Appendix F

GENETIK

Optimisation tool for thermal analyses performed with SYSTEMA

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Abstract

GENETIK is a software developed by CNES to facilitate the detection of thermal sizing cases. It is based on genetic algorithm to explorate solution space and to determine the worst environmental conditions (solar, albedo and earth fluxes).
With some improvements on thermal study management in SYSTEMA V4, and particularly the possibility to perform parametric analyses, the coupling of optimization tool to SYSTEMA is made possible.
The objectives of the presentation are to:

- Present GENETIK functionalities
- Develop the possibilities of this optimisation tool

GENETIK+

OPTIMIZATION TOOL FOR THERMAL ANALYSES (PERFORMED WITH SYSTEMA)

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14 – 15 October 2014

AGENDA

- CONTEXT OF THE STUDY
- 2013 DEVELOPMENTS – GAETAN FUNCTIONNALITIES IMPLEMENTED INTO SYSTEMA
- GENETIK+ OVERVIEW
- APPLICATION CASES
- PERSPECTIVES AND CONCLUSION

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CONTEXT OF THE STUDY

Missions become more complex:

Drifting orbits, complex spacecraft attitudes, challenging thermal control designs…Limitation of classical thermal analyses for:

- Sizing thermal case definition
- Thermal design optimisation (radiator size / coating vs. Heating power budget)
- Calculation margins management

→ Development of GENETIK tool (2005 – 2009)

- GENETIK coupled with THERMICA V3
- Limited to analyses on external fluxes
- Not user friendly…

CONTEXT OF THE STUDY

Evolution of SYSTEMA :

New functionnalities of SYSTEMA V4:

- SYSTEMA easily controlled by Python scripts
- 2013 developments – Introduction of GAETAN main functionalities into SYSTEMA (Python script)

→ Possibility to interface GENETIK with SYSTEMA

- 2014 : Extension of GENETIK possibilities → Development of GENETIK+

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2013 DEVELOPMENTS

2013 – GAETAN main founctionnalities implemented into SYSTEMA:

Development in collaboration with SYSTEMA team.

- GAETAN main functionnalities implemented:
  - Stabilized cycling computation
  - Temperature initialization (file / group /…)
  - …
- Formalism for management of complete thermal analysis with SYSTEMA
  - Calculation case definition = « SYSTEMA skeleton »
  - Global thermal Study definition

2013 DEVELOPMENTS

Calculation case definition:

One file to describe a calculation case:

```
# This is an example of a Computation Case file
#-------------------------------------------------

# Case Name
CASE = calcul_case_1

# Model Definition
#-----------------------
$MODEL
$GMM
  MATERIAL  = material.sysmtr
  MODEL = model\Test.sysmdl
  MESHING  = model\Test.sysmsh
$TMM
  model\user_file.dat

# Load Case Definition
#-----------------------
$LOADCASE
$GMM
  TRAJECTORY  =     { Type=SunSynchronuous,
                      Alt=830, AscNode=22.5,
                      Date="22/10/2013  00:00:00.000",  End=1 }
  KINEMATICS  = { V1=-Z, D1=Sun, V2=-Y, D2=Velocity }
  MISSION  = { Comput=15.0 }
$TMM
        model\inits.mwk
        model\heaters.mwk

# Calculation Process Definition
#-------------------------------------
$PROCESS
# This is where to set a process file (Thermica+Thermisol)  with the command:
# PROCESS = comput.sysprc
# Or to indicate the process by specs
$THERMICA
        SUNCST  = 1400.0
        ALB_EARTH  = 0.31
        T_EARTH  = -25.0
        NB_RAYS_GR  = 10000
        NB_RAYS_SF  =  5000
        GL_THRESH  = 1.0e-4

        SEQUENCE  = NOD + GR + GL + SF + PF

$THERMISOL
  Transient  = SCRANK
```

Nodal Network definition:
- Nodes definition
- Couplings (user files)

Load case definition:
- GMM : External fluxes → Systema mission
- TMM : Heating power, thermal dissipation …(user files)

Computation process definition:
- THERMICA process
- THERMISOL process

2013 DEVELOPMENTS

Complete thermal study management:

One file to define the complete thermal study:

```
#Example of Study file
#-----------------------

#Study name
#-----------
STUDY = SVOM

#Definition of calculation case sequence
#---------------------------------------

$SEQUENCE
    RUN = case_1
    RUN = case_2
    RUN = case_1+case_2

#Optional block to overload GMM and TMM variables
#------------------------------------------------
$PARAMETER

    $TRAJECTORY:altitude=[600,800,50]

    $MODEL:alpha={0.5,0.8,0.9}

    $TMM:heating_power=15

    $TRAJECTORY:altitude={700,800}+$KINEMATICS:angle=[20,50,5]
    +KINEMATICS:pointing_vector=[(1 0 0),(0 1 0),5]

#Definition of post-processing
#-----------------------------
$POSTPRO
POST=T:1000
POST=QS1000
POST=FLUXR(D50,D100,B999,B999)
```

Calculation sequence definition:
- List of calculation cases
- Possible to couple calculation cases

Variables overload definition:
- Simple way to perform parametric analyses

Post processing definition:
- All systema output / subroutines
- Next : loading post-processing file

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GENETIK+ OVERVIEW

GENETIK+ presentation:

Tool based on genetic algorithm :

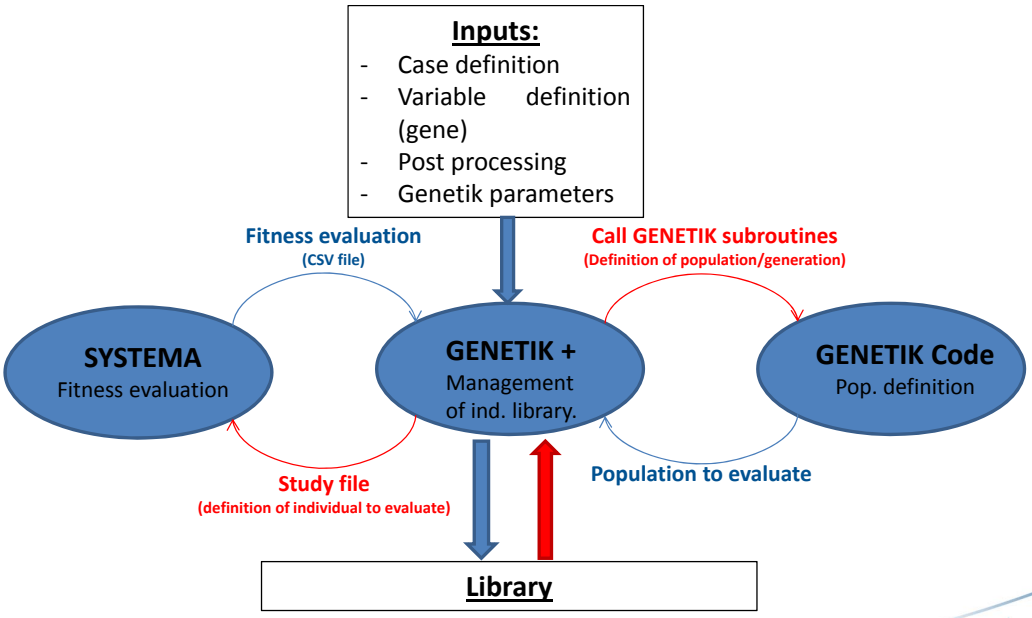
- GENETIK tool developed in CNES between 2005-2009
- Search technics used to find solutions to optimization problems
- Intelligent exploration of space solutions
- Technics inspired by evolutionary biology such as inheritance, mutation, selection, and crossover.

Some vocabulary…

- Gene : parameter of the problem (ex. : spacecraft altitude)
- Individual : combination of genes
- Population : set of individual
- Generation : selection of some individual in the population
- Fitness : evaluation function to optimize

GENETIK+ OVERVIEW

GENETIK+ interfaces GENETIK code with SYSTEMA:



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APPLICATION CASES

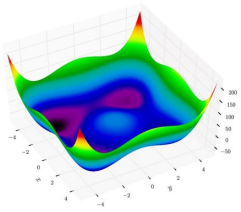
GENETIK + / GENETIK / SYSTEMA Gateways validation:

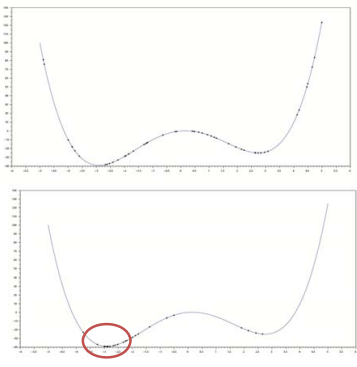
GENETIK+ / GENETIK:

- Use of well known function (Styblinski-Tang function) to evaluate population fitness :
  - Evaluation possible for n parameters
  - Locals and global extrema

$$f(\mathbf{x}) = \frac{\sum_{i=1}^{n} x_i^4 - 16x_i^2 + 5x_i}{2},$$
$$\text{with } -5 \leq x_i \leq 5,$$
$$1 \leq i \leq n.$$

$$f(\underbrace{-2.903534, ..., -2.903534}_{\text{n times}}) = -39.16599n$$





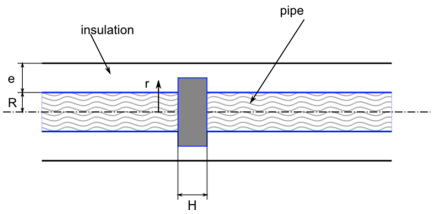
- Validation of GENETIK+ / GENETIK gateway : ***OK***
- Validation of GENETIK algorithm : ***OK***

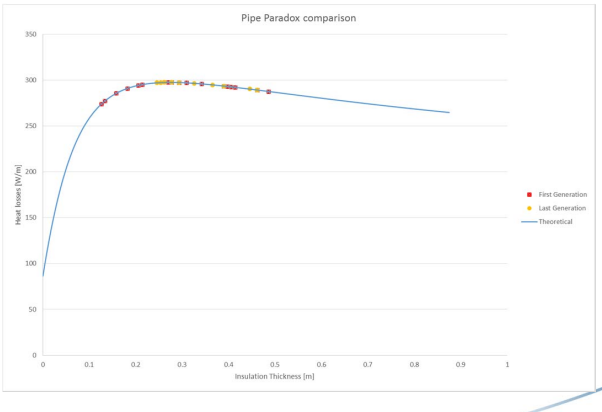
APPLICATION CASES

GENETIK + / GENETIK / SYSTEMA Gateways validation:

GENETIK+ / SYSTEMA

- Simple model with analytic solution - Pipe insulation paradox:
  - In particular configuration → Increase thickness = Increase heat exchange area = Increase losses
  - Find minimum thickness of insulation material to minimize losses





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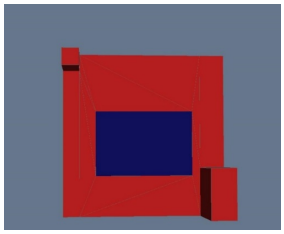
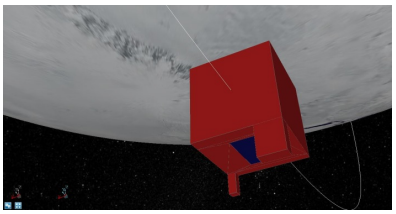
APPLICATION CASES

Application cases for demonstration of GENETIK+ performances:

Thermal control design optimization:

- Radiator size vs. heating power budget for instrument thermal control:
  - Definition of instrument temperature range in OP and NOP mode
  - Optimum temperature for OP mode
  - Definition of maximum OP and NOP heating budget
  - Parametric Radiator shape : 4 parametric points + variable thermo-optical properties (α,ε)
  - Search of radiator size and location → Best compromise to optimize instrument temperature, minimize its variation, minimize the use of heating power
- More than 120 000 possible configurations → 8 hours to reach stagnation criteria
- GENETIK+ gives a solution to analyse for understanding → help for design definition





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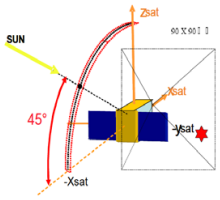
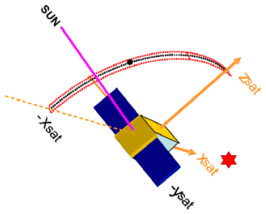
APPLICATION CASES

Application cases for demonstration of GENETIK+ performances:

Detection of sizing thermal case:

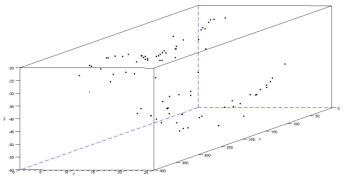
- Analysis of a complex mission for space observation
  - Drifting orbit
  - Complex spacecraft attitude





- No simple way to determine sizing thermal case
  - Thousands of computation cases and data to analyse

- GENETIK+ performances:
  - Full analysis led in 2011 (by hands) → 1 week
  - GENETIK+ → 1 hour to reach stagnation criteria
  - same results



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PERSPECTIVES AND CONCLUSION

GENETIK+ shows real potential:

- Improvement of the optimization tool GENETIK:
  - More possibilities for optimization studies
  - Easy to use
  - Validated
- Potentiality shown on real cases
- Full potential to investigate
  - Exploitation of all data
  - Application cases: thermal model correlation, model reduction, management of calculation uncertainties
- Internship in 2015 to explore capabilities of GENETIK+:
  - Model correlation
  - Management of calculation uncertainties
  - Process to use optimization tool for thermal analyses
  - …