



**PROCEEDINGS OF
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Volume - 1

**Electronics
Electrical Power
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Engineering Physics**

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ELECTRONIC ENGINEERING

Simulation of Short Range Subsonic Surface to Surface Aerospace Launched Vehicle

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Abstract - Design methods for guidance system are of significant interest in the launched vehicle flight control community due to their potential for reducing their size for efficiency. In this paper, the launched vehicle's body, stability and dynamics are simulated using RockSim version 5.021 and RocFlight version 3.1. The short range subsonic surface to surface launched vehicle is considered. The vehicle fin deflection response time is calculated with MATLAB. The system in the research work is scale down system to be able to implement.

Keywords – short range surface to surface launched vehicle, stability control, simulation, RockSim, RocFlight, Matlab.

I. INTRODUCTION

First, the parameters for subsonic surface to surface launched vehicle are considered. Using these parameters, the vehicle body stability and dynamics are simulated in RockSim. According to RockSim simulation results, two suitable engines, I284W and J145, for short range are chosen. Then, the vehicle range is simulated with RocFlight. The control system for the launched vehicle is desired to construct using PIC microcontroller and finally, the response time for the vehicle's fin deflection is calculated by MATLAB.

II. SIMULATION FOR THE VEHICLE BODY, STABILITY AND DYNAMICS

Two simulation softwares are used to simulate the launched vehicle's stability and dynamics. They are RockSim version 5.021 and RocFlight version 3.1.

A. Simulation with RockSim

First, the vehicle body, stability and dynamics are designed using RockSim 5.021 version. The RockSim application is model launched vehicle design and flight simulation software. The vehicle design can be visualized and their flight with various engines and launch conditions can be simulated in RockSim. The components of launched vehicle such as nose cone, body tube and fin set can be designed. System with recovery and without recovery can be assigned. Acceleration, altitude and velocity vary with time can be plotted and two dimensional flight profile can be simulated in the RockSim software. Design consideration is considered with the following factors.

- (i) Minimum burn time
- (ii) Maximum time difference between apogee and impact time
- (iii) Velocity must be less than 1200 ft/sec (365.85 m/sec) (subsonic)
- (iv) Optimal trajectory,
- (v) Maximum range

It is assumed that there is no recovery system the designed vehicle. Table I shows the vehicle data.

TABLE I
LAUNCHED VEHICLE DATA

Name	Victor (YTU Project)
Created at	9:00 PM on 2/01/06
Length	48 in (121.92 cm)
Diameter	3 in (7.62 cm)
No: of fins	3
Span Diameter	13.736 in (34.9 cm)

Using these data, simulated three dimensional picture of Victor is shown in Fig. 1.

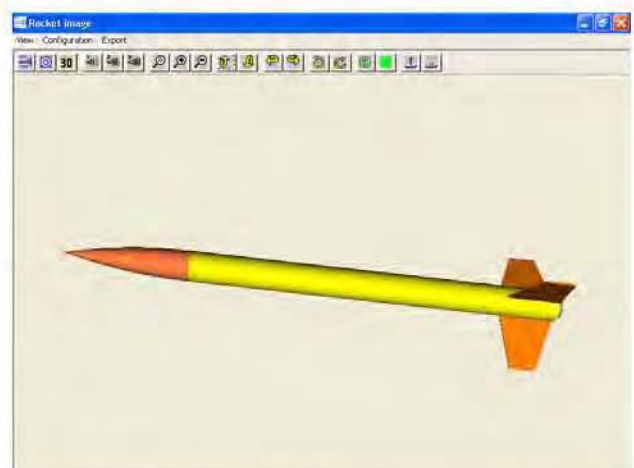


Fig. 1 Simulated three dimensional picture of victor

Then, the trajectory of model vehicle is simulated with various engines. But here only the simulations with the engines that are valid with the required specifications are mentioned. The simulated window with various engine tests is shown in Fig. 2.

After testing with various engines with various diameters, two standard engines are chosen. The results fall in the range of specifications. First of all is the simulation with standard engine I284W. This engine has 38 mm diameter, total impulse of 554.24 Ns and average thrust of 307.91 N. Its burn time is chosen as 1.8 seconds.

Engine	Max. altitude ft.	Max. velocity ft/sec.	Time to apogee s.	Time to impact s.
I284W-6	305.21	435.56	11.50	23.00
I284W-7	5003.02	434.50	10.31	21.44
I284W-8	5001.13	433.45	10.40	21.44
I284W-9	4306.26	432.37	11.23	22.42
I284W-10	4306.92	432.29	12.17	23.26
I284W-11	3243.09	330.27	8.29	16.50
I284W-12	3050.78	319.50	7.25	15.00
I284W-13	3232.95	320.29	10.40	21.44
I284W-14	3195.54	299.09	10.40	21.44
I284W-15	2620.22	232.09	11.01	22.00
I284W-16	2411.99	215.93	10.31	21.44
I284W-17	3196.00	3196.00	14.54	28.00
I284W-18	3144.64	3100.00	14.54	28.00
I284W-19	3144.64	1485.00	13.32	26.00
I284W-20	3103.53	597.25	13.32	26.00
I284W-21	3099.65	484.49	10.64	21.00
I284W-22	3099.65	391.49	10.64	21.00
I284W-23	3095.47	342.12	12.74	25.00
I284W-24	3064.48	490.48	12.74	25.00
I284W-25	3061.34	441.67	11.91	24.00
I284W-26	3059.68	395.28	11.90	24.00
I284W-27	3049.97	343.70	10.45	21.00
I284W-28	3044.20	304.52	10.45	21.00
I284W-29	3141.14	341.10	13.24	25.00
I284W-30	3079.16	329.26	13.25	25.00
I284W-31	3030.79	302.49	10.66	21.00
I284W-32	3020.04	302.07	12.11	24.00
I284W-33	3042.96	329.62	10.45	21.00
I284W-34	3031.88	306.46	10.54	21.00
I284W-35	3030.54	303.04	10.29	20.00
I284W-36	3030.54	303.04	10.29	20.00
I284W-37	3030.54	303.04	10.29	20.00
I284W-38	3030.54	303.04	10.29	20.00
I284W-39	3030.54	303.04	10.29	20.00
I284W-40	3030.54	303.04	10.29	20.00

Fig. 2 Simulation window with various engines

Figure 3 shows the vehicle stability with the engine. Then, the vehicle is launched with 10° from the vertical axis.

Its maximum velocity is 952.27 ft/sec, time to get apogee is 11.43 seconds and time to impact with the surface is 31 seconds.

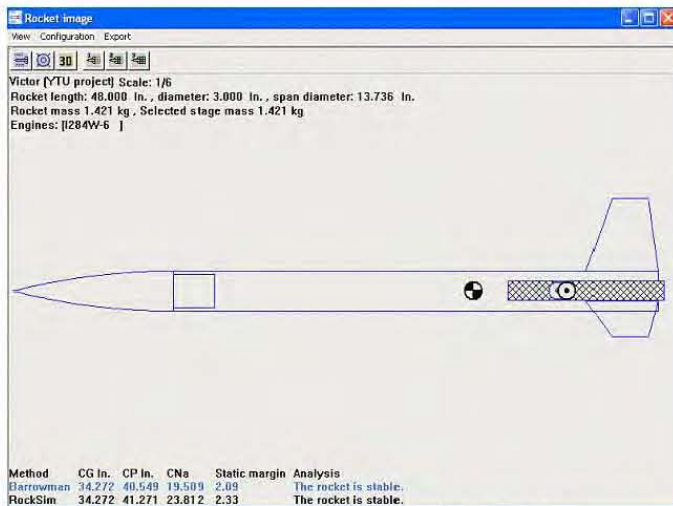


Fig. 3 Vehicle stability with I284W standard engine

The time difference between the apogee and impact conditions is 19.57 seconds. The multi-plot of altitude, velocity and acceleration are shown in Fig. 4.

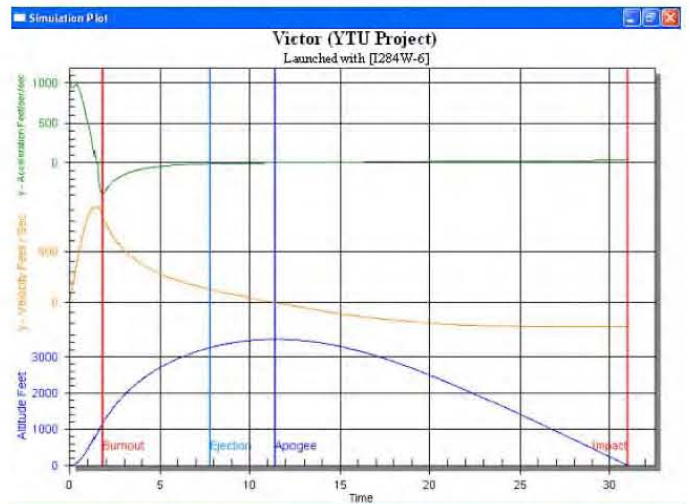


Fig. 4 Altitude, velocity and acceleration curves with I284W engine, launched with 10° from vertical axis

When the vehicle is launched at 45° from the vertical axis, its maximum velocity increased slightly. Time to apogee and time to impact are less than that of values launched with 10°. Its maximum velocity is 957.06 ft/sec and time to apogee is 8.75 seconds and time to impact is 22.5 seconds. The time difference between apogee and impact time is 13.75 seconds. The plot is shown in Fig. 5.

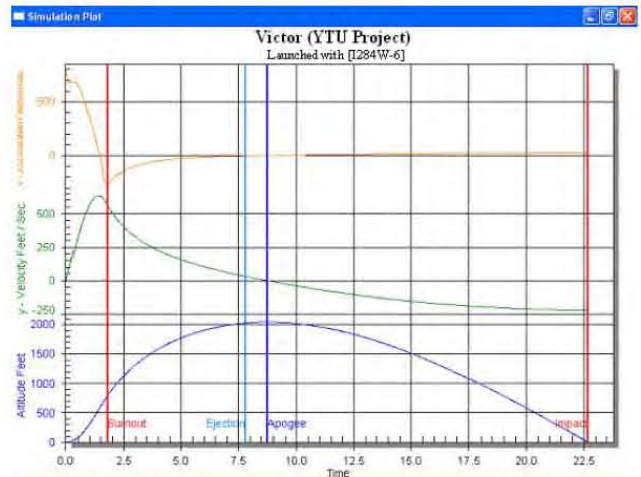


Fig. 5 Altitude, velocity and acceleration curves with I284W engine, launched with 45° from vertical axis

Another simulation result is with the standard engine J145. It has 54 mm diameter, total impulse of 728.72 Ns, and average thrust of 196.95 N. Its burn time is selected as 3.7 seconds. Fig. 6 shows the vehicle stability with the engine. Then, the vehicle is launched with 45° from the vertical axis. Its maximum velocity is 766.68 ft/s, time to get apogee is 10.54 seconds and time to impact with the surface is 24.1 seconds. The time difference between the apogee and impact conditions is 13.56 seconds. The multi-plot of altitude, velocity and acceleration are shown in Fig. 7.

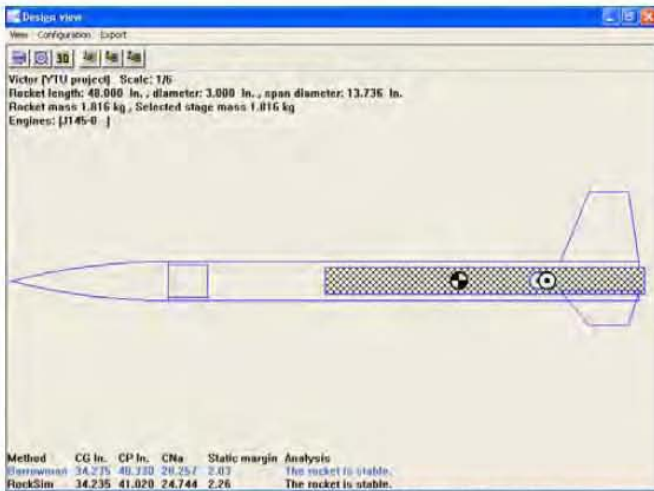


Fig. 6 Vehicle stability with J145 standard engine

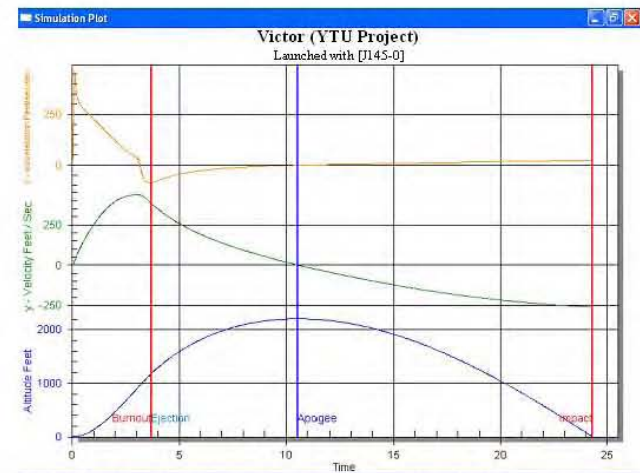


Fig. 7 Altitude, velocity and acceleration curves with J145 engine, launched with 45° from vertical axis

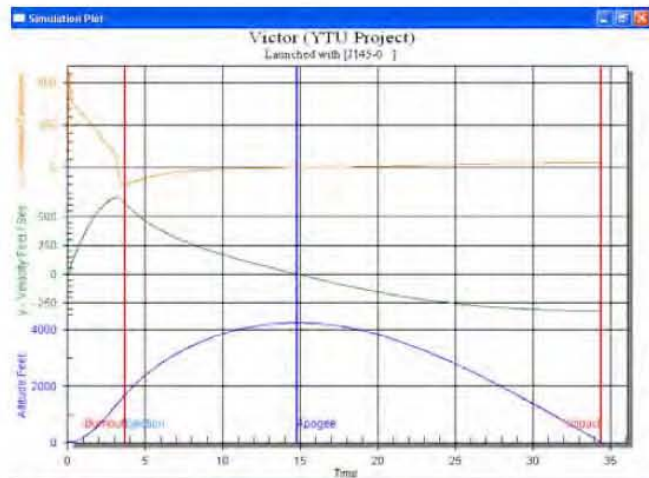


Fig. 8 Altitude, velocity and acceleration curves with J145 engine, launched with 10° from vertical axis

If the vehicle is launched with 10° from the vertical axis, its maximum velocity is 748.72 ft/sec, time to get apogee is 14.55 seconds and time to impact with the surface is 35.1 seconds.

In this case, the time difference between the apogee and impact condition is 20.6 seconds. This graph is shown in Fig. 8. By seeing these results, launched with 10° has larger time difference than that of 45°.

Two dimensional flight profiles can be simulated with RockSim software. Here, they are not shown. The vehicle's range graph cannot be shown in the RockSim demo version. So another trial version is used to plot the vehicle's range.

B. Simulation with RocFlight

RocFlight version 3.1 is the launched vehicle trajectory calculating software which is useful when the vehicle trajectory is simulated by inputting the vehicle's data.

The RocFlight main screen is shown in Fig. 9. It has been organized into two main sections; one for input data, and one for output data. These two sections are called Simulation Input and Simulation Output respectively.

Input data sections include launched vehicle data, motor data, Mach number and drag coefficient data, and missile initial conditions. Output data are overall trajectory summary, trajectory plot, trajectory data file and calculating optimal weight.

RocFlight calculates the two dimensional (single plane) trajectory of a vehicle traveling through the earth's atmosphere. After motor has burned out, the flight is ballistic and no recovery events are considered. The simulation terminates when the vehicle impacts the ground. To compute this trajectory, the forces acting on the vehicle including gravity, drag, and thrust are evaluated as a function of time to determine the vehicle's current acceleration. Fig. 10 shows the trajectory plot.

Using the standard engines (I284W and J145) and the vehicle condition used in simulations with RockSim software, the vehicle range is obtained.



Fig. 9 RocFlight main screen

With I284W engine, the vehicle range is 1739.16 ft when it is launched with 10 degree from the vertical axis. When it is launched with 45 deg from the vertical axis, its range is 5306.23 ft. The result curves are shown in Fig. 11 and 12. Acceleration, velocity, drag, altitude, range, angle, thrust, drag coefficient and Mach number can be simulated with RocFlight software. But in the research work, only acceleration, velocity and range curve are simulated for simplicity. Acceleration

scale 1:10, velocity scale 1:1 and range scale 1:1 are used in this simulation.

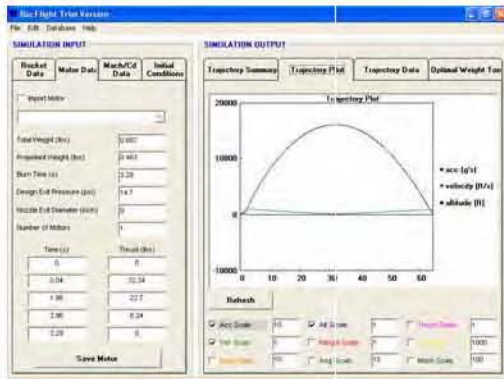


Fig. 10 Trajectory plot

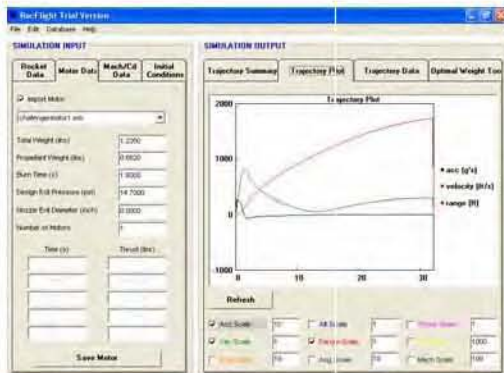


Fig. 11 Simulated range curve with the standard engine I284W (with 10°)

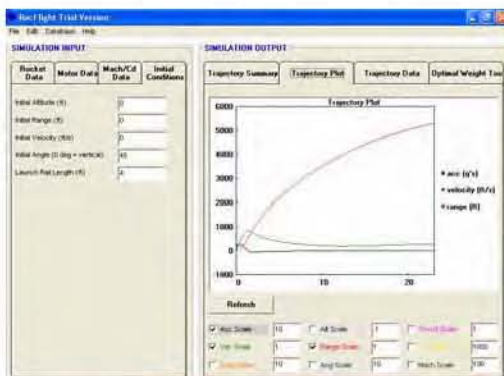


Fig. 12 Simulated range curve with the standard engine I284W (with 45°)

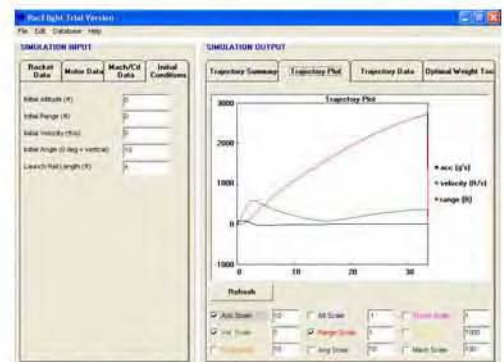


Fig. 13 Simulated range curve with the standard engine J145 (with 10°)

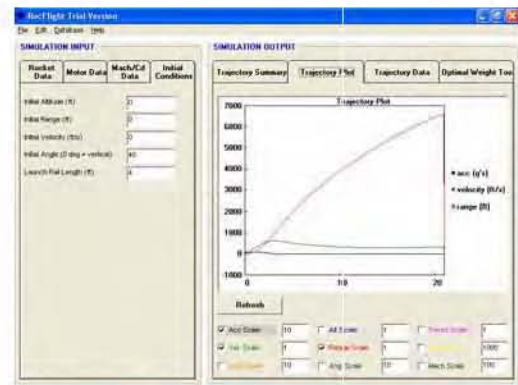


Fig. 14 Simulated range curve with the standard engine J145 (with 45°)

With J145 engine, the vehicle range is 2734.65 ft when it is launched with 10° from the vertical axis. When it is launched with 45° from the vertical axis, the vehicle range is 6640.13 ft. The result curves are shown in Fig. 13 and 14.

III. OPEN LOOP SYSTEM SIMULATION AND RESULTS FOR SYSTEM RESPONSE TIME

MATLAB version 6.1 is used to simulate the system response time of the fin deflection when step input acceleration is applied.

Combination of accelerometer and gyro systems is considered. The state variables in the feedback linearized form of the vehicle dynamics are angular rates (roll, pitch and yaw), linear accelerations (X, Y, Z), fin deflections (rudder, elevator, aileron) and their derivatives.

Figure 15 shows the block diagram of an open loop autopilot which contains the fin servos and airframe.

The state space model Equations are converted into transfer function form and simulated using MATLAB. In the open loop simulation, natural frequency is set as 180. Gains of aileron, elevator and rudder are set as 0.0068. Damping factor is 0.7. Accelerometer is assumed to be mounted on the X axis and $d_x = 0.5$ and $d_y = 0, d_z = 0$. Accelerometer is given a step response of 50 ms^{-2} .

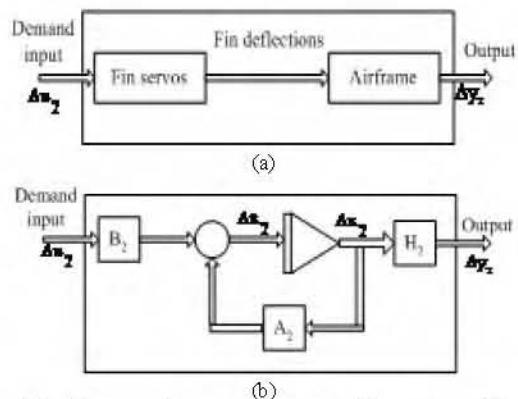


Fig. 15 Block diagram of an open loop autopilot system: (a) schematic diagram and (b) symbolic diagram

The time for system to be stable is about two seconds and the response times at the rudder and elevator are the same. These response curves are shown in Fig. 16 and 17. It can

easily be seen that there are large steady state errors in the figures.

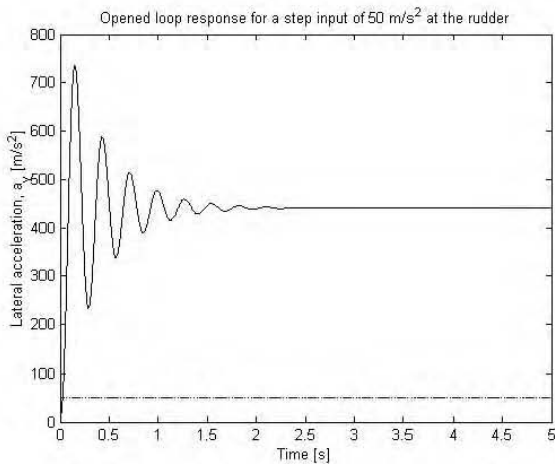


Fig. 16 Open loop simulation: lateral acceleration a_y response

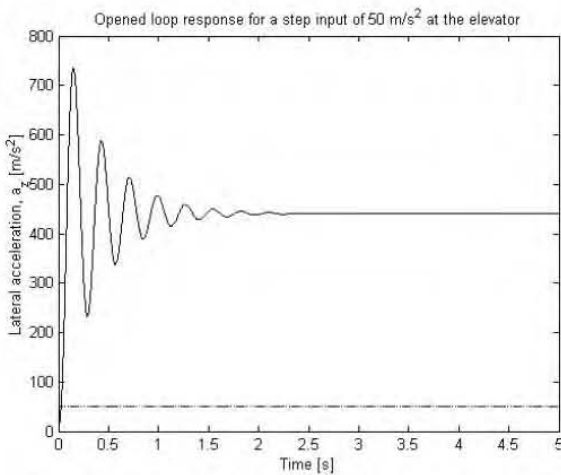


Fig. 17 Open loop simulation: lateral acceleration a_z response

IV. CLOSED LOOP SIMULATION AND RESULTS

Figure 18 is the block diagram of closed loop autopilot system. In this case, the airframe model decouples into two lateral dynamics (pitch and yaw) and one roll dynamics. The lateral autopilot dynamics is considered.

In this case, the instrument (gyro, accelerometer) dynamics are ignored. The measured roll, pitch and yaw angular rates (the gyro outputs) can be expressed as inputs to gyros multiplied the gyro gain, K_{gr} , K_{gp} and K_{gy} respectively.

Similarly, the measured longitudinal acceleration a_x , and lateral accelerations, a_y and a_z , are inputs to the accelerometers multiplied accelerometer gains, K_{ax} , K_{ay} and K_{az} , respectively. The accelerometer gains affect the steady state response and may be set to 1 for transient tests. Rescaling accelerometer gains, after selecting gyro gains, allows a unity gain autopilot to be designed.

The reference signals, generally used for testing the transient time response of the autopilot, are the desired accelerations in yaw direction, a_{y_d} , the pitch direction, a_{z_d} and

roll rate, p_d . The reference roll rate is kept at zero to assess the vehicle dynamics in roll against spurious disturbances.

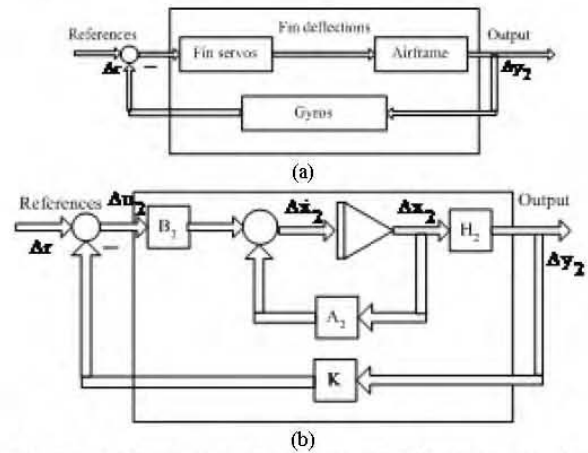


Fig. 18 Block diagram of a closed loop autopilot system: (a) schematic diagram and (b) symbolic diagram

The steady state error in open loop simulation can be reduced with a feedback loop. The feed back gain for roll gyro is 30.75, and yaw gyro is -30.75. The feedback gains for lateral accelerations a_y and a_z are set as 0.825. Natural frequency, damping factor, aileron, elevator and rudder gains are the same as the open loop system.

The response curve is shown in Fig. 19. If the damping factor is set 1.0, the smaller steady state error compared to the former curve with damping factor 0.7 can be obtained. It is shown in Fig. 20. The stabling time for closed loop system is approximately 0.2 seconds.

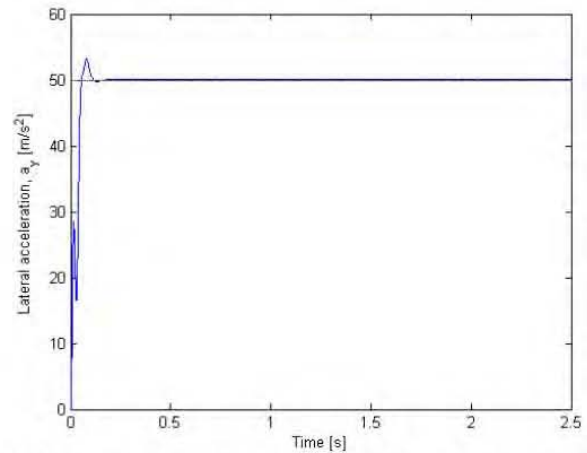


Fig. 19 Closed loop simulation: lateral acceleration a_y response ($\mu=0.7$)

It is difficult to construct such system with PIC microcontroller and pneumatic actuation system. Longer response time is needed to implement the pneumatic actuation system. So, the damping factor is varied to get the suitable stabling time for the system. When the damping factor is set as 2.0, the time for the system to be stable is approximately 1 second. When the damping factor is 2.5 and all other conditions are not changed, the time for system to be stable is 2 seconds. When the damping factor is 3.0, the time to stable is 3 seconds. The system can be constructed with PIC

microcontroller with the response time between 1 second and 5 seconds. So the system is verified with the simulation. The result curves are shown in Fig. 21 through 23.

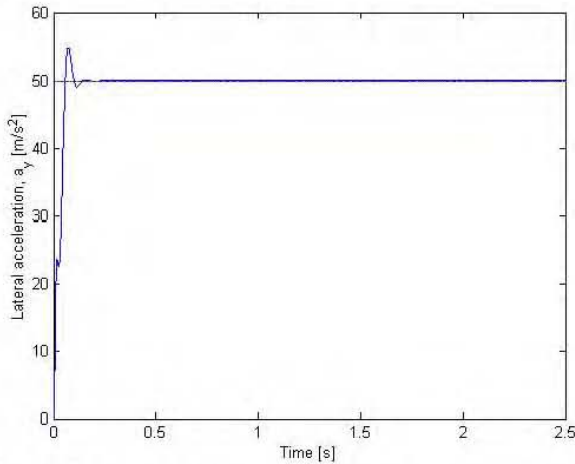


Fig. 20 Closed loop simulation: lateral acceleration a_y response ($\mu=1.0$)

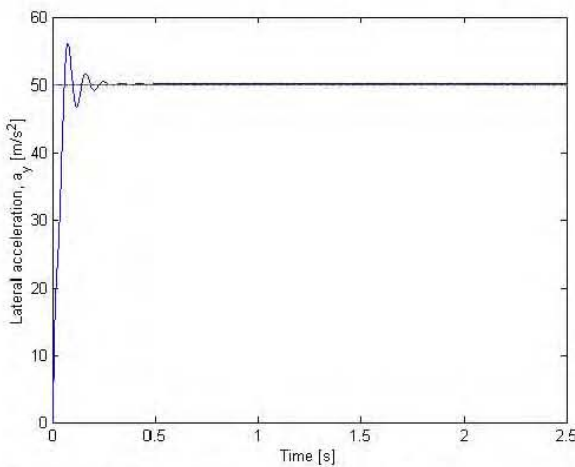


Fig. 21 Closed loop simulation: lateral acceleration a_y response ($\mu=1.5$)

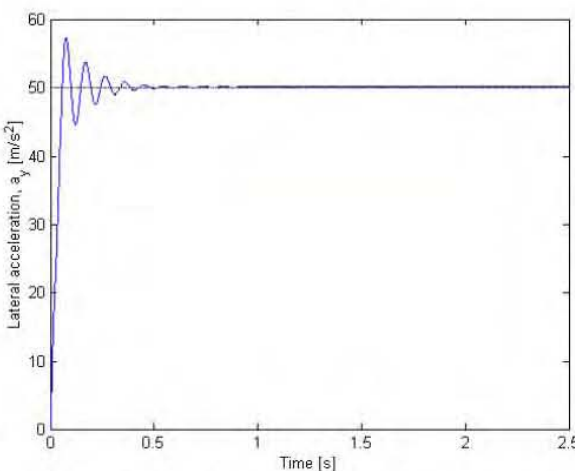


Fig. 22 Closed loop simulation: lateral acceleration a_y response ($\mu=2.0$)

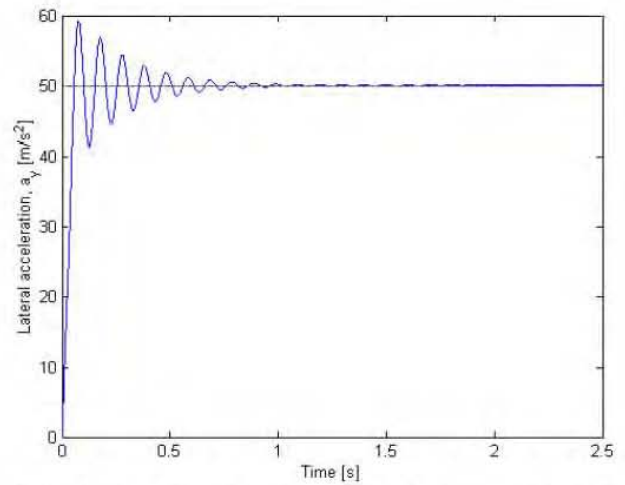


Fig. 23 Closed loop simulation: lateral acceleration a_y response ($\mu=2.5$)

V. SUMMARY OF SIMULATIONS

First, the launched vehicle body design and stability is simulated. From simulation results, missile body with 4 feet in length and 3 inches in diameter is chosen. Two standard engines I284W and J145 are chosen to meet with the requirements of subsonic system. The vehicle launched with 10 degrees from the vertical axis are chosen in simulation with both engine because the time difference between apogee and impact is longer than launched with 45 degrees. With engine I284W the time difference is 19.57 seconds. With J145 engine, the time difference is 20.6 seconds.

In response time simulation with MATLAB, lateral accelerations response time is simulated with varying of damping factor. In this case feedback gains of lateral accelerations are set as 0.25, feedback gain of roll gyro is set as 30.75 and yaw gyro is -30.75. Its natural frequency is 180 Hz and gains of aileron, elevator and rudder are set as 0.0068. The vehicle is given a step input acceleration of 50 ms^{-2} . When the damping factor is less than 1.5, the time to stable is less than 0.5 seconds. When the damping factor is 2, the time to stable is 1 second. Time to stable is 2 seconds when damping factor is 2.5. Time to stable of 2 seconds is chosen to be able to implement with the PIC microcontroller.

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