LISA

LISA PHASE A
PAYLOAD THERMAL ANALYSIS

Sam Heys
Rutherford Appleton Laboratory, UK

Mission Overview and Thermal Requirements

Payload Thermal Design

Geometric Mathematical Model

Thermal Mathematical Model

Payload Thermal Analysis Results

Thermal Analysis Issues

Laser Interferometer Space Antenna (LISA)
Mission Overview

- Gravitational wave detector based on a Space interferometer.
- Measures changes in separation between free falling test masses to 10pm accuracy.
- Six test masses on three spacecraft in an equilateral triangle formation, with 5 million km arm lengths.

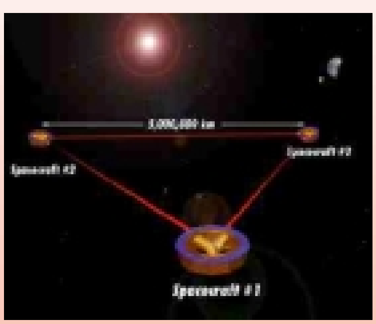
- Thermal disturbances to payload result in:
  - Thermo-elastic distortion of Spacecraft resulting in changing mass distribution around test mass, hence changing acceleration field.
  - Telescope optical path length changes due to thermo-elastic distortion of the support mast separating the Primary and Secondary Mirrors.

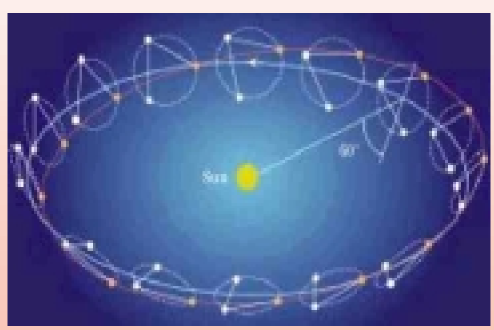
- Major thermal disturbances are due to:
  - Variation in solar constant due to Sun's normal modes of oscillation.
  - Electrical power dissipation fluctuations.

- Thermal Requirements:
  - Optical Bench temperature stability better than $1\mu K/Hz^{1/2}$.
  - Telescope optical path length changes resulting from thermo-elastic effects < $40pm/Hz^{1/2}$
  - Avoid use of MLI

Laser Interferometer Space Antenna (LISA)
Mission Overview

- 1AU Heliocentric orbit
- 20° behind the Earth
- Triangular plane at 60 ° inclination to ecliptic plane





SPACECRAFT ESARAD GMM

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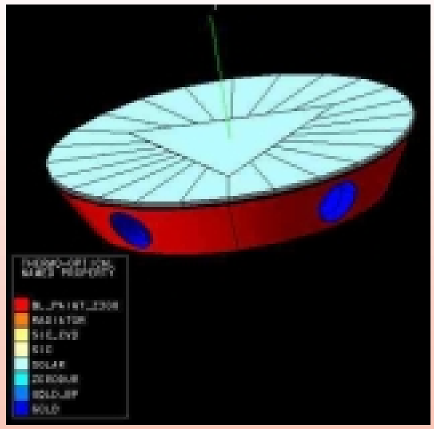

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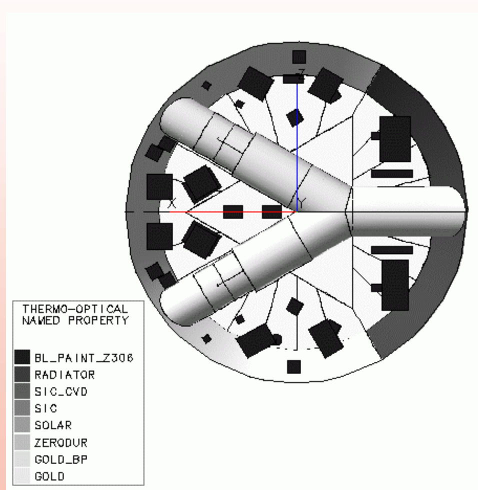
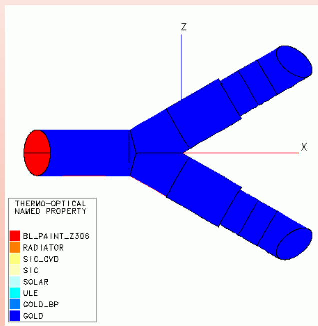
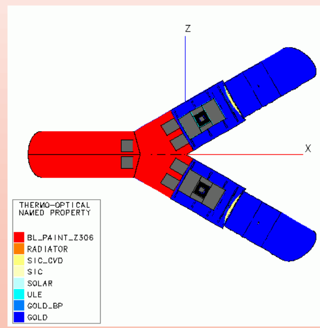


Payload Thermal Design - Y-Shaped Tubes

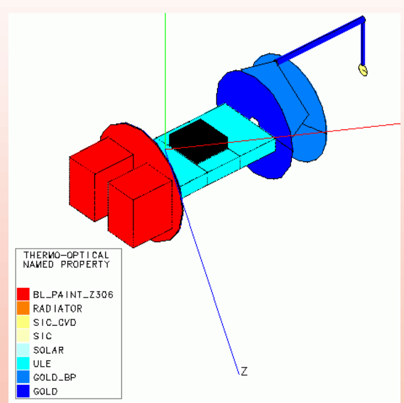
- Payload Y-Shaped Tube goldised on both internal and external surfaces, to radiatively isolate from Spacecraft Y-Shaped Tube.
- Payload Tubes mounted Spacecraft Tube, using insulating GFRP reinforced bands.
- Payload Tubes goldised on external surface, and on internal surfaces around Optical Bench and Telescope.
- Payload Tubes black on internal surfaces between Payload Electronics Plate and end of Tube, to assist heat rejection from Payload and USO Electronics Boxes and hence reduce their temperature.





Payload Thermal Design - Optical Bench

- Supported off Payload Tube using a low conductance structure of Pyroceram struts, titanium bolts and Delrin washers.
- Radiatively isolated from Telescope and Electronics by goldised radiation shields at either end.
- Fabricated from ULE for low thermal expansion.



Payload Thermal Design - Telescope

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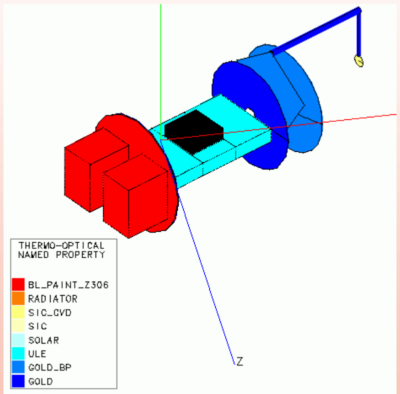
- High conductivity of SiC results in virtually isothermal Telescope.
- Telescope Baseplate mounted off Payload Tube on low conductance, isostatic mounts.
- Primary and Secondary Mirror rear surfaces, Baseplate and Support Mast all goldised, to improve radiative isolation from Payload Tube and to reduce radiative heat leaks to space.



Payload Thermal Design - Electronics Boxes

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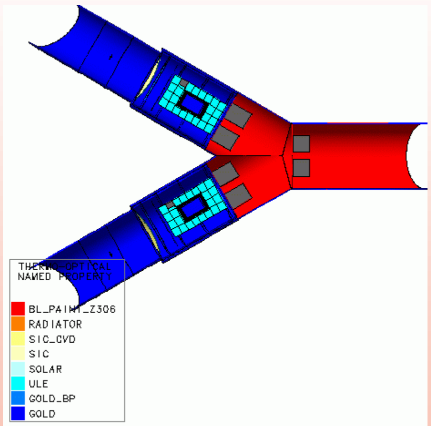
- Analogue and Digital Electronics Boxes hard mounted to Payload Electronics Plates.
- Payload Electronics Plates conductively isolated from Payload Tube using Pyroceram strut supports.
- Boxes painted black - radiate heat to black USO Support Plate.
- Rear surface of Payload Electronics Plates goldised to radiatively isolate from Optical Bench Radiation Shield.
- USO Boxes and Support Plate painted black - radiate heat directly to Deep Space.



ESARAD Payload GMM

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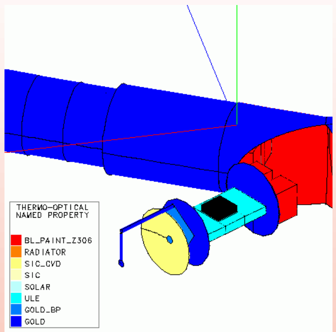

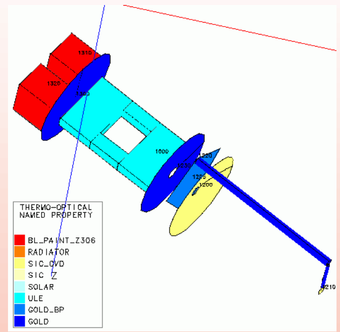

ESARAD Payload GMM

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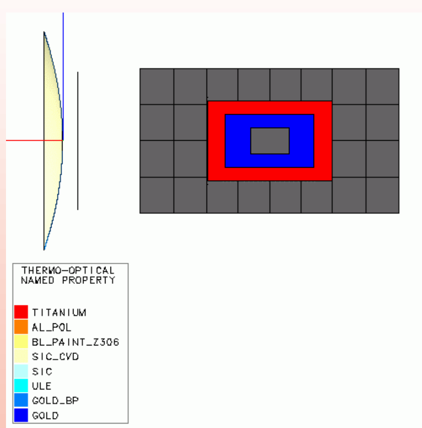

ESATAN TMM

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- Thermal Mathematical Model created in ESATAN v8.4.2
- Radiative exchange factors calculated in ESARAD.
- Environmental loads calculated by hand.
- Fluctuations in solar intensity calculated from the relationship:

$$\delta L = 1.3\text{x}10^{-4}\ f^{-1/3}\ L_0\ (\text{W/m}^2)/\text{Hz}^{1/2}$$

- Fluctuations in power dissipation within the SVM and Payload Electronics are nominal fractions of overall power. These are used to calculate transfer functions between power dissipation fluctuation and resulting temperature fluctuation.

Steady-State Analysis

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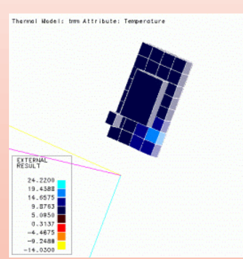
Steady-State Case Definition

Parameter	HOT Case	COLD Case
Solar Constant (W/m2)	1440 W/m^2	1302 W/m^2
Surface Properties	EOL	BOL
Total SVM Power Dissipation (W)	154.2 W	154.2 W
Total Payload Power Dissipation (W)	24.2W	24.2 W

Steady-State Results

Location	Node Number	HOT Case	COLD Case
		T (°C)	T (°C)
Optical Bench	1000	11.2	9.1
Proof Mass	1100	10.6	8.4
Sensor	1110	10.6	8.4
Primary Mirror	1200	-12.0	-14.0
Telescope Baseplate	1205	-11.1	-13.2
Secondary Mirror	1210	-11.6	-13.6
Secondary Mirror Support Mast	1220	-11.5	-13.6
Analogue Electronics Box	1310	27.8	25.6
Digital Electronics Box	1320	28.1	26.0
USO Electronics Box A	3120	-3.7	-5.6
USO Electronics Box B	3130	-5.5	-7.4



Solar Intensity Fluctuation Cases

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Solar Intensity Fluctuation Cases:

Power Spectral Density of Solar Intensity Fluctuations:

$$\delta L = 1.3\text{x}10^{-4}\, f^{-1/3}\, L_0 \;\; (W/m^2)\; /\; Hz^{1/2}$$

Parameter	Solar Fluctuation $((W/m^2)/Hz^{1/2})$			Transfer Function $(K/(W/m^2))$			Response $(K/\sqrt{Hz})$		
	10^{-1} Hz	10^{-3} Hz	10^{-4} Hz	10^{-1} Hz	10^{-3} Hz	10^{-4} Hz	10^{-1} Hz	10^{-3} Hz	10^{-4} Hz
Optical Bench	0.364	1.69	3.64	<3.3E-12	2.4E-11	3.1E-07	<1.0E-12	3.8E-11	1.1E-06
Primary Mirror				<3.3E-12	2.2E-11	2.8E-07	<1.0E-12	3.5E-11	9.9E-07
A & D Electronics Boxes				<3.3E-12	2.2E-11	6.3E-06	<1.0E-12	3.5E-11	2.2E-05

Electrical Power Fluctuation Cases

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- **Electrical Power Fluctuation Cases:**

	Case 1	Case 3	Case 5
Components	All SVM EUs	All Payload EUs	Optical Bench
Power (W)	154.2	21.3	1.447
Fluctuation	1.0%	1.0%	5.57µW/√Hz
Frequency (Hz)	10^{-4}	10^{-4}	10^{-3}

Component	Case 1		Case 3		Case 5	
	Temperature Fluctuation (K)	Transfer Function (K/W)	Temperature Fluctuation (K)	Transfer Function (K/W)	Temperature Fluctuation (K)	Transfer Function (K/W)
Optical Bench	6.5E-05	4.2E-05	3.3E-04	1.5E-03	6.370	3.5E-05
Primary Mirror	3.0E-05	1.9E-05	4.0E-06	1.9E-05	-	-
A & D Electronics Boxes	1.0E-03	6.5E-05	5.2E-02	2.4E-01	-	-

Telescope Optical Path Length Changes

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Optical path length fluctuations due to thermo-elastic distortions:

- **SiC Telescope**
- **CTE = 2.0E-6/K**
- **Support Mast length = 0.52m**

Solar Constant Fluctuations		
	Case 3: 10^{-4} Hz, 0.3 %	
	Temperature Response $[K]/[Hz]^{1/2}$	Thermal Expansion/ Contraction $[pm]/[Hz]^{1/2}$
Mast	1.3E-06	1.4

Power Fluctuations				
Component	Case 1: 10^{-4} Hz, 1% (all SVM EUs)		Case 3: 10^{-4} Hz, 1% (all P/L EUs)	
	Transfer Function [K]/[W]	Thermal Expansion/ Contraction [pm]/ [W]	Transfer Function [K]/[W]	Thermal Expansion/ Contraction [pm]/[W]
Mast	3.2E-05	33.3	1.6E-05	16.6

Thermal Analysis Conclusions

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- Steady-State Temperatures:
  - **Payload steady-state temperatures within specified range.**
- Temperature Stability:
  - **Temperature response due to solar constant fluctuations well within specification of 1µK/√Hz at 1mHz.**
  - **Temperature response due to power dissipation fluctuations calculated in terms of transfer functions for Spacecraft Electronics, Payload Electronics and Optical Bench components.**
  - **These transfer functions will be used to specify acceptable noise levels for electronics components.**
- Telescope optical path length:
  - **Max length change due to temperature fluctuations is 33pm/√Hz - meets specification of <40pm/√Hz.**

- The requirement to detect very small temperature changes requires ESATAN convergence criteria to be set to sufficiently small values (10D-12). Fluctuations below 10-11 degrees considered insignificant.
- Numerical errors investigated to verify repeatability of results using different time steps and convergence criteria.
- During transient cases results showed an initial instability significantly larger than the fluctuations due to the input disturbance. Therefore it was necessary to run the model for long time periods until overall stability achieved and underlying fluctuations could be detected.