Appendix S

Experience of Co-simulation for Space Thermal Analysis

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Abstract

Thermal models for space analysis are more and more complex and the idea of having one homogenous model covering different physics such as heat transfer, fluid-dynamics, thermo-dynamics and thermo-elastic is difficult to support. One solution is to open the code to others tools dedicated to bring a complementary physics. The co-simulation is a good candidate to solve the exchange of heterogeneous calculation results but many different techniques and options should be considered at software design level. According to the performances and architecture of the simulators, a co-simulation can be generic or hybrid and impact of the choice of this option may be very expensive. Depending on the physics context, the developer should determine which code would be the master or slave, depending of physics time constants involved in both codes. More depending on computer constraints, an important choice is to specify the communication protocol (such as shared memory or TCP-IP). Some standards such as FMI (Functional Mock Up Interface) are pointing and seam to be pretty candidates, but most of tools provide their own interfaces.
In this presentation we would discuss about DOREA experience and chosen strategy while mixing both CAE simulators : e-Therm (thermal analysis software) bringing the satellite system nodal model and LMS Siemens AMEsim (CFD), especially the dedicated AMErun module with the co-simulation option, to solve the fluids and thermo-dynamics (dysphasic fluxes of a fluid loop) for transient but also steady state calculations.


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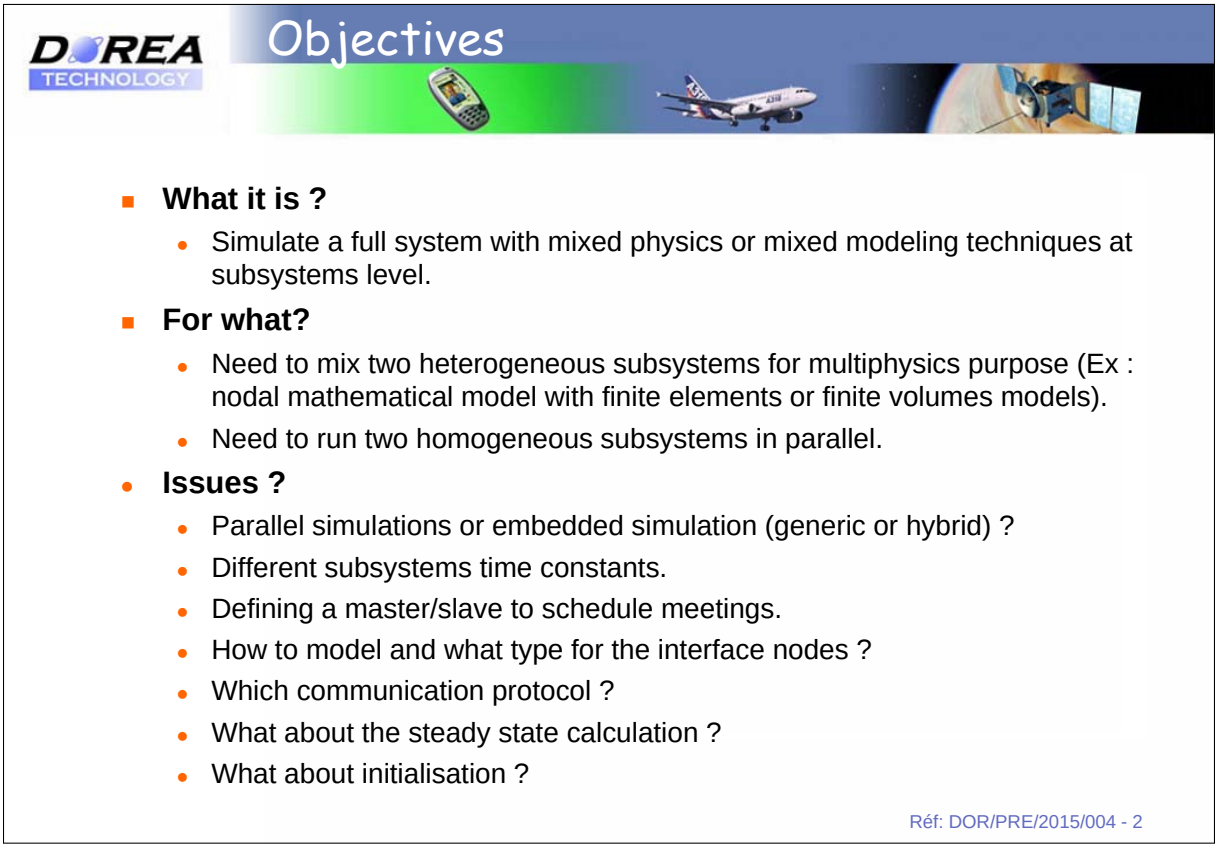
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Objectives
What it is ?
Simulate a full system with mixed physics or mixed modeling techniques at subsystems level.
For what?
Need to mix two heterogeneous subsystems for multiphysics purpose (Ex : nodal mathematical model with finite elements or finite volumes models).
Need to run two homogeneous subsystems in parallel.
Issues ?
Parallel simulations or embedded simulation (generic or hybrid) ?
Different subsystems time constants.
Defining a master/slave to schedule meetings.
How to model and what type for the interface nodes ?
Which communication protocol ?
What about the steady state calculation ?
What about initialisation ?
Réf: DOR/PRE/2015/004 - 2

DOREA experience

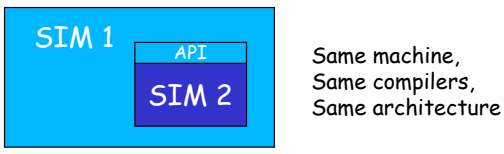
- **In the frame of a CNES project:**
  - For thermal analysis purpose, development of MPL dysphasic fluid loop simulation within the full spacecraft global system.
  - e-Therm (TAS thermal analysis software) should interface with Siemens LMS AMEsim (AMErun).
- **Actors:**
  - Thales Alenia Space implements the integration of MPL within the next generation of platforms.
  - Airbus Defence and Space improves its thermal analysis suite of tools : Systema (Thermisol).
  - DOREA develops the integration of MPL simulation within e-Therm.
- **State of the art:**
  - DOREA succeeded in connecting with LMS AMErun via generic co-simulation module, exchanging results between both tools by shared memory.

Réf: DOR/PRE/2015/004 - 3

Co-simulation architectures

- **Generic co-simulation:**
  - deploys the both simulators (2 executables) in parallel, with a dedicated communication protocol on a given protocol layer.

- **Hybrid co-simulation:**
  - links the both simulations into one executable. Simulators exchanges thanks to an API (Application Programming Interface).



Réf: DOR/PRE/2015/004 - 4

Co-simulation architectures

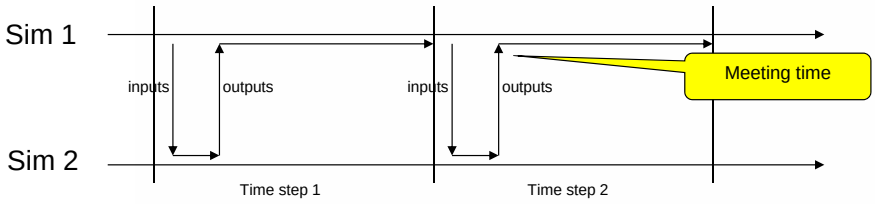
Generic vs Hybrid co-simulations

	Generic	Hybrid
Advantages	•CPU simulation times are done in parallel by several cores (faster). •Both tools are safe to connect or reconnect without interferences.	•Only 1 executable to deploy.
Drawbacks	•TCP-IP may be unsafe and may increase simulation elapsed times	•Compilers, OS and architecture shoud be the same for both tools.

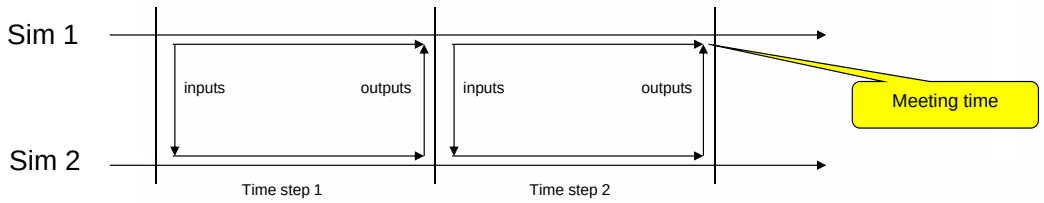
Réf: DOR/PRE/2015/004 - 5

Dynamics of communication

- **Sequential approach:**
  - Simulator 1 is waiting results of Simulator 2 before calculating owns.



- **Parallel approach:**
  - Simulator 1 performs calculation with Simulator 2 previous time step results.

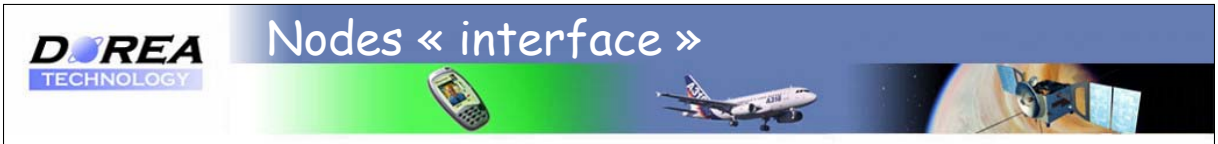


Réf: DOR/PRE/2015/004 - 6

- **To share works, we need to define who is giving orders. Recall of the co-simulation protocol:**
  - **The master:**
    - *« Take my inputs, perform your calculation, we will meet at this time. »*
  - **The slave:**
    - *« I finished my calculation. It is time to meet. Take my outputs. »*

- **Who should be the master:**
  - **If one of the both simulators drives the full system, it is clear that this one should be the master.**
  - **If one of the both systems has a biggest time constant, this one should be the master.**
  - **If all subsystems are identical, it does not care who is master.**

Réf: DOR/PRE/2015/004 - 7



- **To connect the physics with a nodal model (here thermal analysis mathematical model), we need to define nodes as « interfaces ».**
  - **These nodes are shared by the both models.**
  - **For the subsystem that is not « nodal », it is considered as a constant characteristic of the model (here temperature or exchanged power).**
  - **If both subsystems are nodal models, we can consider conductive or radiative couplings to this node.**
  - **For the subsystem that is « nodal », we need to define if the node is boundary or diffusive.**
- **In our example (thermal analysis for space):**
  - **The « interface » nodes are considered as an input characteristics at AMEsim level and diffusive into e-Therm.**
  - **The temperature is given by e-Therm and the exchange power is returned by AMEsim.**
  - **In our case (heat transfer), the exchange power of interface nodes are considered as internal powers within the equation.**

Réf: DOR/PRE/2015/004 - 8

Protocols and Layers

- **Generic co-simulation protocol layers**
  - **The both executables may communicate thanks to shared memory. They should run on the same cluster node.**
  - **The both executables may also communicate via TCP-IP. Don't care about machines OS, memory or architecture (64 or 32 bits).**

Note : It is obvious that if the meeting time span is short (around the second), TCP-IP is not recommended because of network instabilities.

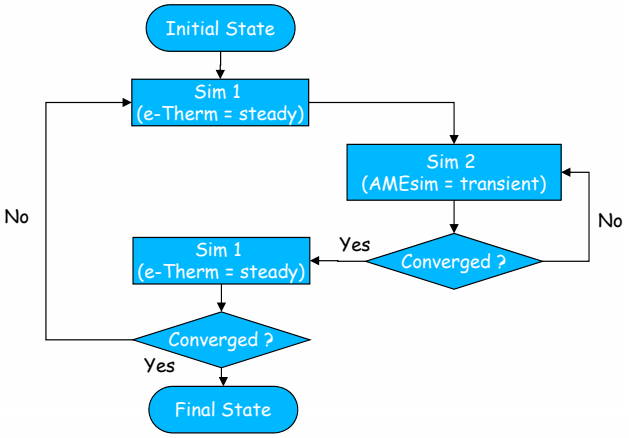
- **Hybrid co-simulation protocols**
  - **No need of a dedicated protocol, the master calls routines from the API provided by the slave simulator. Warning : time CPU of simulation computation can be added (sequential).**
- **Existing protocols**
  - **The most common protocol is FMI (Functional Mock Up Interface), but native protocols (AMEsim, Simulink, ...) are also provided by developers.**

Réf: DOR/PRE/2015/004 - 9

Convergence (here with AMEsim)

- **Transient State:**
  - **Based on the convergence of the slave simulation, results are taken into account for the calculation of the next time step.**
- **Steady State:**

AMEsim does not provide a steady state calculation, a transient with a stop condition has to be considered.



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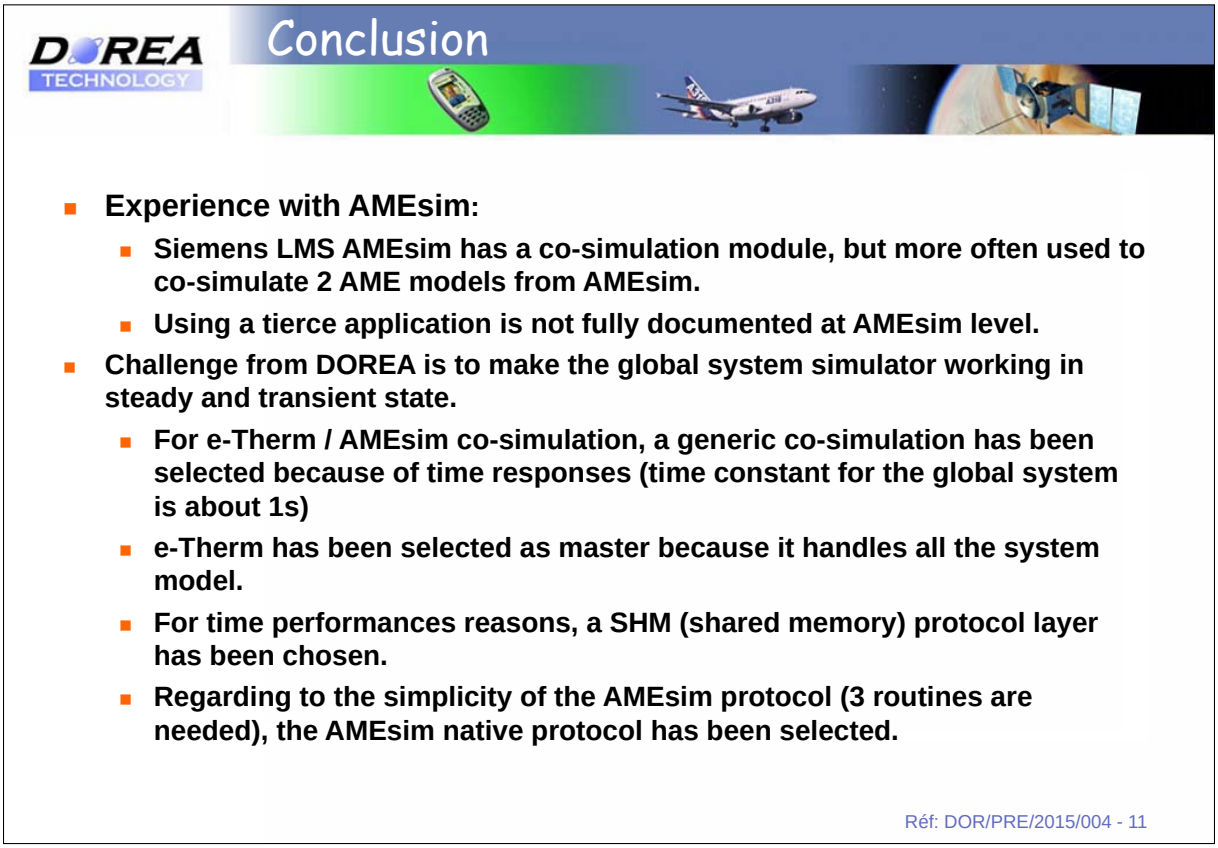

- **Experience with AMEsim:**
  - **Siemens LMS AMEsim has a co-simulation module, but more often used to co-simulate 2 AME models from AMEsim.**
  - **Using a tierce application is not fully documented at AMEsim level.**
- **Challenge from DOREA is to make the global system simulator working in steady and transient state.**
  - **For e-Therm / AMEsim co-simulation, a generic co-simulation has been selected because of time responses (time constant for the global system is about 1s)**
  - **e-Therm has been selected as master because it handles all the system model.**
  - **For time performances reasons, a SHM (shared memory) protocol layer has been chosen.**
  - **Regarding to the simplicity of the AMEsim protocol (3 routines are needed), the AMEsim native protocol has been selected.**