Appendix Q

Thermal Spacecraft Simulator Based on TMM Nodal Model
Return of Experience

Sandrine Leroy François Brunetti
(DOREA, France)

Abstract

Many advantages have been depicted to use the same thermal mathematical model from early design phases to operational phases of the satellite : higher reliability of the thermal model, cost reduction by reusing the model and adaptations work load minimisation.
The dynamic spacecraft system simulator is used to validate the spacecraft control center, but also to train operators. This last user case implies the simulator to react to not predicable events, unplanned scenarios while respecting the physics of the environment.
The thermal analysis model is used to validate the satellite design by predicting temperature ranges for embedded units by calculating temperatures of thermal control elements for given configurations of the environment. Because it is also important to simulate the logic of the flight software (such as thermal regulation), an implementation of the transient state based on simulated time cannot be avoided.
The implementation of a satellite simulator connected to the real flight software using the same thermal nodal model faces many challenges such as the recalculation "on the fly" of the view factors, solar, albedo and earth fluxes impacts on the external CAD model. Another challenge is to make the loop flight software - power dissipation generator - thermal calculator not hanging. For this reason, the thermal simulator regulation must be switched off in order to let the flight software drive the thermostats and thermal temperatures time response should also be adjusted in order to fit the physics time .
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. Thanks to the very good time performances of the e-Therm thermal core calculator (external fluxes, view factors and temperatures calculations), a real time module with parallelism features have been implemented to fit the challenge.
After the success of the O3B Networks and Alphasat dynamic spacecraft simulators in 2013, Thales Alenia Space asked DOREA to implement all the following thermal simulators such as Iridium Next, TKM, SGDC and in the future T3S, K5 and KA7.


DOREA
TECHNOLOGY
Dorea
http://www.dorea.fr
Headquarter
Rés. de l'Olivet, Bat F
06110 Le Cannet
Tel : +33 4 93 69 07 48
Technical Center
« Les Alisiers »
Zone 3 moulins
06600 Sophia Antipolis
Tel : +33 4 92 90 08 29
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TECHNOLOGY
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Based on TMM Nodal Model
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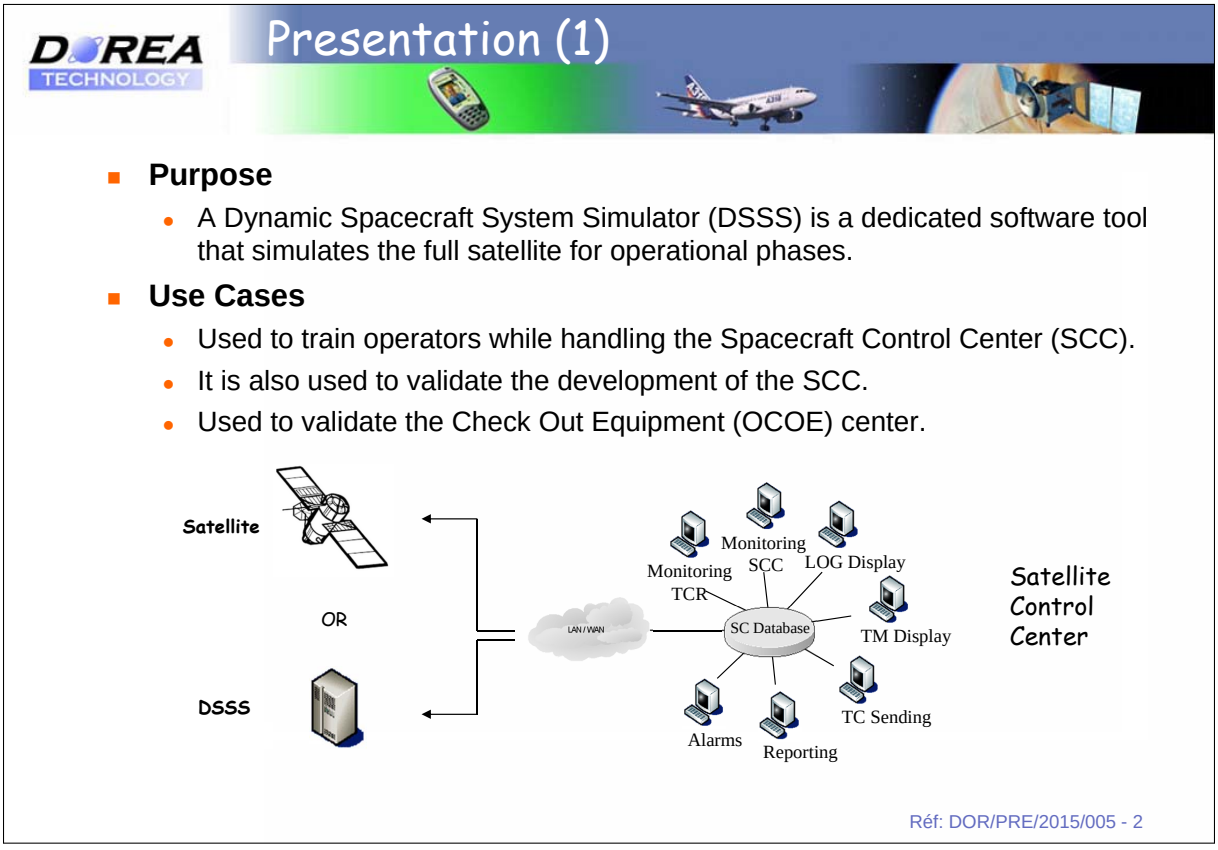
sandrine.leroy@dorea.fr
francois.brunetti@dorea.fr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Presentation (1)
Purpose
A Dynamic Spacecraft System Simulator (DSSS) is a dedicated software tool that simulates the full satellite for operational phases.
Use Cases
Used to train operators while handling the Spacecraft Control Center (SCC).
It is also used to validate the development of the SCC.
Used to validate the Check Out Equipment (OCOE) center.
Satellite
OR
DSSS
LAN / WAN
Monitoring TCR
Monitoring SCC
LOG Display
SC Database
TM Display
TC Sending
Alarms
Reporting
Satellite Control Center
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Presentation (2)

- **DSSS Components:**
  - Real OnBoard flight Software (OBS).
  - Payload / PLIU and TTC modeling,
  - AOCS models,
  - Power "dissipator" module,
  - Thermal TMM Model (TCS).
- **DSSS Characteristics :**
  - It is a real time application,
  - It should simulate the environment and physics as much as possible,
  - Thermal is the subsystem that needs the simulation of physics. A processor is dedicated to the thermal simulator.
- **Advantages**
  - The scope is to reduce the development cost of the DSSS.
  - Using the TMM provided at CDR or PSR has an enormous advantage to fit with the qualifications.

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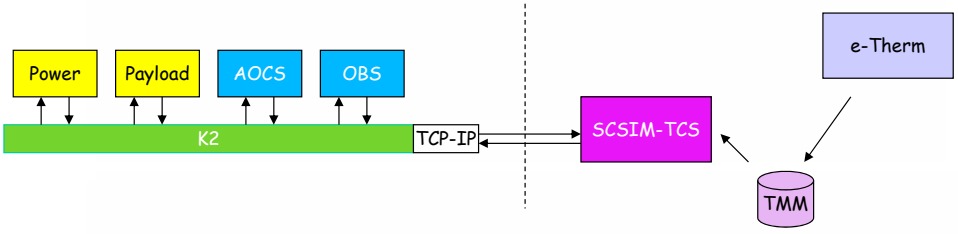
Architecture of SCSIM-TCS

- **Thermal Simulator module (TCS):**
  - DOREA implemented for Thales Alenia Space (TAS) a thermal simulator (SCSIM-TCS) part of the DSSS (SCSIM). The calculator is based on e-Therm CORE module.
  - As it is CPU consuming, a dedicated processor is allocated to the thermal simulator.
  - The architecture is using a co-simulation between the SCSIM (scheduler including the flight software) and the thermal simulator (SCSIM-TCS). The used protocol layer is TCP-IP with a native protocol interface (exchanging binary data values).



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SCSIM-TCS Characteristics

- **Thermal Simulator module (TCS):**
  - SCSIM-TCS performs offline conductive and radiative couplings with a storage in a database of couplings according to the kinematics of the spacecraft.
  - SCSIM-TCS performs a online solar, albedo and earth flux calculation "on the fly".
  - Temperature calculation is calculated in a separate process in parallel of the external fluxes calculation.
  - Temperature regulation is performed by the control loop flight software <=> TCS.
- **Customisation:**
  - The time constant of the thermal simulator is deduced from the thermal analysis (around 1s) and the meeting time with the flight software is not less than 32s (speed x1).
  - External fluxes calculation is performed with a threshold based on the Sun/Sat/Earth angles.

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Validation

- **Successful deployment:**
  - The SCSIM-TCS thermal simulator has been validated in operational conditions for the satellites Alphasat (CNES/ESA/ADS/TAS) and O3B Networks, TKM, Iridium Next satellites (TAS Cannes).
  - It is currently running for SGDC and T3S, K7 and K5A are in preparation.
  - Requirements on T° : delta < 5°C on TM (telemetry = thermistances)
- **Validation approach:**
  - DOREA implemented an automated validation process able to compare given scenarii results provided by e-Therm (decided at KoM) with SCSIM-TCS with automated report generation.
  - DOREA provided a recorder mode enable to store all the flight software inputs in order to reproduce the orbital and powers dissipation "off line".

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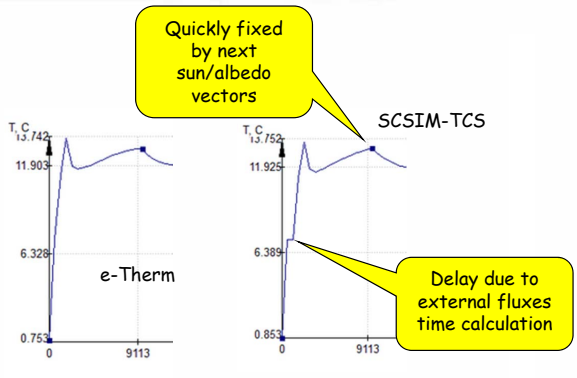
Issues

- **Main Issue:**
  - SCSIM-TCS does know nothing about the future of the scenario.
  - SCSIM- TCS has to calculate on the fly the moving of the sun and earth (for instance positioning to SAM). At thermal analysis level, the calculator knows at the start all the different modes.



- **Solutions:**
  - Both calculators (external fluxes and temperatures) are running in parallel.
  - Discretisation of the external geometry is tuned to reach a good compromise speed / fluxes error.
  - GMM is reduced in order to not decrease TH precision.
  - A CPU time of 20s is reached to a full external fluxes recalculation.

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Model Adaptation

- **Adaptation of GMM**
  - If the model comes from other tools such as ESATAN TMS or SYSTEMA, models are converted thanks to STEP-TAS.
  - From the model provided at CDR or PSR, a GMM reduction should be performed to avoid previous issue (up to 1200 faces).

- **Adaptation of TMM**
  - If the model comes from other tools such as ESATAN TMS or SYSTEMA, models are converted thanks to TMRT.
  - A simplified tubing model and a simplified reccurent part of the geometry will be inserted.
  - If needed (up to 6000 nodes) the TMM should be reduced thanks to TMRT.
  - Missing TH (thermistances) should be added.

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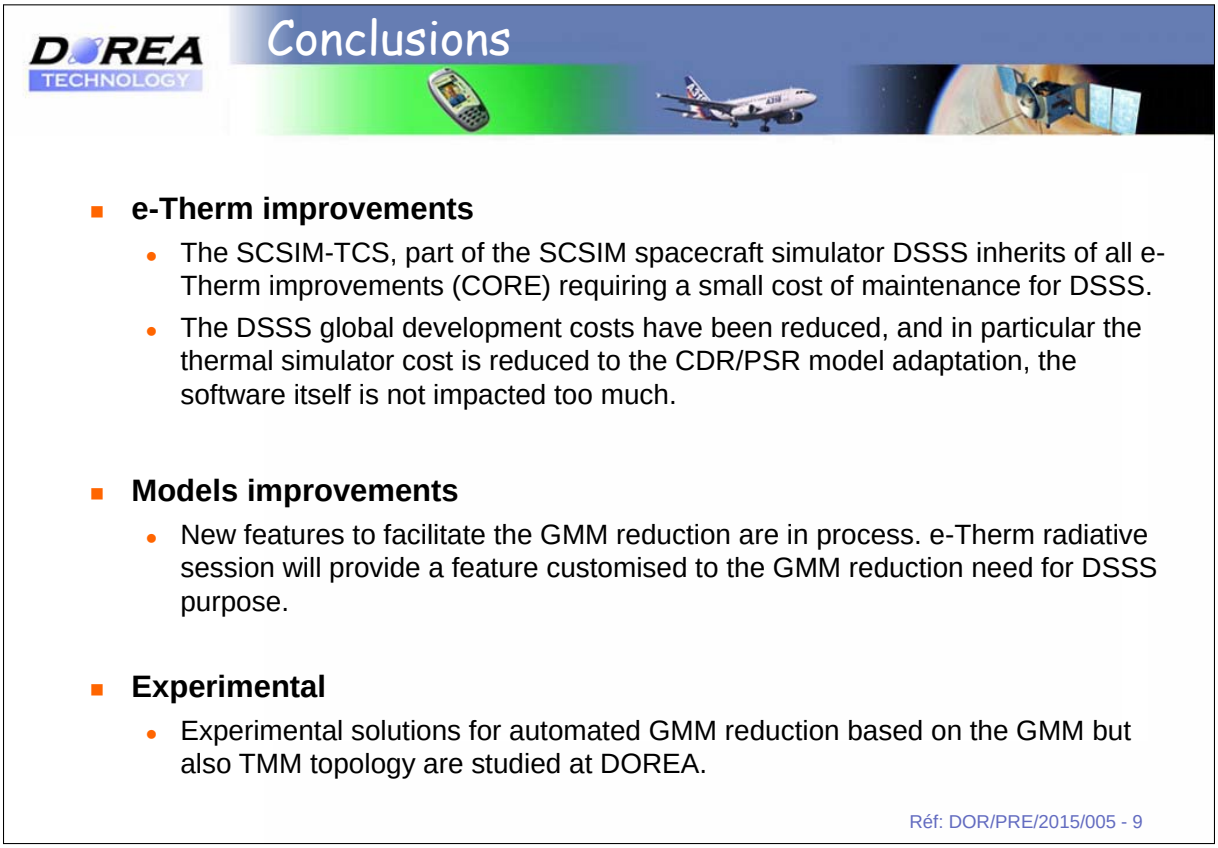
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Conclusions
e-Therm improvements
The SCSIM-TCS, part of the SCSIM spacecraft simulator DSSS inherits of all e-Therm improvements (CORE) requiring a small cost of maintenance for DSSS.
The DSSS global development costs have been reduced, and in particular the thermal simulator cost is reduced to the CDR/PSR model adaptation, the software itself is not impacted too much.
Models improvements
New features to facilitate the GMM reduction are in process. e-Therm radiative session will provide a feature customised to the GMM reduction need for DSSS purpose.
Experimental
Experimental solutions for automated GMM reduction based on the GMM but also TMM topology are studied at DOREA.
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