Full Sim Experiment - Nominal

```
motorRes = [.4 .4 .4 .4];
load params/batteryParams.mat;
load params/Q_coef;
global batteryParams;

% original battery capacitance
Q_orig = 3.8712;

% iterations
k      = 375;

% voltage profiles
v{k,1} = [];

% soc profiles
z{k,1} = [];

% current profiles
c{k,1} = [];

% power profiles
p{k,1} = [];

% ss power vals
pows   = zeros(1,k);

% final landing position  <-- system performance parameter (but no position
% controller, so this gets off very quickly)
posf   = zeros(2,k);

% total power consumption <-- system performance parameter
powt   = zeros(1,k);

% motor resistance vals
mval   = zeros(1,k);

% final soc               <-- system performance parameter (if the
% remaining soc after 50% of the mission goes below a certain threshold,
% then the uav can't return)
soce   = zeros(1,k);

% battery capacitance vals
Qa     = zeros(1,k);

% estimated capacitance
Qe     = Qa;

% predicted capacitance
Qp     = Qa;
```

```
% ss rpm
rpms    = zeros(1,k);

% estimated rpm
RPMe    = rpms;

% predicted rpm
RPMp    = rpms;

% rpm residual
rpmr    = rpms;

% battery residual
batr    = Qa;

% prediction horizon
horizon = 10;

% to save eol vals (set in loop)
eolBatt = 1;
eolMot  = 1;
eolSys  = 1;

% battery prediction/estimation variables
maintWarnBatt = 1;
maintNoticeBatt = false;
failWarnBatt = 1;
failNoticeBatt = false;

maintThreshBatt = 3.48;
failThreshBatt  = 3.0922;

maintFlagBatt = false;
failFlagBatt  = false;

% motor prediction/estimation variables
maintWarnMot    = 1;
maintNoticeMot = false;
failWarnMot     = 1;
failNoticeMot   = false;

% set on first iteration
maintThreshMot = 1;
failThreshMot  = 1;
setRPM         = 1;

maintFlagMot = false;
failFlagMot  = false;

time = 0;

f = waitbar(0, 'simulation starting...');
tic
for i = 1:k
```

```
% -------------------- progress bar ----------------------
waitbar(round((i/k), 2),f, ['simulation in progress, iteration: ' num2str(i) ', elapsed tim
% --------------------------------------------------------

% execute the simulation
sim('MavicProComplete_oct22');

% save some variables
v{i}  = v_batt_hat.Data;
z{i}  = soc_hat.Data;
c{i}  = i_batt.Data;
p{i}  = power.Data;
time  = time + tout(end);

% get steady state power consumption
pows(i) = power.Data(uint16(length(tout)/2));

% get total power consumption
powt(i) = sum(power.Data);

% add the motor resistance to the list
mval(i) = motorRes(1);

% get the final SOC
soce(i) = soc_hat.Data(end);

% track the rpm and current consumption residuals
rpmr(i) = sum(rpm_res.Data.^2);
batr(i) = sum(r.Data.^2);

% get the final position
posf(:,i) = [round(pos(end,1),1), round(pos(end,2),1)];

% add the current capacitance to the list
Qa(i) = batteryParams.Q;

% get the steady state rpm
rpms(i) = rpm.Data(uint16(length(tout)/2));

% use the steady state rpm in the first run as the setRPM (nominal)
if i == 1
    setRPM = rpms(i);
    maintThreshMot = .95 * rpms(i);
    failThreshMot  = .9 * rpms(i);
end

% update the degradation parameters according to their degredation
% functions
batteryParams.Q  = polyval(Q_coef, i);
motorRes(1) = motorRes(1) + .001;

% sample the rpm and capacitance from a normal distribution
RPMe(i) = normrnd(rpms(i), 30);
```

```
    Qe(i) = normrnd(Qa(i), .03);

    save('params/batteryParams.mat', 'batteryParams');

    if i >= horizon
        x = ((i-(horizon-1)):1:i)';

        % --------------------------------- Battery -----------------------
        % fit a linear curve for estimation using the sampled capacitance
        q_poly = polyfit(x, smoothdata(Qe((i-(horizon-1)):i)', 'rlowess', 5), 1);

        % for plotting
        q_pred = polyval(q_poly, i+5);
        Qp(i) = q_pred;

        % for prediction
        q_pred = polyval(q_poly, i+horizon);

        % threshold checking ---------------------------------------------
        if ~maintFlagBatt && q_pred <= maintThreshBatt
            maintFlagBatt = true;
            maintWarnBatt = i;
            disp(["Battery Maintenance threshold will be reached at cycle: "  num2str(i+horizon
            disp(["Cumulative flight hours: "  num2str(time/60/60)]);
        end

        if ~maintNoticeBatt && Qe(i) >= .995*maintThreshBatt && Qe(i) <= 1.01*maintThreshBatt
            maintNoticeBatt = true;
            disp(["Battery Maintenance Required. Current cycle: " num2str(i)]);
            disp(["Cumulative flight hours: "  num2str(time/60/60)]);
        end

        if ~failFlagBatt && q_pred <= failThreshBatt
            failFlagBatt = true;
            failWarnBatt = i;
            disp(["Battery Failure threshold will be reached at cycle: "  num2str(i+horizon)  '
            disp(["Cumulative flight hours: "  num2str(time/60/60)]);
        end

        if ~failNoticeBatt && Qe(i) >= .995*failThreshBatt && Qe(i) <= 1.01*failThreshBatt
            failNoticeBatt = true;
            disp(["Estimated battery failure is reached. Current cycle: " num2str(i)]);
            disp(["Cumulative flight hours: "  num2str(time/60/60)]);
        end

        if Qa(i) <= failThreshBatt
            disp(["Actual battery failure is reached. Current cycle: " num2str(i)]);
            disp(["Cumulative flight hours: "  num2str(time/60/60)]);
            eolBatt = i;
            break
        end

        % --------------------------------- Motor -----------------------
```

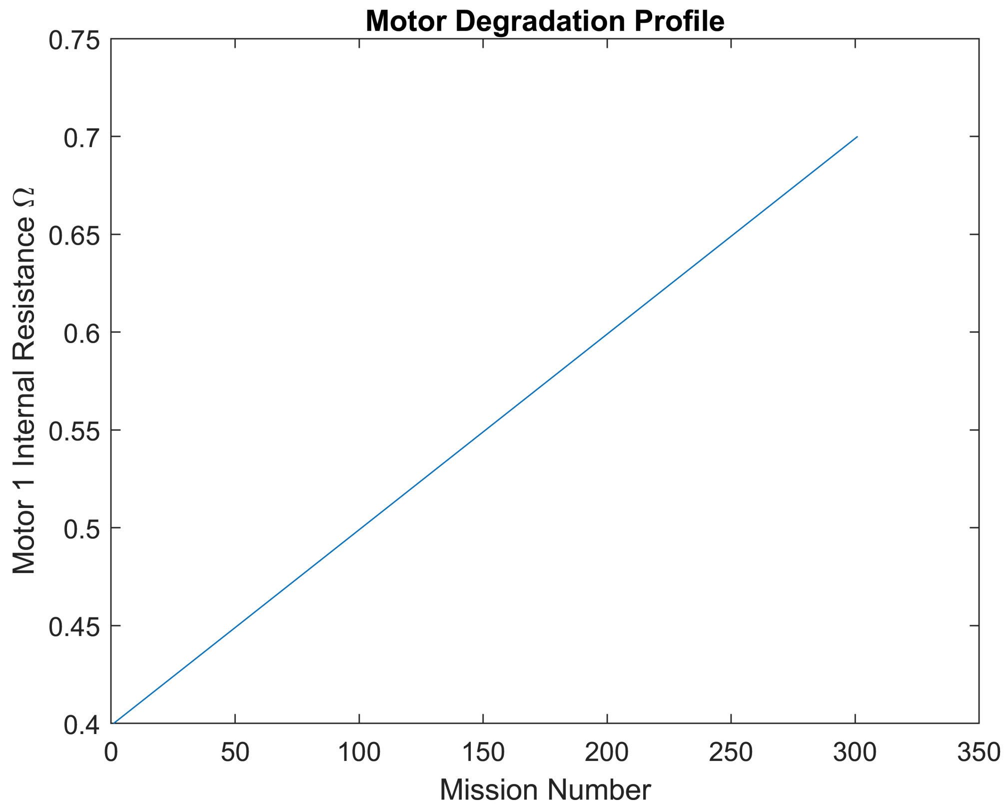
```
        % fit a linear curve for estimation using the sampled rpm data
        p_rpm = polyfit(x, smoothdata(RPMe((i-(horizon-1)):i)', 'rlowess', 15), 1);

        % for plotting
        RPMp(i) = polyval(p_rpm, i+5);

        % for prediction
        rpm_pred = polyval(p_rpm, i+horizon);

        % threshold checking ----------------------------------------
        if ~maintFlagMot && rpm_pred <= maintThreshMot
            maintFlagMot = true;
            maintWarnMot = i;
            disp(["Motor Maintenance threshold will be reached at cycle: "  num2str(i+horizon)
            disp(["Cumulative flight hours: "  num2str(time/60/60)]);
        end

        if ~maintNoticeMot && RPMp(i) >= .995*maintThreshMot && RPMp(i) <= 1.01*maintThreshMot
            maintNoticeMot = true;
            disp(["Motor Maintenance Required. Current cycle: " num2str(i)]);
            disp(["Cumulative flight hours: "  num2str(time/60/60)]);
        end

        if ~failFlagMot && rpm_pred <= failThreshMot
            failFlagMot = true;
            failWarnMot = i;
            disp(["Motor Failure threshold will be reached at cycle: "  num2str(i+horizon)  ".'
            disp(["Cumulative flight hours: "  num2str(time/60/60)]);
        end

        if ~failNoticeMot && RPMp(i) >= .995*failThreshMot && RPMp(i) <= 1.01*failThreshMot
            failNoticeMot = true;
            disp(["Estimated Motor failure is reached. Current cycle: " num2str(i)]);
            disp(["Cumulative flight hours: "  num2str(time/60/60)]);
        end

        if rpms(i) <= failThreshMot
            disp(["Actual Motor failure is reached. Current cycle: " num2str(i)]);
            disp(["Cumulative flight hours: "  num2str(time/60/60)]);
            eolMot = i;
            break
        end

        % -------------------------------- System ----------------------


    end
end
toc

pgon = polyshape([failWarnMot failWarnMot eolMot eolMot], [rpms(failWarnMot)-8 rpms(failWarnMot
motorResults.setRPM    = setRPM;
motorResults.rpms      = rpms;
motorResults.mvals     = mval;
```

```
motorResults.RPMe     = RPMe;
motorResults.RPMpreds = RPMp;
motorResults.eol      = eolMot;
motorResults.pgon     = pgon;
motorResults.rpmr     = rpmr;

motorResults.failThresh  = failThreshMot;
motorResults.failWarn    = failWarnMot;
motorResults.maintWarn   = maintWarnMot;
motorResults.maintThresh = maintThreshMot;


save('motorResults.mat', 'motorResults');

pgon = polyshape([failWarnBatt failWarnBatt eolBatt eolBatt], [Qa(failWarnBatt)+.03 Qa(failWarn
batteryResults.Qe    = Qe(1:eolBatt);
batteryResults.Qp = Qp(1:eolBatt);
batteryResults.Qa    = Qa(1:eolBatt);
batteryResults.pgon  = pgon;
batteryResults.eol   = eolBatt;
batteryResults.v     = v;
batteryResults.z     = z;
batteryResults.batr  = batr;

batteryResults.maintWarn   = maintWarnBatt;
batteryResults.failWarn    = failWarnBatt;
batteryResults.maintThresh = maintThreshBatt;
batteryResults.failThresh  = failThreshBatt;

batteryParams.Q  = Q_orig;
save('batteryResults.mat', "batteryResults");
save('params/batteryParams.mat', 'batteryParams');

close(f);
```

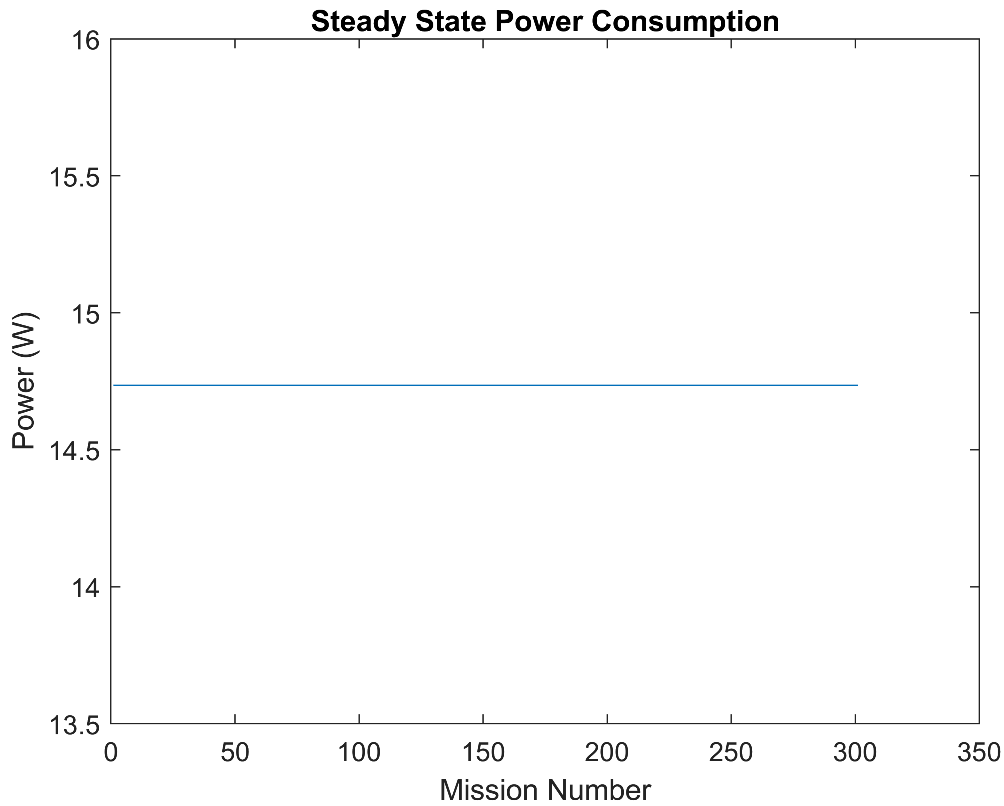
```
disp("mission took: " + num2str(tout(end)) + "seconds");
disp("rpm residual: " + num2str(mean(rpm_res/100)));
disp("final position: " + num2str(round(pos(end,1),1)) + "," + num2str(round(pos(end,2),1)));
disp("soc: " + num2str(soc.Data(end)));
```

Prognostic Experiment Plots

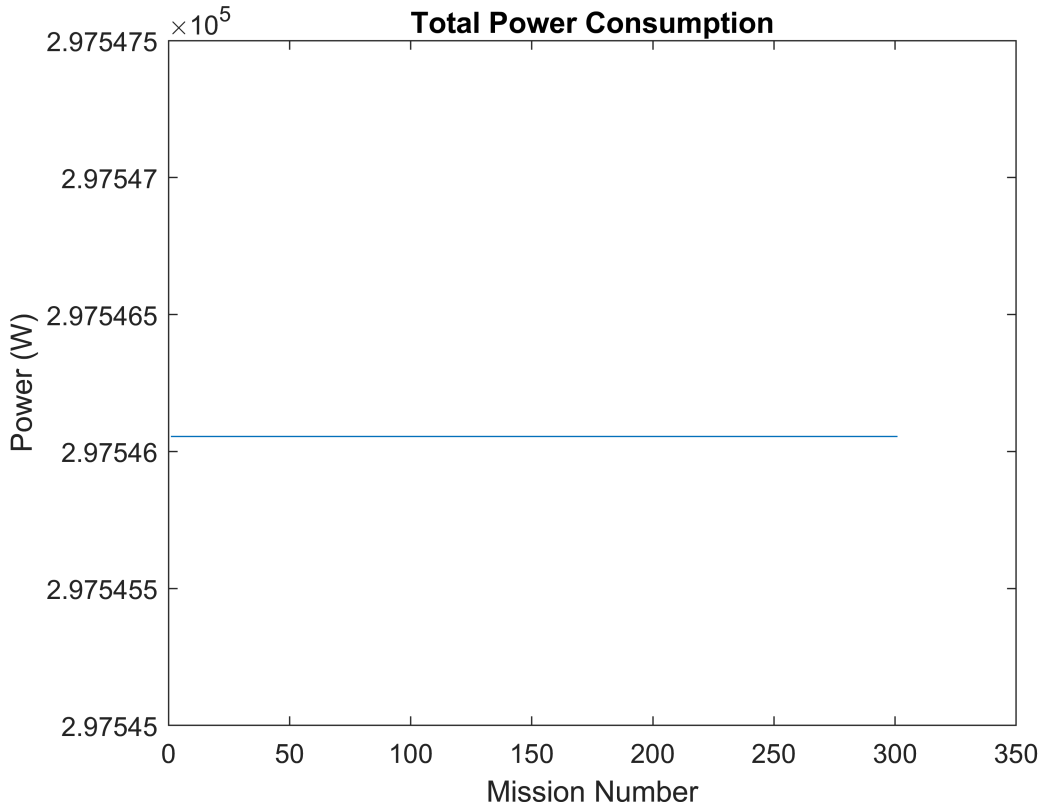
```
plot(mval(1:eolBatt));
title("Motor Degradation Profile");
xlabel("Mission Number");
ylabel("Motor 1 Internal Resistance {\Omega}")
```



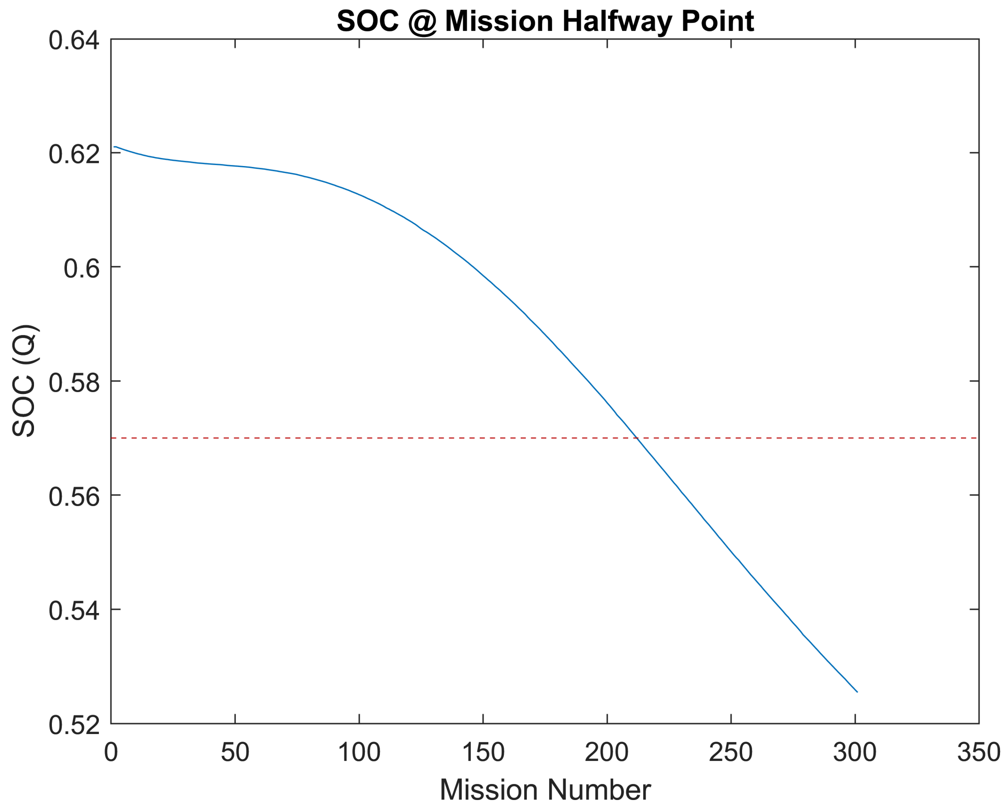

```
plot(pows(1:eolBatt));
title("Steady State Power Consumption");
xlabel("Mission Number")
ylabel("Power (W)");
```



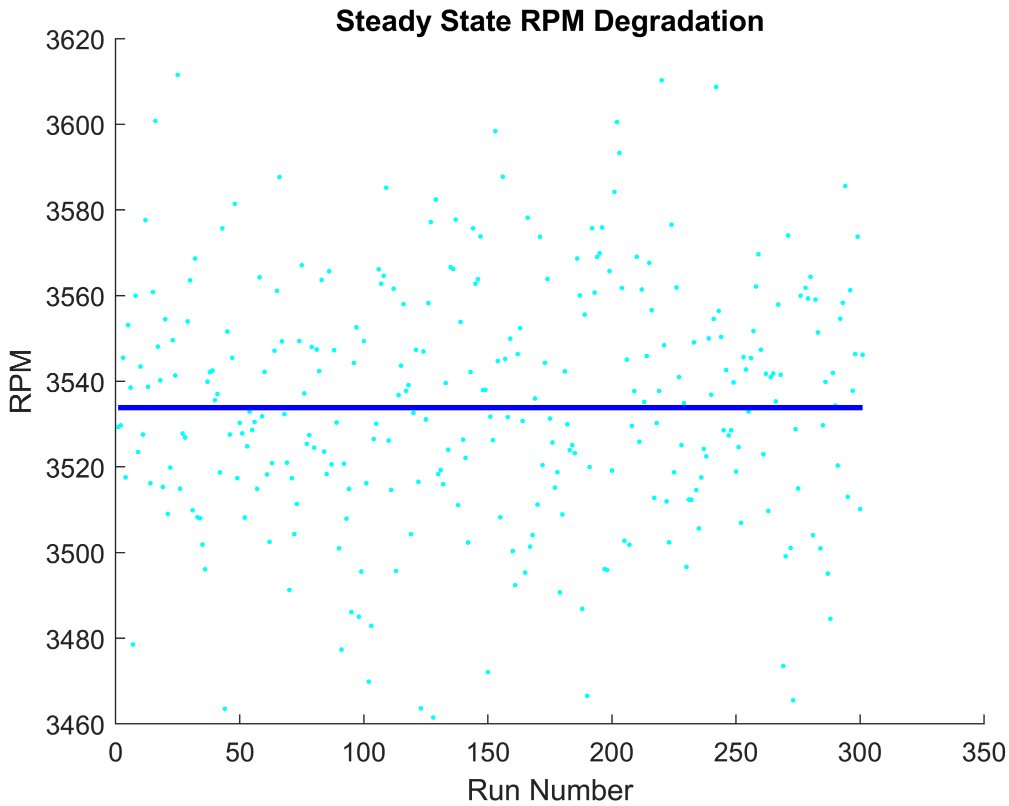

```
plot(powt(1:eolBatt));
title("Total Power Consumption");
xlabel("Mission Number");
ylabel("Power (W)");
```




```
plot(soce(1:eolBatt));
title("SOC @ Mission Halfway Point");
yline(.57, 'r--');
xlabel("Mission Number");
ylabel("SOC (Q)");
```

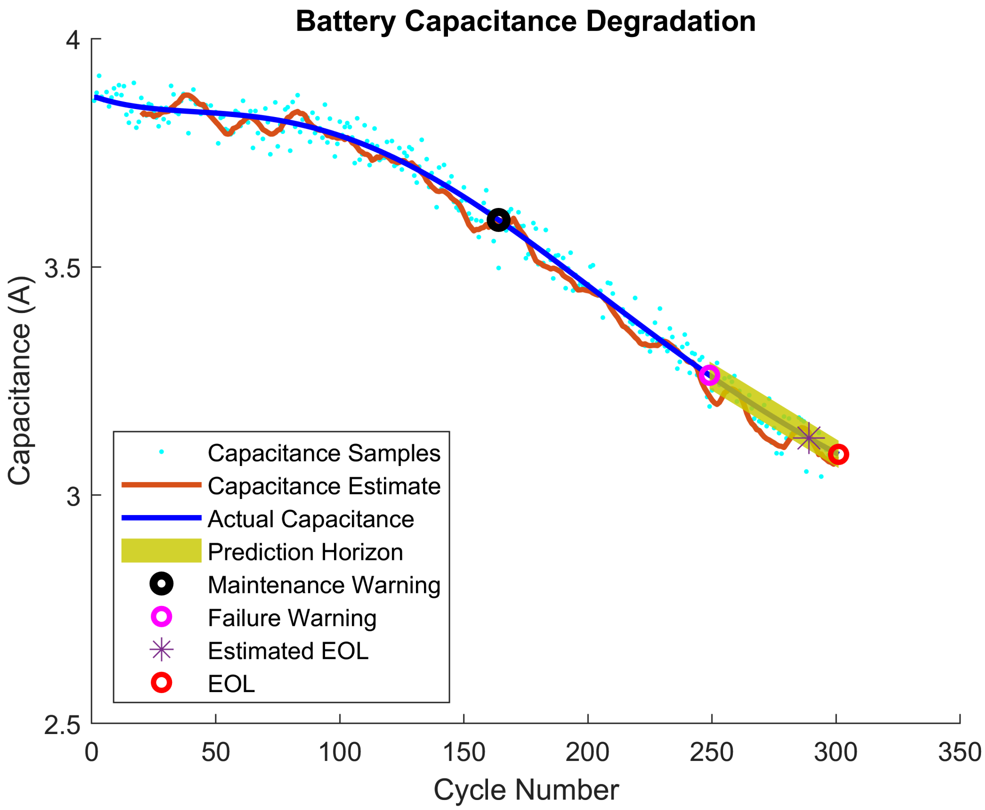



```
eolMot = 301;
fmot = figure(100); clf;
hold on;
plot(RPMe(1:eolMot), 'c.');
%plot([20:1:eolMot]',smoothdata(RPMp(20:eolMot), 'movmean', 15), 'linew', 2);
plot(rpms(1:eolMot), 'b', 'linew', 2);
%pgon = polyshape([failWarnMot failWarnMot eolMot eolMot], [rpms(failWarnMot)-8 rpms(failWarnMo
%plot(pgon, 'FaceColor', 'yellow', 'FaceAlpha', .89, 'EdgeColor', 'none');
%plot(maintWarnMot+40, rpms(maintWarnMot+40), 'ko', 'linew', 3);
%plot(failWarnMot, rpms(failWarnMot), 'mo', 'linew', 2);
%plot(failWarnMot+40, rpms(failWarnMot+37), '*', 'MarkerSize', 12);
%plot(eolMot, rpms(eolMot), 'ro', 'linew', 2);
hold off;
title("Steady State RPM Degradation");
xlabel("Run Number");
ylabel("RPM");
```




```
%legend(["RPM Samples", "RPM Estimate", "Actual RPM", "Prediction Horizon", "Maintenance Warnir
```

```
fbat = figure(101); clf;
hold on;
plot(Qe(1:eolBatt), 'c.');
plot([20:1:eolBatt]',smoothdata(Qp(20:eolBatt), 'movmean', 10), 'linew', 2);
plot(Qa(1:eolBatt), 'b', 'linew', 2);
pgon = polyshape([failWarnBatt failWarnBatt eolBatt eolBatt], [Qa(failWarnBatt)+.03 Qa(failWarr
plot(pgon, 'FaceColor', 'yellow', 'FaceAlpha', .79, 'EdgeColor', 'none');
plot(maintWarnBatt, Qa(maintWarnBatt), 'ko', 'linew', 3);
plot(failWarnBatt, Qa(failWarnBatt), 'mo', 'linew', 2);
plot(failWarnBatt+40, Qa(failWarnBatt+40), '*', 'MarkerSize', 12);
plot(eolBatt, Qa(eolBatt), 'ro', 'linew', 2);
hold off;
%set(get(get(s, 'Annotation'), 'LegendInformation'), 'IconDisplayStyle', 'off');
title("Battery Capacitance Degradation");
xlabel("Cycle Number");
ylabel("Capacitance (A)");
ylim([2.5 4]);
legend(["Capacitance Samples", "Capacitance Estimate", "Actual Capacitance", "Prediction Horizo
```



Single Run Plots

```
f1 = figure(1); clf;
set(gcf, 'Position', [0 0 600 400]);
hold on;
plot(soc.Time, soc.Data);
plot(soc_hat.Time, soc_hat.Data);
title("SOC Estimation");
legend(["Actual SOC", "Estimated SOC"]);
ylabel("SOC");
xlabel("Time (s)");
hold off;
```

```
f2 = figure(2); clf;
hold on;
plot(noisy_v.Time, noisy_v.Data, 'g');
plot(v_batt_hat.Time, smoothdata(v_batt_hat.Data, 'movmean', 500), 'r', 'linewidth', 2);
plot(v_batt.Time, smoothdata(v_batt.Data, 'movmean', 500), 'b--', 'linewidth', 2);
hold off;
title("Voltage Curve During Flight");
xlabel("Time (s)");
ylabel("Voltage");
legend(["Noisy Voltage Reading", "Estimated Voltage", "Actual Voltage"]);
```

```
i_hatData = i_hat.Data(1,:);
```

```
f3 = figure(3); clf;
hold on;
plot(i_hat.Time, i_hatData, 'g');
plot(i_mot.Time, i_mot.Data, 'b', 'linewidth', 2);
hold off;
% title("Single Motor Current Draw");
xlabel("Time (s)");
ylabel("Current (A)");
legend(["Estimated Current", "Actual Current: " + num2str(i_mot.Data(1000))]);
ylim([0 4]);
```

```
f4 = figure(4); clf;
hold on;
plot(rpm_hat.Time, rpm_hat.Data, 'g');
plot(rpm.Time, rpm.Data, 'b', 'linewidth', 2);
hold off;
xlabel("Time (s)");
ylabel("RPM");
ylim([0 4500]);
title("Single Motor RPM");
legend(["Estimated RPM", "Actual RPM"]);
```

```
f5 = figure(5); clf;
set(gcf, 'Position', [0 0 600 400]);
plot3(pos(:,1), pos(:,2), pos(:,3));
%xlim([-1 1]);
xlabel("Offset (m)");
ylabel("Distance (m)");
zlabel("Altitude (m)");
title("UAV Trajectory");
```

```
f6 = figure(6); clf;
plot(i_batt.Time, i_batt.Data, 'linewidth', 2);
title("Total Current Draw");
xlabel("Time (s)");
ylim([0 18]);
ylabel("Current (A)");
legend(["Steady State: " + num2str(i_batt.Data(1000))]);
```

```
f7 = figure(7); clf;
plot(m1_throttle.Time, m1_throttle.Data, 'linewidth', 2);
title("Motor 1 Throttle");
xlabel("Time (s)");
ylabel("Throttle (%)");
ylim([0 50]);
```

```
f8 = figure(8); clf;
set(gcf, 'Position', [0 0 1400 400]);
subplot(131);
plot(tout, pos(:,3));
```

```
title("Altitude");
xlabel("Time (s)");
ylabel("Height (m)");
subplot(132);
plot(tout, pos(:,2));
title("Distance Travelled");
xlabel("Time (s)");
ylabel("Distance (m)");
subplot(133);
plot(tout, pos(:,1));
title("Tracking Error");
xlabel("Time (s)");
ylabel("Error (m)");
```

```
f10 = figure(10); clf;
set(gcf, 'Resize', 'On');
plot(power.Time, power.Data, 'linew', 2);
title("Power Consumption During Flight");
xlabel("Time (s)");
ylabel("Power Consumption (w)");
ylim([0 50]);
```

```

```