Demisability of Optical Payloads

James Beck, Ian Holbrough; Belstead Research
Jim Merrifield, Sam Bainbridge; Fluid Gravity Engineering
Peter Doel; UCL

ESA Clean Space Industrial Days
24th-26th October 2017
PR00026/D10

Optical Payload Demise

- "Identify design solutions to improve the demisability of optical payloads carried by satellites flying in LEO, without impacting the payload performance"
  - Create a novel way of modelling destructive re-entry, ensuring the uncertainties are captured
  - Identify critical payload components
  - Derive D4D techniques
  - Assess the D4D techniques on reference optical payloads
  - Create a set of guidelines and requirements for payload manufacturers and designers

Optical Payload Breakdown

Fore Optics (telescope)

Reflective or refractive optics Generally Largest optics (for light gathering) Light-weighted

Cassegrain, Three Mirror Anastigmat (Korsch)

Processing Optics

Imager: Relay optics, dichroic filters, broad and narrow band filters, beam-splitters. polarisers., ½ and ¼ wave plates

Spectrometer: Grating, prisms, interferometers slit

Radiometer: Calibration sources -black body cavities, solar diffusers

Lidar: Laser head components, choppers

Mechanism: Filter wheels, steering/scanning mirrors

Focal Plane Assembly FPA

Detector: CCD, CMOS , and Photo-Voltaic silicon diodes and for NIR and IR applications Mercury Cadmium Telluride (HgCdTe), Indium Gallium Arsenide (InGaAs)

Filters, windows

Mechanisms: Readout electronics, Vacuum vessel, coolers/pumps radiators

Optical Breadboard

Support structure for optical components - A high specific stiffness and thermal stability

Selected Payloads

- Four Payloads Considered; All Analysed Fully
  - Sentinel-2 Multi-Spectral Instrument (MSI)
    - Silicon Carbide optical bench and mirrors
  - Pleiades High Resolution (HR) Instrument
    - CFRP optical bench, zerodur mirrors
  - Sentinel-3 Sea and Land Surface Temperature Radiometer (SLSTR)
    - CFRP structure, zerodur/beryllium mirrors, cryogenic cooler
  - Metop-SG 3MI imager
    - Refractive instrument, titanium telescopes with lenses

Use of SAM Re-entry Tool

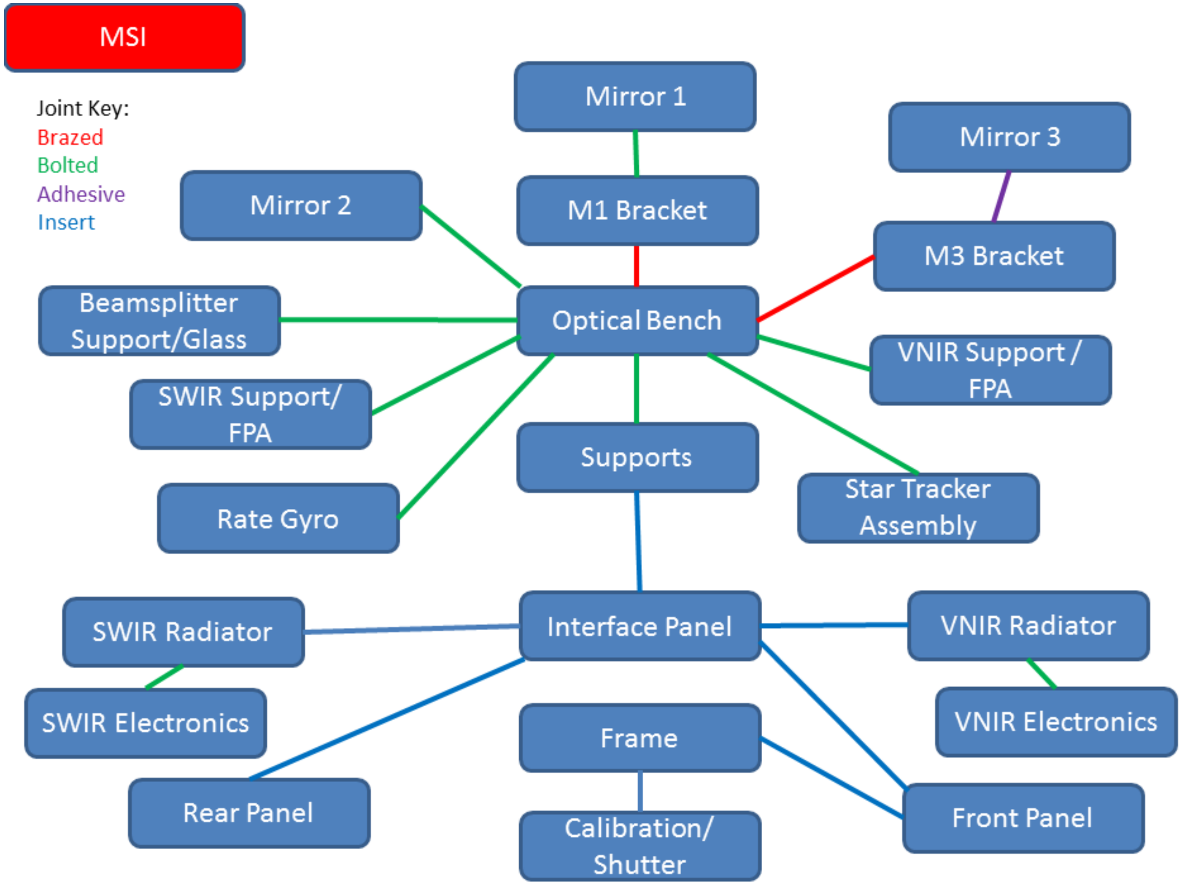
- Activity Requires Increasing Complexity
  - Building Blocks (simple models)
  - Payload Level (joined components)
  - Spacecraft Level
- SAM has Capability to Model all Levels
  - Consistent modelling throughout
  - Often difficult to understand differences between models
    - Don’t have this problem
  - Identify Reasons for Predicted Behaviour
    - In D4D activity, identified different reasons for criticality
    - Granularity (batteries), Heating model (MTQ)

SAM Spacecraft

- Spacecraft is a Set of Components
  - Connected by Joints
  - Predictive Fragmentation
    - Force and Temperature Based
  - At Component Level switch to Object Approach
    - Substantially better heating models
    - Geometric approximation smaller error than heating models
    - Full nesting models and multi-point heating

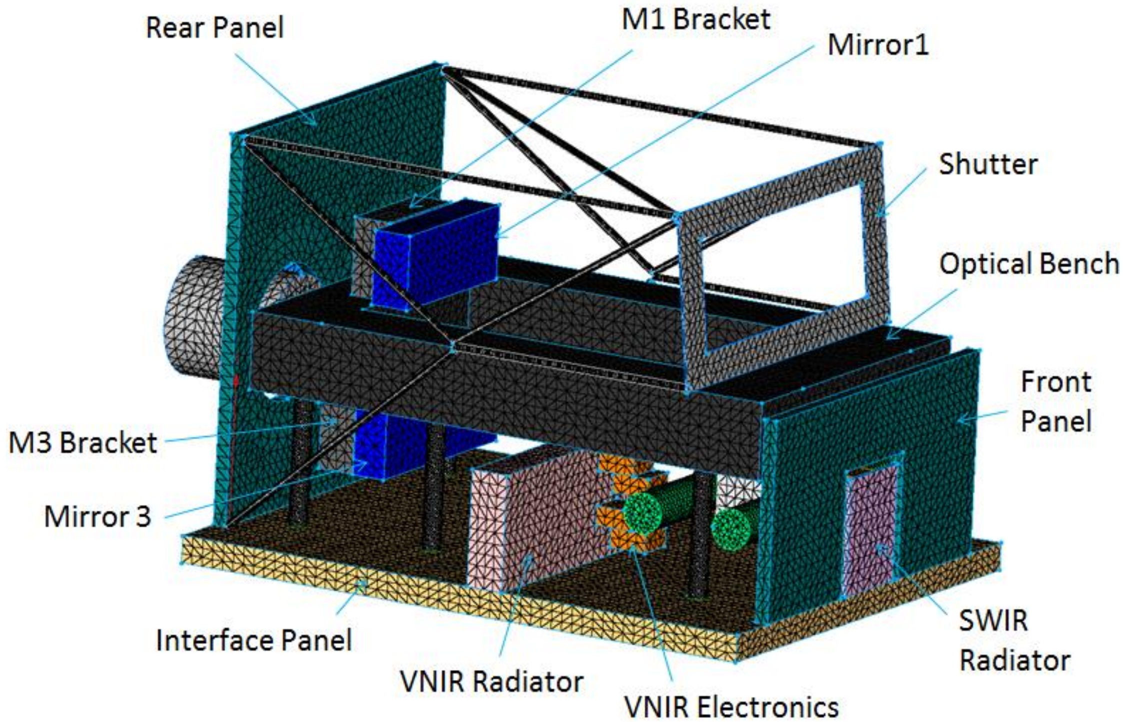
Building a SAM Spacecraft

- Set of Primitive Components (Sentinel-2 MSI payload)



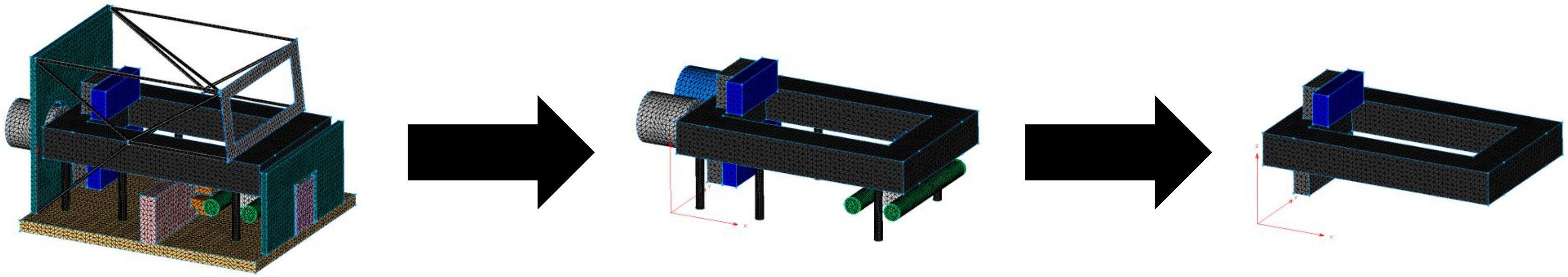
Building a SAM Spacecraft

- Full Panel Representation
  - Balance fidelity with approximate geometry
  - Avoid high fidelity geometry / low fidelity physics issues



Building a SAM Spacecraft

- Fragmentation Modelling
  - Based on Joint Failure
    - Remaining component links assessed and fragments found
    - Multiple component fragment → spacecraft oriented
    - Single component fragment → object oriented
  - Repeat geometries allow database storage
    - Monte Carlo capability



General Modelling

- Identification of Key Parts
  - Model all parts which could be expected to survive
    - Small parts not ignored
    - 15J limit modelled, not assumed
  - Equivalent material method avoided
    - Partial non-demise can be missed using average demise
    - Small fused silica element in aluminium will survive
  - Where elements are monolithic use single material
    - Tend to conservatism for objects which may fragment

Joint Modelling

- Four Key Joint Types
- Adhesive
  - Any adhesive link connection which will fail first
- Insert
  - Potted inserts into sandwich structures
- Bolts
  - Bolted connection with no identified weaker point
- High Temperature Braze (SiC)

Uncertainty Modelling

- Fragmentation process is chaotic
- Modelling is highly uncertain
  - Capture key uncertainties
    - First D4D activity to use statistics with sensible sample size – 1000 samples for each assessment

Parameter	**Distribution**	**Range**
Aerothermodynamic Heating	Uniform	±20%
Fragmentation Altitude	Uniform	78km ± 10%
Speed	Uniform	7700m/s to 7850m/s
Flight Path Angle	Uniform	-0.05^0 to -0.5^0
Material Emissivity	Uniform	ε-0.2(1-ε) to ε+0.5(1-ε)
Initial Attitude	Uniform	Attack -180^0 to 180^0 Sideslip -90^0 to 90^0
Joint Fragmentation Criteria	Uniform	Fail temperature ± 100K Fail force ± 200N

Materials List

- 'Exotic Materials'
  - C-SiC
  - Mirror materials
    - Zerodur
    - ULE
  - Lens materials
    - Fused Silica
    - Borosilicate Glass
    - Calcium Fluoride
    - Germanium
    - Zinc Sulphide
    - Zinc Selenide

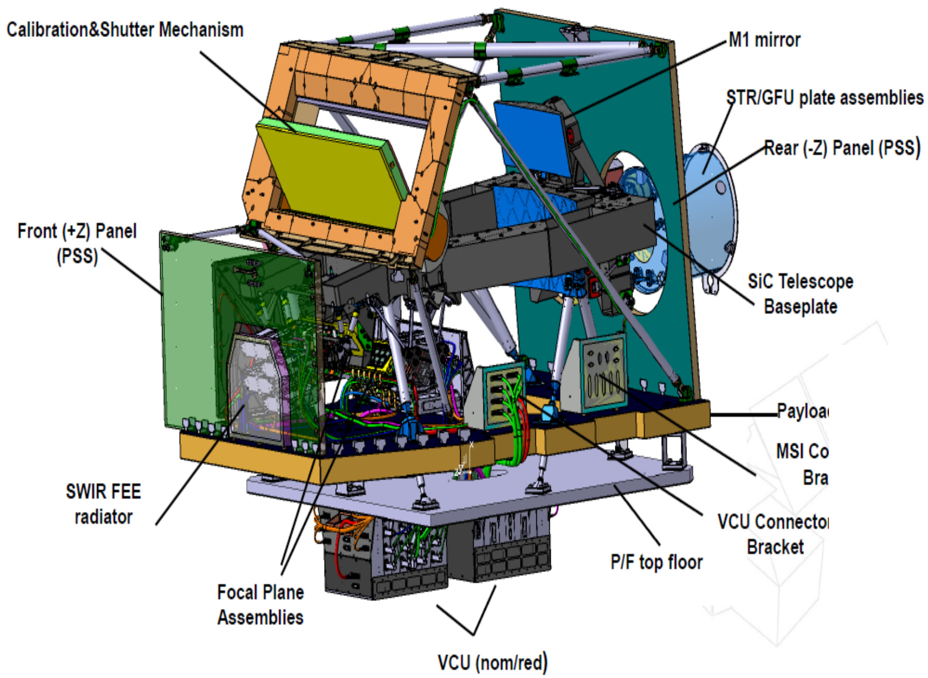
Use SiC Model

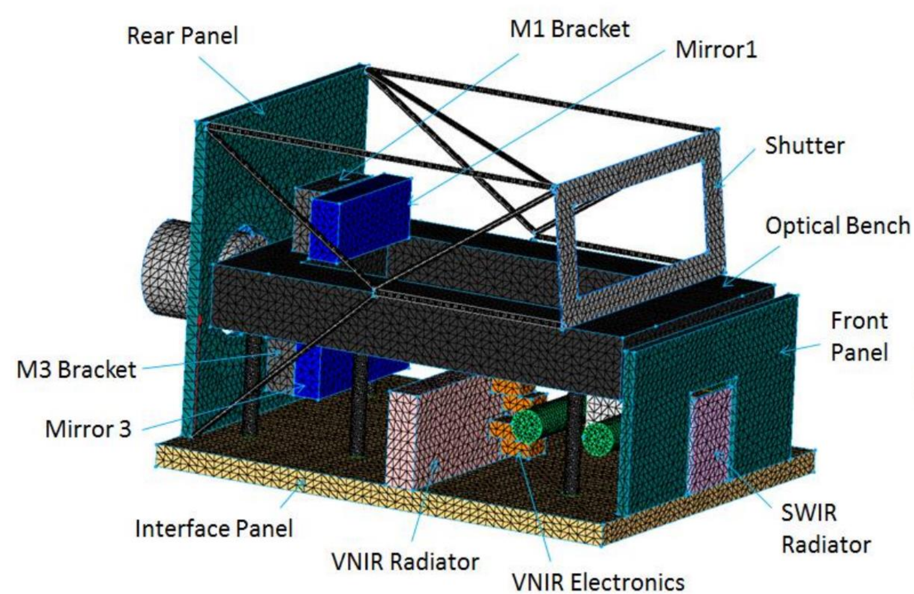
Glasses — New Model

Melters — Existing Model

Thermally Decompose — Adapt Model

Sentinel-2 MSI

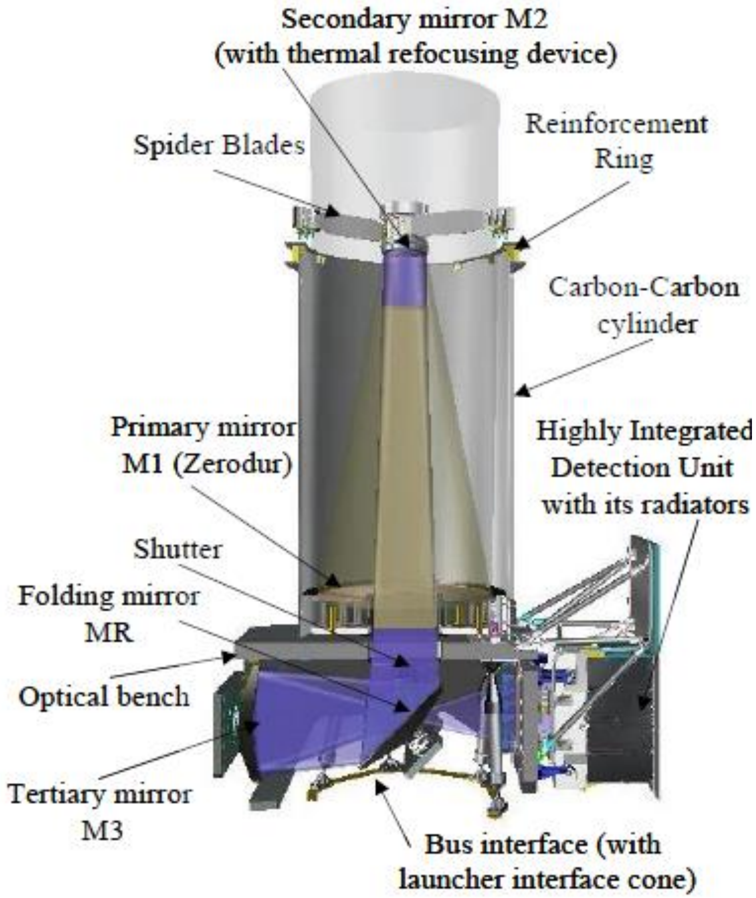


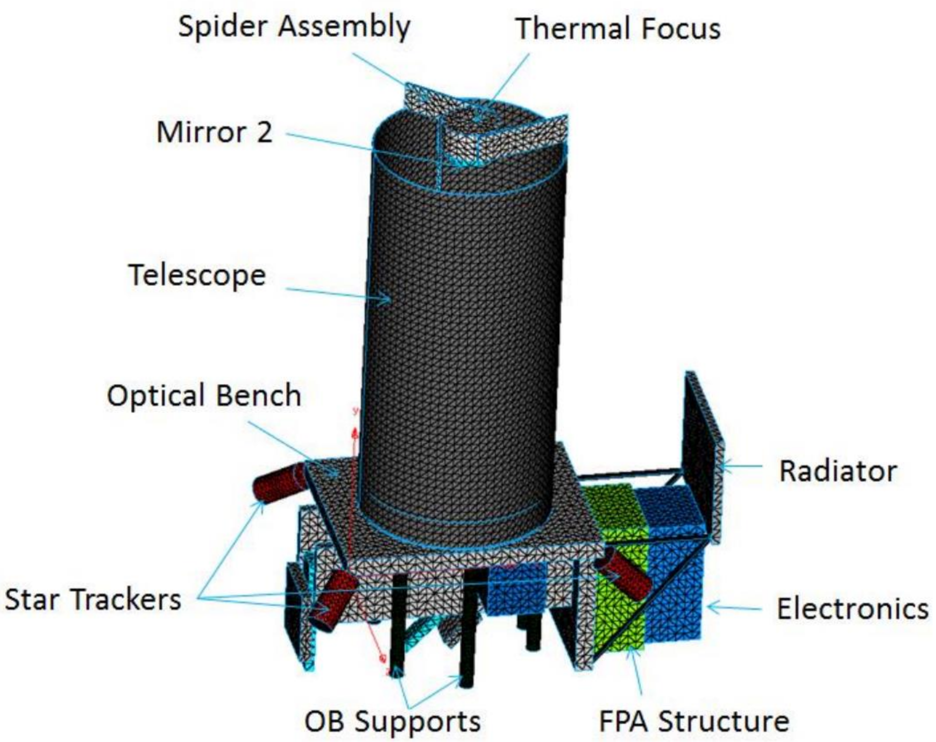


Key Aspects

- Number of Undemisable SiC Objects
  - Prevention of separation
  - Material change
- Beamsplitter Glass
  - Two panels survive
  - Size, material change
- Interface Panel
  - Modularity
  - Issues of CFRP sandwich modelling

Pleiades HR

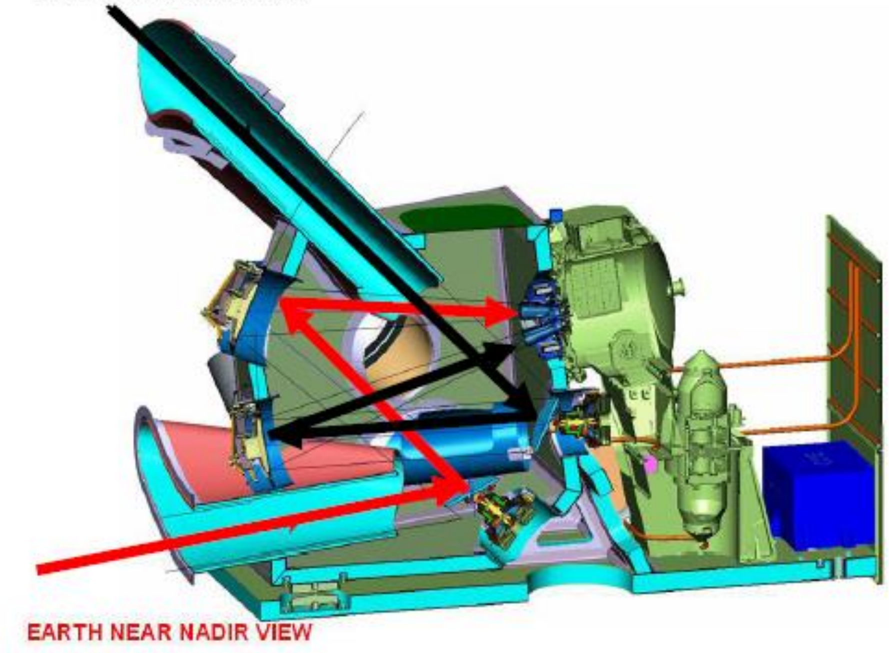

Secondary mirror M2
(with thermal refocusing device)
Spider Blades
Reinforcement
Ring
Carbon-Carbon
cylinder
Primary mirror
M1 (Zerodur)
Highly Integrated
Detection Unit
with its radiators
Shutter
Folding mirror
MR
Optical bench
Tertiary mirror
M3
Bus interface (with
launcher interface cone)

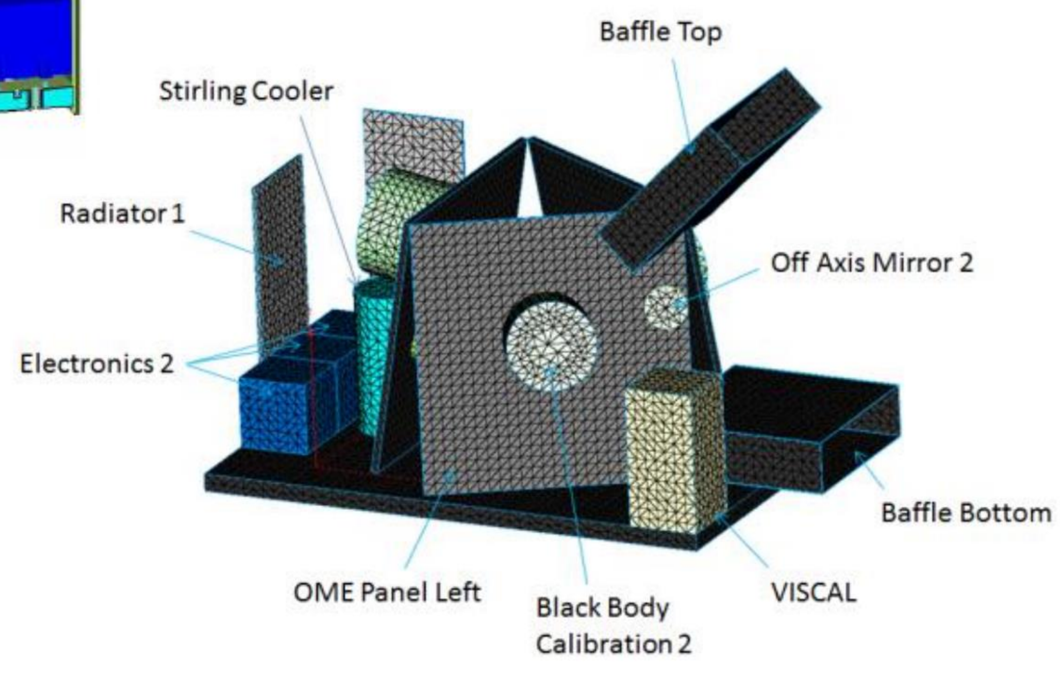

Spider Assembly
Thermal Focus
Mirror 2
Telescope
Optical Bench
Radiator
Star Trackers
Electronics
OB Supports
FPA Structure

Key Aspects

- Payload separates with modular design
  - Thin structures; different from MSI
- Critical parts are well separated
  - Focus is on individual components
  - Telescope, mirrors, FPA
  - FPA containment

Sentinel-3 SLSTR



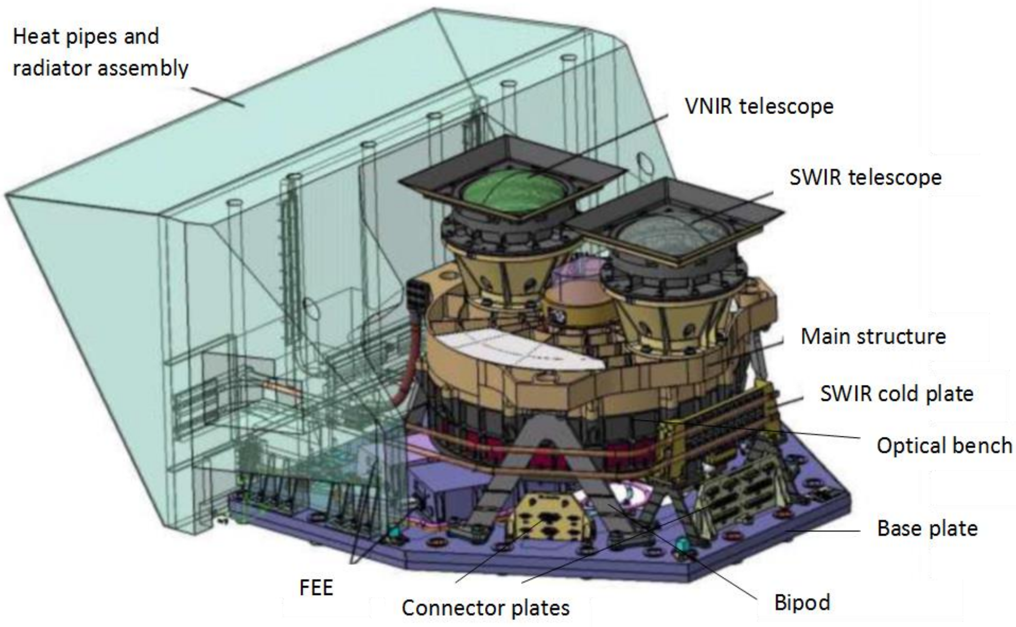


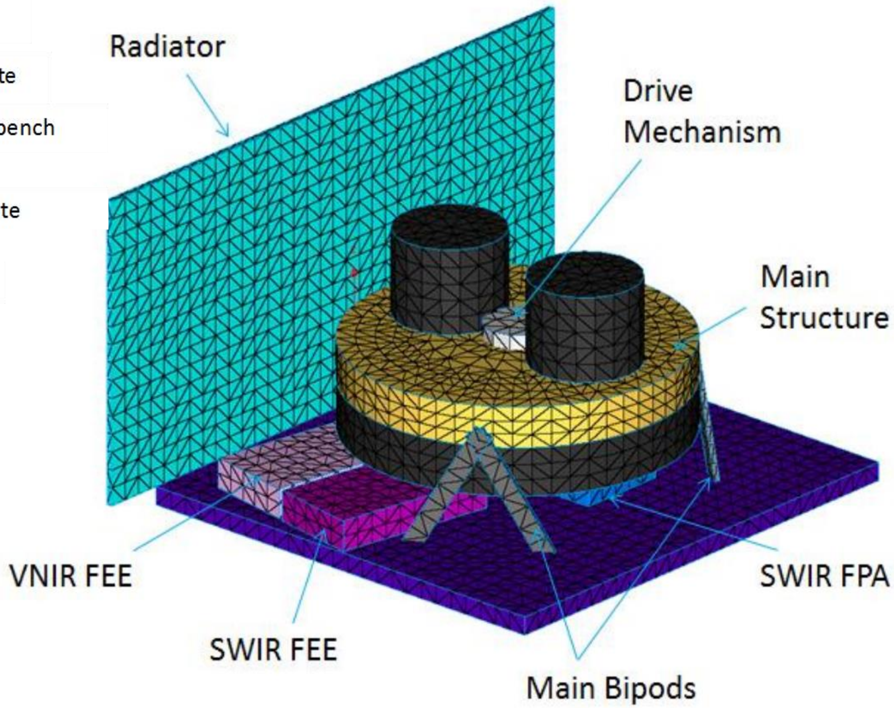
Belstead

Key Aspects

- Some undemisable parts
  - Beryllium, titanium (scan mirrors), Zerodur
  - Focal plane assembly has many parts
    - Containment?
- Most parts are demisable
  - Aluminium, CFRP
  - Target optical bench and baffles for easy gain
  - Early separation
  - Component mass/size

Metop-SG 3MI


Heat pipes and
radiator assembly
VNIR telescope
SWIR telescope
Main structure
SWIR cold plate
Optical bench
Base plate
FEE
Connector plates
Bipod


Radiator
Drive
Mechanism
Main
Structure
VNIR FEE
SWIR FEE
Main Bipods
SWIR FPA

Key Aspects

- Generally more Benign Payload
- Telescopes/Lenses
  - Significant number of surviving lenses released on telescope demise
  - Titanium can melt if a container
- Remaining Contributions are Small
  - Bipods are major contributor

Summary

- Three very similar payloads
  - Mass, Size, Capability (MSI, HR, SLSTR)
- Four different demise signatures
  - MSI is SiC based
    - Land as unit for minimum risk
  - HR has separated critical components
    - Target individual components
  - SLSTR has theoretically demisable components
    - Early separation is key aspect
  - 3MI has potential release of undemisable parts
    - Containment

Guidelines

- Use Simple Q&A Format
  - Try to identify payload demise characteristic
  - Try to identify D4D techniques to improve demise
  - Work from least impact on payload design to greater impact changes
    - Can we use undemisable joints?
    - Do we want to improve breakup (adhesive joints)?
    - Can we use containment?
    - Can we reduce sizes of critical items?
    - Can we change material?

Guidelines

- Techniques to Consider at Design Stage
  - Basic techniques, and recommendations for use

Technique	Applicable	Recommendations
Undemisable Joints	Undemisable structure	Appropriate for silicon carbide structures
Adhesive Joining Technologies	Components constructed from potentially demisable materials	
Containment	Group of undemisable components are housed together within another component	Do not use titanium for the undemisable housing. It can demise when a shell on a larger object. Carbon-carbon is preferred
Smaller Components	All components of potentially demisable materials	In general, smaller components are more demisable
Reduce Size Below 15J Threshold	Components under ~100g	Likely to be possible for many lenses
Material Change	Components of undemisable material	Only applicable where performance, mass and cost are minimally affected

Recommendations

- Establish a Risk Budget for the Payload
  - Of the order of six small surviving objects
- Identify Critical Components
- Identify Payload Demisability Characteristic
  - Identify potential techniques using Q&A
- Consult with Demise Experts
  - Consolidate understanding and likely effectiveness of possible techniques