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, PID controllors are designed for the linearized system for dynamic analysis and motion stability control.

Then,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. Flying maneuvers such as ‘Skid to turn’ and ‘Bank to turn’ are realized through linearized system.

Chapter 1: Introduction

The ASW28, as a Standard Class glider with a fifteen-meter span built of modern fiber reinforced composites, has sailplane with a T-shaped horizontal tail plane and 15-meter wingspan. The upper wing surface has Schempp-Hirth brake flaps.

This report uses ASW28 model data 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 Chart

This report focuses more on the controller design for the system block diagram than the conditions which may alter the flight stability, however, the flight/environment conditions, propulsion system influences on inertia and mass change may also be coverd as well.

Chapter 2: ASW28 Flight Control System

2.1 State Equations

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

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

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

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

Figure 2-1. Control System State Equations

The above figure shows the 12 state-equations which are the base of control system, which is also the basic theory for block diagrams[1]

2.2 Control System Design

2.2.1 Overall System Design

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

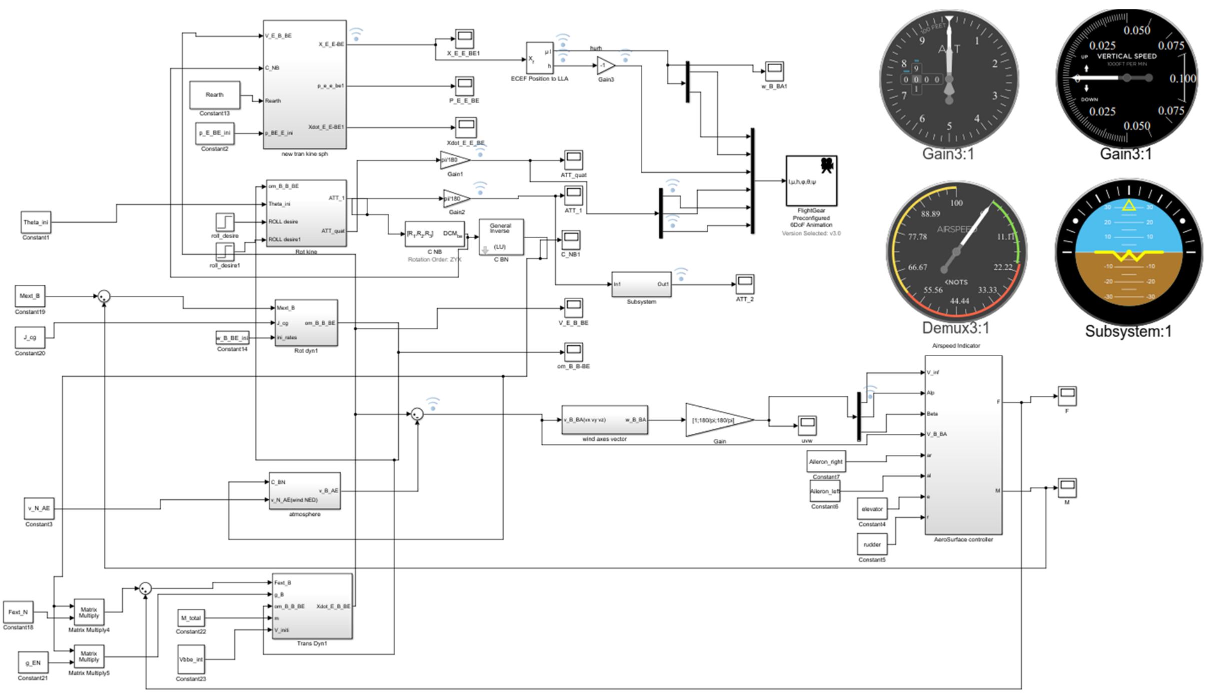


Figure 2-2. Control System

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

2.2.2 Aero Surface Controller Design

For the real-time force and moment calculation, the aero surface infections

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

```
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;
```

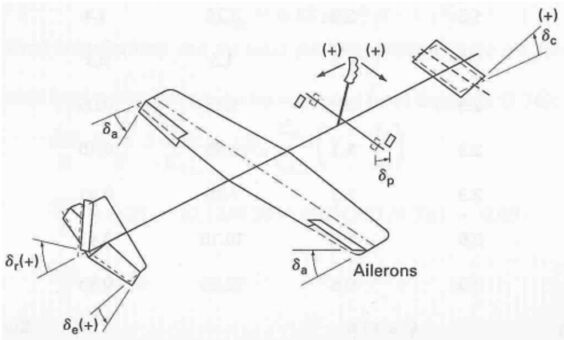


Figure 2-3 Full Span Control Surface coefficient

could be added to the CL_s according to the blocks. What should be noticed is the

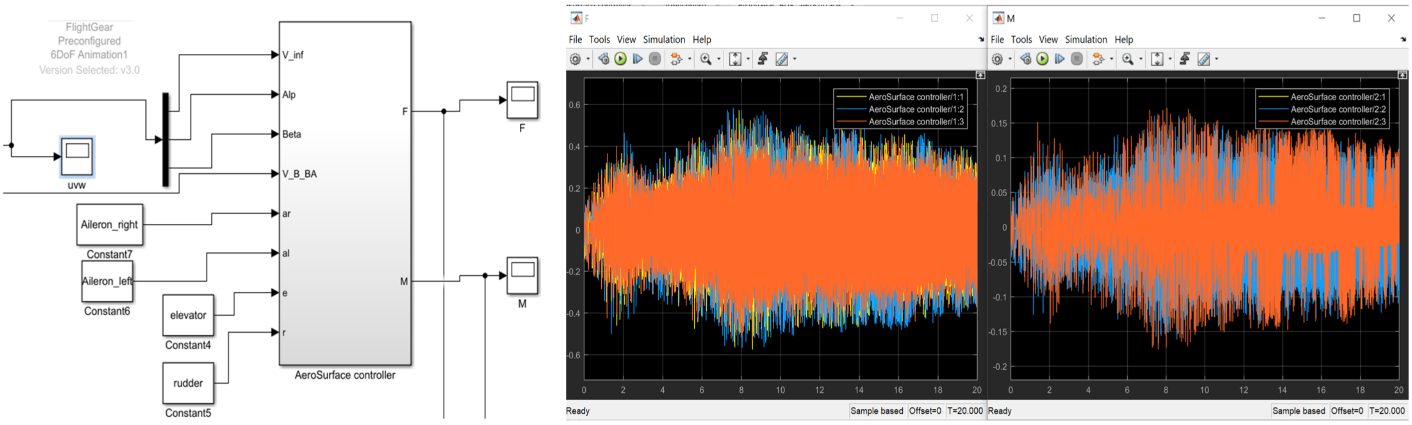


Figure 2-4 Aero Surface Block and Real-time Inner Force and Moment

experimental parameters are all 0.5 regard to the item [aero surface area/ controlled surface area]

2.2.3 Propeller Design

Adding propeller with rotating set of angled blades could provide thrust[2] for an airplane, as the figure 2-5 shows. In this design, the propeller direction is set to be [0;0;1] which could provide redundant lift for ASW28 model.

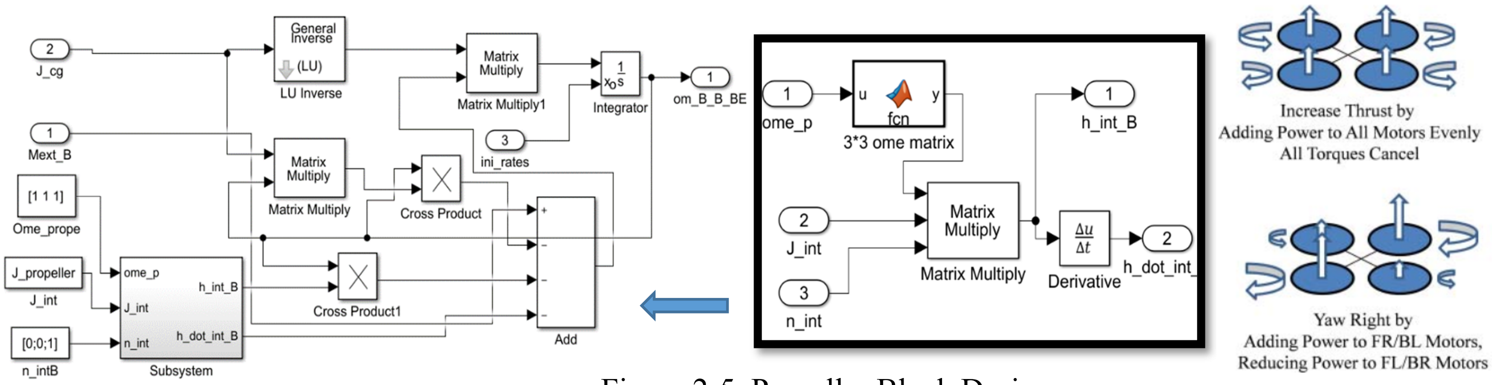


Figure 2-5. Propeller Block Design

2.3 Controller Design

2.3.1 Autopilot Controller Concepts

The figure shows how autopilot control system works by using inner and outer

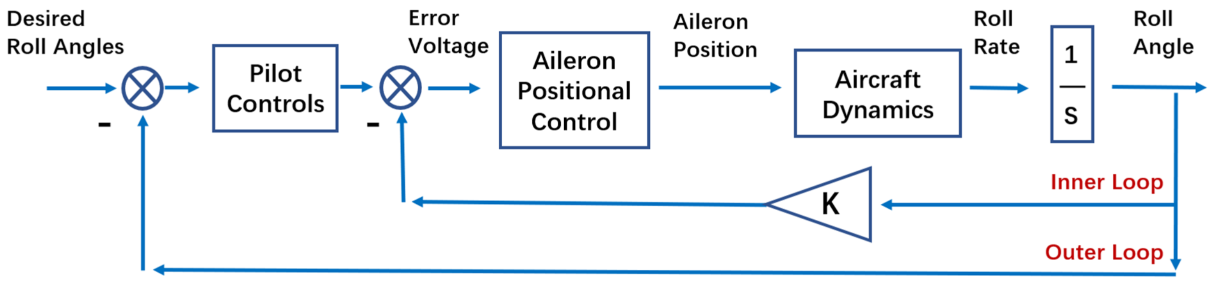


Figure 2-6. Autopilot Roll Angle Control Design

feedback loop to control ailerons then reach desired roll positions. Following the same principle, we could 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.

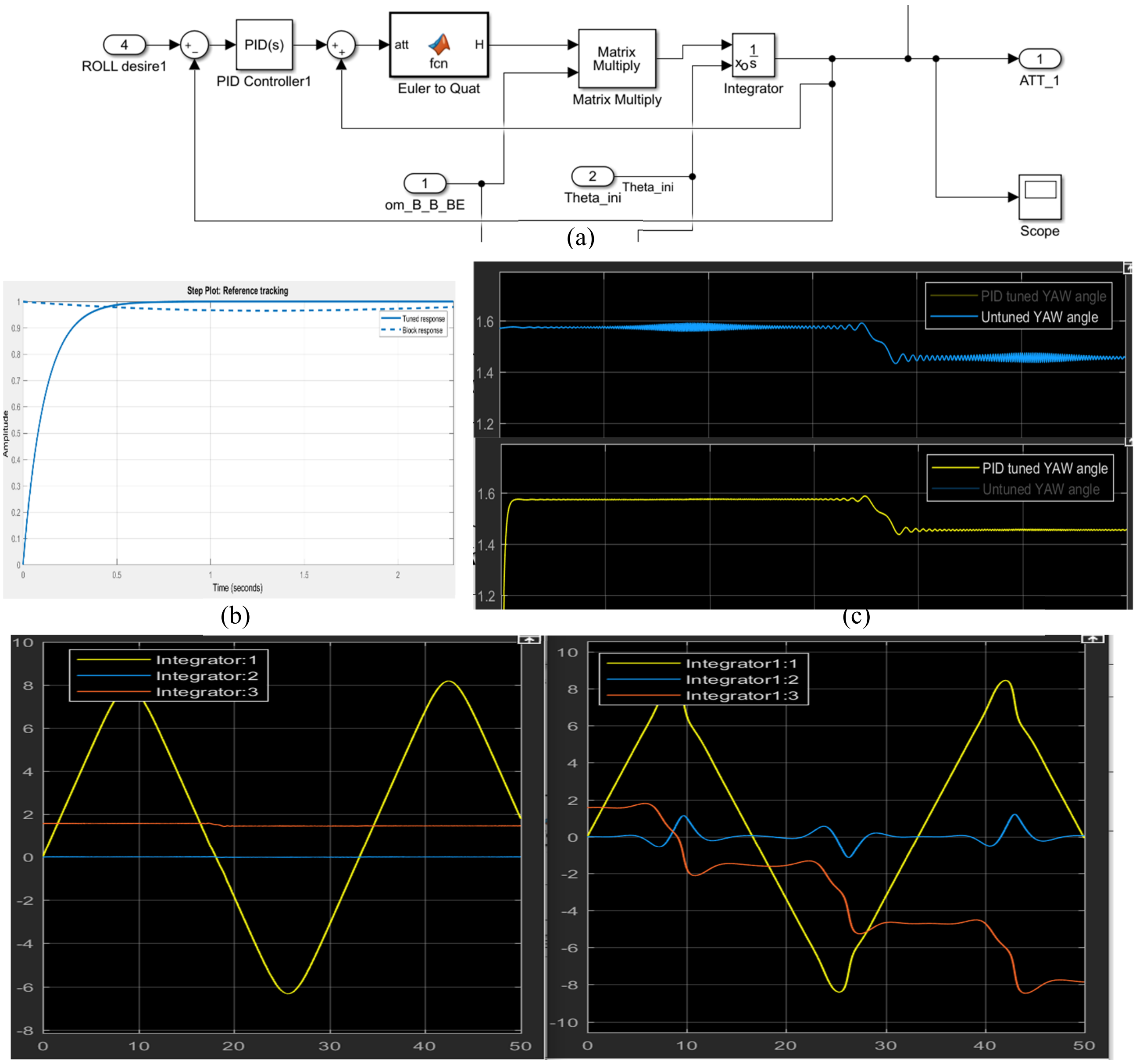
Rolling moments are created by sideslip alone[3], by the control action of the ailerons and the rudder, and as damping moments resisting rolling and yawing motion.

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

2.3.2 PID controller design

1) PID in Rotational Kinematics 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



(a) (b) (c) (d) (e)

Figure 2-7. PID Controller Design for vibration elimination

rotational rates in Body system respect to Earth reference frame. By using PID tuning system, the pitch and yaw offset curve vibration could be reduced.

2) PID for System Damping

As subfigure 2-7 (b) and (c) show, the yaw angle is seperated from Euler angles is tuned for eliminating vibrations.

3) Decoupled PID controller Design (Failed)

The three angles are coupled then I tried to use the separate PID controllers to decouple them at the first time

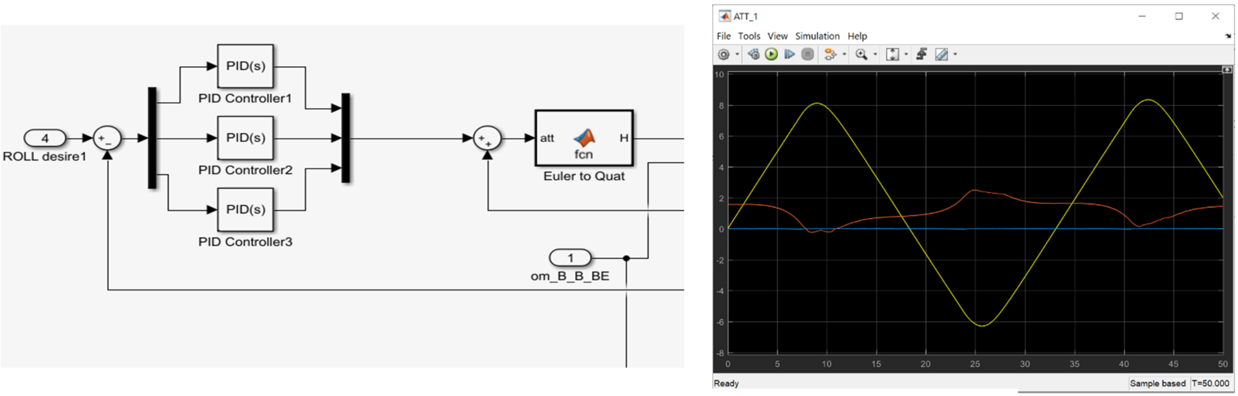


Figure 2-8. Control System

*Supplement

<u>Controllability and observability check using Gramians in MATLAB</u>

By using the gram() command in matlab, it has the limitation of A as A’s all eigenvalues have negative real part in continuous time, and magnitude strictly less than one in discrete time. However, we have unstable eigenvalues in the A which

$$W_c = \int_0^{\infty} e^{A\tau} B B^T e^{A^T \tau} d\tau$$

$$W_o = \int_0^{\infty} e^{A^T \tau} C^T C e^{A\tau} d\tau$$

may infect the results of ‘gram’

The controllability Gramian is positive definite if and only if (A, B) is controllable. The observability Gramian is positive definite if and only if (A, C) is observable. However, the Gramian of system controllability and observability have negative parts and evenly contributed, which make the Gramian check for system impossible.

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 3-1. 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.

From figure 3-2, the trimmed model results can be much more stable and linearized.

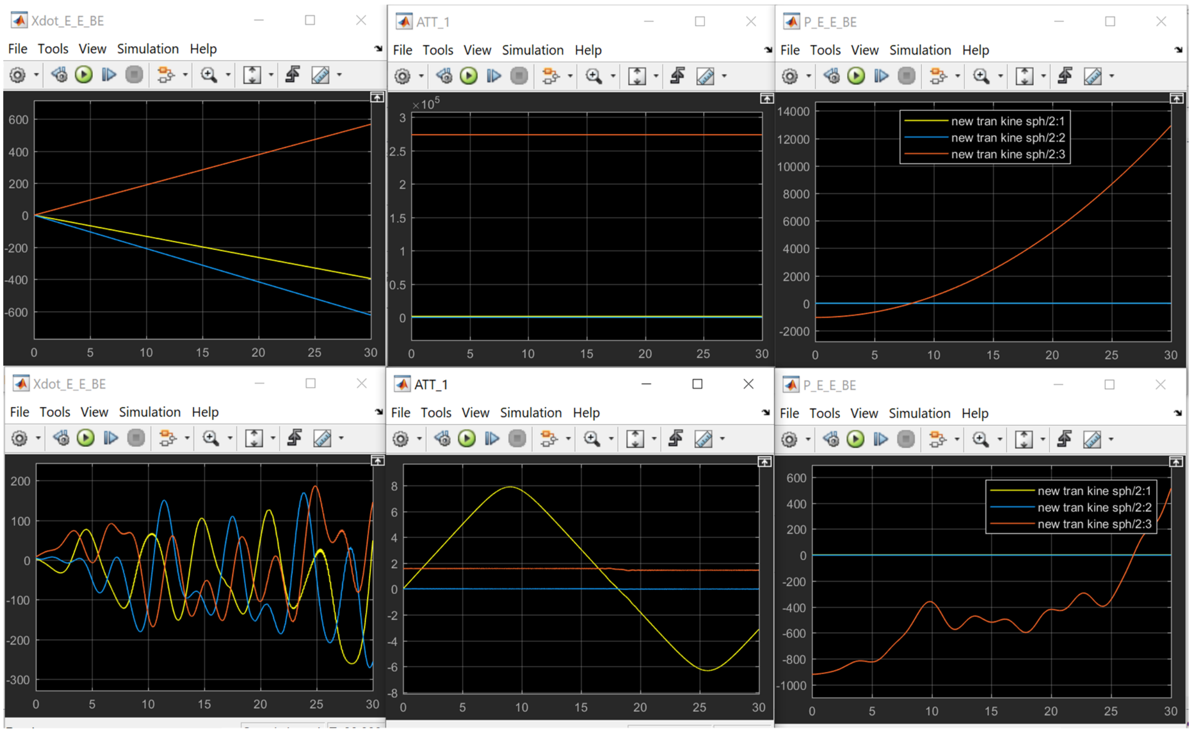


Figure 3-2. Trim Results (up: trimmed; down: untrimmed)

3.1.2 Model Trim (with aero surface)

After applying the aero surfaces into the system as the figure 3-3 shows, however, for both

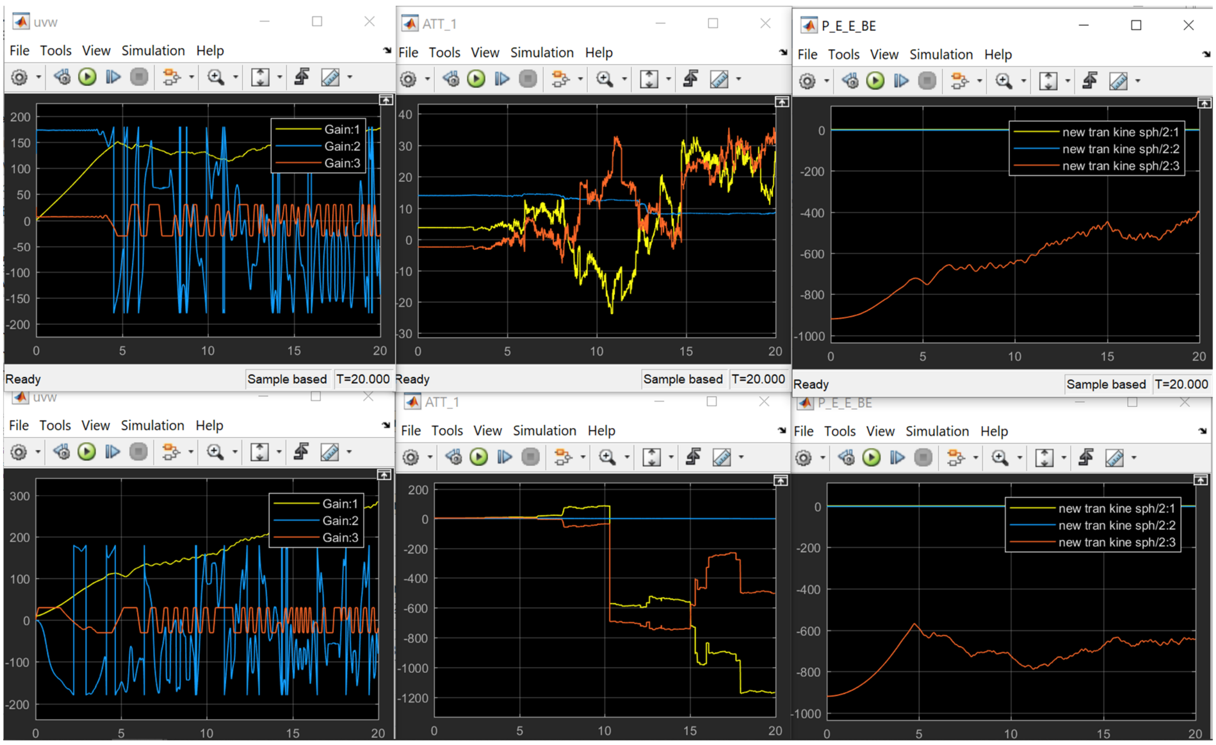
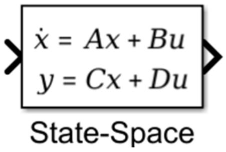


Figure 3-3. Trim Results (up: trimmed; down: untrimmed)

states

3.2 Model Linearization and Steady-state Flight

A simple analysis of a generalized multiple-input-multiple-output (MIMO)



$$s\,X(s) = A\,x(s) + B\,u(s)$$

$$Y(s) = C\,x(s)$$

Figure 3-4. State-space equations

system is using Laplace transform for the state space system(left) and setting the feed forward term to zero (right). The system matrices in the certain initial conditions are listed below.[4]

A	P	Q	R	PHI	THETA	PSI	U	V	W
P_dot	-4.65E-06	0.00017	-0.00028	0	0	0	-2.56E-06	-7.97E-06	3.61E-06
Q_dot	9.76E-07	0	0.004509	0	0	0	-0.00094	0.000719	-0.00111
R_dot	0.00011	0.00178	4.65E-06	0	0	0	-4.48E-05	-0.00013	6.26E-05
PHI_dot	1	0.3858	-0.8841	-0.00016	0.000664	0	0	0	0
THETA_do	0	-0.9165	-0.3999	-0.00034	0	0	0	0	0
PSI_dot	0	0.5557	-1.273	-0.00023	0.000461	0	0	0	0
U_dot	0	-0.00335	0.002001	-3.476	-2.786	3.102	0.000153	-0.0003	-0.00013
V_dot	0.003349	0	0.002582	-30.67	-2.13	30.73	0.000275	7.64E-05	0.00463
W_dot	-0.002	-0.00258	0	-1.42E-10	-22.26	-3.329	0.000131	-0.00455	-0.00018

B	A_R	A_L	ELE	RUD	eig(A)		
P_dot	-7.98E-09	7.83E-09	1.68E-09	2.75E-10	0.13043	+	0.22751i
Q_dot	-9.33E-09	-9.33E-09	-5.90E-09	4.71E-09	0.13043	-	0.22751i
R_dot	-6.69E-09	1.92E-08	5.77E-09	-1.52E-09	-0.2636	+	0i
PHI_dot	0	0	0	0	0.13629	+	0i
THETA_do	0	0	0	0	-0.06734	+	0.11758i
PSI_dot	0	0	0	0	-0.06734	-	0.11758i
U_dot	4.37E-09	4.37E-09	1.24E-09	-3.42E-10	-0.00043	+	0i
V_dot	-4.02E-09	-4.02E-09	-1.12E-09	2.94E-10	0.000719	+	0.00033019i
W_dot	-1.88E-09	-1.88E-09	-6.21E-10	2.47E-10	0.000719	-	0.00033019i

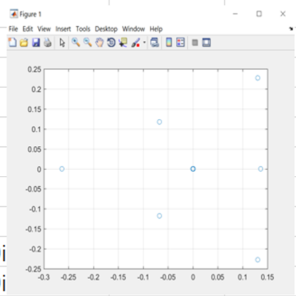


Figure 3-5. Initial A and B matrix (False)

3.3 Linear States Analysis

3.3.1 Aircraft Dynamic Stability Analysis

1) Dutch Roll Mode

Through the eigenvalues of A matrix, we could have the following modes:

Spiral Mode (unstable/source)				Roll Mode		
0.000719	+	0.00033019i	**Phugoid**	-0.00043	+	0i
0.000719	-	0.00033019i	**Phugoid**	-0.2636	+	0i
0.13043	+	0.22751i	**Short-period**	Dutch Roll Mode		
0.13043	-	0.22751i	**Short-period**	-0.06734	+	0.11758i
Roll Mode (unstable)				-0.06734	-	0.11758i
0.13629	+	0i				

$$\lambda = \begin{cases} -\zeta\omega_n \pm \omega_n\sqrt{\zeta^2-1} & \text{for } \zeta > 1 \\ -\zeta\omega_n & \text{for } \zeta = 1 \\ -\zeta\omega_n \pm i\omega_n\sqrt{1-\zeta^2} & \text{for } \zeta < 1 \end{cases}$$

Damping Ratio	0.49698
Natural Freq	0.1355
Time Period	46.347(s)

Figure 3-6. Flight Mode Analysis

The Dutch Roll Mode can be excited by aircraft rudder produces both rolling andyawing moments. By using eigenvalue mathmatical methods, the time period and damping ratio are 46.347s and 0.49838, which means the dutch roll period is quiet long with large oscillation damped.

2) Roll Mode (stable)

In the first order system, the roll modes incliding (2 305.5s) and fast roll response (3.7936s)

$$\lambda_{roll} = -\frac{1}{\tau} = L_p$$

Roll Mode			Time Constant
-0.00043375	+	0i	2305.5(s)
-0.2636	+	0i	3.7936(s)

Figure 3-7. Time constant calculation

3) Linearized Matrix Analysis

From the A matrix linearized from the non-linear system, the Q_dot could never change Q, which may cause lots of problem like we could not control the pitch angle while running the system. In the next section the system would be optimized and re-linearized as to change it's behavior.

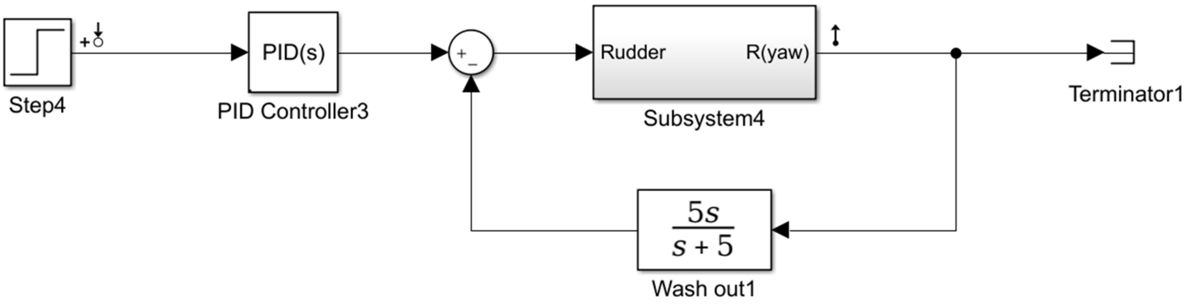
3.3.2 Lateral/Longitudinal Motion Control

For this section, PID controller design is applied to optimize the dutch roll mode parameters for faster rudder response. As we all know, analysis of MIMO (Multiple-input-multiple-output) systems using basic loop shaping techniques, especially for root-locus analysis, requires that only one loop at a time can be closed. From the figure, the inner loop of [rudder-R] is designed to damp the

Dutch Roll Mode and the root-locus could be used for closed loop gain selection due to different damping coefficient.

1) Linearized System and Behavior Analysis

By relinearize the [Rudder-R] system with PID controller and 'wash out' blocks,



A	P	Q	R	PHI	THETA	PSI	U	V	W	Wash out
P_dot	-1	0.00017	-0.000284	0	0	0	-2.56E-06	-7.97E-06	3.61E-06	6.88E-09
Q_dot	9.76E-07	-1	0.004509	0	0	0	-0.00094	0.000719	-0.001111	1.18E-07
R_dot	0.00011	0.00178	-1	0	0	0	-4.48E-05	-0.00013	6.26E-05	-3.80E-08
PHI_dot	1	0.3858	-0.8841	-1	0.000664	0	0	0	0	0
THETA_dot	0	-0.9165	-0.3999	-0.000344	-1	0	0	0	0	0
PSI_dot	0	0.5557	-1.273	-0.000229	0.000461	-1	0	0	0	0
U_dot	0	-0.00335	0.002001	-3.476	-2.786	3.102	-0.9998	-0.0003	-0.0001301	-8.55E-09
V_dot	0.003349	0	0.002582	-30.67	-2.13	30.73	0.000275	7.64E-05	0.00463	7.35E-09
W_dot	-0.002	-0.00258	-1.24E-09	-1.42E-10	-22.26	-3.329	0.000131	-0.00455	-1	6.18E-09
Wash out	0	0	1	0	0	0	0	0	0	-5.00E+00

Short-period			Dutch Roll Mode			Roll Mode			Time Constant(s)	
-0.86282	+	0.25016i	-1.0241	+	0.058674i	-1.0002	+	0i	0.99980004	
-0.86282	-	0.25016i	-1.0241	-	0.058674i	-0.99896	+	0i	1.00104108	
						-0.9549	+	0i	1.04723008	
Damping Ratio		0.96045	Damping Ratio		0.99836	-1.2786	+	0i	0.78210543	
Natural Freq (rad/s)		0.89835	Natural Freq (rad/s)		1.0258	Roll Mode (unstable)			Time Constant(s)	
Time Period (s)		6.9906	Time Period (s)		6.1221	0.0068486	+	0i	146.015244	(Long)

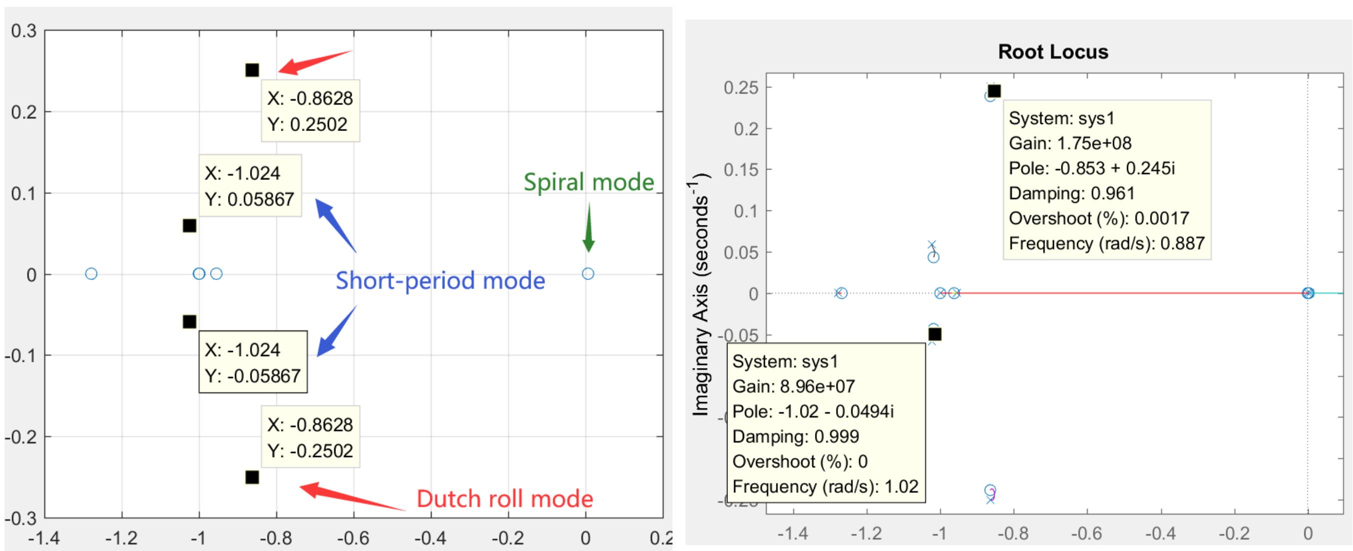


Figure 3-8. Dutch Roll Mode Analysis

we have A matrix and eigenvalues as the figure 3-8 shows.

From the eigenvalues plot graph comparing with rlocus graph, the Dutch roll mode/roll mode behaviors pole distributions are corresponding to each other. However, through the rlocus plot, there're not enough adjusting range for both Dutch roll and roll mode behaviors.

In addition, for this ASW28 case, the Dutch roll mode and roll mode have similar large damping ratio and time period.

2) Aero-surface Control

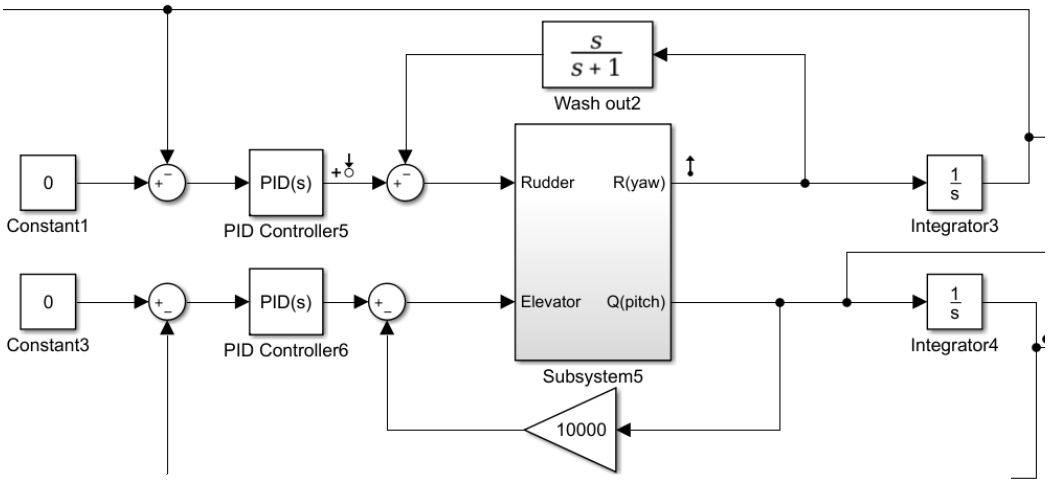


Figure 3-9. Aero surface control

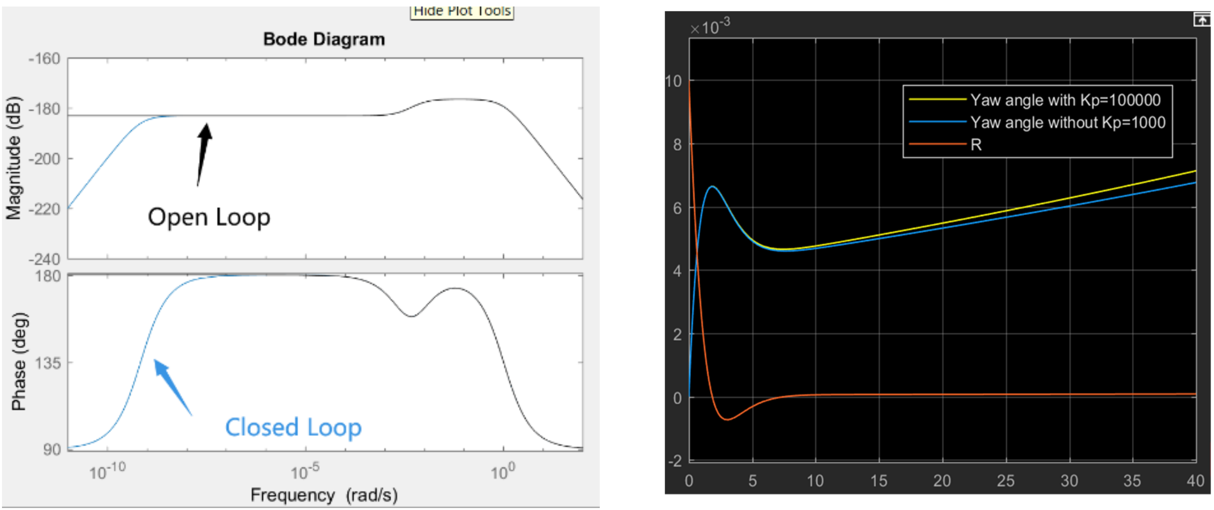


Figure 3-10. Trim Results (up: trimmed; down: untrimmed)

By adding the first order actuator into the linearized system as the figure below shows, the system yawing angles can respond to the rudder paddle changes in a linearized way.

According to the book, much higher gain will demand excessive control deflection rates of rudder and the gain will be designed due to rlocus and multiple tries. Also from the Bode diagram figure and comparing figure for the [rudder-yaw] the ‘wash out’ as it doesn't contribute much for the performance but adding a roll mode with short time constant (The wash out pole set to be ‘-1’). The outer loop.

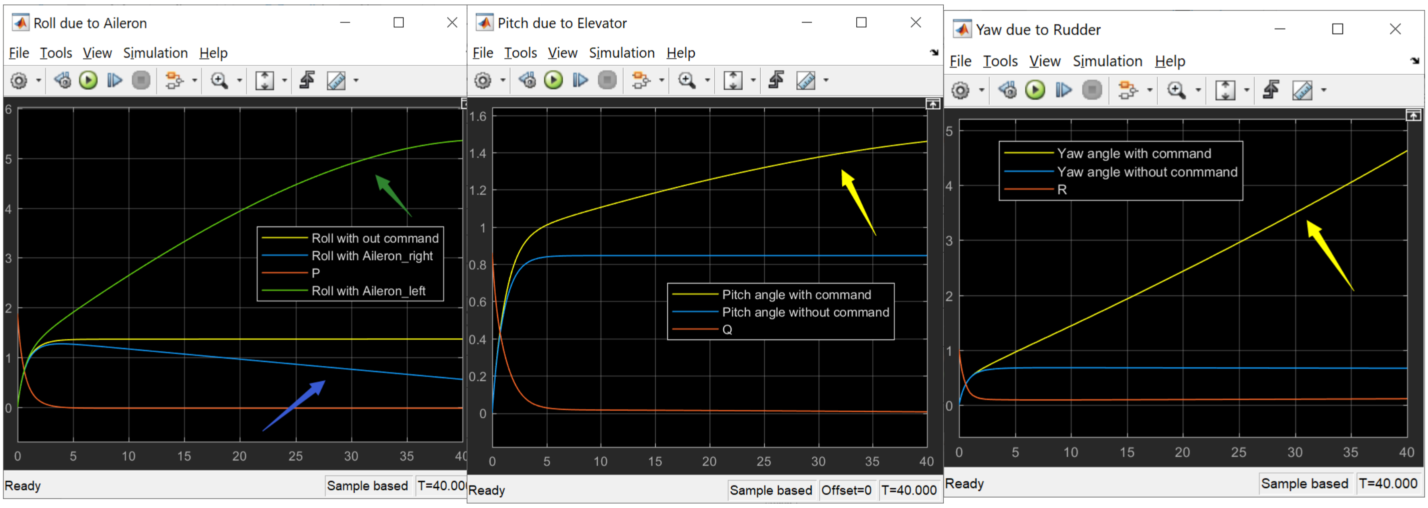


Figure 3-11. Aero surface linear control for Roll Pitch and Yaw (left to right)

From the [SISO] system, with certain command applied into the aero surfaces, the euler angle would linearly response to it. However, in real linear control system, we need to

3) System Control Loop Tolerance

The tolerance of system can be determined by input command size range. From the figure, curves may start to slowly decreasing due to the large command size.

With fixed PID controller, by changing the pilot command size of the separate loop system for Euler angles, the best command ranges are set to be:

- Aliron(left): [10000-28000]
- Elevator: [15000-21000]
- Rudder: Larger command, faster response

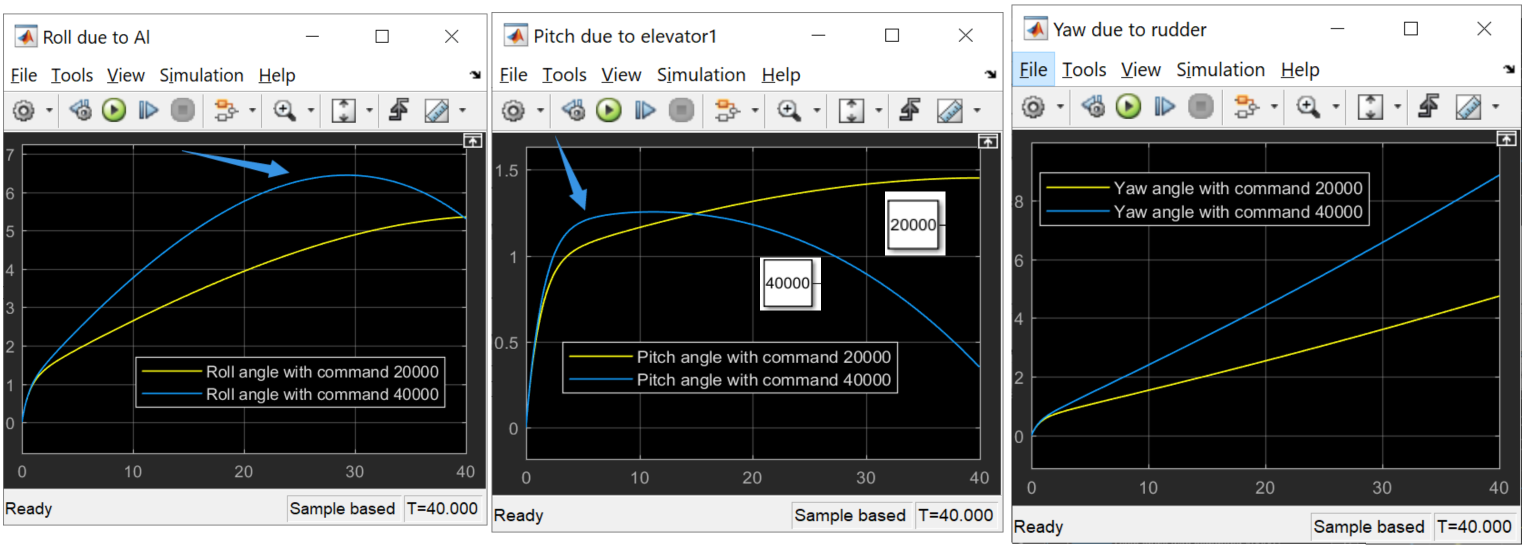


Figure 3-12. Command Size Comparing

(4) Basic Theory

(why PQR are controled for angle computations)

Using [Elevator-pitch] block, form the curve comparison the yaw angle we use dirrectely from 9 states output may is not start from 0 and have a sudden slope which is not perfect. Also we could place the intefral in the loop for control design

First order actuator added for slowly increased command performances

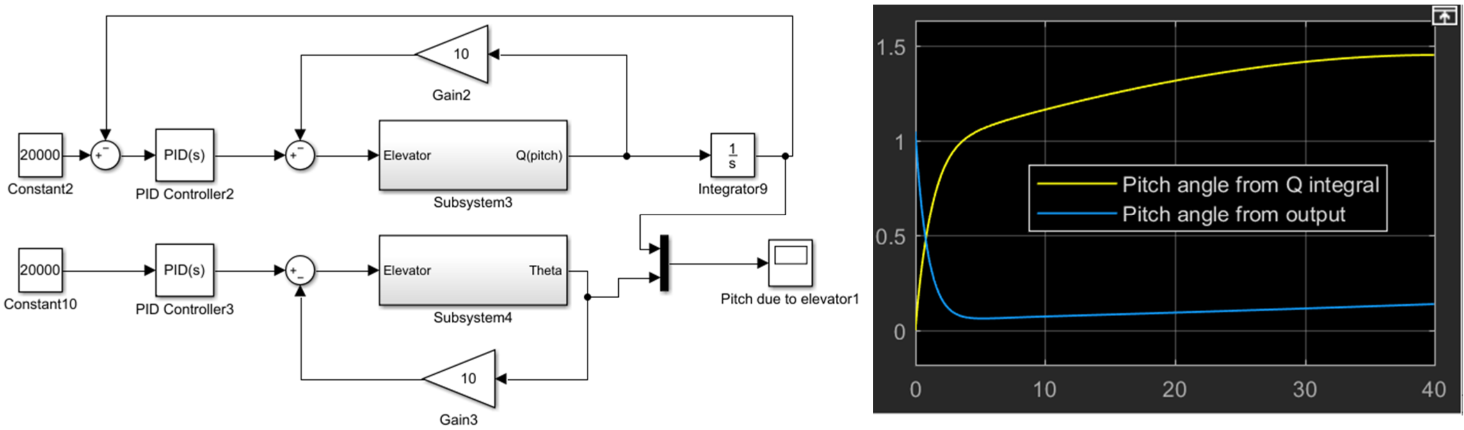


Figure 3-13. Trim Results (up: trimmed; down: untrimmed)

on both sides work as the sensor in deefback loop. From the different Kp applied in the loop, the yawing angle with change along it with different speed, from which, we could control the

3.3.2 Linear Controller Design

1) Step Input for V

For the linearized system, the step input and PID controllor[6] are applied to 'V' state in three conditions:

(a) No step input

(b) Step magnitude =10; step time =5.

(c) Step magnitude =10; step time =5; PID saturation limit =5.

As (c) shows, the PID saturation can set the limit to the output (from 10 to 5). It may also works on the angle range.

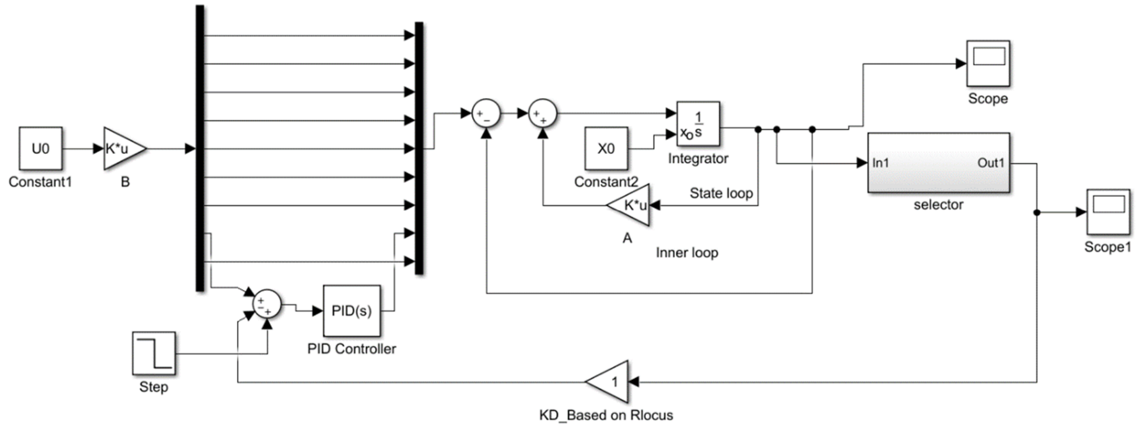
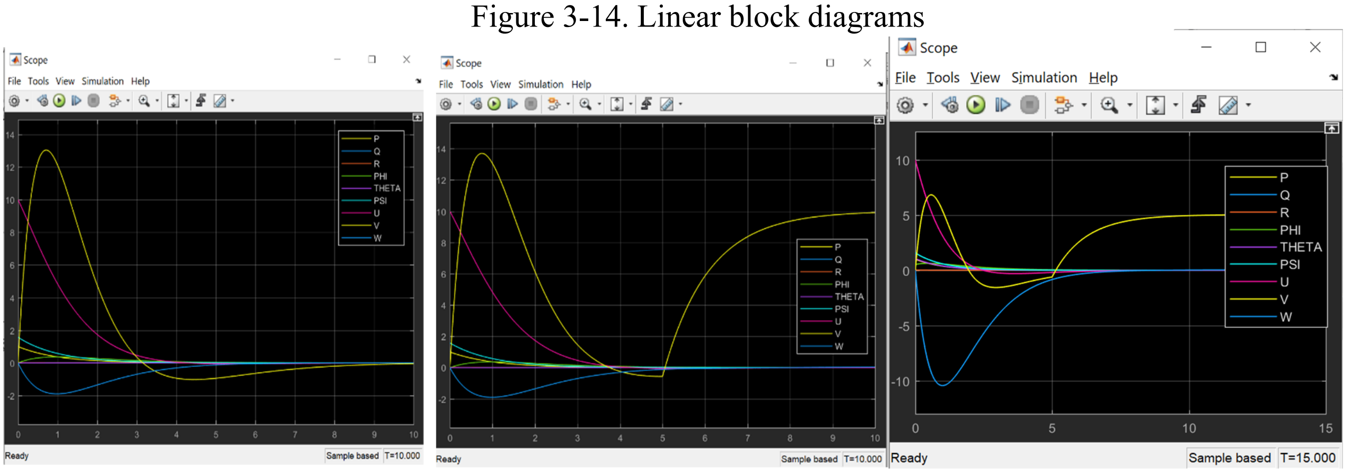


Figure 3-14. Linear block diagrams



(a) (b) (c)

Figure 3-15. Set up conditions

2) PID design for 'V'

(a) [Kp, Ki, Kd]=[1,0,0]; Step=5 at 5sec (b)[Kp, Ki, Kd]=[100,0,0]; Step=5 at 5sec

(c)[Kp, Ki,Kd]=[100,0,0]; Ramp=1 at 5sec

The system with different PIDs could response differently.

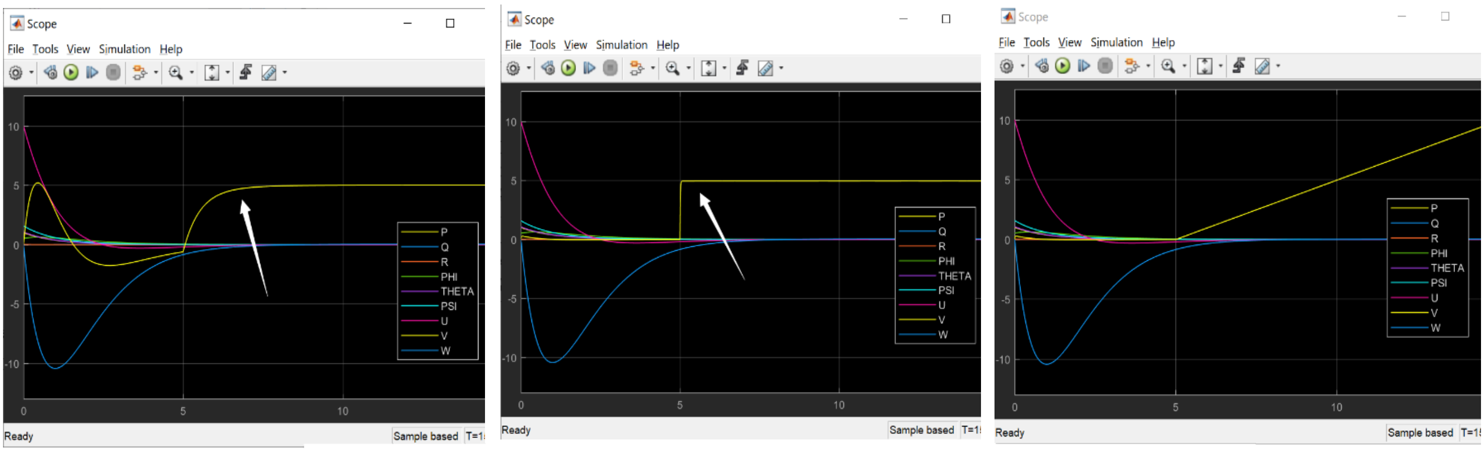
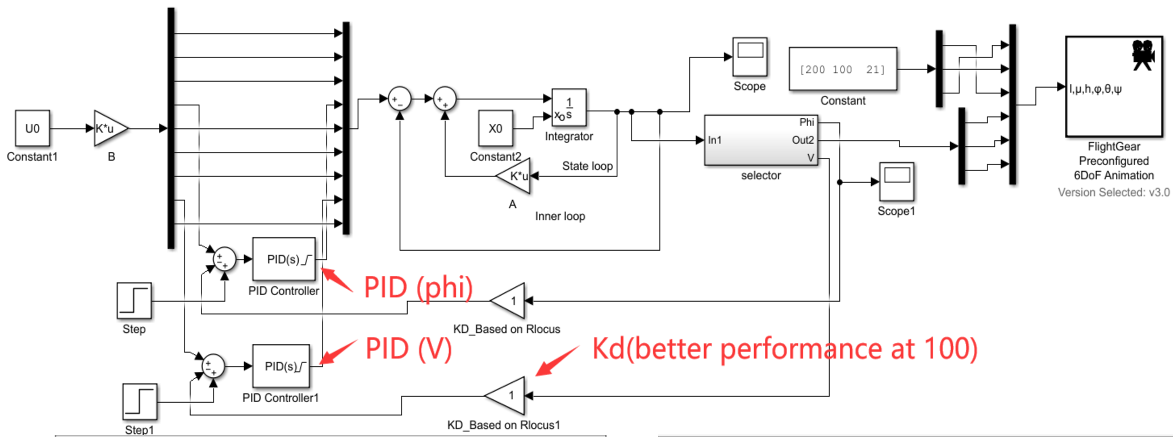


Figure 3-16. Linear System Behaviors due to input and PID

3) PID Design for Coupled Parameters



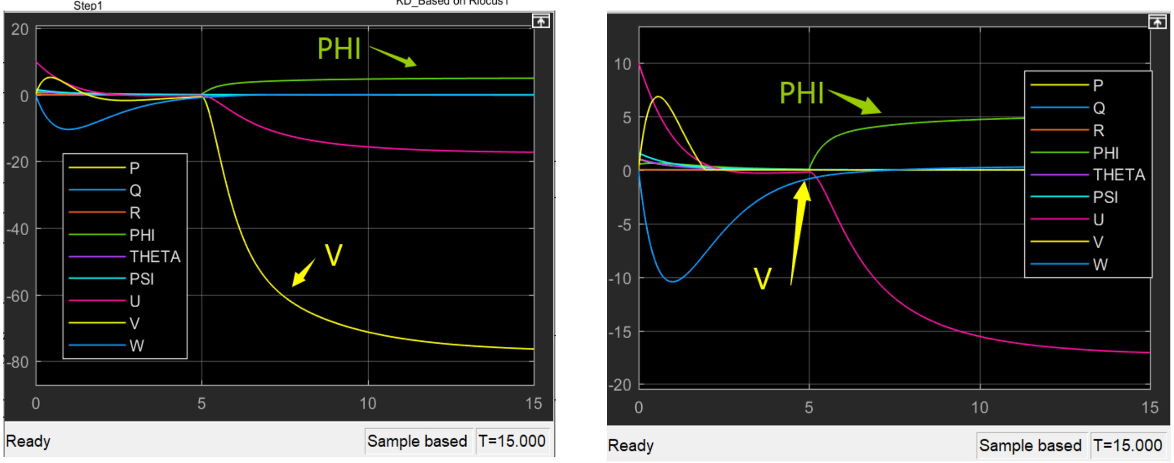


Figure 3-16. [PID applied to phi] [PID applied to phi and V]

3.3.3 LQR for Full Linearized System

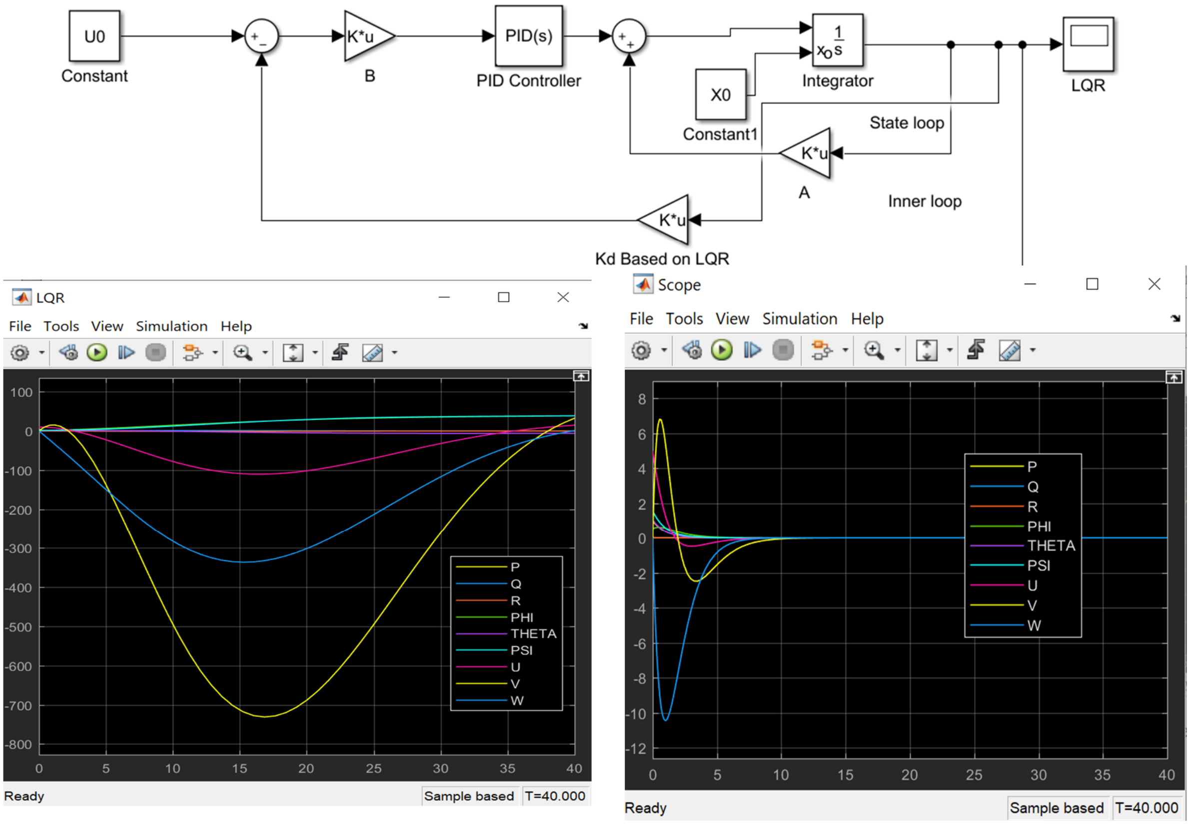


Figure 3-17. LQR applied(left); Without LQR(right)

Chapter 4: ASW28 Flight Dynamic Analysis

4.1 Introduction

In this chaptar, the dynamics flying parameters are set as table-1. The bank and attack angle in ANSYS- fluent are set to be all ‘0’

Table 4-1: Flight Environment Parameters

Model Name	Velocity(m/s)	Temperatue($^{\circ}$ F)	Altitute(m)	Air Density(kg/m^3)
ASW28	400	77	1000	1.074

4.2 XFLR5 Dynamic Analysis

4.2.1 Model Design

The model uses NACA 2412 data for main wing and elevator section and NACA 0009 for ruder section.[5] By choosing proper sweepback angle and taper, the coefficients change along different alpha degree(-1.5 to 30 [deg])

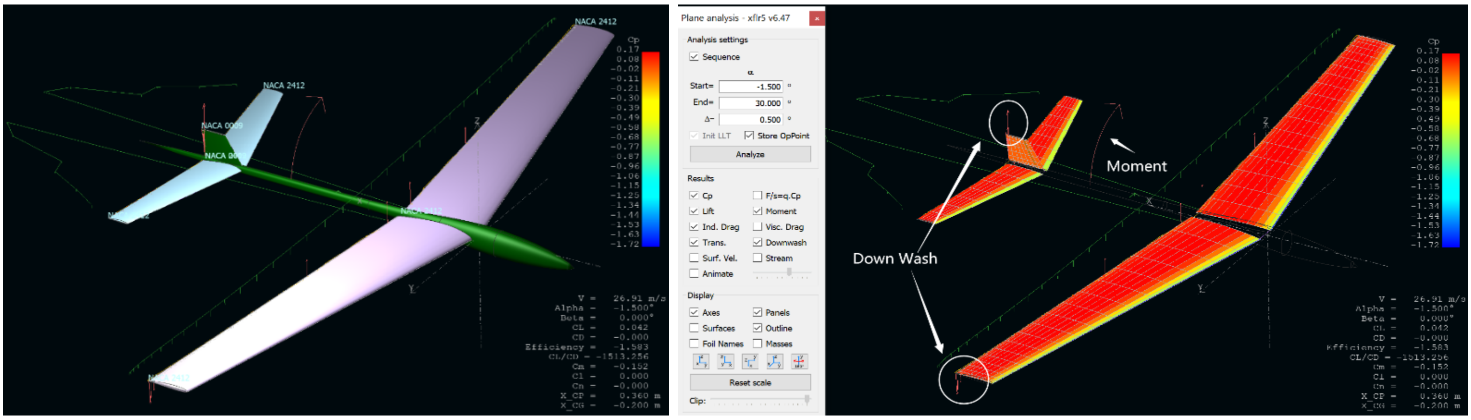


Figure 4-1 XFLR5 Analysis.

4.2.2 Dynamic Coefficient Calculation

The figure 4-2 below shows without offset points. The aero coefficients shows different coefficients distribution. However, from the [Cl-alpha] curve, we could the slope remains unchange which is not very similar to the real situation. In addition, the dynamic data calculated from XFLR5 can not fit the ASW28 model we used for the main project calculation.

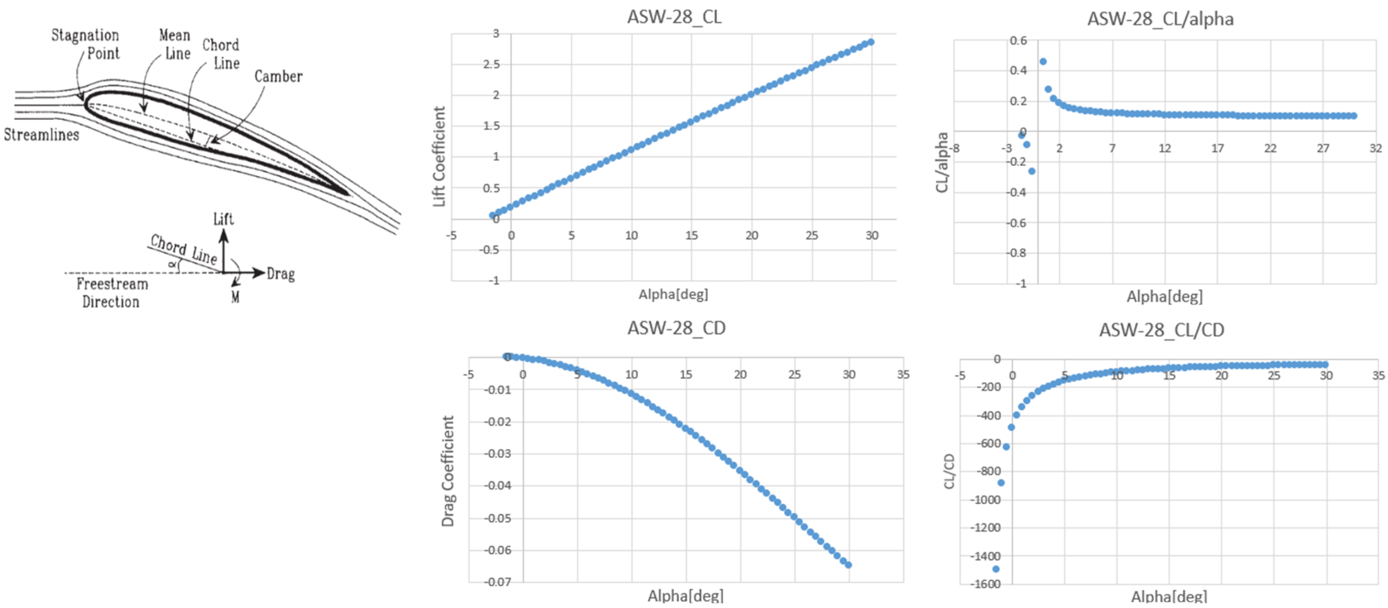


Figure 4-2. Definitions associated with an airfoil and Dynamic Coefficients

4.3. ANSYS Dynamic Analysis

4.3.1 Finite Element Analysis

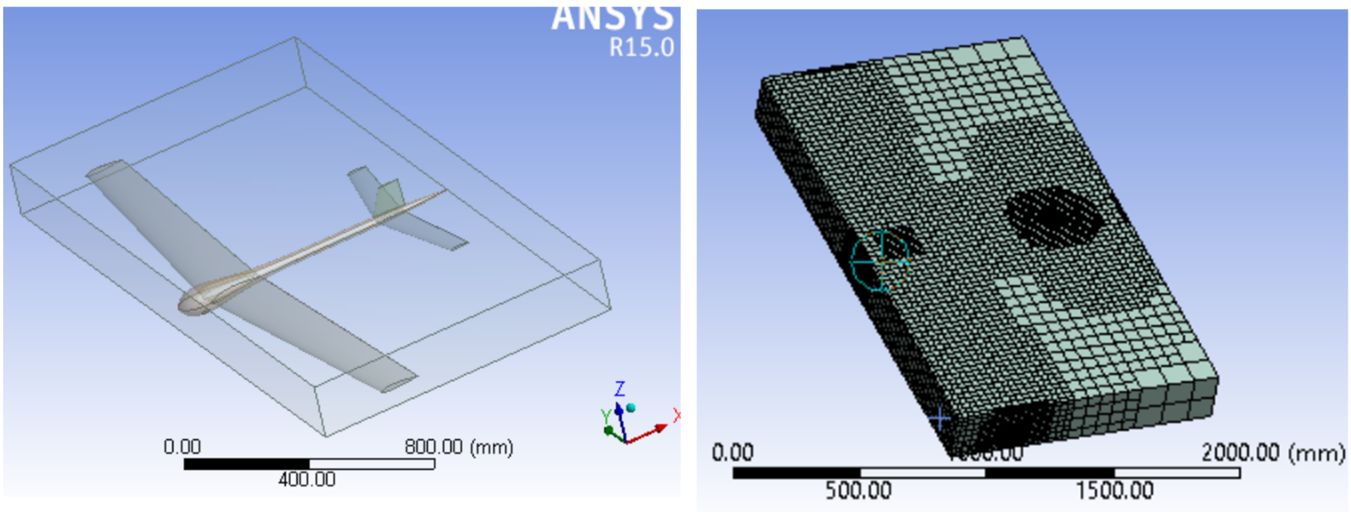


Figure 4-3 FEA on ASW28

By use ANSYS FLUENT module(as figure 4-3 shows), the FEA analysis is applied to the whole ASW28 exported from XFLR5

4.3.2 Aerodynamic Distribution

1) Pressure Distribution

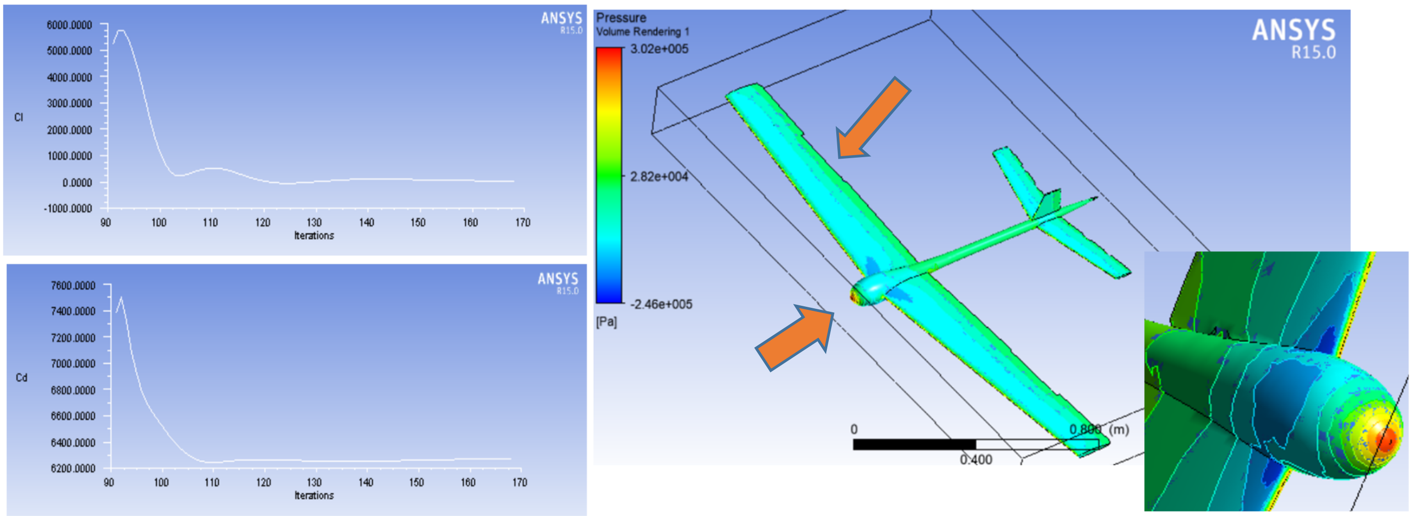


Figure 4-4 Cl, Cd and pressure distribution.

We could see it clear among the cephalic cone and connection parts between body and wing. As the influences of ailerons are ignore in the fluent analysis, the pressure among the aero surfaces remain indifferent.

2) Velocity Distribution

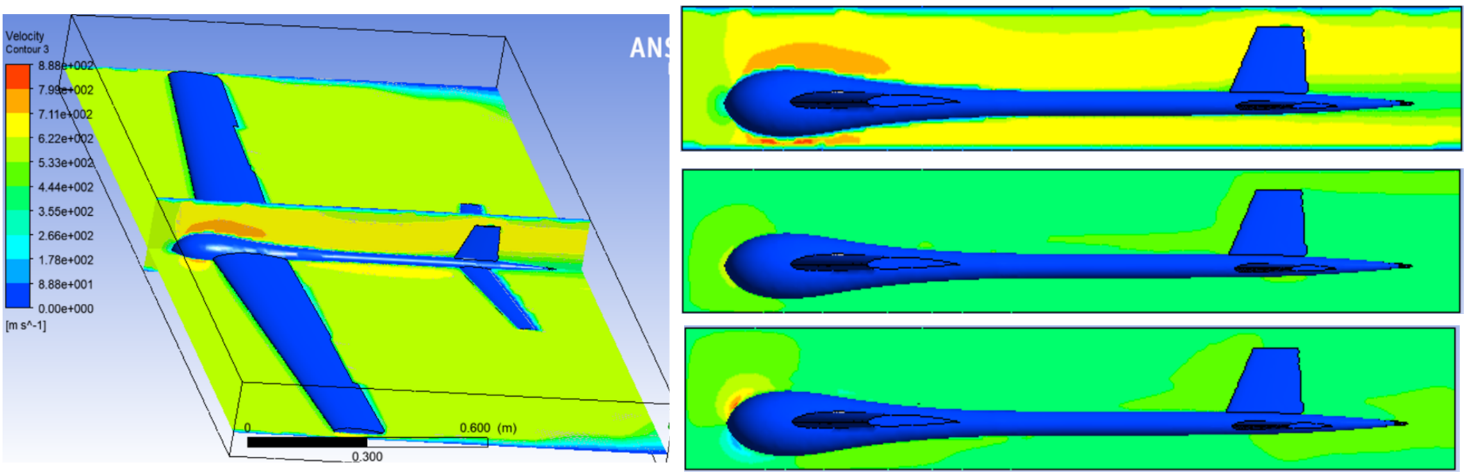


Figure 4-5. Velocity Contour (left); [u; v; w] in Longitudinal Symmetry Plane

Among the (lateral and) longitudinal symmetry plane velocity distrubution, the "u" velocity has the largest component of the velocity.

Chapter 5: Simulation

5.1 Simulink to FlightGear

The block in aerospace basket is used to conneck MATLAB Simulink to FlightGear for better performance simulated[9].

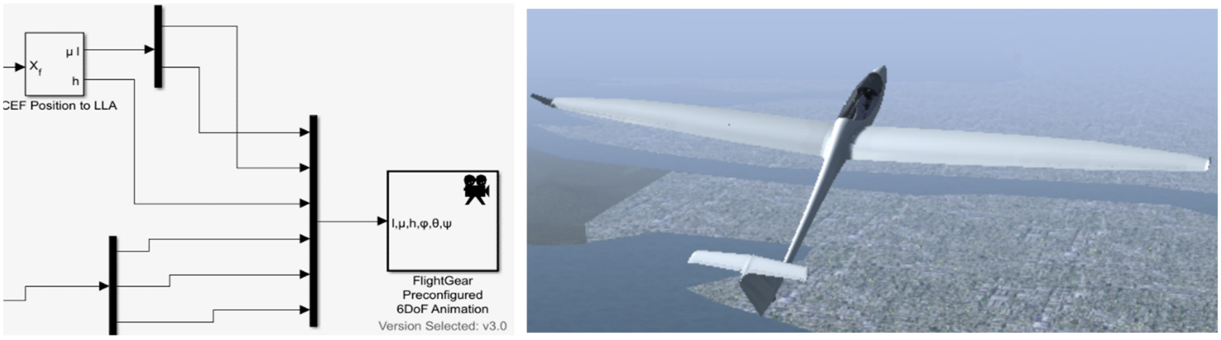


Figure 5-1. Definitions associated with an airfoil.

```
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
```

Figure 5-2. Definitions associated with an airfoil.

For flight control

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.

5.2 Maneuver in Steady-state Flight

5.2.1 Pilot Control Simulation

Adding time delay to the system provided a very characteristic response for a system that has a human in the loop. The noise are also added for better situation simulated[10].

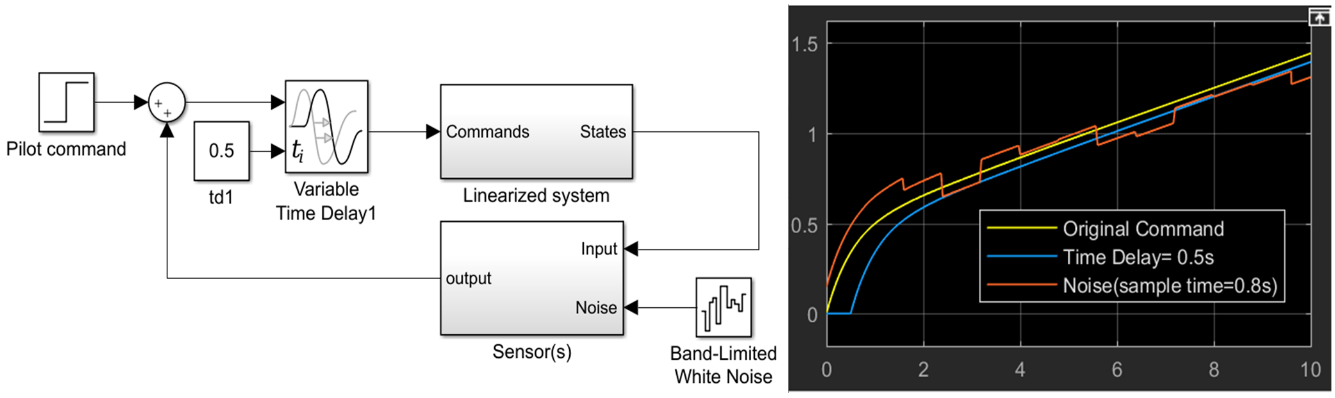


Figure 5-3. Pilot Control System.

5.2.2 Skid to Turn

1) Skid to turn Theory

Skid-to-turn is an aeronautical vehicle reference for how such a vehicle may be turned. It applies to vehicles such as aircraft and missiles. In skid-to-turn, the vehicle does not roll to a preferred angle. Instead commands to the control surfaces are mixed to produce the maneuver in the desired direction.

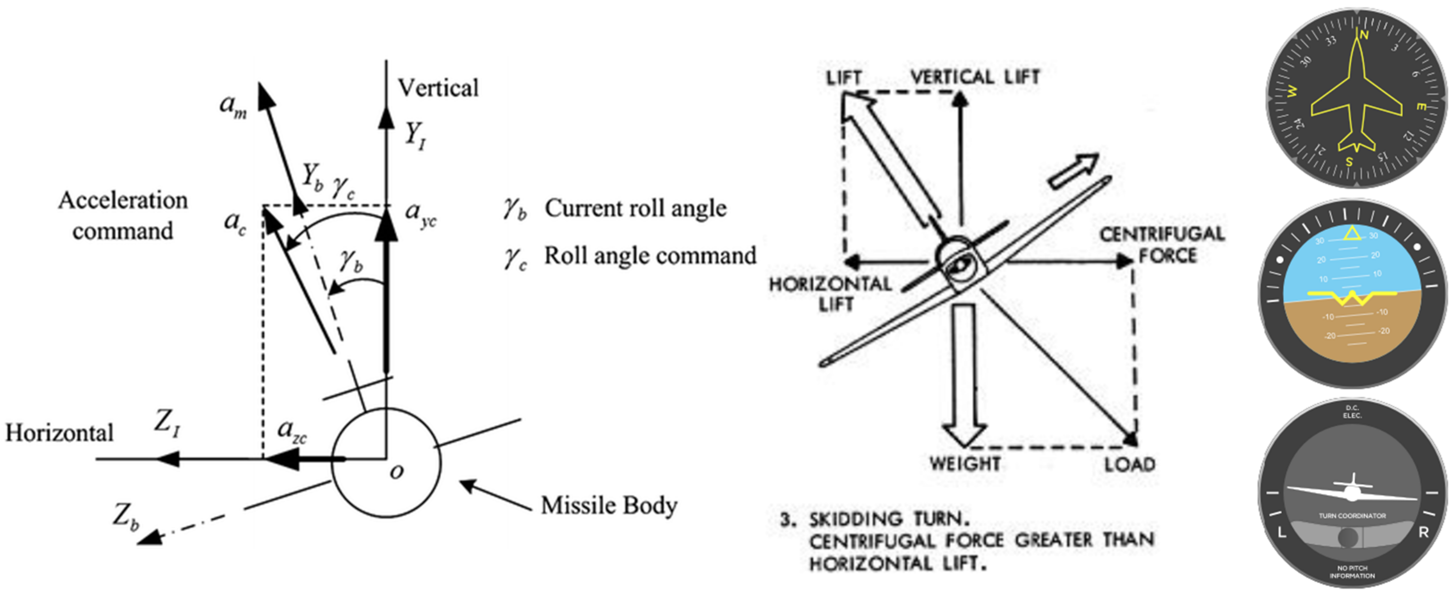


Figure 5-4. Skid to turn Theory.

Linear analysis of the system provides a good starting point to consider design modifications that would allow ASW28 to perform skidding turns better.

2) SISO System control

If we seperately contol the [SISO] system, the euler angle behavior would be the figure below.

From figure 5-5, the

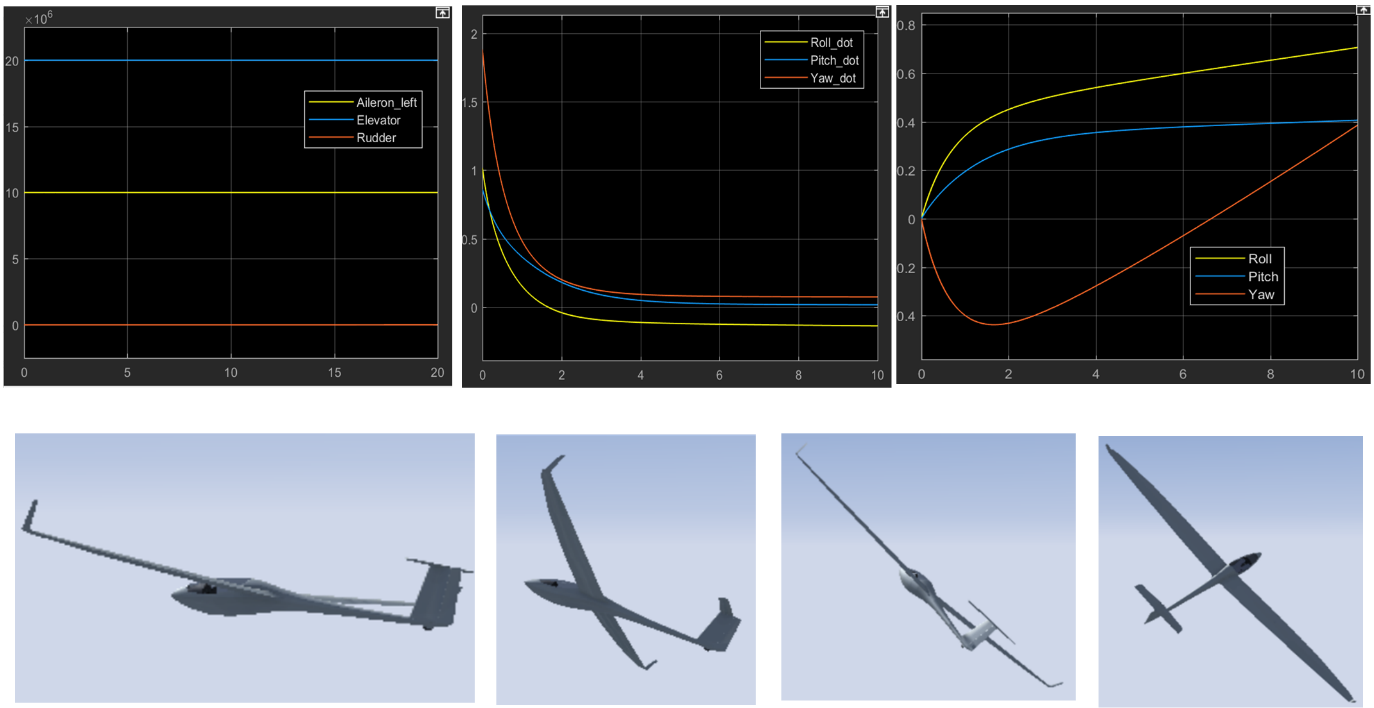


Figure 5-5. Pilot Control System.

However, the system is coupled and we could not simply decouple them by seperate the blocks. Also, the command control need to bring the aircraft back to the lateral stable position

3) MIMO coupled system control

In the MIMO system[11], larger Kp, faster turning point. Also command input

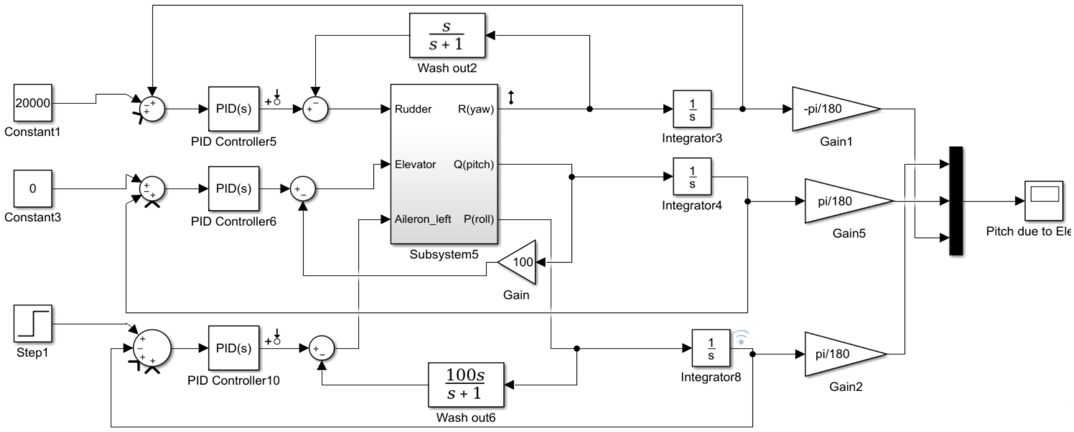


Figure 5-6 Coupled Linear System

control the curve slope and magnitute. However, as the three of them is coupled, the step input applied to one of the angles may affact others:

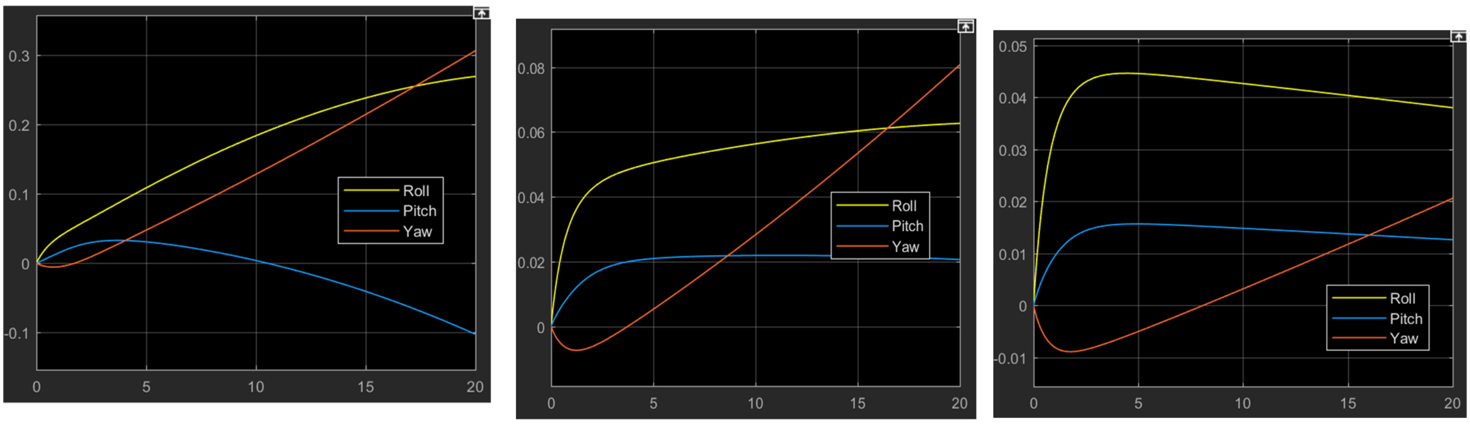


Figure 5-7. [Aileron_left command = 65000] [Elevator command=40000] [Rudder=20000]

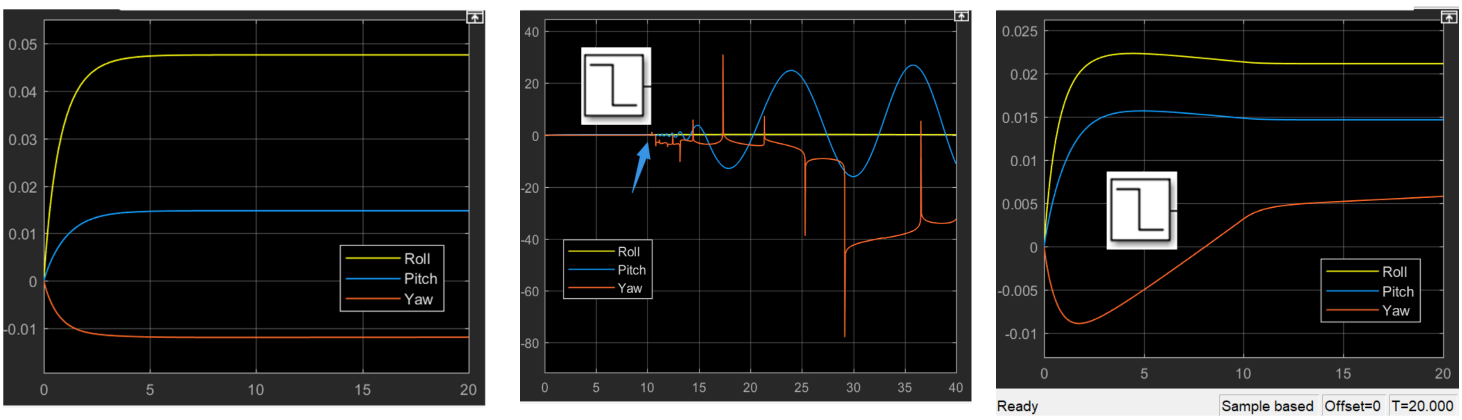


Figure 5-8. [No signal] [adding large signal to elevator] [Command and Step input attached to rudder]

4) Skidded turn in FlightGear

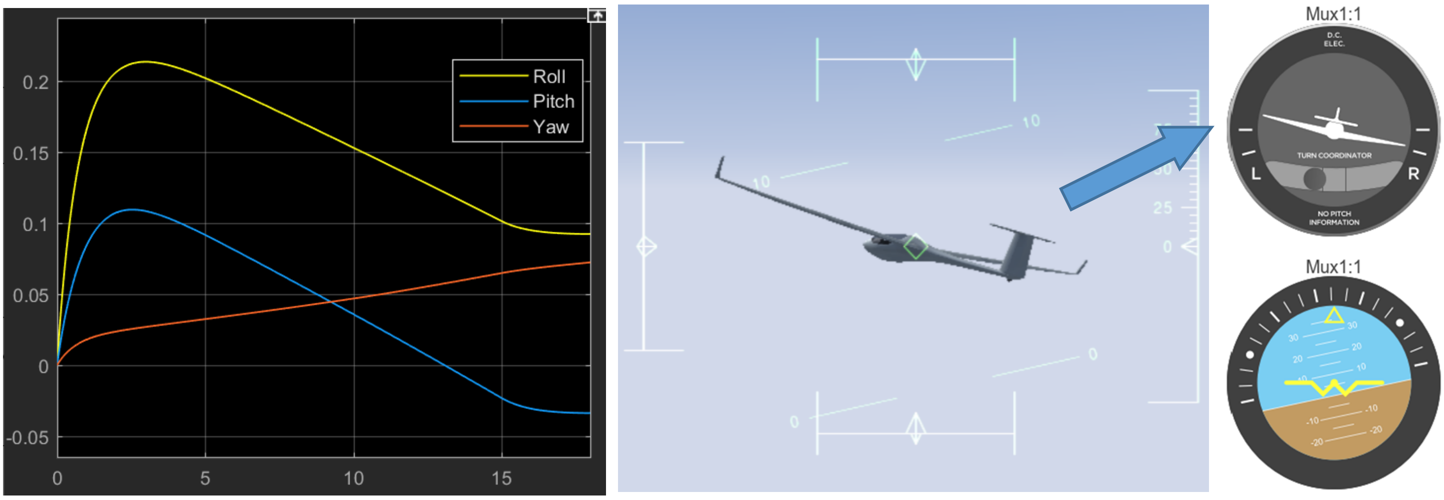


Figure 5-9. Skid to turn in coupled linear system.

After applied almost equivalent Aileron and Rudder commands to the MIMO system, the ASW could achieved small angle 'skid to turn' for the whole process about 15 sec then go back to a certain euler angles.

5.2.3 Slipping Turn

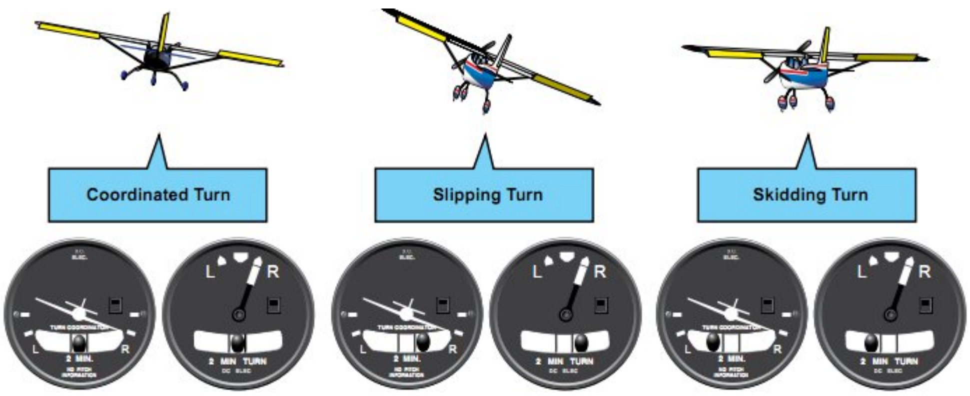


Figure 5-9. Skid to turn in coupled linear system.

Slipping is when the nose of the airplane is outside of the turn while the tail of the aircraft is inside the turn. In this situation the angle of bank is too great for the rate of the turn. You could correct it either by reducing your bank angle or by applying rudder to the direction of the turn. <u>Happens when pilot applies too much rudder and give less aileron.</u>

Conclusions

During the discussion above, the following conclusions are achieved:
1)

References

[1].STEVENS, B.L., F.L. LEWIS and E.N. JOHNSON, 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., Flight Stability and Automatic Control 2nd Ed.

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

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

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

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

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

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

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

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

[11] Tanner Austin Sims, Design and Control Considerations for a Skid-to-Turn Unmanned Aerial Vehicle, 2009

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=LzQPJRt00Ng
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
https://www.mathworks.com/help/slcontrol/ug/linearize-simulink-model.html
Eigenvalue behaviors
http://www.sosmath.com/diffeq/system/linear/qualin/qualin.html
https://courses.cit.cornell.edu/mae5070/DynamicStability.pdf
http://www.dept.aoe.vt.edu/~lutze/AOE3134/AircraftDynamics.pdf
Skid to turn
https://www.researchgate.net/figure/M27-h20-000ft-Achieved-fin-deflections_fig4_268571198