



# VELOCITY/~~AIR~~SPEED HOLD

–and its importance



Prepared  
by

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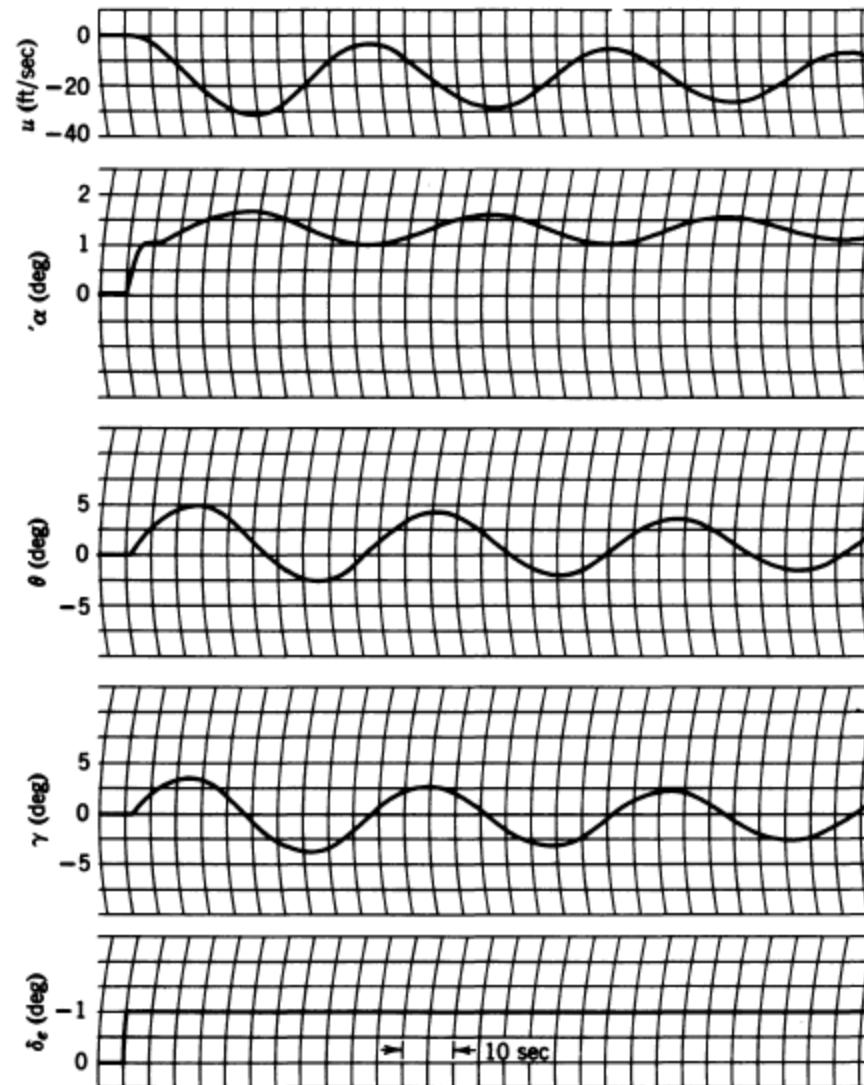
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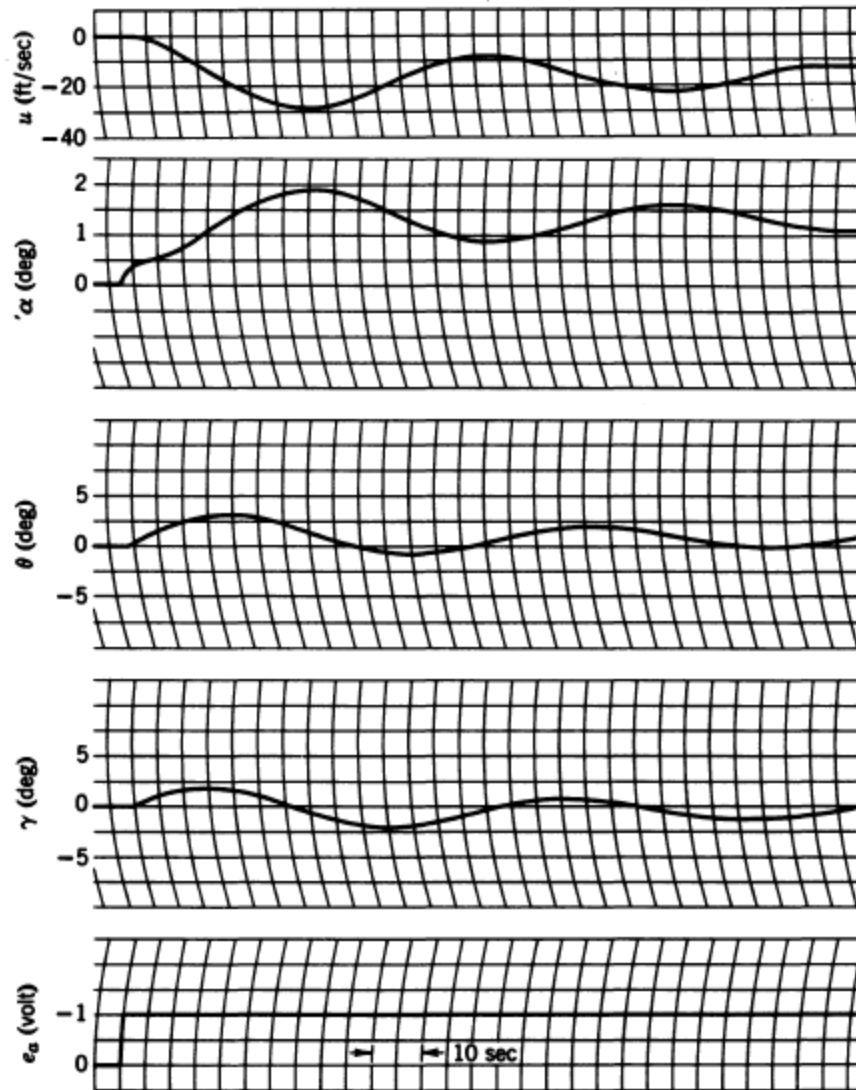
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- The design of a glide slope coupler, an automatic flare control system, and an altitude hold control system have one thing in common, that is, **the control of the flight path angle**.
- The automatic control of the flight path angle without simultaneous control of the airspeed, either manual or automatic, is impossible.
- The graph in the Figure.1 shows the response of pitch attitude for a step elevator input without velocity control during approach or Landing mode configuration.
- The effect of pitch rate feedback effect is shown in figure 2. It is noted that the pitch rate feedback provides little bit damping effect on phugoid mode.
- And also system produces damping in flight path angle.



**Figure 1. Transient response of the jet transport in the landing configuration at sea level at 280 ft / sec for an elevator step input**

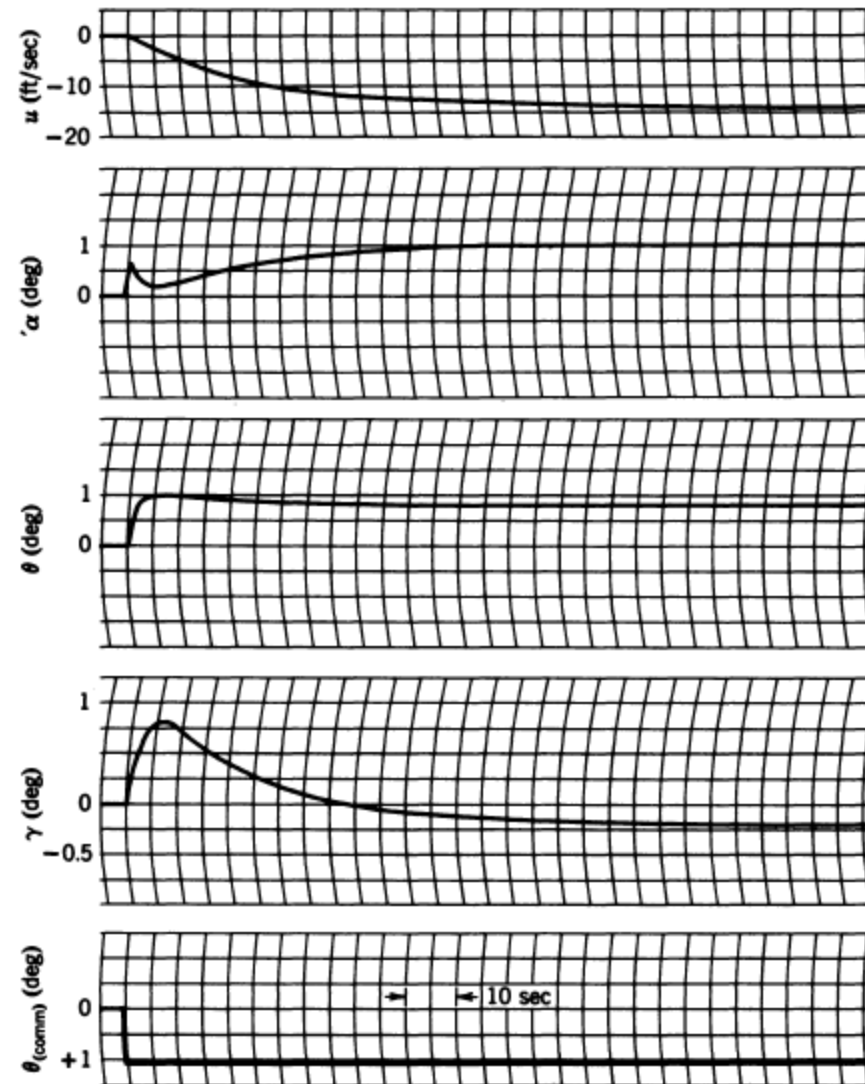


**Figure 2. Transient response of the jet transport with pitch-rate feedback**

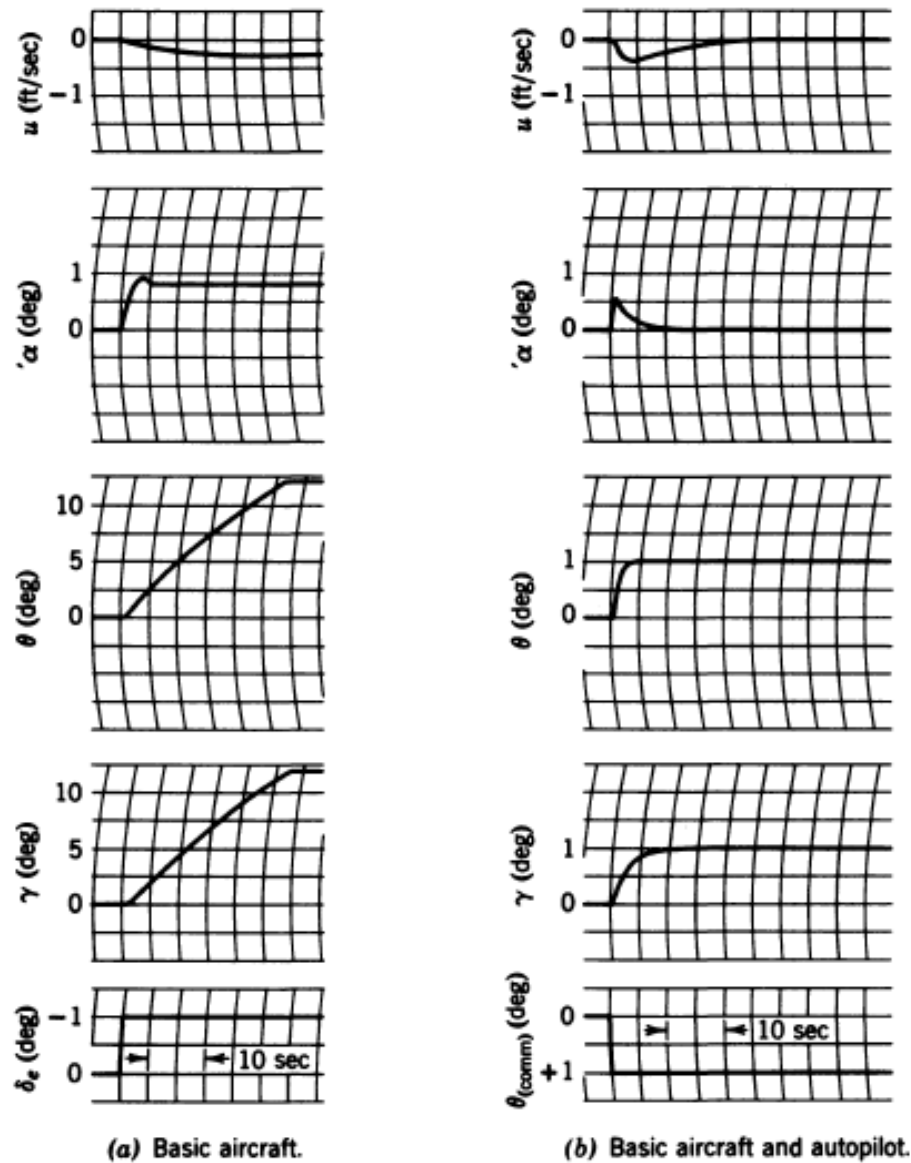
- The positive step elevator command results aircraft to climb at an angle (positive flight path angle). As a result the forward speed of the aircraft start decreasing.
- Once it reach maximum altitude the aircraft start nose down result in increasing the speed of the aircraft this process is repeated. It is generally represented as phugoid oscillation.
- In order to maintain the Lift, the angle of attack gets adjusted by itself results the aircraft start glide instead of following  $\theta_{command}$
- In the steady state the change in angle of attack is greater than the change in ,  $\theta$ , Where

$$\gamma = \theta + \alpha$$

- The flight path angle may vary the steady state error of about  $(-0.2$  to  $+0.2)$  or constant during the flight or step elevator input.
- The above problem all arise because of changes in the velocity of the aircraft.
- If the velocity of aircraft is maintained by separate control system, the changes in the angle of attack gets arrested as a result the flight path angle and pitch angle of aircraft gets easily controlled by the elevator input
- Figure 3. shows the effect of velocity control in pitch attitude control system.



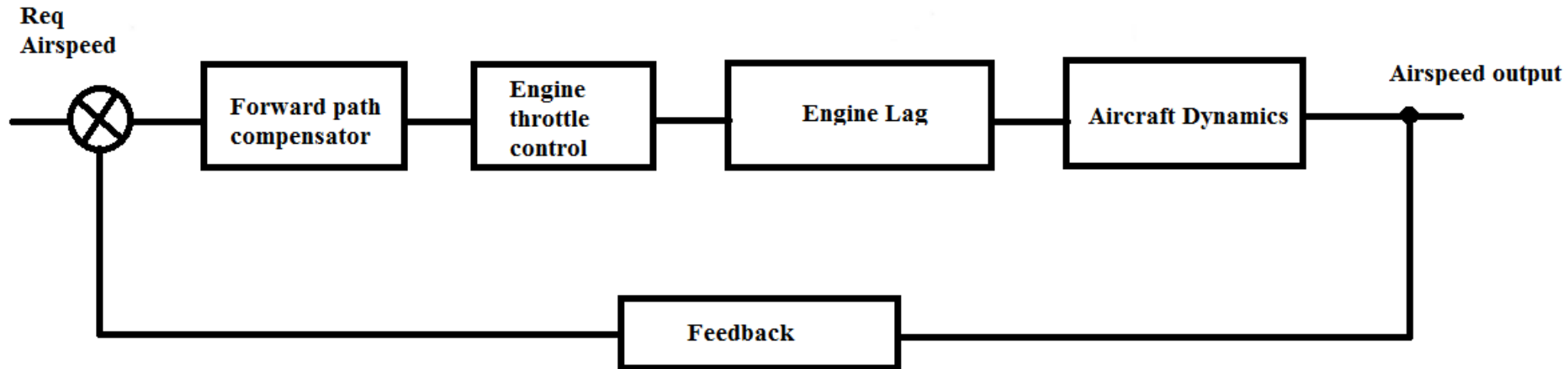
**Figure 3. Transient response of the Jet transport and basic autopilot with velocity control system**



**Figure 4. Transient response of Jet transport, with and without the basic autopilot, showing the effects of velocity control.**



# Velocity/Airspeed hold using auto throttles



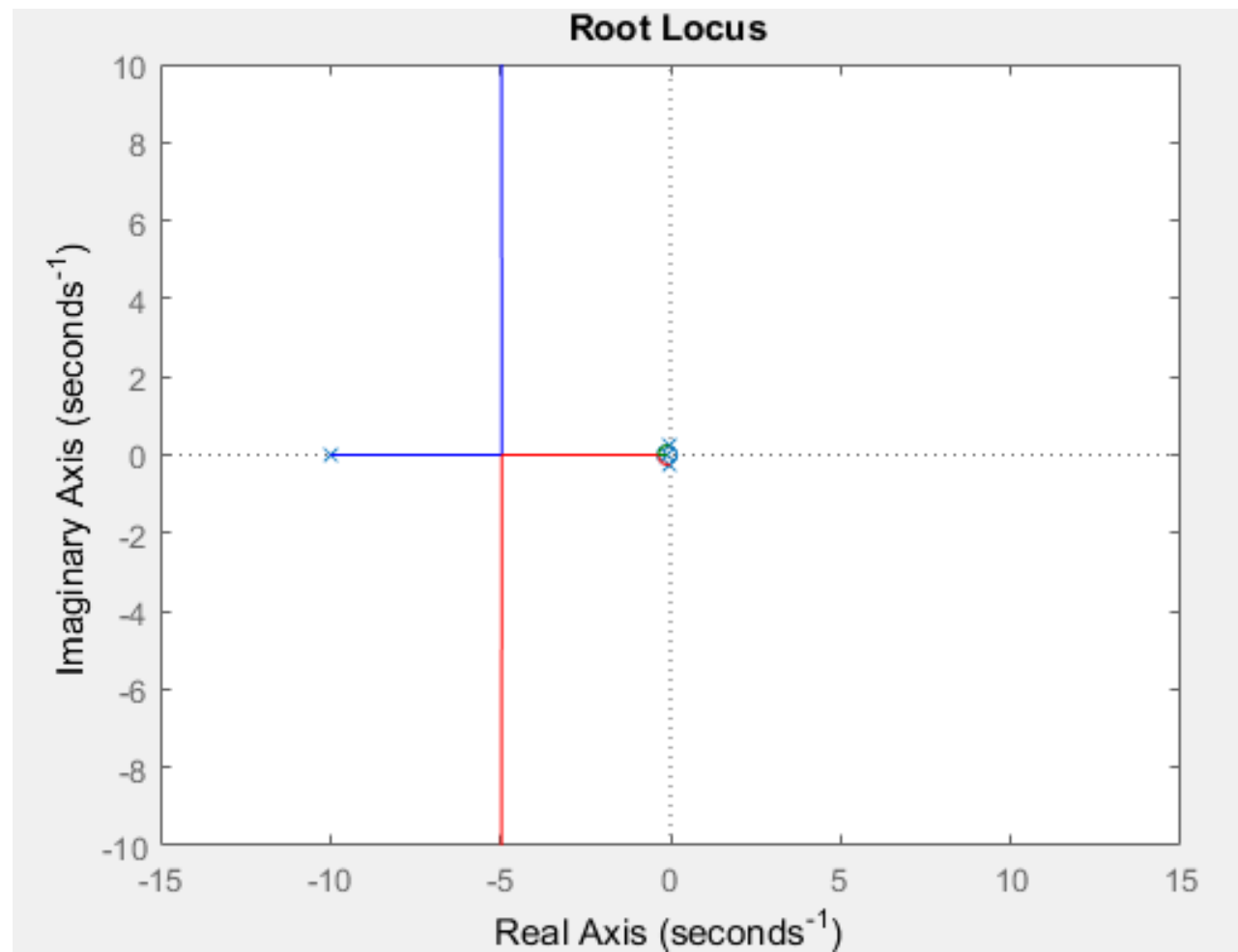
$$G(s)_{throttle} = \frac{10}{s + 10}$$

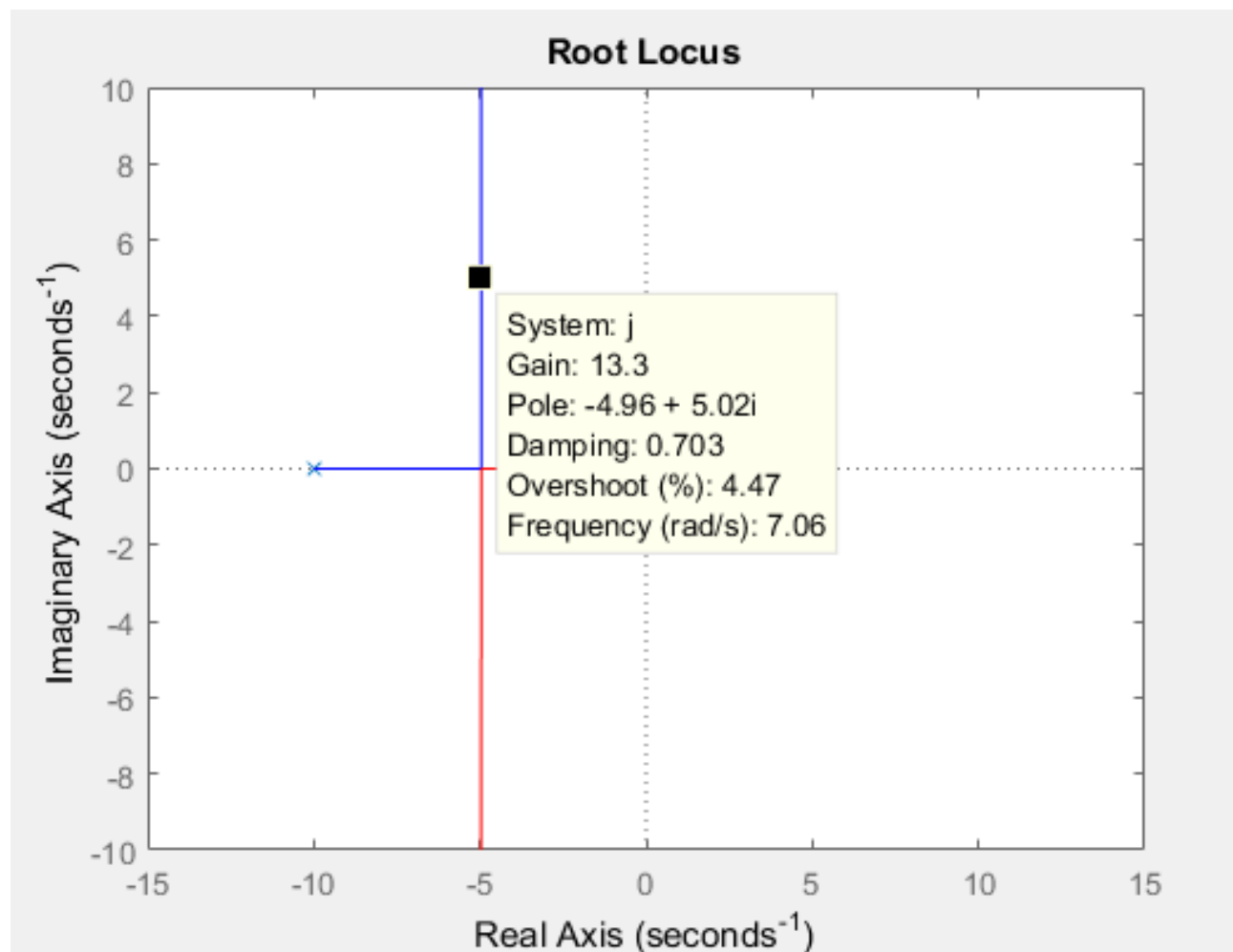
$$G(s)_{engine\ lag} = \frac{1}{s + 0.1}$$

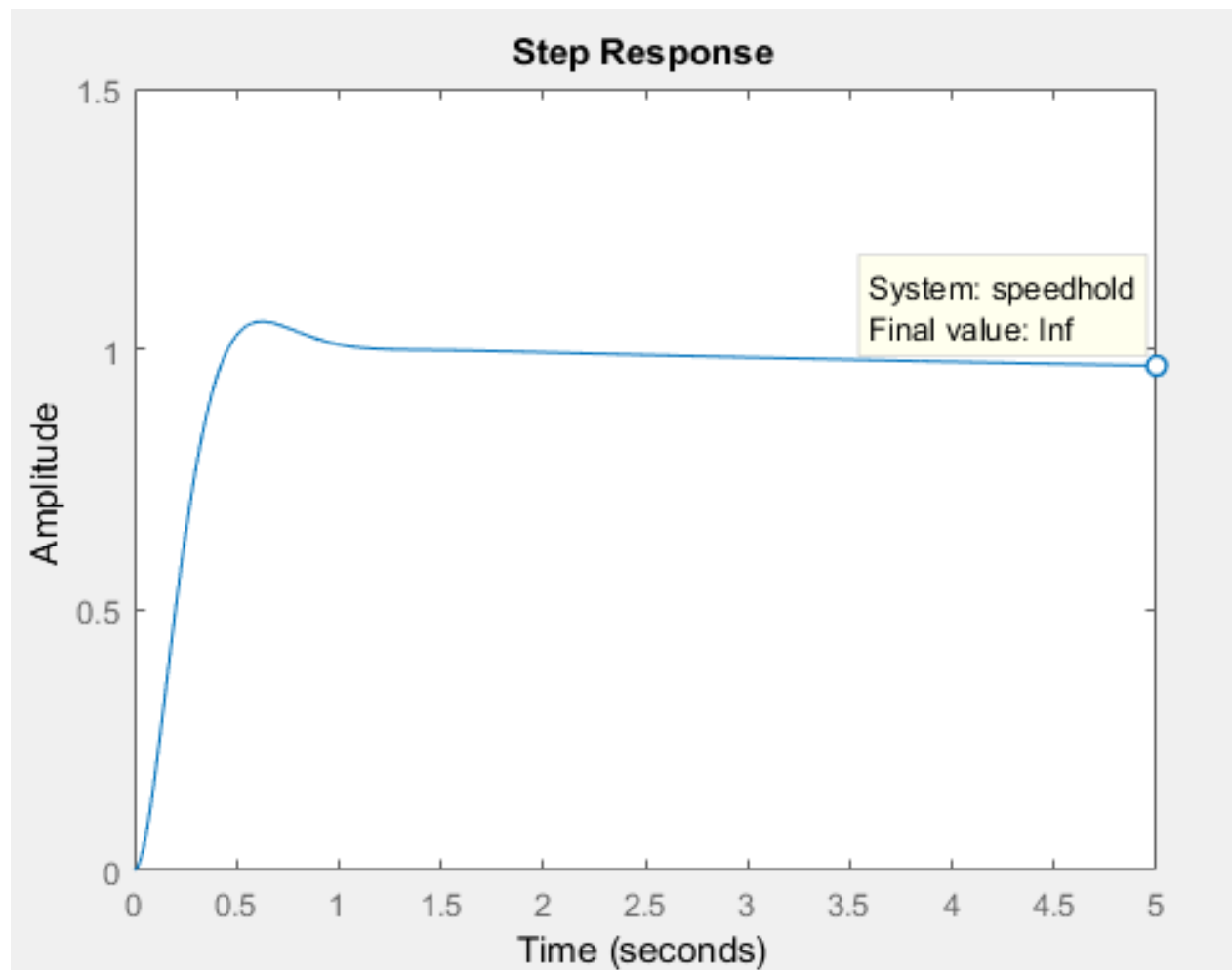
$$\frac{\Delta u}{\Delta \delta_T} = \frac{0.038s}{s^2 + 0.039s + 0.053}$$

- For this autopilot both the change in the velocity and acceleration are used in the feedback path. The feedback transfer function is assume to be as

$$H(s) = 10s + 1$$







- Note that for a gain corresponding to a damping of about 0.707 the response is very fast but there is a steady state error.
- On the other hand the steady state error can be reduced by increasing the gain.
- However, larger gain means a lower damping ratio and the response has a larger over shoot.
- To improve the performance and additional compensator may needed.

- In the auto throttle system the actuator servo moves the engine throttle result in adjust the fuel supply to the engines. The engine responds with increase in the thrust.
- The engine to throttle gain is represented by  $K_T$  which can be expressed in lbs/in of throttle movement or lbs/rad or lbs/deg.
- Engine thrust response to throttle motion can be represented by a first order lag with a break frequency of  $c$  rad/sec.
- In the feedback path the airspeed sensor are also represented as first order lag (because such systems are normally depend on pressure difference in static port and lines a certain amount of lag is evident. with a break frequency of  $b$  rad/sec.
- It should observe that auto throttle system such as in the above figure uses three first order lag system result in 270 deg phase lag. There fore the relative stability always a concern.

- Let us consider the airplane the lift to drag ratio on final approach is about 7. The thrust required is therefore  $564000/7=80571\text{lbs}$ , the max available thrust in the airplane is about  $198000\text{lbs}$ . Assuming a  $0.5\text{radian}$  throttle movement from the approach thrust setting. The engine to throttle gain is  $(198000-80571)/0.5=234858\text{lbs/rad}$ . It will be assumed that the engine have a spool up time constant of 5 sec. This give the engine break frequency of  $0.2\text{ rad/sec}$ .

$$\text{Engine model TF : } K_T \frac{c}{s+c} = 234858 \frac{0.2}{s+0.2}$$

$564000\text{ lbs} = \text{Approaching weight}$



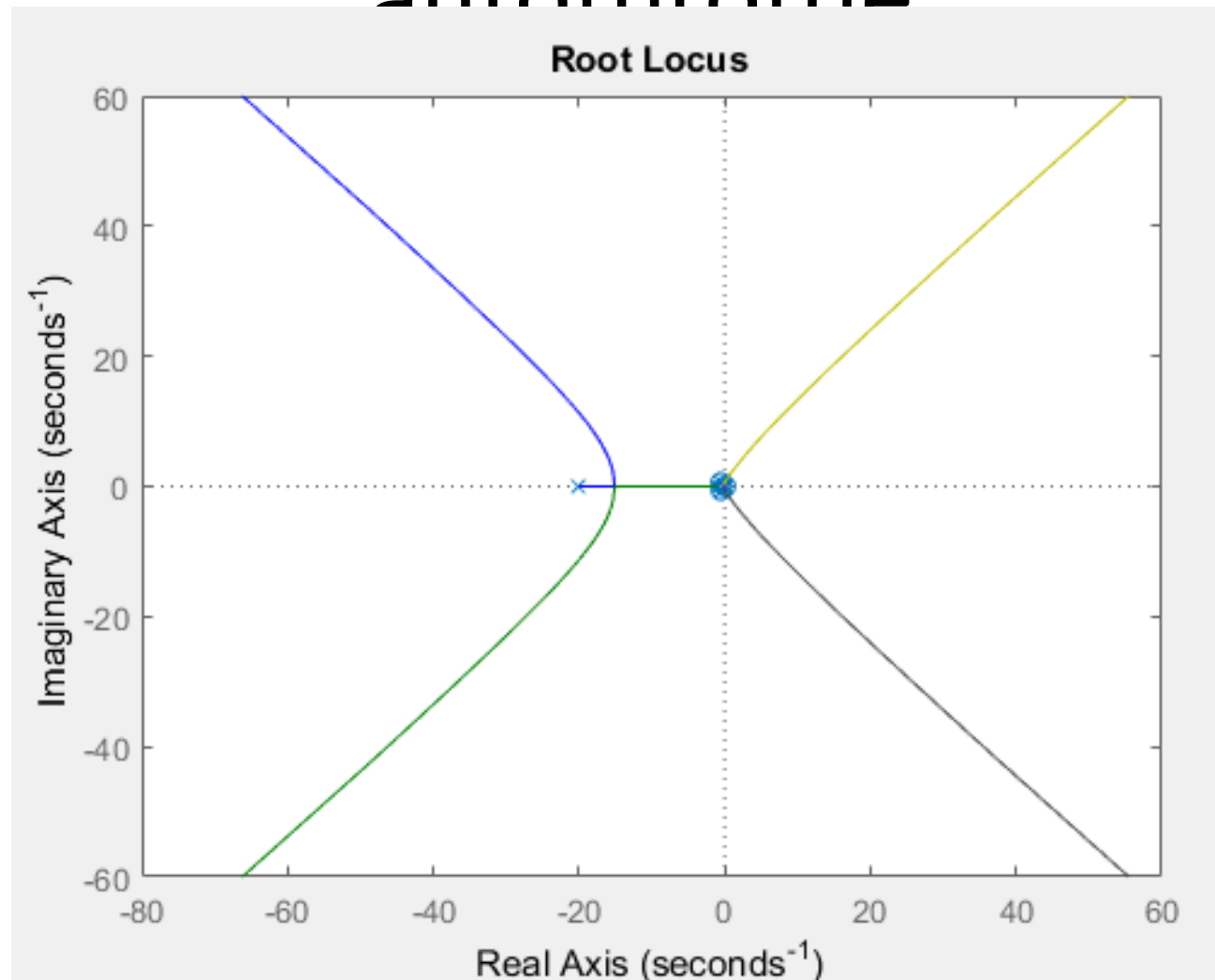
$$\text{Servo TF} : \frac{a}{(s+a)} = \frac{20}{(s+20)}$$

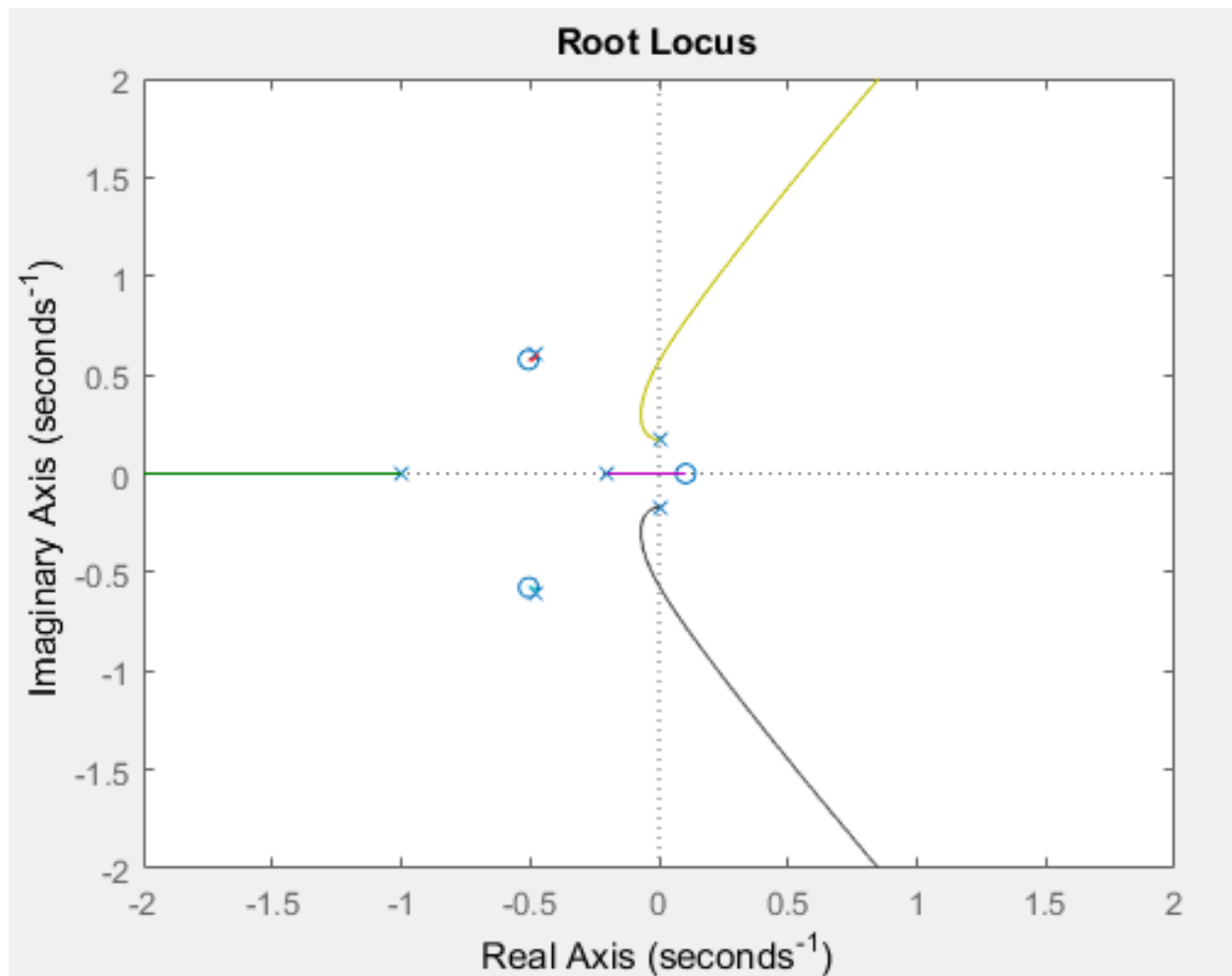
$$\frac{u(s)}{\Delta T(s)} = \frac{0.0033}{228.5} \left( \frac{(s-0.11)(s^2+1.015s+0.599)}{(s^2+0.951s+0.594)(s^2-0.0005s+0.0281)} \right)$$

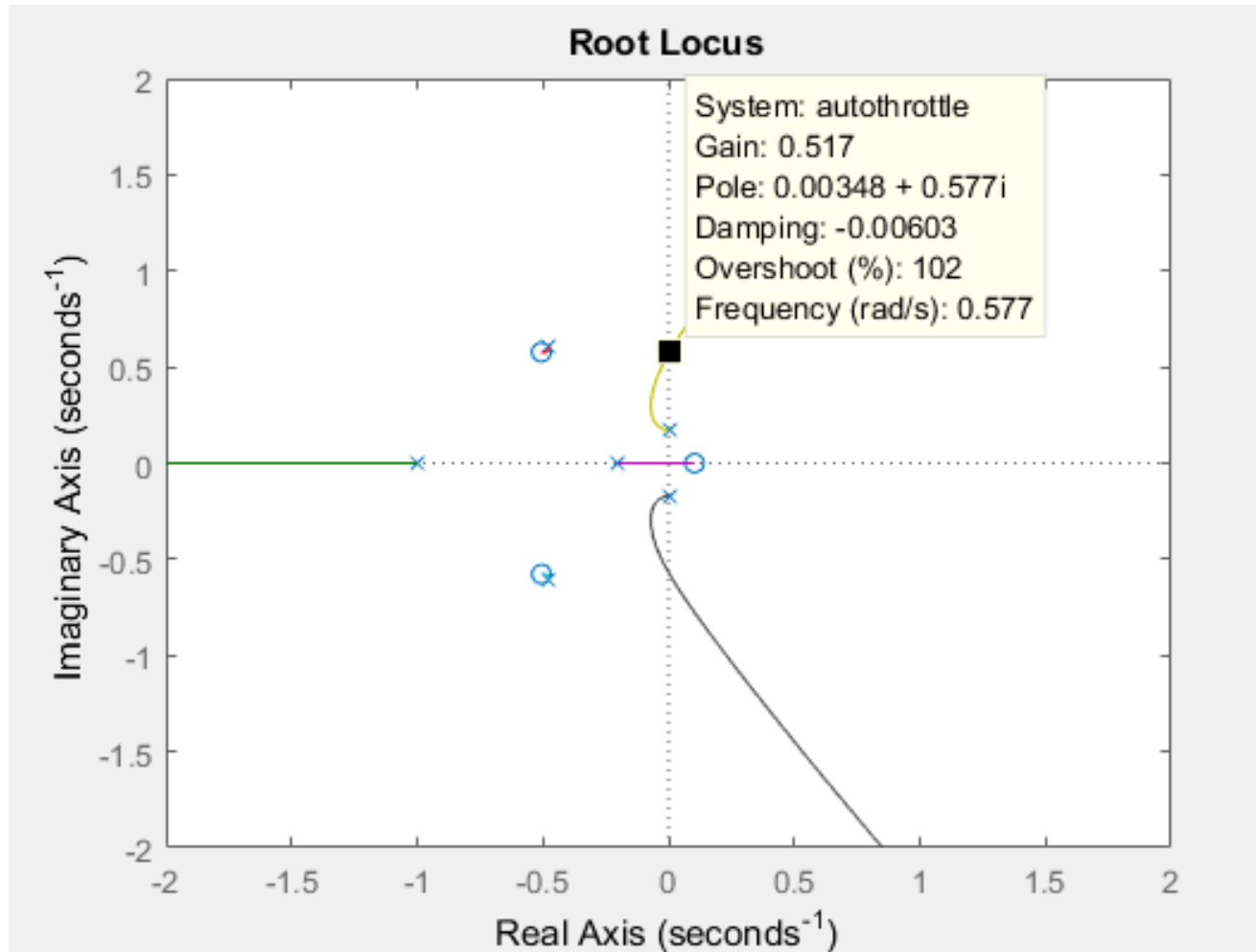
$$\frac{u(s)}{\Delta T(s)} = \left( \frac{0.0033s^3 + 0.0030s^2 + 0.0016s - 0.0002}{228.5s^4 + 217.2s^3 + 141.96s^2 + 6.043s + 3.815} \right)$$

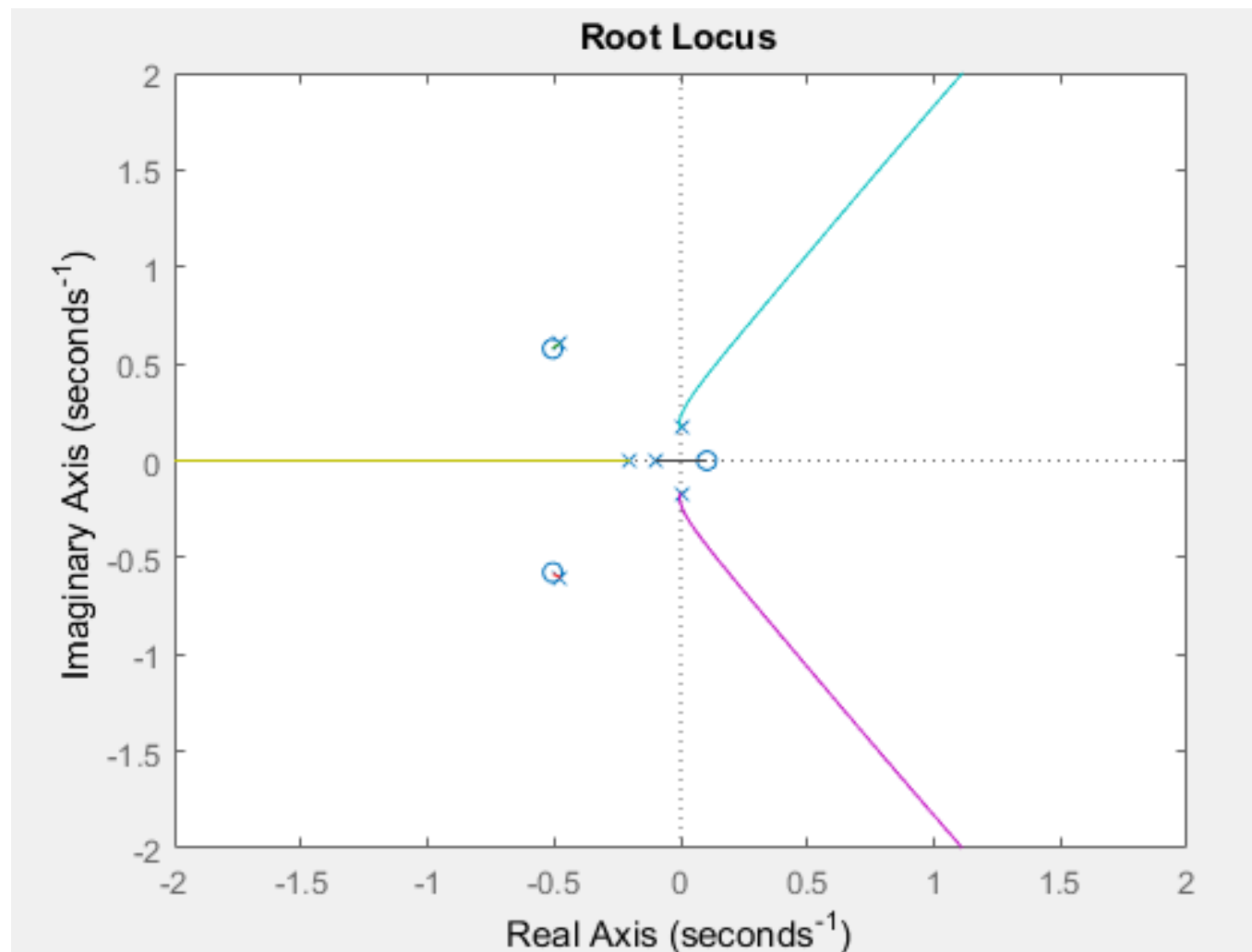
$$\text{Airspeed sensor TF} : \frac{b}{(s+b)} = \frac{1}{(s+1)}$$

# autothrottle









- It is noted that the airspeed hold mode affects only the **phugoid mode**.
- The entire system will work satisfactory depends upon the spool up time constant and speed sensor time constant (speed sensor lag).
- If the engine spool up time constant of 10 and speed sensor time constant of 5, the system no longer has acceptable closed loop characteristic.
- So care must be taken before designing the loop. The designer first check the spool up constant of engine and speed time constant of sensor before designing such a loop.

- Auto throttle advantages

- The aft end of the fuselage is free for Auxiliary power unit installation.
- Because of the lower required thrust setting on final approach , there will be less fuel consumption and less noise.

- Auto throttle disadvantages

- In turbulent air, due to the long spool-up time of the engine, there is considerable throttle activity. This results in the engine whining up and down which can be disturbing to passengers. Also, this results in more engine wear and tear
- In the case of go around, because the engines are operating at a relatively low thrust level, the spool up time can result in flight path response delay.



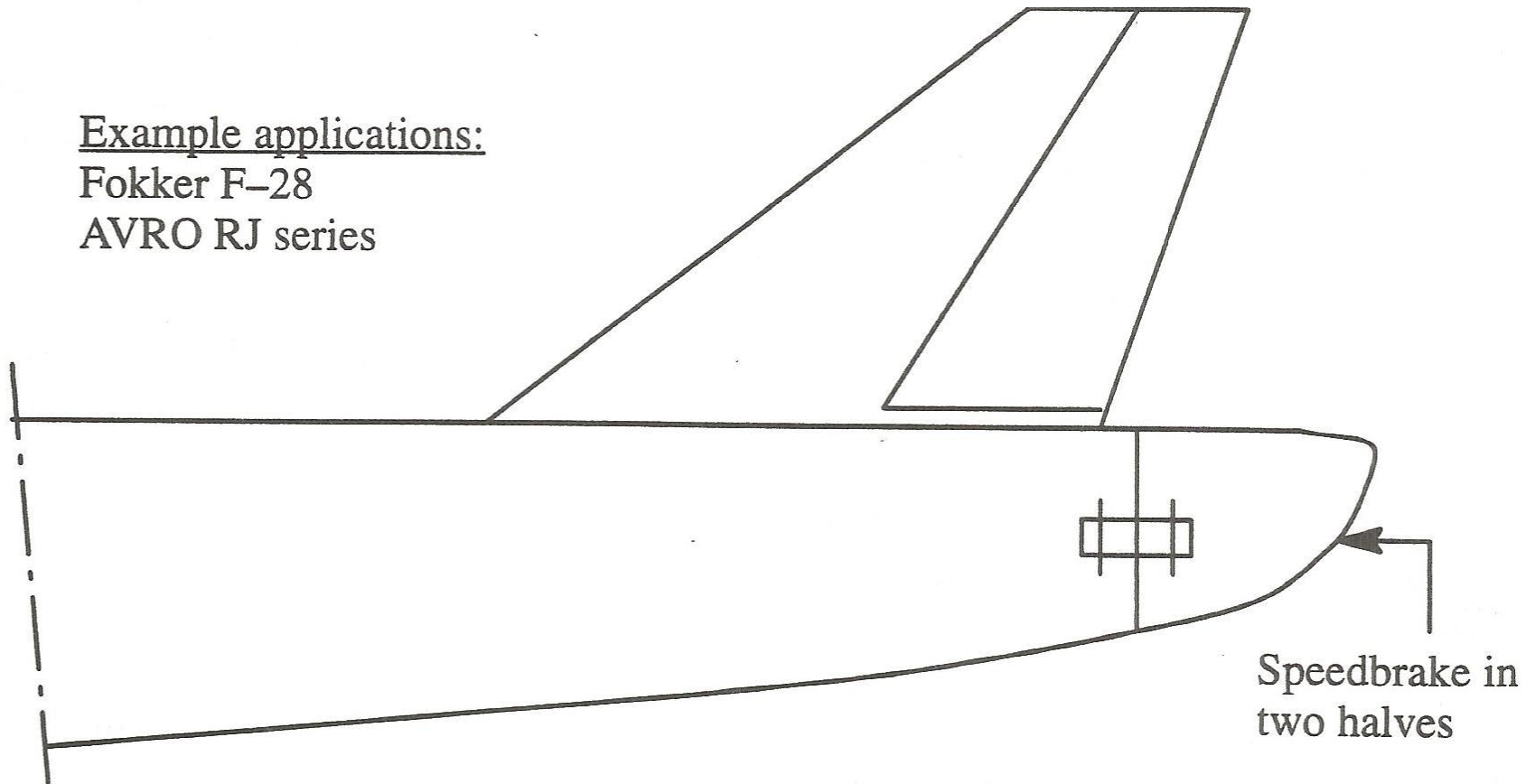


# Airspeed using speed brakes

Example applications:

Fokker F-28

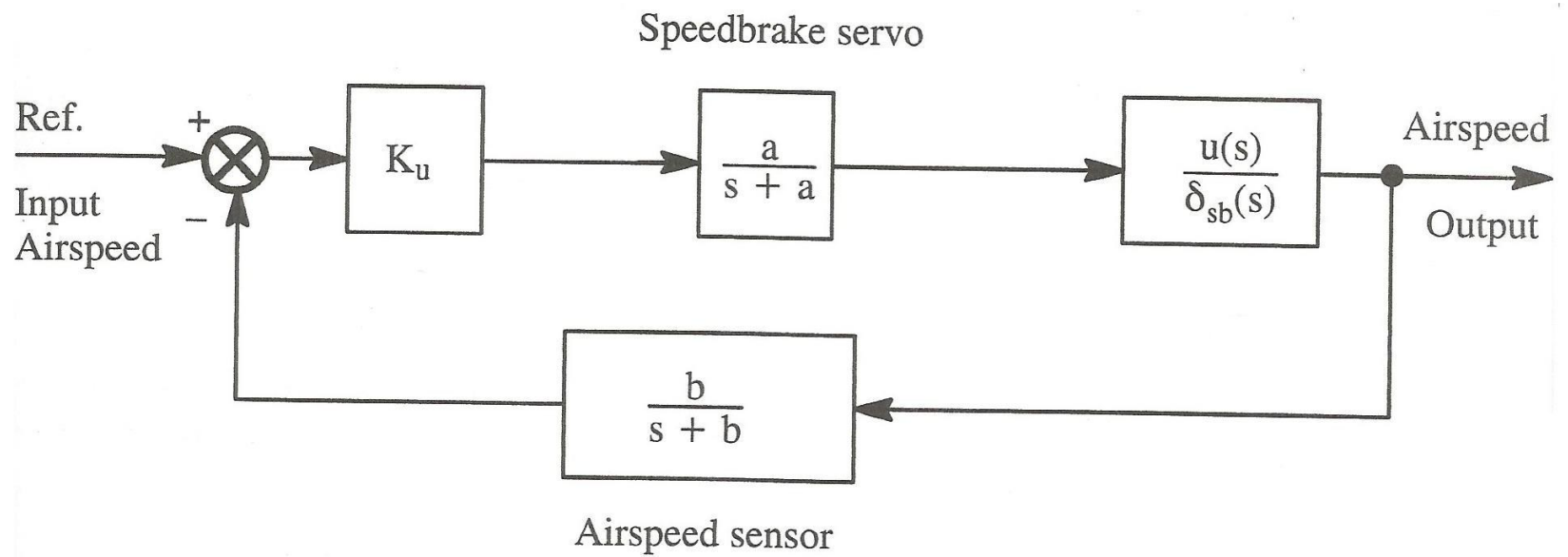
AVRO RJ series







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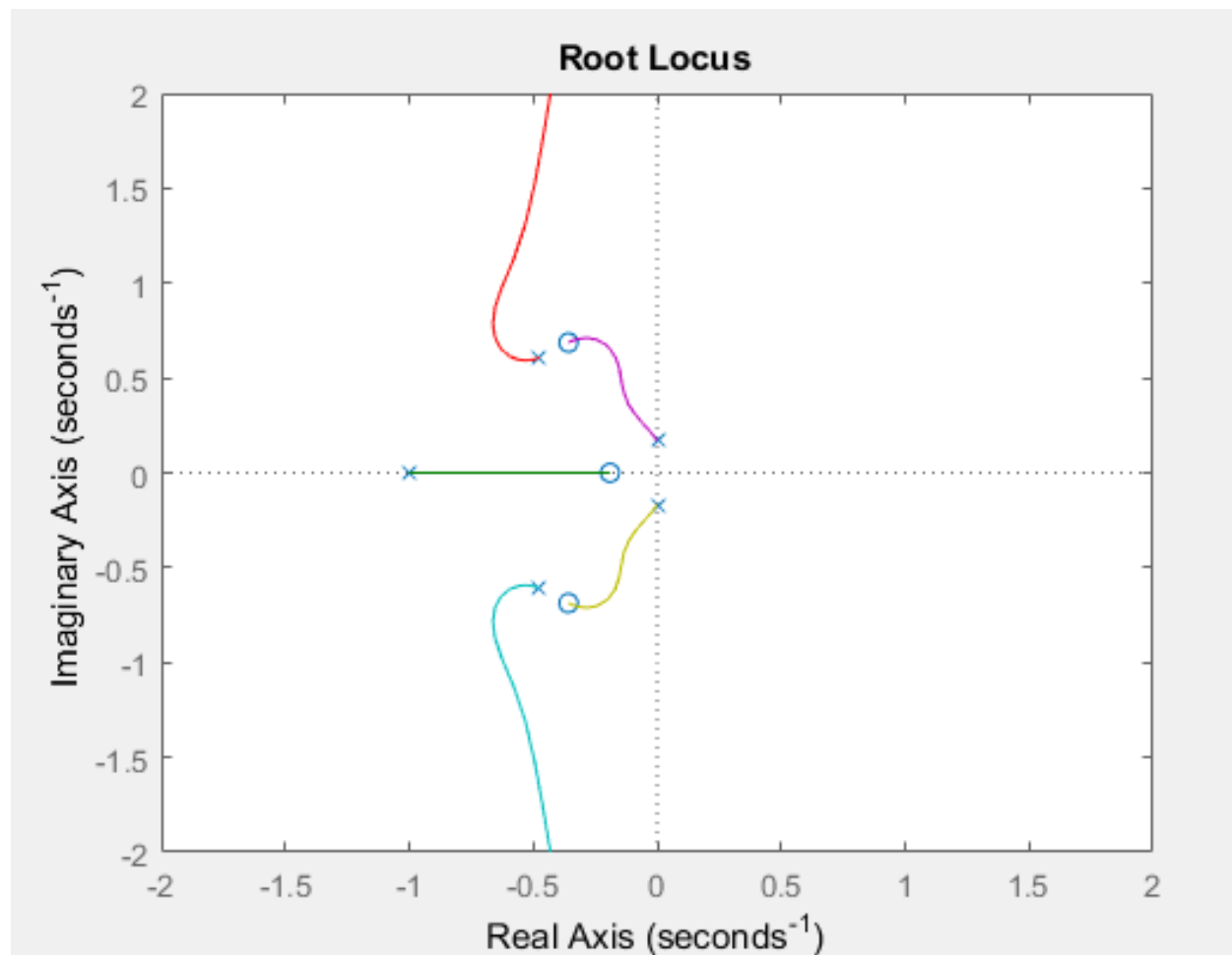


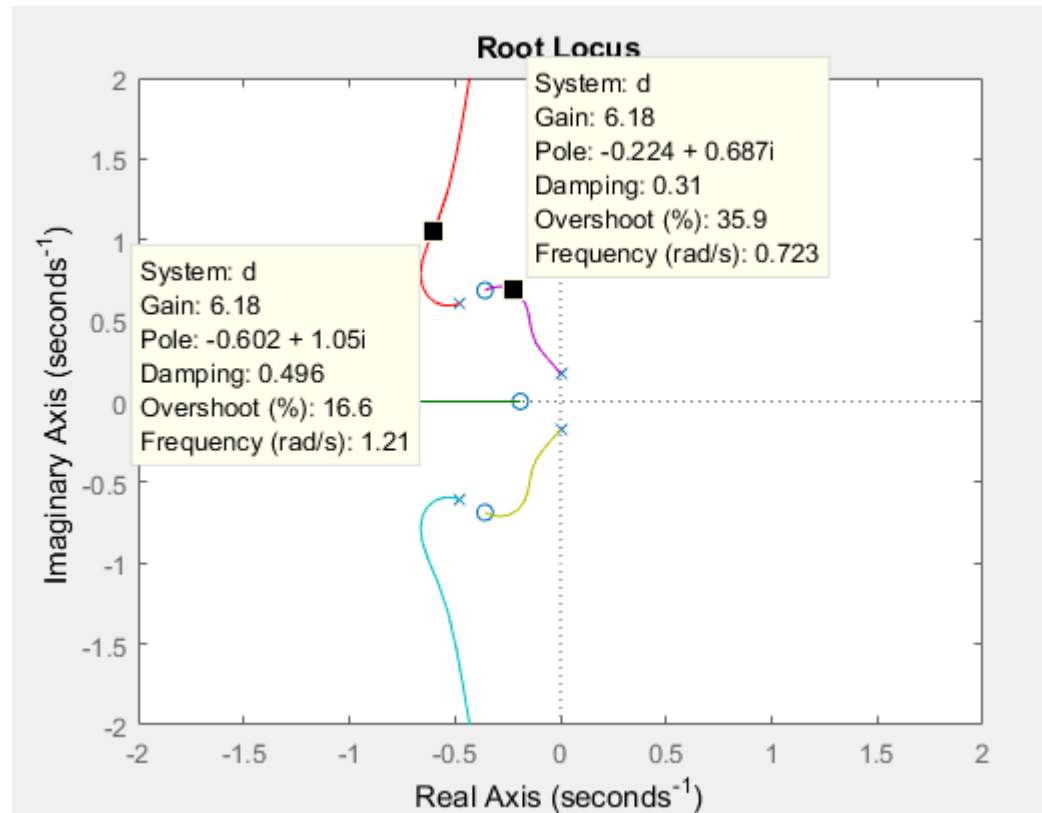
$$\text{Servo TF} : \frac{a}{(s+a)} = \frac{20}{(s+20)}$$

$$\frac{u(s)}{\delta_{sb}(s)} = \frac{-52.0}{228.5} \left( \frac{(s+0.19)(s^2+0.715s+0.60)}{(s^2+0.951s+0.594)(s^2-0.0005s+0.0281)} \right)$$

$$\frac{u(s)}{\delta_{sb}(s)} = \left( \frac{(-52.0s^3 - 47.1s^2 - 38.25s - 5.936)}{228.5s^4 + 217.2s^3 + 141.96s^2 + 6.043s + 3.815} \right)$$

$$\text{Airspeed sensor TF} : \frac{b}{(s+b)} = \frac{1}{(s+1)}$$





- Auto speed brakes advantages

- The thrust in turbulent air is kept constant, the speed brakes controls the speed of the aircraft this creates less engine wear and tear and also not disturbing passengers.
- Engines are operated at relatively high thrust level, the response to go around command is faster.

- Auto speed brakes disadvantages

- Because of added drag a high engine thrust power is required. This result in high fuel consumption.
- Preferred installation of speed brakers a the aft end of the fuselage , it is difficult to install auxiliary power units at the location. (Idle location for APU is aft of Fuselage).



THANK YOU