Flight Mechanics

12503

Refik Mert Geçim -110210058

Turgut Demircan - 110230731

Serkan Emir Bilecen - 110230732

Asst. Prof. Barış Başpınar

Serkan Emir Bilecen (Climb)
Turgut Demircan (Cruise)
Refik Mert Geçim (Descent)
Part A, Turns, Take-off, Landing -> Collaboration

Part A

In this section, we present a comparative analysis of three aircraft based on data extracted from .OPF files. Analytical calculations were performed to evaluate the performance of each aircraft, leading to the selection of the first aircraft as the most suitable option. The primary selection criteria included take-off distance and flight range. Wind speed was assumed to be zero for all calculations, and Method 1 was applied in accordance with project guidelines.

The following equations were used to determine the necessary performance metrics:

$$E_m = \frac{1}{2\sqrt{CD_2 CD_0}}$$

$$\sigma_c = \left(\frac{1}{E_m \left(\frac{T}{W}\right)_{sl}} \right)$$

$$V_{br} = \sqrt{\frac{2\left(\frac{W}{S}\right)}{\rho_{sl}\sigma} \left(\frac{3CD_2}{CD_0}\right)^{0.25}}$$

$$c = Cf_1 \left(1 + \frac{V_{br}}{Cf_2}\right) \ (BADA\ user\ manual)$$

$$X_{br;V,Cl} = 0.866 \frac{E_m V_{br}}{c} \ln\left(\frac{1}{1-\zeta}\right)$$

The results of these calculations allowed for the elimination of the second aircraft, leaving the following performance data:

Aircraft 1 -> $X_{br;V,Cl} = 11564km$

Aircraft 2 -> $X_{br;V,Cl} = 5060km$

Aircraft 3-> $X_{br;V,Cl} = 8489km$

$$S_G = \frac{V_G^2}{\bar{a}}$$

$$\bar{a} = \frac{g}{W}\left[T_{avg} - D_{avg} - W\phi - \mu_r\left(W - L_{avg}\right)\right]$$

The take-off ground run distances were calculated as follows: $S_{g1} = 3387.8m \;\; Sg_3 = 4401m$. Given that the runway length at Beijing Capital International Airport (PEK) is 3,800 meters, aircraft 3 was deemed unsuitable. Consequently, aircraft 1 was selected for the mission.

Part B

For Part B, dynamic equations from Homework 3 and lecture notes on take-off and landing procedures were utilized. Euler's iteration method was employed to calculate fuel consumption and performance metrics. The ceiling altitude was calculated using the formulas provided in the lectures. The cruise altitude was set 1,054 meters below the ceiling altitude, resulting in a cruise altitude of 8,500 meters ().

The graded cruise climb method was applied, incorporating two turns, descent, approach, flare, and landing configurations. The iteration process continued until the difference between the last two results was less than 1%. The final trip fuel required for the mission was determined to be 43,270.6 kilograms.

Additional fuel components were calculated as follows:

- **Taxi Fuel**: 1,000 kg (20 minutes of taxi time)
- **Contingency Fuel**: 7% of trip fuel (3,029 kg)
- **Additional Fuel**: 3% of trip fuel (1,298.1 kg)
- **Final Reserve Fuel**: 1,846.1 kg (30-minute hold at 1,500 ft)
- **Alternate Fuel**: 35.69 kg (flight to alternate airport 70 km before SVO)

The total fuel required for the flight is summarized in the following table:

FUEL TYPES	KILOGRAMS	NEWTONS
TRIP FUEL	43270.6	424340
ADDITIONAL FUEL	1298.1	12730
CONTINGENCY FUEL	3029	29704
TAXI FUEL	1000	9806
FINAL RESERVE FUEL	1846.1	18104
ALTERNATE FUEL	35.69	350
TOTAL	50479.39	495034

Part C

After calculating the total fuel required for our aircraft, we proceeded to run our simulation. The simulation commenced with the take-off phase. The formulas referenced in the lecture notes, as specified in Part A, were applied during this phase. Upon executing the simulation, the take-off time was determined to be 90 seconds, with a take-off distance of 2833 meters (± 1%). Additionally, the fuel consumption during take-off was calculated to be 288.5 kilograms (± 1%).

Following take-off, the climb phase was initiated. A maximum climb thrust setting was employed, and the aircraft ascended at a climb angle of 3 degrees until reaching the target altitude, which was set 1054 meters below the ceiling altitude. This ceiling altitude was derived using the sigma formula detailed in Part A, with density ratios interpolated accordingly. The climb phase duration was 1200 seconds, achieving an altitude of 8500 meters (± 1%). Fuel consumption for this phase amounted to 3827.8 kilograms (± 1%).

During the cruise phase, a turn was executed to align the aircraft with the direction of SVO airport, which is situated at a heading of 166.4 degrees east. A bank angle of 35 degrees, as specified in the BADA user manual, was applied. The target heading of 166.4 degrees was computed through conditioning. The dynamic equation from Homework 3 was iterated using Euler's Method until the desired heading was achieved, at which point the bank angle was reduced to zero.

To implement the graded cruise climb method, the climb angle was calculated using the formula provided in the lecture slides:

$$\gamma = \frac{7.25\ c}{VE} = 2.9380 * 10^{-4}\ Rad$$

This climb angle facilitated the determination of step size and step number. A step height of 600 meters was defined for this calculation. The following equations were applied:

$$X_n = \frac{600}{\tan(\gamma)} \rightarrow Step\ size$$

$$step = \frac{X_2}{X_n} \rightarrow Step\ number\ (Where\ X_2 is\ the\ distance\ left)$$

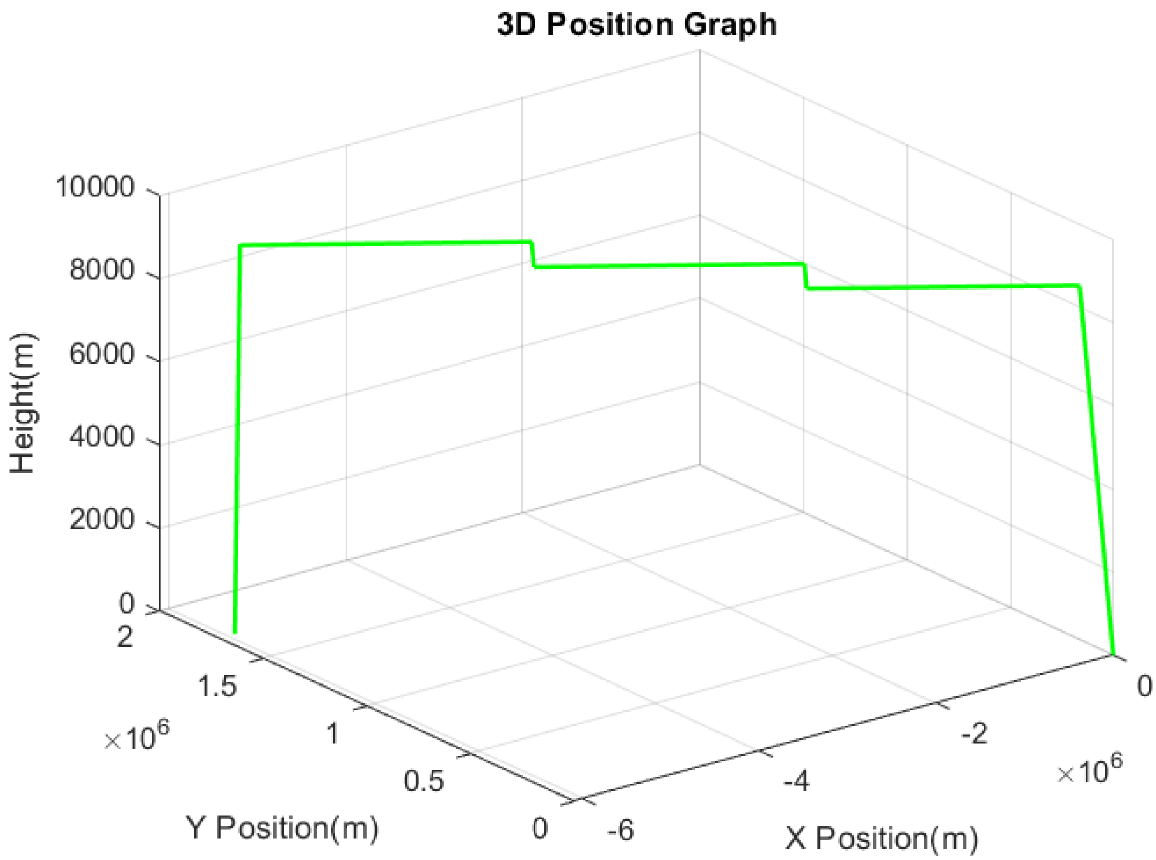
A cruise climb setting of 2 degrees was established, and loops were implemented in the code to alternate between climb and cruise phases. When the cruise distance covered equaled the calculated step size, the aircraft initiated a climb. The climb phase concluded upon reaching an altitude difference of 600 meters, prompting an update to the step size condition. This process repeated until the cruise phase concluded at a predefined distance from SVO airport. The remaining distance was calculated based on altitude and a descent angle of 2.64 degrees, derived through geometric analysis.

A final turn was executed to align the aircraft with SVO airport's runway heading. A bank angle of 35 degrees was applied, and the heading constraint was set to the runway alignment angle. The turn concluded once the desired heading was achieved, thereby terminating the loop in the code.

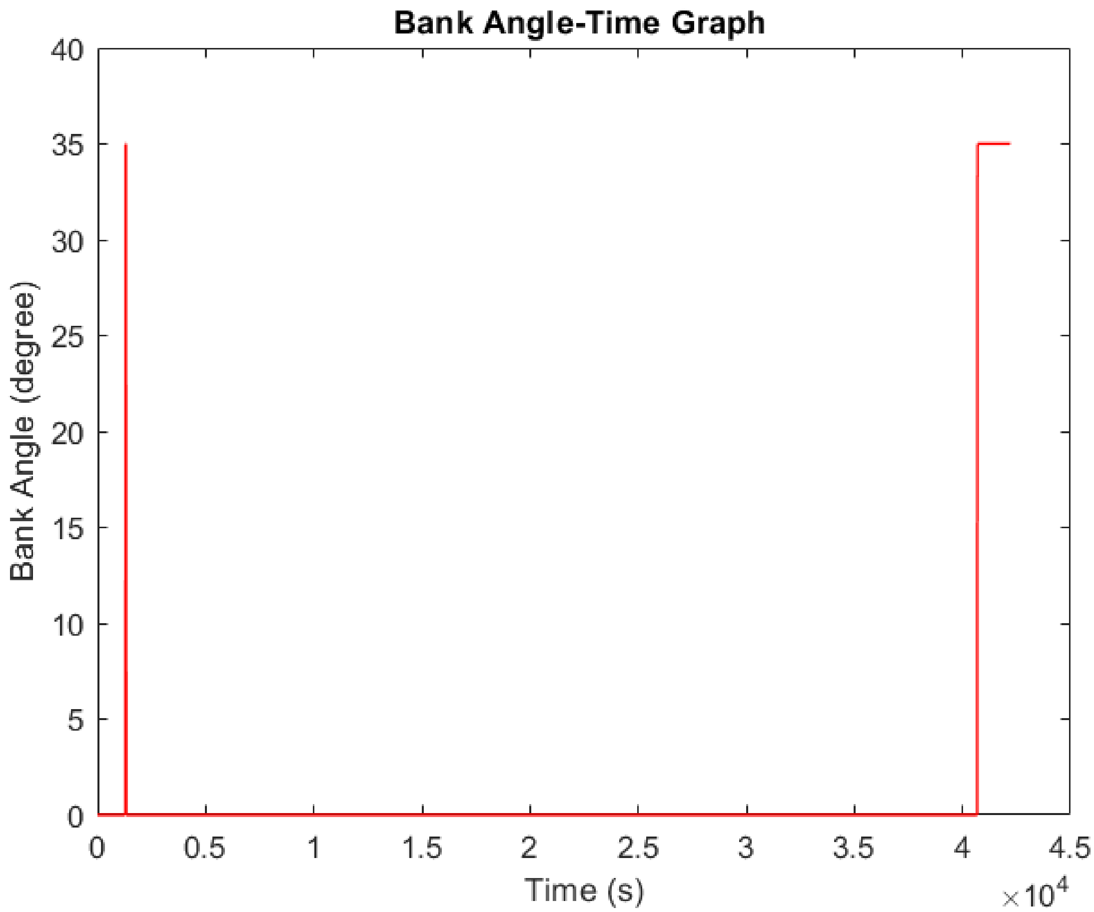
The descent phase comprised multiple sub-phases: descent, approach, flare, and touchdown. A descent angle of 2.64 degrees was maintained until reaching meters. Descent thrust settings from Homework 2 were utilized. During this phase, fuel consumption totaled 330.4 kilograms over a 1000-second interval. Upon reaching 2438.3 meters, the aircraft entered the approach phase, during which speed was adjusted to while maintaining a nose-down attitude.

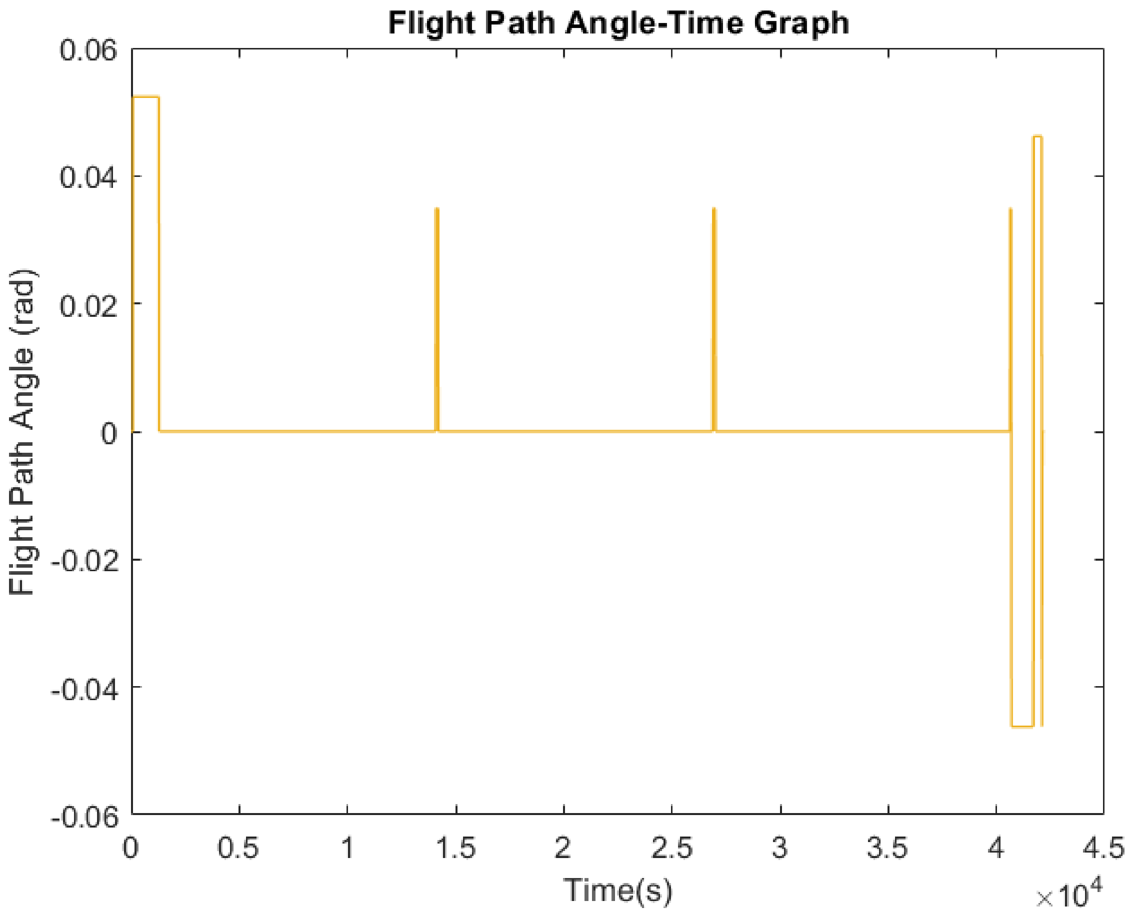
As the aircraft descended to an altitude equal to its wingspan (60.12 meters), the flare configuration was activated. In this phase, the aircraft's nose was pitched upward to facilitate landing. Upon touchdown, the aircraft's tires made contact with the runway, but the nose required additional downward pitching, which was implemented in the code over a short time interval with a minimal angle. Gear configuration was added to the drag coefficient during landing, resulting in a landing distance of 3084 meters, thereby concluding the simulation.

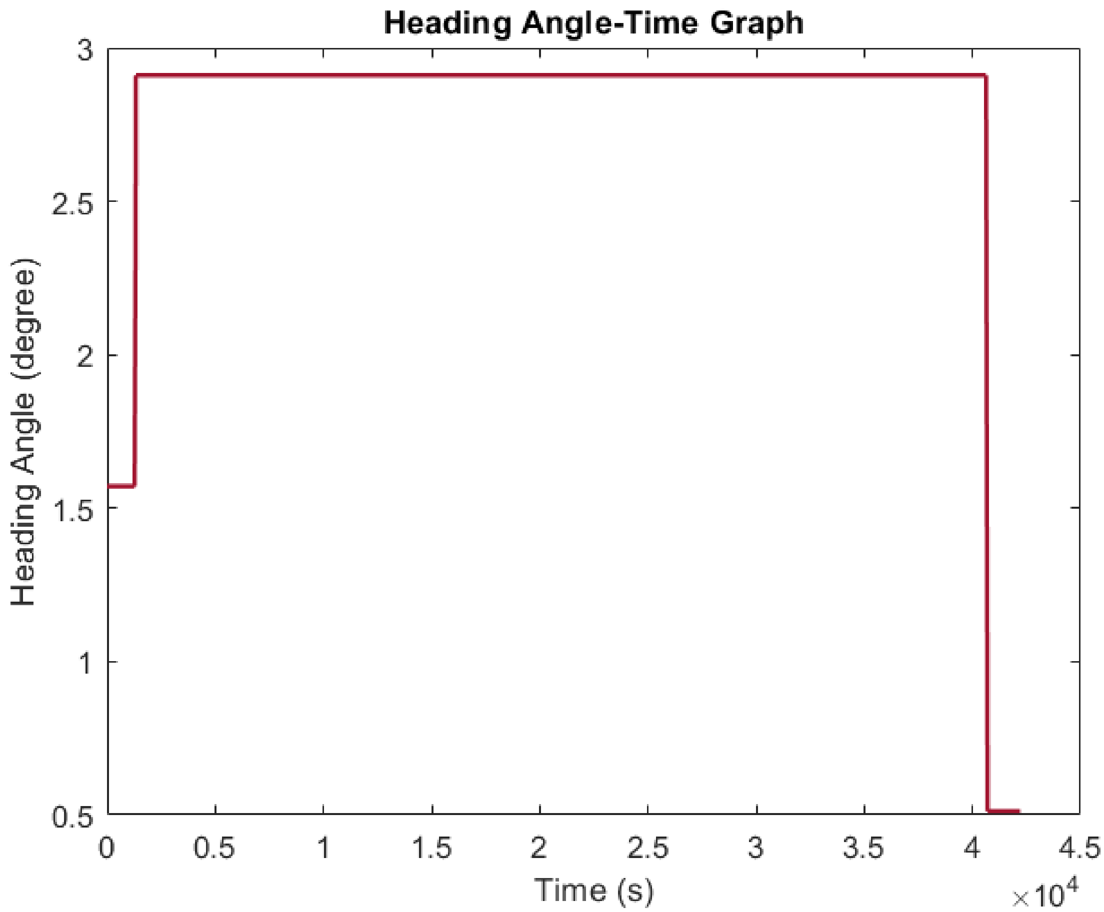
APPENDIX



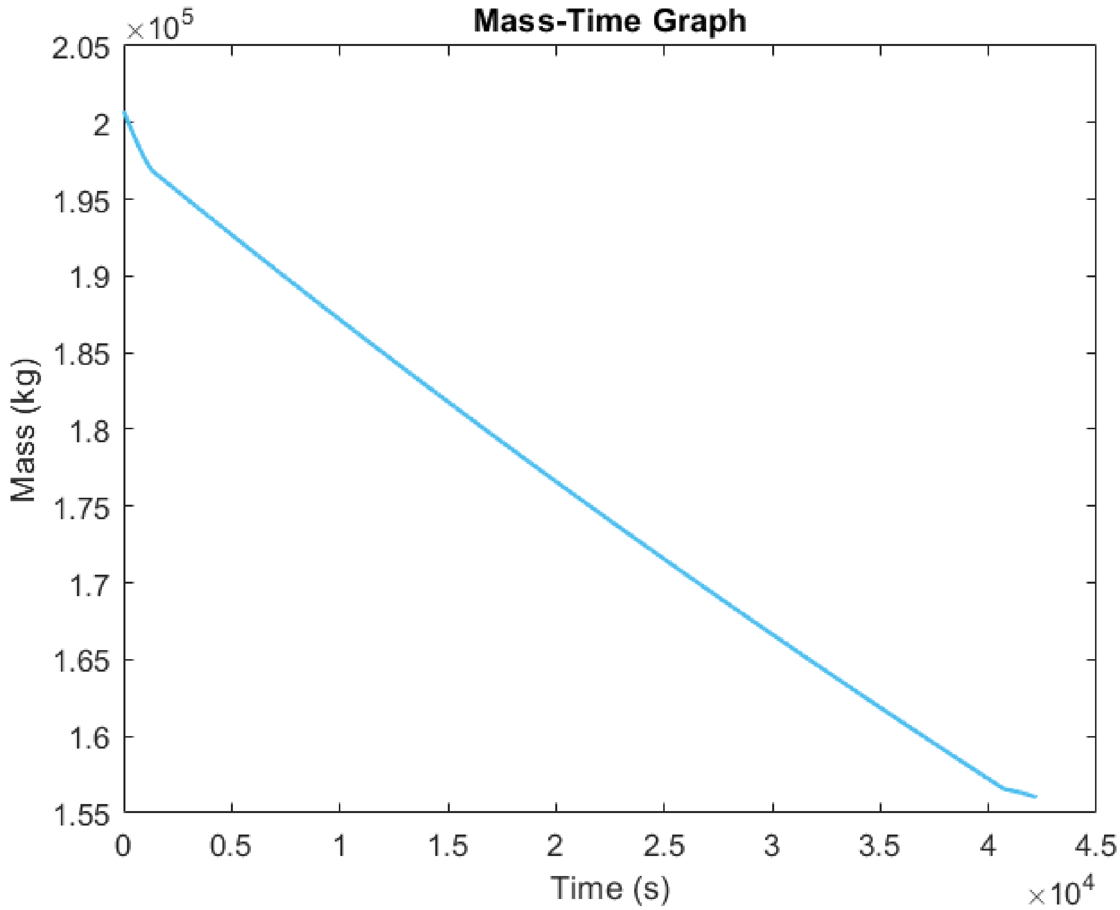
3D Position Graph
10000
8000
6000
4000
2000
0
Height(m)
2
1.5
1
0.5
0
$\times 10^6$
Y Position(m)
-6
-4
-2
0
$\times 10^6$
X Position(m)


Bank Angle-Time Graph
Bank Angle (degree)
40
35
30
25
20
15
10
5
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
Time (s)
×10^4

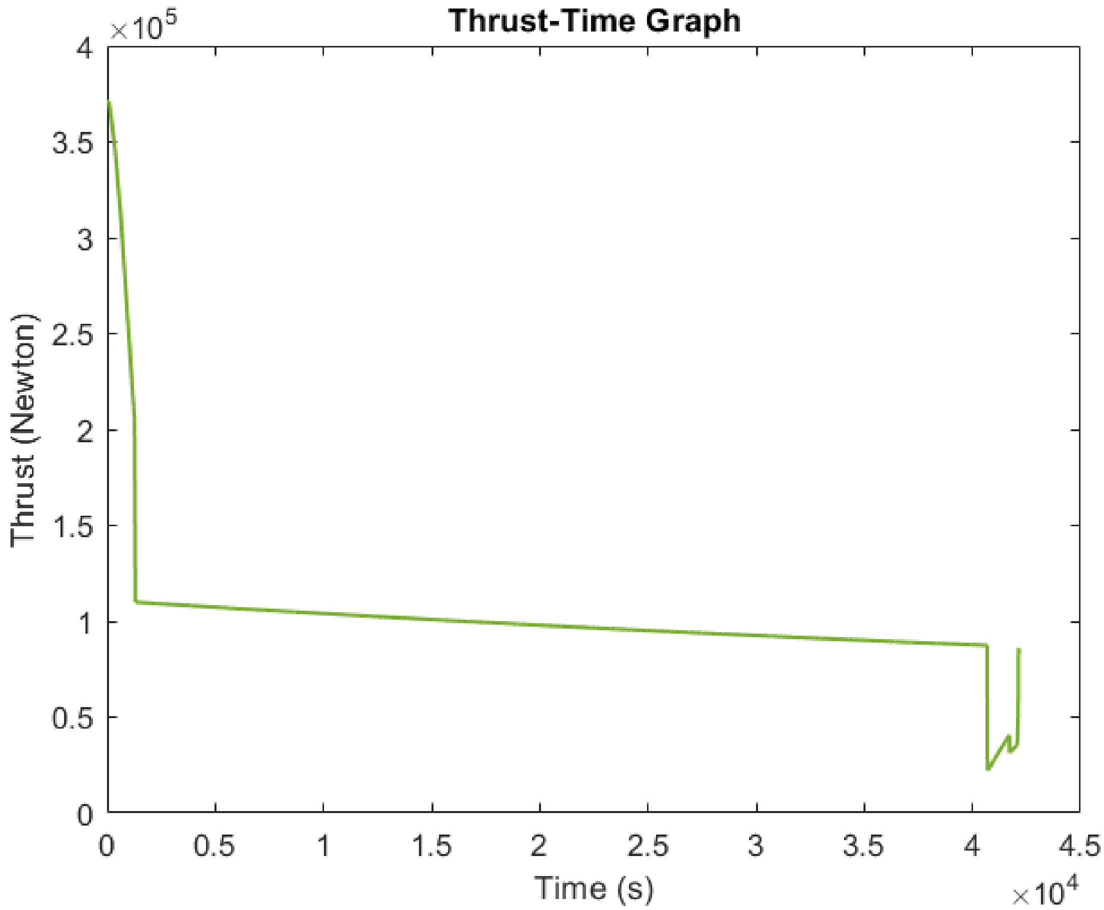

Flight Path Angle-Time Graph
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
Flight Path Angle (rad)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
Time(s)
×10^4



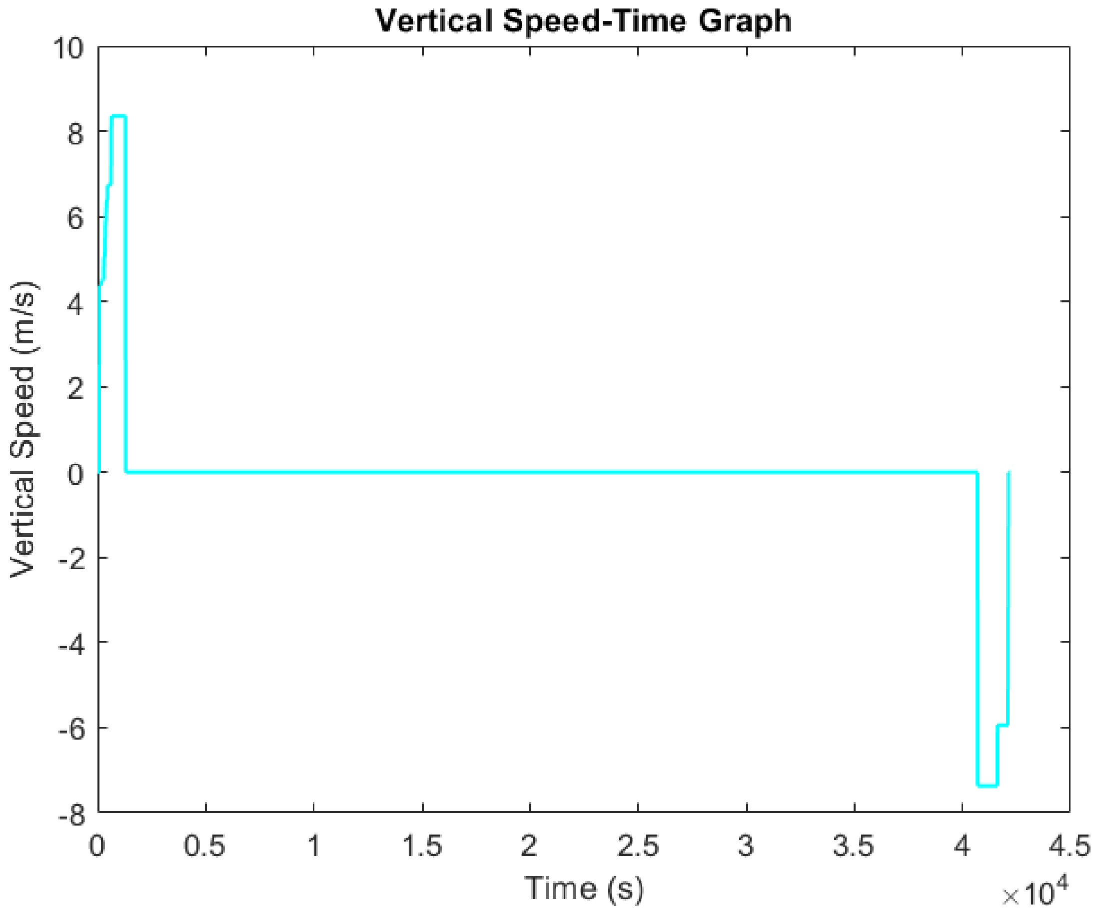
Heading Angle-Time Graph
3
2.5
2
1.5
1
0.5
Heading Angle (degree)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
Time (s)
$\times 10^4$

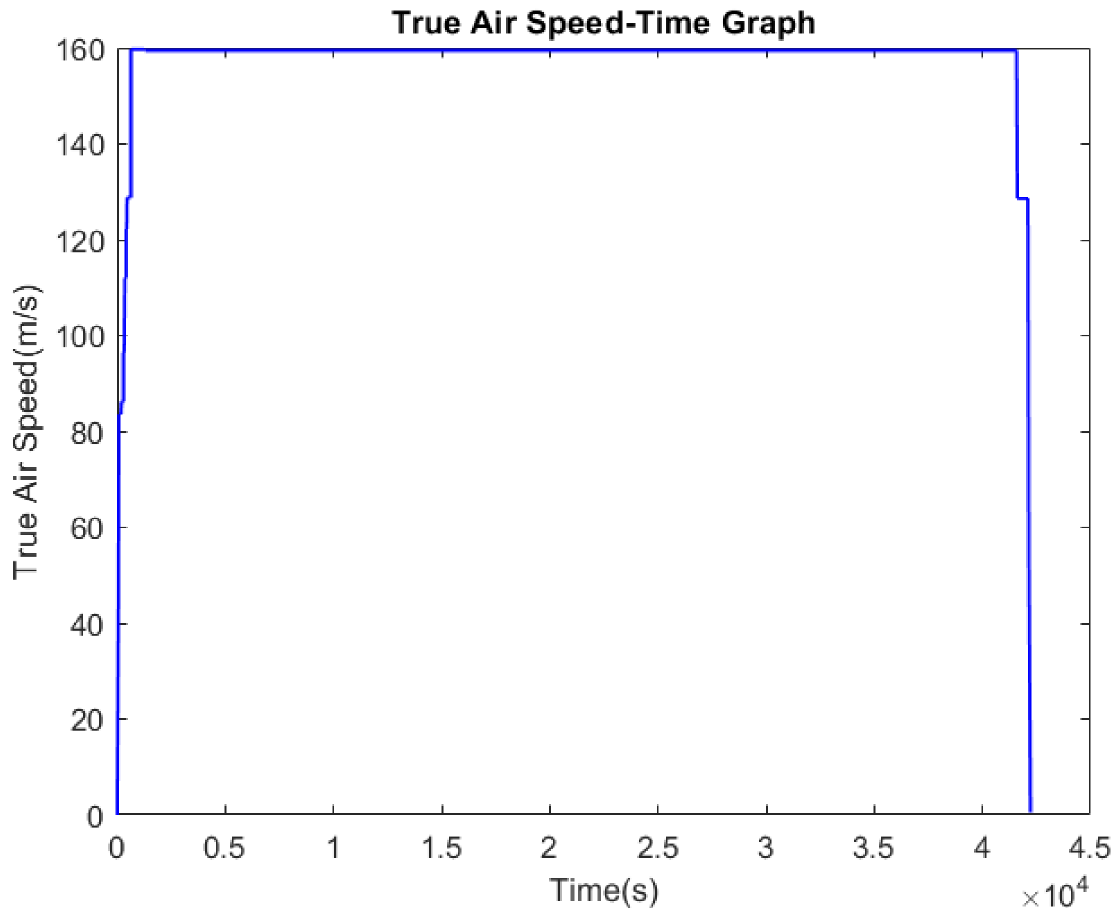


Mass-Time Graph
×10^5
2.05
2
1.95
1.9
1.85
1.8
1.75
1.7
1.65
1.6
1.55
Mass (kg)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
Time (s)
×10^4



Thrust-Time Graph
×10^5
4
3.5
3
2.5
2
1.5
1
0.5
0
Thrust (Newton)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
Time (s)
×10^4


Vertical Speed-Time Graph
10
8
6
4
2
0
-2
-4
-6
-8
Vertical Speed (m/s)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
Time (s)
×10^4


True Air Speed-Time Graph
True Air Speed(m/s)
0
20
40
60
80
100
120
140
160
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
Time(s)
×10^4