Appendix I

Thermal model correlation using Genetic Algorithms

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THERMAL MODEL CORRELATION USING GENETIC ALGORITHMS

21st European Workshop on Thermal and ECLS Software

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All the space you need

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- Study context
- Basics about genetic algorithm
- Test plan definition
- Test results
- conclusion

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Study context

- ESA contract number: 19840/06/NL/PA
- **Goal**: Evaluate feasibility of using **Genetic Algorithms** (GAs) to address the general issue of **post- test thermal model correlation.**
- Thermal model correlation = An optimization problem
  Reduce difference between model predictions and test measurements
- Thermal background: problem is complex:
  ⇒ *Collaboration with optimization specialized researchers to find/perfect a method appropriate to our problem.*

  Nicolas DURAND: DSNA/DTI/R&D/POM (*ENAC Toulouse*)
  Use of GAs to solve Air Traffic Control problems

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Description of Thermal model correlation problem

A complex problem…

- Many variables to be simultaneously correlated
- Function shape is very hilly ⇒ Many different local minimums
- No analytical expression of the function.

Use of a global method to explore the whole domain and identify the global solution.

- Deterministic methods: Restricted to reduced number of parameters and specific problems.
- Stochastic methods (GAs, etc): Results depend from previous data computed but also random seeds. Suitable to many problems

Note: Thermal model correlation process specificity:

Fitness function computation cost very high compared to usual optimization problems

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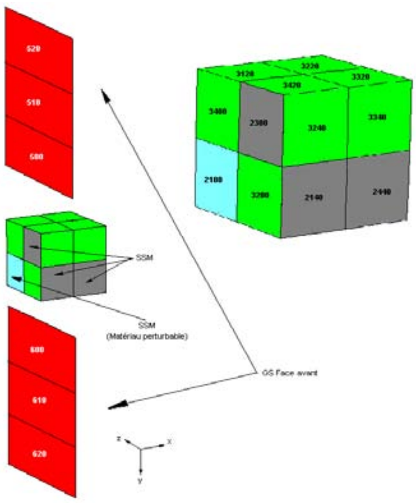
Chosen approach: Method testing rationale

- Use of a ***"theoretical" numerical based only approach***
  - Models are perturbed by changing parameter values.
  - 'Test measurements' temperatures used for correlation correspond to model predictions, before introducing perturbation.
- **Simultaneous** correlation for two test cases (hot + cold), steady-state conditions only.
- Test Cases definition
  - Tested on small size TMM models only (up to 280 Nodes)
  - Test first the method for a reduced number of correlation parameters (5).
  - Then extend it to a larger number of parameters representative of future industrial problems (up to 20 parameters).

Tested models



- Model1: Studybook case model
  - 100 nodes, usual modelling situations (dissip. unit in enclosure+ radiator, MLI, structural panels , solar array
  - 21 TMM parameters: Dissipation and conductive aspects (λ longi & transverse, thickness, Contact and MLI eficiciency.
    - 2 measurement point sets ⇒ *Evaluate impact of instrumentation*
- Model 2: instrument phase B model

  280 nodes,17 TMM parameters (dissipation & conductive aspects).

Note: Model computation speed increased by directly running executable file (correlation parameters values read from input file)

Basics about Genetic Algorithms (1/3)

- Optimization method based on Darwin evolution's theory

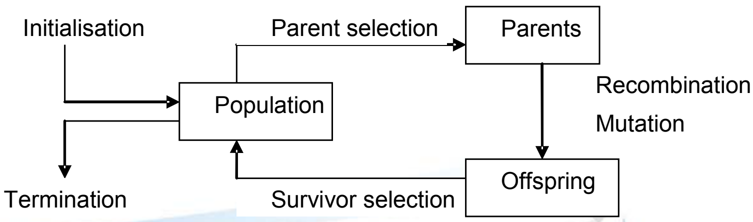
" Within a given population, only the most suited individuals survive and have offspring "

⇒ *The specie improves with elapsed time.*

- Transposition to numerical world

Life	Mathematics	*TMM correlation*
Chromosome	function parameter	*TMM parameter*
Adaptation criterion	function result	ΔT(Test measurement, TMM prediction)

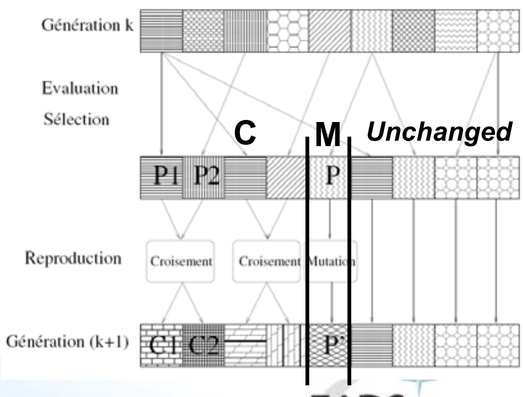
- How does it work in practice ?



Basics about Genetic Algorithms (2/3)

Remarks

- Operators
  - Variation operators: Allow to explore the domain (close or far from current solution).
    - Mutation is common to all stochastic methods.
    - Crossover is specific to Genetic Algorithms: exploit parents properties to propose a new solution
  - Selection operator: allows to converge to the best solution.



Basics about Genetic Algorithms (3/3)

Remarks (end)

- Good GA operation = Balance between domain exploration and fast convergence
- GA Implementation
  - Many possible technical solutions for the elementary bricks
  - Many associated GA parameters may be tuned to get a better behaviour

GA kernel good programming is a matter of experience

GA optimization itself is problem specific and also a matter of experience

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Practical applicability of GA to thermal model correlation

- **Any change in correlation problem definition generate a new optimization problem**
  - TMM used
  - Modelling change in TMM
  - Correlation parameters used
  - Measurement points used

- **Thermal engineers are not optimization / GA specialists**

  Questions to be answered by the study:

  - Does GA allow to find the solution to the thermal problem ?
  - Is there a given (≈frozen) simple GA parameterization globally suitable to thermal correlation problem ?

  ⇒To be evaluated in this study for two small models only

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Test plan definition (1/3)

- Evaluate which value(s) of three most important GA parameters should be suited to thermal problem :
  - Population size
  - Crossover rate
  - Mutation
- Evaluate robustness of GA to different thermal model problems
  - Change of TMM
  - Change of correlation parameter set used
  - Change of measurement point set used

Test plan definition (2/3)

For each model

- 4 to 5 different values of population size

  values defined based on number of correlation parameters used
- 10 different (Crossover rate x Mutation rate) configurations

	Crossover rate			
Mutation rate	0	0,2	0,4	0,6
0,2	x	x	x	x
0,4	x	x	x	
0,6	x	x		
0,8	x			

- Tested TMM correlation parameter configurations
  - 8 different reduced configurations (5 parameters)
  - 1 large configuration (~ 20 parameters)
- Two different measurement point sets
- For a given test case, 4 to 5 different runs with different random seeds

Test plan definition (3/3)

Stop criterion

- Fitness function definition

$$FF = \sum_{thcases} \sum_{measnodes} (T_{pred} - T_{meas})^2$$

Note: Standardized measurement of model discrepancy

Average Model Correlation Accuracy (AMCA) in °C:

$$AMCA = \sqrt{\frac{\sum_{thcases} \sum_{measnodes} (T_{pred} - T_{meas})^2}{nbcases.nbmeasnodes}}$$

- Success definition
  - FF<0.01 ⇒Max discrepancy on any point<0.1°C
  - Max nb of computed generations = 500

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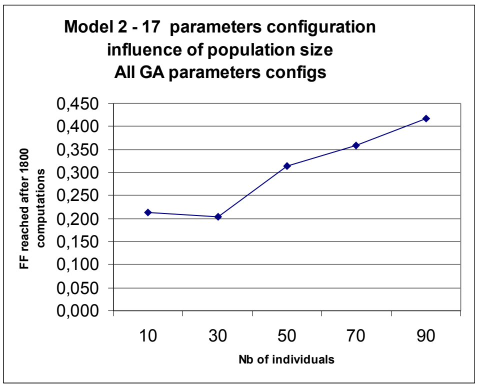
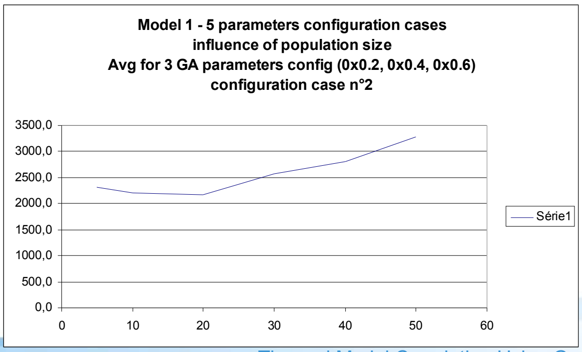
Tests results : Sensitivity to population size

better results with small values

Optimum seems to be between nb correl. parameter & 2 x nb.correl. parameter

Note: Never go lower than 10 to still have a GA.





⇒ Are GA a suited method ?

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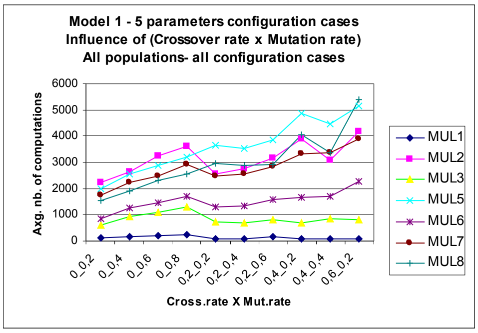
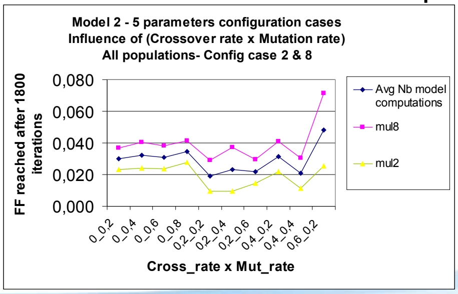
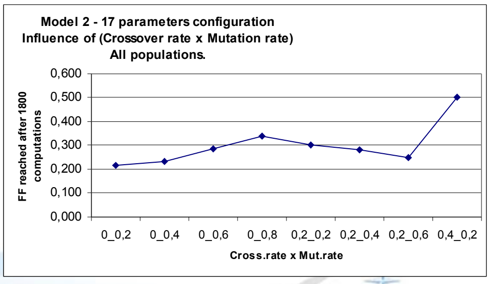
Tests results : Crossover rate x Mutation rate



- Easy situations
  - No crossover needed
  - Mutation should be low (0.2)
- Difficult situations
  - A bit of crossover may be used (0.2)
    - Mutation should be kept low

Note: Crossover is the GA specific feature ⇒ Are GA a suited method ?





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Tests results:
Influence of parameter set used for correlation

- Simulation duration increases with number of involved parameters.

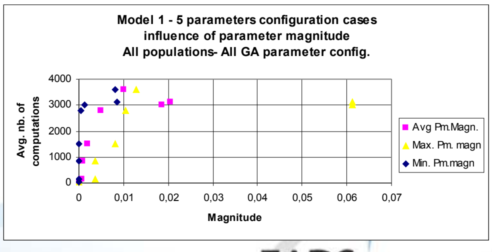
Test cases	Avg nb.Comp.
5 param.config. Population: 20 to 40 individuals Easy configuration Hard configuration	 843 3208
21 param.config Population: 60 to 100 individuals	 33072

- GA operation depends on parameter configuration
- Simulation duration increases with magnitude of parameters.

Magnitude= Potential impact of parameter on FF value when varying in its allowed domain.

Note: Only main magnitude params. are initially taken into account by the optimization process

⇒ *Incremental correlation approach?*



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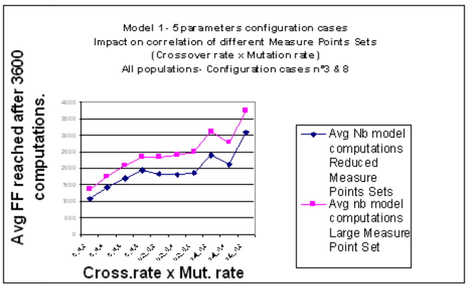
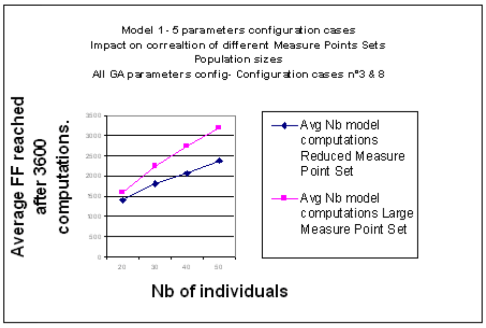
Tests results :
Influence of Measurement set used.

- Tested on model1
  - 1st Measurement set used (standard): 22 points
  - 2nd Measurement set used: 35 points

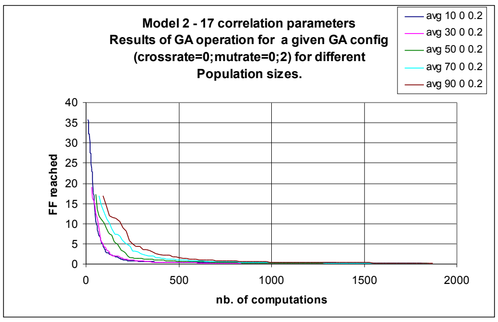
    FF success criterion trimmed to get comparable results.
- Similar results obtained for 2ns measurement point sets.
  - Model more difficult to correlate: More constraints to be solved

  Due to more points involved ?





Tests results : Convergence speed



- GA has a fast initial convergence (to find areas where are solutions) but a slow finishing

$\Rightarrow$ No interest of insisting with GA operation

<u>Note:</u> Results obtained with GA are already interesting.

Example

Model 1 – 21 parameters

AMCA ≈ 0.1°C after 1000 computations

But problem (model, nb of measure points) remains simple

Tests results :

Comparison with random search

Fitness obtained for a given number of model computations = 4000 in random search

Tested for 5 parameters configuration from model 1

	GA results		Random search	
	nb. Runs	end FF	Nb runs	end FF
MUL2	2471	0,01	4000	0,1
MUL8	1991	0,01	4000	0,56

GA is much better than a random search !

Conclusion (1/3)

- GA allows to identify areas where the best correlation solution is … but not to converge finely on it.
  – This convergence may be sufficient.
  The whole allowed domain has been explored
  → *The order of magnitude of correlation reachable with this model has been found.*
  ⇒ For additional correlation improvement, need to change model:
    - Correlation parameter choice
    - Variation domain for parameters
    - TMM modelling
- Capacity to correlate several cases in one shot
  (fitness function definition)

Conclusion (2/3)

- GA parameterization:

  Some simple preliminary guide lines for thermal model correlation may be proposed

  (TBC, for DSNA/POM GA implementation only)
- Computation cost is a key issue.

Estimated –minimum-: Run of 500 to 1000 cases for just one correlation simulation.

⇒Needs to drastically increase computation power available to address industrial cases: (large model, transient conditions).

Clusters + parallelization …

⇒Optimization process to be improved**:**

- Evaluation of alternative global methods.
- Couple local method to initial global method step.

Conclusion (3/3)

GAs Evaluated on 2 small models only

Results need to be confirmed by much more tests on different models.

- Thermal model correlation is a complex problem requiring complementary skills:

  Thermal engineering/ Numerical optimization/ Software engineering

- Fruitful collaboration achieved with DSNA/DTI/R&D/POM team have allowed to really progress on the matter

Great thanks to Nicolas DURAND for its 1st class support all along this project !