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DYNAMIC TESTING AND FATIGUE ANALYSIS OF THE I-31P NOSE LANDING GEAR

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Abstract
The landing gear is a critical safety component of any aircraft, playing a key role in managing the significant loads experienced during landing and ground maneuvers. In the case of the I-31P aircraft, a redesign of the I-23 landing gear system, required comprehensive testing to validate its performance, after change of landing gear parts manufacturer and minor updates to materials and technologies. This study focuses on the dynamic testing of the I-31P nose landing gear (NLG), particularly to assess its energy dissipation and fatigue resistance under operational conditions. Dynamic tests, performed in accordance with CS-23 standards, utilized strain gauges to monitor potential stress concentrations, especially on the half-fork design. Results demonstrated that the I-31P nose landing gear meets the required safety standards, with key performance metrics such as deflection and load factors within acceptable limits. The findings also highlighted the importance of continued monitoring for potential fatigue issues, offering valuable insights for future design enhancements.

Keywords: I-31P, nose landing gear (NLG), laboratory tests, dynamic testing.
Article category: research article

INTRODUCTION/I-31 AIRCRAFT

The landing gear plays a key role in ensuring aircraft safety, by dissipating the landing loads acting on the aircraft. The use of landing gear is not limited only to start and landing ; it is also critical in ground maneuvers in most situations (Currey, 1988). As the landing gear is one of the main components of the aircraft, it undergoes rigorous testing in order to ensure the safety of both passengers and cargo.

Aircraft often remain in production and in service for extended periods, during which manufacturing of various parts may be transferred to different companies. If this happens for a certified component such as landing gear, any such transition necessitates renewed testing to verify the new manufacturer's ability to produce a system that meets safety and design specifications. Additionally, shifting production after some time may prompt a need to redesign components due to new technologies or the availability of new materials. Such changes, if they occur, are typically incremental, reflecting lessons learned from experience operating the aircraft.

Despite extensive laboratory testing, the landing gear may still face such issues as component fatigue, and previously unrecognized weaknesses in the design may emerge over time (Kurdelski & Leski, 2011). It is important to note that any modifications made during an aircraft's operational life necessitate repeating the full test campaign, as such changes can affect the aircraft's performance under different operational conditions; data gathered during operation is also crucial for such testing (Reymer et al., 2014; Leski et al.)

The I-31 aircraft is a redesigned version of the I-23 airplane (Fig. 1). While no major changes to the design of its landing gear were made, some materials and manufacturing technologies were updated. In keeping with the above-mentioned principle, these modifications, although not altering the overall design of the parts, resulted in the necessity of repeating the qualification tests to ensure compliance with safety standards.

Figure 1. I-31P (top) and I-23 (bottom) airplane. *Source:* L-ILot.

In light of these considerations, to ensure safety and performance, the objective of this study was to subject the I-31P nose landing gear to comprehensive testing to assess its energy dissipation and fatigue resistance. These tests focused on validating updated materials and addressing potential stress issues, confirming the landing gear's compliance with safety standards and suitability for long-term operation.

NOSE LANDING GEAR

The I-31P nose landing gear (NLG) is of the telescopic type (Fig. 7), equipped with oleo-gas shock absorber (Wołejsza et al., 2005). It is fully controllable/steerable by the pilot while on the ground and is equipped with a wheel centering mechanism during retraction. Due to mass and space restraints, a half-fork was used for wheel support instead of a full-fork, resulting in a much more stress-prone design. As stated earlier, unforeseen issues may arise during operation, such as, in this case, the potential fatigue resistance of the half-fork due to component overload. Given that the half-fork is one of the main components of the landing gear, it was determined that it requires special attention in terms of the level of forces/loads it experiences as well as its susceptibility to fatigue during the current operation, possibly leading the formation of cracks in the component (Kurdelski & Leski, 2011). Given advancements in Structure Health Monitoring (SHM) techniques (Skorupka & Tywoniuk, 2019; Dziendzikowski et al., 2021) it is advisable for future designs to incorporate such systems to monitor aeras of concern identified in current tests.

The remaining structure of the I-31P nose landing gear consists of a quite typical aluminum/high strength steel design. Table 1 presents selected parameters of the nose landing gear and the I-31P aircraft itself.

Table 1. I-31 Nose Landing Gear parameters

Parameter Name	Value	Unit
Configuration	telescopic	-
Aircraft Landing Mass	1117	kg
Aircraft Landing Weight	1096	daN
Vertical Landing Speed (Limit)	2.93	m/s
Horizontal Landing Speed (Limit)	37.8	m/s
Acceleration Coefficient during landing with Limit Vertical Landing Speed	4.86	-
Maximum Tyre Deflection	68	mm
Maximum Shock Absorber Deflection	124.6	mm

Friction pair materials were tested in order to collect data for ensuring their properties and to provide feedback for brake assembly design (laboratory tests).

DESCRIPTION OF THE TEST PROCEDURE

- Tests were carried out according Part 23 (CS, FAR) regulations to ensure compliance with existing certification standards (European Aviation Safety Agency (EASA), n/a).
- Tests were made for two fillings/chargings of the shock absorber, using the same techniques and filling/charging parameters. Any differences in the results obtained should be treated as the envelope of landing gear parameters.

- There were concerns that the half-fork could be subjected to excessive stress exceeding the material's strength, potentially leading to premature fatigue failure of the component. To investigate this, strain gauges were applied (Figs. 2, 3) in order to collect data corresponding to the loads and landing cases encountered.
- As reference and as input parameters for performing the drop test, parameters from the certification tests of the I-23 Nose Landing Gear were taken (Tab. 2.).

Table 2. Input Parameters and reference values of the tests

Input Parameters		
Parameter Name	Value	Unit
Shock Absorber Pressure	0.95	MPa
Tyre Pressure	0.31	MPa
Vertical Landing Speed (Limit)	2.93	m/s
Horizontal Landing Speed (Limit)	37.8	m/s
Reference Values		
Vertical Force (Fz)	17.38	kN
Horizontal Force (Fx)	6.40	kN
Acceleration Coefficient (nz)	4.86	-
Landing Gear Deflection (Uk)	183.5	mm
Shock Absorber Deflection (Ua)	115.8	mm

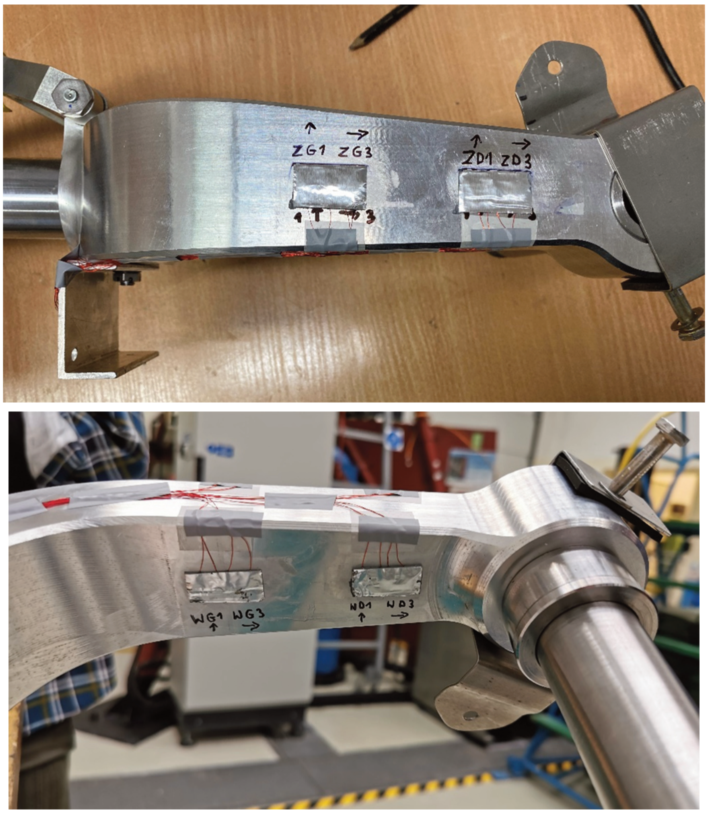

Figure 2. Strain gauge placement on the NLG half-fork. *Source:* L-ILot.

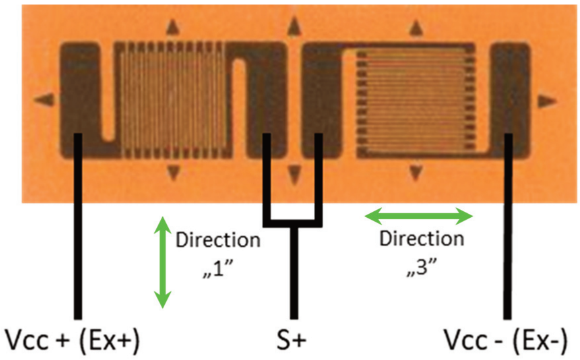

Figure 3. Strain gauge configuration. *Source:* L-ILot.

The strain gauges used were Tenmex TFxy-4/120 with the following specifications: k = 2.19±0.5%, R = 120.2[Ω]±0.2%, oriented with direction "1" along half-fork axis and direction "3" across the half-fork axis.

Measurement points:

- ZD – outside (opposite to wheel axis side) bottom.
- WD – outside (opposite to wheel axis side) bottom.
- ZG – inside (wheel axis side) top.
- WG – inside (wheel axis side) top.

STATIC TESTS

Static tests of the shock absorber were made according to the Technical Specification (WT-800.42.00. Technical Conditions of Aircraft I-23: Front Landing Gear. Drawing No. 800.42.00.00.00.) of the I-23 aircraft. The static characteristics were measured using the 40/20T Press test stand (Fig. 4) at the Landing Structures Testing Laboratory (formerly the Landing Gear Laboratory) at the Lukasiewicz Research Network – Institute of Aviation. The test stand is a hydraulic press designed for high load-testing of shock absorbers and wheels.

Test stand parameters:

- Forces: Vertical up to 392kN, Horizontal force up to 196kN
- Total vertical displacement 400mm
- Velocities: Vertical up to 300mm/min, Horizontal up to 600mm/min
- Work area: Horizontal 800 × 760mm, Vertical 190 up to 2000mm
- Force or displacement control (continuous or step)
- Force and displacement acquisition (and up to 8 external analogue signals)

Scope of tests: static tests, force-displacement characteristics, shock absorbers, dampers, material characteristics, wheel static tests.

Two sets of static characteristics were obtained in order to define the load envelope for the shock absorber parameters. Two separate filings/chargings of the shock absorber were performed, following the concept of using the same parameters and techniques for each filling/charging. The static tests were interspersed with dynamic tests for each filling/charging. A total of four tests were performed for each case of shock absorber filling/charging in order to collect data on the repeatability of the shock absorber's behavior. Since there were no major differences between the tests, only one test from each case is presented in this paper. The characteristic points (P1 to P4) correspond to the measurement points required by the landing gear technical specification (WT-800.42.10. Technical Conditions of Aircraft I-23: Front Landing Gear Shock Absorber. Drawing No. 800.42.10.00) which standardizes the static tests performance across various laboratories.

Figure 4. 40/20T Press.
Source: Landing Gear Laboratory, L-ILot.

Example results from the static tests of the I-31P nose landing gear are shown in Figs. 5 and 6:

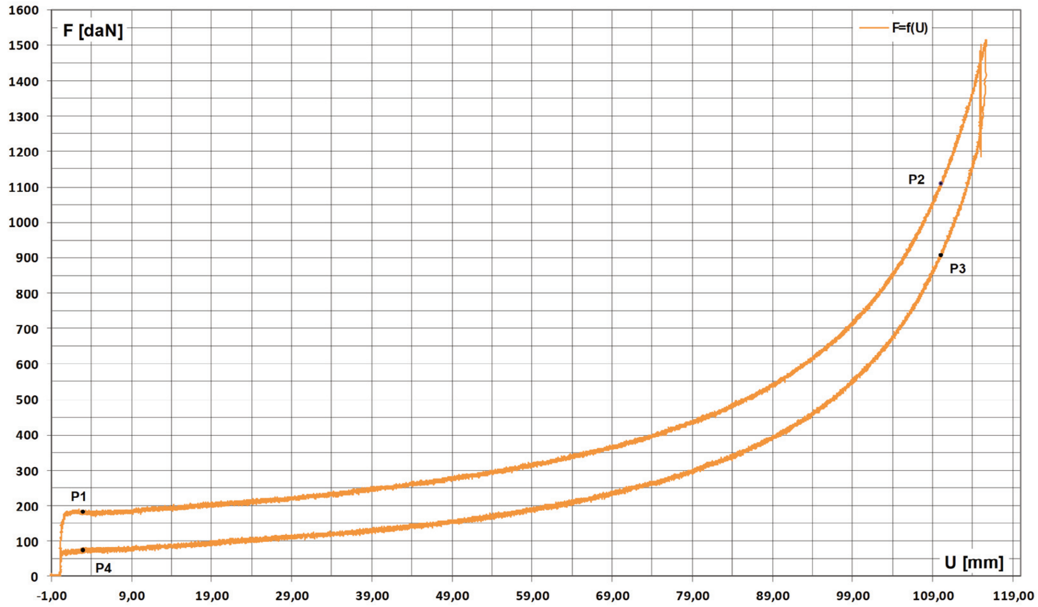

Figure 5. 1st filling/charging, 0326-I31PP-st-P40-0031, for data comparison see Table 5.
Source: L-ILot.

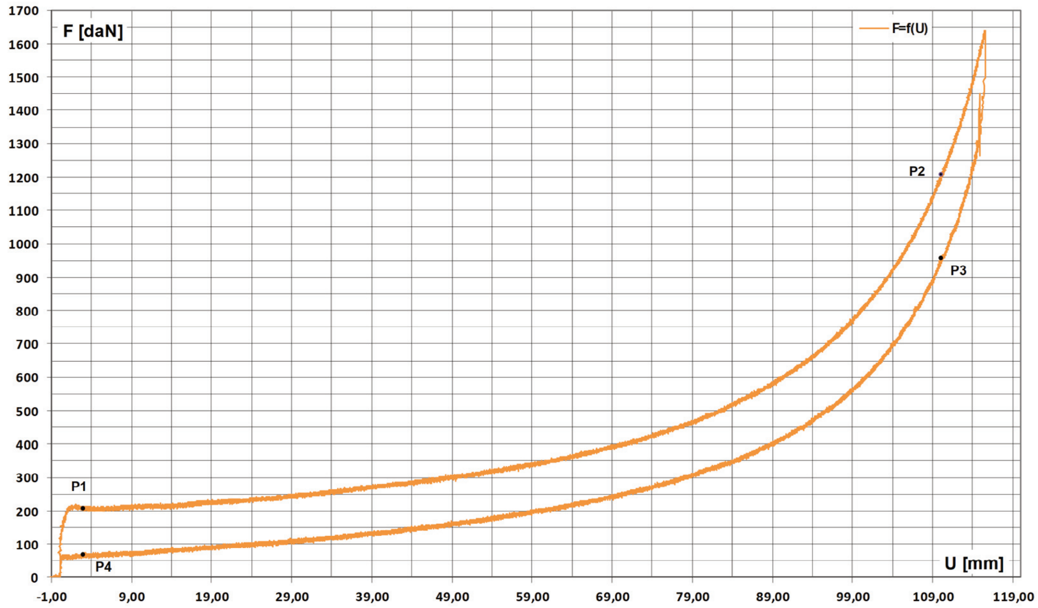

Figure 6. 2nd filling/charging, 0326-I31PP-st-P40, for data comparison see Table 5.
Source: L-ILot.

DYNAMIC TESTS

Dynamic tests of landing gears are simulate the landing process in a controlled environment. In order to achieve correct results, drop test stands (also known as drop test hammers) are used. These stands are designed to support the landing gear with appropriate hardware but not to interfere (e.g., by introducing friction that could reduce the energy dissipated by the landing gear and undesirably lower the loads acting on the fuselage). The test involves a free drop from a height corresponding the desired landing speed (Skorupka, 2017). The parameters for the drop tests were based on the certification tests of the I-23 nose landing gear (Table 2 and 14/ZB/BW-C6/00. Test Report: Front Landing Gear of Aircraft I-23. November 2000). The landing gear was prepared according to the Technical Specification of the I-23 (WT-800.42.00. Technical Conditions of Aircraft I-23: Front Landing Gear. Drawing No.800.42.00.00.00) and the technical documentation of the I-31P nose landing gear (3900.042.100.000.00. Front Landing Gear).

The tests were performed on the M10T drop test stand (Fig. 7) at the Landing Structures Testing Laboratory (formerly the Landing Gear Laboratory) at the Lukasiewicz Research Network – Institute of Aviation.

The M10T test stand parameters are as follows:

- Maximum mass of test object including mounting parts: 10T
- Maximum force in drop tests: Vertical: 392kN, Horizontal: 196kN, Side: 157kN
- Maximum buffer pressure (lift): 3 MPa
- Maximum wheel spin-up velocity: 111 m/s
- Maximum free-fall velocity up to 8 m/s – varies depending on test object height

Scope of tests: drop tests, wheel static tests, and functional tests.

As with the static tests, drop tests were performed in two sets, corresponding to different shock absorber fillings/chargings. Test results are presented in Figs. 8 to 11.

Figure 7. M10T test stand – overview example (left), I-31 NLG mounted (right).
Source: L-ILot.

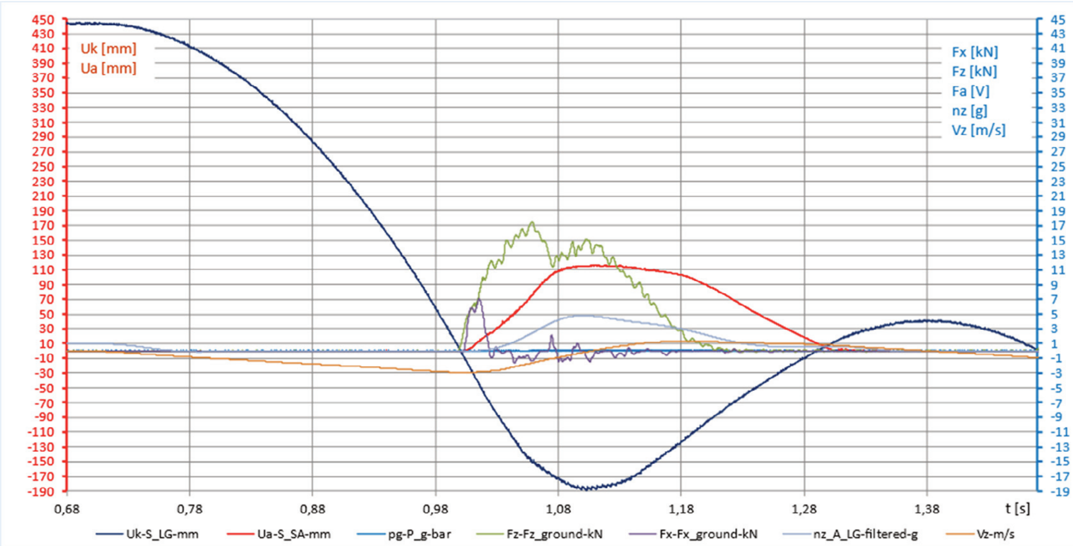

Figure 8. Example of full-scale dynamic I-31 NLG drop tests, general results.
1st filling/charging, 0326-dt-NLGI31-M10T-064, for data comparison see Table 3.
Source: L-ILot

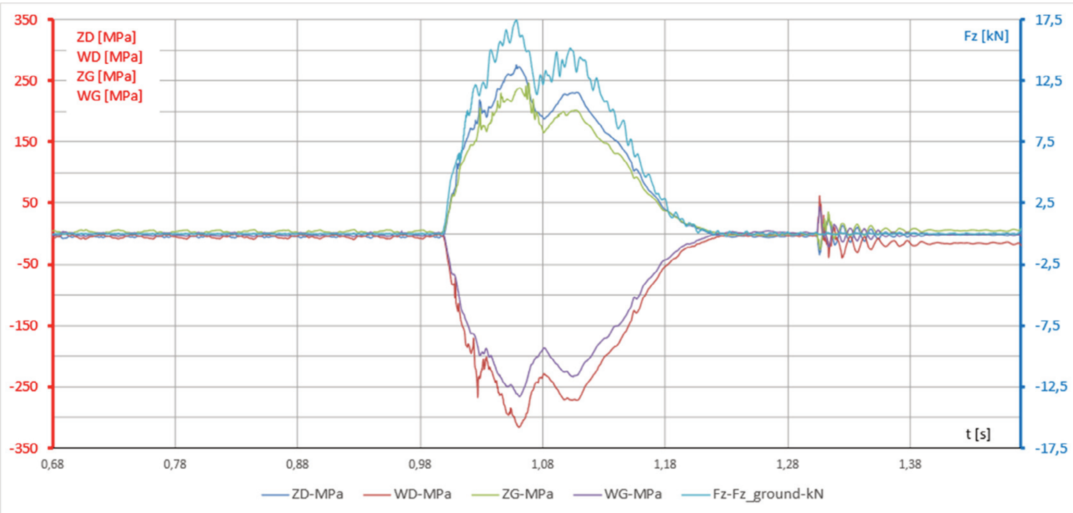

Figure 9. Example of full-scale dynamic I-31P NLG drop tests, strain gauge results.
1st filling/charging, 0326-dt-NLGI31-M10T-064, for data comparison see Table 4.
Source: L-ILot

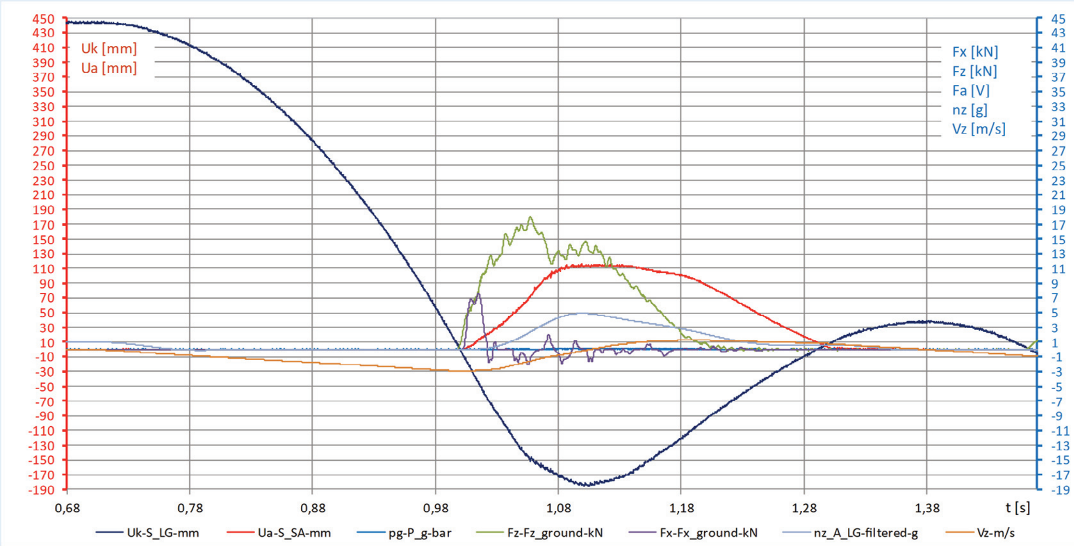

Figure 10. Example of full-scale dynamic I-31P NLG drop tests, general results. 2nd filling/charging, 0326-dt-NLGI31-M10T-094, for data comparison see Table 3. *Source*: L-ILot

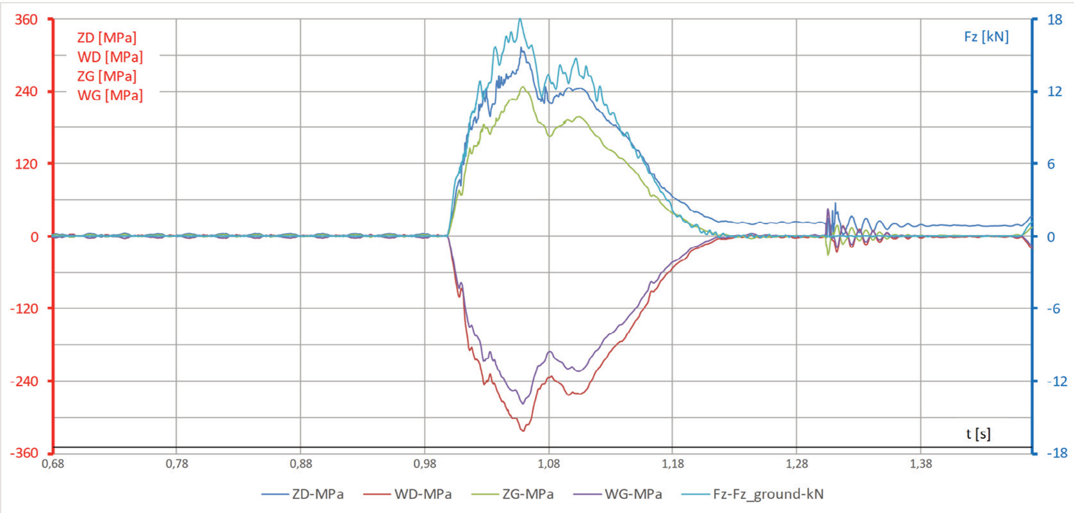

Figure 11. Example of full-scale dynamic I-31P NLG drop tests, strain gauge results. 2nd filling/charging, 0326-dt-NLGI31-M10T-094, for data comparison see Table 4. *Source*: L-ILot

TEST RESULTS – COMPARISON

The results obtained in all test categories are summarized in Tables 3 to 5 below.

Table 3. Dynamic Tests (Limit Conditions)

Parameters	Reference	1st charging	2nd charging	Unit
	Value			
Shock Absorber Pressure	0.95			MPa
Tyre Pressure	0.31			MPa
Landing angle (φ)	0°			
Vertical Landing Speed (Vz)	2.93	2.93	2.93	m/s
Horizontal Landing Speed (Vx)	37.8	39.06	40.07	m/s
Vertical Force (Fz)	17.38	17.47	18.04	kN
Horizontal Force (Fx)	6.40	7.1	7.6	kN
Acceleration Coefficient (nz)	4.86	4.80	4.89	-
Landing Gear Deflection (Uk)	183.5	189.3	185.8	mm
Shock Absorber Deflection (Ua)	115.8	116.1	114.3	mm

Table 4. Dynamic Tests (Limit Conditions) – Stress on Half Fork

Parameters	1st charging	2nd charging	Unit
	Value		
ZD – outside (opposite to wheel axis side) bottom	275.67	313.52	MPa
WD – outside (opposite to wheel axis side) bottom	-316.13	-323.31	MPa
ZG – inside (wheel axis side) top	246.59	248.41	MPa
WG – inside (wheel axis side) top	-266.32	-277.75	MPa
Vertical Force (Fz)	17.47	18.04	kN

Table 5. Static Tests/Characteristics

Characteristic points	1st charging	2nd charging	Unit
	Value		
P1	182	207	daN
P2	1109	1206	daN
P3	904	956	daN
P4	74	68	daN

SUMMARY

Safety is one of the key factors in aviation. Both passengers and cargo must be transported with the confidence that every step of their journey is verified and complies with strict safety standards. Regulatory authorities require not only that every new aircraft design should be thoroughly tested but also that tests are repeated when major changes to the existing design are made. Since landing gear is one of the key safety components of an aircraft, the forementioned proviso must be taken even more seriously.

The aim of this paper has been to address the challenges associated with aircraft lifespan, taking the landing gear as an example. The key points summarizing the findings are as follows:

- Change of manufacturer or/and updates of materials and technologies in landing gears results in need for repeating the certification tests.
- As reference for these tests, results from previous certification tests were used.
- Due to concerns about the strength of the half-fork, strain gauges were applied in designated areas.
- The tests validated the performance of the landing gear and replicated the previous results with acceptable repeatability – e.g. the deflections of both shock absorber and landing gear were found to differ by not more than 3%, the vertical force by no more than 3%, and the load factor by no more than 1.25%.
- Tests were carried out for two fillings/chargings of the shock absorber. The technique and filling/charging parameters were the same for both tests. Differences in main parameters (loads and deflections), which did not exceed 10%, should be treated as the acceptable performance envelope of the landing gear parameters.

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