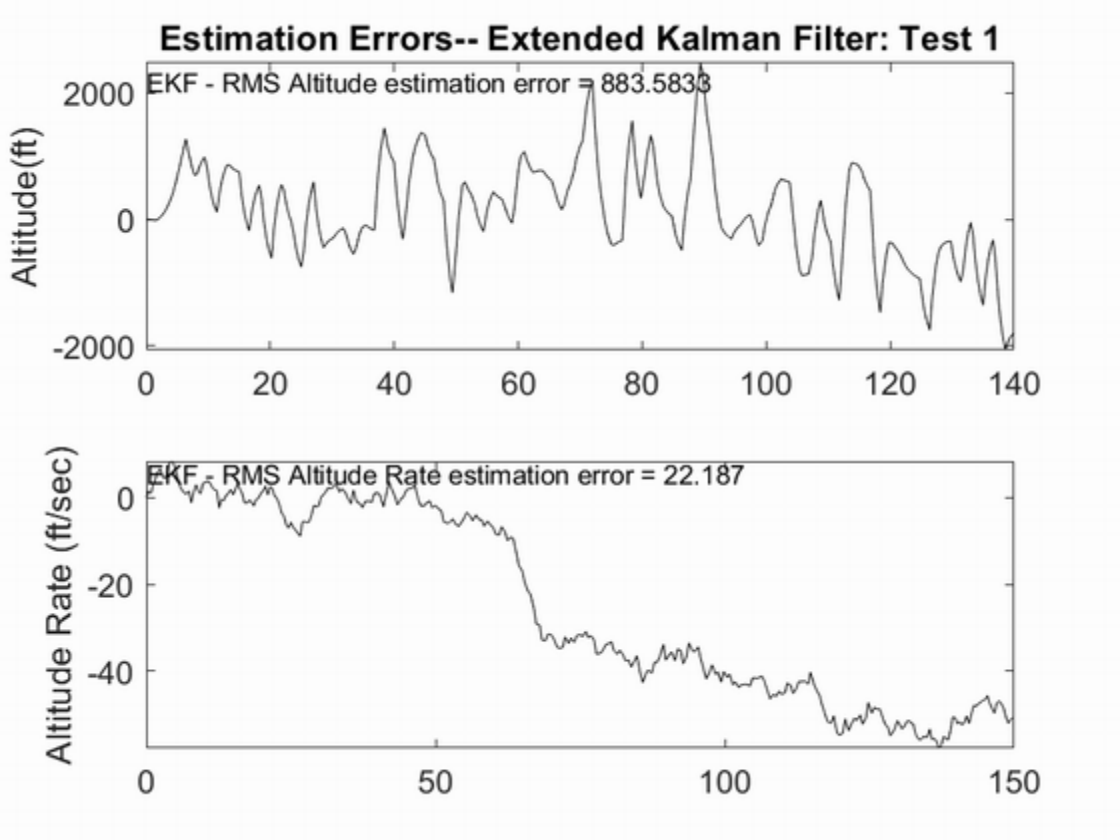
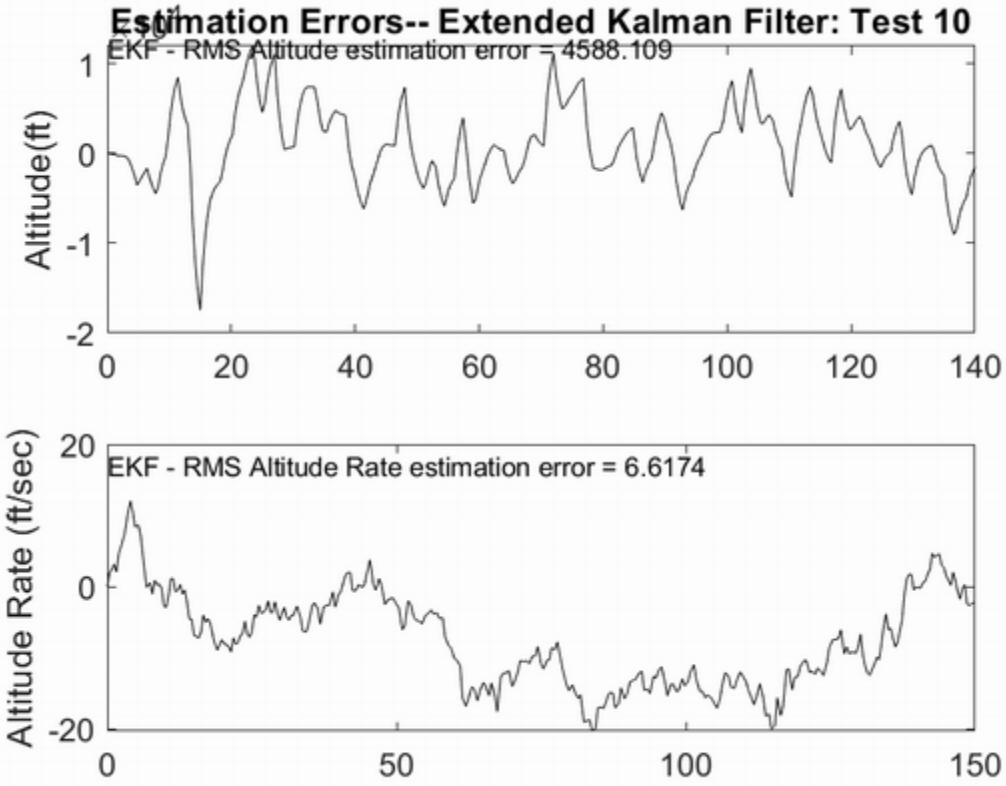
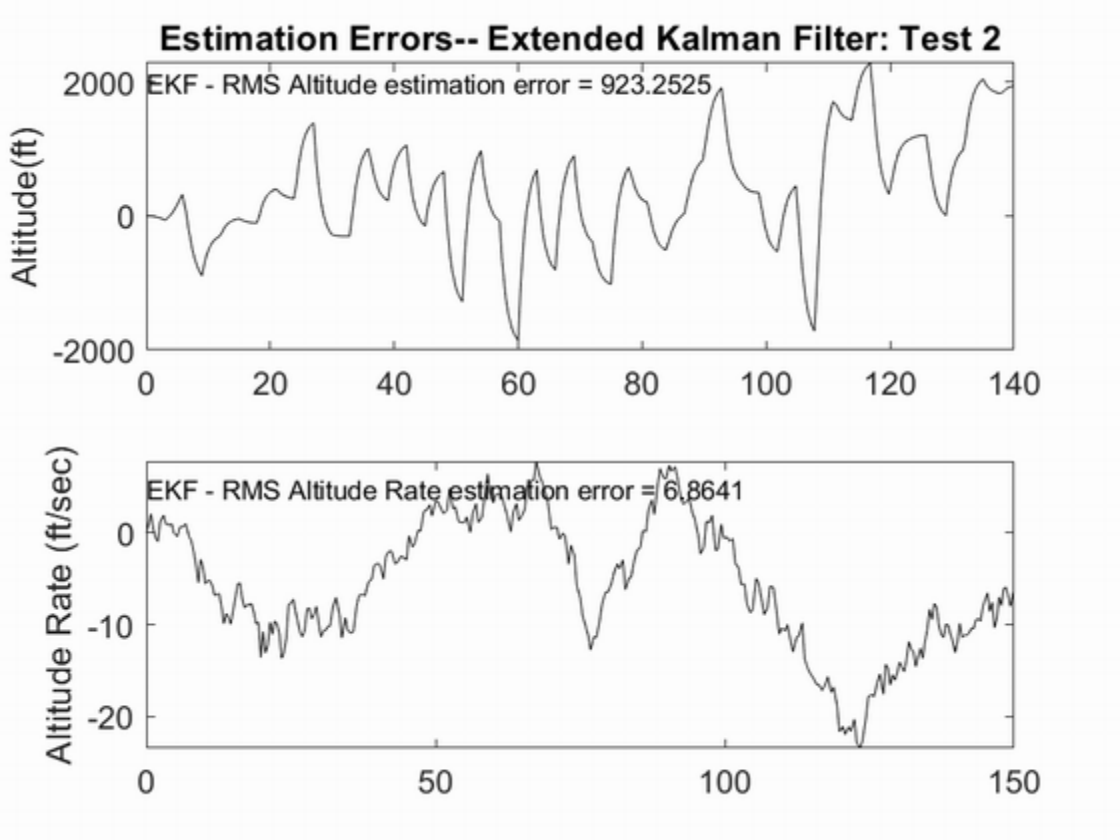
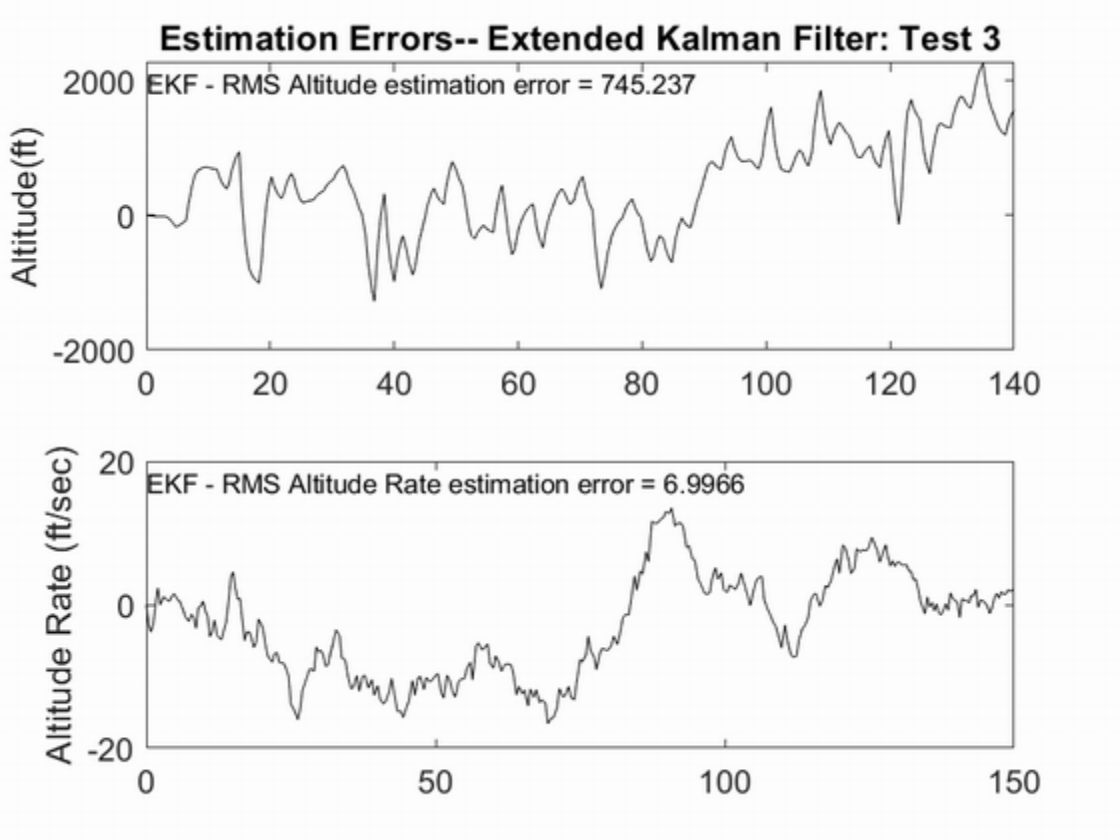
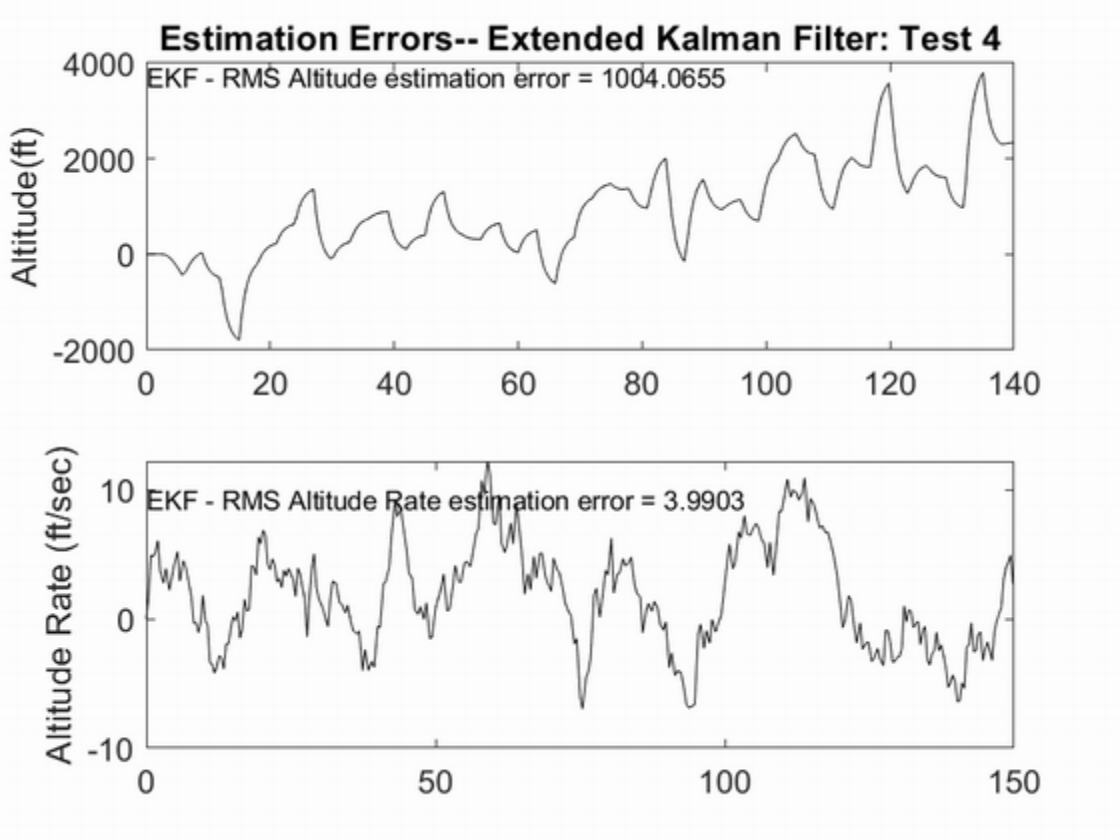
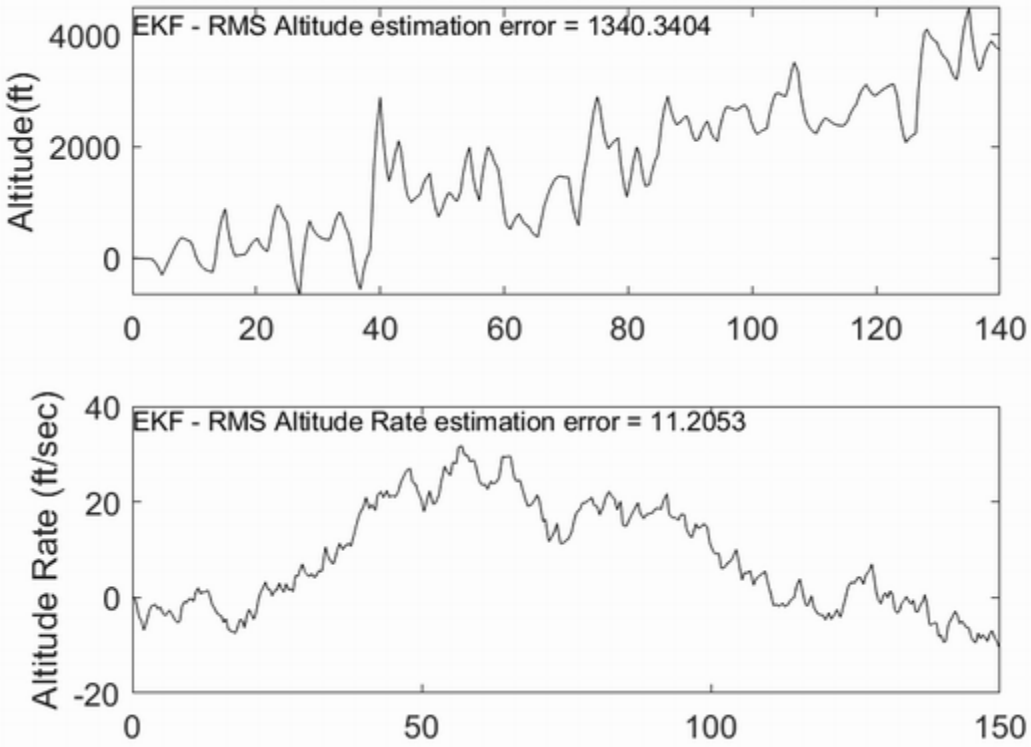

Estimation Errors-- Extended Kalman Filter: Test 1
EKF - RMS Altitude estimation error = 883.5833
Altitude(ft)
2000
0
-2000
0
20
40
60
80
100
120
140
EKF - RMS Altitude Rate estimation error = 22.187
Altitude Rate (ft/sec)
0
-20
-40
0
50
100
150

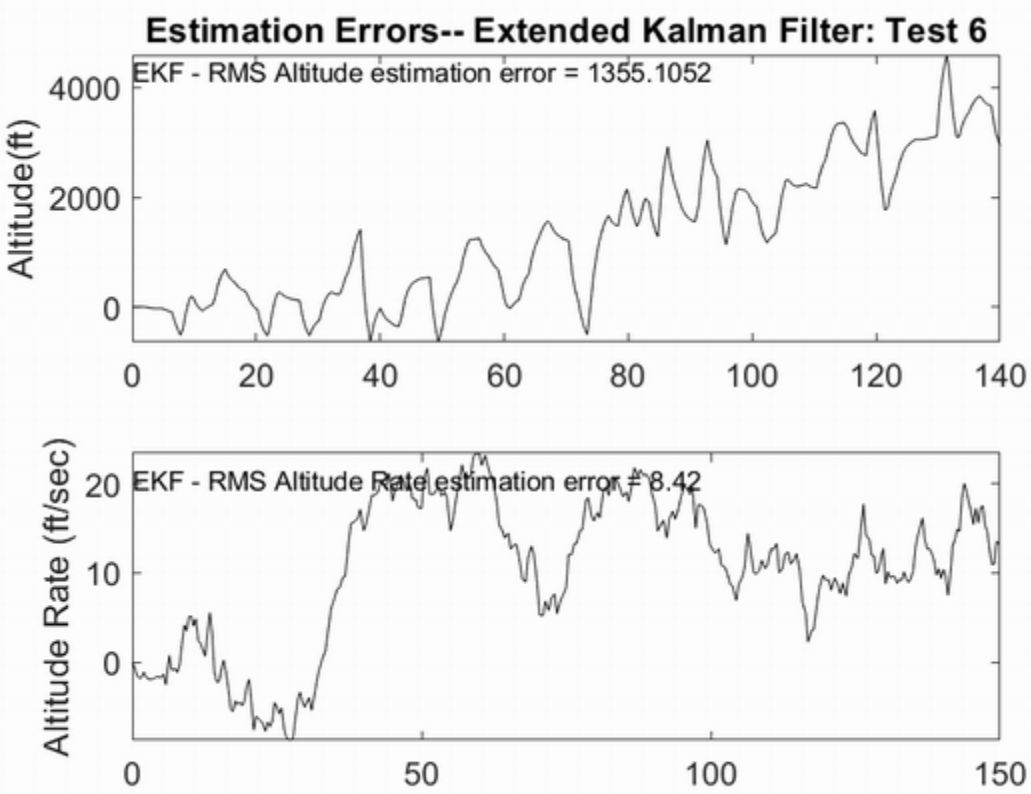

Estimation Errors-- Extended Kalman Filter: Test 10
EKF - RMS Altitude estimation error = 4588.109
Altitude(ft)
1
0
-1
-2
0
20
40
60
80
100
120
140
EKF - RMS Altitude Rate estimation error = 6.6174
Altitude Rate (ft/sec)
20
0
-20
0
50
100
150

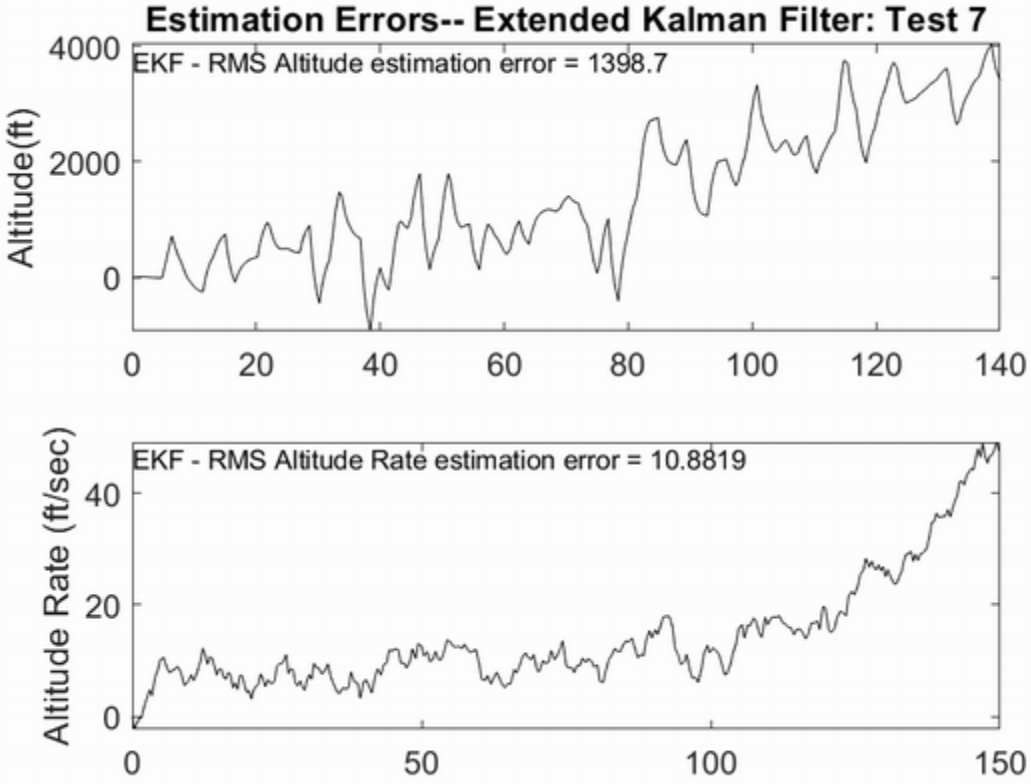

Estimation Errors-- Extended Kalman Filter: Test 2
EKF - RMS Altitude estimation error = 923.2525
Altitude(ft)
2000
0
-2000
0
20
40
60
80
100
120
140
EKF - RMS Altitude Rate estimation error = 6.8641
Altitude Rate (ft/sec)
0
-10
-20
0
50
100
150

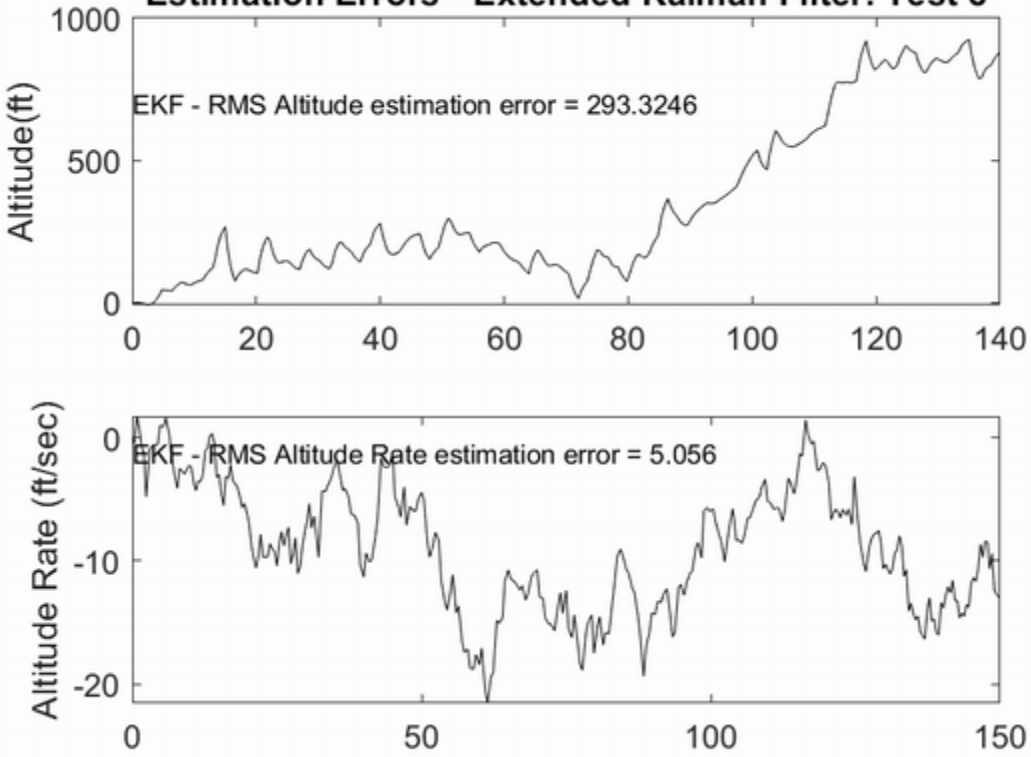

Estimation Errors-- Extended Kalman Filter: Test 3
EKF - RMS Altitude estimation error = 745.237
Altitude(ft)
2000
0
-2000
0
20
40
60
80
100
120
140
EKF - RMS Altitude Rate estimation error = 6.9966
Altitude Rate (ft/sec)
20
0
-20
0
50
100
150

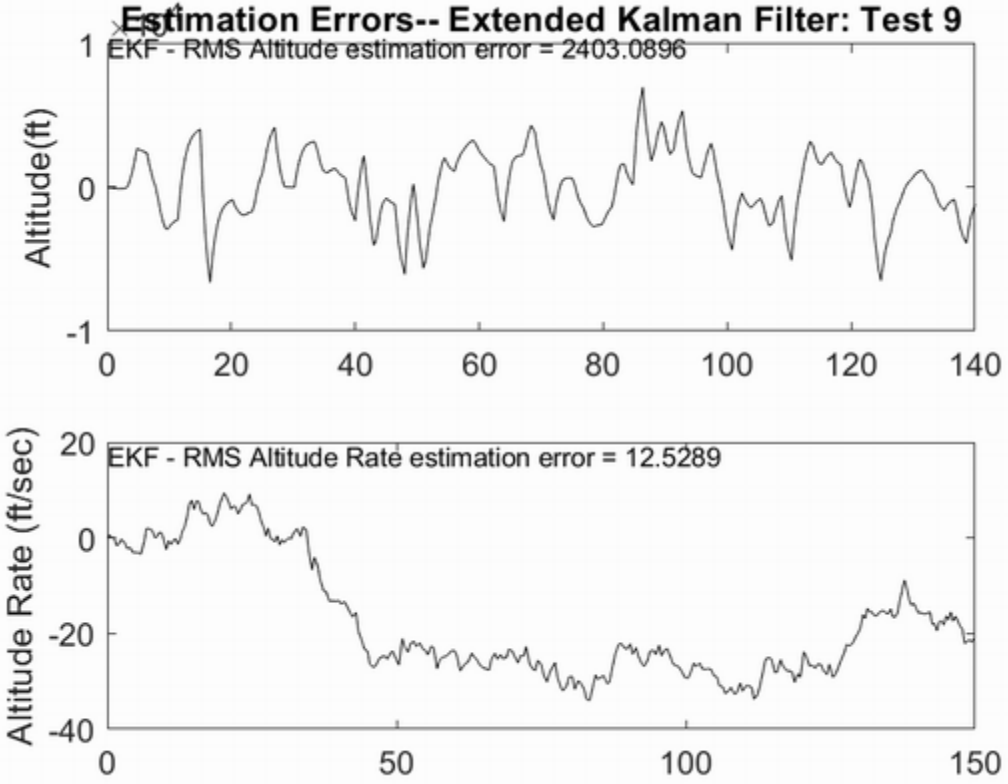

Estimation Errors-- Extended Kalman Filter: Test 4
EKF - RMS Altitude estimation error = 1004.0655
Altitude(ft)
4000
2000
0
-2000
0
20
40
60
80
100
120
140
EKF - RMS Altitude Rate estimation error = 3.9903
Altitude Rate (ft/sec)
10
0
-10
0
50
100
150

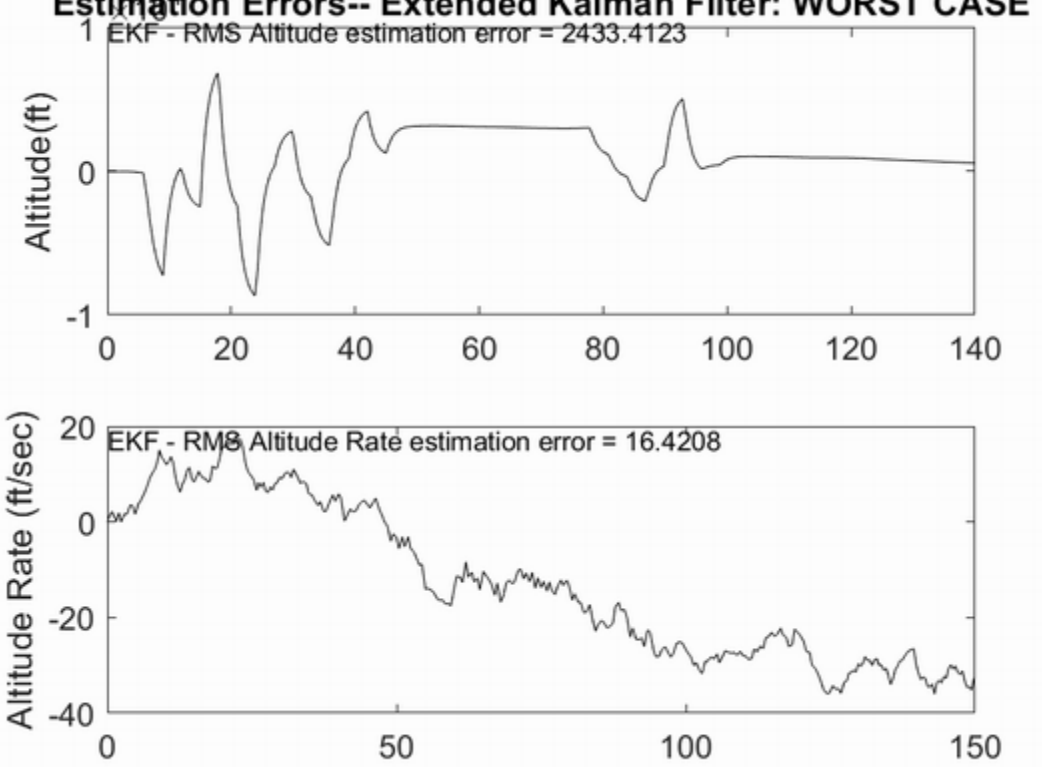

Estimation Errors-- Extended Kalman Filter: Test 5
EKF - RMS Altitude estimation error = 1340.3404
Altitude(ft)
4000
2000
0
0
20
40
60
80
100
120
140
EKF - RMS Altitude Rate estimation error = 11.2053
Altitude Rate (ft/sec)
40
20
0
-20
0
50
100
150

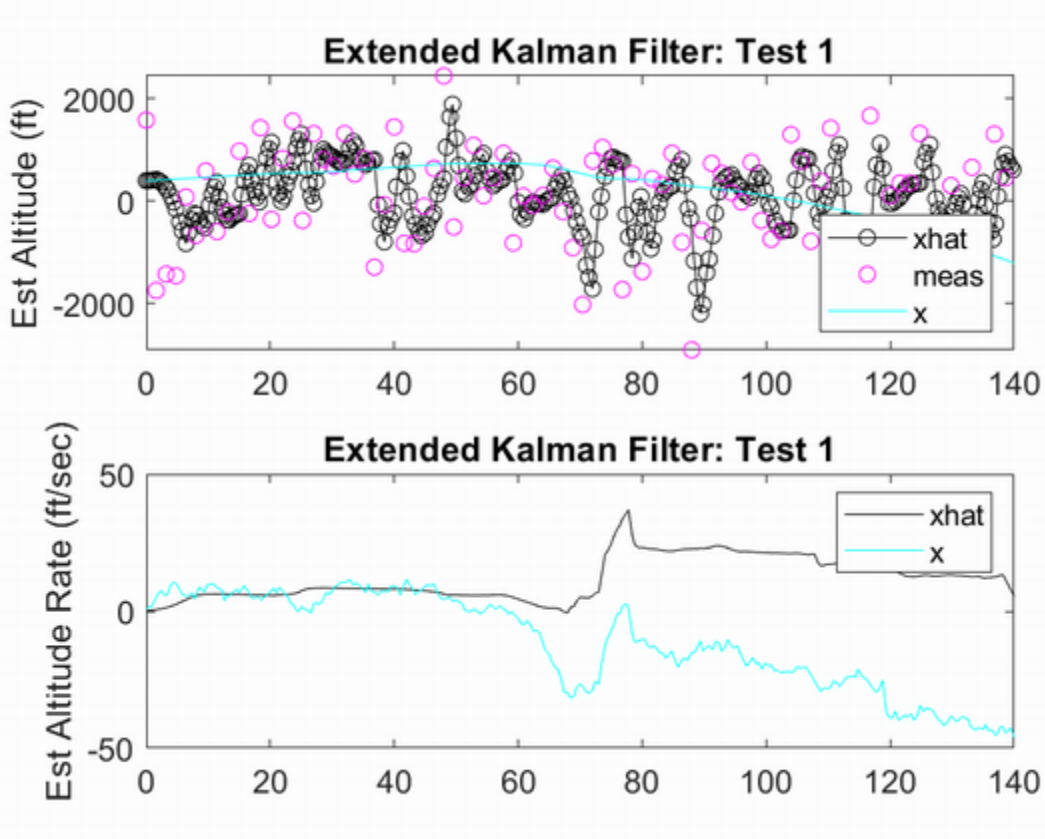

Estimation Errors-- Extended Kalman Filter: Test 6
EKF - RMS Altitude estimation error = 1355.1052
Altitude(ft)
4000
2000
0
0
20
40
60
80
100
120
140
EKF - RMS Altitude Rate estimation error = 8.42
Altitude Rate (ft/sec)
20
10
0
0
50
100
150

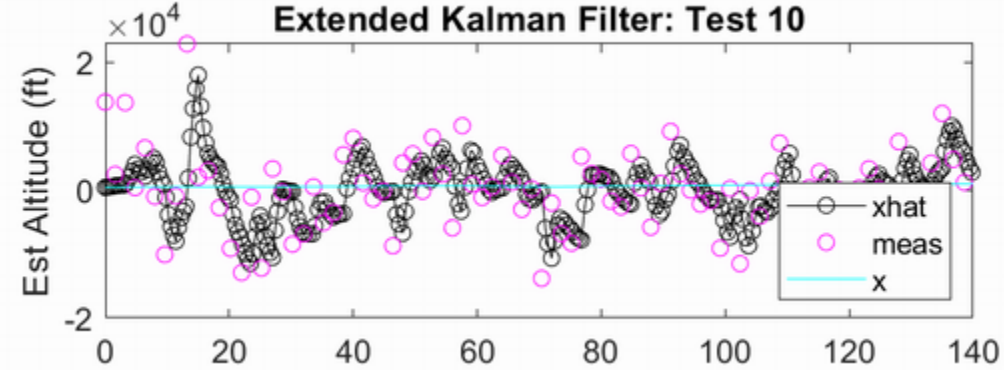

Estimation Errors-- Extended Kalman Filter: Test 7
EKF - RMS Altitude estimation error = 1398.7
Altitude(ft)
4000
2000
0
0
20
40
60
80
100
120
140
EKF - RMS Altitude Rate estimation error = 10.8819
Altitude Rate (ft/sec)
40
20
0
0
50
100
150

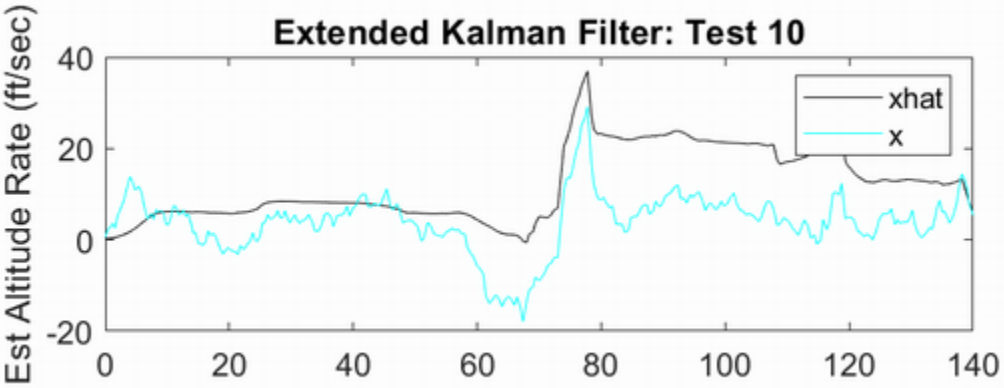

Estimation Errors-- Extended Kalman Filter: Test 8
EKF - RMS Altitude estimation error = 293.3246
Altitude(ft)
1000
500
0
0
20
40
60
80
100
120
140
EKF - RMS Altitude Rate estimation error = 5.056
Altitude Rate (ft/sec)
0
-10
-20
0
50
100
150

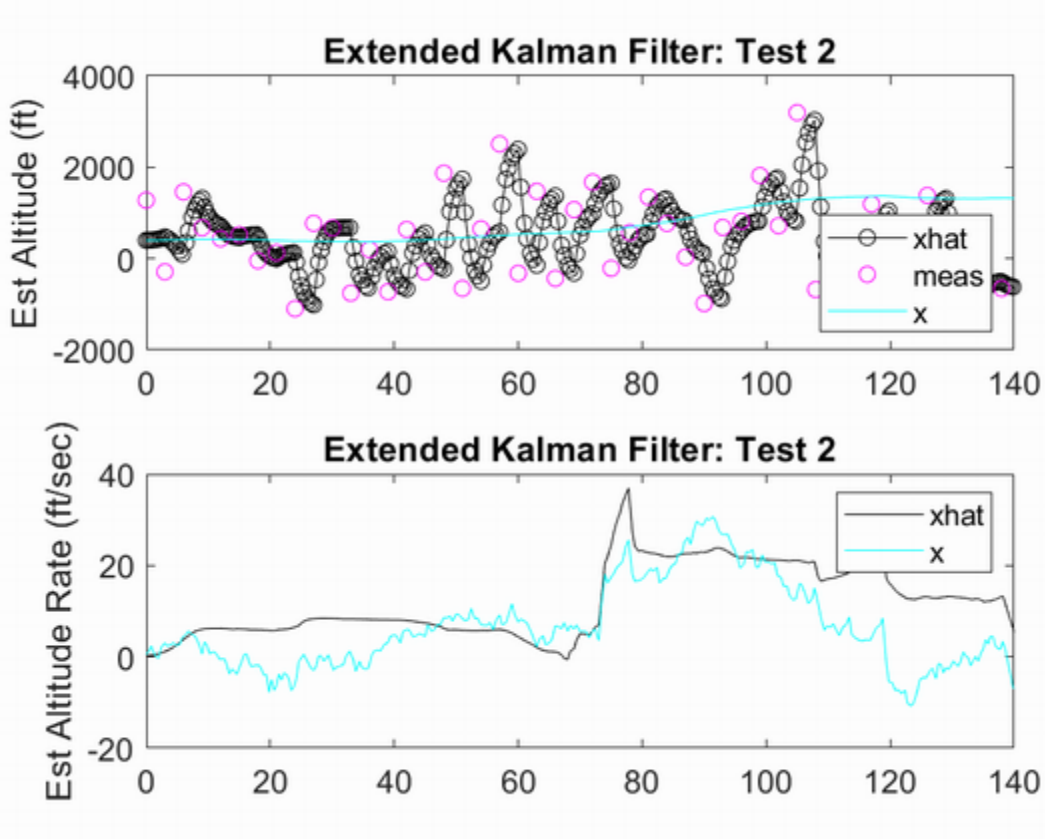

Estimation Errors-- Extended Kalman Filter: Test 9
EKF - RMS Altitude estimation error = 2403.0896
Altitude(ft)
1
0
-1
0
20
40
60
80
100
120
140
EKF - RMS Altitude Rate estimation error = 12.5289
Altitude Rate (ft/sec)
20
0
-20
-40
0
50
100
150

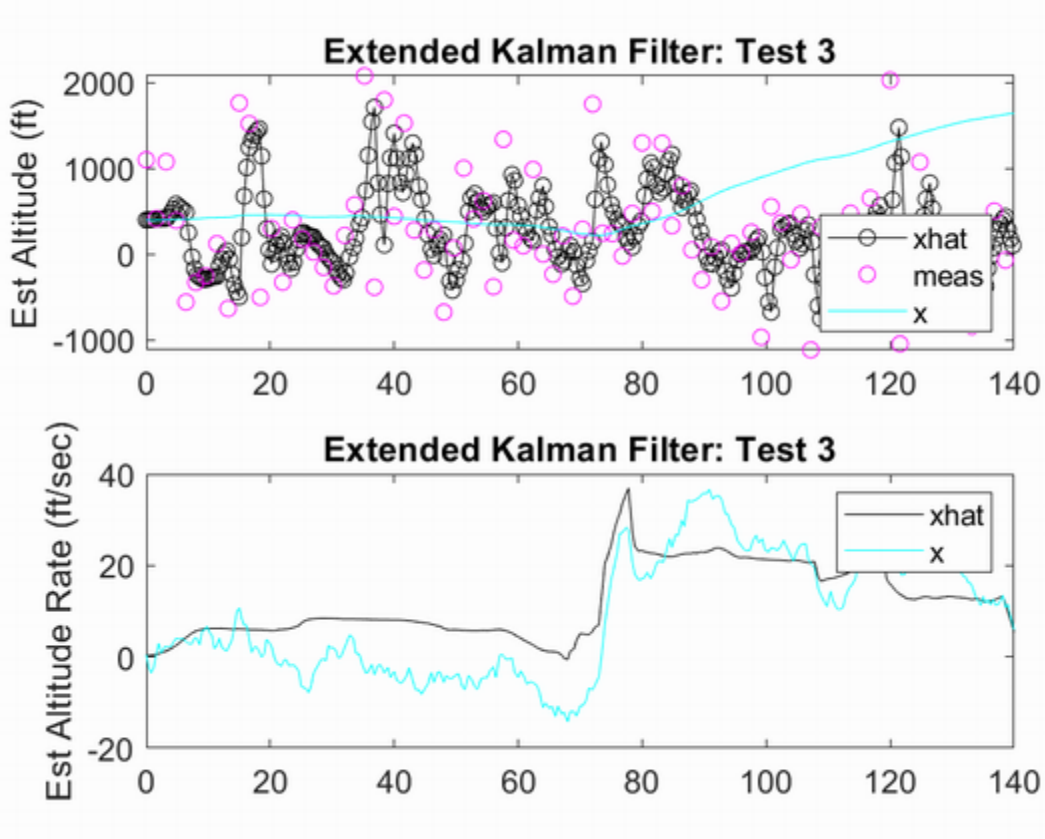

Estimation Errors-- Extended Kalman Filter: WORST CASE
EKF - RMS Altitude estimation error = 2433.4123
Altitude(ft)
1
0
-1
0
20
40
60
80
100
120
140
EKF - RMS Altitude Rate estimation error = 16.4208
Altitude Rate (ft/sec)
20
0
-20
-40
0
50
100
150

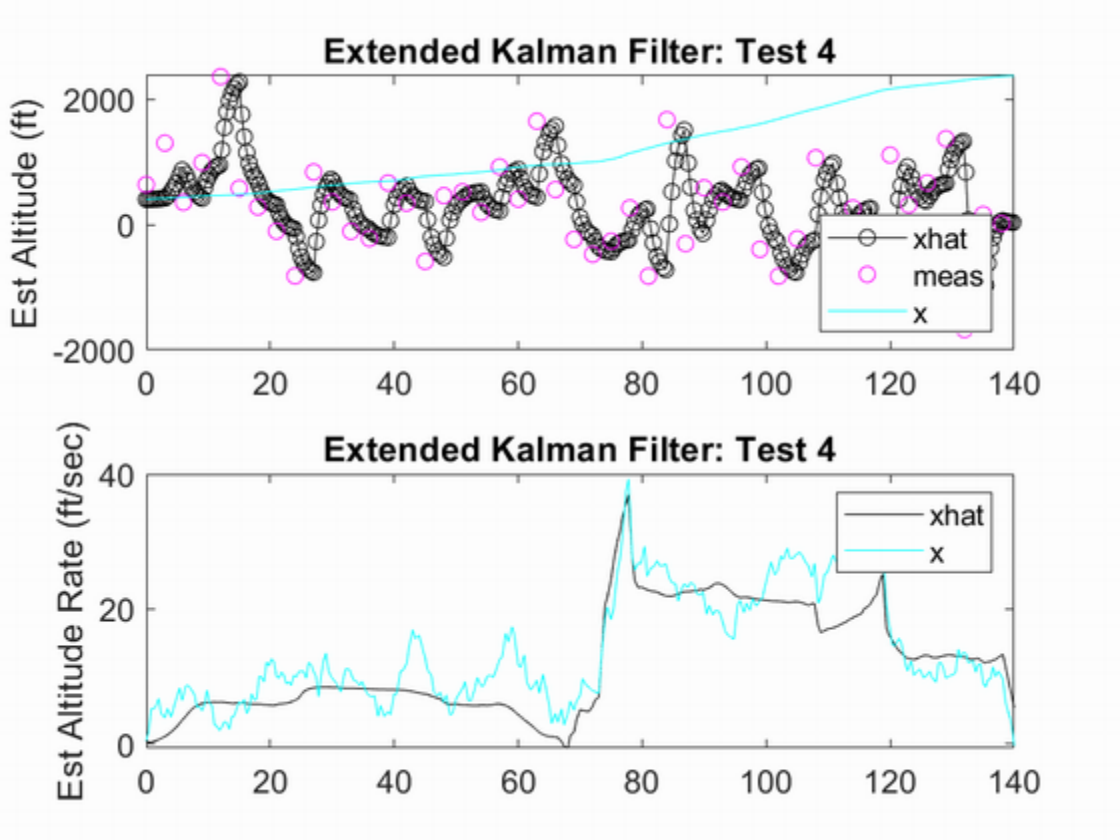

Extended Kalman Filter: Test 1
Est Altitude (ft)
2000
0
-2000
0
20
40
60
80
100
120
140
xhat
meas
x
Extended Kalman Filter: Test 1
Est Altitude Rate (ft/sec)
50
0
-50
0
20
40
60
80
100
120
140
xhat
x

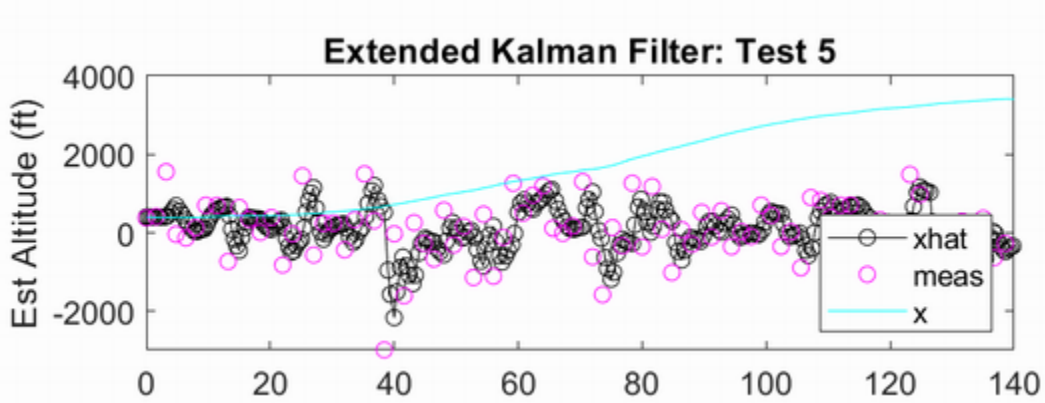

Extended Kalman Filter: Test 10
×10^4
Est Altitude (ft)
2
0
-2
0
20
40
60
80
100
120
140
xhat
meas
x

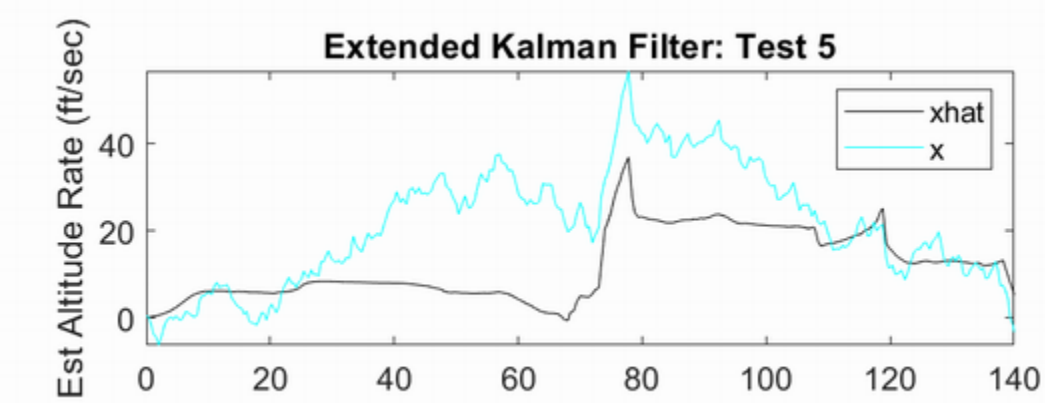

Extended Kalman Filter: Test 10
Est Altitude Rate (ft/sec)
40
20
0
-20
0
20
40
60
80
100
120
140
xhat
x

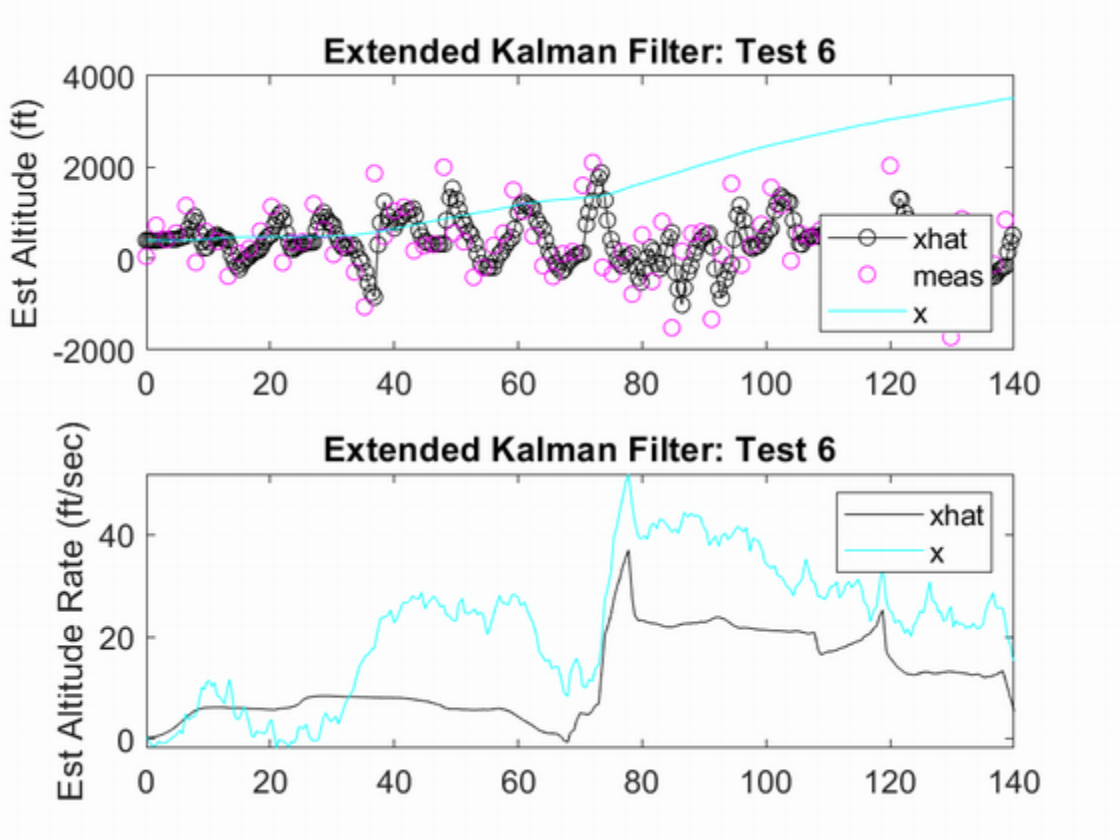

Extended Kalman Filter: Test 2
Est Altitude (ft)
4000
2000
0
-2000
0
20
40
60
80
100
120
140
xhat
meas
x
Extended Kalman Filter: Test 2
Est Altitude Rate (ft/sec)
40
20
0
-20
0
20
40
60
80
100
120
140
xhat
x

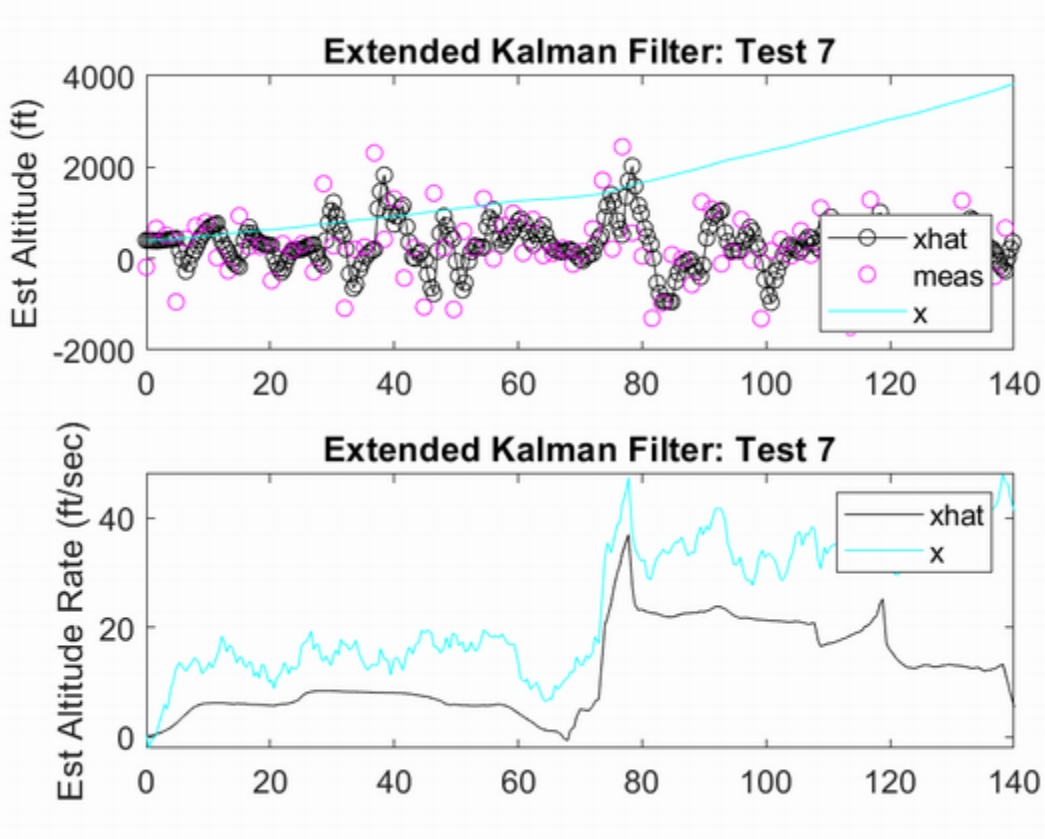

Extended Kalman Filter: Test 3
Est Altitude (ft)
2000
1000
0
-1000
0
20
40
60
80
100
120
140
xhat
meas
x
Extended Kalman Filter: Test 3
Est Altitude Rate (ft/sec)
40
20
0
-20
0
20
40
60
80
100
120
140
xhat
x

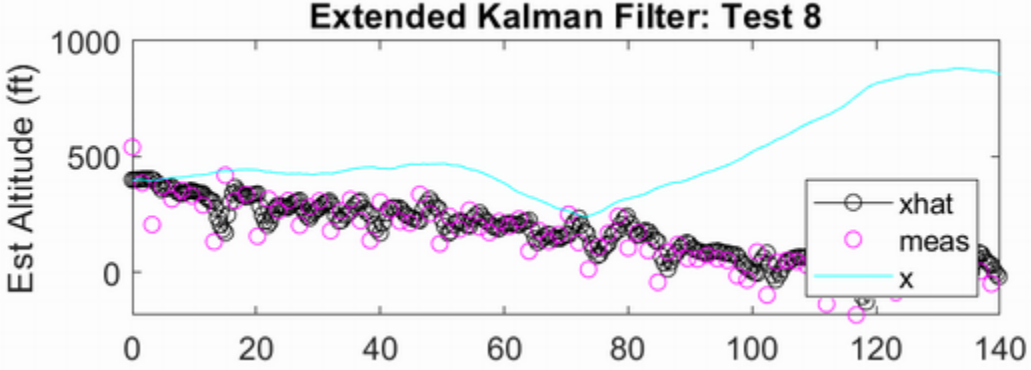

Extended Kalman Filter: Test 4
Est Altitude (ft)
2000
0
-2000
0
20
40
60
80
100
120
140
xhat
meas
x
Extended Kalman Filter: Test 4
Est Altitude Rate (ft/sec)
40
20
0
0
20
40
60
80
100
120
140
xhat
x

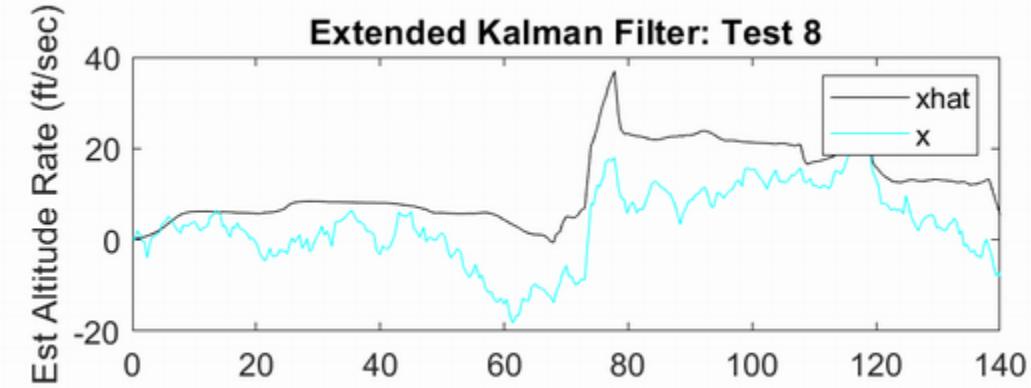

Extended Kalman Filter: Test 5
Est Altitude (ft)
4000
2000
0
-2000
0
20
40
60
80
100
120
140
xhat
meas
x

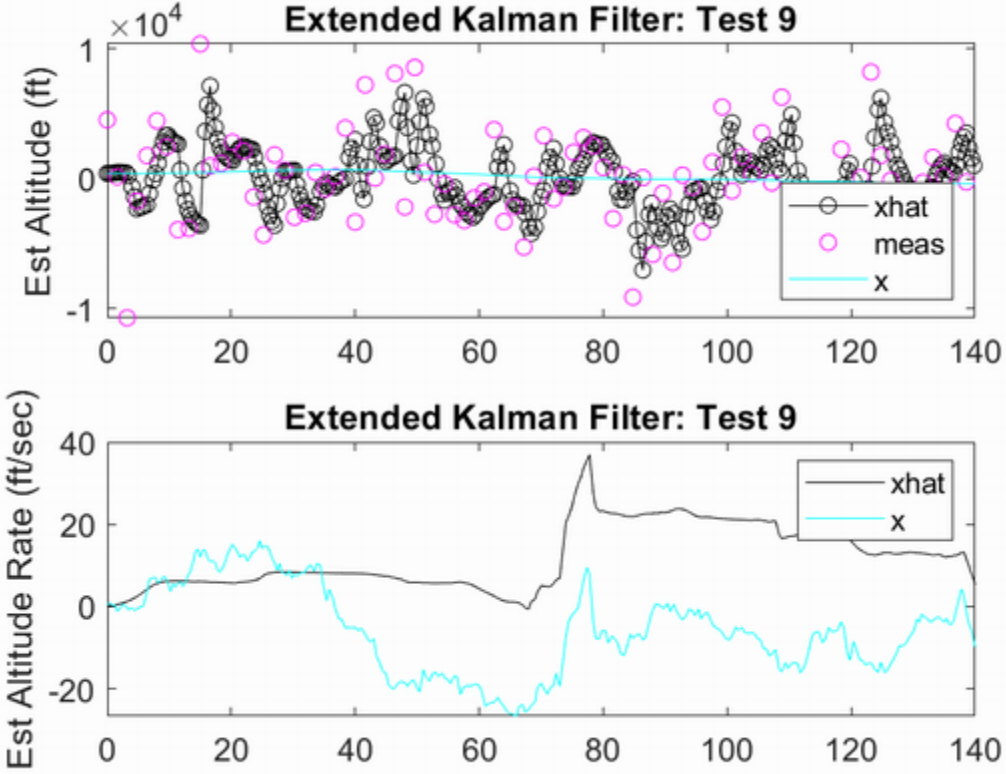

Extended Kalman Filter: Test 5
Est Altitude Rate (ft/sec)
40
20
0
0
20
40
60
80
100
120
140
xhat
x

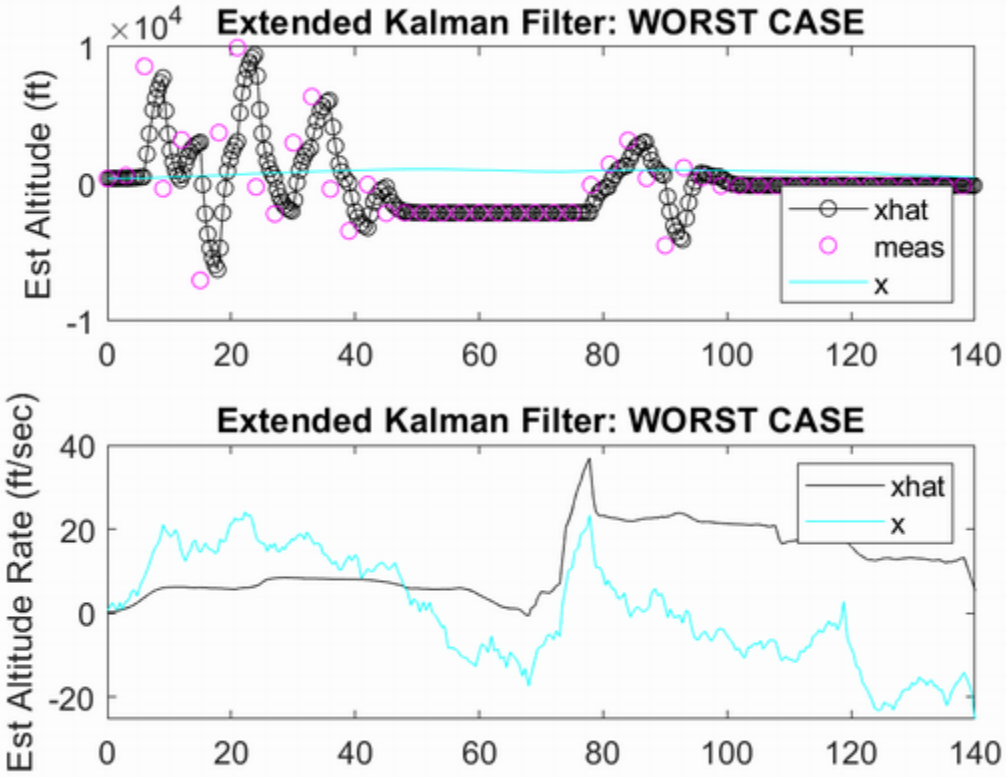

Extended Kalman Filter: Test 6
Est Altitude (ft)
4000
2000
0
-2000
0
20
40
60
80
100
120
140
xhat
meas
x
Extended Kalman Filter: Test 6
Est Altitude Rate (ft/sec)
40
20
0
0
20
40
60
80
100
120
140
xhat
x

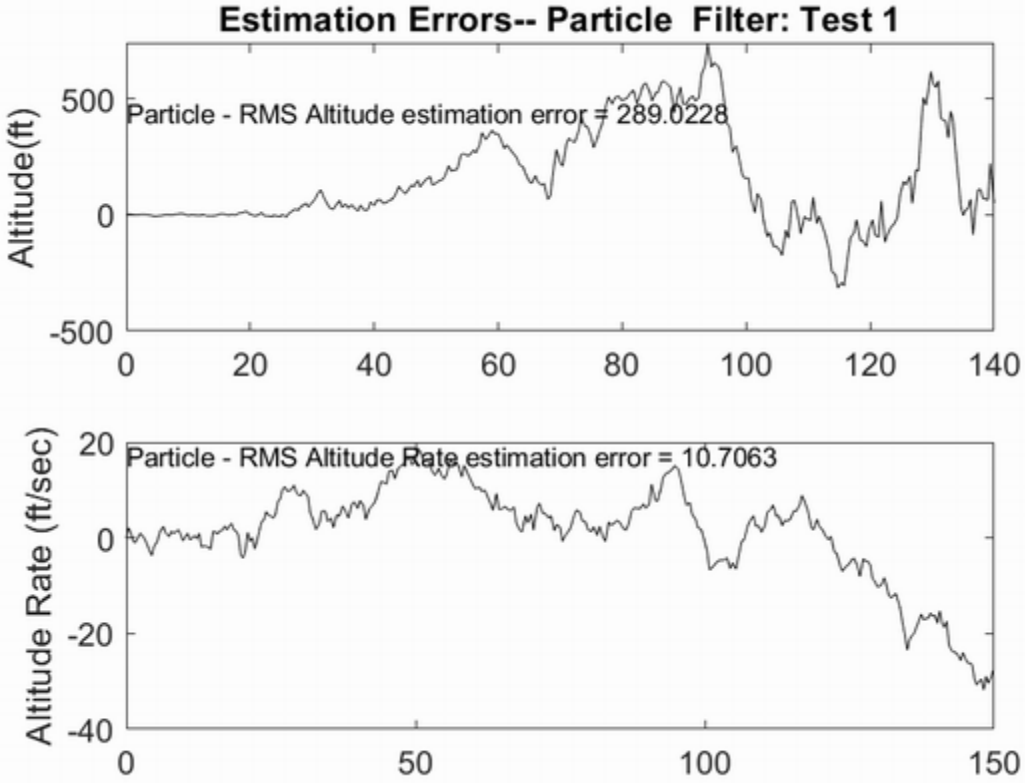

Extended Kalman Filter: Test 7
Est Altitude (ft)
4000
2000
0
-2000
0
20
40
60
80
100
120
140
xhat
meas
x
Extended Kalman Filter: Test 7
Est Altitude Rate (ft/sec)
40
20
0
0
20
40
60
80
100
120
140
xhat
x

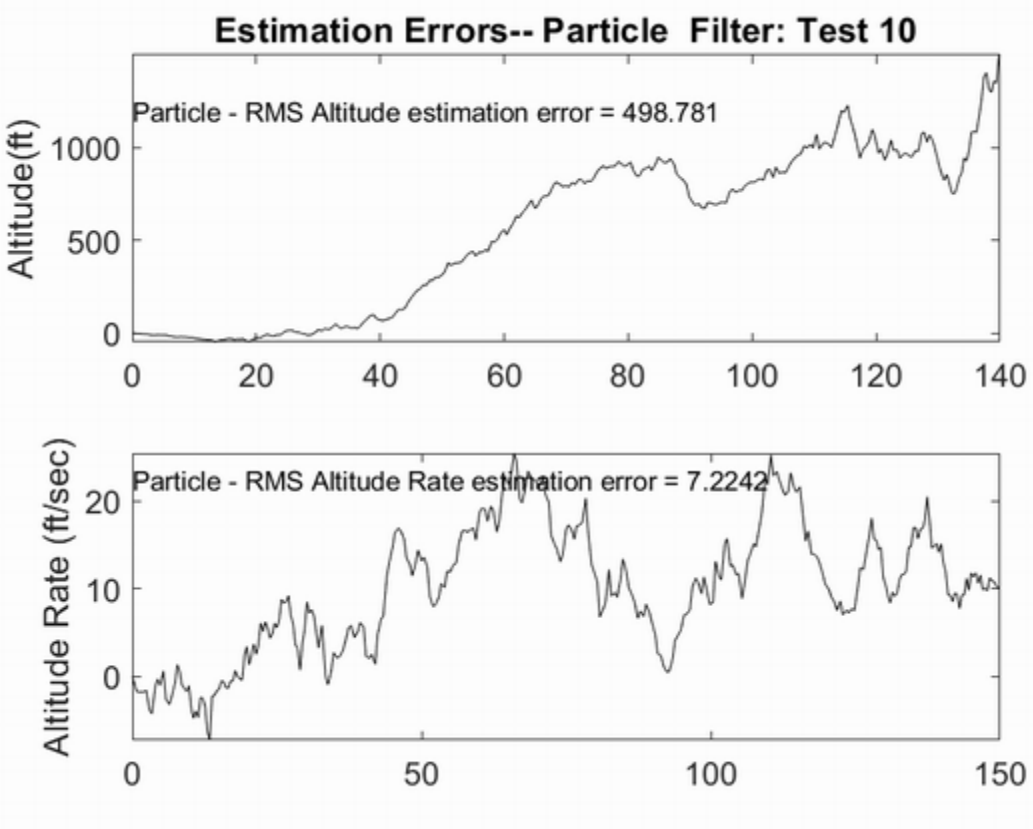

Extended Kalman Filter: Test 8
Est Altitude (ft)
1000
500
0
0
20
40
60
80
100
120
140
xhat
meas
x

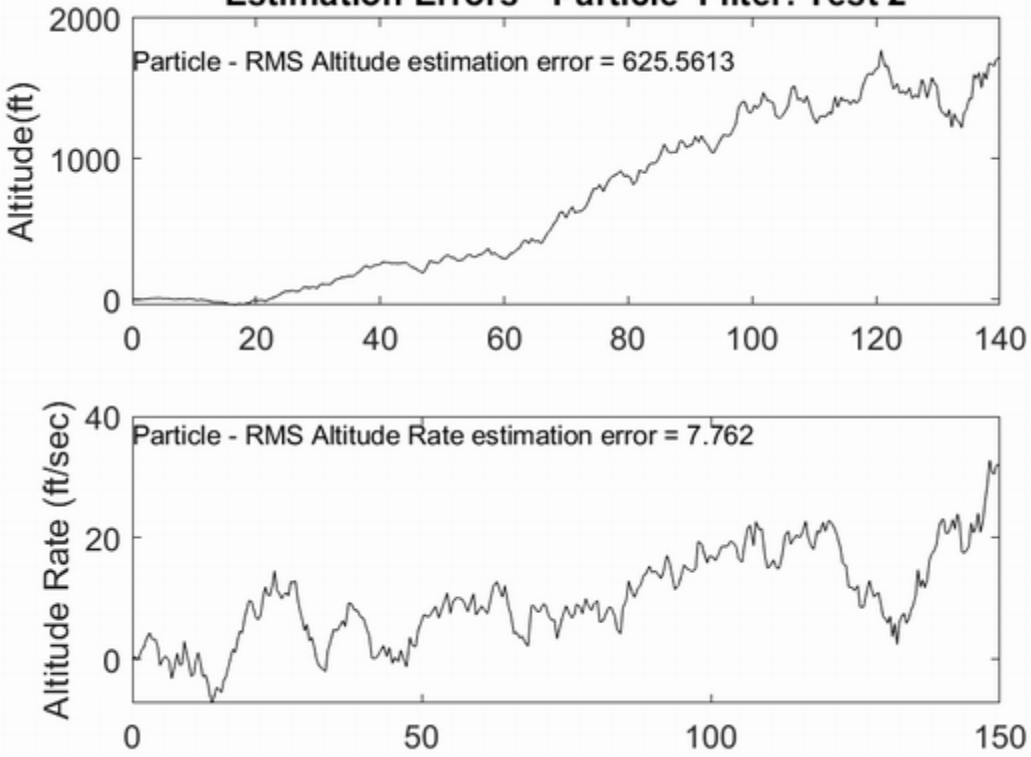

Extended Kalman Filter: Test 8
Est Altitude Rate (ft/sec)
40
20
0
-20
0
20
40
60
80
100
120
140
xhat
x

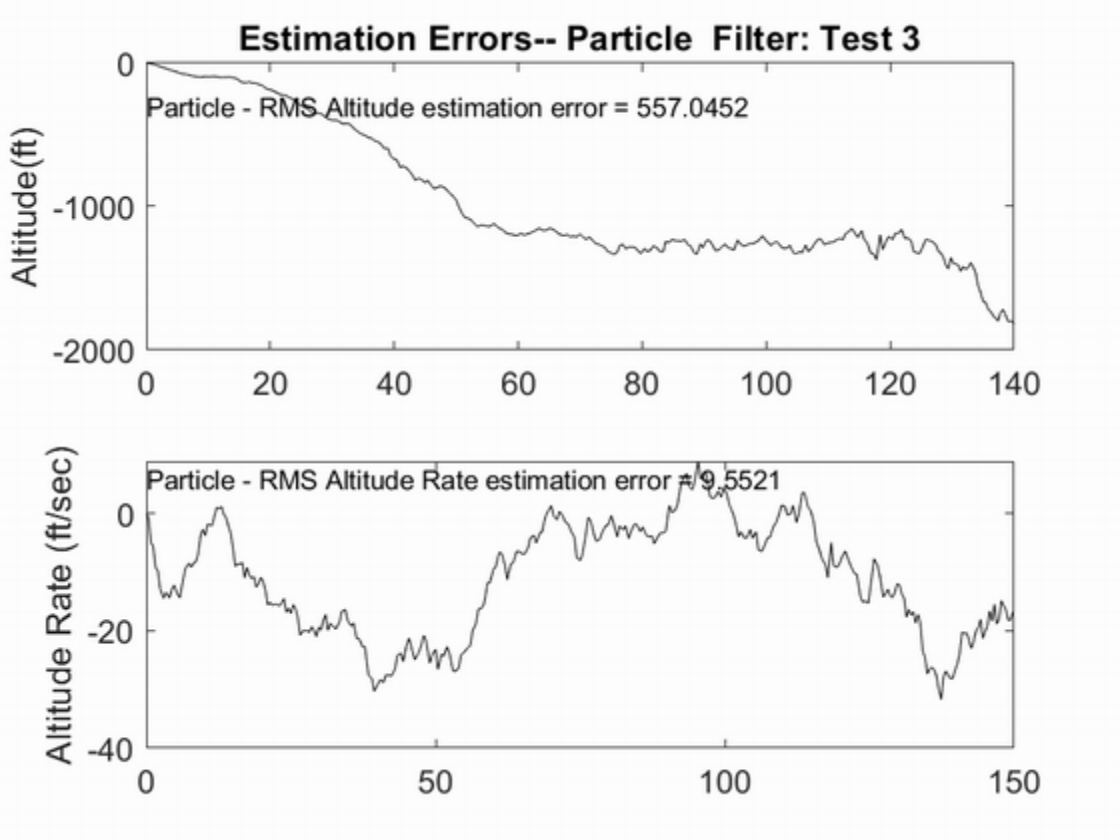

Extended Kalman Filter: Test 9
×10^4
Est Altitude (ft)
xhat
meas
x
Extended Kalman Filter: Test 9
Est Altitude Rate (ft/sec)
xhat
x

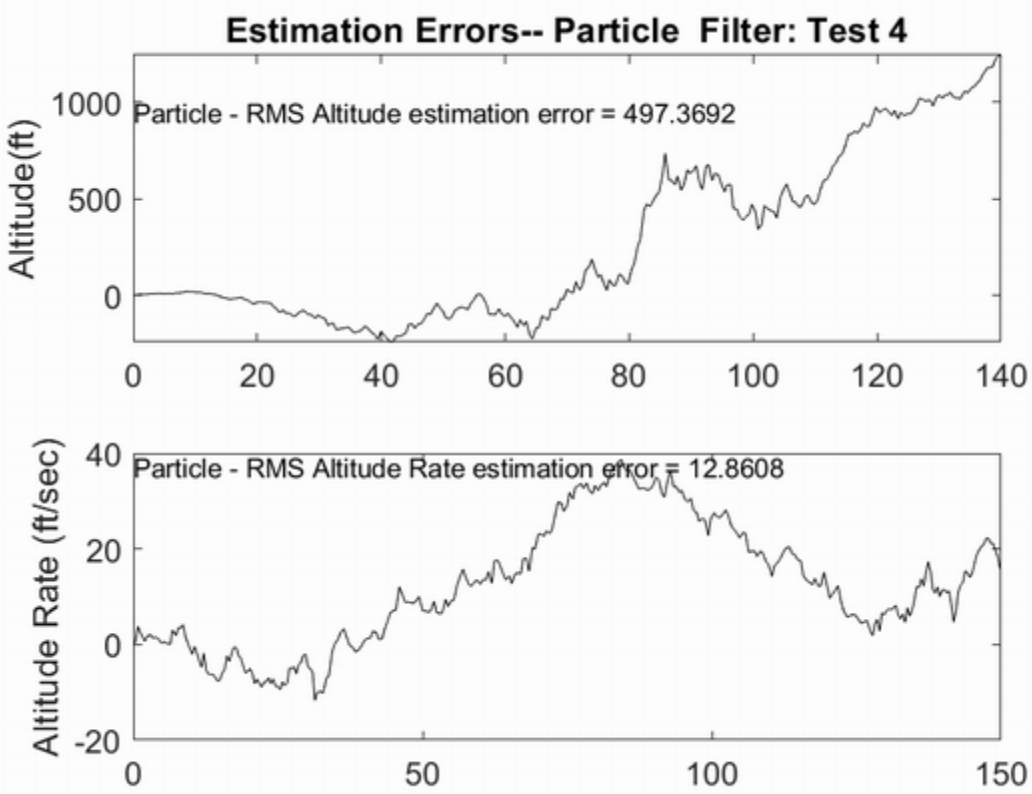

Extended Kalman Filter: WORST CASE
×10^4
Est Altitude (ft)
1
0
-1
0
20
40
60
80
100
120
140
xhat
meas
x
Extended Kalman Filter: WORST CASE
Est Altitude Rate (ft/sec)
40
20
0
-20
0
20
40
60
80
100
120
140
xhat
x

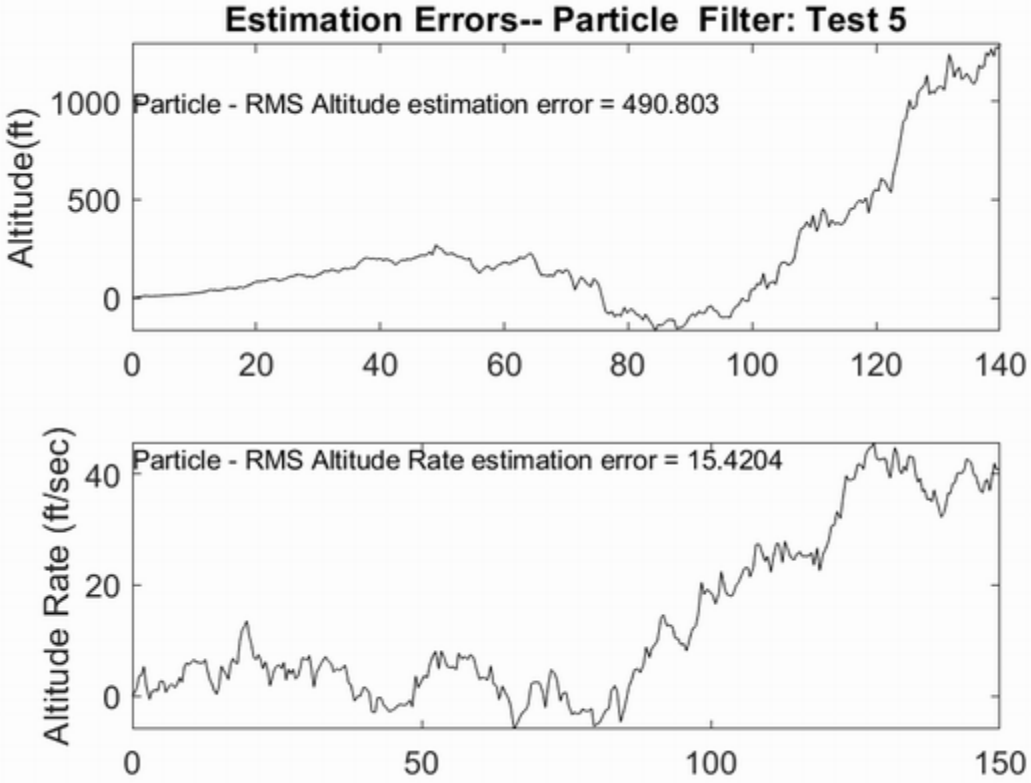

Estimation Errors-- Particle Filter: Test 1
Particle - RMS Altitude estimation error = 289.0228
Altitude(ft)
500
0
-500
0
20
40
60
80
100
120
140
Particle - RMS Altitude Rate estimation error = 10.7063
Altitude Rate (ft/sec)
20
0
-20
-40
0
50
100
150

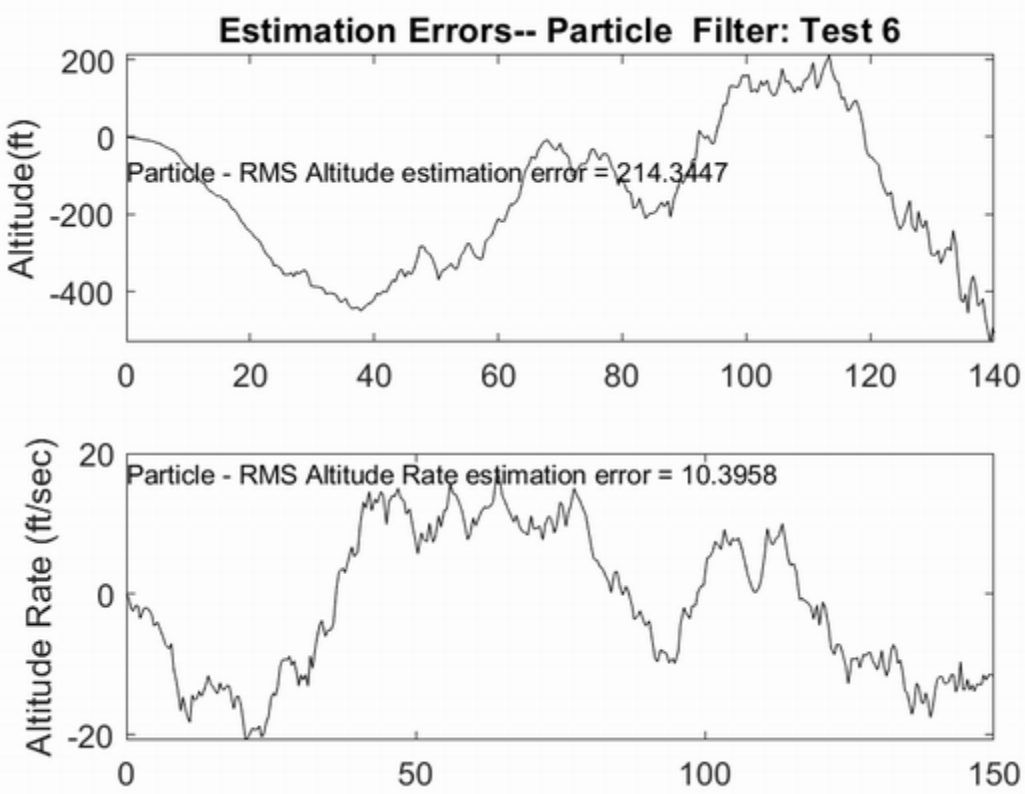

Estimation Errors-- Particle Filter: Test 10
Particle - RMS Altitude estimation error = 498.781
Altitude(ft)
1000
500
0
0
20
40
60
80
100
120
140
Particle - RMS Altitude Rate estimation error = 7.2242
Altitude Rate (ft/sec)
20
10
0
0
50
100
150

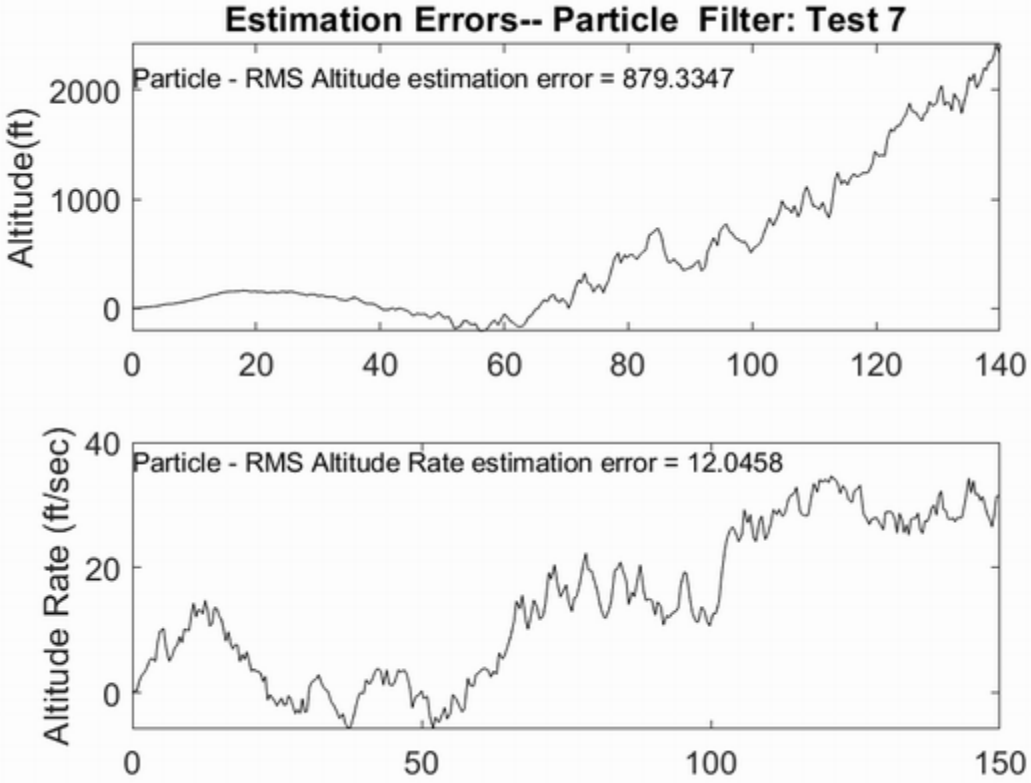

Estimation Errors-- Particle Filter: Test 2
Particle - RMS Altitude estimation error = 625.5613
Altitude(ft)
2000
1000
0
0
20
40
60
80
100
120
140
Particle - RMS Altitude Rate estimation error = 7.762
Altitude Rate (ft/sec)
40
20
0
0
50
100
150

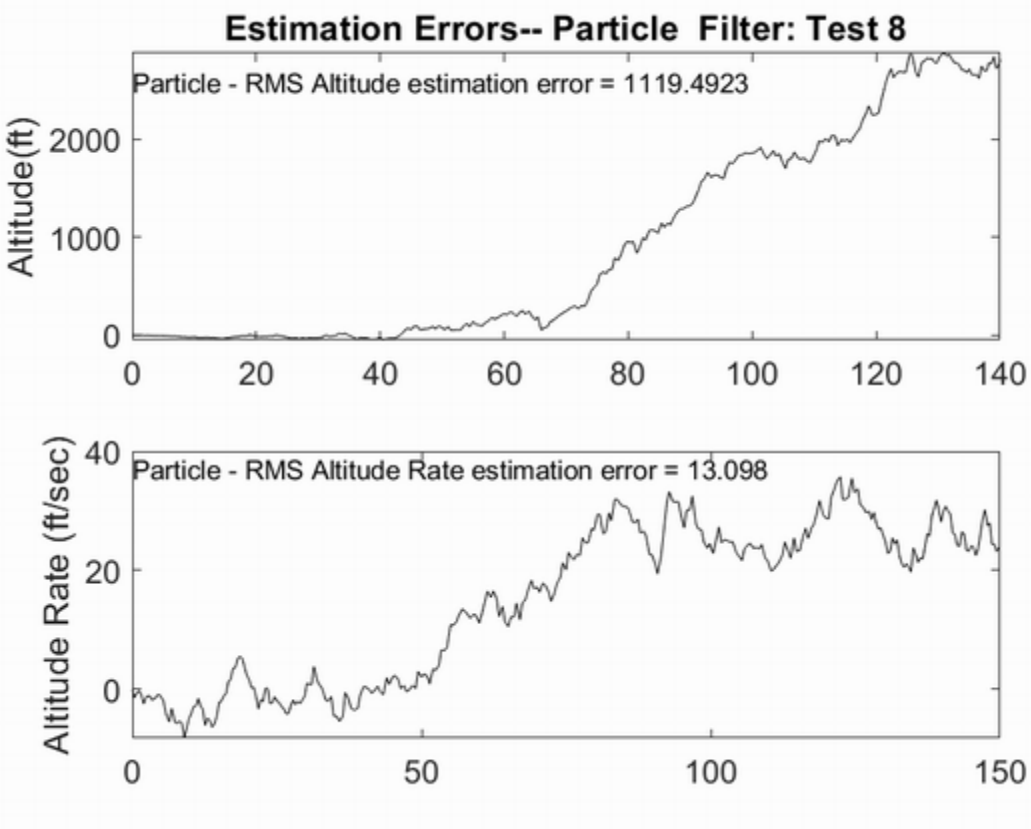

Estimation Errors-- Particle Filter: Test 3
Particle - RMS Altitude estimation error = 557.0452
Altitude(ft)
0
-1000
-2000
0
20
40
60
80
100
120
140
Particle - RMS Altitude Rate estimation error = 9.5521
Altitude Rate (ft/sec)
0
-20
-40
0
50
100
150

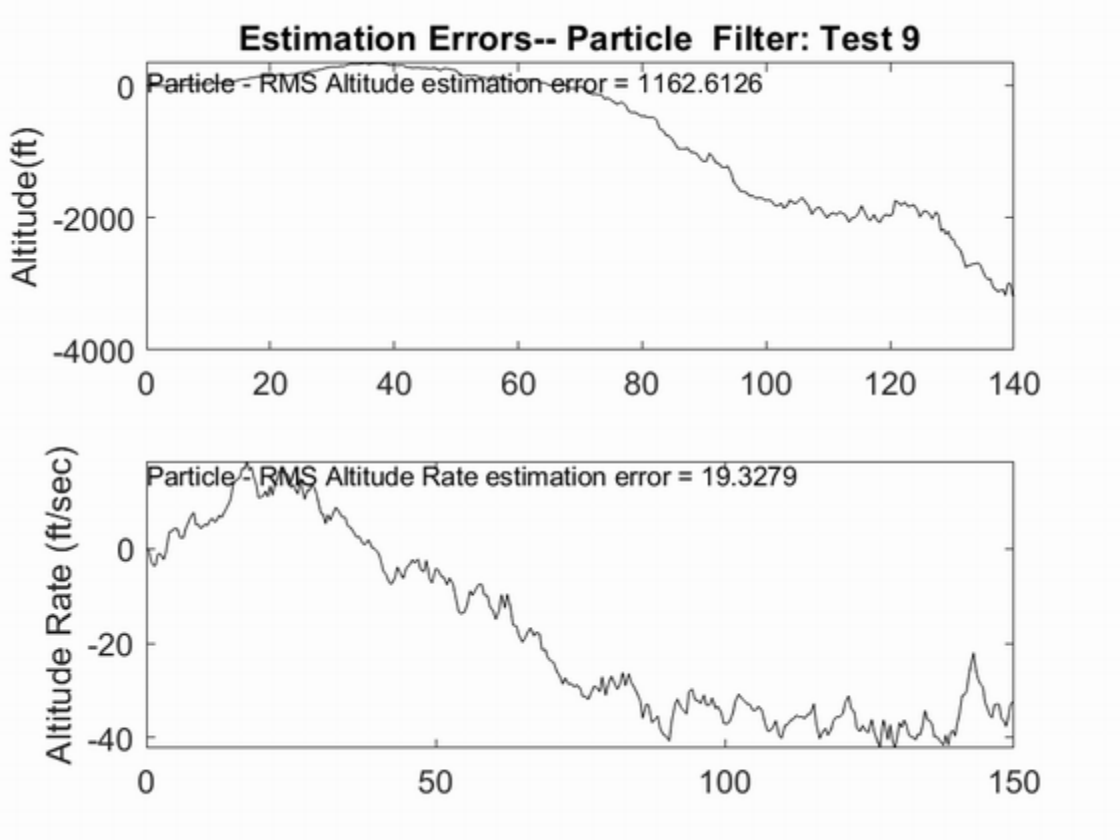

Estimation Errors-- Particle Filter: Test 4
Particle - RMS Altitude estimation error = 497.3692
Altitude(ft)
1000
500
0
0
20
40
60
80
100
120
140
Particle - RMS Altitude Rate estimation error = 12.8608
Altitude Rate (ft/sec)
40
20
0
-20
0
50
100
150

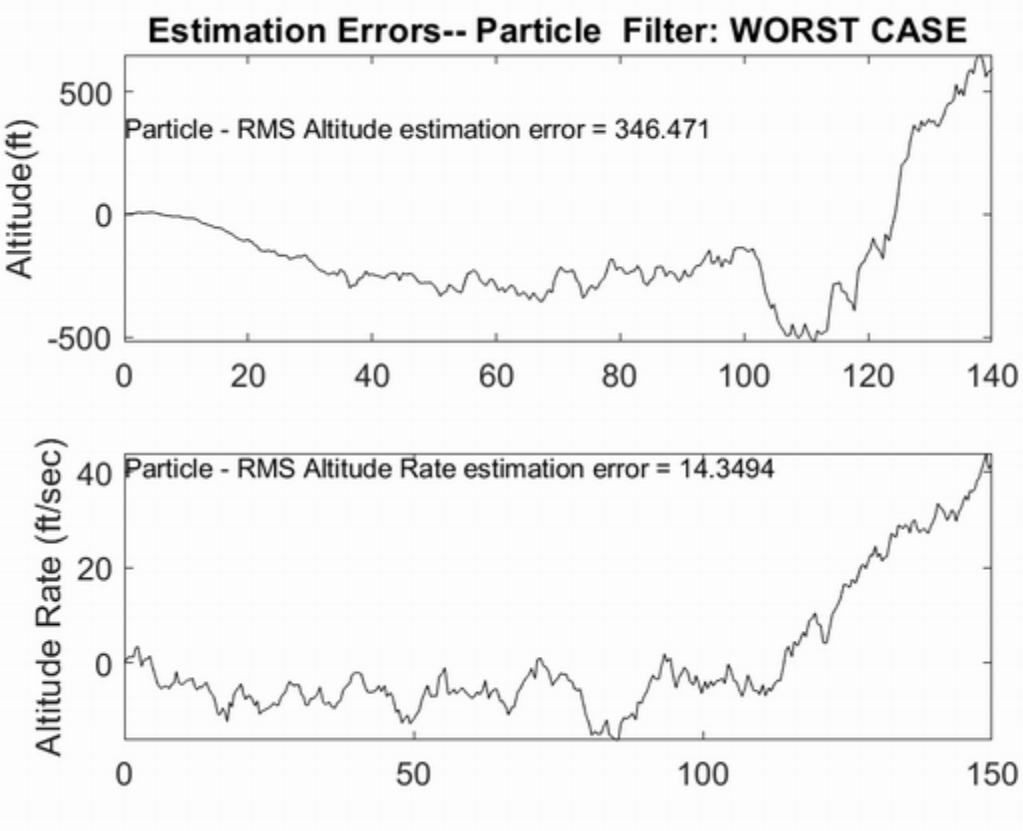

Estimation Errors-- Particle Filter: Test 5
Particle - RMS Altitude estimation error = 490.803
Altitude(ft)
1000
500
0
0
20
40
60
80
100
120
140
Particle - RMS Altitude Rate estimation error = 15.4204
Altitude Rate (ft/sec)
40
20
0
0
50
100
150

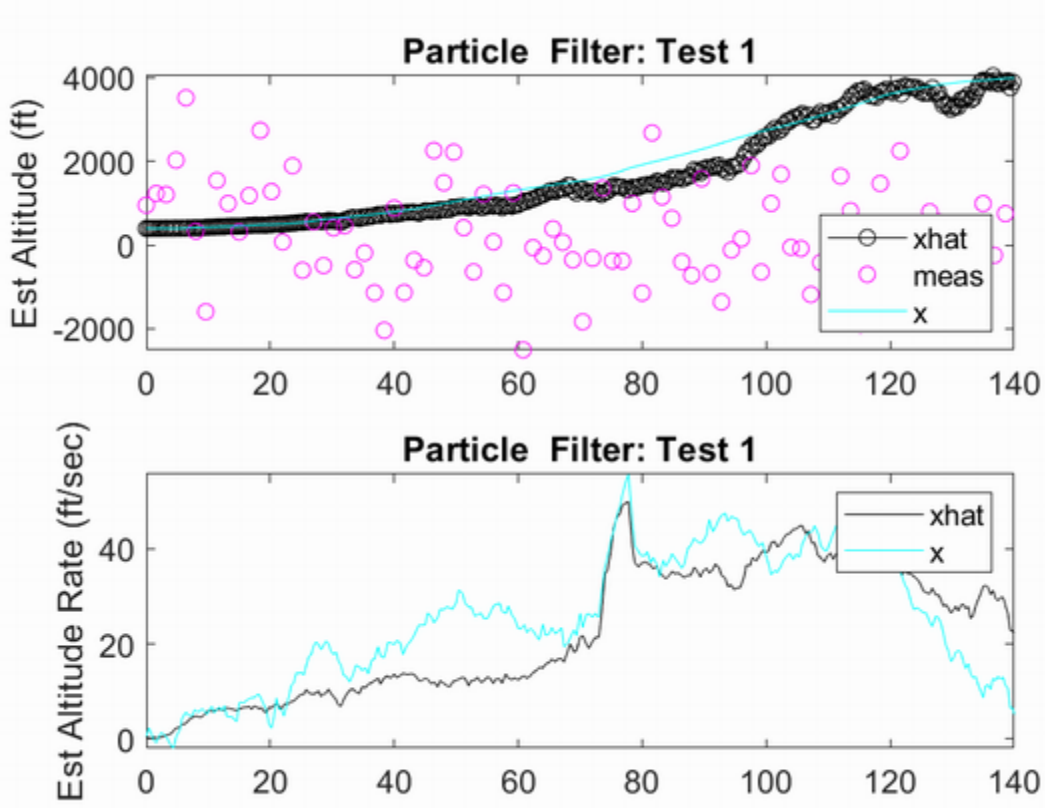

Estimation Errors-- Particle Filter: Test 6
Altitude(ft)
200
0
-200
-400
Particle - RMS Altitude estimation error = 214.3447
0
20
40
60
80
100
120
140
Altitude Rate (ft/sec)
20
0
-20
Particle - RMS Altitude Rate estimation error = 10.3958
0
50
100
150

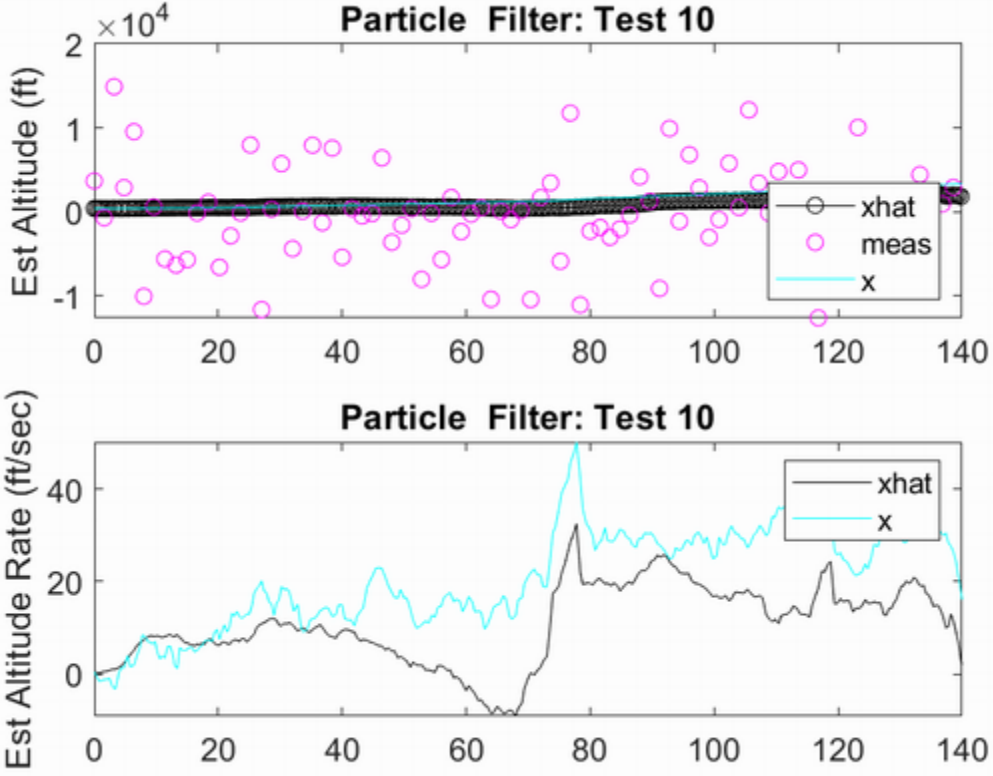

Estimation Errors-- Particle Filter: Test 7
Particle - RMS Altitude estimation error = 879.3347
Altitude(ft)
2000
1000
0
0
20
40
60
80
100
120
140
Particle - RMS Altitude Rate estimation error = 12.0458
Altitude Rate (ft/sec)
40
20
0
0
50
100
150

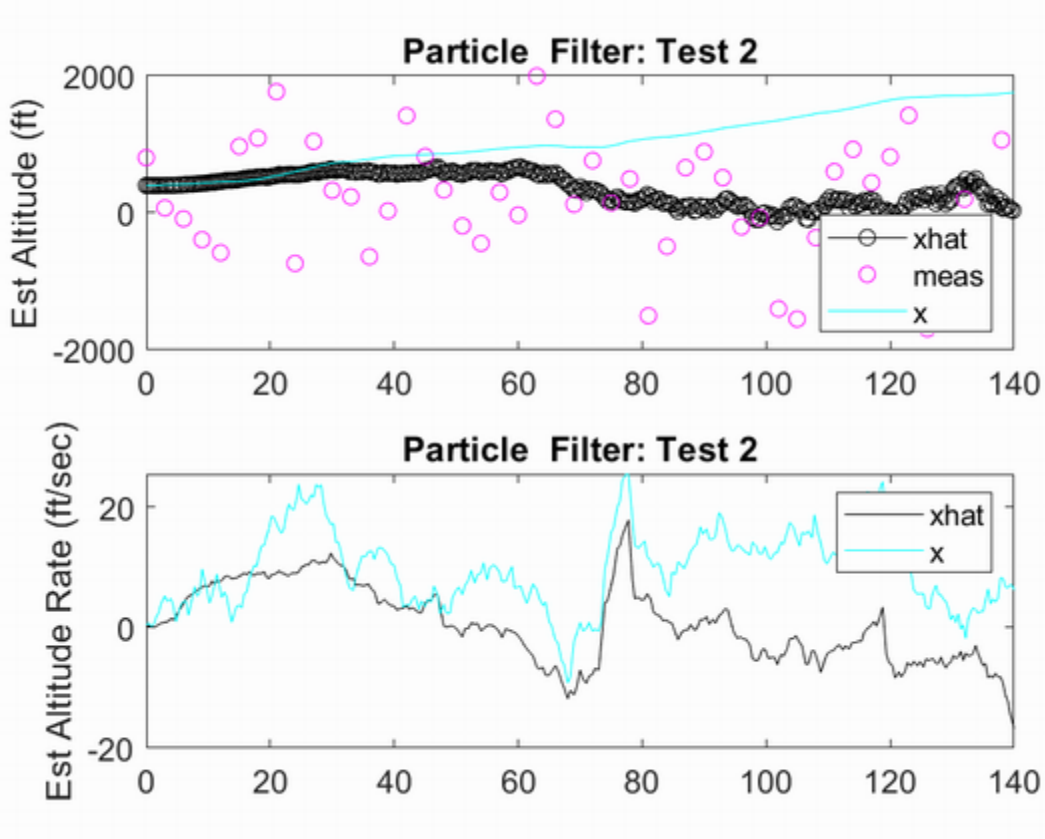

Estimation Errors-- Particle Filter: Test 8
Particle - RMS Altitude estimation error = 1119.4923
Altitude(ft)
2000
1000
0
0
20
40
60
80
100
120
140
Particle - RMS Altitude Rate estimation error = 13.098
Altitude Rate (ft/sec)
40
20
0
0
50
100
150

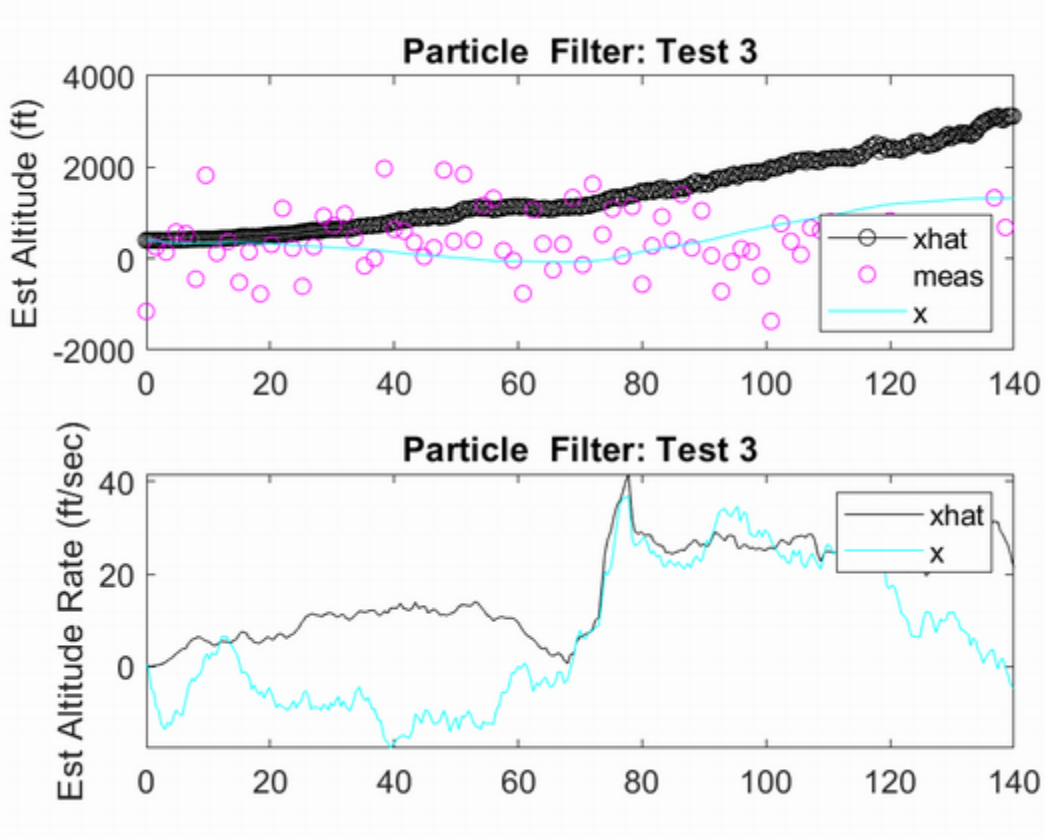

Estimation Errors-- Particle Filter: Test 9
Particle - RMS Altitude estimation error = 1162.6126
Altitude(ft)
0
-2000
-4000
0
20
40
60
80
100
120
140
Particle - RMS Altitude Rate estimation error = 19.3279
Altitude Rate (ft/sec)
0
-20
-40
0
50
100
150

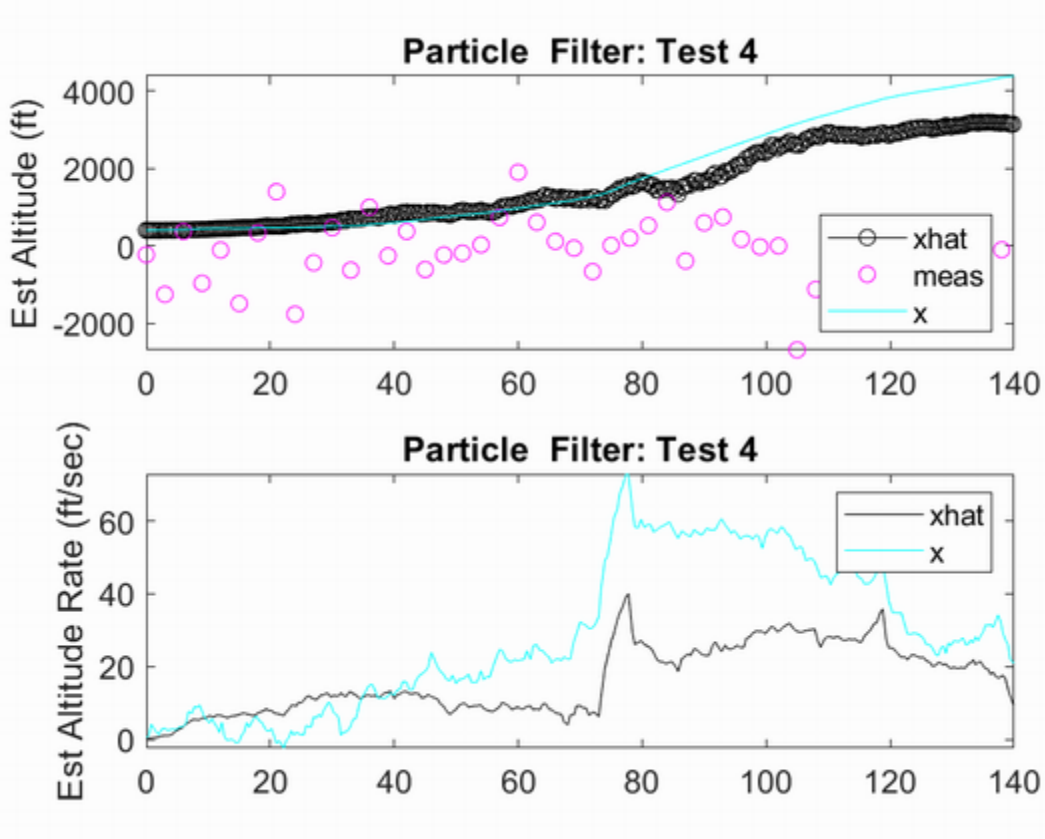

Estimation Errors-- Particle Filter: WORST CASE
Particle - RMS Altitude estimation error = 346.471
Altitude(ft)
500
0
-500
0
20
40
60
80
100
120
140
Particle - RMS Altitude Rate estimation error = 14.3494
Altitude Rate (ft/sec)
40
20
0
0
50
100
150

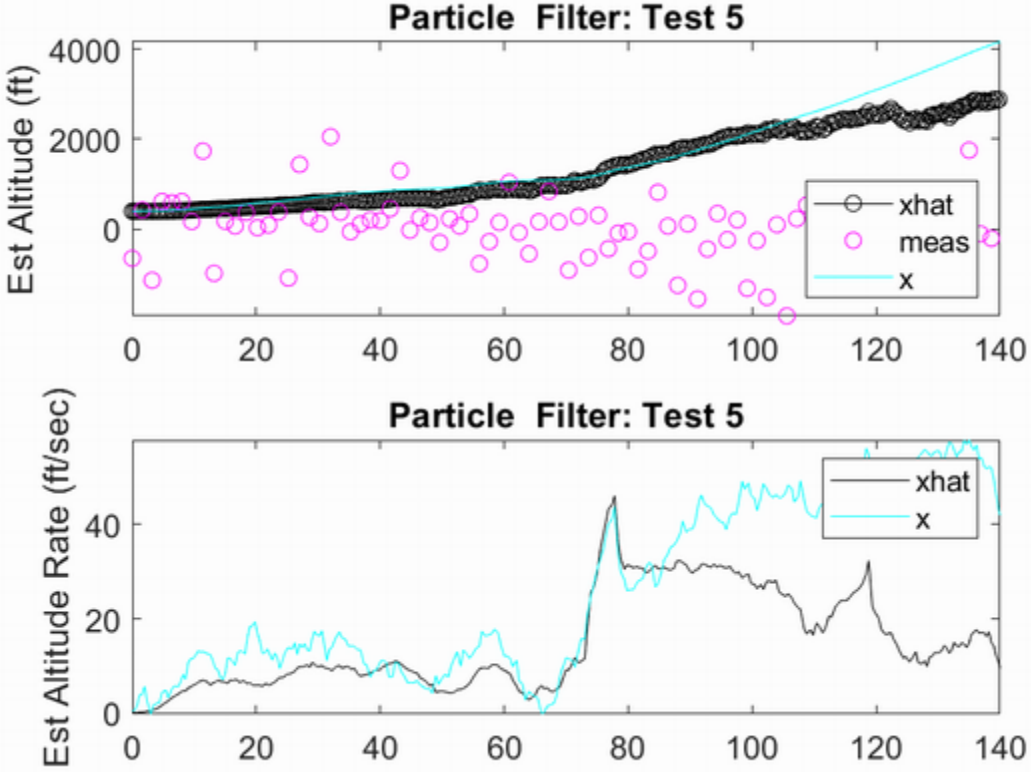

Particle Filter: Test 1
Est Altitude (ft)
4000
2000
0
-2000
0
20
40
60
80
100
120
140
xhat
meas
x
Particle Filter: Test 1
Est Altitude Rate (ft/sec)
40
20
0
0
20
40
60
80
100
120
140
xhat
x

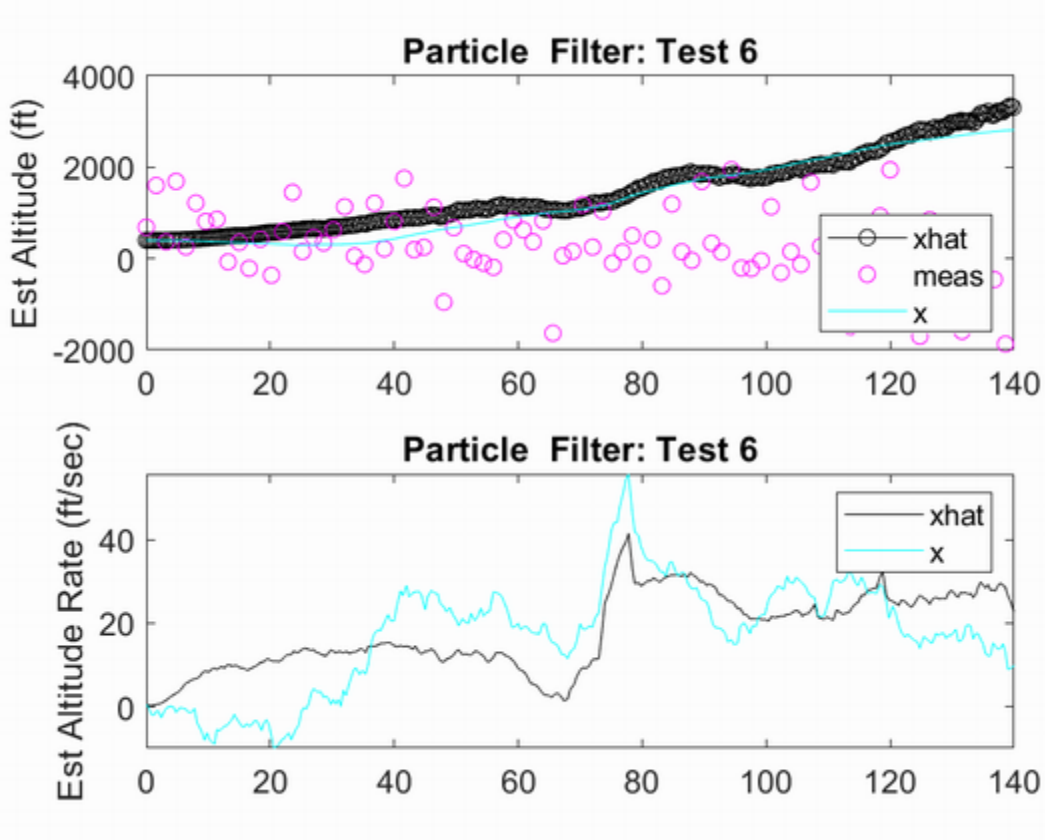

Particle Filter: Test 10
×10^4
Est Altitude (ft)
xhat
meas
x
Particle Filter: Test 10
Est Altitude Rate (ft/sec)
xhat
x

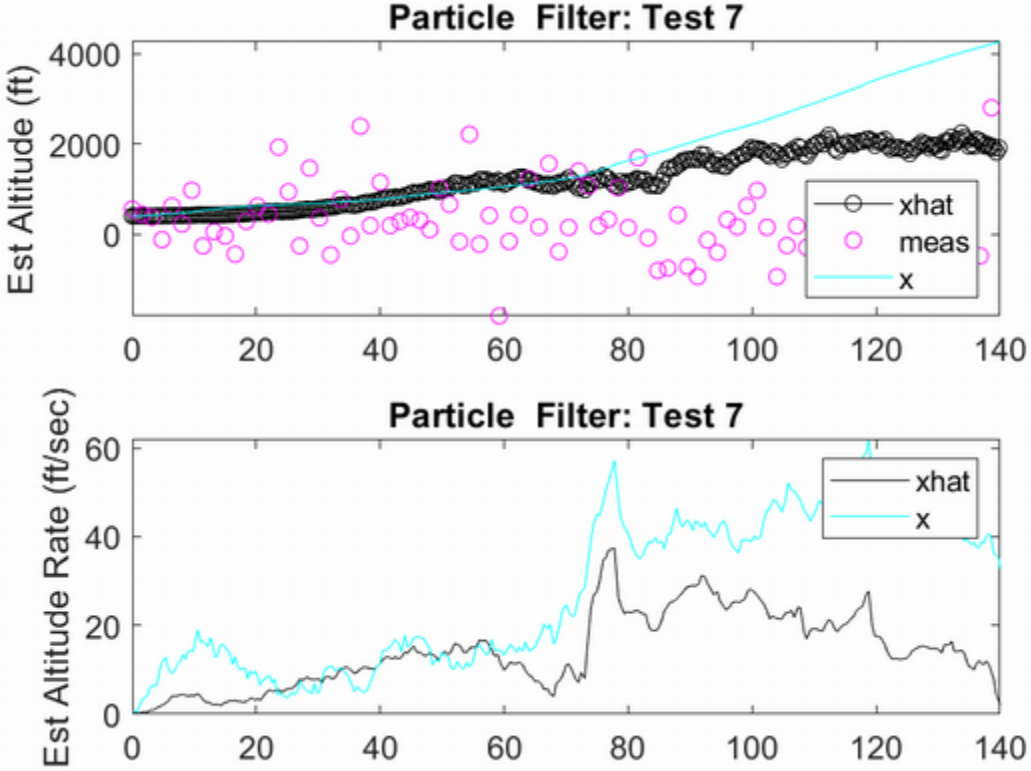

Particle Filter: Test 2
Est Altitude (ft)
2000
0
-2000
0
20
40
60
80
100
120
140
xhat
meas
x
Particle Filter: Test 2
Est Altitude Rate (ft/sec)
20
0
-20
0
20
40
60
80
100
120
140
xhat
x

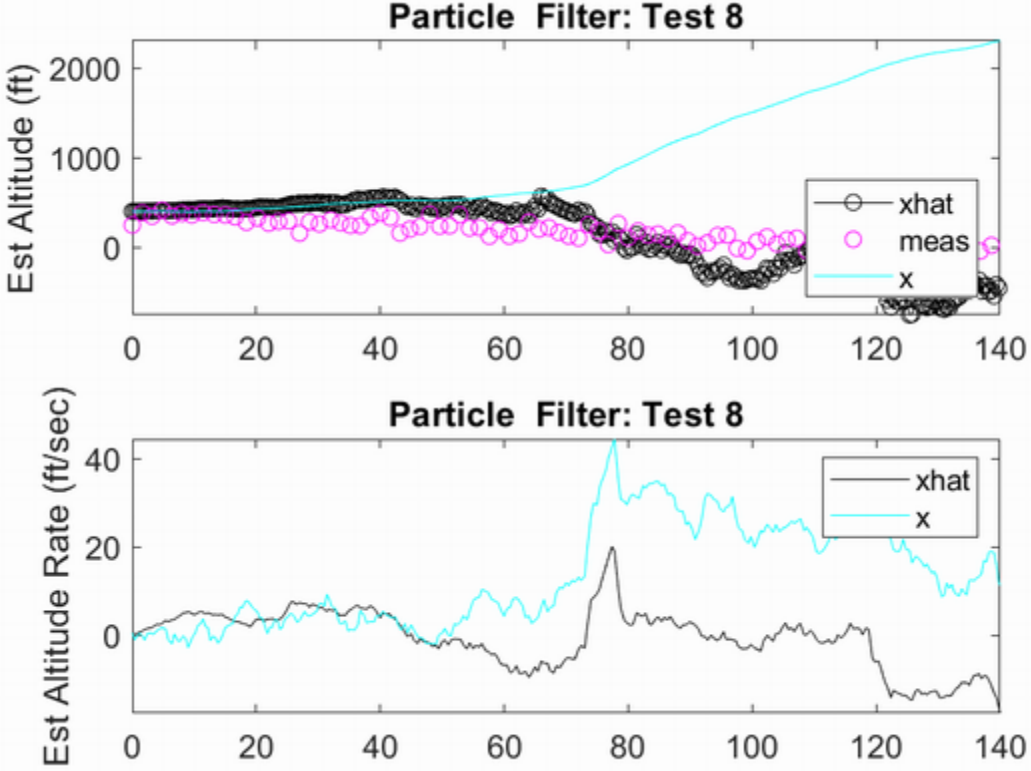

Particle Filter: Test 3
Est Altitude (ft)
4000
2000
0
-2000
0
20
40
60
80
100
120
140
xhat
meas
x
Particle Filter: Test 3
Est Altitude Rate (ft/sec)
40
20
0
0
20
40
60
80
100
120
140
xhat
x

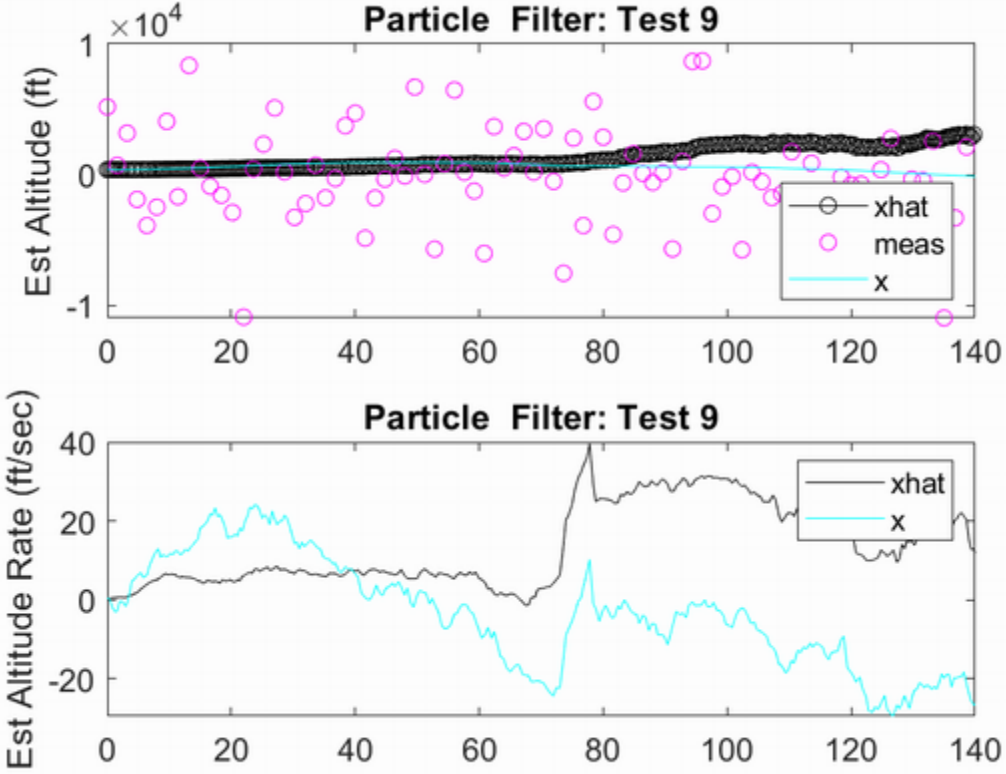

Particle Filter: Test 4
Est Altitude (ft)
4000
2000
0
-2000
0
20
40
60
80
100
120
140
xhat
meas
x
Particle Filter: Test 4
Est Altitude Rate (ft/sec)
60
40
20
0
0
20
40
60
80
100
120
140
xhat
x

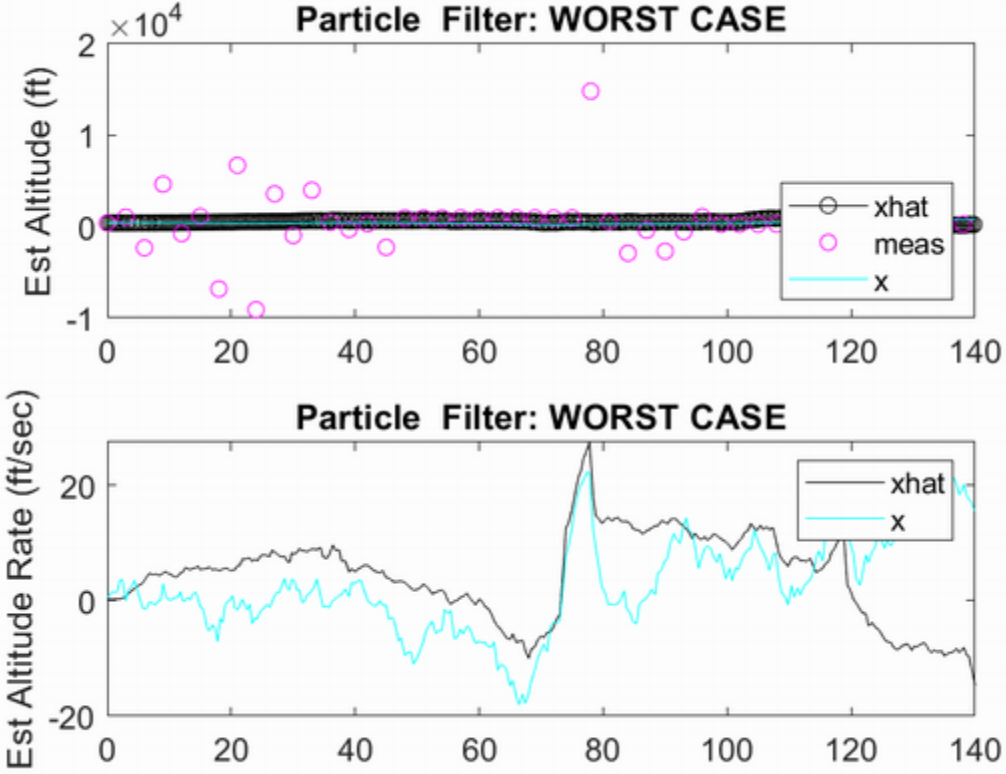

Particle Filter: Test 5
Est Altitude (ft)
4000
2000
0
0
20
40
60
80
100
120
140
xhat
meas
x
Particle Filter: Test 5
Est Altitude Rate (ft/sec)
40
20
0
0
20
40
60
80
100
120
140
xhat
x

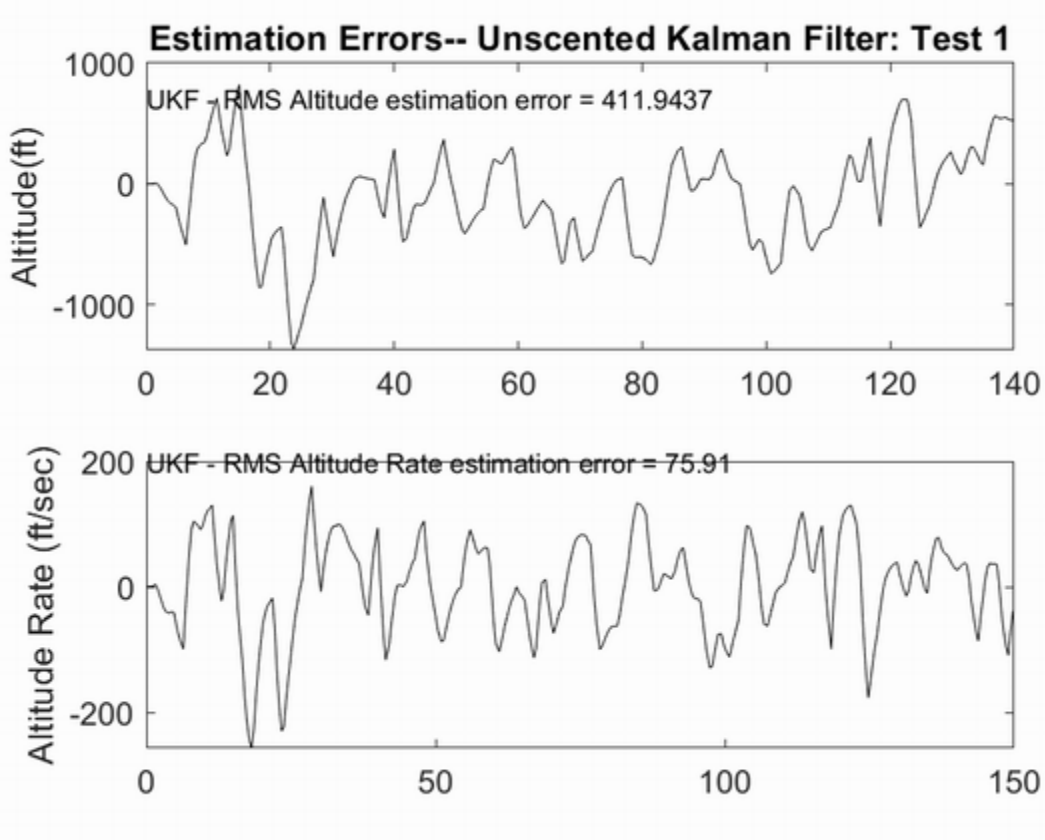

Particle Filter: Test 6
Est Altitude (ft)
4000
2000
0
-2000
0
20
40
60
80
100
120
140
xhat
meas
x
Particle Filter: Test 6
Est Altitude Rate (ft/sec)
40
20
0
0
20
40
60
80
100
120
140
xhat
x

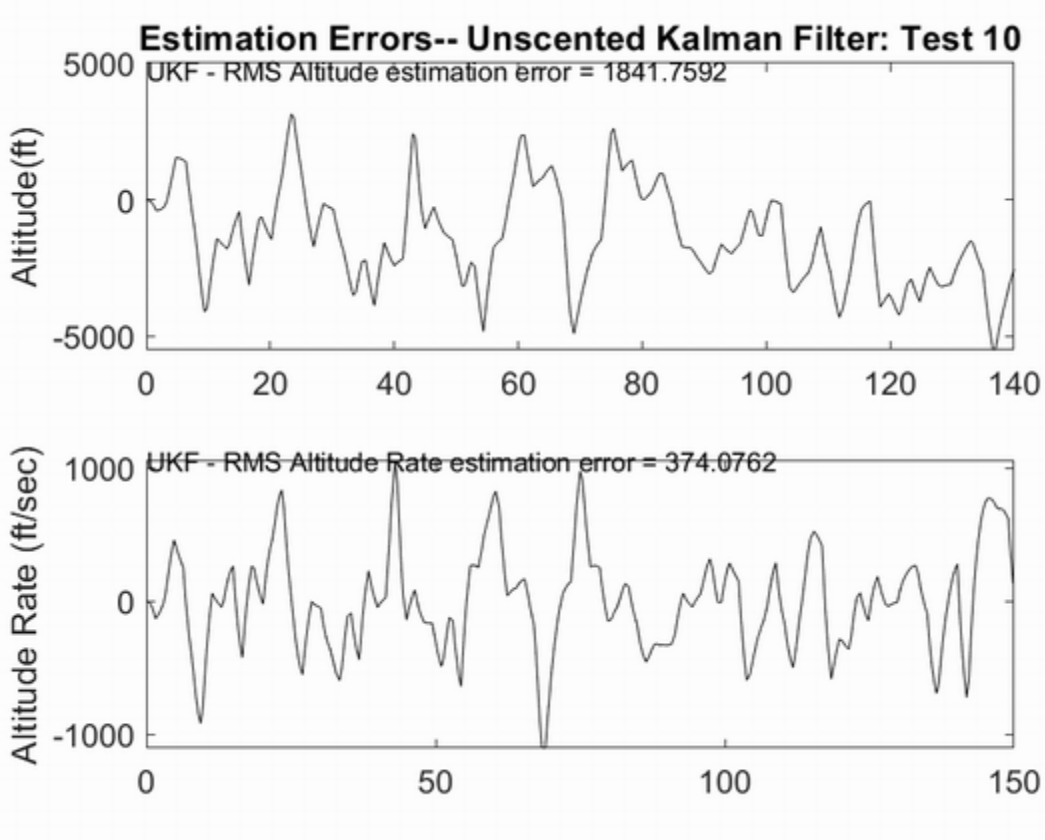

Particle Filter: Test 7
Est Altitude (ft)
4000
2000
0
0
20
40
60
80
100
120
140
xhat
meas
x
Particle Filter: Test 7
Est Altitude Rate (ft/sec)
60
40
20
0
0
20
40
60
80
100
120
140
xhat
x

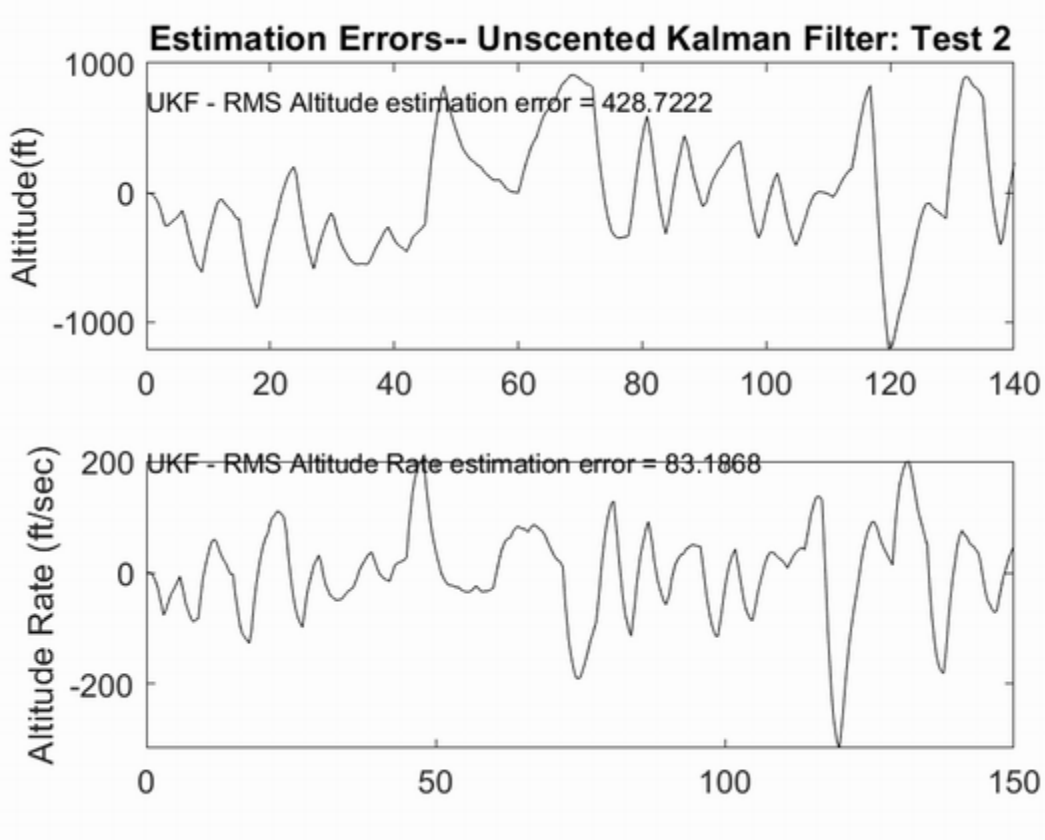

Particle Filter: Test 8
Est Altitude (ft)
2000
1000
0
xhat
meas
x
0
20
40
60
80
100
120
140
Particle Filter: Test 8
Est Altitude Rate (ft/sec)
40
20
0
xhat
x
0
20
40
60
80
100
120
140

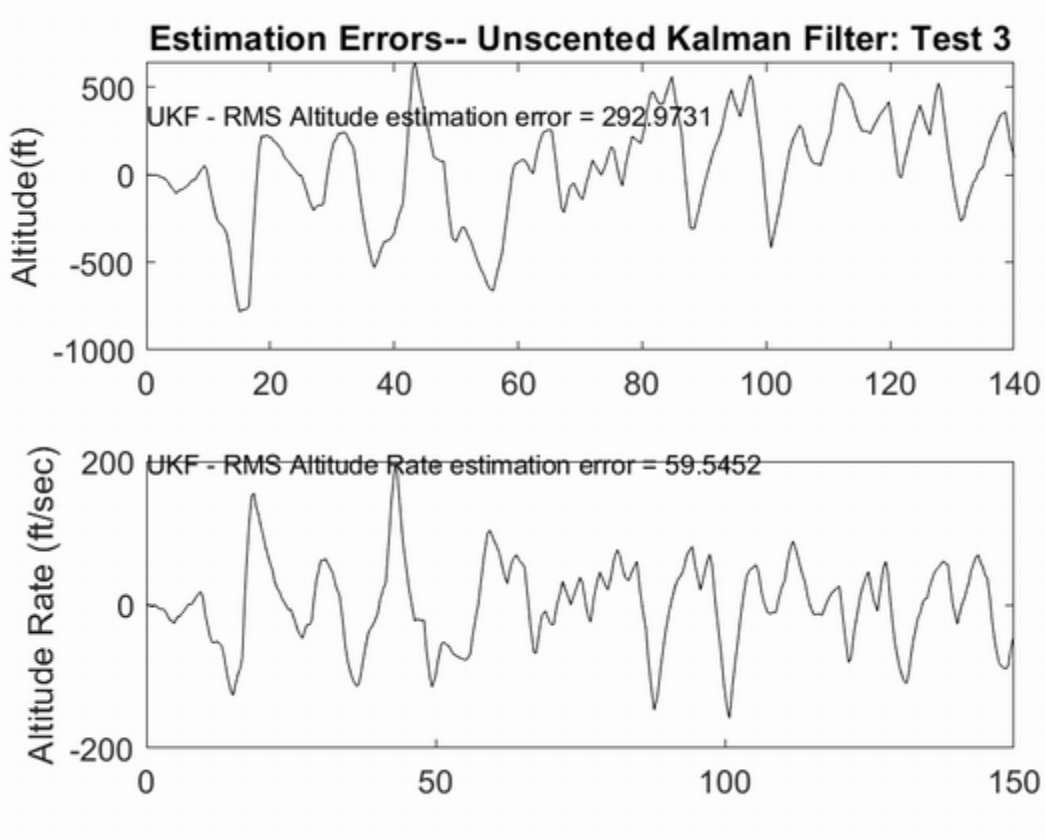

Particle Filter: Test 9
×10^4
Est Altitude (ft)
xhat
meas
x
Particle Filter: Test 9
Est Altitude Rate (ft/sec)
xhat
x

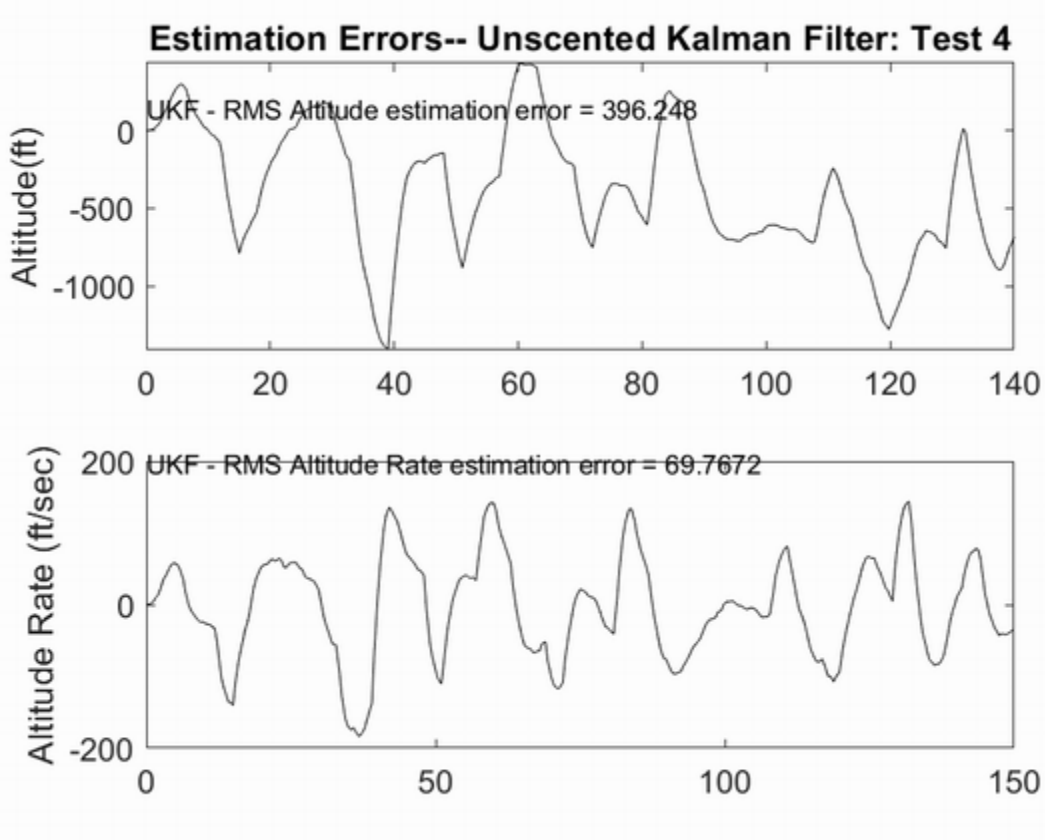

Particle Filter: WORST CASE
×10^4
Est Altitude (ft)
xhat
meas
x
Particle Filter: WORST CASE
Est Altitude Rate (ft/sec)
xhat
x

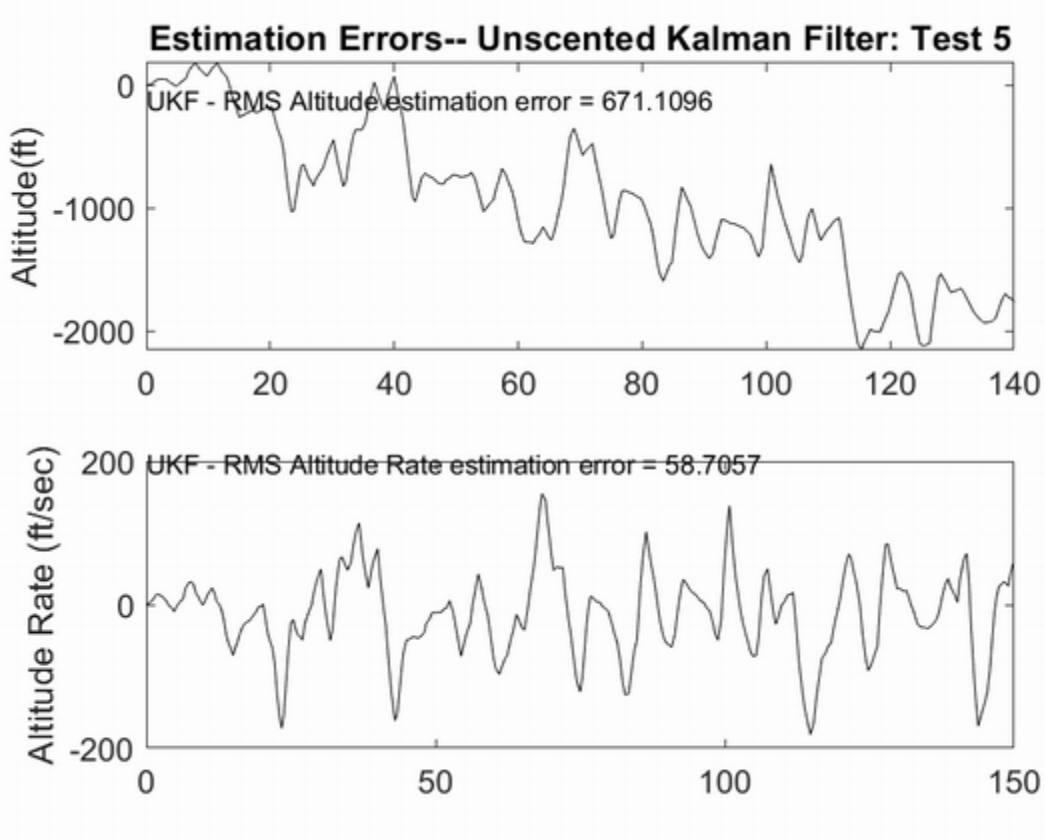

Estimation Errors-- Unscented Kalman Filter: Test 1
UKF - RMS Altitude estimation error = 411.9437
Altitude(ft)
1000
0
-1000
0
20
40
60
80
100
120
140
UKF - RMS Altitude Rate estimation error = 75.91
Altitude Rate (ft/sec)
200
0
-200
0
50
100
150

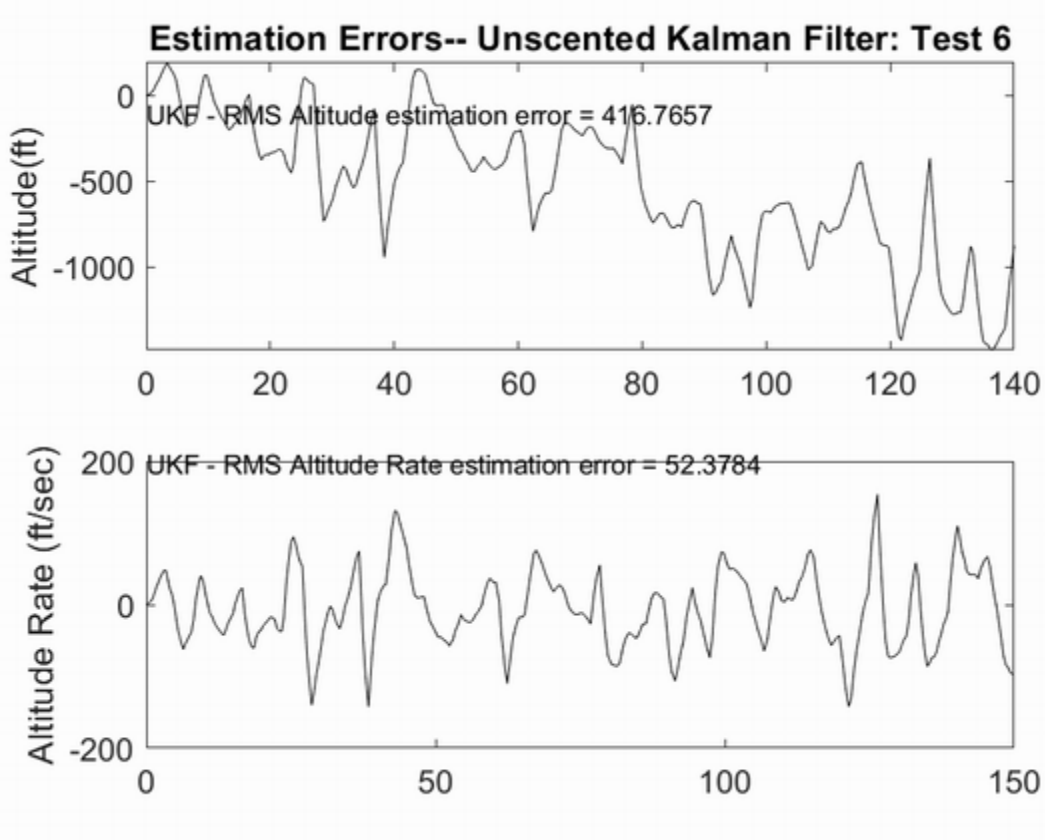

Estimation Errors-- Unscented Kalman Filter: Test 10
UKF - RMS Altitude estimation error = 1841.7592
Altitude(ft)
5000
0
-5000
0
20
40
60
80
100
120
140
UKF - RMS Altitude Rate estimation error = 374.0762
Altitude Rate (ft/sec)
1000
0
-1000
0
50
100
150

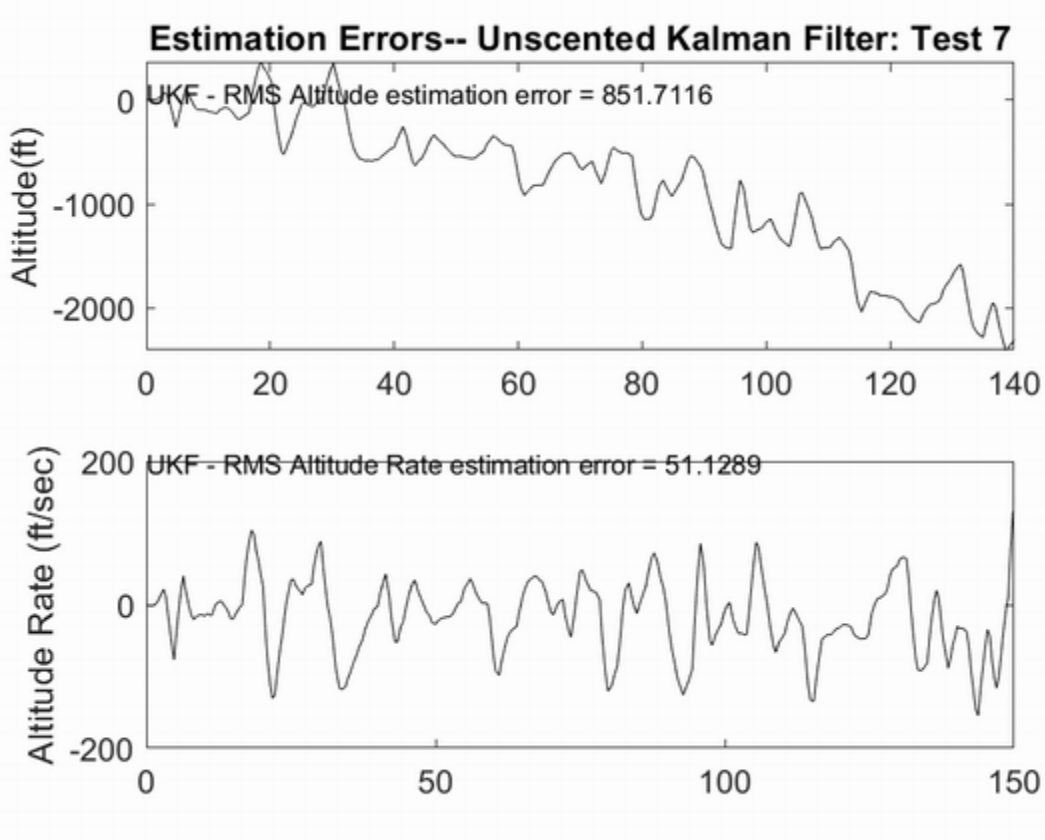

Estimation Errors-- Unscented Kalman Filter: Test 2
UKF - RMS Altitude estimation error = 428.7222
Altitude(ft)
1000
0
-1000
0
20
40
60
80
100
120
140
UKF - RMS Altitude Rate estimation error = 83.1868
Altitude Rate (ft/sec)
200
0
-200
0
50
100
150

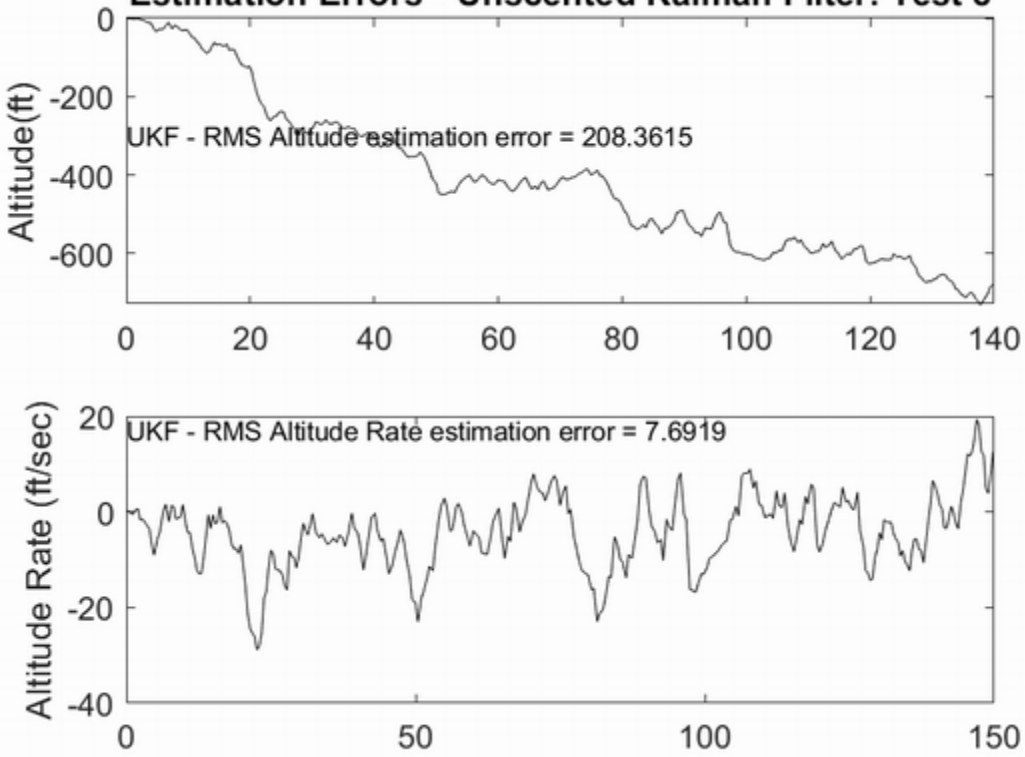

Estimation Errors-- Unscented Kalman Filter: Test 3
UKF - RMS Altitude estimation error = 292.9731
Altitude(ft)
500
0
-500
-1000
0
20
40
60
80
100
120
140
UKF - RMS Altitude Rate estimation error = 59.5452
Altitude Rate (ft/sec)
200
0
-200
0
50
100
150

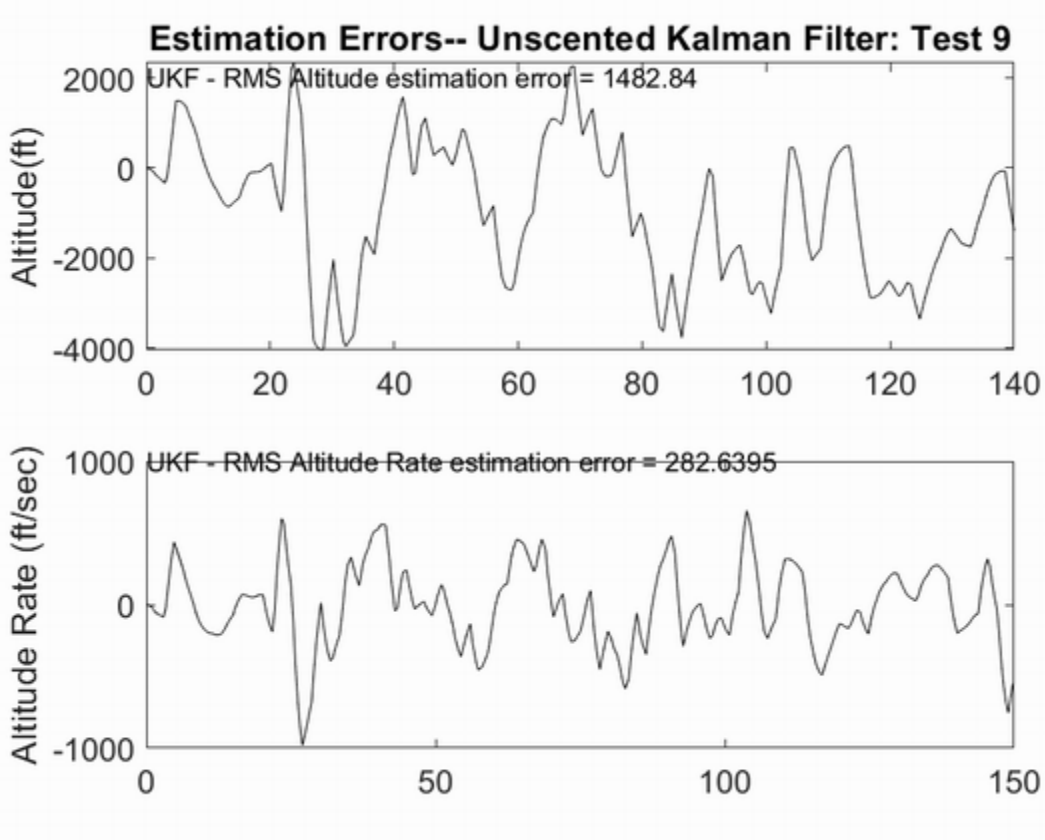

Estimation Errors-- Unscented Kalman Filter: Test 4
UKF - RMS Altitude estimation error = 396.248
Altitude(ft)
0
-500
-1000
0
20
40
60
80
100
120
140
UKF - RMS Altitude Rate estimation error = 69.7672
Altitude Rate (ft/sec)
200
0
-200
0
50
100
150

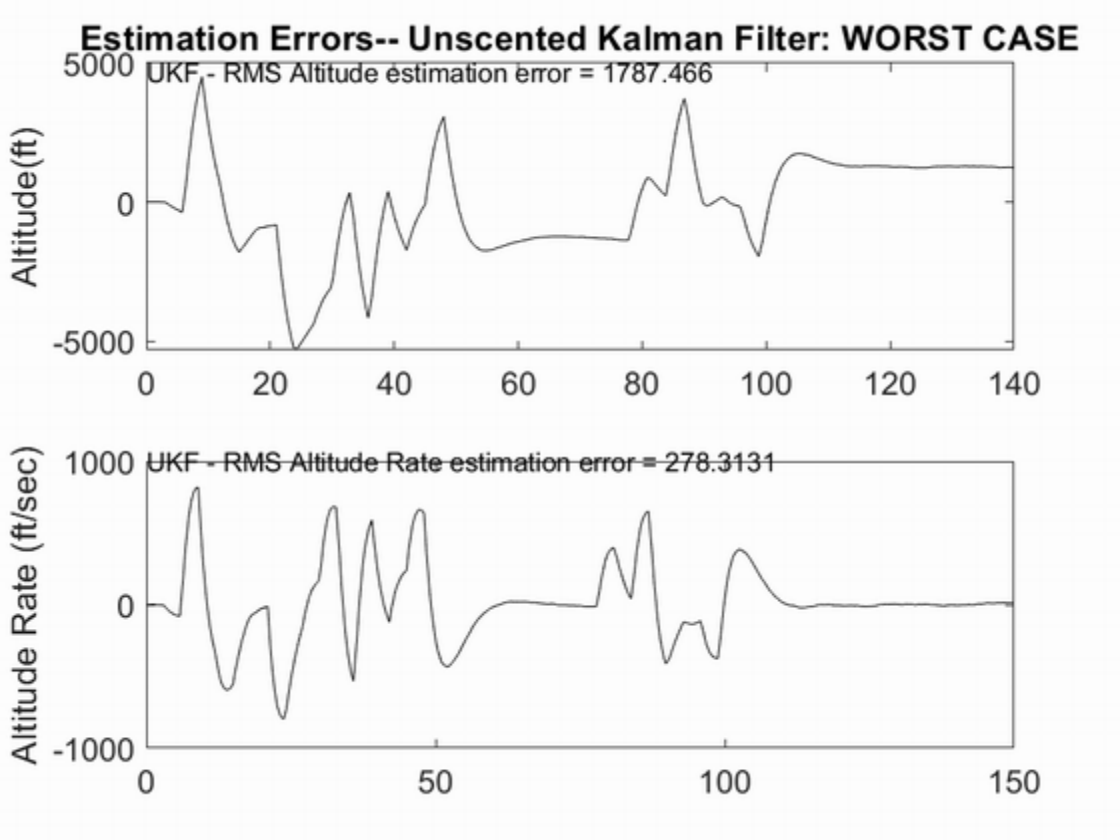

Estimation Errors-- Unscented Kalman Filter: Test 5
UKF - RMS Altitude estimation error = 671.1096
Altitude(ft)
0
-1000
-2000
0
20
40
60
80
100
120
140
UKF - RMS Altitude Rate estimation error = 58.7057
Altitude Rate (ft/sec)
200
0
-200
0
50
100
150

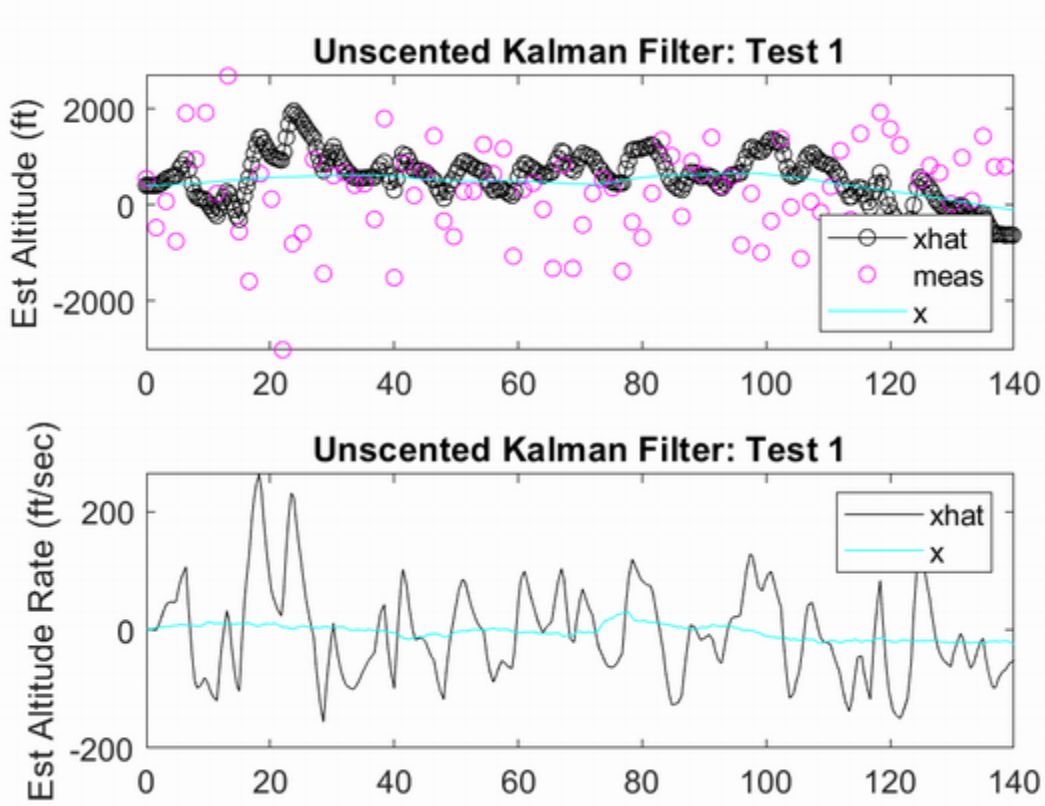

Estimation Errors-- Unscented Kalman Filter: Test 6
UKF - RMS Altitude estimation error = 416.7657
Altitude(ft)
0
-500
-1000
0
20
40
60
80
100
120
140
UKF - RMS Altitude Rate estimation error = 52.3784
Altitude Rate (ft/sec)
200
0
-200
0
50
100
150

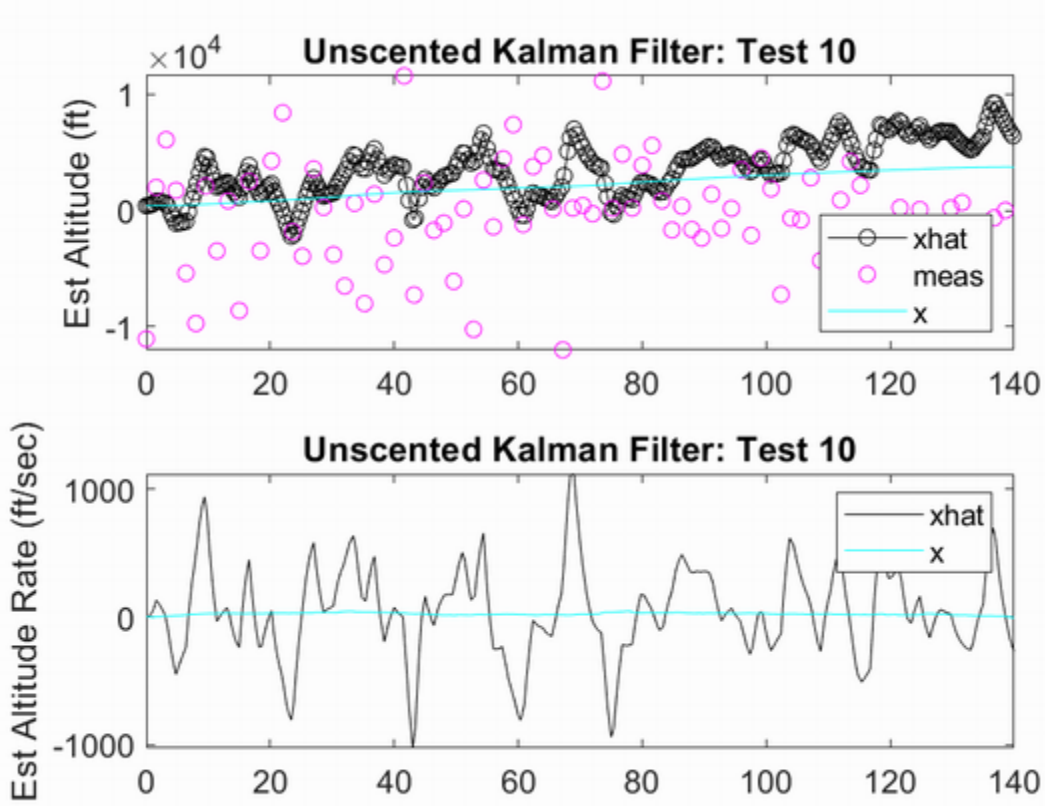

Estimation Errors-- Unscented Kalman Filter: Test 7
UKF - RMS Altitude estimation error = 851.7116
Altitude(ft)
0
-1000
-2000
0
20
40
60
80
100
120
140
UKF - RMS Altitude Rate estimation error = 51.1289
Altitude Rate (ft/sec)
200
0
-200
0
50
100
150

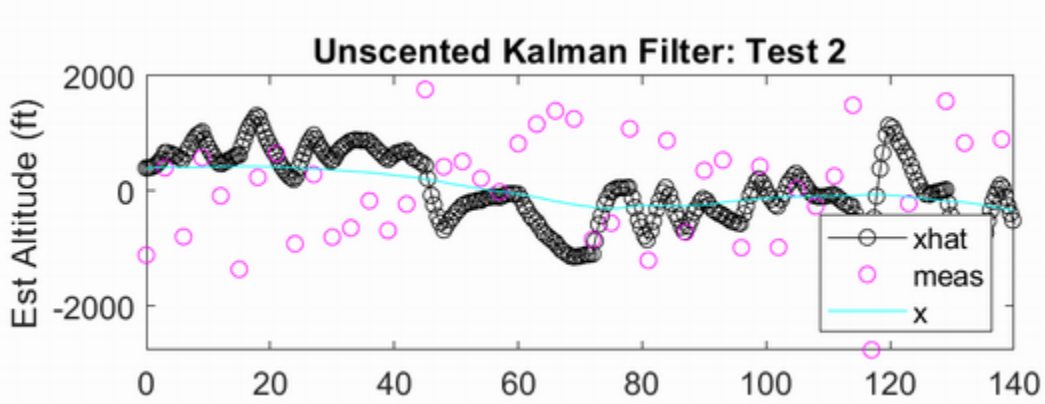

Estimation Errors-- Unscented Kalman Filter: Test 8
Altitude(ft)
0
-200
-400
-600
UKF - RMS Altitude estimation error = 208.3615
0
20
40
60
80
100
120
140
Altitude Rate (ft/sec)
20
0
-20
-40
UKF - RMS Altitude Rate estimation error = 7.6919
0
50
100
150

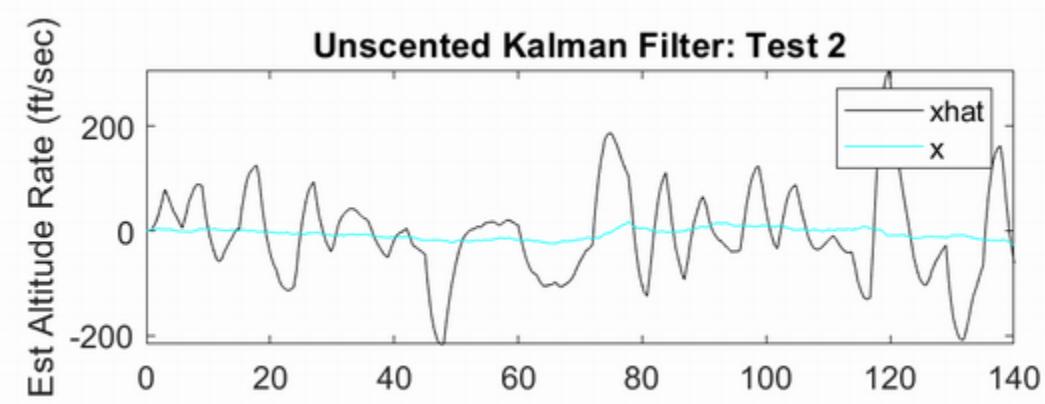

Estimation Errors-- Unscented Kalman Filter: Test 9
UKF - RMS Altitude estimation error = 1482.84
Altitude(ft)
2000
0
-2000
-4000
0
20
40
60
80
100
120
140
UKF - RMS Altitude Rate estimation error = 282.6395
Altitude Rate (ft/sec)
1000
0
-1000
0
50
100
150

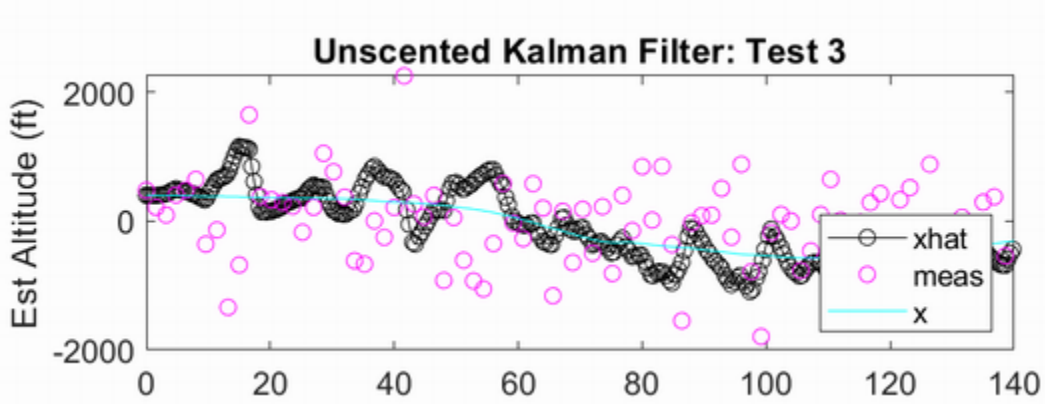

Estimation Errors-- Unscented Kalman Filter: WORST CASE
UKF - RMS Altitude estimation error = 1787.466
Altitude(ft)
5000
0
-5000
0
20
40
60
80
100
120
140
UKF - RMS Altitude Rate estimation error = 278.3131
Altitude Rate (ft/sec)
1000
0
-1000
0
50
100
150

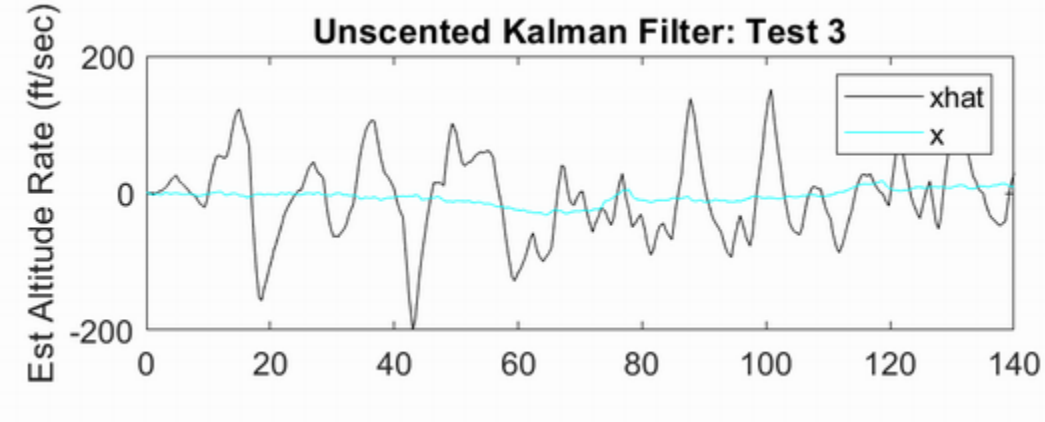

Unscented Kalman Filter: Test 1
Est Altitude (ft)
2000
0
-2000
0
20
40
60
80
100
120
140
xhat
meas
x
Unscented Kalman Filter: Test 1
Est Altitude Rate (ft/sec)
200
0
-200
0
20
40
60
80
100
120
140
xhat
x

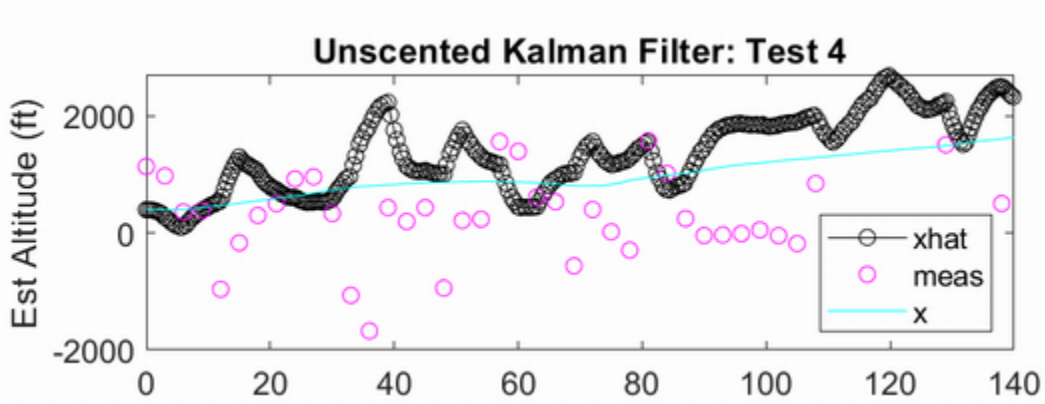

Unscented Kalman Filter: Test 10
×10^4
Est Altitude (ft)
1
0
-1
0
20
40
60
80
100
120
140
xhat
meas
x
Unscented Kalman Filter: Test 10
Est Altitude Rate (ft/sec)
1000
0
-1000
0
20
40
60
80
100
120
140
xhat
x

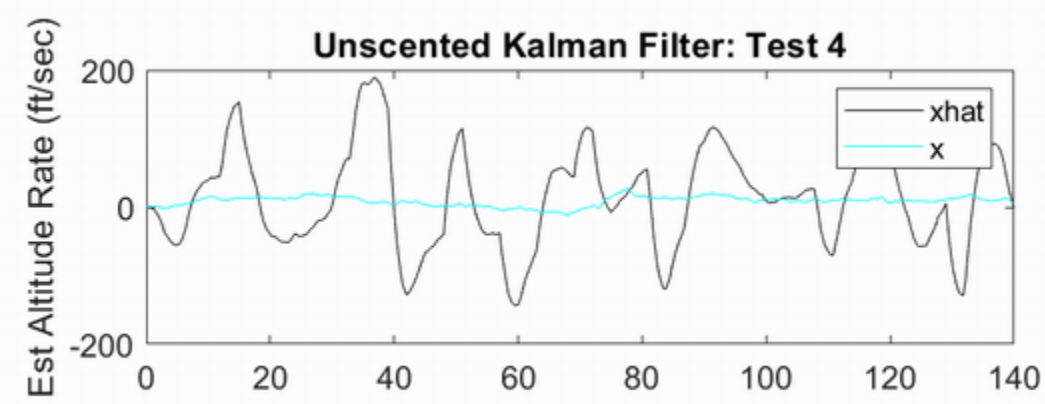

Unscented Kalman Filter: Test 2
Est Altitude (ft)
2000
0
-2000
0
20
40
60
80
100
120
140
xhat
meas
x

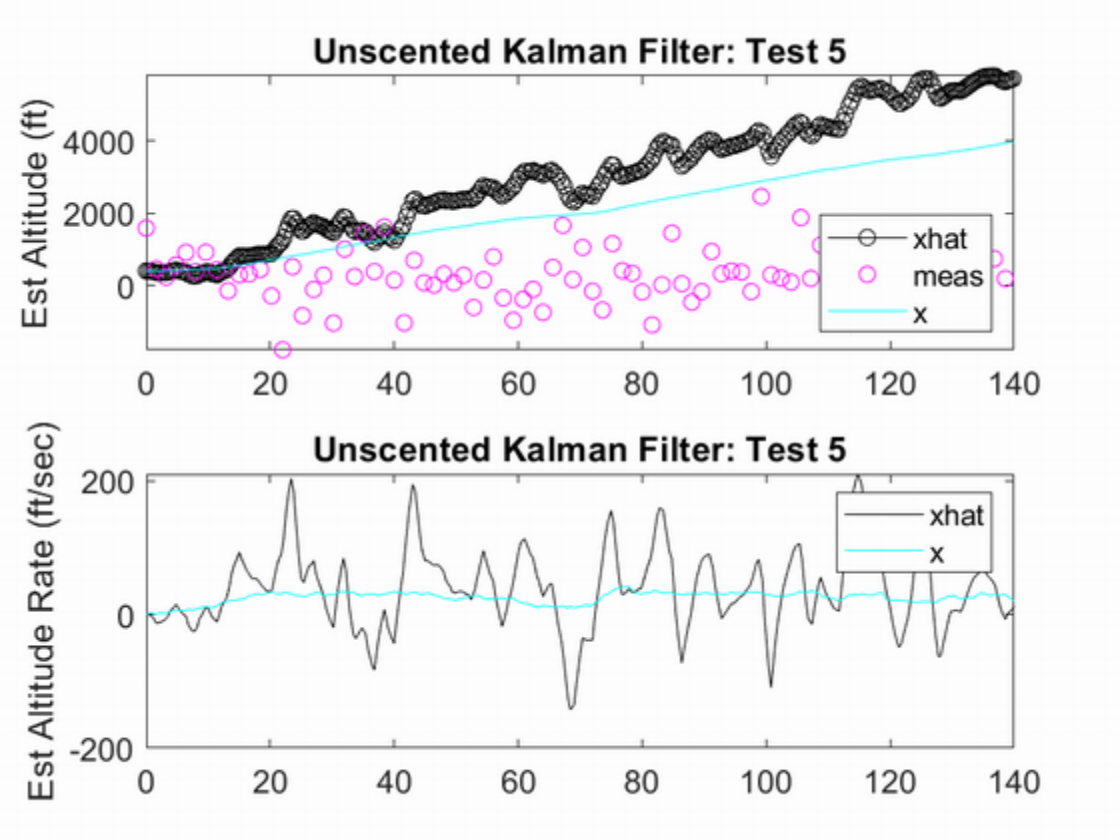

Unscented Kalman Filter: Test 2
Est Altitude Rate (ft/sec)
200
0
-200
0
20
40
60
80
100
120
140
xhat
x

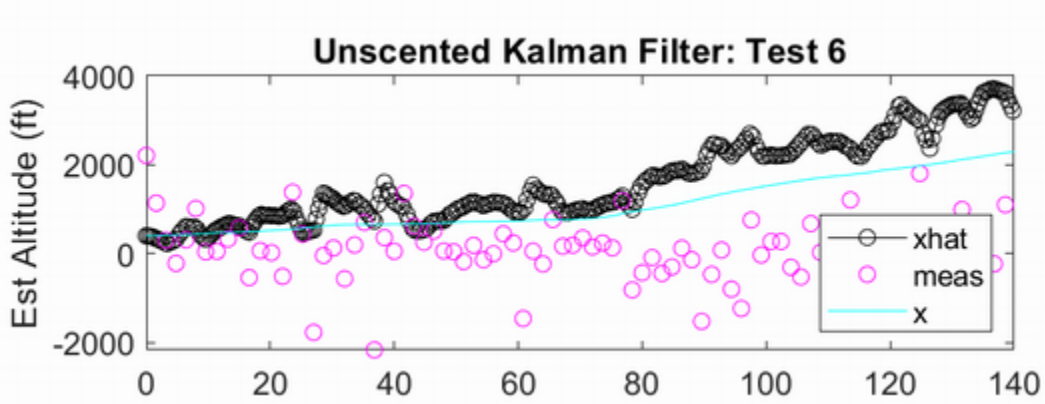

Unscented Kalman Filter: Test 3
Est Altitude (ft)
2000
0
-2000
0
20
40
60
80
100
120
140
xhat
meas
x

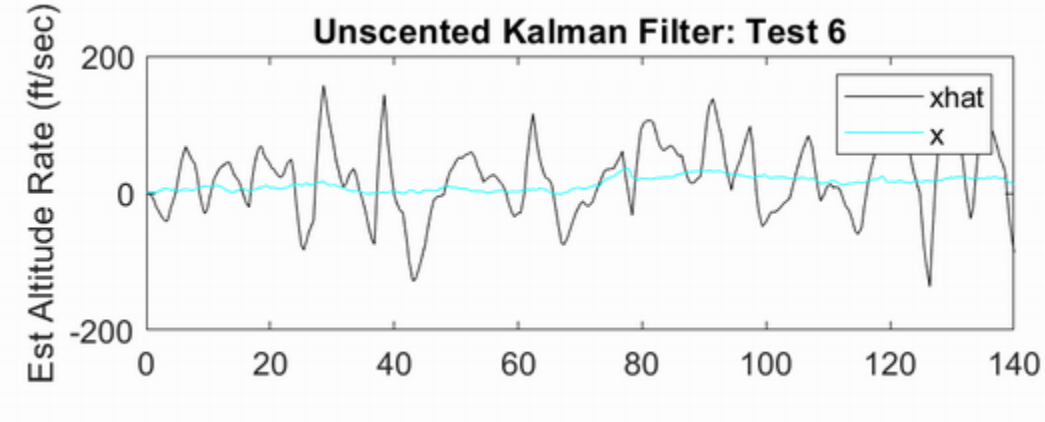

Unscented Kalman Filter: Test 3
Est Altitude Rate (ft/sec)
200
0
-200
0
20
40
60
80
100
120
140
xhat
x

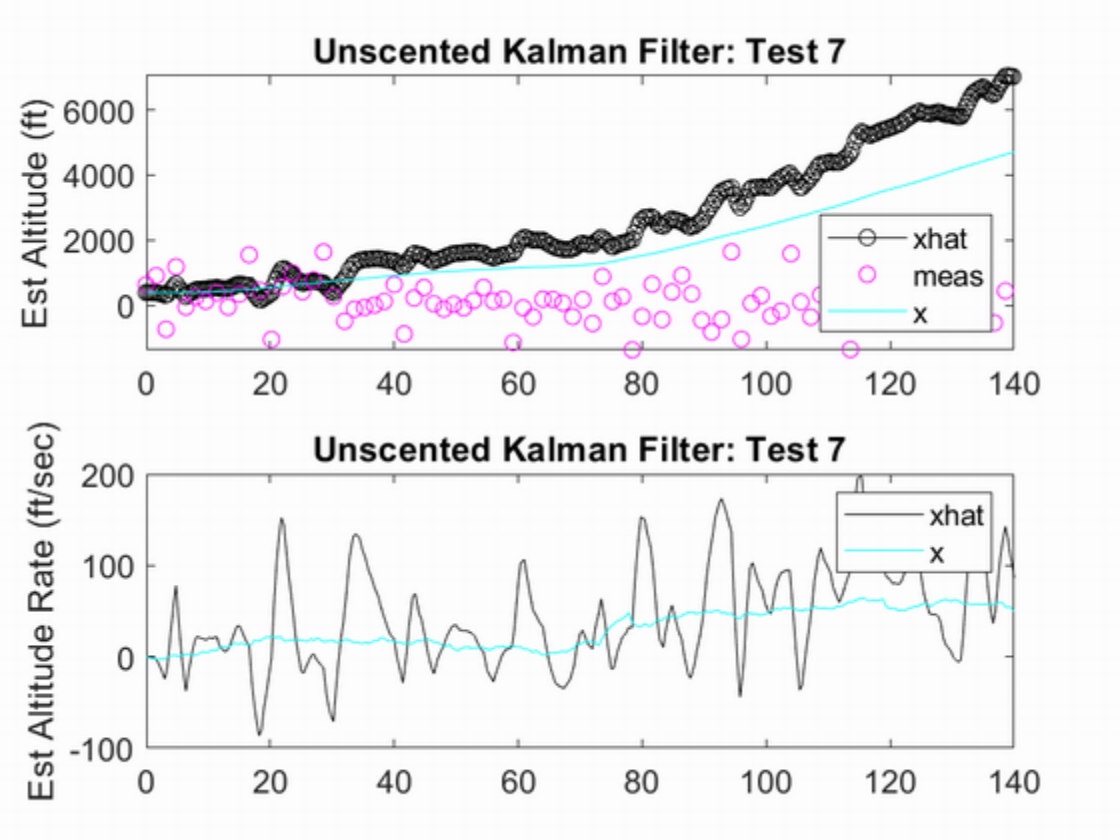

Unscented Kalman Filter: Test 4
Est Altitude (ft)
2000
0
-2000
0
20
40
60
80
100
120
140
xhat
meas
x

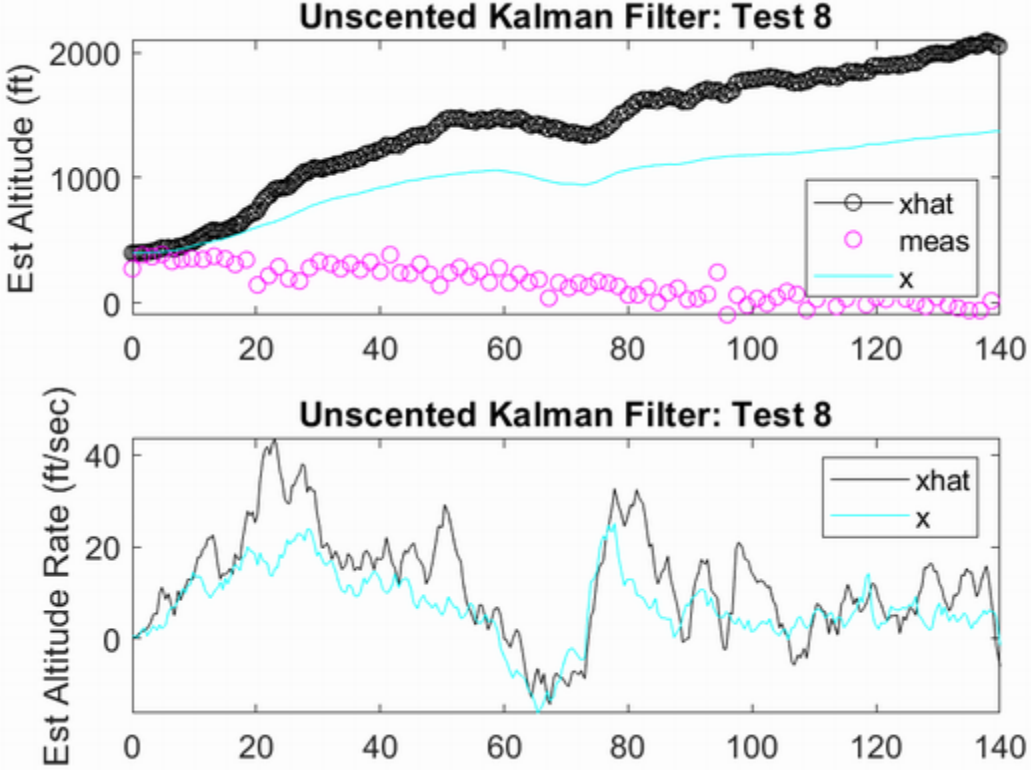

Unscented Kalman Filter: Test 4
Est Altitude Rate (ft/sec)
200
0
-200
0
20
40
60
80
100
120
140
xhat
x

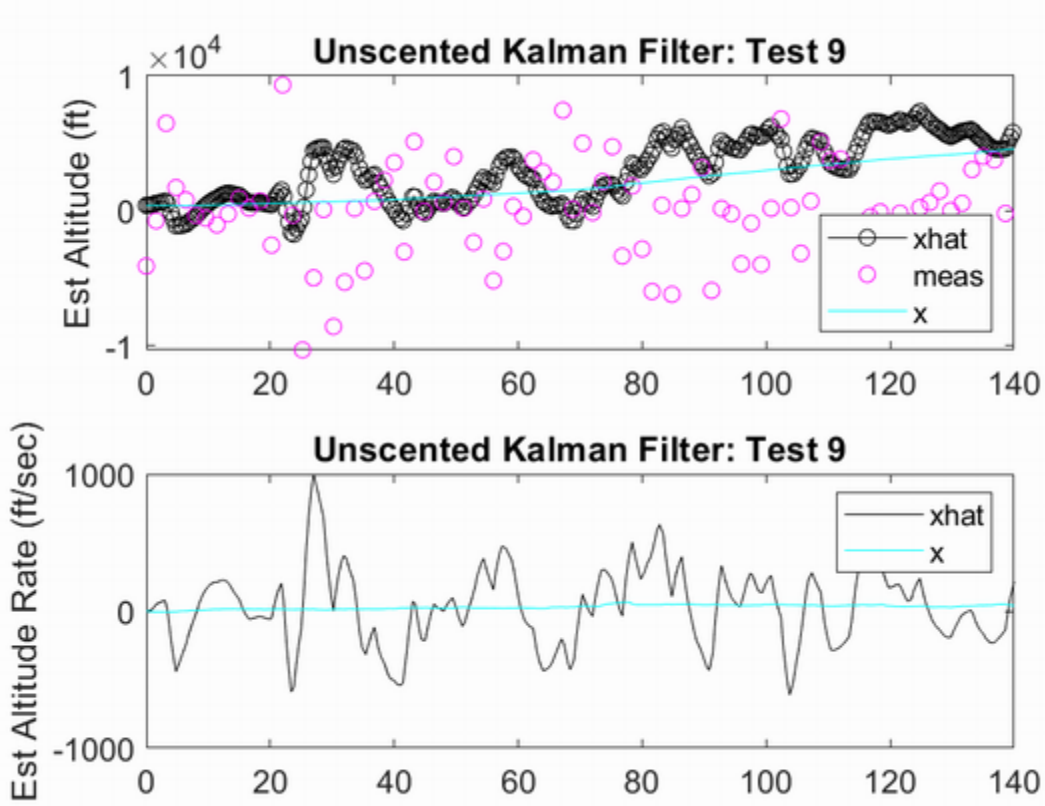

Unscented Kalman Filter: Test 5
Est Altitude (ft)
4000
2000
0
xhat
meas
x
0
20
40
60
80
100
120
140
Unscented Kalman Filter: Test 5
Est Altitude Rate (ft/sec)
200
0
-200
xhat
x
0
20
40
60
80
100
120
140

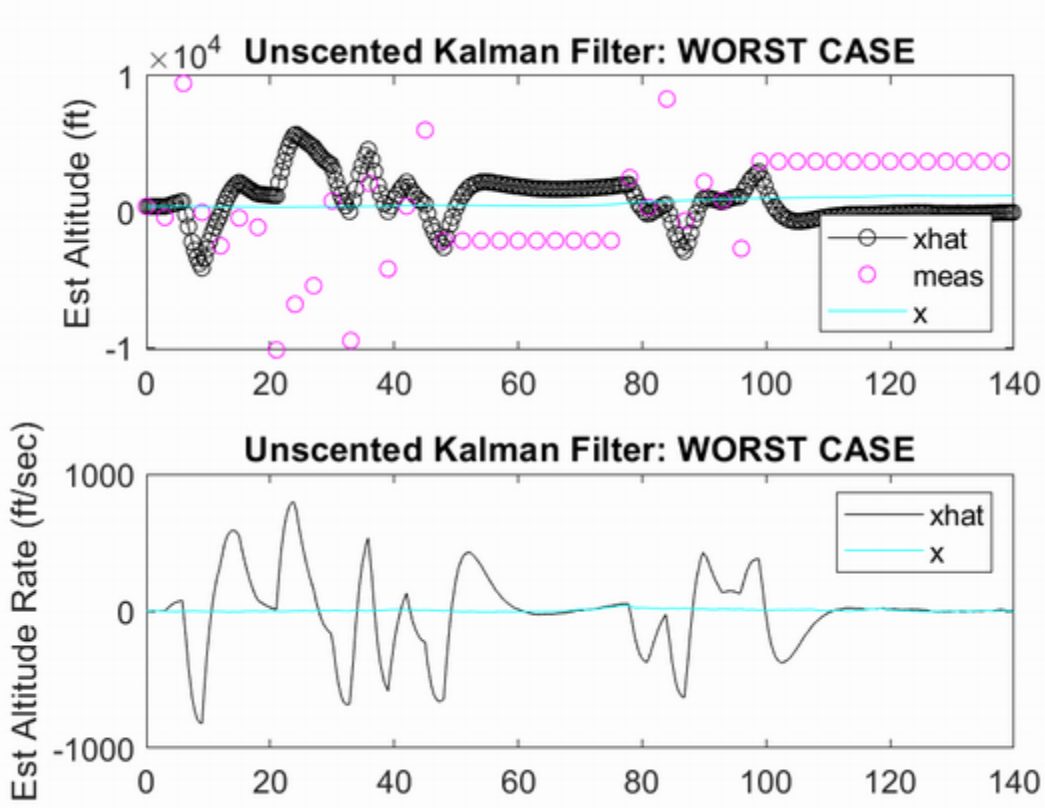

Unscented Kalman Filter: Test 6
Est Altitude (ft)
4000
2000
0
-2000
0
20
40
60
80
100
120
140
xhat
meas
x

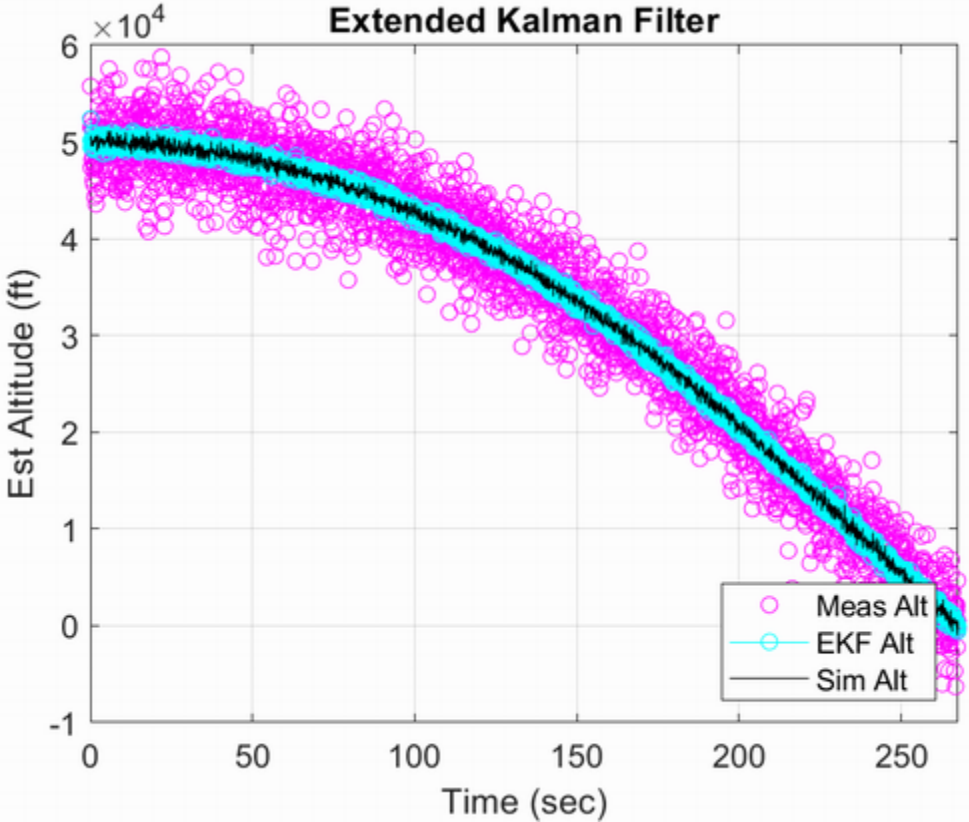

Unscented Kalman Filter: Test 6
Est Altitude Rate (ft/sec)
200
0
-200
0
20
40
60
80
100
120
140
xhat
x

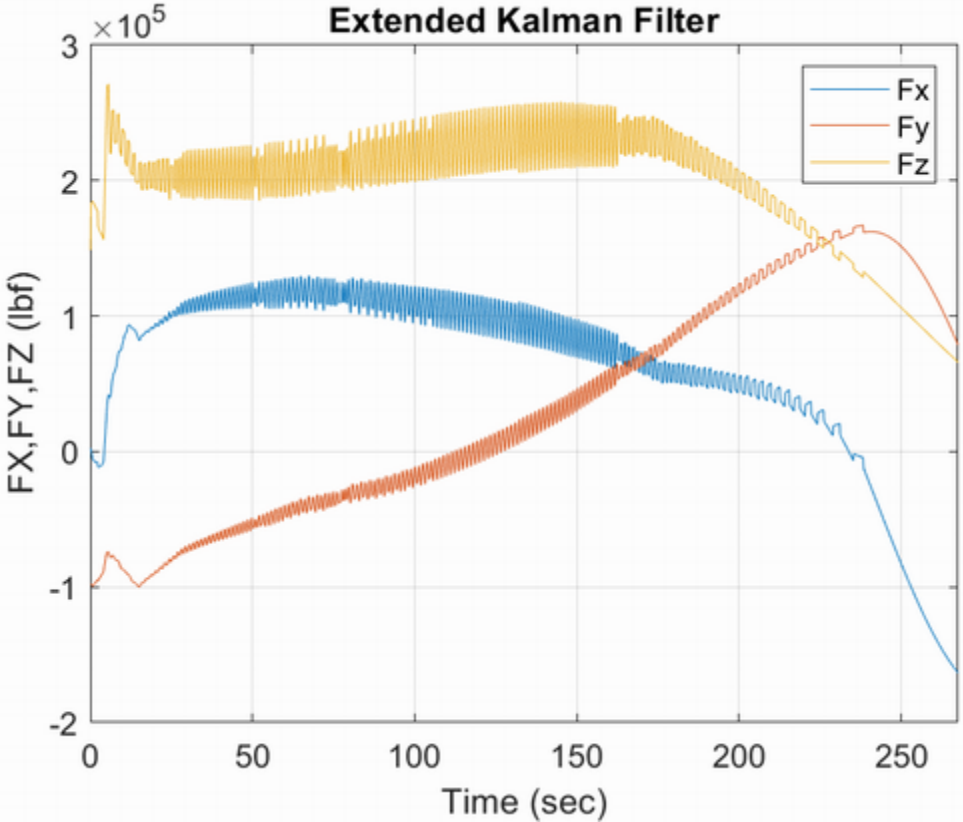

Unscented Kalman Filter: Test 7
Est Altitude (ft)
6000
4000
2000
0
xhat
meas
x
0
20
40
60
80
100
120
140
Unscented Kalman Filter: Test 7
Est Altitude Rate (ft/sec)
200
100
0
-100
xhat
x
0
20
40
60
80
100
120
140

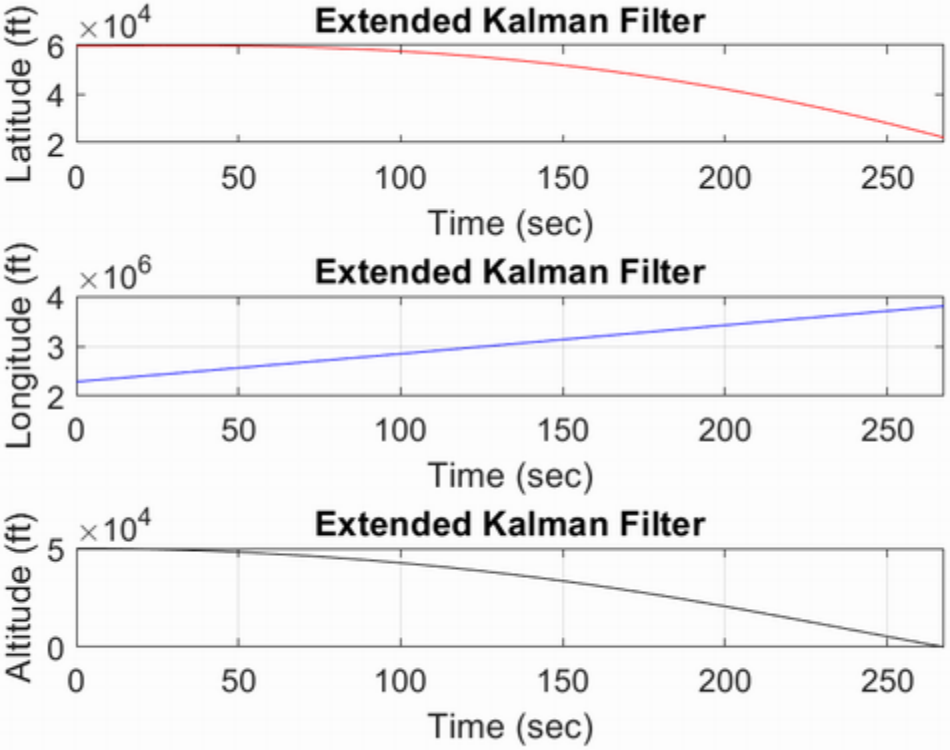

Unscented Kalman Filter: Test 8
Est Altitude (ft)
2000
1000
0
0
20
40
60
80
100
120
140
xhat
meas
x
Unscented Kalman Filter: Test 8
Est Altitude Rate (ft/sec)
40
20
0
0
20
40
60
80
100
120
140
xhat
x

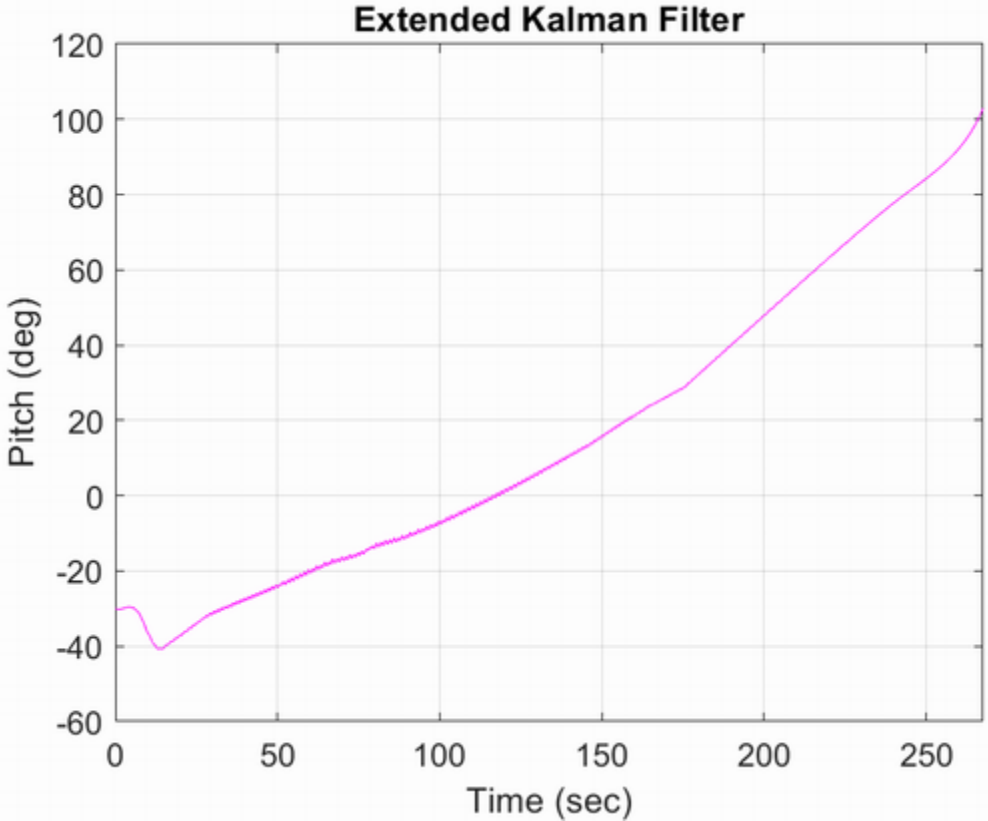

Unscented Kalman Filter: Test 9
×10^4
1
0
-1
Est Altitude (ft)
xhat
meas
x
0
20
40
60
80
100
120
140
Unscented Kalman Filter: Test 9
1000
0
-1000
Est Altitude Rate (ft/sec)
xhat
x
0
20
40
60
80
100
120
140

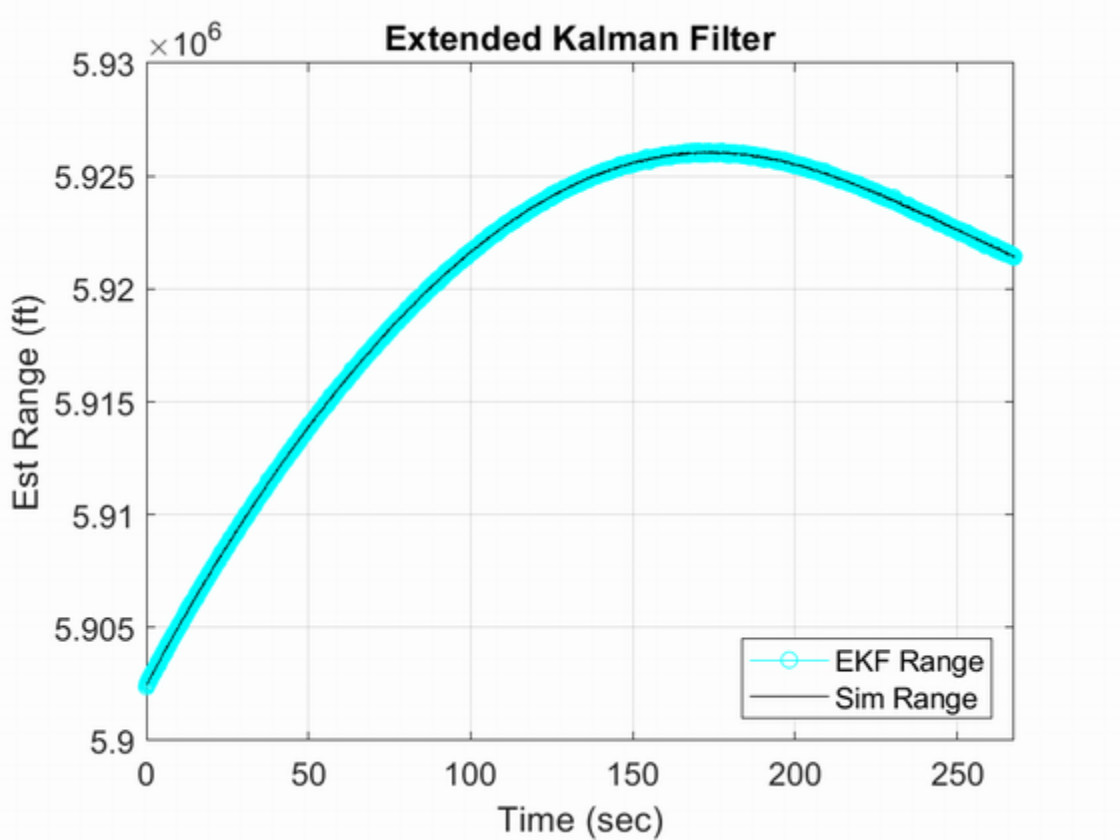

Unscented Kalman Filter: WORST CASE
×10^4
Est Altitude (ft)
xhat
meas
x
Unscented Kalman Filter: WORST CASE
Est Altitude Rate (ft/sec)
xhat
x

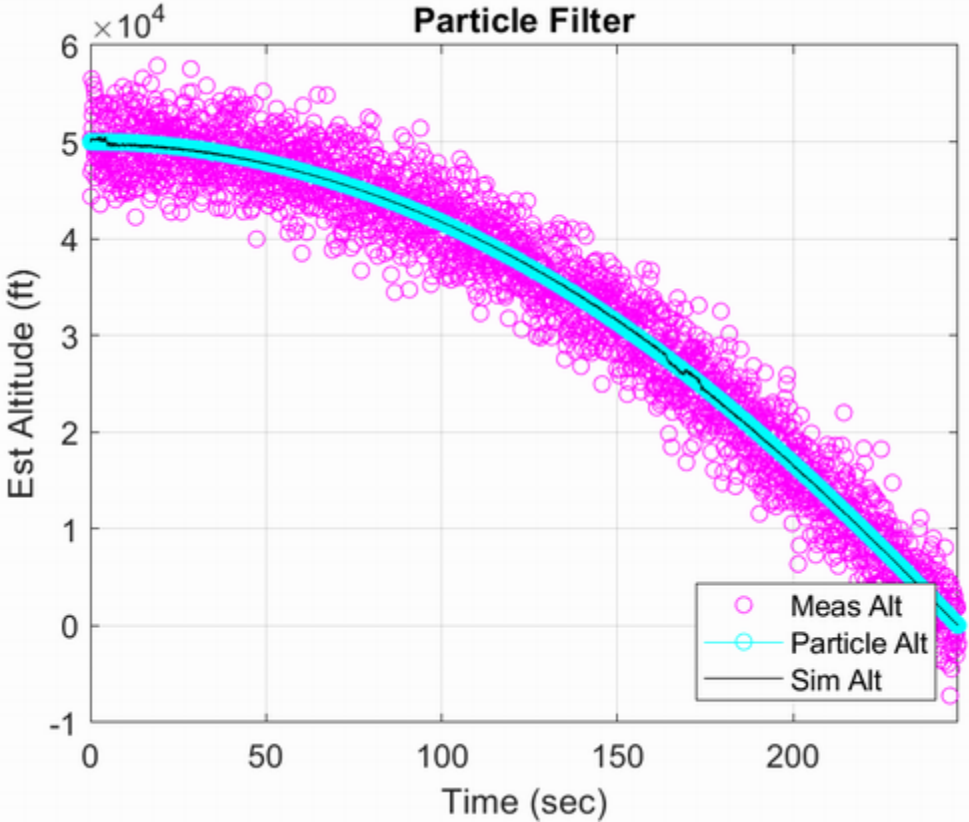

Extended Kalman Filter
×10^4
6
5
4
3
2
1
0
-1
Est Altitude (ft)
0
50
100
150
200
250
Time (sec)
Meas Alt
EKF Alt
Sim Alt

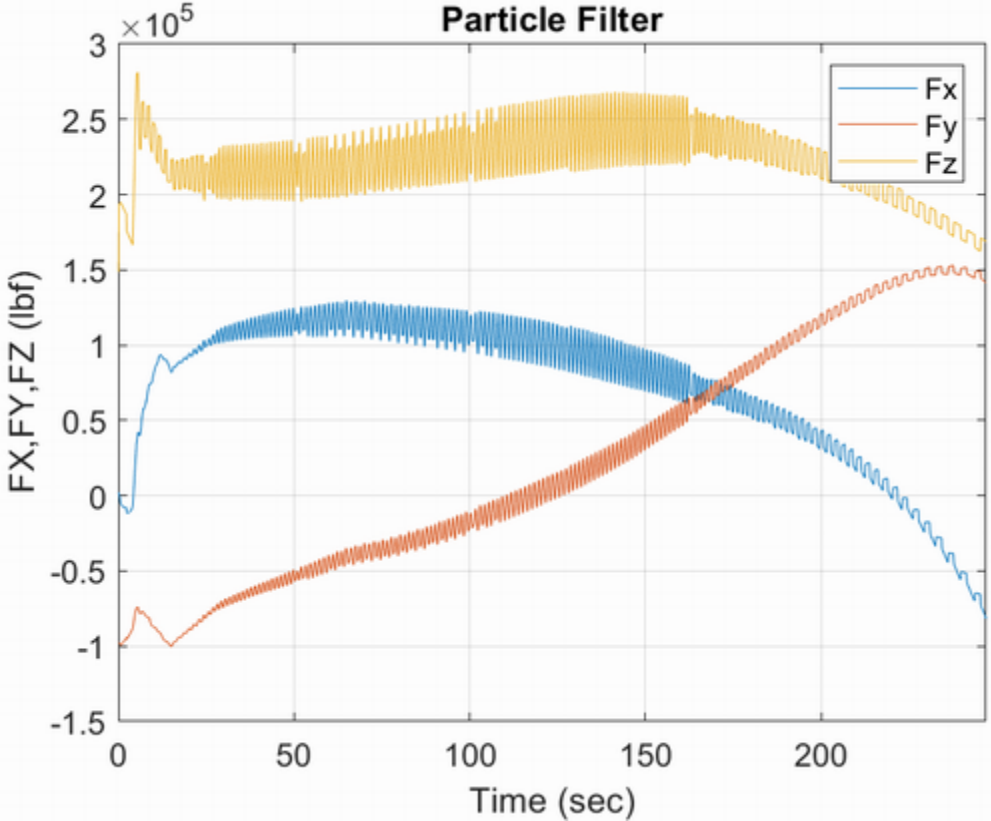

Extended Kalman Filter
×10^5
3
2
1
0
-1
-2
FX,FY,FZ (lbf)
0
50
100
150
200
250
Time (sec)
Fx
Fy
Fz

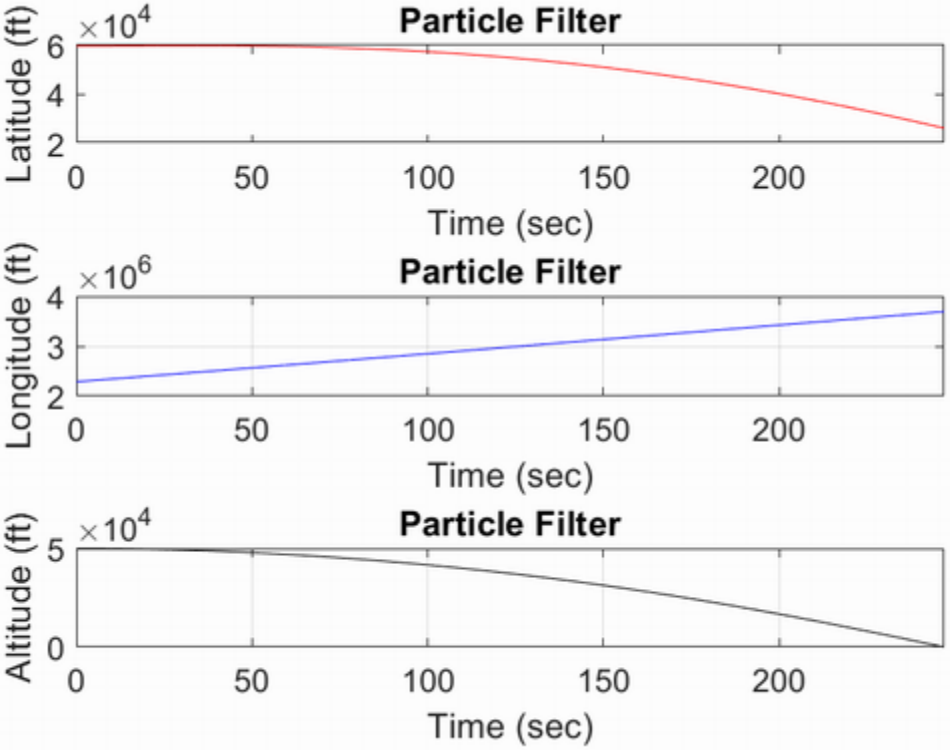

Extended Kalman Filter
×10^4
Latitude (ft)
6
4
2
0
50
100
150
200
250
Time (sec)
Extended Kalman Filter
×10^6
Longitude (ft)
4
3
2
0
50
100
150
200
250
Time (sec)
Extended Kalman Filter
×10^4
Altitude (ft)
5
0
0
50
100
150
200
250
Time (sec)

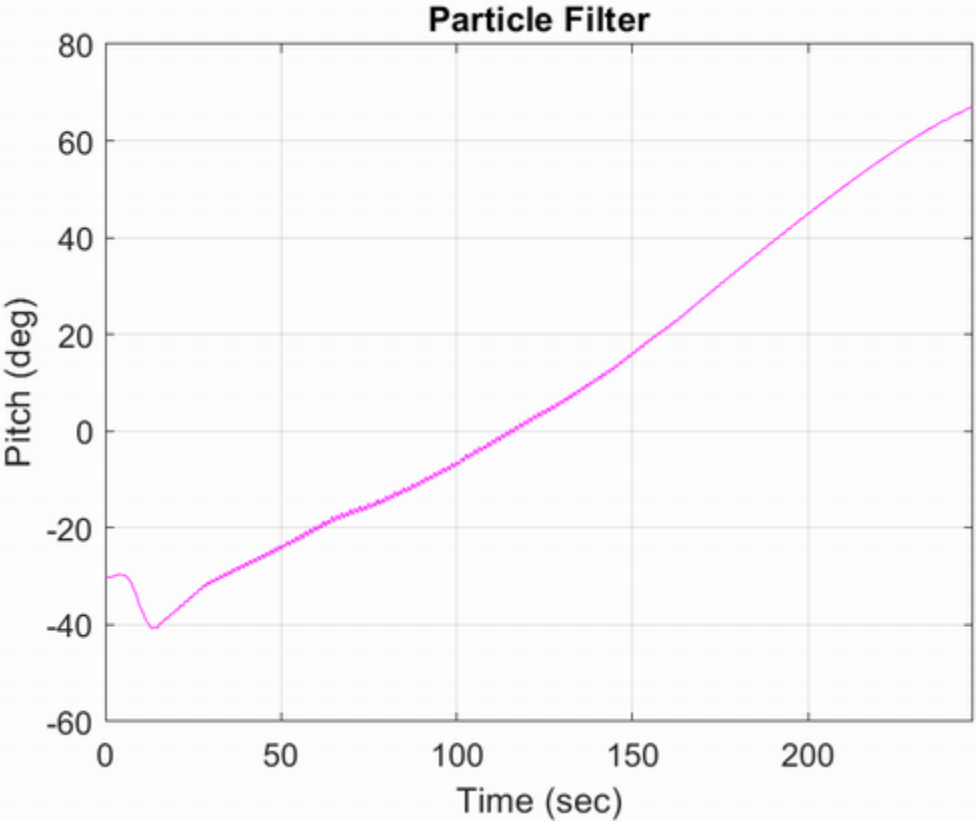

Extended Kalman Filter
120
100
80
60
40
20
0
-20
-40
-60
Pitch (deg)
0
50
100
150
200
250
Time (sec)

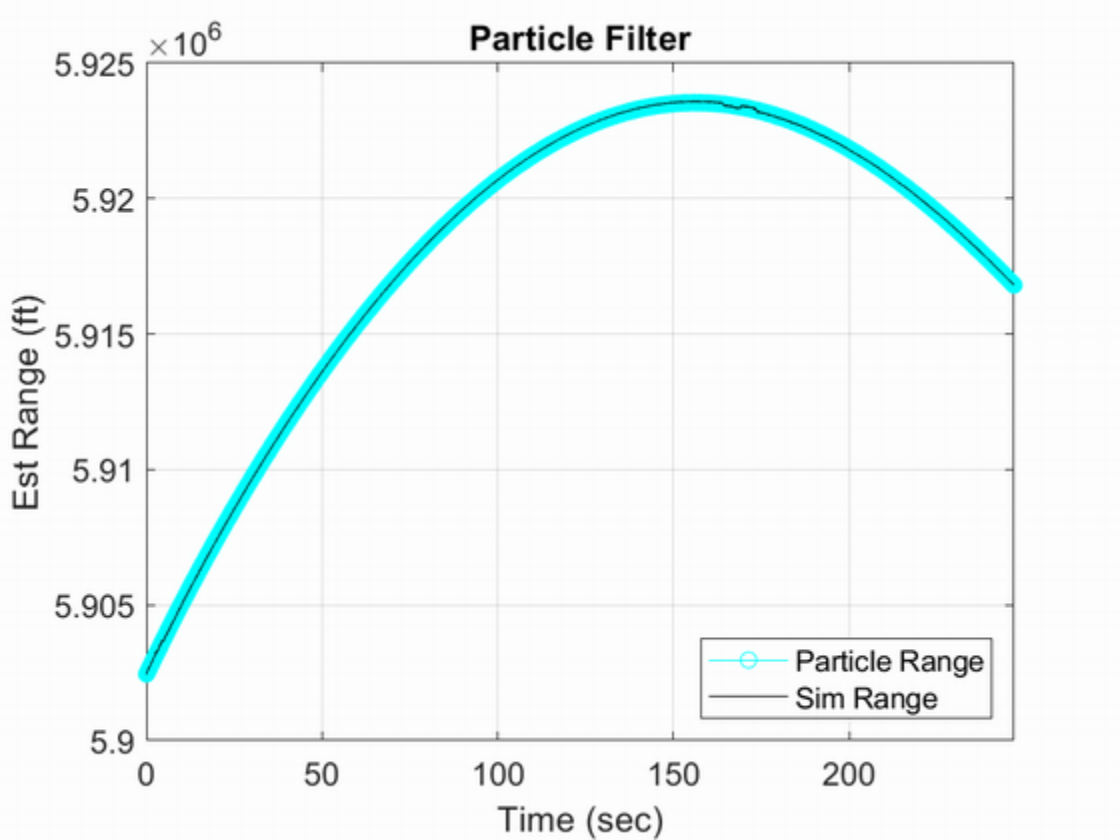

Extended Kalman Filter
×10^6
5.93
5.925
5.92
5.915
5.91
5.905
5.9
Est Range (ft)
0
50
100
150
200
250
Time (sec)
EKF Range
Sim Range

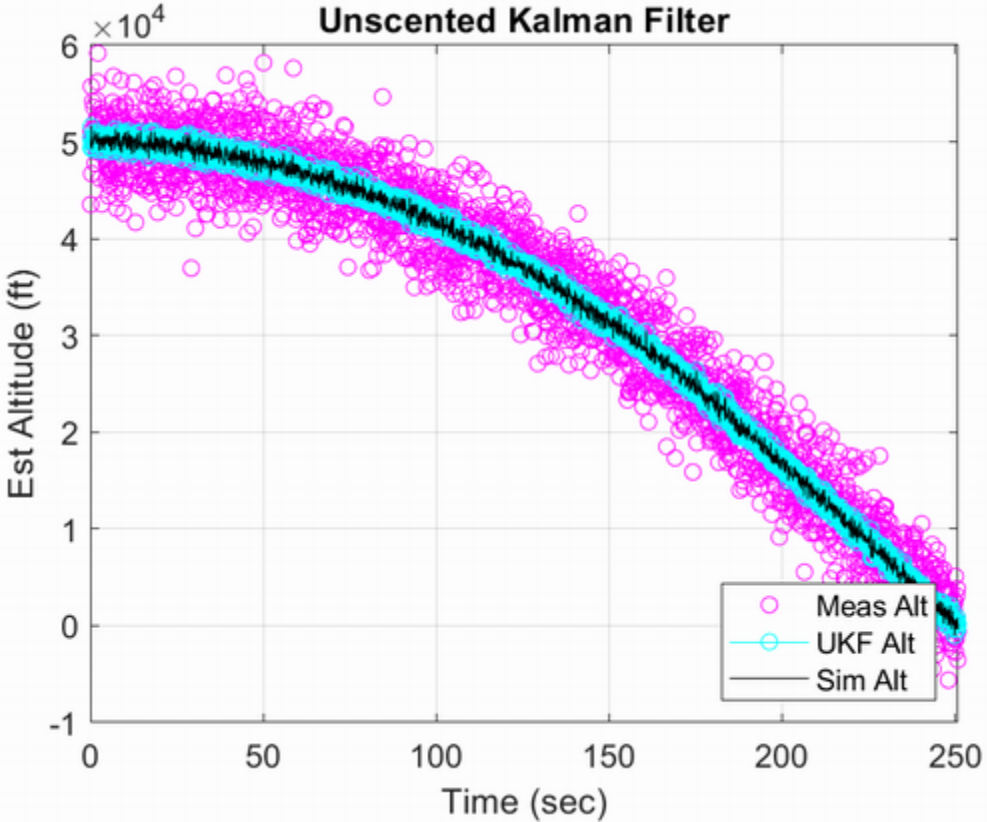

Particle Filter
×10^4
6
5
4
3
2
1
0
-1
Est Altitude (ft)
0
50
100
150
200
Time (sec)
Meas Alt
Particle Alt
Sim Alt

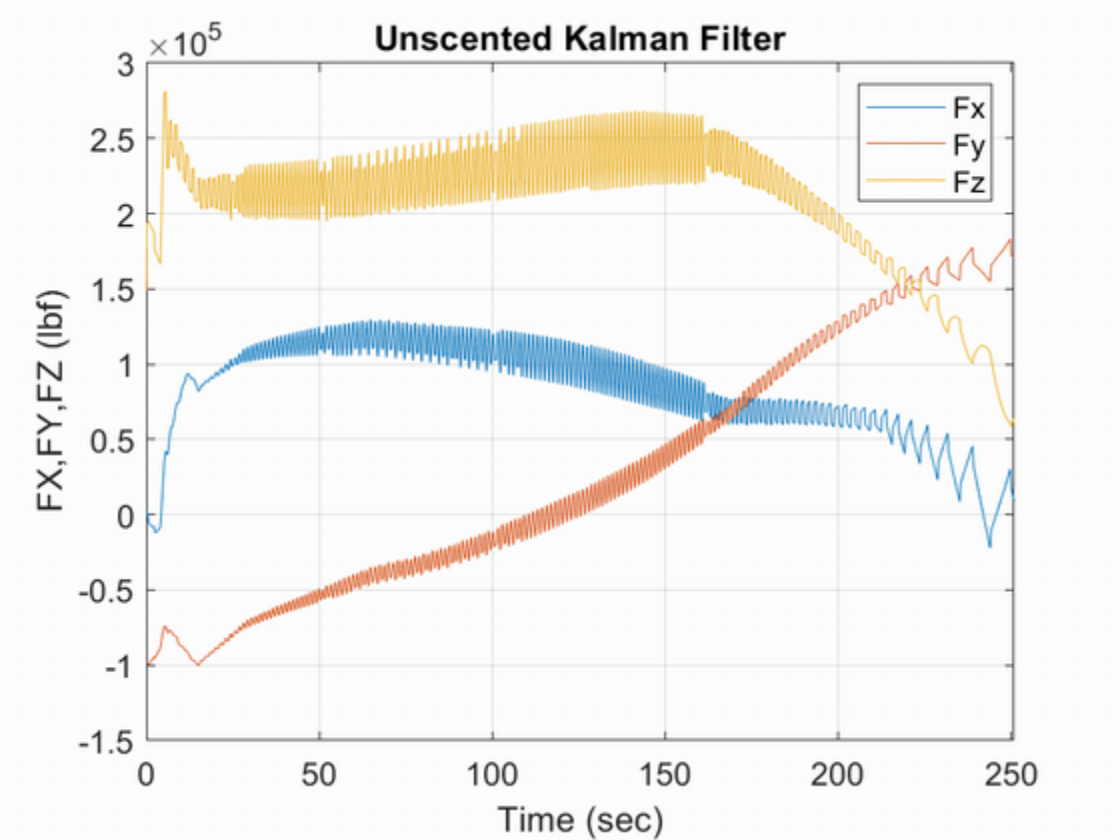

Particle Filter
×10^5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
FX,FY,FZ (lbf)
0
50
100
150
200
Time (sec)
Fx
Fy
Fz

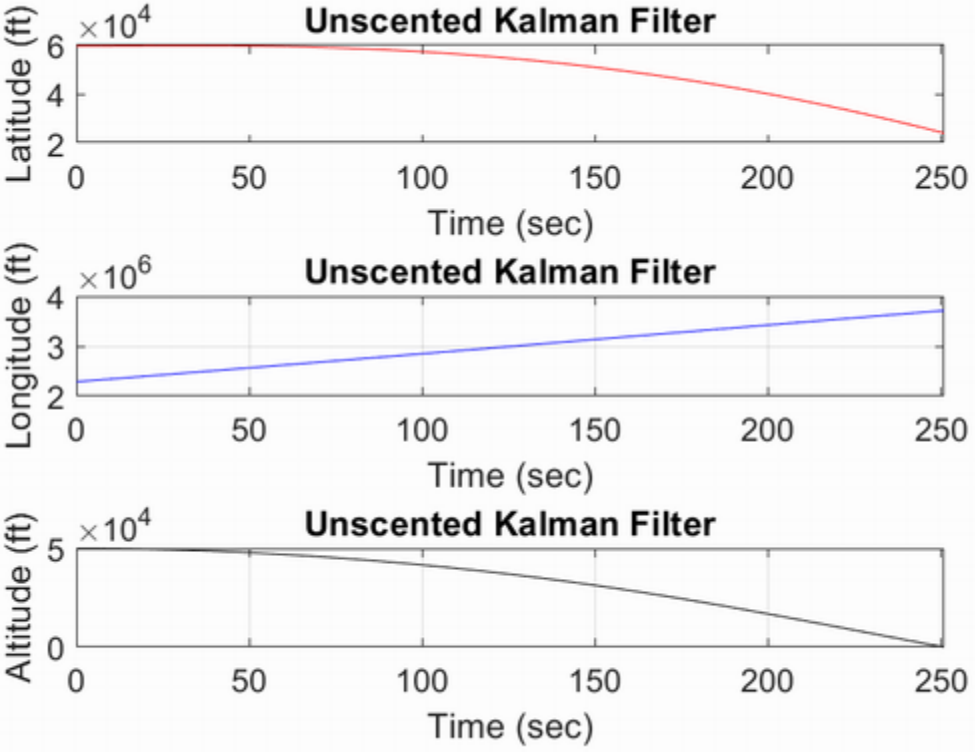

Particle Filter
×10^4
Latitude (ft)
6
4
2
0
50
100
150
200
Time (sec)
Particle Filter
×10^6
Longitude (ft)
4
3
2
0
50
100
150
200
Time (sec)
Particle Filter
×10^4
Altitude (ft)
5
0
0
50
100
150
200
Time (sec)

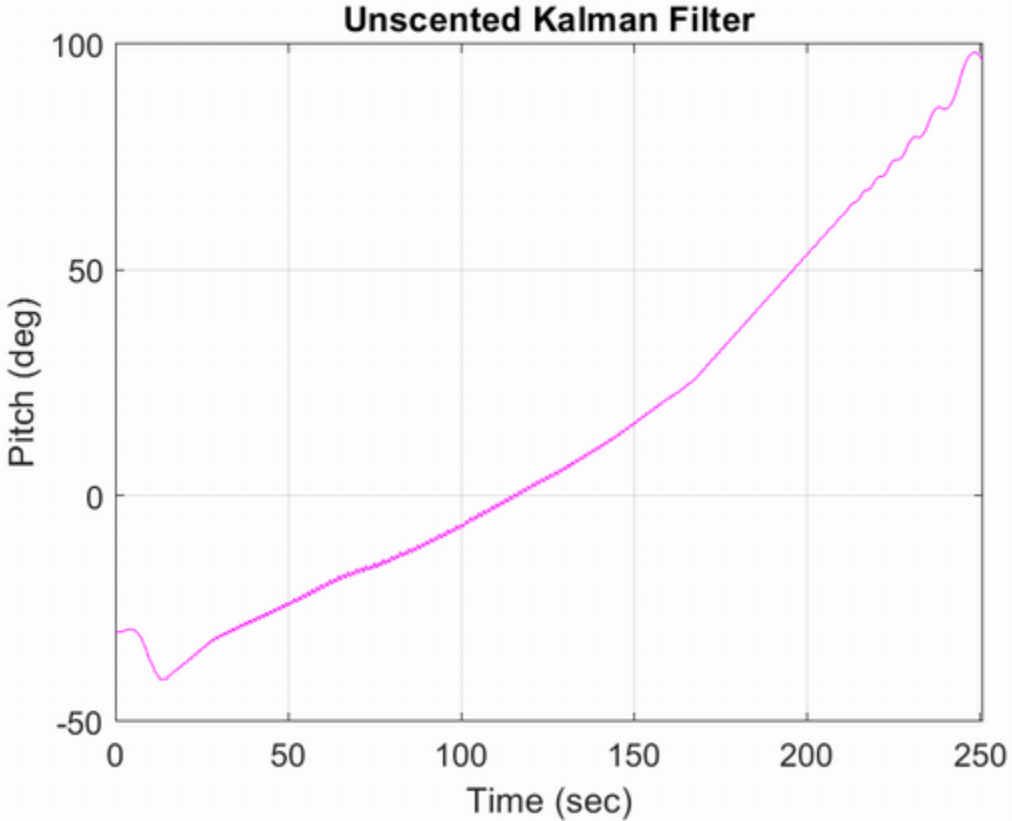

Particle Filter
80
60
40
20
0
-20
-40
-60
Pitch (deg)
0
50
100
150
200
Time (sec)

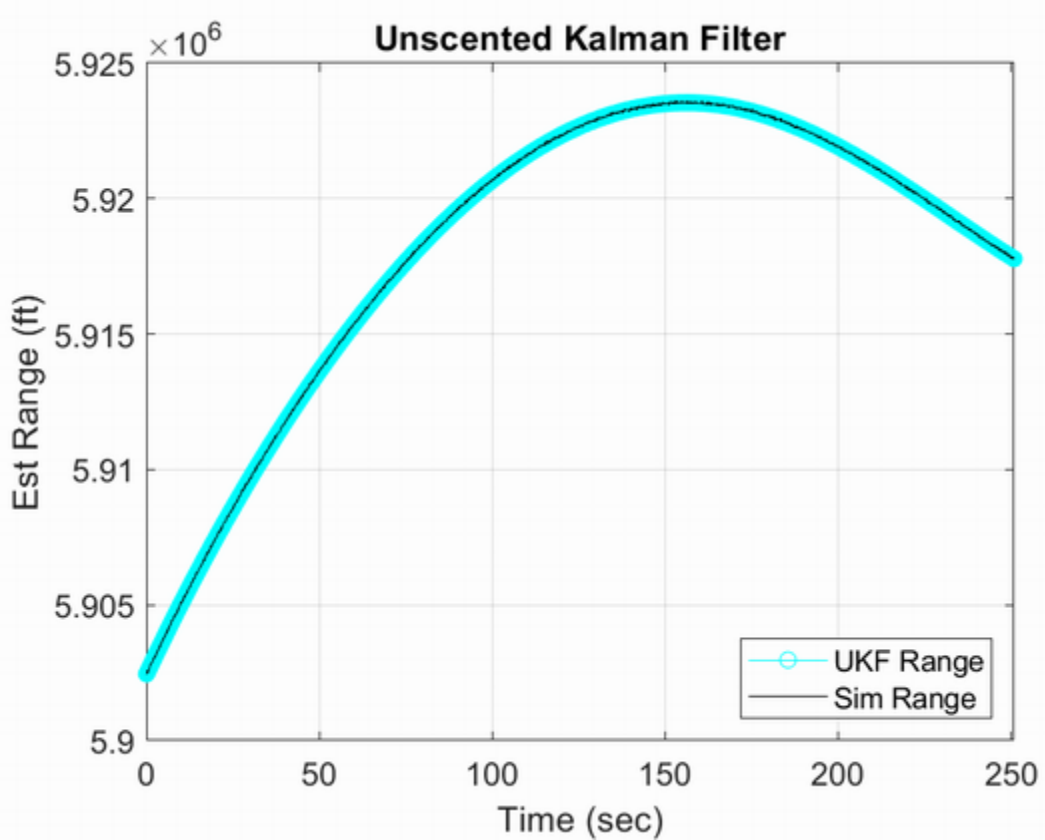

Particle Filter
×10^6
5.925
5.92
5.915
5.91
5.905
5.9
Est Range (ft)
0
50
100
150
200
Time (sec)
Particle Range
Sim Range


Unscented Kalman Filter
×10^4
6
5
4
3
2
1
0
-1
Est Altitude (ft)
0
50
100
150
200
250
Time (sec)
Meas Alt
UKF Alt
Sim Alt


Unscented Kalman Filter
×10^5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
FX,FY,FZ (lbf)
0
50
100
150
200
250
Time (sec)
Fx
Fy
Fz


Unscented Kalman Filter
×10^4
Latitude (ft)
6
4
2
0
50
100
150
200
250
Time (sec)
Unscented Kalman Filter
×10^6
Longitude (ft)
4
3
2
0
50
100
150
200
250
Time (sec)
Unscented Kalman Filter
×10^4
Altitude (ft)
5
0
0
50
100
150
200
250
Time (sec)


Unscented Kalman Filter
100
50
0
-50
Pitch (deg)
0
50
100
150
200
250
Time (sec)


Unscented Kalman Filter
×10^6
5.925
5.92
5.915
5.91
5.905
5.9
Est Range (ft)
0
50
100
150
200
250
Time (sec)
UKF Range
Sim Range

```
%% AE6505 Final Project -- Apollo 11 Final Descent: Extended Kalman Filter
% Use of an EKF to improve estimates of the true altitude and range from
% unreliable proximity sensor data
% Author: Erin McNeil
% Date: 4-25-2024

function [Att_Cmd,Accel_Cmd_X,Accel_Cmd_Y,Accel_Cmd_Z,x,xhat,P,y_meas] = fcn(tclock,x,↙
xhat,P,alt,pitch, Accel_D,x_ecef,y_ecef,z_ecef)

% conversion from ECEF coord to AER
    % Sea of Tranquility (target landing site)
    lat0 = 0.6;
    lon0 = 23.5;
    h0 = 0.0012;

    semimajor_axis = 384000; %km
    eccentricity = 0.0549;

    a  = semimajor_axis;
    e2 = eccentricity^2;
    f = e2 / (1 + sqrt(1 - e2));

    h = h0;
    r = h + a;

    phi = lat0;
    rho = r .* cos(phi);

    lambda = lon0;
    z0 = r .* sin(phi);
    x0 = rho .* cos(lambda);
    y0 = rho .* sin(lambda);

    u = x_ecef - x0;
    v = y_ecef - y0;
    w = z_ecef - z0;

    cosPhi = cos(lat0);
    sinPhi = sin(lat0);
    cosLambda = cos(lon0);
    sinLambda = sin(lon0);

    t     =  cosLambda .* u + sinLambda .* v;
    uEast = -sinLambda .* u + cosLambda .* v;

    wUp    =  cosPhi .* t + sinPhi .* w;
    vNorth = -sinPhi .* t + cosPhi .* w;

    xEast = uEast;
    yNorth = vNorth;
```

```
    zUp = wUp;

    deg360 = 2*atan2(0,-1);
    r = hypot(xEast,yNorth);
    slantRange = hypot(r,zUp);
    elevationAngle = atan2(zUp,r);
    azimuthAngle = mod(atan2(xEast,yNorth),deg360);


    range_x = sqrt(abs((alt^2)-(slantRange^2))); %260nmi*6076 = 1579760 ft from target

        %% parameter inputs
        g = 5.315; %gravity (ft/sec^2)

        %% noise and covariance matrices
        R = 1000; % Measurement noise covariance
        Q = [200000 0;0 1000]; %process noise

        %% Iterations
        dt = 0.005;

        %% Simulation
        altitude = alt; %ft
        Range = range_x; %ft

        x = [altitude;Range] + diag(sqrt(Q)*randn);

        Noise = 7000;
        deg = 500;
        y_meas = x(1) + (Noise*cos(deg*tclock)*randn);

    %% Start of EKF
    A = [0 1; 0 0];
    H = [1 0];

    xhat = [altitude;Range] + diag(sqrt(Q)*randn);

    y_comp = xhat(1) + sqrt(R)*randn; %Range (ft)

    Pdot = A*P + P*A' + Q;
    P = P + P*dt;

    K = P * H' * inv(H * P * H' + R);
    xhat = xhat + K * (y_meas - y_comp);
    P = (eye(2) - K*H)*P*(eye(2) - K*H)' + K*R*K';

%%    Attitude Commands per Altitude Estimation

    if (28000 < xhat(1)) && (xhat(1) < 38887)
        cmd_Roll = 0*(pi/180); %rad
```

```
        cmd_Pitch = 0*(pi/180); %rad
        cmd_Yaw = 0*(pi/180); %rad
        Att_Cmd = [-30*(pi/180) -10*(pi/180) -60*(pi/180)] + [cmd_Roll cmd_Pitch
cmd_Yaw];
    elseif (22000 < xhat(1)) && (xhat(1) < 28000)
        cmd_Roll = 0*(pi/180); %rad
        cmd_Pitch = 15*(pi/180); %rad
        cmd_Yaw = 0*(pi/180); %rad
        Att_Cmd = [-30*(pi/180) 0 -60*(pi/180)] + [cmd_Roll cmd_Pitch cmd_Yaw];
    elseif (5000 < xhat(1)) && (xhat(1) < 28000)
        cmd_Roll = 0*(pi/180); %rad
        cmd_Pitch = 35*(pi/180); %rad
        cmd_Yaw = 0*(pi/180); %rad
        Att_Cmd = [-30*(pi/180) 0 -60*(pi/180)] + [cmd_Roll cmd_Pitch cmd_Yaw];
    elseif (0 < xhat(1)) && (xhat(1) < 5000)
        cmd_Roll = 0*(pi/180); %rad
        cmd_Pitch = 45*(pi/180); %rad
        cmd_Yaw = 0*(pi/180); %rad
        Att_Cmd = [-30*(pi/180) 0 -60*(pi/180)] + [cmd_Roll cmd_Pitch cmd_Yaw];
    else
        cmd_Roll = 0*(pi/180); %rad
        cmd_Pitch = -10*(pi/180); %rad
        cmd_Yaw = 0*(pi/180); %rad
       Att_Cmd = [-30*(pi/180) 0 -60*(pi/180)] + [cmd_Roll cmd_Pitch cmd_Yaw];
    end

    %% LM Descent Engine
    if 0 < xhat(1) < 38887
        Accel_Cmd_X = 0;
        Accel_Cmd_Y = 0;
        Accel_Cmd_Z = 900;
    else
        Accel_Cmd_X = 0;
        Accel_Cmd_Y = 0;
        Accel_Cmd_Z = 0;
    end

end
```

```
%% AE6505 Final Project -- Apollo 11 Final Descent: Particle Filter
% Use of an Particle Filter to improve estimates of the true altitude and range from
% unreliable proximity sensor data
% Author: Erin McNeil
% Date: 4-25-2024

function [Att_Cmd,Accel_Cmd_X,Accel_Cmd_Y,Accel_Cmd_Z,x,xhatPart,P,y_meas] = fcn↙
(tclock,x,xhatPart,P,alt,pitch, Accel_D,x_ecef,y_ecef,z_ecef)

%   initialize data types
    N = 100; % number of particles
    xpart = double(zeros(2,N));
    vhat = double(zeros(1,N));
    q = double(zeros(1,N));

%  conversion from ECEF coord to AER
    %Sea of Tranquility (target landing site)
    lat0 = 0.6;
    lon0 = 23.5;
    h0 = 0.0012;

    semimajor_axis = 384000; %km
    eccentricity = 0.0549;

    a  = semimajor_axis;
    e2 = eccentricity^2;
    f = e2 / (1 + sqrt(1 - e2));

    h = h0;
    r = h + a;

    phi = lat0;
    rho = r .* cos(phi);

    lambda = lon0;
    z0 = r .* sin(phi);
    x0 = rho .* cos(lambda);
    y0 = rho .* sin(lambda);

    u = x_ecef - x0;
    v = y_ecef - y0;
    w = z_ecef - z0;

    cosPhi = cos(lat0);
    sinPhi = sin(lat0);
    cosLambda = cos(lon0);
    sinLambda = sin(lon0);

    t     =  cosLambda .* u + sinLambda .* v;
    uEast = -sinLambda .* u + cosLambda .* v;
```

```
    wUp    =  cosPhi .* t + sinPhi .* w;
    vNorth = -sinPhi .* t + cosPhi .* w;

    xEast = uEast;
    yNorth = vNorth;
    zUp = wUp;

    deg360 = 2*atan2(0,-1);
    r = hypot(xEast,yNorth);
    slantRange = hypot(r,zUp);
    elevationAngle = atan2(zUp,r);
    azimuthAngle = mod(atan2(xEast,yNorth),deg360);


    range_x = sqrt(abs((alt^2)-(slantRange^2)));

        %% parameter inputs
        g = 5.315; %gravity (ft/sec^2)
        total_mass = 33296; % Mass [lb]; % vehicle + remaining prop(slugs)

        %% noise and covariance matrices
        R = 1000; % Measurement noise covariance
        Q = [30000 0;0 1000]; %process noise

        %% initialize particles
%         N = 1000; % number of particles
        RoughParam = 0.05;
        xhatPart = x;
        % Initialize the particle filter
        for j = 1 : N
            xpart(:,j) = x + sqrt(P) * [randn; randn];
        end
        randn('state',sum(100*tclock)); % random number generator seed (investigate↙
different randn settings)

        %% Iterations
        dt = 0.005;
        dtt = 0.005;
        T = 0.005; % measurement time step

        %% Simulation
        altitude = alt; %ft
        Range = range_x; %ft

        x = [altitude;Range] + diag(sqrt(Q)*randn);

        y_comp = x(1) + sqrt(R)*randn; %Alt (ft)

        Noise = 7000;
```

```
        deg = 500;
        y_meas = x(1) + (Noise*cos(deg*tclock)*randn);

       %% Particle filter
    xpartminus = xpart;
    for i = 1 : N
        xtemp = xpartminus(:,i);

        xpartminus(:,i) = [altitude;Range] + diag(sqrt(Q)*randn);

        y = xpartminus(1);
        ypart = y + sqrt(R)*randn;

        vhat(:,i) = (y_meas- y_comp) - ypart; %
    end

    vhatscale = max(abs(vhat(1,i))) / 4;
    qsum = [0];
    for i = 1 : N
        q(1,i) = (1 / sqrt(abs(R(1,1))) / sqrt((2*pi)*N)) * exp(-(vhat(1,i)/vhatscale)↙
^2 / 2 / R(1,1));
        qsum = qsum + q(:,i);
    end
    % Normalize the likelihood of each a priori estimate.
    for i = 1 : N
        q(1,i) = q(1,i) / qsum(1);
    end
    % Resample.
    for i = 1 : N
        u = rand; % uniform random number between 0 and 1
        qtempsum = [0];
        for j = 1 : N
            qtempsum(1) = qtempsum(1) + q(1,j);
            if qtempsum(1) >= u
                xpart(:,i) = xpartminus(:,j);
                % Use roughening to prevent sample impoverishment.
                E = max(xpartminus')' - min(xpartminus')';
                sigma = RoughParam * E * N^(-1/length(x));
                xpart(:,i) = xpart(:,i) + sigma .* [randn; randn];
                break;
            end
        end
    end
    % The particle filter estimate is the mean of the particles.
    xhatPart = [0;0];
    for i = 1 : N
        xhatPart = xhatPart + xpart(:,i);
    end
    xhatPart = xhatPart / N;
```

```
%%    Attitude Commands per Altitude Estimation

    if (28000 < xhatPart(1)) && (xhatPart(1) < 38887)
        cmd_Roll = 0*(pi/180); %rad
        cmd_Pitch = 0*(pi/180); %rad
        cmd_Yaw = 0*(pi/180); %rad
        Att_Cmd = [-30*(pi/180) -10*(pi/180) -60*(pi/180)] + [cmd_Roll cmd_Pitch↙
cmd_Yaw];
    elseif (22000 < xhatPart(1)) && (xhatPart(1) < 28000)
        cmd_Roll = 0*(pi/180); %rad
        cmd_Pitch = 15*(pi/180); %rad
        cmd_Yaw = 0*(pi/180); %rad
        Att_Cmd = [-30*(pi/180) 0 -60*(pi/180)] + [cmd_Roll cmd_Pitch cmd_Yaw];
    elseif (5000 < xhatPart(1)) && (xhatPart(1) < 28000)
        cmd_Roll = 0*(pi/180); %rad
        cmd_Pitch = 35*(pi/180); %rad
        cmd_Yaw = 0*(pi/180); %rad
        Att_Cmd = [-30*(pi/180) 0 -60*(pi/180)] + [cmd_Roll cmd_Pitch cmd_Yaw];
    elseif (0 < xhatPart(1)) && (xhatPart(1) < 5000)
        cmd_Roll = 0*(pi/180); %rad
        cmd_Pitch = 45*(pi/180); %rad
        cmd_Yaw = 0*(pi/180); %rad
        Att_Cmd = [-30*(pi/180) 0 -60*(pi/180)] + [cmd_Roll cmd_Pitch cmd_Yaw];
    else
        cmd_Roll = 0*(pi/180); %rad
        cmd_Pitch = -10*(pi/180); %rad
        cmd_Yaw = 0*(pi/180); %rad
       Att_Cmd = [-30*(pi/180) 0 -60*(pi/180)] + [cmd_Roll cmd_Pitch cmd_Yaw];
    end

    %% LM Descent Engine
    if 0 < xhatPart(1) < 38887
        Accel_Cmd_X = 0;
        Accel_Cmd_Y = 0;
        Accel_Cmd_Z = 1000;
    else
        Accel_Cmd_X = 0;
        Accel_Cmd_Y = 0;
        Accel_Cmd_Z = 0;
    end

end
```

```
%% AE6505 Final Project -- Apollo 11 Final Descent: Unscented Kalman Filter
% Use of an UKF to improve estimates of the true altitude and range from
% unreliable proximity sensor data
% Author: Erin McNeil
% Date: 4-25-2024

function [Att_Cmd,Accel_Cmd_X,Accel_Cmd_Y,Accel_Cmd_Z,x,xhatukfs,Pukfs,y_meas] = fcn↙
(tclock,x,xhatukfs,Pukfs,alt,pitch, Accel_D,x_ecef,y_ecef,z_ecef)

%   initialize data types
    sigmas = double(zeros(2,4));
    xbreve = double(zeros(2,4));
    zukf = double(zeros(1,4));
    xbrevedot = double(zeros(2,1));

%   conversion from ECEF coord to AER
    % Sea of Tranquility
    lat0 = 0.6;
    lon0 = 23.5;
    h0 = 0.0012;

    semimajor_axis = 384000; %km
    eccentricity = 0.0549;

    a  = semimajor_axis;
    e2 = eccentricity^2;
    f = e2 / (1 + sqrt(1 - e2));

    h = h0;
    r = h + a;

    phi = lat0;
    rho = r .* cos(phi);

    lambda = lon0;
    z0 = r .* sin(phi);
    x0 = rho .* cos(lambda);
    y0 = rho .* sin(lambda);

    u = x_ecef - x0;
    v = y_ecef - y0;
    w = z_ecef - z0;

    cosPhi = cos(lat0);
    sinPhi = sin(lat0);
    cosLambda = cos(lon0);
    sinLambda = sin(lon0);

    t     =  cosLambda .* u + sinLambda .* v;
    uEast = -sinLambda .* u + cosLambda .* v;
```

```
wUp    =  cosPhi .* t + sinPhi .* w;
vNorth = -sinPhi .* t + cosPhi .* w;

xEast = uEast;
yNorth = vNorth;
zUp = wUp;

deg360 = 2*atan2(0,-1);
r = hypot(xEast,yNorth);
slantRange = hypot(r,zUp);
elevationAngle = atan2(zUp,r);
azimuthAngle = mod(atan2(xEast,yNorth),deg360);

range_x = sqrt(abs((alt^2)-(slantRange^2)));

    %% UKF init
    N = 2;
    Ws = ones(2*N,1) / 2 / N; % standard UKF weights W = 1/2n

    %% parameter inputs
    g = 5.315; %gravity (ft/sec^2)
    total_mass = 33296; % Mass [lb]; % vehicle + remaining prop(slugs)

    %% noise and covariance matrices
    R = 1000; % Measurement noise covariance
    Q = [300000 0;0 1000]; %process noise
    %% Iterations
    dt = 0.005;
    dtt = 0.005;
    T = 0.005; % measurement time step

    %% Simulation
    altitude = alt; %ft
    Range = range_x; %ft

    x = [altitude;Range] + diag(sqrt(Q)*randn);

    y_comp = x(1) + sqrt(R)*randn; %Alt (ft)

    Noise = 7000;
    deg = 500;
    y_meas = x(1) + (Noise*cos(deg*tclock)*randn);


   %% Start of standard UKF - generate the UKF sigma points.
[root,p] = chol(N*Pukfs); %sqrt(n*P)
for i = 1 : N
    sigmas(:,i) = xhatukfs + root(i,:)'; %xhatsigma = xhat + xtilde
    sigmas(:,i+N) = xhatukfs - root(i,:)'; %xhatsigma = xhat - xtilde
```

```
end
for i = 1 : 2*N
    xbreve(:,i) = sigmas(:,i); %collect the sigmas into xbreve's
end
% Standard UKF time update (Eqn 14.59)
for i = 1 : 2*N
    for tau = dtt : dtt : T
        xbreve(:,i) = [altitude;Range];
    end
end
%Eqn 14.60
xhatukfs = zeros(N,1);
for i = 1 : 2*N
    xhatukfs = xhatukfs + Ws(i) * xbreve(:,i); %(Eqn. 14.60)
end
%Eqn 14.61
Pukfs = Q;
for i = 1 : 2*N
    Pukfs = Pukfs + Ws(i) * (xbreve(:,i) - xhatukfs) * (xbreve(:,i) - xhatukfs)';
end

% Standard UKF measurement update

% generate the UKF sigma points.
[root,p] = chol(N*Pukfs); %sqrt(n*P) (Eqn 14.62)
for i = 1 : N
    sigmas(:,i) = xhatukfs + root(i,:)'; %xhatsigma = xhat + xtilde
    sigmas(:,i+N) = xhatukfs - root(i,:)'; %xhatsigma = xhat - xtilde
end
for i = 1 : 2*N
    xbreve(:,i) = sigmas(:,i); %collect the sigmas into breve's
end

 %Eqn 14.63
for i = 1 : 2*N
    yukf = xbreve(1,i); %Altitude (ft)
    zukf(:,i) = (y_meas - yukf);
end
%Eqn 14.64
zhat = 0;
for i = 1 : 2*N
    zhat = zhat + Ws(i) * zukf(:,i);
end
%Eqn 14.65 and 66
Py = R;
Pxy = zeros(N,1);
for i = 1 : 2*N
    Py = Py + Ws(i) * (zukf(:,i) - [zhat]) * (zukf(:,i) - [zhat])';
    Pxy = Pxy + Ws(i) * (xbreve(:,i) - xhatukfs) * (zukf(:,i) - [zhat])';
end
```

```
    %Eqn 14.67
    Kukf = Pxy * inv(Py);
    xhatukfs = xhatukfs + Kukf * ((y_meas - y_comp) - [zhat]); %
    Pukfs = Pukfs - Kukf * Py * Kukf';

%%    Attitude Commands per Altitude Estimation

    if (28000 < xhatukfs(1)) && (xhatukfs(1) < 38887)
        cmd_Roll = 0*(pi/180); %rad
        cmd_Pitch = 0*(pi/180); %rad
        cmd_Yaw = 0*(pi/180); %rad
        Att_Cmd = [-30*(pi/180) -10*(pi/180) -60*(pi/180)] + [cmd_Roll cmd_Pitch
cmd_Yaw];
    elseif (22000 < xhatukfs(1)) && (xhatukfs(1) < 28000)
        cmd_Roll = 0*(pi/180); %rad
        cmd_Pitch = 15*(pi/180); %rad
        cmd_Yaw = 0*(pi/180); %rad
        Att_Cmd = [-30*(pi/180) 0 -60*(pi/180)] + [cmd_Roll cmd_Pitch cmd_Yaw];
    elseif (5000 < xhatukfs(1)) && (xhatukfs(1) < 28000)
        cmd_Roll = 0*(pi/180); %rad
        cmd_Pitch = 35*(pi/180); %rad
        cmd_Yaw = 0*(pi/180); %rad
        Att_Cmd = [-30*(pi/180) 0 -60*(pi/180)] + [cmd_Roll cmd_Pitch cmd_Yaw];
    elseif (0 < xhatukfs(1)) && (xhatukfs(1) < 5000)
        cmd_Roll = 0*(pi/180); %rad
        cmd_Pitch = 45*(pi/180); %rad
        cmd_Yaw = 0*(pi/180); %rad
        Att_Cmd = [-30*(pi/180) 0 -60*(pi/180)] + [cmd_Roll cmd_Pitch cmd_Yaw];
    else
        cmd_Roll = 0*(pi/180); %rad
        cmd_Pitch = -10*(pi/180); %rad
        cmd_Yaw = 0*(pi/180); %rad
       Att_Cmd = [-30*(pi/180) 0 -60*(pi/180)] + [cmd_Roll cmd_Pitch cmd_Yaw];
    end

    %% LM Descent Engine
    if 0 < xhatukfs(1) < 38887
        Accel_Cmd_X = 0;
        Accel_Cmd_Y = 0;
        Accel_Cmd_Z = 1000;
    else
        Accel_Cmd_X = 0;
        Accel_Cmd_Y = 0;
        Accel_Cmd_Z = 0;
    end

end
```