Introduction to the Control System of

Rocket Propelled Spacecraft

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Contents

Basic Introduction of the System

Structure
•Lightweight body
•Payload (cargo, satellites, astronauts)
•Nose cone (reduces drag)
Propulsion
•Engines generate thrust
•Propellant types: Solid, Liquid, Hybrid
Key Concepts
•**Thrust**: Force from expelling gases (Newton's Third Law)
•**Stages**: Multiple stages for efficient propulsion
Guidance and Control
•Navigation: Position and velocity tracking
•Control: Trajectory adjustments using gimbaled engines and thrusters
Launch and Flight
•Liftoff: Overcoming gravity and drag
•Stage separation: Jettisoning used stages
•Orbital insertion: Achieving desired orbit

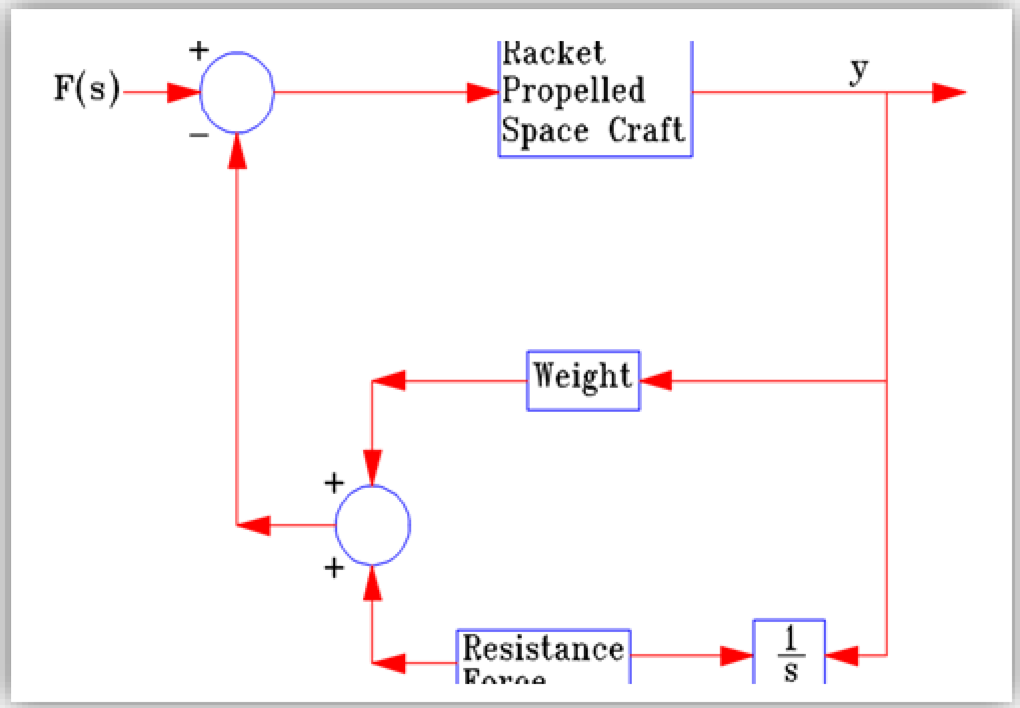
Basic Introduction of the System

Forces in the System:

- F(t) or thrust force which is time dependent
- Force of gravity or $mg\left(\frac{R}{R+y}\right)^2$
- Inhibitory aerodynamic forces $k\left(\frac{dy}{dt}\right)^2 \exp\left(-\frac{y}{r}\right)$

Basic Introduction of the System

Schematic of the system



Determination of State Matrices of the System

determining the equations and input-output relations

$$mg\left(\frac{R}{R+y}\right)+K(\dot{y})^2\exp\left(\frac{-y}{r}\right)$$

$$m\ddot{y}=f(t)-mg\left(\frac{R}{R+y}\right)+K(\dot{y})^2\exp\left(\frac{-y}{r}\right)$$

$y \rightarrow$ خروجی سیستم

$f(t) \rightarrow$ ورودی سیستم

$$y=x_1$$

$$\dot{y}=\dot{x}_1=x_2$$

$$\ddot{x}=\dot{x}_2$$

$$m\dot{x}_2=f(t)-mg\left(\frac{R}{R+x_1}\right)+K(x_2)^2\exp\left(\frac{-x_1}{r}\right)$$

maximum recorded speed is 252792 km/h

maximum recorded y is 3.000.000 Km

Determination of State Matrices of the System

Linearization Point which is for Position and

$$x^* = [10000\,Km \quad 10000\,Km/h]$$

$$J(1000010000) = \begin{pmatrix} 0 & 1 \\ mg\left(\frac{R}{R+x_1}\right) + K(x_2)^2 \exp\left(\frac{-x_1}{r}\right) & -2K(x_2)^2 \exp\left(\frac{-x_1}{r}\right) \end{pmatrix} = A$$

$$B = \begin{bmatrix} 1 \\ 0 \end{bmatrix}$$

$$C = [1 \quad 0]$$

$$\dot{x} = Ax + Bu$$

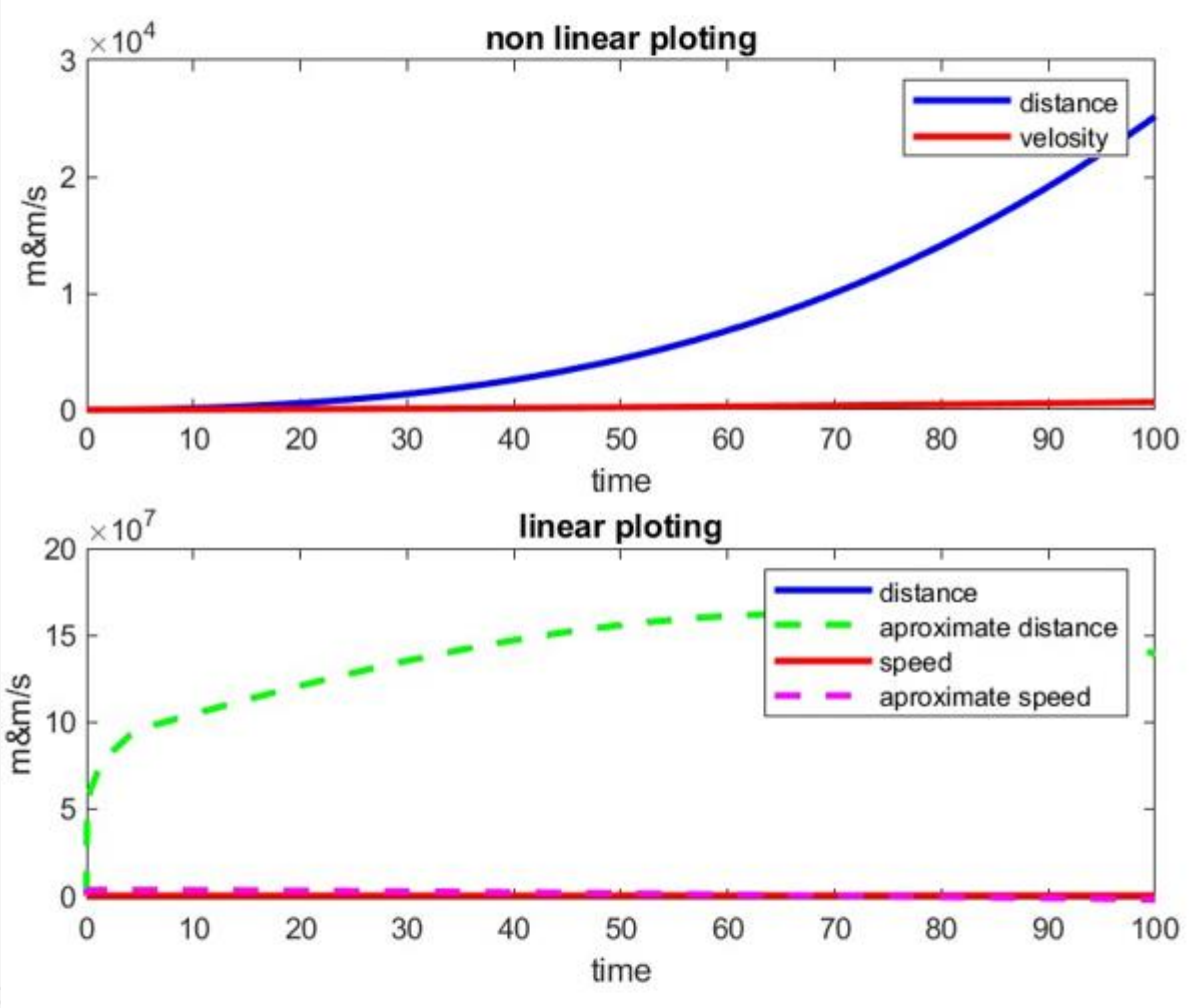
$$y = Cx$$

Giving input to the system

We gave an step input to the system with a value of 1000

Note that our system instinctively has a significance amount of errors, in order to run a simulation, we neglect most of them

Here is the response of the system



Controllability and Observability of the System

1. The whole concept of Controllability and Observability
2. How do we asses the mentioned features in a system?

Controllability and Observability of the System

In order to asses the mentioned features we obtain the

Controllability matrice and Observability matrice via MATLAB

$$C = \begin{bmatrix} 1 & 0 \\ 0 & 9.8 \end{bmatrix}$$

$$O = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

System is controllable and observable

Realization and Stability

- The poles are 3.1305 and -3.1305 so according to the stability law of Lyapunov one of the modes is stable and the positive one is unstable

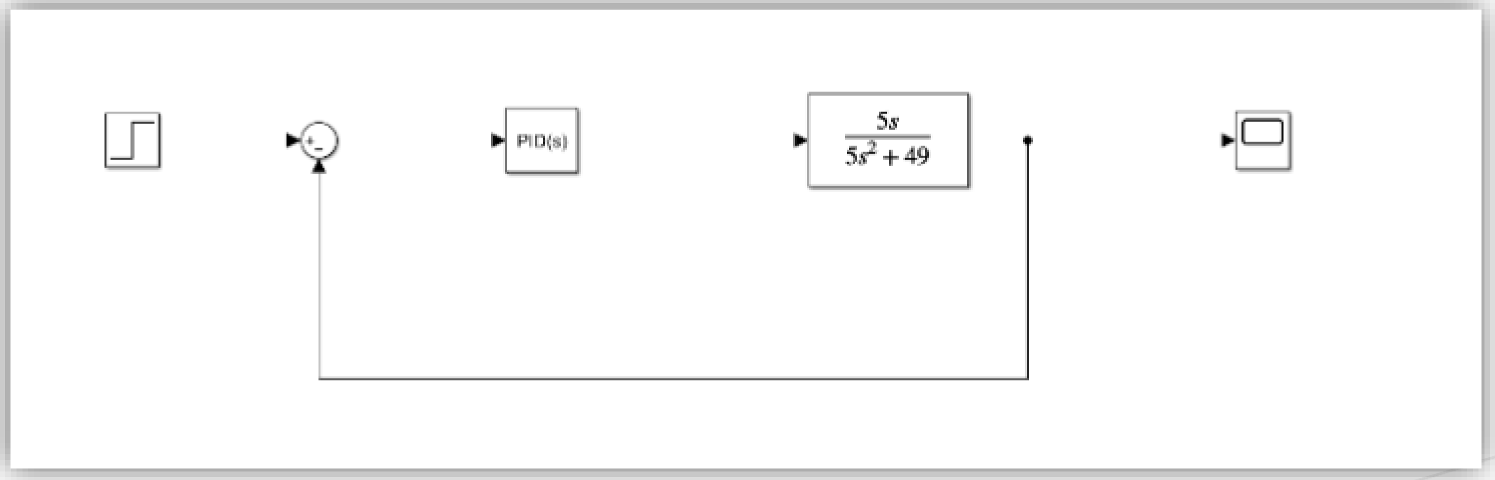
- According to the poles, here is the Jordan Realization of the system

$$\dot{x} = \begin{bmatrix} -3.1305 & 0 \\ 0 & 3.1305 \end{bmatrix} x + \begin{bmatrix} 1 \\ 0 \end{bmatrix} u \qquad y = \begin{bmatrix} 1 & 0 \end{bmatrix} x$$

Designing a controller

In order to design a controller for the system we put a PID controller in the system

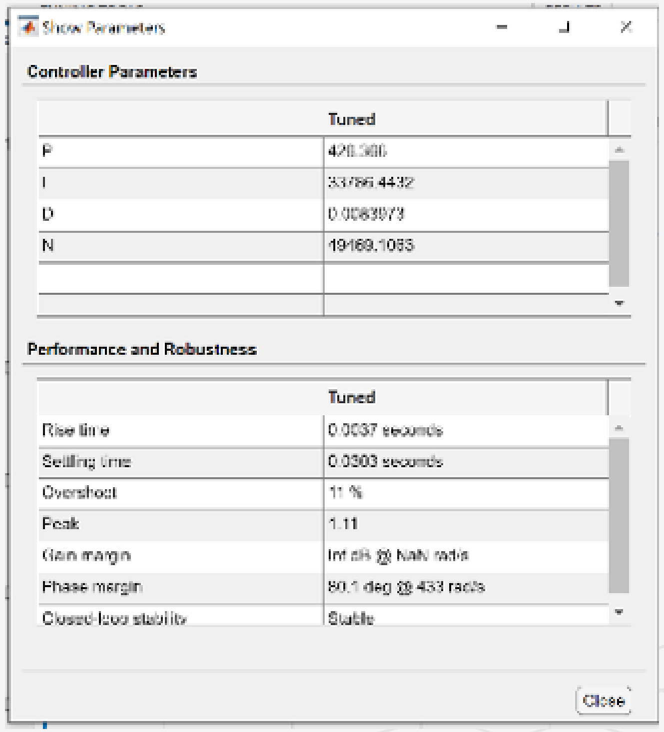
Here is the schematic in the Simulink



Designing a controller

We open PID tuner in order to tune the controller and reach to 0.707 zeta

As you can see the numbers are so big and the implication is near impossible, for example this is for the overshoot of 11%



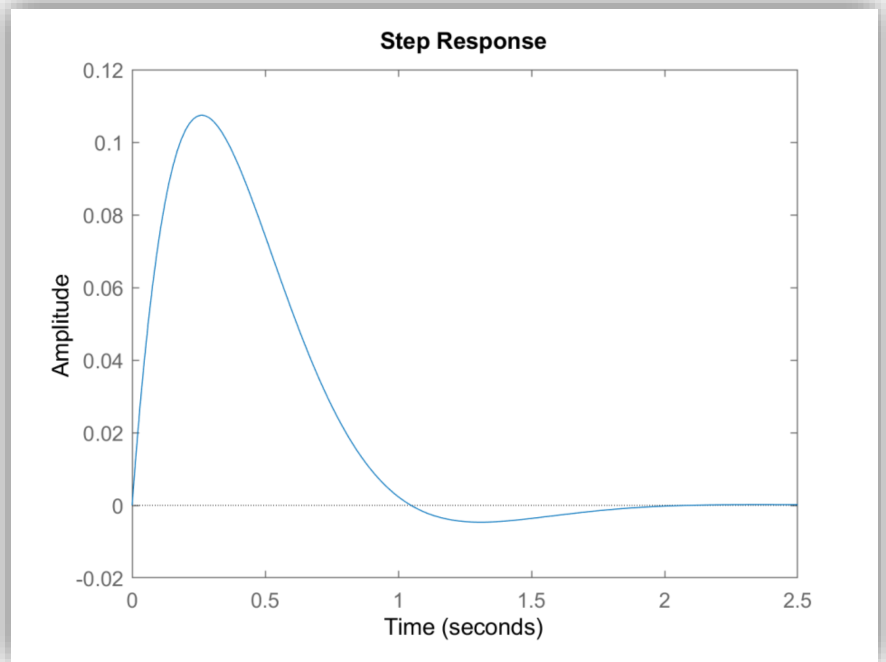
Designing a controller

The previous results confirm the necessity of using modern control techniques

In order to do this we design a step feedback for the poles to be in -3+-3j

In the MATLAB Code the obtained feedback gain is 62.6387

The result are shown in this graph, the system is stable using state feedback

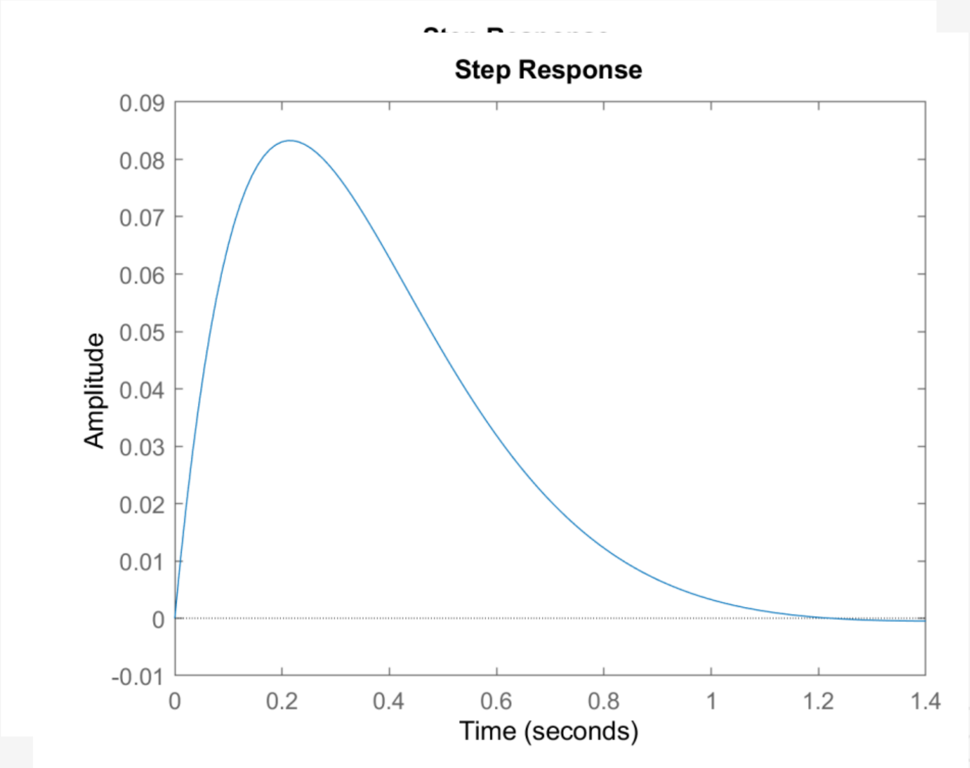


Designing a controller

In order to design a LQR controller set the diagonal elements of the Q to be 2 and 5 and use the lqr() command in MATLAB to obtain the state feedback gain

State feedback gains are 3.4495 and 8.3433

Here are the results:



State Observer

We know that the dynamic modes of the system are the displacement and the velocity of the spacecraft

In order to design an observer we need Velocity and displacement sensors

we use A_T and C_T to set the poles to be in 15+-15j

The obtained gains are -30 and 459

Refrences

- [1]Gina Hagler, Modeling Ships and Space Craft: The Science and Art of Mastering the Oceans and Sky, Springer, 2013

Thanks for your attention

All of the codes are provided in github