# Numerical Modelling of Explosion Relief Devices

***6th CIMAC CASCADES 2015, February 26th – 27th***

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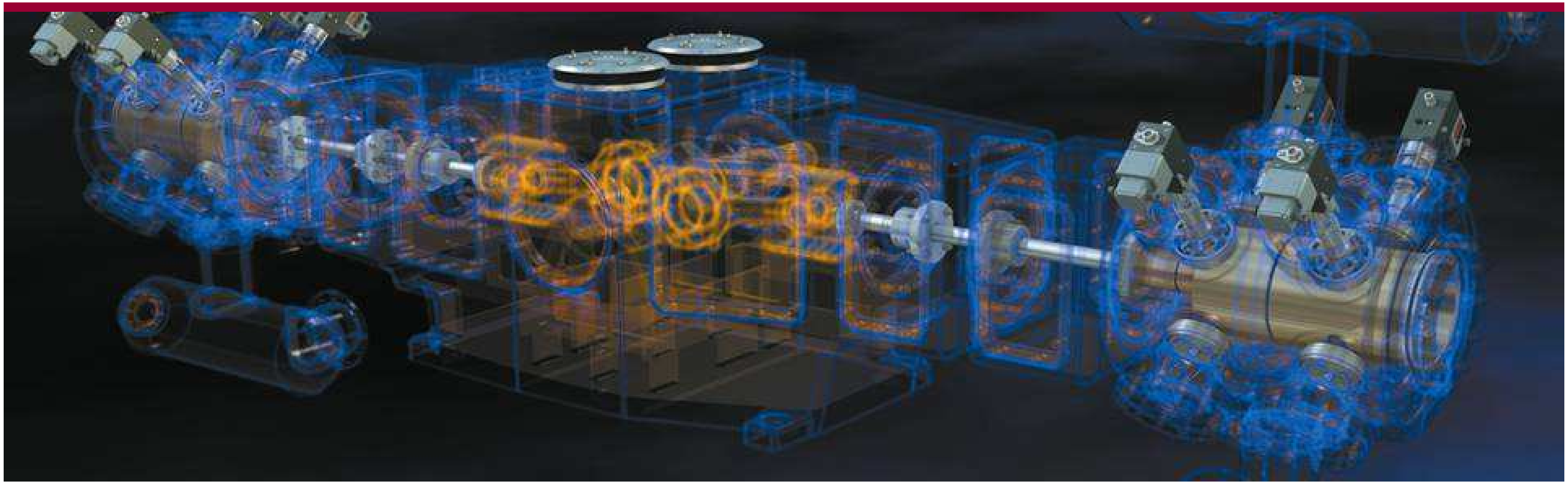

# Content

- Introduction, Overview and Flame Propagation
- State-of-the-art Safety Solutions and System Design
- Numerics and User Interface
- Experimental Verification

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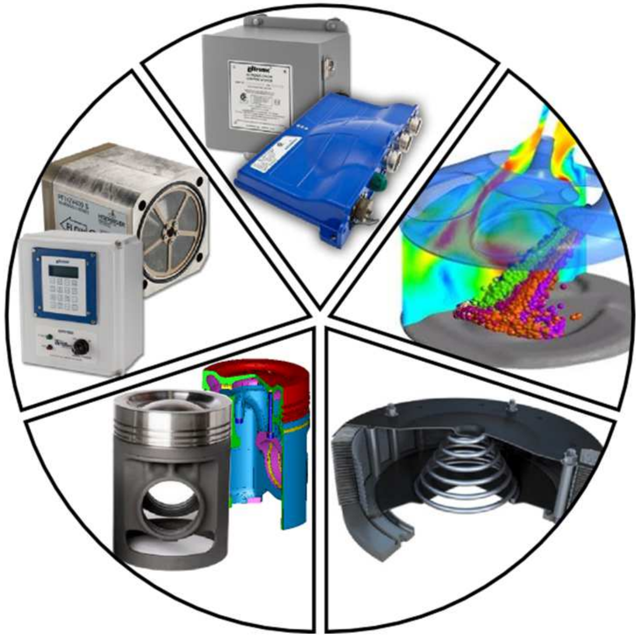
# Introduction – Large gas engines and duel fuel engines

**… gain popularity over diesels thanks to R&D activities and components with greatly improved performance.**



- New materials and designs
  for pistons, valves, bearings, …
- Mechatronics
  New injection and duel-fuel systems, …
- Electronics
  Ignition systems, engine control systems
- Fluid- and thermodynamics
  Development of new combustion strategies, …

**Drawback: risk of explosions in the inlet and exhaust manifold**

**➔ Safety solutions are a vital yet neglected area namely in terms of**

- efficiency – lack of reliable, accurate and fast engineering methods
- optimality – minimizing costs without sacrificing safety

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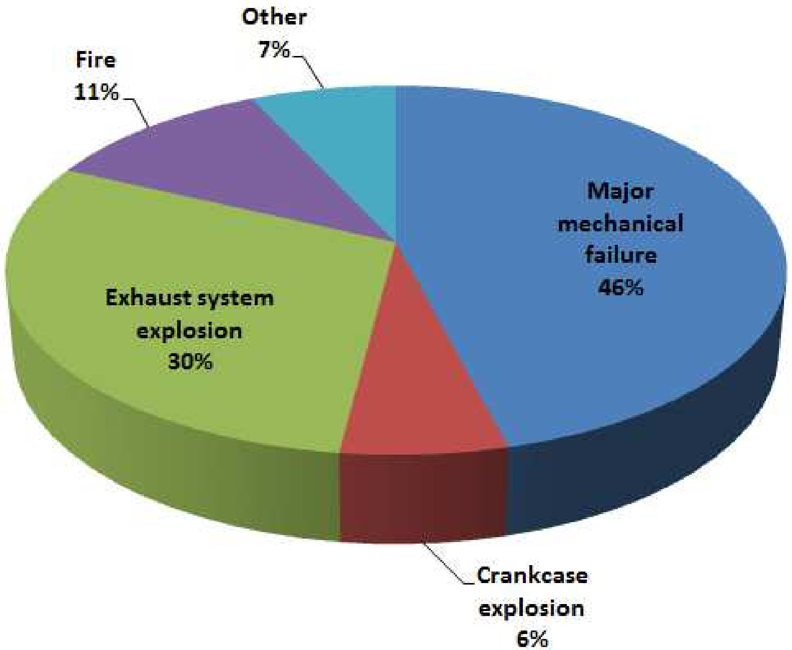
# Introduction – Exhaust system explosions

**Study - Analysis of gas engine in cogeneration applications in Denmark:**

De Wit, J.: *Safety matters: Experience with the operation of gas engine CHP units*;
Cogeneration and On-site Power Production, Vol.7, Issue 5, 2006




- 800 – 900 gas engines installed representing a total of some 950 MWe power capacity
- Number of incidents each year:
  20 (1997)
  5 (2005)
- 30% of all recorded incidents due to exhaust systems explosions

➔ **0.5 % of all installed engines face severe damage and shutdown time due to exhaust system explosions every year!**

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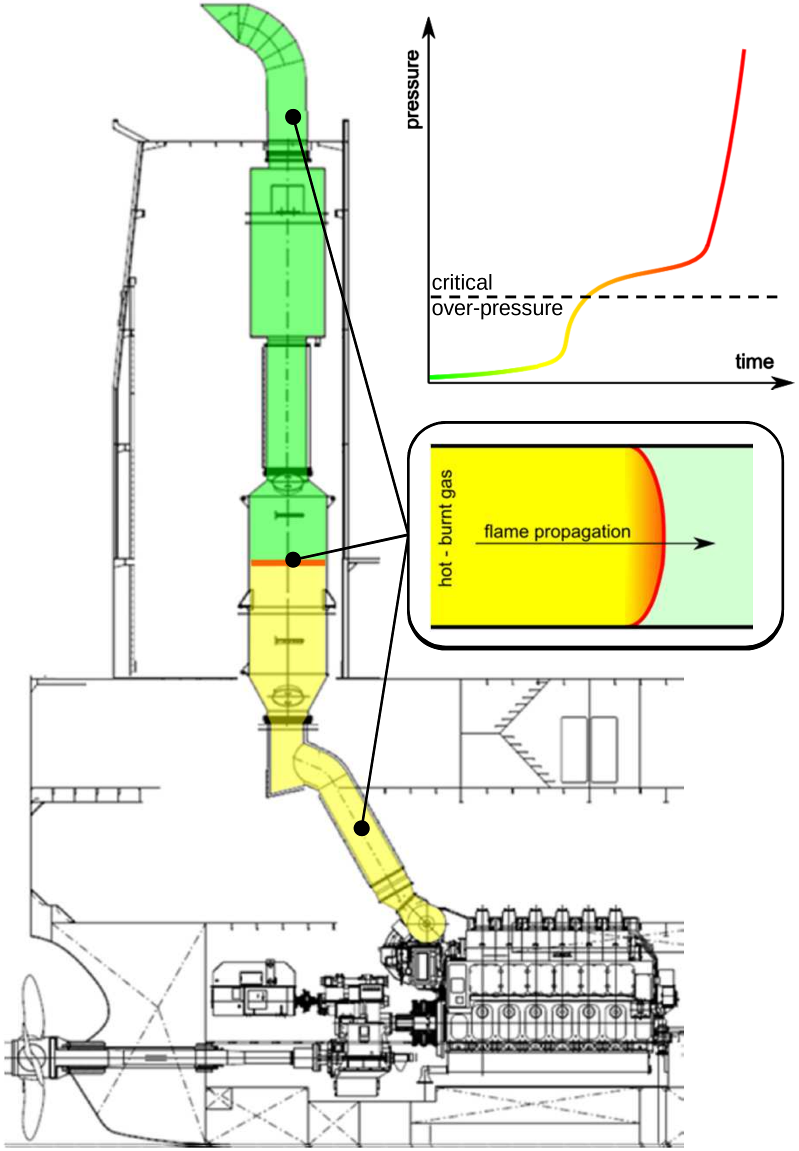
# Physics – Flame propagation




- **Ignition at a “hot spot”**
- **Deflagration** - laminar
  - Laminar flame propagation
  - Released heat induces flow field
  - ➔ Flow field generates turbulence
- **Deflagration** - turbulent
  - Transition from laminar to turbulent flame propagation
  - ➔ Flame acceleration
  - ➔ Critical over-pressure level
- **Detonation**
  - Potential transition from deflagration to detonation
  - ➔ Critical over-pressure level exceeded

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# Safety solutions – State-of-the-art Measures

| | Measures on the gas engine | Measures on the exhaust system |
|---|---|---|
| Type of prevention | prevent combustible mixture built-up | prevent damaging overpressure |
| Measures | ▪ Blower / purging<br>▪ Limiting number of start attempts<br>▪ Detecting misfiring<br>▪ … | ▪ Burst discs<br>▪ Explosion relief valves<br>▪ … |

➔ **Smart combination of engine and exhaust system measures necessary !**

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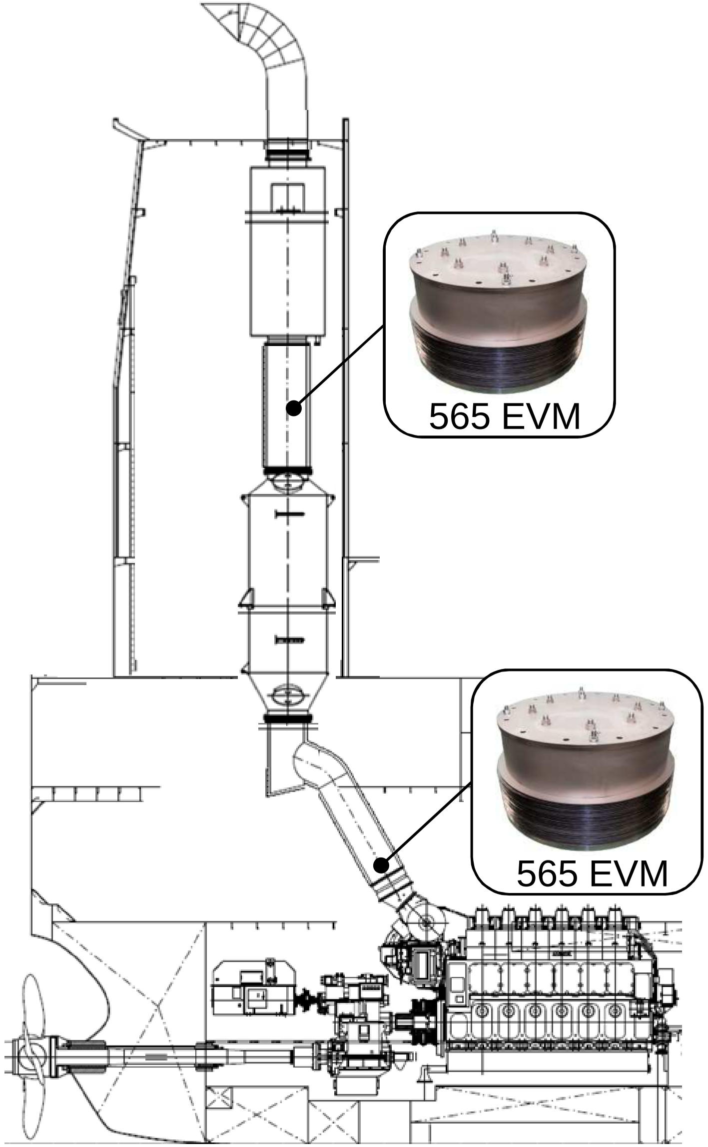
# Safety solutions – Design and safety criteria




I. Prevent critical over-pressure levels

II. Prevent flame transmission into the engine room

III. Uninterrupted operation of engine

IV. No engine load reduction

V. Keep the costs low

➔ **Optimizing the system under all design and safety criteria calls for an engineering tool!**

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# Numerics – State-of-the-art methods

## Method

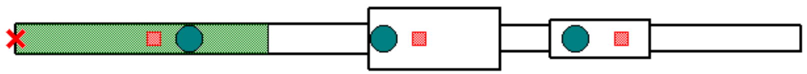
- Algebraic equations

typically given by standards e.g. EN 14994

$$p_{red} = p_{stat} + \left(0.023 \cdot S_{ui}{}^{2} \cdot K \cdot W \cdot (L/D)^{1/3}\right)/V^{1/3}$$

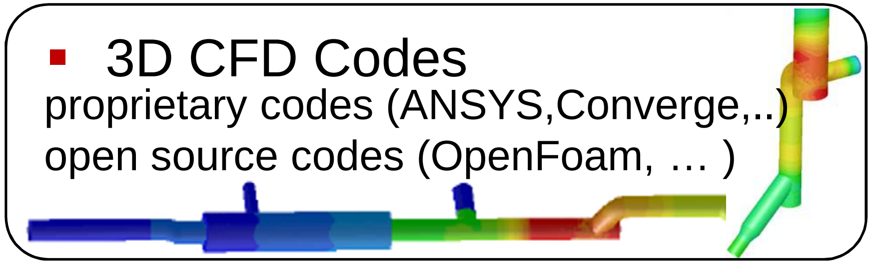
- 1D approach

1d solver for Euler-equations

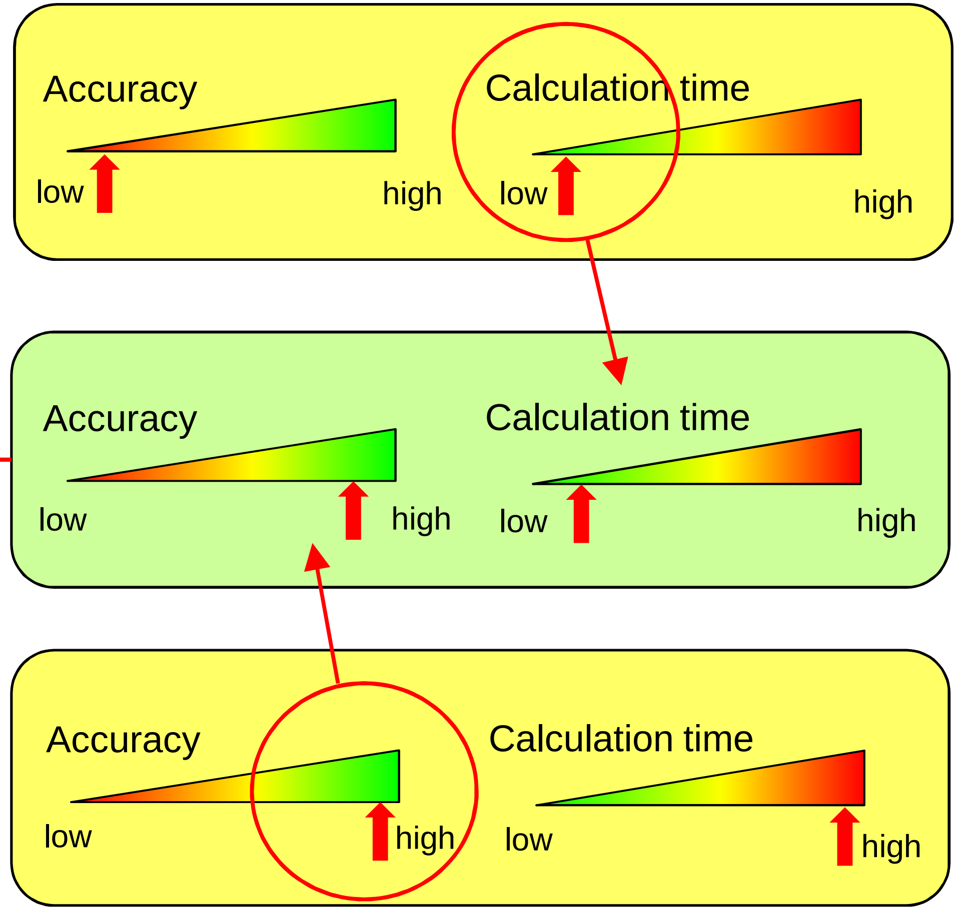


- 3D CFD Codes

proprietary codes (ANSYS,Converge,..)
open source codes (OpenFoam, … )



## Performance

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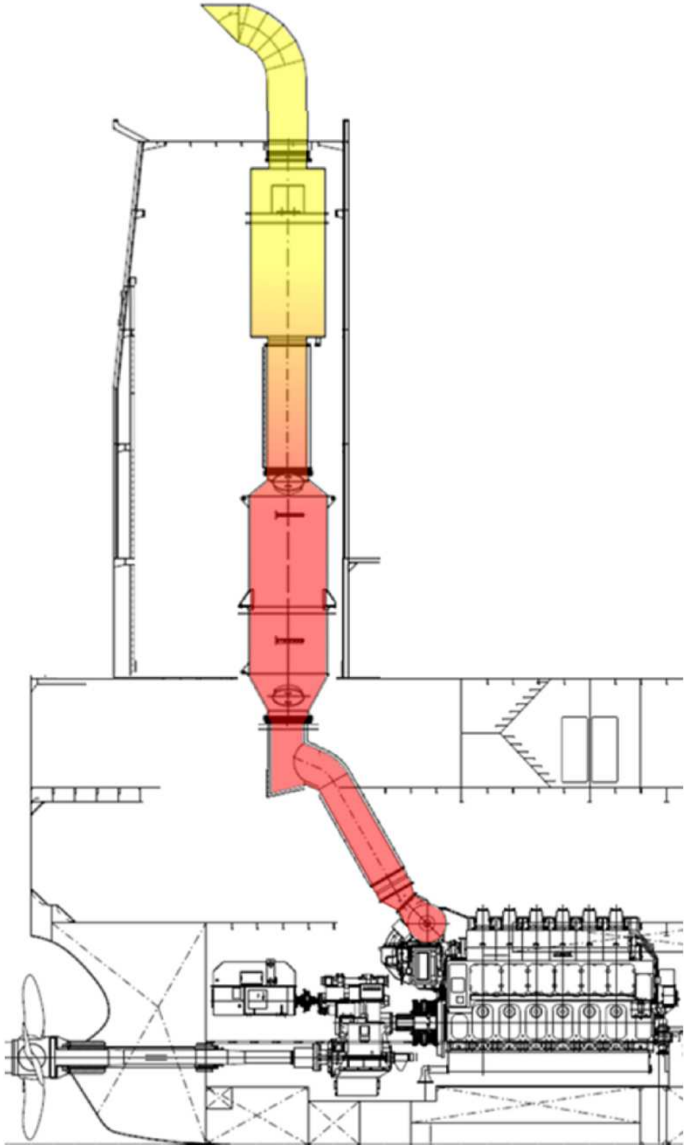
# Numerics – Modelling



- **Gas dynamics**
  - Unsteady 1d - Euler equations
  - Prandtl's - turbulence model
- **Flame propagation**
  - Flame tracking method
  - Burning laws – laminar/turbulent
- **Internals**
  - Source term modelling of heat exchangers, silencers, catalysts, …
- **Relief valves**
  - Valve dynamics
  - Heat transfer: gas – flame arrester
- **Adjacent rooms** (e.g. Machine room,…)
  - Pressure
  - Temperature

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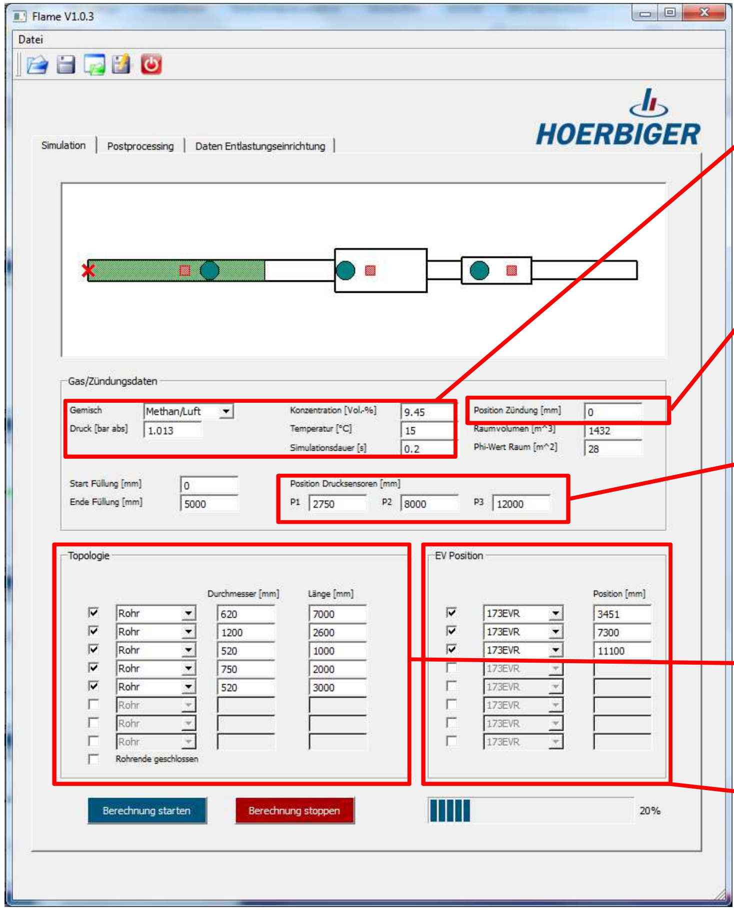
# Numerics – User Interface – data input

## Explosion Simulation and Engineering tool - ExploSE




### Define failure mode

- Define gas mixture
  *concentration, pressure, position, …*
- Define ignition point

### Define post-processing data

- Define pressure sensors

### Define system topology

- Define exhaust system topology
  *piping, elbows, other internals, …*
- Define explosion relief devices
  *Valves, burst discs*

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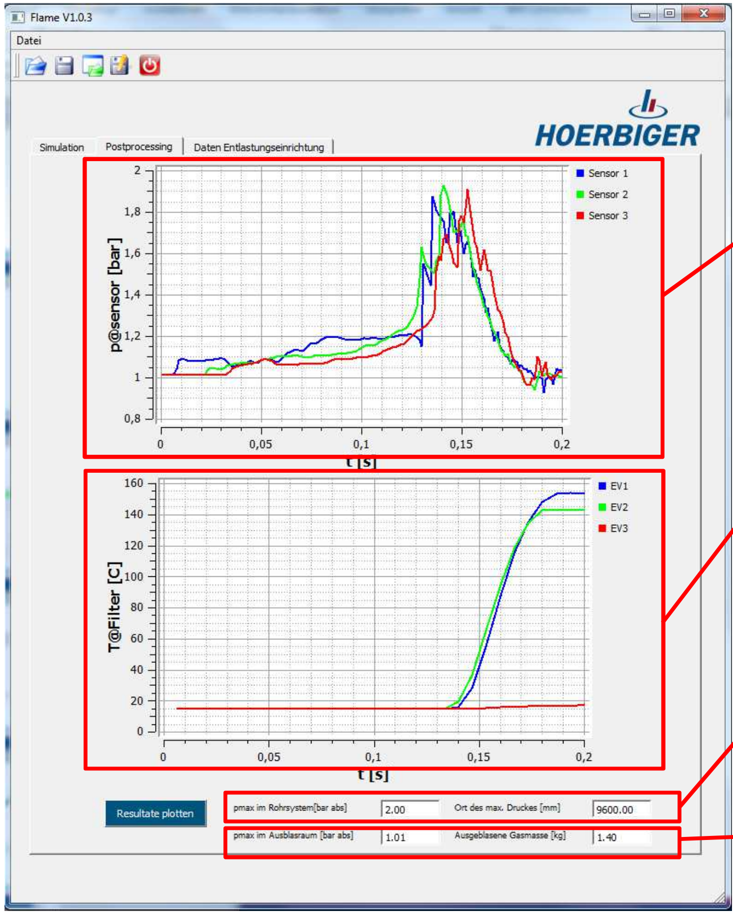
# Numerics – User Interface – post-processing
## Explosion Simulation and Engineering tool - ExploSE




**Pressures**
at the defined sensor positions

**Flame filter temperatures**

**Max. system pressure**
and position

**Pressure rise adjacent room**

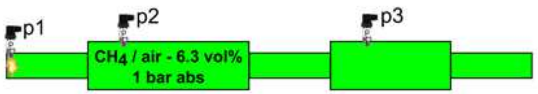
# Numerics – Failure modes

**Failure mode I: ($CH_4$ 9.45vol%)**

Shut-down after detected misfiring and ignition at the turbocharger

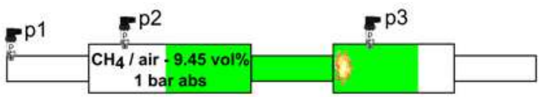

**Failure mode II: ($CH_4$ 6.3vol%)**

Shut-down after detected misfiring, blower venting the mixture and ignition at the turbocharger

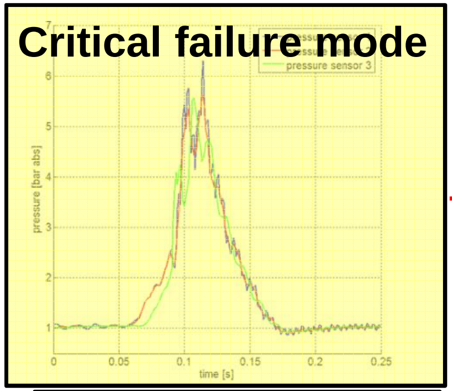



**Failure mode III:: ($CH_4$ 9.45vol%)**

Shut-down after detected misfiring, and ignition at the catalyst




**Critical failure mode**



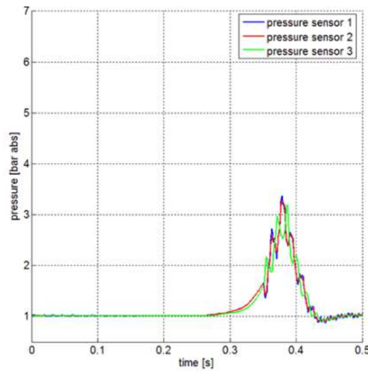

**Optimization**

Explosion relief valves

- number
- size
- position

**Critical failure mode ?**

- pressure level
- temperature
- …

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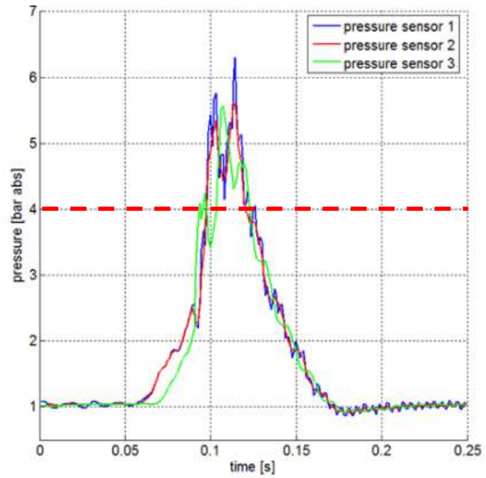
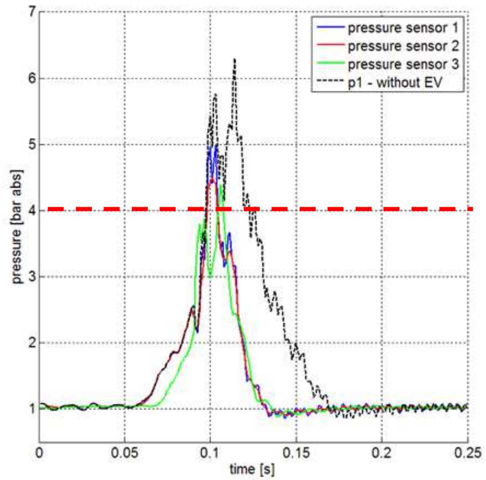
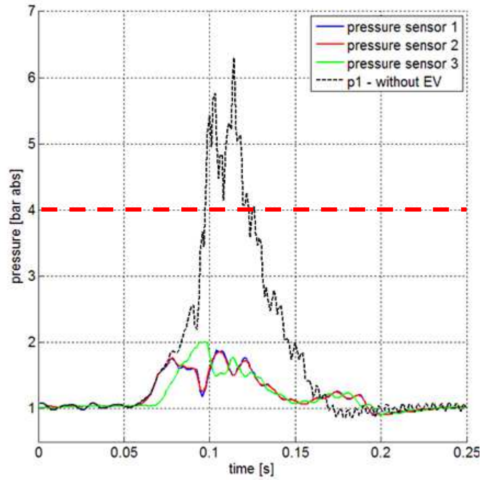
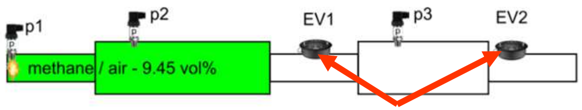
# Numerics – Optimization



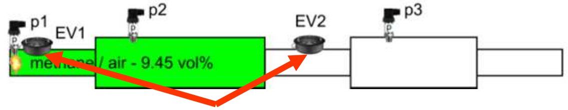








**Position 1 of Explosion relief valves**




**Position 2 of Explosion relief valves**

**<u>Original configuration</u> (without explosion venting)**

max. pressure: 6.2 bar

**<u>Safety solution I</u> (Explosion relief valve positioning 1)**

max. pressure: 5.0 bar

**Safety solution II (Explosion relief valve positioning 2)**

max. pressure: 2.0 bar

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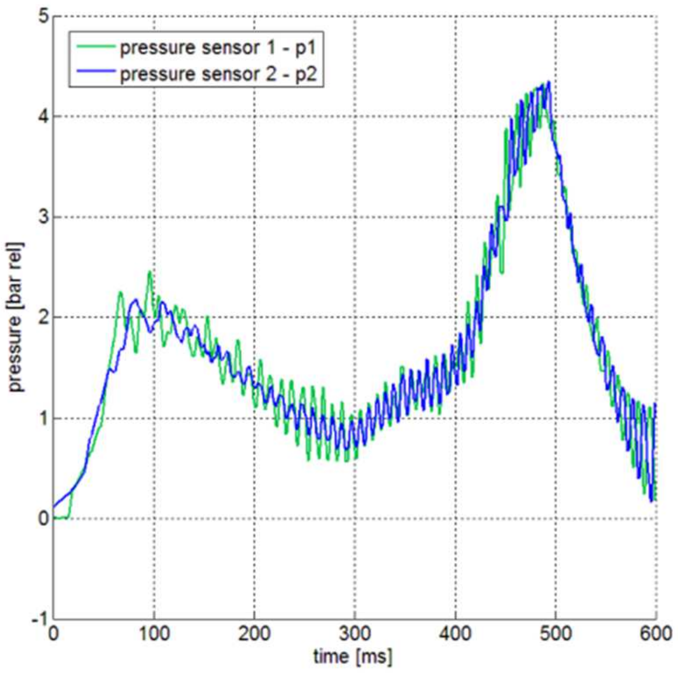
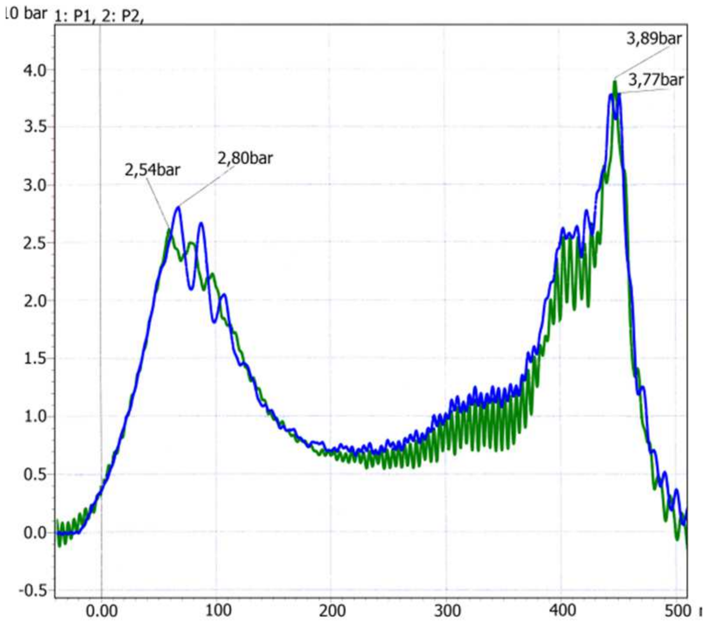
# Experiment – Validation

**Experimental setup**

Test facility - FTZU Ostrava


**Simulation data**




**Experimental data**

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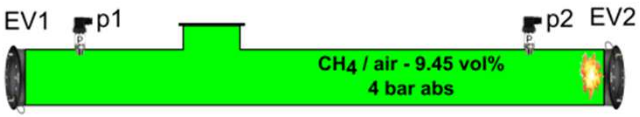
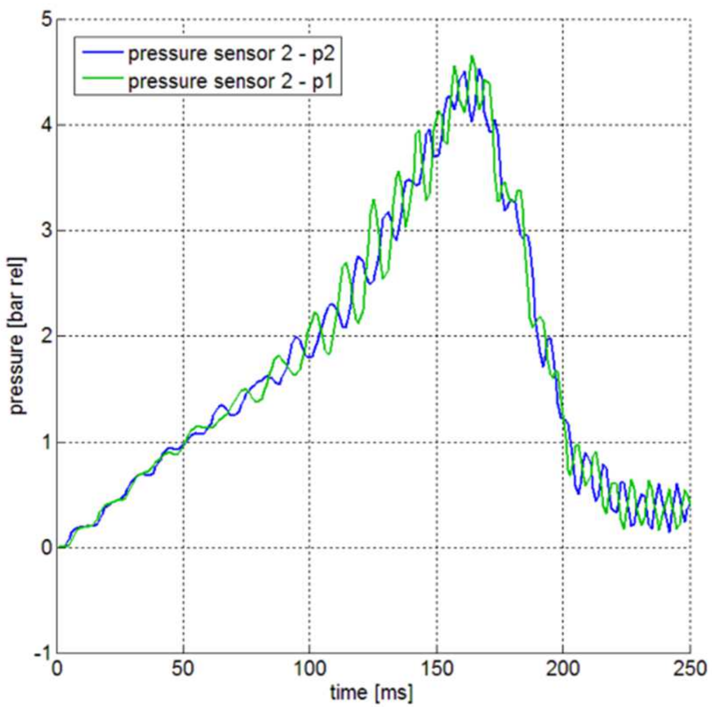
# Experiment – Validation

**Experimental setup**
Test facility - FTZU Ostrava

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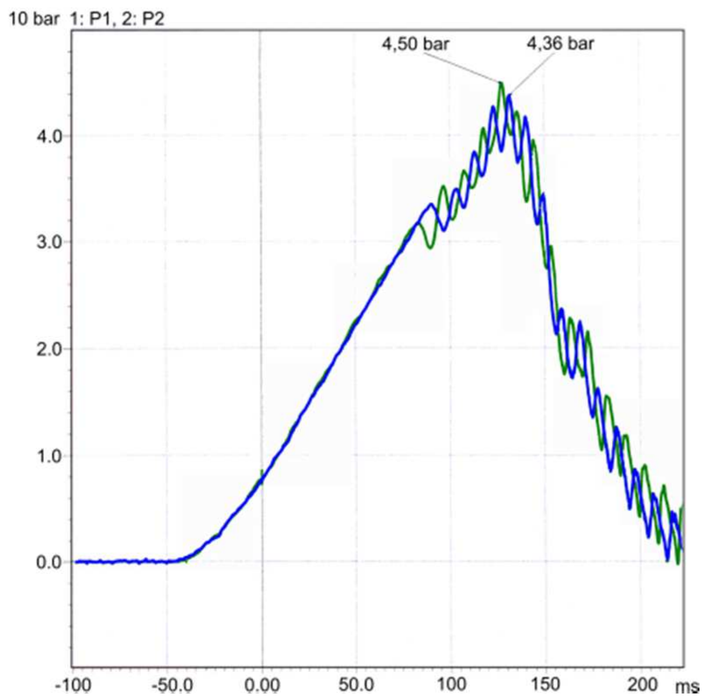


**Experimental data**

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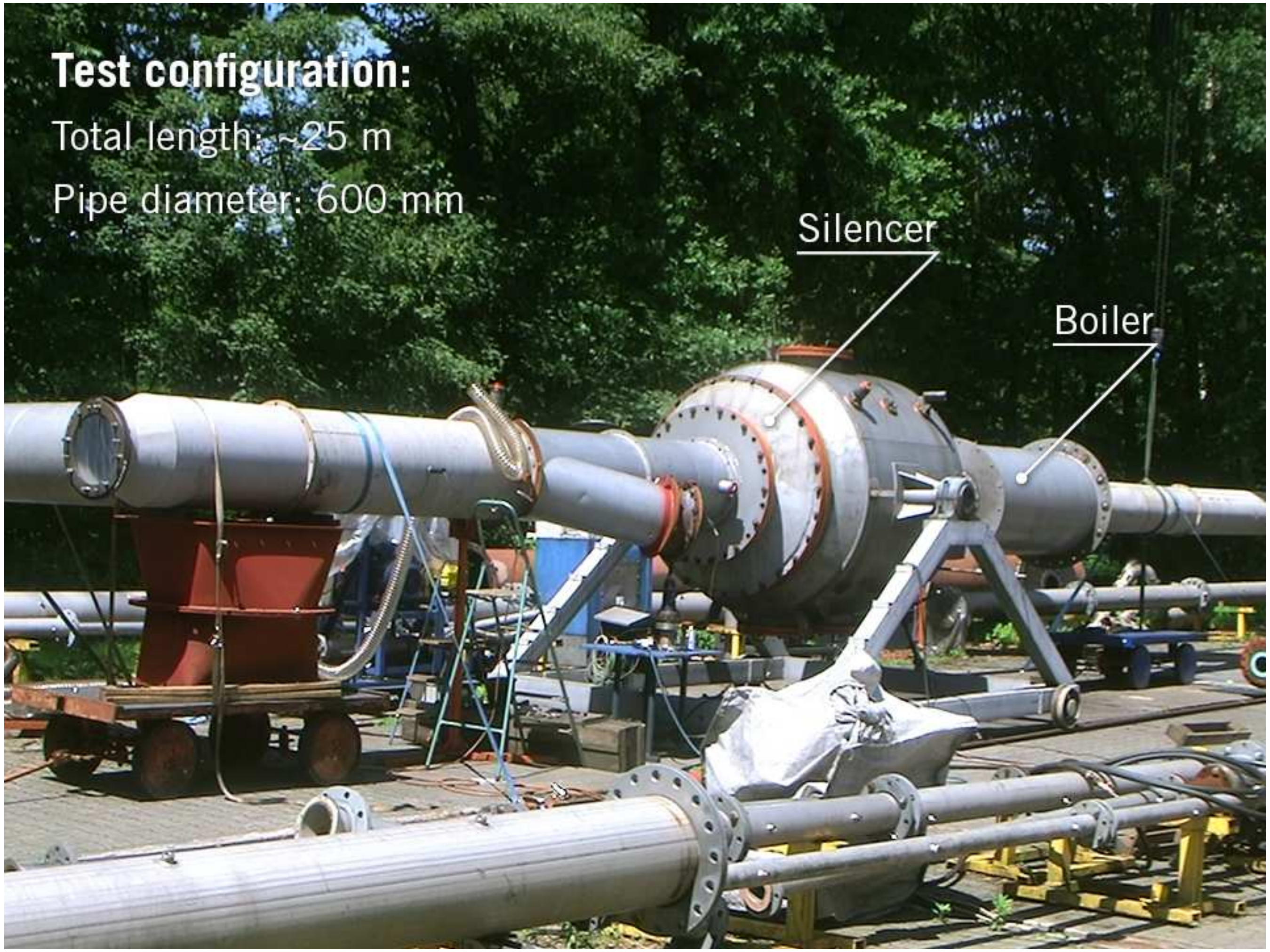
# Experiment – Validation




➔ **ExploSE has proven its capabilities also on a "real-world" exhaust system topology**

# Conclusions & Summary

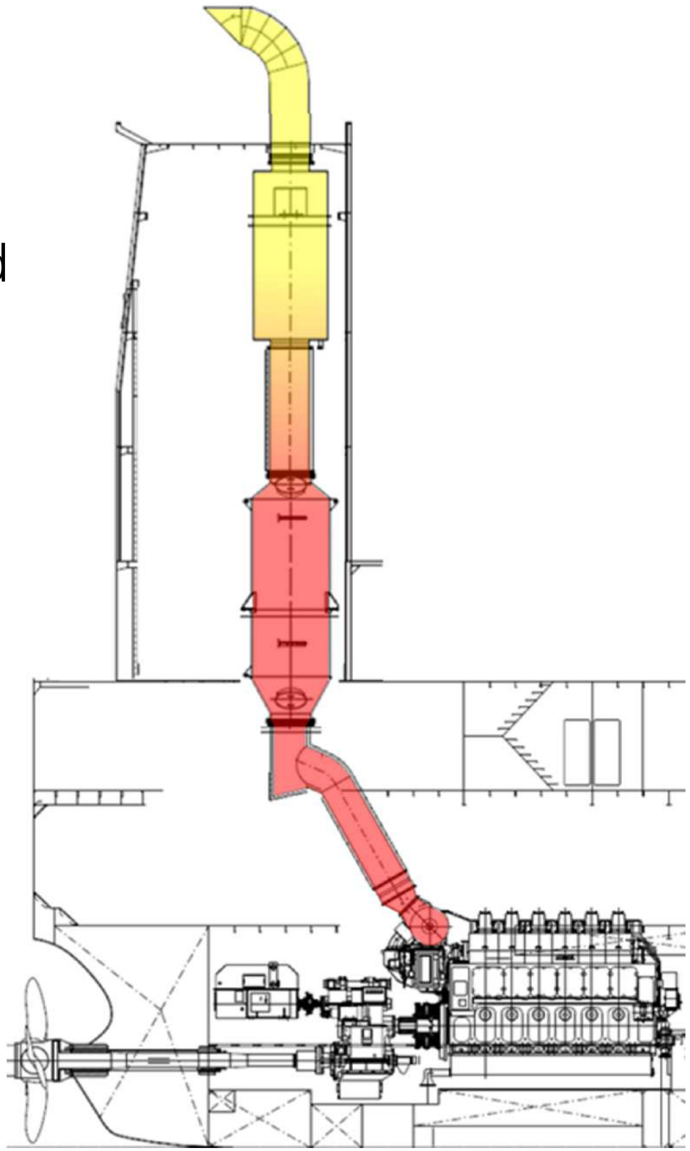
**ExploSE opens the door for customized …**

- … evaluation of the potential failure modes and their impact
- … optimization of the number of explosion relief valves
- … optimization of explosion relief valves arrangement

➔ Secure uninterrupted operation of engine

➔ minimizing the risk of severe damage due to exhaust system explosions

➔ minimizing the cost of safety devices without sacrificing safety level



# Thanks for your attention!

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