AER4420

Autopilot Project

TEAM3

February 24, 2025

AEROSPACE ENGINEERING

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Flight Mechanics Review

- General Rigid Body Dynamics Equations in 3D (12 Equations)

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- Attitude Representations: Advantages and Disadvantages

Numerical solution of ODEs

- Numerical Solving Algorithms

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- Using Runge-Kutta 4th order Solver (RK4)

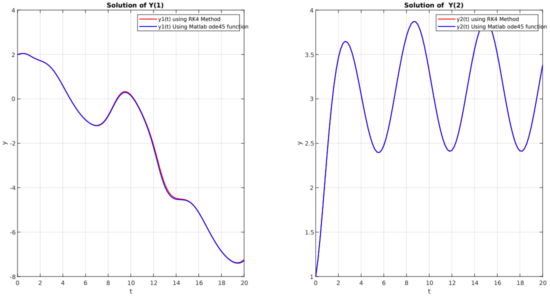


Figure: Our Code VS MATLAB

Simulink Model

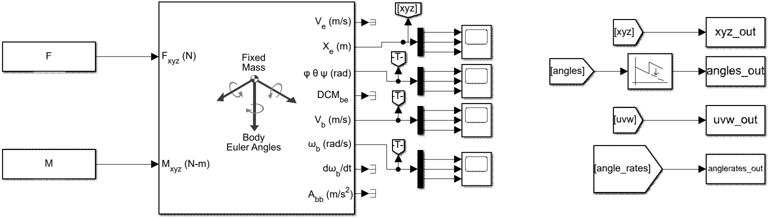


Figure: Simulink Model Used

Given Data

$$m = 11 \text{ kg}$$

$$\boldsymbol{I} = \begin{bmatrix} 1 & -2 & -1 \\ -2 & 5 & -4 \\ -1 & -4 & 0.2 \end{bmatrix} \text{kg} \cdot \text{m}^2$$

$$[u, v, w, p, q, r, \phi, \theta, \psi, x, y, z]_{t=0} =$$

$$\left[10, 2, 0, 2 * \frac{\pi}{180}, 1 * \frac{\pi}{180}, 0 * \frac{\pi}{180}, 20 * \frac{\pi}{180}, 15 * \frac{\pi}{180}, 30 * \frac{\pi}{180}, 2, 4, 7\right]$$

$$F = [\ 2 \quad 8 \quad 3\ ]\ N$$

$$M = [\ 14 \quad 20 \quad 7\ ]\ N.m$$

$$t_f = 25\ s$$

Sampling Time Selection in Aircraft Simulation

The choice of T_s depends on the fastest dynamics of the system. Based on digital control principles [1, 2], common sampling times for aircraft systems are:

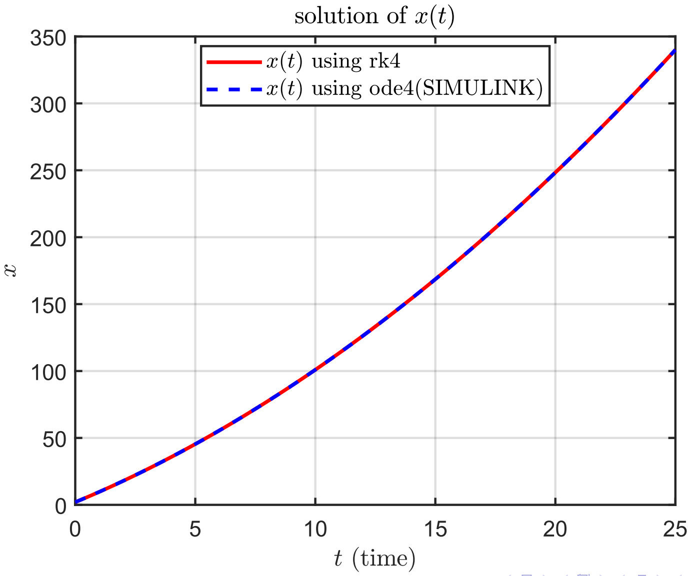
- **Slow response systems (e.g., navigation, autopilot):** $T_s = 50$ ms (0.05 s)
- **Flight control (inner loops, stability augmentation):** $T_s = 10$ ms (0.01 s)
- **High-bandwidth actuator control:** $T_s = 1$ ms (0.001 s)

Numerical ODE Solver Considerations

When using RK4 for solving the equations of motion, the internal solver step Δt should be smaller than T_s. As recommended in numerical integration literature [3, 4], a good practice is:

$$\Delta t = \frac{T_s}{5} \text{ or } \frac{T_s}{10} \tag{1}$$

States Comparsion



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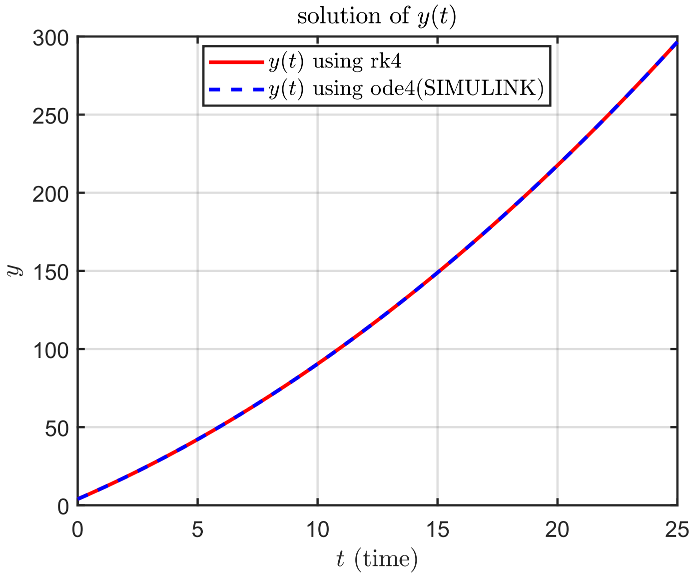

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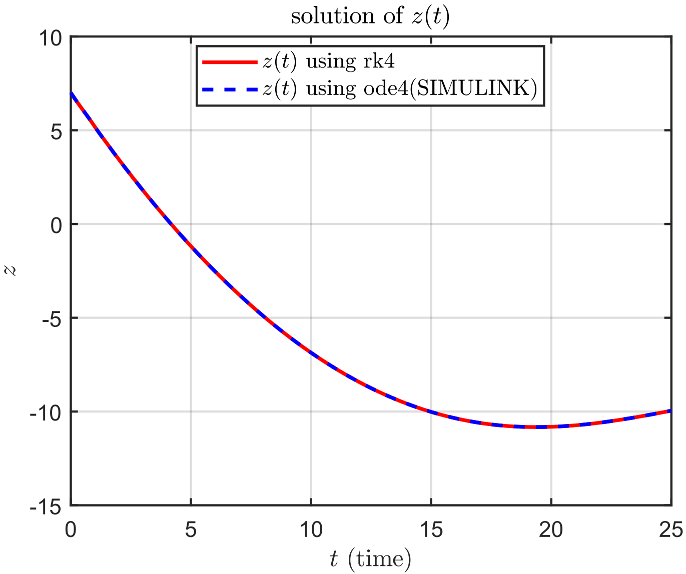

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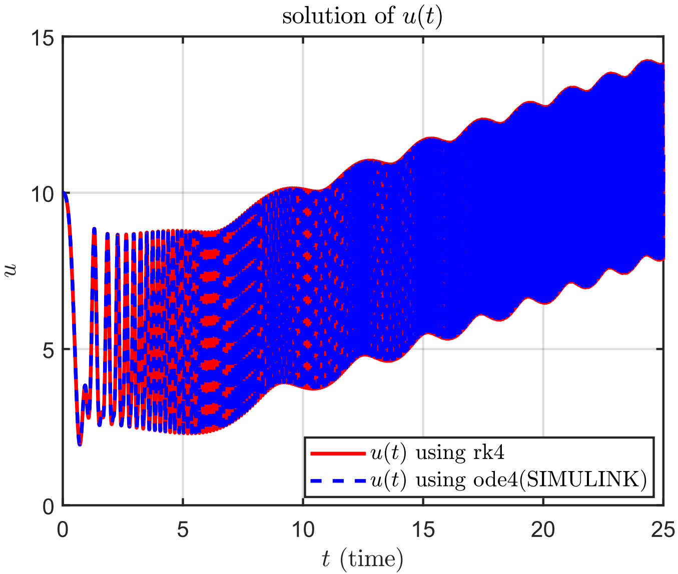

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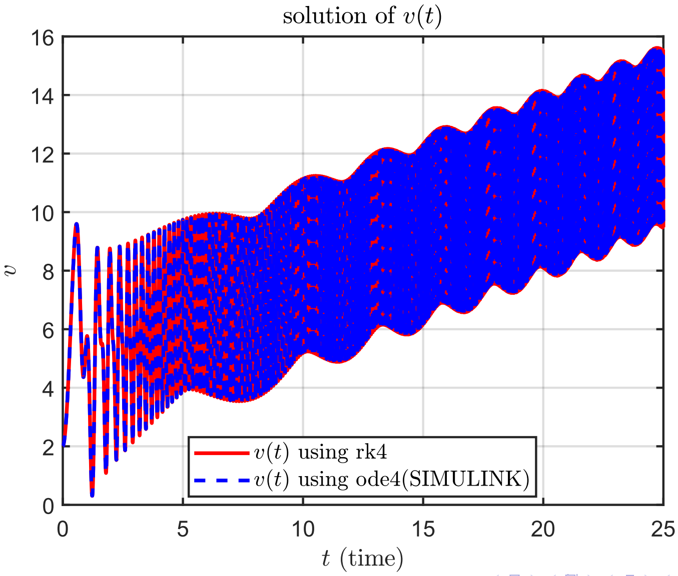

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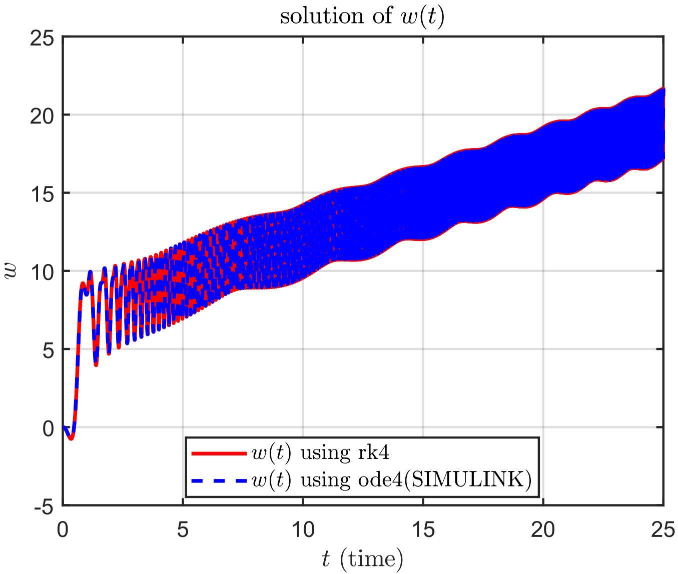

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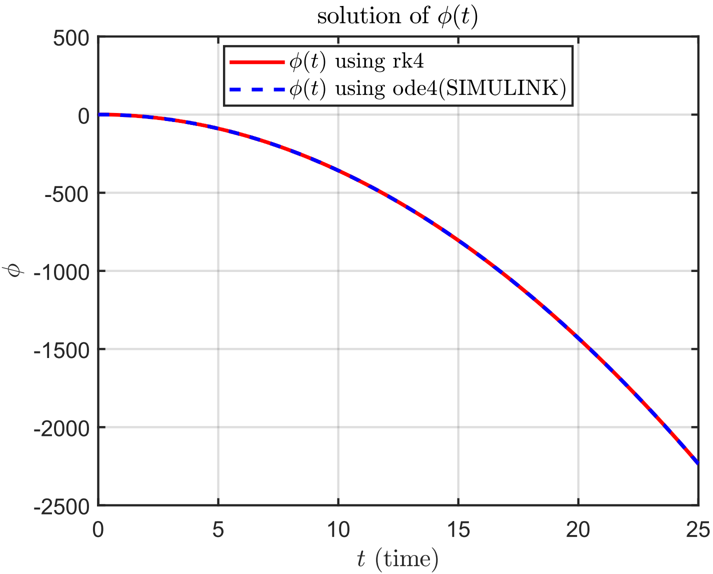

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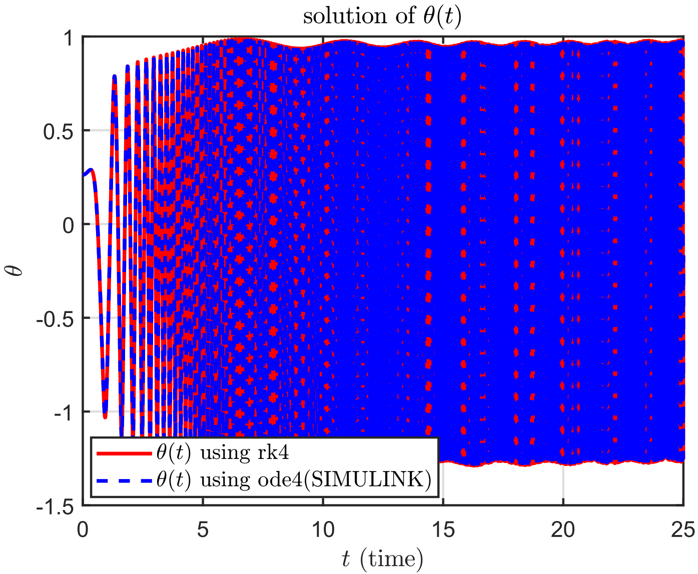

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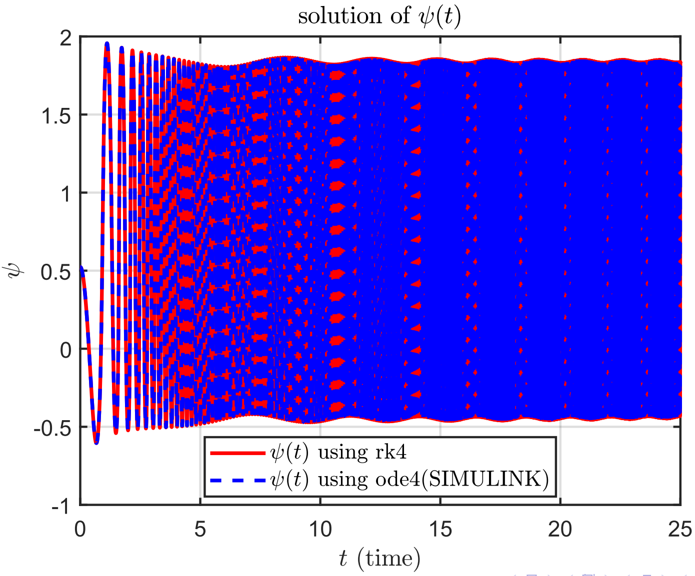

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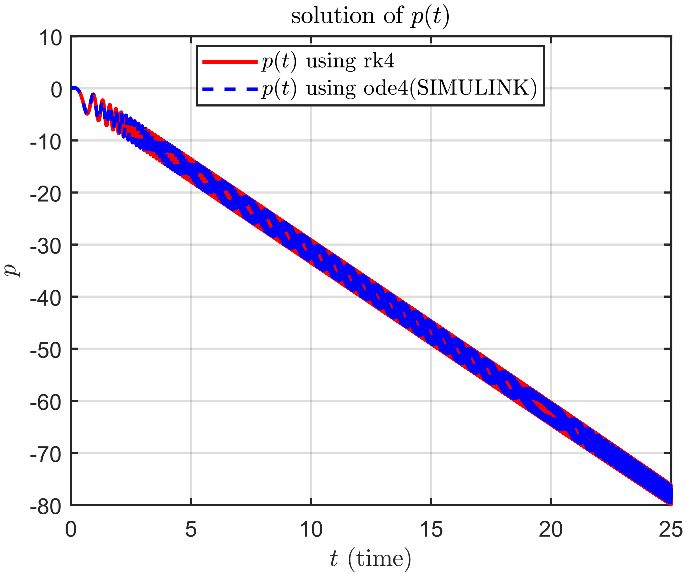

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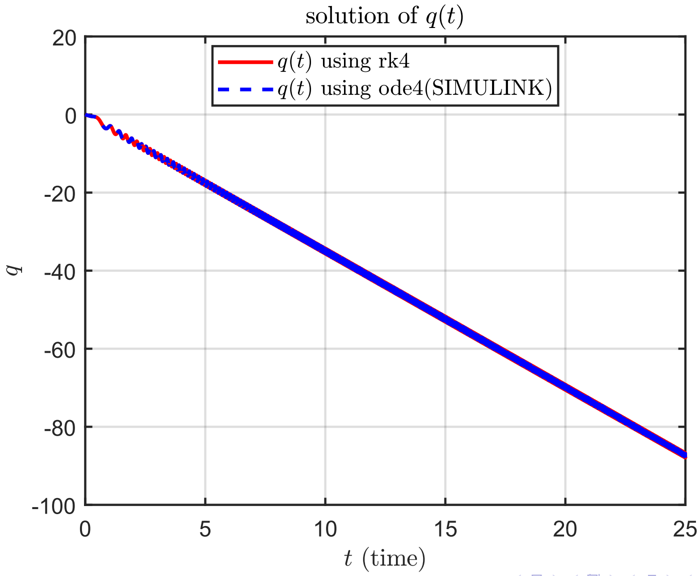

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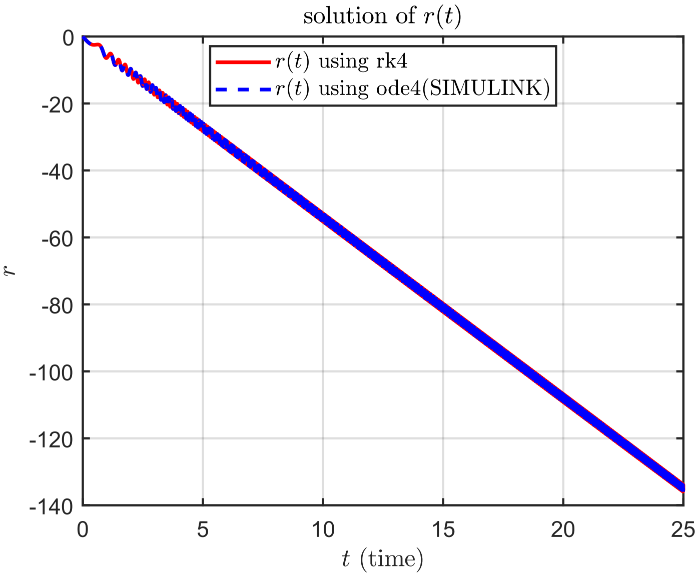

Error Computation

We calculated the deviation between RK4 and Simulink solutions:

- Mean absolute error for each state variable.
- Root Mean Square Error (RMSE) to measure average deviation.
- Maximum error to identify the worst-case difference.

References

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Mean Absolute Error (MAE) for each state:
    1.0e-09 *[0.0037 0.0036 0.0027 0.0050 0.0016 0.0028 0.0031 0.0012 0.0027
        0.1684 0.1931 0.0672]
Root Mean Square Error (RMSE) for each state:
    1.0e-09 *[0.0053 0.0052 0.0039 0.0071 0.0022 0.0040 0.0049 0.0019 0.0041
        0.2815 0.3240 0.1358]
Max Error for each state:
    1.0e-09 *[0.0132 0.0133 0.0099 0.0156 0.0049 0.0089 0.0193 0.0053 0.0136
        0.8145 0.9377 0.4579]
```


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