AME532a Second Proposal Report

Jiaoran Wang

6205909903

Contents

Abstract

The aerodynamic model of this report is based on the data of ASW28 model and 12 equations of steady state. The research objectives are the design of model control system and the basic aerodynamic analysis. Firstly, the system block diagram is built as well as controllers applied using MATLAB & Simulink. Secondly, the dynamic analysis results from XFLR5 and ANSYS FLUENT are compaired to enhence the comprehension of flight dynamics and also optimize the dynamatic coefficients in control systems. Finally, the block diagrams connect with FlightGear for the controller simulation display.

Chapter 1: Introduction

This report uses ASW28 model for base model calculation:

```
%% Define Aircraft Mass and Geometry Properties (using grams)
%     mass     xSize     ySize     zSize     xLoc     yLoc     zLoc
%     1        2         3         4         5        6        7
componentMassesAndGeom = ...
    [90      0.1       0.96      0.01      -0.23     0.44     0;          % RightWing+Servo
     90      0.1       0.96      0.01      -0.23    -0.44     0;          % LeftWing+Servo
     13      0.075     0.35      0.002     -0.76    0         0.16;       % Elevator
     72      0.065     0.035     0.015     -0.05    0         0.03;       % Battery
     106     0.87      0.07      0.07      -0.4     0         0;          % Fuselage
     27      0.05      0.03      0.005     -0.05    0         0.02;       % Motor Controller
     10      0.04      0.02      0.005     0.1      0         0.02;       % Radio
     20      0.05      0.01      0.01      -0.014   0         0;          % 2 Servos
     40      0.03      0.02      0.02      0.02     0         0.01;       % Motor
     12      0         0.26      0.025     0.05     0         0.01];      % Propeller
```

For project, use geometry from above to define position of each aero surface (x_B_B_s2R, s4R, s5R), as well as chord, span, area, and aspect ratio. For rudder (attached to the fuselage) use the following:

```
x_s3 = [-0.76; 0; -0.09]; c_s3 = 0.08; b_s3 = 0.08;
```

Figure 1-1. ASW28 Data

Chapter 2: ASW28 Flight Control System

2.1 State Equations

$$\begin{bmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix} = \begin{bmatrix} 1 & \sin\phi\tan\theta & \cos\phi\tan\theta \\ 0 & \cos\phi & -\sin\phi \\ 0 & \sin\phi/\cos\theta & \cos\phi/\cos\theta \end{bmatrix} \begin{bmatrix} P \\ Q \\ R \end{bmatrix} \tag{2-1}$$

$$\mathbf{v}_{P/a} = \mathbf{v}_{Q/a} + (\mathbf{v}_{P/b} + \boldsymbol{\omega}_{b/a} \times \mathbf{p}_{P/Q}) \tag{2-2}$$

$$^{e}\dot{\mathbf{v}}_{cm/e} = \frac{1}{\mathrm{m}}\mathbf{F} + \mathbf{G} - \boldsymbol{\omega}_{e/i} \times (\boldsymbol{\omega}_{e/i} \times \mathbf{p}_{cm/O}) - 2\,\boldsymbol{\omega}_{e/i} \times \mathbf{v}_{cm/e} \tag{2-3}$$

$$^{b}\dot{\boldsymbol{\omega}}^{bf}_{b/i} = (J^{bf})^{-1}\left[\mathbf{M}^{bf} \ - \tilde{\boldsymbol{\omega}}^{bf}_{b/i} J^{bf} \ \boldsymbol{\omega}^{bf}_{b/i}\right] \tag{2-4}$$

Figure 1-1. Control System

The above figure shows the 12 state-equations which are the base of control system.

Or maybe this? The flat-Earth equations of motion:

$$\begin{aligned}
C_{frd/tp} &= fn(\Phi) \\
\dot{\Phi} &= H(\Phi)\,\boldsymbol{\omega}^{frd}_{b/e} \\
^{e}\dot{\mathbf{p}}^{tp}_{cm/Q} &= C_{tp/frd}\,\mathbf{v}^{frd}_{cm/e} \\
^{b}\dot{\mathbf{v}}^{frd}_{cm/e} &= \frac{1}{\mathrm{m}}\mathbf{F}^{frd} + C_{frd/tp}\mathbf{g}^{tp} - \tilde{\boldsymbol{\omega}}^{frd}_{b/e}\,\mathbf{v}^{frd}_{cm/e} \\
^{b}\dot{\boldsymbol{\omega}}^{frd}_{b/e} &= \left(J^{frd}\right)^{-1}\left[\mathbf{M}^{frd} - \tilde{\boldsymbol{\omega}}^{frd}_{b/e} J^{frd} \boldsymbol{\omega}^{frd}_{b/e}\right]
\end{aligned}$$

2.2 Control System Design

2.2.1 Overall System

The dynamic control system contains five sub systems: Translational Kinematics & Dynamics, Rotational Kinematics & Dynamics and Aero Surface. Most of the imported

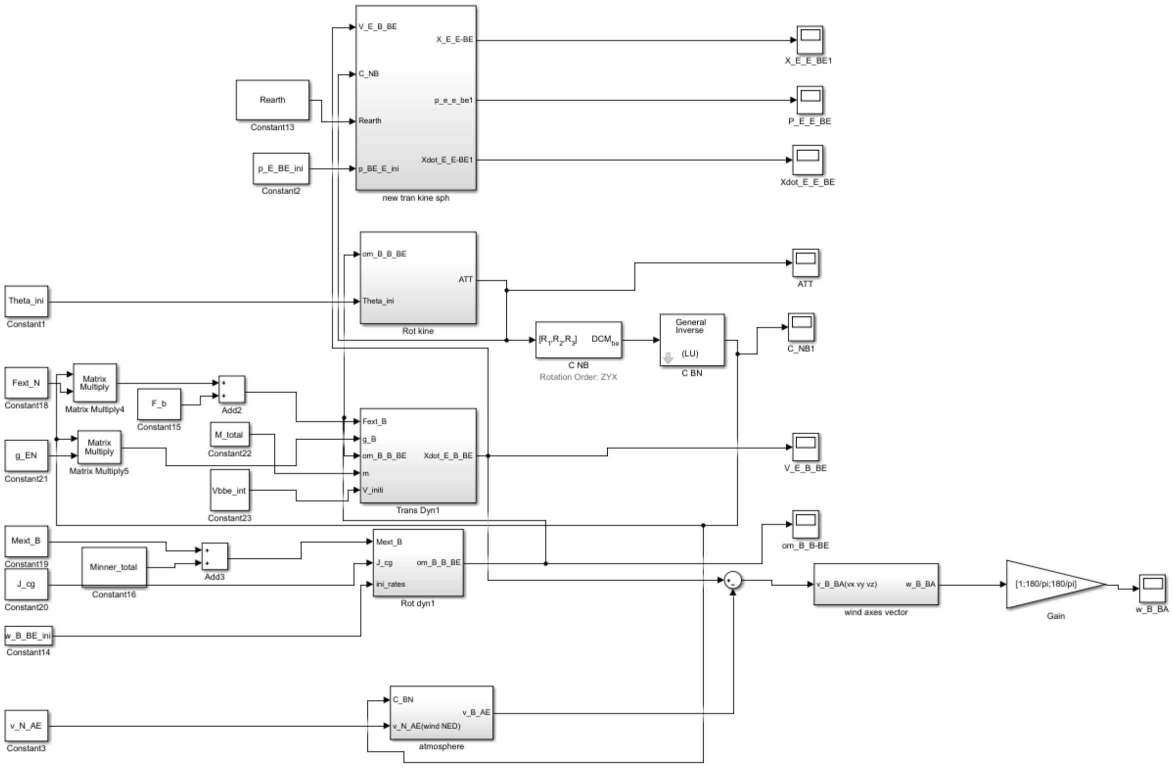


Figure 1-1. Control System

parameters are calculated outside the Simulink blocks in order to reduce the number of systems calculating steps.

2.2.2 Aero Surface Controller Design

The CL_s could be adding the aero surface infections according to the blocks

$$C_\ell = C_\ell(\alpha,\beta,M) + \Delta C_{\ell_{\delta a}}(\alpha,\beta,M,\delta_r) + \Delta C_{\ell_{\delta r}}(\alpha,\beta,M,\delta_a)$$
$$+ \frac{b}{2V_T}\left[C_{\ell_p}(\alpha,M)P + C_{\ell_r}(\alpha,M)R\right],$$

```
CL1=CL0_2345(1)+CLa(1).*a_ss1+3*elevator*0.5;
CL2=CL0_2345(2)+CLa(2).*a_ss2+3*rudder*0.5;
CL3=CL0_2345(3)+CLa(3).*a_ss3+3*aileron_r*0.5;
CL4=CL0_2345(4)+CLa(4).*a_ss4+3*aileron_l*0.5;
```

Figure 1-1 Full Span Control Surface coefficient

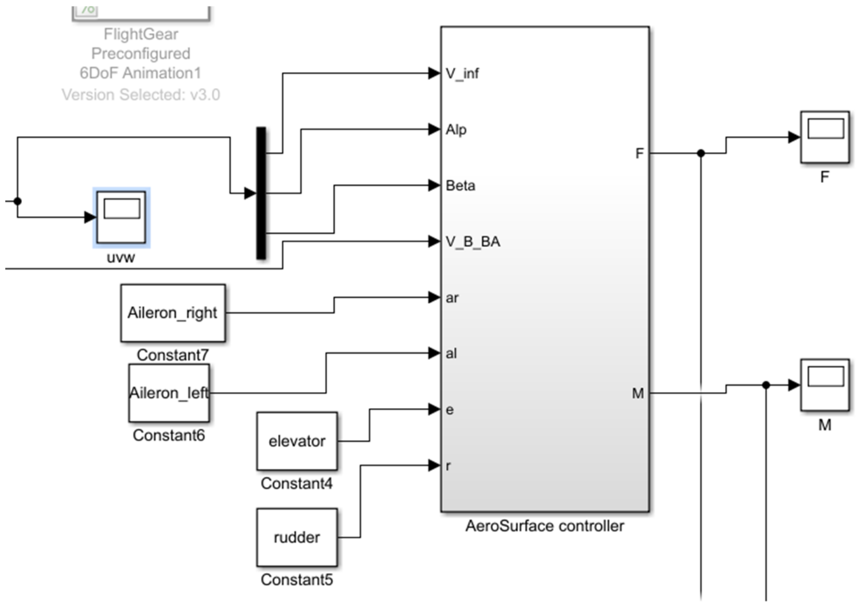


Figure 1-1. Aero Surface Controller

2.3 Controller Design

2.3.1 Autopilot Controller Concepts

The figure shows how autopilot control system works by using inner and outer feedback loop to control ailerons then reach desired roll positions. Following the same principle, we could

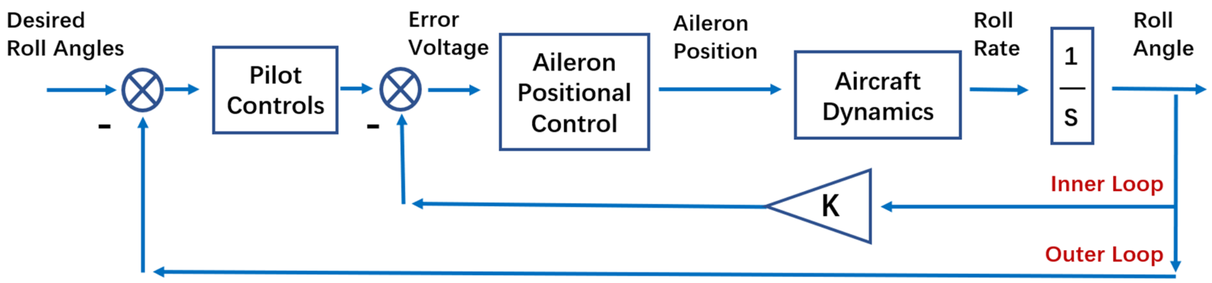


Figure 1-1. Autopilot Roll Angle Control Design

design different controllers for elevator to control pitch and rudder for yaw angles, in which case, the aero control system is added into the system. Besides, the parameters (such as V_inf) should change in real time.

1) Rolling Moment

Rolling moments are created by sideslip alone, by the control action of the ailerons and the rudder, and as damping moments resisting rolling and yawing motion.

After applying the aero surface into the blocks, the inner force and moment will change in real time.

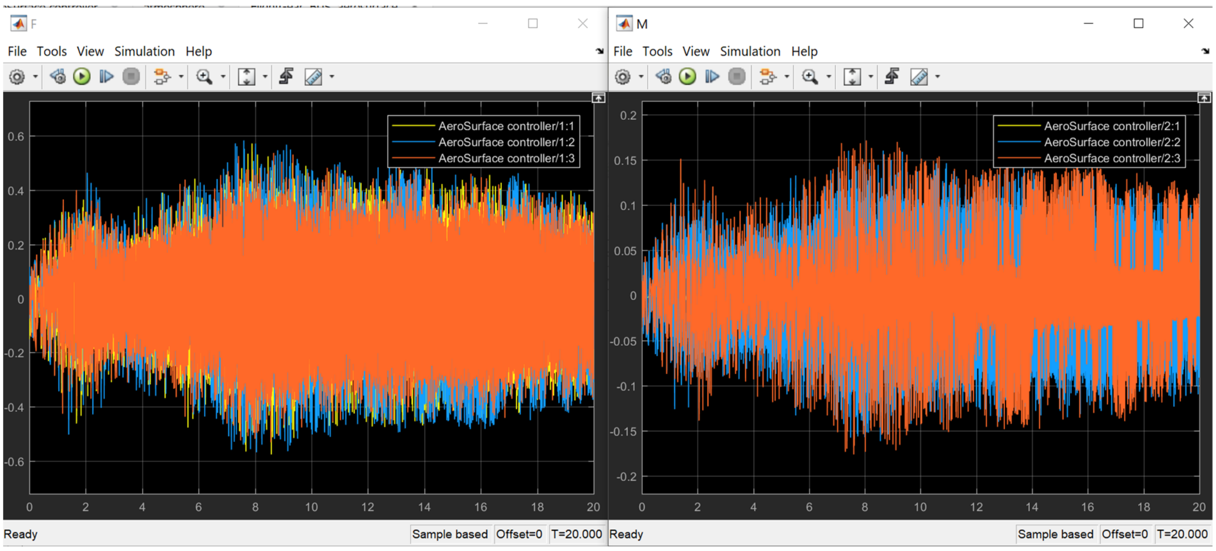


Figure 1-1 Real Time Inner Force and Moment

2.3.2 PID controller design

1) PID in Rotational Kinemics loop

Inside Rotational Dynamics, The PID controller is set up to eliminate the flight tremor during the cruising flight. Enlightened by autopilot block design in simulation, the PID controller is applied before Euler angle changed along the rotational rates in Body system respect to Earth reference frame. By using PID tuning system, the pitch and yaw offset curve could be trimmed

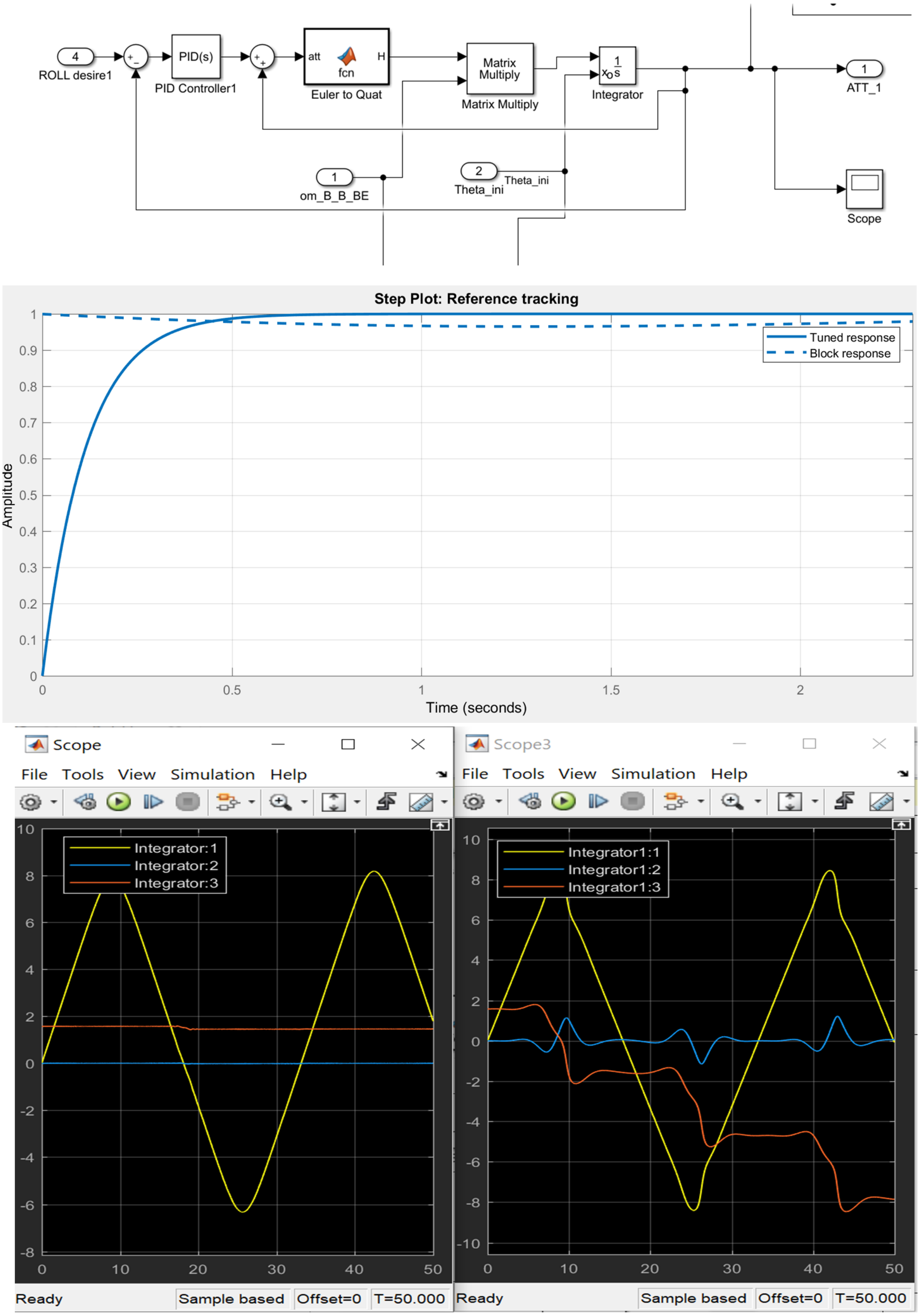


Figure 1-1. PID Controller Design for vibration elimination

2) PID for Single Angle Design

Yaw angle tuned

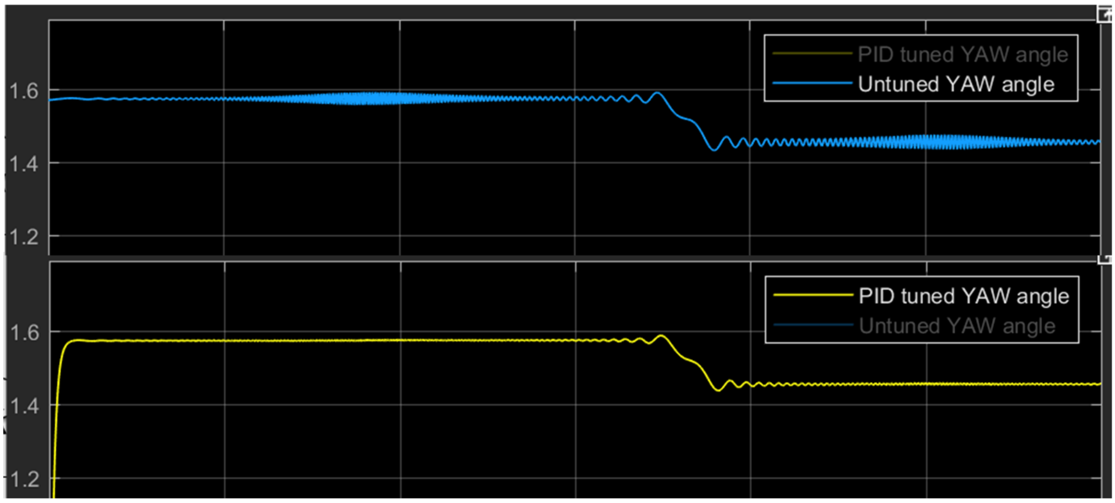


Figure 1-1. PID Controller Design for vibration elimination

3) Separate PID controller Design (Failed)

The three angles are coupled then I tried to use the separate:

Could not decouple them

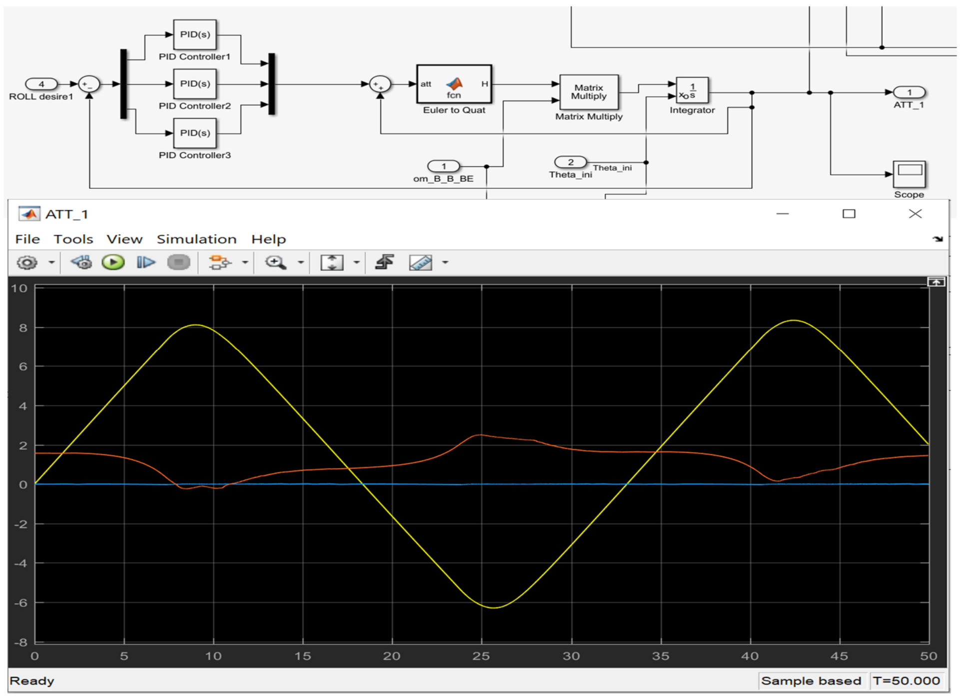


Figure 1-1. Control System

Chapter 3: Model Trim and Linearization

3.1 Model Trim

By using Linear Analysis in Simulink, the twelve states could be trim to linearize the outputs. After discussing with teammates, we decide to trim these seven states: [Alt, Phi, Psi, V, P, Q, R]

3.1.1 Model Trim (without aero surface)

Edit: op_trim3

Optimizer Output | Details

State | Input | Output

State	Desired Value	Actual Value	Desired dx	Actual dx
FlightGear_BUS_trim/Rot dyn1/Integrator				
State - 1	[-Inf , Inf]	0.074562	0	3.5035e-07
State - 2	[-Inf , Inf]	0.00074562	0	-9.0197e-05
State - 3	[-Inf , Inf]	0.00074562	0	2.1251e-05
FlightGear_BUS_trim/Rot kine/Integrator				
State - 1	[-Inf , Inf]	180.3976	0	0.076377
State - 2	[-Inf , Inf]	-7039.4817	N/A	0.00075466
State - 3	[-Inf , Inf]	429.3898	0	0.001959
FlightGear_BUS_trim/Trans Dyn1/Integrator				
State - 1	10	10	N/A	28.4981
State - 2	[-Inf , Inf]	1.197	0	0.57963
State - 3	[-Inf , Inf]	-65.6745	N/A	-11.2915
FlightGear_BUS_trim/new tran kine sph/Integrator				
State - 1	[-Inf , Inf]	-2718118.837	0	4.3914
State - 2	[-Inf , Inf]	-4265110.7431	0	-57.8781
State - 3	[-Inf , Inf]	2116798.011	0	-32.333

Figure 1-1. Linear Analysis Trim States

The results are showed below. The trimmed states are much linearized than untrimmed one. To be more particularly, the final simulation results have changed.

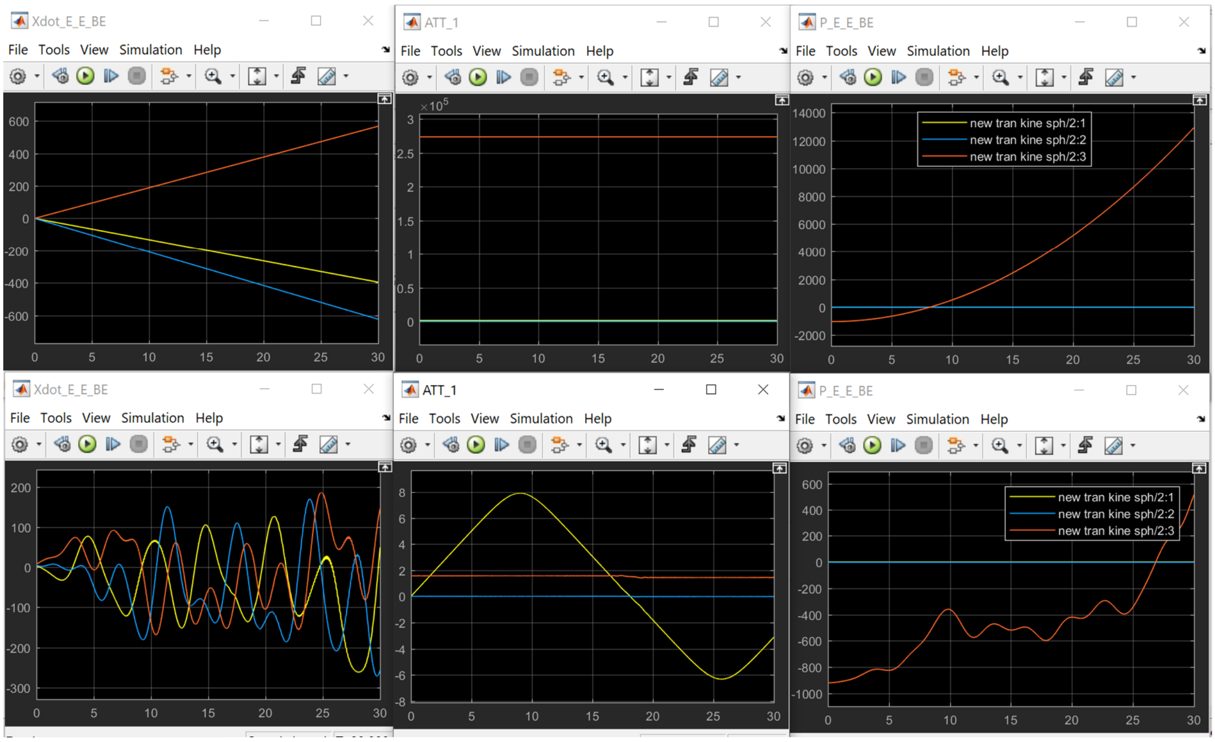


Figure 1-1. Trim Results (up: trimmed; down: untrimmed)

3.1.2 Model Trim (with aero surface)

After I apply the aero surfaces into the system:

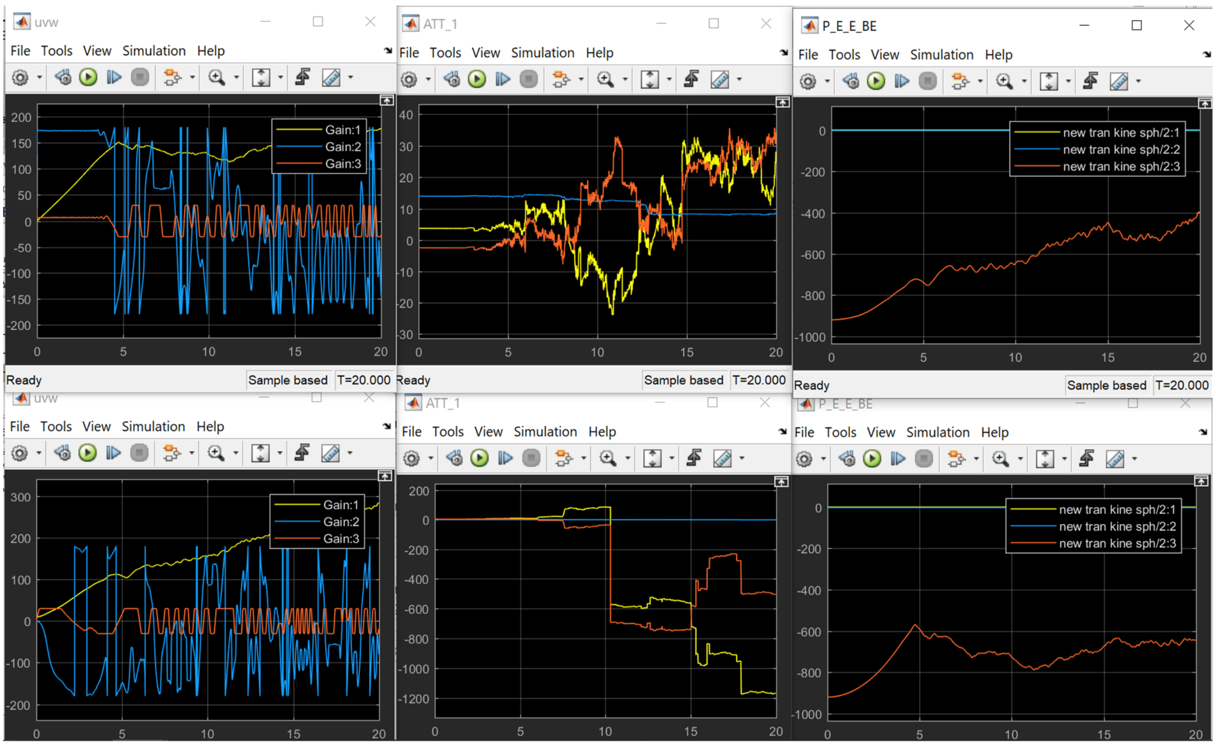
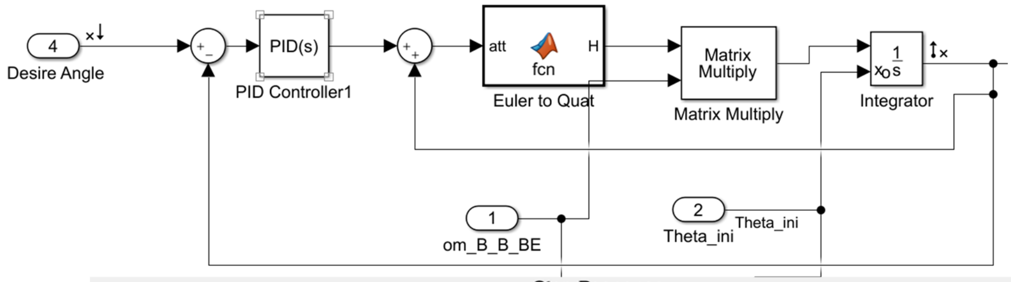


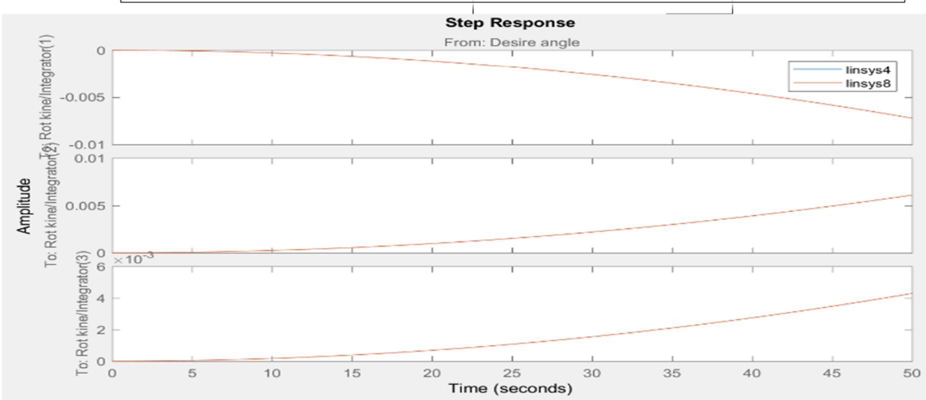
Figure 1-1. Trim Results (up: trimmed; down: untrimmed)

3.2 Model Linearization

3.2.1 Rotational Kinemics System Linearization

The linmode() in Simulink should

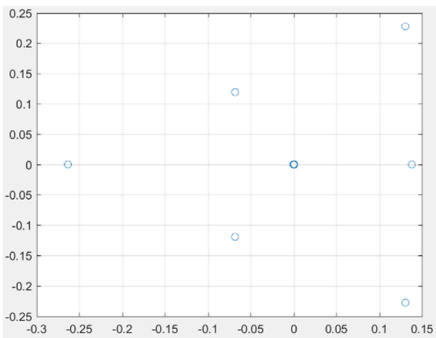




3.2.2 Full System Linearization

4.65E-06	0.000321	-0.00028	0	0	0	-3.61E-06	-1.11E-05	5.08E-06
-0.00048	0	0.004483	0	0	0	-0.00094	0.000719	-0.00111
0.00011	0.001788	-4.65E-06	0	0	0	-4.49E-05	-0.00014	6.27E-05
1	0.3858	-0.8841	-0.00016	0.000664	0	0	0	0
0	-0.9165	-0.3999	-0.00034	0	0	0	0	0
0	0.5557	-1.273	-0.00023	0.000461	0	0	0	0
0	-0.00335	0.002001	-3.476	-2.786	3.102	0.000153	-0.0003	-0.00013
0.003349	0	0.002582	-30.67	-2.13	30.73	0.000275	7.64E-05	0.00463
-0.002	-0.00258	0	-1.42E-10	-22.26	-3.329	0.000131	-0.00455	-0.00018

```
ans =
     -0.26354 +         0i
      0.13047 +    0.2275i
      0.13047 -    0.2275i
        0.138 +         0i
    -0.068307 +   0.11913i
    -0.068307 -   0.11913i
  -0.00033021 +         0i
   0.00071533 + 0.00032101i
   0.00071533 - 0.00032101i
```



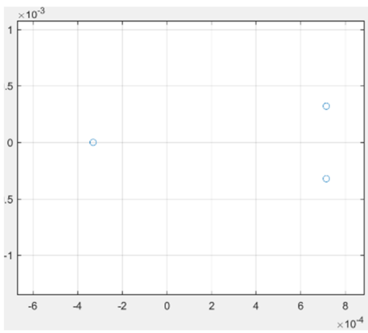
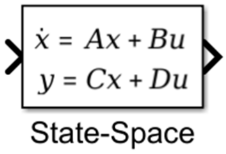


Figure 1-1. Trim Results (up: trimmed; down: untrimmed)

3.3 Linear States Analysis

3.3.1 Perfect Linear states



3.3.2 Comparison

Chapter 4: ASW28 Flight Dynamic Analysis

4.1 Introduction

In this chaptar,

Table-1: Flight Environment Parameters

Model Name	Velocity(m/s)	Temperatue(º F)	Altitute(m)	Air Density(kg/m^3)
ASW28	400	77	1000	1.074

4.2 XFLR5 Dynamic Analysis

4.2.1 Model Design

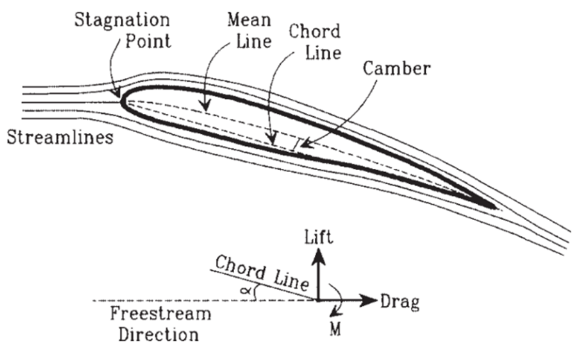


Figure 2.2-1 Definitions associated with an airfoil.

The model uses NACA 2412 data for main wing and elevator section and NACA 0009 for ruder section. By choosing proper sweepback angle and taper, the coefficients change along different alpha degree(-1.5 to 30 [deg])

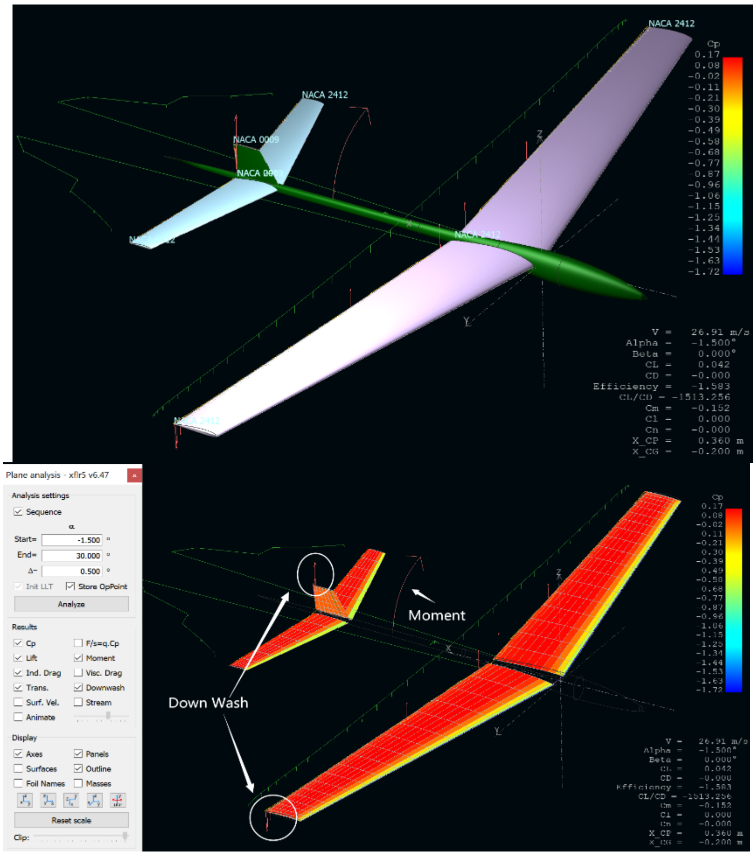


Figure 2.2-1 Definitions associated with an airfoil.

4.2.2 Dynamic Coefficient Calculation

The figure below shows without offset points.

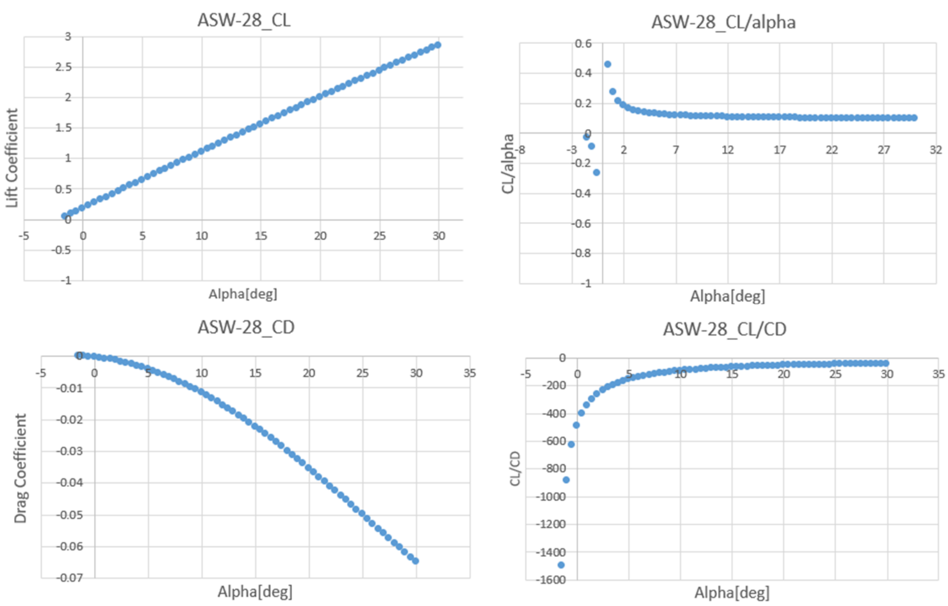


Figure 2.2-1 Definitions associated with an airfoil.

4.3. ANSYS Dynamic Analysis

4.3.1 Finite Element Analysis

By use ANSYS FLUENT module, the FEA analysis is applied to the whole

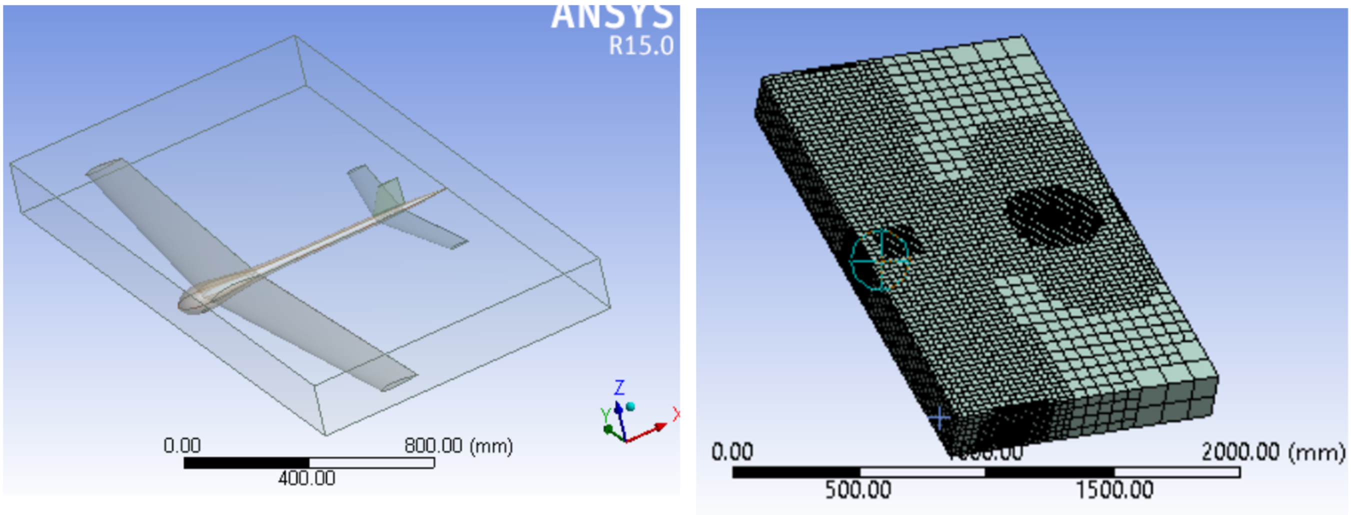


Figure 2.2-1 Definitions associated with an airfoil.

In order to control the variables in two methods, the model imported into ANSYS

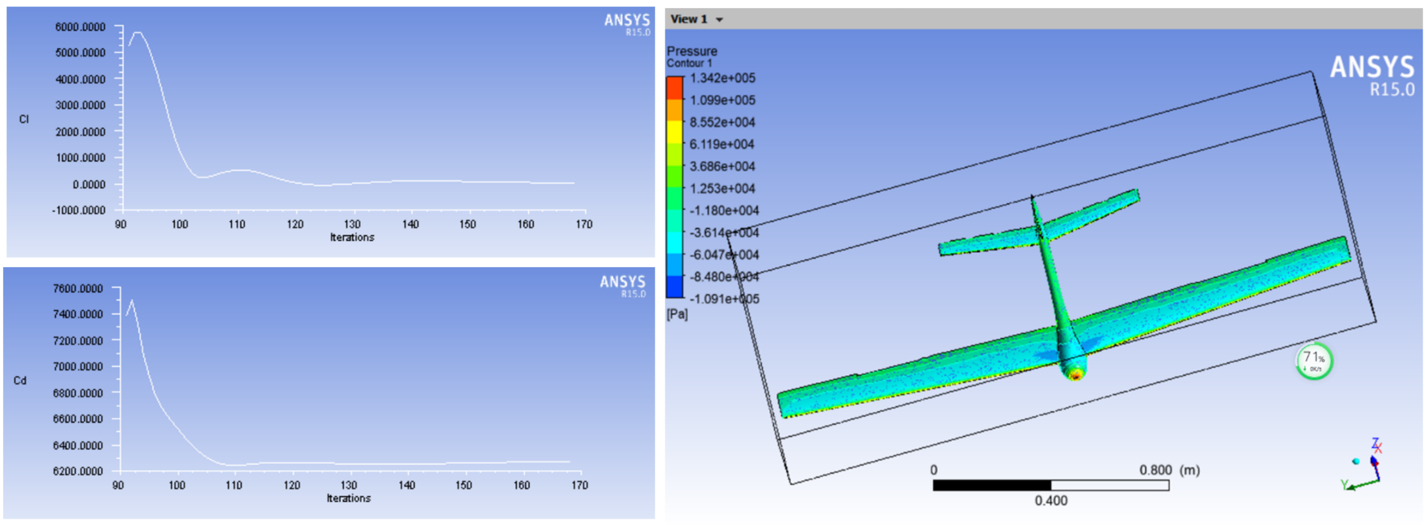


Figure 2.2-1 Definitions associated with an airfoil.

4.4. Results Comparison

4.4.1 Fuselage Analysis

4.4.2 Method Differences

4.4.3 Aerodynamic Parameter Distribution

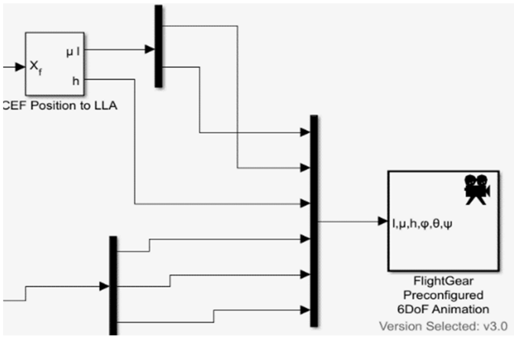
1) Pressure Distribution
2) Streamline Distribution

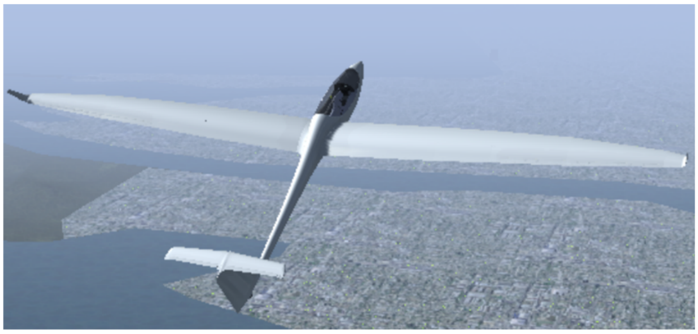
4.5 Conclusions

Chapter 5: Simulation

5.1 Connection to FlightGear

The block in aerospace basket is used to conneck MATLAB Simulink to FlightGear





```
C:
cd C:\Program Files\FlightGear
SET FG_ROOT=C:\Program Files\FlightGear\data
SET FG_SCENERY=C:\Program Files\FlightGear\data\Scenery;C:\Program Files\FlightGear\scenery;C:\Program
Files\FlightGear\terrasync
.\\bin\win64\fgfs --aircraft=asw28 --fdm=null --enable-auto-coordination --native-
fdm=socket,in,30,localhost,5502,udp --fog-disable --enable-clouds3d --start-date-lat=2004:06:01:09:00:00
--enable-sound --visibility=15000 --in-air --prop:/engines/engine0/running=true --disable-freeze --
airport=LAX --runway=06 --altitude=8000 --heading=0 --offset-distance=0 --offset-azimuth=0 --enable-
rembrandt
```

5.2 Lateral Motion Control

(See the book)

This could be a PID controller with the input from your current roll and a reference of zero. Output should go to your aileron-cmd.

5.3 Longitude Motion Control

5.4 Auto pilot

Conclusions

References

[1].STEVENS, B.L., F.L. LEWIS and E.N. JOHNSON, [1] Aircraft Control and Simulation Third Edition Dynamics, Controls Design, and Autonomous Systems, United States of America: John Wiley & Sons, Inc., Hoboken, New Jersey

[2]. Dr. Nelson, R.C., [2] Flight Stability and Automatic Control 2nd Ed.

[3]. Kaloust, J., C. Ham and Z. Qu, [3] Nonlinear autopilot control design for a 2-DOF helicopter model.

[4]. Chen, C., [4] System Theory and Design. Second Edition ed: Oxford University Press.

[5]. Yechout, T.R., et al., [5] Introduction to aircraft flight mechanics: American Institute of Aeronautics and Astronautics, Inc.1801 Alexander Bell Drive, Reston, VA 20191-4344.

[6]. Michael Basler, M.S., et al., [6] The FlightGear Manual for FlightGear Version 3.6.0.

[7]. Chambers, J.R. and R.M. Hall, [7] Historical Review of Uncommanded Lateral-Directional Motions at Transonic Conditions. JOURNAL OF AIRCRAFT, (Vol. 41, No. 3, May – June 2004).

[8]. Rauf, A., et al. [8] Aerodynamic modeling and state-space model extraction of a UAV using DATCOM and Simulink. 2011: IEEE.

[9]. Rysdyk, R., [9] Course and Heading Changes in significant wind. JOURNAL OF GUIDANCE, CONTROL, AND DYNAMICS, (Vol. 30, No. 4, July – August 2007).

[10]. Kubica, F. and T. Livet, [10] Flight Control Law Synthesis for A Flexible Aircraft. American Institute of Aeronautics, 1994.

Useful links

How to dynamically change a block parameter value during simulation run-time?
https://www.mathworks.com/matlabcentral/answers/334224-how-to-dynamically-change-a-block-parameter-value-during-simulation-run-time
https://www.mathworks.com/help/releases/R2017a/simulink/ug/using-tunable-parameters.html
https://uk.mathworks.com/help/simulink/ug/tune-and-visualize-your-model-with-dashboard-blocks.html
Send fdm to flightgear
https://www.mathworks.com/help/aeroblks/sendnet_fdmpackettoflightgear.html
https://www.mathworks.com/help/aeroblks/sendnet_fdmpackettoflightgear.html
https://www.mathworks.com/help/aeroblks/packnet_fdmpacketforflightgear.html
https://www.youtube.com/watch?v=jB-80cvV1Ao
https://forum.flightgear.org/viewtopic.php?f=36&t=32707
https://www.mathworks.com/help/aeroblks/packnet_fdmpacketforflightgear.html
S function/UDP
https://www.mathworks.com/help/simulink/sfg/sim-viewing-devices-in-external-mode.html
https://www.mathworks.com/help/simulink/sfg/example-of-a-basic-c-mex-s-function.html#f8-82449
https://www.mathworks.com/help/aeroblks/packnet_fdmpacketforflightgear.html
https://www.mathworks.com/matlabcentral/answers/309926-matlab-udp-recieve-error
Simulink Animation
https://www.mathworks.com/videos/modeling-simulation-and-flight-control-design-of-an-aircraft-with-simulink-81546.html
https://www.mathworks.com/products/aerospace-toolbox.html

ANSYS FLUENT

https://www.youtube.com/watch?v=2x1Qx15pzm0
https://www.youtube.com/watch?v=HGzcVkDPHe4
https://www.youtube.com/watch?v=kuEqlSmyAos
MODEL ASW28 to FG
https://www.youtube.com/watch?v=Wb9bzS80ThA
http://wiki.flightgear.org/Blender_AC3D_import_and_export
SOLIDWORKS
https://www.youtube.com/watch?v=2iE_zo16bWM
https://www.youtube.com/watch?v=c_QEEPGUxDg
https://www.youtube.com/watch?v=aT9z-D_dwU4
Controller design
https://www.mathworks.com/videos/pid-control-made-easy-81646.html
https://www.mathworks.com/videos/trim-linearization-and-control-design-for-an-aircraft-68880.html

https://www.youtube.com/watch?v=LzQPJRt0ONg
https://www.mathworks.com/videos/automatic-tuning-of-a-helicopter-flight-control-system-90590.html
https://www.mathworks.com/videos/linear-system-analysis-in-simulink-81587.html
https://www.youtube.com/watch?v=CJGlKCfGEA0
AutoPilot Design
http://wiki.flightgear.org/Howto:Design_an_autopilot
Linmod()
https://www.mathworks.com/help/slcontrol/ug/linearize-at-trimmed-operating-point.html
https://www.mathworks.com/help/slcontrol/ug/linearize-simulink-model.html
https://www.mathworks.com/help/slcontrol/ug/specify-model-portion-to-linearize.html
https://www.mathworks.com/help/slcontrol/ug/linearize-at-simulation-snapshot.html
https://www.mathworks.com/videos/linear-system-analysis-in-simulink-81587.html