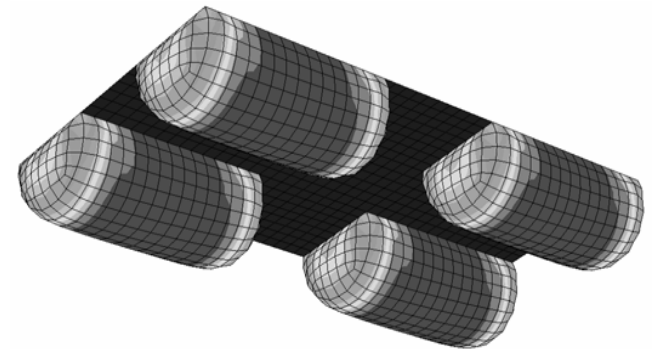
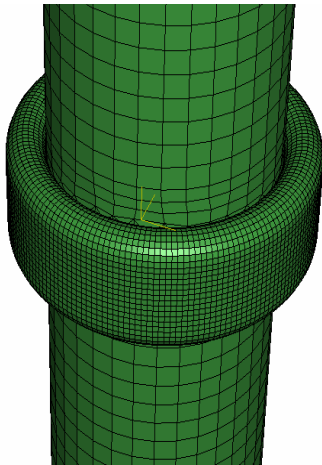


ADAPTIVE INFLATABLE STRUCTURES FOR IMPACT ABSORPTION

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IPPT PAN

SMART-TECH Centre



Smart Structures and Materials

III ECCOMAS THEMATIC CONFERENCE, 9-11 JULY 2007, GDAŃSK, POLAND

Presentation outline:

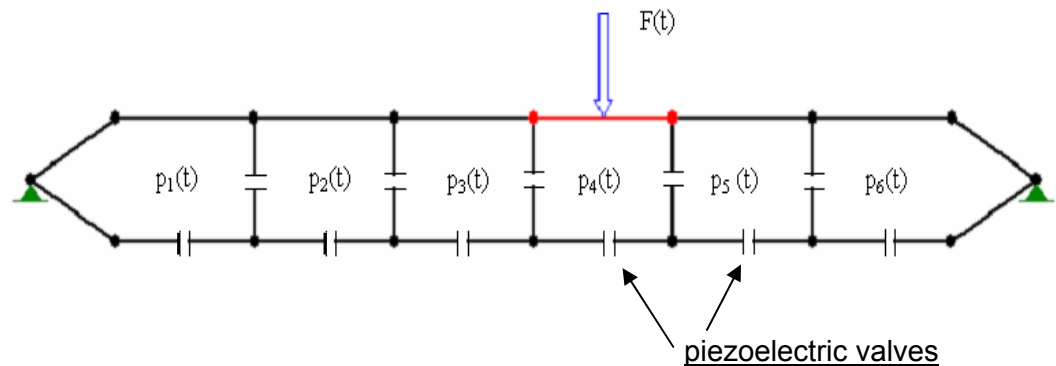
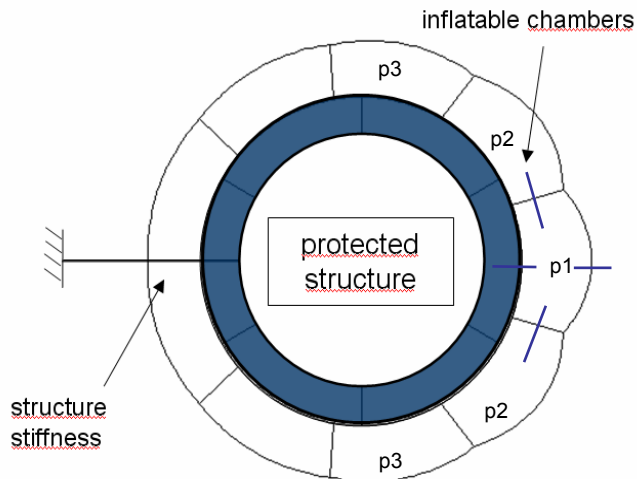
- I. Idea, modelling and control of **Adaptive Inflatable Structures (AIS)**
- II. **Automotive** applications (adaptive crashworthiness)
 - inflatable car door
 - adaptive pneumatic road barrier
- III. **Waterborne** applications
 - protection of offshore structures, bridge pillars, etc.
 - air-filled hull compartments
- IV. **Aeronautical** applications
 - adaptive airbags for helicopter emergency landing
 - adaptive pneumatic landing gear for small plane
- V. Conclusions and references

Idea of Adaptive Inflatable Structures

Inflatable structure – the structure that can be filled with gas and that maintains its size and shape due to internal pressure



Adaptive Inflatable Structure - can change its properties due to applied loading by controlling inflation and pressure release



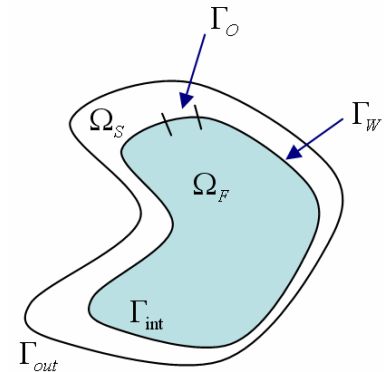
Main application of AIS: Adaptive Impact Absorption

Modelling of Adaptive Inflatable Structures

Nonlinear solid mechanics equations for the structure

Navier-Stokes equations for the fluid (mass + momentum + energy)

- Displacement and stress-type coupling conditions
- Definition of the controllable valves



Simplified method of modelling:

1. Equation of motion:

$$\mathbf{M}\ddot{\mathbf{q}}(t) + \mathbf{C}\dot{\mathbf{q}}(t) + \mathbf{K}(\mathbf{q})\mathbf{q}(t) = \mathbf{F}(\mathbf{p}(t), \mathbf{q}) + \mathbf{F}_l$$

$$\mathbf{q}(0) = \mathbf{q}_0, \dot{\mathbf{q}}(0) = \mathbf{V}_0$$

2. Ideal gas law:

$$\bar{p}(t)V(t) = m(t)R\bar{\theta}(t)$$

3. Conservation of mass:

$$m(t) = m_0 + \int_0^t q_m(\bar{t})d\bar{t}$$

4. Mass flow rate definition:

$$\Delta p(t) = C_v q_m(t) + C_H q_m(t) |q_m(t)|$$

5. Conservation of the energy:

$$dQ + dH = dE + dW$$

Modelling and control of AIS

Implementation:

ABAQUS Standard / ABAQUS Explicit / ANSYS

FORTRAN subroutines for:

- additional features: models of inflators, models of gas release
- controlling flow of the fluid

MATLAB + toolboxes:

- automatic input / output
- executing multiple analysis
- applying optimisation procedures

Control problems:

1. maximisation of allowable impact energy
2. minimisation of hitting object accelerations
3. minimisation of hitting object rebound
4. minimisation of internal pressure

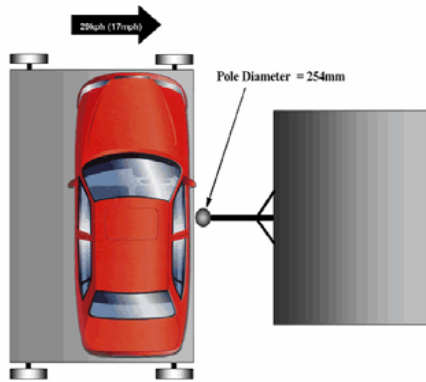
- general dissipator properties
- } protection of impacting object
- protection of impacted body

Constraints imposed on:

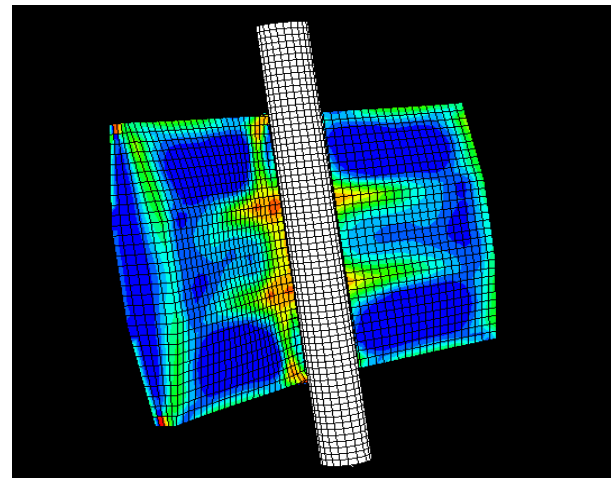
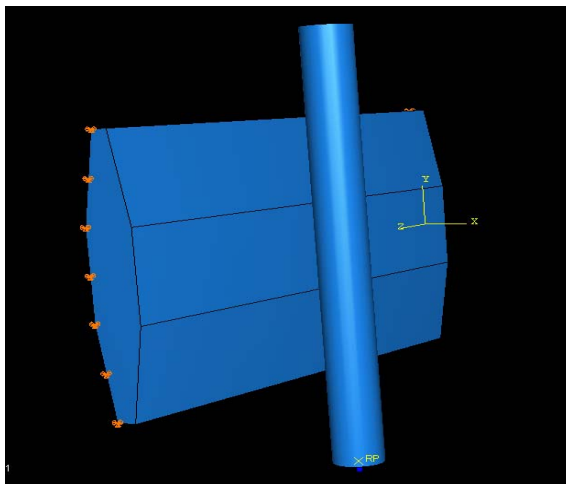
- design variables: initial pressure p_0 , flow resistance coefficients $C_v(t)$
- maximal acceleration, pressure, rebound, etc

Inflatable car door: motivation

- Small crashworthiness of thin-wall structures in case of side impact (NCAP pole impact test)



- Numerical model of side collision, deformation and maximal principal stress

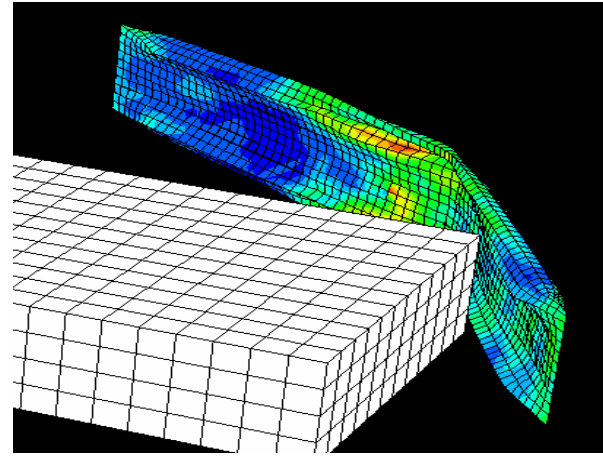
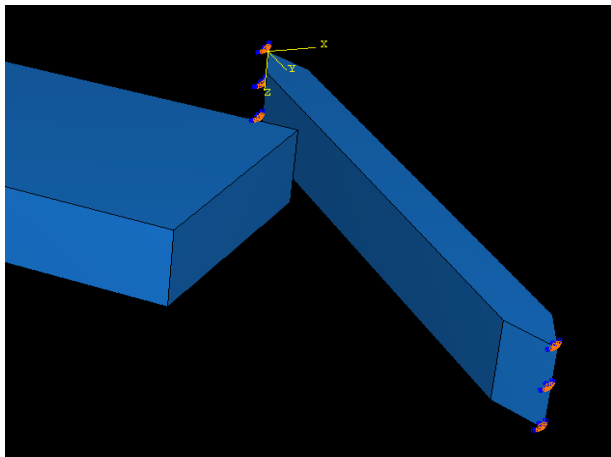


Inflatable road barrier: motivation

- Road barriers are not adjusted to mass and velocity of the impacting object
- Usually too stiff for light objects or low impact velocity



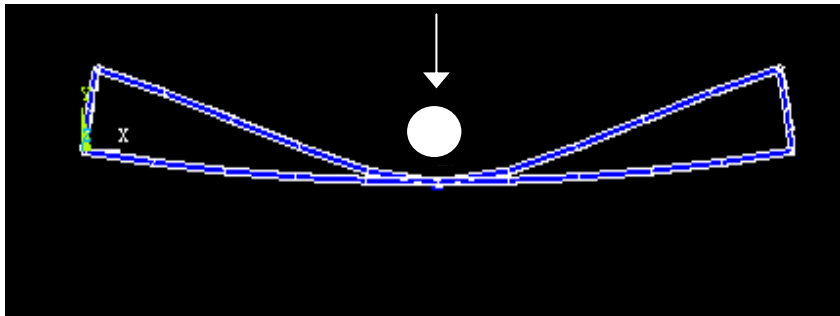
- Numerical model of collision of rigid object and barrier:



Basic feasibility study

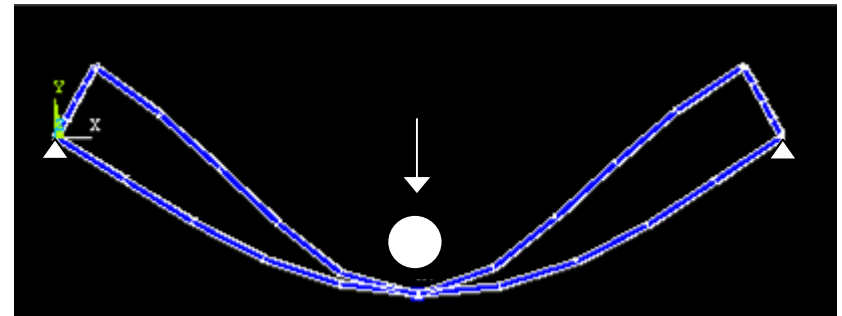
- Simplified two-dimensional model of Adaptive Inflatable Structure
 - initial pressure adjusted to impact energy
 - release of pressure during impact controlled by piezoelectric valves
- Admissible deformation S_q :
 - 1) $dist(mass, lower\ beam) > 0$ for $t \in (0, t_{stop})$
 - 2) $u_{max}(m, p, t_{stop}) \leq u_{adm}$
- Structure load capacity: $\max \{m \mid \mathbf{u}(m, p, t) \in S_q\}$

$p = 1\text{ atm}$



$m = 540\text{kg}, u = 0.135\text{m}, t = 0.124\text{s}$

$p = 7,4\text{ atm}$

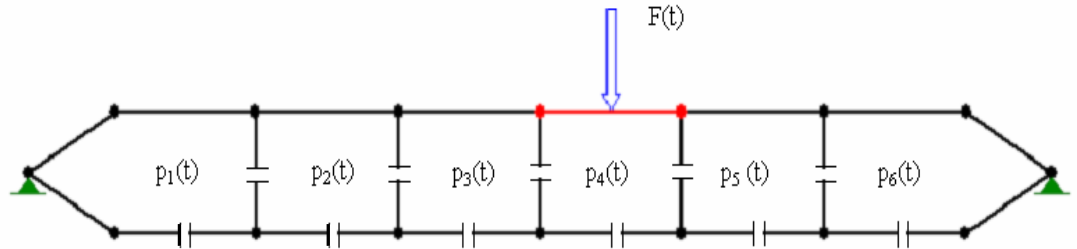


$m = 2710\text{kg}, u = 0.3\text{m}, t = 0.310\text{s}$

[movie](#)

Maximisation of load capacity

Possibility of improvement:

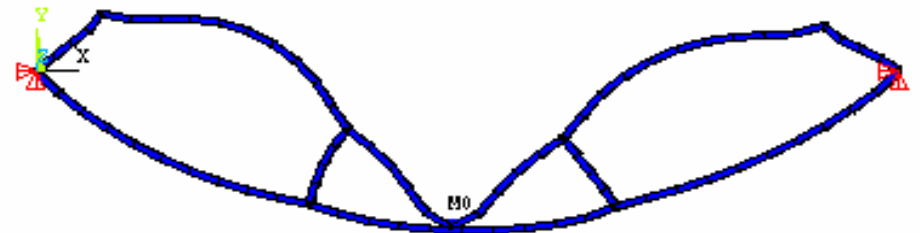


- Division into several pressurized packages, valve in every package
- Control can be applied by changing: $\mathbf{p} = \{p_1(t), p_2(t), \dots, p_n(t)\}$

Optimization problem: Find $\max_{\mathbf{p}} \{m \mid \mathbf{u}(m, \mathbf{p}, t) \in S_q\}$

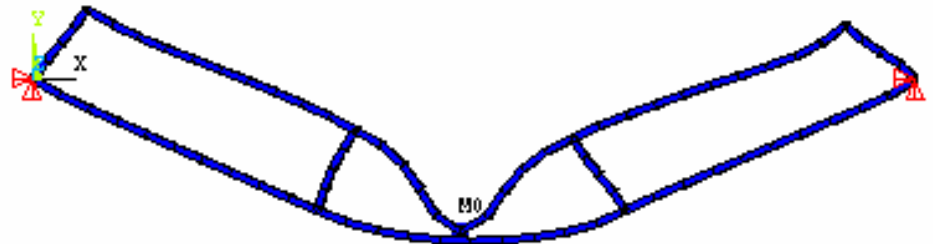
Inflation of all chambers:

Profit up to: 7,6 x



Stronger inflation of middle chamber

Profit up to: 9,1 x

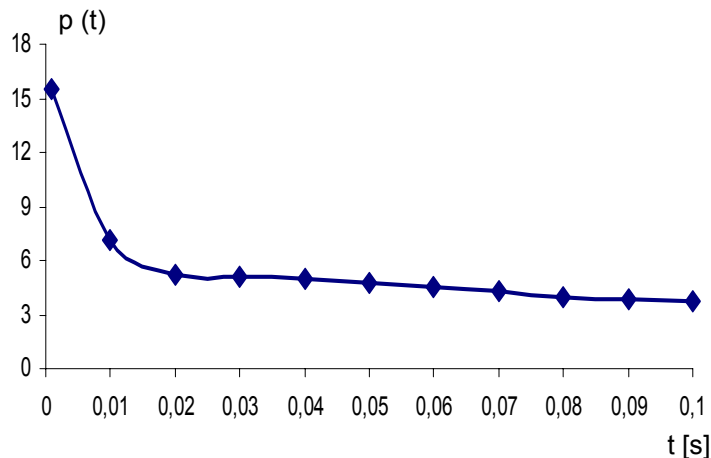


Minimisation of accelerations

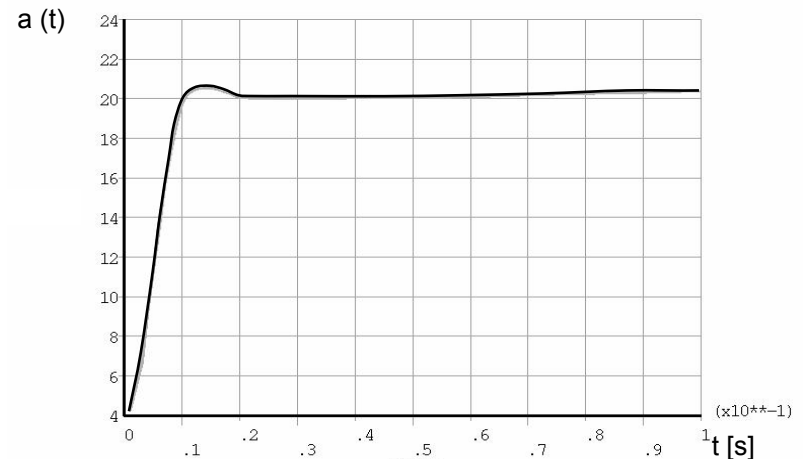
- **The objective:** protection of the hitting object
(controlling its displacement and acceleration)
- Optimal trajectory: second order curve (constant acceleration)
- Optimization problem assumes the form:

$$\text{Find: } \min\{\Phi(\mathbf{p}(t)) \mid \mathbf{u}(m, \mathbf{p}, t) \in S_q\}$$

$$\text{where } \Phi(\mathbf{p}(t)) = \int_0^{t_{stop}} [u_m(t) - u_m^{opt}(t)]^2 dt$$



Optimal change of pressure



Resulting acceleration of impacting mass

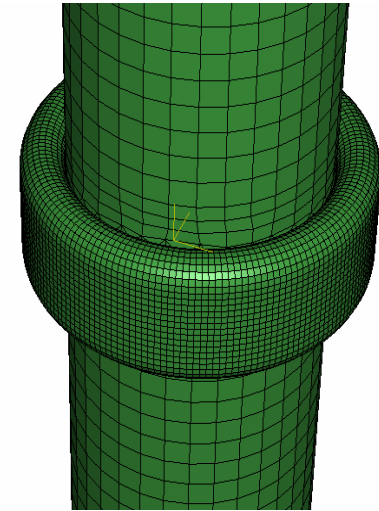
Protection of offshore structures



Offshore oil platform

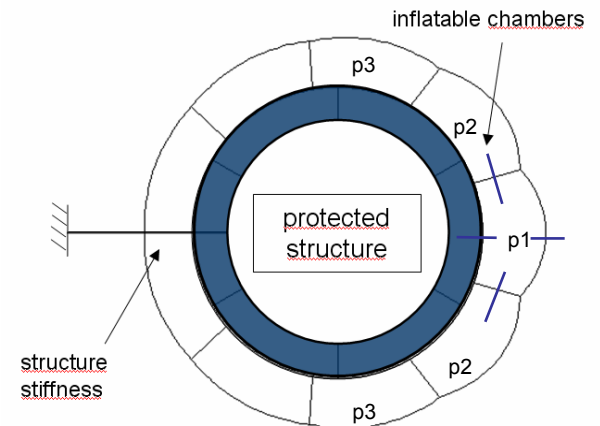


Wind turbines farm



Pylon surrounded by inflatable structure

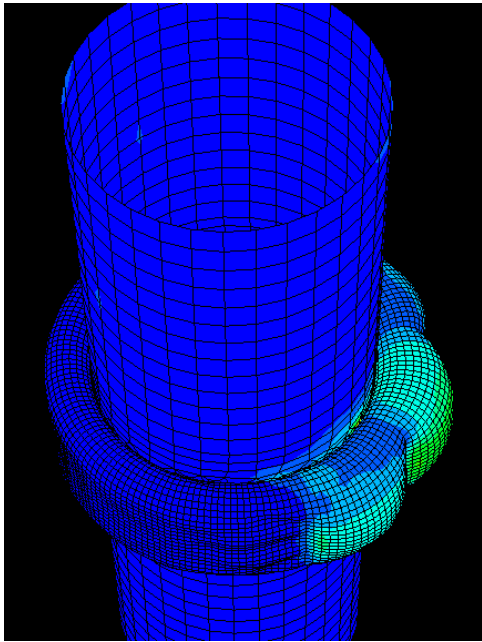
- Torus-shaped structure on the water level
- Dimensions: height 2m, thickness 0,7m
- Material: rubber reinforced by steel rods
- Effective protection against collisions with service boats



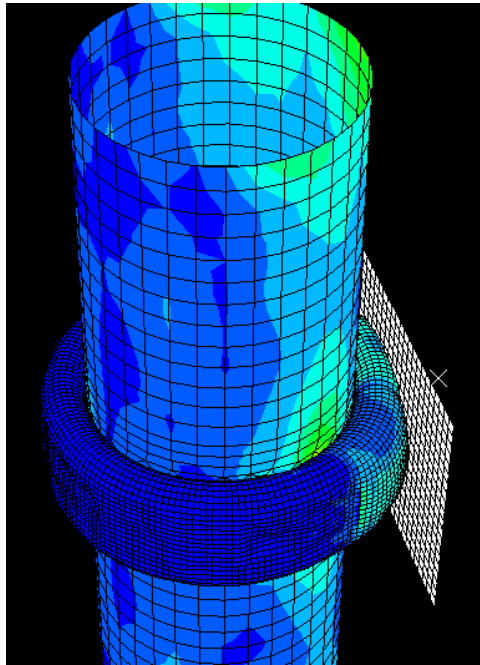
Division into several air chambers

Protection of offshore structures: simulation

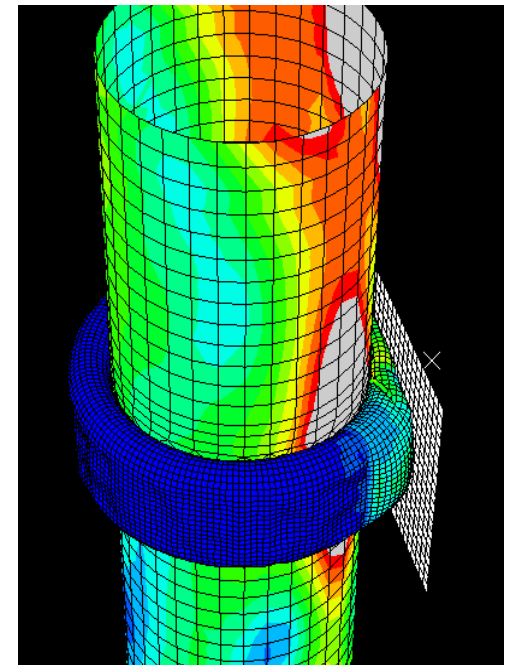
- 3D model of the lower part of the wind turbine tower
- Tower: shell elements, inflatable structure: membrane elements
- Ship impact modelled as a contact problem



Deformation of inflatable structure
after inflation (pressure 5 atm)



Deformations at the beginning of
ship collision



Final deformation and stresses

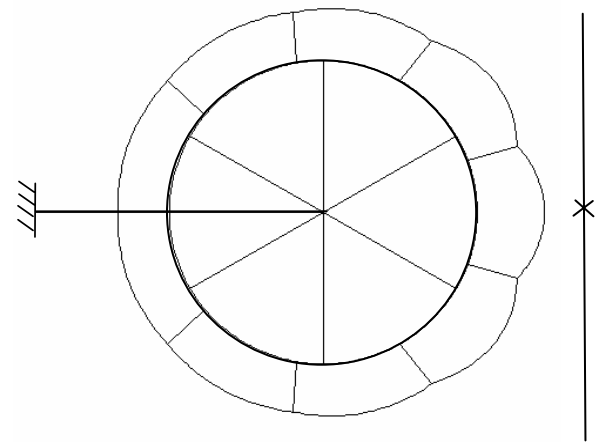
[movie](#)

Protection of offshore structures: impact energy dissipation

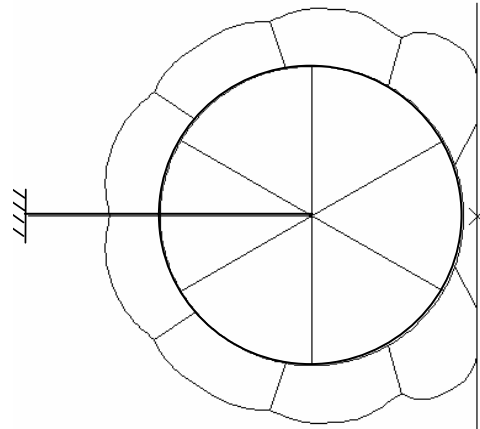
Purpose: dissipation of ship kinetic energy, minimization of ship rebound

Dissipation mechanism:

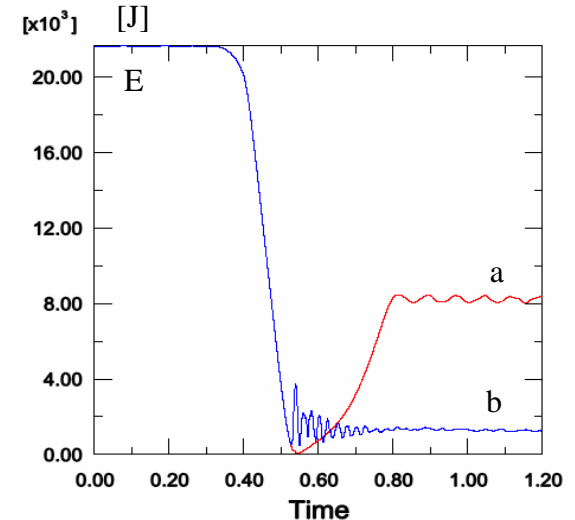
1. changing kinetic energy into gas energy and AIS strain energy
2. dissipating gas energy by removing compressed gas to environment



Inflation before the collision



Ship colliding into wind turbine

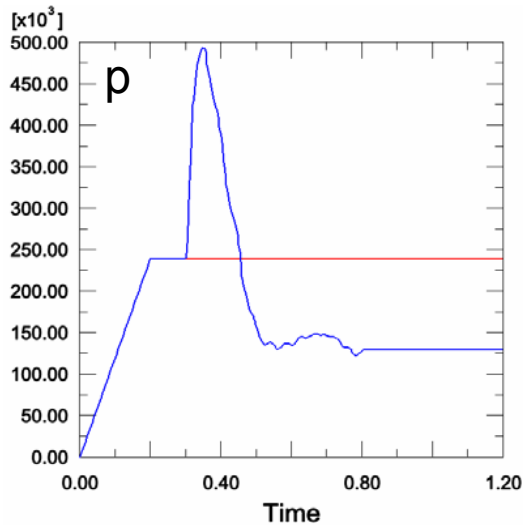


Energy dissipation

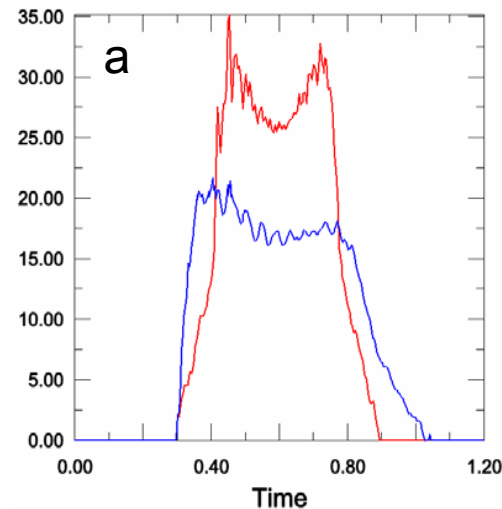
[movie](#)

Protection of offshore structures: acceleration mitigation

- **Optimal pressure value changes in time due to:**
 - various area of the contact between the ship and AIS
 - necessity of eliminating the influence of rubber deformation
- **Control method:**
 - active change of pressure based on acceleration measurement



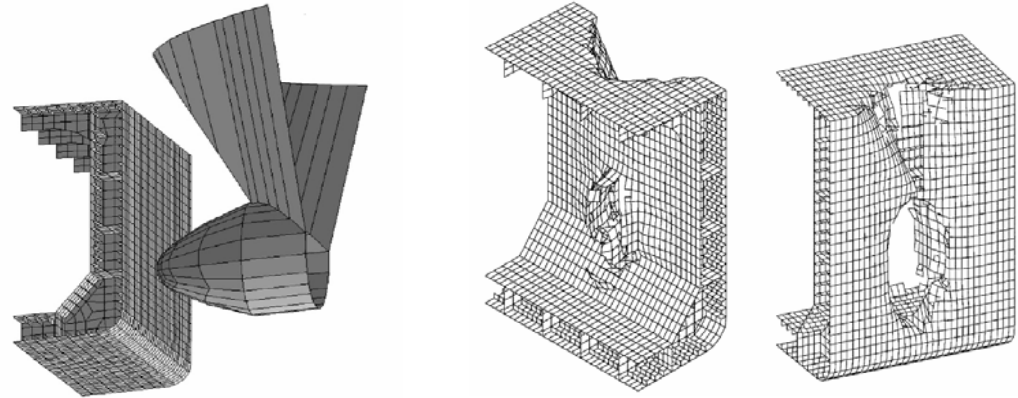
Constant and optimal pressure



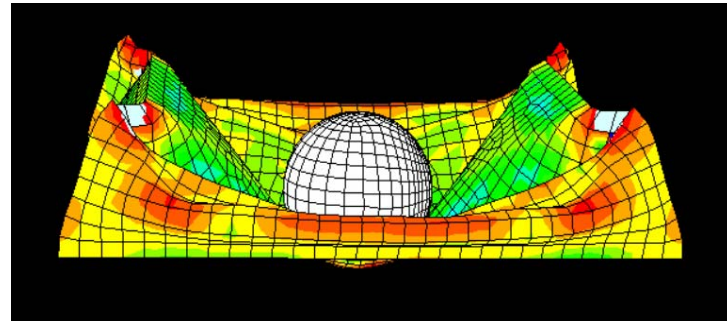
Resulting ship accelerations

Air-filled hull compartments

- Collision of double hull carrier and vessel with bulbous bow:

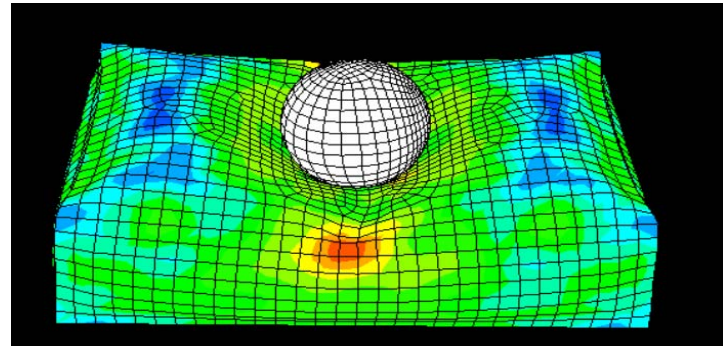


- Rigid object striking single compartment of the hull



[movie](#)

- Proposed solution
 - sealing and appropriate inflation of endangered hull compartment
 - release of pressure during collision



[movie](#)

Flow-control based airbags

- Main concept:

Using external adaptive airbags attached to the helicopter chassis to increase safety of the passengers and integrity of the structure

- Target machine: polish helicopter PZL W-3 Sokół (PZL Świdnik)

- System of sensors:

ultrasound velocity sensor, pressure sensor



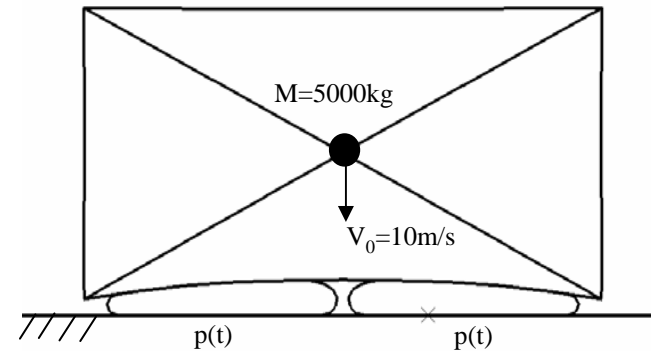
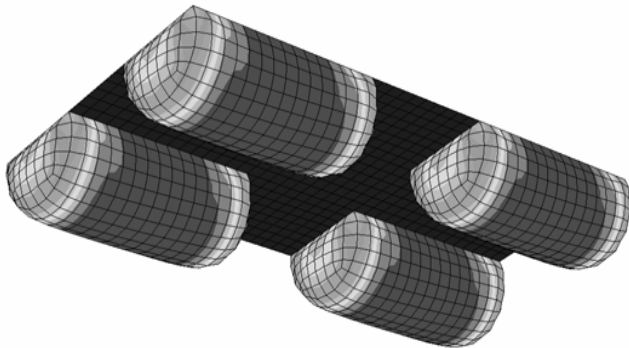
Control objectives:

- Mitigation of acceleration acting on passengers
- Alleviation of forces acting on helicopter and stresses arising in undercarriage
- Stabilization of the helicopter during touch-down

Flow-control based airbags: numerical model

Numerical model:

- falling helicopter is modelled by beam elements and point masses (total mass: 5000 kg)
- impact velocity: 5m/s to 10m/s (free falling from 5,1 m)

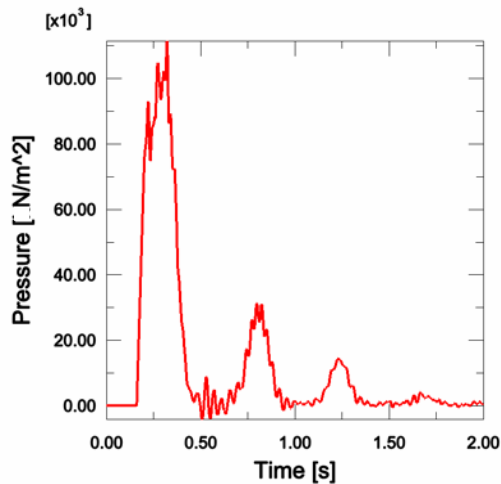


Estimation of required parameters:

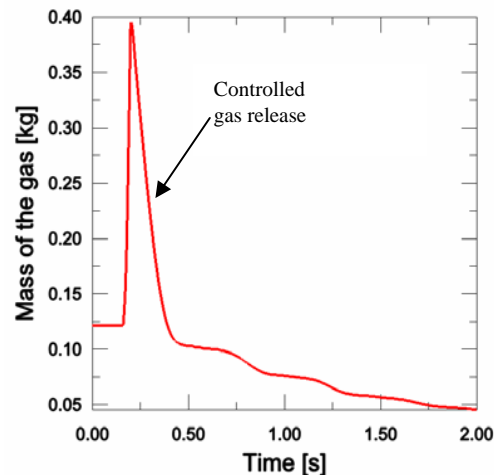
- total dimensions of the airbags: $4\text{m}^2 \times 0.5\text{m}$
- constant pressure in the airbags necessary to avoid direct collision with ground for velocity 10m/s: **1.25 atm** overpressure

Flow-control based airbags: control strategy

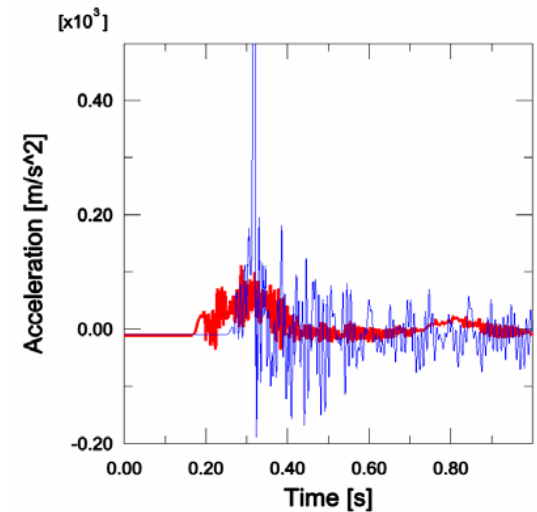
- using whole stroke of the airbag to reduce accelerations
- keeping constant value of total force acting on helicopter
- significant release of pressure when helicopter velocity drops to zero
- Applied control strategy and comparison of the results:



Pressure [N/m²]



Mass of the gas [kg]



Acceleration [m/s²]

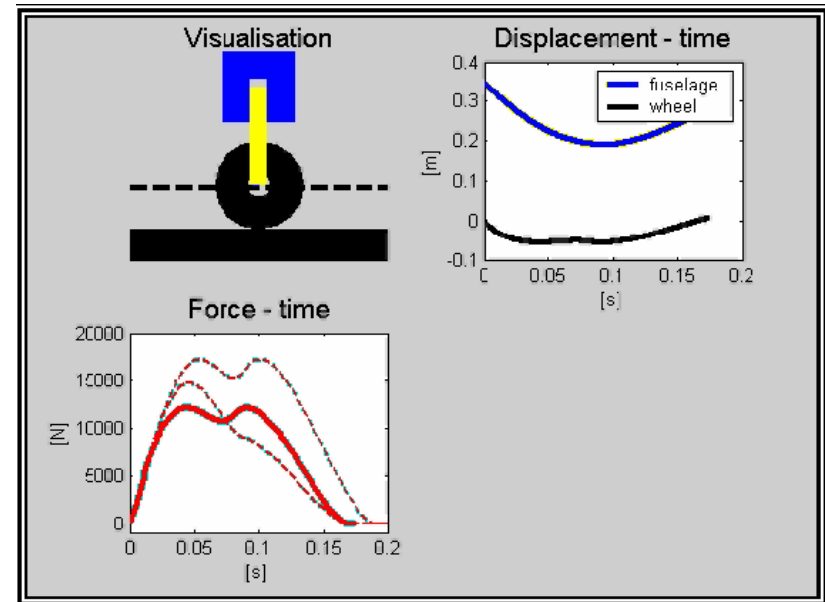
- Emergency landing with adaptive flow-based airbag

[movie](#)



Adaptive landing gear: ADLAND Project

- Development of an adaptive system aiming at minimization of the loads transferred on aircraft fuselages
- The project assumes utilization of MR fluid or Piezo valves as the real time active control actuators of the smart device.
- A full breakthrough technology was developed and tested in the airfield tests



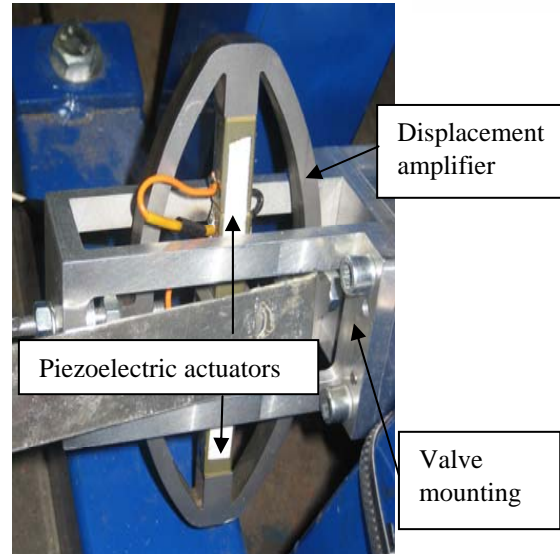
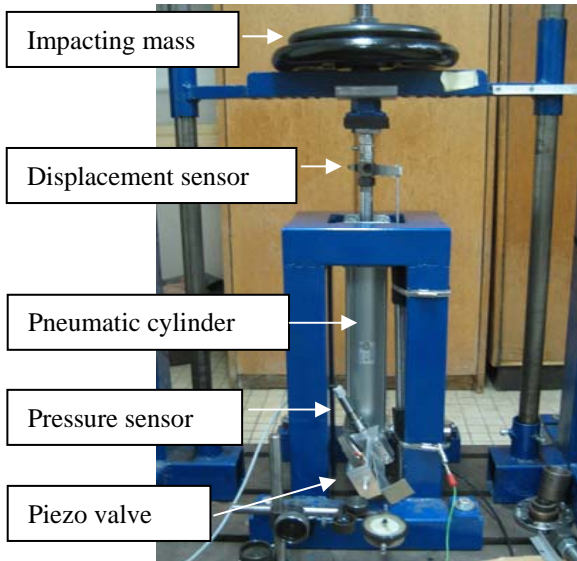
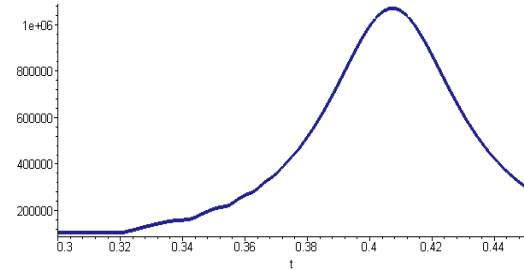
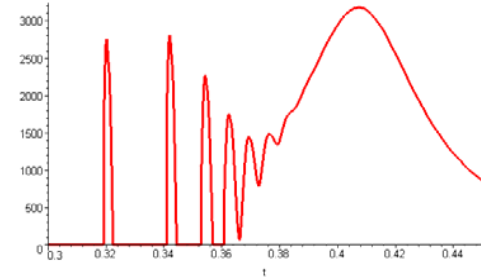
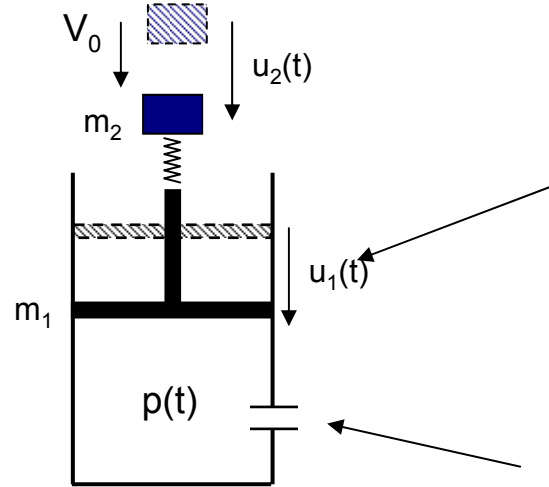
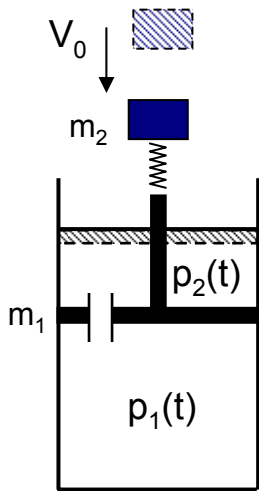
LAB TESTS



FIELD TESTS



Adaptive pneumatic landing gear



Monography:

„SMART TECHNOLOGIES FOR STRUCTURAL SAFETY”

1. Introduction
2. *Virtual Distortion Method* for structural remodelling and inverse problems
3. *VDM* based methods in health monitoring of engineering systems
4. Impact load monitoring
5. Adaptive Impact Absorption
6. Optimal remodelling of adaptive structures exposed to impact loads
7. Adaptive Damping of Vibration
8. Adaptive vibroacoustics
9. Conclusions and further challenges

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- 17 Co-Authors