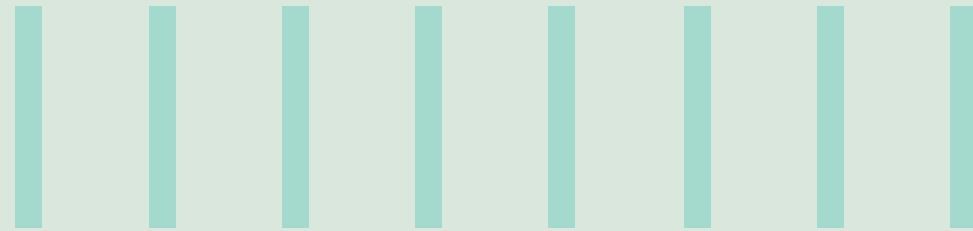




# AIRCRAFT LANDING GEAR DESIGN & DEVELOPMENT

How Advanced Technologies are helping to meet the challenges?



## Abstract

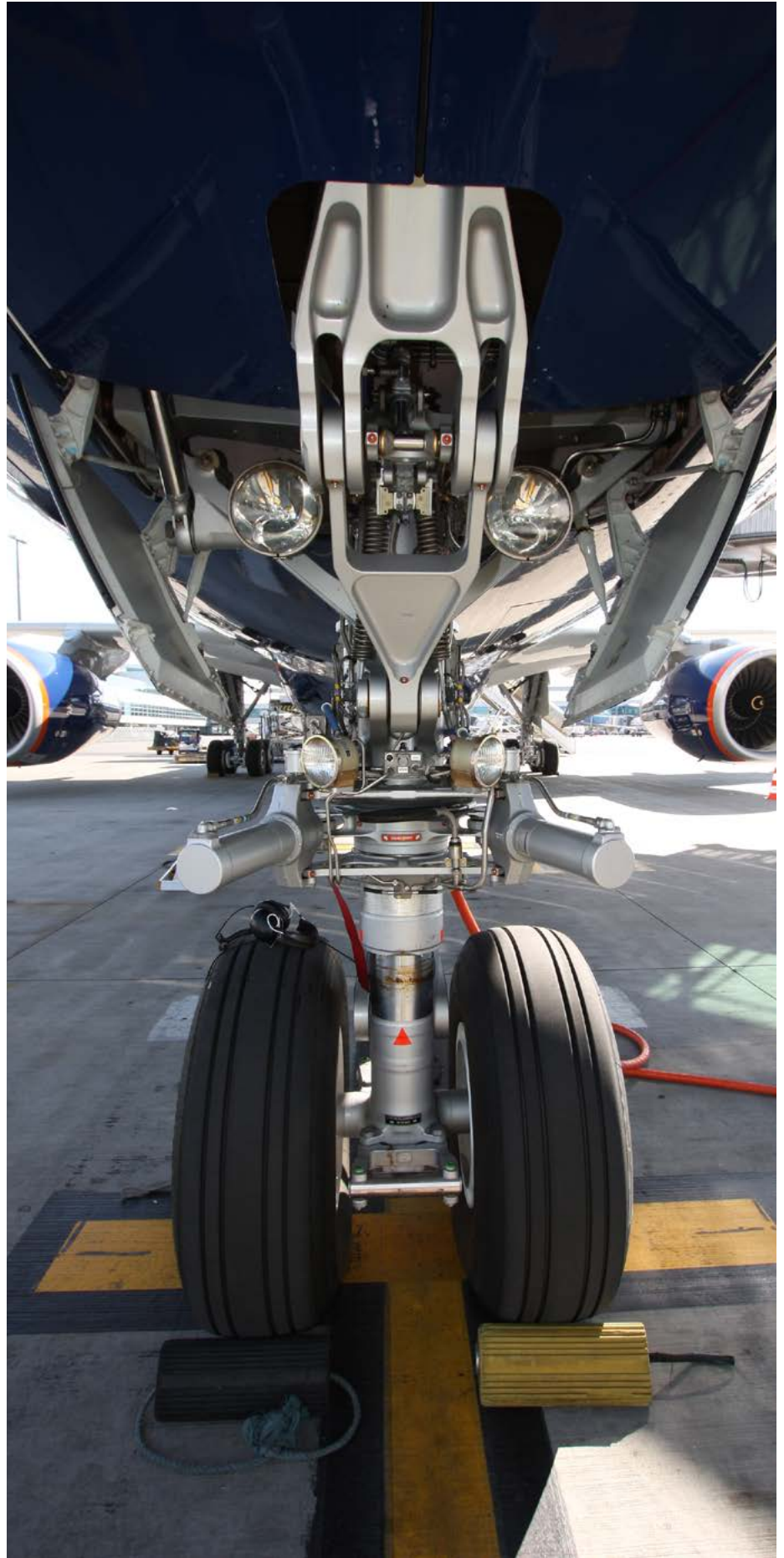
Landing gear is one of the critical subsystems of an aircraft. The need to design landing gear with minimum weight, minimum volume, high performance, improved life, and reduced life cycle cost have posed many challenges to landing gear designers and practitioners. Further, it is essential to reduce the landing gear design and development cycle time while meeting all the regulatory and safety requirements. Many technologies have been developed over the years to meet these challenges in design and development of landing gear. This paper presents a perspective on various stages of landing gear design and development, current technology landscape and how these technologies are helping us to meet the challenges involved in the development of landing gear and how they are going to evolve in future.

## Introduction

Landing Gear system is one of the critical subsystems of an aircraft and is often configured along with the aircraft structure because of its substantial influence on the aircraft structural configuration itself. Landing gear detail design is taken up early in the aircraft design cycle due to its long product development cycle time. The need to design landing gear with minimum weight, minimum volume, reduced life cycle cost, and short development cycle time, poses many challenges to landing gear designers and practitioners. These challenges have to be met by employing advanced technologies, materials, analysis methods, processes and production methods. Various design and analysis tools have been developed over the years and new ones are still being developed.

The purpose of the landing gear in an aircraft is to provide a suspension system during taxi, take-off and landing. It is designed to absorb and dissipate the kinetic energy of landing impact, thereby reducing the impact loads transmitted to the airframe. The landing gear also facilitates braking of the aircraft using a wheel braking system and provides directional control of the aircraft on ground using a wheel steering system. It is often made retractable to minimize the aerodynamic drag on the aircraft while flying.

The landing gear design takes into account various requirements of strength, stability, stiffness, ground clearance, control and damping under all possible ground attitudes of the aircraft. These requirements are stipulated by the Airworthiness Regulations to meet operational requirements and safety. The landing gear should occupy minimum volume in order to reduce the stowage space requirement in the aircraft. Further, weight should be at minimum to increase the performance of the aircraft. The service life of the landing gears should be same as that of the aircraft.



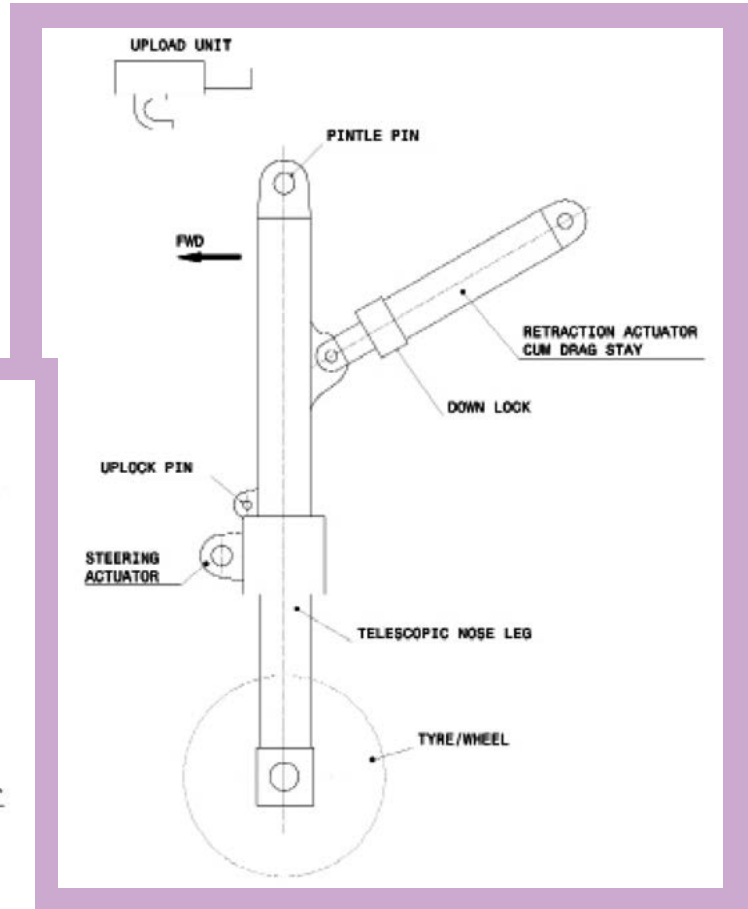
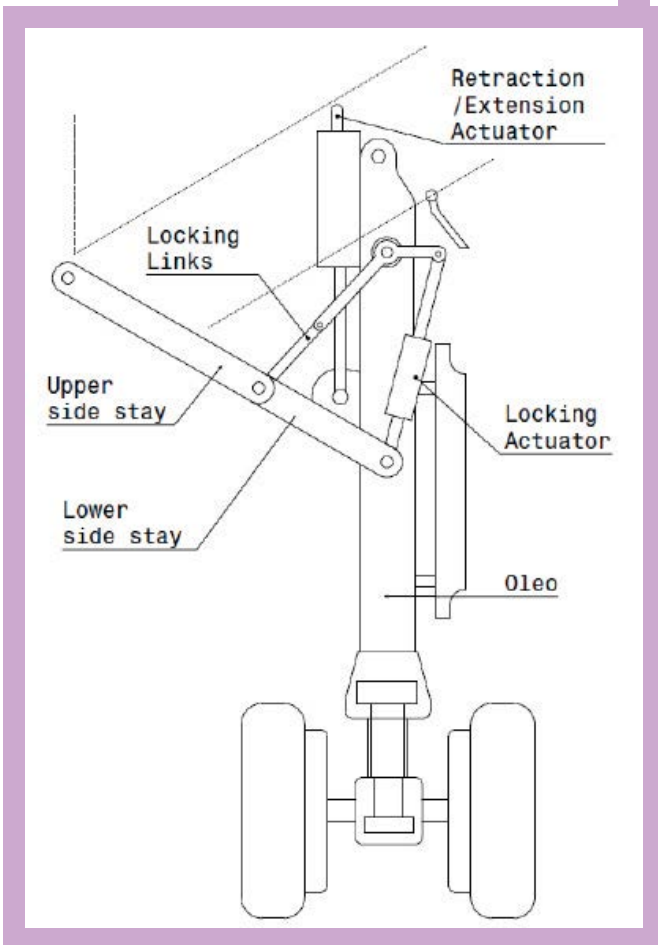
A Landing Gear system comprises of many structural and system components. The structural components include Main fitting, Shock absorber, Bogie beam/ Trailing arm, Axle, Torque links, Drag/ Side braces, Retraction actuator, Down lock mechanism, Up lock, Wheel, Tire etc. The system components are Brake unit, Antiskid system, retraction system components.

Typical Main Landing Gear (MLG) and Nose Landing Gear (NLG) are shown in Figure 1. The nose gear will have additional elements like steering actuator and steering mechanism.

Infosys is providing various structural and system product development services for various commercial and military aircraft programs across the globe.

These include design, analysis, manufacturing and testing support for landing gears. This paper presents a perspective on current challenges and how advanced tools, processes and technologies are supporting to meet these challenges in the life cycle of landing gears.

**Main Landing Gear** ▼



▲ **Nose Landing Gear**

Figure 1 Aircraft Landing Gears



Some of these Airworthiness Regulations are given in Table 1.

| Aircraft Type                   | Regulations/ Specifications         |
|---------------------------------|-------------------------------------|
| Utility and Aerobatic Airplanes | FAR 23, CS 23, CAR 23               |
| Civil Transport Airplanes       | FAR 25, CS 25, CAR 25               |
| Military Aircraft               | US MIL Specifications, DEF-STAN-970 |

Table 1: Airworthiness Regulations

A brief summary of various life cycle stages of landing gear design and development are described below:

### Concept Design

The concept design starts with a study of all design specifications and airworthiness regulations. A concept is then evolved while meeting the functional and regulatory requirements. Major design drivers are performance, safety, cost, time frame, technology and resources. The landing gear location is arrived at and type of landing gear is selected. The landing gear geometry is defined along with kinematics. Steering concepts are also identified in this phase. The ground loads are estimated using dynamic simulations for material selection and preliminary sizing of components. The actuation mechanisms and loads are also worked out in this phase. Various tradeoff studies are performed to enhance weight, volume and cost. Based on these trade-off studies a best concept is selected.

### Preliminary Design

In the preliminary design phase, dynamic simulations are carried out for landing, take off and retraction kinematics to arrive at data required for sizing of components and material selection. Preliminary design of components is performed and weight estimates are arrived at.

## An Overview of Landing Gear Design and Development

The landing gear design and integration process encompasses knowledge of many engineering disciplines such as structures, dynamics, kinematics, fluid mechanics and runway flotation. The geometry, flotation requirements, mission requirements and operational requirements of the aircraft govern the landing gear configuration.

The configuration design includes choice of number of wheels, tire sizes, pressures, type of shock absorbers, landing gear layout, retraction kinematics and bay geometry design.

Airworthiness regulations play a crucial role in arriving at the landing gear configuration, such as sink rate, allowable load factors and ground maneuvering conditions, stipulated in the applicable airworthiness regulations.

## Detailed Design

In this phase the detailed design of all the landing gear components is performed and an integrated landing gear system is defined with all interfaces and associated systems. Component loads are estimated and material selection and sizing are done in this phase. Reduction in part count by making closed die forgings for complex shapes is done through 3D CAD modeling that enable computer controlled 3D machining. Dynamic analysis and simulation is carried out to fine tune certain design parameters for energy absorption, shimmy suppression and retraction/extension. In this phase digital mock-up of the landing gear is developed which is essentially the virtual prototype of the landing gear. All lessons learned and best practices evolved over the years are utilized in the detail design to realize a reliable design.

## Stress & Fatigue Analysis

Finite element modeling and analysis and conventional hand calculation methods are used for landing gear stress analysis. Landing gear is designed as a safe life structure and fatigue analysis methods are used for prediction of life. Safe life requirements demand as high as 60,000 landings for a commercial aircraft landing gear whereas military aircraft requirements are often not more than 10,000 landings. Low cycle, high stress fatigue analysis is employed for landing gear life evaluation. Damage tolerant design is not practicable in most of the landing gears because of the usage of very high strength materials which have critical flaw sizes too small to be detected by present day NDT techniques.

## Reliability & Maintainability Analysis

Proper failure mode and effect and criticality analysis (FMECA) is performed to assess reliability. Data on failure modes and failure rate are collected from previous designs to conduct this analysis and reliability is predicted before the design freeze.

Quality, reliability and maintainability are important to cut down operational costs and to ensure aircraft availability for service. The design aims at increased mean time between failures (MTBF) and reduced mean time to repair (MTTR). Periodic preventive maintenance schedules and on-condition maintenance requirements are specified as required. Various best practices evolved are followed in design to ensure good maintainability.

Health monitoring systems are being evolved to move towards condition based maintenance practice from scheduled maintenance practice, which will lead to enhanced safety and reduction in maintenance costs.

## Manufacturing & Assembly

The landing gear manufacturing involves development of many closed die forgings, machined components from ultra-high strength steels, titanium and aluminum alloys. Precision tolerances are required for components like actuator cylinder, piston, shock absorber parts and axle. Heat treatment of parts is performed after rough machining followed by final machining, plating and painting. Reliability of the product is enhanced through stringent quality assurance requirements.

## Qualification Testing

The qualification testing of landing gears involves functional tests, structural tests for strength, stiffness and fatigue life tests, and environmental tests. Platform drop tests are conducted on rigs with load cell platform, wheel spinning facility and lift simulation devices to verify shock absorber performance. For structural strength tests of the landing gear, loads are applied through loading actuators in required directions and strain data is acquired through strain gauging.

Fatigue tests including impulse fatigue tests on actuators, are conducted by block wise loading with sufficient instrumentation for data acquisition. Endurance cycling tests are conducted in

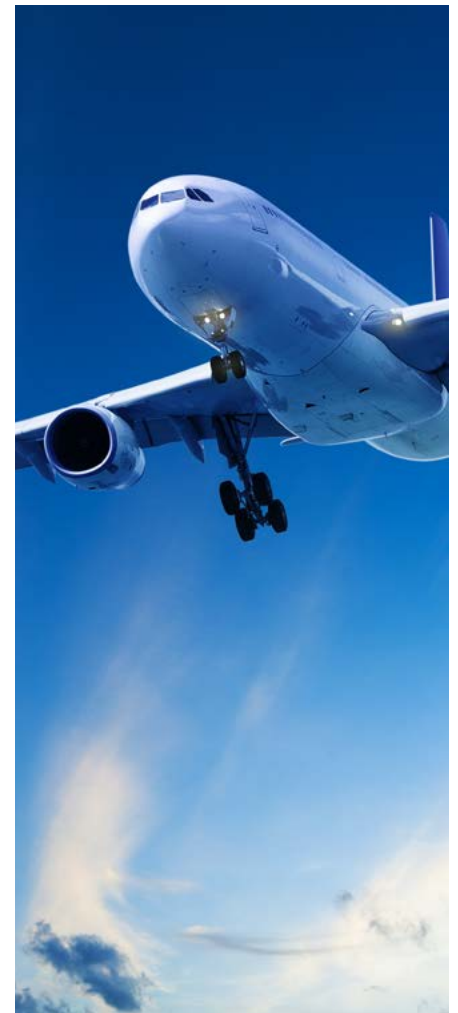
special rigs. Environmental tests including vibration, acceleration, temperature, altitude, salt spray, sand and dust etc. are performed.

## On- Aircraft Testing

The final integration tests of the landing gear are carried out after installation on the aircraft followed by taxi tests, braking and steering tests. Fine tuning of certain design parameters are done during this phase. This is followed by flight testing phase where the capability of the landing gear is evaluated.

## In- service Evaluation

In -service evaluation includes evaluation in various types of airfield conditions and ambient conditions. Feedbacks on reliability and maintainability results are taken for further improvements in the system and data generation.





## Challenges in Landing Gear Design & Development

The need to design landing gear with minimum weight, minimum volume, high performance, improved life and reduced life cycle cost poses many challenges. Further, the design and development cycle time of landing gear should be compressed to reduce costs and to bring the product to market faster. These challenges are met, while adhering to all regulatory requirements of safety, by employing advanced technologies, materials, processes, analysis and production methods.

### Weight

Landing gear is heavily loaded structure. Its weight varies from 3% of aircraft all-up weight for a fixed type to about 6% for a retractable type landing gear. The challenge is to reduce the weight of the landing gear without compromising on its functional, operational, performance, safety and maintenance requirements. This is made possible by using materials of higher strength, fracture toughness and fatigue properties and by making correct choice for each application. These materials include ultra-high strength alloy steels, corrosion resistant steels, titanium alloys and high strength aluminum alloys.

### Volume

Space is one of the most important constraints within which an aircraft component needs to be designed, especially in a military aircraft. A retractable landing gear contains more components and mechanisms than a fixed landing gear. By proper choice of material and design of the geometry of mechanism it is ensured that requirement of retracted volume is brought down to a minimum.

### Performance

High performance of the landing gear is expected in order to reduce the ground loads transmitted to the airframe. This is ensured by accurate dynamic analysis and simulation to arrive at key performance characteristics like orifice sizing, air and oil volumes. Efficiencies as high as 85% to 90% are achievable in landing energy absorption with passive orifice damping with proper metering pin or valve system. Further, the pursuit for high performance leads to semi-active or active control shock absorber systems. It is found that substantial damage is caused due to loads in taxi phase and performance improvement during taxi phase requires either semi-active or active damping systems.

The semi-active system works by varying the viscosity of the fluid as required for the damping. In active control it is aimed to control the stiffness and damping characteristic so as to control the ground loads.

For higher performance of actuation systems for landing gear, nose wheel steering and brakes, alternate systems are being evolved. Use of hydraulic systems in place of mechanical systems or use of electric systems in place of hydraulic systems is studied for optimizing performance. Use of electronic control also enhances the performance of control systems.

### Life

Long life and minimum maintenance requirements are vital for reduction in operating and maintenance costs while minimizing the overall life cycle cost. This dictates the choice of materials, its corrosion properties and fatigue properties.

### Development Time

The landing gear design is iterative involving trade-off studies between various configurations and their impact on weight and cost benefits.

This usually takes substantial time and effort. It is essential to reduce this product development cycle time by automating the design process using CAD/CAE/CAM tools. These tools help reducing the development time through virtual prototyping which can be evaluated before testing on actual prototypes. Further, Knowledge Based Engineering (KBE) concepts and tools are playing important role in reducing development cycle time.

### Life cycle cost

Use of advanced technologies like health management systems and maintenance philosophies helps in reducing the life cycle costs. Design for condition based maintenance instead of scheduled maintenance is one such trend and is compatible with health management systems.

## Landing Gear Technologies

Landing gear technologies are continuously evolving to meet the challenges of functional and non-functional requirements. Some of these important technologies are presented below:

### Steering System

Steering control systems are moving towards electronic control systems replacing hydro-mechanical systems. The main advantage with electronic control system is its accuracy and its ability to incorporate changes in design parameters like steering rate and steering ratio with ease.

### Actuation System

In actuation systems, more electric or all electric systems are replacing the conventional hydraulic systems. The electric systems offered today have become weight competitive with use of brushless high power motors. Further, electric systems help to overcome problems of leakage and fire hazard.



### Brake system

Electronically controlled antiskid brake management systems are replacing old mechanical or electric antiskid systems. Electronic systems are more efficient and trouble free.

### Tires

Radial tire is one of the advanced technologies employed in aircraft for the past 25 years. Landing gear radial tires offer lighter tires with longer life compared to bias ply tires.

### Up-locks

Hydro-mechanical locking systems and proximity switches are replacing mechanical locks and micro-switches. They have higher reliability.

### Materials

Composites are being used in some components of landing gear because of their superior specific strength and stiffness properties. Cost used to be one factor against their favor, which is now being overcome with improved manufacturing techniques. Ultra-high strength steels are used due to its high strength to weight ratio and size advantage.

The choice of material for a landing gear component is decided depending on its application and this requires trade off studies of strength, stiffness and cost to arrive at the optimal choice. Fatigue and fracture toughness properties and aspects like protection against stress corrosion, wear, reliability in service etc. are other considerations in the selection of material for the landing gear.

Carbon composite brake disc offers reduced weight, longer life and maintenance free wheel brakes thereby reducing the cost per landing.

### Corrosion protection

Good corrosion protection is important for the landing gear components as they are susceptible for easy environment attack. Apart from normal electrolytic finishes like cadmium plating, hard chromium plating, HVOF etc. epoxy or polyurethane primer and polyurethane top coats are applied for the exposed landing gear parts. Use of corrosion resistant materials is also becoming increasingly popular.

## CAX Technologies

Many commercially available CAD/CAM/CAE/CFD and Dynamic Simulation software tools are used in the design and development of landing gear. These tools have helped in virtual product development of landing gear before actual prototype is being fabricated. These help to improve designs with reduced cycle time and cost. Few of them include

|                          |   |
|--------------------------|---|
| CAD Tools                | CATIA V5, UG, Solid works,                    |
| CAE Tools                | NASTRAN, ABAQUS, ANSYS, Hypermesh, Optistruct |
| Dynamic Simulation Tools | MATLAB, SIMULINK, ADAMS                       |
| CFD Tools                | Flow works, Ansys-Fluent, Ansys-CFX, Star-CD  |
| Kinematics               | CATIA V5, UG, Solid works,                    |

Table 2: CAX Tools

## Knowledge Based Engineering (KBE)

Many Knowledge Based Engineering (KBE) tools and information intelligence tools are being developed and used by landing gear designers to automate many engineering processes while retaining company specific knowledge. These tools leads to drastic reduction in development cycle time, reduction in human errors, ability to redesign iteratively and capturing organizational knowledge. Few of these tools include

- Tools for selection of number of tires and pressures taking the ground flotation requirement
- Wheel / Brake sizing tools
- Ground load estimation tools

- Tools to compute axle travels requirements
- Tools to analyze retraction actuation
- Shock absorber performance optimization tools
- Rake and Trail requirements analysis tools
- Shimmy analysis tools

## Dynamic Simulation

Dynamic simulation helps to predict the performance of a component or assembly. The results of these simulations will be more accurate compared to hand calculations. These simulations help in handling large number of studies in short time.

The landing gear shock absorber performance is evaluated by a dynamic simulation of the landing and taxiing. This takes into account the hydraulic damping, air spring characteristics and friction effects and structural flexibility in the landing gear. Using the computer models developed for this purpose the shock absorber parameters are enhance to maximize its efficiency and peak reaction behavior. This helps in preliminary estimation of impact loads and taxi loads to arrive at the sizing of the landing gear elements for use in geometric modeling and kinematic analysis.

The retraction / extension kinematics and actuation are also simulated by dynamic modeling of the hydraulic actuation and CFD analysis to arrive at the actuator sizing. The CFD analysis is used to arrive at the aerodynamic loads acting on the landing gear during retraction / extension process.

Thus simulations helps to mitigate the risk in the design and development process, which otherwise requires iterations after extensive and expensive testing.

Shimmy oscillations are a perennial problem in design and operation of landing gears and proper analysis is required to control / overcome it.

Adequate torsional stiffness and damping are required to ensure a shimmy free landing gear. Mathematical models are used to predict onset of shimmy and to design damping devices to control the shimmy oscillations.

## Health monitoring

Landing gear is a maintenance intensive system of the aircraft next to only engine. Health monitoring of landing gear is gaining importance as suitable sensors and processing units are available today. Wireless sensor network and RFID technologies are being employed in health management of aircraft systems and structures including landing gear. Health monitoring not only improves the safety and reduces both operational and maintenance costs, but also helps in extending the life of the landing gear beyond designed service life.





## Summary of Future Landing Gear Technologies

In future landing gear design and development will use high strength materials, active damping systems and accurate load estimation techniques. Active damping system aims at reducing taxi loads which are known to be a very significant contributor of fatigue failure. It is found that taxi damages are close to 50% of total damages in a commercial aircraft. Future is also expected to witness increased use of composite materials for many components. In actuation system

design, 'more electric' or 'all electric' concepts are gaining momentum to replace hydraulic actuation, which is known for its problems of leaks and flammability. Electric actuation systems are becoming weight competitive enough to displace the old hydraulic actuation systems. Carbon composite brake materials have become a mature technology like the radial tires and will be used widely in future landing gears. CAX and KBE will be used more effectively. In addition, integrated health management systems for diagnostic and prognostic analysis will employ next generation

smart sensors that are more durable and energy efficient and will drive towards condition based maintenance philosophy. Big Data technologies, advanced analytics techniques and tools will help in capturing and reusing the operational and maintenance data providing greater insights. This will help in reducing the maintenance and operational costs drastically. Crashworthy landing gears for use on helicopters pose additional challenges in absorbing large quantities of energy resulting from a crash. This includes fuse orifices and additional chambers in the oleo.

| Technology   | Helps to meet which challenge? |        |             |      |      |                  |
|--|--------------------------------|--------|-------------|------|------|------------------|
|  | Weight                         | Volume | Performance | Life | Cost | Development Time |
| Electronic Control System for Steering                     |                                |        | ✓           | ✓    | ✓    |                  |
| Electric Actuation System                                  |                                |        | ✓           | ✓    | ✓    |                  |
| Electronically controlled antiskid brake management system |                                |        | ✓           | ✓    | ✓    |                  |
| Hydro-mechanical locking system                            |                                |        | ✓           | ✓    | ✓    |                  |
| Radial Tires   | ✓                              |        | ✓           | ✓    | ✓    |                  |
| Ultra high strength metallic materials                     | ✓                              | ✓      |             |      |      |                  |
| Advanced Composites  | ✓                              |        | ✓           | ✓    | ✓    |                  |
| Corrosion resistant materials & PU/ Epoxy based coatings   |                                |        |             | ✓    | ✓    |                  |
| Health Monitoring  | ✓                              |        | ✓           | ✓    | ✓    |                  |
| CAX/KBE technologies                                       | ✓                              | ✓      | ✓           |      | ✓    | ✓                |
| Computer simulations                                       | ✓                              | ✓      | ✓           | ✓    | ✓    | ✓                |

Table 3: How Technologies Help to meet Challenges?

| <i>Design Life Cycle Stage</i> | <i>Technology Trend</i>  |
|--------------------------------|--|
| Material Selection             | ➤➤ Ultra high strength metallic materials, advanced composites, Radial tires, Carbon composite brake discs |
| Design                         | ➤➤ 3D modeling and design, Simulation, virtual prototyping, KBE  |
| Systems                        | ➤➤ All electric actuation, Electronic control  |
| Analysis                       | ➤➤ FEA, Fatigue and Damage Tolerance Analysis  |
| Testing                        | ➤➤ More Accurate systems for strain gauging and data acquisition   |
| Maintenance                    | ➤➤ Health monitoring, Wireless Sensor Networks, RFID technologies  |
| Reliability                    | ➤➤ Accurate failure rates based on feedback data from field  |

*Table 4: Technology trends for future landing design*



## Conclusions

The need to design landing gear with minimum weight, minimum volume, high performance, improved life and reduced life cycle cost have posed many challenges to landing gear designers and practitioners. Further it is essential to reduce the landing gear design and development cycle time while meeting all the safety and regulatory requirements. Many technologies have been developed over the years to meet the challenges of landing gear design and development.

These technologies have matured over the years and widely used in the current landing gear system and new technologies will continue to evolve in future.

The future landing gear design for aircraft poses many new challenges in configuration design, use of materials, design and analysis methods. These challenges can be met, while adhering to all regulatory requirements of safety, by employing advanced technologies,

materials, analysis methods, processes and production methods. By applying functional simulation and developing design tools, the development time and cost are reduced considerably. Use of higher strength materials, composites, and technologies like active damping control, electric systems, along with CAX, KBE and health monitoring technologies will steer the landing gear design in the days to come.

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