



ACS COLLEGE OF ENGINEERING

Kambipura, Mysore Road, Bangalore 560074

DEPARTMENT OF AERONAUTICAL ENGINEERING

VI SEMESTER B.E.

BAEL606 – FLIGHT SIMULATION LAB

ACADEMIC YEAR 2024– 2025

LABORATORY MANUAL

NAME OF THE STUDENT :

BRANCH :

UNIVERSITY SEAT No. :

SEMESTER & SECTION :

BATCH :

LIST OF EXPERIMENTS

Sl. No.	Name of the Experiment	Page No.
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Course objectives:

- Understand the root locus and bode plot.
- Understand the spring mass damper system and the servo mechanism system with feedback.
- Acquire the knowledge to use computational tools to model aeronautical vehicle dynamics.

Assessment Details (both CIE and SEE)

The weightage of Continuous Internal Evaluation (CIE) is 50% and for Semester End Exam (SEE) is 50%. The minimum passing mark for the CIE is 40% of the maximum marks (20 marks out of 50) and for the SEE minimum passing mark is 35% of the maximum marks (18 out of 50 marks). A student shall be deemed to have satisfied the academic requirements and earned the credits allotted to each subject/ course if the student secures a minimum of 40% (40 marks out of 100) in the sum total of the CIE (Continuous Internal Evaluation) and SEE (Semester End Examination) taken together.

Continuous Internal Evaluation (CIE):

CIE marks for the practical course are 50 Marks.

The split-up of CIE marks for record/ journal and test are in the ratio 60:40.

Each experiment is to be evaluated for conduction with an observation sheet and record write-up. Rubrics for the evaluation of the journal/write-up for hardware/software experiments are designed by the faculty who is handling the laboratory session and are made known to students at the beginning of the practical session.

- Record should contain all the specified experiments in the syllabus and each experiment write-up will be evaluated for 10 marks.
- Total marks scored by the students are scaled down to 30 marks (60% of maximum marks).
- Weightage to be given for neatness and submission of record/write-up on time.
- Department shall conduct a test of 100 marks after the completion of all the experiments listed in the syllabus.
- In a test, test write-up, conduction of experiment, acceptable result, and procedural knowledge will carry a weightage of 60% and the rest 40% for viva-voce.
- The suitable rubrics can be designed to evaluate each student's performance and learning ability.
- The marks scored shall be scaled down to 20 marks (40% of the maximum marks).

The Sum of scaled-down marks scored in the report write-up/journal and marks of a test is the total CIE marks scored by the student.

Semester End Evaluation (SEE):

- SEE marks for the practical course are 50 Marks.
- SEE shall be conducted jointly by the two examiners of the same institute, examiners are appointed by the Head of the Institute.
- The examination schedule and names of examiners are informed to the university before the conduction of the examination. These practical examinations are to be conducted between the schedule mentioned in the academic calendar of the University.

- All laboratory experiments are to be included for practical examination.
- (Rubrics) Breakup of marks and the instructions printed on the cover page of the answer script to be strictly adhered to by the examiners. OR based on the course requirement evaluation rubrics shall be decided jointly by examiners.
- Students can pick one question (experiment) from the questions lot prepared by the examiners jointly.
- Evaluation of test write-up/ conduction procedure and result/viva will be conducted jointly by examiners.
- General rubrics suggested for SEE are mentioned here, writeup-20%, Conduction procedure and result in -60%, Viva-voce 20% of maximum marks. SEE for practical shall be evaluated for 100 marks and scored marks shall be scaled down to 50 marks (however, based on course type, rubrics shall be decided by the examiners)
- Change of experiment is allowed only once and 15% of Marks allotted to the procedure part are to be made zero.

Course outcomes (Course Skill Set):

At the end of the course the student will be able to:

- Plot the root locus and bode plot.
- Calculate the dynamics response of aircraft.
- Use computational tools to model aircraft trajectory.

Suggested Learning Resources:

- <https://www.mccormick.northwestern.edu/documents/students/undergraduate/introduction-tomatlab.pdf>

EXPERIMENT NO-1**POLE-ZERO MAP OF A DYNAMIC SYSTEM MODEL WITH PLOT CUSTOMIZATION****AIM:**

To draw a Pole-Zero Map of a Dynamic System Model

THEORY

A system is often defined in terms of the poles and zeros of its transfer function. The poles of a transfer function are the values of the Laplace transform variable, s , that cause the transfer function to become infinite. The zeros of a transfer function are the values of the Laplace transform variable, s , that cause the transfer function to become zero

A system can be defined by its transfer function, which is a ratio of polynomials in the Laplace variable "s".

$$H(s) = \frac{b_0s^2 + b_1s + b_2}{a_0s^3 + a_1s^2 + a_2s + a_3}$$

The above transfer function $H(s)$ can be represented in the form of Pole-Zero representation as

$$H(s) = k \frac{(s - z_1)(s - z_2)}{(s - p_1)(s - p_2)(s - p_3)}$$

The constant $k=b_0/a_0$. The z_i terms are the zeros of the transfer function; as $s \rightarrow z_i$ the numerator polynomial goes to zero, so the transfer function also goes to zero. The p_i terms are the poles of the transfer function; as $s \rightarrow p_i$ the denominator polynomial is zero, so the transfer function goes to infinity.

A pole-zero plot is a graphical representation of a rational transfer function in the complex plane which helps to convey certain properties of the system such as stability, Causality etc.,.

In Mat lab, `pzplot(sys)` computes the poles and (transmission) zeros of the dynamic system model `sys` and plots them in the complex plane. The poles are plotted as X's and the zeros are plotted as O's. It also returns the plot handle `h`. You can use this handle to customize the plot with the `get` options and `set` options commands

Example :Plot the poles and zeros of the continuous-time system represented by the following transfer function:

$$sys(s) = \frac{2s^2 + 5s + 1}{s^2 + 3s + 5}$$

MATLAB CODE:

```
clear all;
clc;
sys = tf([2 5 1],[1 3 5]);
h = pzplot(sys);
grid on
p = getoptions(h);
p.Title.Color = [1,0,0];
setoptions(h,p);
```

Problem 1: Plot the poles and zeros of the continuous-time system represented by the following transfer function with plot customization on Xaxis and Yaxis. Sketch the results

$$H(s) = \frac{6s^2 + 18s + 12}{2s^3 + 10s^2 + 16s + 12}$$

Problem 2: Plot the poles and zeros of the continuous-time system represented by the following transfer function with plot customization. Sketch the results

$$G(s) = \frac{2s^2 + s + 3}{3s^3 + 4s^2 + 1}$$

VIVA QUESTIONS

1. What is MatLab?
2. Name some of the basic commands in MatLab?
3. What are all the functions of the commands in the above program?
4. How MatLab is superior to other software simulation?
5. What is a Pole and Zero?
6. What is the prediction obtained from a Pole zero plot?

EXPERIMENT NO-2**ROOT LOCUS FOR A DYNAMIC SYSTEM.****AIM:**

- To Plot the root locus with variables in transfer function
- To Plot the root locus of a dynamic system

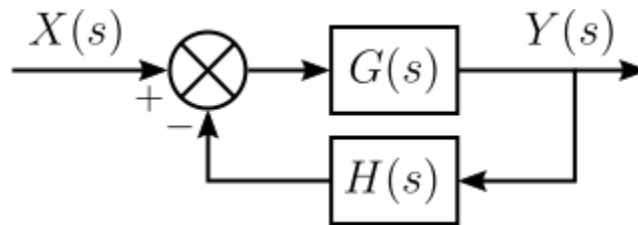
THEORY

Root locus analysis is a graphical method for examining how the roots of a system change with variation of a certain system parameter, commonly a gain within a feedback system. This is a technique used as a stability criterion in the field of classical control theory developed by Walter R. Evans which can determine stability of the system. The root locus plots the poles of the closed loop transfer function in the complex s-plane as a function of a gain parameter.

Locus is defined as a set of all points satisfying a set of conditions, the term root refers to the roots of the characteristic equation which are the poles of the closed loop transfer function. These poles define the time response of the system and hence the performance and stability of the system.

The root locus of a feedback system is the graphical representation in the complex s-plane of the possible locations of its closed-loop poles for varying values of a certain system parameter. The points that are part of the root locus satisfy the angle condition. The value of the parameter for a certain point of the root locus can be obtained using the magnitude condition.

Suppose there is a feedback system with input signal $X(s)$ and output signal $Y(s)$. The forward path transfer function is $G(s)$, the feedback path transfer function is $H(s)$



For this system, the closed-loop transfer function is given by

$$T(s) = \frac{Y(s)}{X(s)} = \frac{G(s)}{1 + G(s)H(s)}$$

Thus, the closed-loop poles of the closed-loop transfer function are the roots of the characteristic equation $1+G(s)H(s)=0$. The roots of this equation may be found wherever $G(s)H(s)=-1$

In systems without pure delay, the product $G(s)H(s)$ is a rational polynomial function and may be expressed as

$$G(s)H(s) = K \frac{(s + z_1)(s + z_2) \cdots (s + z_m)}{(s + p_1)(s + p_2) \cdots (s + p_n)}$$

$$G(s)H(s) = K \frac{num}{den}$$

Where num is the numerator of the polynomial and den is the denominator polynomial and K is the gain ($K>0$). The vector K contains all the gain values for which the closed loop poles are to be computed

The root loci is plotted by using the MATLAB Command

$$rlocus(num,den)$$

The gain vector K is supplied by the user

Example: A plant to be controlled is described by a transfer function

$$G(s) = \frac{s + 5}{s^2 + 7s + 25}$$

Obtain the root locus plot using MATLAB

MATLAB CODE

```
clear all;
clc;
num=[1 5];
den=[1 7 25];
G=tf(num,den);
rlocus(G);
```

PROBLEMS

1. Obtain the mathematical model of a Spring Mass Damper system and plot its root locus for different system parameters using MATLAB
2. Plot the root locus using MATLAB for a system whose OLTf $G(s)H(s)$ is given by

$$G(s)H(s) = \frac{(s + 3)}{(s^2 + 3s + 4)(s^2 + 2s + 7)}$$

VIVA QUESTIONS

1. What is root locus?
2. What can be interpreted from the root locus analysis?
3. What is stability?
4. What are the steps involved in root locus method?
5. Which command is used to obtain the root locus of any dynamic system in MATLAB

EXPERIMENT NO-3**FREQUENCY DOMAIN ANALYSIS****AIM:**

To draw the bode plot of a transfer function and analyze the same in frequency domain

THEORY

A Bode plot is a graph of the frequency response of a system. It is usually a combination of a Bode magnitude plot, expressing the magnitude (usually in decibels) of the frequency response, and a Bode phase plot, expressing the phase shift.

The Bode plot for a linear, time-invariant system with transfer function $H(s)$ (s being the complex frequency in the Laplace domain) consists of a magnitude plot and a phase plot.

The Bode magnitude plot is the graph of the function $|H(s=jw)|$ of frequency w (with j being the imaginary unit). The w -axis of the magnitude plot is logarithmic and the magnitude is given in decibels, i.e., a value for the magnitude $|H|$ is plotted on the axis at $20\log_{10} |H|$.

The Bode phase plot is the graph of the phase, commonly expressed in degrees, of the transfer function $\arg(H(s=jw))$ as a function of w . The phase is plotted on the same logarithmic w -axis as the magnitude plot, but the value for the phase is plotted on a linear vertical axis.

The MATLAB command “bode” obtains the magnitudes and phase angles of the frequency response of continuous time linear time invariant systems

The MATLAB bode commands commonly used are:

`Bode(num,den)`

`Bode(num,den,w)`

`Margin(num,den)`

`[mag,phase,w]=bode(num,den)`

Where w is the frequency vector.

Example: Write a program in MATLAB to obtain a Bode Plot for the transfer function

$$G(s) = \frac{15}{(s + 3)(0.7s + 5)}$$

MATLAB CODE:

```
clear all;  
clc;  
num=[1 5];  
den=conv([1 0], conv([1 3],[0.7 5]));  
G=tf(num,den);  
Bode(G);
```

Problems:

1. Write a program in MATLAB to obtain a Bode Plot for the transfer function and obtain its phase and gain margin. Sketch the results

$$1) G(s) = \frac{(7s^3 + 15s^2 + 7s + 80)}{s^4 + 8s^3 + 12s^2 + 70s + 110}$$

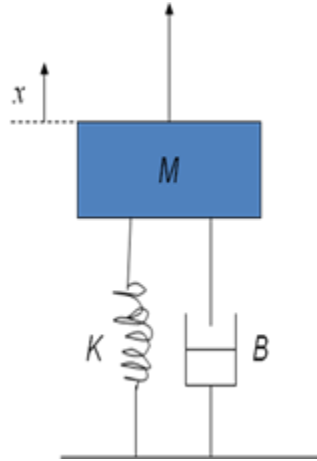
$$2) G(s) = \frac{K}{(s + 3)(s + 5)}$$

VIVA QUESTIONS

1. What is frequency domain analysis?
2. What are the frequency domain specifications of a system?
3. What are the advantages of frequency domain analysis?
4. What is a feedback and what is the effect of it on a system?
5. What is gain and Phase Margin?

EXPERIMENT NO-4**SIMULATE A SPRING MASS – DAMPER SYSTEM WITH AND WITHOUT A FORCING FUNCTION THROUGH SIMULINK.****AIM:**

To generate and analyze the response of a spring mass motion to a step and ramp input

THEORY

The Mathematical model of the system is described by:

$$\ddot{x} = \frac{1}{M} (-B\dot{x} - Kx + f(t))$$

Let Mass $M=2\text{kg}$; Stiffness Constant $K=2 \text{ N/m}$; $B = 2 \text{ Ns/m}$. Then,

$$\ddot{x} = \frac{1}{2} (-2\dot{x} - 2x + f(t))$$

PROCEDURE FOR SIMULATION:

Set $f(t)=0$ for free oscillation response or set it to a constant value. For $f(t)=0$ the equation becomes:

$$\ddot{x} + \dot{x} + x = 0$$

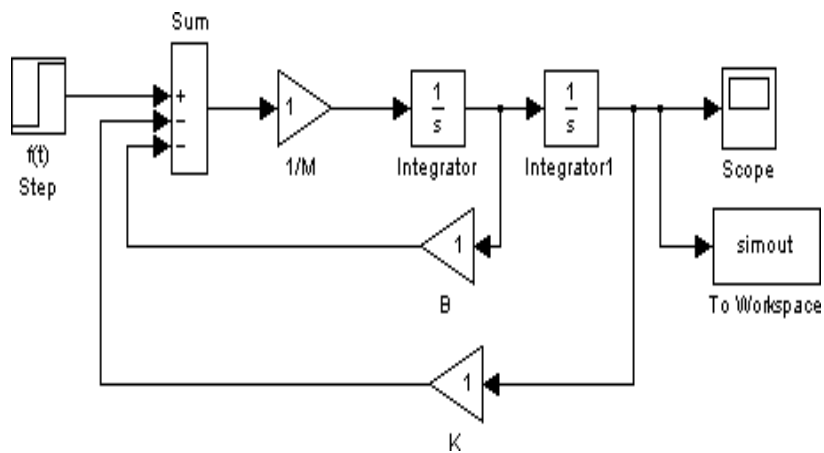
STEP 1: Open MATLAB, Type “simulink” in command window.

STEP 2: Go to File, Open a New Model.

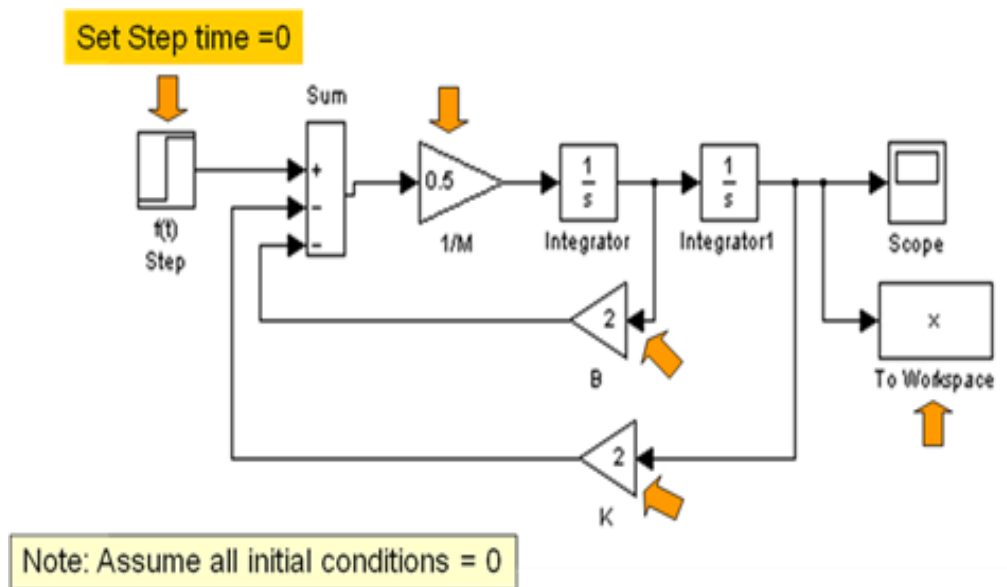
STEP 3: Drag and place the following blocks from the corresponding library

Select BLOCK set	Location in Simulink Library
Step	Sources
Sum	Math Operation
Gain	Math Operation
Integrator	Continuous
Scope	Sinks

STEP 4: Make Connections

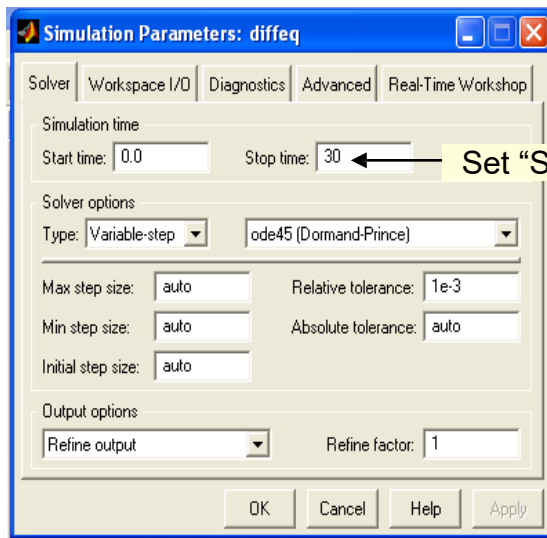


STEP 5: Set Parameters



STEP 6: Running Simulations

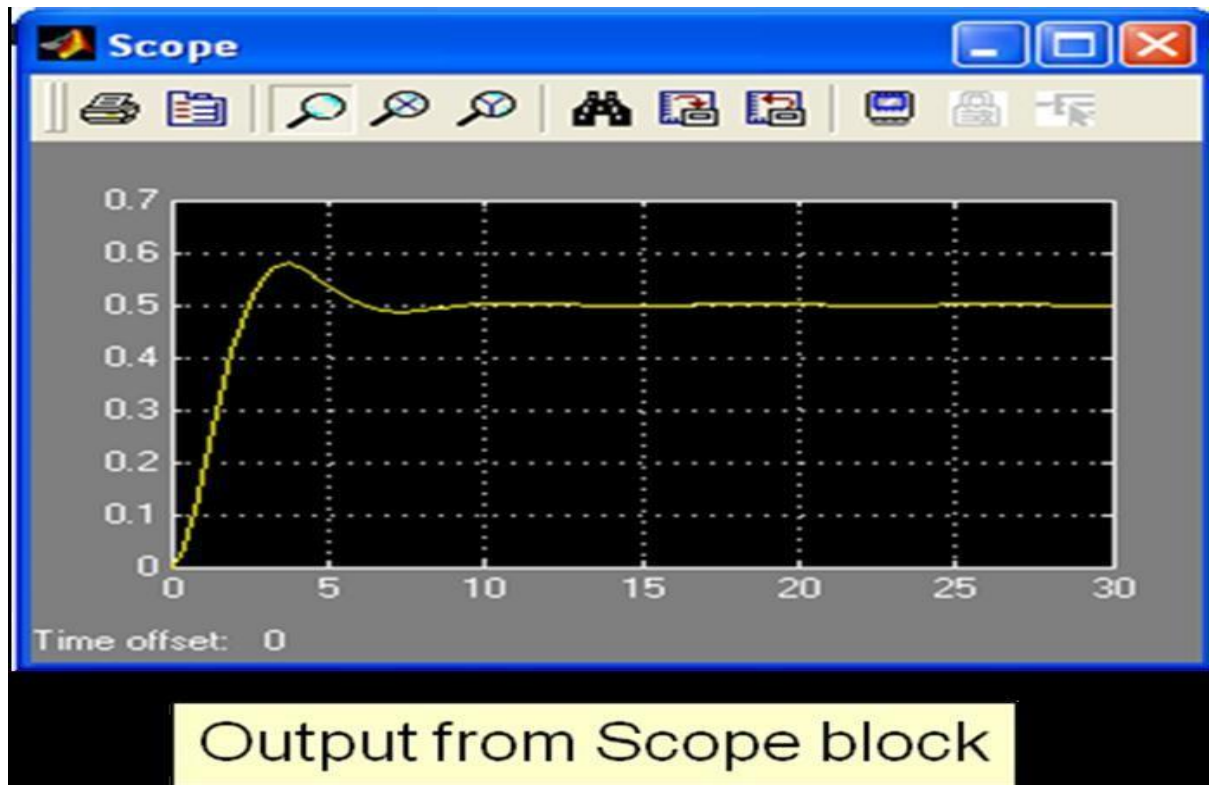
Open “simulation parameters”



2

**RUN
Simulation**

STEP 7: Viewing Results



VIVA QUESTIONS

1. What is Simulink?
2. What are types of math operators are used in MatLab?
3. What is a mathematical model and how it is helpful?
4. What are the different types of inputs given to the system?
5. What is damping ratio and what does it signifies?
6. What is stiffness?
7. What is viscous damping?

EXPERIMENT NO-5

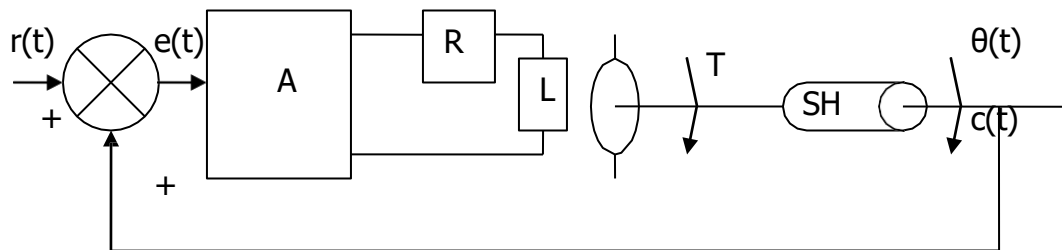
SIMULATION OF SIMPLE SERVOMECHANISM FEEDBACK SYSTEM

AIM:

To simulate a simple servo-mechanism feedback system in „S“ domain and plot its response to a step input.

THEORY:

Consider a servomechanism system as shown in the following figure.



Where,

A = Gain of Amplifier

R = Resistance of Motor Winding

L = Inductance of Motor Winding

SH = Shaft

It consists of the following elements,

- (a) An electrical input which acts as a “reference” of shaft angle. It is referred as $r(t)$.

In the „S“ domain this can be represented by $R(s)$.

- (b) A differential amplifier which compares the output $c(t)$ i.e the controlled shaft angle withy input reference proportional to shaft angle.

Mathematical equations for this may be described as,

$$e(t) = r(t) - c(t)$$

where $r(t)$ is the reference input, $c(t)$ is the controlled shaft angle and $e(t)$ is the output of the differential amplifier which acts as an input to the amplifier.

In the „S“ domain this can be represented by,

$$E(s) = R(s) - C(s)$$

- (c) An output amplifier amplifies the output of this differential amplifier. Its input is $e(t)$ and output is $v(t)$. Its mathematical equation may be described as,

$$v(t) = A e(t)$$

In the „S“ domain this can be represented by,

$$V(s) = AE(s)$$

(d) An electrical d.c shunt motor which controls the controlled shaft. The torque T, generated by the motor proportional to the field current and represented by,

$$T/I = K$$

Where K is a constant determined by the characteristics of the motor. The ratio of the field current I and amplifier output is,

$$V(t) = R.I + L (dI/dt)$$

where L and R are the inductance and resistance respectively of the motor field winding.

In the „S“ domain this can be represented by,

$$V(s) = R. I(s) + L S I(s)$$

(e) The equation of the shaft angle $\theta(t)$ can be written by the application of Newton's Second Law as,

$$T = L (d^2 \theta(t) / dt^2) + F (d \theta(t)/dt)$$

In the „S“ domain this can be represented by,

$$\begin{aligned} T(s) &= JS^2\theta(s) + FS \theta(s) \\ &= (JS^2 + FS) \theta(s) \end{aligned}$$

The output voltage is $c(t) = B \theta(t)$, and in „S“ domain this can be written as

$$C(s) = B \theta(s)$$

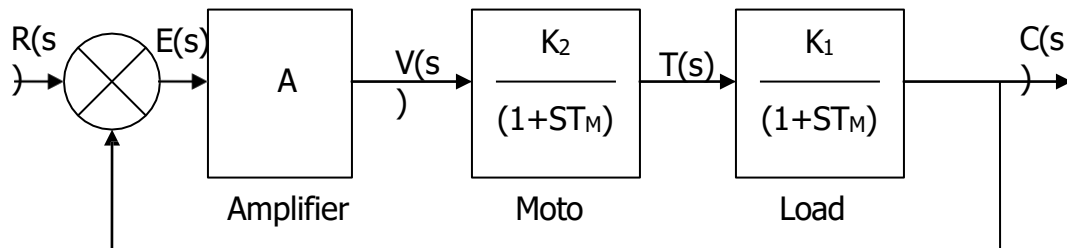
From the above equations we can obtain,

$$C(s) / T(s) = (1/S) . (K_1 / (1+ST_L))$$

$$T(s) / V(s) = K_2 / (1+ST_M)$$

Therefore the above diagram can be reduced to its block diagram representation in “s” domain

as,



PROCEDURE FOR SIMULATION:

STEP 1: Open MATLAB, Type “simulink” in command window.

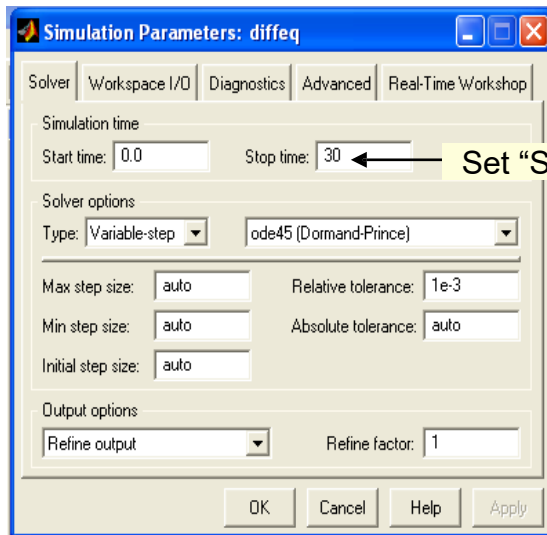
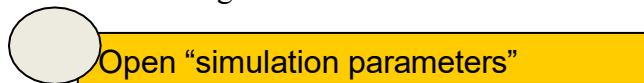
STEP 2: Go to File, Open a New Model.

STEP 3: Drag and place the following blocks from the corresponding library

Select BLOCK set	Location in Simulink Library
Step	Sources
Sum	Math Operation
Transfer Function	Continuous
Scope	Sinks

STEP 4: Make Connections as shown in the reduced block diagram above

STEP 6: Running Simulations



STEP 7: View the response plot by double clicking on the scope block

VIVA QUESTIONS

1. What is a frequency Response?
2. What is the gain of an amplifier?
3. What is the inductance of motor winding?
4. What are the different types of controllers used?
5. What is the advantage of taking Laplace Transform of parameter in Control system?
6. What is the requirement of ideal control system?
7. What is an open loop and closed loop control system? Differentiate.

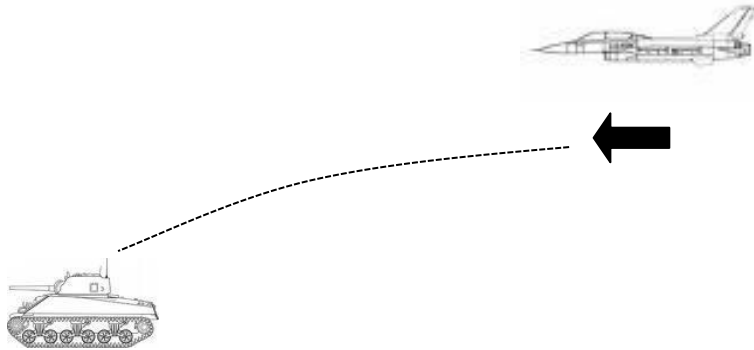
EXPERIMENT NO-6

SIMULATE A BOMB DROP FROM AN AIRCRAFT ON A MOVING TANK FOR PURE-PURSUIT MOTION

AIM:

To simulate a bomb drop from an aircraft on a moving tank for pure pursuit motion and plot the trajectory.

THEORY:



Assumptions:

1. Target and the pursuer are moving in the same horizontal plane when the pursuer first sights the tank.
2. The Pursuer speed is constant.
3. Forward speed of the bomb remains constant.

Let us assume a pursuer (fighter) at a height y_0 from the ground moving in the same plane as that of the target and also in the same direction. Let the pure pursuit velocity be v_0 . Let the angle of elevation with respect to the horizon of the fighter be θ . If t is the total time of flight for the trajectory, then equation of motion can be represented by,

$$y = \left(\frac{-g}{2} \right) t^2 + (V \sin \theta) t + y_0$$

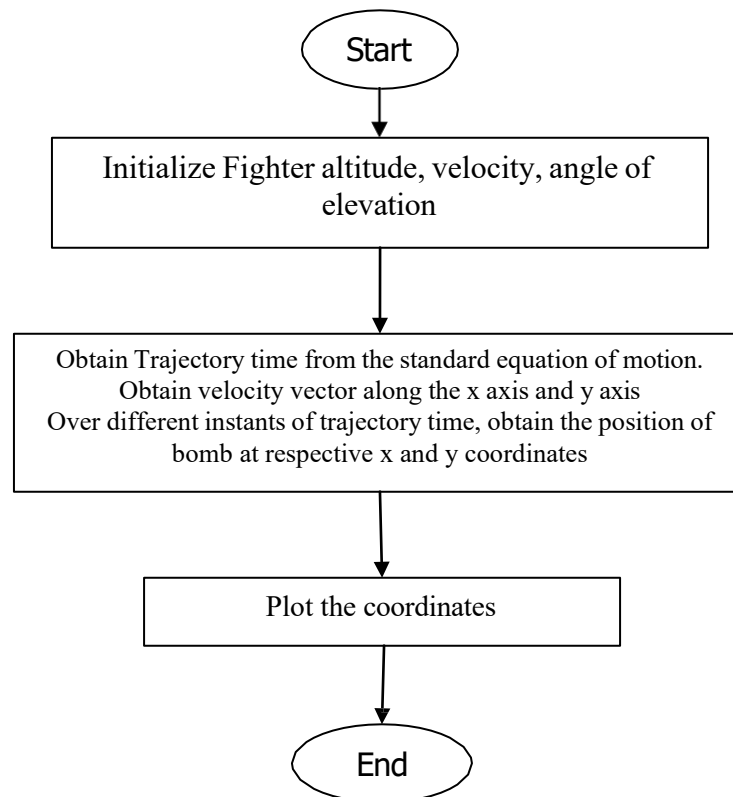
The above equation is of the form $s = ut + (1/2)at^2$. Thus solving the above equation we get the total time of trajectory for the bomb drop. The velocity vector along the x axis is given by

$x = V_0 \cos(\theta)$ and that along the y axis is given by $y = V_0 \sin(\theta)$. Therefore the new position

vector at any instant along the x axis is given by $x = xt$ and that along the y axis is given by,

$$y = \left(\frac{-g}{2} \right) t^2 + y_0 + y_0$$

FLOW CHART:



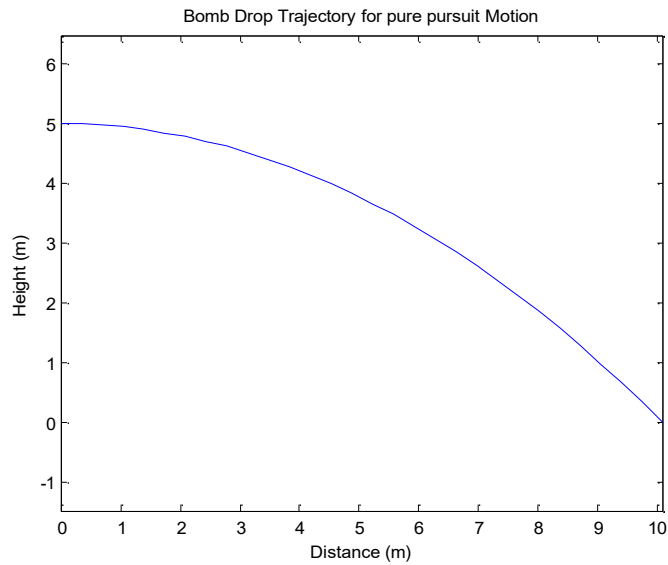
MATLAB CODE:

```

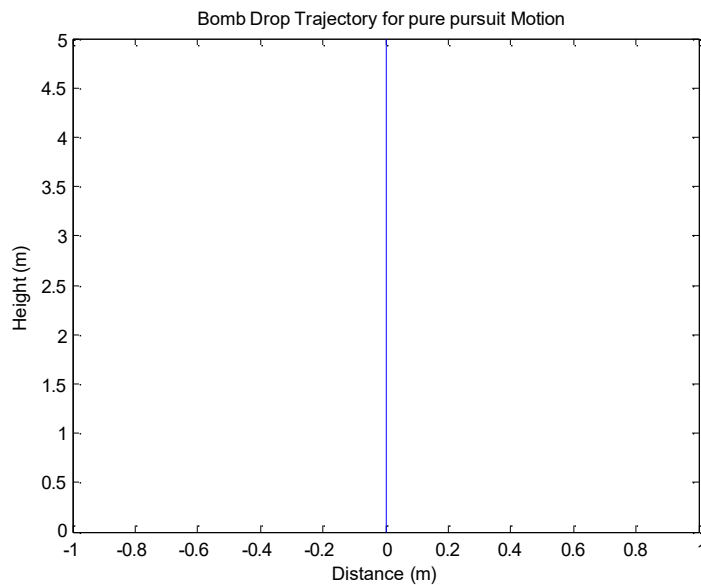
clc;
clear all;
y0=5;    % initial height in m
v0=10;   % initial velocity in m/s
theta=0; % trajectory elevation w.r.t horizon in deg
g=9.81;  % acceleration due to gravity in m/s^2
b=v0*sin(pi*(theta/180));
a=-g/2;
c=y0;
t_flight=(-b-sqrt(b^2-4*a*c))/(2*a);
t=linspace(0,t_flight,30);
xdot0=v0*cos(pi*(theta/180));
ydot0=v0*sin(pi*(theta/180));
x=xdot0*t+x0;
y=-(g/2)*t.^2+ydot0*t+y0;
plot(x,y);
xlabel('Distance (m)');
ylabel('Height (m)');
title('Bomb Drop Trajectory for pure pursuit Motion');
  
```

Result:

Case1: $v_0=10$;



Case2: $v_0=0$;



VIVA QUESTIONS

1. What is the initial velocity of the bomb when it is dropped?
2. What are the forces acting on a falling bomb?
3. What are the directions of the above forces?
4. What are the uncertain forces acting on the falling body?
5. What are the effects of these forces?
6. What is the shape traced by the bomb falling from aircraft under ideal condition?
7. Explain pure pursuit motion?
8. What is the function of linspace in MatLab?

EXPERIMENT NO-7**SIMULATE AIRCRAFT TAKE-OFF AND LANDING WITH TRAJECTORY TRACING****AIM:**

To calculate Lift – off and Landing distance of Aircraft and also study the effect due to other parameters.

THEORY:

1. Takeoff Performance:

The total takeoff distance, as defined in the Federal Aviation Requirements (FAR), is the sum of the ground roll distance S_{LO} and the distance (measured along the ground) to clear a 35-ft height (for jet-powered civilian transports) or a 50-ft height (for all other airplanes).

Lift off distance

$$S_{LO} = \frac{1.44W^2}{g\rho_{\infty}SC_{L(max)}\{T - (D + \mu_r(W - L))_{av}\}}$$

1. Liftoff distance is very sensitive to the weight of the airplane, varying directly as W^2 . If the weight is doubled, the ground roll of the airplane is quadrupled.
2. Liftoff distance is dependent on the ambient density ρ_{∞} . If we assume that thrust is directly proportional to ρ_{∞}

$$S_{LO} = \frac{1}{\rho_{\infty}^2}$$

3. The liftoff distance can be decreased by increasing the wing area, increasing $C_L(max)$, and increasing the thrust, all of which simply make common sense.

Velocity Liftoff:

$$V_{LO} = 1.2V_{Stall} = 1.2 \sqrt{\frac{2W}{\rho_{\infty}SC_{L(max)}}}$$

Lift:

$$L = \frac{1}{2}\rho_{\infty}V^2SC_{L(max)}$$

Drag:

$$D = \frac{1}{2}\rho_{\infty}V^2S(C_{D0} + \phi \frac{C_L^2}{\pi e(AR)})$$

$$\phi = \frac{(16h/b)^2}{1 + (16h/b)^2}$$

2. Landing Performance:

The total landing distance, as defined in FAR, is the sum of the ground roll distance and the distance (measured along the ground) to achieve touchdown in a glide from a 50-ft height. During the landing ground roll, the pilot is applying brakes. Modern jet transports utilize thrust reversal during the landing ground roll. Thrust reversal is created by ducting air from the jet engines and blowing it in the upstream direction. Opposite to the usual downstream direction when normal thrust is produced.

Landing Distance:

$$S_{LO} = \frac{1.69W^2}{g\rho_{\infty}SC_{L(max)}\{T_R + (D + \mu_r(W - L))_{0.7F_T}\}}$$

T_r is the reserved thrust

$$V_T = 1.3V_{Stall} = 1.3 \sqrt{\frac{2W}{\rho_{\infty}SC_{L(max)}}}$$

MATLAB Code:

```

clc;
w=10000:20:15000;
k=10^-5;
Slo=k*(w.^2);
plot(Slo,w);
title('takeoff distance v/s weight:')
xlabel('Liftoff Distance')
ylabel('Weight')
figure(2)
s=90:1:100;
k=10^5;
Slo=k./s;
plot(Slo,s);
title('takeoff distance v/s wing area:')
xlabel('Liftoff Distance')
ylabel('Wing Area')
figure(3)
w=10000:20:15000;
k=10^-5;
Slo=k*(w.^2);
plot(Slo,w);
title('Landing distance v/s weight:')
xlabel('Landing Distance')
ylabel('Weight')
figure(4)
s=90:1:100;
k=10^5;
Slo=k./s;
plot(Slo,s);
title('Landing distance v/s wing area:')
xlabel('Landing Distance')
ylabel('Wing Area')

```

Viva Questions:

1. Explain the modes of flight?
2. Explain Take-off performance?
3. Explain the factors affecting takeoff performance?
4. Explain the minimum power required for Takeoff?
5. Explain landing performance?
6. Explain the factors affecting Landing distance?
7. Explain the clearance height required for landing and takeoff?

EXPERIMENT NO-8

SIMULATE STALL OF AIRCRAFT AND SHOWS THE EFFECT OF VARIATION IN STATIC MARGIN ON STALL CHARACTERISTICS

AIM:

To Simulate stall Characteristics of aircraft and the effect of variation in Static Margin

THEORY:

1. Stall:

The factors that affect the stalling characteristics of the airplane are: balance (load distribution), bank (wing loading), pitch attitude (critical angle of attack), coordination (control movement), drag (gear or flaps), and power. The pilot should learn the effect of each on the stall characteristics of the airplane being flown and what should be done to affect the proper correction. It should be reemphasized here that a stall can occur at any airspeed, in any attitude, or at any power setting, depending on the total number of factors affecting the particular airplane.

A number of factors may be induced as the result of other factors. For example, when the airplane is in a nose high turning attitude, the angle of bank has a tendency to increase. This occurs because with the airspeed decreasing, the airplane begins flying in a smaller and smaller arc. Since the outer wing is moving in a larger radius and thus traveling faster than the inner wing, it has more lift and causes an overbanking tendency. At the same time, because of the decreasing airspeed and decreasing lift on both wings, the pitch attitude tends to lower. In addition, since the airspeed is decreasing while the power setting remains constant, the effect of torque becomes more prominent, causing the airplane to yaw.

During the practice of nose high turning stalls, to compensate for these factors and to maintain a constant flight attitude until the stall occurs, aileron pressure must be continually adjusted to keep the bank attitude constant. At the same time, back elevator pressure must be continually increased to maintain the pitch attitude, as well as right rudder pressure increased to prevent adverse yaw from changing the turn rate. If the bank is allowed to become too steep, the vertical component of lift decreases and makes it even more difficult to maintain a constant pitch attitude.

Whenever practicing turning stalls, a constant pitch and bank attitude should be maintained until the stall occurs. Whatever control pressures are necessary should be applied even though the controls appear to be crossed (aileron pressure in one direction, rudder pressure in the opposite direction). During the entry to a power on turning stall to the right in particular, the controls will be crossed to some extent. This is due to right rudder pressure being used to overcome torque and left aileron pressure being used to prevent the bank from increasing.

2. Static Margin:

If an aircraft in flight suffers a disturbance in pitch that causes an increase (or decrease) in angle of attack, it is desirable that the aerodynamic forces on the aircraft cause a decrease (or increase) in angle of attack so that the disturbance does not cause a continuous increase (or decrease) in angle of attack. This is longitudinal static stability.

Static margin is a concept used to characterize the static longitudinal stability and controllability of aircraft and missiles.

In aircraft analysis, static margin is defined as the distance between the center of gravity and the neutral point of the aircraft, expressed as a percentage of the mean aerodynamic chord of the wing. The greater this distance and the narrower the wing, the more stable the aircraft.

Conventionally, the neutral point is aft of the c.g., although in rare cases (computer-controlled fighter aircraft) it may be forward of the c.g., i.e. slightly unstable, to obtain quickness of response in combat. Too great longitudinal stability makes the aircraft "stiff" in pitch, resulting in such undesirable features as difficulty in obtaining the necessary stalled nose-up pitch when landing.

The position of the neutral point is found by taking the algebraic net moment of all horizontal surfaces, measured from the nose of the aircraft, in the same manner as the c.g. is determined, i.e. the sum of all such moments divided by their total area. The stabilizer and elevator dominate this result, but it is necessary to account for all surfaces such as fuselage, landing gear, prop-normal, etc. It is also necessary to take account of the center of pressure of the wing, which can move a good deal fore and aft as angle of attack of a flat-bottom wing section (Clark Y) changes, or not at all in the case of self-stabilizing sections such as the M6.

The neutral point in conventional aircraft is a short distance behind the c.g. ("The feathers of the arrow must be at the back"); but in unconventional aircraft such as canards and those with dual-wings, such as the Quickie, this will not be so. The overall rule stated above must hold, i.e. the neutral point must be aft of the c.g., wherever that may be.

Static margin (SM) reflects the distance between the

- center of mass (C_M) and the net center of pressure (C_P)
- Body Axes
- Normalized by mean aerodynamic chord
- Does not reflect Z position of center of pressure
- Positive SM if C_P is behind C_M .

$$SM = \frac{100(X_{CM} - X_{CP_{net}})_B}{\bar{c}} \%$$

Effect of Static Margin on Pitching Coefficient:

- Zero crossing determines trim angle of attack, i.e., sum of moments = 0
- Negative slope required for static stability
- Slope, $\partial C_M / \partial \alpha$ varies with static margin.

$$M_B = (C_{M_0} + C_{M_\alpha}) \bar{q} S \bar{c}$$

MATLAB Code:

```

clc;
close all;
[v,T,vT]=xlsread('C:\Users\rohit\Documents\MATLAB\covsalpha.xlsx'
);
% 'xlsx' for exell
%v: Double
%T and vT : cell
%use v containing numbers
alpha=v(:,1);cl=v(:,2);
cd=v(:,3); cm=v(:,4);
%if u have to plot second colone depending on first:
plot(alpha,cl)
grid on
title('CL v/s Alpha (NACA0012)')
xlabel('Alpha')
ylabel('Cl')
figure(2)
plot(alpha,cd)
grid on
title('Cd v/s Alpha (NACA0012)')
xlabel('Alpha')
ylabel('Cd')
figure(3)
plot(alpha,cm)
grid on
title('Cm v/s Alpha (NACA0012)')
xlabel('Alpha')
ylabel('Cm')

```

Viva Questions:

- Q1. Explain Stall of an aircraft?
- Q2. Explain the factor affecting Stalling in the aircraft?
- Q3. Explain the precautions to be taken to avoid stall?
- Q4. Explain Static Margin?
- Q5. What is Neutral Point?
- Q6. Explain longitudinal stability?
- Q7. Explain how static margin affect the stability of an aircraft?
- Q8. Explain the effect of static margin on stall characteristics?

EXPERIMENT NO-9

SIMULATE AIRCRAFT LONGITUDINAL MOTION AND DEMONSTRATE THE EFFECT OF STATIC MARGIN VARIATION FOR A PULSE INPUT IN PITCH THAT IS INTENDED TO BLEED THE AIRSPEED

AIM:

To simulate aircraft longitudinal motion and demonstrate the effect of static margin variation for a pulse input in pitch that is intended to bleed the airspeed.

THEORY:

The simulation of the aircraft longitudinal motion would be obtained from the longitudinal control transfer functions for elevator deflections a control inputs. Hence the first step towards that is to obtain the said transfer functions.

The linearized small-disturbance longitudinal rigid body equation of motion is given by:

$$\begin{aligned} \left(\frac{d}{dt} - X_u\right) \Delta u - X_w \Delta w + (g \cos \theta_0) \Delta \theta &= X_{\delta_e} \Delta \delta_e + X_{\delta_T} \Delta \delta_T \\ -Z_u \Delta u + \left((1 - Z_{\dot{w}}) \frac{d}{dt} - Z_w\right) \Delta w - \left((u_0 + Z_q) \frac{d}{dt} - g \sin \theta_0\right) \Delta \theta &= Z_{\delta_e} \Delta \delta_e + Z_{\delta_T} \Delta \delta_T \\ -M_u \Delta u - \left(M_{\dot{w}} \frac{d}{dt} + M_w\right) \Delta w + \left(\frac{d^2}{dt^2} - M_q \frac{d}{dt}\right) \Delta \theta &= M_{\delta_e} \Delta \delta_e + M_{\delta_T} \Delta \delta_T \end{aligned}$$

The expressions of stability parameters estimated for, are as follows:

$$\begin{aligned} X_u &= \frac{-(C_{D_u} + 2C_{D_0})QS}{m u_0} (s^{-1}) & X_w &= \frac{-(C_{D_w} - C_{L_0})QS}{m u_0} (s^{-1}) \\ Z_u &= \frac{-(C_{L_u} + 2C_{L_0})QS}{m u_0} (s^{-1}) & Z_w &= -C_{z_w} \frac{c}{2u_0} QS / (u_0 m) \\ Z_w &= \frac{-(C_{L_w} + C_{D_0})QS}{m u_0} (s^{-1}) & Z_{\dot{w}} &= u_0 Z_w (ft/s) or (m/s) \\ Z_q &= -C_{z_q} \frac{c}{2u_0} QS / m (ft/s) or (m/s) & Z_{\dot{\alpha}} &= -C_{z_{\dot{\alpha}}} QS / m (ft/s^2) \\ M_u &= C_{m_u} \frac{(QSc)}{u_0 I_y} \left(\frac{1}{ft \cdot s}\right) or \left(\frac{1}{m \cdot s}\right) & M_w &= C_{m_w} \frac{\bar{c}}{2u_0} \frac{QSc}{u_0 I_y} (ft^{-1}) \\ M_w &= C_{m_w} \frac{(QSc)}{u_0 I_y} \left(\frac{1}{ft \cdot s}\right) or \left(\frac{1}{m \cdot s}\right) & M_{\dot{w}} &= u_0 M_w (s^{-1}) \\ M_{\alpha} &= u_0 M_w (s^{-2}) & M_{\delta_e} &= C_{m_{\delta_e}} (QSc) / I_y (s^{-2}) \\ M_q &= C_{m_q} \frac{\bar{c}}{2u_0} (QSc) / I_y (s^{-1}) & & \end{aligned}$$

The transfer function gives the relationship between the output of and input to a system. In the case of aircraft dynamics it specifies the relationship between the motion variables and the control input. The transfer function is defined as the ratio of the Laplace transform of the output to the Laplace transform of the input with all the initial conditions set to 0. (i.e, the system is assumed to be initially in equilibrium).

In this case the linearized equations of motion with the help of the stability parameters, will be used to generate the longitudinal control transfer functions.

The longitudinal control transfer function will be having a general form of

$$T(s) = \frac{U(s)}{\delta_e(s)} = \frac{N_{\delta}^u}{\Delta_{long}}$$

Where,

N_{δ}^u = Numerator polynomial of the transfer function, forward velocity vs elevator deflection.

Δ_{long} = Denominator polynomial of the longitudinal transfer function, which remains same for all longitudinal control transfer functions.

Where in which the numerator and denominator polynomials can be written generally as:

$$\frac{N_{\delta}^u}{\Delta_{long}} = [A_u s^3 + B_u s^2 + C_u s + D_u] / [A s^4 + B s^3 + C s^2 + D s + E]$$

The coefficients A, B, C, D and E belongs to the denominator polynomial and coefficients A_u , B_u , C_u and D_u are of the numerator polynomial. Similar representation is available for the transfer function such as $\frac{\theta(s)}{\delta_e(s)}$ and $\frac{W(s)}{\delta_e(s)}$

The table below shows the simplified expressions to estimate the coefficients of the transfer functions.

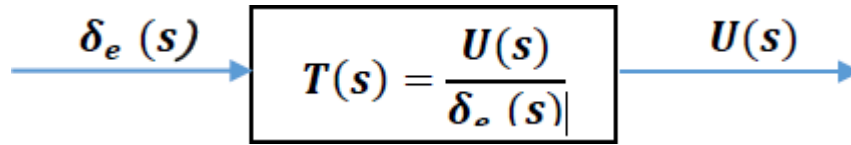
Longitudinal control transfer functions

	A	B	C	D	E
Δ_{long}	1	$-M_{\dot{q}} - u_0 M_{\dot{w}} - Z_w - X_u$	$Z_w M_{\dot{q}} - u_0 M_w - X_w Z_u$ $+ X_u (M_{\dot{q}} + u_0 M_w + Z_w)$	$-X_w (Z_w M_{\dot{q}} - u_0 M_w)$ $+ Z_u (X_w M_{\dot{q}} + g M_w)$ $- M_w (u_0 X_w - g)$	$g (Z_u M_w - M_w Z_w)$
N_{δ}^u	$M_{\delta} + Z_{\delta} M_{\dot{w}}$	$X_{\delta} (Z_w M_{\dot{w}} + M_w)$ $+ Z_{\delta} (M_w - X_w M_{\dot{w}})$ $- M_{\delta} (X_w + Z_w)$	$X_{\delta} (Z_w M_w - Z_w M_{\dot{w}})$ $+ Z_{\delta} (M_w X_w - M_w X_u)$ $+ M_{\delta} (Z_w X_u - X_w Z_u)$		
$N_{\delta}^{\dot{w}}$	Z_{δ}	$X_{\delta} Z_w - Z_{\delta} (X_w + M_{\dot{q}}) + M_{\delta} u_0$	$X_{\delta} (u_0 M_w - Z_w M_{\dot{q}})$ $+ Z_{\delta} X_w M_{\dot{q}} - u_0 M_{\delta} X_u$	$g (Z_{\delta} M_w - M_{\delta} Z_w)$	
N_{δ}^{θ}	X_{δ}	$-X_{\delta} (Z_w + M_{\dot{q}} + u_0 M_{\dot{w}}) + Z_{\delta} X_w$	$X_{\delta} (Z_w M_{\dot{q}} - u_0 M_w)$ $- Z_{\delta} (X_w M_{\dot{q}} + g M_w)$ $+ M_{\delta} (u_0 X_w - g)$	$g (M_{\delta} Z_w - Z_{\delta} M_w)$	

Upon using the provided relationships with the basic flight parameters, stability derivatives and aerodynamics coefficients the required transfer function can be estimated.

Impulse Response:

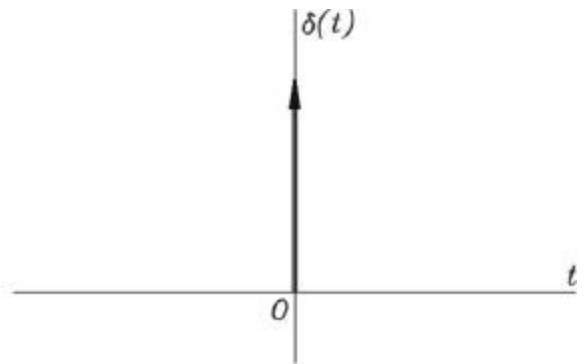
The aircraft time response can be summarized as follows:



Here, $\delta(s)$ is the input function, upon multiplying the input function with the system transfer function the Laplace transform of the output, $U(s)$, will be obtained. The inverse Laplace transform of the output would give the time function of the output $u(t)$.

In this experiment, the system transfer function connects the input variable $\delta(s)$, elevator deflection, and the controlled variable is the $U(s)$, the forward velocity. Here, the input is an input function $\delta(t)$. Defined as:

$$\delta(t) \begin{cases} = 0 & \text{for } t \leq 0^-; \\ \rightarrow \infty & \text{for } 0^- < t < 0^+; \\ = 0 & \text{for } t \geq 0^+ \end{cases}$$



The unit impulse is defined as a function of time that is zero everywhere, except for an infinitesimally small neighbourhood around the origin, in which the function attains unbounded values. However, its time integral from $-\infty$ to $+\infty$ is exactly +1. Thus, if we denote by 0^- and 0^+ the instants just before and just after 0, respectively, the unit-impulse function. The height of the arrow, then, denotes the time integral of the associated impulse function on the whole real axis. The Laplace transform of the function is equivalent to 1.

Case 1:

Static Margin = 0.2211

```

clc
A = 1; % Coefficients in the characteristic equation A - E
B = 1.2632;
C = 0.9618;
D = 0.09786;
E = 0.0127;
Au = 0.9710; % Coefficients in the Numerator polynomial Au, Bu,
Cu, & Du
Bu = 0.0903;
Cu = 1.6882;
Du = 10.5012;
DTF = [A B C D E]; % Denominator polynomial of the TF
Nu = [Au Bu Cu Du]; % Numerator polynomial of the TF
TFu = tf([Nu], [DTF]) % TF: forward velocity vs elevator
deflection [U(s)/de(s)]
    
```

```
figure
impzplot(TFu) % Impulse response of the TF [U(s)/de(s)]
grid on
```

Case 2:

Static Margin = 0.6633.

```
clc
A =1; % Coefficients in the characteristic equation A - E
B = 1.2632;
C = 2.0199;
D = 0.2121;
E = 0.0310;
Au = 0.9710; % Coefficients in the Numerator polynomial Au, Bu,
Cu, & Du
Bu = 0.0903;
Cu = 2.7156;
Du = 9.3144;
DTF = [A B C D E]; % Denominator polynomial of the TF
Nu = [Au Bu Cu Du]; % Numerator polynomial of the TF
TFu = tf([Nu], [DTF]) % TF: forward velocity vs elevator
deflection [U(s)/de(s)]
figure
impzplot(TFu) % Impulse response of the TF [U(s)/de(s)]
grid on
```

Note:

The reduction in the forward velocity, $u(t)$, for the impulse response upon varying, increasing, the static margin is significant and easily observable.

Viva Questions:

1. How the Linearized Equations of Motion for an aircraft are obtained.
2. What are stability derivatives?
3. What are stability parameters
4. What do you understand by Time response of a system?
5. State few standard test signals.
6. What do you understand by Short period and Phugoid motion?
7. How is the time response of a first order system differ from a second or higher order system, for a unit impulse input?
8. What effect the change in static margin bring in the forward velocity of an aircraft for certain elevator control deflection.
9. Mention the physical meaning of implementation of an Impulse function as an elevation command.
10. State few time response specifications applicable for higher order system and mention its physical significance as well.

EXPERIMENT NO-10
SIMULATE AIRCRAFT LONGITUDINAL MOTION AND
DEMONSTRATE THE EFFECT OF STATIC MARGIN VARIATION
FOR A DOUBLET INPUT IN PITCH

AIM:

To simulate aircraft longitudinal motion and demonstrate the effect of static margin variation for a pulse input in pitch that is intended to bleed the airspeed.

THEORY:

The simulation of the aircraft longitudinal motion would be obtained from the longitudinal control transfer functions for elevator deflections a control inputs. Hence the first step towards that is to obtain the said transfer functions.

The linearized small-disturbance longitudinal rigid body equation of motion is given by:

$$\begin{aligned} \left(\frac{d}{dt} - X_u\right) \Delta u - X_w \Delta w + (g \cos \theta_0) \Delta \theta &= X_{\delta_e} \Delta \delta_e + X_{\delta_T} \Delta \delta_T \\ -Z_u \Delta u + \left((1 - Z_{\dot{w}}) \frac{d}{dt} - Z_w\right) \Delta w - \left((u_0 + Z_q) \frac{d}{dt} - g \sin \theta_0\right) \Delta \theta &= Z_{\delta_e} \Delta \delta_e + Z_{\delta_T} \Delta \delta_T \\ -M_u \Delta u - \left(M_{\dot{w}} \frac{d}{dt} + M_w\right) \Delta w + \left(\frac{d^2}{dt^2} - M_q \frac{d}{dt}\right) \Delta \theta &= M_{\delta_e} \Delta \delta_e + M_{\delta_T} \Delta \delta_T \end{aligned}$$

The expressions of stability parameters estimated for, are as follows:

$$\begin{aligned} X_u &= \frac{-(C_{D_u} + 2C_{D_0})QS}{m u_0} (s^{-1}) & X_w &= \frac{-(C_{D_w} - C_{L_0})QS}{m u_0} (s^{-1}) \\ Z_u &= \frac{-(C_{L_u} + 2C_{L_0})QS}{m u_0} (s^{-1}) & Z_w &= -C_{z_w} \frac{c}{2u_0} QS / (u_0 m) \\ Z_w &= \frac{-(C_{L_w} + C_{D_0})QS}{m u_0} (s^{-1}) & Z_{\dot{w}} &= u_0 Z_w (ft/s) or (m/s) \\ Z_\alpha &= u_0 Z_w (ft/s^2) or (m/s^2) & Z_{\delta_e} &= -C_{z_{\delta_e}} QS / m (ft/s^2) \\ Z_q &= -C_{z_q} \frac{c}{2u_0} QS / m (ft/s) or (m/s) & & \\ M_u &= C_{m_u} \frac{(QSc)}{u_0 I_y} \left(\frac{1}{ft \cdot s}\right) or \left(\frac{1}{m \cdot s}\right) & M_{\dot{w}} &= C_{m_{\dot{w}}} \frac{\bar{c}}{2u_0} \frac{QSc}{u_0 I_y} (ft^{-1}) \\ M_w &= C_{m_w} \frac{(QSc)}{u_0 I_y} \left(\frac{1}{ft \cdot s}\right) or \left(\frac{1}{m \cdot s}\right) & M_\alpha &= u_0 M_{\dot{w}} (s^{-1}) \\ M_{\dot{w}} &= u_0 M_w (s^{-2}) & M_{\delta_e} &= C_{m_{\delta_e}} (QSc) / I_y (s^{-2}) \\ M_q &= C_{m_q} \frac{\bar{c}}{2u_0} (QSc) / I_y (s^{-1}) & & \end{aligned}$$

The transfer function gives the relationship between the output of and input to a system. In the case of aircraft dynamics it specifies the relationship between the motion variables and the control input. The transfer function is defined as the ratio of the Laplace transform of the output to the Laplace transform of the input with all the initial conditions set to 0. (i.e, the system is assumed to be initially in equilibrium).

In this case the linearized equations of motion with the help of the stability parameters, will be used to generate the longitudinal control transfer functions.

The longitudinal control transfer function will be having a general form of

$$T(s) = \frac{U(s)}{\delta_e(s)} = \frac{N_{\delta}^u}{\Delta_{long}}$$

Where,

N_{δ}^u = Numerator polynomial of the transfer function, forward velocity vs elevator deflection.

Δ_{long} = Denominator polynomial of the longitudinal transfer function, which remains same for all longitudinal control transfer functions.

Where in which the numerator and denominator polynomials can be written generally as:

$$\frac{N_{\delta}^u}{\Delta_{long}} = [A_u s^3 + B_u s^2 + C_u s + D_u] / [A s^4 + B s^3 + C s^2 + D s + E]$$

The coefficients A, B, C, D and E belongs to the denominator polynomial and coefficients A_u , B_u , C_u and D_u are of the numerator polynomial. Similar representation is available for the transfer function such as $\frac{\theta(s)}{\delta_e(s)}$ and $\frac{W(s)}{\delta_e(s)}$

The table below shows the simplified expressions to estimate the coefficients of the transfer functions.

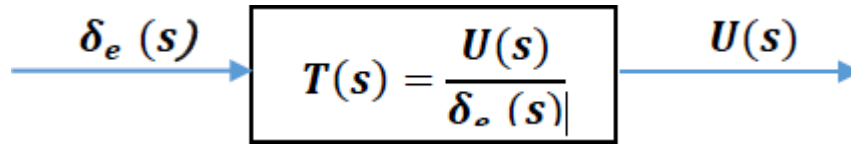
Longitudinal control transfer functions

	A	B	C	D	E
Δ_{long}	1	$-M_{\dot{q}} - u_0 M_{\dot{w}} - Z_w - X_u$	$Z_w M_{\dot{q}} - u_0 M_w - X_w Z_u$ $+ X_u (M_{\dot{q}} + u_0 M_w + Z_w)$	$-X_w (Z_w M_{\dot{q}} - u_0 M_w)$ $+ Z_u (X_w M_{\dot{q}} + g M_w)$ $- M_w (u_0 X_w - g)$	$g(Z_w M_w - M_w Z_w)$
N_{δ}^u	$M_{\delta} + Z_{\delta} M_{\dot{w}}$	$X_{\delta} (Z_w M_{\dot{w}} + M_w)$ $+ Z_{\delta} (M_w - X_w M_w)$ $- M_{\delta} (X_w + Z_w)$	$X_{\delta} (Z_w M_w - Z_w M_w)$ $+ Z_{\delta} (M_w X_w - M_w X_w)$ $+ M_{\delta} (Z_w X_w - X_w Z_w)$		
N_{δ}^{θ}	Z_{δ}	$X_{\delta} Z_w - Z_{\delta} (X_w + M_{\dot{q}}) + M_{\delta} u_0$	$X_{\delta} (u_0 M_w - Z_w M_{\dot{q}})$ $+ Z_{\delta} X_w M_{\dot{q}} - u_0 M_{\delta} X_w$	$g(Z_{\delta} M_w - M_{\delta} Z_w)$	
N_{δ}^W	X_{δ}	$-X_{\delta} (Z_w + M_{\dot{q}} + u_0 M_w) + Z_{\delta} X_w$	$X_{\delta} (Z_w M_{\dot{q}} - u_0 M_w)$ $- Z_{\delta} (X_w M_{\dot{q}} + g M_w)$ $+ M_{\delta} (u_0 X_w - g)$	$g(M_{\delta} Z_w - Z_{\delta} M_w)$	

Upon using the provided relationships with the basic flight parameters, stability derivatives and aerodynamics coefficients the required transfer function can be estimated.

Impulse Response:

The aircraft time response can be summarized as follows:



Here, $\delta(s)$ is the input function, upon multiplying the input function with the system transfer function the Laplace transform of the output, $U(s)$, will be obtained. The inverse Laplace transform of the output would give the time function of the output $u(t)$.

In this experiment, the system transfer function connects the input variable $\delta(s)$, elevator deflection, and the controlled variable is the $U(s)$, the forward velocity. Here, the input is an input function $\delta(t)$. The time derivative of a unit impulse, $\dot{\delta}(t)$, is called the doublet function. It is formally defined as:

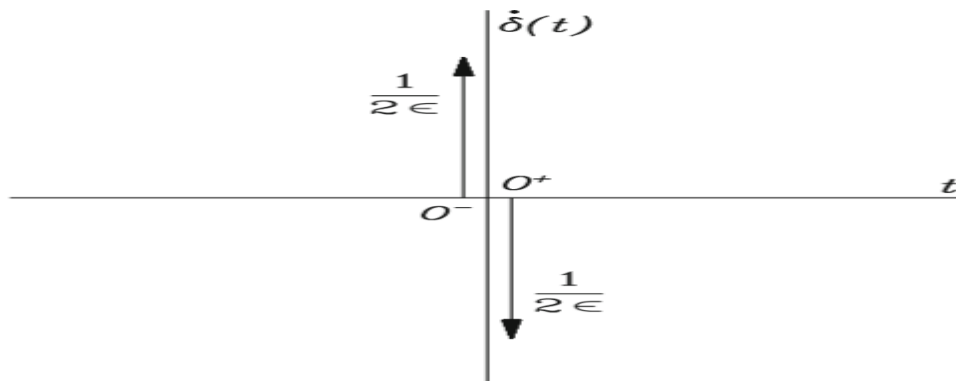
$$\dot{\delta}(t) = \frac{d}{dt} \delta(t)$$

Using the definition of the time-derivative:

$$\dot{\delta}(t) = \lim_{\epsilon \rightarrow 0} \frac{\delta(t + \epsilon) - \delta(t - \epsilon)}{2\epsilon} = \lim_{\epsilon \rightarrow 0} \left[\frac{1}{2\epsilon} \delta(t + \epsilon) - \frac{1}{2\epsilon} \delta(t - \epsilon) \right]$$

With ϵ being defined as: $2\epsilon \equiv 0^+ - 0^-$

Therefore, the physical interpretation of a doublet is the limiting case of two impulses of ∞ amplitude, one applied at $t = 0^-$ and the other at $t = 0^+$, the latter being the negative of the former. As shown below:



The Laplace transform of doublet function, $\dot{\delta}(t)$, will be equals to $-s$. Hence, upon applying the doublet function as the input, the output definition would be simply the system transfer function with the order of the numerator polynomial increases by 1, with the coefficient of s^0 will be 0.

Note:

The method adopted in this experiment to obtain the doublet response of the system is by increasing the order of the numerator polynomial, in the same order of defined coefficients, and the coefficient of s^0 becoming 0, and taking the impulse response of this modified transfer function. The Procedure is depicted in the following section.

MATLAB Code

Case 1:

Static Margin = 0.2211.

```
%-Boeing B747-8, Sea Level Condition, M = 0.25, Sm = 0.2211-%
clc
A =1; % Coefficients in the characteristic equation A - E
B = 1.2632;
C = 0.9618;
D = 0.0979;
E = 0.0127;
Atheta = -0.5602; % Coefficients in the Numerator polynomial Au,
Bu, Cu, & Du
Btheta = -0.3867;
Ctheta = -0.0440;
DTF = [A B C D E]; % Denominator polynomial of the TF
Ntheta = [Atheta Btheta Ctheta 0]; % TF Numerator polynomial
TFtheta = tf([Ntheta],[DTF]) % TF: [theta(s)/de(s)]
figure
impzplot(TFtheta) % Impulse response of the TF
grid on
```

Case 2:

Static Margin = 0.6633.

```
%----- Boeing B747-8, Sea Level Condition, M = 0.25, Sm = 0.6633-
-----%
clc
A =1; % Coefficients in the characteristic equation A - E
B = 1.2632;
C = 2.0199;
D = 0.2121;
E = 0.0310;
Atheta = -0.5602; % Coefficients in the Numerator polynomial Au,
Bu, Cu, & Du
Btheta = -0.3498;
Ctheta = -0.0395;
DTF = [A B C D E]; % Denominator polynomial of the TF
Ntheta = [Atheta Btheta Ctheta 0]; % Numerator polynomial of the
TF
TFtheta = tf([Ntheta],[DTF]) % TF: forward velocity vs elevator
deflection [theta(s)/de(s)]
figure
impzplot(TFtheta) % Impulse response of the TF
[theta(s)/de(s)]
grid on
```

Viva Questions:

1. Which all are the force equations?
2. Which all are the kinematic equations?
3. What do you understand by Euler angles?
4. What do understand by time response of a system?
5. How do you differentiate Short period and Phugoid motion?
6. What do you understand by Small-Disturbance Theory,?
7. What are stability parameters?
8. What do understand by order and type of a system?
9. How is the time response of a first order and higher order system differ for a doublet input?
10. What do you understand by Static Margin and how it influences the longitudinal stability of an aircraft?

EXPERIMENT NO-11

GIVEN A QUADRATIC EQUATION, DETERMINE TWO QUADRATICS THAT SHALL RESULT IN SHORT PERIOD OSCILLATION AND POLES OF PHUGOID. VARY THE COEFFICIENTS OF POLYNOMIAL TO STUDY THE MOVEMENT OF POLES.

AIM:

To investigate the poles of short period oscillation and phugoid mode.

THEORY:

The fourth order characteristic equation for longitudinal motion can be written as the product of two second order polynomials as:

$$(s^2 + 2\xi_{sp}\omega_{n_{sp}}s + \omega_{n_{sp}}^2)(s^2 + 2\xi_{ph}\omega_{n_{ph}}s + \omega_{n_{ph}}^2) = 0$$

The fourth order characteristic equation can be converted into Bi-quadratic equations where one will define as short period and other as phugoid period mode. The coefficients of each characteristic equation change with flight condition, airplane mass, mass distribution airplane geometry and aerodynamics characteristics. These changes translate to zeta and ω_n

1. Short period Mode:

Characterized by complex conjugate roots with moderate to relatively high damping ratio, high natural and damping frequency. The control action can be easily demonstrated by first trimming the aircraft then disturbing it from trim with a forward aft natural stick input (Commonly called doublet).

The resulting response back to trim maybe first order (exponential decay) or second order (oscillatory) significant vibrations to angle of attack (α) and pitch attitude (θ) longitudinal motion occurs while the airspeed remains fairly constant.

Trim is generally regained in few seconds, thus the descriptive name short period and the small vibration in airspeed.

2. Phugoid Mode:

Characterized by complex conjugate roots, with a relatively low damping ratio, natural and damping frequency.

Control action can be demonstrated by trimming the aircraft in level flight, then input aftstick for 2-3 seconds bleed off some airspeed and then returning the stick to the natural (trimmed) position. The resulting response is usually oscillatory with significant vibrations in pitch attitude and airspeed, while angle of attack remains relatively constant. As the oscillation starts the airspeed decreases while the airplane gain altitude (Pitch angle is positive). The aircraft then begins to lose altitude and airspeed increases while pitch angle decreases. The period of phugoid is typically quite long (30-120s).

Characteristics equation

$$s^4 + 4.589s^3 + 21.653584s^2 + 0.251526s + 0.18792 = 0$$

MATLAB CODE**CASE 1:**

```

clc;
x=[1 4.5898 21.653584 0.251526 0.18792];
sys_g=tf([-0.08924 -29.9945 -0.31579805],x);
figure(1)
h=pzplot(sys_g,'r');
p=getoptions(h);
p.Title.Color=[0,0,1];
setoptions(h,p);
y=roots(x);
z1=[1 -(y(1)+y(2)) y(1)*y(2)];
z2=[1 -(y(3)+y(4)) y(3)*y(4)];
wn1=(y(1)*y(2))^0.5;
wn2=(y(3)*y(4))^0.5;
if (wn1>wn2)
sp = poly2sym(sym(z2))
wn_sp=wn2
eta_sp=(z2(2)/(2*wn_sp))
ph = poly2sym(sym(z1))
wn_ph=wn1
eta_ph=(z1(2)/(2*wn_ph))
figure(2)
sys1=tf([1],z2);
sys2=tf([1],z1);
h1=pzplot(sys1,'r',sys2,'b');
q=getoptions(h1);
q.Title.Color=[1,0,0];
setoptions(h1,p);
else
sp = poly2sym(sym(z1))
wn_sp=wn1
eta_sp=(z1(2)/(2*wn_sp))
ph = poly2sym(sym(z2))
wn_ph=wn2
eta_ph=(z2(2)/(2*wn_ph))
figure(2)
sys1=tf([1],z2);
sys2=tf([1],z1);
h1=pzplot(sys1,'b',sys2,'r');
q=getoptions(h1);
q.Title.Color=[1,0,0];
setoptions(h1,p);
end

```

CASE 2:

Substitute the value of x in case 1:

```
x=[1 8.2 21.653584 0.251526 0.18792];
```

VIVA QUESTIONS:

1. Explain Short Period Mode?
2. Explain Phugoid period?
3. What is meant by damping ratio?
4. Explain the difference between natural and damped frequency?
5. Explain Longitudinal stability?
6. Explain the Parameters affect the Short Period Mode?
7. Explain the Parameters affect the Phugoid Mode?

EXPERIMENT NO-12**GIVEN A QUARTIC CHARACTERISTICS EQUATION, DETERMINE POLES AND TIME CONSTANT FOR ROLL MODE, SPIRAL MODE AND DUTCH ROLL. VARY THE COEFFICIENTS OF POLYNOMIAL TO STUDY THE MOVEMENTS OF POLES****AIM:**

To determine poles and time constant for Roll mode, Spiral Mode and Dutch roll from a given quartic equation and study the movement of poles.

THEORY:

Three-degree-of-freedom analysis of the lateral-directional modes of motion

The preceding development of transfer functions for the three lateral-directional motion variables , β , ϕ and ψ leads to a 3-DOF solution for lateral-directional motion. Normally, the fourth-order characteristic equation for lateral-directional motion is written as the product of one second-order (oscillatory) and two first-order (non-oscillatory) polynomials.

Dutch Roll, Spiral and Roll three lateral-directional dynamic modes. Each of these polynomials can be thought of as a separate characteristic equation that defines the dynamic characteristics of its respective mode.

As with the longitudinal case, the coefficients (and roots) of each characteristic equation change with flight condition, airplane mass, mass distribution, airplane geometry, and aerodynamic characteristics. These changes translate to changes in $w_{(DR)}$, ξ_{DR} , τ_s and τ_r but the fundamental presence of the Dutch roll, roll, and spiral modes is maintained.

The dutch roll mode is a second-order response (complex conjugate roots) usually characterized by concurrent oscillations in the three lateral-directional motion variables β , ϕ and ψ .

The roll mode has a real root and a first-order (non-oscillatory) response that involves almost a pure rolling motion about the x stability axis. It is usually stable at low and moderate angles of attack but may be unstable at high angles of attack. The roll mode can be excited by a disturbance or an aileron input.

The spiral mode is a first-order response (real root) that involves a relatively slow roll and yawing motion of the aircraft. It may be stable or unstable. The spiral is usually initiated by a displacement in roll angle and appears as a descending turn with increasing roll angle if unstable. If the spiral is stable, the aircraft simply returns to wings level after a roll angle displacement. The primary motion variables during the spiral are ϕ and ψ , while β remains close to zero. A high degree of lateral stability $C_{l\beta}$ will tend to make the spiral stable.

The fourth order characteristic equation can be defined as:

$$\left(s^2 + 2\xi_{DR}\omega_{n(DR)}s + \omega_{n(DR)}^2\right)\left(s + \frac{1}{\tau_r}\right)\left(s + \frac{1}{\tau_s}\right) = 0$$

DR- Dutch Roll

r- Roll Mode

s- Spiral Mode

MATLAB Code:

```

clc;
close all;
x=[1 102 202 201 100]; %characteristic equation
sys_g=tf([1],x);% Transfer Function
figure(1)
h=pzplot(sys_g,'r');% Pole-Zero plot for transfer function
p=getoptions(h);
p.Title.Color=[0,0,1];
setoptions(h,p);
y=roots(x);
z1=abs(y(1));
z2=abs(y(2));
if (z1>z2)
roll_mode= poly2sym(sym([1 z1]))% Equation for Roll mode
ploes_rollmode=y(1)
timeconstant_roll=(1/y(1))
spiral_mode= poly2sym(sym([1 z2]))% Equation for Spiral mode
ploes_spiralmode=y(2)
timeconstant_spiral=(1/y(2))
else
roll_mode= poly2sym(sym([1 z2]))% Equation for Roll mode
ploes_rollmode=y(2)
timeconstant_roll=(1/y(2))
spiral_mode= poly2sym(sym([1 z1]))% Equation for Spiral mode
ploes_spiralmode=y(1)
timeconstant_spiral=(1/y(1))
end
z3=[1 -(y(3)+y(4)) y(3)*y(4)];
dutchroll_mode= poly2sym(sym(z3))% Equation for Dutchroll mode
poles_dutchroll=y(3)
poles_dutchroll2=y(4)
y5=abs((y(3)+y(4))/2);
timeconstant_dutchroll=(1/y5)

```

VIVA QUESTIONS:

1. Explain Roll Mode?
2. Explain Spiral Mode?
3. Explain Dutch Roll Mode?
4. Derive the damping ratio and natural frequency for the Dutch roll?
5. Explain the time constant for first and second order system?
6. Explain Lateral-Directional Motion?
7. Explain the factors affecting lateral-directional Motion?