COMPUTATIONAL METHODS & MODELLING 3 MECE09033

LONGITUDINAL FLIGHT DYNAMICS REPORT

School of Engineering, The University of Edinburgh

Group 9

Omar Sharkas, Amulya Regmi Bagale, David Jose, Gordon Manzie, Roberto Fregonara, Stanley Heap, Tyler Johnstone

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Peer Contribution Table

Team Member	Contribution
Omar Sharkas	Plot programming, meeting scheduling and booking, equations sheet and brief annotation, documenting sections 2,3,4
Amulya Regmi Bagale	Secondary programming of numerical methods and report writing for section 2
David Jose	GUI and documenting section 2
Gordon Manzie	Documenting sections 1, 2 and 4
Roberto Fregonara	Documenting section 4
Stanley Heap	GUI and documenting section 5
Tyler Johnstone	Primary programming of all numerical methods

1. Introduction

This report sets out to implement code to analyse an in-flight simulation of a small airplane and to see how different parameters respond to different input conditions. Using predetermined experimental data, equations of motion are solved by numerical methods to form the conclusion that it is possible to trim the airplane and analyse any climb reporting how much thrust and elevator angle is needed to fly at a certain speed and flight path angle. Finally, it is possible to conclude the length of time it takes to go from one specific altitude to another, given set parameters and to observe the planes dynamic response.

2. Numerical Methods Used to Implement Functionalities

To model the longitudinal flight dynamics of the aircraft, the aerodynamic coefficients were computed using ***scipy.optimize.curve_fit*** [1] by numerically fitting the aircraft flight data from the aero_table given. This function was the optimal choice as it allowed robust curve fitting for different data trends. Furthermore, it accepts an initial guess, increasing convergence speed. The aerodynamic coefficients were then used to find the lift, drag, and pitch moment for the subsequent simulations' calculations.

Computing the angle of attack, α, required the use of a viable root-finding method. For this case, ***scipy.optimize.root*** [1] was chosen. It uses a modified powell method which is derivative free. The method was easily accessible and allowed for an initial guess with increased convergence speed.

In the context of an airplane, where solutions exhibit oscillations, a 4th method of 'Runga-Kutta 4-5' is implemented using ***scipy.integrate.solve_ivp*** [1] to provide more stable and accurate results of the 3 degrees of freedom equations of motion for the airplane. This is more suitable than other methods of lower order such as the Euler method.

3. Validation and Results Comparison

The validity of the code is substantiated by the accuracy of the computed values of aerodynamic coefficients (table 3.1) and trim conditions (table 3.2,3.3), which showed a 0% relative error to the true values. Furthermore, the graphs (figure 3.4) for the trim condition of V =100 ms^{-1} and γ increasing by 10% from -0.0520° to -0.0572 are identical to the true graphs

Coefficient Results Comparison Table		
Coefficient	**True Value**	**Computed Value**
C_{L_0}	0.047	0.047
C_{L_α}	0.093	0.093
$C_{L_{\delta_E}}$	0.0028	0.0028
C_{M_0}	-0.0072	-0.0072
C_{M_α}	-0.0068	-0.0068
$C_{M_{\delta_E}}$	-0.0046	-0.0046
C_{D_0}	0.027	0.027
K	0.044	0.044

Table 3.1: Coefficient results comparison

Trim Condition 1 Comparison Table					
Type	Parameter	Symbol	Unit	True Value	Computed Value
Input	Velocity	V	ms^{-1}	100	100
	Flight path angle	γ	rad	0.05	0.05
	Angular velocity	q	$rads^{-1}$	0	0
Output	Angle of attack	α	rad	0.0164	0.0164
	Elevator angle	δ_E	rad	-0.0519	-0.052
	Thrust	T	N	3392.35	3392.35
	Pitch Angle	θ	rad	0.0664	0.0664
	Body axis velocity	u_b	ms^{-1}	99.986	99.986
	Body axis velocity	w_b	ms^{-1}	1.641	1.641

Table 3.2: Trim Condition 1 results

Trim Condition 2 Comparison Table					
Type	Parameter	Symbol	Unit	True Value	Computed Value
Input	Velocity	V	ms^{-1}	80	80
	Flight path angle	γ	rad	0	0
	Angular velocity	q	$rads^{-1}$	0	0
Output	Angle of attack	α	rad	0.0304	0.0304
	Elevator angle	δ_E	rad	-0.0728	-0.0728
	Thrust	T	N	1828.7	1828.7
	Pitch Angle	θ	rad	0.0304	0.0304
	Body axis velocity	u_b	ms^{-1}	79.96	79.96
	Body axis velocity	w_b	ms^{-1}	2.43	2.43

Table 3.3: Trim Condition 2 Results

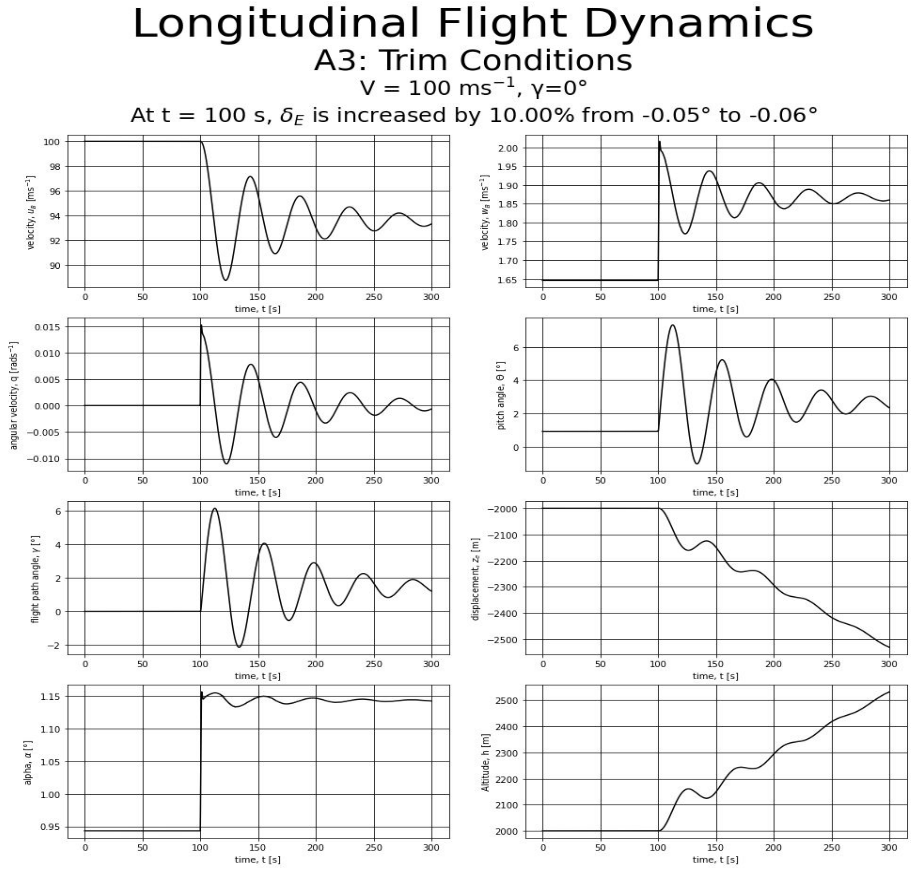

Figure 3.4: Trim Conditions Graph

4. Presentation & Results

The plots in Figure 4.1 represent the relationship between variables in longitudinal flight path correction. There is a relationship between thrust and elevator angle and their adjustments can impact an aircraft's velocity and flight path angle.

The code implemented combines velocities ranging from 36 ms^{-1} to 120 ms^{-1}. The lower limit was chosen as below 36 ms^{-1} the angle of attack is less than –20° which is less than the bounds set and would violate the physical constraints. The upper limit is set to 120 ms^{-1}, which is consistent with the maximum speed for a single-engine piston aircraft, Zivko Edge 540[2]. The flight path angles range from -12° to 10. The Lower limit is chosen because prior to that the thrust is negative which is not possible. The upper limit is chosen because this is a typical positive climb angle for a small airplane[3].

A higher flight path angle will not always result in a larger thrust increase although they do usually coincide. It can be observed by the graphs for thrust and elevator angle vs flight path angle, that as the flight path angle increases there is a need for added thrust to overcome the drag forces at play and keep the airplane at a constant velocity. It can be similarly concluded by the graphs of thrust and elevator angle vs velocity, that as the velocity increases there is also a need for added thrust to maintain a constant flight path angle. The graphs therefore identify the exact numerical values needed to achieve different airplane trim conditions.

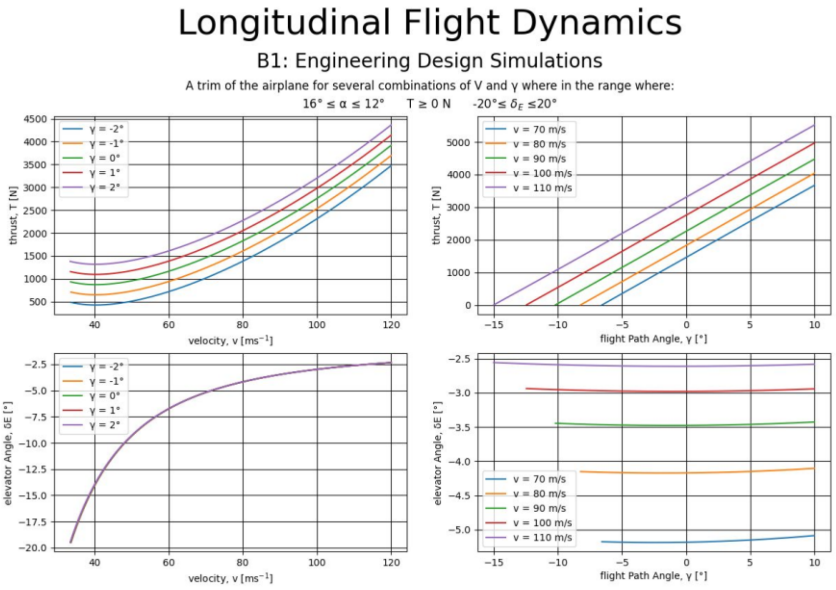

Figure 4.1: B1 Engineering Design Simulation Trim Conditions

This clim analysis simulation (figure 4.2) analyses a climb from horizontal flight at an altitude of 1000 m to horizontal flight at 2000 m. This is modelled by 3 trim conditions: at constant altitude, increasing altitude, and then at constant altitude again.

In trim condition 1, there is a constant pitch angle for 10 s as the plane is at an equilibrium state and altitude of 1000 m. In trim condition 2, the system is excited by increasing the flight path angle to 2° which increases the thrust and causes damped oscillations as the altitude rises to 2000 m. In trim condition 3, the system returns to the equilibrium state of trim condition 1 but at a higher altitude of 2000 m.

It can be concluded that it takes approximately 240 s to climb from 1000m to 2000m at a constant flight path angle of 2 ° and constant velocity of 119 ms^{-1}. At t ~ 240s, there is a sudden dip under 2000m. This oscillatory motion of the aircraft is characteristic of phugoid between equilibrium states based on the longitudinal stability theory [4].

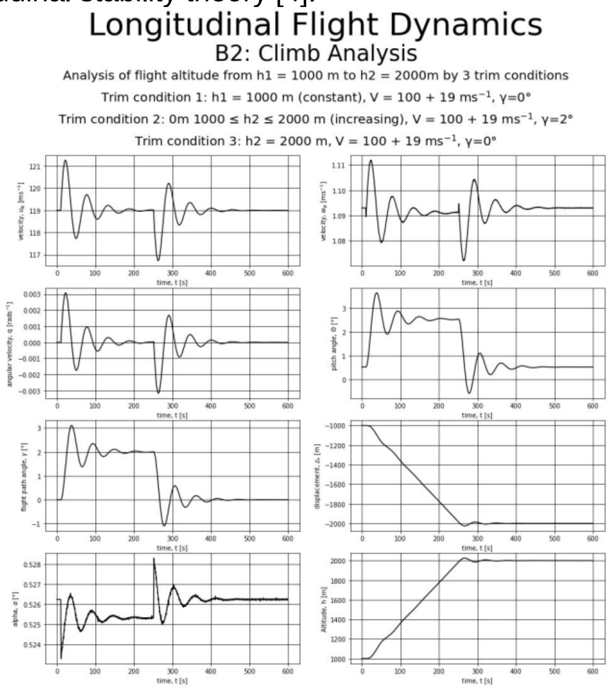

Figure 4.2: Longitudinal Flight Dynamics for climb analysis

5. User Interface

PySimpleGUI[5] (figure 5.1) was used to code the interface as it has a professional window format and is user-friendly. The code uses a list of objects to define the interface layout. There are two functions: Trim simulation and custom simulation. The trim simulation function allows the user to input velocity and flight path angle, the code then returns the necessary thrust, angle of attack and elevator angle to achieve the trim condition. The custom simulation function takes the outputs from the trim simulation and allows the user to make percentage changes to elevator angle and thrust at specified times. This solves the 3 degrees of freedom equations and plots the variables against time.

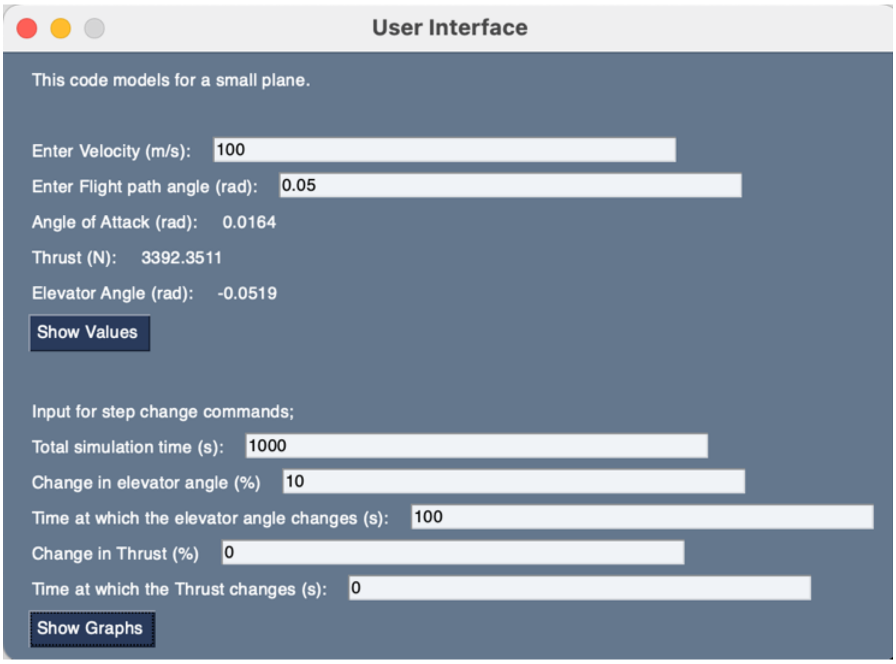

Figure 5.1: User Interface

6. References

[1] SciPy, “SciPy.” Accessed: Nov. 15, 2023. [Online]. Available: https://scipy.org/

[2] Hangar Flights, “The Fastest Single Engine Airplanes Flying Around Today.” Accessed: Nov. 19, 2023. [Online]. Available: https://hangar.flights/airplanes/fastest-single-engine-airplanes/

[3] Federal Aviation Administration, “FAA Regulations | Federal Aviation Administration.” Accessed: Nov. 19, 2023. [Online]. Available: https://www.faa.gov/regulations_policies/faa_regulations

[4] H. Smith, “Aircraft Modes of Motion — Aircraft Flight Mechanics by Harry Smith, PhD.” Accessed: Nov. 19, 2023. [Online]. Available: https://aircraftflightmechanics.com/Dynamics/ModesofMotion.html

[5] PyPI, “PySimpleGUI.” Accessed: Nov. 19, 2023. [Online]. Available: https://www.pysimplegui.org/en/latest/