Kapton MLI</i> |
|  | <i>Radiator (OSR)</i> |
|  | <i>Composite (Black)</i> |

- | |
|---|
| Orbit set to $\beta = 0^\circ$ (orbit plane is parallel from solar vector) |
| - Bus held at -20°C |
| - Solar Heating: 1322 W/m^2 |
| - Earth IR: 222 W/m^2 |
| - Albedo: 0.24 |



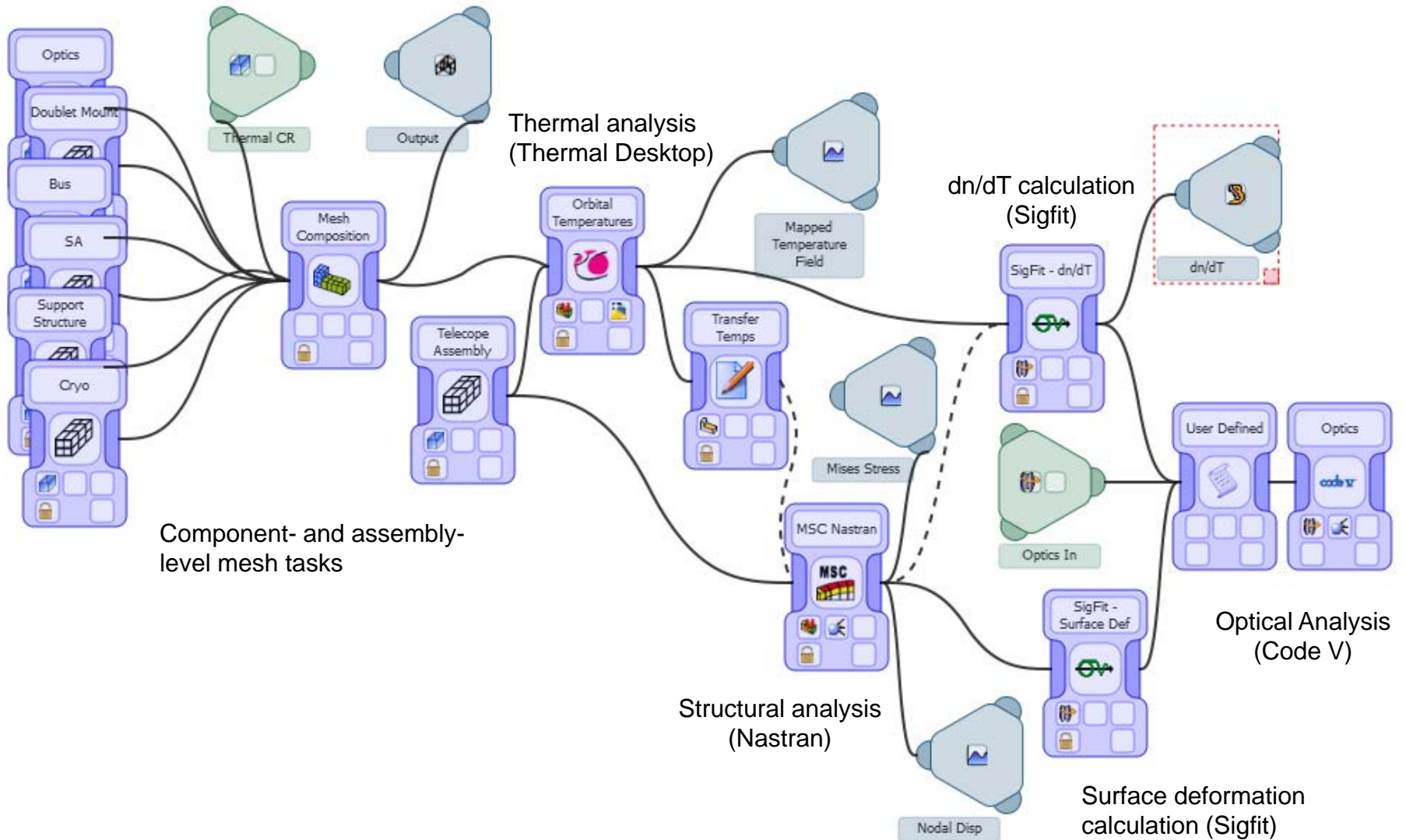
Notes: Part of the Barrel is removed to show interior optics, Barrel Exterior is covered with Aluminized Kapton MLI

Cold Case Temperature Distribution

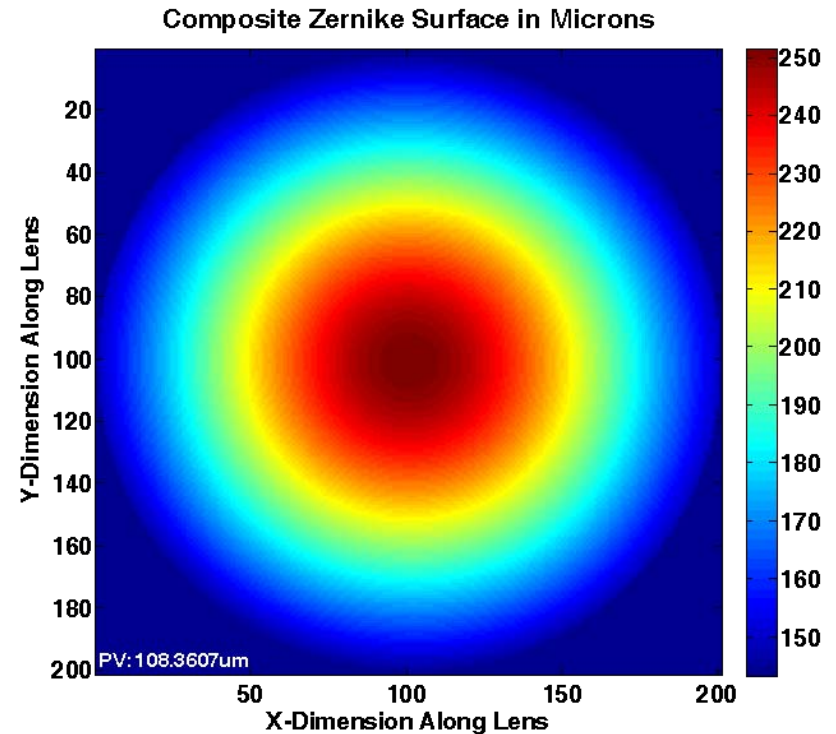
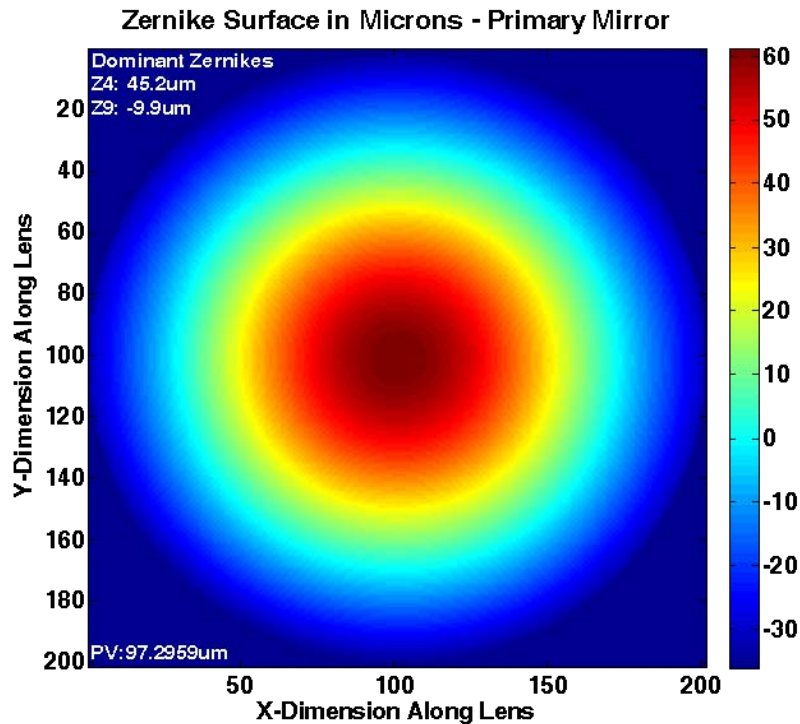


Temperature [C], Time = 16850 sec

Integrated STOP Simulation Process



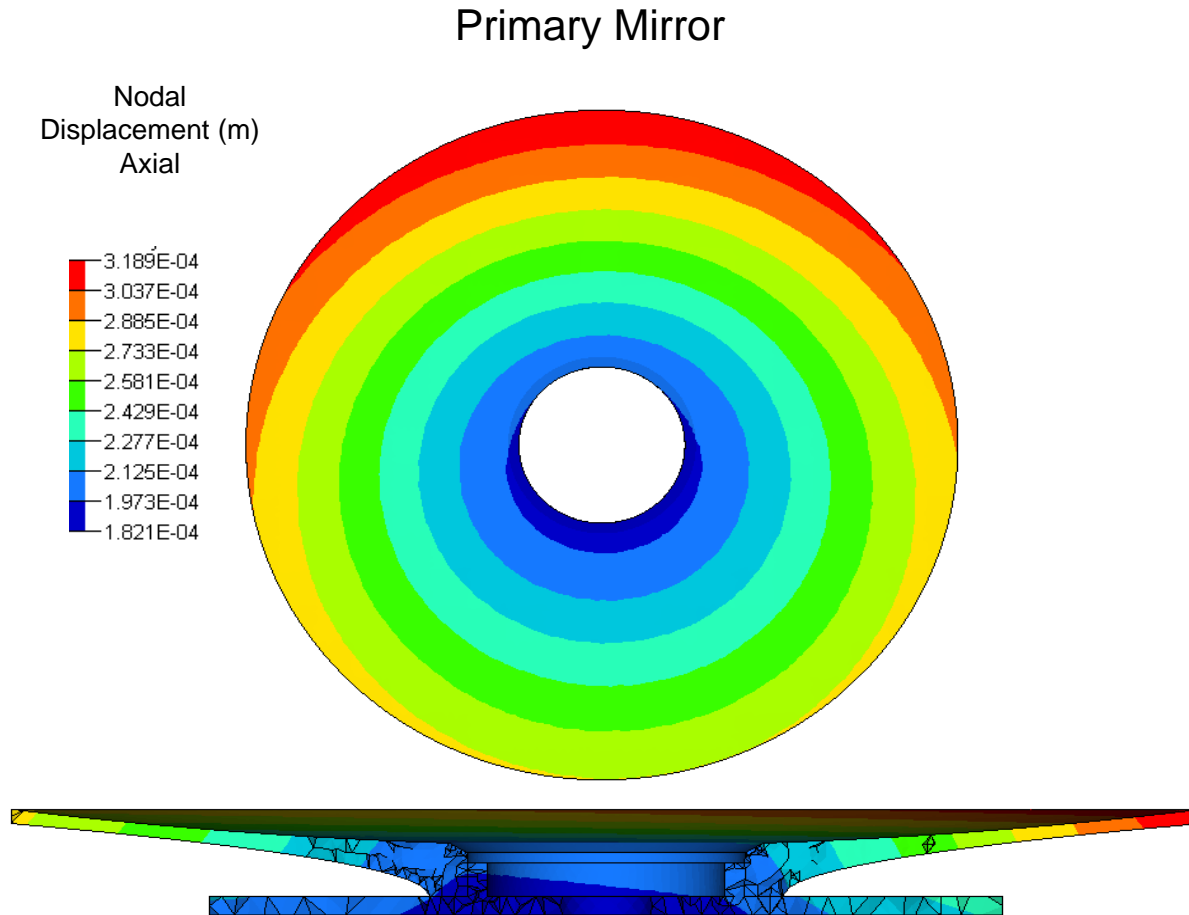
Cold case wavefront error predictions



A large amount of focus error and spherical aberration are evident.

Wavefront error is dominated by primary mirror figure errors.

Structural node displacements for primary mirror



With tilt removed the peak to valley nodal displacement is $\sim 98 \mu\text{m}$.

Mirror is bending due to unrealistically high mount stresses at the hub mount interface.

Conclusions

A concurrent engineering approach to the design of space-borne EO sensors has been presented using an example of an IR telescope payload.

Concurrent engineering seeks to better integrate the efforts of the various engineering disciplines needed to design EO payloads so that delays and errors at the points where information is exchanged between disciplines are reduced, and design cycle times – i.e., the time it takes to execute a single iterative change to the sensor design as it evolves – are dramatically reduced.

For example, once the Simulation Process for STOP analysis is set up, the effects of minor design changes or different thermal environments on optical performance can be re-evaluated in one day or less even for complex opto-mechanical designs.

The material provided here represents an initial pass through the design of the entire IR telescope system that provides both a solid design starting point for each technical discipline area and robust, physical insight into the interactions between the different components of the system.

The same integrated model may now be iterated to correct design problems in each technical discipline area while assessing the impacts of those design changes on all aspects of system performance.