Engine Modeling with Modelica

Dr. John J. Batteh

Ford Motor Company
Transient Engine Simulation Group
Powertrain Research Department

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Contributors

- **Eric Curtis** (Group Leader, ecurtis@ford.com)
  - Modelica technical lead

- **Michael Tiller** (mtiller@ford.com)
  - Engine and combustion modeling

- **Charles Newman** (cnewman@ford.com)
  - Heat transfer/thermal flow, liquid fuel effects

- **John Batteh** (jbatteh@ford.com)
  - Engine and combustion modeling

- **Chris Puchalsky** (former group member)
  - Liquid fuel effects

- **Allan Watson** (awatso12@ford.com)
  - Hydraulics/thermal flow, lash adjuster

- **Kartik Ramanathan** (kramana2@ford.com)
  - Manifold dynamics
Engine analysis requires multi-domain physical models!!
Model Applications

- Engine-level analyses
  - Throttle response
  - Liquid fuel effects (wall wetting)
  - Spark control response
  - Valve timing response
  - Manifold dynamics
  - Thermal warm-up characterization

- Vehicle-level analyses
  - Drive cycle analyses
    - Fuel economy
    - Emissions
  - Vehicle control strategy development
  - Energy management studies
  - Powertrain analyses
    - Efficiency
    - NVH/shift quality

Wide array of applications necessitates flexibility!!
Model Characteristics

- **Transient**
- **Flexible**
  - Predictive vs. fixed combustion
  - Fidelity of component models
    - Accuracy-speed tradeoff?
  - Working fluid calculations (medium models)
  - Fuel and air composition
- **Configurable**
  - Single vs. multi-cylinder
- **Reusable**
  - Same interfaces and similar basic components across different analyses
- **User-friendly**
Outline

- Introduction
- Interfaces
- Medium Model Concept
- Signal Bus Concept
- Sample Results
- Final Remarks
Interfaces

- **Key to flexibility**
  - Clearly define system interactions
  - Promote orthogonal model development
  - Provide framework for model compatibility

- **Examples**
  - Cylinder interface
  - Engine interface
  - Thermal architecture
Cylinder Interface

- Framework for all cylinder models
  - Partial model
- Defines external connections for cylinder

Induction System (Thermodynamic)
Exhaust System (Thermodynamic)

Camshaft (1D rotational flange)
Engine block (1D rotational flange)
Cylinder thermal environment (Thermal)
Crankshaft (1D rotational flange)
Engine Interface

- Framework for all engine models
  - Partial model
- Defines external connections for engine
- Extending models define plenum configuration
  - Single plenum
  - Dual plenum

Diagram:
- Engine block (1D rotational flange)
- Engine thermal environment (Thermal)
- Crankshaft (1D rotational flange)
Complete Engine

- Plug-n-Play with a variety of engine configurations
  - Replaceable cylinder model fits in all engine configurations
Thermal Architecture

- Provides framework for interaction between cycle simulation and engine temperature models
  - Cycle simulation models
    - Responsible for metal-gas interactions
  - Transient engine temperature models
    - Responsible for metal-fluid interactions

- Allows orthogonal selection of models
  - Cycle simulation
  - Engine temperature
Cylinder Thermal Environment

- “Connector of connectors”
- Thermal bus
- Comprised of connectors for standard components which interact with various models
  - Thermal connectors for various engine components (piston, block, head, etc.)
  - Thermal connectors for engine fluids (oil, coolant)
  - Friction connectors
- Used with “break-out box” in low level models
Engine Thermal Environment

- **Engine level connector**
  - Array of cylinder thermal environment connectors to allow for multiple cylinders

- **Features**
  - Parametric connector representation for engines with multiple cylinders
  - Consolidates signals to minimize connections
    - Single, engine-level connection
Using the Thermal Architecture

Single-Cylinder Analysis

Engine Temperature Model

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Challenges

- **Difficult to connect to connectors within connectors**
  - Direct connection not possible
  - Requires termination of all flow variables before connection (terminator model)
    - Signals requiring termination grows exponentially with number of cylinders

- **Resolving varying level of details in cycle simulation and engine temp. models**

  - Requires:
    - Averaging temperature
    - Dividing heat transfer rate
Medium Models

- Define specific working fluid
- Consistent set of models, functions, constants, connectors
  - Material properties (enthalpy, energy, viscosity)
  - Equation of state
  - Chemical representation (# of species)
  - Chemical kinetics of combustion
  - Helper functions (air-fuel ratio, etc.)
- Implemented via replaceable packages

Features
- Orthogonal development of property models and the component models which use them
- Consistent framework for development of medium models with varying levels of detail
- Consistent application of changes throughout model hierarchy
- Organized
  - Information entirely contained within medium model package
- Change working fluid at “flip of switch” at highest level

```model EngineTest
    Engine engine(redeclare package MediumModel=Air)
end EngineTest;
```
Challenges

- **More fool-proof specification of working fluid**
  - Currently requires redeclaration of medium model in each component
  - Single redeclaration that automatically propagates via connections should be possible

- **Generic implementation?**
  - Applicable in all areas of modeling
    - Working fluids in hydraulics models
    - Fuel composition in wall wetting models
    - Material properties in heat transfer models
Engine Interface…Revisited

- How do we propagate control signals for modular hierarchies with replaceable components?
  - Redeclaring component model may change information required
    - Generic cylinder
    - Cylinder with variable cam timing
  - Impossible to anticipate all types of signals that might be required by a specific implementation
  - Not practical to propagate signals via connectors
Signal Bus

- **Signal bus idiom**
  - Facilitates propagation of control signals for replaceable component models
  - Uses inner/outer semantics
    - Outer required to be subtype of inner
  - Allows top-level definition for union of all control signals
  - Allows selective definition/use of signals at low level

Signal bus carries control signals
Wall Wetting Model

- Model details
  - Multiple control volumes
  - Multi-component fuel
  - Evaporation
  - Fluid flow
  - Puddle shattering (backflow)
  - Transient engine cycle simulation
  - Transient engine temperature model

- Applications
  - Throttle and speed transients
  - Fuel composition studies
  - Injector targeting studies

1. Port Film
2. Valve Film
3. Upstream Film
4. In-Cylinder Film
Wall Wetting Results
Final Remarks

- Interfaces provide framework for extensible, flexible engine models by independently choosing:
  - Combustion models
  - Transient engine temperature models
  - Medium models
  - Engine configurations

- Modelica language features highly suited to flexible modeling
  - Extends
  - Replaceable + Redeclare
  - Inner/outer semantics
  - Record semantics
  - Documentation and graphical annotations

- Looking ahead…
  - Challenges still exist
    - Zero mass with intensive properties

- Discussion and new ideas?