

## AERONAUTICAL APPLICATIONS OF ADAPTIVE INFLATABLE STRUCTURES

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**Summary.** The paper presents the concept of using Adaptive Inflatable Structures (AIS) for efficient impact absorption. Two aeronautical applications of inflatable structures are described: an adaptive landing gear for lightweight plane and an external adaptive airbag dedicated for helicopter emergency landings. In each case the optimal strategy of pressure release providing adjustment for various impact scenarios is proposed and the benefits of using active pneumatic system are proved. Experimental set-up is developed to verify the effectiveness of the introduced system.

### 1 INTRODUCTION

Adaptive impact absorption focuses on active adaptation of energy absorbing structures to extreme overloading by means of system of sensors detecting and identifying impact in advance and controllable dissipaters (structural fuses)<sup>1,2</sup>. A semi-active or fully-active solutions can be realized via controllable dissipative devices (with no need for significant power supply) based on magneto-rheological fluids<sup>3</sup> or piezo actuated valves<sup>4</sup>.

Adaptive Inflatable Structures (AIS) are one of the special approaches to adaptive impact absorption. AIS are structures filled with gas which pressure is appropriately adjusted during the event. Inflatable structures analysed so far by authors are adaptive pressurised road barriers<sup>5</sup> and torus-shaped structures for protecting offshore wind turbines<sup>6</sup>. Present work concerns two additional applications: a landing gear for lightweight unmanned plane<sup>9</sup> and an external airbag dedicated for helicopter emergency landing<sup>10</sup>.

The idea of using compressed air and its controlled release makes inflatable structures easily adaptable for various impact scenarios. Additional improvement of AIS can be achieved by dividing the structure into several cells separated by flexible walls which allows to adjust the level of initial pressure in different parts of the structure. Fast reacting pyrotechnical gas generator can be used for immediate gas pumping. Controlled release of pressure is executed by opening exit piezo-valves during the collision so the stiffness of the pneumatic structure can be adjusted in the subsequent stages of impact. The release of

pressure helps to prevent excessive stresses and accelerations in the system and to control dissipation of the energy.

## 2 ADAPTIVE LANDING GEAR FOR LIGHTWEIGHT PLANE

An active pneumatic landing gear is proposed in order to mitigate high forces and accelerations arising during landing of the light unmanned planes. Small mass of considered planes does not exceed 15kg which excludes using oil-based devices and simultaneously allows the application of the pneumatic system.

The functioning of the device is demonstrated on experimental drop testing stand (cf.Fig.2) where falling mass hits the pneumatic cylinder. The system is equipped with a piezoelectric force sensor and an accelerometer located on the piston, which enable real-time impacting mass and velocity identification. Piezo valve allows the gas flow between the cylinder and the environment and hence changes the characteristics of the air spring, cf. <sup>7,8</sup>. The design of the valve utilizes mechanically amplified piezo actuator which changes the position of the element covering the outlet from the cylinder. The response time of the valve is below 1ms and obtained displacement equals around 0.11mm.

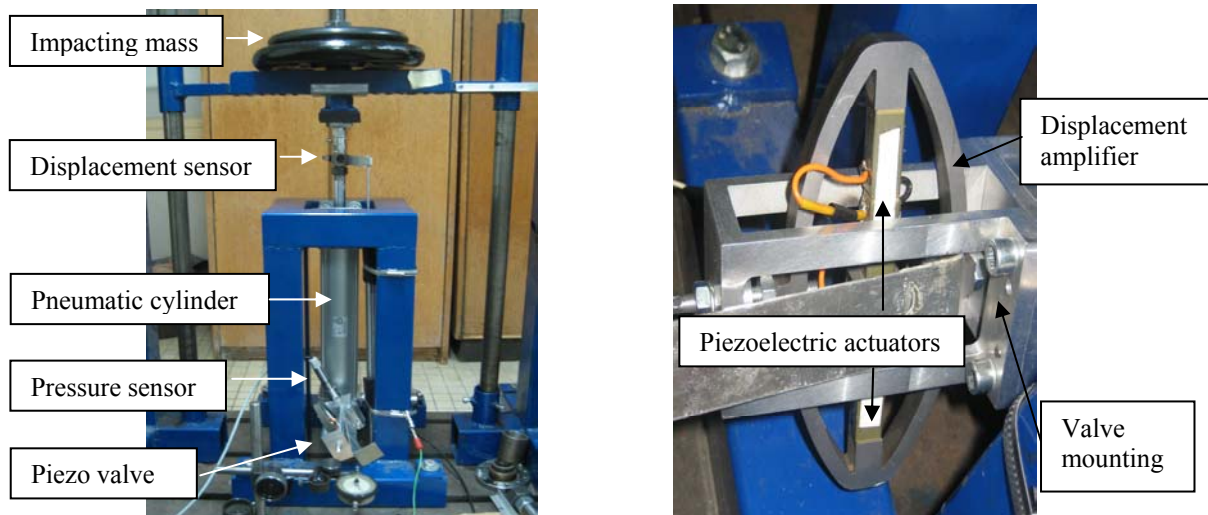


Figure 1a. Experimental set-up for adaptive impact absorption; 1b. Piezo-actuated valve

Control strategy can be applied by means of hardware controller or LABVIEW system. The signal from inductive displacement sensor and pressure sensor can be used as a feedback for control system. Four cases of pneumatic landing gear behavior are considered:

1. Passive: constant orifice opening adjusted for harshest landing conditions
2. Semi-active: orifice opening adjusted according to actual landing velocity
3. Active: orifice opening actively controlled during landing process
4. Active: adjustment of initial pressure and actively controlled orifice opening

Conducted experiments show that small change of piezo valve opening allows to change gas spring characteristics and significantly reduce level of arising forces.

### 3 FLOW CONTROL BASED EMERGENCY AIRBAG

The second application considered is an adaptive external airbag for helicopter. The system is designed for extremely severe, emergency landing. It consists of a multi-chamber air filled cushions attached to the helicopter undercarriage (cf. Fig. 2). Deployment of these cushions is executed just before touchdown by means of pyrotechnic system. Release of pressure is due to fabric leakage and additional piezoelectric based controllable high speed and stroke valves.

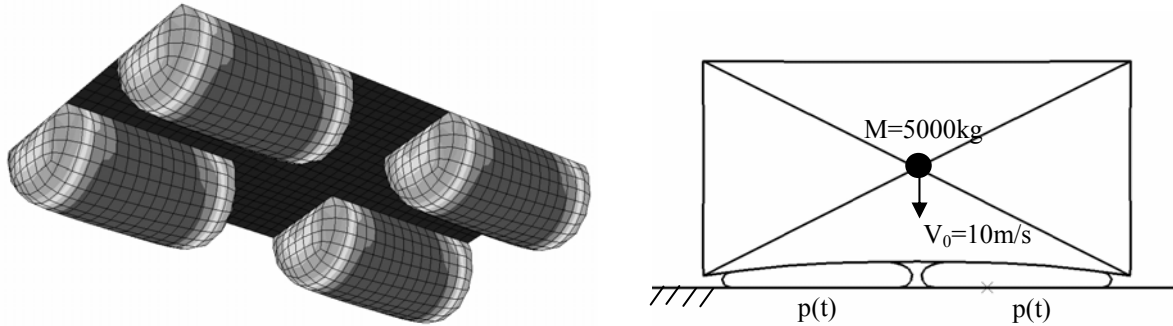


Figure 2a. Considered model of the airbags; 2b. Simplified simulation of landing

In numerical example the considered helicopter is modelled by deformable beams and point masses. The total mass of the model equals 5000kg (mass of a typical civil helicopter). The velocity of emergency landing equals 10m/s which is equivalent to free falling from 5,1m. Estimated dimensions of the airbag are  $4\text{m}^2 \times 0.5\text{m}$ . Constant pressure in the airbags necessary to avoid direct collision with ground calculated directly from energy balance equals 1.25 atm overpressure (2.25 atm total pressure).

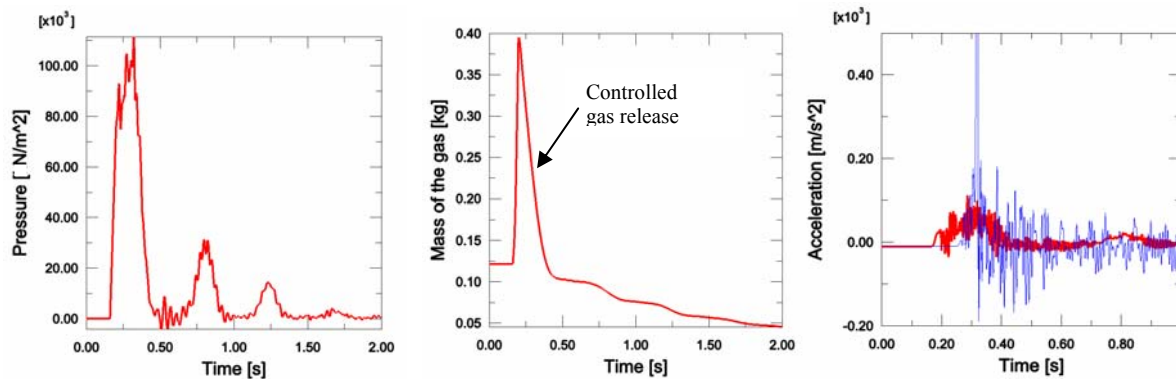


Figure 3. Applied control strategy: a) change of pressure inside the airbag, b) mass of the gas inside airbag c) reduction of accelerations obtained as a result of applied control strategy

Control strategy is oriented towards: minimization of accelerations acting on passengers, alleviation of forces acting on the helicopter and stresses arising in undercarriage and stabilization of helicopter during touchdown. To fulfil objectives mentioned, the whole stroke of the airbag is used during the landing, the total force acting on helicopter is kept on constant

level and significant release of pressure is applied when helicopter velocity drops to zero. The subsequent peaks on pressure plot (Fig 3a) are related to the rebounds of the falling object. In applied control strategy the amount of the gas inside the airbag has to increase strongly at the beginning of the process (inflation of the airbag) and then the gas is gradually removed.

Conducted simulations prove that proposed devices and control strategies efficiently decrease arising accelerations and hence increase the safety of emergency landing.

#### 4 CONCLUSIONS

Adaptive Inflatable Structures are based on a concept of pressurized packages and controlled pressure outlets. Conducted simulations and experiments indicate that inflatable structures can be effectively utilised in aeronautical applications. By applying precise control of valve flow major part of impact energy can be dissipated and forces and accelerations arising during impact can be minimized.

AIS equipped with sensors able to detect and identify (in real time) the impact load can serve as an on-line adaptive impact absorbing system. The optimal control strategies have to be pre-computed and stored in memory of hardware controllers to make the process feasible.

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#### REFERENCES

- [1] J. Holnicki-Szulc (Ed.), *Smart Technologies for Structural Safety*, J.Wiley, 2007, in preparation
- [2] J.Holnicki, G.Mikulowski, A. Mroz, P. Pawlowski, "Adaptive Impact Absorption", The Fifth International Conference on Engineering Computational Technology, September 2006, Las Palmas de Gran Canaria, Spain
- [3] G. Mikulowski, J. Holnicki-Szulc, "Fast Controller and Control Algorithms for MR Based Adaptive Impact Absorbers - Force Based Control", *Machine Dynamics Problems*, **30**, No 2, 113-122 (2006)
- [4] EU Project ADLAND IST-FP6-2002-2006, <http://smart.ippt.gov.pl/adland/>
- [5] C.Graczykowski, J. Holnicki-Szulc, "Adaptive pressurized structures for improved impact absorption, Structural Membranes 2005, Stuttgart, Germany.
- [6] C.Graczykowski, J.Heinonen, "Adaptive Inflatable Structures for protecting wind turbines against ship collisions", VTT Working Pappers, Espoo 2006
- [7] A.Mroz, J.Holnicki, "Semi-active control of wind impact effects by means of pneumatic system", NNMAE 2006, July 2006, Thessaloniki, Greece
- [8] J.Wang, J.Pu, P. Moore, "A practical control strategy for servo-pneumatic actuator systems", *Control Engineering Practice* **7**, 1483-1488 (1999).
- [9] Patent claim: Adaptive Pneumatic Landing Gear
- [10] Patent claim: Adaptive Emergency Airbag