Systems Simulation

Third DOE Workshop on

Crosscut Lean Emissions Reduction Simulation (CLEERS)

October 16-18, 2001, Ford SRL

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Why Systems Modeling?

- Engine Performance
- PM Control
- N0x Control
- Reagent Generation Control
- Sulfur Control
- Heat Management Control
- **Full Vehicle Performance**

Exhaust Gas Aftertreatment Technologies

- PM Traps
- SCR
- Reagent Generation
- N0x Adsorbers
- In-Cylinder Combustion Control

Caterpillar Engine Families

- Small Engines: <1L/cyl
- Medium-Duty: 6.6L - 9L
- Heavy-Duty: 10L - 16L
- Large Engines: >5 L/cyl

Engine Applications

- On Highway
- Agricultural
- Construction
- Marine
- Power Generation
- Locomotive
- Mining

Product Design Challenge

- Geometry
- Materials
- Catalysts
- Configuration
- Customization

- *Combinations!*

Systems Modeling Characteristics

- Steady-State and/or Transient
- Stand-Alone and/or Coupled with other subsystems
- Phenomenological and/or First Principle Based
- Accuracy vs. Compute Time
- Model Validation

Available Modeling Tools

- Cycle Simulation Tools
- Aftertreatment Simulation Tools
- Dynamic Simulation Tools
- Structural Analysis Tools
- CFD

Cycle Simulation Tools

- Proprietary Code
- Commercial Codes

EGA Simulation Tools

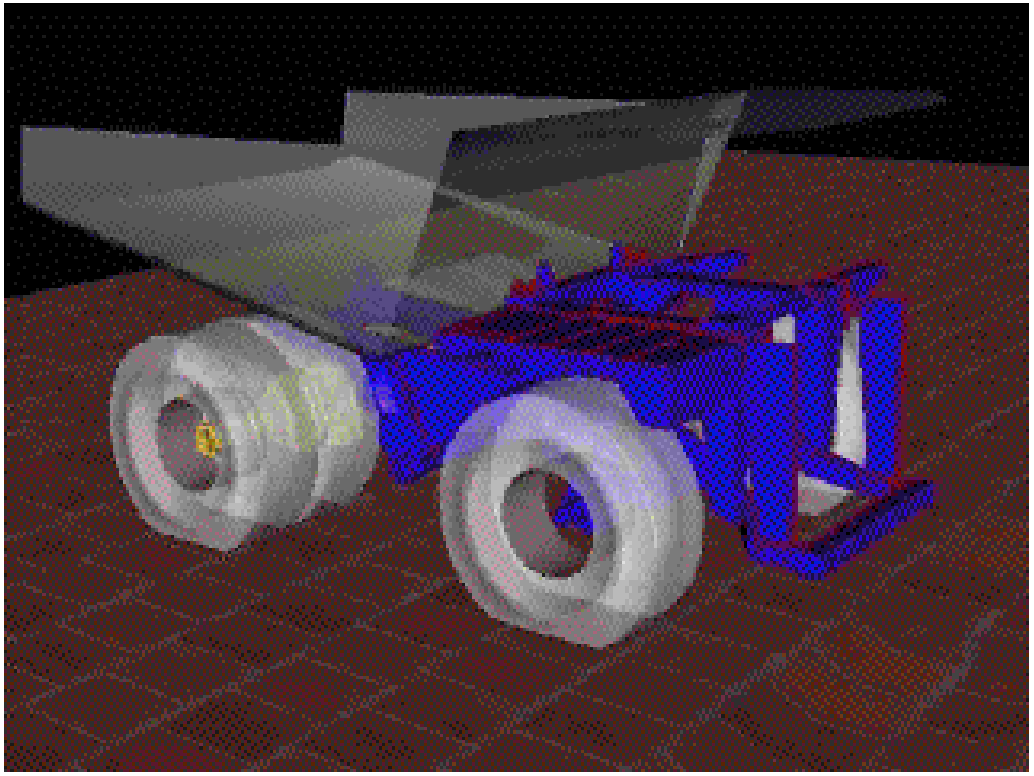
- Proprietary Models
- Other Models

Dynamic Simulation Tools

Dynamic Simulation Tools

The Power of Systems Simulation

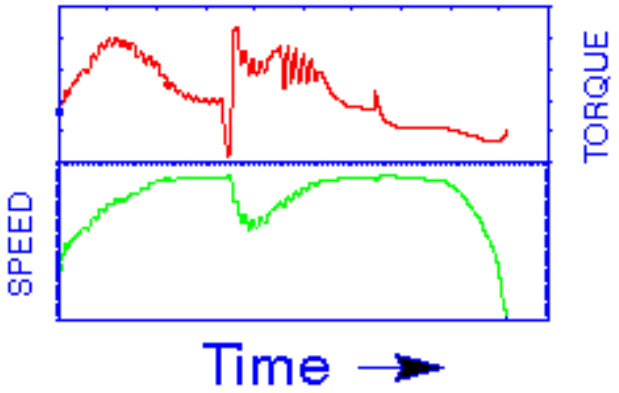
- Make better design decisions by exploring and validating multiple design concepts and applications
- Enhance product performance by identifying key design tradeoffs and optimum configurations
- Shorten time to market by developing virtual prototypes
- Reduce field problems by better understanding of complex system behavior and interactions
- Enhance communication by sharing models across distributed design teams and with suppliers



Dynasty Overview

Integrated Dynamic Simulations of

- Thermodynamic Systems
- Mechanical Systems
- Hydraulic Systems
- Electrical Systems
- Digital Systems



In the Time Domain….

Dynasty Overview

What Makes Dynasty Unique?

- Modeling Flexibility and Model Reuse
- Ease of Use (Modeling *and* Simulation)
- Large, *Multi-Discipline* Component Library Containing Low-Level *and* High-Level Components
- Proven Time and Again ...

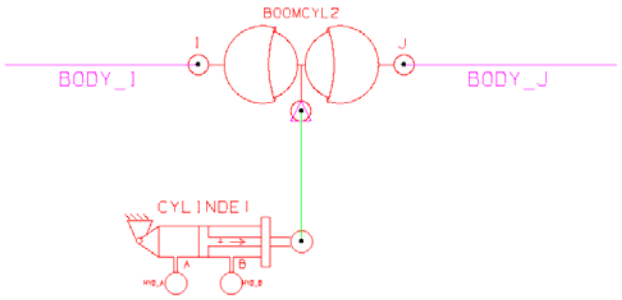
  ... On Real-World Problems

Dynasty Overview

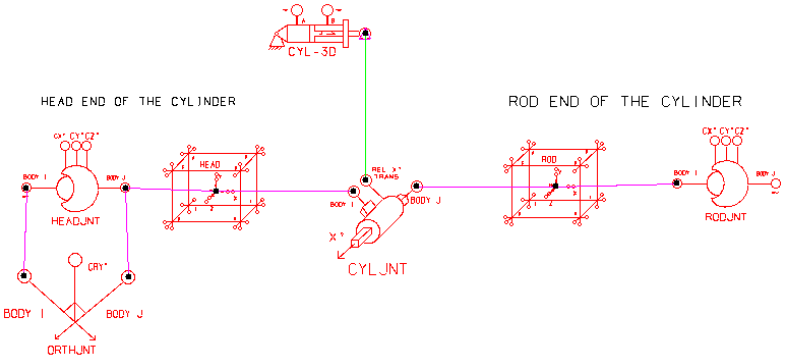
Flexible

- Sub-Systems Modeled Separately or Together
- Can Start Simple and Add Complexity as Needed
- Models Can Be Easily Reused for Different Needs
- 220+ Components Range from Simple to Complex
- Users Can Add Their Own Components

1D Model



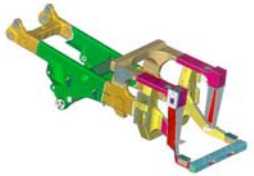
3D Model



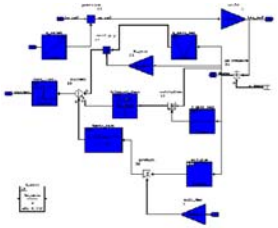
Dynasty Overview

Multi-Disciplinary Scope -- Dynasty's flexible, component based architecture spans a broad application cross-section:

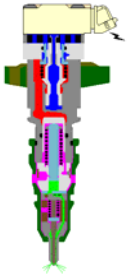
Linkages & Structures
- 2D & 3D rigid bodies
- Flexible body dynamics



Powertrains
- Transmissions
- Final drives
- Wheels & Tracks
- Gear dynamics

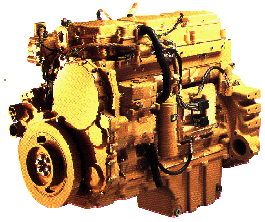


Controls & Electronics
- Component & full vehicle simulation
- Algorithm development
- User programming
- Co-simulation

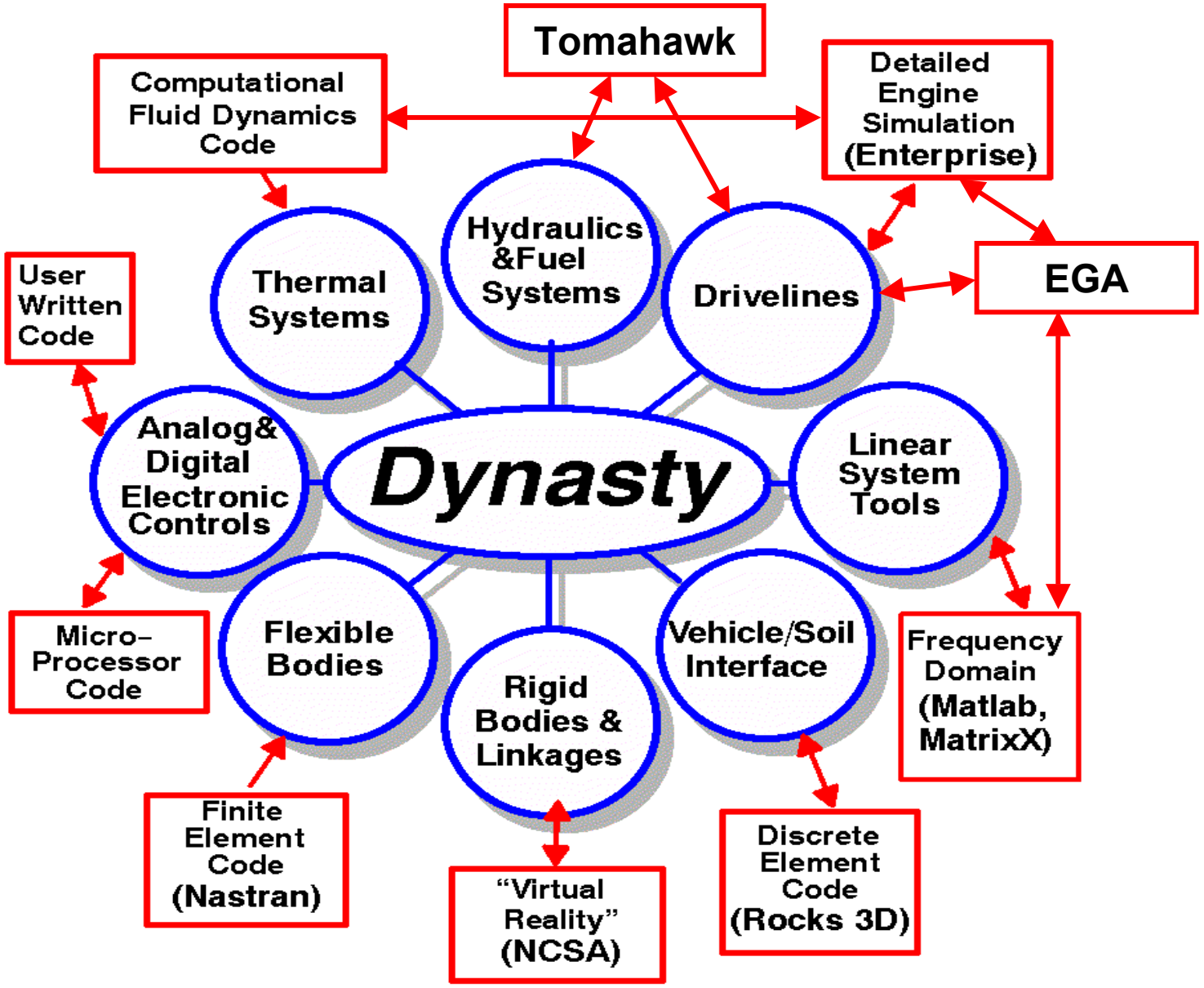


Fluid Systems
- Fuel
- Hydraulic
- Brake
- Steering
- Lube

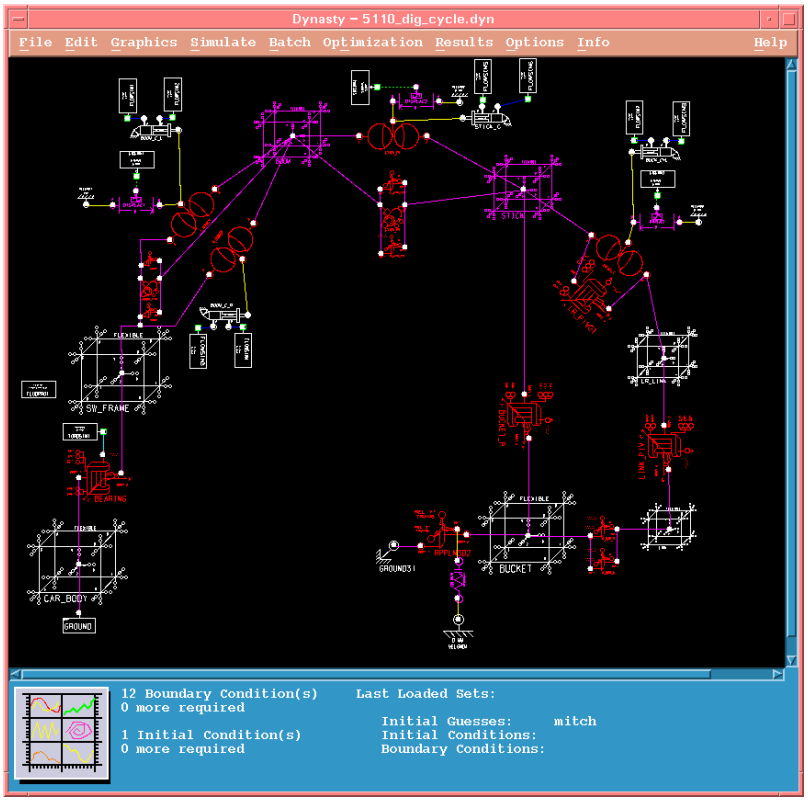
Engine Systems
- Cycle simulation
- Valve trains
- Crankshafts
- Emissions & Aftertreatment



Cooling Systems
- Radiators
- ATAAC
- Fans
- A/C
- Parasitics


Tomahawk
Computational Fluid Dynamics Code
Detailed Engine Simulation (Enterprise)
Hydraulics &Fuel Systems
Thermal Systems
Drivelines
EGA
User Written Code
Analog& Digital Electronic Controls
Dynasty
Linear System Tools
Micro-Processor Code
Flexible Bodies
Rigid Bodies & Linkages
Vehicle/Soil Interface
Frequency Domain (Matlab, MatrixX)
Finite Element Code (Nastran)
"Virtual Reality" (NCSA)
Discrete Element Code (Rocks 3D)

Dynasty Overview

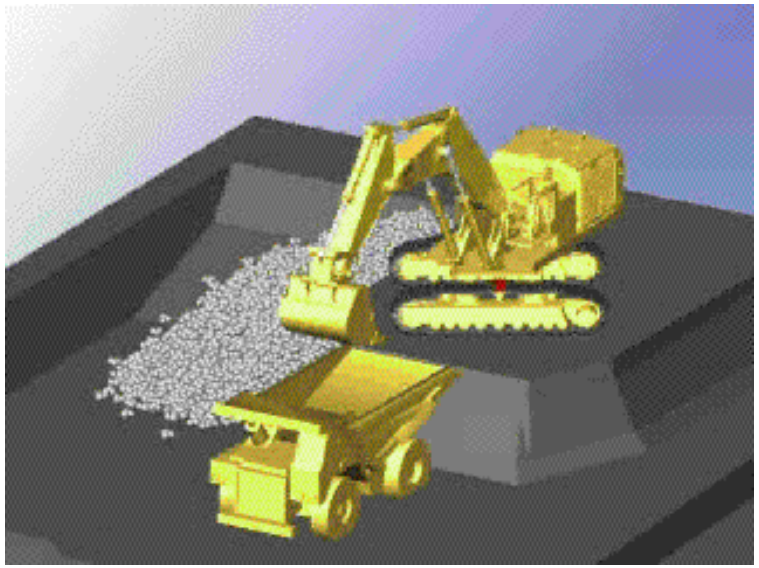


Easy to Use

- Point and Click Model Building
- Work with Real-World Components Like Engines, Clutches, Transmissions, Vehicles, ...
- Solver Muscles Through Problems That Cause Other Tools to Sputter and Die

Dynasty Overview

Proven Time and Again ...



Dynasty has been successfully applied to analyze designs ranging from the smallest fuel system component to the largest off highway truck.

It may be used in all phases of the product development process -- from simple concept models for directional decision making to full high-fidelity, optimization simulations.

EGA Modeling Approach

Aftertreatment Models

PM Trap | N0x Trap | S0x Trap | DeN0x | Urea SCR | .....

Engine Variables

Flow Rate | Temp | Press | Speed | Load | .....

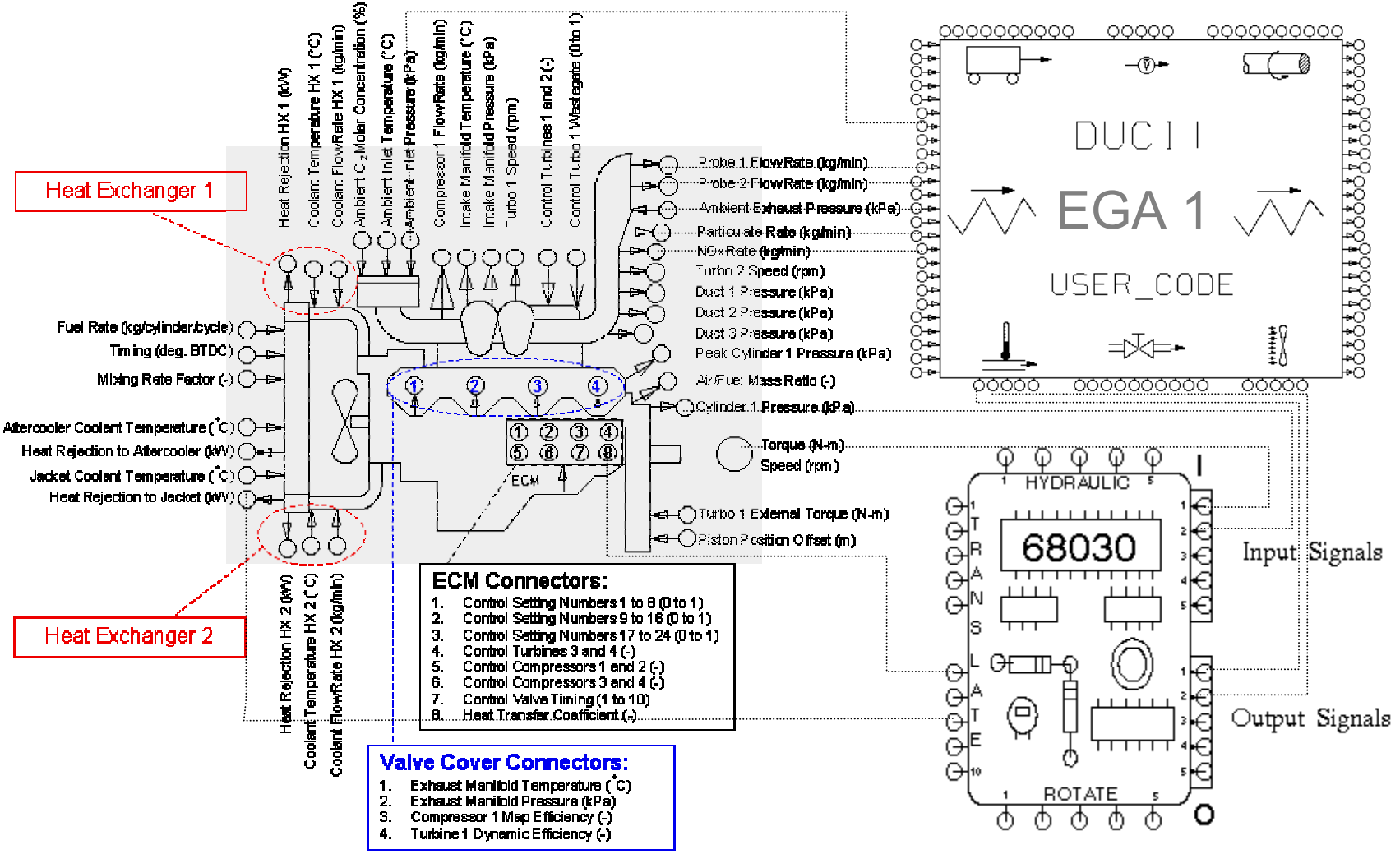
Engine Emissions

PM | N0x | S | HC | O_2 | .....

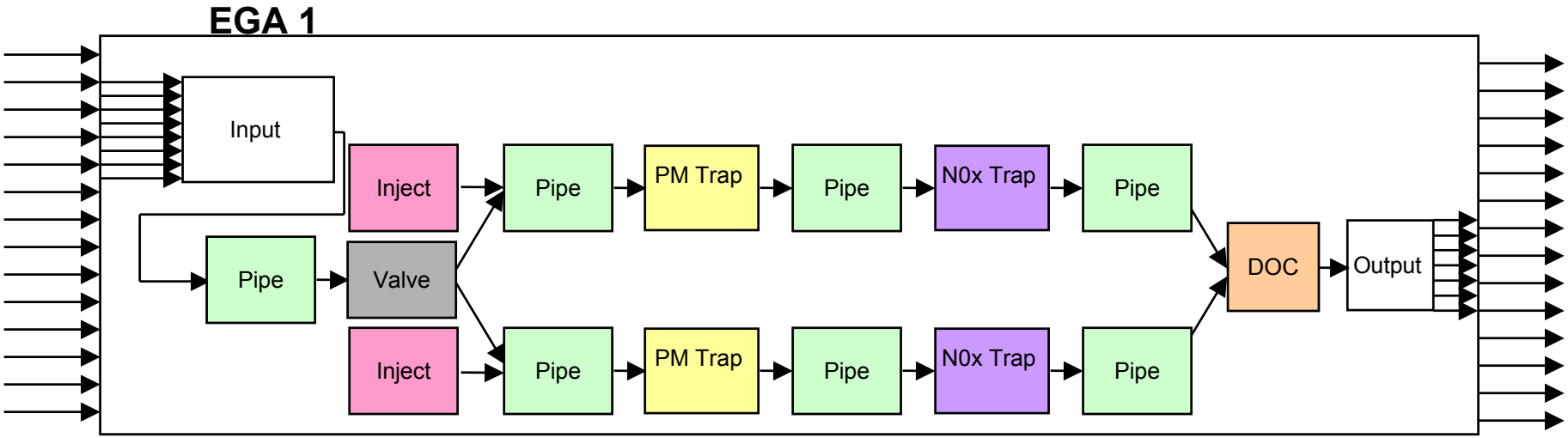
Flow Connections

Pipe | Junct | Valve | Inject | HX | .....

EGA Modeling Example



EGA Module Example

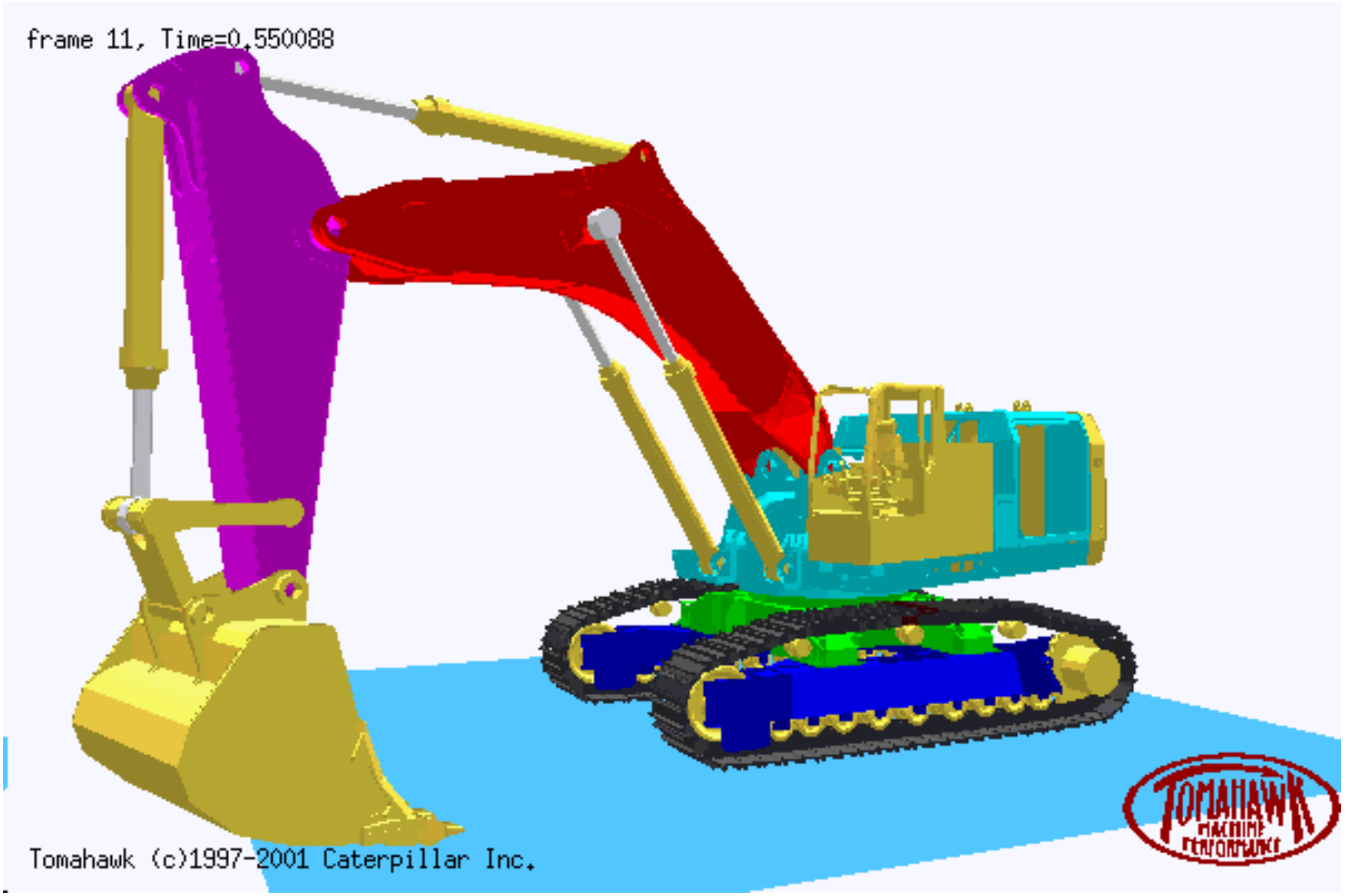


Modeling Flexibility

- Models can be written in Matlab, Fortran or C++ then ported to *DYNASTY*
- Simple or Complex
- Any number of species
- Any number of reactions
- Any number of modules
- Any number of combinations

Dynamic System Simulation Code Availability

- *DYNASTY* is Currently Proprietary
- Leasing Programs through Caterpillar
- Continued Code Development
- Customer Training and Support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Tomahawk (c)1997-2001 Caterpillar Inc.
TOMAHAWK
MACHINE PERFORMANCE