REVIEW OF AIRCRAFT LANDING GEAR TESTS AS PART OF STRUCTURAL TESTING

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Abstract: Aircraft Landing Gears are the one of the most important safety systems onboard ensuring the well-being of cargo and passengers on board the aircraft. It is also the system which gives aircraft ability to take off, land, and manoeuvre on the ground while taxiing. Due to the safety role in aircraft, Landing Gears have their own requirements defined in regulations and are subjected to many tests going beyond the minimal legal and technical requirements. The full set of Landing Gear tests covers the tests of individual parts, full Landing Gear assemblies, and whole Landing Gear systems. The tests are made in laboratories for initial proof of safety and operation and inflight for full operation testing. The tests are done for various operation conditions beginning from static/strength tests, dynamic tests, to fatigue tests. These tests are performed on specialized test stands in dedicated laboratories and in most of the cases are excluded from being defined as structural tests. Although except from the part of dynamic tests most of the Landing Gear tests share similarities with other types of structural test in means of load introduction, measurement systems. In this paper authors present a comprehensive review of aircraft Landing Gear tests, including the current state of the Landing Gear tests; modern approaches and capabilities of Landing Gear manufacturers and Laboratories; and Landing Gears health monitoring as complementary testing methods. The review is extended to show that Landing Gear tests should be considered as part of structural testing even when tests are performed for Landing Gear only. In the last, the paper reviews and discusses the certification requirement for Landing Gears of existing aircraft, as well as a brief outlook on the Landing Gears testing methods and requirements for future new aircraft configuration such as eVTOL.

Keywords: structural tests, Landing Gear, test stands

INTRODUCTION TO LANDING GEAR TESTING

The landing gear is one of the fundamental components of the aircraft by providing the ability for taking off, landing, and ground manoeuvring [1]. Main function of landing gear is to dissipate the energy of landing and reducing loads acting on the aircraft's fuselage [2] making it aircraft safety system as well. Landing loads generated during touchdown and decelerating the aircraft by braking are coming from both the vertical and horizontal speeds and can cause catastrophic damage to the aircraft if not controlled correctly. Design of the landing gears must be reliable enough in order to withstand the acting loads, light enough not to cause aircraft to consume too much fuel during flight, and as compact as possible not to take too much of cargo or passenger space on board the aircraft. All these factors are required to consider for optimizing the landing gear design while ensuring it can withstand the design limit loads, which must use a minimum 1.5 safety factor required by the regulations, e.g. CS 23.726 [3].

The regulations themselves [3] don't describe landing gear testing methodology for meeting the requirements. They say that it needs to be proven in tests. Due to that there is a full flexibility on how to perform needed tests, in order to simplify the process and to make it more unified, SAE International [4] issued their document describing overall methodology and best practices for comparable tests. More or less all of mentioned documents (e.g. [3], [4], [5]) cover the topic of Landing Gear tests the same way. Detailed procedure for the tests is to be determined by the testing facility but it needs to be convincing and proven to provide testing evidence and data that are acceptable by the regulators. The only suggestion in aviation regulations is to use the equivalent mass method, but direct lift force simulation is also permissible.

In general landing gear tests can be divided into the following four groups:

1) Static/Quasistatic
2) Dynamic
3) Functional
4) Fatigue

The first group contains all the tests which are done in static or very slow velocities of loading rate. These tests are mostly done by loading the landing gear with the constant force corresponding to the expected dynamic load for a defined time period in order to prove the rigidity of the landing gear. Another common static test is the load/deflection curve of shock absorber. The latter can be also treated as functional test. Static tests are usually made on modular test stands that can accommodate landing gears and load actuators similar to other structural testing, quasi-static tests can be made on the stress/strain tests stands or any other test stands being able to load the landing gear with a constant loading speed.

Dynamic tests are usually the drop tests which are the core of landing gear testing and certification these tests are made in order to optimize landing gear, prove its operation and fulfil certification requirements given by the aviation regulations. Dynamic/drop tests are made on specialized test stands (Figure. 1) capable of free fall drop tests in controlled conditions or in case of full-scale or complete aircraft drop tests cranes can be used but in limited measurement capabilities.

Functional tests are the tests which test and prove certain functionalities of the landing gear, e.g., roll on tests, shimmy tests, obstacle run tests, extension/retraction tests etc. These tests can be done either under dynamic or static condition depending on the test. Functional tests are usually made on specialized tests stands such as rolling drums with/without built in controlled inertia or on the drop test stands as they can be used as loading platforms or supporting ones e.g. for retraction of single landing gear tests.

Fatigue tests prove the lifetime of whole landing gears or the individual/groups of components and can be done in quasistatic or dynamic conditions. For landing gears, the component fatigue testing is done mostly using standard fatigue tests techniques (e.g. subject to cyclic loading, constant amplitude or random loading spectrum), this also applies to full landing gear sets if the certain and controlled loads must be applied. For lifetime fatigue tests of whole landing gears, a set of drop tests simulating a spectrum of landing loads/speeds is made [6]. The tests are usually made on modular test stands similar to the structural testing ones in case of single/multi component cycle load tests (Figure. 2.). Tests can also be made on drop tests stands for whole landing gear spectrum load tests resembling the drop tests but sometimes with different instrumentation used.

Also, there is a number of tests covering other aspect of landing gear operation such as brake, wheel, and birdstrike tests. These tests are usually done separately by landing gear laboratories or by the manufacturers of brakes and wheels due to the separate certification as brakes or wheels can be used in several different landing gears. As the above-mentioned tests are the category of their own, despite being the part of landing gears tests, this paper will not review them in detail.

Figure 1. 10 Ton Drop Test Stand (Semi-Automatic) (source: L-ILOT).

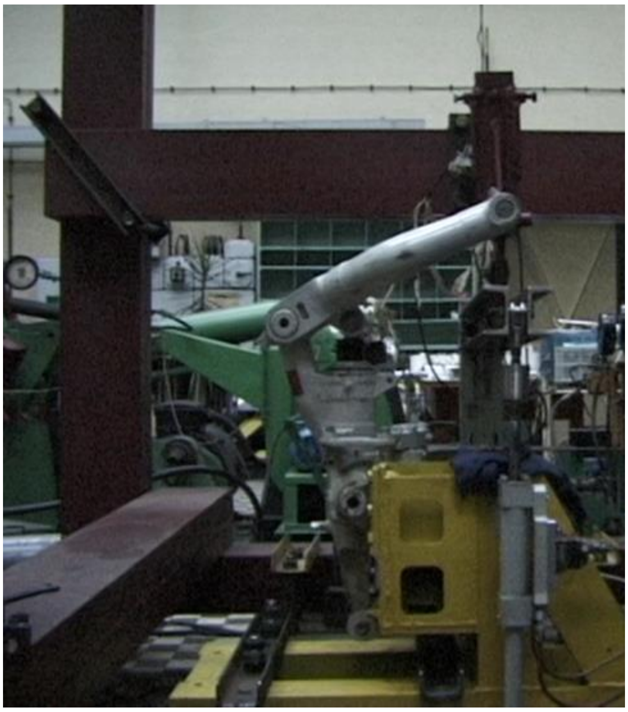

Figure 2. Example of multi component quasistatic fatigue test (source: L-ILOT).

MODERN LANDING GEAR TESTING APPROACH/CAPABILITIES

A quick survey was carried out to give the overall knowledge about the landing gear facilities and manufacturers. Although the number of designed and produced aircraft is high, most of the commercial aircraft is operated the landing gear made by a limited number of companies including Heroux-Devtek (Canada) [7], Collins Aerospace (USA) [8], Safran (France) [9] or Revima (France) [10] specializing in replacement parts and systems including landing gears. The first three mentioned companies are one of the biggest designers and manufacturers of the landing gears and, according to commonly available information, are capable of many of the tests of the landing gears needed for optimization and certification purposes. In most of the companies mentioned above maintain tests stands for drop tests as well as for the static test. Rest of the tests including fatigue, wheel and brake testing are outsourced to the external companies specializing in aviation equipment testing including landing gears. Sometimes even tests in the range of companies are outsourced due to the economical or logistic reasons – on a case-by-case basis for each project.

Outsourced tests are carried out by the companies or research institutes all over the world with comprehensive testing capabilities, e.g. Łukasiewcz Reseach Network – Institute of Aviation, Poland [11] specializing in tests of landing gears, wheels and brakes including brake linings materials as well as fatigue and structural testing. Also, there is a number of companies which design and deliver solutions for landing gear testing for laboratories, e.g. Kistler (Switzerland) [12] specializing in measurement equipment including force measurement plate based on piezoelectric sensors.

Reviewing the available data it can be seen that, in general landing gear design [13] and testing, not much has changed in many years in means of test scope/range and general approach to test execution [14]. Schmidt, R. Kyle [15] also touches the problem of economical purpose of fatigue testing which is nowadays the main factor for not performing non-essential testing and the reason of seeking for cheaper alternative in simulations [16].

Also, use of the advanced materials in landing gear design requires not revolutionary but incremental changes in approach to the testing process and safety procedures. The more common use of the composite materials [17] especially in spring type landing gears leads [16] to the challenges not known from metallic materials such as possibility of rapid cracking of composites instead of initial plastic deformation and gradual cracking of the metal structures. In this case the simulations of composite behaviour are the most promising solution for pre-test validation of the design [18] [16] but still not as the replacement for both laboratory and in flight testing.

There are some novel approaches to the composite materials where the "classic" composite is enhanced with metal, e.g., aluminium in its structure (which creates a hybrid structure) [17]. On the other hand the use of the high tensile steels and aluminium alloys [17] is not new in the landing gears – as the landing gear is subjected to the impact of highest forces that act on the aircraft structure – but it is necessary to remember that highest tensile strength and ability to design lighter (by the use of less material) landing gear comes with the trade-off of being more susceptible to e.g. intercrystalline corrosion and can be less fatigue resistant what makes the expensive and time consuming landing gear fatigue testing more advisable and necessary.

The real novelty and advancement in Landing Gear testing mostly focus on creating more efficient designs for test stands rather than on changing the test procedures themselves. First improvement is to use finite element analysis in order to prove the design and operation of test rigs [19]. The second improvement in landing gear testing optimization comes in twofold: advanced materials and improved measurement methods.

1) The material approach results in more stable test stands that use less of the materials that are stiffer and more resistant to the fatigue during testing especially in dynamic conditions – improving the lifetime of drop test carriages. The core (support legs) of the test stands is basically the same but the simplification bases on using the one leg design not preferred earlier due to the more bend and deformation of the drop carriage due to the dynamic loads. The material improvements are seen mostly in new built designs although in existing tests stands some of the replaceable parts (e.g., drop carriages) are nowadays redesigned in order to take advantage of improved materials and manufacturing technologies [17].
2) On the improvements of the measurement methods, progress made in last two decades is huge especially in data acquisition speed what can result in faster record frequencies and better time resolution of recorded signals. For example, the drop test lasts for about 0.3 seconds, a decade ago 1kHz was the main sample rate of data acquisition for the tests, this would give 300 measurement points for the whole process. Nowadays the new DAQ can easily reach 10x the frequency that gives much more data to work with. Usually in drop tests 5kHz is used which gives 1500 measurement point for the test and is enough for detailed evaluation of data. In addition, the fast speed of modern measurement systems can make some of the signal adjustments in real-time, or simultaneously record raw signal and adjusted one in case the adjustment was incorrect (e.g., used signal filter or mathematical equation converting one data into another). Also, data can now be logged directly to the data banks via network protocols which result in ability to separate data measurement from data storage resulting in the possibility of building an acquisition system as close to the test as possible and avoiding losing stored data when something occurs. When data was stored directly in the measurement system its malfunction due to the possible damage during testing in most the cases could result in destroying data storage in the process. Moreover, when distance between sensors and acquisition system is shortened, analogue measurement lines are much less prone to possible interferences.

Also, the storage capacity dramatically increased in recent years as its speed due to the use of large traditional magnetic discs for storage and reliability plus solid-state drives for fast data recording. This combined with relatively low prices results in ability to acquire large number of measurement signals with relatively high speeds.

The second measurement improvement is more affordable high-speed video that can be used as replacement of some of the traditional electrical sensors or as the measurement system where the more traditional methods cannot be used. This is the future of some of the measurement systems but still it needs to be taken with a grain of salt due to the certain issues with correct calibration of the method. This corresponds mainly to the issues with correct placement of the camera in relation to the measured object. By the correct position it means that optical axis of the camera lens is perpendicular to the measured phenomenon, e.g. the velocity of the moving side of the object. Also the focal distance must be always the same for the repeatable measurements because every change of focal length or relation to specific focal point can result in measured image distortion falsifying correct measurement.

Also, the gradual improvements to the exiting testing methods such as adding new measurements on the test stands for controlling more data are making the tests much closer to the actual landing gear behaviour in laboratory environment, e.g. by adding direct lift force measurement [20] which can be used to directly measure the true lift force instead of indirect lift simulation system pressure measurement.

In order to be as close to the real-life operation of the aircraft one cannot forget about full scale tests made on complete aircraft in laboratory setting. The most recent and published examples are the tests of naval version of F-35 multirole fighter aircraft [21] in multiple landing scenarios. These complex tests need tailor made test stand and measurement equipment. In this case the drop mechanism and wing lift simulation were designed as well as force/load measurement plates for each wheel were made only for these tests among other equipment. Such tests are usually made in improvised laboratories using aircraft hangars and both modular laboratory equipment acquired from specialized laboratory as well as tailor-made one procured for that particular test only.

Last example of high-end testing is a tire and landing gear test facility that has been developed in the mid-1990s and incorporated into a Convair 990 aircraft for the Shuttle Orbiter by NASA [22]. The facility could simultaneously simulate the vertical load, tire slip, velocity, and surface for an entire aircraft landing in real-life conditions but in controlled tests environment.

Both landing gear manufacturers and research facilities agree on the new technologies and tests for landing gears such as new materials development and testing including carbon fibre composites, additive manufacturing, electrification of actuation systems [23].

LANDING GEAR HEALTH MONITORING AS COMPLEMENTARY TEST METHOD

Health monitoring in aviation – as in other industries – is a growing trend due to both safety and economic benefits. The real-time knowledge about condition (state) of the mechanical system enables detection of the possible faults, premature wear or help with lifetime prediction during normal operation and can induce protective measures when failure occurs. Also gathering real-time data through the longer time can supply with information helpful in closer approximation of the fatigue data to the reality and confront it with fatigue tests results made before operation of the aircraft – during certification – based on either statistical data taken from similar aircraft or on standardized approach [6]. This can lead to the extension or reducing the safe lifetime of the components according to the data collected.

Therefore, the health-monitoring should not only be treated as failure detection abut also as the continuous test that can aid or replace some of the long running tests for lifetime evaluation made for various aircraft.

Nowadays there are many approaches and propositions to the health monitoring in aviation in relation to landing gears. Most common approach is to monitor loads acting on both landing gears and aircraft structure using various techniques. The one of them is use of fibreoptics in wide range of applications. For example, the impact load measurement by a wide-range fibre Bragg grating (FBG) strain sensor with a surface-attached carbon fibre matrix [24], with combination of multivariate linear load regression method, can simultaneously monitor and predict the three-way load (vertical, heading/horizontal), and lateral/side) of landing gear. The feasibility of this method was verified by carrying out ground static loading test. The other use of Fibre Bragg Grating (FBG) sensors is to integrate them onto an aircraft landing gear for remote and real-time load monitoring [25]. Several FBGs strain sensors, both in a linear and tri-axial configuration, have been integrated on different locations of landing gears (both Main and Nose gears). Obtained results were in good agreement with those provided by reference electrical strain gauges located very close to their optical counterparts. Using fibreoptics the results of loads such as crack detection can be detected and monitored by the longitudinal separation of two cleaved plastic optical fibres (POFs) facing each other what results in a change of the output light intensity when crack is formed [26].

More traditional approach is to use strain gauge-based load sensors that can be built into the mounting pins of the landing gears which measure loads acting on the aircraft structure and landing gears [27] or to implement of Messier-Dowty (Safran) Strainlogger system for monitoring in real-time the loads on landing gears using the strain gauges for measurement. The tests were done on Dassault Falcon 20 in National Research Council Flight Research Laboratory in Ottawa, Canada [28].

Another proposition is to use of the accelerometers mounted on landing gears [29]. Tests have shown good correlation between the indirect vertical landing load measurement via acceleration measurement and direct load measurement using the strain gauges-based sensors.

Not only the load and strain measurement can be used in real-time health monitoring but several other sensors like the pressure sensors installed on the shock absorbers or wheels [30] for real-time monitoring of vital landing parameters – in this case pressures needed for safe operation of landing gear.

Another proposed system for observing the condition of aircraft landing gears automatically is an Electro-Mechanical Impedance (EMI) testing system as monitoring method [31]. According to the authors, some information on structural integrity can be obtained by comparing the data changes in the data (frequency spectra, intensity, and their peaks) acquired from pristine and new landing gears, and the same data acquired during the routine inspections in operation. The data obtained with the wireless EMI-system on the landing gear of the glider airplane show that it is feasible to implement this technique in a real structural application.

The health monitoring systems can also use existing data from sensors onboard using a machine learning approach [32] to investigate the predictability of loads induced in the landing gear from flight parameters recorded on the aircraft (such as accelerations, velocities, etc.). In this case Gaussian Process regression is used to model the relation between flight parameters and induced loads, using a database of flight test data.

From this survey it is evident that health monitoring is based on a wide range of data from techniques and sensors that are used in the laboratory testing. This approach can be easily treated as extension of the laboratory tests or tests on its own complementing. Health monitoring can be used as the feedback to the laboratory tests and leads to enhanced testing capability.

There is one more possible health monitoring area, connected to the safety of the landing gear operation, such as corrosion detection. As mentioned earlier the high tensile steels and aluminium alloys are very susceptible to intercrystalline corrosion and other corrosion forms especially in tight spaces or closed hollow parts. The real-time corrosion detection can prevent catastrophic failure in places where regular visual inspection may be impossible or hard to perform.

LANDING GEAR TESTING AS PART OF STRUCTURAL TESTING

Landing gears are critical structures of aircraft and its testing has to be treated as a part of structural testing. The majority of the tests made on landing gears – including required most important drop tests – are made on specific tests stands dedicate to the landing gear testing. This can give the false feeling that landing gears can be treated as the outside system to the structure. This is not true since the landing gears are a deeply integrated part of the aircraft structure acting on the wing or fuselage with various high loads especially during landing. The static and most of the fatigue tests on the landing gears [5] are done the same way as on other parts of the aircraft structures, except for the dynamic fatigue tests which are performed as the drop tests [5].

A good example of the similarity of landing gear testing to the tests of the other structural components can be the modular test bench/stand with hydraulic protection module for quick affordable fatigue and static/strength tests of landing gears. A test rig was developed by Messier-Dowty which is now part of Safran [33], the test stand is a reconfigurable frame with standardized load actuators and measurement equipment (Figure. 3.).

Figure 3. Example of Safran modular test stand for landing gear testing [22]

Figure 4. Example of L-ILot modular test stand for landing gear testing (source: L-ILOT)

The Lukasiewicz Research Network - Institute of Aviation Landing Gear Laboratory has a similar test stand for simple static testing of the landing gears (Figure. 4.).

The second scope of the tests are the full-scale tests performed on complete aircraft. Example of such a test is mentioned before, i.e., full-scale tests of landing gears for naval version of F-35 multirole fighter aircraft [21] in multiple landing scenarios. These tests not only assessed the landing gear related data but also data related to other structures of the aircraft in the same testing scenarios.

Many of the tests can be made in structural integrity laboratories using existing equipment (e.g. Structural Integrity Laboratory in National Research Council in Ottawa [34]) but remembering that for the test campaign at least one test engineer should have some expertise and knowledge about landing gears in case of need for troubleshooting onsite.

CERTIFICATION REQUIREMENTS FOR LANDING GEARS (SAE, CS)

In general, the most important certification (Airworthiness) test according to modern CS (Europe), FAR (USA), CAR (Canada) regulations, is the energy absorption test which must be done for two energies – limit and extended. The regulations state that landing gear must pass the limit energy (e.g. CS 23.725: vertical speed up to 10ft/s or 3.05 m/s which correspond to a drop height of 0.474 m) test with no damage and extended energy (e.g. CS 23.727: not less than 1.2 limit vertical speed or 1.44 drop height) with damage which won't compromise safe landing of the aircraft – landing gear cannot be broken or fall off from the aircraft but can be deformed and not usable for next flight (e.g. CS 23.723(b)). It is necessary to remember that the requirements for these tests is described in Landing Gear part of the regulations mentioned above but also in indirect or direct way in, for example Subpart C – Structure for CS or Strength requirements for CAR regulations subpoints CS23.307 and CAR527.307 [5] respectively. It is worth to mention that the structure of most aviation regulations is the same, so subpoint ".307" will refer to the same requirement in all CS, FAR and CAR regulations.

Regulations also specify the requirements for the Landing Gear design according to the ground loads (including drag loads from the brakes if necessary) for a number of load cases. To certify the landing gear for specific aircraft the design must follow the regulations in order to be proven first in the design by calculations or simulations, and next in static tests.

Other types of tests required for certification by the aviation regulators are not landing gear specific but rather refer to the wide range of the tests for the structure of the aircraft where a landing gear is a component. The mentioned tests are the tests of limit and ultimate loads proving safety factor of 1.5 and fatigue tests for proving the reliability of the design. For example, CAR527.571 states that: "(a) General. Each portion of the flight structure (the flight structure includes rotors, rotor drive systems between the engines and the rotor hubs, controls, fuselage, landing gear, and their related primary attachments), the failure of which could be catastrophic, must be identified and must be evaluated under paragraph (b), (c), (d) or (e) of this section.". This can be interpreted in various ways where the last word belongs to the aviation authorities.

Last to mention, although not reviewed in detail in this paper, are the tests and requirements for wheels and brakes. These tests are made for wheels and brakes for their certification as aviation product to be used in various designs. Since the wheels are the part of drop tests – the tests must be done in certified configuration of the aircraft. The brakes can be tested with full landing gear assembly on the specialized test stand – this is not directly required by the regulations but in some cases can be enforced by the aviation authorities.

This section summaries general certification requirements for Landing Gears. As the Airworthiness must be proven before the authorities and regulations give the outline for the actions needed there will always be a difference in certification path for specific aircraft, for example an eVTOL aircraft.

eVTOL aircraft are being seen as one of the future directions in aviation industry, as the eVTOLs are based on two main principles – vertical takeoff and landing and electrical propulsion. Due to the current efficiency of electrical engines, it is possible to design and make only smaller aircraft. The size of current eVTOL aircraft being developed is mainly up to pilot plus four or five passengers [34]. As the eVTOLs are planned to be personal and flexible their intended use is as air taxis or personal mobility aircraft. Current designs aim mostly for urban mobility as it is possible today with use of the helicopters but on much more global scale.

Currently there are more than 600 projects of eVTOL aircraft being in various development stages ranging from concept stage to flying porotypes [35] (Fig.5.).

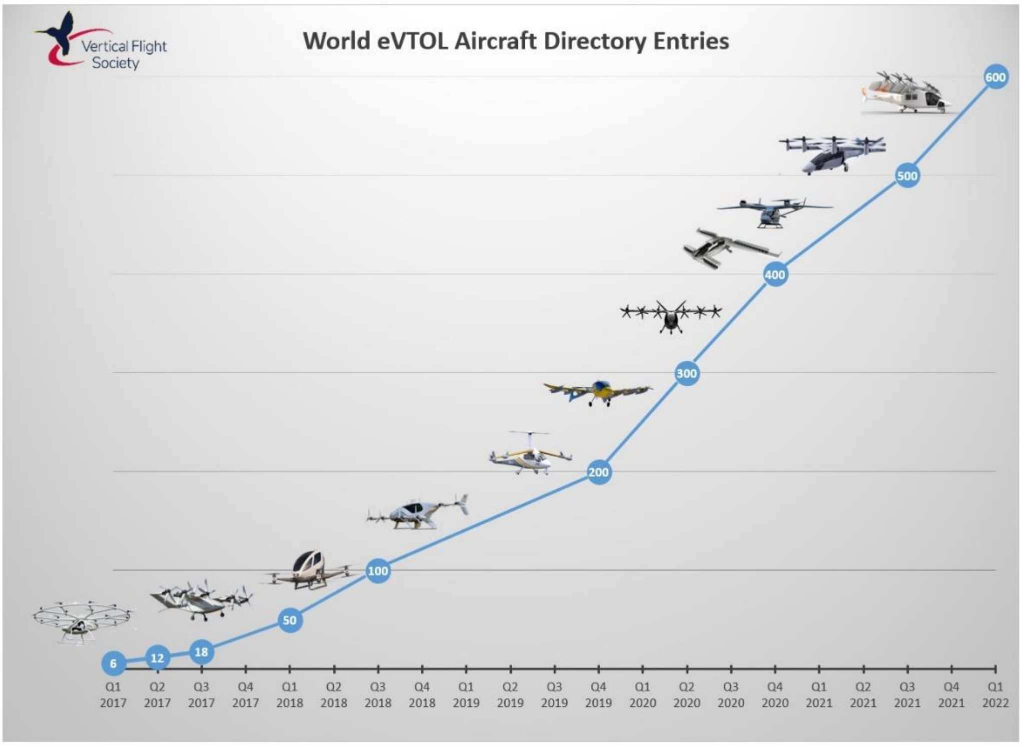

Figure 5. World eVTOL Aircraft Directory Entries as for January 2022 [36]

The market for eVTOL is also booming reaching $6.73 billion in 2021 and expected to grow to $18.92 billion in 2026 [37]. Some examples of eVTOL projects are [35]:

- The S-4, Joby Aviation (Marina, California), range: 150 miles, cruise speed 200 mph, power plant of six electric motors, configuration: tilt rotor, capacity: one pilot and four passengers. Planned commercial operation 2024 [38].
- Journey, Jaunt Air Mobility (Dallas, Texas), range: 80 miles, cruise speed 175 mph, power plant N/A, configuration: main rotor plus horizontal engines, capacity: one pilot and four passengers. Planned commercial operation 2026.
- Archer Aviation (Palo Alto Airport, California), range: 60 miles, cruise speed 150 mph, power plant six battery powered engines, configuration: tilt rotor, capacity: one pilot and four passengers. Planned commercial operation 2024 [39].
- VoloCity, Volocopter (Bruschal, Germany), range: 22 miles, cruise speed 68 mph, power plant Nine lithium-ion battery packs, brushless DC electric motor, 18 rotors, configuration: fixed multi rotor, capacity: two passengers, with room for hand luggage, commercial operation 2025 [40]
- The Lilium Jet, Lilium (Munich, Germany), range: 186 miles, cruise speed 186 mph, power plant: 36 electric motors powered by a 1 MW lithium-ion battery, configuration: fixed horizontal engines, capacity: one pilot and four passengers. Planned commercial operation 2025.
- The Cora, Wisk (California and New Zealand), range: 25 miles, cruise speed 100 mph, power plant: 12 independent electric battery-powered lifting propellers, configuration: fixed vertical multirotor, capacity: two passengers. Planned commercial operation N/A.
- CityAirbus Demonstrator, Airbus (Toulouse, France), range: 60 miles, cruise speed 75 mph, power plant eight 100 kW electric motors, eight fixed-pitch propellers, configuration: vertical fixed rotors, capacity: four passengers. Planned commercial operation N/A – demonstrator.
- EH216, Ehang (Guangzhou, China), range: 21 miles, cruise speed 83 mph, power plant electric batteries, 8 twin rotors, configuration: fixed horizontal rotors, capacity: two passengers. Planned commercial operation 2024.
- VA-1x, Vertical Aerospace (Bristol, U.K.), range: 100 miles, cruise speed 150 mph, power plant Eight electric battery-powered propulsors, configuration: tilt rotor, capacity: one pilot four passengers. Planned commercial operation 2024.

- CityHawk, Urban Aeronautics (Tel Aviv, Israel), range: 93 miles, cruise speed 145 mph, power plant: Electric motors and hydrogen fuel cell stacks, configuration: two tunnelled fans on each end of the aircraft, capacity: one pilot five passengers (air taxi version or ambulance version). Planned commercial operation 2025 [41].

Most of the modern eVTOL projects prefer the use of composite materials as much as possible due to the weight and maintenance cost reduction. This requires to test structures of the aircraft accordingly to the aviation requirements that are not exactly covering unique nature of the modern eVTOLs. For example, the Joby aviation S-4 was certified using the FAA's Part 23 (Small Airplanes) requirements [42] with the special conditions listed in the G1 added to account for its unique nature. In May 2022 it was successfully certified under FAA Part 135 (Air Carrier and Operator Certification) [43].

The FAA Part 23 (CS-23 in EU, CAR523 in Canada) seems to be flexible enough for airplane-like eVTOLs as well as Part 27 (CS-27 in EU, CAR527 in Canada) for helicopter-like eVTOLs. There is a bit of confusion how to classify the configuration of the eVTOL but a logical way would be to take regulation that fits mostly as a basis, and then fill the special conditions with requirements from the second regulations, for example, if the eVTOL is mostly the airplane the certification basis would be Part 23, but if it has tilted rotors and can behave like helicopter, there will be special requirements based on Part 27.

This approach reflects on testing as well. The test requirements would be more likely the mixture of multiple required categories, considering the harder ones and covering for multiple requirements. The approach should be defined by the aviation authorities reviewing airworthiness for each project separately.

SUMMARY

In this paper authors wanted to review and highlight some of the modern landing gear testing related topics. As the review shows, the landing gear testing has not changed dramatically over the years. The regulations approach and test methodology are literally the same. The main difference is that more simulation is present during the testing phase as the pre-processing activities in order to make the test as efficient as possible due to the lower cost of the established simulations than tests. Certification still requires the essential tests to be done in order to prove the operation and strength of the landing gears. Also, the development in the digital technologies has made it possible to acquire more data faster and be able to store it for further offline analysis if necessary. Fast and portable acquisition systems made possible real-time capture and process data from various sensors making them viable sources of real-time health monitoring, this capability can be used to improve test efficiency, detect faults and dangers or just to provide real-time data for possible optimizing testing processes. As the landing gears testing requires specialized test stands for dynamic tests, the static or some of the fatigue tests can be carried out using the typical equipment from structural integrity testing. A brief outlook on the Landing Gears testing methods and requirements for eVTOL aircraft was presented, the test requirements would be more likely the mixture of multiple certification categories.

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