3D Rocket Trajectory Simulation

A MATLAB-Based Physical and Visual Model

This undergraduate project presents a dynamic rocket trajectory simulation combining physics-based modelling, custom geometry and professional-grade visualization.

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Tools & methods: MATLAB, numerical integration, aerodynamic modelling and custom 3D visualization.

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Simulation Parameters

This section summarizes this values used for the simulation of the Super Heavy rocket trajectory. These parameters include both the rocket's physical properties and the environmental conditions.

Rocket Characteristics

Parameter	Symbol	Value	Unit
Structural Mass	m_{rocket}	200 000	kg
Propellant Mass	m_{fuel}	3 400 000	kg
Diameter	D	9	m
Height	H	69	m
Nose Shape	-	conical	-
Initial Drag Coefficient	Cd_o	0.4732	-

Propulsion and Burn

Parameter	Symbol	Value	Unit
Thrust	F	72 000 000	N
Specific Impulse	I_{sp}	250	s
Burn Time	t_{burn}	109.00	s

Environmental Conditions

Parameter	Symbol	Value	Unit
Gravity	g	9.81	m/s^2
Wind Speed	v_{wind}	15.40	m/s
Wind Direction	θ_{wind}	135.00	° *(degrees)*

Simulation Setup

Parameter	Symbol	Value	Unit
Latitud	L	25.99	°
Launch Angle (Z axis)	α_Z	85.00	° *(degrees)*
Launch Angle (XY plane)	α_{XY}	15.30	° *(degrees)*
Time Step	dt	0.1	s

3D Rocket Trajectory Simulation

```
clc;
clear;
close all;
disp('Welcome to the project: 3D Rocket Trajectory Simulation');
```

```
Welcome to the project: 3D Rocket Trajectory Simulation
```

Rocket Parameters:

```
m_cohete = input('Enter the structural mass of the rocket (kg): ');
m_combustible = input('Enter the mass of the fuel (kg): ');
g = 9.81;
rho0 = 1.225;
Cd = 0.75;
thrust = input('Enter the thrust applied to the rocket (N): ');
dt = 0.1;
H = 8442;
latitud = input('Enter the launch site latitude (degrees): ');
V_wind = input('Enter the crosswind speed (m/s): ');
theta_wind = input('Enter the crosswind direction (degrees): ');
```

Rocket Geometry:

```
diameter = input('Enter the rocket diameter (m): ');
height = input('Enter the rocket height (m): ');
A = pi * (diameter / 2)^2;

disp('Select the rocket nose cone shape:');
```

```
Select the rocket nose cone shape:
```

```
disp('1. Conical');
```

```
1. Conical
```

```
disp('2. Ogive');
```

```
2. Ogive
```

```
disp('3. Parabolic');
```

```
3. Parabolic
```

```
disp('4. Hemispherical');
```

```
4. Hemispherical
```

```
nose_choice = input('Enter the corresponding number: ');
```

```
if nose_choice == 1
    nose_shape = "conical";
elseif nose_choice == 2
    nose_shape = "ogive";
elseif nose_choice == 3
    nose_shape = "parabolic";
elseif nose_choice == 4
    nose_shape = "hemispherical";
end

fprintf('Selected nose shape: %s\n', nose_shape);
```

```
Selected nose shape: conical
```

Propellant:

```
disp('Select the type of propellant:')
```

```
Select the type of propellant:
```

```
disp('1. Liquid Hydrogen (LH2 + LOX) - Isp: 430 s');
```

```
1. Liquid Hydrogen (LH2 + LOX) - Isp: 430 s
```

```
disp('2. RP-1 (kerosene) + LOX - Isp: 300 s');
```

```
2. RP-1 (kerosene) + LOX - Isp: 300 s
```

```
disp('3. Ammonium Perchlorate (AP) + Aluminum - Isp: 250 s');
```

```
3. Ammonium Perchlorate (AP) + Aluminum - Isp: 250 s
```

```
disp('4. Nitrous Oxide (N2O) + HTPB - Isp: 300 s');
```

```
4. Nitrous Oxide (N2O) + HTPB - Isp: 300 s
```

```
fuel_type = input('Enter the number corresponding to the propellant: ');

switch fuel_type
    case 1
        Isp = 430;
    case 2
        Isp = 300;
    case 3
        Isp = 250;
    case 4
        Isp = 300;
    otherwise
        Isp = 300;
end
```

```
burn_time = (m_combustible * Isp * g)/thrust;
```

Launch Angle:

```
theta_z = input('Enter the elevation angle (Z) in degrees: ');
theta_xy = input('Enter the angle in the XY plane in degrees: ');
```

Calculate the initial drag coefficient (Cd0):

```
v0 = 0.1;
alpha = 0;
num_fins = 4;
Cd0 = calculate_Cd0(nose_shape, diameter, height, num_fins, alpha, v0, rho0);
fprintf('Initial drag coefficient (Cd0): %.4f\n', Cd0);
```

```
Initial drag coefficient (Cd0): 0.4732
```

Simulation Parameters Summary:

```
disp('-- Simulation Parameters Summary --');
```

```
-- Simulation Parameters Summary --
```

```
fprintf('Rocket structural mass: %.2f kg\n', m_cohete);
```

```
Rocket structural mass: 200000.00 kg
```

```
fprintf('Fuel mass: %.2f kg\n', m_combustible);
```

```
Fuel mass: 3200000.00 kg
```

```
fprintf('Thrust: %.2f N\n', thrust);
```

```
Thrust: 72000000.00 N
```

```
fprintf('Estimated burn time: %.2f s\n', m_combustible / (thrust / (Isp * g)));
```

```
Estimated burn time: 109.00 s
```

```
fprintf('Isp: %.2f s\n', Isp);
```

```
Isp: 250.00 s
```

```
fprintf('Nose shape: %s\n', nose_shape);
```

```
Nose shape: conical
```

```
fprintf('Rocket diameter: %.2f m\n', diameter);
```

```
Rocket diameter: 9.00 m
```

```
fprintf('Rocket height: %.2f m\n', height);
```

```
Rocket height: 69.00 m
```

```
fprintf('Latitude: %.2f°\n', latitud);
```

```
Latitude: 25.99°
```

```
fprintf('Wind speed: %.2f m/s\n', V_wind);
```

```
Wind speed: 15.40 m/s
```

```
fprintf('Wind direction: %.2f°\n', theta_wind);
```

```
Wind direction: 135.00°
```

```
fprintf('Launch angle (Z axis): %.2f°\n', theta_z);
```

```
Launch angle (Z axis): 85.00°
```

```
fprintf('Launch angle in XY plane: %.2f°\n', theta_xy);
```

```
Launch angle in XY plane: 15.30°
```

```
fprintf('Initial drag coefficient (Cd0): %.4f\n', Cd0);
```

```
Initial drag coefficient (Cd0): 0.4732
```

```
disp('-------------------------------------');
```

```
-----------------------------------
```

Run Simulation:

```
try
    trajectory = simulate_rocket_3d(m_cohete, m_combustible, g, rho0, Cd0, A,
thrust, burn_time, dt, theta_z, theta_xy, Isp, nose_shape, diameter, latitud,
V_wind, theta_wind);
    fprintf('Simulation completed successfully.\n');
catch ME
    fprintf('Error during simulation: %s\n', ME.message);
    return;
end
```

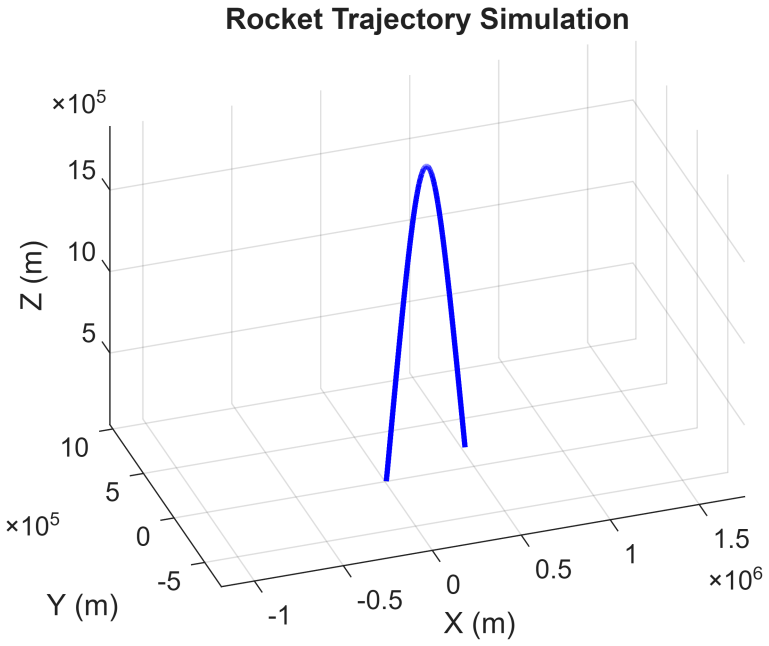
```
Simulation completed successfully.
```

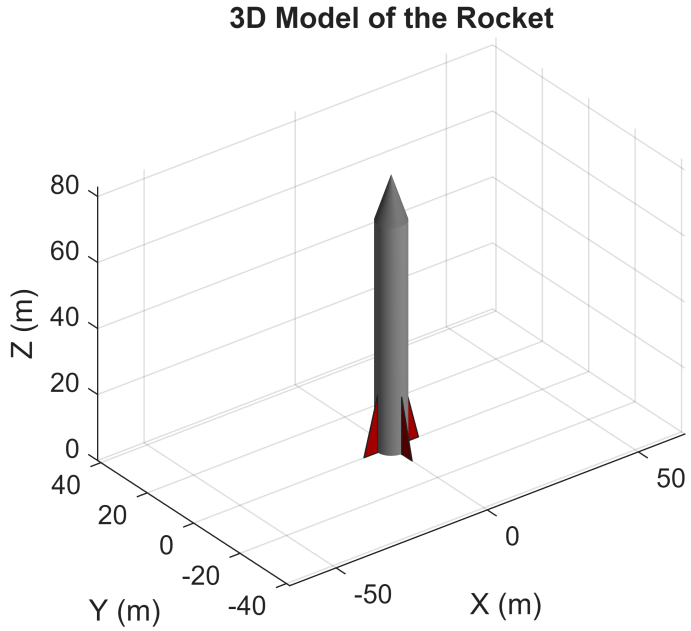
3D Trajectory Visualization:

```
try
    disp('Generating 3D visualization...');
    radius = diameter / 2;
    nose_height = height * 0.2;
    simulate_and_draw_rocket3D(trajectory, radius, height, nose_height, nose_shape);
catch ME
```

```
    fprintf('Error during visualization: %s\n', ME.message);
    return;
end
```

```
Generating 3D visualization...
```

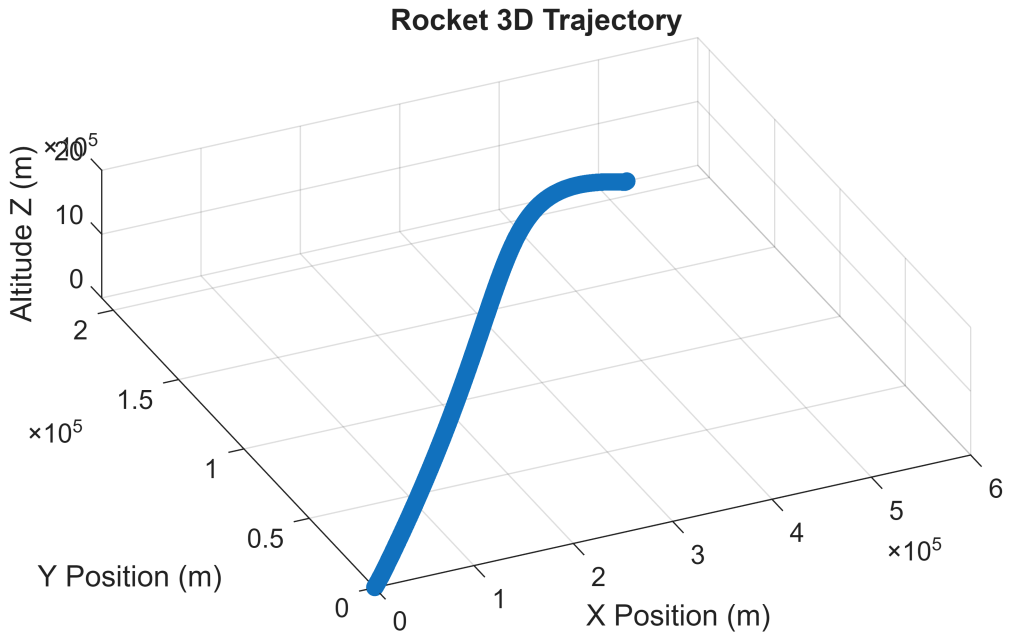




Position and Displacement:

```
figure;
plot3(trajectory(:,1), trajectory(:,2), trajectory(:,3), '-o');
xlabel('X Position (m)');
ylabel('Y Position (m)');
```

```
zlabel('Altitude Z (m)');
title('Rocket 3D Trajectory');

grid on;
view(3);
exportgraphics(gcf, 'rocket_3D_trajectory.png', 'Resolution', 300);
```



Summary of key trajectory points

```
start_point = trajectory(1,:);
end_point = trajectory(end,:);
[~, idx_max_alt] = max(trajectory(:,3));
max_point = trajectory(idx_max_alt, :);

T = table(...
    ["Start"; "Max Altitude"; "End"], ...
    [start_point(1); max_point(1); end_point(1)], ...
    [start_point(2); max_point(2); end_point(2)], ...
    [start_point(3); max_point(3); end_point(3)], ...
    'VariableNames', {'Point', 'X (m)', 'Y (m)', 'Z (m)'});

disp('Summary of Key Trajectory Points:');
```

```
Summary of Key Trajectory Points:
```

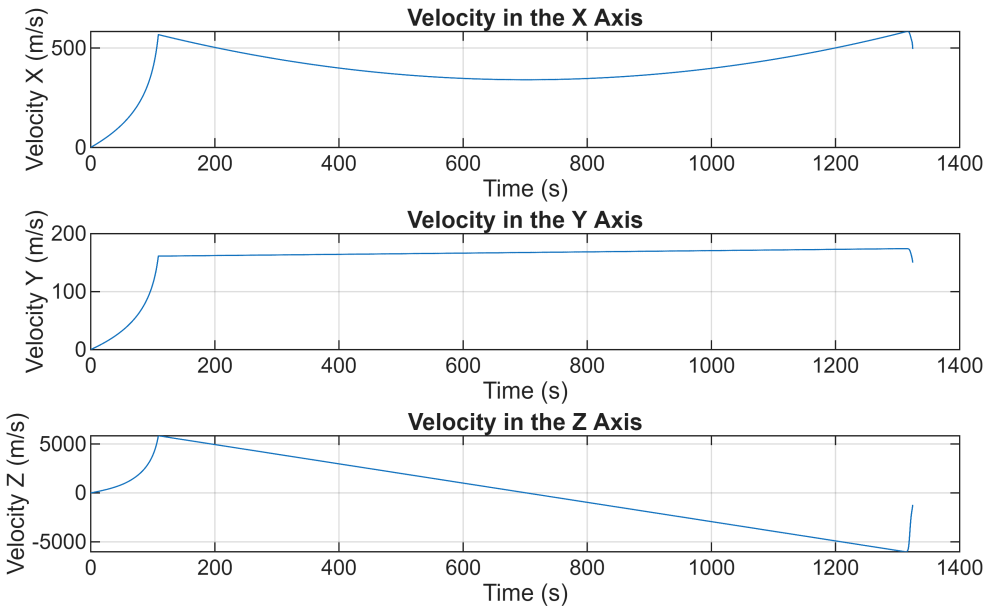
```
disp(T);
```

Point	X (m)	Y (m)	Z (m)
"Start"	0.017818	0.0048744	0.11304

```
"Max Altitude"    2.6475e+05    1.0251e+05    1.8884e+06
"End"             5.2851e+05    2.0883e+05       -42.656
```

Velocity:

```
figure;
subplot(3,1,1);
plot(trajectory(:,4), gradient(trajectory(:,1), dt), '-');
xlabel('Time (s)');
ylabel('Velocity X (m/s)');
title('Velocity in the X Axis');
grid on;

subplot(3,1,2);
plot(trajectory(:,4), gradient(trajectory(:,2), dt), '-');
xlabel('Time (s)');
ylabel('Velocity Y (m/s)');
title('Velocity in the Y Axis');
grid on;

subplot(3,1,3);
plot(trajectory(:,4), gradient(trajectory(:,3), dt), '-');
xlabel('Time (s)');
ylabel('Velocity Z (m/s)');
title('Velocity in the Z Axis');
grid on;

exportgraphics(gcf, 'velocity_XYZ.png', 'Resolution', 300);
```



Velocity Event Analysis for All Axes

```
vel_x_eq = zeros(size(trajectory, 1), 1);
vel_y_eq = zeros(size(trajectory, 1), 1);
vel_z_eq = zeros(size(trajectory, 1), 1);

for i = 2:size(trajectory, 1)
    ax = trajectory(i, 5);
    ay = trajectory(i, 6);
    az = trajectory(i, 7);

    vel_x_eq(i) = vel_x_eq(i-1) + ax * dt;
    vel_y_eq(i) = vel_y_eq(i-1) + ay * dt;
    vel_z_eq(i) = vel_z_eq(i-1) + az * dt;
end

axes_labels = ["X", "Y", "Z"];
velocities = {vel_x_eq, vel_y_eq, vel_z_eq};
results = [];

for i = 1:3
    v = velocities{i};
    [v_max, idx_max] = max(v);
    [v_min, idx_min] = min(v);
    idx_zero = find(abs(v) < 1e-3 & trajectory(:,4) > 0, 1);

    if isempty(idx_zero)
        t_zero = NaN;
        v_zero = NaN;
    else
        t_zero = trajectory(idx_zero, 4);
        v_zero = v(idx_zero);
    end

    results = [results;
        {axes_labels(i), "Max Velocity", trajectory(idx_max, 4), v_max};
        {axes_labels(i), "Min Velocity", trajectory(idx_min, 4), v_min};
        {axes_labels(i), "Zero Crossing", t_zero, v_zero}];

    v_sign = sign(v);
    crossing_indices = find(diff(v_sign) ~= 0);

    for j = 1:length(crossing_indices)
        idx = crossing_indices(j) + 1;
        if trajectory(idx, 4) >= 0.5
            results = [results;
                {axes_labels(i), sprintf("Zero Crossing %d", j), trajectory(idx,
4), v(idx)}];
```

```
        end
    end
end

VelocitySummary = cell2table(results, ...
    'VariableNames', {'Axis', 'Event', 'Time (s)', 'Velocity (m/s)'});

disp('🔍 Summary of Velocity Events in Each Axis:');
```

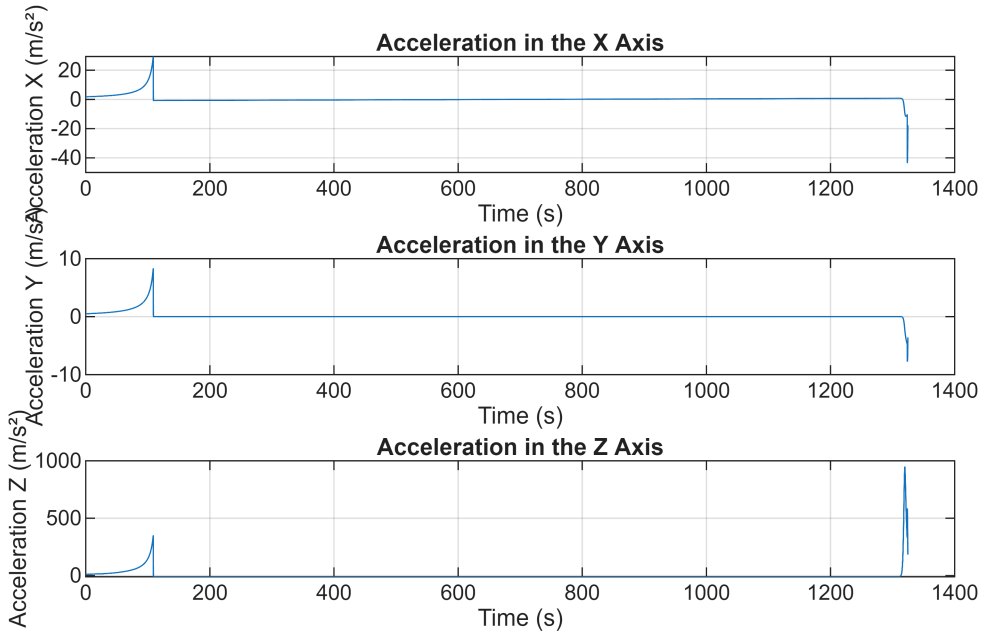
```
🔍 Summary of Velocity Events in Each Axis:
```

```
disp(VelocitySummary);
```

```
    Axis          Event          Time (s)    Velocity (m/s)
    ____    ________________    ________    ______________

    "X"     "Max Velocity"        1316.2          583.14
    "X"     "Min Velocity"             0               0
    "X"     "Zero Crossing"          NaN             NaN
    "Y"     "Max Velocity"        1313.4          174.08
    "Y"     "Min Velocity"             0               0
    "Y"     "Zero Crossing"          NaN             NaN
    "Z"     "Max Velocity"           109          5841.1
    "Z"     "Min Velocity"        1313.4         -6017.1
    "Z"     "Zero Crossing"          NaN             NaN
    "Z"     "Zero Crossing 2"      701.8        -0.41474
```

Acceleration:

```
figure;
subplot(3,1,1);
plot(trajectory(:,4), gradient(gradient(trajectory(:,1), dt), dt), '-');
xlabel('Time (s)');
ylabel('Acceleration X (m/s²)');
title('Acceleration in the X Axis');
grid on;

subplot(3,1,2);
plot(trajectory(:,4), gradient(gradient(trajectory(:,2), dt), dt), '-');
xlabel('Time (s)');
ylabel('Acceleration Y (m/s²)');
title('Acceleration in the Y Axis');
grid on;

subplot(3,1,3);
plot(trajectory(:,4), gradient(gradient(trajectory(:,3), dt), dt), '-');
xlabel('Time (s)');
ylabel('Acceleration Z (m/s²)');
title('Acceleration in the Z Axis');
grid on;

exportgraphics(gcf, 'acceleration_XYZ.png', 'Resolution', 300);
```



Acceleration Event Analysis for All Axes

```
ax_eq = gradient(vel_x_eq, dt);
ay_eq = gradient(vel_y_eq, dt);
az_eq = gradient(vel_z_eq, dt);

axes_labels = ["X", "Y", "Z"];
accelerations = {ax_eq, ay_eq, az_eq};
accel_results = [];

for i = 1:3
    a = accelerations{i};
    [a_max, idx_max] = max(a);
    [a_min, idx_min] = min(a);

    accel_results = [accel_results;
        {axes_labels(i), "Max Acceleration", trajectory(idx_max, 4), a_max};
        {axes_labels(i), "Min Acceleration", trajectory(idx_min, 4), a_min}];
end

% Display acceleration summary
AccelerationSummary = cell2table(accel_results, ...
    'VariableNames', {'Axis', 'Event', 'Time (s)', 'Acceleration (m/s²)'});

disp('⚡ Summary of Acceleration Events in Each Axis:');
```

```
⚡ Summary of Acceleration Events in Each Axis:
```

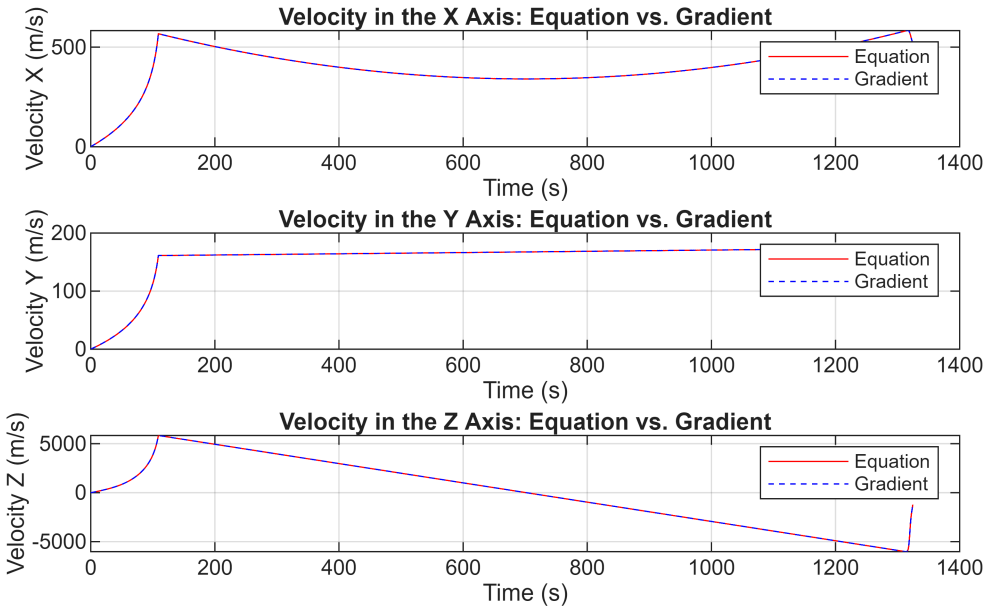
```
disp(AccelerationSummary);
```

Axis	Event	Time (s)	Acceleration (m/s²)
"X"	"Max Acceleration"	108.9	29.499
"X"	"Min Acceleration"	1323.8	-44.154
"Y"	"Max Acceleration"	108.9	8.2896
"Y"	"Min Acceleration"	1323.8	-7.7534
"Z"	"Max Acceleration"	1319.8	947.84
"Z"	"Min Acceleration"	109.1	-9.8741

Velocity comparaison: Gradient vs. Equations

```
vel_x_eq = zeros(size(trajectory, 1), 1);
vel_y_eq = zeros(size(trajectory, 1), 1);
vel_z_eq = zeros(size(trajectory, 1), 1);

for i = 2:size(trajectory, 1)

    ax = trajectory(i, 5);
    ay = trajectory(i, 6);
    az = trajectory(i, 7);

    vel_x_eq(i) = vel_x_eq(i-1) + ax*dt;
    vel_y_eq(i) = vel_y_eq(i-1) + ay*dt;
    vel_z_eq(i) = vel_z_eq(i-1) + az*dt;
end

vel_x_grad = gradient(trajectory(:,1), dt);
vel_y_grad = gradient(trajectory(:,2), dt);
vel_z_grad = gradient(trajectory(:,3), dt);

figure;
subplot(3,1,1);
plot(trajectory(:,4), vel_x_eq, '-r', 'DisplayName', 'Equation');
hold on;
plot(trajectory(:,4), vel_x_grad, '--b', 'DisplayName', 'Gradient');
xlabel('Time (s)');
ylabel('Velocity X (m/s)');
title('Velocity in the X Axis: Equation vs. Gradient');
legend;
grid on;

subplot(3,1,2);
plot(trajectory(:,4), vel_y_eq, '-r', 'DisplayName', 'Equation');
hold on;
plot(trajectory(:,4), vel_y_grad, '--b', 'DisplayName', 'Gradient');
xlabel('Time (s)');
ylabel('Velocity Y (m/s)');
title('Velocity in the Y Axis: Equation vs. Gradient');
legend;
```

```
grid on;

subplot(3,1,3);
plot(trajectory(:,4), vel_z_eq, '-r', 'DisplayName', 'Equation');
hold on;
plot(trajectory(:,4), vel_z_grad, '--b', 'DisplayName', 'Gradient');
xlabel('Time (s)');
ylabel('Velocity Z (m/s)');
title('Velocity in the Z Axis: Equation vs. Gradient');
legend;
grid on;
```



Simulation with and without crosswind

```
disp('Simulating with crosswind...');
```

```
Simulating with crosswind...
```

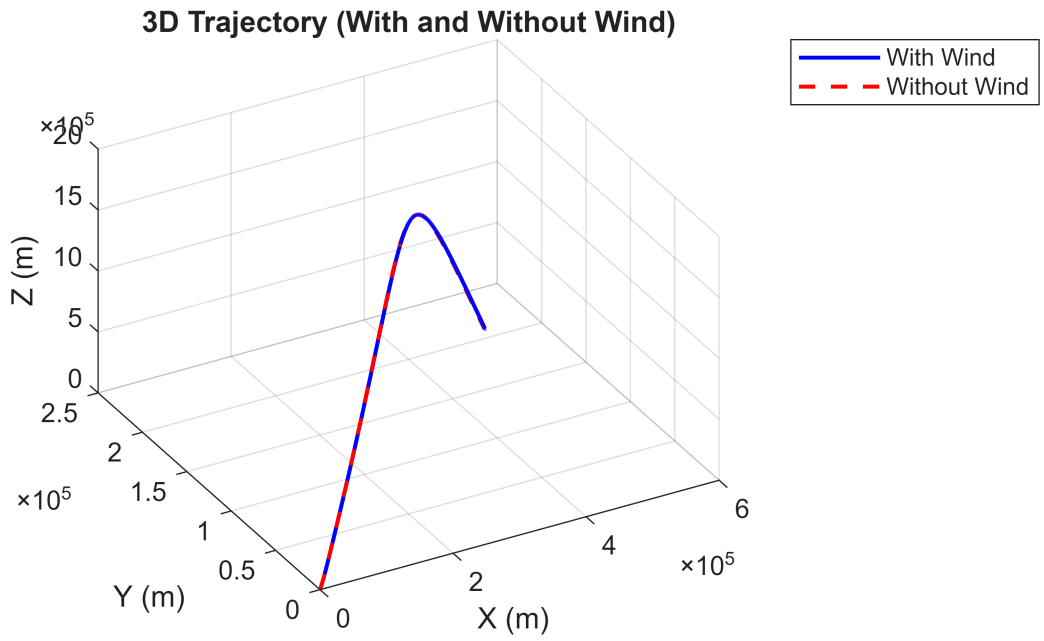
```
trajectory_with_wind = simulate_rocket_3d(m_cohete, m_combustible, g, rho0, Cd0,
A, thrust, burn_time, dt, theta_z, theta_xy, Isp, nose_shape, diameter, latitud,
V_wind, theta_wind);

disp('Simulating without crosswind...');
```

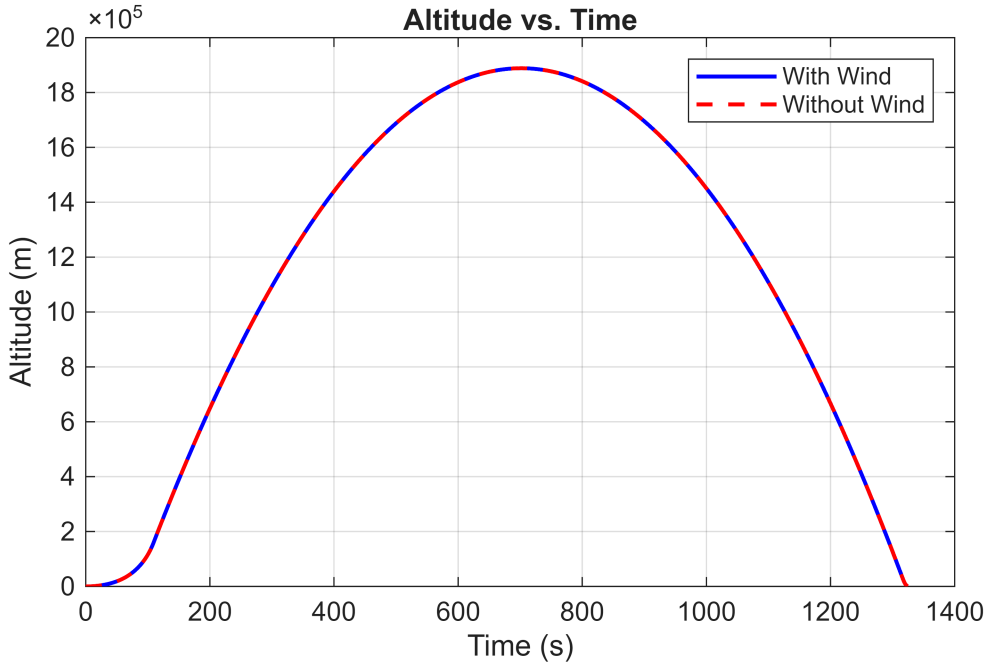
```
Simulating without crosswind...
```

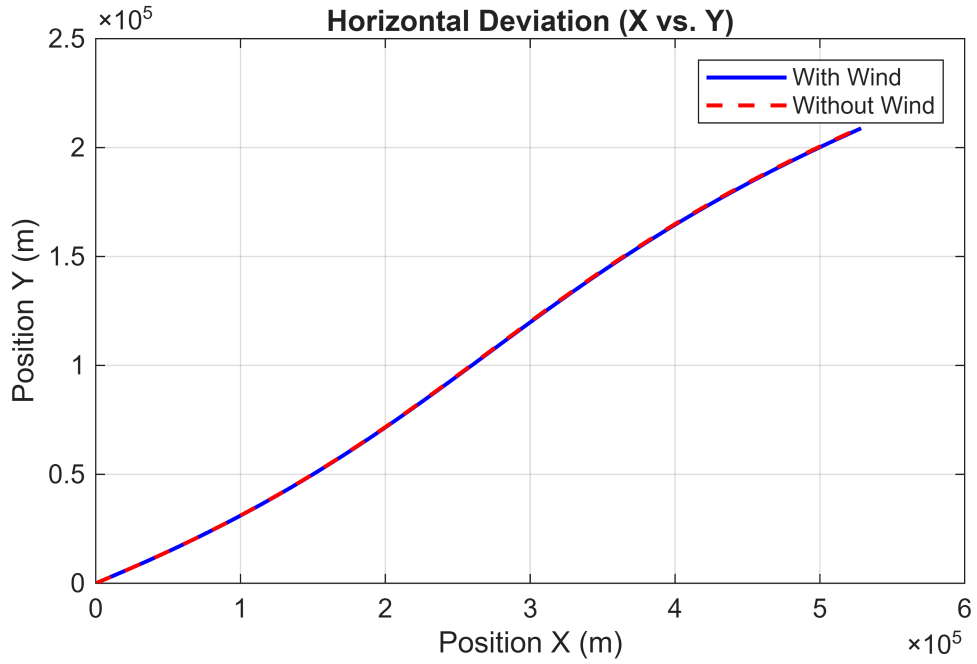
```
trajectory_no_wind = simulate_rocket_3d(m_cohete, m_combustible, g, rho0, Cd0, A,
thrust, burn_time, dt, theta_z, theta_xy, Isp, nose_shape, diameter, latitud, 0, 0);

min_length = min(size(trajectory_with_wind, 1), size(trajectory_no_wind, 1));
trajectory_with_wind = trajectory_with_wind(1:min_length, :);
```

```
trajectory_no_wind = trajectory_no_wind(1:min_length, :);

try
    disp('Generating comparison plots...');
    compare_wind_effect(trajectory_with_wind, trajectory_no_wind);
    fprintf('Comparison plots generated successfully.\n');
catch ME
    fprintf('Error while generating comparison plots: %s\n', ME.message);
end
```

```
Generating comparison plots...
```








```
Comparison plots generated successfully.
```