**ISSN:** 1231-4005
**e-ISSN:** 2354-0133
**DOI:** 10.5604/01.3001.0012.2851

# ADAPTIVE LANDING GEAR CONTROL SYSTEM ASSUMPTIONS

**Zbigniew Skorupka**

*Institute of Aviation*
*Krakowska Av. 110/114, 02-256 Warszawa, Poland*
*tel.:+48 228460011 ext. 657, fax: +48 943426753*
*e-mail: zbigniew.skorupka@ilot.edu.pl*

***Abstract***

*In the present time, landing energy dissipation process in aviation shock absorber design is optimized for the most demanding, but still safe, landing scenario (reserve energy landing conditions). Most of the current solutions are based on a fixed hole (orifice) or a set of holes regulating hydraulic fluid flow in the shock absorber. This approach although safe provides no optimization of the forces acting on the fuselage in different (less energetic than limit energy) conditions. Due to the progress in hydraulic flow control, it is possible to design and control a proper system for extended optimization of the landing process energy dissipation. The complete system contains two parts, one of which is a direct flow executive electro-mechanical system and second of which is an electronic control system. The electronic control system directly manages executive system via a set of inputs, thus creating proper output signals for the optimal flow control.*

*In this article, the author presents the idea of the computer control part of the adaptive hydraulic flow control system. The author describes a set of possible control input and output signals both external and internal, from the landing gear reference system, characterizing their role in the landing process. The author also defines possible control algorithms selected to fit the assumptions of the adaptive landing gear system. Finally, the author presents a proposal for the laboratory grade control system for future testing of the assumptions described in this article.*

***Keywords:*** *laboratory testing, landing gear, adaptive control, control system*

## 1. Introduction

Typically, landing gear shock absorbers are designed as passive devices with characteristics adjusted to the highest impact loads [1] according to the aviation regulations [5]. Passive devices, by definition are fixed to one or several (usually not exceeding two or three) work scenarios [2]. In order to achieve optimal results in the wide range of work conditions it is necessary to introduce active or controllable solution.

Every active solution has to be controlled somehow; nowadays most common way to do so is to create proper electronic control device based on industrial grade microprocessor. Hardware to this solution is common and widely available therefore the price/capabilities ratio is the limit.

What makes the set of electronics hardware real control system is the software based on the properly defined algorithm created on correct assumptions.

When defining assumptions it is necessary to know what and how will be controlled in order not only to achieve optimal results but also to have any control at all.

In the next chapters assumptions for active flow control will be presented along with the overall description of the proposed software

## 2. Object of control

The controlled object in the presented case is the landing gear (L/G) system of the utility helicopter W3 also known as “Sokół” (Fig. 1). Design of the W3 dates back to 1970’s and it was proven reliable. In order to maintain the W3 helicopters in ready-to-use state for years to come it is necessary to make modernizations. One of them is to introduce active damping system to landing gear shock absorbers in order to achieve more safety, reliability, and in the future raise the cargo capabilities of the helicopter [6]. Active shock absorption system has to allow lowering of the loads acting on the helicopter's fuselage by adaptively adjusting damping according to landing scenarios/forces [4].

Adaptive damping control will be achieved by the flow control via number of piezo-actuator based valves inside of the shock absorbers. The solution was initially (Fig. 2) introduced during the ADLAND (mid-range airplane smart/adaptive landing gear) project but was not excessively tested due to the lack of the proper control system – back then only the proof of concept was made [3]. Current project called ROLAND (utility helicopter adaptive landing gear) is based on the new design but on the same principle.


*Fig. 1. W3 Helicopter. Source PZL-Świdnik*

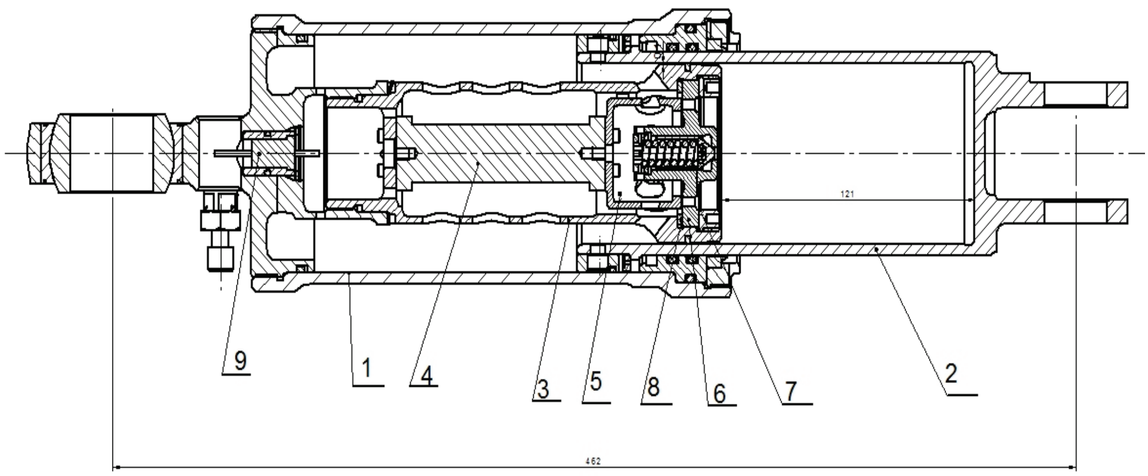


*Fig. 2. ADLAND project piezo-valve solution: 1 – cylinder, 2 – piston, 3 – plunger, 4 – piezo-actuator, 5 – valve head 6 – suppressing plate, 7 – nut, 8 – adjusting plate, 9 – culvert. Source ILot*

## 3. Adaptive system control assumptions

### 3.1. System architecture and modes

Due to the complexity of the landing process and uncertainty of the both electric (control system, sensors response etc.) and mechanical (piezo-actuator along with flow control parts attached to it) systems, two-stage control system is proposed.

First stage (approach) – the landing phase commencing before touch down (L/G over the ground) – will be used to preliminary set the correct orifice according to the landing parameters taken from dedicated sensors and built-in aviation systems of the helicopter. Control in this phase will commence as close to real time control as possible where potential delays of signals from built-in avionics and external sensors can occur. As this phase is much less dynamic than touch down phase there is no necessity to define very quick changes in the control system. Frequency of changes on the level of 1 Hz is enough – input signal sampling frequency will be set up to 1000 Hz if available.

Second stage (deflection) – landing phase commenced after touch down (L/G on the ground) – will use the first phase settings as initial and then control the orifice (flow of hydraulic fluid) in real time using internal sensors connected only to L/G system. All avionics and sensors used in the first phase will be disengaged. In this phase the control will be divided to every L/G, as deflection conditions could be different for each of them. Deflection phase is much more dynamic than approach phase (it lasts no more than 3 seconds) so the frequency of orifice changes will be set to 100 Hz maximum with input signal sampling frequency not less than 1000 Hz and up to 5000 Hz (latter is optimal).

The block diagram of the control system is shown in Fig. 3. All used symbols and signals are explained in the next chapters.

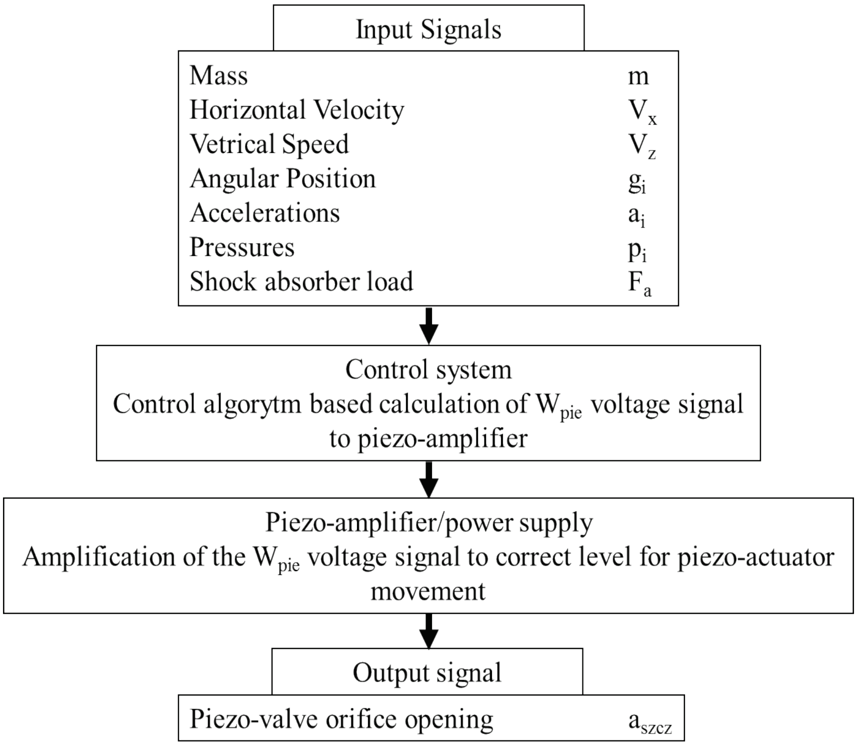


*Fig. 3. Block diagram of the designed adaptive landing gear control system, source ILot*

### 3.2. Input signals

Proposed input parameters for both phases of the control:

- Phase one (approach):
  - mass m – for calibrating needed energy dissipation, parameter set before start. It must be updated according to changes in mass of the helicopter due to the fuel consumption and changes in cargo,
  - horizontal speed $V_x$ – parameter taken from built-in avionics,
  - vertical speed $V_z$ – parameter taken from built-in avionics,

– angular position $\gamma_1$, $\gamma_2$ – parameters taken from built-in avionics. Will be used to predict landing scenario based on the helicopter attitude (two point or three point landing and helicopter side angle),
– acceleration $a_x$, $a_y$, $a_z$ in the approach phase – as the validation and redundancy parameters to the built-in avionics signals.

Phase two (deflection or landing):

– pressures in the shock absorber, $p_i$ – set of pressure signals inside the shock absorber that show the start of the L/G deflection and later level of forces acting on the fuselage – changes in pressures are also the quickest way to evaluate flow control,
– force in the shock absorber $F_a$ – direct shock absorber load measurement connected directly with pressures inside shock absorber. This signal is used as verification and redundancy to the pressure signals.

In addition, number of auxiliary input signals needed for proper operation of the control system is assumed. These signals are not essential for proper operation of the adaptive control so their description is omitted in this article.

All of the described signals will be verified during tests of the control system. Some of the signals can be abandoned after the tests.

### 3.3. Output signals

There is only one control output signal in the control system for both phases:

– control voltage signal $W_{pie}$ – signal sent to the piezo-actuator amplifier in order to set piezo-valve position (every piezo-actuator has one amplifier; therefore number of outputs resembles number of piezo-valves).

As for input signals there is a number of assumed auxiliary output signals needed for proper operation of the control system – description of these signals is omitted in this article.

### 3.4. Main control algorithm and software

Output parameters will be calculated continuously as the result of input parameters. Fuzzy Logic will be used for this purpose due to the possibility of using the expert knowledge, which is often empirical and difficult to express in a mathematical way as in the case of phenomena occurring during shock absorber operation. The outputs will be calculated use of a rule base, which can be created with multiple simple IF and THEN statements using adjectives and adverbs. Rule base for the fuzzy controller will be created using experience as well as data gained in the testing process of adaptive shock absorber. Data for the rule base and its size will be defined for optimum performance as a result of laboratory tests where a set of parameters corresponding to the specific landing conditions will be acquired.

As an alternative or supplement to the Fuzzy Logic, output parameters will be predicted continuously as the result of input parameters matrix sweep. The matrix (array) of parameters should allow in least complicated cases for faster (faster than arithmetic calculations) adjustment of the size of the damping orifice (valve movement) during the landing process. Data for the matrix and its size will be defined for optimum performance as a result of laboratory tests where a set of parameters corresponding to the specific landing conditions will be recorded. If during controller tests, input of parameters will not generally correspond directly to any of the predefined control algorithm matrix scenario it will be more proper to rely entirely on Fuzzy Logic.

Control software will be divided to several layers:

– input layer where input signals are acquired in native formats of measurement sensors and avionic systems,
– control layer where acquired signals are converted to proper formats, then all signals are processed with the control algorithm in order to calculate proper output signal for piezo-

actuator movement (orifice change). In this layer previously described logic and arrays are embedded,
- output and feedback layer where piezo-actuator control signal is sent to the amplifier, all feedback signals are collected (pressure, force) and then sent to the input layer,
- safety and human machine interaction layer where all safety, fault signalisation, and control system current state signalisation is implemented,
- autodiagnostics layer where all internal diagnostics take place including start-up diagnostics, periodic fault control etc. Autodiagnostics are performed automatically as part of the extended safety protocols.

## 5. Summary

Presented assumptions for the adaptive control system are the result of author's previous works in the adaptive aviation systems and aviation control systems in general. Based on guidelines described in this article laboratory control system is being prepared in order to check the functionality and the operation of the presented solution. Validation of the control system will require large number of tests to optimise software and to teach Fuzzy Logic and/or parameters matrix correct responses to the input signals, in other words control system needs to be taught proper control behaviour.

Please note that not all of the described software layers will be present in the laboratory control system (safety and autodiagnostics layers). These layers will be introduced in the implementation phase to the final aviation grade control system, which meets all of the regulations based requirements.

Work presented in this article was performed in the Landing Gear Laboratory of Institute of Aviation in Warsaw (one of the few independent laboratories performing Landing Gear tests, optimization and scientific research in EU), Poland where the author works on daily basis.

Presented work is the part of the ROLAND project ("Adaptacyjne podwozie nowego wiropłatu", agreement number INNOLOT/1/12/NCBR/2016) coo financed by the Polish Ministry of Science as part of the INNOLOT programme.

## References

[1] Currey, N. S., *Aircraft Landing Gear Design Principles and Practices*, Washington AIAA 1988.
[2] Kowalski, W., et al., *State of the art in landing gear shock absorbers,* Transactions of the Institute of Aviation, No. 181, 2005.
[3] Kowalski, W, Skorupka, Z., et al., *Landing Gear Active Shock Absorption*, AVT STO-170, 2011.
[4] *0169/16/ZTET/2017/SPR – Conceptual design of the PZL helicopter W-3A adaptive landing gear system*, Report, ILot, Warsaw 2017.
[5] *Certification Specifications for Large Rotorcraft*, CS-29, European Aviation Safety Agency (EASA).
[6] *Technical Requirements for the PZL W-3A Helicopter Adaptive Landing Gear System Design*, Świdnik 2017.

*Manuscript received 12 February 2018; approved for printing 05 June 2018*