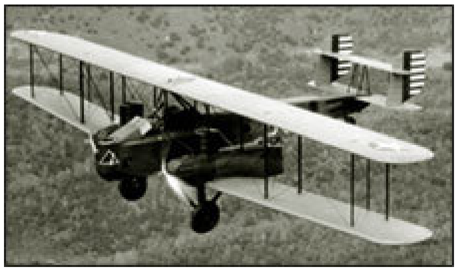
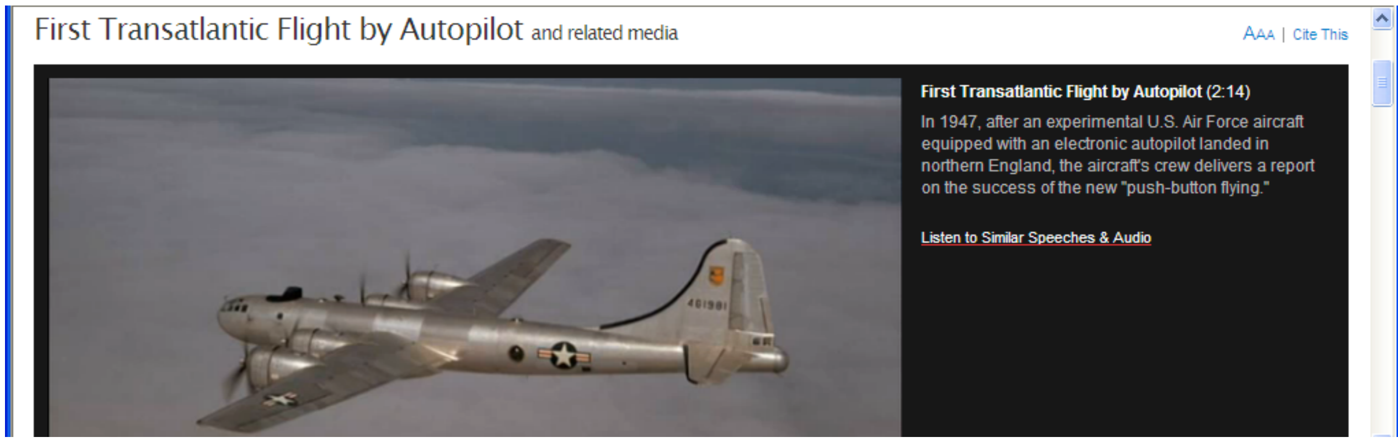
III. Attitude hold autopilots.

Stabilization of aircraft pitch, roll and yaw angles. Multiloop SISO design approach. Proporional and integrating control laws.

Stabilization of attitude angles: attitude hold autopilots

- attitude-hold autopilots (stabilizers / reference trackers of pitch, roll and yaw angles) are essential first-level automatic control (i.e. “lost pilot’s authority” – - compare with dampers) loops of any FCS
- basic functionality of autopilots for piloted aircraft (for almost a century ☺) as well as control systems for UAV’s



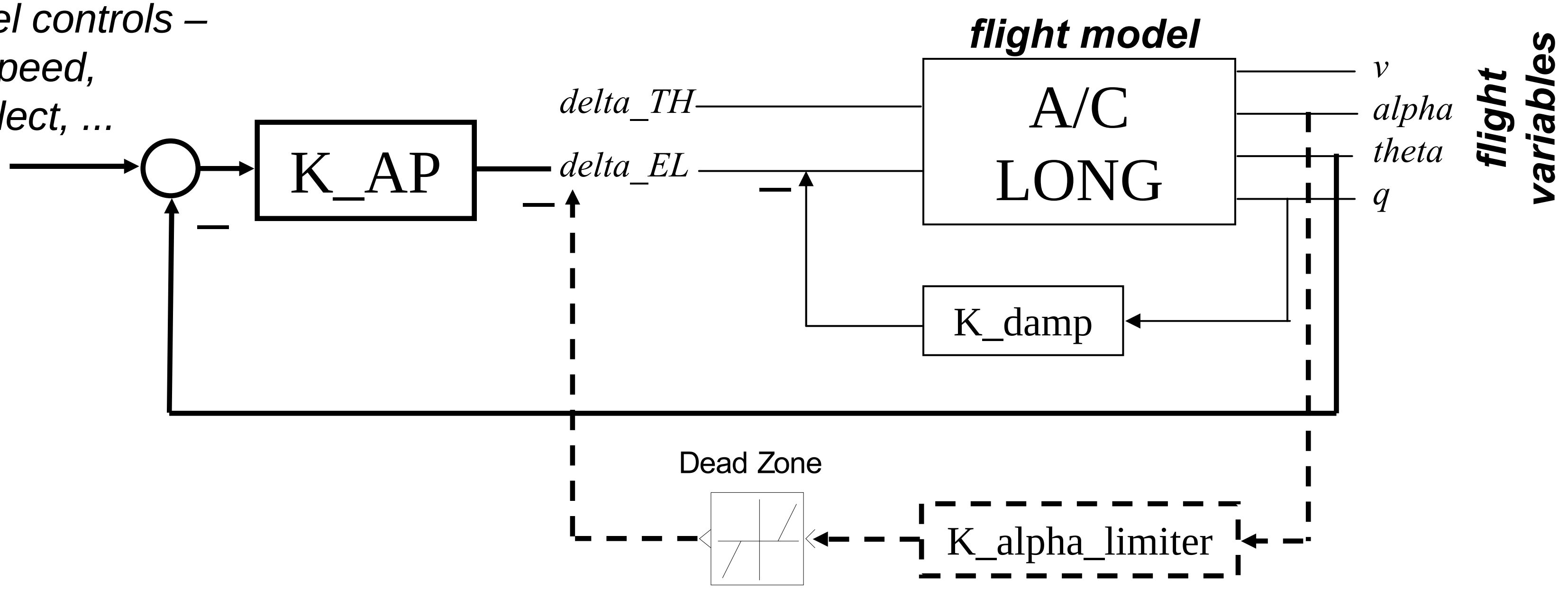


- if the attitude-hold circuits (codes) work properly, all subsequent loops (VOR / GPS navigation, ILS, altitude select, vertical speed, ...) are easy to design
- careful design of the autopilots is therefore essential (transients, rise times, robustness w.r.t. parameter changes and flight envelope variables, ...)
- design approaches: nested SISO loops (with pre-designed separate dampers), or MIMO design (with integrated dampers functionality – LQ control to be discussed later, H2/Hinf synthesis etc.)

Stabilization of attitude angles: attitude hold autopilots

Pitch autopilot: signal diagram

*pitch angle reference (by **pilot** or higher-level controls – - vertical speed, altitude select, ...*



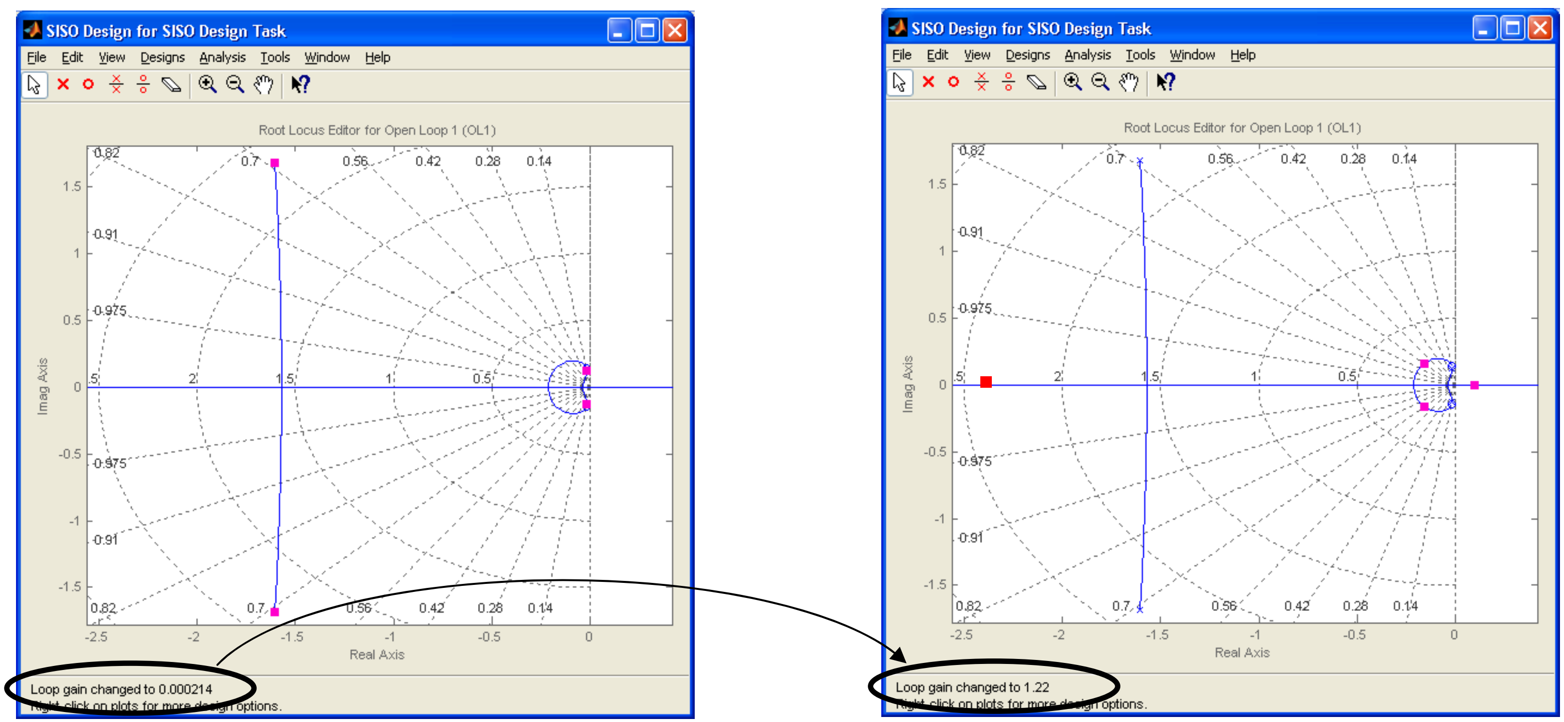
K_AP ... is just a gain (proportional controller) sufficient? How about PI controller ...

Stabilization of attitude angles: attitude hold autopilots

A remark on alpha feedback and statically unstable aircraft ...

- the effect of decreasing stability margin of the LONG equations can be illustrated by artificially introduced *positive* feedback alpha -> EL

- simulates statically-unstable A/C: stabilization effect of the A/C (tail surfaces mainly) with alpha is insufficient. pitching moment curve has positive slope (for some alpha range). note the exponentially-unstable mode + 3rd mode oscillation (“as fast as PHUG, as damped as SP”):



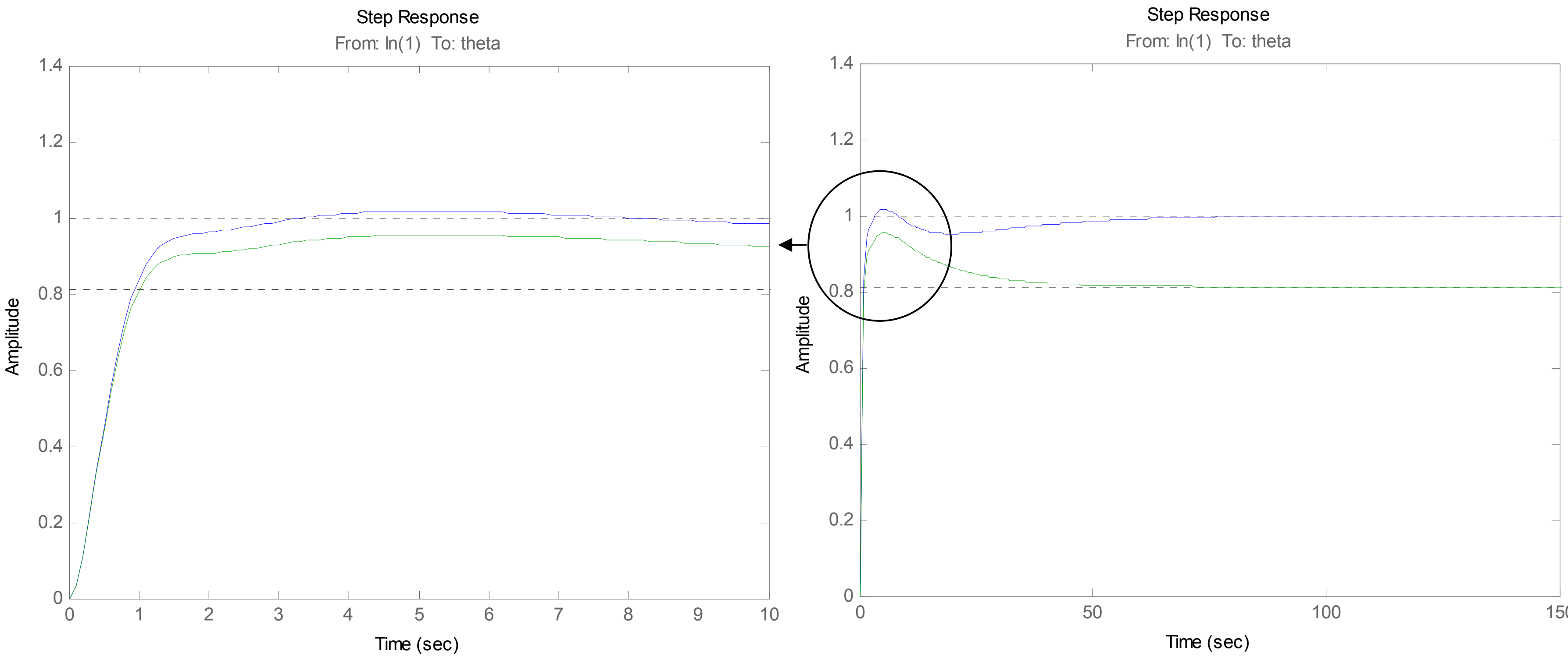
- adversely: alpha-feedback is used to stabilize statically-unstable A/C (nowadays just fighters but who knows for future ... ☺). Reference: Stevens, Lewis, Aircraft control and

Stabilization of attitude angles: attitude hold autopilots

Pitch autopilot: proportional vs. PI control law

K_AP ... is just a gain (proportional controller) sufficient? How about PI controller ...

- P controller (K = 2) green, PI controller (K = 2*(1+0.1/s)) blue. Step response.

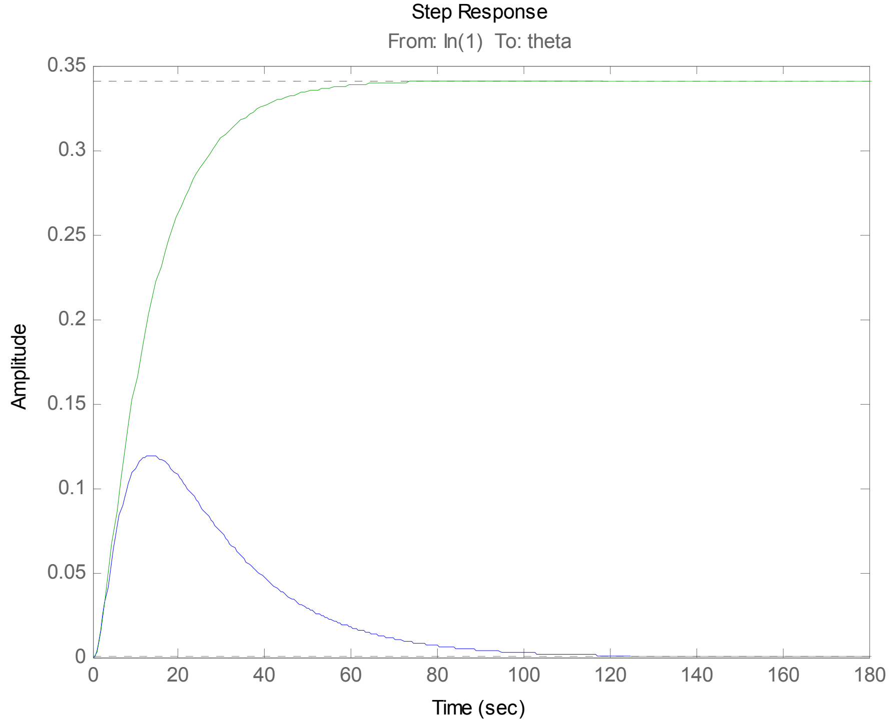


- similar situation for constant disturbance (try step to thrust input, simulating front/rear wind)

Stabilization of attitude angles: attitude hold autopilots

Pitch autopilot: proportional vs. PI control law

- similar situation for constant disturbance (try step to thrust input, simulating front/rear wind)
- P controller (K = 2) green, PI controller (K = 2*(1+0.1/s)) blue. Step response in thrust.

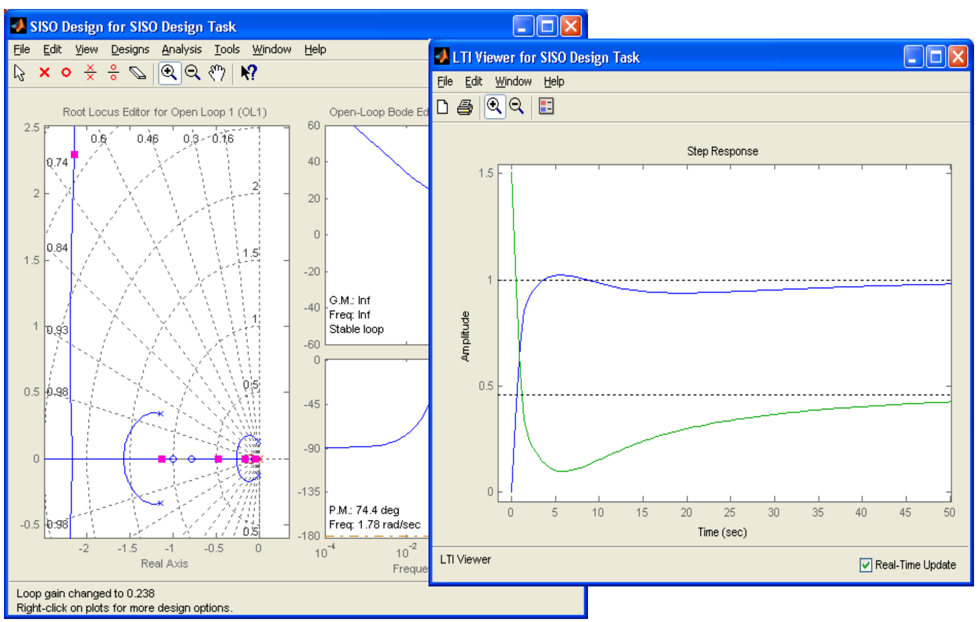


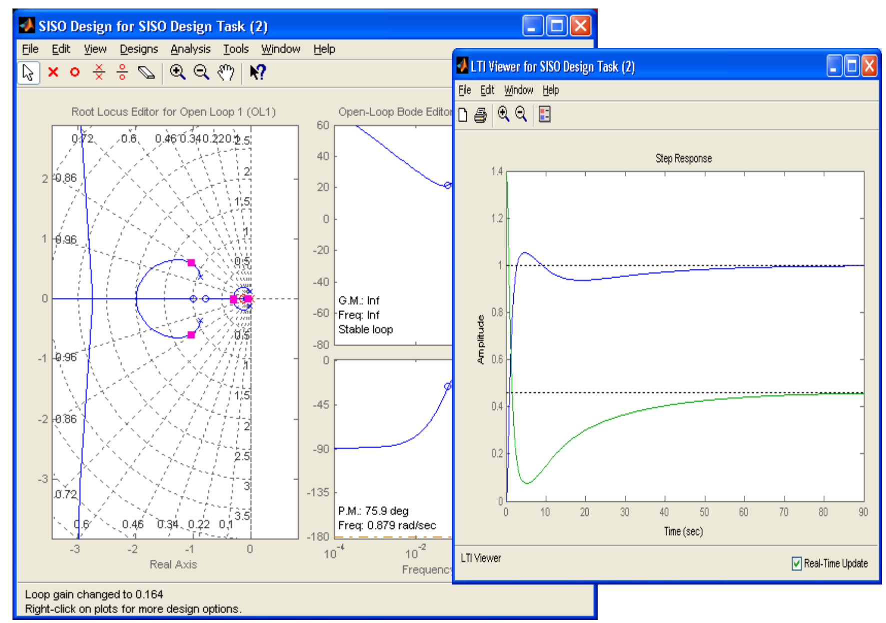
Stabilization of attitude angles: attitude hold autopilots

Pitch autopilot: interaction with pitch damper

- pre-designed pitch damper pre-determines, to considerble extent, achievable performance of the pitch-angle stabilizer (pitch autopilot) – overshoot, settling time, gain/phase margins, ...
- tedious re-designs of already computed controllers (pitch damper, in this case) are often required, during this loop-by-loop procedure, in order to achieve acceptable performance
- K_damp = 0.5 K_damp = 1

(... well, best results I got ☺, for comparable maximum EL deflection and gain / phase margins)



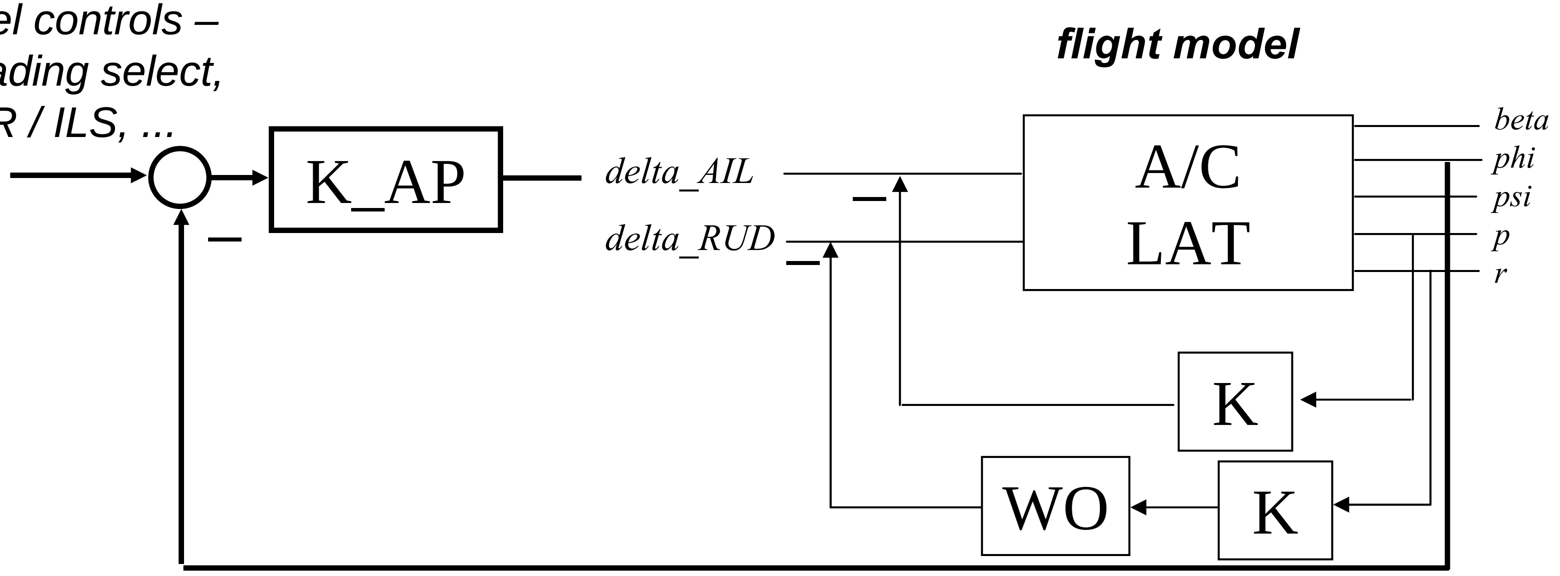


- this trouble can be avoided / reduced if advanced MIMO design procedures are used (e.g. LQ control)

Stabilization of attitude angles: attitude hold autopilots

Bank (roll) autopilot: signal diagram

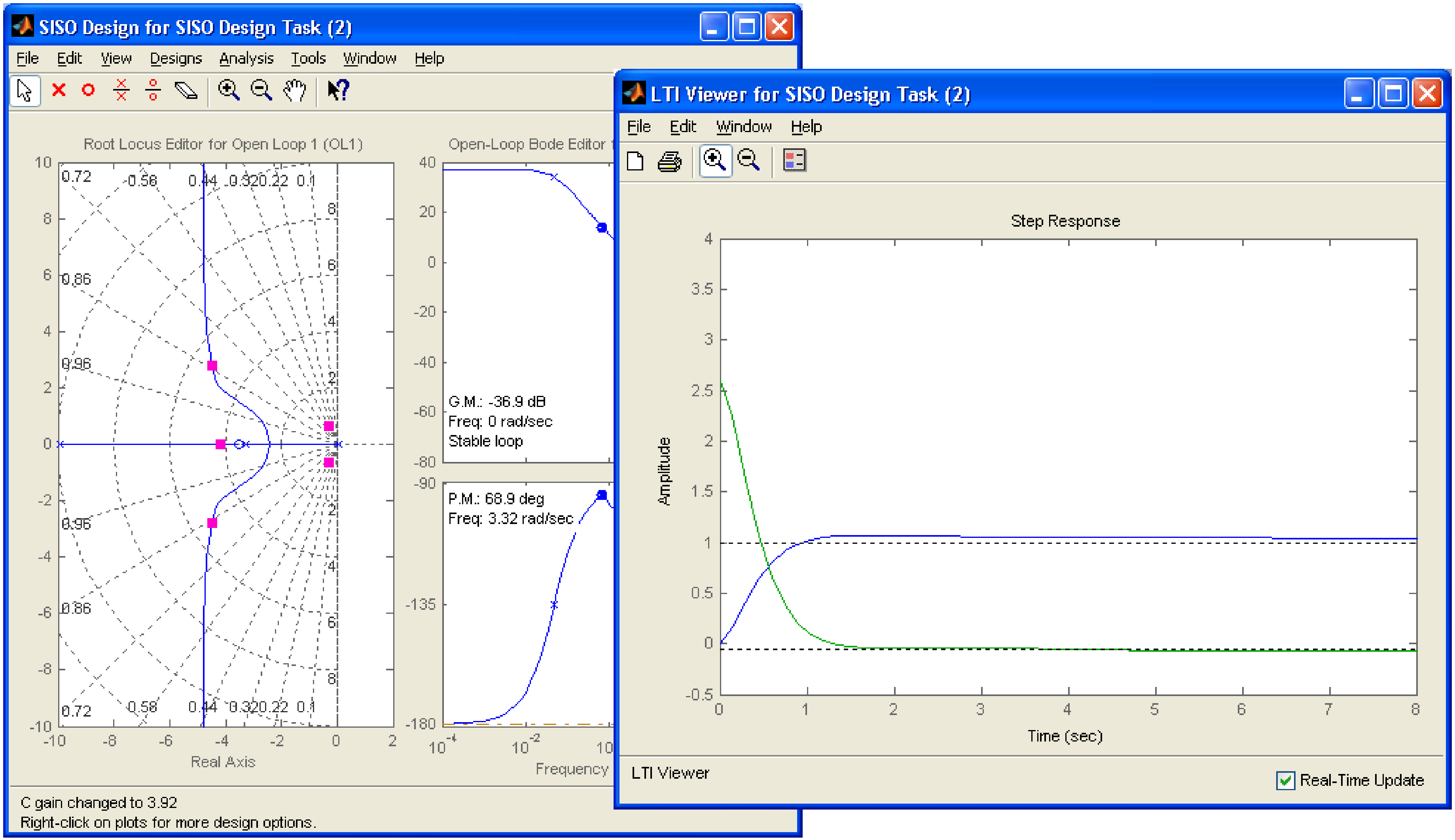
*bank angle reference (by **pilot** or higher-level controls – - turn / heading select, NAV / VOR / ILS, ...*



K_AP ... is just a gain (proportional controller) sufficient? How about PI controller ... the same story ...

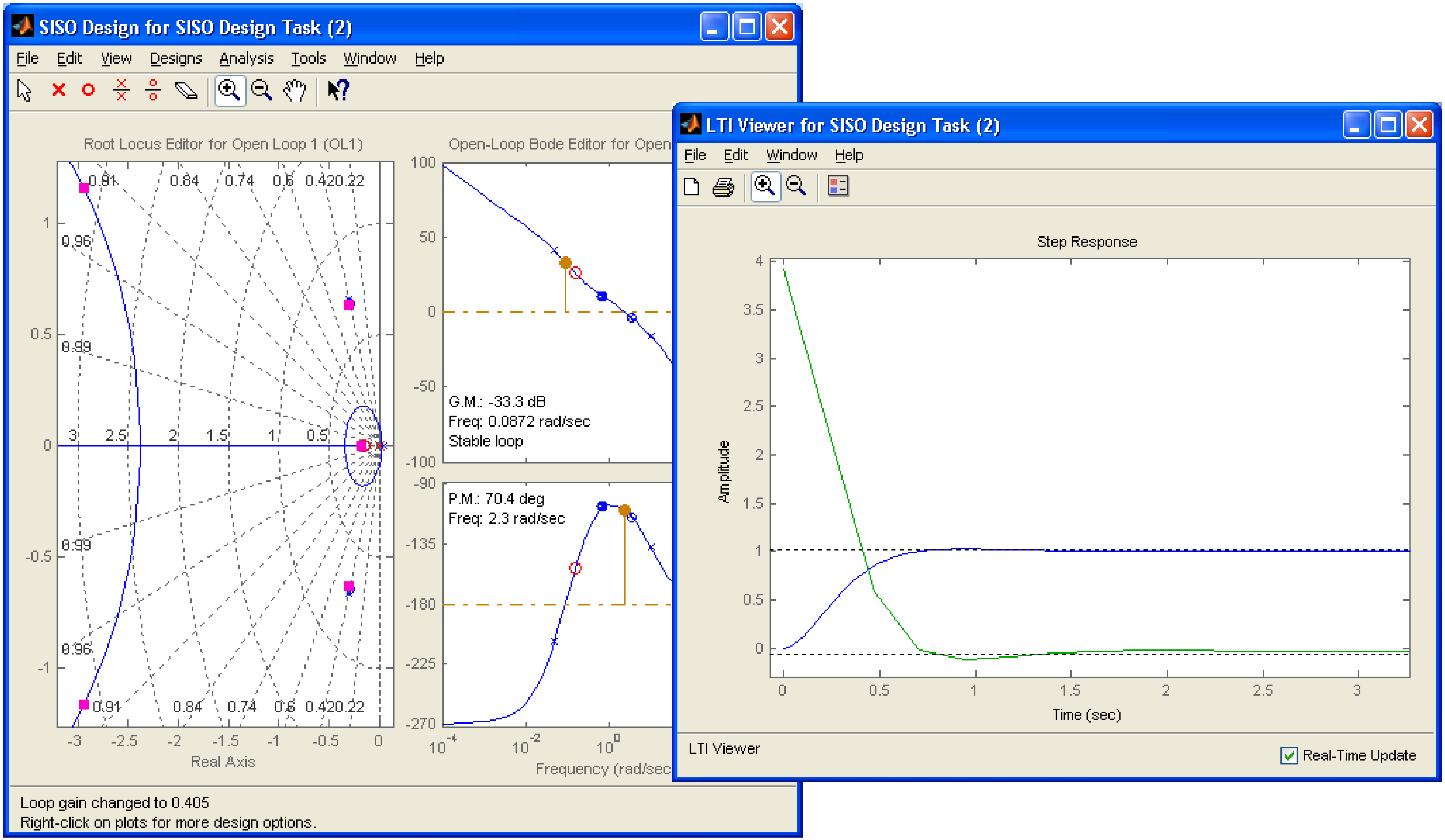
Stabilization of attitude angles: attitude hold autopilots

Bank (roll) autopilot: step response (in reference bank angle), P controller



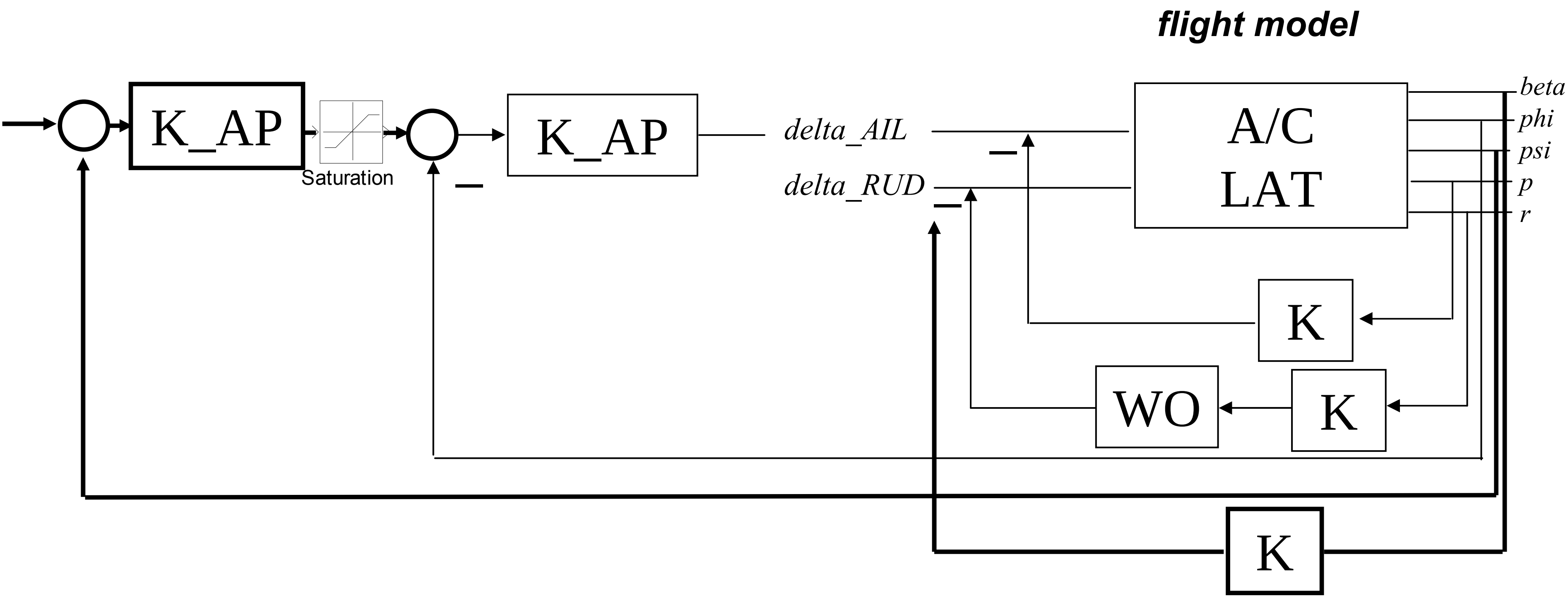
Stabilization of attitude angles: attitude hold autopilots

Bank (roll) autopilot: step response (in reference bank angle), PI controller



Stabilization of attitude angles: attitude hold autopilots

Yaw autopilot – heading select: signal diagram



Stabilization of attitude angles: attitude hold autopilots

Yaw autopilot – heading select

- two loops added on top of bank autopilot for coordinated (correct) turn
- yaw-angle (heading) loop, giving setpoint for bank autopilot (mind the artificially added saturation to avoid excessive bank angles for large yaw angle setpoint changes
- beta stabilization – for turn coordination (beta should be zero, assuring zero on-board side acceleration)
- roll angle and yaw rate are given **for coordinated turn** by the equation

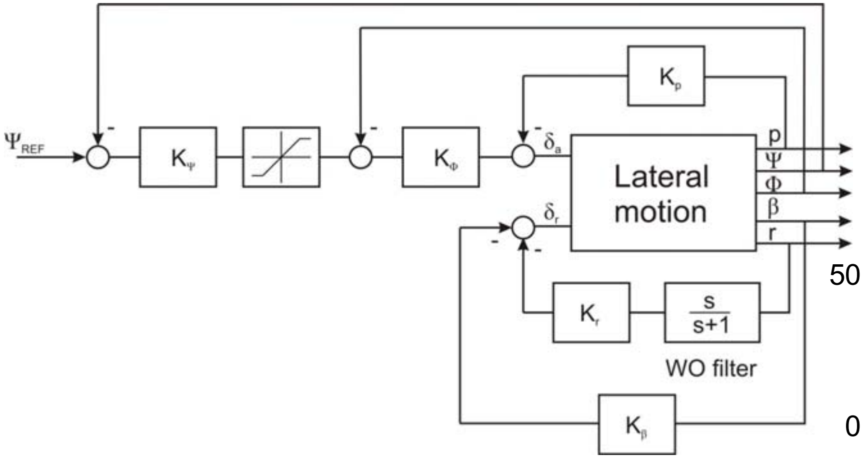
$$\Omega = \frac{g}{V} tg\phi$$

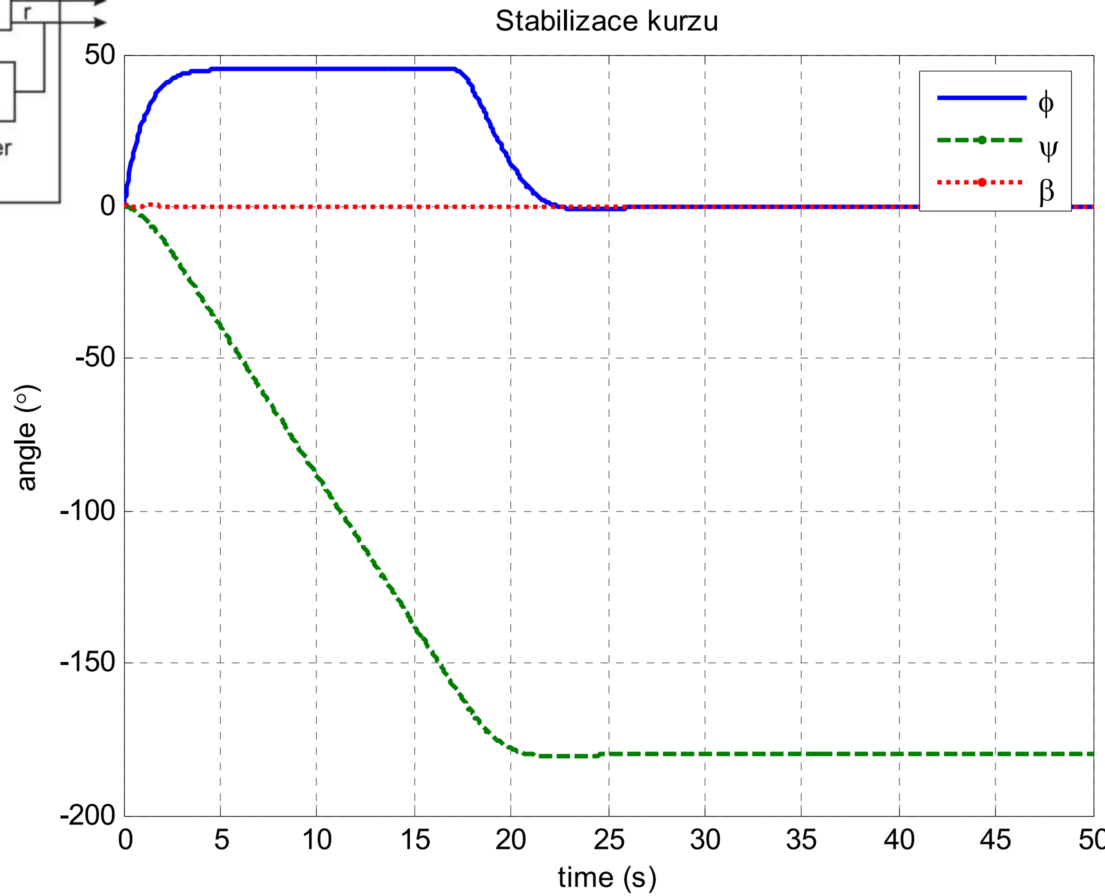
(independent of A/C physical parameters competely ...)

- the beta stabilizer has also other purposes – landing at side-wind, OEI (one engine inoperative) flight, ...

Stabilization of attitude angles: attitude hold autopilots

Yaw autopilot: step response (in reference bank angle), PI controller





- yaw-angle (heading) loop, giving setpoint for bank autopilot
- artificially added saturation to avoid excessive bank angles for large yaw angle setpoint changes
- beta stabilization

- **P or PI ontrol? A bit tricky.**
  - REF vs. DIST ...
  - mind ainti-windup ...