Integrated Systems approach in thermal modeling by using GT-Suite

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Outline:

New industry requirements

Challenges in thermal modeling:

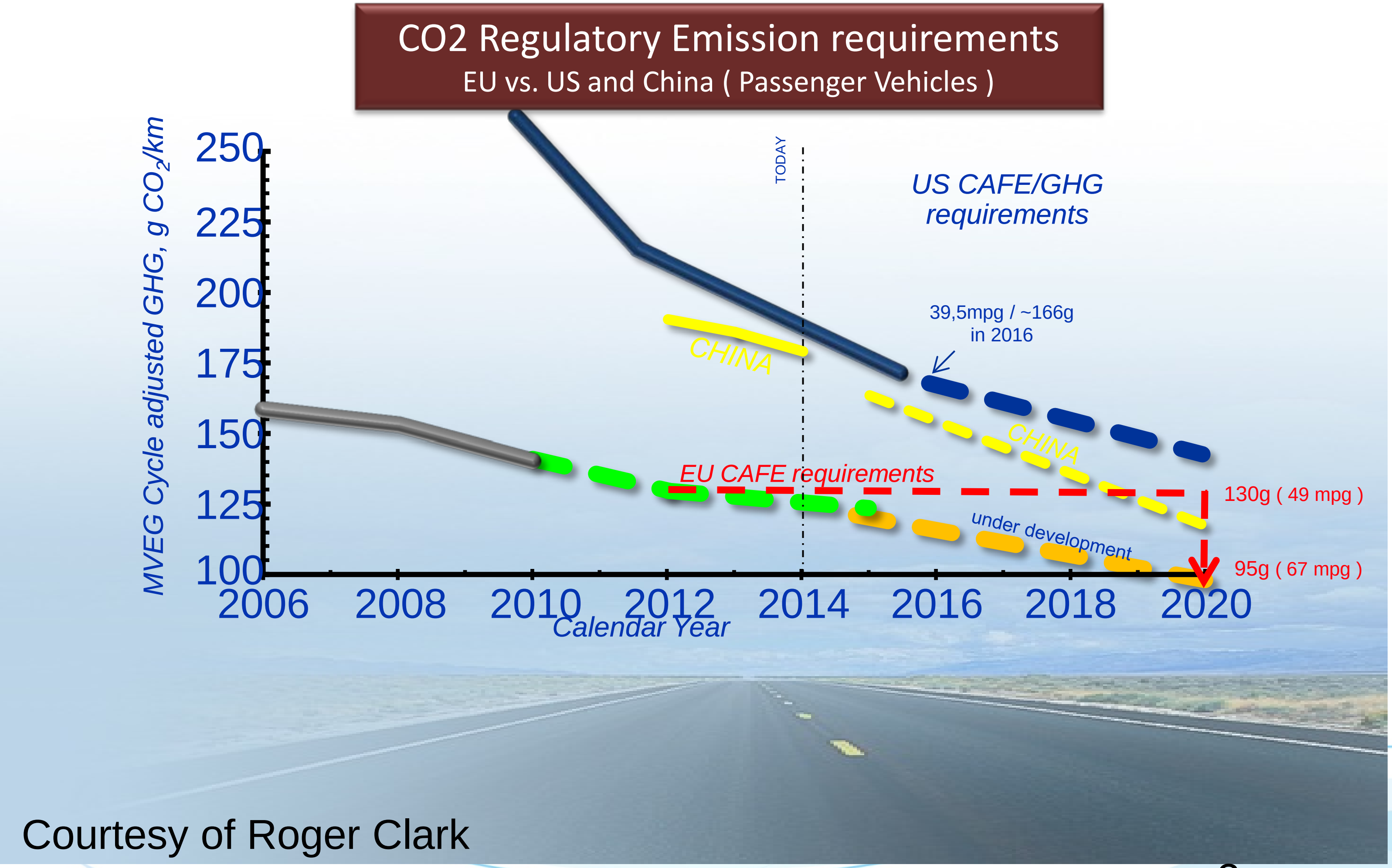
- Fast warm-up vs Cooling capability
- Fuel Economy/ Performance

Modeling approaches

Model applications:

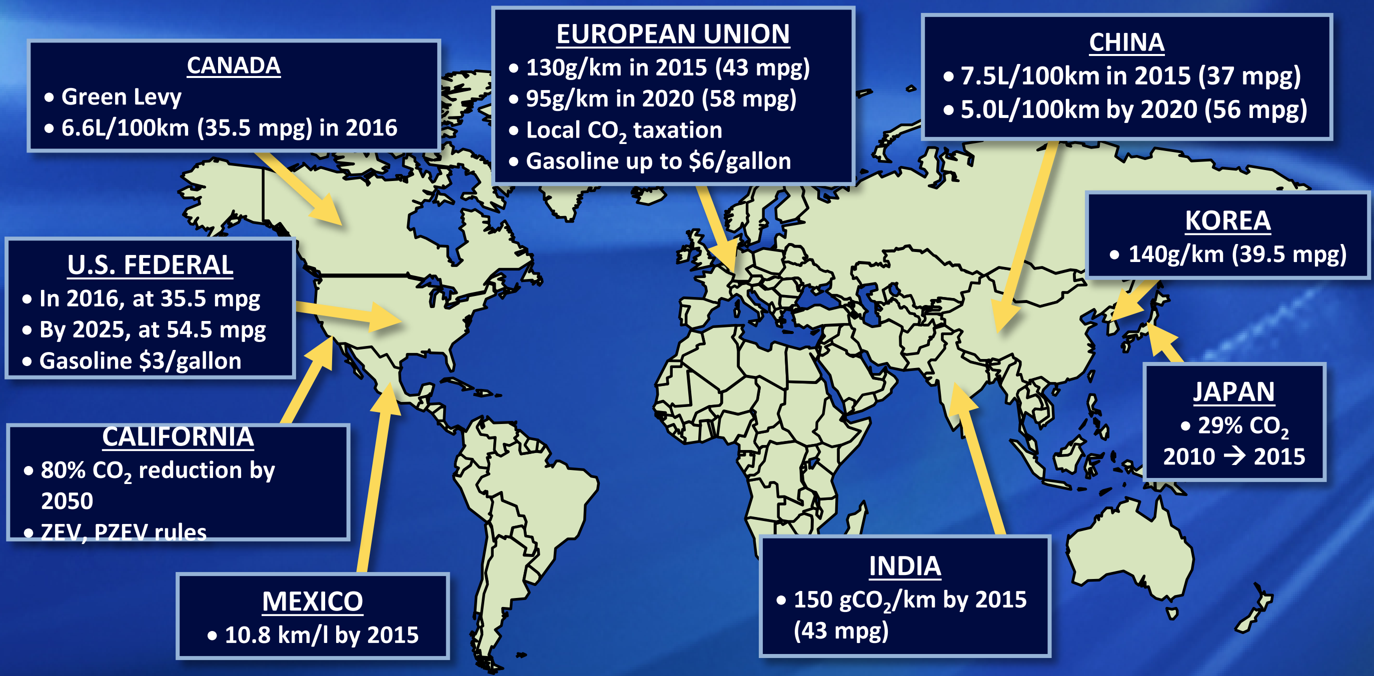
- ✓ Steady state simulations;
- ✓ Warm up studies – evaluation of contributors;
- ✓ Engine oil cooler assessment
- ✓ Calibration support
- ✓ DFSS studies

New industry requirements



Courtesy of Roger Clark

OUTLOOK FOR GLOBAL FUEL ECONOMY AND GREEN HOUSE GAS REQUIREMENTS



Courtesy of Roger Clark

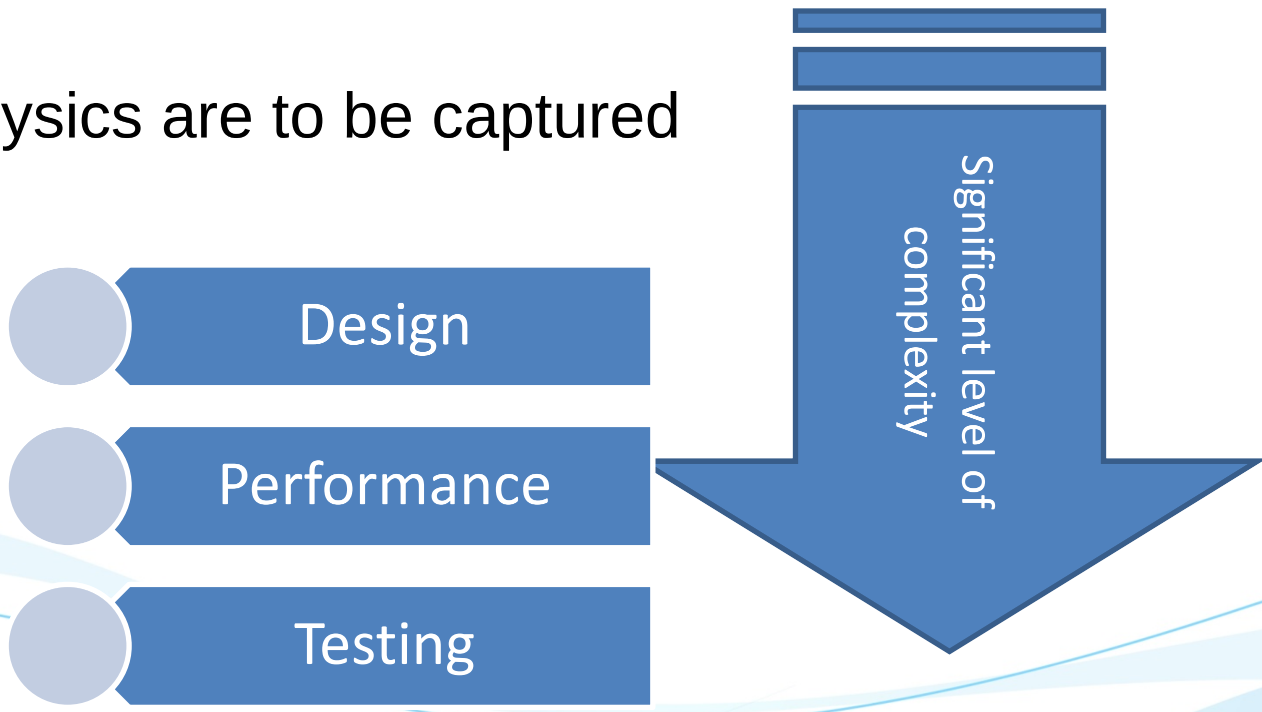
Challenges in thermal modeling

- Fast engine warm up:
  - Fuel energy redistribution – from Energy to Coolant to Energy to Engine thermal masses;
  - Define a proper threshold to avoid boiling;
  - Deliver a min coolant flow to maintain the engine thermal balance
- Cooling capability:
  - Higher coolant capability is needed for a stoichiometric engine operation and for a hotter running engines in general

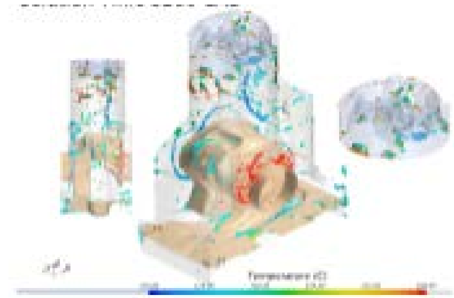
Challenges in thermal modeling

- All subsystems contributing to the engine thermal balance are to be included

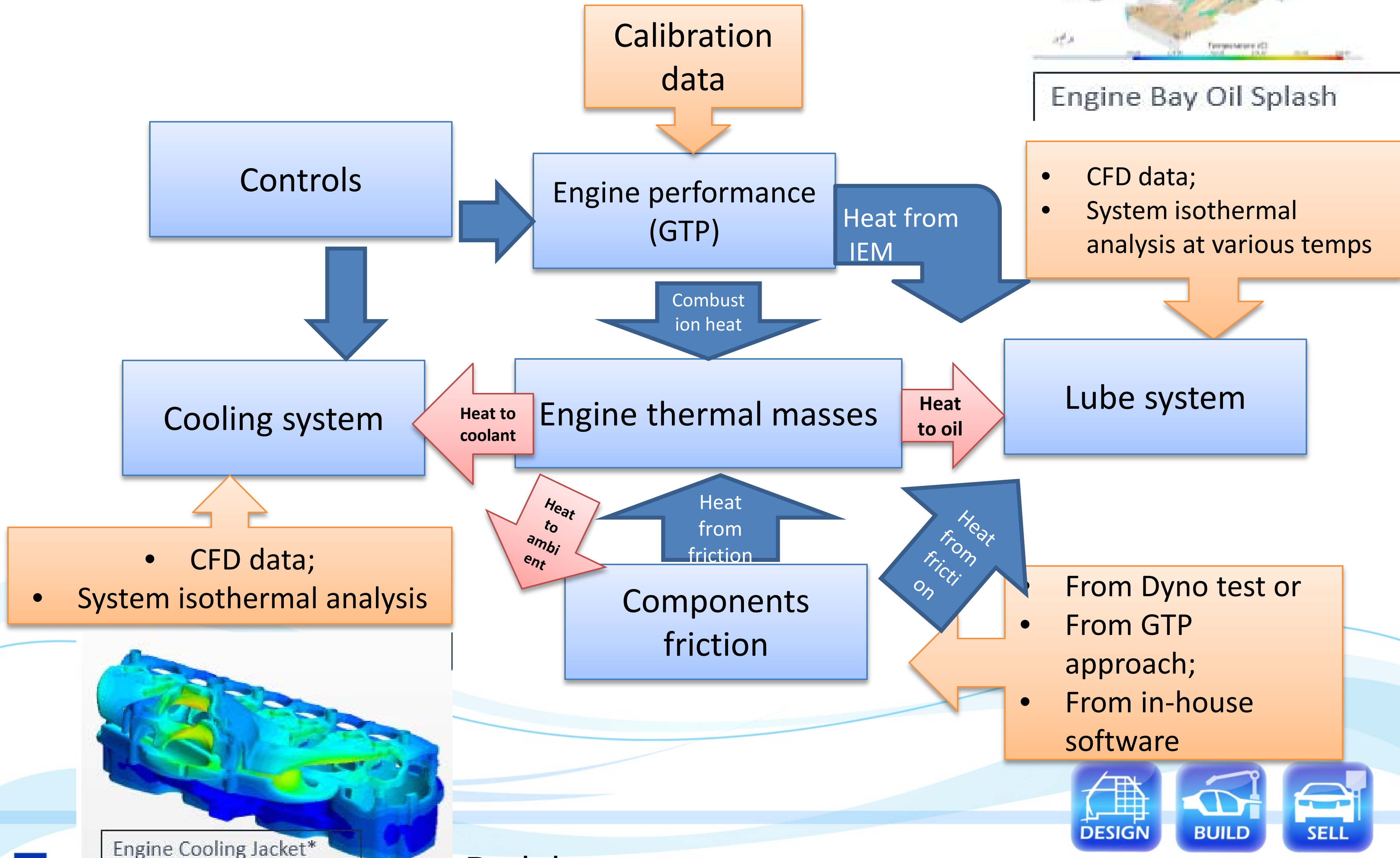
- All physics are to be captured



Modeling approaches

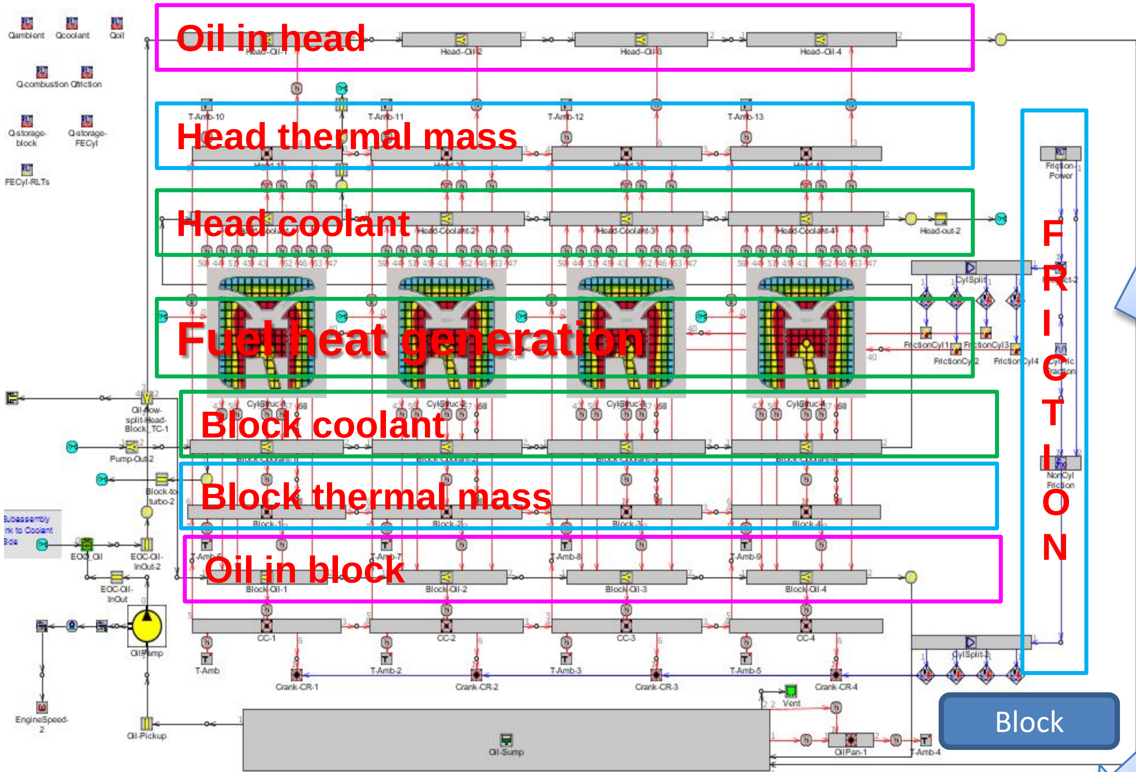


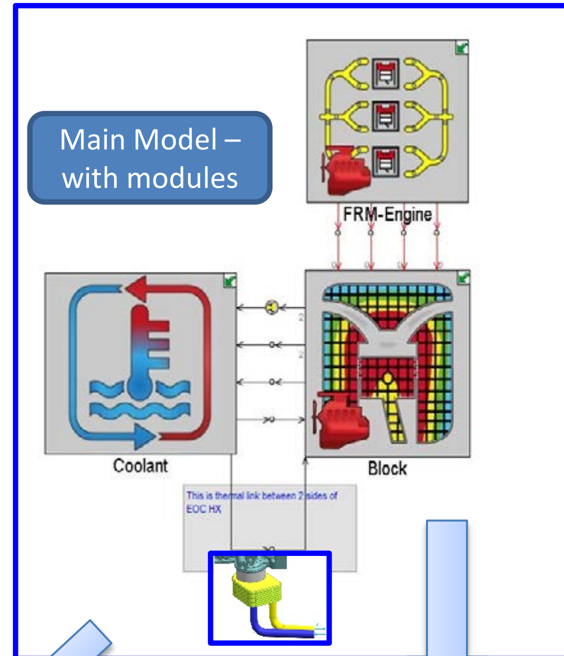
Engine Bay Oil Splash

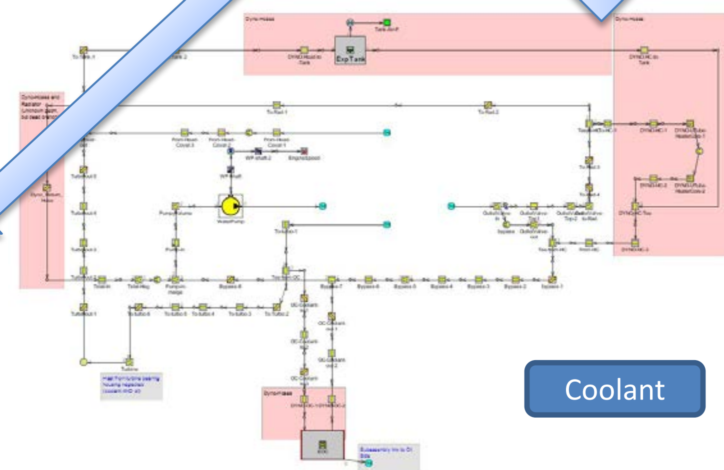


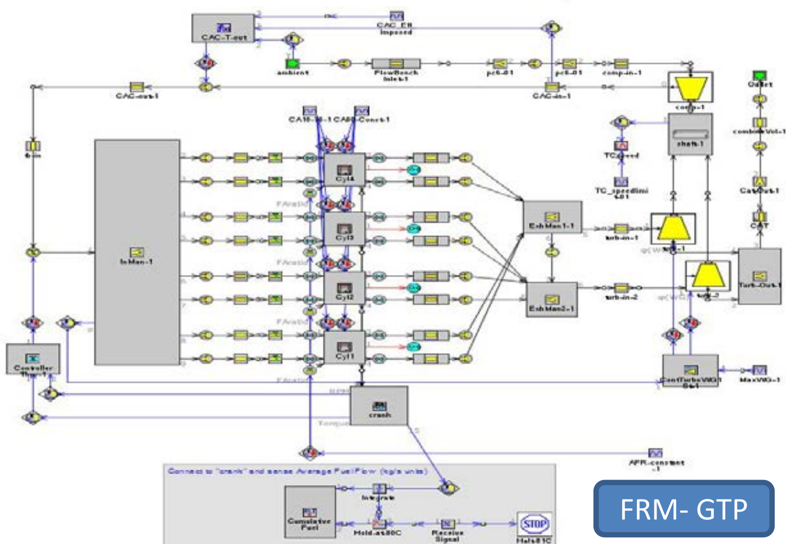
Engine Cooling Jacket*

Modeling approaches









Modeling approaches

- Cooling system:
  - Engine cooling system that includes engine specific components;
  - Coolant pump (s) thru pump performance curves (flow rate as a function of RPM and Pressure);
  - Thermostat (s) / Cooling control valve (s)
  - Dyno or Vehicle cooling system – depending on project request;
  - Heat exchangers require both fluid inputs

Modeling approaches

- <u>Lubrication system</u>:
  - The major components included in the model are:
    - Oil pump performance that usually comes from the isolated lube system analysis:
      - ➢ pump curves at various RPM and oil temps for two pressure modes of the variable displacement pump (if applicable)
    - Engine oil cooler and turbocharger (if applicable)
    - Oil block flow passage that includes main gallery, main and rod bearings, piston squirters;
    - Oil head flow passage with cam bearings, cam phasers and lifters;
    - Oil pan (oil sump)

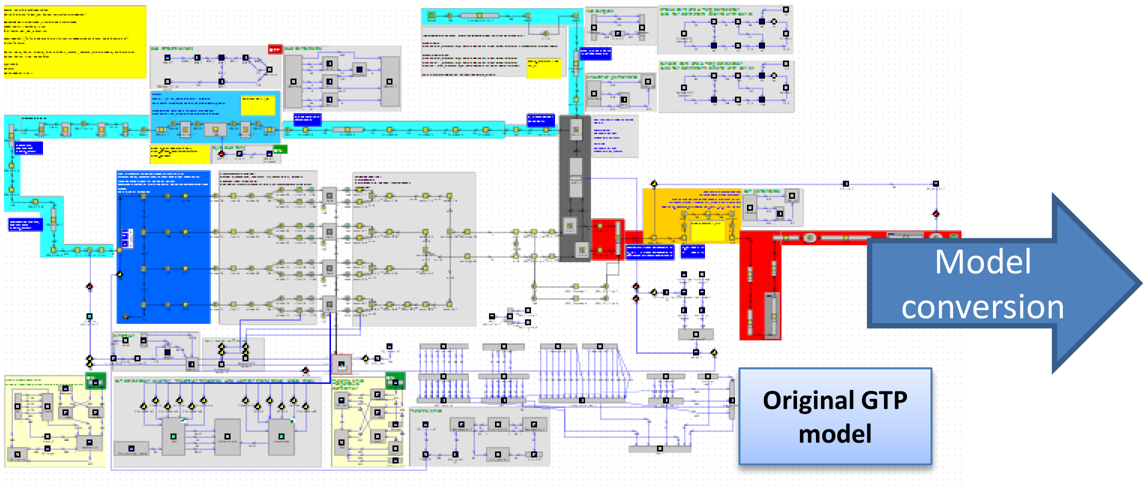
Such a representation supports friction module connections

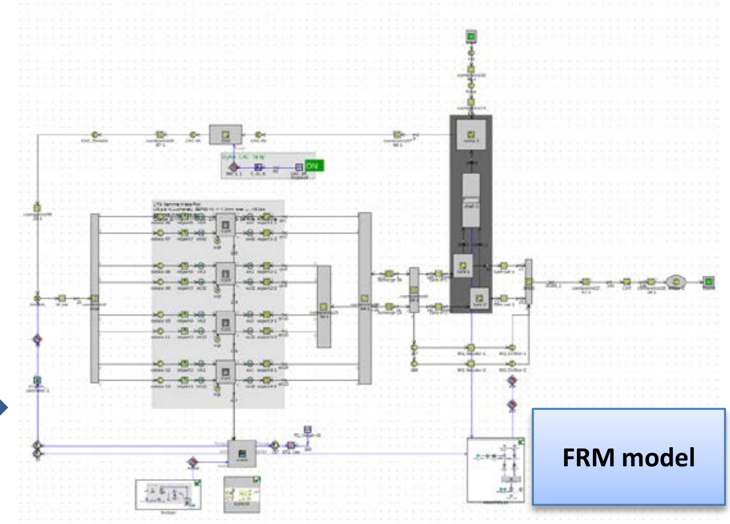
Modeling approaches

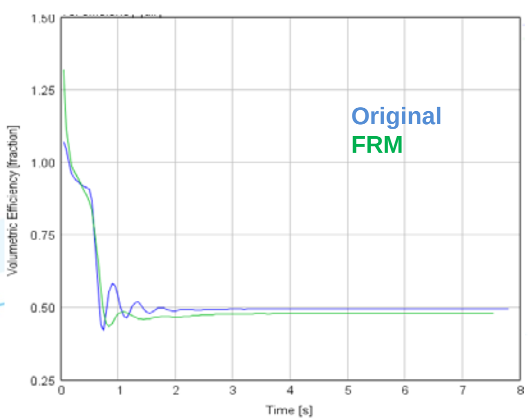
- Air flow/Combustion system:
  - In order to provide the fuel energy coming to the system at a certain engine speed/load condition a stand alone GTP model is integrated into the engine thermal model;
  - FRM (Fast Run Model) for both Steady State and Transient Operations
    - Intake and Exhaust Systems – Simplified but still capture main tuning effects
    - Combustion Characteristics – Contains accurate attributes for specified operating conditions
    - **Controls** – Contains representative algorithms for proper engine controls; ie: throttle, camshafts, waste gate, spark, etc
- Exhaust system:
  - Conventional exhaust system - represented thru the GTP model;
  - System with integrated exhaust manifold - an additional heat exchange between the IEM gasses and engine thermal mass is to be included

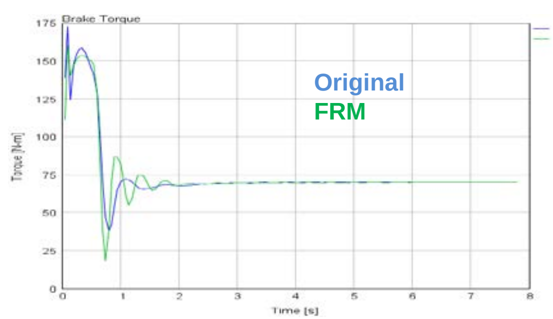
Modeling approaches

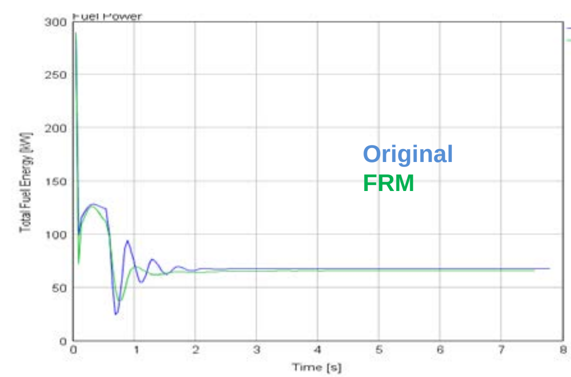
In engine performance - FRM model transient/steady state

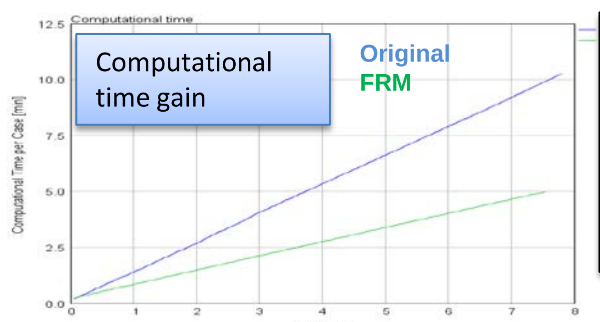












Run time:

Original GTP model – 80 X RT;
FRM with component reduction – 40 X RT;
FRM with GTP model recalibration – 3 X RT

Modeling approaches

- <u>Engine thermal structure</u>:
  - Thermal mass partitioning:
    - Each cylinder is represented separately – cylinder to cylinder temp gradient
    - Traditional block and head masses;
    - More detailed cylinder head masses split – if refined temp distribution is needed;
    - Each cylinder Block mass split between a liner+ block mass attached to a liner and the rest of the block mass
  - Crankshaft and crankcase are represented as separated masses – due to high contribution in an overall engine mass;
  - Oil pan – to account for heat lost thru the pan to ambient

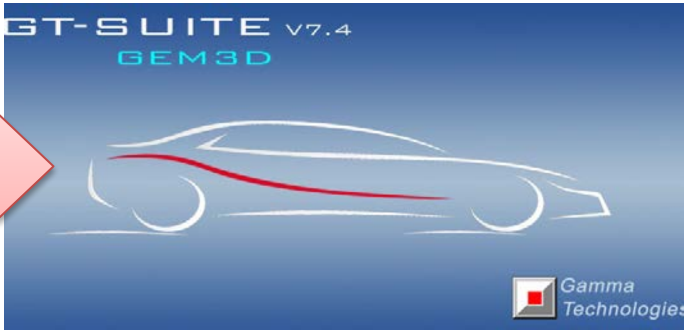
Modeling approaches

- <u>Engine thermal structure</u>:

Additional GT tools are to be used for a model build simplification

Engine math model from CAD

Extracted fluid and gas volumes



Partitioned Solids and fluid cores translated into GTS components

Modeling approaches

- <u>Friction</u>
  - Several levels of simplifications:
    - As defined in GTP module;
    - Split between major contributors:
      - Piston;
      - Main and rod bearings;
      - Cam bearings;
      - Others
  - Additional friction heat is a function of temperature

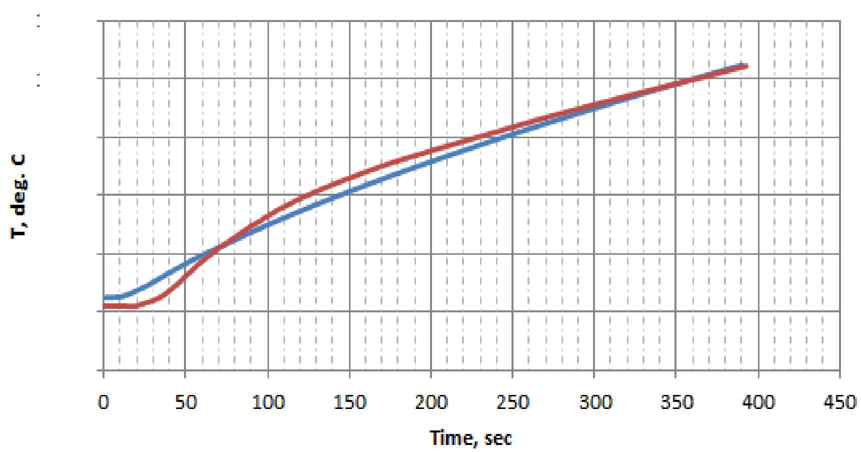
Model applications:

- Steady state cases;
- Transient warm up;
- Maximum cooling modes;
- Oil cooler determination;
- Calibrations
- DFSS studies

Model applications - Steady state cases :

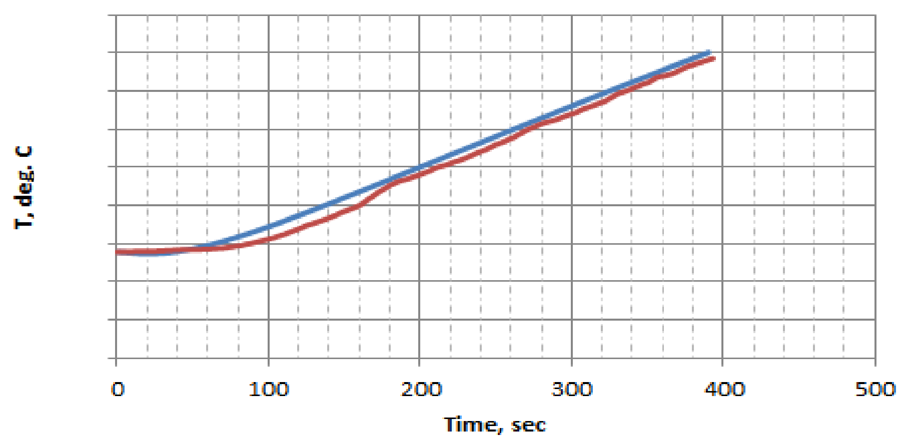
- Serve primarily as model validation

Engine Coolant out temps - Fixed RPM



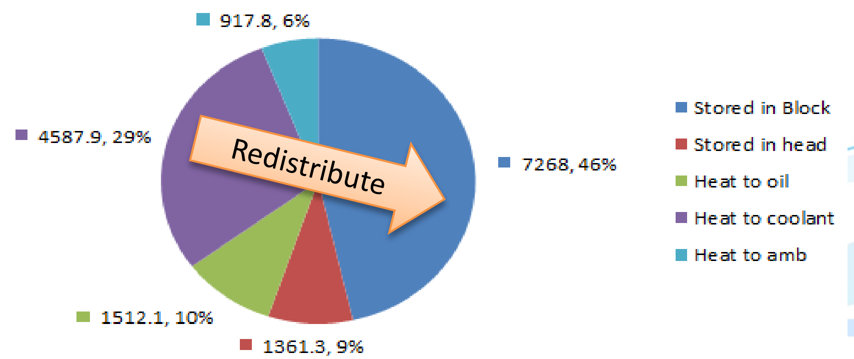
Analysis Test

Oil sump temps - Fixed RPM



Analysis Test

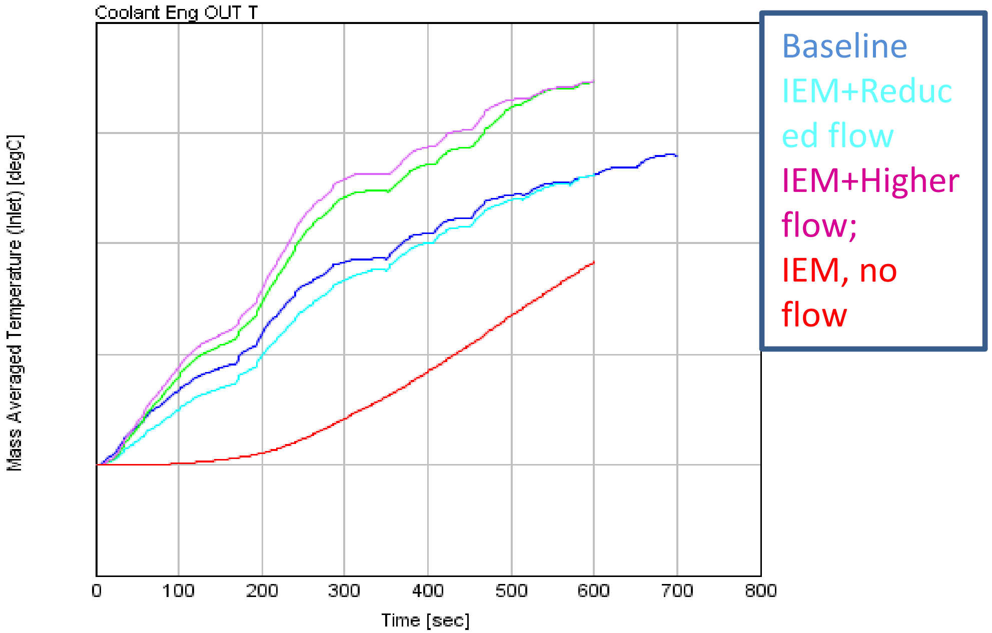
heat transfer, fixed RPM, at 245 sec.

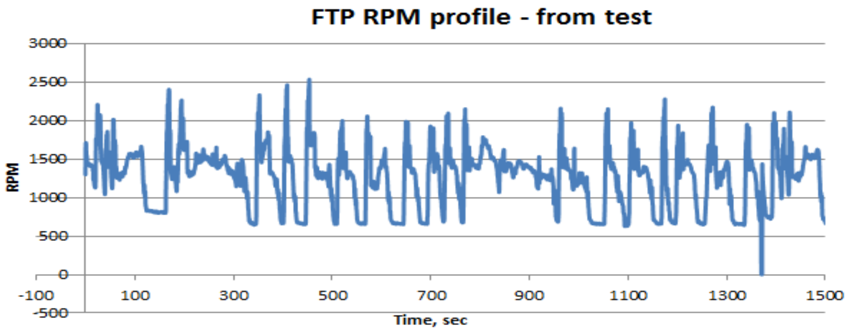


Model applications – Transient warm-up:

- Standard and non-standard driving cycles;
- Evaluation of fluids, metal, surfaces temps over time;
- <u>Inputs</u>:
  - RPM vs. time;
  - Load vs. time;
  - With open cooling circuit loop or with an electric pump (coolant on demand) – flow vs. time
- <u>Outputs</u>:
  - Energy split;
  - Bulk Metal, fluid temps vs. time;
  - Combustion, waterjacket surface temps

Warm-up analytical results:





- Warm up rate;
- Fuel consumption

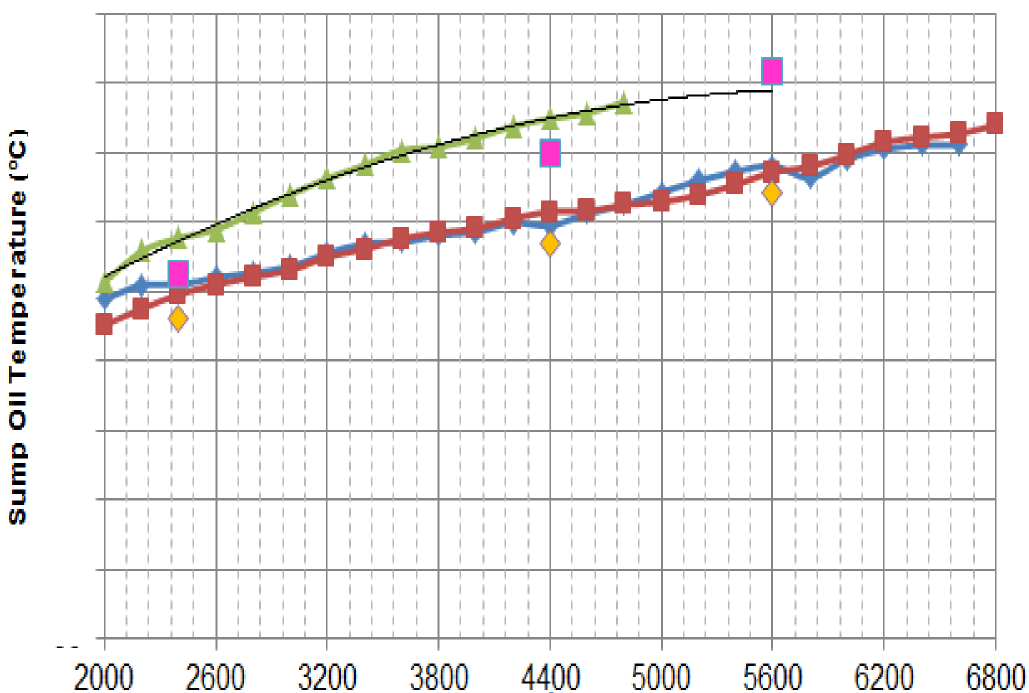
Baseline	
Mod.1	0.99%
Mod.2	1.35%
Mod.3	2.29%

Model applications – Oil cooler determination:

- Steady state analysis at various coolant inlet temps and RPM;
- Open cooling circuit (vehicle components are not included);
- The simulations are performed for two cases:
  - System without cooler;
  - System with cooler.

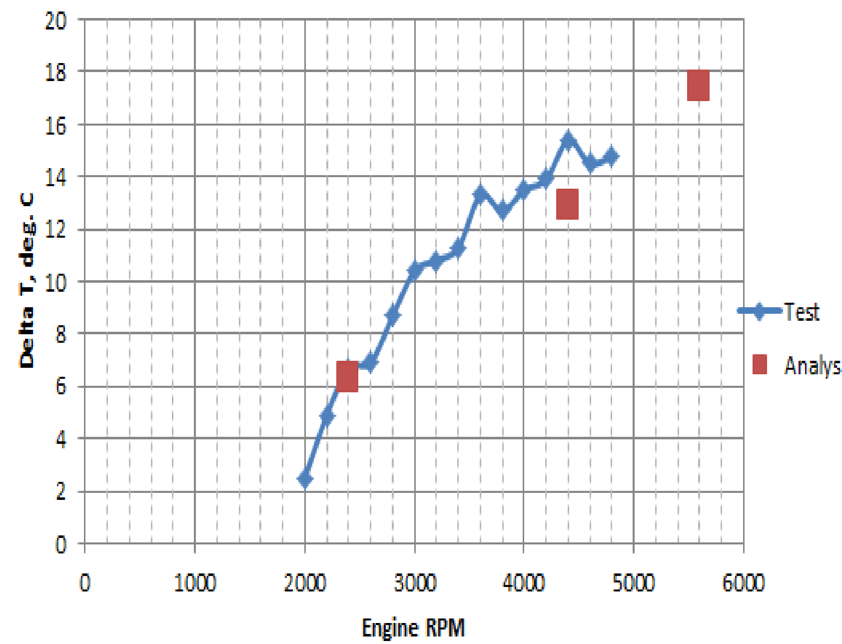
Analysis vs. test: oil sump temp vs. RPM @ fixed coolant T °C

Oil sump temperature vs. RPM: with EOC and w/o EOC



Test, with EOC
Repeat test, with EOC
Analysis, with TOC
Test, no EOC
Analysis, no EOC

Sump temperature difference due to EOC

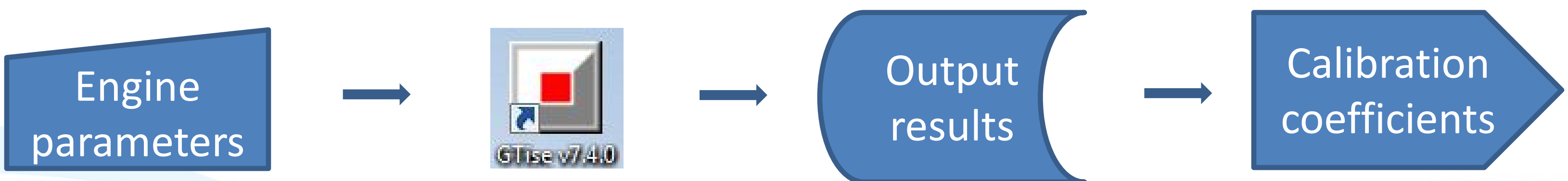


Oil cooler impact evaluation;
Oil cooler sizing

Model applications – Calibration

- Analytical calibration;

- Steady state analysis to cover the entire range of the engine operating conditions:
  - Idle to max speed;
  - Light to WOT loads

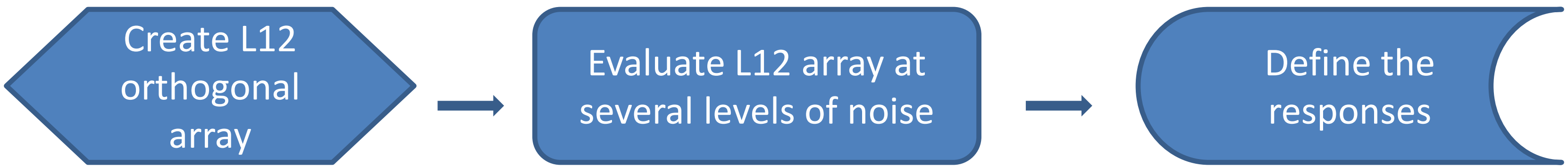


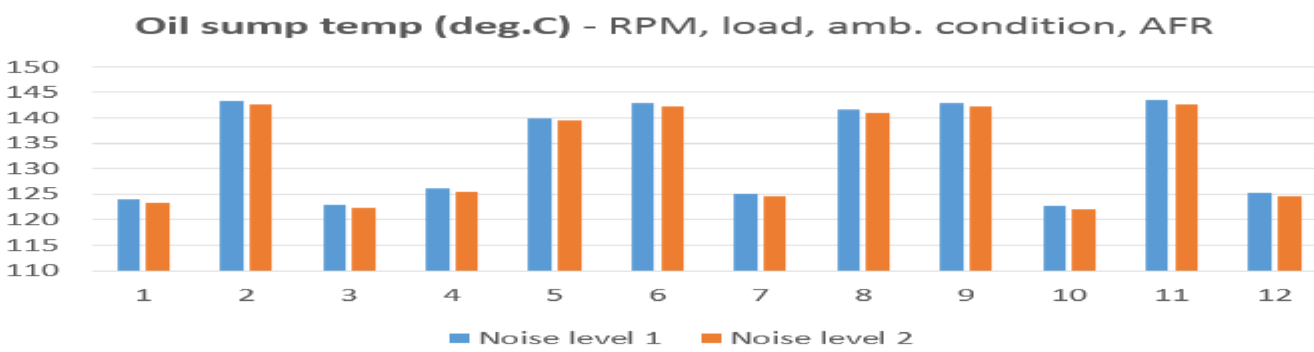
Model applications – DFSS studies

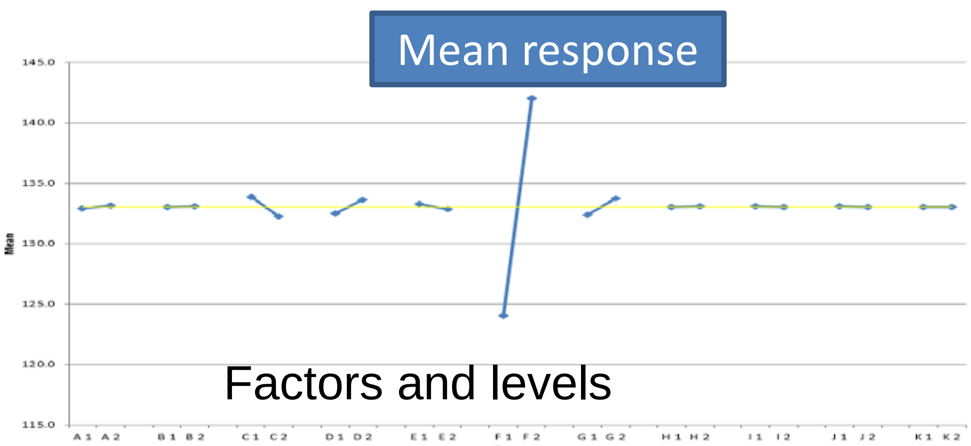
- Design for six sigma methodology
- Use the GTS DOE functions to:
  - Create a new DOE;
  - Input control parameters;
  - Run a complete DOE study;
  - Analyze the results or post-process them in the other DFSS tools

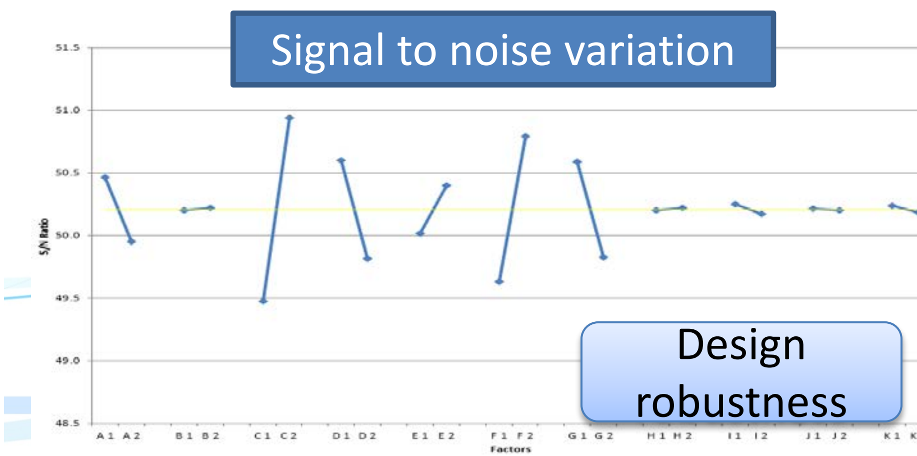
Model applications – DFSS studies

One of the examples - **Impact of key parameters on Oil sump temperature**









Summary

The GTS software has shown to be a useful tool to resolve the current industry needs in the design and analysis of thermal management systems, it enables one to:

- Combine both modules – heat generation and heat management.
- Study various scenarios and design alternatives.
- Provide the thermal parameters that cannot be directly measured in tests, but needed for engine calibration.

- The simulation results have proven to be reliable when obtained from validated models

- The base engine thermal model serves as a template for an engine models family that address various design needs

Acknowledgements

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