University of Glasgow

James Watt School of Engineering

Simulation of Aerospace Systems

Assignment: Instrument Landing System Lateral Beam Guidance System

Introduction

Most major airports have an Instrument Landing System (ILS) which can be used for automated or assisted landing of aircraft. Basically this is a short range navigational aid which provides azimuth (horizontal) and vertical position information. This assignment involves the development of a mathematical model and simulation of this system for lateral beam guidance. Firstly, background information is provided, followed by the problem specification for the simulation.

Background

The ground-based elements of ILS comprise of a *localiser transmitter*, a *glideslope transmitter* and *marker beacons*. These provide the azimuth, vertical and distance signals respectively (see Figure 1).

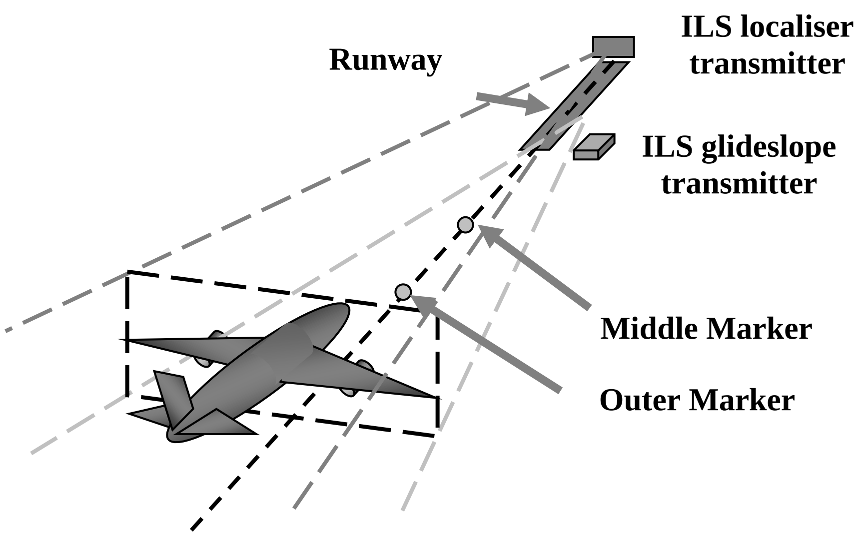

Figure 1: ILS Diagram

On the aircraft there is a *localiser antenna*, *a glideslope antenna*, *an ILS receiver unit* and *a marker beacon antenna and receiver*. The position of the aircraft relative to the localiser and glideslope is displayed on an indicator in the cockpit and is used to land safely.

The Localiser System

The localiser transmitter is positioned at the far end of the runway which the aircraft is approaching. It transmits on a given frequency in the band 108 MHz to 112MHz. The signals radiate to the left and right of the centre line of the runway as shown in Figure 2. The signal to the left is modulated by a

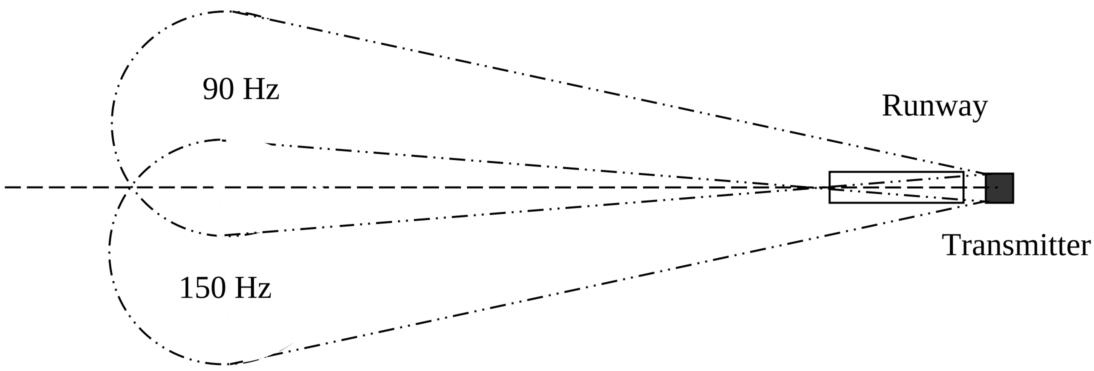

Figure 2: Localiser Beams

90 Hz component while the corresponding frequency for the signal on the right is 150 Hz. The two signals overlap in the middle. The autopilot uses the stronger overlapping signal region to position the aircraft within the ILS approach corridor.

The Glideslope System

The glideslope transmitter is located near the point of touchdown (threshold) on the runway and transmits on a given frequency in the range 329.3 MHz and 335.0 MHz. The radiated signal pattern is similar to that of the localiser but provides vertical guidance relative to a descent path (see Figure 3).

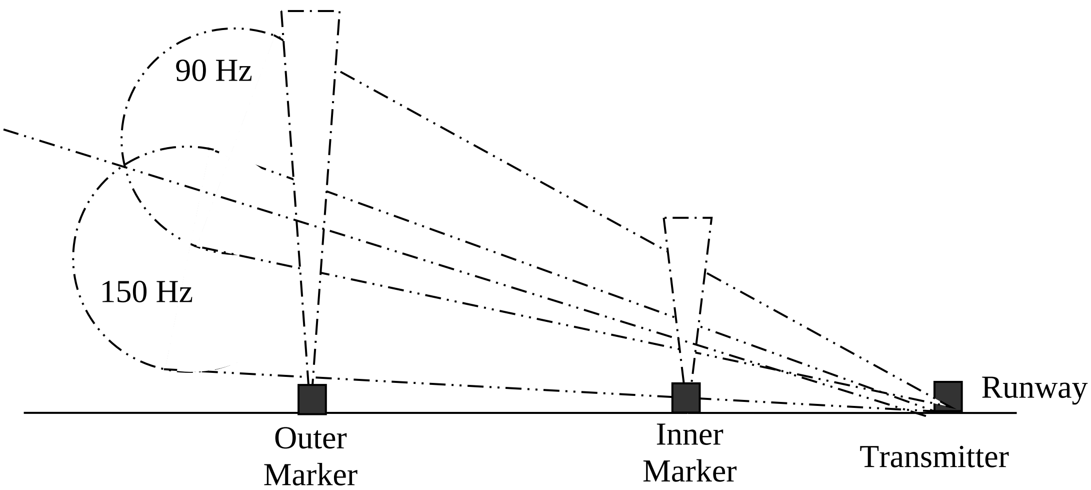

Figure 3: Glideslope and Marker Beams

The Marker Beacons

Marker beacons transmitters are located along the approach path and provide 75 MHz signals beamed vertically into the approach corridor. The beacons are located 7.4 km (outer marker) and 1.1 km (inner marker) from the runway threshold. These markers provide distance signals so that the speed of descent can be monitored and adjusted.

Problem Specification

The ILS can be used for automated landing where direction, descent and speed are all controlled through automated control systems. In order to achieve this, the aircraft must be equipped with the necessary systems to ensure the automatic guidance of the aircraft along the approach corridor. The general principle of completely automated landing systems is to feed information from the localiser and glideslope beams into the aircraft's autopilot. The final approach speed is governed by an automatic throttle subsystem.

In this study we will consider the development of a simulation that represents the automated lateral beam guidance system only. This system involves the coupling of the localiser receiver to the lateral autopilot. The glideslope and throttle systems are not considered here.

The geometry of the lateral beam guidance is shown in Figure 4.

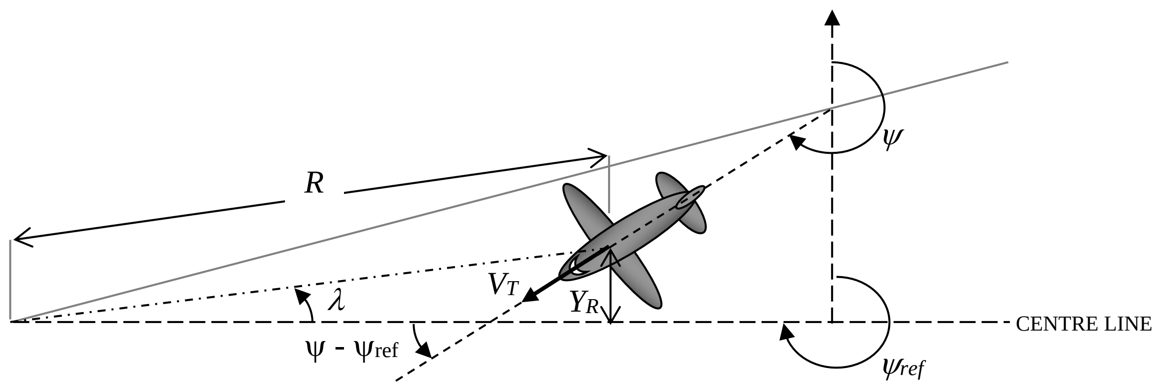

Figure 4: Approximate Geometry of lateral beam guidance

The lateral beam guidance system produces the required aileron commands to generate a coordinated banking manoeuvre that positions the aircraft within the localiser beams. It achieves this by combining the roll control system with the heading control for the aircraft. A diagram of the total system is shown in Figure 5.

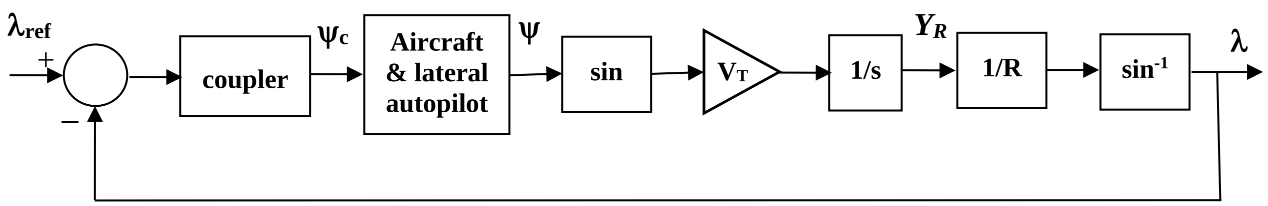

Figure 5: Lateral Beam Guidance System

From Figure 5 it can be seen that the Lateral Beam Guidance System takes a value for the reference angular error between the aircraft and the centre line, λ_{ref}, and compares it with the actual error, λ. In this case the values for λ_{ref} and ψ_{ref} (the reference heading) are taken to be zero. The comparison of these values is performed by the *coupler* which is effectively a PI controller of the following form:

$$\psi_c = G_c\left(\lambda_{ref} - \lambda\right) \tag{1}$$

The resulting commanded heading angle ψ_c is then fed into the lateral autopilot to generate an appropriate heading for the aircraft to follow (ψ). Once the heading has been changed so that the aircraft approaches the centre line of the runway, it directly influences the lateral speed of the aircraft, $\dot{Y}_R$ (m/s). This is used to calculate the lateral displacement of the aircraft, Y_R (m), which is then used to estimate the angular error between the aircraft and the centre line. This is then used to estimate the angular error between the aircraft and the centre line by considering the trigonometric relationship between Y_R and λ i.e.

$$sin\lambda = \frac{Y_R}{R} \tag{2}$$

This is an overview of the entire system.

A key part of the overall lateral beam guidance system is the lateral autopilot and its interaction with the lateral dynamics of the aircraft. In Figure 5 this system is regarded as the conversion process between the commanded heading, ψ_c (radians), and the actual heading of the aircraft, ψ (radians). This process is more involved that this simplified system diagram would lead you to believe.

The Lateral Autopilot has numerous components that provide the actuator commands to the main banking actuators – *the ailerons*. These control surfaces are positioned at the end of the wings and provide the required rolling moments to produce a coordinated banking turn. A detailed description of this system and how it interacts with the aircraft can be seen in Figure 6.

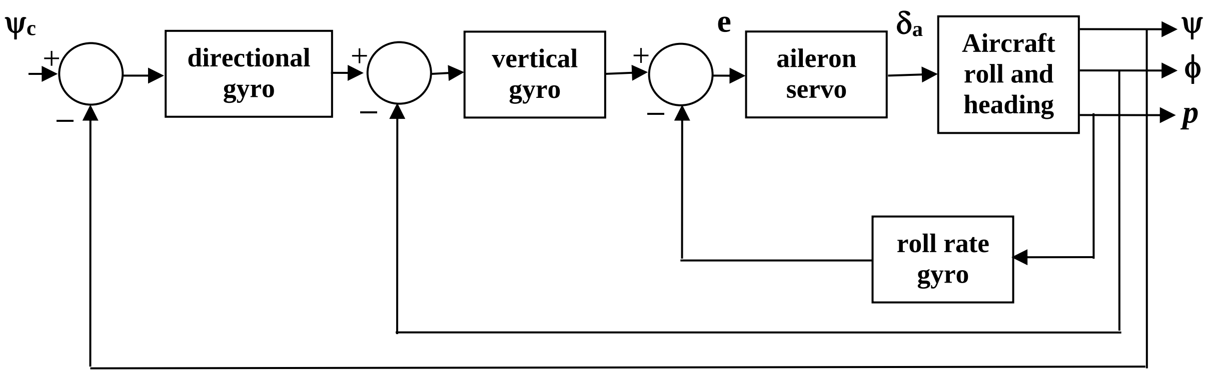

Figure 6: Aircraft and Lateral Autopilot

The Lateral Autopilot forms 3 feedback loops around the aircraft roll and heading dynamics. The outer loop provides a comparison between the commanded heading from the coupler and the actual heading of the aircraft. This comparison passes through the directional gyro which can be represented by a simple gain K_D. The resulting signal is then a representation of the required roll angle that needs to be applied in order to provide the banked turn. This commanded roll angle is compared with the actual roll angle of the aircraft, ϕ (radians), by means of the second loop. This comparison passes through the vertical gyro which is represented by a simple gain K_V. The output from this gyro provides a commanded roll rate to stabilise the speed at which the aircraft is rolling. This forms the input for the final inner loop which measures the aircraft's roll rate, p (rad/s), via the roll rate gyro (note: $p = \dot{\phi}$). This gyro is represented by the simple gain K_R.

Ultimately these three feedback loops generate an input signal for the aileron actuator. In this case the actuator is a dc motor, and its electro-mechanics can be represented by the following relationships:

$$L_A \frac{di}{dt} + R_A i + K_E \frac{d\delta_a}{dt} = V_A \tag{3}$$

$$J_M \frac{d^2\delta_a}{dt^2} + B_{SM} \frac{d\delta_a}{dt} = K_T i \tag{4}$$

Here i is the motor armature current (A), δ_a is the angular displacement of the ailerons and associated actuators (radians), J_M is the moment of inertia for the motor and the aileron (kgm^2), L_A is the inductance (H), R_A is the resistance (Ω), B_{SM} is the damping coefficient, K_T is the torque constant and K_E is the back emf constant.

This relationship provides the main control surface input for the aircraft and thus stimulates the aircraft to perform the required banking turn to attain the centre line of the runway. The aileron dc motor is configured as a servo-motor as shown in Figure 7.

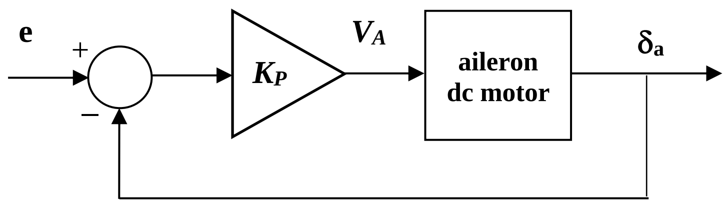

Figure 7: Aileron Servo

This servo-motor configuration regulates the aileron angular so that it follows the reference signal e. The reference signal is compared to the aileron deflection angle δ_a, and the difference is amplified by gain K_P to produce the input voltage for the dc motor, V_A (V).

The dynamics of the aircraft are formed through two relationships: the conversion of aileron deflection, δ_a, to roll angle, ϕ, and the conversion between the roll angle and the heading angle, ψ. These form the following two equations:

$$T_A \frac{d^2\phi}{dt^2} + \frac{d\phi}{dt} = K_A \delta_a \tag{5}$$

$$\frac{d\psi}{dt} = \frac{g}{V_T} \phi \tag{6}$$

Here g is the acceleration due to gravity and V_T is the forward velocity of the aircraft. These equations represent the behaviour of this ILS Lateral Guidance System.

Assignment Specifications

The combination of all these elements produces a mathematical model for the Lateral Beam Guidance System, which you will use as the basis of your assignment. Using this model as a basis, perform your assignment by following steps of an investigation:

Mathematical Modelling & Continuous Time Simulation

1. Use the description given above to derive the state space model for the Lateral Beam Guidance System.
2. Use this model and the parameter values given in the Appendix A to produce an equation or script-based simulation of the Lateral Beam Guidance System in MATLAB.
3. Employ a suitable numerical integration solver with a suitable step-size in the simulation of your system. Justify your choice of both solver and step-size. **Do not** use the in-built Matlab integration functions.
4. Analyse the dynamic response of the system. Do you think this a good design for the coupler in this system? Explain your answer.

Block Diagram & Validation

5. Using basic, commonly used blocks in Simulink, construct a block diagram simulation of the Lateral Beam Guidance System.
6. Use the responses from this block diagram simulation to validate your MATLAB model from steps (1) & (2) and simulation responses from step (3).

Control System Design & Implementation

7. Using your MATLAB script-based simulation and the parameter values in Appendix A, investigate the effect of varying the coupler gain G_c on the performance of the Lateral Beam Guidance System.
8. In order to improve the performance of the coupler further it is normal practice to include an integral term within the coupler of such a Lateral Beam Guidance System. Use your MATLAB simulation and the best value for G_c (found in step 7 above) to investigate the effect of introducing the integral term into your coupler and varying the associated gain K_I. Is the performance of this system improved further?

Interpolation

9. So far the longitudinal dynamics of the aircraft have not been considered. One way to incorporate these dynamics is to vary the range of the aircraft, R. Within your MATLAB simulation use the data presented in Table 1 (Appendix B) to represent the change in the range of the aircraft as time progresses by using Newton's Divided Difference interpolation method. Firstly, use this method to calculate by hand the interpolating polynomial that represents the range values that connect the data points in Table 1.
10. Implement the resulting interpolating polynomial within your MATLAB simulation code and analyse the effect of forward motion on the Lateral Beam Guidance System. **Do not** use the in-built Matlab interpolation functions i.e. write your own code.

Variations & Limitations

11. Investigate the effect of different longitudinal velocities, V_T, on the performance of your system. Consider values on either side of 55m/s e.g. 50 m/s and 60 m/s.
12. The ailerons on an aircraft have actuator limitations. Three possible actuator specifications are presented in Table 2 (Appendix C). Use your Matlab simulation to investigate the effects of these limits on the performance of the system and determine which actuator gives best performance.

Report Specifications

Once you have completed your study, write a technical report outlining the development of your model and simulation, and your assessment of this system. Include your Matlab code and Simulink diagram in your submission. Your completed report should not exceed 25 pages in length and it should be submitted through the moodle submission portal before 4:30pm on **6th December 2024**.

Appendix A: Parameter Values

The following parameters are typical for the Lateral Beam Guidance System:

$B_{SM} = 0.7$
$g = 9.81$ m/s^2
$G_c = 45.5$
$J_M = 0.006$
$K_A = 1.2$
$K_D = 0.9$
$K_E = 0.9$
$K_P = 52.5$
$K_R = 1.2$
$K_T = 1.7$
$K_V = 1.3$
$L_A = 0.2$H
$R_A = 10\ \Omega$
$T_A = 2.0$ seconds

Typical initial conditions are:

$\psi_o = -20°$
$\phi_o = 0°$
$R_o = 6000$m
$Y_{Ro} = 150$m
$V_T = 55$ m/s

Appendix B: Range Variation

The following table contains data points that describe how the range of an aircraft on ILS approach changes with time:

Table 1: Range Data

Time (s)	0	24	30	56	88	100
Range (m)	6500	5200	4000	3100	1900	430

Appendix C: Actuator Limits

The following table contains actuator rate and amplitude limits:

Actuator Number	1	2	3
Amplitude limit (degrees)	10	15	20
Rate limit (degrees/sec)	5	7.5	10

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