```
clear;

BEGIN_ACADO
acadoSet('problemname','Quad_MPC');
```

Define state and control variables.

Position $\mathbf{p} = [p_x \ p_y \ p_z]^T$ (world frame)

Velocity $\mathbf{v} = [v_x \ v_y \ v_z]^T$ (world frame)

Orientation (in quaternion form) $\mathbf{q} = [q_w \ q_x \ q_y \ q_z]^T$ (world frame)

Angular veloctiy $\mathbf{w} = [w_x \ w_y \ w_z]^T$ (body frame)

Thrust $\mathbf{T} = [0 \ 0 \ T]^T$ (body frame)

$\mathbf{x} = [\mathbf{p} \ \mathbf{v} \ \mathbf{q}]^T$
$\mathbf{u} = [T \ \mathbf{w}^T]^T$

```
DifferentialState    p_x p_y p_z;
DifferentialState    q_w q_x q_y q_z;
DifferentialState    v_x v_y v_z;
Control              T w_x w_y w_z;
```

```
input1 = acado.MexInput;        % initial time for simulation
input2 = acado.MexInputVector;  % reference for objective function (14 element vector)
input3 = acado.MexInputVector;  % initial state (10 element vector)
input4 = acado.MexInputMatrix;  % reference for simulation (15 element vector)

% Parameters
t_start = 0.0;      % Initial time [s]
t_end = 1.0;        % Time horizon [s]
dt = 0.1;           % Discretization time [s]
N = round(t_end/dt);  % Number of nodes
g_z = 9.8066;       % Gravity is everywhere [m/s^2]
w_max_yaw = 1;      % Maximal yaw rate [rad/s]
w_max_xy = 3;       % Maximal pitch and roll rate [rad/s]
T_min = 2;          % Minimal thrust [N]
T_max = 20;         % Maximal thrust [N]
```

Dynamics

$$\dot{\mathbf{p}} = \mathbf{v}$$
$$\dot{\mathbf{v}} = \mathbf{g} + \mathbf{q} \odot \mathbf{T}$$
$$\dot{\mathbf{q}} = \frac{1}{2}\Lambda(\mathbf{w}) \cdot \mathbf{q}$$

where,

$$\Lambda(\mathbf{w}) = \begin{bmatrix} 0 & -w_x & -w_y & -w_z \\ w_x & 0 & w_z & -w_y \\ w_y & -w_z & 0 & w_z \\ w_z & w_y & -w_x & 0 \end{bmatrix} \text{, and}$$

$$\mathbf{q} \odot \mathbf{T} = \begin{bmatrix} 1 - 2q_y^2 - 2q_z^2 & 2(q_xq_y + q_wq_z) & 2(q_xq_z - q_wq_y) \\ 2(q_xq_y - q_wq_z) & 1 - 2q_x^2 - 2q_z^2 & 2(q_yq_z + q_wq_x) \\ 2(q_xq_z + q_wq_y) & 2(q_yq_z - q_wq_x) & 1 - 2q_x^2 - 2q_y^2 \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ T \end{bmatrix}$$

```
% System Dynamics
f = acado.DifferentialEquation();

f.add(dot(p_x) ==  v_x);
f.add(dot(p_y) ==  v_y);
f.add(dot(p_z) ==  v_z);
f.add(dot(q_w) ==  0.5 * ( - w_x * q_x - w_y * q_y - w_z * q_z));
f.add(dot(q_x) ==  0.5 * ( w_x * q_w + w_z * q_y - w_y * q_z));
f.add(dot(q_y) ==  0.5 * ( w_y * q_w - w_z * q_x + w_x * q_z));
f.add(dot(q_z) ==  0.5 * ( w_z * q_w + w_y * q_x + w_z * q_y));
f.add(dot(v_x) ==  2 * ( q_w * q_y + q_x * q_z ) * T);
f.add(dot(v_y) ==  2 * ( q_y * q_z - q_w * q_x ) * T);
f.add(dot(v_z) ==  ( 1 - 2 * q_x * q_x - 2 * q_y * q_y ) * T - g_z);
```

Setting up the optimization problem

Objective function $L = \tilde{x}_N^T Q_N \tilde{x}_N + \sum_{i=1}^{N-1} ([\tilde{x}_i^T, \tilde{u}_i^T]Q_i[\tilde{x}_i^T, \tilde{u}_i^T]^T)$

```
ocp = acado.OCP( t_start, t_end, N );

h = {p_x, p_y, p_z,...
     q_w, q_x, q_y, q_z,...
     v_x, v_y, v_z,...
     T, w_x, w_y, w_z};
% for final(Nth) step, does not include control terms
hN = {p_x, p_y, p_z,...
       q_w, q_x, q_y, q_z,...
       v_x, v_y, v_z};
r = input2;
rN = input2;
% weights (variables in same order as h )
Q = diag([100;100;100;...
          100;100;100;100;...
```

2

```
            10;10;10;
            1;1;1;1]);
QN = Q(1:10,1:10);       % control not included

ocp.minimizeLSQ( Q, h, r );
ocp.minimizeLSQEndTerm( QN, hN, rN );

% Add system dynamics
ocp.subjectTo( f );
% Add constraints
ocp.subjectTo(-w_max_xy <= w_x <= w_max_xy);
ocp.subjectTo(-w_max_xy <= w_y <= w_max_xy);
ocp.subjectTo(-w_max_yaw <= w_z <= w_max_yaw);
ocp.subjectTo(T_min <= T <= T_max);
```

Setting up the MPC controller algorithm

```
% SETTING UP THE MPC CONTROLLER:
algo = acado.RealTimeAlgorithm(ocp, 0.1);
algo.set('MAX_NUM_ITERATIONS', 3);  % number of optimization iterations per cycle
% Set some algorithm parameters
algo.set( 'INTEGRATOR_TOLERANCE', 1e-6 );
algo.set( 'KKT_TOLERANCE', 1e-3 );
algo.set('HESSIAN_APPROXIMATION',  'GAUSS_NEWTON');        % is robust, stable
algo.set('DISCRETIZATION_TYPE',     'MULTIPLE_SHOOTING');   % good convergence

% Static reference trajectory that the ControlLaw aims to track.
ref = acado.StaticReferenceTrajectory(input4);

% Online control law for obtaining the control inputs of a process
controller = acado.Controller( algo,ref );
```

Simulation environment uses same system dynamics but we could define different dynamics for it. Integrator algorithm - 4th order Runge-Kutta

```
% SETTING UP THE (SIMULATED) PROCESS
identity = acado.OutputFcn();
dynamicSystem = acado.DynamicSystem(f, identity);
process = acado.Process(dynamicSystem, 'INT_RK45');
% SETTING UP THE SIMULATION ENVIRONMENT, RUN THE EXAMPLE..
sim = acado.SimulationEnvironment( 0.0,5.0,process,controller );
sim.init(input3);
%
% controller.init(input1, input3);
% controller.step(input1, input3);

END_ACADO
```

```
Writing c++ files...
ans = 57
Compiling c++ files...
Building with 'Microsoft Visual C++ 2017'.
```

3

```
MEX completed successfully.
```

Running this once make a mex file and can be called as a matlab function.

Example run - takeoff and hover at 2 m

```
out = Quad_MPC_RUN(1,[0,0,2,1,0,0,0,0,0,0,10,0,0,0],[0,0,0,1,0,0,0,0,0,0],[0,0,0,2,1,0,0,0,0,0
```

```
ACADO Toolkit for Matlab - Developed by David Ariens and Rien Quirynen, 2009-2013
Support available at http://www.acadotoolkit.org/matlab


ACADO Toolkit::SCPmethod -- A Sequential Quadratic Programming Algorithm.
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qpOASES -- An Implementation of the Online Active Set Strategy.
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*** SIMULATION LOOP NO. 1 (starting at time 0.000) ***
sqp it | qp its |       kkt tol |       obj val |      merit val |      ls param |
     1 |      0 | 2.191388e+01 | 2.266131e+02 | 2.266131e+02 | 1.000000e+00 |
     2 |      0 | 2.274621e-14 | 2.266131e+02 | 2.266131e+02 | 1.000000e+00 |
     3 |      0 | 2.015970e-15 | 2.266131e+02 | 2.266131e+02 | 1.000000e+00 |

*** SIMULATION LOOP NO. 2 (starting at time 0.100) ***
sqp it | qp its |       kkt tol |       obj val |      merit val |      ls param |
     1 |      0 | 6.225601e+01 | 2.069678e+02 | 2.069678e+02 | 1.000000e+00 |
     2 |      0 | 2.231924e-14 | 2.069678e+02 | 2.069678e+02 | 1.000000e+00 |
     3 |      0 | 1.922667e-15 | 2.069678e+02 | 2.069678e+02 | 1.000000e+00 |

*** SIMULATION LOOP NO. 3 (starting at time 0.200) ***
sqp it | qp its |       kkt tol |       obj val |      merit val |      ls param |
     1 |      0 | 7.607206e+01 | 1.837923e+02 | 1.837923e+02 | 1.000000e+00 |
     2 |      0 | 3.299757e-14 | 1.837923e+02 | 1.837923e+02 | 1.000000e+00 |
     3 |      0 | 1.867092e-14 | 1.837923e+02 | 1.837923e+02 | 1.000000e+00 |

*** SIMULATION LOOP NO. 4 (starting at time 0.300) ***
sqp it | qp its |       kkt tol |       obj val |      merit val |      ls param |
     1 |      0 | 8.434108e+01 | 1.590238e+02 | 1.590238e+02 | 1.000000e+00 |
     2 |      0 | 8.850950e-14 | 1.590238e+02 | 1.590238e+02 | 1.000000e+00 |
     3 |      0 | 2.638487e-14 | 1.590238e+02 | 1.590238e+02 | 1.000000e+00 |

*** SIMULATION LOOP NO. 5 (starting at time 0.400) ***
sqp it | qp its |       kkt tol |       obj val |      merit val |      ls param |
     1 |      0 | 8.690034e+01 | 1.343255e+02 | 1.343255e+02 | 1.000000e+00 |
```

```
         2 |        0 |  1.330121e-13 |  1.343255e+02 |  1.343255e+02 |  1.000000e+00 |
         3 |        0 |  2.477669e-14 |  1.343255e+02 |  1.343255e+02 |  1.000000e+00 |

*** SIMULATION LOOP NO. 6 (starting at time 0.500) ***
sqp it | qp its |       kkt tol |       obj val |      merit val |      ls param |
         1 |        0 |  8.462068e+01 |  1.109511e+02 |  1.109511e+02 |  1.000000e+00 |
         2 |        0 |  6.671108e-14 |  1.109511e+02 |  1.109511e+02 |  1.000000e+00 |
         3 |        0 |  3.389783e-14 |  1.109511e+02 |  1.109511e+02 |  1.000000e+00 |

*** SIMULATION LOOP NO. 7 (starting at time 0.600) ***
sqp it | qp its |       kkt tol |       obj val |      merit val |      ls param |
         1 |        0 |  7.877055e+01 |  8.973109e+01 |  8.973109e+01 |  1.000000e+00 |
         2 |        0 |  6.696133e-14 |  8.973109e+01 |  8.973109e+01 |  1.000000e+00 |
         3 |        0 |  4.705313e-14 |  8.973109e+01 |  8.973109e+01 |  1.000000e+00 |

*** SIMULATION LOOP NO. 8 (starting at time 0.700) ***
sqp it | qp its |       kkt tol |       obj val |      merit val |      ls param |
         1 |        0 |  7.064659e+01 |  7.112137e+01 |  7.112137e+01 |  1.000000e+00 |
         2 |        0 |  6.312844e-14 |  7.112137e+01 |  7.112137e+01 |  1.000000e+00 |
         3 |        0 |  1.873545e-30 |  7.112137e+01 |  7.112137e+01 |  1.000000e+00 |

*** SIMULATION LOOP NO. 9 (starting at time 0.800) ***
sqp it | qp its |       kkt tol |       obj val |      merit val |      ls param |
         1 |        0 |  6.138193e+01 |  5.527981e+01 |  5.527981e+01 |  1.000000e+00 |
         2 |        0 |  7.804706e-14 |  5.527981e+01 |  5.527981e+01 |  1.000000e+00 |
         3 |        0 |  4.926407e-15 |  5.527981e+01 |  5.527981e+01 |  1.000000e+00 |

*** SIMULATION LOOP NO. 10 (starting at time 0.900) ***
sqp it | qp its |       kkt tol |       obj val |      merit val |      ls param |
         1 |        0 |  5.186756e+01 |  4.214716e+01 |  4.214716e+01 |  1.000000e+00 |
         2 |        0 |  1.321697e-14 |  4.214716e+01 |  4.214716e+01 |  1.000000e+00 |
         3 |        0 |  2.958228e-31 |  4.214716e+01 |  4.214716e+01 |  1.000000e+00 |

*** SIMULATION LOOP NO. 11 (starting at time 1.000) ***
sqp it | qp its |       kkt tol |       obj val |      merit val |      ls param |
         1 |        0 |  4.274114e+01 |  3.152100e+01 |  3.152100e+01 |  1.000000e+00 |
         2 |        0 |  7.062373e-14 |  3.152100e+01 |  3.152100e+01 |  1.000000e+00 |
         3 |        0 |  1.906527e-14 |  3.152100e+01 |  3.152100e+01 |  1.000000e+00 |

*** SIMULATION LOOP NO. 12 (starting at time 1.100) ***
sqp it | qp its |       kkt tol |       obj val |      merit val |      ls param |
         1 |        0 |  3.441215e+01 |  2.311670e+01 |  2.311670e+01 |  1.000000e+00 |
         2 |        0 |  1.178505e-13 |  2.311670e+01 |  2.311670e+01 |  1.000000e+00 |
         3 |        0 |  5.916457e-31 |  2.311670e+01 |  2.311670e+01 |  1.000000e+00 |

*** SIMULATION LOOP NO. 13 (starting at time 1.200) ***
sqp it | qp its |       kkt tol |       obj val |      merit val |      ls param |
         1 |        0 |  2.710327e+01 |  1.661430e+01 |  1.661430e+01 |  1.000000e+00 |
         2 |        0 |  8.816575e-14 |  1.661430e+01 |  1.661430e+01 |  1.000000e+00 |
         3 |        0 |  2.037496e-14 |  1.661430e+01 |  1.661430e+01 |  1.000000e+00 |

*** SIMULATION LOOP NO. 14 (starting at time 1.300) ***
sqp it | qp its |       kkt tol |       obj val |      merit val |      ls param |
         1 |        0 |  2.089577e+01 |  1.169180e+01 |  1.169180e+01 |  1.000000e+00 |
         2 |        0 |  8.989613e-14 |  1.169180e+01 |  1.169180e+01 |  1.000000e+00 |
         3 |        0 |  2.589756e-14 |  1.169180e+01 |  1.169180e+01 |  1.000000e+00 |

*** SIMULATION LOOP NO. 15 (starting at time 1.400) ***
sqp it | qp its |       kkt tol |       obj val |      merit val |      ls param |
         1 |        0 |  1.577164e+01 |  8.046955e+00 |  8.046955e+00 |  1.000000e+00 |
         2 |        0 |  4.444737e-14 |  8.046955e+00 |  8.046955e+00 |  1.000000e+00 |
         3 |        0 |  2.034515e-15 |  8.046955e+00 |  8.046955e+00 |  1.000000e+00 |

*** SIMULATION LOOP NO. 16 (starting at time 1.500) ***
sqp it | qp its |       kkt tol |       obj val |      merit val |      ls param |
```

```
   1 |      0 |  1.164935e+01 |  5.409926e+00 |  5.409926e+00 |  1.000000e+00 |
   2 |      0 |  6.303796e-14 |  5.409926e+00 |  5.409926e+00 |  1.000000e+00 |
   3 |      0 |  3.260515e-15 |  5.409926e+00 |  5.409926e+00 |  1.000000e+00 |

*** SIMULATION LOOP NO. 17 (starting at time 1.600) ***
sqp it | qp its |       kkt tol |       obj val |      merit val |       ls param |
   1 |      0 |  8.412045e+00 |  3.549083e+00 |  3.549083e+00 |  1.000000e+00 |
   2 |      0 |  4.312765e-14 |  3.549083e+00 |  3.549083e+00 |  1.000000e+00 |
   3 |      0 |  1.272654e-14 |  3.549083e+00 |  3.549083e+00 |  1.000000e+00 |

*** SIMULATION LOOP NO. 18 (starting at time 1.700) ***
sqp it | qp its |       kkt tol |       obj val |      merit val |       ls param |
   1 |      0 |  5.928309e+00 |  2.272001e+00 |  2.272001e+00 |  1.000000e+00 |
   2 |      0 |  1.162062e-15 |  2.272001e+00 |  2.272001e+00 |  1.000000e+00 |
   3 |      0 |  1.162062e-15 |  2.272001e+00 |  2.272001e+00 |  1.000000e+00 |

*** SIMULATION LOOP NO. 19 (starting at time 1.800) ***
sqp it | qp its |       kkt tol |       obj val |      merit val |       ls param |
   1 |      0 |  4.066536e+00 |  1.423383e+00 |  1.423383e+00 |  1.000000e+00 |
   2 |      0 |  1.876975e-15 |  1.423383e+00 |  1.423383e+00 |  1.000000e+00 |
   3 |      0 |  2.024770e-15 |  1.423383e+00 |  1.423383e+00 |  1.000000e+00 |

*** SIMULATION LOOP NO. 20 (starting at time 1.900) ***
sqp it | qp its |       kkt tol |       obj val |      merit val |       ls param |
   1 |      0 |  2.704030e+00 |  8.811811e-01 |  8.811811e-01 |  1.000000e+00 |
   2 |      0 |  3.395434e-15 |  8.811811e-01 |  8.811811e-01 |  1.000000e+00 |
   3 |      0 |  5.108921e-16 |  8.811811e-01 |  8.811811e-01 |  1.000000e+00 |

*** SIMULATION LOOP NO. 21 (starting at time 2.000) ***
sqp it | qp its |       kkt tol |       obj val |      merit val |       ls param |
   1 |      0 |  1.732083e+00 |  5.518910e-01 |  5.518910e-01 |  1.000000e+00 |
   2 |      0 |  2.316060e-15 |  5.518910e-01 |  5.518910e-01 |  1.000000e+00 |
   3 |      0 |  1.839483e-15 |  5.518910e-01 |  5.518910e-01 |  1.000000e+00 |

*** SIMULATION LOOP NO. 22 (starting at time 2.100) ***
sqp it | qp its |       kkt tol |       obj val |      merit val |       ls param |
   1 |      0 |  1.058135e+00 |  3.656728e-01 |  3.656728e-01 |  1.000000e+00 |
   2 |      0 |  3.158642e-15 |  3.656728e-01 |  3.656728e-01 |  1.000000e+00 |
   3 |      0 |  2.710977e-15 |  3.656728e-01 |  3.656728e-01 |  1.000000e+00 |

*** SIMULATION LOOP NO. 23 (starting at time 2.200) ***
sqp it | qp its |       kkt tol |       obj val |      merit val |       ls param |
   1 |      0 |  6.059500e-01 |  2.717172e-01 |  2.717172e-01 |  1.000000e+00 |
   2 |      0 |  3.904297e-15 |  2.717172e-01 |  2.717172e-01 |  1.000000e+00 |
   3 |      0 |  3.762933e-16 |  2.717172e-01 |  2.717172e-01 |  1.000000e+00 |

*** SIMULATION LOOP NO. 24 (starting at time 2.300) ***
sqp it | qp its |       kkt tol |       obj val |      merit val |       ls param |
   1 |      0 |  3.145527e-01 |  2.340992e-01 |  2.340992e-01 |  1.000000e+00 |
   2 |      0 |  1.838355e-14 |  2.340992e-01 |  2.340992e-01 |  1.000000e+00 |
   3 |      0 |  5.846626e-16 |  2.340992e-01 |  2.340992e-01 |  1.000000e+00 |

*** SIMULATION LOOP NO. 25 (starting at time 2.400) ***
sqp it | qp its |       kkt tol |       obj val |      merit val |       ls param |
   1 |      0 |  1.364817e-01 |  2.282274e-01 |  2.282274e-01 |  1.000000e+00 |
   2 |      0 |  6.672482e-16 |  2.282274e-01 |  2.282274e-01 |  1.000000e+00 |
   3 |      0 |  5.040896e-16 |  2.282274e-01 |  2.282274e-01 |  1.000000e+00 |

*** SIMULATION LOOP NO. 26 (starting at time 2.500) ***
sqp it | qp its |       kkt tol |       obj val |      merit val |       ls param |
   1 |      0 |  3.575126e-02 |  2.379130e-01 |  2.379130e-01 |  1.000000e+00 |
   2 |      0 |  2.245353e-14 |  2.379130e-01 |  2.379130e-01 |  1.000000e+00 |
   3 |      0 |  1.000846e-15 |  2.379130e-01 |  2.379130e-01 |  1.000000e+00 |

*** SIMULATION LOOP NO. 27 (starting at time 2.600) ***
```

```
sqp it | qp its |       kkt tol |       obj val |      merit val |       ls param |
     1 |      0 | 1.420947e-02 | 2.530238e-01 | 2.530238e-01 | 1.000000e+00 |
     2 |      0 | 2.369416e-14 | 2.530238e-01 | 2.530238e-01 | 1.000000e+00 |
     3 |      0 | 5.809180e-16 | 2.530238e-01 | 2.530238e-01 | 1.000000e+00 |

*** SIMULATION LOOP NO. 28 (starting at time 2.700) ***
sqp it | qp its |       kkt tol |       obj val |      merit val |       ls param |
     1 |      0 | 3.247985e-02 | 2.676608e-01 | 2.676608e-01 | 1.000000e+00 |
     2 |      0 | 3.385904e-14 | 2.676608e-01 | 2.676608e-01 | 1.000000e+00 |
     3 |      0 | 1.168657e-14 | 2.676608e-01 | 2.676608e-01 | 1.000000e+00 |

*** SIMULATION LOOP NO. 29 (starting at time 2.800) ***
sqp it | qp its |       kkt tol |       obj val |      merit val |       ls param |
     1 |      0 | 3.234349e-02 | 2.787793e-01 | 2.787793e-01 | 1.000000e+00 |
     2 |      0 | 1.528656e-14 | 2.787793e-01 | 2.787793e-01 | 1.000000e+00 |
     3 |      0 | 2.608066e-16 | 2.787793e-01 | 2.787793e-01 | 1.000000e+00 |

*** SIMULATION LOOP NO. 30 (starting at time 2.900) ***
sqp it | qp its |       kkt tol |       obj val |      merit val |       ls param |
     1 |      0 | 2.272147e-02 | 2.851755e-01 | 2.851755e-01 | 1.000000e+00 |
     2 |      0 | 3.058740e-15 | 2.851755e-01 | 2.851755e-01 | 1.000000e+00 |
     3 |      0 | 1.089393e-16 | 2.851755e-01 | 2.851755e-01 | 1.000000e+00 |

*** SIMULATION LOOP NO. 31 (starting at time 3.000) ***
sqp it | qp its |       kkt tol |       obj val |      merit val |       ls param |
     1 |      0 | 9.341367e-03 | 2.867625e-01 | 2.867625e-01 | 1.000000e+00 |
     2 |      0 | 9.298448e-15 | 2.867625e-01 | 2.867625e-01 | 1.000000e+00 |
     3 |      0 | 9.428549e-17 | 2.867625e-01 | 2.867625e-01 | 1.000000e+00 |

*** SIMULATION LOOP NO. 32 (starting at time 3.100) ***
sqp it | qp its |       kkt tol |       obj val |      merit val |       ls param |
     1 |      0 | 4.338508e-03 | 2.840714e-01 | 2.840714e-01 | 1.000000e+00 |
     2 |      0 | 6.119790e-15 | 2.840714e-01 | 2.840714e-01 | 1.000000e+00 |
     3 |      0 | 1.766039e-16 | 2.840714e-01 | 2.840714e-01 | 1.000000e+00 |

*** SIMULATION LOOP NO. 33 (starting at time 3.200) ***
sqp it | qp its |       kkt tol |       obj val |      merit val |       ls param |
     1 |      0 | 1.641936e-02 | 2.779194e-01 | 2.779194e-01 | 1.000000e+00 |
     2 |      0 | 3.131377e-15 | 2.779194e-01 | 2.779194e-01 | 1.000000e+00 |
     3 |      0 | 1.500348e-16 | 2.779194e-01 | 2.779194e-01 | 1.000000e+00 |

*** SIMULATION LOOP NO. 34 (starting at time 3.300) ***
sqp it | qp its |       kkt tol |       obj val |      merit val |       ls param |
     1 |      0 | 2.603208e-02 | 2.692013e-01 | 2.692013e-01 | 1.000000e+00 |
     2 |      0 | 1.193887e-14 | 2.692013e-01 | 2.692013e-01 | 1.000000e+00 |
     3 |      0 | 9.597955e-17 | 2.692013e-01 | 2.692013e-01 | 1.000000e+00 |

*** SIMULATION LOOP NO. 35 (starting at time 3.400) ***
sqp it | qp its |       kkt tol |       obj val |      merit val |       ls param |
     1 |      0 | 3.295315e-02 | 2.587658e-01 | 2.587658e-01 | 1.000000e+00 |
     2 |      0 | 5.736844e-15 | 2.587658e-01 | 2.587658e-01 | 1.000000e+00 |
     3 |      0 | 6.743231e-17 | 2.587658e-01 | 2.587658e-01 | 1.000000e+00 |

*** SIMULATION LOOP NO. 36 (starting at time 3.500) ***
sqp it | qp its |       kkt tol |       obj val |      merit val |       ls param |
     1 |      0 | 3.733485e-02 | 2.473527e-01 | 2.473527e-01 | 1.000000e+00 |
     2 |      0 | 5.673696e-15 | 2.473527e-01 | 2.473527e-01 | 1.000000e+00 |
     3 |      0 | 1.115756e-17 | 2.473527e-01 | 2.473527e-01 | 1.000000e+00 |

*** SIMULATION LOOP NO. 37 (starting at time 3.600) ***
sqp it | qp its |       kkt tol |       obj val |      merit val |       ls param |
     1 |      0 | 3.952252e-02 | 2.355663e-01 | 2.355663e-01 | 1.000000e+00 |
     2 |      0 | 1.393842e-14 | 2.355663e-01 | 2.355663e-01 | 1.000000e+00 |
     3 |      0 | 1.739236e-16 | 2.355663e-01 | 2.355663e-01 | 1.000000e+00 |
```

```
*** SIMULATION LOOP NO. 38 (starting at time 3.700) ***
sqp it | qp its |       kkt tol |       obj val |      merit val |      ls param |
     1 |      0 |  3.993614e-02 |  2.238740e-01 |  2.238740e-01 |  1.000000e+00 |
     2 |      0 |  1.351208e-14 |  2.238740e-01 |  2.238740e-01 |  1.000000e+00 |
     3 |      0 |  4.457342e-17 |  2.238740e-01 |  2.238740e-01 |  1.000000e+00 |

*** SIMULATION LOOP NO. 39 (starting at time 3.800) ***
sqp it | qp its |       kkt tol |       obj val |      merit val |      ls param |
     1 |      0 |  3.899808e-02 |  2.126176e-01 |  2.126176e-01 |  1.000000e+00 |
     2 |      0 |  1.844096e-14 |  2.126176e-01 |  2.126176e-01 |  1.000000e+00 |
     3 |      0 |  1.063150e-16 |  2.126176e-01 |  2.126176e-01 |  1.000000e+00 |

*** SIMULATION LOOP NO. 40 (starting at time 3.900) ***
sqp it | qp its |       kkt tol |       obj val |      merit val |      ls param |
     1 |      0 |  3.709285e-02 |  2.020305e-01 |  2.020305e-01 |  1.000000e+00 |
     2 |      0 |  5.166090e-15 |  2.020305e-01 |  2.020305e-01 |  1.000000e+00 |
     3 |      0 |  1.313206e-16 |  2.020305e-01 |  2.020305e-01 |  1.000000e+00 |

*** SIMULATION LOOP NO. 41 (starting at time 4.000) ***
sqp it | qp its |       kkt tol |       obj val |      merit val |      ls param |
     1 |      0 |  3.454809e-02 |  1.922583e-01 |  1.922583e-01 |  1.000000e+00 |
     2 |      0 |  5.014022e-15 |  1.922583e-01 |  1.922583e-01 |  1.000000e+00 |
     3 |      0 |  1.551526e-16 |  1.922583e-01 |  1.922583e-01 |  1.000000e+00 |

*** SIMULATION LOOP NO. 42 (starting at time 4.100) ***
sqp it | qp its |       kkt tol |       obj val |      merit val |      ls param |
     1 |      0 |  3.162918e-02 |  1.833770e-01 |  1.833770e-01 |  1.000000e+00 |
     2 |      0 |  2.595251e-15 |  1.833770e-01 |  1.833770e-01 |  1.000000e+00 |
     3 |      0 |  1.659464e-16 |  1.833770e-01 |  1.833770e-01 |  1.000000e+00 |

*** SIMULATION LOOP NO. 43 (starting at time 4.200) ***
sqp it | qp its |       kkt tol |       obj val |      merit val |      ls param |
     1 |      0 |  2.854168e-02 |  1.754110e-01 |  1.754110e-01 |  1.000000e+00 |
     2 |      0 |  4.885080e-15 |  1.754110e-01 |  1.754110e-01 |  1.000000e+00 |
     3 |      0 |  1.335812e-16 |  1.754110e-01 |  1.754110e-01 |  1.000000e+00 |

*** SIMULATION LOOP NO. 44 (starting at time 4.300) ***
sqp it | qp its |       kkt tol |       obj val |      merit val |      ls param |
     1 |      0 |  2.543814e-02 |  1.683469e-01 |  1.683469e-01 |  1.000000e+00 |
     2 |      0 |  7.121306e-15 |  1.683469e-01 |  1.683469e-01 |  1.000000e+00 |
     3 |      0 |  1.288954e-16 |  1.683469e-01 |  1.683469e-01 |  1.000000e+00 |

*** SIMULATION LOOP NO. 45 (starting at time 4.400) ***
sqp it | qp its |       kkt tol |       obj val |      merit val |      ls param |
     1 |      0 |  2.242648e-02 |  1.621460e-01 |  1.621460e-01 |  1.000000e+00 |
     2 |      0 |  2.325402e-15 |  1.621460e-01 |  1.621460e-01 |  1.000000e+00 |
     3 |      0 |  1.346113e-16 |  1.621460e-01 |  1.621460e-01 |  1.000000e+00 |

*** SIMULATION LOOP NO. 46 (starting at time 4.500) ***
sqp it | qp its |       kkt tol |       obj val |      merit val |      ls param |
     1 |      0 |  1.957872e-02 |  1.567528e-01 |  1.567528e-01 |  1.000000e+00 |
     2 |      0 |  9.014732e-15 |  1.567528e-01 |  1.567528e-01 |  1.000000e+00 |
     3 |      0 |  7.845221e-17 |  1.567528e-01 |  1.567528e-01 |  1.000000e+00 |

*** SIMULATION LOOP NO. 47 (starting at time 4.600) ***
sqp it | qp its |       kkt tol |       obj val |      merit val |      ls param |
     1 |      0 |  1.693896e-02 |  1.521027e-01 |  1.521027e-01 |  1.000000e+00 |
     2 |      0 |  4.456626e-15 |  1.521027e-01 |  1.521027e-01 |  1.000000e+00 |
     3 |      0 |  7.725128e-17 |  1.521027e-01 |  1.521027e-01 |  1.000000e+00 |

*** SIMULATION LOOP NO. 48 (starting at time 4.700) ***
sqp it | qp its |       kkt tol |       obj val |      merit val |      ls param |
     1 |      0 |  1.453039e-02 |  1.481264e-01 |  1.481264e-01 |  1.000000e+00 |
     2 |      0 |  8.780231e-17 |  1.481264e-01 |  1.481264e-01 |  1.000000e+00 |
     3 |      0 |  1.026616e-16 |  1.481264e-01 |  1.481264e-01 |  1.000000e+00 |
```

```
*** SIMULATION LOOP NO. 49 (starting at time 4.800) ***
sqp it | qp its |       kkt tol |       obj val |      merit val |      ls param |
     1 |      0 | 1.236102e-02 | 1.447543e-01 | 1.447543e-01 | 1.000000e+00 |
     2 |      0 | 6.487865e-15 | 1.447543e-01 | 1.447543e-01 | 1.000000e+00 |
     3 |      0 | 1.707444e-16 | 1.447543e-01 | 1.447543e-01 | 1.000000e+00 |

*** SIMULATION LOOP NO. 50 (starting at time 4.900) ***
sqp it | qp its |       kkt tol |       obj val |      merit val |      ls param |
     1 |      0 | 1.042826e-02 | 1.419185e-01 | 1.419185e-01 | 1.000000e+00 |
     2 |      0 | 6.225979e-17 | 1.419185e-01 | 1.419185e-01 | 1.000000e+00 |
     3 |      0 | 9.565629e-17 | 1.419185e-01 | 1.419185e-01 | 1.000000e+00 |

*** SIMULATION LOOP NO. 51 (starting at time 5.000) ***
sqp it | qp its |       kkt tol |       obj val |      merit val |      ls param |
     1 |      0 | 8.722502e-03 | 1.395547e-01 | 1.395547e-01 | 1.000000e+00 |
     2 |      0 | 1.055039e-14 | 1.395547e-01 | 1.395547e-01 | 1.000000e+00 |
     3 |      0 | 2.962973e-17 | 1.395547e-01 | 1.395547e-01 | 1.000000e+00 |

out = struct with fields:

        STATES_SAMPLED: [588×11 double]
             CONTROLS: [520×5 double]
           PARAMETERS: [0×1 double]
               STATES: [588×11 double]
       ALGEBRAICSTATES: [0×1 double]
   CONVERGENCE_ACHIEVED: 1
```