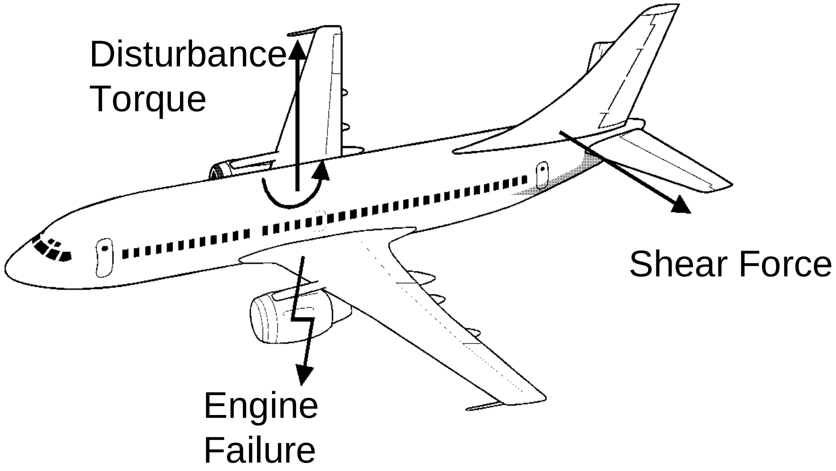
The engine out problem

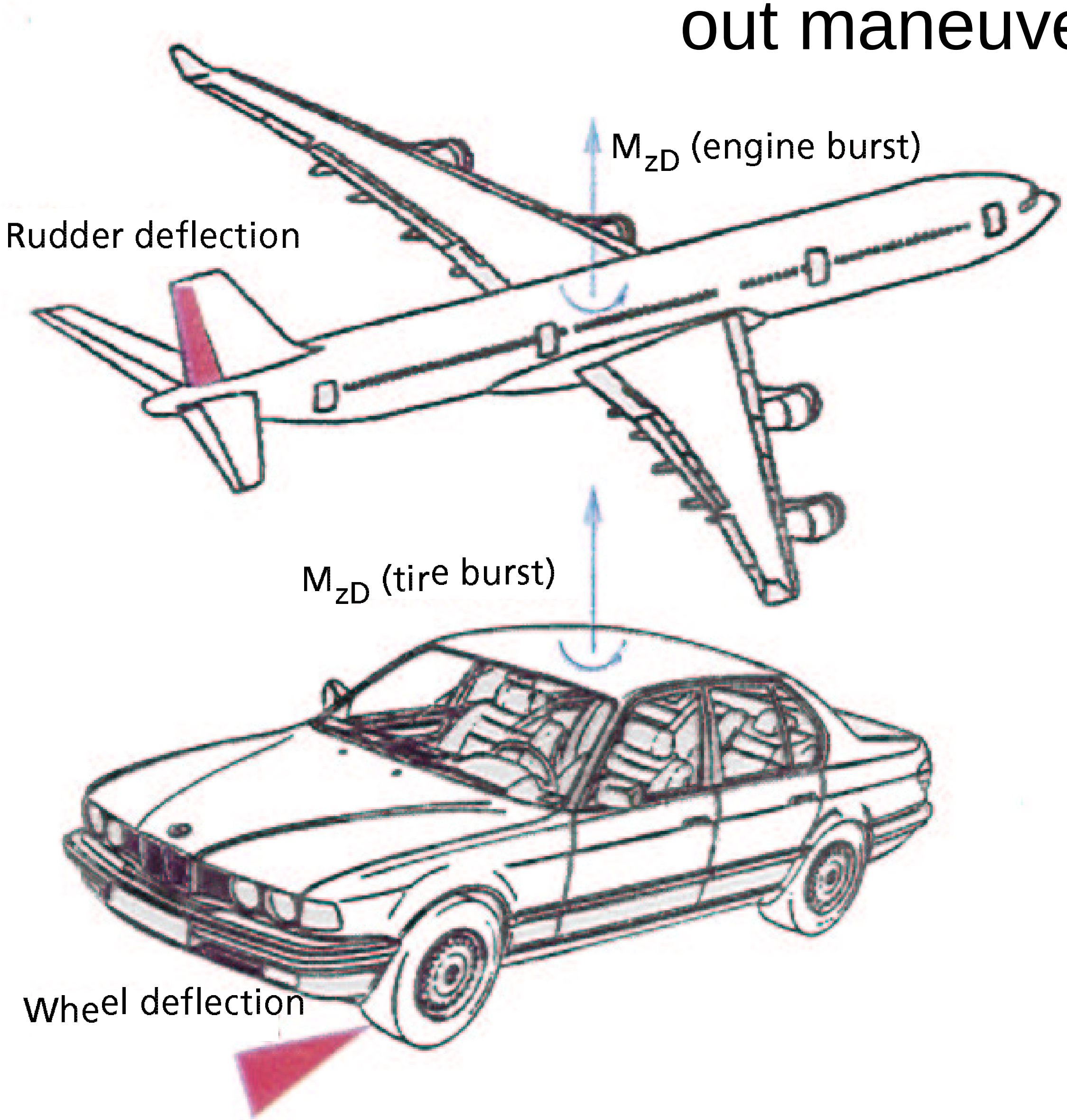


- Engine failure causes disturbance torque
  Corrective torque requires high shear force (and torques) at root of vertical fin

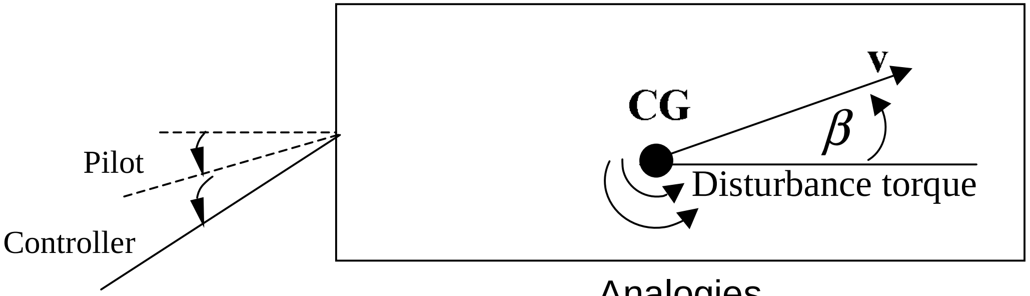
- Delayed and exaggerated pilot reaction increases peak forces and torques

- Automatic control shall reduce peak forces and torques in order to reduce loads / weight

Transfer car steering result to aircraft engine out maneuver



Transfer car steering result to aircraft: Most severe disturbance torque is tire burst ≙ engine burst. Yaw rate increases rapidly. Controller must counteract by tire / rudder deflection faster and more precisely than the driver / pilot can do it.



Analogies

Disturbance torques M_{zD}

Aircraft	Car
one engine out	flat tire
	μ-split braking
wind gusts	wind gusts

$$\begin{bmatrix}\dot{\beta}\\ \dot{r}\end{bmatrix} = \begin{bmatrix}a_{11} & a_{12}\\ a_{21} & a_{22}\end{bmatrix}\begin{bmatrix}\beta\\ r\end{bmatrix} + \begin{bmatrix}b_1\\ b_2\end{bmatrix}[\delta_{Pilot} + \delta_{Control}] + \begin{bmatrix}0\\ 1/I_z\end{bmatrix}M_{zD}$$

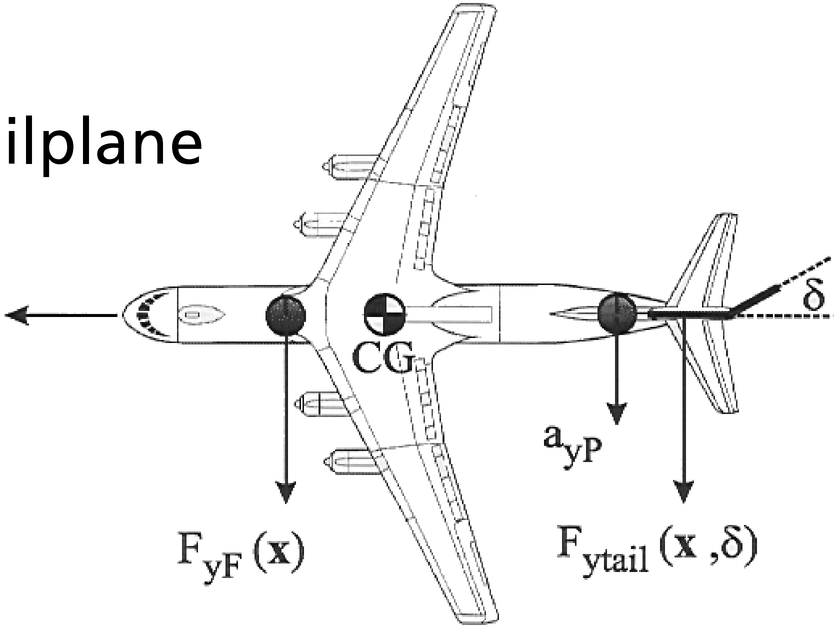
$\bar{q}$	: dynamic pressure	μ	: friction coefficient
m	: mass	m	: mass
I_z	: moment of inertia	I_z	: moment of inertia
v	: velocity	v	: velocity
C_{ij}	: derivatives	c_V, c_H	: front and rear cornering stiffness

Differences

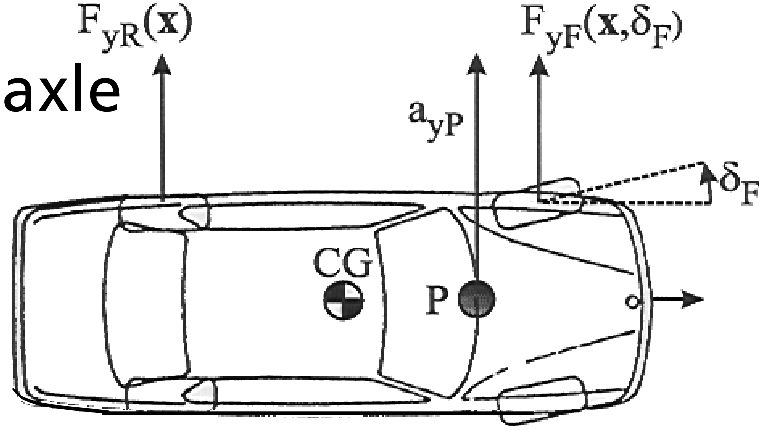
Aircraft	Car
Purpose	
Avoid energy transfer into roll motion Reduce structural load	Avoid skidding Improve handling
Present Control	
Lateral basic controller for yaw angle exists, but is too slow Engine fault detection exists, takes up to 0.5 Seconds	Car steering is controlled only by the driver
Decoupling point P	
P near tailplane	P near front axle

Decoupling point P

F_{yF} (x) $\nrightarrow$ a_{yP}, P near tailplane



F_{yR} (x) $\nrightarrow$ a_{yP}, P near front axle



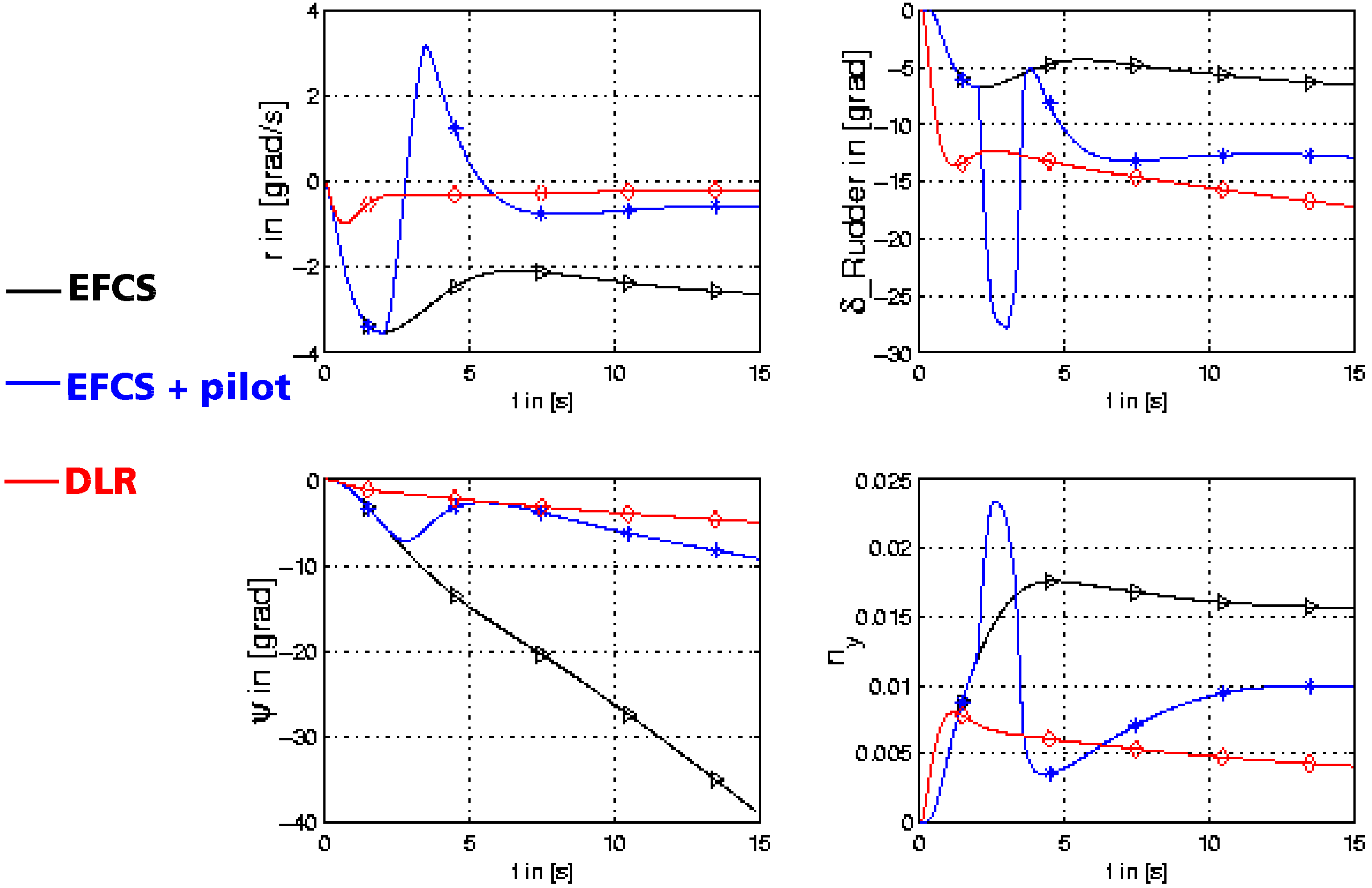
The yaw rate r influences a_{yP} only via $F_{ytail}(\underline{x},\delta)$ (or $F_{yF}(x,\delta_F)$).

This force is uncertain. It becomes independent of r, however, if the argument $\underline{x}$, is made independent of r.

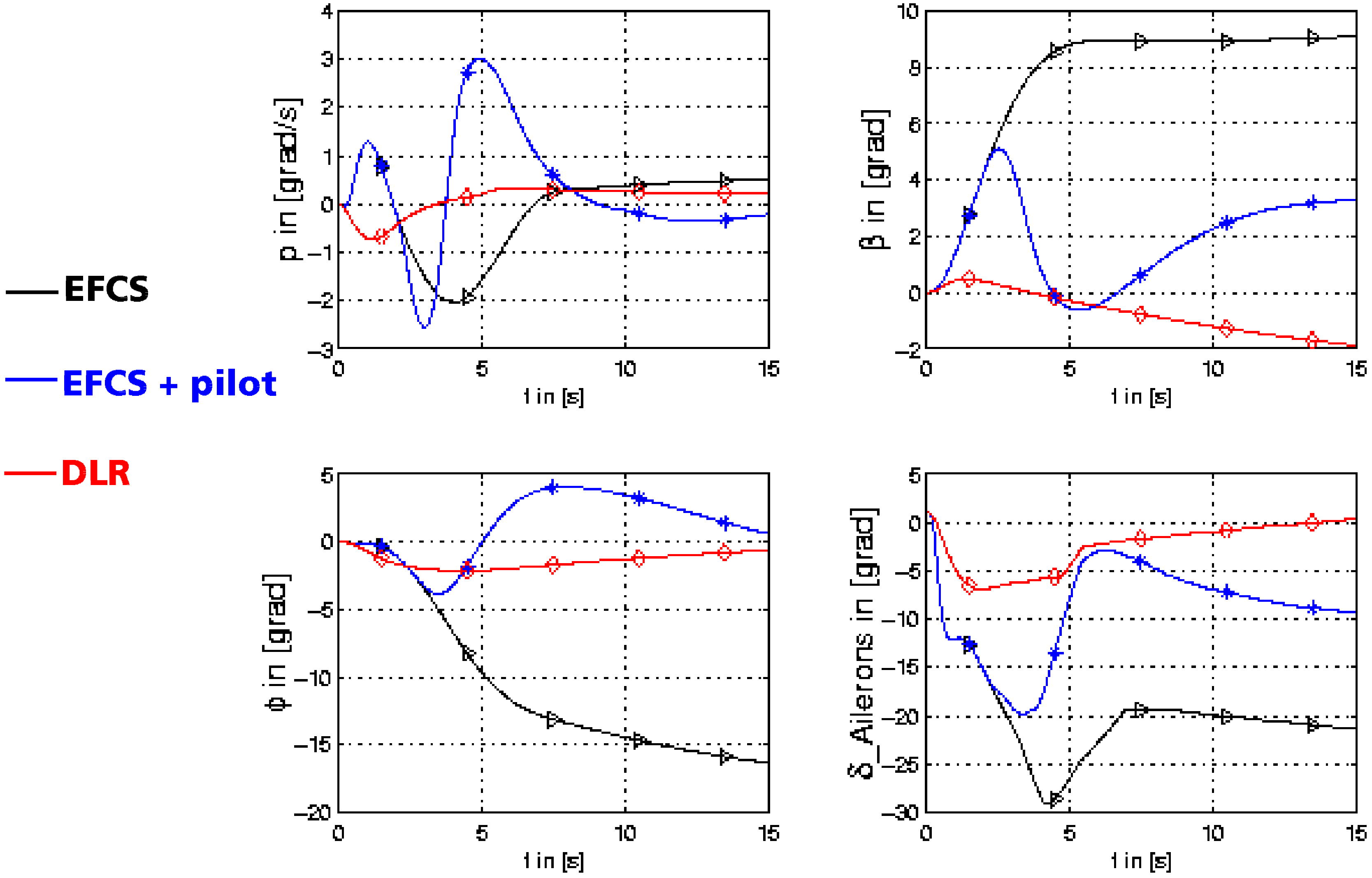
$\underline{x} = [\beta\ r]^T$ has a known dependence on r that can be compensated by δ such that $r \nrightarrow F_{ytail}(\underline{x},\delta)$.

The control law has been derived using a planar model of the aircraft involving no coupling with roll dynamics. Verification by simulation with the full model including the standard electronic flight control system (EFCS) and the „pilot panic reaction“ according to JAR 25.367.

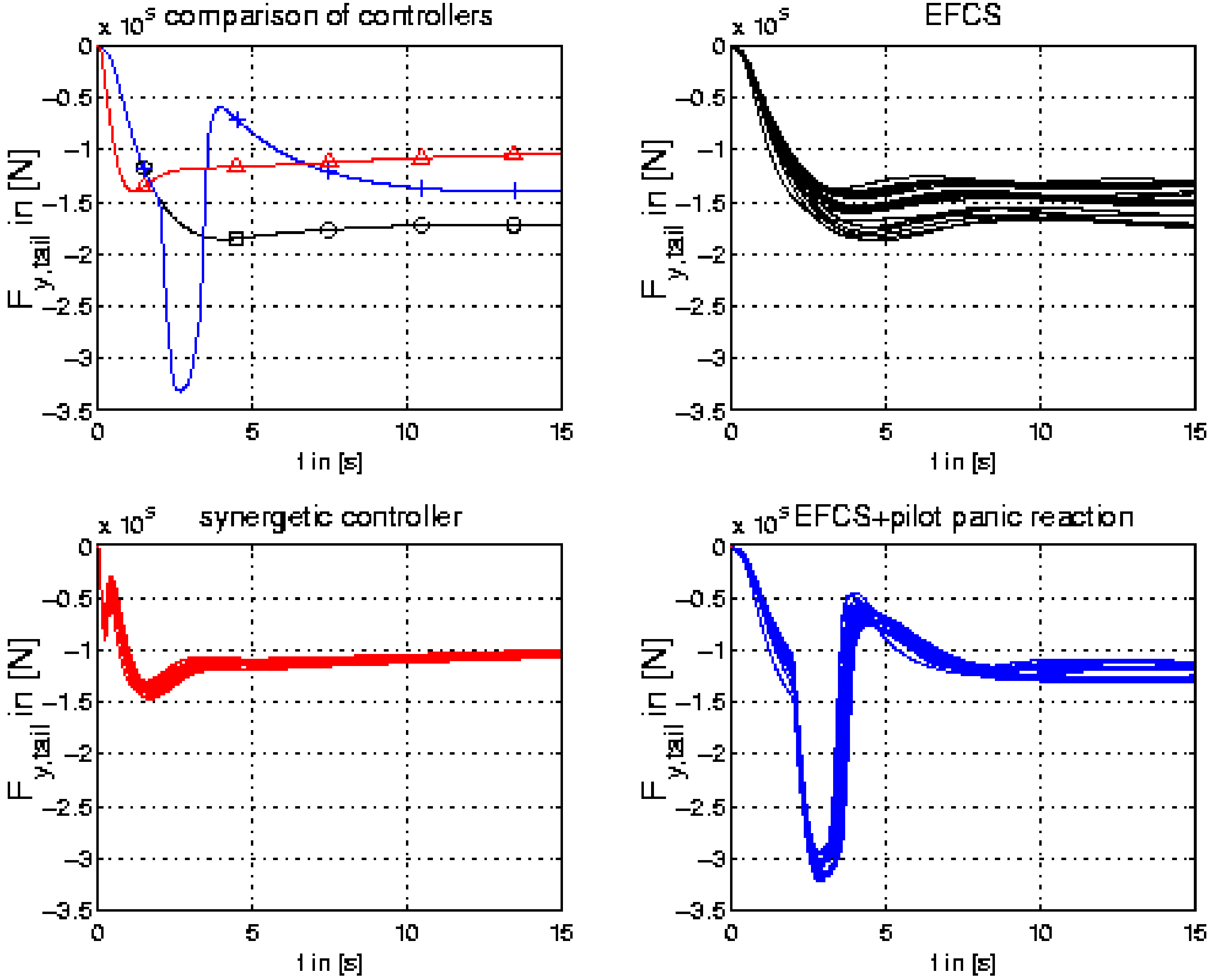
Primary effect in the planar motion



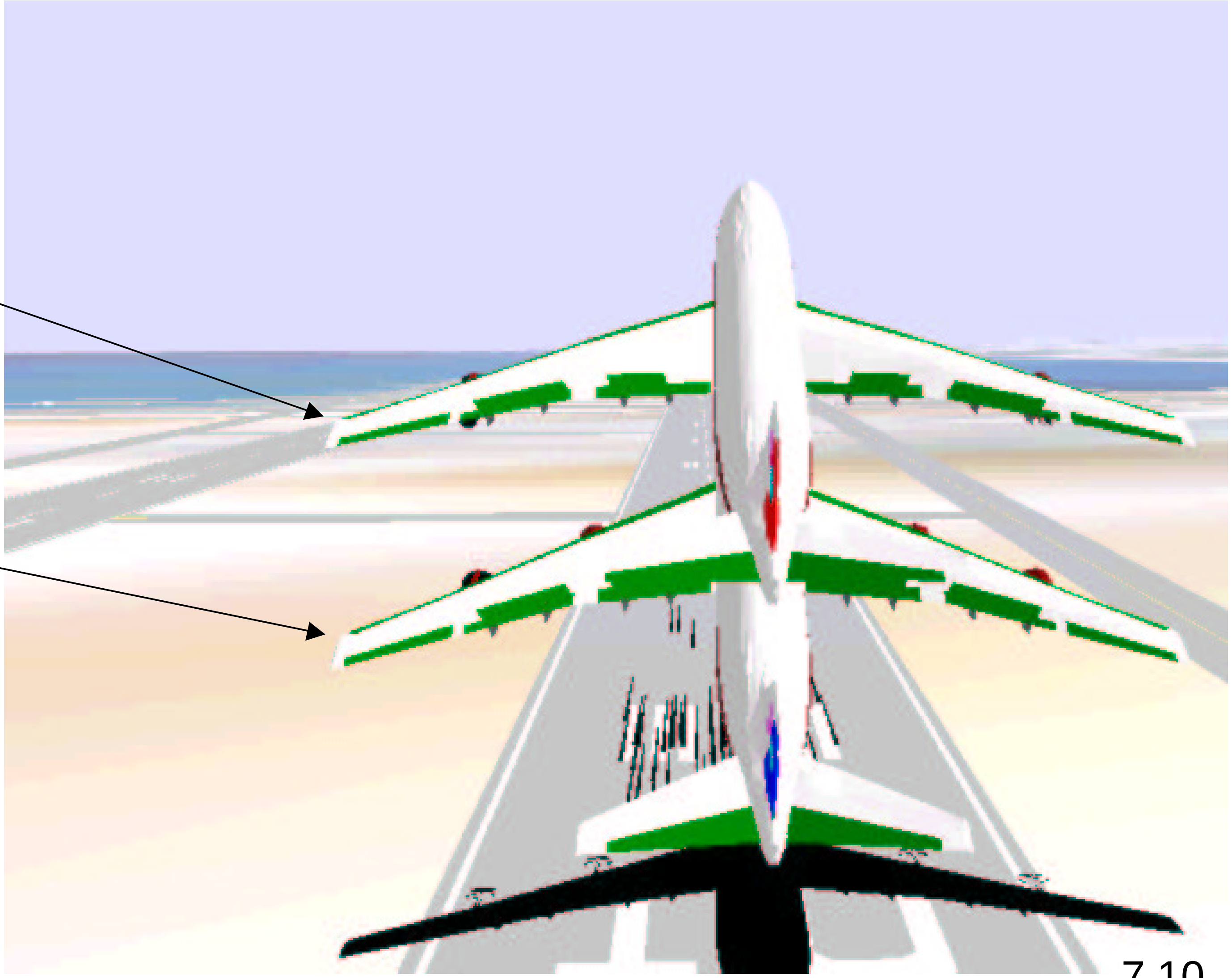
Secondary effect in the roll motion



Robustness analysis for 50 representative operating conditions

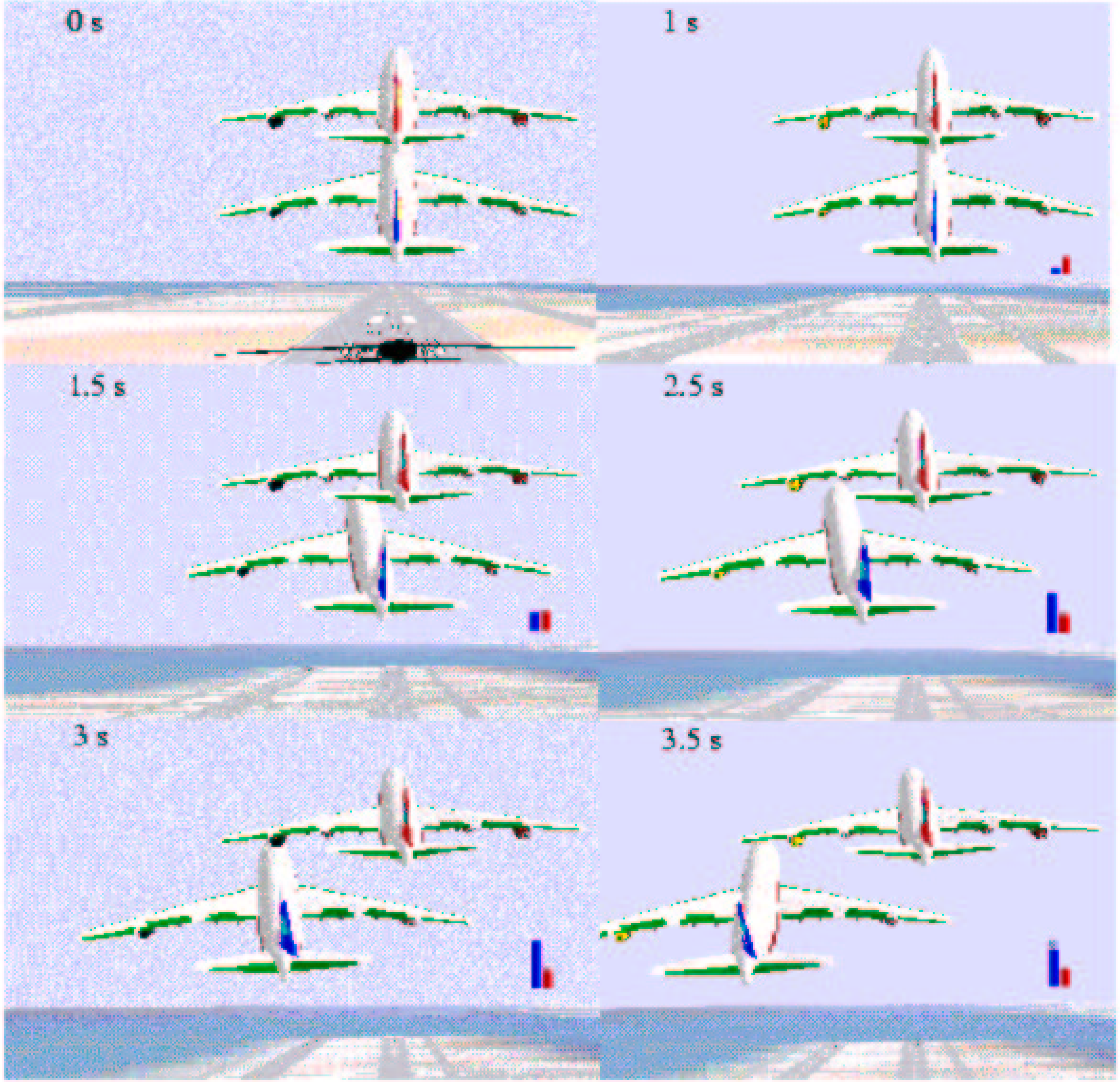


Outer left Engine-Out Maneuver



Robust Decoupling Engine-Out Controller

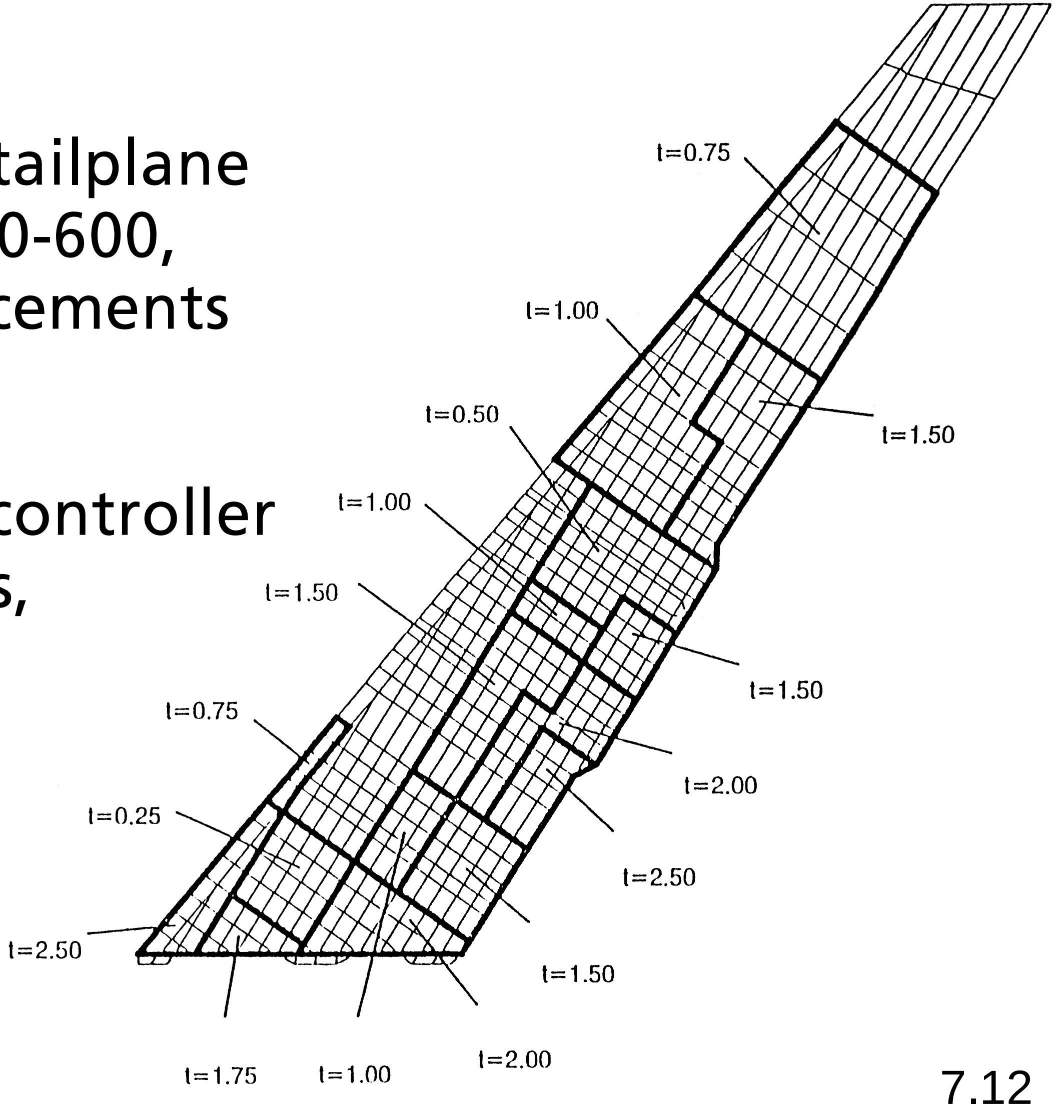
Conventional Aircraft with pilot panic reaction


0 s
1 s
1.5 s
2.5 s
3 s
3.5 s

Result

Old Plan: Reinforce tailplane of A 330-200 for A340-600, Figure shows reinforcements

New Plan: Use DLR controller leave tailplane as it is, save about 100kg, have communality, also for other Airbus models.



Conclusions

1 The robust decoupling concept for car steering yields significant safety advantages.

2 The concept is transferred to the aircraft yaw motion under engine burst.

3 In both cases the main effect is due to the immediate reaction as soon as a yaw rate occurs that was not commanded by the pilot. Thereby the human reaction time (and later overreaction) is avoided.

4 The specific advantages of robust control for the aircraft are:

No panic reaction → more safety
Reduced structural load → cheaper airplane
Low energy transfer into roll motion → comfort
Small aileron activity → reduced drag
Robustness → Uniform improvement for all operating conditions

5 The advantages of the control system are not restricted to the engine-out case. The same control system also attenuates the effect of other disturbance torques.