Appendix S

Dynamic Thermal Spacecraft Simulator based on nodal mathematical model

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Abstract

To improve the quality and reliability of the dynamic spacecraft simulator, Thales Alenia Space Cannes asked DOREA to implement the thermal real-time simulator based on the thermal mathematical model (TMM) provided by thermal analysis team.

Both SYSTEMA/Thermisol (from EADS Astrium) and ETHERM (from Thales Alenia Space) nodal models have been converted and integrated into a new DSS product line called SCSIM (SpaceCraft SIMulator). A set of ESA tools were used in an industrial context to solve this technical challenge: reduction tool TMRT (without reduction) has been used to convert TMM from SYSTEMA/Thermisol nodal definition; STEP-TAS and TASverter to convert geometrical model from THERMICA and thermal post processing tool ESATAP for thermal model comparison and debugging.

Ray-tracing calculator and temperatures resolution from internal ETHERM core module (former CORATHERM) have been successfully improved to fit the real-time constraints. Parallelisation has been largely used to make the calculation most reactive in order to fit as much as possible the physics behaviour.

New SCSIM based on TMM has been successfully validated on Alphasat (@bus platform) and O3B Networks satellite.
SCSIM-TCS
Thermal Dynamic Simulator

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Introduction

- **The challenge was:**
  - to implement a DSSS (Dynamic Spacecraft System Simulator) integrating a thermal simulator based on the TMM model used by thermal analysis,
  - but also to use the same software bricks than thermal analysis (here ETHERM former CORATHERM calculator).

- **The gains are:**
  - To have a better fit with thermal analysis specifications as an input of the DSSS.
  - To have a generic implementation independent from the spacecraft model.
  - To benefit of a thermal calculator able to behave as much as possible as the physics,
  - To reduce convergence time of thermal simulator development.

Introduction to SCSIM

SCSIM Introduction
Introduction

K2 “simulators” are used for several satellites families:
- Constellation: Globalstar 2, O3B, IRIDIUM NEXT
- Telecom: SpaceBus 4000, Alphabus / @SAT
- OOS: Sentinel 3, GKT, EXOMARS, MTG FCI

K2 is used inside numerical multi-domain simulators to perform verification of:
- OBSW validation procedures
- OBSW patches in SAV phases
- Functional Chain Validation procedures
- AIT Test sequences
- Operational procedures

K2 is also used inside hybrid simulators with Hardware-In-The-Loop to realize any test bench:
- Avionics Test Bench for Functional or AIT phase
- Platform Simulator for Payload AIT
- AIT bench or EGSE for Satellite AIT

This generic approach will be presented at ESA Workshop SESP in September 2012
Generic incremental process

Simulation kernel

Generic incremental process

- AIT preparation
- AIT

Operations preparation

Study (AOCS, …)

OBWS Validation

OnBoard Computer

Emulator

Front-end HW interface

Satellite Equipments

Simulation kernel

Operations preparation

SAV – patch validation

Typical use case

- As a numerical multi-domain simulator:

  - Satellite models
    - PAYLOAD / PLIU and TTC models
    - AOCs Models
    - Power models
    - Thermal model
    - On Board Computer

  - Functional models
    - Coupler models

  - K2 (core) – Simulation kernel

  - K2 extensions
    - Local MMI

  - Ground models
    - ATB bench models
    - SCC models
    - EGSE models

  - OCOE

  - Satellite Control Center

  - OCOE
Typical use case

As a hybrid simulator with real OBC:

- Satellite models
  - PAYLOAD model
  - AOCS Models
  - Power models
  - Thermal model
- Satellite Equipments
  - On Board Computer (EM)
  - HW Layer
- K2 (core) – Simulation kernel
- Ground models
  - ATB bench models
  - OCOE

K2 Software Development Kit content

Different software of the K2 product line:

- K2 platform library
  - API for models development (C++)
  - Integration and test API (python), also known as Control of Test
- MMI (Man Machine Interface)
  - Command and control a simulator
  - Optionally add the daemon to enhance MMI services and functionalities
- Development assistance (datassim): model template generation, variant (integrated simulator) generation, documentation generation
- Bridges:
  - lucassim (data generation from lucile SDB to simulator)
  - Matlab (encapsulate Matlab models into K2 platform)
  - Smp2 (encapsulate SMP2 models into K2 and vice-versa)
Simulator building

Off-the-shelf models
- PAYLOAD models
- AOCS models
- Avionics models (Power,...)
- Thermal model
- On Board Computer OBSW

Satellite models

Ground Models
- EGSE models
- ATB bench models
- SCC Models

Ground Models

Satellite Control Center

Integrate simulator
Model instances with connections

Specific Models
Manager Model

Assemble a simulator with:
- off-the-shelf model instances (ie shared by several programs)
- model instances specific to the program
- connections between model instances

K2 platform – Core description

- The K2 Core platform offers different kind of services
  - Data exchange: as shown
    - Scheduler: is responsible for the co-ordination and processing of all events within the Simulation Kernel. An event on the schedule identifies an action that needs to be performed at a specified time in simulated time
    - Time Keeper: is responsible for maintaining and providing models and the MMI with the correct simulation-Time. It provides time in four formats, Simulation-Time, Epoch-Time, Zulu-Time and Correlated Zulu-Time. This is a family of SIMSAT compatible models enabling a realistic simulations
    - Data explorer: is responsible for making the values of both model and Kernel data items available for display in an MMI.

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K2 Components Off-the-shelf

- K2 simulator target: Linux 64 bits and 32 bits
- MMI target: full java program, can run on JRE 6 supported platform.
- K2 3rd party components: mostly based on open source software
  - Gcc 4.3.3
  - Python 2.6
  - Swig 1.3
  - Java 6
  - ...

The Man-Machine Interface (MMI) is the part of the simulation infrastructure that provides the graphical, user-friendly, configurable interface to any simulator.

- Local MMI are in charge of:
  - initialization
  - simulation control
  - events activation
  - failures activation
  - internal variables control
  - Satellite Database control and command
  - Mimics display
  - Graph display

Design:

- Simulator Object (Python)
- K2 Kernel (C++)
- SWIG Wrapper (Python)
- XML-RPC Server (Python)
- XML-RPC Client (Java)
- MMI (Java)
• The “SDB explorer” panel provides the following features:
  ■ Quick access to SDB TM / TC data sorted by subsystem / equipments
  ■ Perform SDB TC send
  ■ Perform SDB TM decommutation

Problems to solve

- **DSSS has to compute in real time:**
  - to take care of equipment powers as input,
  - the solar, albedo and IR earth fluxes depending on the spacecraft attitude,
  - the temperatures based on a static conductive and radiative matrices, updated according to external fluxes,
  - the SA movements.

- **DSSS requirements:**
  - Performances have to be improved, ray tracing and temperatures recalculation based on geometry and nodal model, especially during SHM or spin.

- **TMM and GMM conversion:**
  - TMM models come from THERMISOL, ESATAN and ETHERM
  - GMM models come from ESARAD, THERMICA and ETHERM.
**Solutions**

- **Real time solution:**
  - Few benches have been made to measure calculator speeds, and it appears that ETHERM (based on CORATHERM optimized code) is the faster of known calculators. Temperature time tick (Runge Kutta) for a model up to 3500 nodes is performed in 19ms (linux machine with i7-3610 processor).

- **Model requirements:**
  - Models have now to be reduced in order to have the best time response on stress cases (SC spin for instance).
  - TMRT (ESA/EADS Astrium/TAS tool) for nodes reduction for instances,
  - Actually manual reduction of number of faces for @sat (performed by EADS Astrium team).

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**TMM model requirements**

- **Use of model reduction:**
  - As far as we knew before implementation, real time requirements implied to have a limited number of nodes and faces.
  - Reduced nodal model for temperatures recalculation,
  - Reduced geometry for external fluxes calculation.

- **Applied for models:**
  - DSSS using SC SIM-TCS is successfully validated for @sat (EADS Astrium/TAS) and O3B (TAS) that have been reduced:
    - 470 nodes and 950 faces for Alphasat
    - 3200 nodes and 1250 faces for O3B.
### TMM/GMM models conversion

- **TMM conversion:**
  - @sat models have been converted (SSEOL, SAFE) into ETHERM format (former CORATHERM) using TMRT with no reduction.

- **GMM conversion**
  - @sat models have been converted into STEP-TAS via TASverter and read by ETHERM.

![TMM/GMM models conversion diagram](image)

### TMM/GMM model comparison and debug

- **Model conversion:**
  - Run on ESATAN:
    - DMPTAS to import results (1 orbit) from ESATAN
  - Run on ETHERM:
    - Implementation of a specific box to read in CSV format the temperatures from ETHERM for 1 orbit

![TMM/GMM model comparison and debug diagram](image)
A dedicated ESATAP component and task has been implemented to calculate time constants for each node (formula taken from ETHERM / RPT):

- calculated from temperatures, capacitances, GR and GL for each nodes, for model on ESATAN format.

ESATAP =>

ESATAP was an asset to:

- 1) Reduce temperature calculation time by analysing and tuning the time constants for temperature cycles convergence,
- 2) Identify the nodes with very small capacitances (near to zero) and fix some capacitances in the original model.

Another problem was detected by ESATAP when comparing temperatures on thermistances during 1 orbit:

from EADS Astrium, node 214

Anomaly
**Investigation:**
- A dedicated ESATAP component has been implemented in order to calculate all the conductive and radiative (internal and external) paths to nodes with powers.

**Given result after analysis all the leaf nodes that have powers:**
- A difference is noted for a power (QS) from some external nodes during a short period of time.
- The decrease of the temperature for these nodes is due to the shadow of the reflector.
- After having analysed the GMM, we found that transmissivity was not correctly set on the GMM.
SCSIM-TCS integration

- **SCSIM-TCS:**
  - Standalone thermal simulator connected via TCP-IP with the SCSIM scheduler,
  - Multi-threading has been largely used for communication process but also to separate external fluxes and temperatures calculations.

- **ETHERM modules integration:**
  - ETHERM 1.3 view surfaces, solar and albedo flux, earth IR calculator (SV) and temperatures calculator (RPT) have been integrated into SCSIM-TCS.

- **Capabilities:**
  - Temperatures recalculation according to equipment power real-time settings (from OBS) including regulation,
  - Solar, earth vector and fluxes handling in real time and thresholds handling,
  - Multi-configurations (new GMM/TMM) is handled and conf switches are taken into account in less than 1 s,
  - Regulation can be switched on/off for debugging.

SCSIM-TCS performances

- **Size of the reduced models:**
  - @sat: 470 nodes, 956 faces
  - Stress test model: 3500, 1300 faces

- **Measured at DOREA, from a dedicated stress test:**
  - Initialisation: 110 ms (loading ETHERM model)
  - Solar + Albedo + IR recalculation: 23s of CPU
  - $T^\circ$ calc in 1 loop of 80 iterations: 1500ms of CPU

- **Measured from Alphasat model:**
  - Initialisation: 110 ms (loading ETHERM model)
  - Solar flux calculation: 6.8s of CPU
  - $T^\circ$ calc in 1 loop of 32 iterations: 500 ms of CPU

- **Precision:**
  - Compared to @sat thermal analysis results, SCSIM-TCS temperatures restitution confidence is from +/- 0.1 degC to +/- 1.7 degC for the max on thermistances.
Conclusion

- **Actually, the SCSIM-TCS has been integrated into SCSIM**
- The full SCSIM including thermal simulator SCSIM-TCS is accepted for the following S/C:
  - Alphasat (EADS Astrium as prime),
  - O3B (O3B Networks Ltd)
- **In the near future (2013 / 2014):**
  - Iridium Next
  - Turkmenistan Telecom Satellite