A THERMAL AND MECHANICAL ANALYSIS OF TRIO CINEMA CUBESAT MISSION

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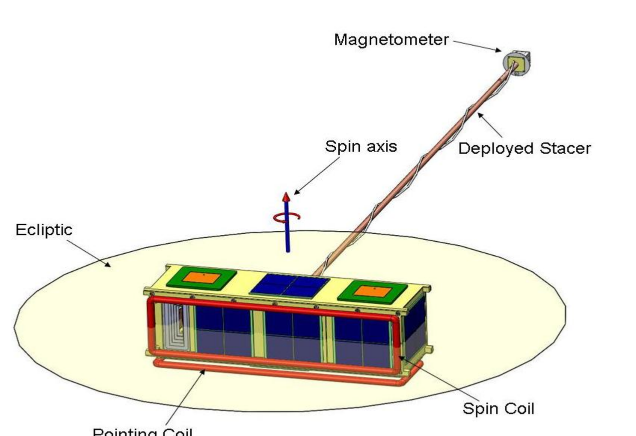
ABSTRACT

TRIO (TRiplet Ionospheric Observatory) CINEMA (CubeSat for Ion, Neutral, Electron, MAgnetic fields) is a space science mission with three identical CubeSats. Three institutes are collaborating to develop CINEMA CubeSats : i) two CubeSats by Kyung Hee University (KHU) under its World Class University (WCU) program, ii) one CubeSat by UC Berkeley under the NSF support, and iii) three magnetometers by Imperial College, respectively. In this paper, we present results of thermal and mechanical analysis for TRIO CINEMA mission. In order to get the result of thermal and mechanical analysis, we are using the NX6.0 program and NASTRAN program. Through this analysis, we have increased the average temperature of top & bottom solar panels by 30℃ and derived natural frequency of the spacecraft is near 339.1 Hz.

INTRODUCTION

CINEMA is a 3-unit CubeSat, with an approximate size of 10 cm x 10 cm x 30 cm and mass less than 2.9 kgs. An attitude control system (ACS) uses torque coils, a sun sensor and the magnetometers and spins CINEMA spacecraft at 4 rpm with the spin axis perpendicular to the ecliptic plane. Each satellite is equipped with a SupraThermal Electron, Ion, Neutral (STEIN) instrument covering the energy range ~2-200 keV, and a 3-axis magnetometer of magnetoresistive sensors.



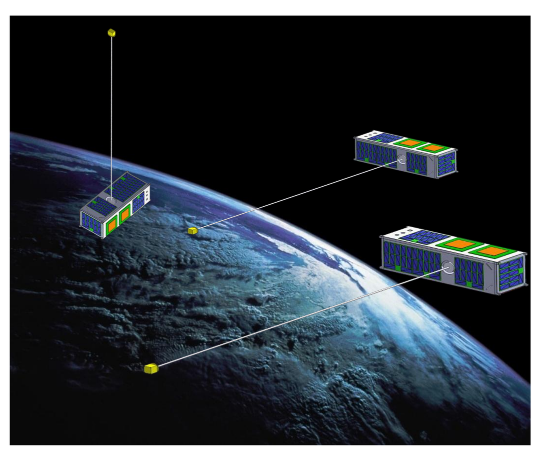


Figure 14 Mass Budget	
Subsystem	Mass, g
Chassis	463
Solar Arrays	375
MAG Boom system	160
Sun Sensors	10
Antennas	140
Avionics	500
Transmitter	57
Torque Coils	85
STEIN Detector Head	261
STEIN Electronics	90
STEIN HVPS	150
MAG electronics	45
Instrument Digital	90
Instrument LVPS	150
Harnessing	100
Thermal	50
TOTAL	2726

Modes:		SAFE MODE		ACS Mode		Normal Mode	
	Base, mW	Duty	Power, mW	Duty	Power, mW	Duty	Power, mW
SAFE							
Bus	120	100.0%	120	100.0%	120	100.0%	120
COM Rx	1,167	100.0%	1167	3.4%	40	3.4%	40
COM Tx	1,889	0.0%	0	0.6%	12	0.6%	12
Science Tx	9,750	0.0%	0	0.0%	0	2.8%	273
Instrument, LR	796	0.0%	0	100.0%	796	0.0%	0
Instrument, HR	1,653	0.0%	0	0.0%	0	100.0%	1,653
ACS	8,000	0.0%	0	10.0%	800	0.0%	0
		Total:	1,287		1,768		2,097
		Margin	49%		30%		44%
		Available	2,513		2,513		3,776

MECHANICAL ANALYSIS

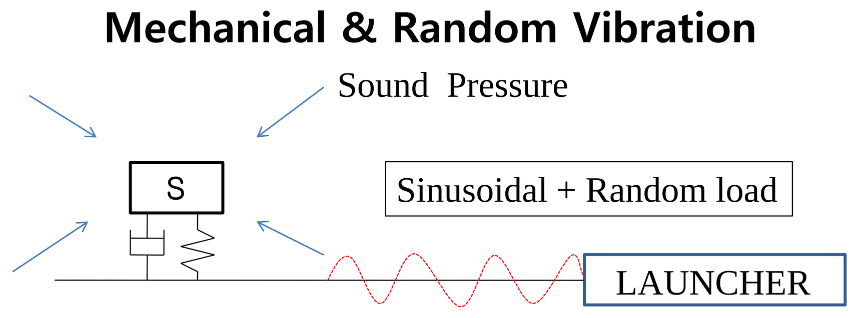
Process for Mechanical Analysis

So, It has to control the material density to get a natural frequency. The theory of random vibration can be expressed by

$$\ddot{x}_s = \sqrt{\frac{\pi}{2} f_n Q W_{\ddot{u}}(f_n)}$$

Here, $\ddot{x}_s$ is the RMS acceleration, Q is amplification factor, (f_n) is natural frequency, $W_{\ddot{u}}(f_n)$ is PSD of enforced acceleration

Mechanical & Random Vibration

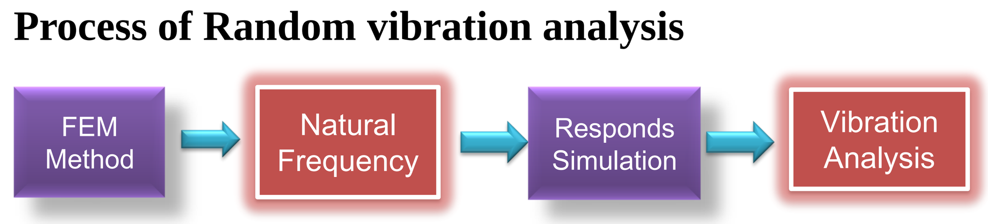


In the single degree of freedom, the natural frequency can be expressed by

$$\omega_n = \sqrt{\frac{k}{m}}$$

Here, ω_n is natural frequency, k is spring stiffness, m is mass

Process of Random vibration analysis

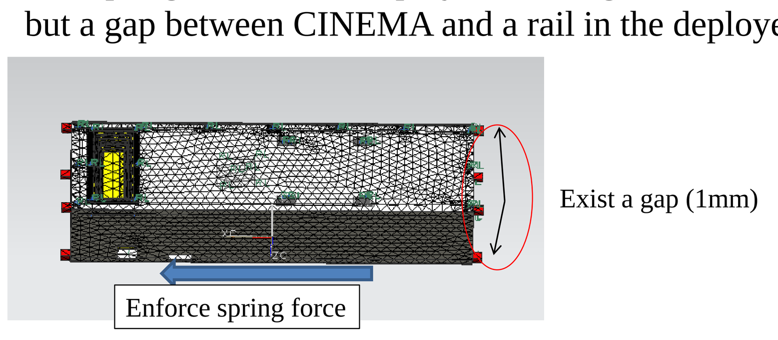


Assumption & Boundary Conditions

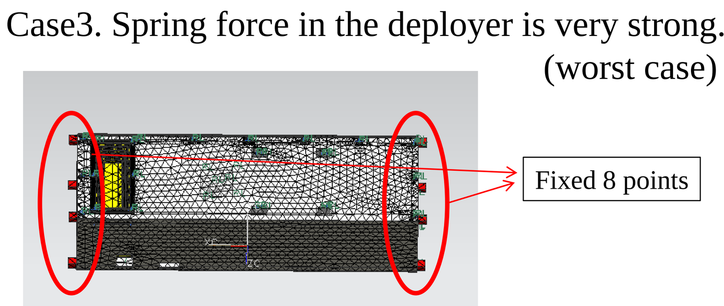
We assumed three cases boundary condition

Case1. Spring force in the deployer is too weak (No boundary condition)

Case2. Spring force in the deployer is strong, but a gap between CINEMA and a rail in the deployer

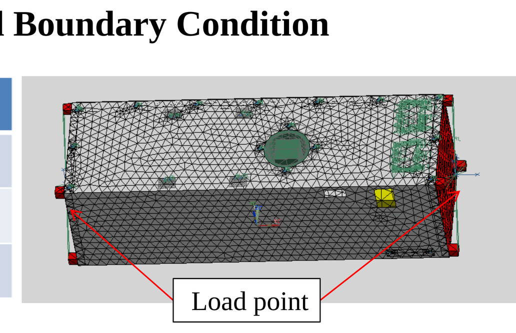


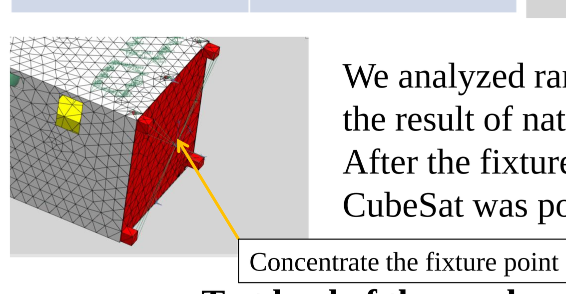
Case3. Spring force in the deployer is very strong. (worst case)



Mesh Summary and Boundary Condition

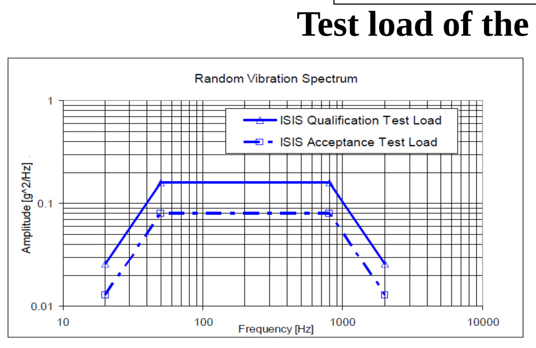
Mesh Summery	
Idealized Part	28 EA
Node	52736 EA
Element	34114 EA





We analyzed random vibration that based on the result of natural frequency in the case 3. After the fixture point was concentrated, the CubeSat was powered through the load point.

Test load of the random vibration

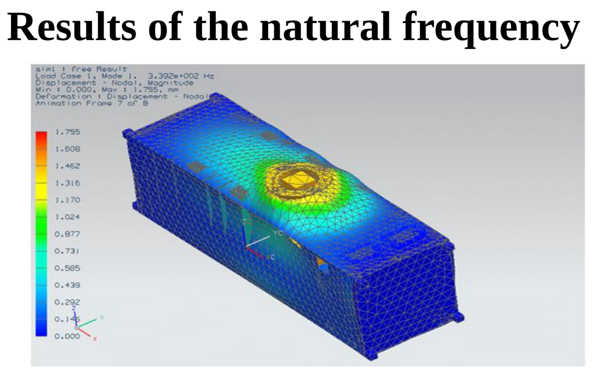


Frequency [Hz]	Amplitude [g^2/Hz]	
20 - 50	0.026 - 0.16	GRMS 14.1[g]
50 -800	0.16	Applied probability =3 σ
800 - 2000	0.16- 0.26	Duration =120 [sec]/axis

A uniform constant damping ratio of 0.02 was assumed for all simulations.

Results

Results of the natural frequency

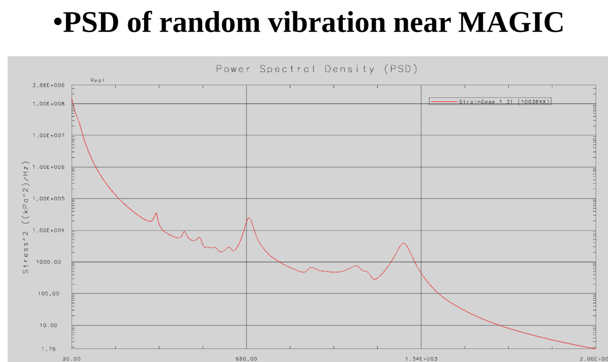


1st Mode Natural frequency		
Case 1	Case 2	Case 3
413 Hz	339.2 Hz	339.1 Hz

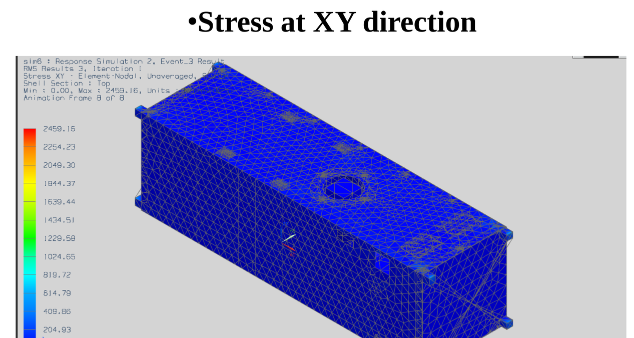
The 1st mode occurred near at the MAGIC. So, we measured the stress at the MAGIC, and calculated RMS value of displacement and stress.

Results of the random vibration analysis

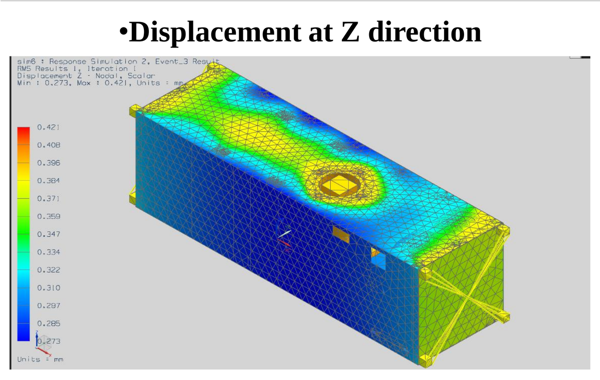
•PSD of random vibration near MAGIC



•Stress at XY direction



•Displacement at Z direction



Result of the random vibration analysis

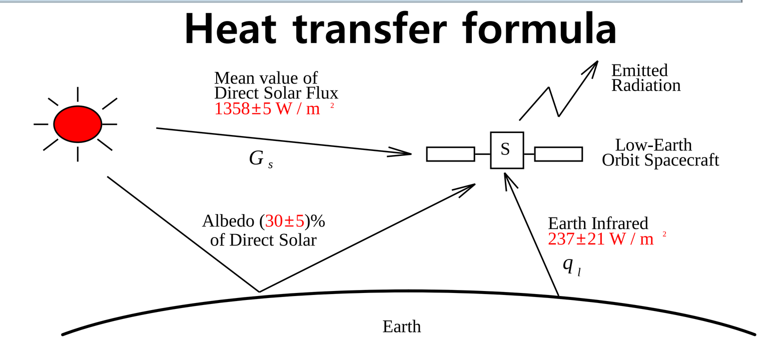
Direction	Maximum Displacement	Direction	Maximum Stress
X	0.272 [mm]	XY	2459 [MPa]
Y	0.494 [mm]	YZ	2521 [MPa]
Z	0.421 [mm]	ZX	1721 [MPa]

THERMAL ANALYSIS

Process for thermal analysis

The main thermal source when the satellite in the space is the Sun and heat transfer by below basic formula.

Heat transfer formula



<Stefan-Boltzmann's law>

$$Q = A\sigma T^4 \times \epsilon$$

<Three factors of heat transfer >

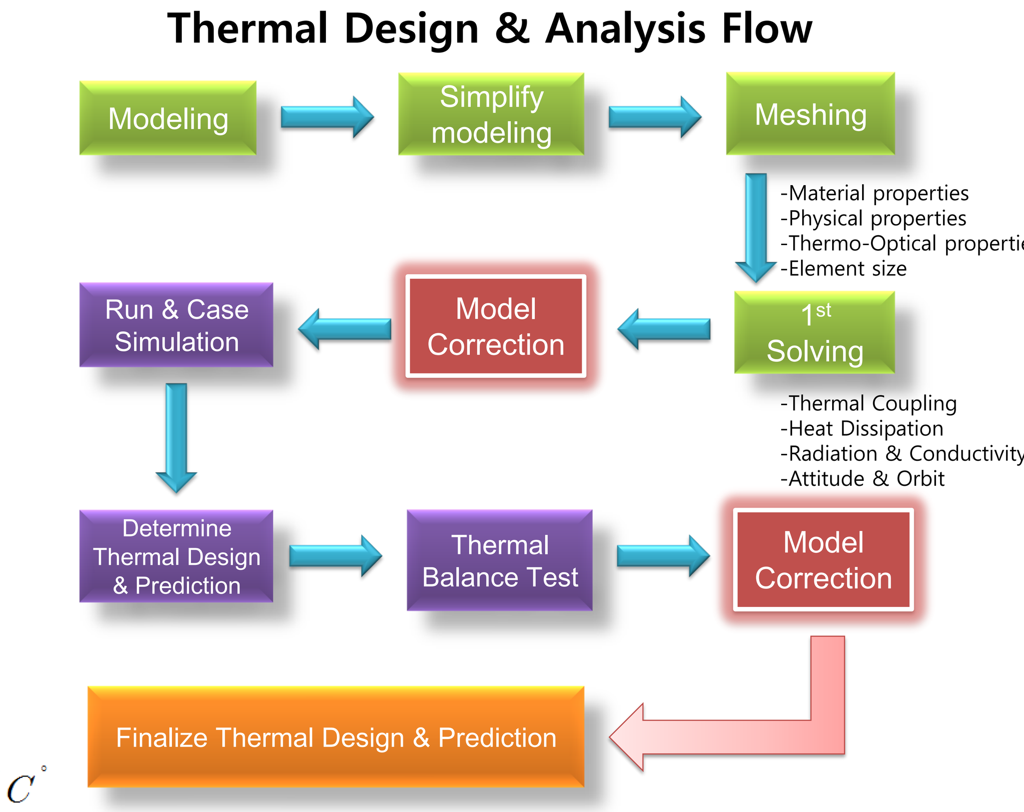
α : Solar absorptivity
ε : Infrared emissivity
A : area

$$\cdot\ \sigma A \epsilon T^4 = Q_{\text{(generated from satellite, electric power, heater, etc.)}}$$
$$+ F_{Sun} A \alpha S_{(1300\sim1400\,W/m^2)}$$
$$+ F_{albedo} A \alpha S_{(420\,W/m^2)}$$
$$+ F_{Earth} A \epsilon Q_{Earth}{}^{(237\,W/m^2)} \quad (F\text{: view factor})$$

• Total Conductance

$$K = k(conductivity) \cdot \frac{wL(AREA)}{d(Node\,distance)}\ W/C^{\circ}$$

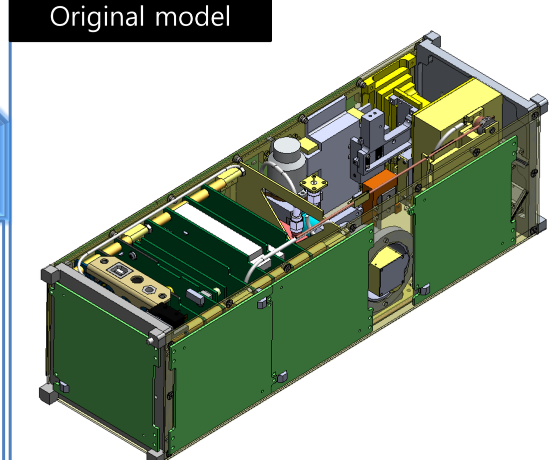
Thermal Design & Analysis Flow



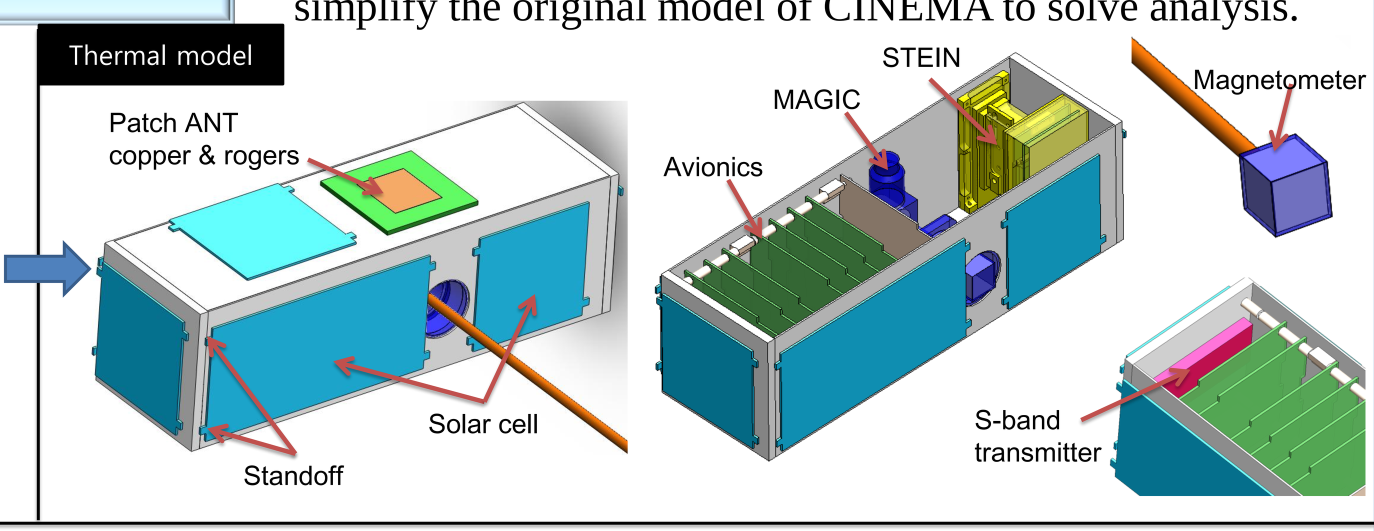
Assumptions & Conditions

Main components of CINEMA is shown below and we simplify the original model of CINEMA to solve analysis.

Original model



Thermal model



We used these properties of each component and assumed that the orbit condition is like this.

Orbit condition

Parameter	Value
Planet	Earth
Orbit type	Sun-synchronous
Altitude	600km
Eccentricity	0
Orbit Inclination	97.76 deg
Solar Declination	0 deg
Solar Flux	1377.804781 W/m²
IR Flux	237 W/m²
Albedo vs Latitude	0.306
Number of Intervals per orbit	10
Number of calculations per spin	6
Internal heat dissipation	3W

Material properties of components

Part	material	Density (kg/m³)	k (W/m-K)	Heat capacity (J/kg-K)
Chassis (Top & bottom)	Al 5052-H32	2680	138	880
Chassis (End plate)	Al 6061-T6	2700	167	896
Solar cell PCB	FR4	1900	0.23	1200
Standoff	Al6061-T6	2700	167	896
Patch ANT copper	Copper(C10200)	8940	391	385
Patch ANT rogers	RT_duroid_6002	2100	0.6	930
Avionics Frame	Al 6061-T6	2700	167	896
Avionics PCB	FR4	1900	0.23	1200
MAG	Al 6061-T6	2700	167	896
Magnetometer	Al 6061-T6	2700	167	896
Stacer boom	Elgiloy	8300	12.5	703
STEIN_Housing & Mount block	Al 6061-T6	2700	167	896
STEIN_PCB	FR4	1900	0.23	1200
STEIN_Detector	Silicon	2300	124	794
Baffles	BeCu alloy (UNS C81800)	8620	218	420

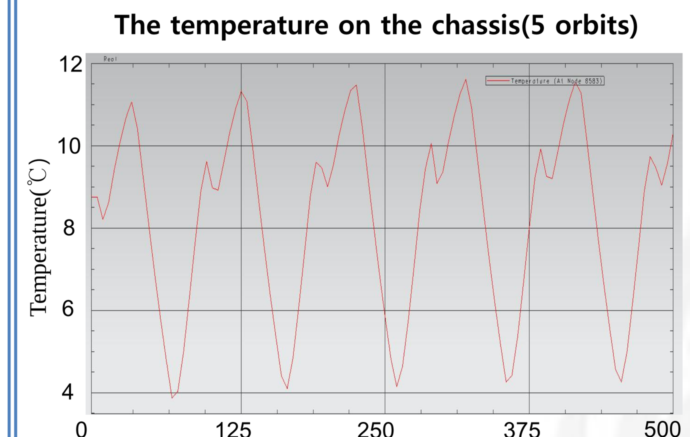
Thermo-optical properties of components

Part	optical property	α	ε	α/ε ratio
Chassis (Top & bottom)	Alodined_Aluminum and Black Paint	0.20 0.95	0.04 0.89	5 1.07
Chassis (End plate)	Alodined_Aluminum	0.20	0.04	5
Solar cell	ITO-GaAs	0.92	0.85	1.08
Solar cell PCB	FR4 and Black Paint	0.80 0.95	0.80 0.89	1 1.07
Patch ANT copper	copper	0.30	0.03	10
Patch ANT rogers	rogers	0.60	0.80	0.75
Avionics Frame	Alodined_Aluminum	0.04		-
Avionics PCB	FR4	0.6		-
MAG	Alodined_Aluminum	0.20	0.04	5
Magnetometer	Alodined_Aluminum	0.20	0.04	5
Stacer boom	Black_paint	0.95	0.89	1.07
STEIN_Housing & Mount block	Alodined_Aluminum	0.04		-
STEIN_PCB	FR4	0.6		-
STEIN_Detector	Aluminum_ vapor_deposited	0.08	0.02	4
Baffles	Ebanol_C	0.9	0.11	8.18

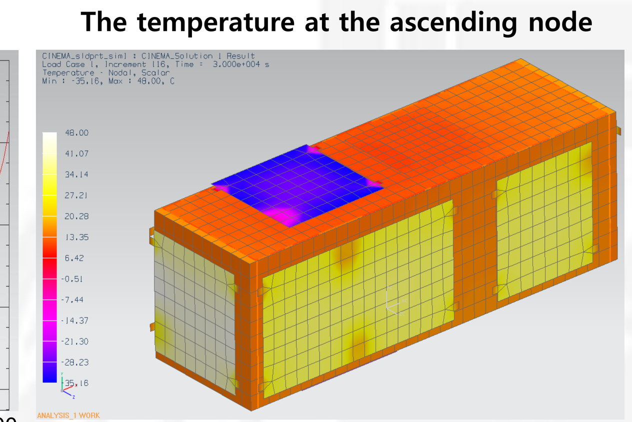
Results

These are thermal analysis results of CINEMA at the safe mode using NX6.0 program and all temperature is centigrade degree.

The temperature on the chassis(5 orbits)

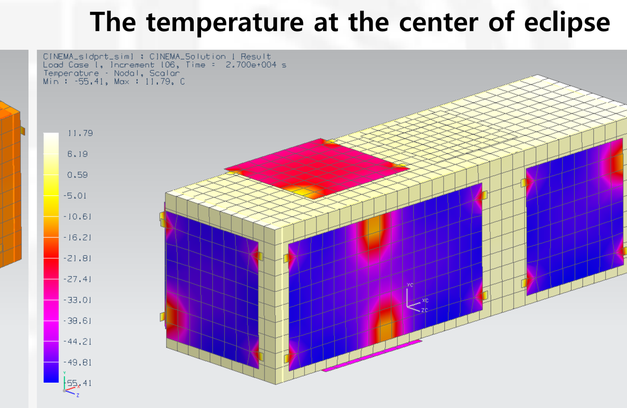


The temperature at the ascending node



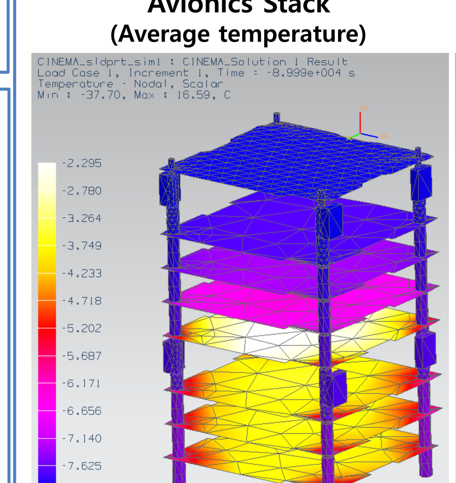
(Dayside)

The temperature at the center of eclipse

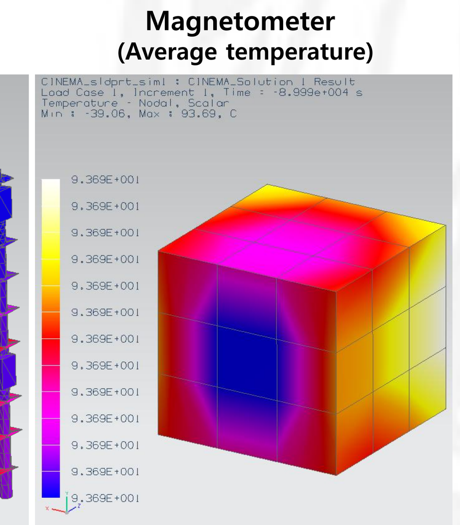


(Nightside)

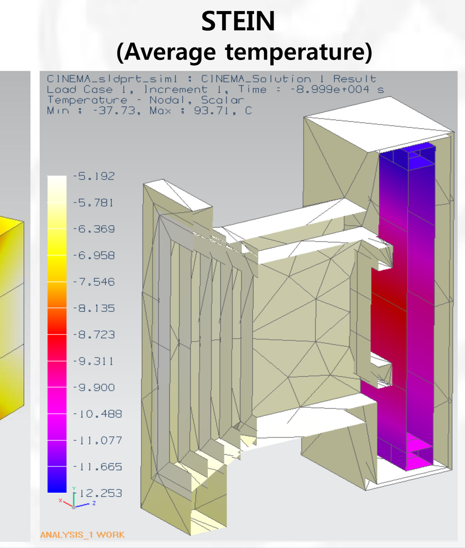
Avionics Stack (Average temperature)



Magnetometer (Average temperature)



STEIN (Average temperature)



Result of thermal analysis

Components	Analysis temperature(℃)
Chassis	avg:+10℃ , +4 to +13
Solar Panels (Top & bottom)	avg:-23℃ , -46 to 0
Solar panels(side)	avg:+5℃ , -49 to +42
Avionics PCB	avg:-7℃ , -14 to 0
Magnetometer	avg:+93℃ , +87 to +98
STEIN Detector	avg:-5℃

Conclusion

In this thermal analysis, we can increase the average temperature of top and bottom solar panels by 30℃ from using black paint to the surface of chassis and the inside of top & bottom solar panels. Furthermore, in order to decrease the temperature of magnetometer, we are considering changing the surface property to black paint. In mechanical analysis, the 1st mode is 339 Hz and the result of vibration test is competent value. Because the chassis of CINEMA is made from Al6061-T6 which has 96.5GPa of fatigue strength, 68.9 GPa of Modulus of Elasticity. From the result, we are confident that the CINEMA is stable state on the launcher.

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