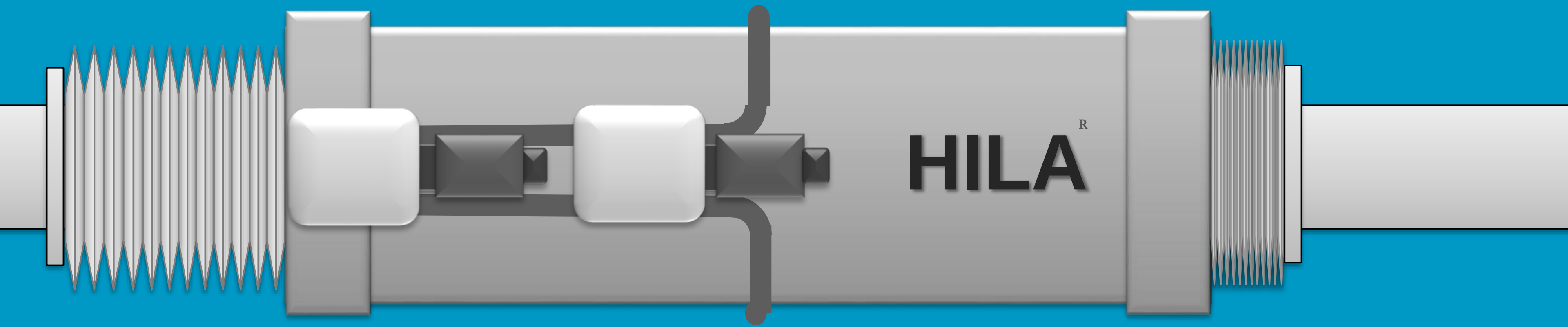


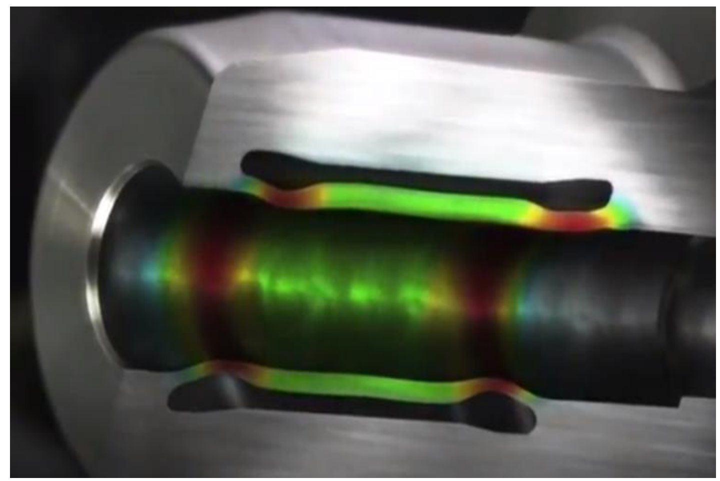
Simulation and optimization of HILA cylinder for elevator applications

Robert Braun, Linköping University

Magnus Landberg, Saab AB

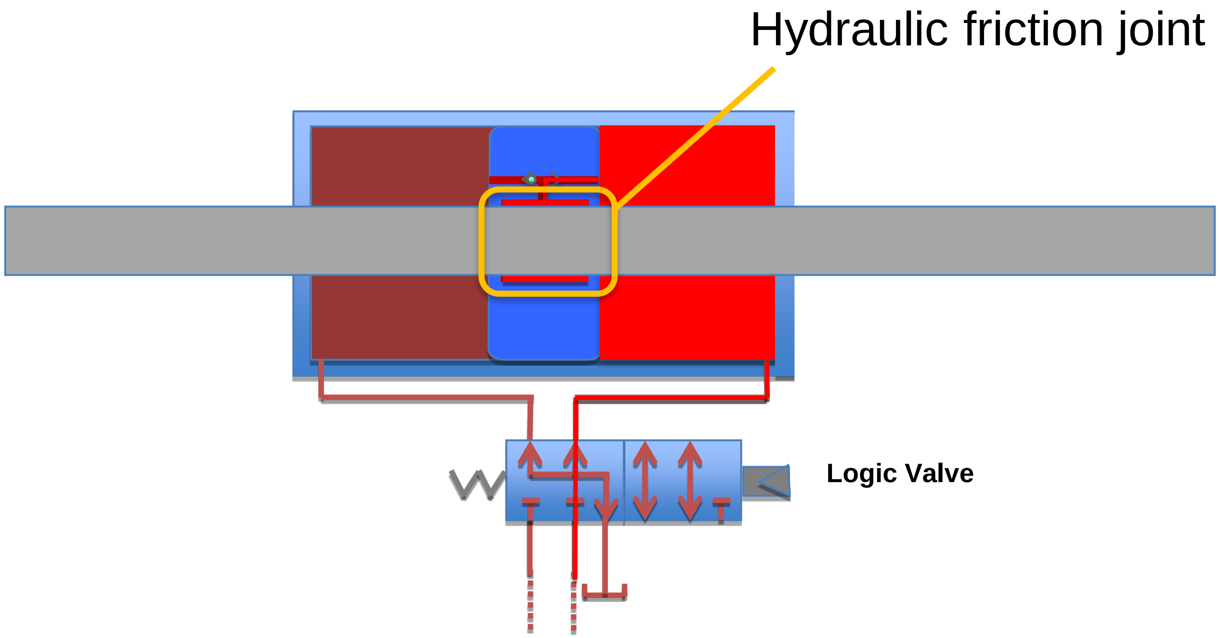
LINKÖPING UNIVERSITY

The invention
– a recombination of known techology

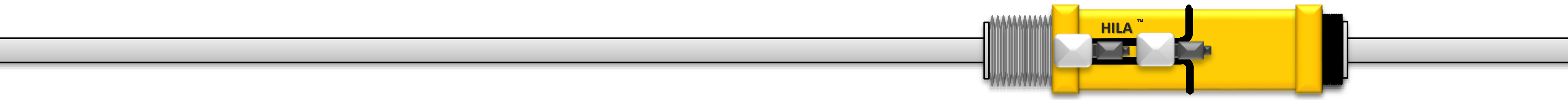


Risk Mitigation: Well proven technology used in a new application

A hydraulic cylinder with a releasable piston



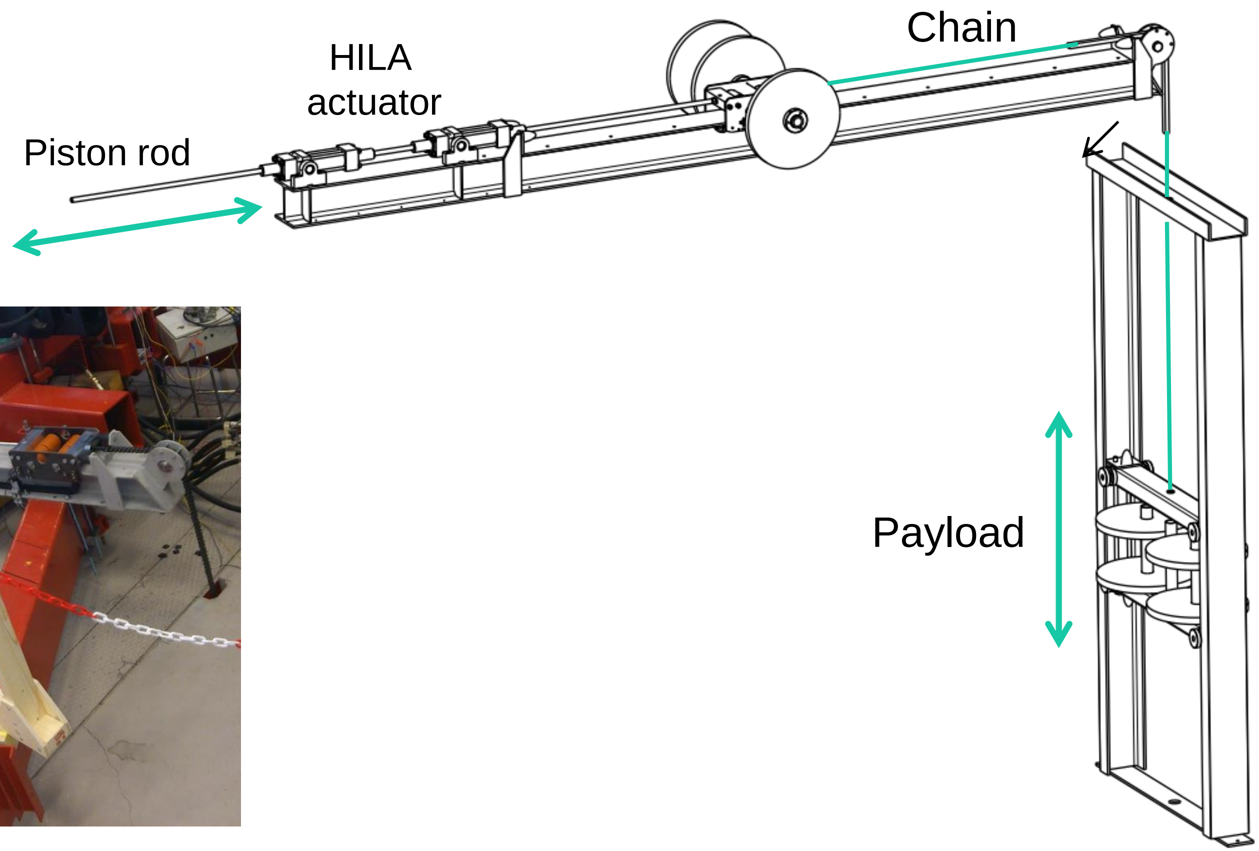
HILA TECHNOLOGY



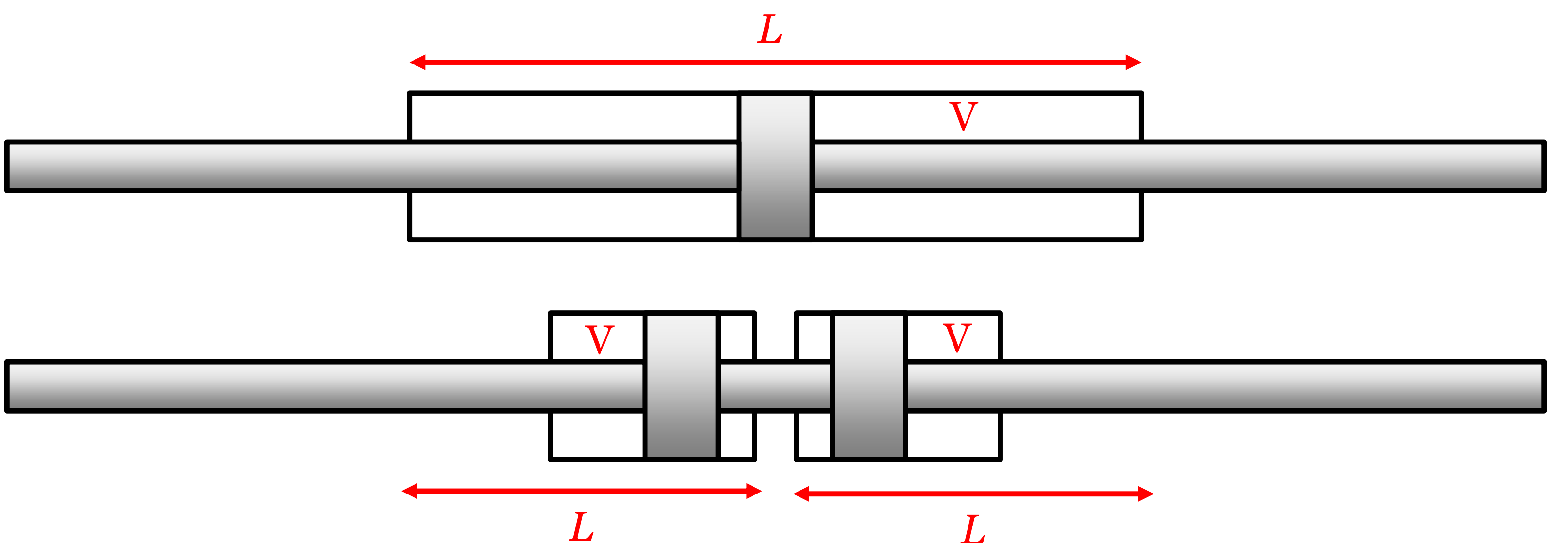
- **EXTENDED WORKING RANGE**
  - Long piston rods open up new areas and applications for hydraulic cylinders for example in elevators, additive manufacturing, portal robots, tooling machines etc
- **INCREASED CONTROL STABILITY**
  - Higher stiffness, higher natural frequency and higher system pressure
- **COMPACTNESS**
  – Shorter, lighter cylinder and higher system pressure - > Significant reductions in weight and volume, more cost-efficient and compact overall system designs, especially reservoirs. The cylinder can be placed in confined spaces.

Tests in Flumes lab at Linköping University

(sponsored by the Swedish Energy Agency)



HILA vs. conventional actuator



- Smaller chamber volumes
- Shorter piston stroke

HILA vs. conventional actuator

$$\left(\frac{\Delta F}{\Delta x}\right)_{min} = \frac{4\beta_e A_p^2}{V_t}$$

Smaller chamber volume → Higher stiffness

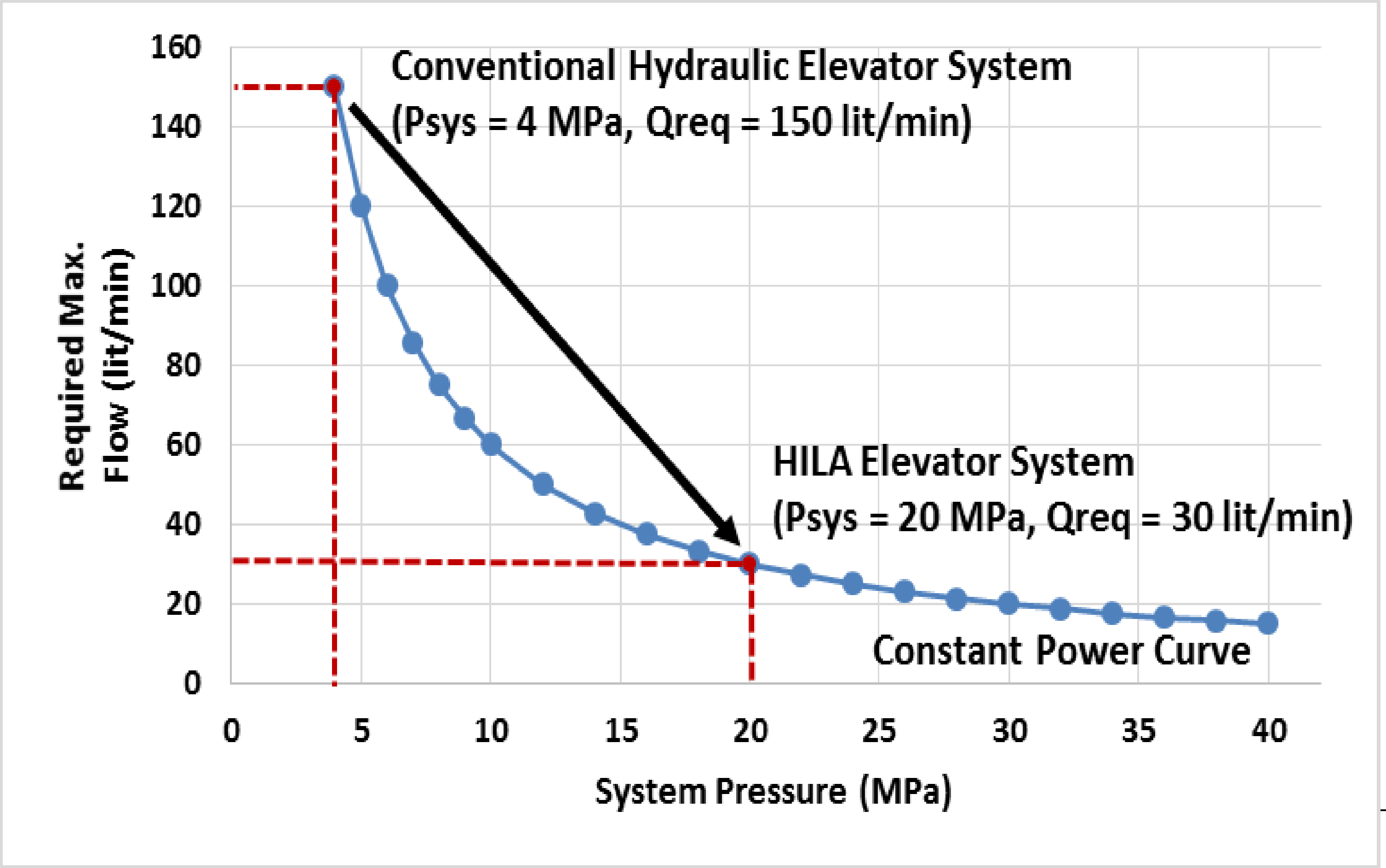
$$\omega_h = \sqrt{\frac{4\beta_e A_p^2}{M_t V_t}}$$

Smaller chamber volume → Higher eigen frequency

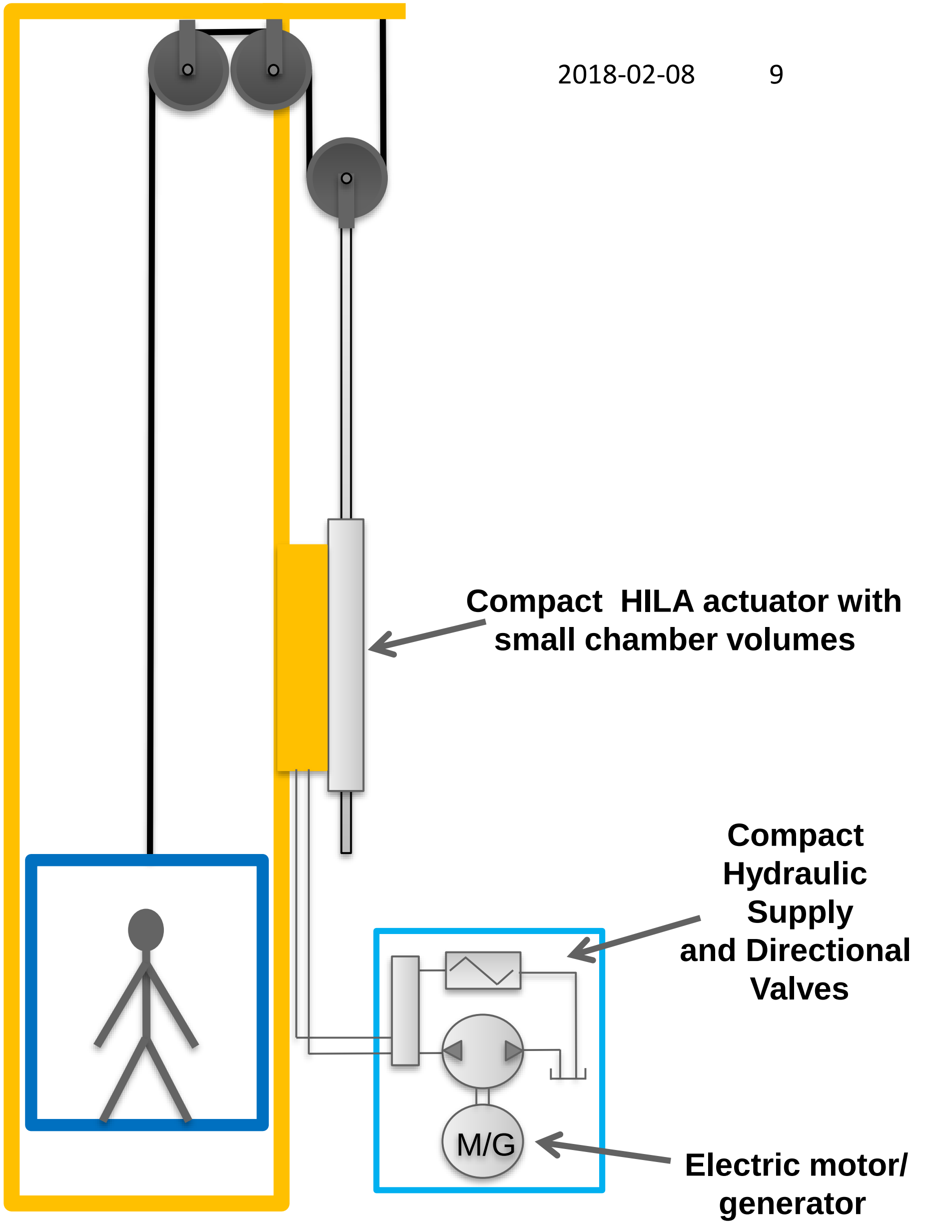
$$\omega_n \propto \sqrt{\frac{\beta}{L_{stroke} P_{system}}}$$

Shorter stroke → Enables higher system pressure (and smaller flow)

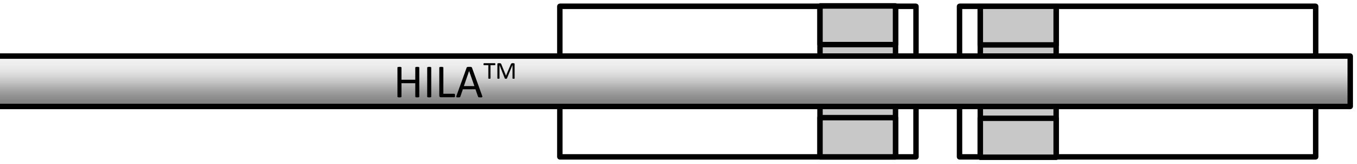
High System Pressure



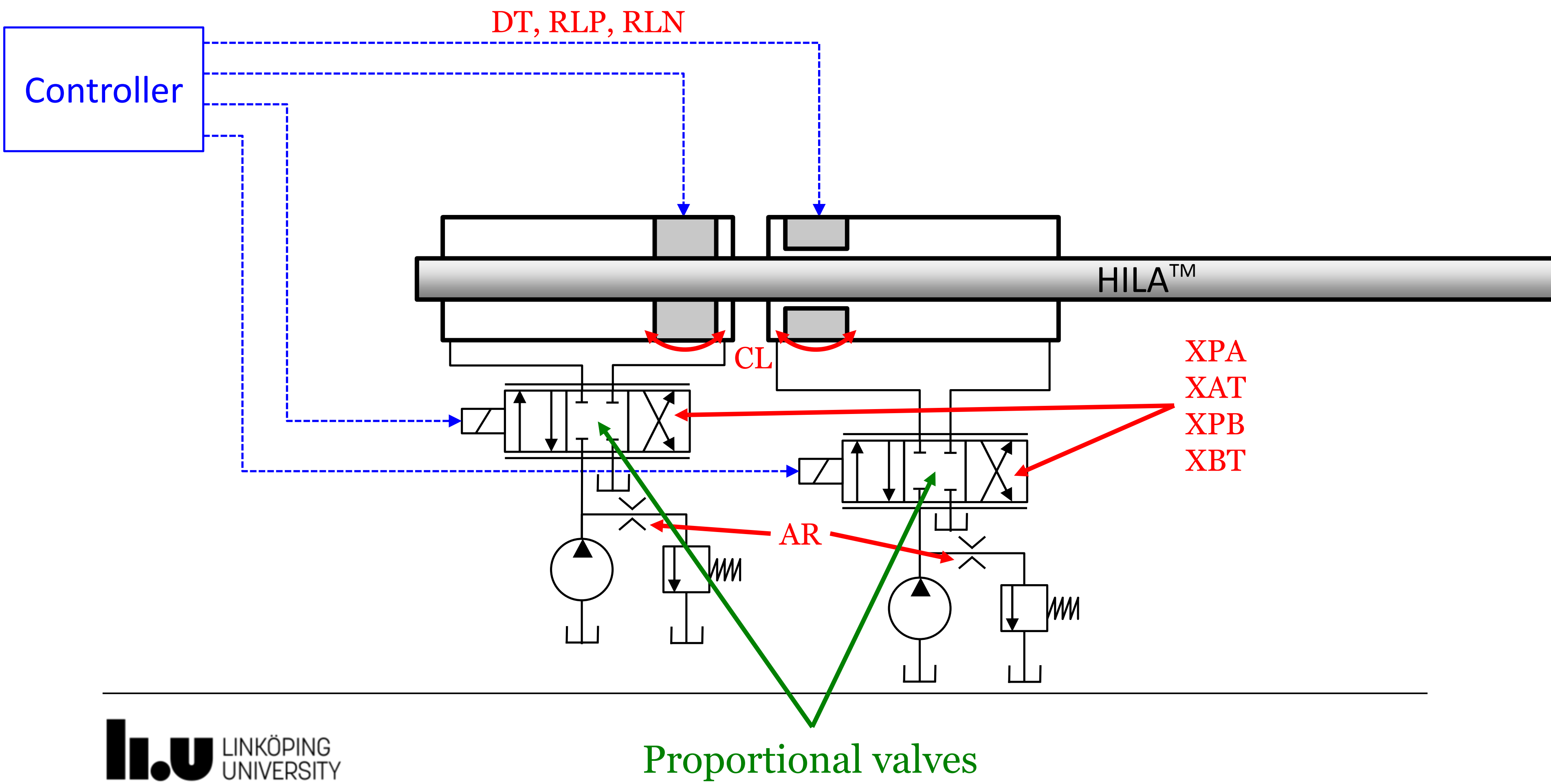
MRL HILA Elevator



Hydraulic Infinite Linear Actuator



Hydraulic Infinite Linear Actuator



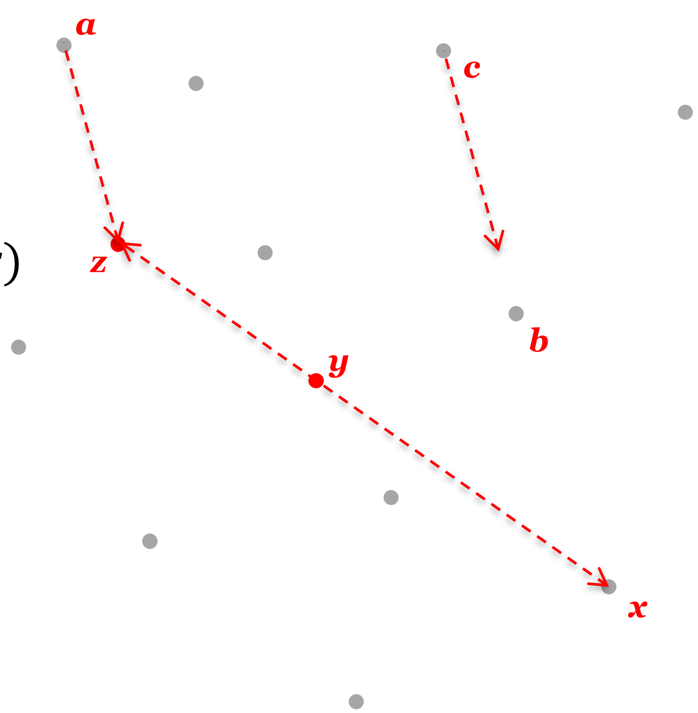
Optimization algorithms

- Complex RF(P)
  - High risk to find false optima
- Particle swarm
  - Brute-force, time consuming
- Differential evolution
  - Decent trade-off

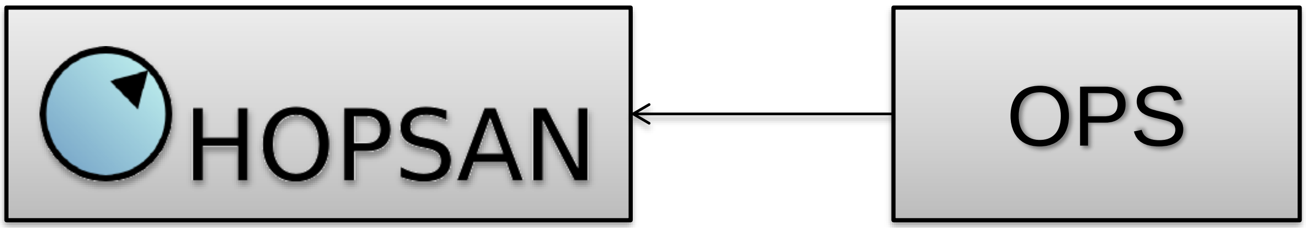
Differential Evolution

For each point $\boldsymbol{x}$ in the population:

1. Pick three other random points ($\boldsymbol{a}$, $\boldsymbol{b}$ and $\boldsymbol{c}$)
2. Compute intermediate point :
$$\boldsymbol{z} = \boldsymbol{a} + F \times (\boldsymbol{b} - \boldsymbol{c})$$
3. Perform binary crossover of $\boldsymbol{x}$ and $\boldsymbol{z}$
4. If $f(\boldsymbol{y}) > f(\boldsymbol{x})$: Replace $\boldsymbol{x}$ with $\boldsymbol{y}$



Optimization Software



API:

```
virtual void evaluateCandidate(int idx);
void setCandidateObjectiveValue(int idx, double value);
double getCandidateParameter(int pointIdx, int parIdx);
```

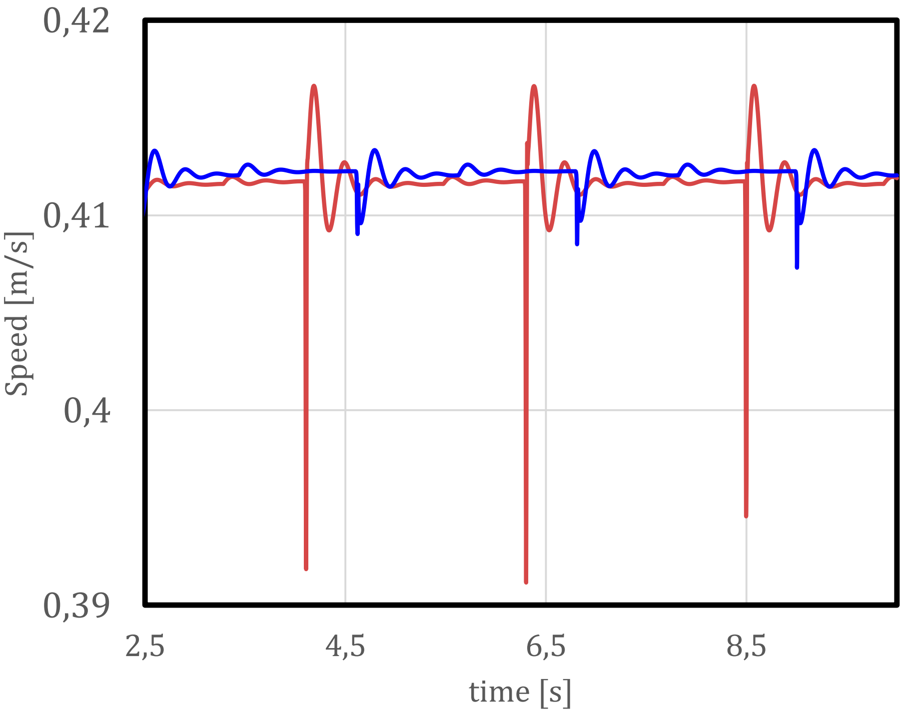
Algorithms:

- Nelder-Mead Simplex
- Box Complex-RF(P)
- Differential Evolution
- Particle-Swarm Optimization
- Controlled Random Search
- Parameter Sweep

Parallel (Box Complex-RF(P) through Parameter Sweep)

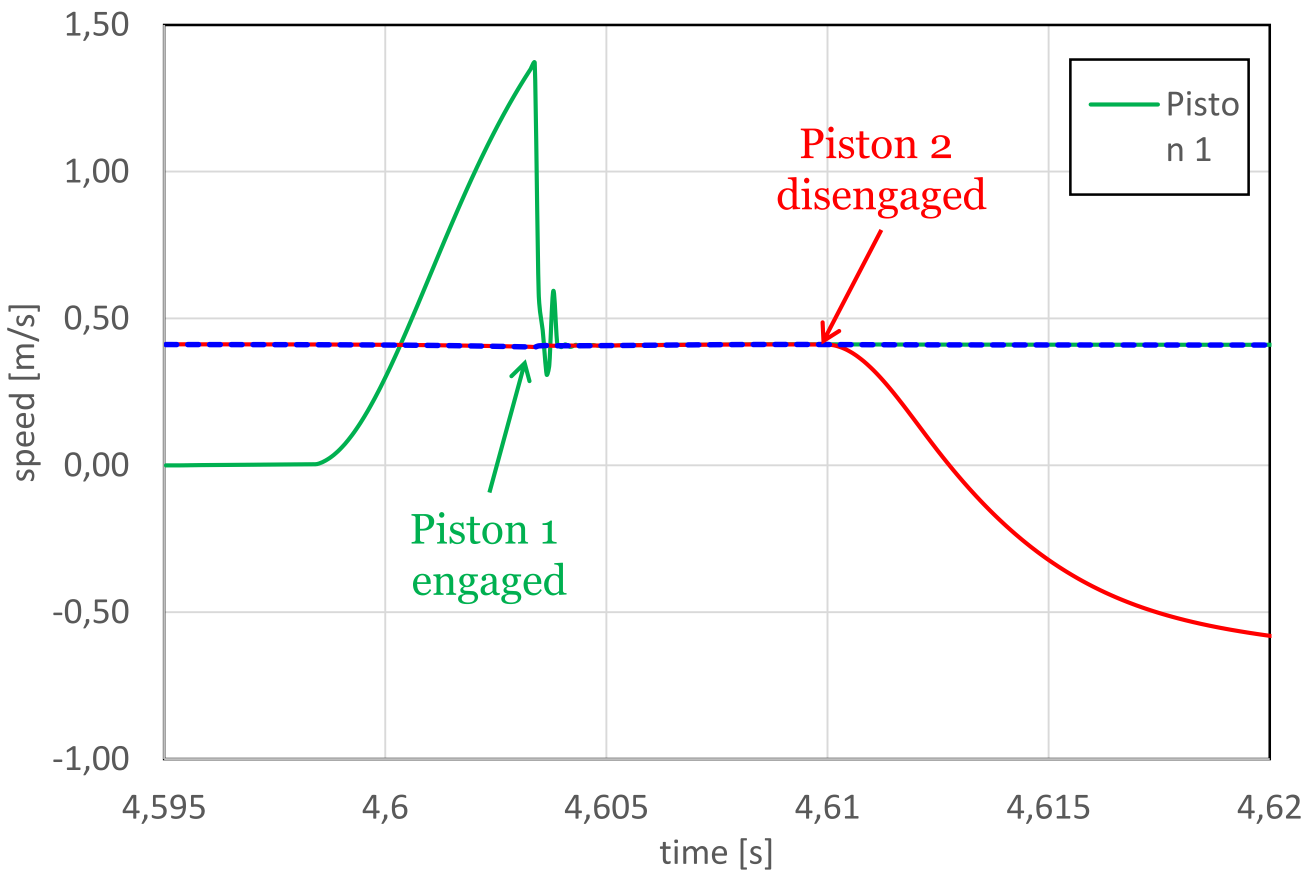
Optimization results

Name	Value	Unit	Description
AR	2.54e-6	m^2	Restrictor area
CL	1e-11	m^3/sPa	Leakage coeff.
DT	0.0182	s	Time delay
RLP	10000	V/s	Pos. rate limit
RLN	150	V/s	Neg. rate limit
XAT	-0.00067	m	Overlap A-T
XBT	0	m	Overlap B-T
XPA	-0.00093	m	Overlap P-A
XPB	0	m	Overlap P-B

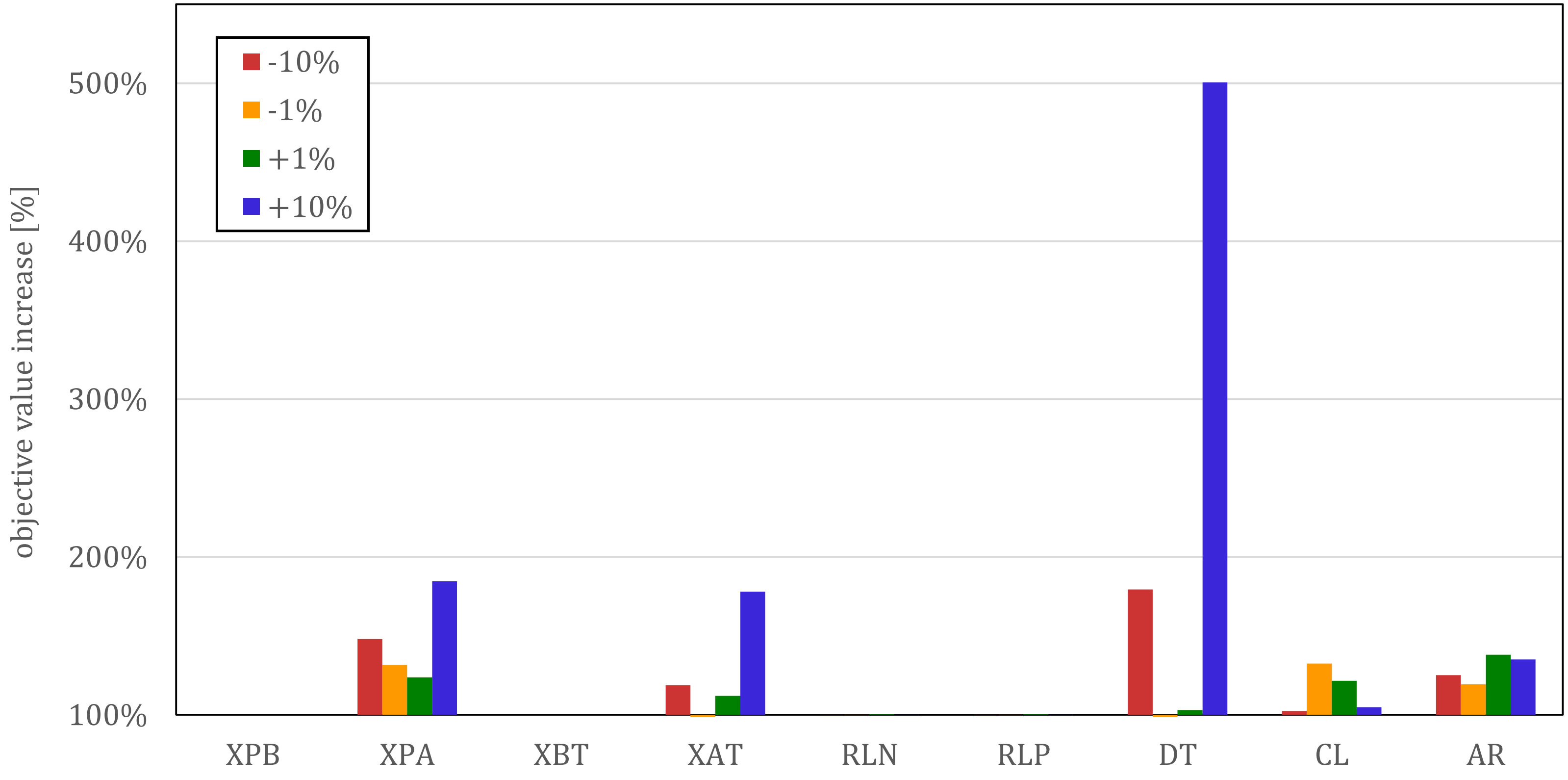


Optimization results

Optimization results



Sensitivity analysis



Design freedom vs sensitivity?

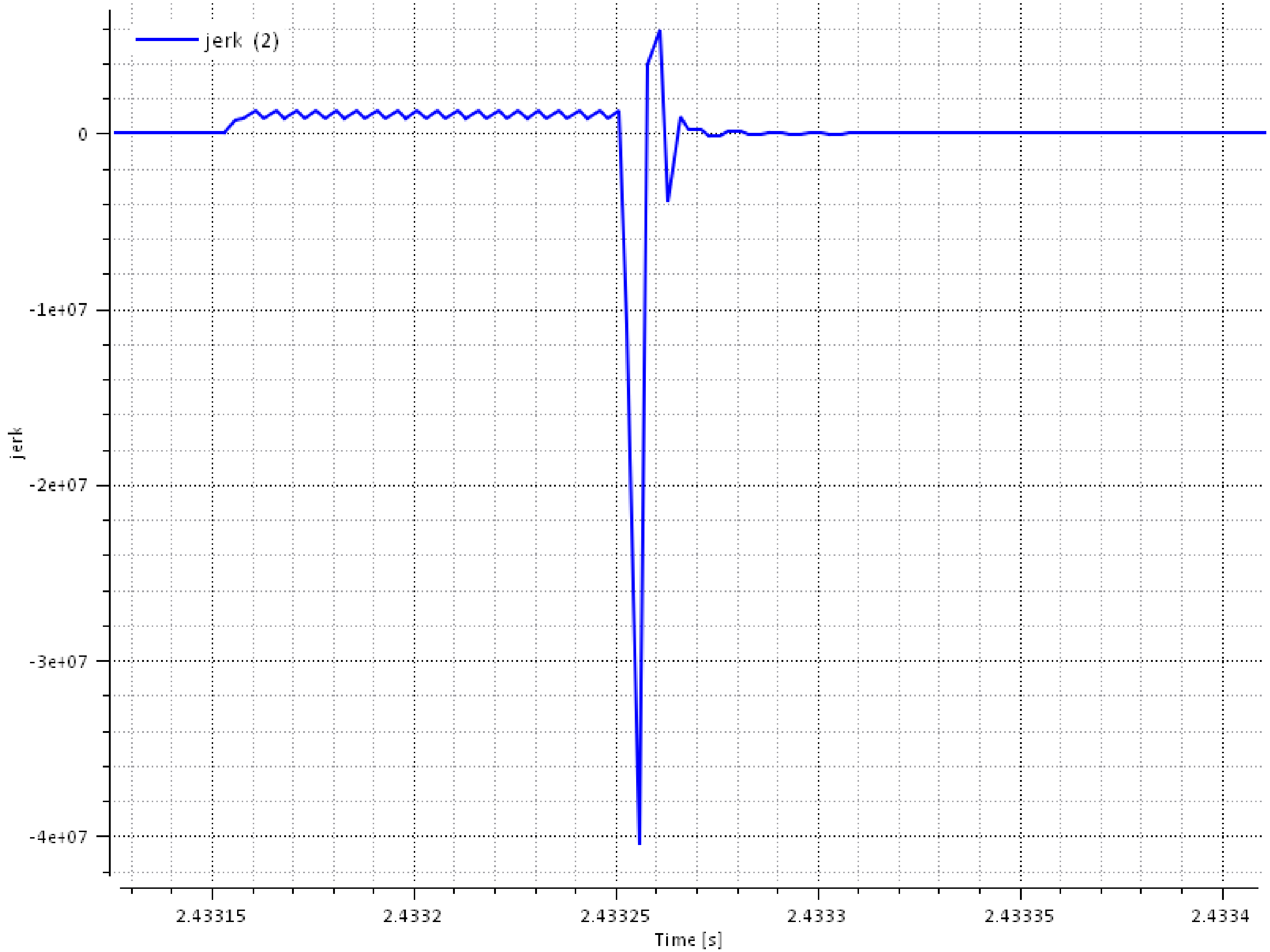
Name	Design freedom	Sensitivity
AR	Large	Medium
CL	Small	Medium
DT	Small	High
RLP	Medium	Low
RLN	Medium	Low
XAT	Large	Medium
XBT	Large	Low
XPA	Large	Medium
XPB	Large	Low

Problem?

Passenger comfort

- Jerk $\bar{\jmath} = \dot{\bar{a}} = \ddot{\bar{v}} = \dddot{\bar{x}}$ [m/s^3]
  - 0.7 m/s^3: hospital environments
  - 2.0 m/s^3: acceptable
  - 7.0 m/s^3: intolerable
- How simulate jerk?
  - Numerical differentiation?
  - Small step size?
  - Dense logging?

Jerk


jerk (2)
0
-1e+07
-2e+07
-3e+07
-4e+07
jerk
2.43315
2.4332
2.43325
2.4333
2.43335
2.4334
Time [s]

Challenges

- Smooth movement without servo valves
- Minimizing jerk
  - Simulating jerk?
- Limiting design freedom
- ”Unknown unknowns”?

www.liu.se

www.liu.se

www.liu.se

LINKÖPING UNIVERSITY