Cruise Control System of Toyota Camry

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Why we selected Cruise Control ???

- ➡ Cruise control is a very important aspect of autonomous driving. Maintaining constant vehicle speed improves fuel efficiency, reduces driver fatigue, and ensures a safer driving process.

- ➡ Some of the techniques that people have used before to solve this problem include using the Proportional Integral Derivative (PID) controller, Model Predictive Control (MPC) for constraint handling, and optimal control methods like LQR for performance balancing

- ➡ We aim to design an automatic cruise control system for a car (Toyota Camry XLE) to maintain a desired constant velocity despite resistive forces like aerodynamic drag and rolling resistance.

- ➡ The project focuses on modeling vehicle dynamics, implementing controllers such as PID, LQR, and Lead-Lag, and comparing their performances.

Here's some explanation about the code..

```
H = 1.455;
W = 1.839;
Shape_Factor = 0.85;
A = H*W*Shape_Factor;

v_vehicle_ref = 27.78;
v_wind = -4.0;
v = v_vehicle_ref + v_wind;

c_d = 0.29;
rho = 1.2;
F_d = (c_d*rho*A*v^2)/2;

c_r = 0.0125;
m = 1655;
g = 9.81;
F_r = c_r*m*g;

F_total = F_d + F_r;

b = F_total/v_vehicle_ref;
```

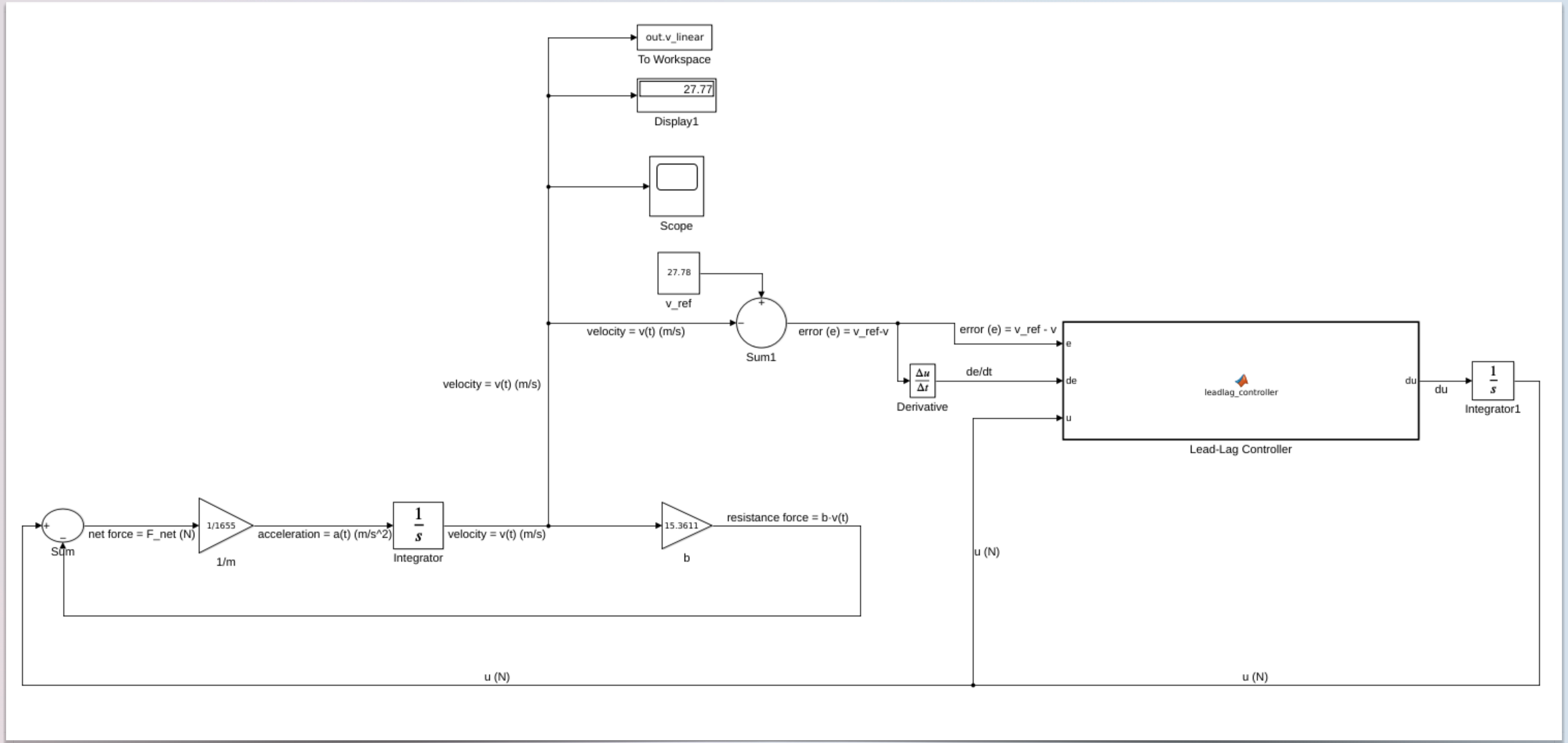
```
% Car Parameters

% Vehicle's Reference Velocity
% Total Velocity

% The Aerodynamic Drag Force,
% The Rolling Resistance Force
% The Total Resistive Force

% Damping Co-eff
```

Plant Model Explanation (our linear system basically..)



We also tried non-linear model :]

Lead-Lag Controller

$$G_{lead-lag}(s) = K \times \frac{s+z}{s+p}$$

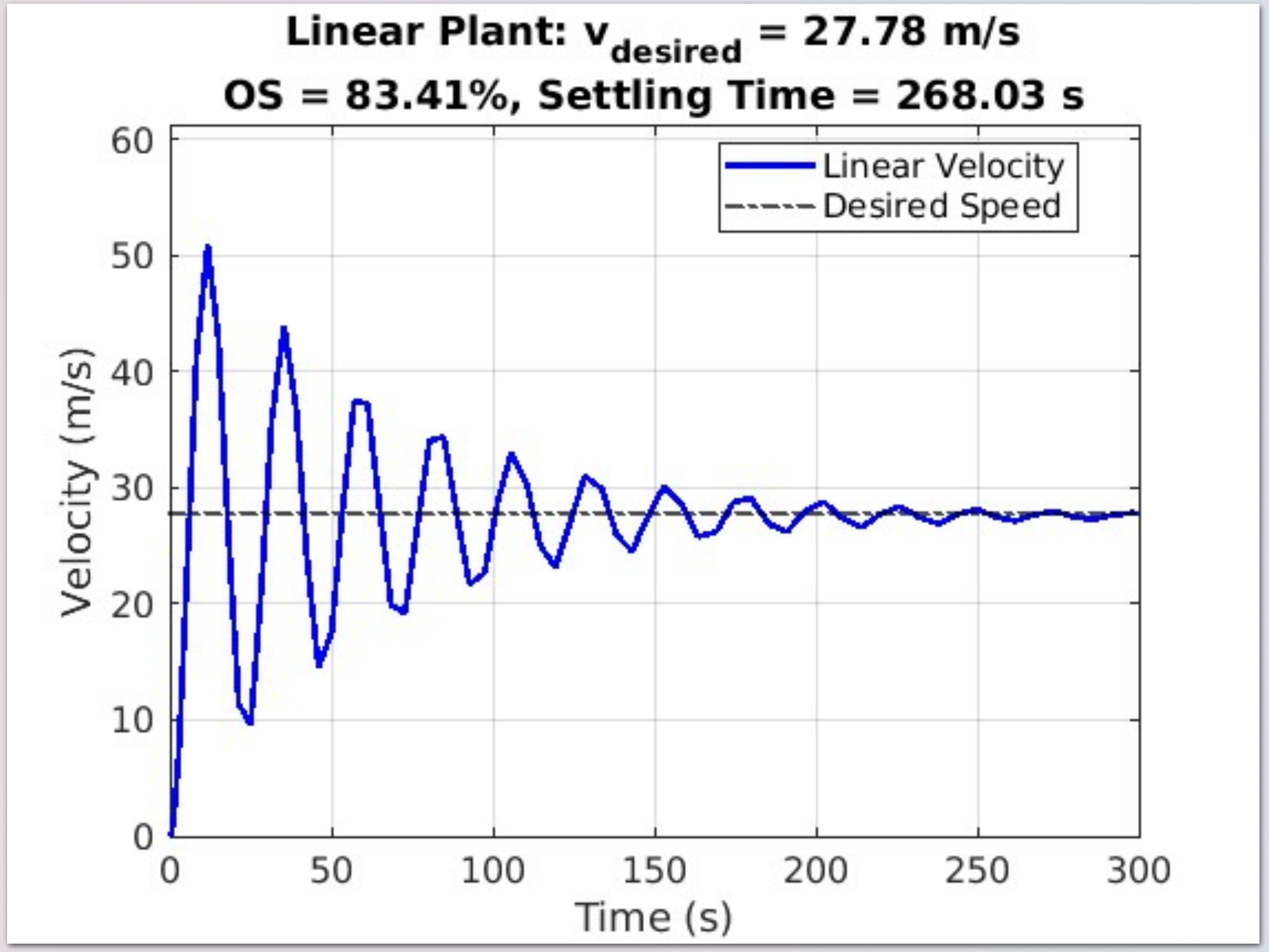
where:

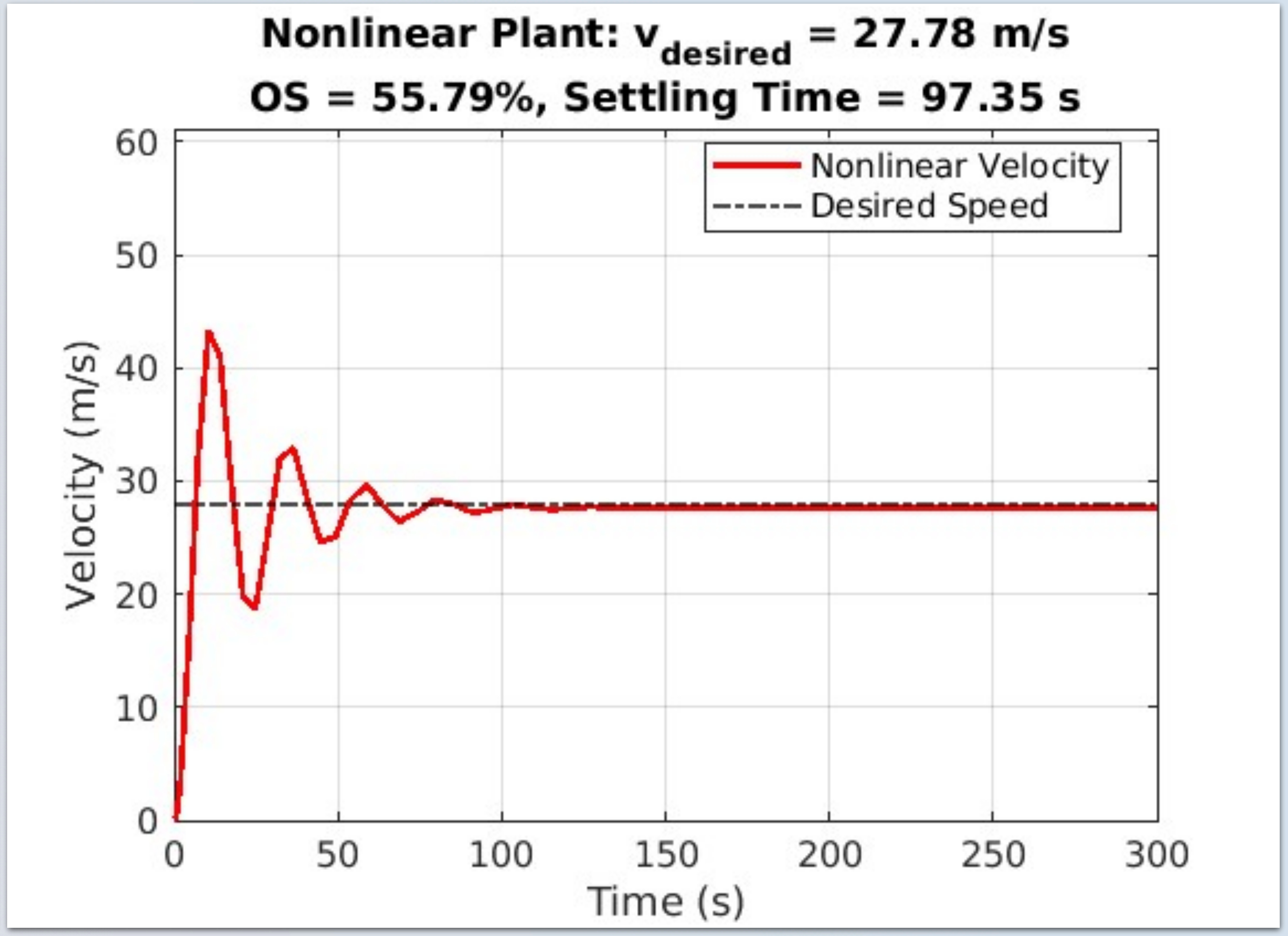
- K = controller gain
- z = zero of the controller (adds phase lead)
- p = pole of the controller (adds phase lag)
- s = Laplace variable

➡ The lead component of the controller helps to reach near the desired velocity very quickly. But due to it's aggressive behavior, it might often overshoot or undershoot the target.

➡ The lag component of the controller helps to counter this problem by slowing down the approach towards the desired velocity, often resulting in less overshoot.

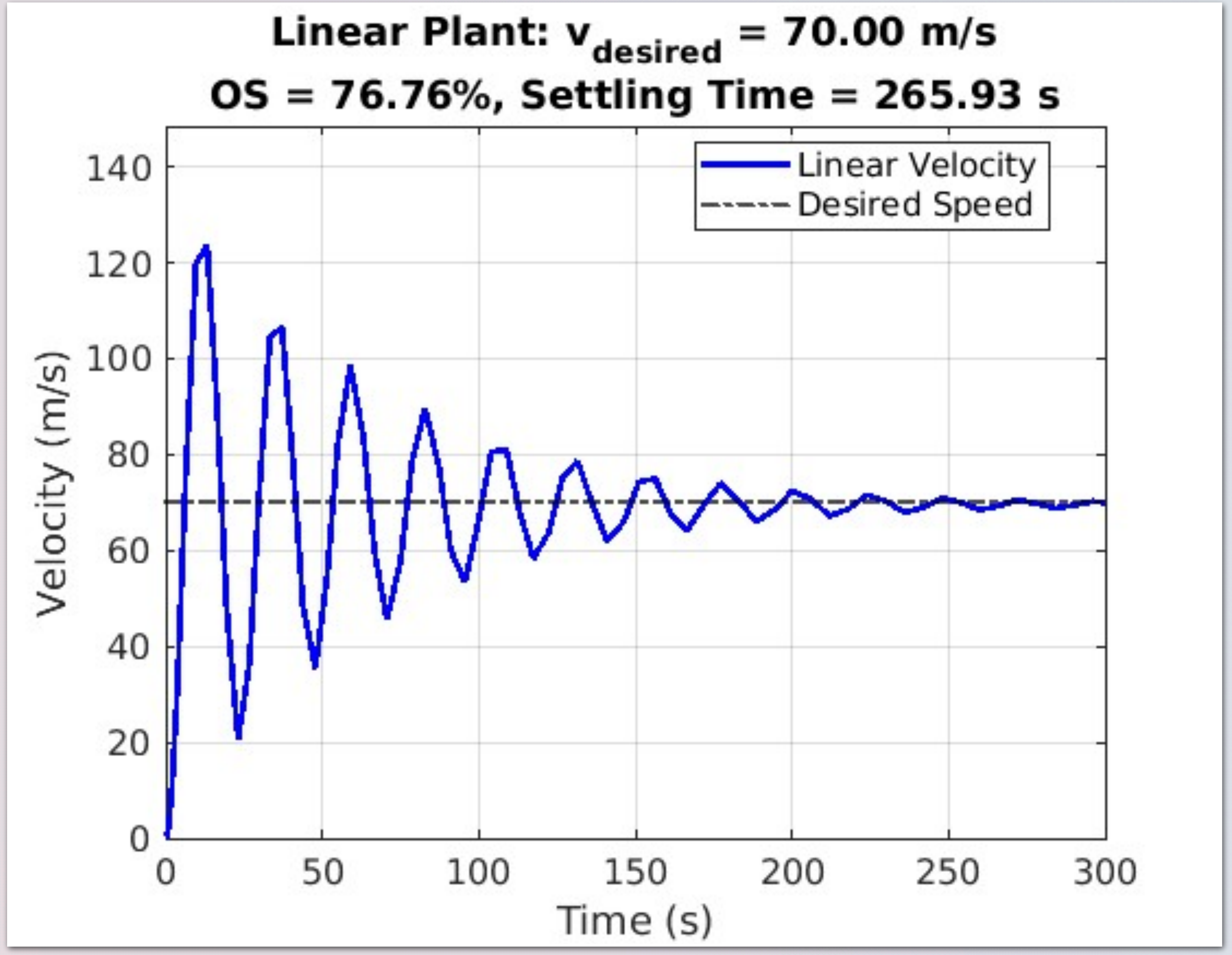
Lead-Lag Controller Output (27.78m/s - Linear vs Non-Linear)

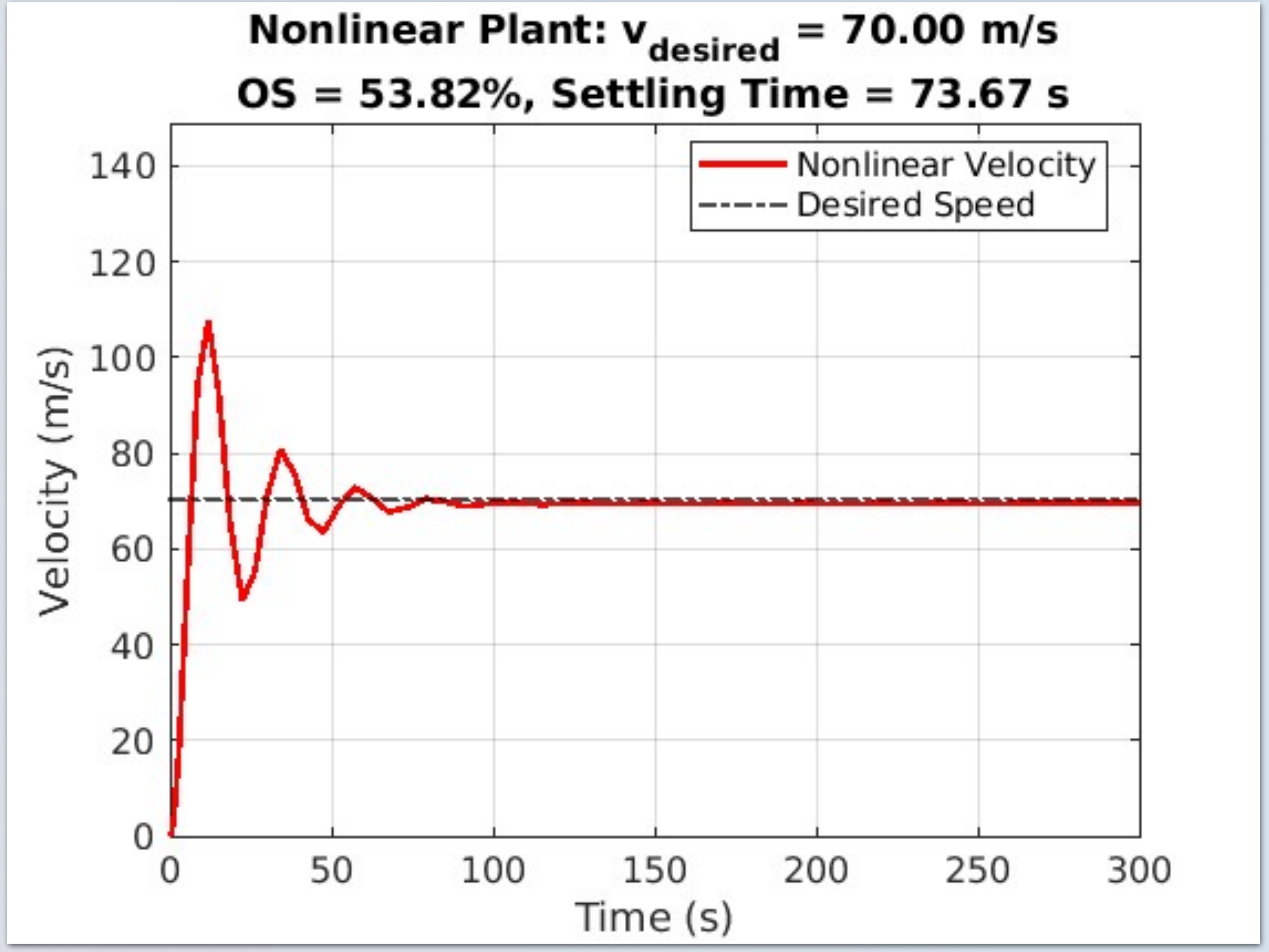




➡ When Desired Cruising Velocity is 27.78 m/s, the linear system converged at a value of 27.77 m/s whereas the non-linear system converged at a value of 27.63 m/s.

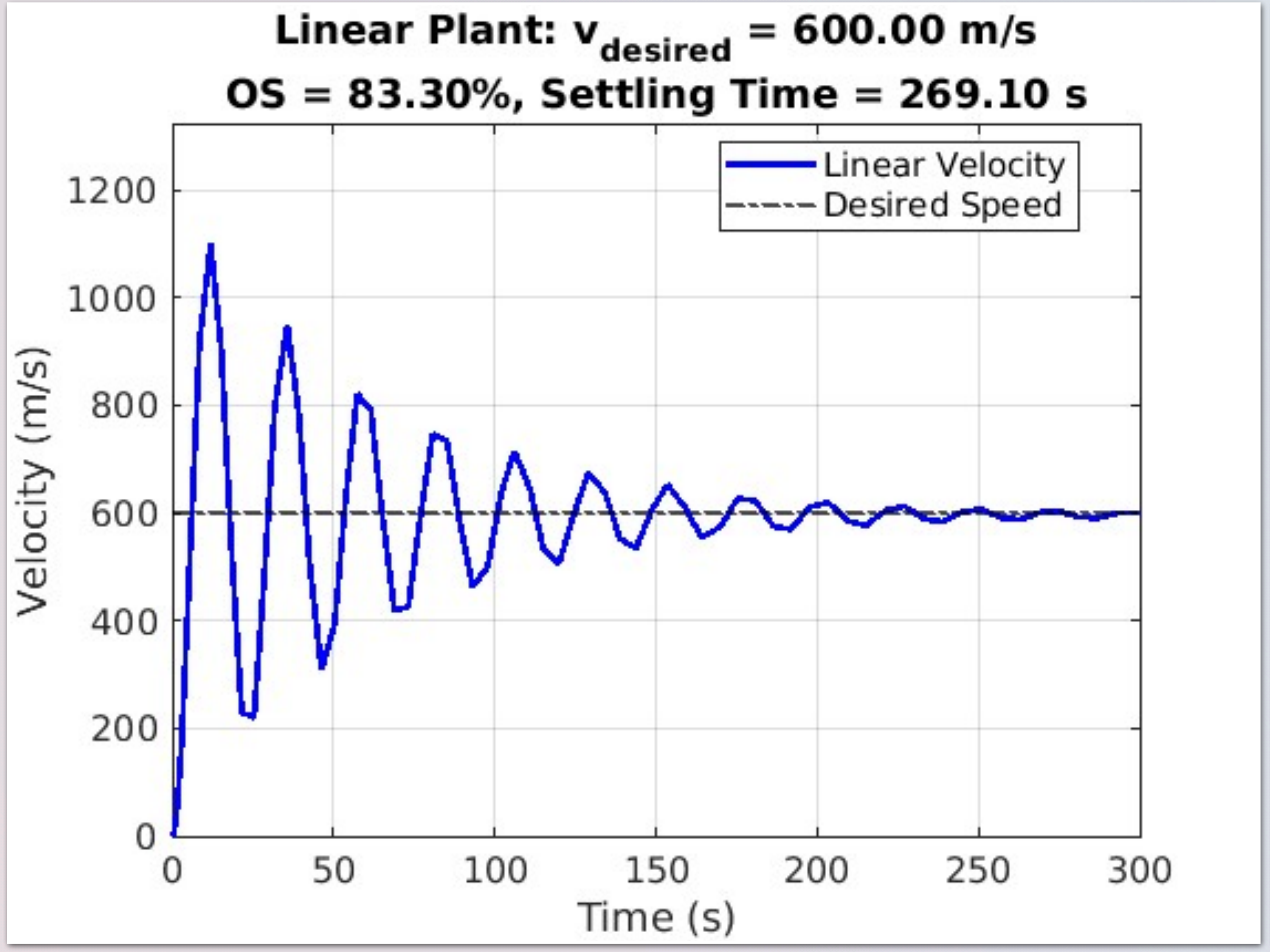
Lead-Lag Controller Output (70.00m/s - Linear vs Non-Linear)

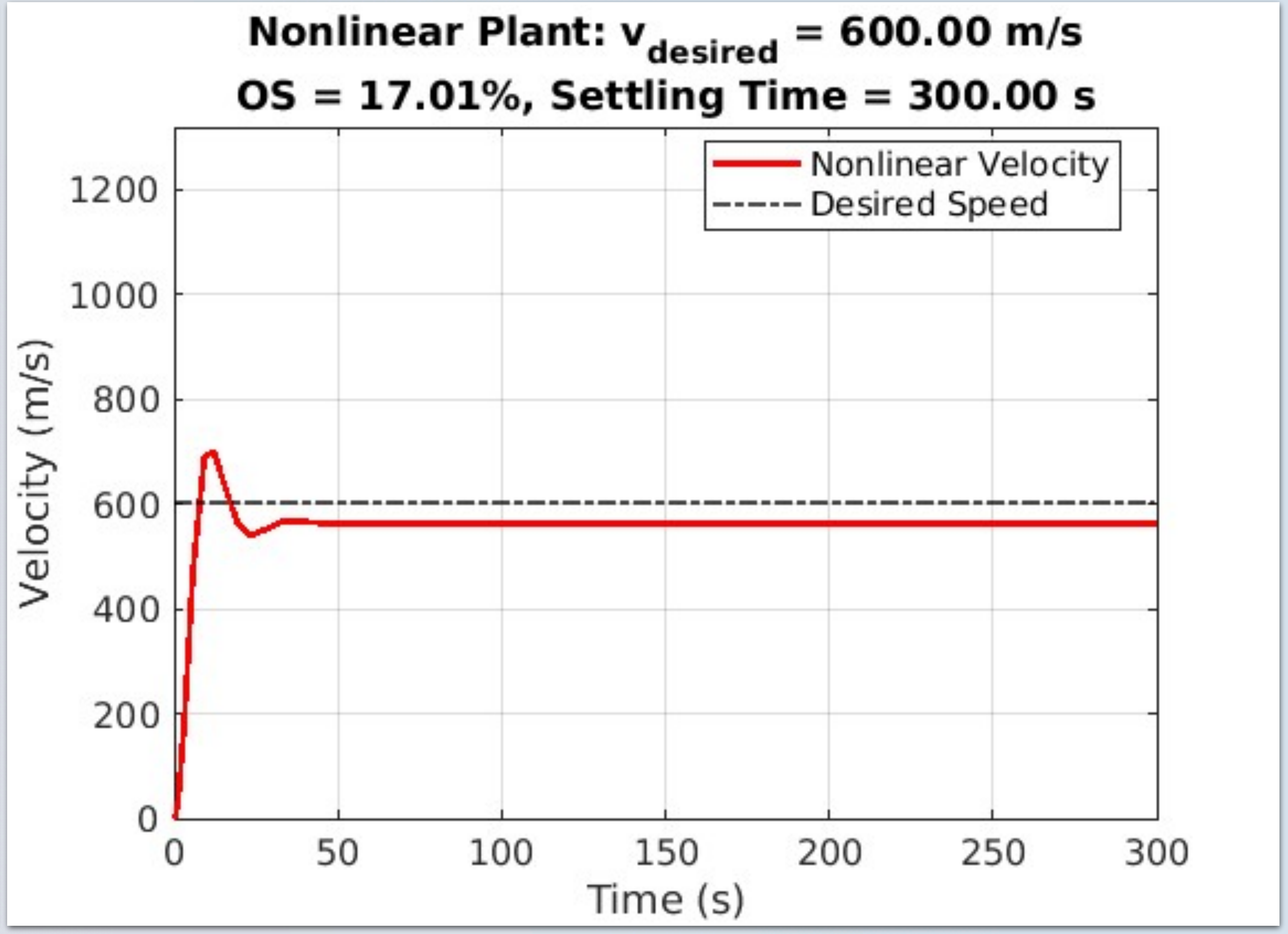




- ➡ When Desired Cruising Velocity is 70.00 m/s, the linear system converged at a value of 69.97 m/s whereas the non-linear system converged at a value of 69.42 m/s.

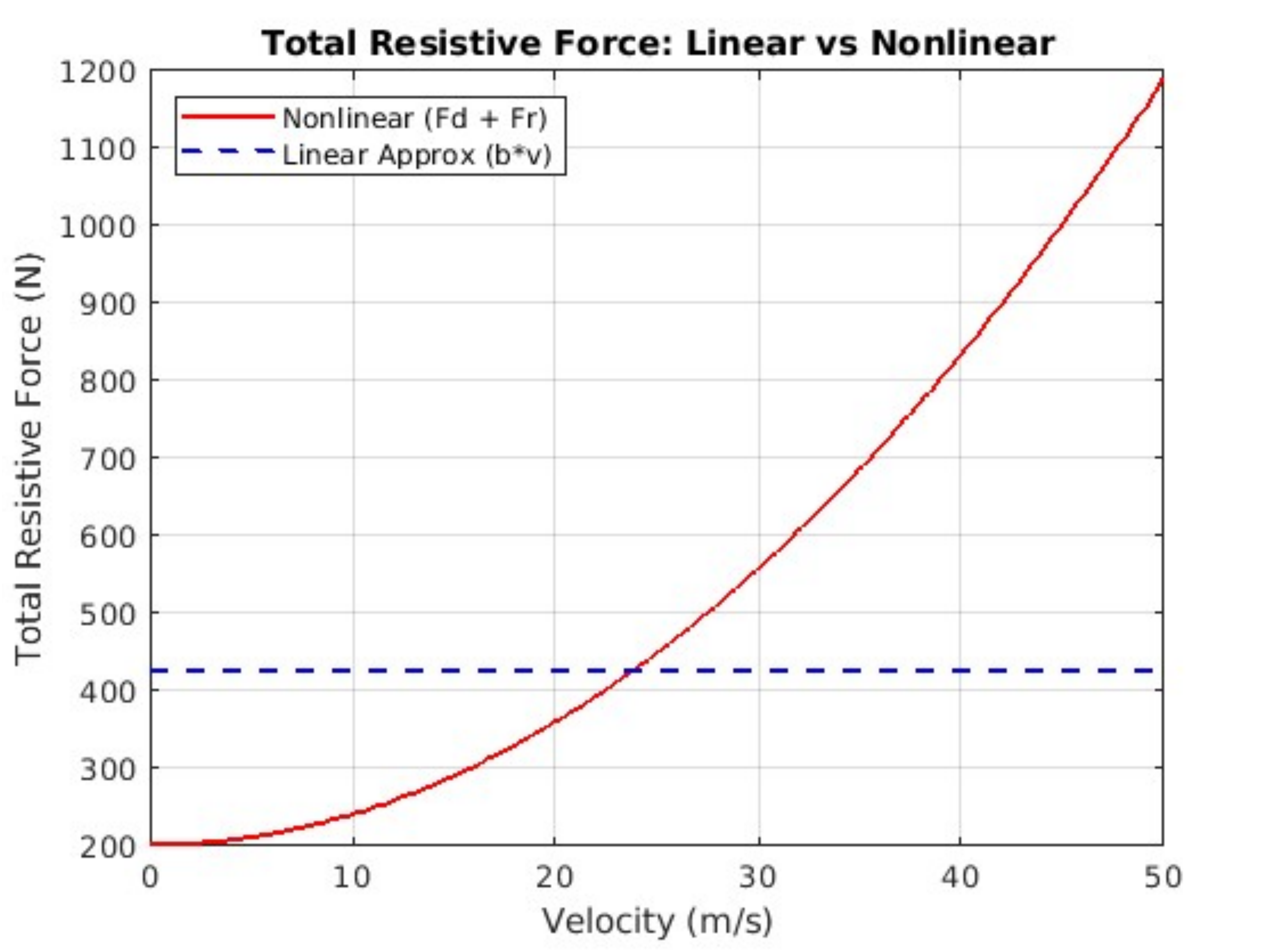
Lead-Lag Controller Output (600m/s - Linear vs Non-Linear)





➡ When Desired Cruising Velocity is 600.0 m/s, the linear system converged at a value of 599.8 m/s whereas the non-linear system converged at a value of 563.8 m/s.

Lead-Lag Controller Output (Total Resistive Force - Linear vs Non-Linear)



The OG - PID Controller

$$u(t) = K_p e(t) + K_i \int_0^t e(\tau) d\tau + K_d \frac{d}{dt} e(t)$$

➡ Kp is the proportional gain.

Applies a force proportional to the current error e(t). As the error increases, the force grows, helping the vehicle approach the target speed. However, as the error decreases, the force may become too small to eliminate the error fully.

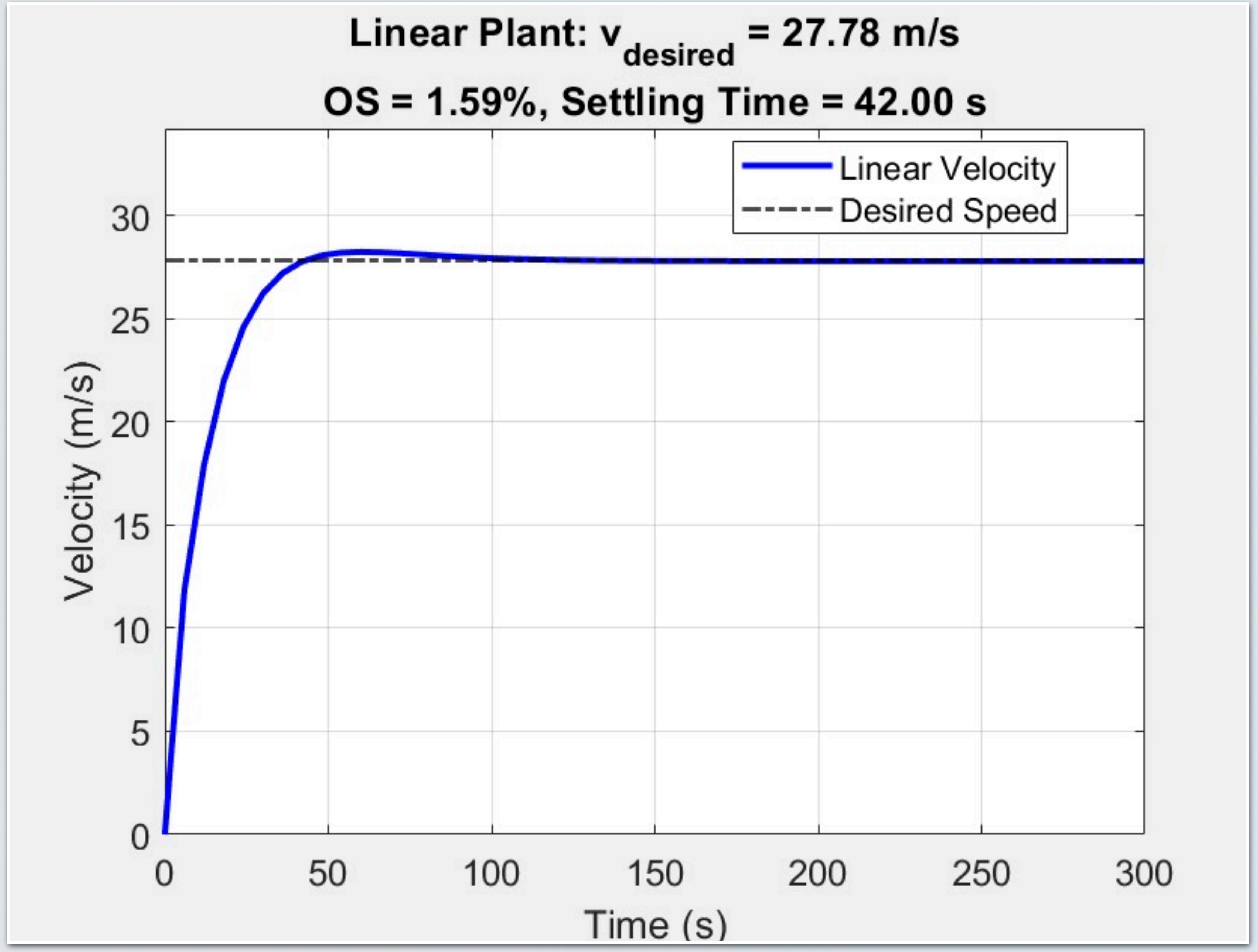
➡ Ki is the integral gain.

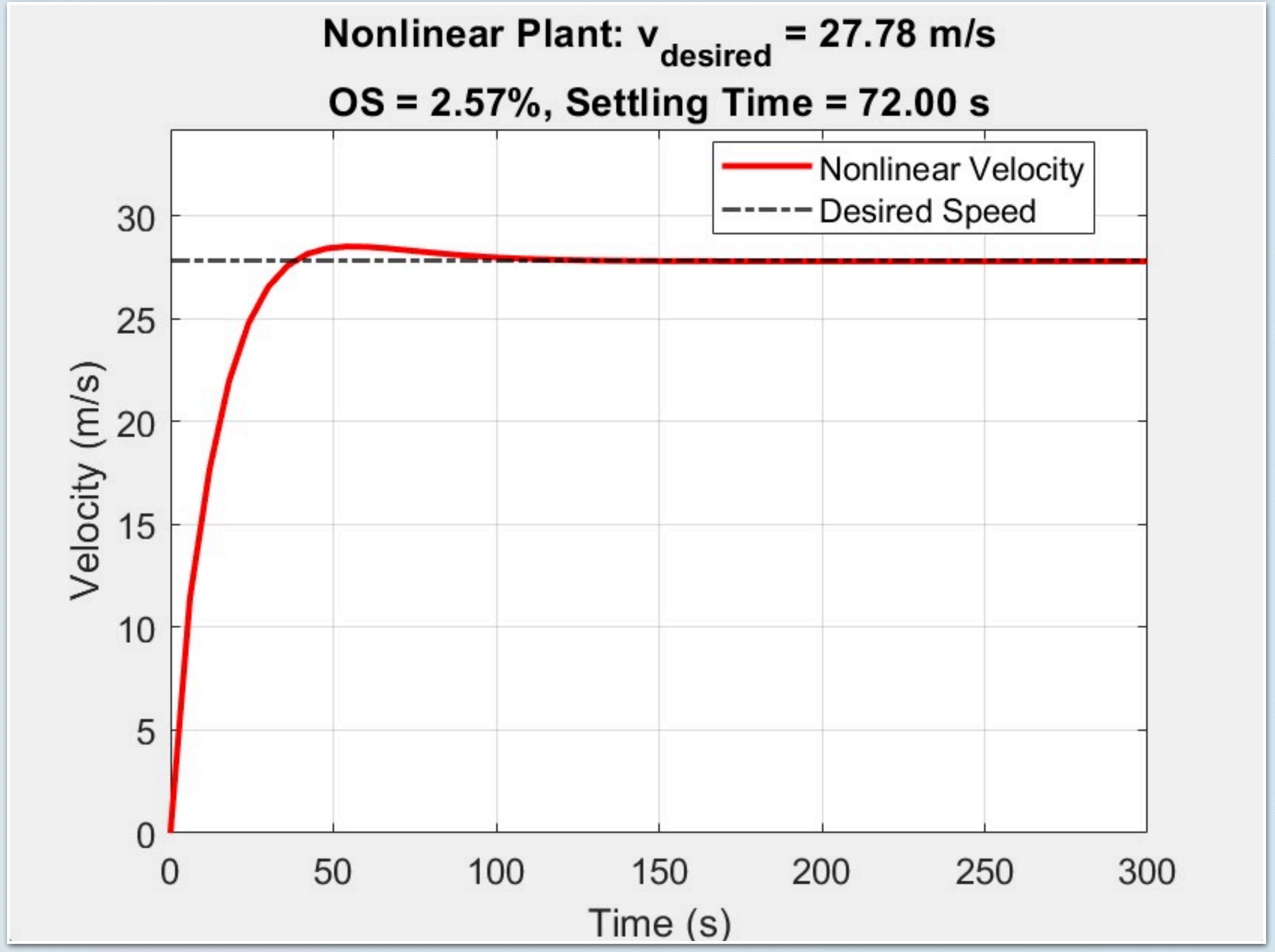
Accumulates past errors over time. When the vehicle is close but not quite at the target speed, the integral term increases the force, driving the system to the desired velocity. However, the accumulated error can cause overshoot and oscillations even after reaching the target.

➡ Kd is the derivative gain.

Responds to the rate of change of the error. As the vehicle crosses the desired speed, both the error and its rate of change become negative, generating a force that opposes motion. This helps dampen oscillations and stabilize the vehicle around the target speed.

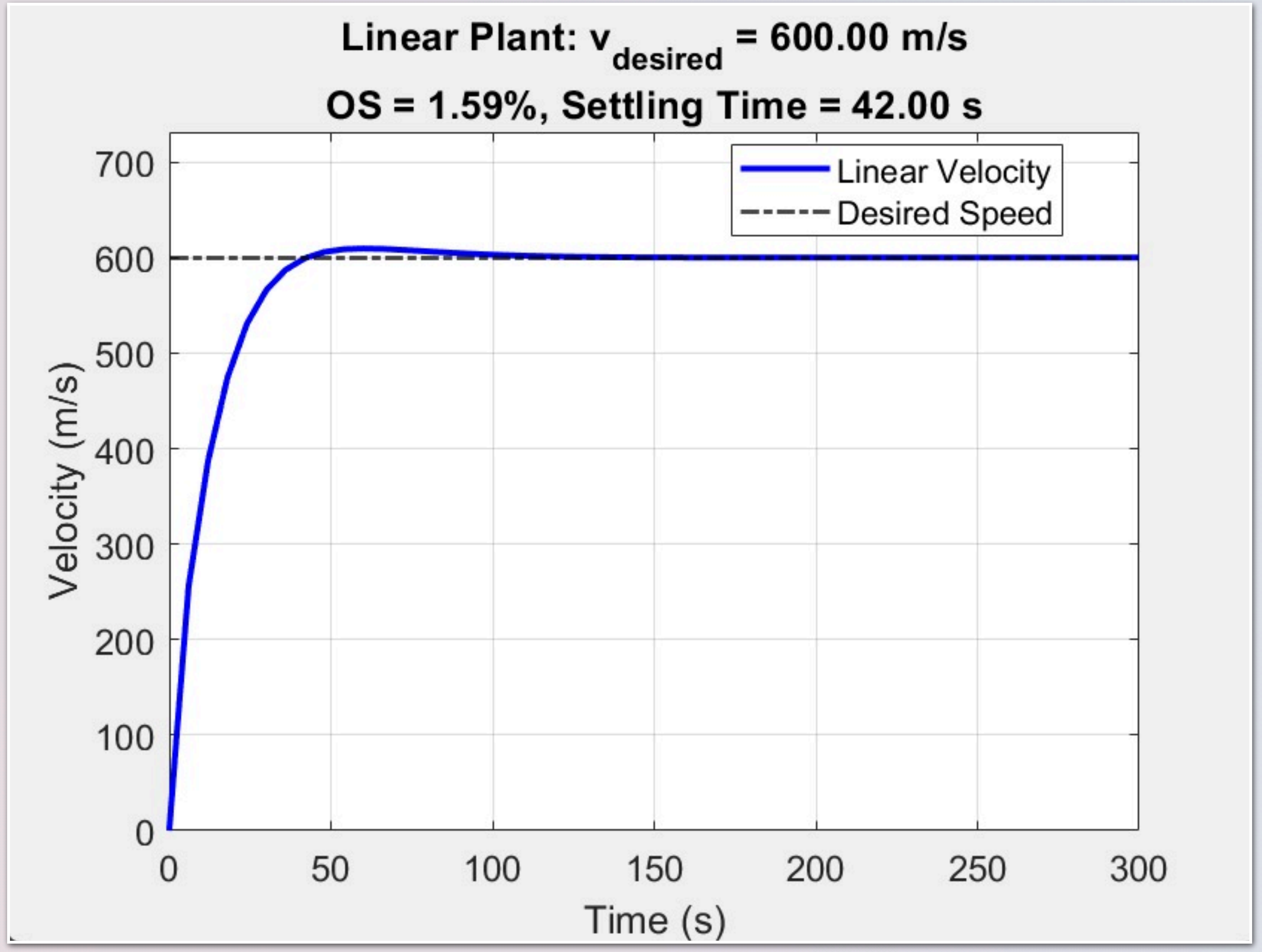
PID Controller Output (27.78m/s - Linear vs Non-Linear)

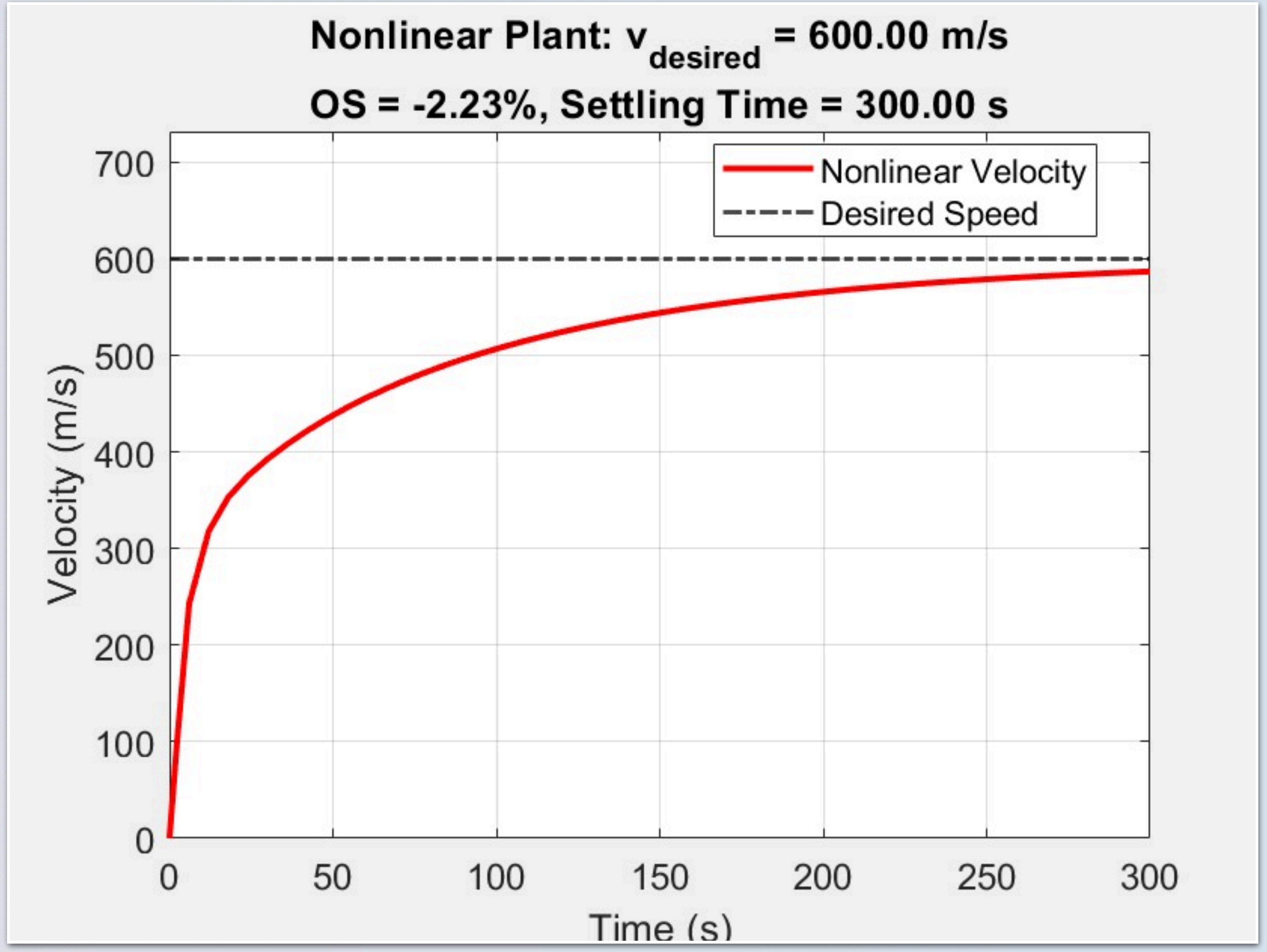




➡ At a desired speed of 27.78 m/s, both the linear and nonlinear plants successfully converged to 27.78 m/s.

PID Controller Output (600m/s - Linear vs Non-Linear)





➡ At a desired speed of 600 m/s, the linear plant achieved 599.9 m/s, while the nonlinear plant settled at 586.59 m/s.

LQR Controller

We are minimizing the **infinite-horizon quadratic cost**:

$$J = \int_0^\infty \left(Q\,x(t)^2 + R\,u(t)^2\right)\,dt$$

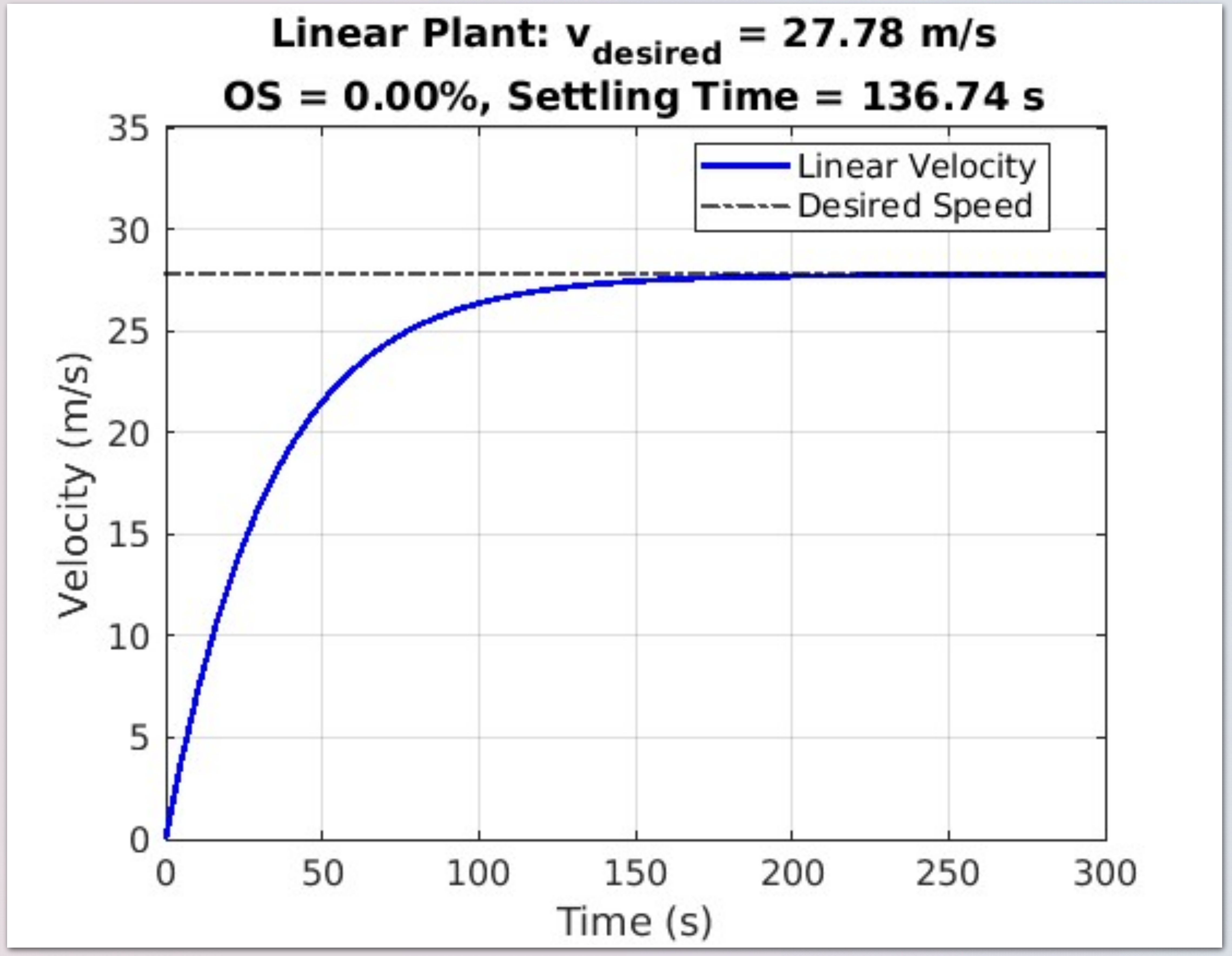
where:

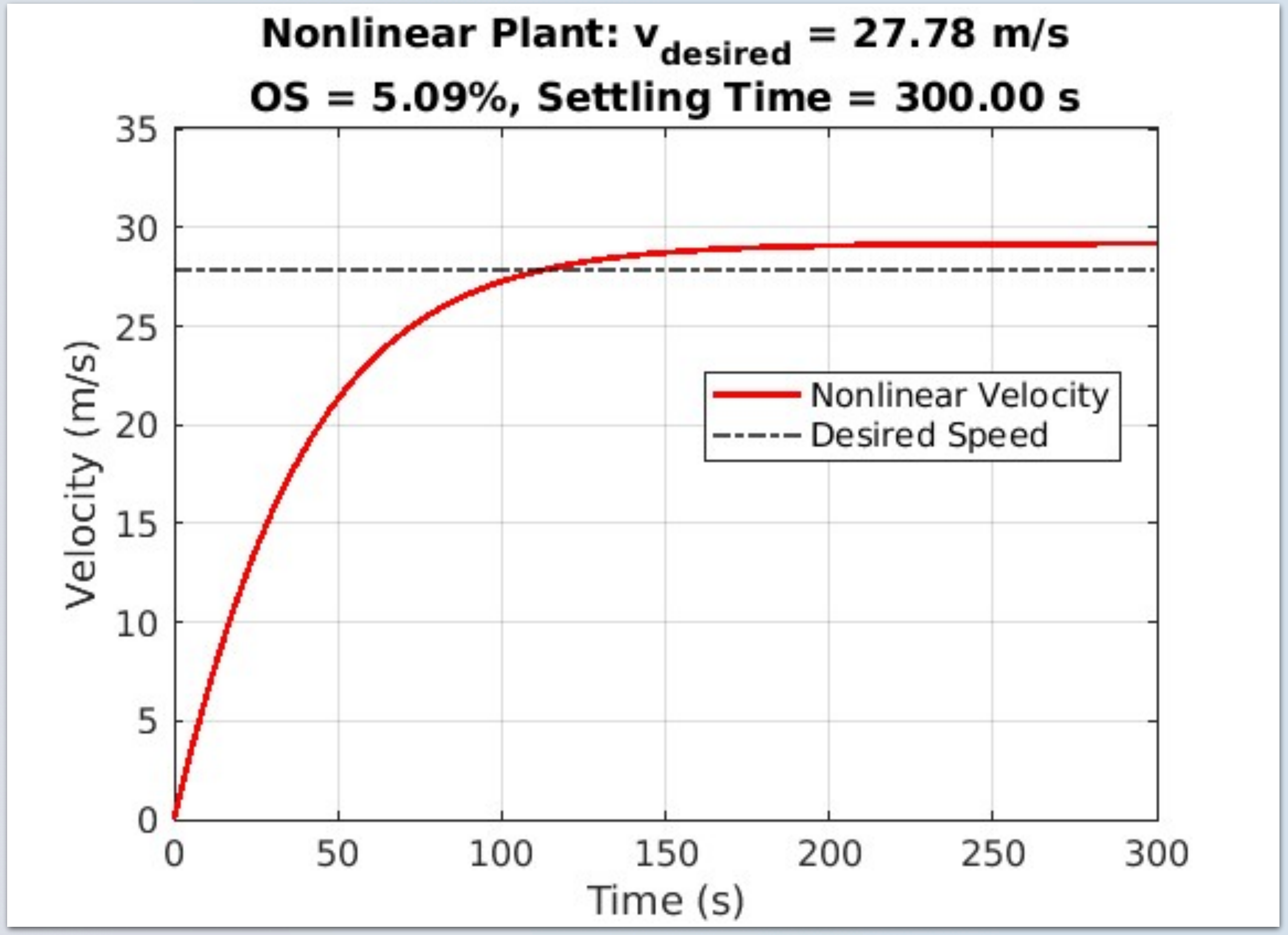
- $x(t)$ = **velocity error** (difference from desired speed)
- $u(t)$ = **control input** (force applied by the car)
- Q = penalty on **state deviation** (how far the car is from desired speed)
- R = penalty on **control effort** (how much force is being used)

➡ Penalize deviation from target speed (x(t)) heavily. Penalize huge forces (u(t)) mildly (when R is small), or more strictly (if R is large).

➡ The LQR controller minimizes a cost combining deviation from desired speed and control force, balancing tracking accuracy against control effort.

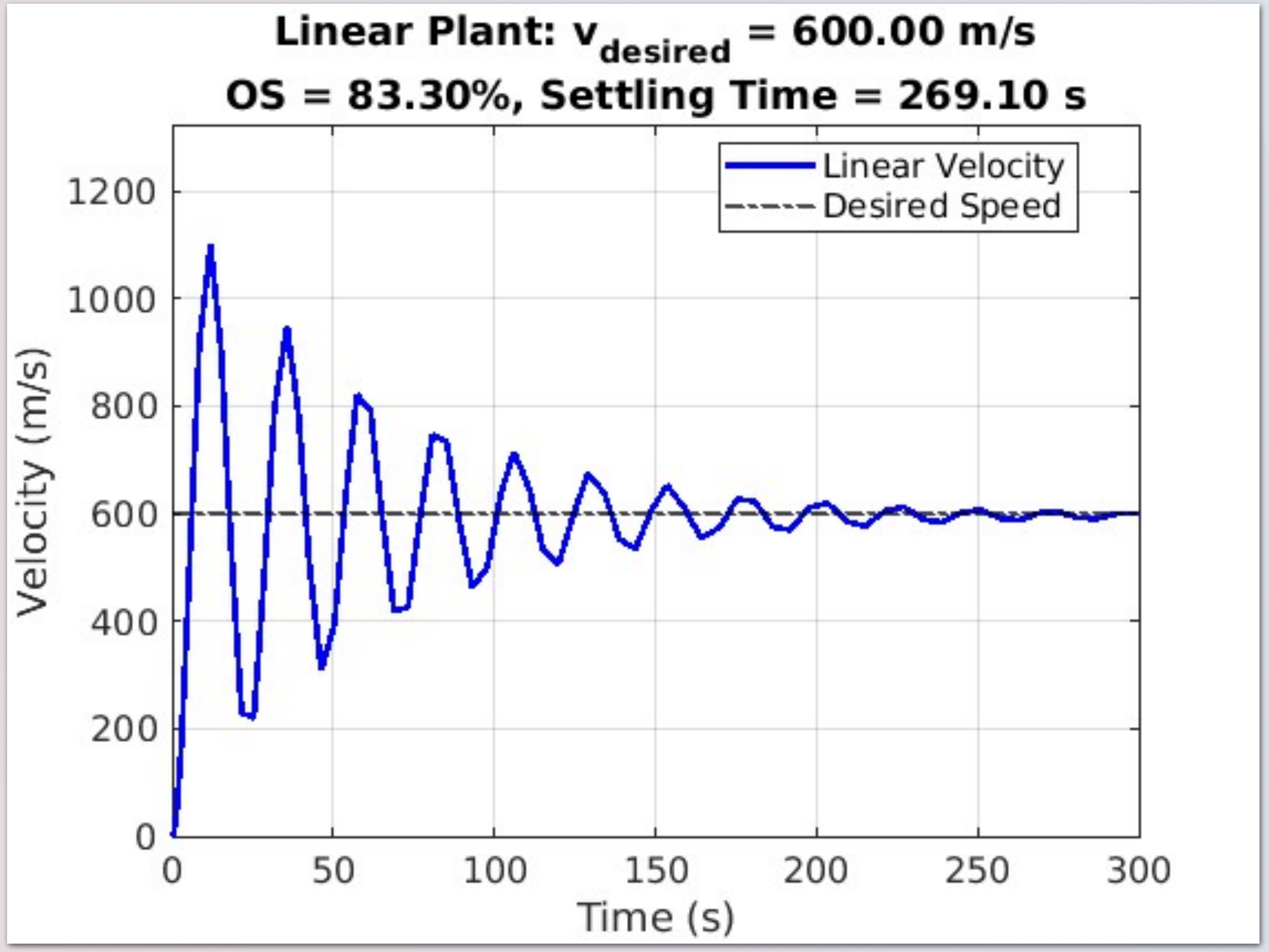
LQR Controller Output (27.78m/s - Linear vs Non-Linear)

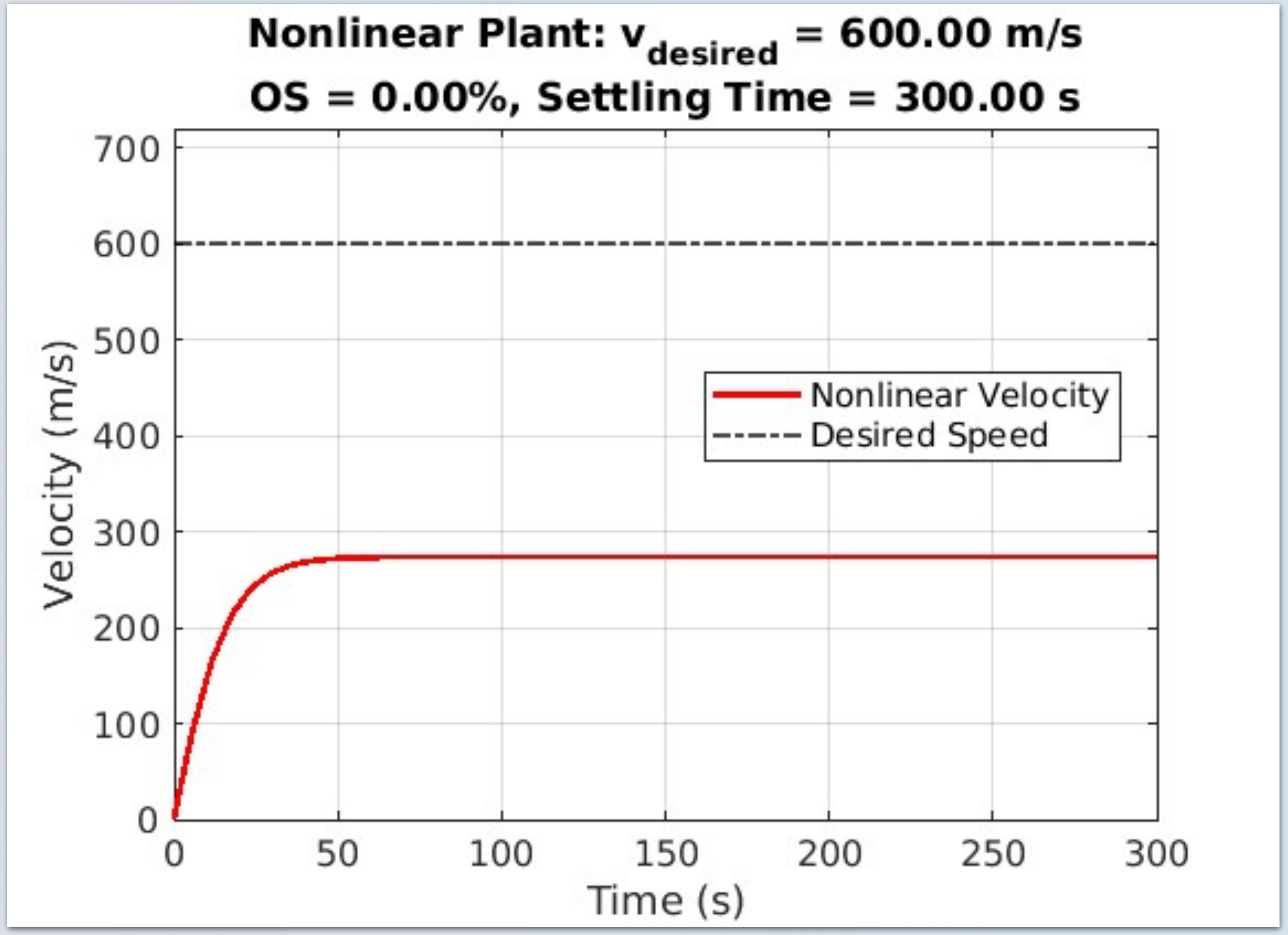




➡ LQR converges at a velocity of 27.78 m/s for the linear case and at 29.2 m/s for nonlinear case when the desired speed is 27.78 m/s.

LQR Controller Output (600m/s - Linear vs Non-Linear)





- ➡ LQR converges at a velocity of 599.9 m/s for the linear case and at 273.7 m/s for nonlinear case when the desired speed is 600 m/s.

The Conclusion ..

- ➡ PID, Lead-Lag, and LQR controllers were designed and implemented to regulate vehicle velocity to desired set-points. PID and Lead-Lag controllers showed robust performance even under plant nonlinearities, while LQR excelled on linear models but showed sensitivity to modeling errors.

- ➡ Nonlinear dynamics caused slower settling and steady-state tracking errors at higher speeds, highlighting the limitations of fixed-gain designs.

- ➡ Future work can include adaptive control strategies or nonlinear model predictive control to better handle system nonlinearities and environmental disturbances.

Thank You for Listening US!