Appendix R

Lessons Learned on Modelling of Cryogenic Systems

Moritz Branco
(ESA/ESTEC, The Netherlands)

Abstract

The use of ESATAN-TMS as a thermal modeling tool for systems in the cryogenic domain (< 120 K), gives rise to specific issues on model convergence and the results analysis. This presentation's purpose is to present some of the issues found and solutions considered while working on a model for a compact cryostat with a full cryogenic chain from 300 K to 2 K.

Lessons Learned on Modelling of Cryogenic Systems with ESATAN-TMS

25th European Workshop on Thermal and ECLS Software

Moritz Branco

ESTEC, Noordwijk, The Netherlands

8-9/11/2011

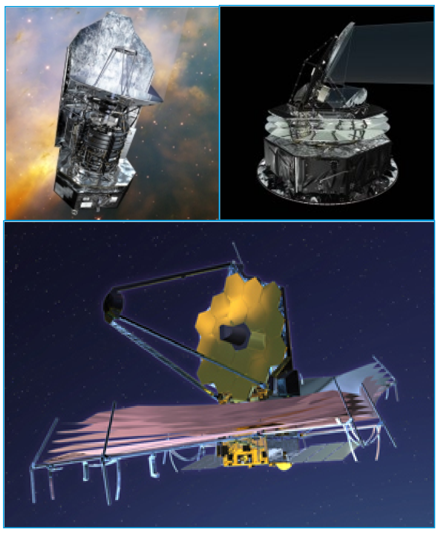
European Space Agency

Lessons Learned on Cryogenics Modelling
Contents

1. Context:
   The XMS Cryo-Chain

2. Problems Encountered / Solutions Proposed

3. Results Analysis: Specific Issues



Lessons Learned on Modeling of Cryogenic Systems with ESATAN-TMS | Moritz Branco | 14/04/2011 | Noordwijk | Pag. 2

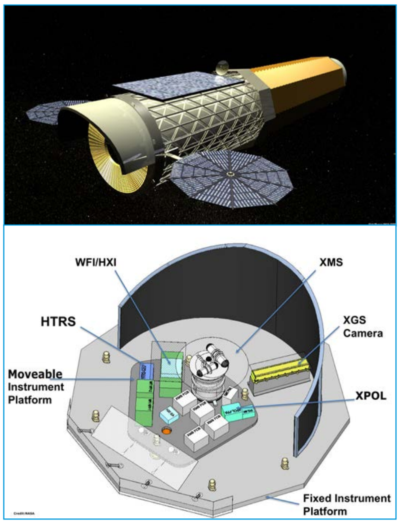
European Space Agency

Lessons Learned on Cryogenics Modelling
The XMS Cryo-Chain

esa

Brief Description:

- X-ray microcalorimeter spectrometer (XMS)
- Instrument aboard ATHENA, previously called IXO
- Requires cooling down to 50 mK with 1 µW cooling power available
- No liquid cryogens (5-10 years life)



Depictions of IXO, whole and XIM

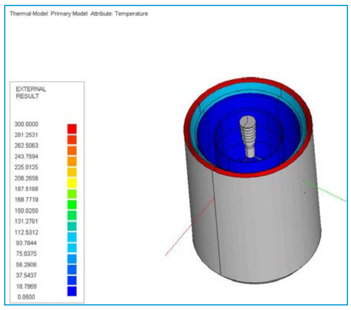
European Space Agency

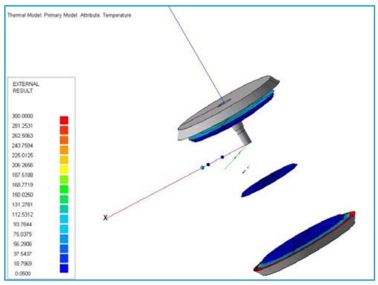
Lessons Learned on Cryogenics Modelling
The XMS Cryo-Chain

esa

The ESATAN-TMS model:

- Russian Doll type configuration (different T stages, 100 K, 15 K, 2K..)
- Performance Data from available cryo coolers
- Data on MLI, harness, mechanical supports from previous studies and missions
- Detailed analysis of the optical baffle
- Study on flexible thermal links
- Modelling of interdependent behaviour of cryocoolers





European Space Agency

Lessons Learned on Cryogenics Modelling Problems Encountered / Solutions

Problem: TABS = 0.0

- In the model.d file the node block defines all nodes with a T=0.0, no matter the TABS considered.
- Solver crashes

```
$NODES
  D100 = 'Filter50m', T = 0.0,
   C = 1.963495E-008 * Cp_Kapton * Dens_Kapton,
   A = 0.001963, ALP = 0.460000, EPS = 0.020000,
   FX = -0.0125000, FY = 1.53076E-018, FZ = 0.530020;
  D1000 = 'Filter1K', T = 0.0,
   C = 3.926991E-008 * Cp_Kapton * Dens_Kapton,
   A = 0.003927, ALP = 0.460000, EPS = 0.020000,
   FX = -0.0125000, FY = 1.53076E-018, FZ = 0.610020;
  D2000 = 'Filter15K', T = 0.0,
   C = 5.473353E-009 * Cp_AlAl * Dens_AlAl,
   A = 0.000547, ALP = 0.460000, EPS = 0.020000,
   FX = -0.00466667, FY = 5.71483E-019, FZ = 0.695020;
  D2005 = 'Filter15K', T = 0.0,
   C = 1.642006E-008 * Cp_AlAl * Dens_AlAl,
   A = 0.001642, ALP = 0.460000, EPS = 0.020000,
   FX = -0.0140000, FY = 1.71445E-018, FZ = 0.695020;
  D2010 = 'Filter15K', T = 0.0,
   C = 2.736676E-008 * Cp_AlAl * Dens_AlAl,
   A = 0.002737, ALP = 0.460000, EPS = 0.020000,
   FX = -0.0233333, FY = 2.85741E-018, FZ = 0.695020;
```

Solutions proposed:

- Setting an initial temperature boundary condition to all nodes: not flexible and didn't work.
- Setting an initialization routine in the template file with SETNDR. Worked.

```
$INITIAL
C set initial temperatures
CALL SETNDR(' ',' T ',10.0D0, CURRENT)
```

European Space Agency

Lessons Learned on Cryogenics Modelling Problems Encountered / Solutions

Problem: MLI modelling

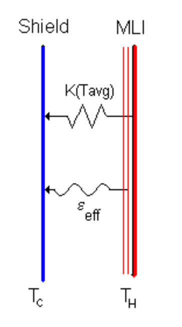
- MLI is modelled as having an effective emissivity and a temperature dependent pseudo-conductivity

	$q = (a\,(T_H + T_C)/2 + b)\,(T_H - T_C) + \varepsilon\,\sigma\,((T_H{}^4 - T_C{}^4)$		
	a	b	ε
10-layer MLI	8.720E-06	2.353E-05	0.00395
20-layer MLI	4.360E-06	1.177E-05	0.0019725

Table 4-18. Thermal performance of "Herschel" type MLI [RD5]

Solution found:

- Additional shell added, and a conductor depending on average T (T_{MLI} and T_{SHELL}) is entered between each face
- Not flexible:
  - nodal breakdown analysis
  - geometry study
- Possible request feature: Temperature dependent through-conductance in a shell



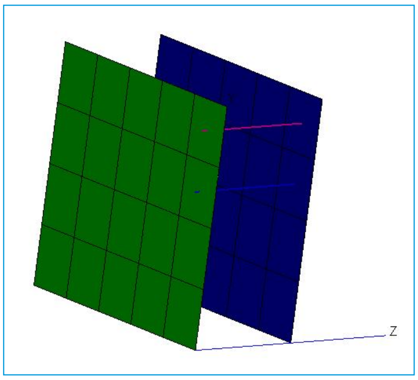
European Space Agency

Lessons Learned on Cryogenics Modelling Problems Encountered / Solutions

esa

Problem: MLI modelling

- MLI is modelled as having an effective emissivity and a temperature dependent pseudo-conductivity



Solution found:

- Additional shell added, and a conductor depending on average T (T_{MLI} and T_{SHELL}) is entered between each face
- Not flexible:
  - nodal breakdown analysis
  - geometry study

$MLIcond(T)=aT+b \quad T=Th/2+Tc/2$

$GL(MLI_i, shell_i)=MLIcond(TMLI_i/2+Tshell_i/2)$

- Possible request feature: Temperature dependent through-conductance in a shell

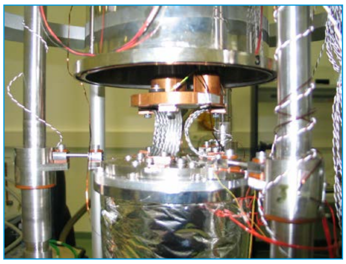
European Space Agency

Lessons Learned on Cryogenics Modelling Problems Encountered / Solutions

esa

Problem: High GL's for small ΔT's

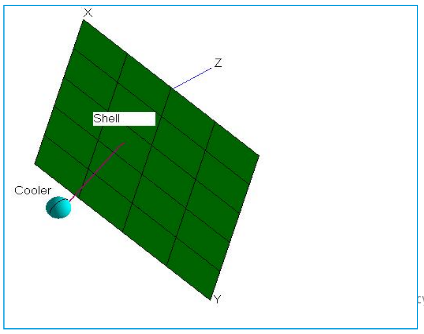
- Highly conductive thermal links (10^0 W/K) for small temperature differences (10^{-1} K) are typical in cryogenic systems (e.g. copper straps).



- Numerical instabilities:

Solver not solving or

Diffusive node (shell node) with a very high relative heat inbalance



Solution found:

- Using SOLVFM / in cases transient
- Applying a damping factor 0.1-0.5
- Initial Temperatures boundary setting to start with a very low ΔT

Lessons Learned on Cryogenics Modelling
Problems Encountered / Solutions

esa

Cooler Modelling

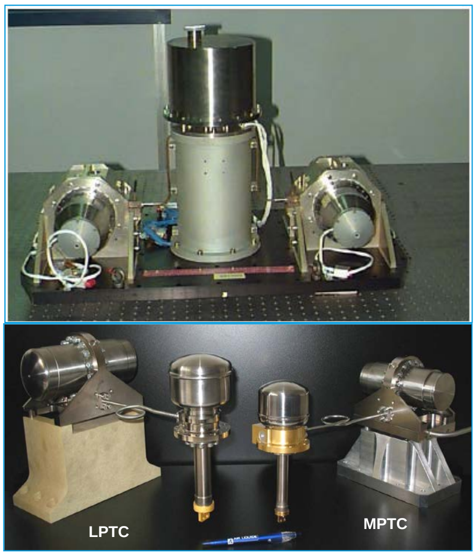
- First Approach: Boundary nodes, T constant

- Diffusive nodes with an balanced QI, given by the cooler performance data.

- Boundary node with T changing every iteration,

  T given by the cooler performance data.

- A damping scheme had to be applied.



European Space Agency

Lessons Learned on Cryogenics Modelling
Problems Encountered / Solutions

esa

Cooler Modelling

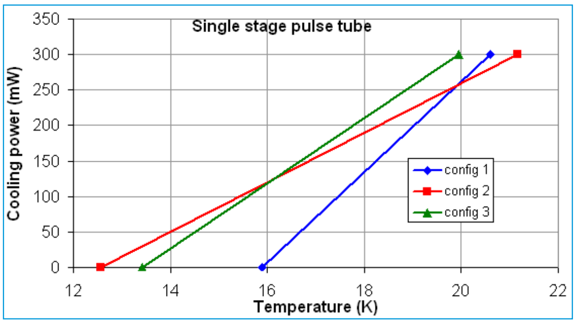
- First Approach: Boundary nodes, T constant

- Diffusive nodes with an balanced QI, given by the cooler performance data.

- Boundary node with T changing every iteration,

  T given by the cooler performance data.

- A damping scheme had to be applied.



Qcool = FLUXGL (Tcooler, Tnode)

T_{i+1} = Performance Curve (Qcool)

Tcooler = Tcooler + DAMPF * (T_{i+1}-T_i)

European Space Agency

Lessons Learned on Cryogenics Modelling
Problems Encountered / Solutions

Cooler Modelling

Problem:

- Cooler temperature was calculated using FLUXGL
- Temperatures result in NaN
- At first iteration, when calling $VARIABLES1, GL's aren't yet calculated

$$Qcool = FLUXGL(Tcooler, Tnode)$$
$$T_{i+1} = Performance\ Curve\ (Qcool)$$
$$Tcooler = Tcooler + DAMPF * (T_{i+1} - T_i)$$

Solution found:

- To manually calculate the GL between cooler and shell node

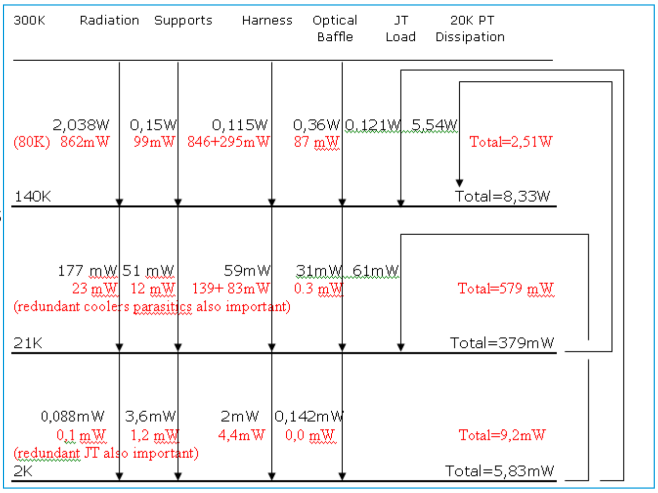
$$Qcool = CNDFN1(Tcooler, Tnode, KThermalStrap, 1) * (Tcooler - Tnode)$$

European Space Agency

Lessons Learned on Cryogenics Modelling
Results Analysis

Results Analysis

- Heat flows are the most important quantity
- Importance of different contributions a general heatflow
- Accuracy of heatflow results is critical, since it could drive the whole system



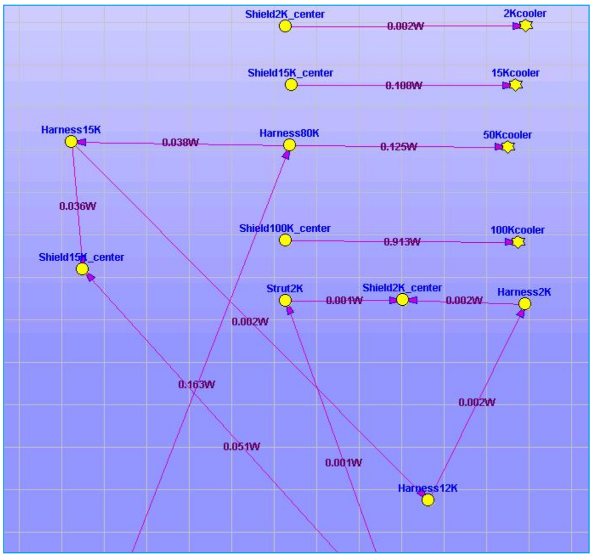
European Space Agency

Lessons Learned on Cryogenics Modelling Results Analysis

Results Analysis

Importance of heat flow accuracy

- Cryogenic models are very sensitive to very small heatflow variations
- At 20 K, every mW counts!
- At 2 K, one mW can drive the whole cryostat configuration



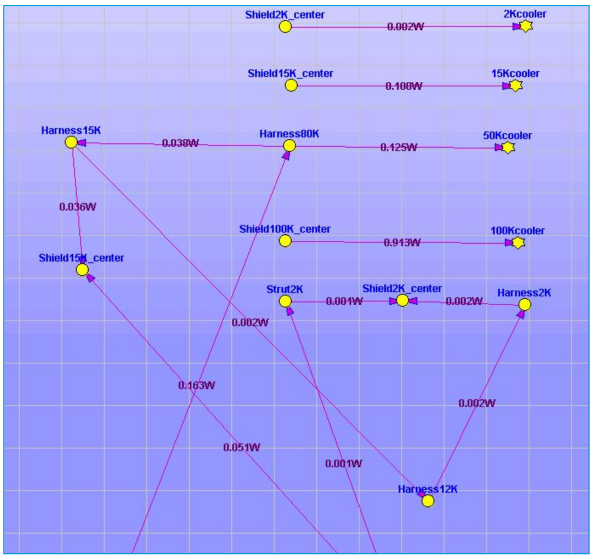
European Space Agency

Lessons Learned on Cryogenics Modelling Results Analysis

Results Analysis

Critical Factors:

- Numerical uncertainties
- Modelling parameters sensitivity
- Low accuracy of results – high engineering margins
- More importance given to empirical knowledge from previous cases



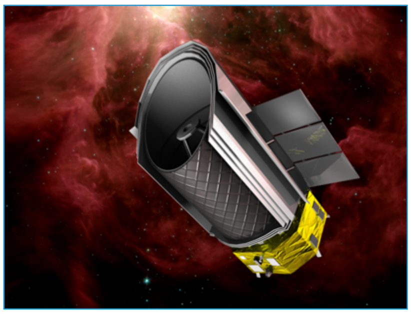
European Space Agency

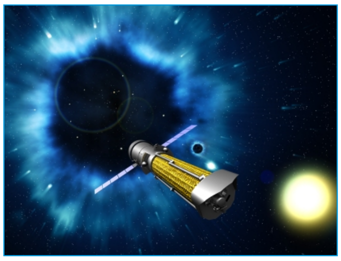
Lessons Learned on Cryogenics Modelling Conclusions

esa

Conclusions

- Specific Issues were tackled
- System level cooler modelling
- Important factors in cryogenic model results analysis
- Empirical knowledge still most valuable





European Space Agency

esa

THANK YOU

Moritz Branco,
Work undergone at TEC-MT
moritz.branco@esa.int

UNIÃO EUROPEIA
Fundo Social Europeu

Ciência.Inovação 2010 Programa Operacional Ciência e Inovação 2010

Governo da República Portuguesa

European Space Agency