Reduced-Order Modelling
How and Why – An Overview
Agenda

- Challenges in Simulation and Why a need for ROMs
- ROM types, workflows and availability
- Static ROMs for Linear and Non-Linear problems
- Dynamic ROMs for Non-Linear problems
  - e.g. Fluids
  - Scalar outputs
  - Field outputs
- Q&A
Challenges in Simulation and why a need for ROMs
A Reduced Order Model (ROM) is a simplification of a high-fidelity dynamical model that preserves essential behaviour and dominant effects, for the purpose of reducing solution time or storage capacity required for the more complex model.

TECHNIQUES FOR RANGE OF PHYSICS
Fluid Flow, Thermal, Mechanical, Electromagnetism

SOLVES IN SECONDS (vs. HOURS)
Characteristics of ROM Simulation

• Large-scale design space exploration
  – “What if” scenarios

• Optimization and uncertainty quantification

• Aim to achieve real-time simulation

• 3D-0D links: e.g. Simplorer
  – Routine analysis and operation applications
  – Useful for simulation-based Failure Modes and Effects Analysis (FMEA)
A Systems V-Cycle Stand point...
ANSYS Capabilities along the Systems V

Model-Based Systems Engineering

ANSYS medini

System Architecture & System Safety Validation

System Simulation & Digital Twin

ANSYS Simpleror

SW Components (FMI)

ROM

System/SW Architecture

ANSYS SCADE Architect

Model-Based Software Engineering

ANSYS SCADE Suite & Display

3D Physical Simulation

ANSYS Mechanical Fluent HFSS Maxwell etc.

ANSYS Fluent HFSS Maxwell etc.
ROM Use Models (1/2)

ROM Usage Types

ROMs for 3D
A ROM or a collection of ROMS which are largely homogeneous with respect to an engineering discipline (e.g. mechanical, electronics, or thermal management) used to speed up simulation time.

ROMs for System Simulation
A system of interconnected heterogeneous ROMs (and other component models) where both the system and interface responses are of interest. ROMs provide a way to reuse modeling assets from 3-D analyses and are integrated with other system level components for building virtual system prototypes.

ROMs for Embedded Controls
A ROM that was created during system simulation and that is made a part of the embedded software in order to enhance the precision of software controls. ROM provide a way to introduce “virtual” sensors that can be used for controls.
ROM Use Models (2/2)

ROMs and System Simulation can be used while an asset is operating and connected to an IoT platform for the purpose of enhanced monitoring, asset optimization, diagnostics and predictive maintenance.

ROMs for IoT Digital Twin Applications

ROMs and System Simulation can be used while an asset is operating and connected to an IoT platform for the purpose of enhanced monitoring, asset optimization, diagnostics and predictive maintenance.

ROMs for Simulation Democratization

A ROM created for non-traditional users to explore the design space. System response and internal field data if of interest. These ROMs can be used by non-experts (e.g. a surgeon inserting a stent) to explore the design space and perform analyses, because they simulate quickly and they deploy easily.
ROM Types

Problem Categorization
Typical ROM Workflow

**ROM Creation**
ROM Builder (and 3D solvers)

- **Parameter Sweep**
  - ANSYS Source (3D) Tool
  - Training Data from ANSYS
  - 3D Simulation Data

- **Training Data Generation**
  - Time: Hours or days

- **ROM Extraction**
  - ANSYS ROM Extraction Tool
  - ANSYS ROM Model

- **ROM Creation**
  - ROM Builder (and 3D solvers)

**ROM Consumption**
3D solvers and System

- **Parameter Sweep**
  - ANSYS ROM post-processing (3D)
  - ANSYS System Tool (or other System tool)
  - System Simulation Data

- **ROM Consumption**
  - Time: ~Mins/Secs

- **Time:**
  - Training Data Generation: Hours or days
  - ROM Extraction: ~Mins
  - ROM Consumption: ~Mins/Secs
Response Surface ROM

Response Surface Modeling

- The values of **output parameters** as a function of **input parameters** are obtained on the design points defined in the design of experiments
- Interpolation methods are essential to the model
Response Surface ROM

Response Surfaces become Reduced-Order Models (DX-ROM)

Export Response Surfaces as FMUs From any Workbench Project
Static ROM Builder

• Produces Field outputs
• Integrated in WB/DX
• Iterative method with accuracy control (leave-one-out)
• Fluent (all features) – Based on existing UDF
• Export Static ROM as FMU from any Workbench project
• Stand-alone ACT based Viewer
  – Beta release in ANSYS 18.2
Underhood Example

- 3D thermo-aerodynamic coupled with radiation
- 500,417 tetrahedral cells
- Standard k-ε model with standard wall-functions

- 2 parameters:
  - Inlet velocity from 5 m/s to 20 m/s
  - Exhaust Temperature from 700K to 900K
Reduced Model Generation Process

- Controlled Accuracy using iterative DOE
- Prediction of accuracy for each set of design points
- Computed accuracy using a fine grid of 200 Design Points

<table>
<thead>
<tr>
<th>DOE size</th>
<th>Predicted Accuracy</th>
<th>Computed Accuracy</th>
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</thead>
<tbody>
<tr>
<td>10 Design Points</td>
<td>0.33%</td>
<td>0.40%</td>
</tr>
<tr>
<td>20 Design Points</td>
<td>0.20%</td>
<td>0.17%</td>
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</tbody>
</table>

- Using 10 Design Points
  - Average error on velocity: 0.066 m/s
  - Average error on temperature: 0.68 °C
  - Quantitative Results on the worst verification point
Static Pressure Comparison

2 hours on 16 core cluster

3 seconds on a laptop

Max difference: 1.2%
Fluid/Solid Coupled Heat Transfer

• Two inlets
  – Main
    constant velocity
    constant temperature
  – Secondary
    constant velocity
    temperature excitation

• One outlet
  – 289302 cells
  – Liquid water and steel
  – Constant fluid and solid properties
  – k-e model with scalable wall functions

• Each Fluent calculation is 26h on 12 cores
Building the temperature field ROM

- Pulsed input temperature profiles used to reconstruct the unsteady temperature field
- Comparison of ROM with Fluent shows good agreement
Temperature Field ROM Validation

- Then use ROM to predict oscillating input temperature
Generic Centrifugal Pump Example

ROM Results

FLUENT Results

* Interpolated Point

<table>
<thead>
<tr>
<th>Cavitation Number</th>
<th>Head Coef.</th>
<th>ROM</th>
<th>Fluent</th>
<th>Err [%]</th>
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<tr>
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</tbody>
</table>
Use Case: Connected Pump Services

- Anomaly detection and alerts
- Failure Prediction
- Prescription
- Data Mining
- Realtime Monitoring
- Performance Optimization
- Remote Diagnostics
- Prognostics
- Next Gen Design
Conclusions and the Future

• ROMs have significant investment, but allow large systems to be modelled efficiently

• Many different ways of creating a ROM, most of which can be resolved with existing tools

• The Future
  – More simulations needed from the analysts
  – More useful analysis data (and handle-turning investigation) for non-specialists
  – Tools fully integrated into ANSYS Workbench