An Adaptive Landing Gear for Extending the Operational Range of Helicopters

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***Abstract*— Conventional skid or wheel based helicopter landing gears severely limit off-field landing possibilities, which are crucial when operating in scenarios such as mountain rescue. In this context, slopes beyond 8° and small obstacles can already pose a substantial hazard. An adaptive landing gear is proposed to overcome these limitations. It consists of four legs with one degree of freedom each. The total weight was minimized to demonstrate economic practicability. This was achieved by an innovative actuation, composed of a parallel arrangement of motor and brake, which relieves the motor from large impact loads during hard landings. The loads are alleviated by a spring-damper system acting in series to the actuation. Each leg is individually force controlled for optimal load distribution on compliant ground and to avoid tipping. The operation of the legs is fully autonomous during the landing phase. A prototype was designed and successfully tested on an unmanned helicopter with a maximum take-off weight of 78 kg. Finally, the implementation of the landing gear concept on aircraft of various scales was discussed.**

Fig. 1. Adaptive landing gear mounted on the unmanned helicopter *Scout B1-100* [3]

I. INTRODUCTION

A. Motivation

The crucial advantage of helicopters compared to airplanes is their ability to land vertically. However, the requirements for a suitable landing site are high: slopes around 8° already pose a considerable hazard since the control inputs are at their limits at this angle, so a small gust of wind can already tilt the helicopter [1]. Similar restrictions are in place for obstacles which can not only interfere with the rotor plane but also result in dynamic rollover. Most importantly, the pilot has no assistance in assessing the terrain. Especially in mountain rescue, these limitations make hover landings and winch rescues inevitable [2]. Such special maneuvers require extensive training and always impose a certain risk. Hence, the opportunity of a safe landing on steep and uneven terrain would extend the operating range and increase helicopters' safety margin.

B. Challenges and Requirements

The weight of a landing gear must be minimized since it determines the economic attractiveness of the system. A heavy landing gear lowers the service ceiling and either payload capacity or operational range. Thus, each component must be optimized for weight while maintaining the strength to withstand the large loads from hard landings. For the certification according to *European Aviation Safety Agency (EASA)* specifications, a drop of the landing gear from a height of 33 cm may not invoke any plastic deformations, and a drop from 50 cm must not result in the breaking of any component [4]. While the actuation only has to withstand the vertical forces, the structure is also subjected to the loads from horizontal velocities during the landing.

Avoiding the build-up of vibrations in every possible operating condition is crucial for the design. This is especially challenging since there are multiple frequencies which might cause resonance (main and tail rotor, engine), while the interaction with the terrain during starts and landings can lead to ground resonance[1] with fatal consequences [5]. Moreover, the resonance frequencies of an adaptive system change with its position. It is virtually impossible to simulate the resonance behavior of the whole system accurately. This necessitates experiments on a full-scale model.

Since the pilot is already entirely occupied with keeping the aircraft stable during the landing procedure, he has no possibility to give any control inputs to the landing gear. Thus, the complete system has to work autonomously during this phase. In case of a partial or total system failure, the pilot has to have a possibility to land the helicopter safely. This

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[1] Ground resonance is an effect which is caused by the interaction between the imbalance of the main rotor and the landing gear touching the ground.

makes (autonomous) safety protocols for the failure of every component or any number thereof necessary.

C. State of the Art

1) Skids: Skids are the most basic and cost-effective landing gears available for helicopters. They require little maintenance and are lightweight. Drawbacks are their limited elastic and damping capacities, which lead to very high forces on the airframe during hard landings and a considerable threat of ground resonance. Additionally, handling on the ground requires auxiliary equipment due to the lack of wheels.

2) Wheels: This type of landing gear is significantly heavier and requires more extensive maintenance. They are often retractable which results in reduced drag during flight. Their elastic and damping properties are typically superior to skid-based landing gears. Run-on landings are possible, and the helicopter is also maneuverable on the ground without further equipment.

3) Prototype of Adaptive Landing Gear: A first prototype of an adaptive landing gear has been developed by the *Defense Advanced Research Projects Agency (DARPA)* [6]. The landing gear has been fitted to a *Rotor Buzz II* UAV, which features a maximum take-off weight (MTOW) of $120\,\mathrm{kg}$.

This solution consists of four actuated legs with two degrees of freedom each. Electric motors with high reduction gearboxes are located in the joints of the legs. The system allows an additional inclination angle of 20°. Extensive simulation has been undertaken to show different applications, i.a. landing on ships on the high seas. However, this concept has several drawbacks:

- Only the position of the legs is controlled and not the force acting on them. Thus, the impedance of the joints cannot be adjusted.
- The gears in the joints are exposed to substantial loads during hard landings. It is unlikely that such a system would fulfill the *EASA* requirements regarding hard landings.
- The second degree of freedom adds weight but offers no substantial advantage, since it can only absorb forces and enable movement in the plane of the leg.
- The actuation was demonstrated to be able to lift the helicopter. A geared motor that provides this power features a significant weight.
- The high reduction gearbox only allows slow movement, insufficient for dynamic landing maneuvers.

D. Platform

In the present project, the *Scout B1-100* has been used as a platform to attach and test the landing gear. Applications of this UAV include airborne laser scanning, surveillance, inspection as well as search and rescue [3]. The *Scout B1-100* features a main rotor diameter of $3.2\,\mathrm{m}$ and a maximum takeoff weight of $78\,\mathrm{kg}$, of which $18\,\mathrm{kg}$ is payload and $2.5\,\mathrm{kg}$ are made up of the original landing gear.

II. SYSTEM DESCRIPTION

A. Overview

The adaptive landing gear consists of four legs with one degree of freedom each for the adaption to the terrain, as illustrated in Fig. 1. This movement is driven by a lightweight actuation, composed of an electric motor and a brake acting on a spindle [7] with a damper in series to relieve large loads. Measuring the current induced in the motors enables force control without any additional force, distance or contact sensors [8].

A modular foot design enables the quick exchange of feet which are optimized for different terrains. The legs are connected to the fuselage by an interface element which can be mounted easily on the slightly modified chassis of the *Scout B1-100*. Overall, the landing gear weighs $15\,\mathrm{kg}$. The system is completely independent of the UAVs' electronics. Its battery enables an excess of 20 landings. A *Raspberry Pi* serves as main processing unit. It is complemented by an *Arduino* as a low-level interface. An IMU provides information about the orientation of the system, which is used to align the helicopter for a level parking position. The control algorithm is implemented in the *Robot Operating System (ROS)*. During the landing procedure, the operation is fully autonomous. The only input needed is a 'Gear Down' or 'Gear Up' command before the landing or after the lift-off, respectively.

B. Leg Structure

A four-legged configuration was chosen, resulting in the highest possible ratio of footprint to total leg length, the latter being the primary driver of weight. One actuated degree of freedom per leg was determined to be adequate, as a solely vertical movement is sufficient for an adaption to uneven terrain. Additional DOF's don't result in substantial advantages, but rather in a considerable increase in weight and a potential displacement of the center of mass.

The used geometry is based on a parallelogram with one side fixed to the fuselage, each edge represented by one

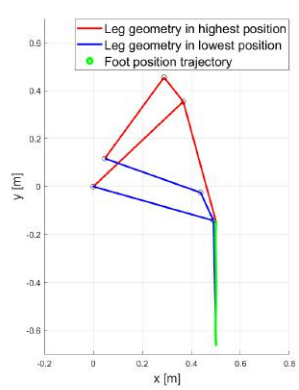

Fig. 2. Leg geometry (without actuation) in highest and lowest position, including the trajectory of the foot position

Fig. 3. Leg structure including the actuation, rods black, joints and spindle grey, brake red, damper yellow, motor green, foot brown

movable element connected at the vertices with bearings. The outer side is elongated to the ground. All parameters in this geometry (side lengths and angles) were optimized to reach a minimal horizontal deviation during the given vertical movement. The optimized geometry shown in Fig. 2 features a lateral deviation of only $0.25\,\mathrm{cm}$ over a vertical movement of $50\,\mathrm{cm}$.

Four legs are attached to the helicopter with a 45° or 135° angle to the direction of flight, respectively. This geometry can compensate slopes of more than 25°, depending on the orientation relative to the slope (Fig. 4). The tail rotor restricts landings with the nose facing downhill.

The leg structure was manufactured from prefabricated carbon fiber reinforced plastic (CFRP) pipes which were glued into the joint elements. Those are made from high-strength Aluminum and hold the bearings. Plain bearings were chosen due to their low weight and small form factor. Each foot is mounted with a lightweight clamping ring, allowing a quick exchange. Thus, the feet can be optimized for different terrains, i.a. a ski for landing on snow or ice. During tests, we mainly used a foot with a rubber profile to avoid slippage and a foam rubber filling with adequate damping properties. This foot provides sufficient friction even on terrain with slopes beyond 25°.

The actuation has to withstand large impact loads during hard landings but only needs to supply a comparatively small amount of power to lift the legs. It consists of a ball screw positioned between two opposite joints of the leg (see Fig. 3). A small motor acts on the spindle, which translates the rotational movement into linear motion. The *Maxon EC 45 flat* motor, weighing only $75\,\mathrm{g}$, is sufficient to reach high foot velocities of over $1\,\mathrm{m/s}$. Additionally, a *Miki Pulley BXR-040-10LE* brake ($170\,\mathrm{g}$) is connected to the spindle to block any leg movement. This enables the actuation to withstand large loads without damaging the motor. In case of a power drop, the brake is automatically blocked by a built-in spring. The whole assembly is shown in Fig. 5 and a cross-sectional view in Fig. 6, respectively. Not pictured is the plastic cover employed to prevent damage of the drivetrain by dust.

To minimize loads from hard landings, a high-performance spring-damper system with a maximal spring deflection of $5.5\,\mathrm{cm}$ is implemented in series to the ball screw. This results in a maximal vertical movement of the foot by $20\,\mathrm{cm}$. The *DT Swiss X 313 Carbon* damper allows fine-tuning of the flexibility and damping parameters, with a weight of only $170\,\mathrm{g}$.

C. Leg-Fuselage Interface

The interface between legs and fuselage must endure large loads, especially moments from ground impact. Furthermore, it is crucial for the vibration behavior of the complete system. It has to feature a large stiffness since small deflections at the mounting of the leg already cause significant movement of the feet. The legs are mounted utilizing four screw nuts per leg, which decreases maintenance effort and simplifies the exchange with the conventional skids (Fig. 7). The component bridging the distance between fuselage and leg was extensively optimized for low weight. The optimal utilization of mass is illustrated by the result of the FEM simulation of the critical load case in Fig. 8. Due to the resulting high complexity of the design, it had to be manufactured additively from high-strength steel using SLM.

To avoid critical resonance phenomena during flight, the eigenfrequencies of the complete system must not be close to existing frequencies originating from the main rotor, tail rotor, and the engine. This condition should be fulfilled for every leg position. Extensive FEM simulations, as well as full-scale tests, were performed to guarantee this. From the FEM simulations, the frequencies and shapes of the resonance modes could be determined, while the full-scale tests were needed to investigate the damping behavior. It could be shown that the resonance behavior can be adjusted by modifying the stiffness of the chassis (linking all four legs) and the mass of the feet. With a weight of $681\,\mathrm{g}$ per leg, the interface component adds a significant amount of weight. Evidently, there is a potential for weight reduction by a more extensive adaption of the fuselage to the landing gear.

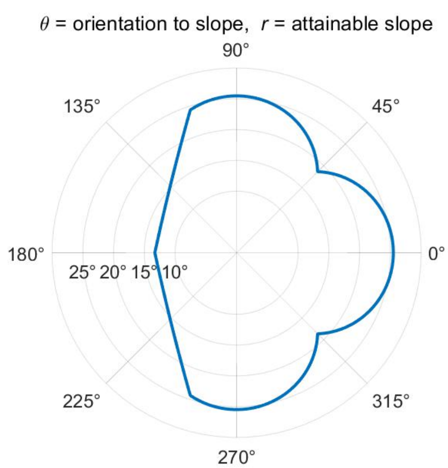

Fig. 4. Maximally attainable slope as a function of the orientation of the fuselage relative to the slope, 0° corresponds to the nose facing uphill

Fig. 5. Built-in actuation with cover removed showing the motor, brake and coupling (from left to right)

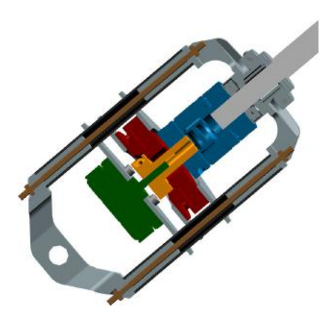

Fig. 6. Cross section through the actuation, rods black, joints and spindle grey, coupling blue, brake red, shaft adaptor yellow, motor green, brace brown

Fig. 7. Leg-fuselage interface including the helicopter chassis and leg

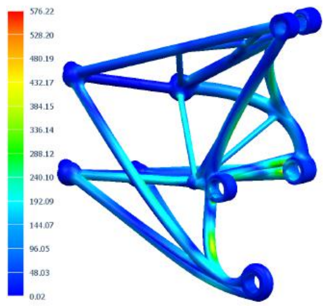

Fig. 8. Simulated stress of the leg-fuselage interface under the critical load case of a 33 cm drop test (Units: MPa)

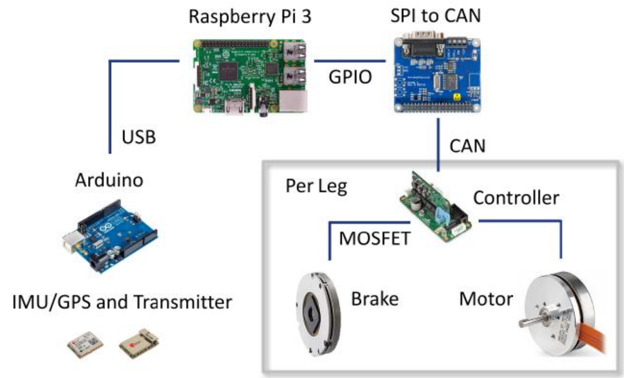

Fig. 9. Overview of all electronic hardware components

However, this was no option for this prototype since it would require a full reevaluation of the helicopters' airworthiness.

D. Electronics

All the electronic equipment apart from the actuation is integrated into a box to shield it from moisture and dust. An overview of all components is given in Fig. 9. A 2.6 Ah lithium polymer battery is used to supply the system with power. *Maxon EPOS2 36/2* digital positioning controllers control the EC-motors. The motor controllers' digital outputs are further used to control the brakes by switching a transistor which provides the brake controllers with the required input voltage via a DC-DC converter.

The microcomputer used as the central control unit is a *Raspberry Pi 3*. Over a serial connection, an *Arduino Nano* is connected to the *Pi*, serving as a secondary control unit. It is capable of opening and closing the brakes and serves as a backup in case of a failure of the central control unit. The microcomputer and the motor controllers communicate via CAN bus. As the *Pi*'s hardware does not support CAN by default, a CAN bus interface board (*SK Pang RSP-PiCAN2*) is used, which translates SPI signals into CAN.

Furthermore, an IMU (*Bosch BNO055*) is used to measure the body orientation. Thus, no connection to the electronics of the *Scout B1-100* is required, making the landing gear a stand-alone system. Inputs by the pilot are passed to the microcomputer using Wi-Fi. For an easy operation during testing, a GUI was implemented on a tablet computer.

E. Software and Control

The software for the control of the system is built upon *ROS*. This enables easy integration of additional sensors and external monitoring of all system parameters. The control system switches between the three modes of the landing gear: *flying mode*, *landing mode*, and *landed mode*.

In the *flying mode*, the system has its legs retracted to minimize air resistance. On the 'Gear Down' command by the pilot, the system switches to *landing mode*, in which the legs are fully extended and switched to force-limited position control. Force control regulates the position of the legs such that they each exert a maximal force of 3 N to the ground. This force is large enough to allow the legs to move with the ground as the helicopter is landing, but small enough to not exert a significant momentum on the helicopter and thus not disturbing the known landing procedure.

When all legs touch the ground but the system is still considerably inclined, the system locks the legs at the lower positioned corners and lets the helicopter move into a horizontal position. When the helicopter is in a safe stationary state the system switches to the *landed mode* which locks all legs. If some legs are already at their kinematic limit and others do not have ground contact yet, an error message can be sent out to inform the pilot that the terrain is too steep or uneven for a safe landing.

The *Arduino* monitors the hardware status such as battery-level, attitude, temperature and input signals. Heartbeats between the main control system on the *Raspberry Pi* and the emergency control on the *Arduino* are continuously sent to ensure a fast reaction to system failure. In case of a main control system failure, the *Arduino* can take over. Depending on the mode the landing gear has been in prior to the system failure the *Arduino* can lock or open the brakes, enable and disable the motors as well as hard-reboot the *Raspberry Pi*. Thus, a safe landing on a flat underground is possible even in case of a partial system failure.

III. TESTS AND RESULTS

The legs were tested for the strength required by *EASA* regulations. Drop tests from 35 cm were conducted repeatedly for single legs with an added mass equivalent to 1/4 of the helicopter, without any deformation of any part. Drop tests from 50 cm were simulated using FEM and showed no plastic deformation either. Thus, the leg structure and damper fulfill their requirements.

Extensive tests on a system level were conducted with and without the helicopter. Thus, the performance and reliability of the landing gear could be validated before flight tests. The system was attached to a rope and lowered onto different slopes and obstacles. A wooden board mounted at an angle was used to simulate slopes while a staple of pallets represented obstacles. Finally, outdoor tests were conducted on stairs and steep terrain as shown in Figs. 10 and 11.

Fig. 10. Outdoor test of the system on a slope with various obstacles

Fig. 11. Adaptive landing gear mounted on the *Scout B1-100* to test the slip resistance

Smooth and reliable adaption was reached on all grounds and obstacles, for slopes of up to $25°$ and obstacles of up to $50\,\mathrm{cm}$.

Horizontal alignment with a deviation of less than $4°$ was achieved even for an initial deflection of more than $15°$, which is the highest inclination that can be expected during touchdown.

Vibration tests were conducted using the system including the *Scout B1-100* on a vibration test bench, consisting of a decoupling mounting and a shaker with variable frequency. No resonance appeared in the vicinity of the critical frequencies. However, the substantial damping in the fuselage led to slight vibrations over the whole spectrum. No significant changes between leg positions could be determined.

For the subsequent flight tests, additional measures to guarantee the safety of the helicopter were undertaken, utilizing a rigid emergency landing gear under the fuselage. Starting, landing and hovering in different leg positions was successfully tested (Fig. 12). Vibrations were only recognizable for the highest $15\,\mathrm{cm}$, which were consequently avoided for the rest of the tests. The plastic friction bearings were identified as the primary cause of the vibrations. Choosing roller bearings in a next iteration of the prototype promises to be a simple solution for this problem. Landing on an obstacle was tested and repeatedly achieved, demonstrating the functionality of the concept[2].

[2]Footage of the successful flight tests can be found at https://www.youtube.com/watch?v=JtoOWS18D3k

Fig. 12. Adaptive landing gear attached to the *Scout B1-100* during a flight test next to the targeted obstacle

IV. Scaling

The scaling of the concept onto aerial vehicles of different sizes was investigated.

- An adaptive landing gear for the *Skeldar V-200* was designed [9]. This UAV with an MTOW of $235\,\mathrm{kg}$ features a conventional skid landing gear which weighs $6.6\,\mathrm{kg}$.
- As an example of a mid-sized transport helicopter, the *AS332 Super Puma* was chosen, featuring an MTOW of $9000\,\mathrm{kg}$ and a conventional three-wheeled landing gear with a mass of $280\,\mathrm{kg}$.
- Furthermore, a downscaled version of the landing gear for a quadcopter (*DJI Mavic Pro*) and a model helicopter (*Walkera Master CP*) each weighing less than $1\,\mathrm{kg}$ was designed and realized.

No changes to the relative leg geometry are made as the scalability of the system is to be reviewed.

A. Scaling Factors

The scaling factors were chosen such that a sufficient support polygon is provided, which has to be at least equivalent to the one of the conventional landing gear. This is evaluated in terms of the ratio of rotor area to support polygon area, which varies significantly for different scales. For the downscaled version, a ratio of 5.1 was chosen, while the landing gears for the *Skeldar V-200* and *Super Puma* feature ratios of 7.4 and 14.2, respectively. While larger legs offer larger achievable slopes and a higher safety factor against tilting, they are considerably heavier. Thus, each application requires a different ratio. E.g., vertical take-off and landing (VTOL) aircraft that only need to compensate for small slopes or obstacles could profit from relatively small legs.

B. Downscaling

The downscaled version for the *DJI Mavic Pro* and *Walkera Master CP* was designed and manufactured with an FDM 3D printer. The actuation is implemented with servo motors *(Bluebird BMS-380MAX)* and force sensing resistors *(Interlink FSR402)* in the legs. On this scale, loads and vibration are significantly less problematic. Thus, damping does not have to be considered. This prototype was used to validate the control algorithm before implementation on the *Scout B1-100*. Fig. 13 shows a successful landing.

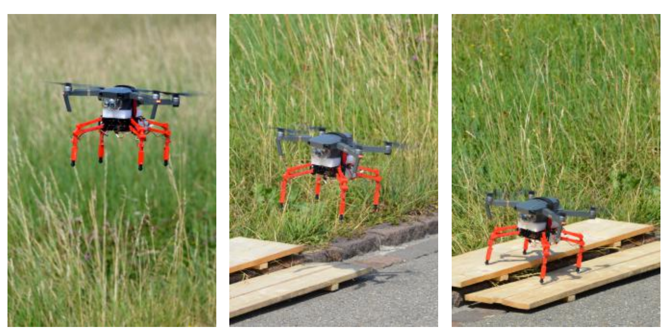

Fig. 13. Landing procedure of the downscaled adaptive landing gear attached to a *DJI Mavic Pro*

Fig. 14. Adaptive landing gear attached to the *Skeldar V-200*

Fig. 15. *Skeldar V-200* leg assembly with custom electric actuation

Fig. 16. Adaptive landing gear attached to the *AS332 Super Puma* in the preferable landing orientation

Fig. 17. *AS332 Super Puma* leg assembly with wheel and hydraulic actuation

C. Upscaling: Skeldar V-200

To enable a simpler interface to the fuselage of the *Skeldar V-200*, the leg structure was slightly modified, namely by changing the angle between the legs. In this version, all legs are pointing in a 90° angle to the flight direction, compared to 45° and 135° angles on the *Scout B1-100* (Fig. 14). The same materials are used: CFRP pipes and Aluminum connections. The structure of the actuation (spindle, motor, damper, brake) and control systems remains the same (Fig. 15), but the assembly is modified to prevent rotor interference and to decrease the risk of vibrations. A computational optimization was performed to select the most lightweight combination of components.

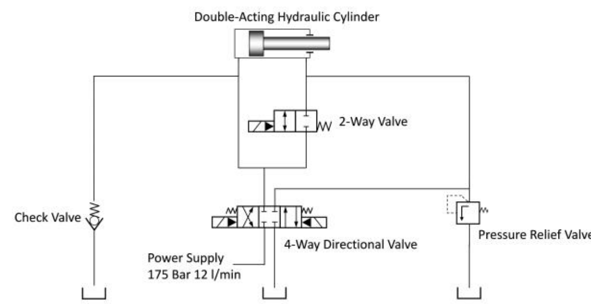

Fig. 18. Diagram of the proposed hydraulic actuation for the *AS332 Super Puma*

D. Upscaling: AS332 Super Puma

For a manned helicopter, it is required that the pilot has no obstacles in his field of view. This restricts the mounting of adaptive landing gears on the front. Thus, a different configuration is employed: The conventional front landing gear is left in place, and the rear landing gears replaced by one leg each (Fig. 16). With this configuration, the operation is not significantly compromised, since landings are rarely performed with the helicopter facing downhill [10].

On this scale, the certification requirements include a drop test from $20\,\mathrm{cm}$ [11]. Furthermore, autorotative landings with remaining horizontal velocity at touchdown have to be supported [12]. This is possible by mounting wheels in place of the foot, which is also essential for the handling on the ground (Fig. 17). For this application, cast Titanium was proposed as the primary material, which is in line with high-end skid landing gears used on manned helicopters. For the *AS332 Super Puma*, a hydraulic concept was developed which utilizes the onboard hydraulic power supply with a pressure of $175\,\mathrm{bar}$ and a maximal flow rate of $12\,\mathrm{l/min}$. Thus, this solution provides an increase in saved weight and reliability, since the use of an additional power source and motor can be avoided. The heaviest component of the actuation, the cylinder, was further optimized for low weight by selecting a composite model *(Parker C-Series L C BA 380 D 100 36 900)*. As the leg has to be able to be retracted and extended, a double acting cylinder is required. Valves are used to control the flow direction and rate. The diagram in Fig. 18 shows the arrangement of the hydraulic cylinder and the valves. The control of this concept is based on a pressure sensor in the hydraulic cylinder. By controlling the pressure inside the two chambers of the cylinder, the position and the flexibility can be adjusted. Furthermore, the valve between the two chambers of the cylinder can be used to modify the damping properties [13].

Theoretically, a passive retraction of the legs is possible by merely opening the valve of the cylinder. However, further tests are necessary to prove whether this leads to excessive moments on the aircraft. The instrumentation in the cockpit would need to be slightly retrofitted by means of a status light for each leg that would inform the pilots whether the respective leg is working correctly, stuck in a certain position or whether the terrain is too steep. The 'Gear Up/Gear Down' lever should furthermore be extended by including a middle position for level landings without adaption.

E. Applications

Ultimately, the adaption by the industry will be decided by the economics of adaptive landing gears. The added capabilities have to outweigh the downside of the increase in weight (reduced payload or decreased range, respectively: see Table I). The benefits are evident for increasing automation of the landing procedure, as it is needed for unmanned transport by helicopters or drones. There, an adaptive landing gear offers a significant increase in safety as well as operational range, especially when including landings on previously unknown terrain.

For the previously mentioned search-and-rescue missions, an adaptive landing gear becomes particularly beneficial if they are conducted by an unmanned helicopter such as the *Kaman K-MAX* [14]. Helicopter missions with landings on ships or platforms on rough, high seas are especially dangerous and challenging since the high relative velocities of the helicopter (subjected to wind) relative to the landing platform (subjected to waves) lead to high stresses on the airframe [15]. Here, an adaptive landing gear has substantial advantages since it can align itself to the moving landing platform and thus significantly reduce the involved risks and stresses. Another interesting area of application would be landing spacecraft on unknown, hazardous terrain [16].

	Skeldar V-200		***AS332 Super Puma***	
	Original	Adaptive	Original	Adaptive
Max. add. inclination	0°	19.3°	0°	11.4°
Weight landing gear [kg]	6.6	33.6	270.0	607.3
Remaining payload [kg]	40.0	13.0	4000	3662.3

TABLE I

COMPARISON OF LANDING GEAR WEIGHT AND REMAINING PAYLOAD

V. CONCLUSION AND OUTLOOK

This project investigated adaptive landing gears for helicopters. A legged structure with one degree of freedom per leg was proposed to allow landings on slopes of up to 25°. Four legs were constructed for a 78 kg helicopter and successfully tested in flight. The essential requirement for the economic viability of such a system is total weight.

The actuation enables a lightweight, actuated system of 15 kg, compared to the previously installed 2.5 kg rigid skid landing gear. By directing the loads on the legs around the motor, it can nevertheless withstand hard landings as required by the *EASA*. Implementing force control was shown to be an effective approach to control the system without any exteroceptive sensors. It enables the reliable operation of the system without any input by the pilot during the landing phase.

Scaling the system was discussed for manned helicopters and drones respectively from 10 000 kg to 1 kg. On large scales, the occurrence of vibrations is an extensive challenge, since there are a multitude of different conditions during flight (leg positions) and landing (ground resonance). Solving this problem requires close integration of the legs in the design of the aircraft. Integrating an adaptive landing gear during the development of a helicopter offers a significant potential for weight reduction: The design of the leg-fuselage interface can be considerably simplified. Furthermore, it promises a more lightweight airframe, as the damper absorbs a substantial share of kinetic energy which ensures lower peak loads.

Scaling down, these problems are less significant. Using 3D-printed plastic parts and off-the-shelf servo motors, realizing an adaptive landing gear for a 1 kg drone featured no considerable challenge. Such a system can offer substantial advantages for various UAV operations by allowing safe and autonomous landings on almost any terrain.

Within this project, the functionality of the concept was successfully demonstrated. Additional tests are scheduled to assess and quantify the performance of this prototype. However, it is already clear that there is much potential for improvements. In a next prototype, additional weight could be saved by another iteration of the drivetrain. A pneumatic or hydraulic actuator could even combine the spring-damper with the motor and brake. The proposed geometry can be adapted for different aircraft with varying requirements such as maximally attainable slope, distance to the fuselage or ability to completely retract the landing gear. This will inevitably lead to varying scaling factors. Another iteration of the structure and especially feet could further include the support for autorotative landings. The application of an adaptive landing gear can offer a significant increase in safety and operational range, especially in the case of autonomously flying vehicles and operations on high seas.

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