E-Motor Modeling : from pre-design to Fine Design including NVH Analysis, Thermal Analysis, System Analysis and with Optimisation

Dr Patrick Lombard
Lead Application Specialist - LF- EM Solutions
HyperWorks Core Development

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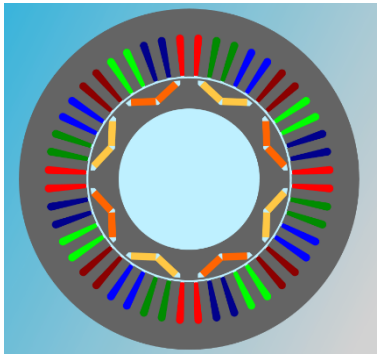
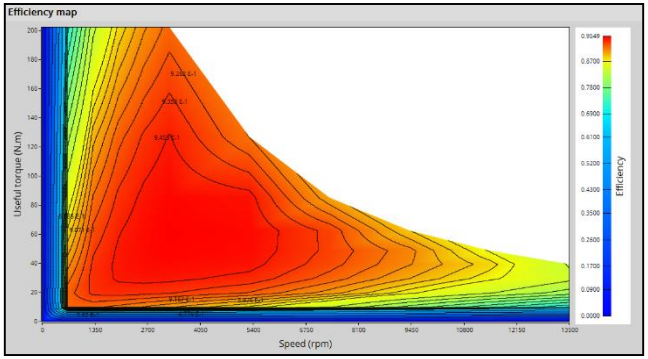
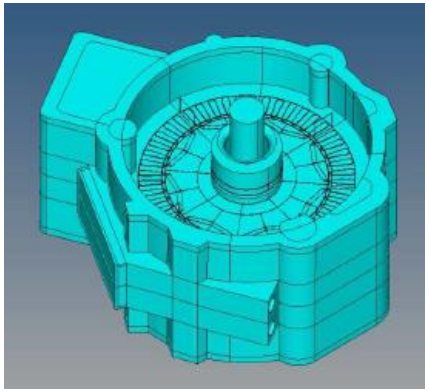
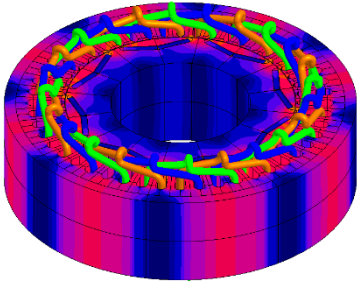
Outline

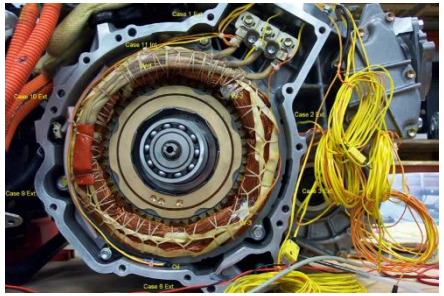
- Introduction
- System Analysis
- Pre-design
- Fine tune Design
- NVH Analysis
- CFD Analysis
- Optimization
- Conclusion











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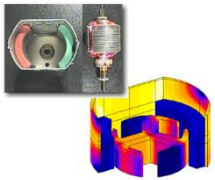
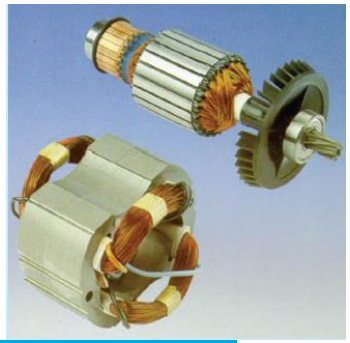
Introduction

- Electric motors are everywhere:
  - Cell phone vibrating
  - Hard disk drives
  - Mixers
  - Electric cars
  - Robots

- More and more constraints
  - Cost
  - Efficiency (new rules imposed by regulator : IE3, NEMA Premium…)
  - Low weight for transportation (bikes, automobile, train, aerospace)
  - New needs for new applications (drone, robots, cobots, IoT…)





- Change is dramatically fast
- Need of new tools and new methods

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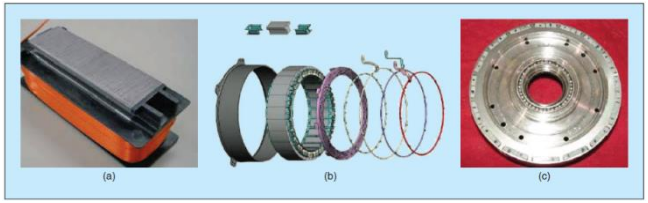
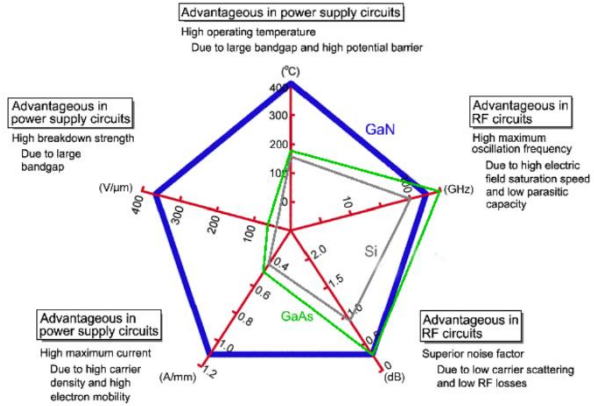
Introduction



- How to improve motors?
  - Magnet with higher energy, and better withstanding temperature
  - Decrease iron losses (new material, new topology, less flux density, …)
  - New insulation material
  - New components for electronic (SIC and Gan technology)
  - High speed
  - Fractionnal slot concentrated winding
  - Better interaction with system
  - …
- Reducing lead times with tools and processes



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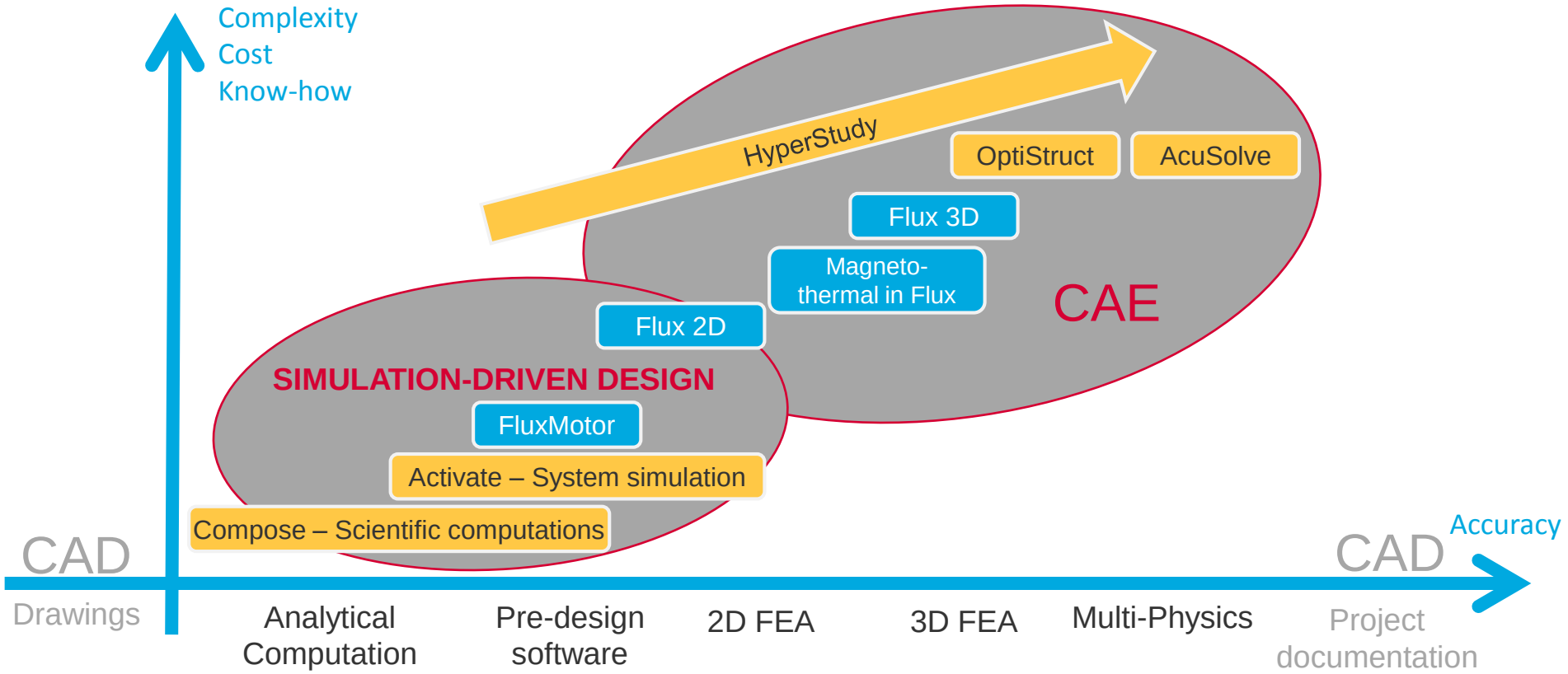
Typical Electric Motor Design Workflow



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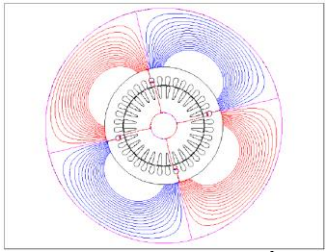
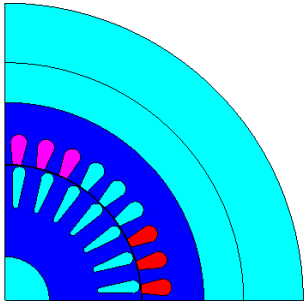
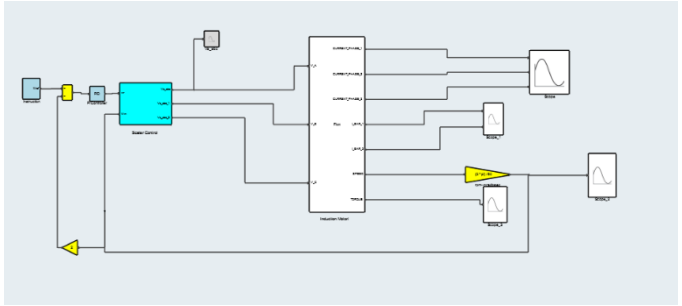
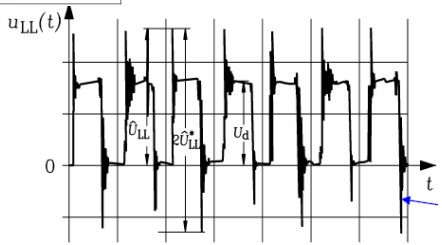
System Modeling

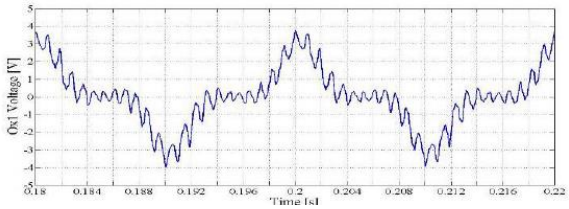
- The motor is embeded in a device, it has to communicate with it !
  - To get instructions of command
  - To have feedback from the motor
  - For health monitoring of the motor

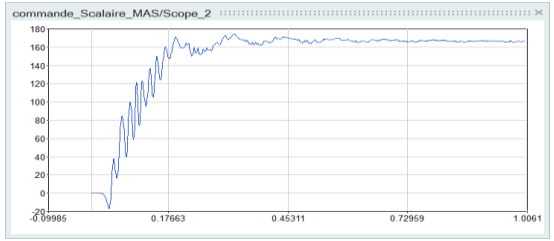












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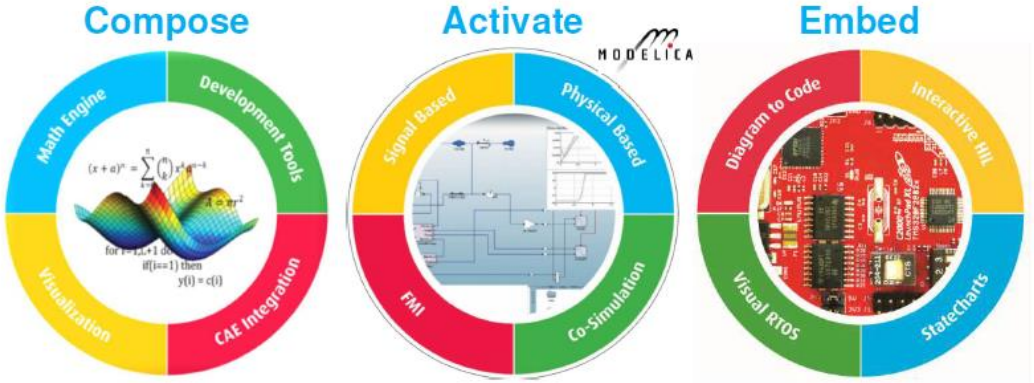
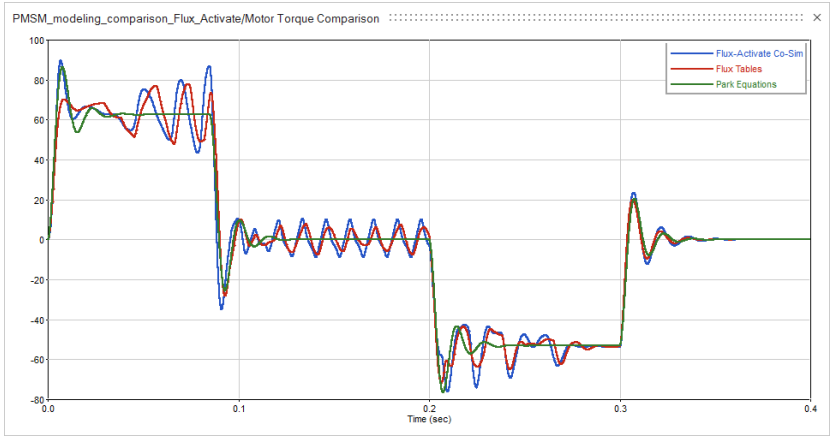
System Modeling

- SolidThinking/Compose
  - System level
- SolidThinking/Activate
  - Allow including equivalent circuit motors)
  - Allow the use of tables
  - Or cosimulate with Flux 2D/SKEW/3D
- SolidThinking/ Embed
  - Real time simulation directly accessible
- Test nominal scenario including all components
  - Battery
  - Mechanical constraints
  - Motor consumption,
  - …





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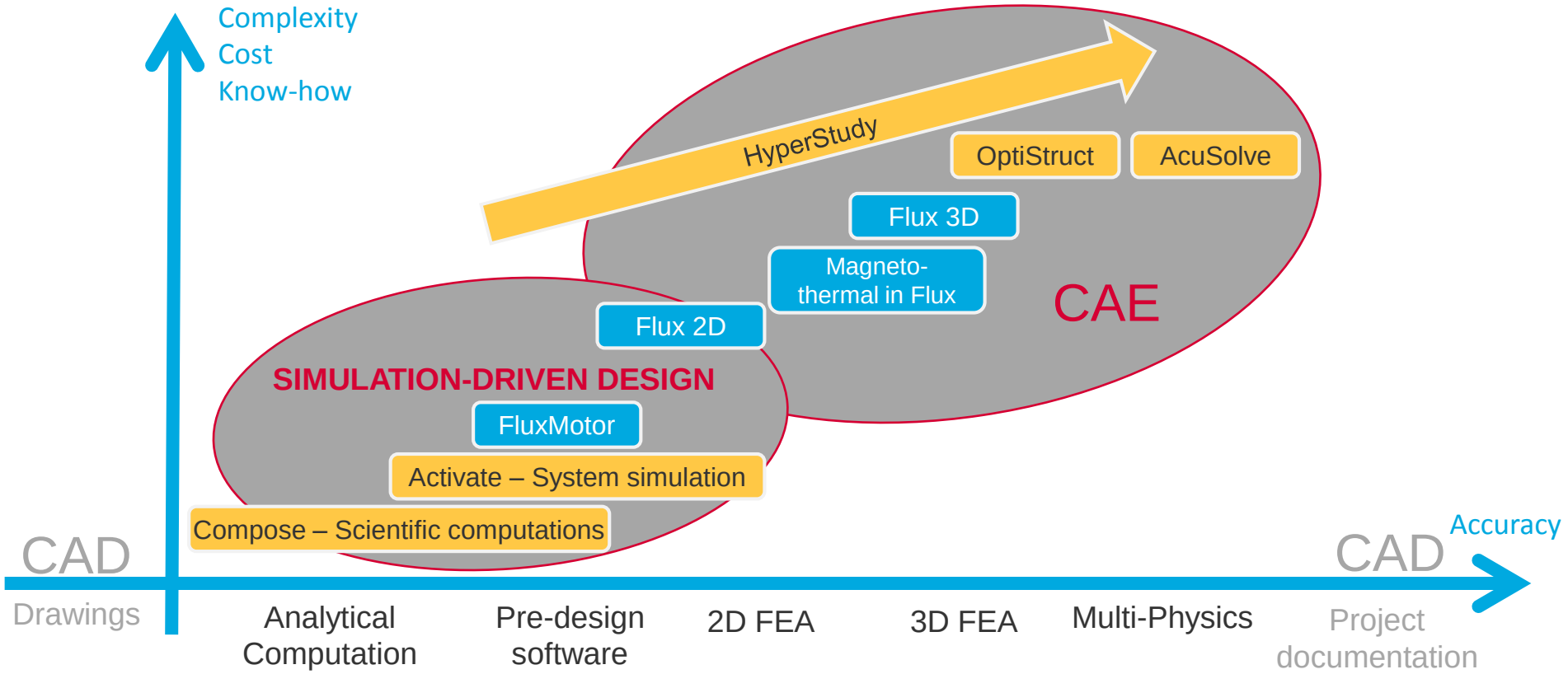
Typical Electric Motor Design Workflow



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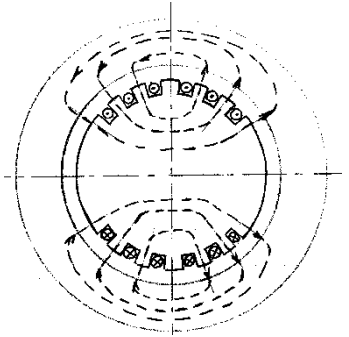
Analytical Computation

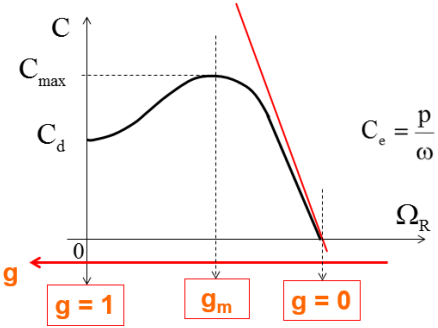


- For each type of motor dedicated formula
- Often available in Excel format, Matlab, Compose or proprietary code

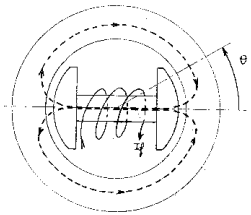
- Advantage
  - Very good correlation (due to X factor coming from experience)
  - All input data are well known

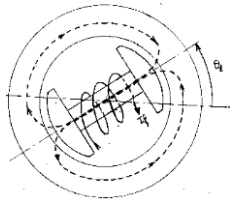
- Disadvantage
  - Limited to one type of motor
  - Experts are retiring

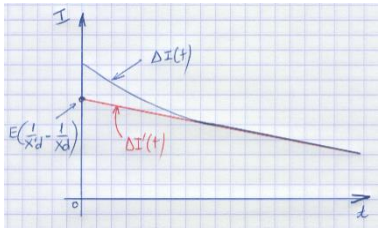
$$C_e = \frac{\frac{p}{\omega} 3 V_1^2 R_2'}{g \omega^2 (L_{f1} + L_{f2}')^2}$$



$$C_e = \frac{p}{\omega} \frac{3 V_1^2 g}{R_2'} = k g$$







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FluxMotor : A New Tool for Electric Machine Design

For machine designers and integrators

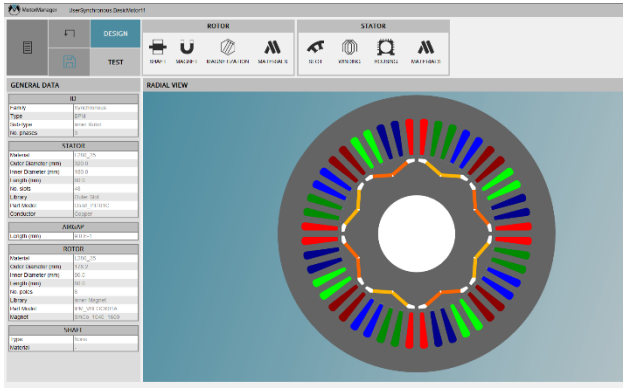
A dedicated tool

- **Customizable templates**
- Winding tool
- **Easy to use**

Fast and accurate

- Mixed analytical/FE based calculations
- Embedded modeling knowledge

High productivity



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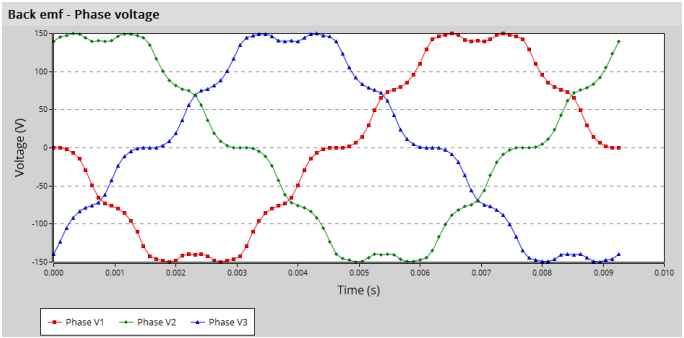
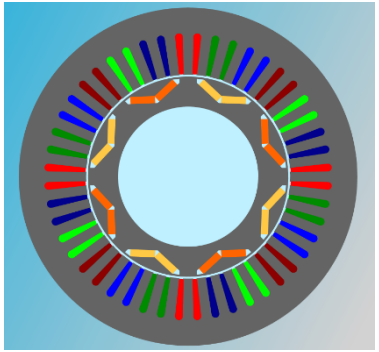
FluxMotor : Checking with Prius 2004

- Old design, and easy to compare to measurement
- All results in less than half an hour

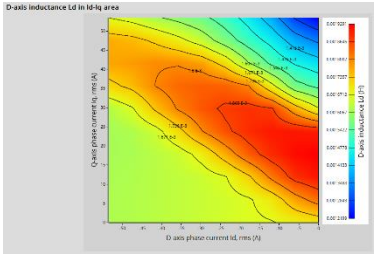


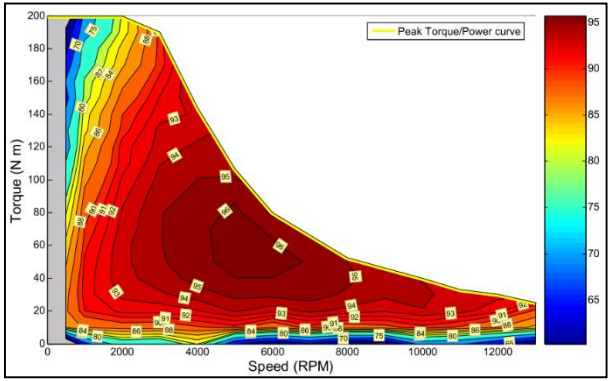


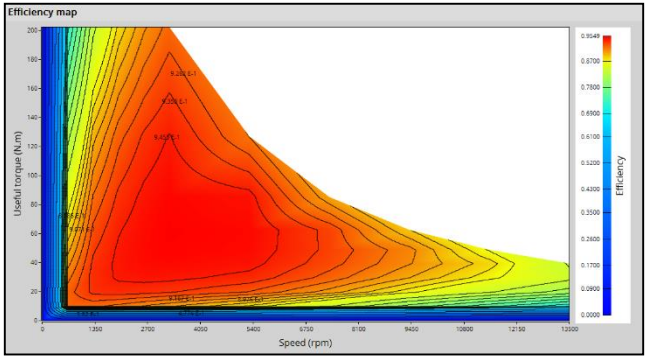
OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

Evaluation of 2004 Toyota Prius Hybrid Electric Drive System

FluxMotor







Efficiency with torque/speed curve

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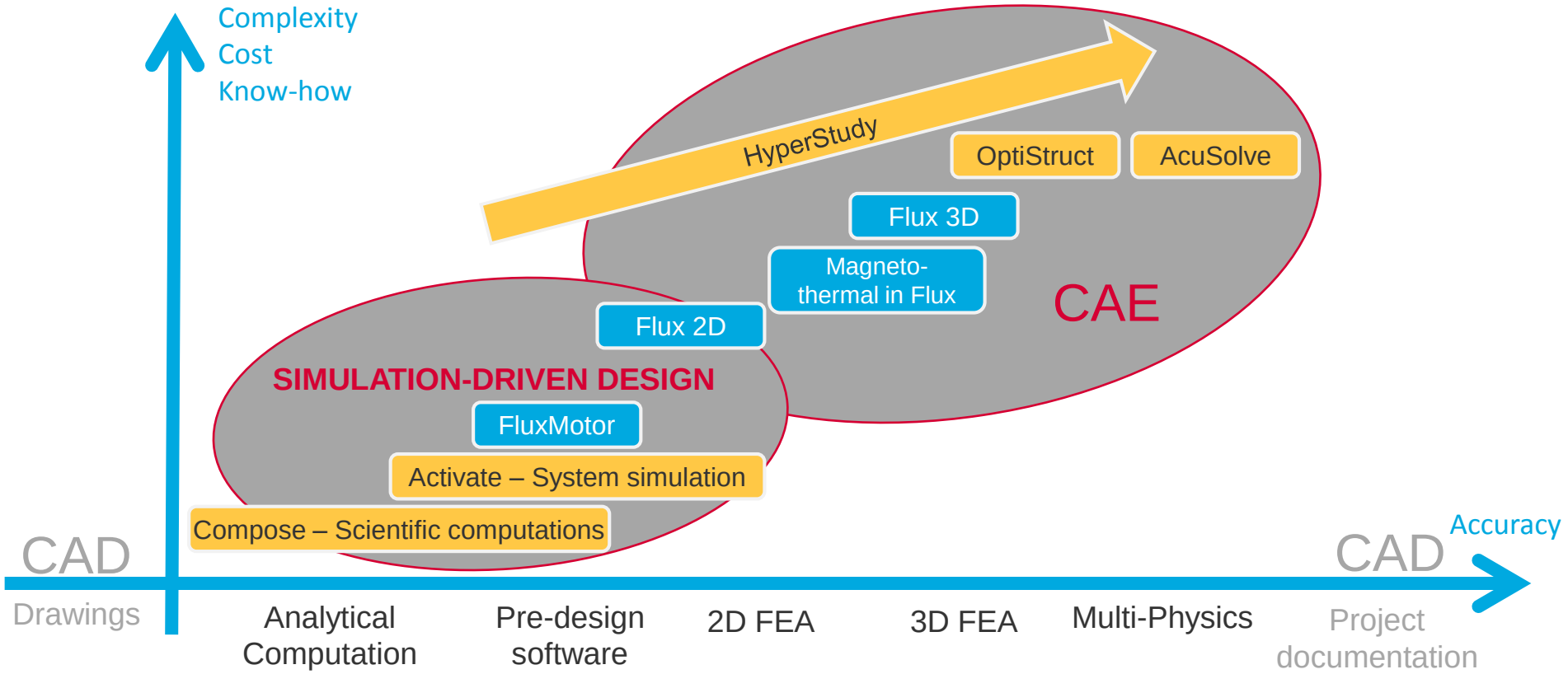
Typical Electric Motor Design Workflow



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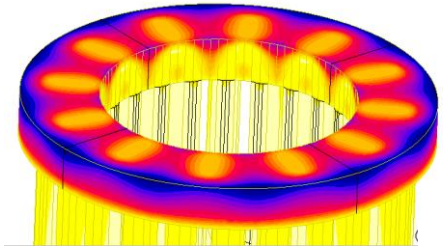
FEA Analysis



Accurate

- Fast and **accurate** solver
- Best-in-class modeling methods
- Efficient modeling of complex situations

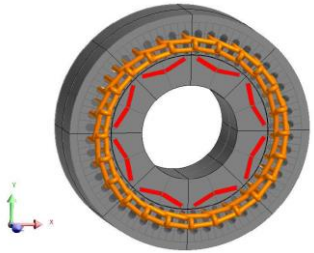
Flux™

Connected

- CAD connection
- Coupled to system simulation
- Coupled to the best tools for multiphysics analysis

Flexible

- **Adjusted to the user needs**
- Wide application coverage
- Customization & Automation



Parametric

- **Fully parameterized** models
- Embedded and easy to use
- Distribution of computation

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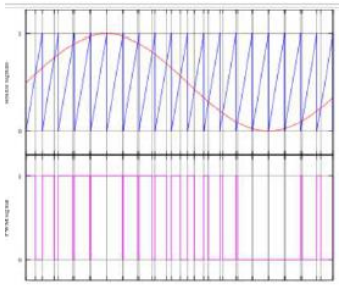
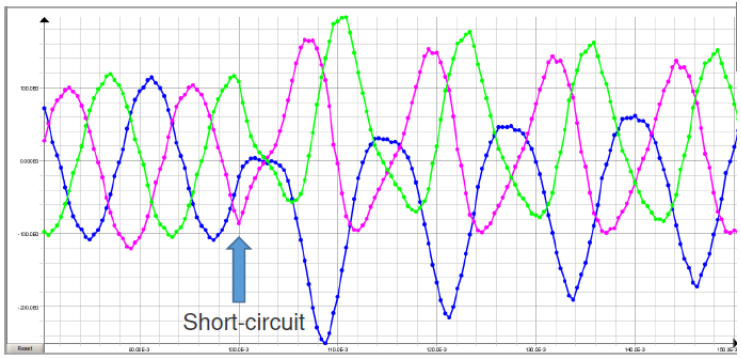
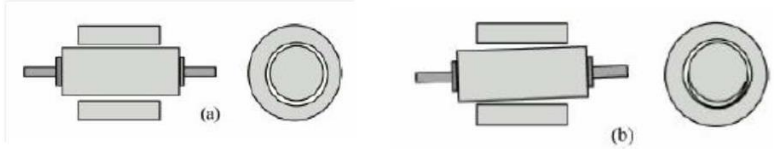
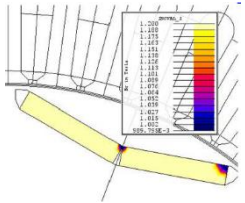
Flux : Prius Example

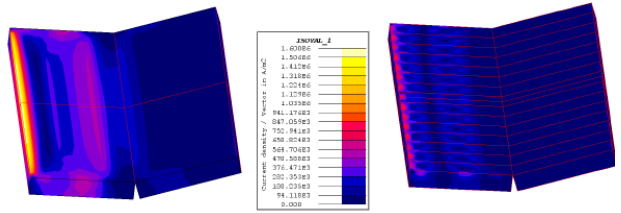


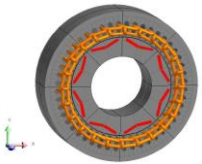


- Simulate default conditions
  - Short-circuit test
  - Winding short-circuit strand
  - Excentricicites
- Compute acurately efficiency or characteristics of the motor
  - Compute losses in the motor due to supply (PWM)
  - Check demagnetization in the magnet
- Improve the motor
  - Reduce losses in the magnet
  - Reduce torque ripples of the motor
  - Reduce space and time harmonics of the torque to reduce noise and vibration
  - Optimize the magnet weight









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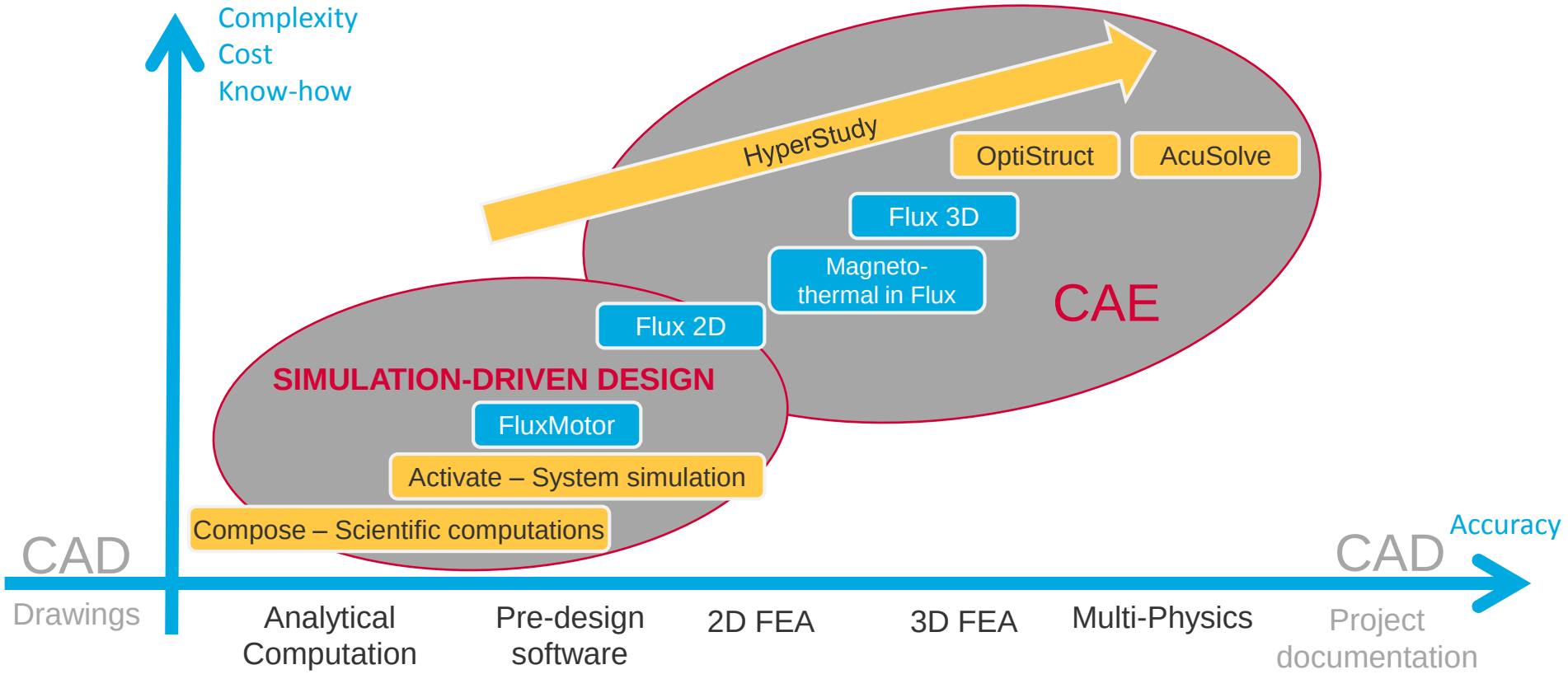
Typical Electric Motor Design Workflow



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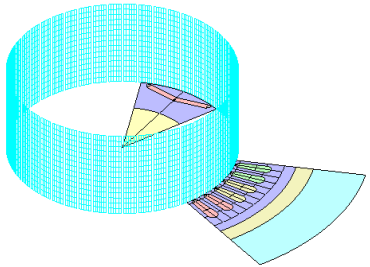
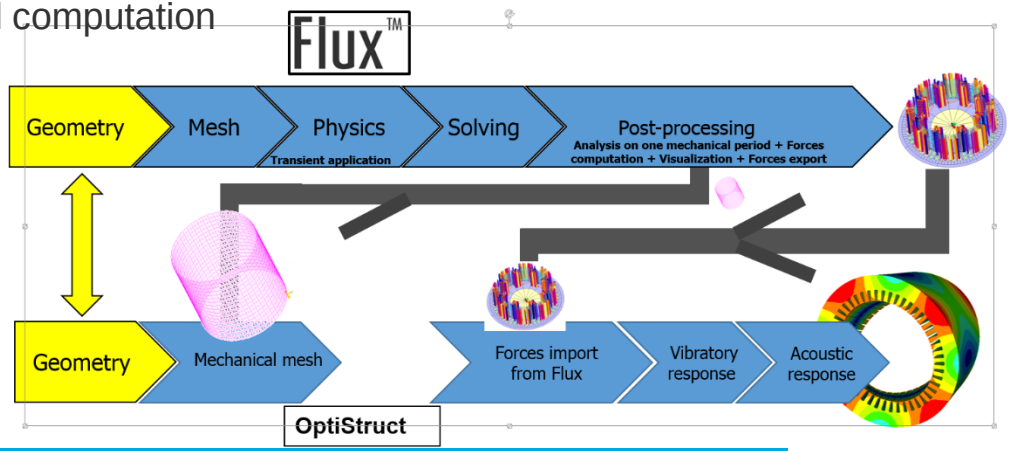
NVH Analysis : Extracting Forces from Flux to OptiStruct

- Goal
  - Compute displacement and vibration generated from forces applied on stator
  - Avoid resonance issue due to the structure
- Principle
  - Extract magnetic forces applied on stator
  - Compute harmonics
  - Use harmonics as load of the mechanical computation
- Note: Flux 2D, or Flux 3D can be used





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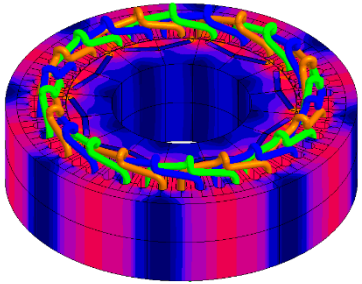
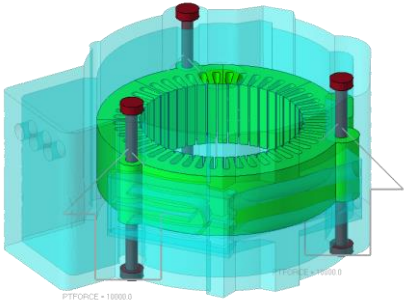
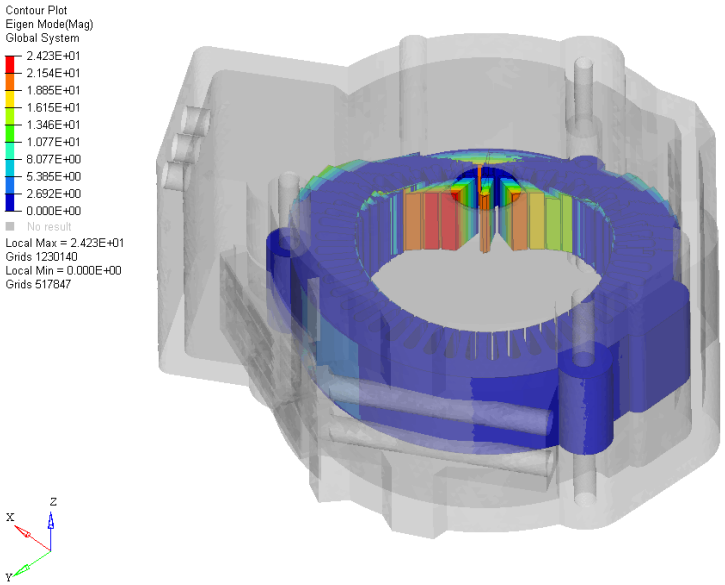
NVH Analysis on Prius Model

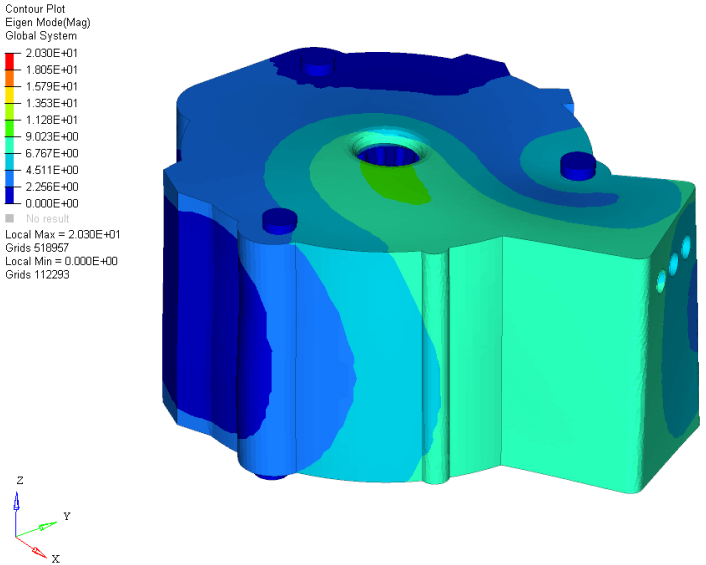




Mode 1: 710 Hz



Mode 4: 1495 Hz



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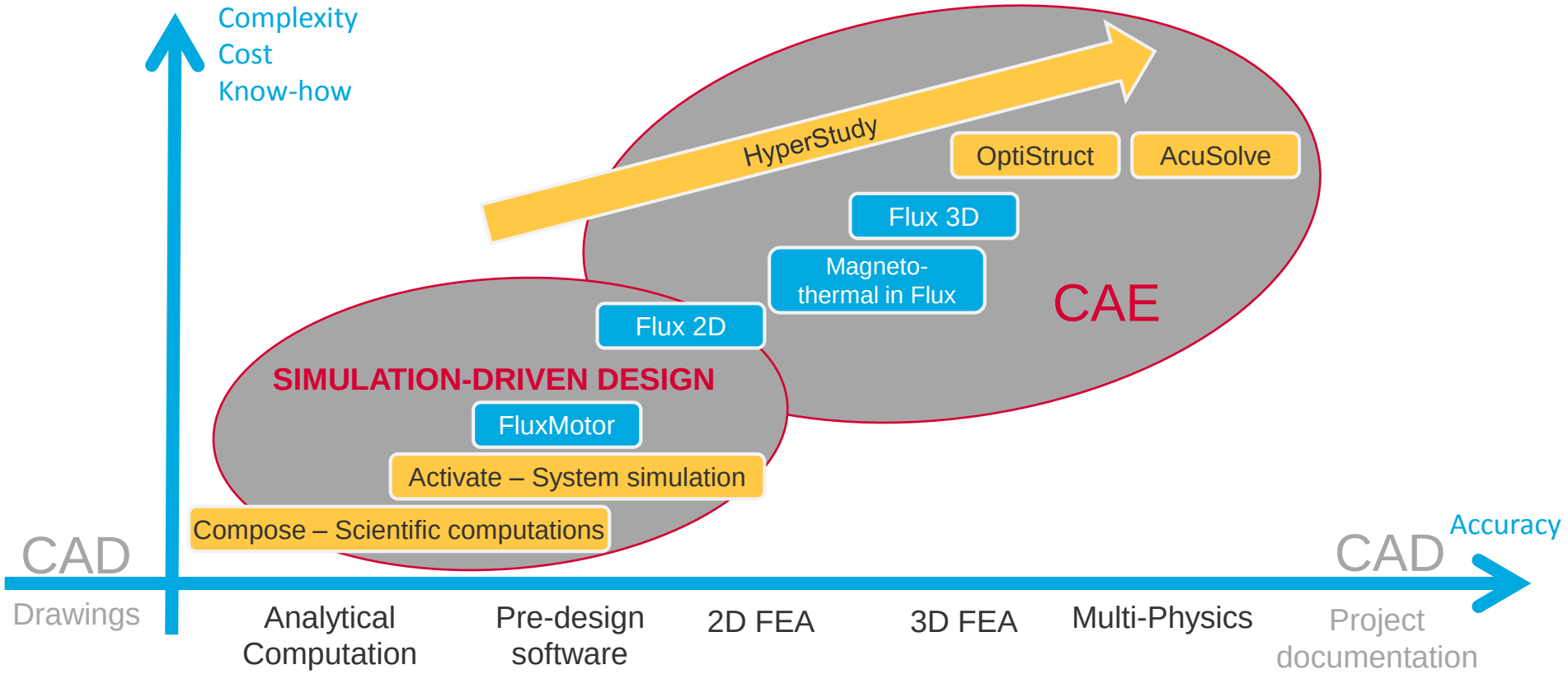
Typical Electric Motor Design Workflow



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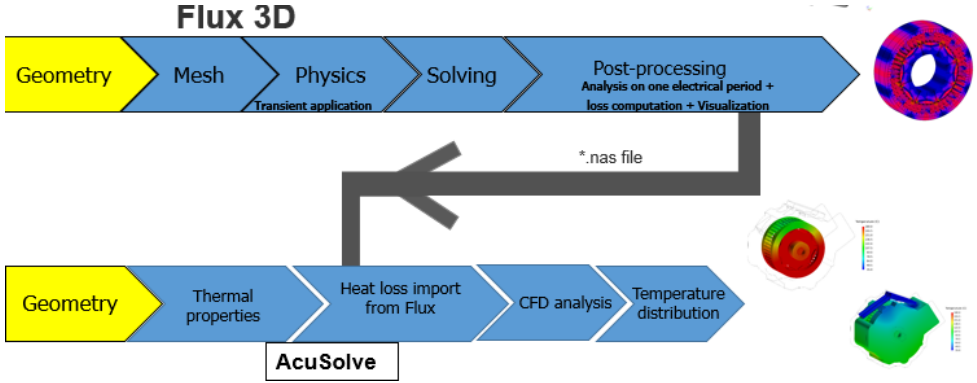
CFD Analysis

- Goal
  - Check different cooling methods
  - Find out hot spot
- Principle
  - Flux is used to model electromagnetic components to determine static thermal loading
  - Results are provided to AcuSolve and are used to define the elements based volumetric heat load

- Today : available in one way coupling
- Soon : available in 2 ways coupling



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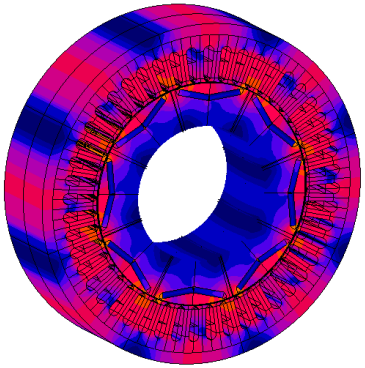
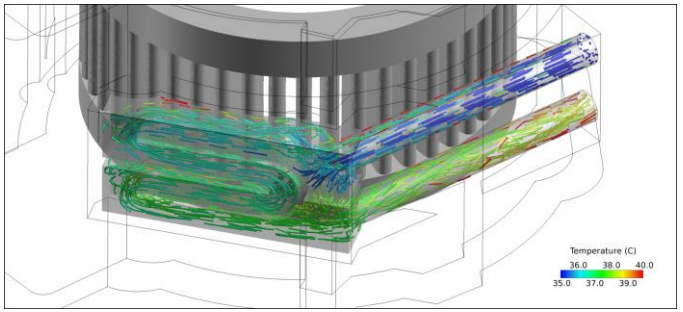
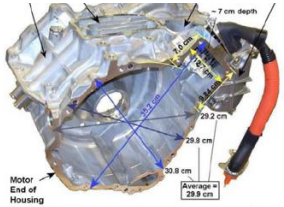
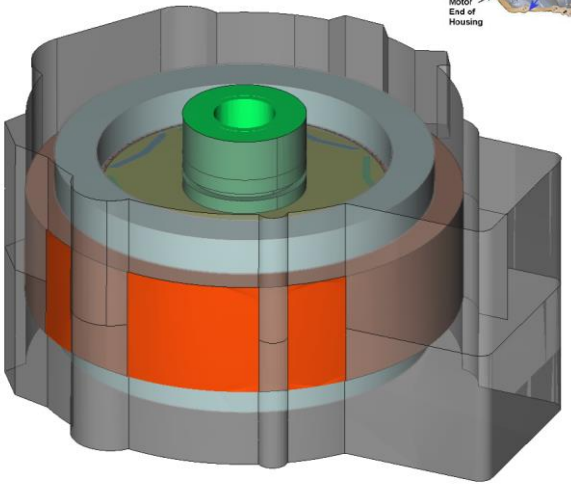
CFD Analysis : Prius Example

- Extract losses
  - Coil
  - Magnet
  - Iron losses

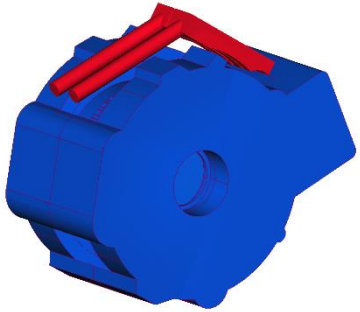


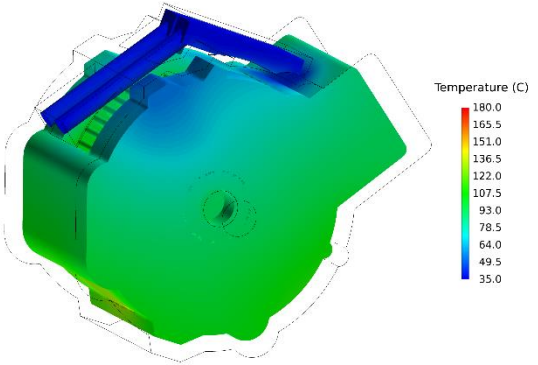






Water Jacket





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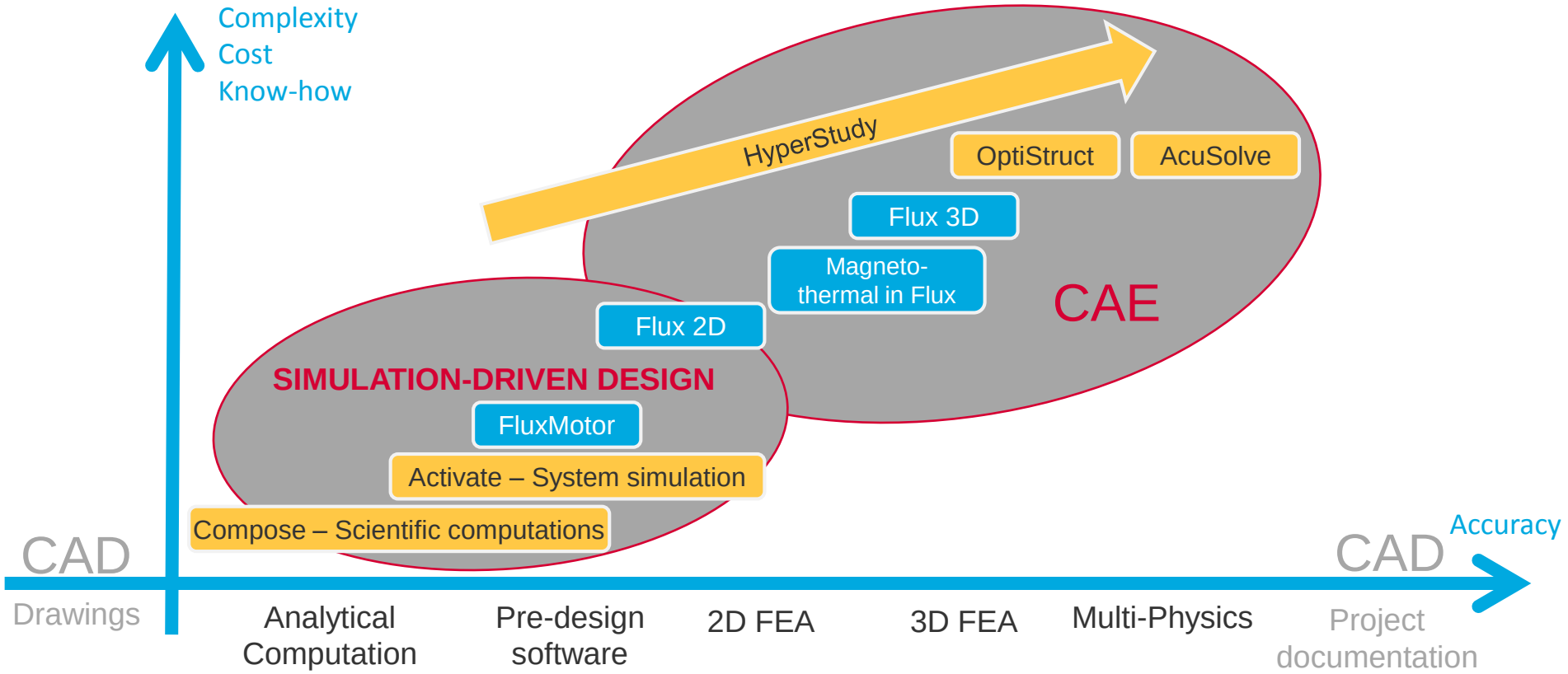
Typical Electric Motor Design Workflow



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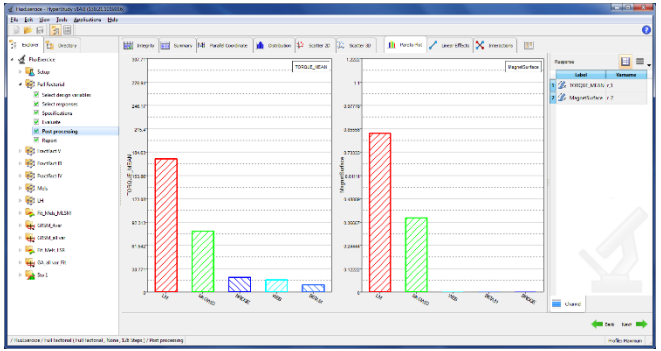
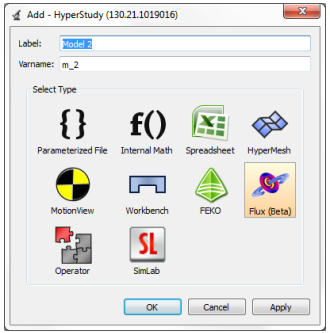
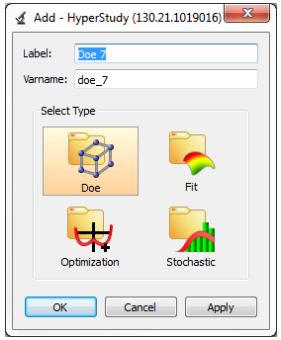
Optimization with HyperStudy

- Multi-disciplinary design exploration, study and optimization software
- Possibility to connect with other softwares
- Different types of use
  - **DoE**: Screening or Space filling
  - **Fit**: Response Surface (RS) building
  - **Optimization**: optimization with or without RS
  - **Stochastic**: Robustness analysis, Optimization taking into account uncertainties







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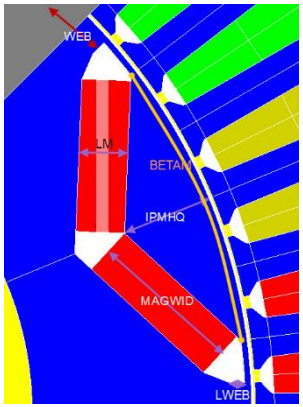
Optimization with Flux : Prius Example

- Optimize the magnet size to reduce the magnet volume by keeping the initial performance

Parameter	Initial Design	Prius Design	HyperStudy optimum
BETAM (mm)	120	140	120
IPMHQ (mm)	15	10	8
BRIDGE (mm)	2	-	0,5
LM (mm)	12	5	5,98
MAGWID (mm)	30	54	39,99
LWEB (mm)	2,75	2,75	0,5
WEB (mm)	10	10	10,96
TORQUE_MEAN (N.m)	**364,98**	**390**	**390,2**
Magnet surface (mm²)	**360**	**270**	**239,14**



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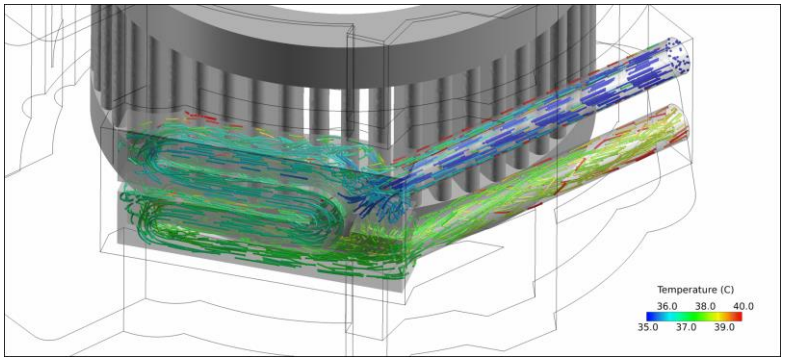
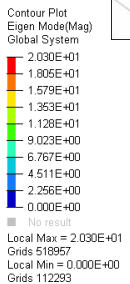
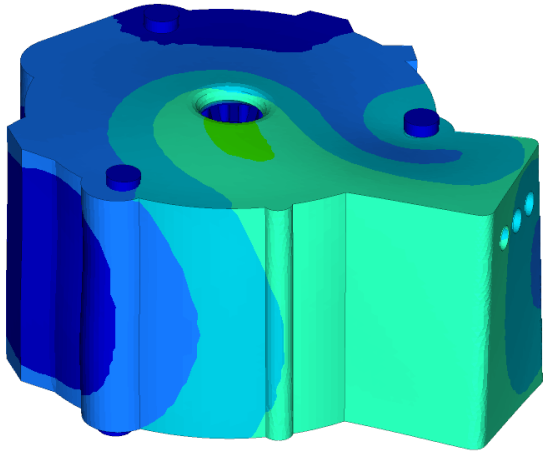
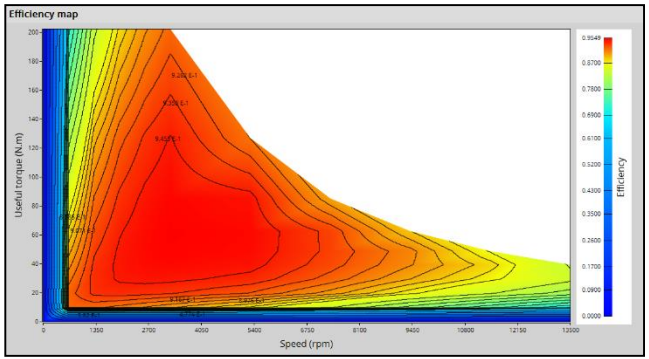
Conclusion

- Altair is the right suite to model E motor
  - Use the right tool at each design stage
  - Connexion between tools allow to save time and energy
  - Get acurate results with the right tool
  - Use optimization on the whole process









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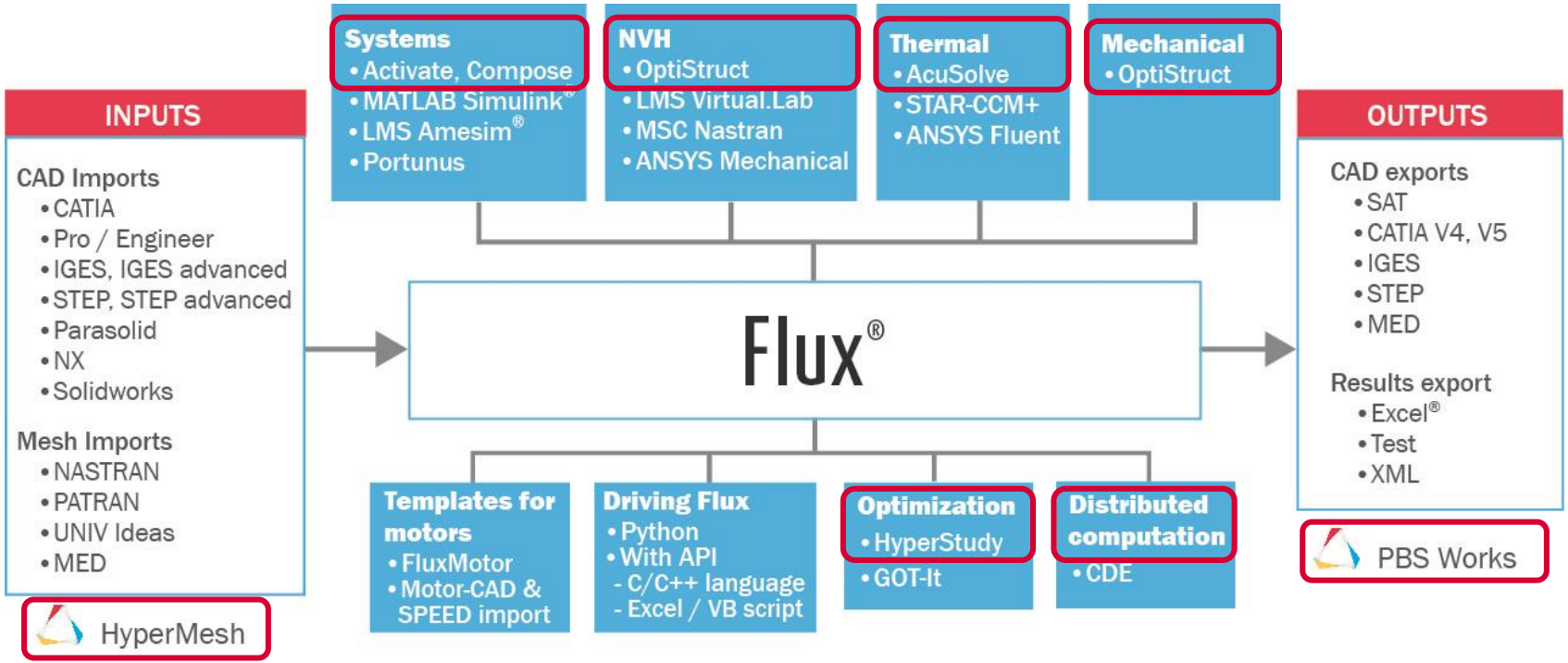
Building Complete Design Workflows



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Thank you for your Attention !

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Thanks to Other Altairians !

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- AcuSolve : Michael Barton
- HyperStudy : Diana Mavrudieva

- Christophe Bailly, Gildas Guilly, Diana Mavrudieva, Patrick Lombard, « Multi-Physics Noise Optimization in Fuel Pump PM Motor », September 2017, ISEM Chamonix