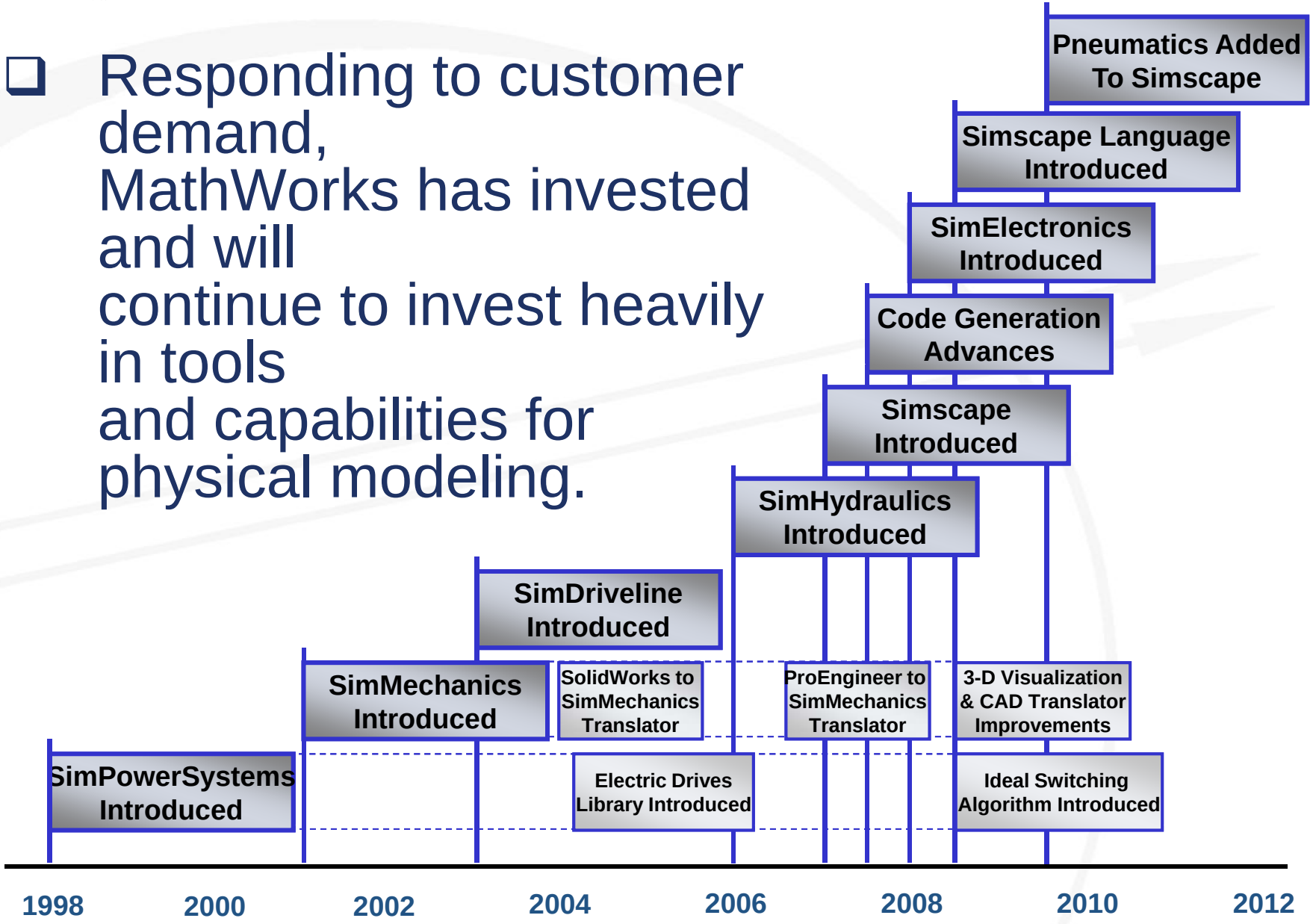
Real-Time Simulation of Simscape Models

MATHWORKS
JEAN-BAPTISTE LANFREY

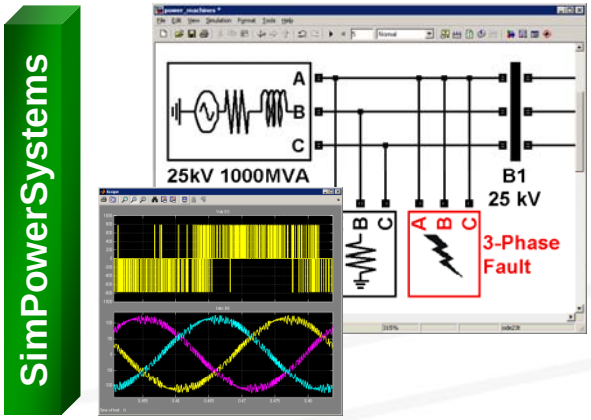
Real-Time 2010
June 27-30, 2010
Paris, France

MathWorks Investment in Physical Modeling

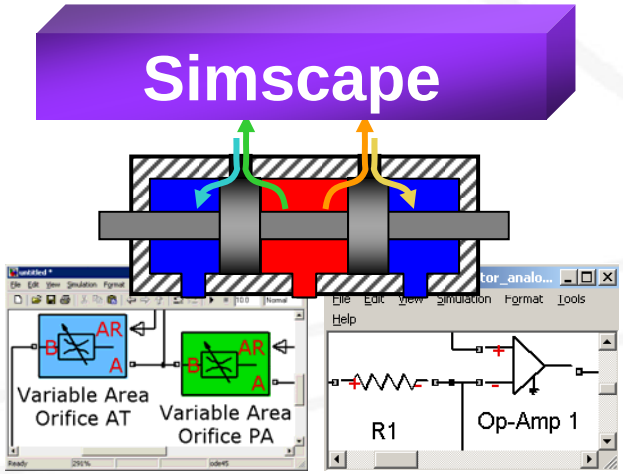
- Responding to customer demand, MathWorks has invested and will continue to invest heavily in tools and capabilities for physical modeling.



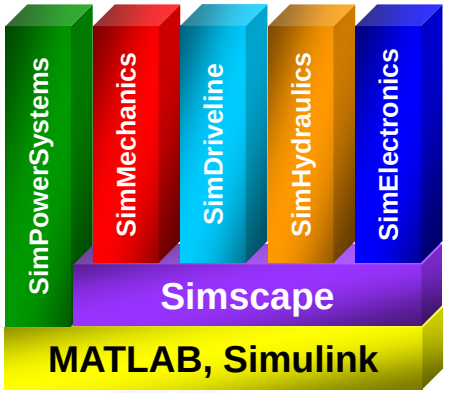
Physical Systems in Simulink

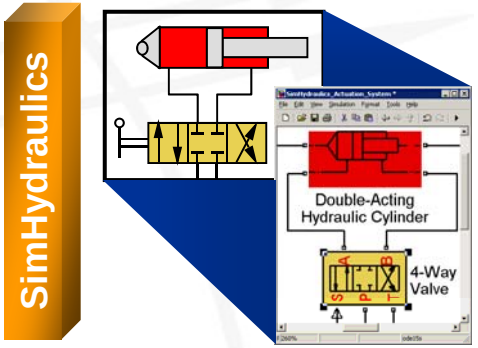


Electrical power systems

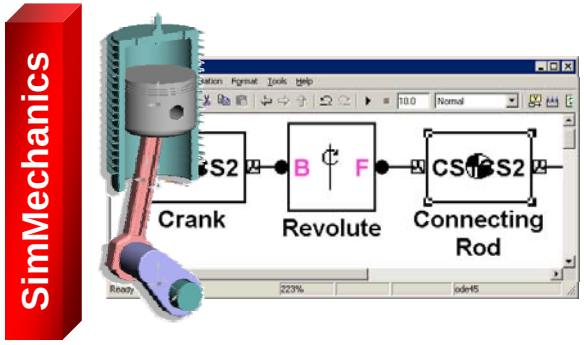


Multidomain physical systems

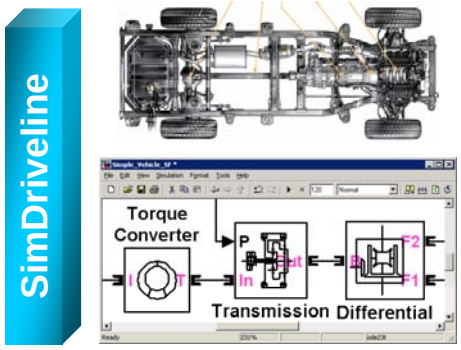




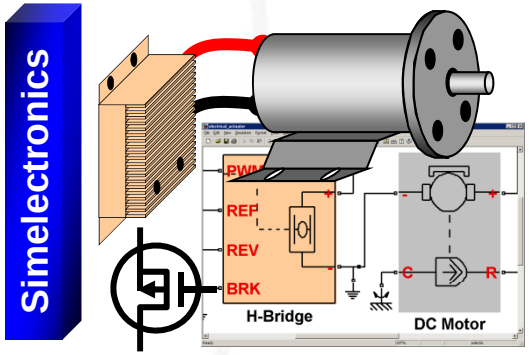
Fluid power and control



Mechanical dynamics (3-D)



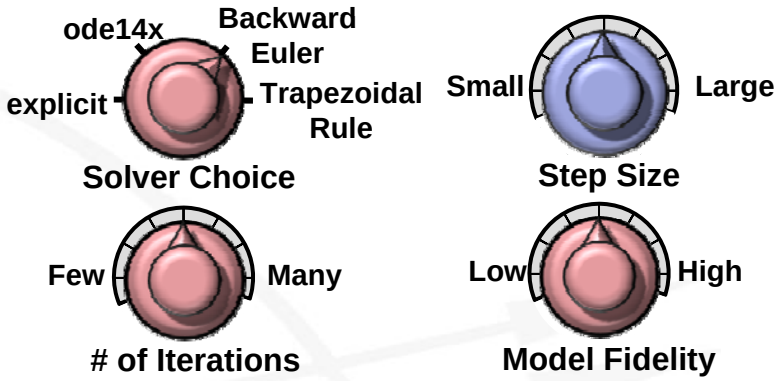
Drivetrain systems (1-D)

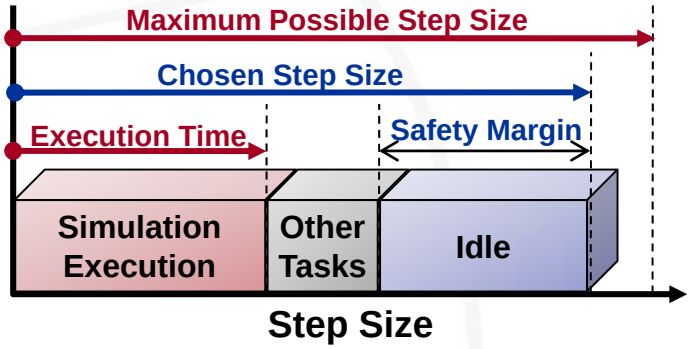


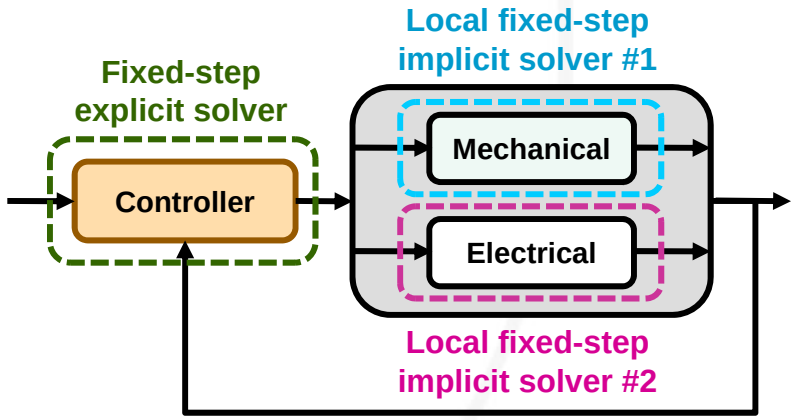
Electromechanical and electronic systems

Key Points

- To move from desktop to real-time simulation, there are four areas where adjustments can be made
- Settings must be found that permit fixed-step, fixed-cost simulation with acceptable accuracy and speed
- Advances in Simscape make it easier to achieve real-time execution with accurate results





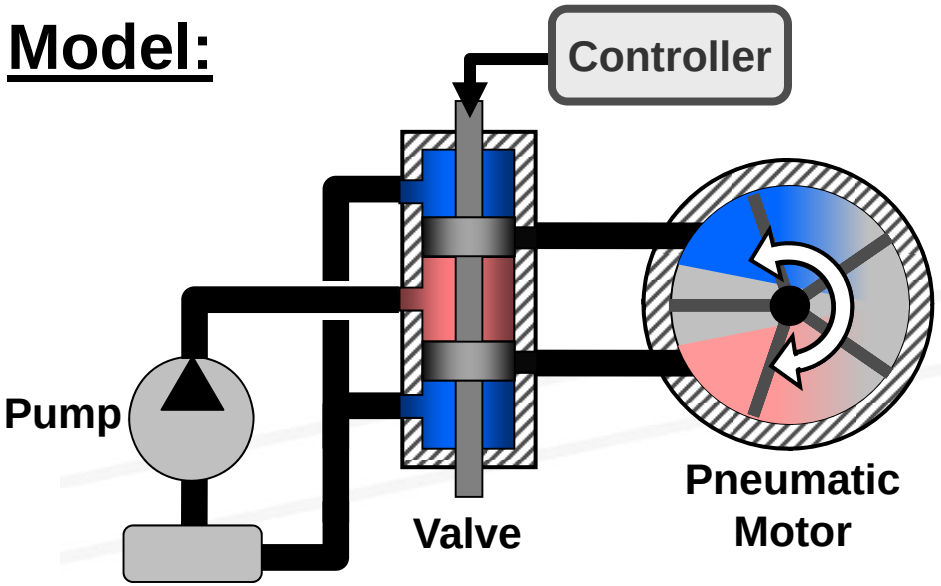


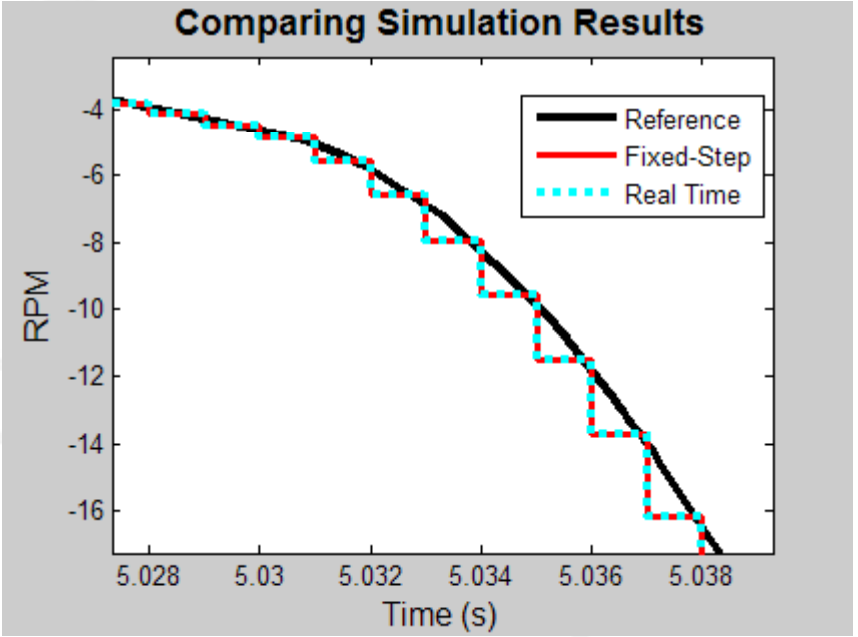
Agenda

- Overview of Application Example (Pneumatic Actuator)
- Uses of Real-Time Simulation
- Challenge of Moving from Desktop to Real-Time
- Configuring Models for Real-Time Simulation
  - Selecting fixed-step solver
  - Configuring fixed-cost simulations

Configuring Simscape Models For Real-Time Simulation

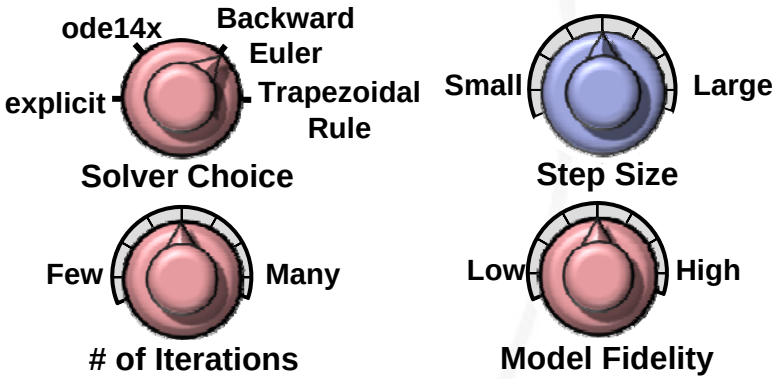
Model:





Problem: Configure the model used for desktop simulation so it can be used for HIL testing

Solution: Use Simscape local solvers and other settings to make the model real-time capable



Uses and Benefits of Real-Time Simulation

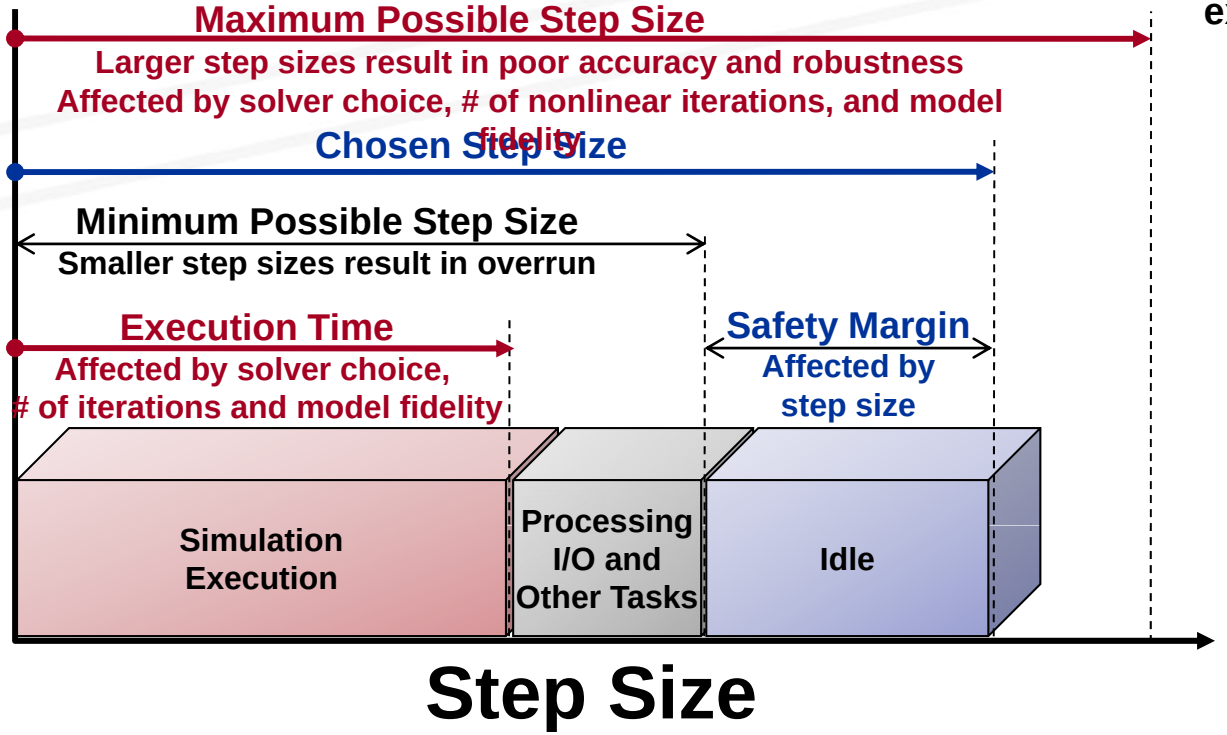
- Uses
  - Hardware-in-the-Loop (HIL) testing
  - Human-in-the-loop (flight simulator)

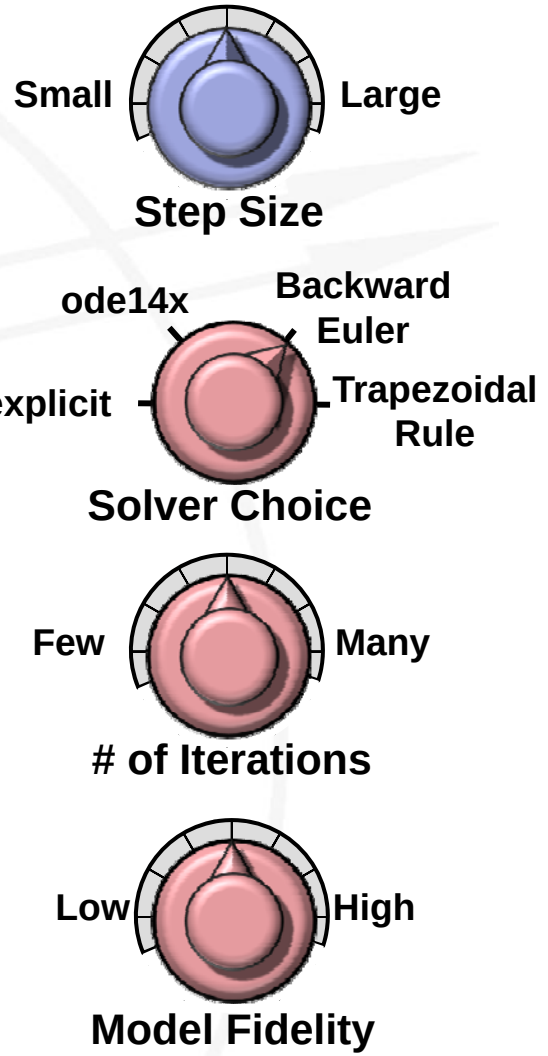
Controller Hardware **Real-Time Computer (physical system)**

- Benefits
  - Ability to test conditions that would damage equipment or personnel
  - Ability to test systems where no prototypes exist
  - Reduced costs in the later phases of development
  - Ability to test 24 hours a day, 7 days a week

Challenge of Moving From Desktop to Real-Time Simulation

- Must find combination of model fidelity and solver settings that permits real-time execution and delivers accurate results

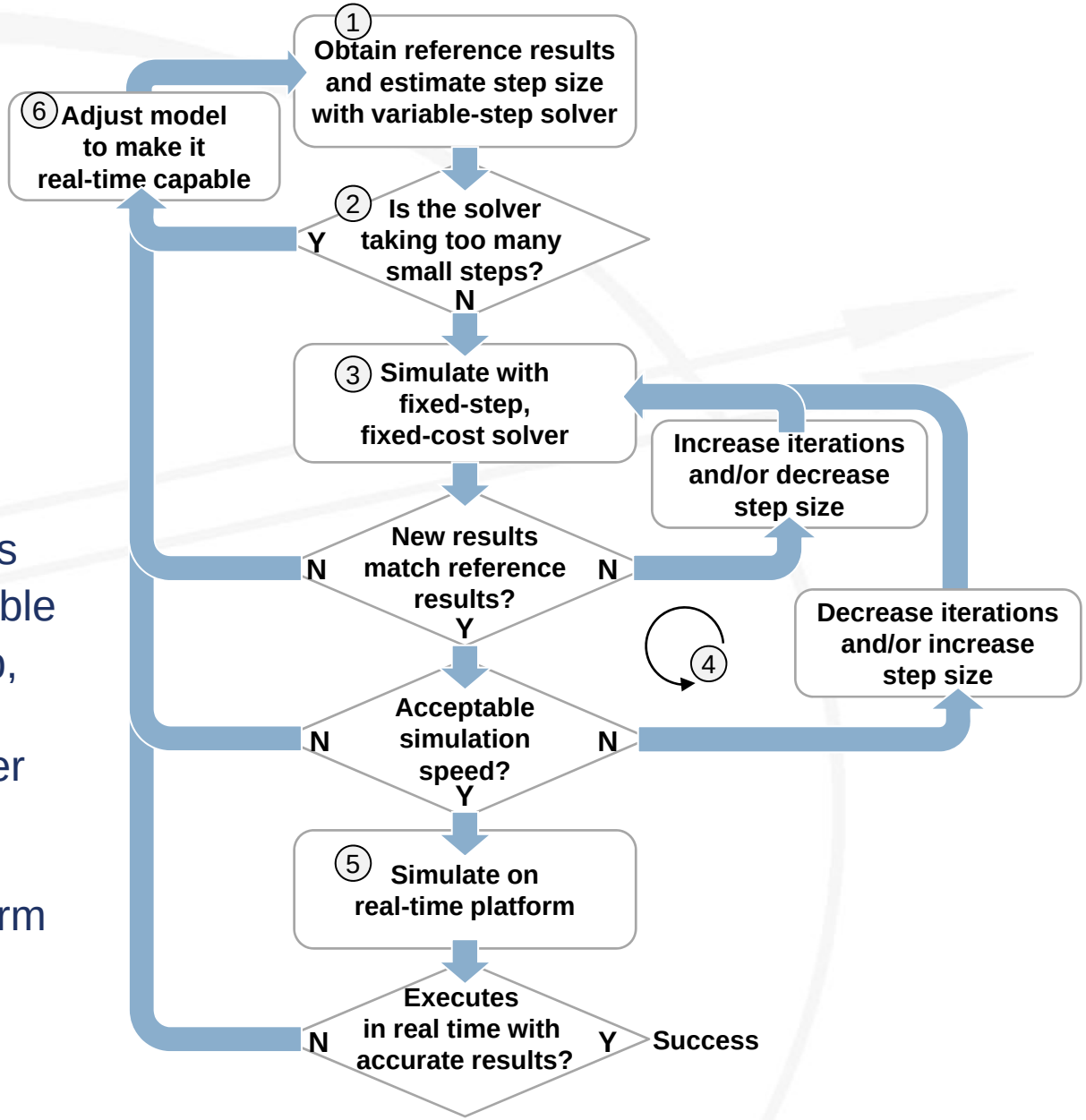




Steps For Moving to Real-Time Simulation

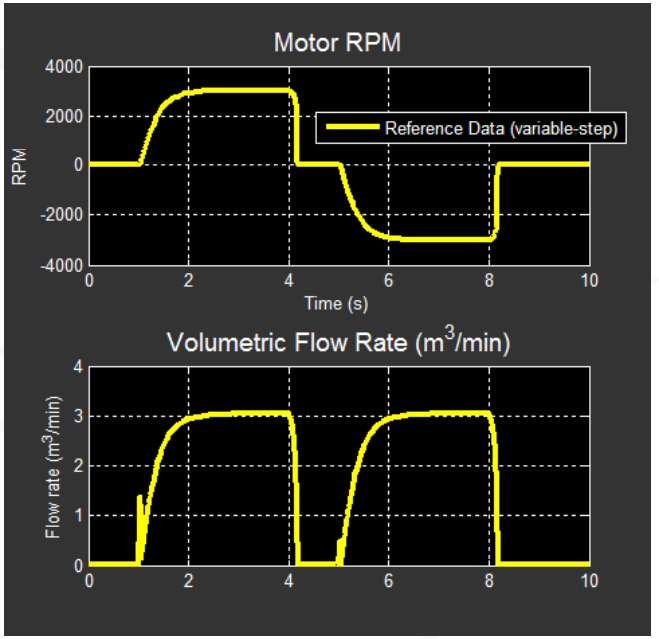
- Flowchart describes steps engineers take

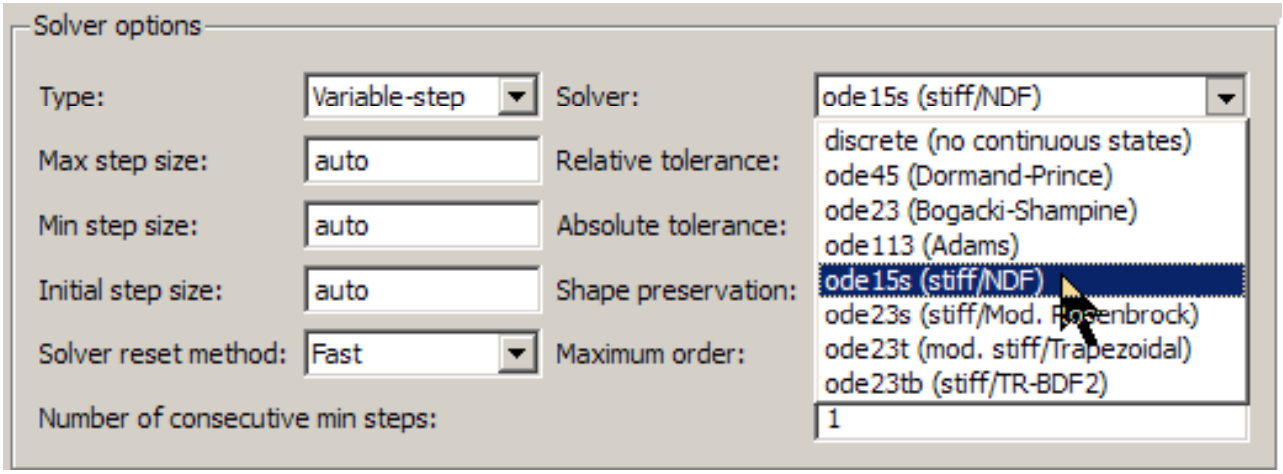
1. Obtain reference results
2. Check if real-time capable
3. Configure for fixed-step, fixed cost simulation
4. Find settings that deliver acceptable results and speed
5. Test on real time platform
6. Adjust if necessary



Obtaining Reference Results With Variable-Step Solver

- Necessary to determine if configuration for real-time simulation delivers acceptable results
- For Simscape models, ode15s or ode23t are recommended

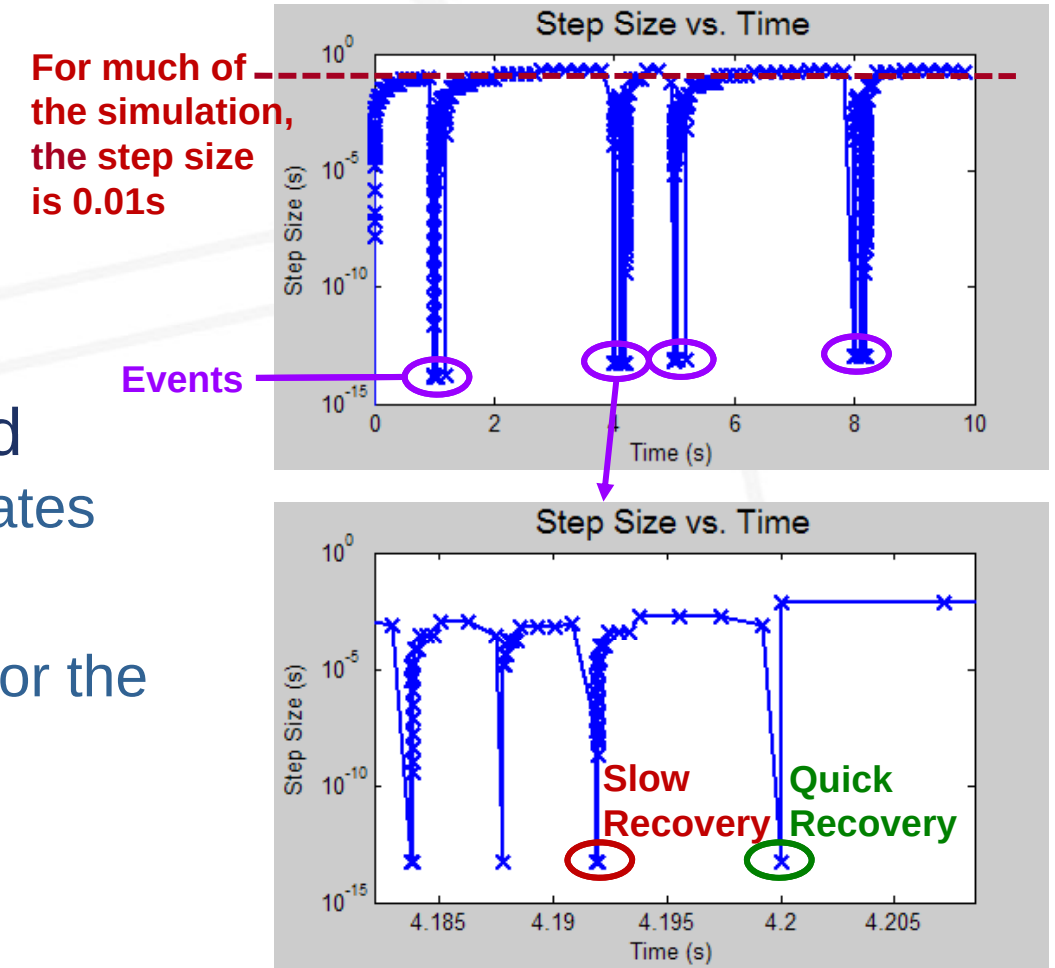




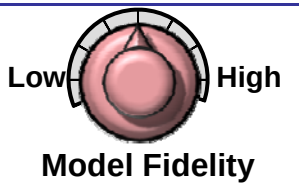
Determining If Model Is Real-Time Capable

- Examine step size during simulation to determine:
  - Rough idea of step size for accurate results
  - Number and type of events
- When step size decreases, an event has occurred
  - Slow recovery indicates dynamics that may require a smaller step size for the fixed-step solver

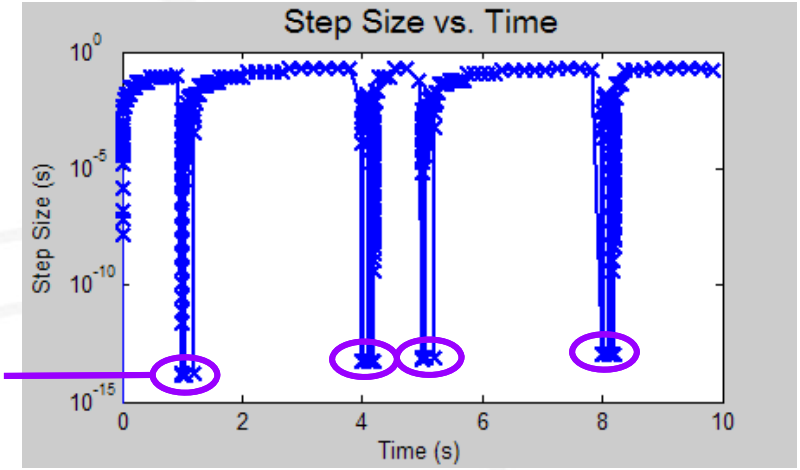
>> semilogy(tout(1:end-1),diff(tout),'-x')

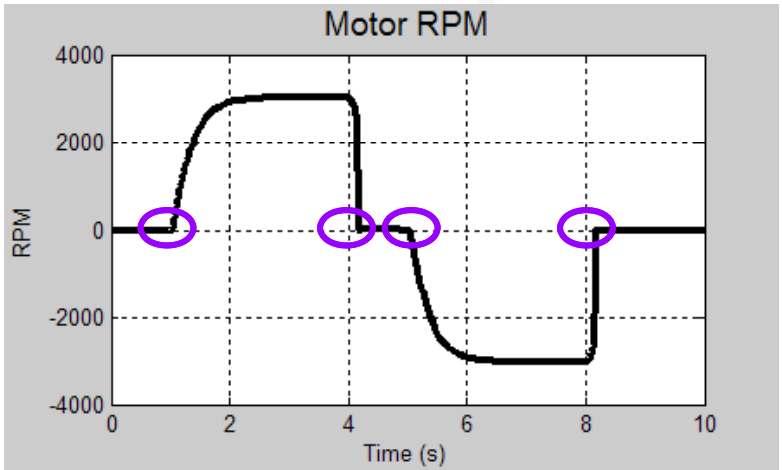


Adjusting Model To Be Real-Time Capable



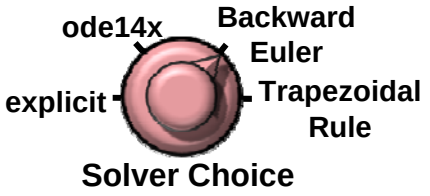
- Examine simulation results to determine when events occur
- Find elements model that will be difficult for fixed-step solvers
  - Discontinuities
    - Hard-stops, stick-slip friction
  - Small time constants
    - Small masses with undamped, stiff springs
    - Hydraulic circuits with small, compressible volumes
- Eliminate or soften these effects

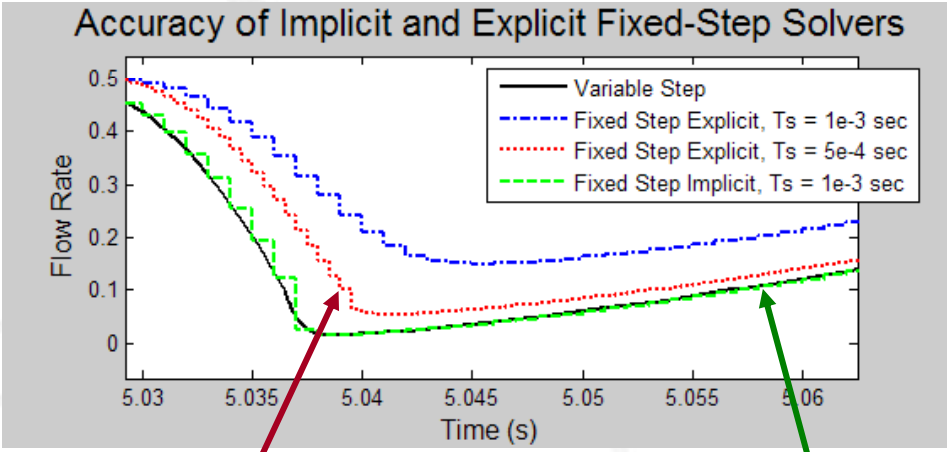




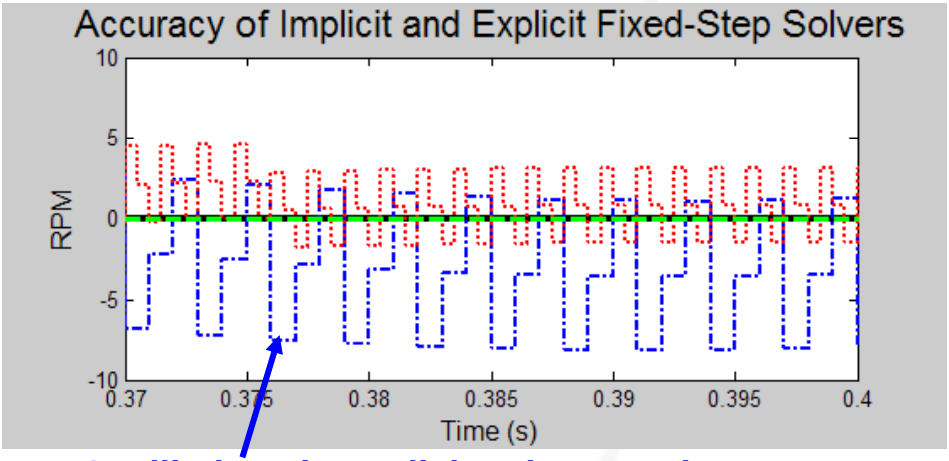
Choosing a Fixed-Step Solver (Explicit vs. Implicit)

- Choose fixed-step solver based on
  - Numerical stiffness of system
  - Computational cost of solver
- Stiff systems simulate best with an implicit solver
  - Can take larger steps and maintain accuracy
- Implicit solvers often require more computational effort per iteration



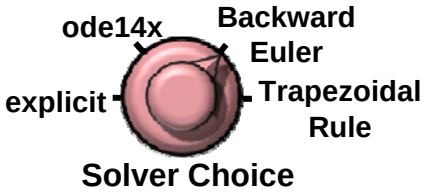


Explicit solver requires smaller time step to achieve accuracy comparable to a implicit solver

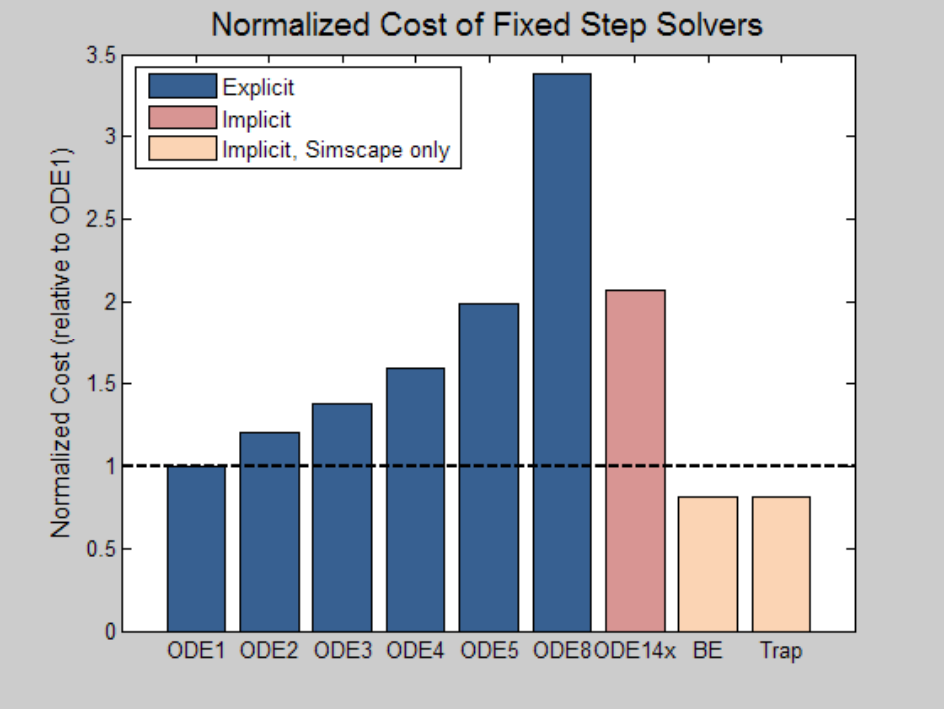


Oscillations in explicit solver results suggest numerical stiffness

Relative Cost of Solvers

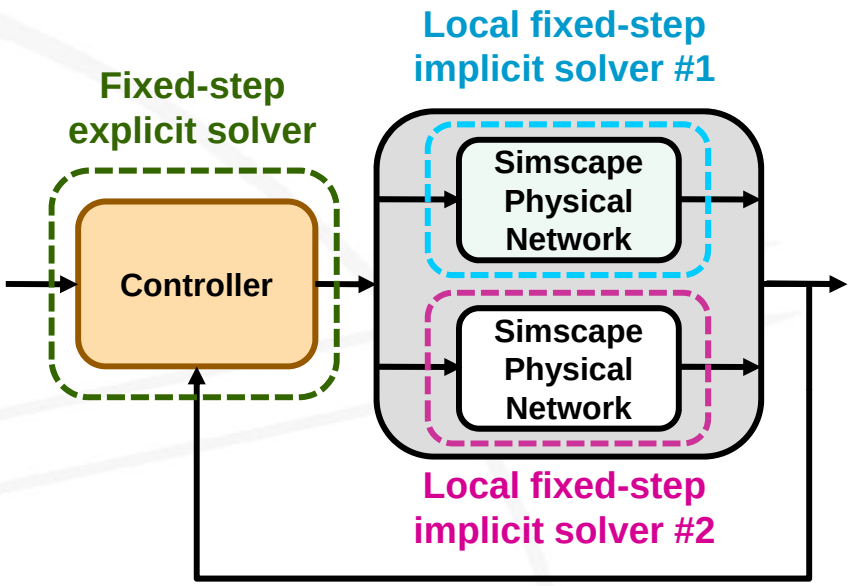


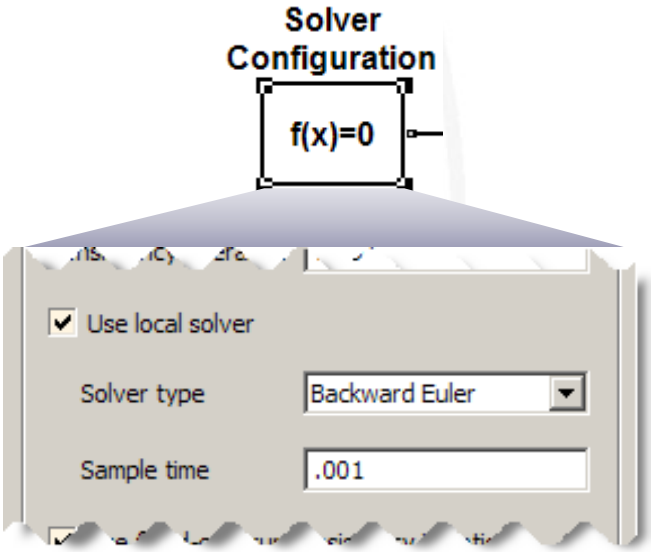
- Test all fixed-step solvers on a nonlinear Simscape model
  - Same step size
  - Same total iterations
- Most explicit solvers require less cost than ode14x, but will require smaller step size for accurate results
- Local solvers in Simscape provide best combination of computational cost and maximum step size



Configuring Local Solvers In Simscape

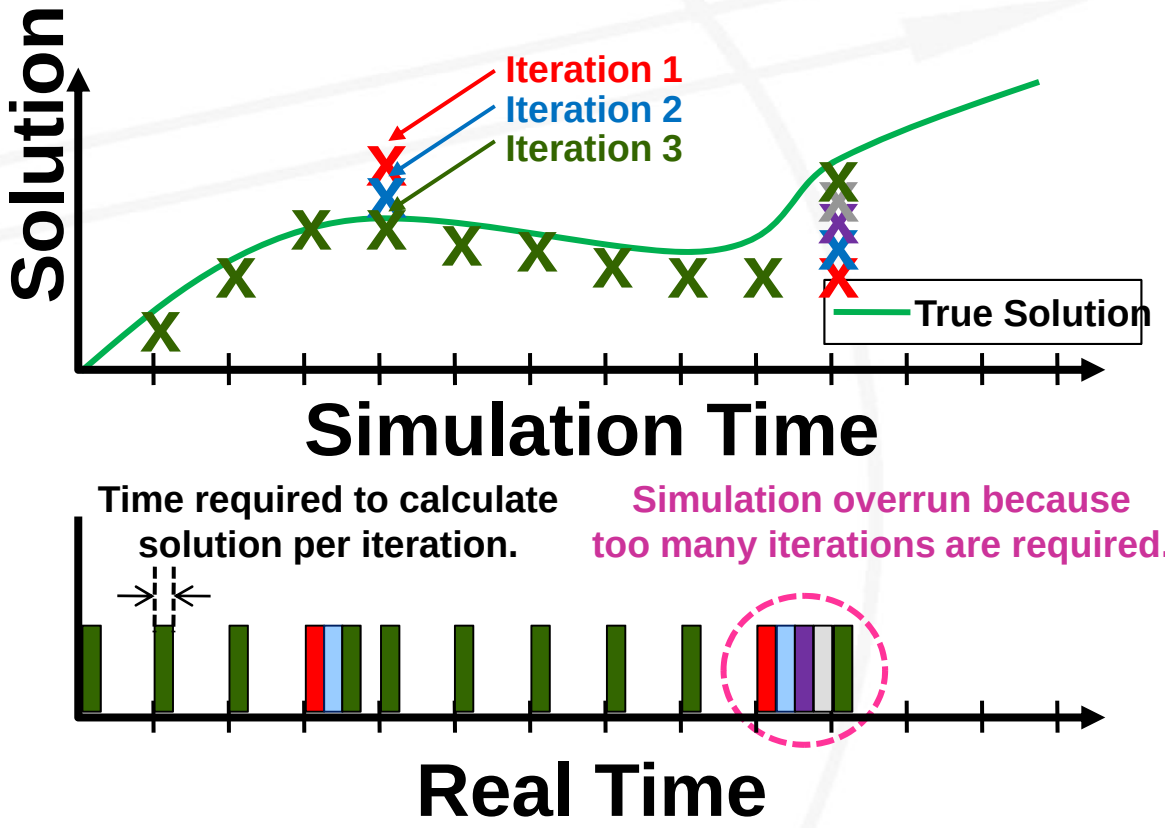
- Configure per physical network
  - Choose solver and sample time
  - Sample rates can be different
    - Must be integer multiple of global sample time
- Backward Euler
  - Designed for robustness
  - Tends to damp oscillations
- Trapezoidal Rule
  - Designed for accuracy
  - Tends to capture oscillations





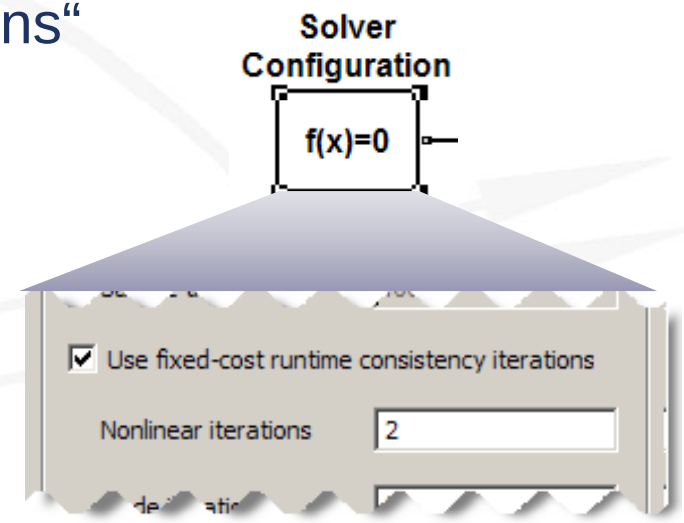
Preventing Overruns With Fixed-Cost Simulations

- To prevent overruns, the amount of time spent calculating the solution during each step must be less than the time step
- Fixed-step solver makes computations per iteration roughly constant
- Fixed cost sets a maximum number of iterations per time step

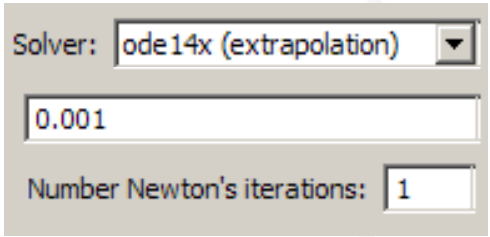


Configuring Fixed-Cost Simulations

- For Simscape models, fixed-cost simulation
  requires setting “Nonlinear Iterations“
  in Solver Configuration block
  for all fixed-step solvers
  - Start with 2 or 3
  - Increase as necessary



- For ode14x, additional setting
  in Solver Configuration panel,
  “Number Newton‘s iterations“
  - If Simscape Local Solvers are used,
    ode14x is only necessary if
    continuous
    equations outside of physical
    network
    are numerically stiff

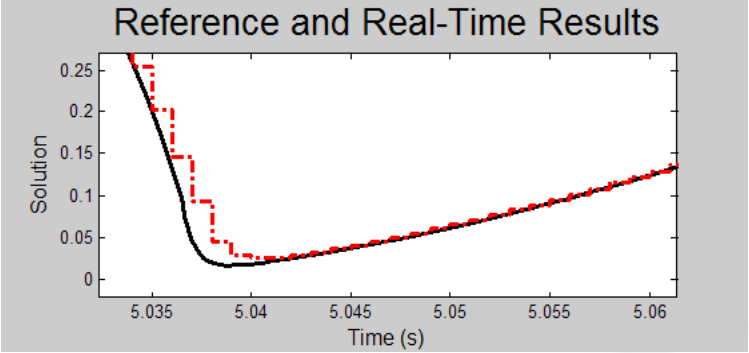


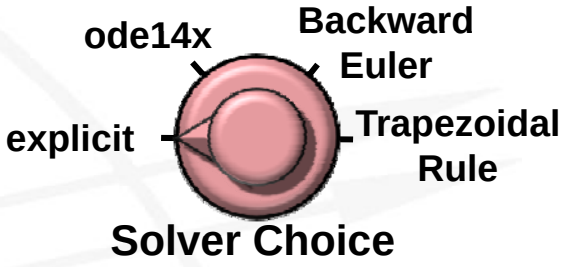
1. Always try using local local solvers
   a. Backward Euler for robustness
   b. Trapezoidal Rule for accuracy

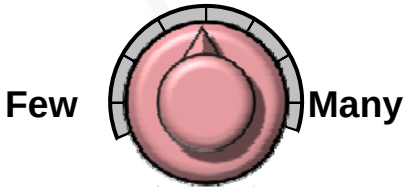
2. Always enable fixed-cost simulation
   a. Nonlinear iterations in Solver Configuration block
   b. Additional setting for ode14x in Solver Configuration panel

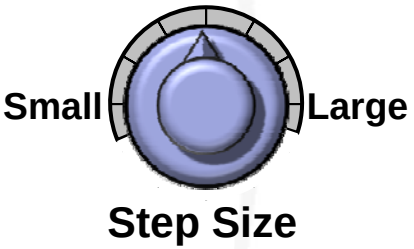
3. Start with number of nonlinear iterations at 2 or 3

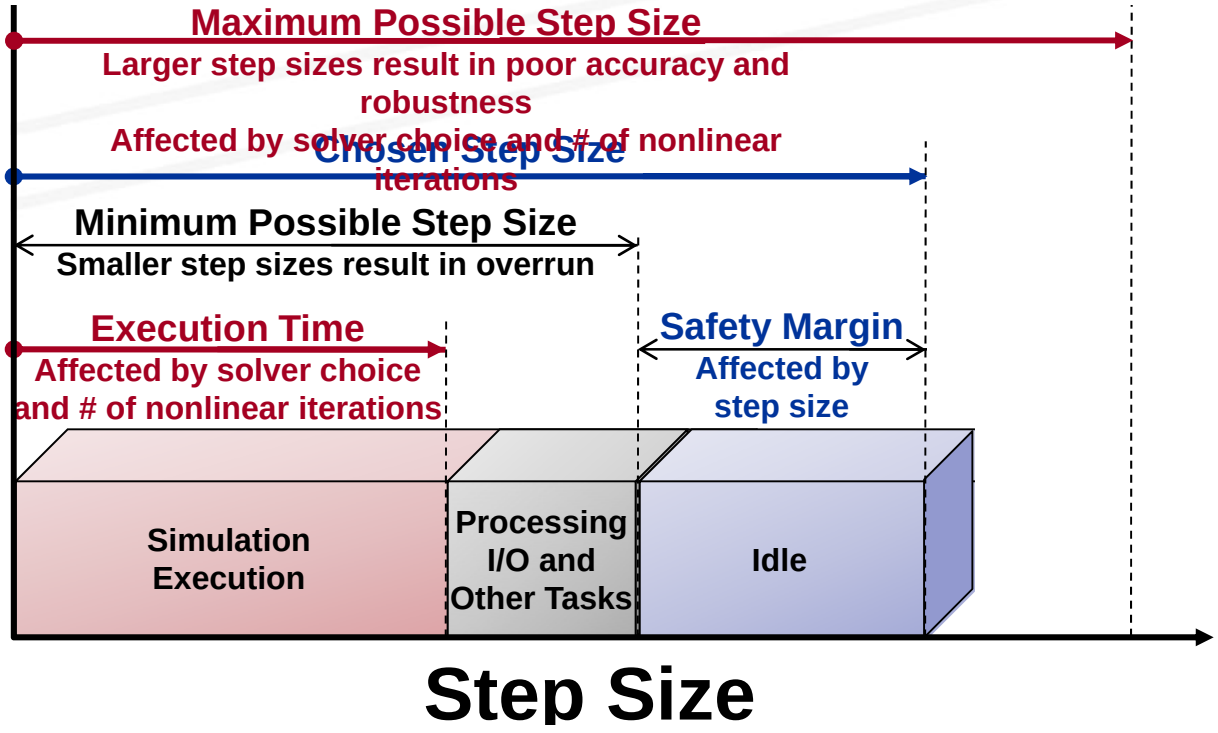
Finding Real-Time Settings





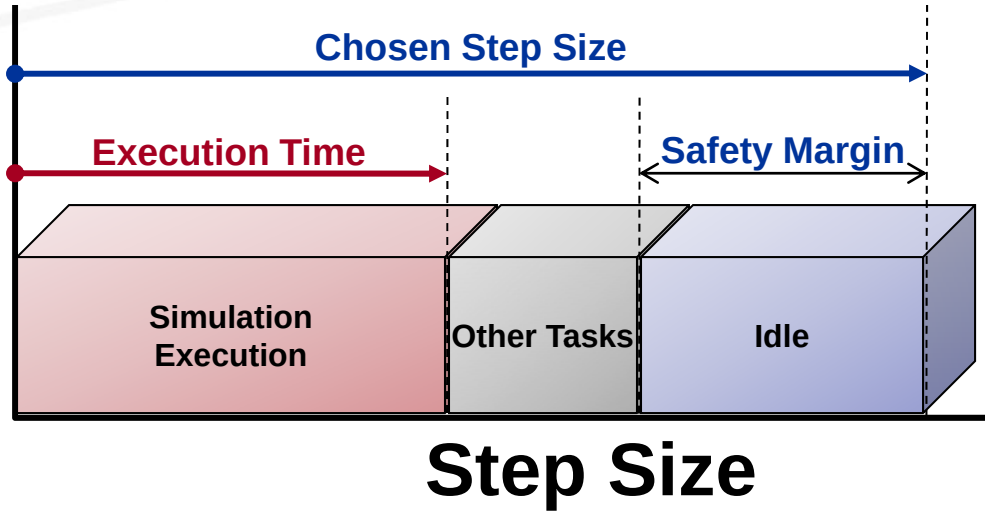






Applying Process To Other Simscape Models

- Process applied to 20 models
  - Hydraulic, electrical, mechanical, pneumatic, thermal elements
  - 18 nonlinear, up to 117 states after equation reduction
- All were able to execute in real-time
  - Intel Core 2 Duo E6700 (2.66GHz) running xPC Target
  - Plenty of time for I/O, other tasks, and safety margin



% of time step spent in simulation execution

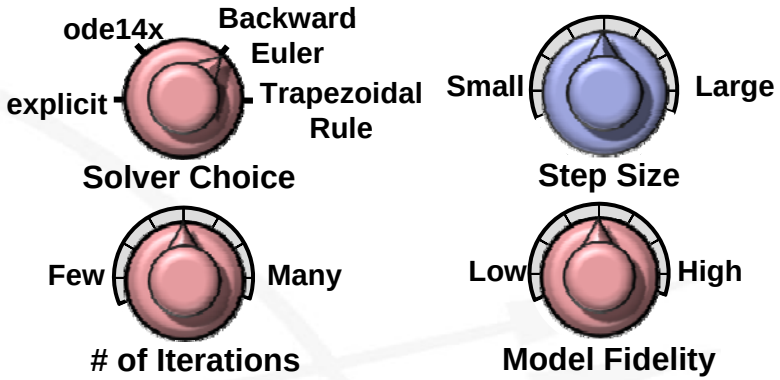
Max = 18%

Average = 3.9%

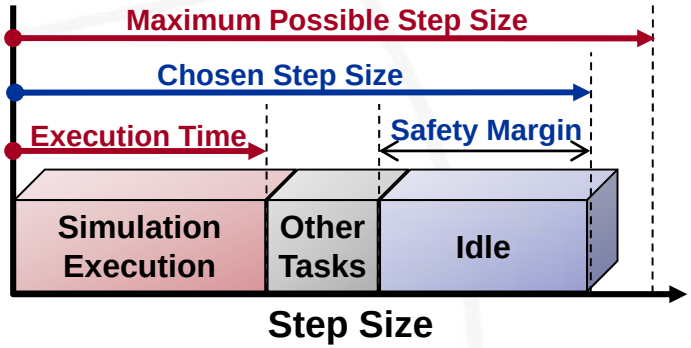
Min = 6e-4%

Key Points

- To move from desktop to real-time simulation, there are four areas where adjustments can be made



- Settings must be found that permit fixed-step, fixed-cost simulation with acceptable accuracy and speed



- Advances in Simscape make it easier to achieve real-time execution with accurate results