**Flight Dynamics & Control**

**Aircraft Dynamics Assessment and Autopilot Design Exercise**

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| Group Number | 07 | Student CIDs | 02488088, 02200298, 02464991  02376386, 02383703, 02402843 |

**Answer the following questions within the space provided using 11pt Arial. Make sure tables and figures are properly formatted and readable. Marks will be deducted for bad formatting.**

Define the conditions under which your tests were conducted. A single altitude, flight speed and loading should have been used for all computations and tests

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| --- | --- | --- | --- |
| Flight Speed (IAS), kt | **190** | Payload weight, lbs | **500** |
| Altitude, ft | **9000** | Fuel weight, lbs | **2400** |
|  |  | CG offset, inch | **0** |

**Q1.** Provide dimensional values for the following inertial properties, stability and control derivatives computed.

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| --- | --- | --- | --- | --- | --- |
| , kg m2 | 47049.99 | , kg m2 | 128216.8 | , kg m2 | 169200.7 |
| , kg m2 | 86.69 | , m | 10.1282 |  |  |
| , Ns/m | -104.286 | , Ns/m | -345.421 | , Ns | 171252.1 |
| , Ns/m | 526.5956 | , Ns/m | -19961.8 | , Ns | -1682377 |
| , Ns/rad | -4814.16 | , Ns/rad | 12688.68 | , Ns/m rad | -311915 |
| , Ns2/m | -22.0644 | , Ns2/m | -154.527 | , Ns2 | -1654.22 |
| , N/rad | -85102.4 | , N/rad | -619141 | , Nm/rad | -5860451 |
| , N | 18454 | , N | 0 | , Nm |  |

Note that in the table above are the throttle derivatives given per % throttle.

**(10% of marks)**

**Q2.** Present your simulation and experimental findings for the aircraft’s open-loop response by plotting the variation of the most relevant states of the phugoid, SPPO, roll subsidence, spiral and Dutch Roll modes. Present them side-by-side and scale the magnitude of your computational results as to allow a direct comparison with the experimental cases. *(Provide plots only)*

**EXPERIMENTAL SIMULATION**

|  |
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| Phugoid |
| SPPO |
| Roll Subsidence |
| Dutch Roll |
| Spiral |

**(10% of marks)**

**Q3.** Provide your computed and experimentally derived values for the eigenvalues of each dynamic mode

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| --- | --- | --- | --- | --- | --- |
|  | Experimental Period, s | Exp Time-to- half/double amplitude, s | Experimental Eigenvalue | Theoretical Eigenvalue | Reduced-order model Eigenvalue |
| Phugoid | 8.1235 | 11.6691 | -0.0118 ± 0.1046 i | -0.0131 ± 0.1689 i | ± 0.1371i |
| SPPO | 0.1593 | 0.1933 | -3.5858 ± 6.1806 i | -3.1312 ± 41.2300 i | -2.8191 ± 36.4548 i |
| Roll Subsidence |  | 0.0766 | -9.0459 | -9.1834 | -7.6572 |
| Dutch Roll | 0.2927  0.2869 | 0.3514 | -1.9724 ± 3.4856 i | -0.5453 + 2.2611 i | -0.4517 ± 1.8890 i |
| Spiral |  | 23.7379 | 0.0292 | 0.0066 | 0.0074 |

**(10% of marks)**

**Q4.** Discuss the quality of your predictions compared to your experimental findings. What might the source of any discrepancies between your computed values and those observed during flight testing be? *Briefly* highlight any issued that may have impacted your experimental values.

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| Himmat – Discussion Notes:   * Differences between exp and theoretical values (%difference) * Explain choice of methods used ie (nlnfit vs the empirical findings) * Compare all parameters and suggest if they are reasonable * Compute %difference * Explain significance of imaginary and real part size of eigen-values on the expected time period ect.. * Calculate predicted time period for phugoid using predictions to compare and for SPPO * Compare order of magnitude and also scale * Compare non ossilitory modes vs ossilitory modes * Compare latteral modes vs * Compare reduced order to actual calculations and which predictions performed best with experimental data   For the Phugoid cases the imaginary parts of the eigenvalues are consistent and in the same order of magnitude ranging between (0.1046, 0.1689), with the theoretical and reduced order models predicting longer periods compared to the experimentally obtained results dues to their relatively larger imaginary parts. The real parts vary for all methods, with the Reduced order models predicting no damping, and the experimental and theoretical values within the same order of magnitude, however the experimental value is 5 times the value showing the damping in the experimental results is more prominent. The experimental eigenvalues were calculated using the discrete method using peaks as there was many prominent peaks and gave us results more consistently across multiple tests.  For SPPO the Theoretical and reduced order finding were similar, showing a fair prediction, however experimental results showed a lower average Imaginary part but a real parts were all consistent and negative across all findings, showing a stable SPPO mode. The difference in the Imaginary parts of the eigenvalues indicates that the periods of oscillation vary for the experimental and other methods, this can be attributed to the…. The real parts are sufficiently high so the Aircraft is sufficiently damped, and it can be seen when exiting the SPPO mode. The  The Roll subsidence mode is very consistent across our methods with the eigenvalues remaining negative real indicating a non-oscillatory and heavily damped mode. |
| For the Phugoid cases the imaginary parts of the eigenvalues are consistent and in the same order of magnitude ranging between (0.1046, 0.1689), with the theoretical and reduced order models predicting longer periods compared to the experimentally obtained results dues to their relatively larger imaginary parts. The real parts vary for all methods, with the Reduced order models predicting no damping, and the experimental and theoretical values within the same order of magnitude, however the experimental value is 5 times the value showing the damping in the experimental results is more prominent. The experimental eigenvalues were calculated using the discrete method using peaks as there was many prominent peaks and gave us results more consistently across multiple tests.  For SPPO the Theoretical and reduced order finding were similar, showing a fair prediction, however experimental results showed a lower average Imaginary part but a real parts were all consistent and negative across all findings, showing a stable SPPO mode. The difference in the Imaginary parts of the eigenvalues indicates that the periods of oscillation vary for the experimental and other methods, this can be attributed to the…. The real parts are sufficiently high so the Aircraft is sufficiently damped, and it can be seen when exiting the SPPO mode. The  The Roll Subsidence mode is very consistent across our methods with the eigenvalues remaining negative real indicating a non-oscillatory and heavily damped mode. The reduced order result under predicted damping although the prediction was in the same order of magnitude as the Theoretical results. The \_\_\_Curve Fitting\_\_\_ for this mode was poor and did not allow yield s satisfactory result so the discrete method was used to calculate the eigenvalue using successive points on the curve. \_\_Describe curve fits vs the Discrete method.  Across all Methods Dutch Roll was a stable mode with damped oscillatory behaviour, indicated by the negative real parts and non-zero imaginary parts of the Eigenvalues. The Experimental results yielded Real parts with a Larger magnitude indicating a larger damping compared to the other methods, with the results being an order of magnitude off of the Theoretical values. Imaginary parts were within the same order of magnitude but varied with the experimental results having the highest imaginary part. This can be attributed to….  The only mildly unstable non oscillatory mode was the Spiral which had positive real eigenvalues across all the methods. Magnitudes were all within a sensible order of magnitude, however the experimental results were an order of magnitude larger than the theoretical and the reduced order methods. these can be attributed to the….>>>  (NEED MENTION PERCENTAGE DIFF)  (DIRECT REFFERNCE TO CURVE FITS ON THE FIGURES) |

**(20% of marks)**

**Q5.** Briefly describe the approach your group took when tuning your controller. What scenarios did you consider and what were your tuning targets (for example rise time, settling time).

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| The PID tuning was conducted using a combination of Simulink's toolbox and manual iterative gain adjustment. This process aimed to prioritize physically reasonable rise times, minimal overshoots, suitable disturbance rejection, and high degrees of robustness. Each of the three controllers mandated a slightly different approach.  The airspeed controller should result in a conservative rise time, as this allows the controller to handle the engine's (unknown, yet non-negligible) spool up time. For similar reasons, this controller must be designed to avoid either max or idle throttle. As such, the tuning process revolved around ensuring that no more than a 10% throttle variation is applied for a 5-knot velocity increase. After all, there is little practical need for extremely rapid changes in velocity, especially for such small deviations away from the equilibrium cruise velocity. As a result, the airspeed controller made use of comparatively small proportional gain. On the other hand, the bank angle controller is expected to be significantly more responsive. Considering that rolling motion is heavily damped, this controller is less susceptible to large overshoot, this enables for very quick rise times to be achieved. Finally, the climb gradient controller should be developed with a heavy emphasis on robustness, this is because the model parameters (and the control derivatives) have the greatest uncertainty. This controller needs to perform well, even if the calculated stability derivatives do not accurately reflect the motion of the flight sim.  The rise time should be fairly rapid, yet to a lesser extent than the roll controller. |

**(5% of marks)**

**Q6.** Provide your PID gains for each of the three controllers your designed. Remember that gains are dimensional and here define the percentage input per degree or knot of measured error.

|  |  |  |  |
| --- | --- | --- | --- |
|  | Proportional Gain | Integral Gain | Derivative Gain |
| Roll |  |  |  |
| Climb Angle |  |  |  |
| Speed |  |  |  |

**(5% of marks)**

**Q7.** Present your simulation and experimental findings for your initial autopilot’s closed-loop performance by plotting the variation of the most relevant states. Present them side-by-side, using equivalent perturbations and scale the magnitude of your computational results as to allow a direct comparison with the experimental test cases. *(Provide plots only)*

**EXPERIMENTAL SIMULATION**

|  |
| --- |
| Roll Controller |
| Climb Angle Controller |
| Speed Controller |

**(10% of marks)**

**Q8.** For each of your controllers briefly describe how you re-tuned their gains based on the responses observed during your testing. Provide the final tunned gains. Present a plot of the final performance of your final standalone controllers to a step change in the setpoint.

|  |
| --- |
| Roll Controller |
| Climb Angle Controller |
| Speed Controller |

**(15% of marks)**

**Q9.** How well did the control gains tuned using your theoretical model perform during flight testing? What might the source of any observed differences in their performance be?

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| The predicted control gains preformed well as initial guesses; all of them resulted in a stable closed-loop system.  The roll controller performed well, both when it came to disturbance rejection and holding a set point. The lateral equations of motion were primarily populated with values from an empirically corrected VLM simulation. These values correspond to the aircraft’s motion in the flight sim with a high degree of accuracy. As a result of high-quality control and stability derivative estimates, the initial PID guesses resulted in minimal overshoots were observed and steady-state error was largely eliminated. Due to an unanticipated flight sim software failure, the roll controller gains were left unaltered, as to prioritize tuning the other controllers. Altering the gains would offer little in the way of tangible improvements in the aircraft’s behaviour. The airspeed controller gains preformed as anticipated, this ultimately stems from having accurate estimates of the thrust related control derivatives. In an effort to decrease rise time slightly, the proportional gain was increased. This caused minor overshoots, and offered very little when it came to making the controller more responsive, as the system is fundamentally limited by the engine’s spool-up time. The climb gradient controller performed poorly with the initial guesses, it was extremely prone to overshoots. As such, the proportional gains were incrementally decreased until this behaviour improved, the derivative gains were then increased slightly. The longitudinal stability and control derivatives were sourced from an amalgamation of wind tunnel and flight sim data. This data is fundamentally inconsistent in the way the plane’s aerodynamics are modelled. Most of the data regarding the tailplane is sourced from wind tunnel testing, but this data is heavily dependent on the upstream flow field, something that is not identically captured by XPlane’s blade element simulations. This may have resulted in underestimating the elevator’s control derivative, or overestimating the tailplane’s contribution to longitudinal damping. |

**(10% of marks)**

**Q10.** Plot your combined pitch and velocity autopilot’s response to a change in the climb angle setpoint. Did you have to adjust the gains to ensure satisfactory performance?

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| Himmat:   * Adjusted gains during lab ect and which controller was adjusted * Plot of climb angle setpoint ect extract from the data from lab and plot * Observations during lab ect. |

**(5% of marks)**