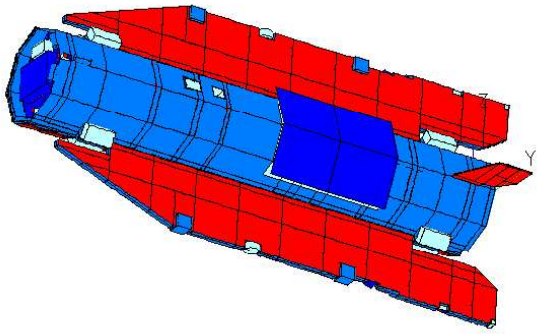
GOCE
Thermo-Elastic Distortion Analysis

22.10.2003



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GOCE - Thermo-Elastic Distortion Analysis
Content

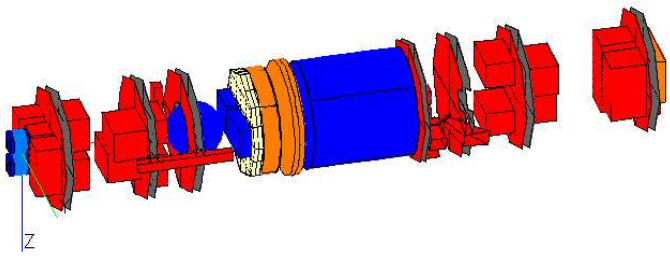
- GOCE Mission
- Analysis Approach
- Mechanical and Thermal Model and Analysis
- Results
- Summary

GOCE - Thermo-Elastic Distortion Analysis
GOCE Mission - Objectives

→ Provide global and regional models of the earth‘s gravity field with high spatial resolution and high accuracy

Measurement Techniques used:

- Satellite gravity gradiometry - SGG - technique (gravity gradient tensor by Gradiometer (EGG))
- Orbit determination by satellite-to-satellite tracking (SST) with GPS and GLONASS and
- Laser Ranging

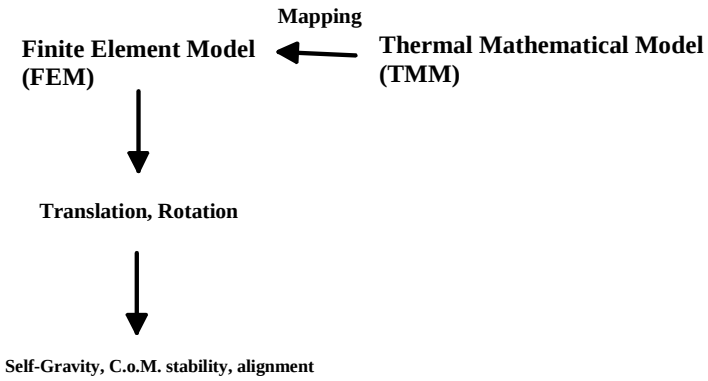


GOCE - Thermo-Elastic Distortion Analysis
GOCE Mission - Requirements

- Stringent requirements for GOCE Platform induced thermal distortions in time and frequency domain cover:
  - Self-gravity acceleration
  - C.o.M. stability
  - Instrument alignment
- MBW: 0.005 Hz to 0.1 Hz
- Thermo-Elastic Distortion Analysis to demonstrate that the requirements are not violated for all measurement phases (incorporates detailed thermal and structure analysis)
- Main distortion sources: time-dependent external heat loads (orbit height = 240-270 km) and internal dissipation of units and thrusters

GOCE - Thermo-Elastic Distortion Analysis

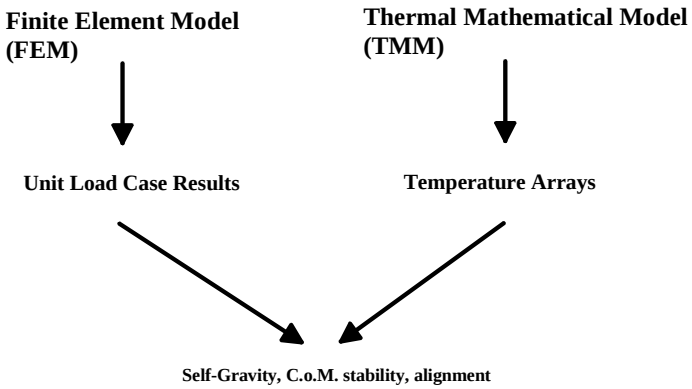
Analysis Approach - Common Approach



- Time for load case runs and re-runs
- Amount of output data/postprocessing
- Amount of data exchange between TMM and FEM (mapping)

GOCE - Thermo-Elastic Distortion Analysis

Analysis Approach – GOCE PFM Approach



+ reduced amount of output data → rapid identification of main distortion sources and design improvements

+ reduced computation time, quick re-analysis, variations and sensitivity analyses possible

+ re-analysis without new FEM analysis

o linearization error for self-gravity computations small

GOCE - Thermo-Elastic Distortion Analysis
Analysis Approach – GOCE PFM Approach

FEM (MSC/Nastran):

- GOCE platform divided into 88 thermal areas
- The thermal areas define the unit load cases
- Starting from a temperature of 20°C for the whole S/C, the temperature of all FE Model nodes of one thermal area is increased by 1°C (remaining FE Model nodes still at 20°C)
- All the required instrument alignment, C.o.M. and self gravity data is calculated per unit load case
- This step is repeated for all unit load cases (thermal areas)

GOCE - Thermo-Elastic Distortion Analysis
Analysis Approach – GOCE PFM Approach

TMM (ESATAN V 8.7, ESARAD V4.2):

- Computation of transient temperatures for the 88 thermal areas for all time steps
- All temperatures with respect to 20°C (undisturbed)

Computation of total distortions for each time step

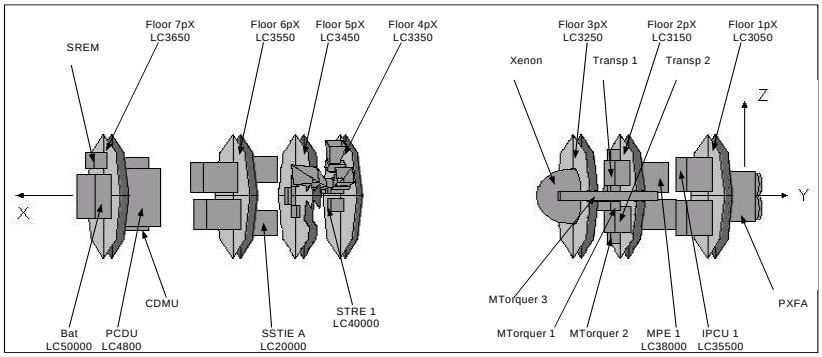
(MS Excel, Mathematica V4.2):

- Multiplication of unit load case results and temperatures (super positioning) → results in time domain
- Fourier transformation afterwards → results in frequency domain (power spectral density - PSD)

GOCE - Thermo-Elastic Distortion Analysis

Mechanical and Thermal Model and Analysis

The unit load case results are multiplied with the in-orbit temperatures, calculated with the TMM by using the principle of superposition



GOCE - Thermo-Elastic Distortion Analysis

Mechanical and Thermal Model and Analysis

Unit load case count				1	2	3	4
Unit load case no.				900	940	1000	1006
Unit load case description			Basic	Launcher I/F Ring	Launcher I/F Ring	S/C Lateral Panel +Z -Y	S/C Lateral Panel +Z -Y
1	GASRF - SSARF 1	phi-xi [rad]	0	2.0450179579E-09	-1.4789500570E-09	1.3813728904E-08	1.2941527920E-08
		phi-yi [rad]	0	1.4721318705E-09	-1.1449934390E-09	9.7900846080E-09	8.1892911810E-08
		phi-zi [rad]	0	2.6024812443E-10	4.8060144420E-10	-8.4465606150E-09	5.8768478390E-09
2	GASRF - SSARF 2	phi-xi [rad]	0	1.8981965241E-09	-1.3824049455E-09	1.3442182235E-08	1.2137558393E-08
		phi-yi [rad]	0	1.4673246385E-09	-1.1424602507E-09	9.8058155040E-09	8.1885897183E-08
		phi-zi [rad]	0	2.5958083233E-10	4.8156813810E-10	-8.4686557730E-09	5.8533052100E-09
3	GASRF - SSARF 3	phi-xi [rad]	0	-1.0728666226E-10	2.1540694826E-09	-4.6104224230E-08	-3.7301955652E-08
		phi-yi [rad]	0	9.1220388973E-10	-4.8020973414E-10	-1.1629826302E-08	2.9276602748E-08
		phi-zi [rad]	0	-3.2646073895E-10	1.0454315763E-09	-3.0290053447E-08	-2.8117901591E-08
4	GASRF - SARF	phi-xi [rad]	0	-2.5743256470E-09	4.2141359027E-09	-2.5694958725E-08	-9.6586837678E-09
		phi-yi [rad]	0	2.7638708409E-08	-2.5737705421E-08	1.7840012717E-07	1.6895566178E-07
		phi-zi [rad]	0	-3.5159165961E-08	3.8763968453E-08	-3.7684338597E-07	-2.0677174323E-07
5	GASRF - GRF	phi-xi [rad]	0	-1.2301600788E-10	1.9295383606E-10	-8.1044716273E-09	-9.3657207478E-09
		phi-yi [rad]	0	1.8805552984E-10	-2.0721312731E-10	-1.7509160973E-08	-1.1105508006E-08
		phi-zi [rad]	0	-9.5468844183E-10	1.9076172623E-09	-2.2125240715E-08	-1.4961697966E-08
6	GASRF - GARF	phi-xi [rad]	0	-6.1306692827E-06	5.0379672508E-06	-4.0458430205E-06	-1.4130023329E-07
		phi-yi [rad]	0	9.2223273830E-07	6.1495512606E-05	4.2069688315E-07	1.8667657530E-07
		phi-zi [rad]	0	3.7238262550E-07	-6.2610583121E-05	1.0506284211E-06	3.4432586857E-07
7	GASRF - MTA -X-Y-Z	phi-xi [rad]	0	-3.2152642739E-07	6.5288479329E-07	-3.2545831229E-08	-3.3663528150E-08
		phi-yi [rad]	0	-2.8256988549E-07	-8.9304318431E-07	3.2077259350E-07	3.4830347968E-07
		phi-zi [rad]	0	-1.4778127199E-06	6.3306277666E-07	1.0148420464E-08	7.4979953208E-08
8	GASRF - MTA +X+Y+Z	phi-xi [rad]	0	4.7938048305E-10	-4.8995452572E-10	3.8415715892E-09	-3.7384855428E-09
		phi-yi [rad]	0	8.5557400299E-10	-1.1065694081E-09	-1.1170631120E-09	4.9037693967E-08
		phi-zi [rad]	0	-3.3377565687E-10	1.3898531150E-10	4.5893007650E-09	2.5161050589E-08
9	GASRF - ITA +Z	phi-xi [rad]	0	-5.6065490868E-09	5.8197352369E-09	-9.4749155112E-08	-4.9036693799E-08
		phi-yi [rad]	0	1.7653220094E-07	1.9014537657E-07	5.9290055225E-07	4.0962574000E-07
		phi-zi [rad]	0	-4.7973758124E-07	4.8069717289E-07	2.6413425651E-07	1.8325968256E-07
10	GASRF - GPS -X	phi-xi [rad]	0	1.4213347151E-08	-1.4017198597E-08	6.1701141282E-09	-1.3388898488E-08
		phi-yi [rad]	0	-2.4358975233E-10	-1.8357473823E-09	2.8764546377E-08	1.3532339641E-07
		phi-zi [rad]	0	-3.8384429625E-08	3.8502896767E-08	2.8500048200E-08	7.1825415137E-08
11	GASRF - GPS +X	phi-xi [rad]	0	9.0694493574E-09	-8.9662037867E-09	3.6628238642E-09	-3.9634244999E-09
		phi-yi [rad]	0	-1.5465026925E-09	-3.3030934658E-09	-4.2241795371E-08	1.4769733180E-07
		phi-zi [rad]	0	4.9872752134E-08	-4.9860463895E-08	2.2761015047E-08	6.3573824187E-08

Alignment Data computed with FEM (Basic Case and Unit Load Case 1-4 shown)

GOCE - Thermo-Elastic Distortion Analysis

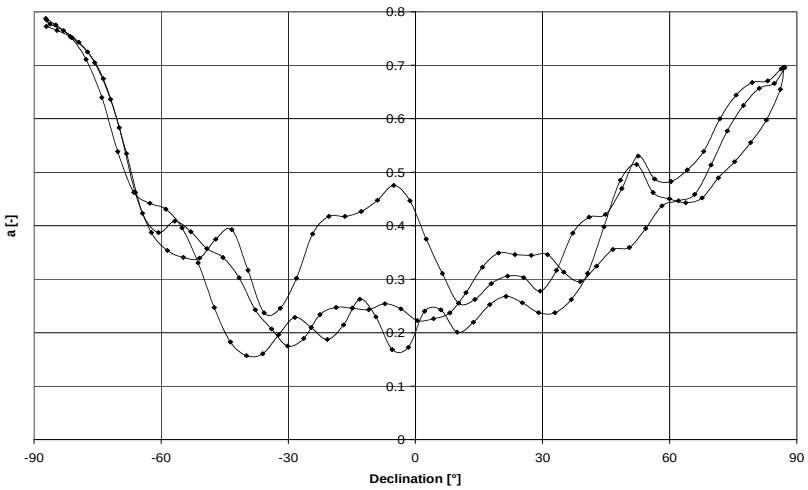
Mechanical and Thermal Model and Analysis

Transient Temperature Computations with the thermal model include:

- Eclipse/ no eclipse phases
- Fluctuation of external heat loads vs. declination (data from CHAMP mission adapted to the GOCE orbit)
- Time dependency of unit power dissipation
- Thrust Profile
- Atmospheric Heating

GOCE - Thermo-Elastic Distortion Analysis

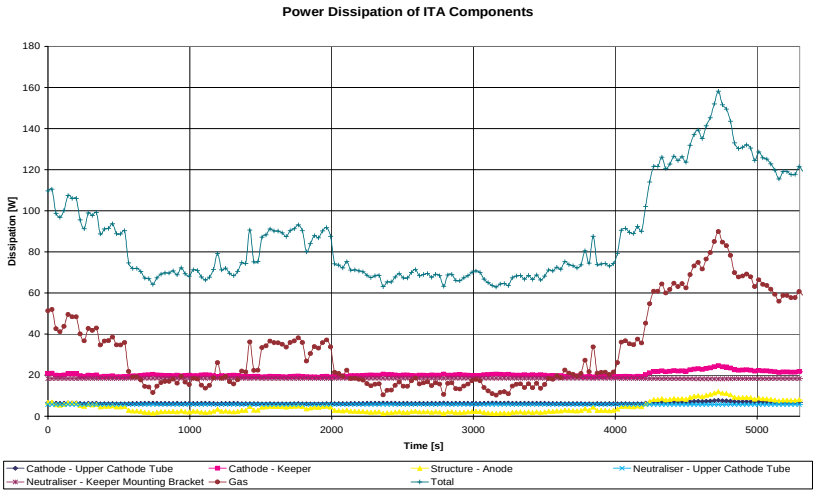
Mechanical and Thermal Model and Analysis



Albedo Factor vs. Declination [deg.]

GOCE - Thermo-Elastic Distortion Analysis

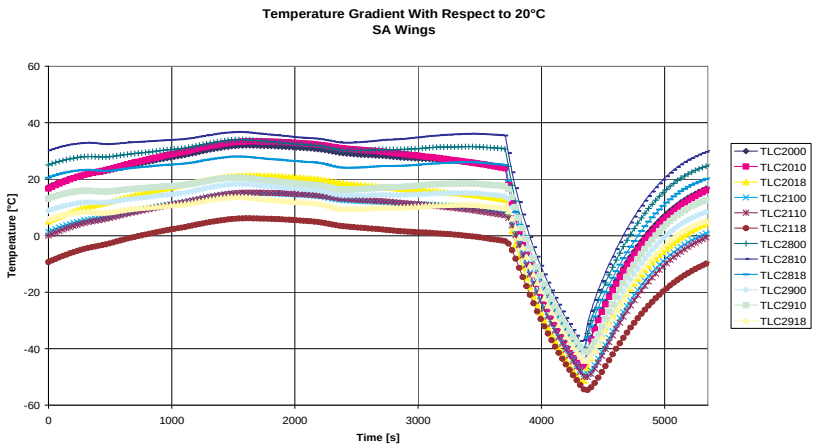
Mechanical and Thermal Model and Analysis



Ion Thruster Power Dissipation [W] per Orbit

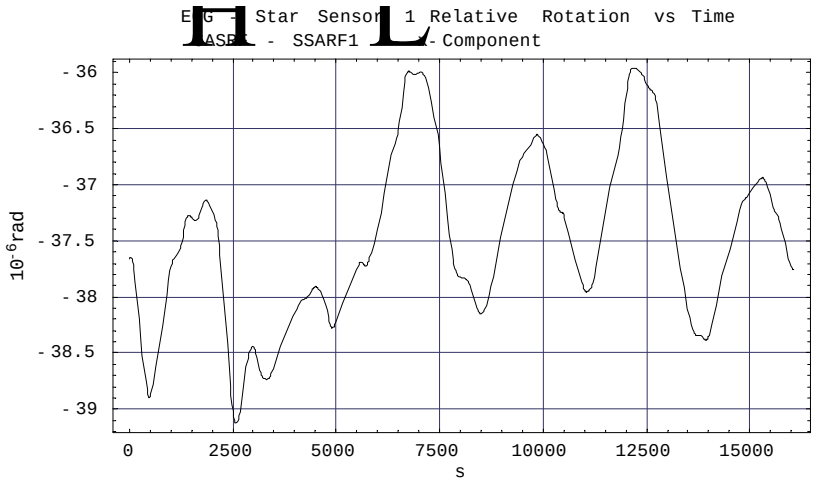
GOCE - Thermo-Elastic Distortion Analysis

Mechanical and Thermal Model and Analysis



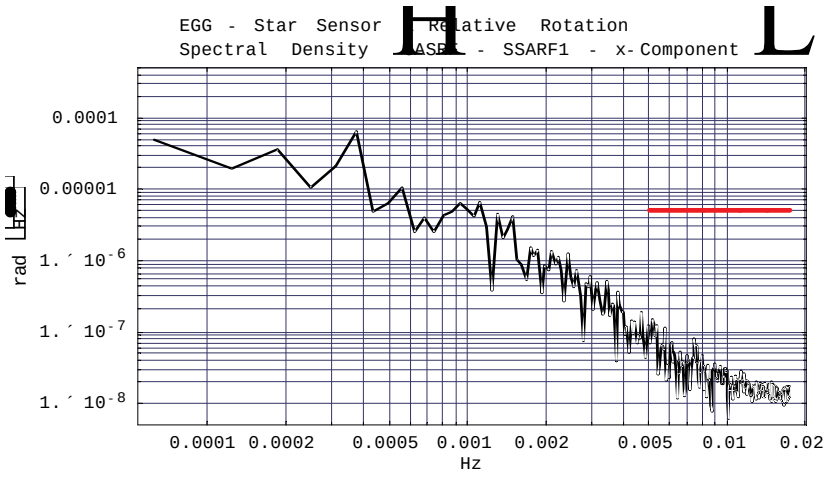
Temperatures for Thermal Areas on Wing [°C]

GOCE - Thermo-Elastic Distortion Analysis
Results



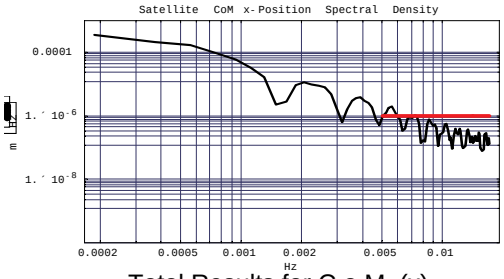
Alignment (Relative Rotation) Hot Case (no Eclipse)

GOCE - Thermo-Elastic Distortion Analysis
Results

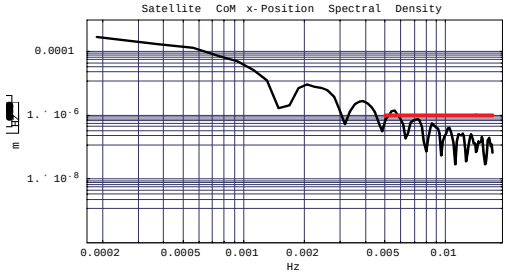


Alignment (Relative Rotation) Spectral Density Hot Case (no Eclipse)

GOCE - Thermo-Elastic Distortion Analysis
Results

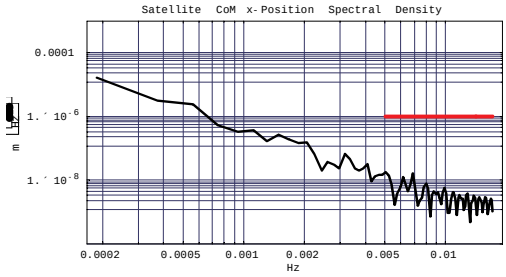


Total Results for C.o.M. (x)



Contribution of Wing

Influence of S/C Components on Total Results



Contribution of S/C Panels

GOCE - Thermo-Elastic Distortion Analysis
Summary

→ Experiences with GOCE PFM analysis approach:

- Fast and reliable check if requirements are met with high accuracy
- Easy to vary parameters and to conduct sensitivity analyses
- Quick configuration checks and determination of influence of individual components on the overall results
- No re-run of FEM required for new thermal load cases

→ Suggestiones for (Software) Improvements:

ESATAN – functionality for processing thermo-elastic distortion relevant data → routines to read ‘unit load case results‘, generate distortion vs. time output (, compute spectral density)

ESARAD – more detailed planet models required → real earth temperature and albedo factor depend on orbit position/ declination

GOCE - Thermo-Elastic Distortion Analysis

Annex

GOCE - Thermo-Elastic Distortion Analysis

GOCE Mission - Orbit and Load Cases

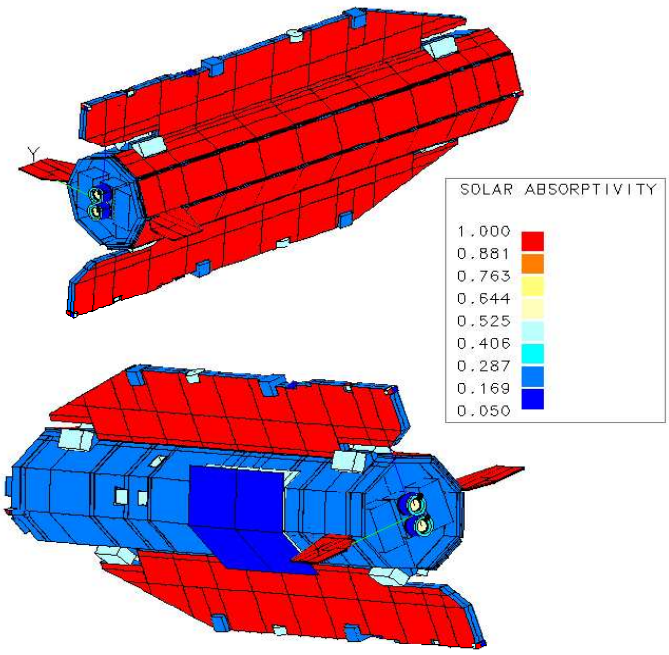
Main Orbit Parameters:

- dawn-dusk or dusk-dawn
- orbit height 240 – 270km
- inclination 96.5°

Case	HOT CASE	COLD CASE
LST Ascending Node	18:00h	6:00h
Thermo-optical Properties	EOL	BOL
Earth IR Flux [W/m²]	261 (average)	189 (average)
Albedo Coefficient	0.4 (average)	0.2 (average)
Altitude [km]	240	250
Inclination [deg]	96.5	96.5
Solar Constant [W/m²] [1]	1408	1323
Solar Declination [deg]	-13.00	23.45
Beta Angle [deg]	83.5	73.05
Eclipse Duration [min]	0	10
Ω Angle [deg]	90 deg	270 deg
Attitude	nominal	nominal
Unit dissipations	Max (EOL)	Min (BOL)
Heaters	Enabled	Enabled

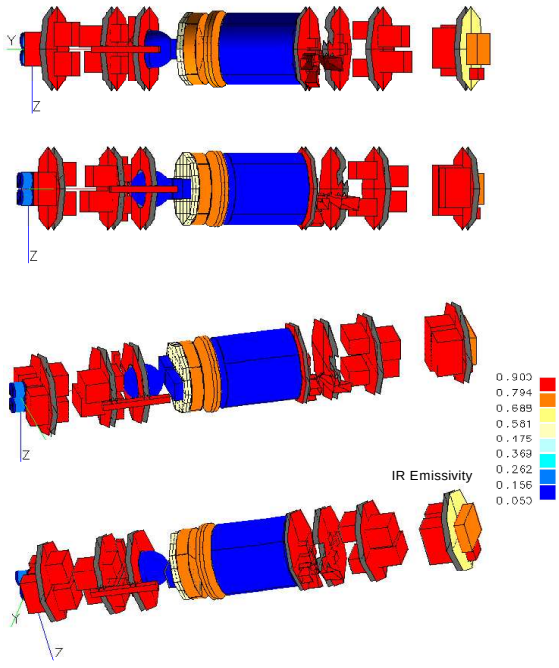
GOCE - Thermo-Elastic Distortion Analysis

GOCE Mission - Configuration 1



GOCE - Thermo-Elastic Distortion Analysis

GOCE Mission - Configuration 2



GOCE - Thermo-Elastic Distortion Analysis

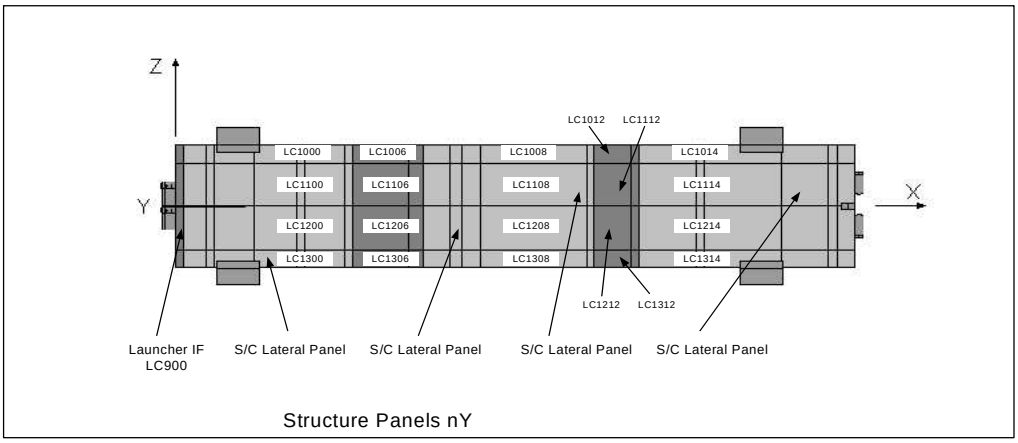
Mechanical and Thermal Model and Analysis

Unit load case count		1	2	3	4
Unit load case no.		900	940	1000	1006
Unit load case description	Basic	Launcher I/F Ring	Launcher I/F Ring	S/C Lateral Panel +Z -Y	S/C Lateral Panel +Z -Y
axi(+x) [m/s^2]	5.2244433632E-09	5.2244437744E-09	5.2244440763E-09	5.2244433262E-09	5.2244431264E-09
axi(-x) [m/s^2]	-6.1323390129E-09	-6.1323382266E-09	-6.1323375849E-09	-6.1323391596E-09	-6.1323390082E-09
ayi(+y) [m/s^2]	-6.7900107660E-09	-6.7900110939E-09	-6.7900097959E-09	-6.7900111551E-09	-6.7900113691E-09
ayi(-y) [m/s^2]	-8.1676499037E-10	-8.1676540917E-10	-8.1676442773E-10	-8.1676682072E-10	-8.1676508200E-10
azi(+z) [m/s^2]	-2.5769425791E-09	-2.5769424682E-09	-2.5769425105E-09	-2.5769425775E-09	-2.5769410747E-09
azi(-z) [m/s^2]	1.4633527638E-09	1.4633526648E-09	1.4633525573E-09	1.4633539866E-09	1.4633535272E-09

Self-Gravity Acceleration Data

GOCE - Thermo-Elastic Distortion Analysis

Mechanical and Thermal Model and Analysis

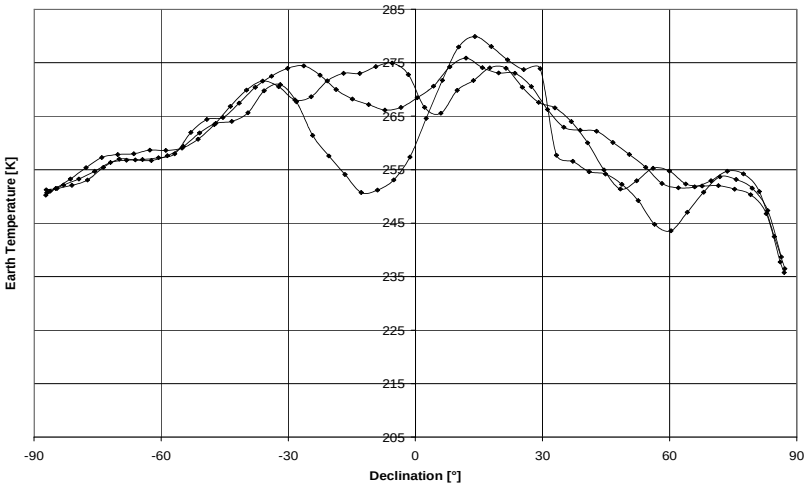


Structure Panels nY

Example - Thermal Areas → Unit Load Cases

GOCE - Thermo-Elastic Distortion Analysis

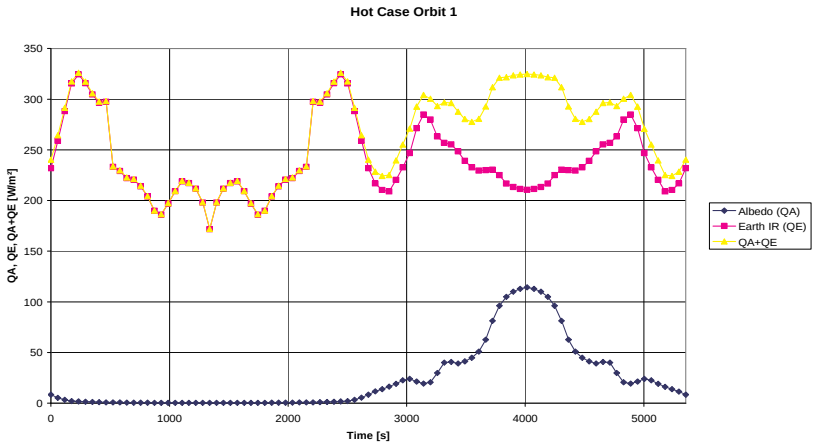
Mechanical and Thermal Model and Analysis



Earth Temperature [K] vs. Declination [deg.]

GOCE - Thermo-Elastic Distortion Analysis

Mechanical and Thermal Model and Analysis



Resulting External Heat Loads [W/m²] vs. Declination [deg.]

GOCE - Thermo-Elastic Distortion Analysis

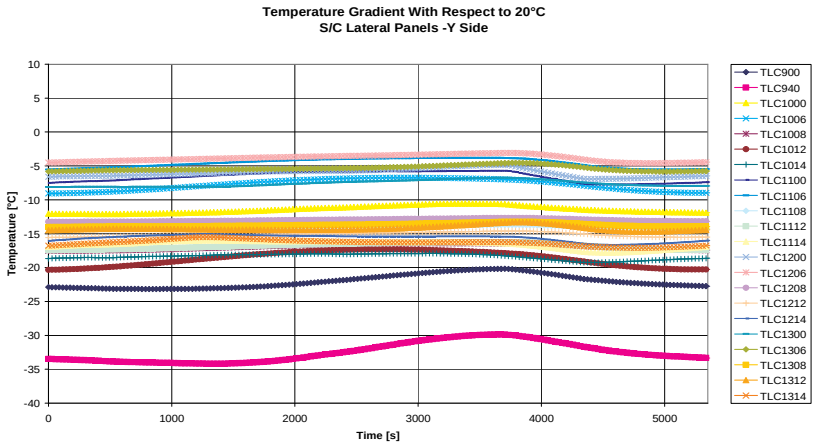
Mechanical and Thermal Model and Analysis

```
INTEGER orbit_index;

/* 97 orbit positions = 92 + 1 start=stop at equator + 4 eclipse entry/exit  */
REAL ALBEDO_FAC [97] = {
  0.14348174,
  0.13528350,
  0.09871711,
  0.05825458,
  0.03680240,
...
  0.13099252,
  0.13296514,
  0.14348174
};

      CALCULATE_PLANET_ABSORBED_FLUX_RAYTRACING (
         ir_paf = COLD_BOL_p23p45.IR_PAF[orbit_index],
         coord = COLD_BOL_p23p45.ORBIT_POSITIONS[orbit_index],
         albedo_paf = COLD_BOL_p23p45.ALBEDO_PAF[orbit_index],
         planet_rad = COLD_BOL_p23p45.ORBIT.PLANET_RADIUS,
         planet_temp = PLANET_TEMP [orbit_index],
         albedo_reflect_coeff = ALBEDO_FAC [orbit_index],
         solar_char = COLD_BOL_p23p45.SOLAR_CONST_OVERRIDE);
```

ESARAD – example albedo factor

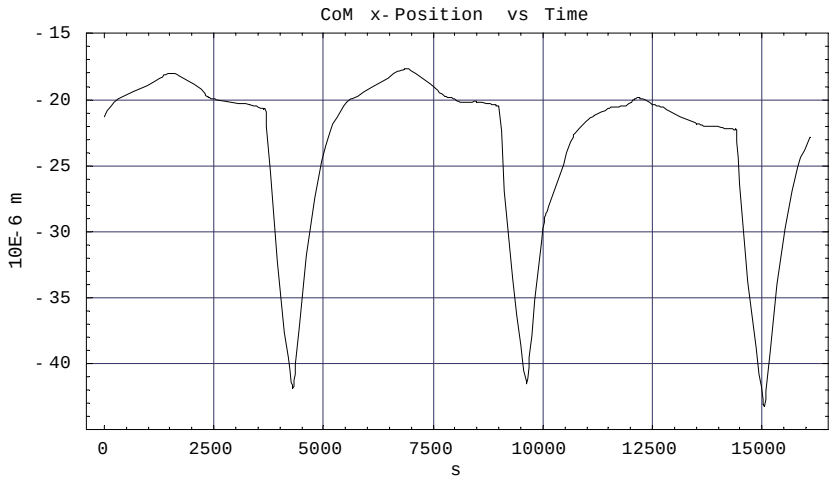
GOCE - Thermo-Elastic Distortion Analysis

Mechanical and Thermal Model and Analysis



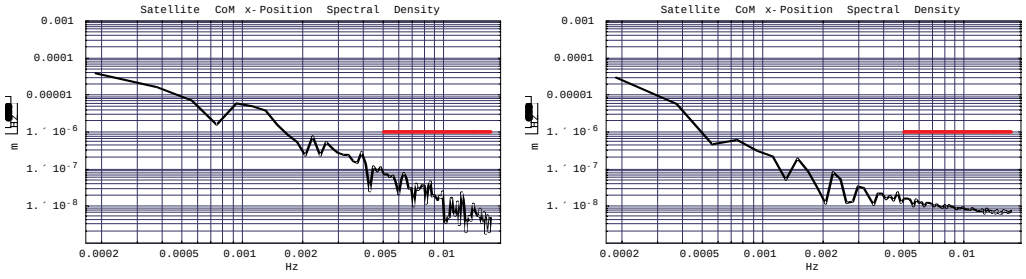
Temperatures for Thermal Areas on S/C Panels [°C]

GOCE - Thermo-Elastic Distortion Analysis
Results



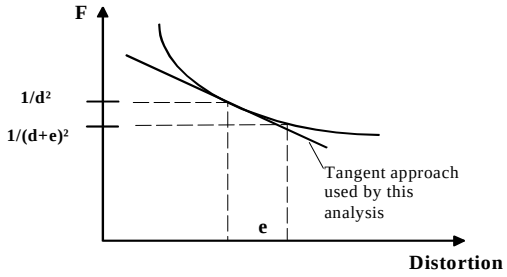
C.o.M Position Change Cold Case (Eclipse)

GOCE - Thermo-Elastic Distortion Analysis
Results



Assessment – Transient vs. Constant External Heat Loads and Unit Power Dissipation

GOCE - Thermo-Elastic Distortion Analysis
Linearization Error



- linearization error is given by the thermal unit load cases
- the gravity potential d is non-linear
- error by multiplying the unit load case result by the actual temperature swing
- error is negligibly small as long as the distortions are in the range of only a few microns and the distance of the mass points are larger than 0.5 m

GOCE - Thermo-Elastic Distortion Analysis
Linearization Error