Appendix O

SYSTEMA — THERMICA

Timothée Soriano Antoine Caugant
(Airbus Defense and Space SAS, France)

Abstract

Systema version 4.8.0 includes many improvements and corrections. Especially, the material database now handles different phases so to be able to set not only beginning-of-life and end-of-life properties but also for any customizable condition.
Moreover, a new ray-tracing algorithm based on a quasi-random approach has been developed and shown a very significant improvement in the accuracy of radiative couplings and external fluxes evaluations.
The python interface keeps being improved with more and more features and there are available scripts to export/import models in ASCII format or to help in the setting of parametric analysis.
Besides, the current developments are focusing on several new features. Some have already well progressed like the integration of Systema in test facilities or the management of convection so to ease the correlation with ambient testing. A particular attention is also given to the Step-Tas interface. The 4.8.0 version stabilizes a lot the export of Systema and Thermisol models (GMM and TMM). In the next 4.8.1 version, the import should also be improved thanks to an improved management of the cutters.

Systema

Systema - Thermica

30th European Space Thermical Analysis Workshop

Timothée Soriano – Antoine Caugant

05-06 October 2016

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Systema

Content

Current status on Systema

Step-TAS and ASCII interfaces

Systema integration in test process

4.8.0 version release

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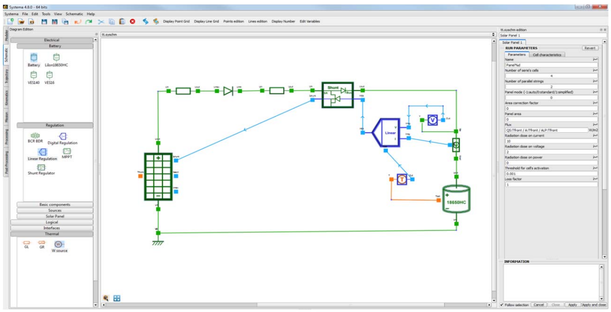
Current status

Long Term Support current version: v4.5.3 (08/2013)

Short Term Support release: v4.8.0 (07/2016)



Demonstration video: https://www.youtube.com/watch?v=oT8ZIjX7nV0

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Systema interfaces

- Step-TAS and ASCII

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Step-TAS interface

Having a more complete and robust Step-TAS interface is one of the main objectives of current developments. The version 4.8.0 stabilizes many features and 2017 developments will also increase the robustness of import / export functionalities.

A guideline is available for Step-TAS / Systema import export

4.8.0 corrections

– Thermo-optical properties are correctly exported (imported) even with transparency
– Truncated Disc / Cylinder / Cone with swapped angles corrected
– Boxes are split into rectangles
– Polygon cutters may be split into extruded triangle cutters

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Step-TAS interface

2017 developments

- **Better support of cutters**
  - Half-space cutter implementation
  - Inside / Outside cutting
  - Finite / Infinite cutters
  - Transformations
- **Corrections**
  - Automatization of polygon splitting on shapes and cutters on export
  - Other fixes (sides numbering on reversed shapes, …)

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ASCII format

Why needing an ASCII interface (other than Step-TAS)

- To be able to read / write easily a meshed model
- To ease copy / paste and model assembly using a simple text file
- To interface with other tools (mainly in-house tools)
- To be able to interface with Excel for geometrical definitions
- … *Because many people asked for it !*

Which ASCII format

Different purpose, different needs, different formats…

- CSV-like: Interface with Excel
- Yaml: Simple indented format easy to read and write (available standard libraries)
- …

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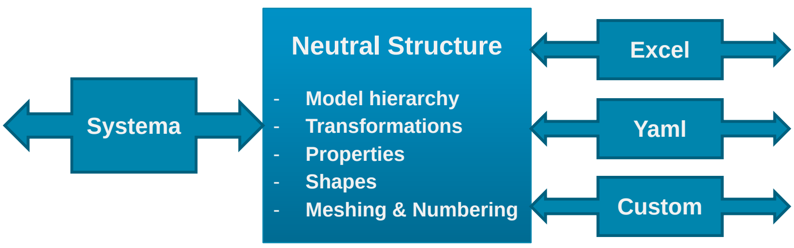
ASCII format

ASCII interfaces: technical choice – Python script

It exists a Python library able to read/write Systema geometrical models

- The library may be used as it is (no Python knowledge required)
- It may be modified independently of Systema (no need to wait for a new release of Systema for updating or correcting a Import/Export)
- It is based on a structure allowing the definition of new format definitions



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ASCII format

Customize your export

Possibilities to (implemented in the existing library but not exhaustive):

- Define bijective export / import (model1 > export > import > model2 = model1)
- Extend properties (no inheritance)
- Remove transformations (all data in main frame)
- Explicit numbering (no numbering rules)
- Use only triangles and quadrangles (split of curved shapes)

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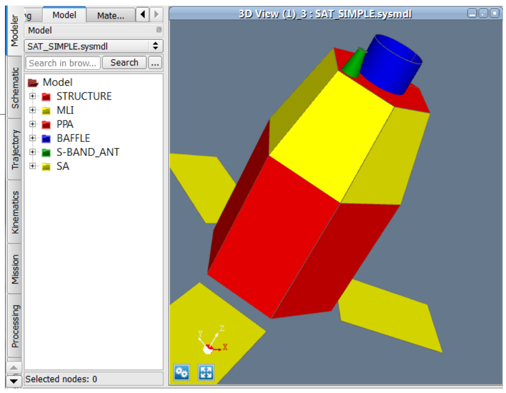
ASCII format

Example of Yaml




```
Model :
    Name: SAT_Simple
    Meshing:
        Subdivision: {a: 1, b: 1, c: 1}
        Numbering: {start: 100, inc: 100}
        Method: Generic
        MeshInc: 1
        Order: '1st dir / 2nd dir'
    Objects:
        - STRUCTURE:
            Color: [255, 0, 0]
            CoatActivity: 'Only positive'
            Coatings:
                Emission: ['Normal', 'Normal']
                Material: ['SM_Ext_MatF', 'SM_Ext_MatF']
            BulkActivity: 'Both sides'
            Bulk:
                Thickness: 0.001
                Material: 'DEF_MAT'
            Shapes:
                - New Quadrangle:
                    Geometry:
                        Type: Quadrangle
                        Points: {P1: (-0.5 0.8 0.06), P2: (0.5 0.8 0.06), P3: (0.5 0.8 1.86), P4: (-0.5 0.8 1.86)}
                - New Quadrangle (1):
                    Geometry:
                        Type: Quadrangle
                        Points: {P1: (-0.5 0.8 1.86), P2: (-0.5 0.8 0.06), P3: (-1 0 0.06), P4: (-1 0 1.86)}
                - New Quadrangle (2):
                    Geometry:
```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Systema integration in test process

- DySCO synergy and convection

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DySCO synergy

DySCO – *Dynaworks-Systema Collaboration*

Objectives

- Allow a smooth thermal process from simulation to tests
- Get rid of manual operations
- Shorten test campaigns

Systema - *simulation*

- Generates mathematical models from digital mock-ups
- Produces prediction data (ex: temperatures)

Dynaworks - *testing*

- Support test campaigns
- Process and store sensors data

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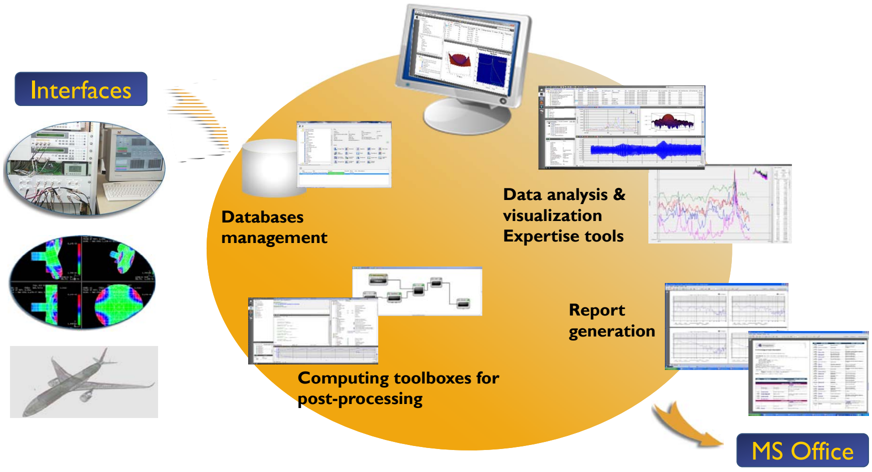
DynaWorks

DynaWorks

- Integrated solution for data management, visualization, processing and reporting



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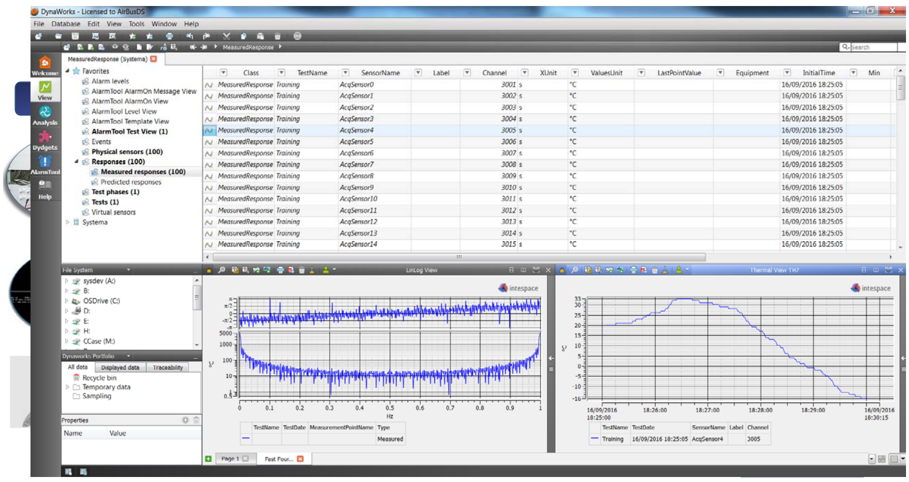
Systema

DynaWorks

DynaWorks

- Integrated solution for data management, visualization, processing and reporting



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Current activities

Systema

Automatic import of simulation data in Dynaworks data-base

- Systema GMM (material, model and meshing) and Step-TAS formats
- Temperature data for every thermal nodes (Thermisol output)
- Thermal node / sensor pairing

Integrated 3D display in Dynaworks

- Large model management and display
- Real-time data over thermal models
- Comparison simulation / tests
- Replay of data sequences

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Upcoming activities

Systema

2017 activities

- Sensor management including invalidation
- Test results exploitation on thermal model
- Test prediction
- Advanced data import

Perspectives

- Integration of Post-prediction: launch of Thermica from Dynaworks

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Systema

Convection

A new Thermica module

- **Setting the convection**

More and more, it is required to take into account in the thermal analysis the contribution of natural and/or forced convection, i.e. the thermal exchange due to the contact of the model surfaces with a fluid (usually called “air nodes” in the TMM).

- **Convection in TMM vs CFD analysis**

The integration of the convection in TMMs requires a simplification of this physical phenomena, not as accurate as a CFD analysis, but allows combining it with radiative and conductive effects within a complete mathematical model.

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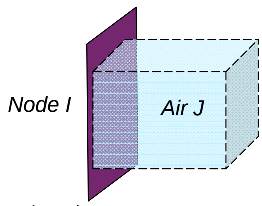
Systema

Convection

Convective exchanges

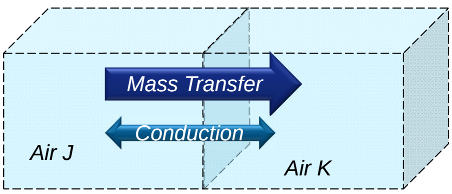
- **Surface / Air nodes conducto-convective couplings**



$$GL(I,J) = k.S.\Delta T^{\alpha}$$

The conducto-convective coupling between the surface and the air node depends on the surface *S* of the contact and two coefficients *k* and α that can be set constant by cavity (usually scaled by comparison with CFD analysis or test), or according to the Mac Adams formulae.

- **Air / Air nodes other couplings**



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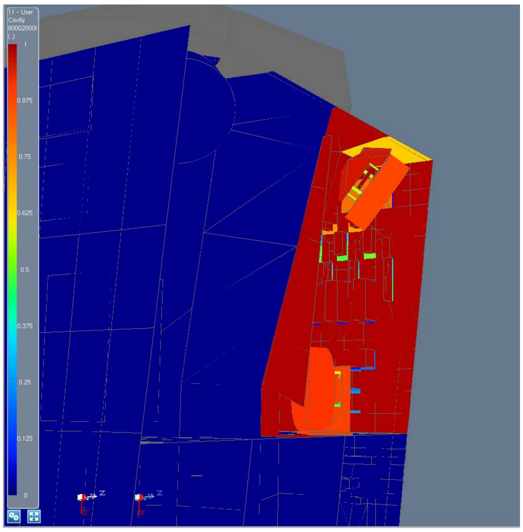
Convection

Cavity identification

This is the major task of this module:

- Identifies and set cavities
- Computes area of nodes belonging to cavities



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Convection

Export of couplings

Surfaces – Air couplings automatically set by cavities using different formula choices written with parametric formulations so to ease the correlations. Couplings are generally written in the form of

$k.S.\Delta T^{\alpha}$

```
#   Convective Couplings
#   --------------------
#
#   File : SAT_A_int_conv.gf.nwk
#   Version : Thermica  V.4.8.1dev1 released on August 2016
#   Executed on : Wed Aug 29 19:49:04 1923
#   Input files :
#      - Sysset : SAT_A_int_conv.sysset


$LOCALS
    K_External = 3.0;
    Alpha_External = 0.25;
    K_Cavity1 = 3.0;
    Alpha_Cavity1 = 0.25;
    K_Cavity2 = 3.0;
    Alpha_Cavity2 = 0.25;
    ...
    ...

$NODES
    # Cavity nodes
    B 8000000 = 'External cavity', T = 0;
    B 80001000 = 'Cavity 1', T = 0;
    B 80002000 = 'Cavity 2', T = 0;
    B 80003000 = 'Cavity 3', T = 0;
    B 80004000 = 'Cavity 4', T = 0;

$CONDUCTORS
    # Conducto-Convective Couplings in Cavity 8000000
        GL( 8000000 , 210000 )  =  K_External * (1.302902E-02 * 5.370652E-02) * (ABS(T:8000000 - T:210000))**Alpha_External;
        GL( 8000000 , 210001 )  =  K_External * (1.082140E-02 * 6.018357E-02) * (ABS(T:8000000 - T:210001))**Alpha_External;
        GL( 8000000 , 210002 )  =  K_External * (6.120670E-03 * 6.666063E-02) * (ABS(T:8000000 - T:210002))**Alpha_External;
        GL( 8000000 , 210003 )  =  K_External * (1.012743E-03 * 7.313768E-02) * (ABS(T:8000000 - T:210003))**Alpha_External;
        GL( 8000000 , 210500 )  =  K_External * (2.071565E-02 * 5.370652E-02) * (ABS(T:8000000 - T:210500))**Alpha_External;
        GL( 8000000 , 210501 )  =  K_External * (1.197503E-02 * 6.018357E-02) * (ABS(T:8000000 - T:210501))**Alpha_External;
        GL( 8000000 , 210502 )  =  K_External * (4.917708E-03 * 6.666063E-02) * (ABS(T:8000000 - T:210502))**Alpha_External;
        ...
        ...
    # Conducto-Convective Couplings in Cavity 80004000
        GL( 80004000 , 13450 )  =  K_Cavity1 * (8.635908E-01 * 5.194920E-01) * (ABS(T:80004000 - T:13450))**Alpha_Cavity1;
        GL( 80004000 , 18302 )  =  K_Cavity1 * (9.939398E-01 * 2.360051E-02) * (ABS(T:80004000 - T:18302))**Alpha_Cavity1;
        GL( 80004000 , 18303 )  =  K_Cavity1 * (6.312625E-01 * 5.120003E-03) * (ABS(T:80004000 - T:18303))**Alpha_Cavity1;
        GL( 80004000 , 18304 )  =  K_Cavity1 * (5.681363E-01 * 5.119996E-03) * (ABS(T:80004000 - T:18304))**Alpha_Cavity1;
        GL( 80004000 , 18305 )  =  K_Cavity1 * (5.571142E-01 * 5.120004E-03) * (ABS(T:80004000 - T:18305))**Alpha_Cavity1;
        GL( 80004000 , 18306 )  =  K_Cavity1 * (6.202405E-01 * 5.119997E-03) * (ABS(T:80004000 - T:18306))**Alpha_Cavity1;
        ...
        ...
    # Conducto-Convective Couplings in Cavity 80003000
        GL( 80003000 , 16500 )  =  K_Cavity2 * (1.000000E+00 * 3.954220E-01) * (ABS(T:80003000 - T:16500))**Alpha_Cavity2;
        GL( 80003000 , 18402 )  =  K_Cavity2 * (1.000000E+00 * 2.360050E-02) * (ABS(T:80003000 - T:18402))**Alpha_Cavity2;
        GL( 80003000 , 18403 )  =  K_Cavity2 * (7.034068E-01 * 5.120000E-03) * (ABS(T:80003000 - T:18403))**Alpha_Cavity2;
        GL( 80003000 , 18404 )  =  K_Cavity2 * (7.034068E-01 * 5.120002E-03) * (ABS(T:80003000 - T:18404))**Alpha_Cavity2;
        GL( 80003000 , 18405 )  =  K_Cavity2 * (7.034068E-01 * 5.120001E-03) * (ABS(T:80003000 - T:18405))**Alpha_Cavity2;
        GL( 80003000 , 18406 )  =  K_Cavity2 * (7.034068E-01 * 5.120000E-03) * (ABS(T:80003000 - T:18406))**Alpha_Cavity2;
        GL( 80003000 , 18407 )  =  K_Cavity2 * (9.195491E-01 * 1.631379E-01) * (ABS(T:80003000 - T:18407))**Alpha_Cavity2;
        GL( 80003000 , 18411 )  =  K_Cavity2 * (9.219219E-01 * 3.420595E-01) * (ABS(T:80003000 - T:18411))**Alpha_Cavity2;
        GL( 80003000 , 40001 )  =  K_Cavity2 * (1.000000E+00 * 2.343217E-02) * (ABS(T:80003000 - T:40001))**Alpha_Cavity2;
```

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Convection

Further improvements

- **Cavity stratification**

The stratification of cavities will allow defining several layer of air nodes within a cavity and getting their properties. This will help the user setting convective couplings.

- **Use of Mac Adams formulas**

As an option, conducto-convective couplings will be written using Mac Adams formulas which take into account the orientation of the shapes (vertical, horizontal upper, horizontal lower surfaces…) and the flow type (laminar or turbulent) according to the value of the Prandtl and Grashof numbers product.

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IR Camera

Another new Thermica module

- **What for ?**

The IR camera simulator is a tool designed to reproduce the behavior of a camera in a test facility. It produces a map of pixels with incoming IR fluxes.
It is then also possible to isolate the reflection of the environment onto the model.

- **Camera modelling**

The camera is modeled taking into account the localization of the instrument and its aperture angle.

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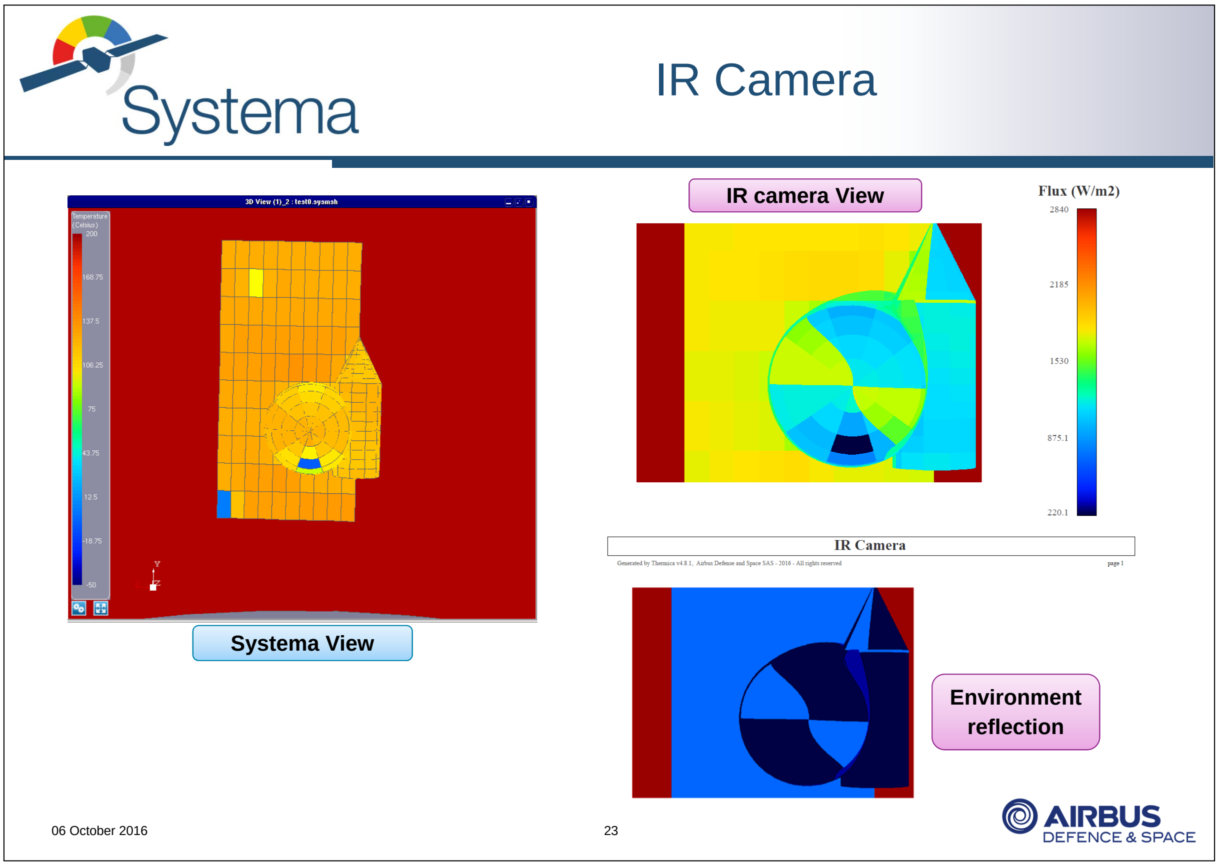
Systema
IR Camera
IR camera View
Flux (W/m2)
2840
2185
1530
875.1
220.1
IR Camera
Systema View
Environment reflection
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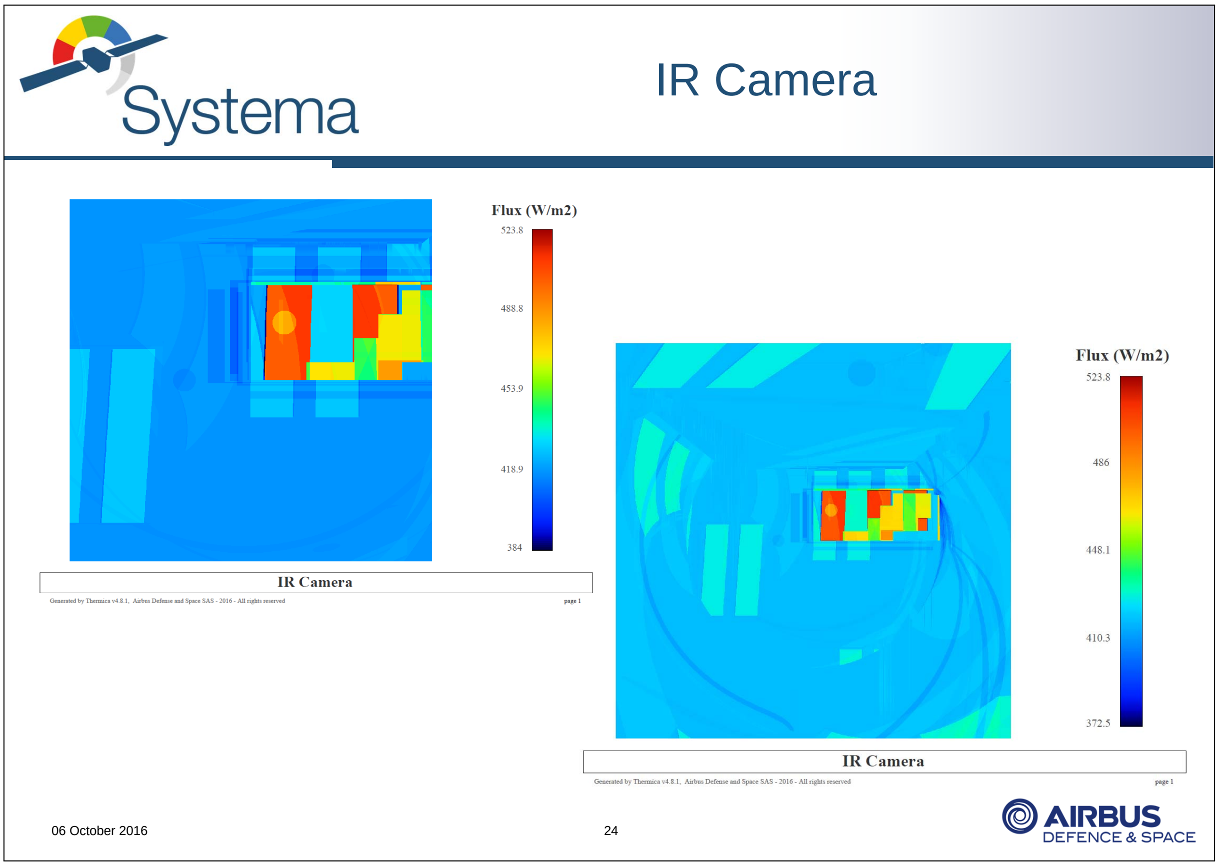
Systema
IR Camera
Flux (W/m2)
523.8
488.8
453.9
418.9
384
IR Camera
Flux (W/m2)
523.8
486
448.1
410.3
372.5
IR Camera
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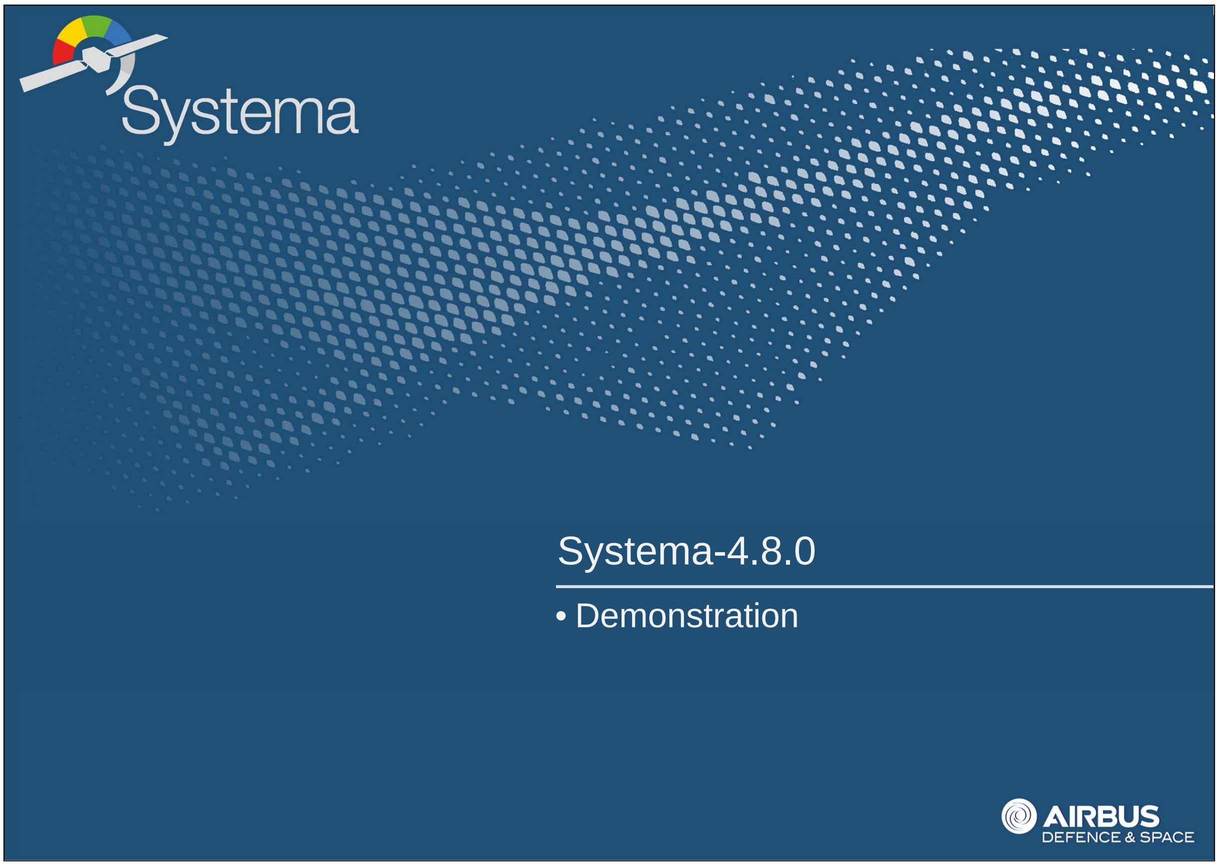
Systema
Systema-4.8.0
• Demonstration
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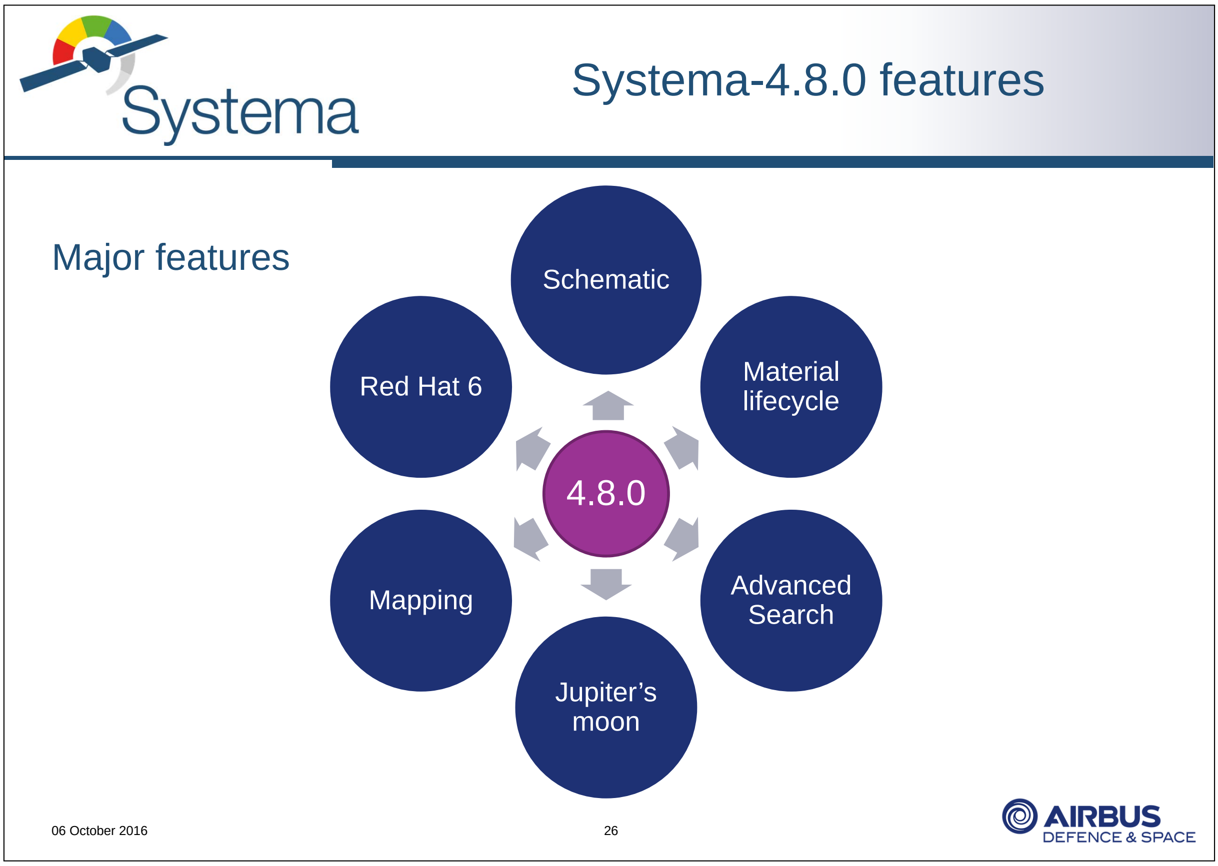
Systema
Systema-4.8.0 features
Major features
Schematic
Red Hat 6
Material lifecycle
4.8.0
Mapping
Advanced Search
Jupiter's moon
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Systema

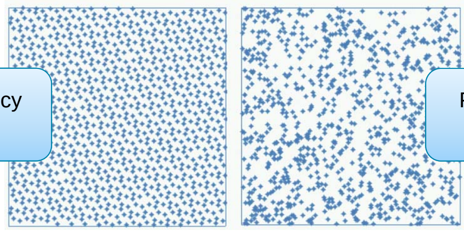
Quasi Monte-Carlo

Improvement of Ray-Tracing accuracy

- **Classical Monte-Carlo**
  - Uses independent random numbers between 0 and 1 for each parameter

  (4 parameters are required for the ray emission; 2 for emission point / 2 for direction)

- **Quasi Monte-Carlo approach**
  - Minimize the discrepancy of parameters



Low discrepancy method

Pseudo random method

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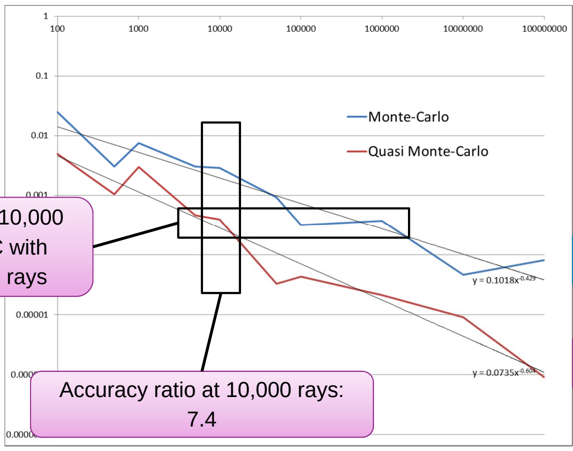
Quasi Monte-Carlo

Improvement of Ray-Tracing accuracy

- **Evaluation of the View Factor convergence between two squares**



Accuracy of QMC with 10,000 rays equivalent to MC with 100,000 or 1,000,000 rays

Convergence rate 0.429

Convergence rate 0.604

Accuracy ratio at 10,000 rays: 7.4

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Quasi Monte-Carlo

Improvement of Ray-Tracing accuracy

- **Example of errors reports from Thermica**

```
IR Gebhart Factor Budget :   (maximum error = 2.6625 %)
--------------------------

 |-----------------------------------------------------------------|
 |     REF   sum : error between        0.1 % and           5 %:   |
 |-----------------------------------------------------------------|
 |         Emission Node       | Rays  Emitted |  REF sum   |  Error   |
 |-----------------------------|---------------|------------|----------|
 |                         164 |     1000      |    1.027   |  2.66 %  |
 |                         100 |     1000      |   0.9742   |  2.58 %  |
 |                         116 |     1000      |    1.026   |  2.56 %  |
 |                         169 |     1000      |    1.023   |  2.26 %  |
 |                         131 |     1000      |   0.9775   |  2.25 %  |
 |                         129 |     1000      |   0.9783   |  2.17 %  |
 .....
 .....
 |                         114 |     1000      |    1.001   |  0.113 % |
 |-----------------------------------------------------------------|
 |  Number  of  REF  (IR)  below     0.1 % of error:      11  (     11.5 %) |
 |-----------------------------------------------------------------|
```

```
IR Gebhart Factor Budget :   (maximum error = 1.29107 %)
--------------------------

 |-----------------------------------------------------------------|
 |     REF   sum : error between        0.1 % and           5 %:   |
 |-----------------------------------------------------------------|
 |         Emission Node       | Rays  Emitted |  REF sum   |  Error   |
 |-----------------------------|---------------|------------|----------|
 |                         153 |     1000      |    1.013   |  1.29 %  |
 |                         177 |     1000      |   0.9875   |  1.25 %  |
 |                         167 |     1000      |   0.9876   |  1.24 %  |
 |                         166 |     1000      |   0.9879   |  1.21 %  |
 |                         117 |     1000      |    1.012   |  1.19 %  |
 |                         156 |     1000      |   0.9886   |  1.14 %  |
 .....
 .....
 |                         107 |     1000      |   0.9989   |  0.112 % |
 |-----------------------------------------------------------------|
 |  Number  of  REF  (IR)  below     0.1 % of error:      16  (     16.7 %) |
 |-----------------------------------------------------------------|
```

MC – 1000 rays

2x More accurate

QMC – 1000 rays

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Quasi Monte-Carlo

Improvement of Ray-Tracing accuracy

- **Example of errors reports from Thermica**

```
IR Gebhart Factor Budget :   (maximum error = 0.969643 %)
--------------------------

 |-----------------------------------------------------------------|
 |     REF   sum : error between        0.1 % and           5 %:   |
 |-----------------------------------------------------------------|
 |         Emission Node       | Rays  Emitted |  REF sum   |  Error   |
 |-----------------------------|---------------|------------|----------|
 |                         113 |     10000     |     1.01   |  0.97 %  |
 |                         150 |     10000     |   0.9928   |  0.719 % |
 |                         137 |     10000     |    0.993   |  0.704 % |
 |                         128 |     10000     |    1.006   |  0.602 % |
 |                         167 |     10000     |    1.006   |  0.573 % |
 |                         116 |     10000     |    1.006   |  0.568 % |
 .....
 .....
 |                         126 |     10000     |   0.9989   |  0.111 % |
 |-----------------------------------------------------------------|
 |  Number  of  REF  (IR)  below     0.1 % of error:      26  (     27.1 %) |
 |-----------------------------------------------------------------|
```

```
IR Gebhart Factor Budget :   (maximum error = 0.222857 %)
--------------------------

 |-----------------------------------------------------------------|
 |     REF   sum : error between        0.1 % and           5 %:   |
 |-----------------------------------------------------------------|
 |         Emission Node       | Rays  Emitted |  REF sum   |  Error   |
 |-----------------------------|---------------|------------|----------|
 |                         106 |     10000     |    1.002   |  0.223 % |
 |                         146 |     10000     |    1.002   |  0.209 % |
 |                         184 |     10000     |    0.998   |  0.204 % |
 |                         137 |     10000     |    0.998   |    0.2 % |
 |                         111 |     10000     |   0.9981   |  0.193 % |
 |                         153 |     10000     |   0.9981   |  0.185 % |
 .....
 .....
 |                         132 |     10000     |    1.001   |  0.101 % |
 |-----------------------------------------------------------------|
 |  Number  of  REF  (IR)  below     0.1 % of error:      66  (     68.8 %) |
 |-----------------------------------------------------------------|
```

MC – 10000 rays

4x More accurate

QMC – 10000 rays

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Systema

Quasi Monte-Carlo

Conclusion

- **Get better accuracy**
  For the same computational effort, the ray-tracing process is much more accurate
  Usually, The computation is about 4 times more accurate with 10,000 rays

- **Save computation time**
  For reaching a certain level of accuracy, the QMC approach will require about 10 times less rays than the classical Monte-Carlo approach, leading to a great computation time reduction
  Especially in the 4.8.0 in which it is possible to automatize the re-run of the Monte-Carlo so to reach a specified level of accuracy

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Conclusion

The 4.8.0 version

- **New features**
  The current version brings many improvements and new features such as
  - The Quasi Monte-Carlo ray-tracing
  - The materials lifecycle management
  - The advanced search
  - Schematic module for thermo-electrical analysis
  - Mapping module
  - Step-TAS export corrections
  - …

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Conclusion

2017 developments

- **More to come…**

  Next year developments will add and stabilize even more new features
  - The convective module
  - The IR camera simulator
  - Extended cutters definitions
  - Step-TAS improvements
  - The DySCO plugins for Dynaworks
  - …

  See you next year to know more about other new developments

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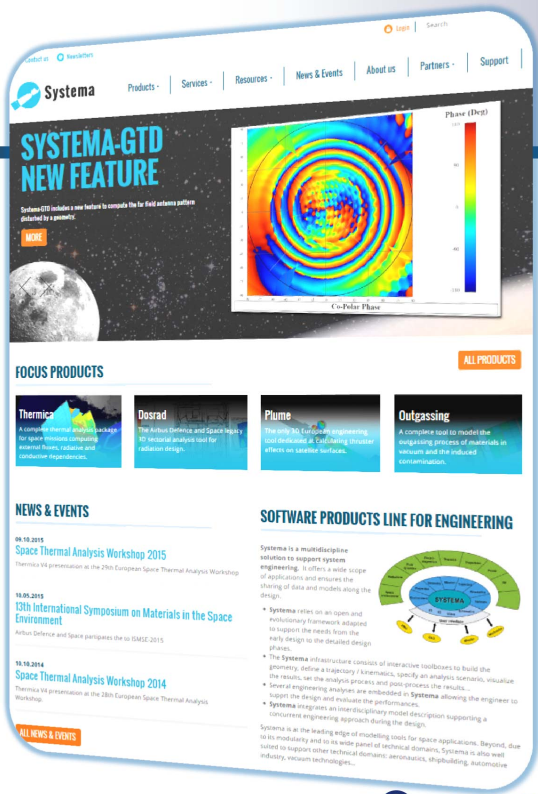

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Contact:
timothee.soriano@airbus.com
antoine.caugant@airbus.com
engineering.software@airbus.com

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