Design and Analysis of F-14 Landing Gear System

MEE 342: Principles of Mechanical Design

Touchdown Mechanics

Aditya Sally, Anuj Shastry, Emily Lopez, Joshua Raya, Kevin Ruiz Lopez, Sanad Dababneh

Yi Ren

February 2, 2026

Table of Contents

Executive Summary

Aircraft landing gear systems represent one of the most critical interfaces between an aircraft and its operating environment. While often overshadowed by propulsion and aerodynamic systems, landing gear must reliably manage some of the highest loads experienced by an aircraft over its service life. During takeoff, landing, taxiing, and ground maneuvering, landing gear is responsible for supporting the full weight of the aircraft, absorbing impact energy, maintaining directional stability, and enabling safe operation on varied surfaces. Unlike many flight-critical systems that operate primarily under controlled conditions, landing gear must perform under high-stress and sometimes unpredictable scenarios. As a result, landing gear design is a multidisciplinary challenge that integrates structural mechanics, kinematics, dynamics, materials, reliability, and system-level design philosophy.

In military aviation, these challenges are amplified. Fighter aircraft operate at higher weights, higher sink rates, and under stricter packaging constraints than most commercial aircraft. Carrier-based aircraft, in particular, experience extreme vertical descent rates and abrupt deceleration during landings. These conditions demand landing gear systems that are not only structurally robust, but also compact, redundant, and mechanically fail-safe. The design must ensure survivability under worst-case loads while maintaining minimal weight and volume.

Figure 1: An F-14A Tomcat aircraft gains altitude after takeoff, its landing gear still down. [2]

The Grumman F-14 Tomcat provides a compelling case study for landing gear design. Developed during the Cold War as a carrier-based fleet defense interceptor, the F-14 combined large size, high landing weights, and variable-sweep wings into a single airframe. These characteristics imposed unique constraints on the landing gear system. The presence of the wing-sweep mechanism limited available fuselage volume, necessitating an inward-retracting main landing gear configuration. At the same time, the aircraft's naval role required the gear to withstand repeated high-energy carrier landings while remaining reliable in corrosive maritime environments.

This project focuses on the conceptual mechanical design and modeling of an F-14–inspired main landing gear system. Rather than attempting to replicate proprietary or classified hardware details, the goal is to capture the underlying engineering principles that govern the system's operation. Emphasis is placed on understanding how geometry, linkages, and constraints are used to achieve controlled motion and mechanical suspension using only 3D printed parts. The design is approached from a systems perspective, viewing the landing gear as an integrated mechanism rather than a collection of isolated components.

Through the use of an angled trunnion axis and a folding drag brace, the system achieves simultaneous upward and inward rotation during retraction, allowing the wheel assembly to stow efficiently within the fuselage. In the deployed configuration, a drag brace provides a passive mechanical lock, ensuring that landing loads are carried structurally rather than hydraulically. This approach reflects common practices in aircraft landing gear design, where simplicity and mechanical reliability are prioritized due to the high consequences of system failure.

Overall, this report presents a structured exploration of landing gear design principles through the lens of the F-14 Tomcat. By combining qualitative design reasoning with kinematic modeling and failure awareness, the project demonstrates how fundamental mechanical engineering concepts are applied in real-world aerospace systems. The work serves both as a design exercise and as an illustrative example of how complex aircraft mechanisms can be reduced to manageable, well-understood mechanical systems suitable for college-level engineering analysis.

System Description and Operating Conditions

The overall function of this project is to create a functional and realistic representation of the landing gear system used in an F-14 aircraft. The landing gear is responsible for supporting the aircraft while on the ground, absorbing loads generated during landing, and enabling controlled ground movement during taxi, takeoff, and landing operations on an aircraft carrier. The system modeled in this project is a scaled mechanical representation designed to reflect the essential behavior and performance of an actual aircraft landing gear system.

The landing gear must be capable of absorbing significant shock loads during landing while maintaining structural integrity under high loading conditions. These loads arise primarily from vertical impact during touchdown, as well as from longitudinal and lateral forces experienced during braking and ground maneuvering. This shall be taken in account while designing the suspension system for the gear. In addition to load absorption, the system must reliably retract and extend during takeoff and landing phases, ensuring proper stowage during flight and stable support during ground operations.

Figure 2: An F-14 aboard USS Enterprise (CVN-65) [1]

The operating conditions considered in this design include static loads resulting from the weight of the aircraft while stationary on the ground, dynamic loads generated during takeoff and landing impact, and transient loads associated with taxiing and braking. The system is also expected to tolerate potential external influences from the operating environment, such as debris, surface irregularities, and weather-related effects. While these environmental factors are not explicitly modeled, their influence informs the overall robustness and reliability requirements of the landing gear design.

Sub-Systems and Key Components

When broken down into subsystems, the prototype begins with the structural support subsystem, which constitutes the majority of the overall system. This subsystem is responsible for carrying applied loads and maintaining geometric stability under operating conditions. It can be further divided into the main strut, which functions as the primary load-bearing beam of the landing gear, the moving arm that enables controlled motion during retraction and extension, and additional brackets or support members required to counteract external forces and transmit loads to the main structure.

The next subsystem consists of components that contribute to absorbing shock applied to the system during landing. This includes elastic elements, such as springs and dampers, which are intended to reduce impact forces and limit load transmission to the structural components. These elements are expected to be sourced externally as they require specific material properties and performance characteristics that are not well suited for 3D printing.

The wheel and kinematic subsystem follows, consisting of the wheel, axle, and associated mounting components required to ensure proper alignment and rotation. This subsystem enables ground contact, rolling motion, and load transfer between the landing surface and the structural elements of the gear. Proper integration of this subsystem is essential for stable ground movement and effective load distribution.

The retraction subsystem includes all components responsible for controlled motion of the landing gear during extension and retraction. This subsystem consists of moving parts such as shafts, pivot joints, and linkages that guide the kinematic motion of the strut and wheel assembly.

Lastly, the fastener subsystem is used for the assembly and integration of the entire system. This includes mechanical fasteners such as bolts, screws, and pins that secure individual components and allow for disassembly, adjustment, and maintenance. Although small in size, these components play a critical role in the overall reliability and functionality of the prototype.

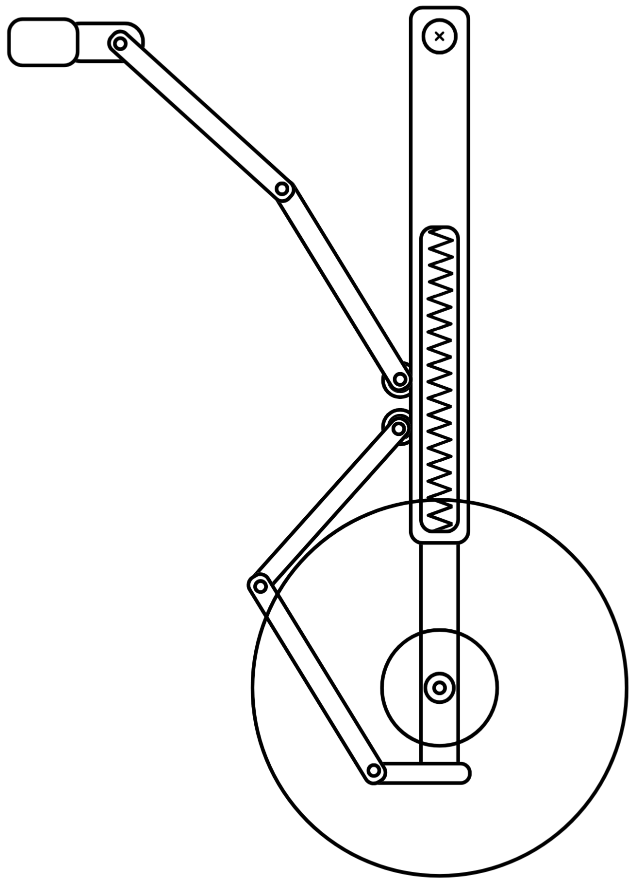


Figure 3: Preliminary Sketch

A preliminary vector drawing was developed to visually represent the conceptual layout and motion of the landing gear system. This drawing illustrates the primary structural elements, including the main vertical strut, wheel and axle assembly, shock-absorbing element, and the interconnected linkages responsible for controlled motion.

The linkage geometry highlights how multiple pivoting arms guide the extension and retraction of the gear while maintaining alignment of the wheel with the strut. The inclusion of a spring element within the strut represents the shock absorption mechanism used to reduce impact loads during landing. Although simplified, this drawing serves as an effective conceptual tool for understanding the dimensions and kinematic behavior of the system. It provides a foundation for further refinement and detailed modeling.

Kinematics and Calculations

Degrees of Freedom and Kinematic Behavior

The motion in the preliminary design is constrained to a single primary motion that occurs at the top joint of the angled arm. Rotational motion takes place about the pinned joints in the preliminary design, labeled as θ_1 and θ_2 (Figure 4). These rotations govern the overall movement of the linkage system. The structural beam in the preliminary design is also subjected to rotational motion; however, this motion is fully dependent on the rotation occurring at the main pin connection.

Since the rotation of the structural beam is directly driven by the rotation at the primary pin, the entire system operates with one degree of freedom. This means that a single input motion is sufficient to define the position of all other components in the mechanism. Additionally, the tire undergoes a combination of translational and rotational motion, translating in the positive Z-direction before rotating about the X-axis as it folds into the fuselage cavity.

Critical Calculations for Modeling Prototype

As discussed previously, the performance of the system is highly dependent on rotational kinematics, making accurate modeling of the kinematic relationships essential to the success of the prototype. Proper characterization of these relationships ensures predictable motion and helps prevent misalignment or interference during operation. In addition to kinematic modeling, calculating the energy absorbed by the spring in the preliminary design is critical for predicting potential failure and evaluating the elastic and structural limits of the prototype.

The force applied to the spring during landing can be estimated using Hooke's Law, $F=k\Delta x$, where Δx represents the displacement of the tire in the vertical direction during landing and k is the spring constant. The energy absorbed by the spring can then be calculated using the basic spring energy equation. These calculations are essential for ensuring that the spring absorbs a significant portion of the landing energy, thereby reducing the load transmitted to the structural beam and minimizing the risk of structural failure.

Directions of Rotation/Motion Path

The arm in the preliminary design is divided into two connected segments that rotate and bend together during motion. In the initial configuration, the upper segment of the arm is oriented at approximately a 45-degree angle, while the lower segment is oriented at approximately a 60-degree angle. When rotation occurs at the primary hinge, the top portion of the arm moves counterclockwise when viewed from the side, while the bottom portion bends and follows the motion of the top arm, rotating in the clockwise direction.

As rotation continues, both segments move upward and progressively align, eventually reaching a near 90-degree orientation. At this point, the two segments overlap to form a nearly straight line, representing the fully retracted configuration of the landing gear when the aircraft is off the ground.

Key States/Position

The rotation and motion of the system are most clearly observed at the hinge located at the top of the arm, as this joint governs the primary degree of freedom of the mechanism (Figure 4). Observing motion at this location allows the full range of arm movement to be visualized and provides clear insight into the relationship between input rotation and system configuration. Key system positions, including the fully deployed and fully retracted states, can be defined based on the rotation of this hinge, making it a useful reference point for both analysis and modeling.

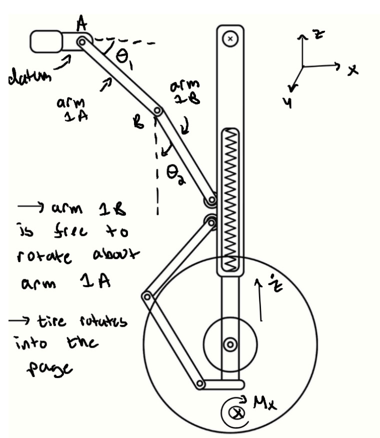


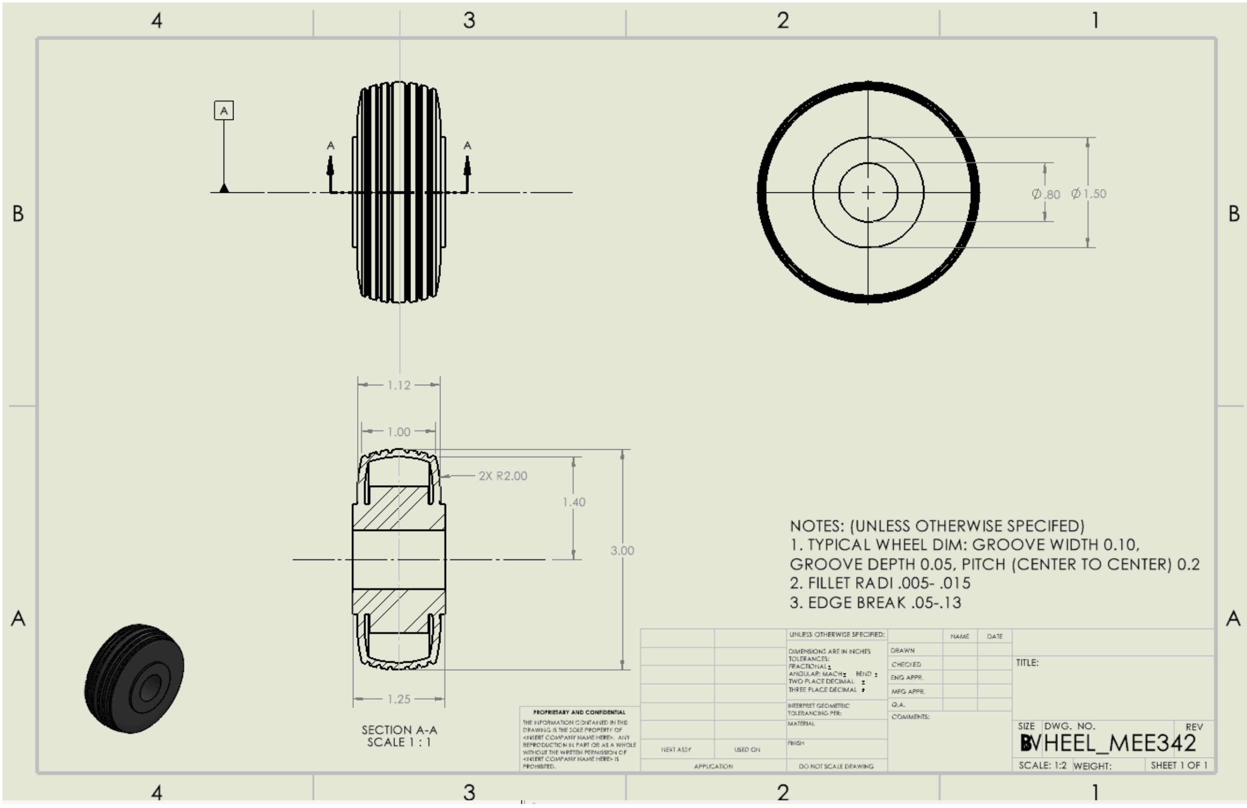
Figure 4: Free Body Diagram

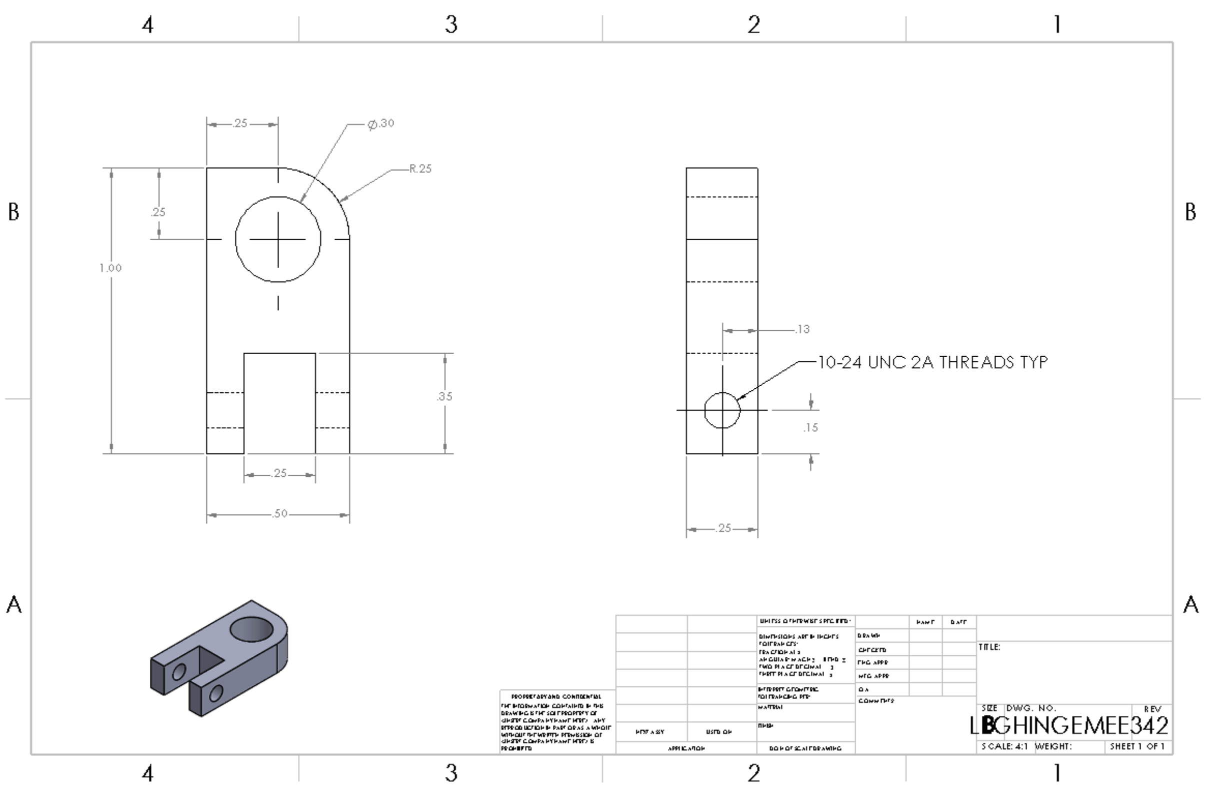
Design Considerations

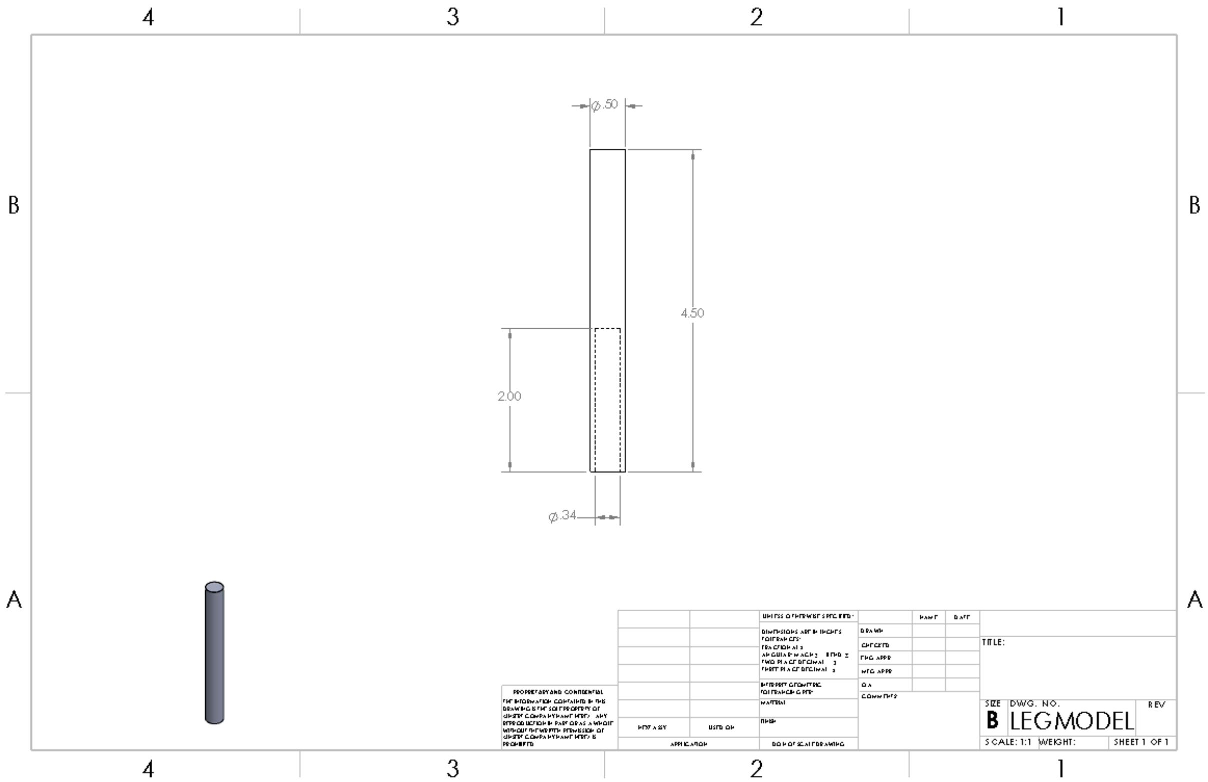
For the preliminary design stage, the basic layout of the landing gear prototype is defined, including the general configuration, number of wheels, and approximate wheel size. These design choices are guided by the expected loads in the scaled system and the need to represent the functional behavior of an F-14–style landing gear, rather than full-scale aircraft operating conditions. The number and size of the wheels are selected based on estimated prototype loads and the ability of the system to safely support and distribute these loads during simulated landing and taxiing conditions.

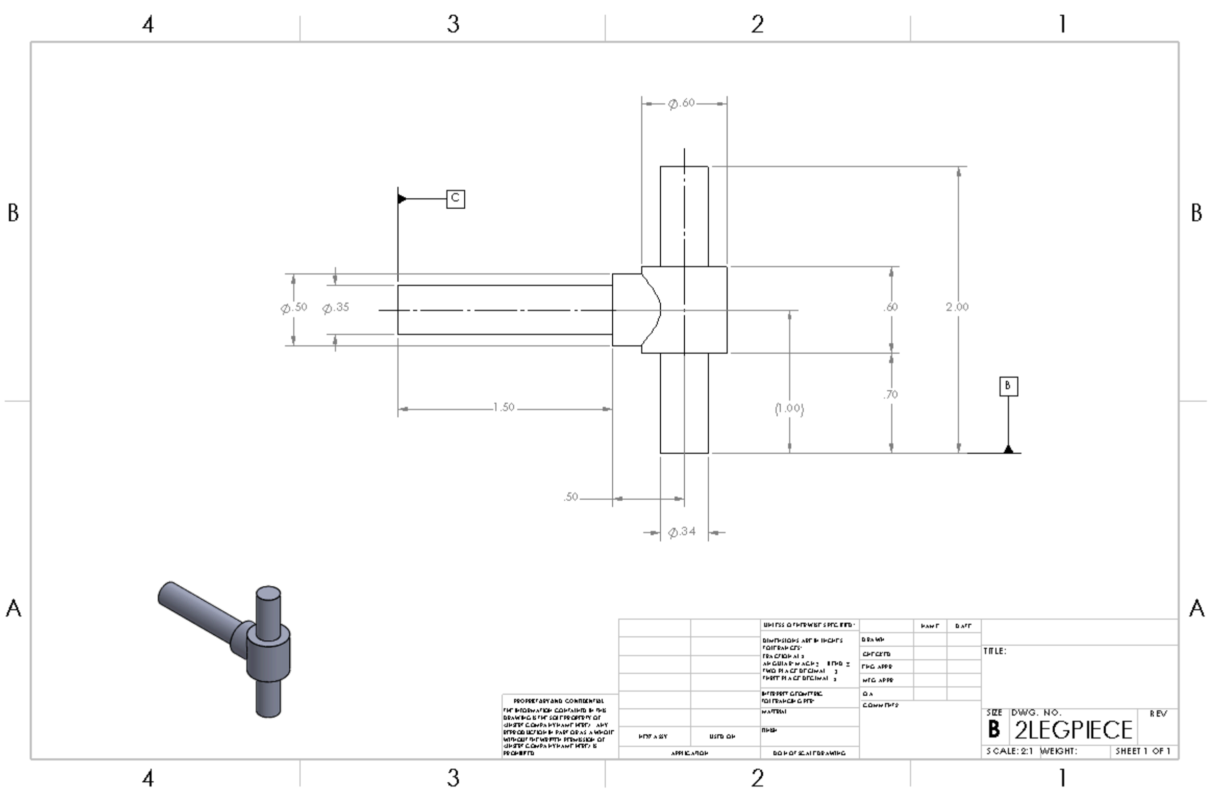
Several components are selected with reference to industry practices and applicable federal guidelines, such as FAA standards, to ensure that the overall design remains realistic and grounded in real-world engineering principles. This includes approximate tire and wheel dimensions, simplified braking considerations, and the selection of a representative shock absorption system. While the prototype is not intended to meet certification requirements, these standards provide useful guidance for reasonable design assumptions. The landing gear is designed with sufficient stroke and damping to absorb expected vertical loads without bottoming out under controlled test conditions.

Additional design considerations include selecting materials suitable for additive manufacturing while maintaining adequate strength and fatigue resistance for repeated testing. Appropriate safety factors are applied to account for uncertainty in material properties and loading conditions. Buckling of the main strut is considered at a conceptual level, and the overall geometry is designed to support reliable retraction, extension, and mechanical locking. Clearances between moving components, structural attachment points, and overall stability during ground contact and simulated landing events are also taken into account to ensure safe and repeatable operation of the prototype.


NOTES: (UNLESS OTHERWISE SPECIFED)
1. TYPICAL WHEEL DIM: GROOVE WIDTH 0.10, GROOVE DEPTH 0.05, PITCH (CENTER TO CENTER) 0.2
2. FILLET RADI .005- .015
3. EDGE BREAK .05-.13
SECTION A-A
SCALE 1 : 1
2X R2.00
1.12
1.00
1.40
3.00
1.25
Ø.80
Ø1.50
BWHEEL_MEE342
SCALE: 1:2
SHEET 1 OF 1


Ø.30
R.25
.25
1.00
.35
.50
.13
10-24 UNC 2A THREADS TYP
.15
LBGHINGEMEE342
SCALE: 4:1
SHEET 1 OF 1


Ø.50
4.50
2.00
Ø.34
TITLE:
SIZE DWG. NO. REV
B LEGMODEL
SCALE: 1:1 WEIGHT: SHEET 1 OF 1


Ø.60
C
Ø.50
Ø.35
.60
2.00
1.50
(1.00)
.70
B
.50
Ø.34
TITLE:
SIZE DWG. NO. REV
B 2LEGPIECE
SCALE: 2:1 WEIGHT: SHEET 1 OF 1

Failure Modes

The landing gear system consists of several mechanical and kinematic components, each of which may fail under different loading, motion, or material conditions. The primary failure modes identified for the scaled 3D-printed prototype, as well as the original model are outlined below.

- **Shock Absorber Failure**
  - Failure may occur due to material fatigue or loss of damping capability in the shock-absorbing element.
  - During a hard landing, the shock absorber may bottom out, fully compressing and losing its ability to absorb additional impact energy.
  - In a 3D-printed system, limited energy absorption and lower material toughness may cause impact loads to be transferred directly into the structural components.

- **Shimmy Instability**
  - Shimmy may occur when the system exhibits low torsional stiffness or insufficient damping.
  - Contributing factors include wheel imbalance, loose or worn joints, inadequate joint constraints, and compliance in 3D-printed linkages.

- **Printing Inaccuracies**
  - Surface roughness and dimensional inaccuracies from printing can amplify these effects in a scaled prototype.
  - Sustained inaccuracies may excite motion in the wheel or surrounding structure causing failure.

- **Material Failure**
  - High cyclic loads during repeated landing and takeoff cycles can lead to cracking, yielding, or buckling of structural components.
  - 3D-printed parts are susceptible to layer delamination, reduced strength across print layers, and stress concentrations at sharp corners.

  - Improper print orientation or insufficient wall thickness can further increase the likelihood of failure.

- **Kinematic and Retraction System Failure**
  - Hinges and pivot joints may jam or experience excessive friction, preventing smooth retraction or extension.
  - Tolerance buildup and wear in printed joints may cause misalignment or incomplete motion.
  - Mechanical locking mechanisms may fail to fully engage, compromising stability in the deployed configuration.

- **Fastener and Joint Failure**
  - Pins, bolts, and screws may loosen under vibration or cyclic loading.
  - Printed holes may deform or creep over time, reducing joint reliability.
  - Inadequate joint reinforcement can lead to increased play and loss of structural stiffness.

By identifying these potential failure modes early in the design process, appropriate design decisions such as reinforced joints, simplified kinematics, conservative load assumptions, and selective use of non-printed components can be made to improve reliability and performance of the prototype.

Conclusion

This project explored the mechanical design and touchdown behavior of an F-14–inspired landing gear system by breaking a complex aerospace mechanism into manageable and well-defined engineering components. By approaching the landing gear as an integrated mechanical system rather than a single structure, the project demonstrated how geometry, kinematics, and load paths govern the performance and reliability of aircraft landing gear.

A key outcome of this work was the demonstration that controlled motion can be achieved through geometry rather than excessive actuation. The use of linkages, an angled trunnion axis, and a passive locking drag brace showed how aircraft landing gear systems are designed to operate with a single degree of freedom while maintaining predictable and repeatable behavior. This approach highlights the importance of mechanical simplicity in aerospace systems, particularly in applications where failure carries severe consequences. The inclusion of a passive locking mechanism further emphasized how aircraft designs prioritize safety and structural load-bearing over reliance on active systems.

Through kinematic analysis and preliminary calculations, the landing gear was shown to successfully manage extension, retraction, and inward rotation while maintaining alignment and stability. The incorporation of shock absorption elements illustrated how impact energy during landing can be reduced before being transmitted into the primary structure. Although the system was modeled as a scaled 3D-printed prototype, the underlying behavior closely reflects that of full-scale aircraft landing gear, reinforcing the applicability of the design approach.

Identifying potential failure modes provided additional insight into the limitations and challenges associated with both real aircraft systems and scaled prototypes. Overall, this project reinforced how fundamental principles of mechanical design are applied in aerospace systems operating under extreme loads and tight packaging constraints. The experience gained through modeling, analysis, and evaluation of the landing gear system provided practical insight into the challenges of designing reliable mechanisms and highlighted the importance of simplicity, robustness, and system-level thinking in mechanical engineering design.

Future Work

Future work on this project would focus on improving both the realism and performance of the landing gear prototype. One major area for improvement is the suspension system, where a more accurate shock absorber and damping mechanism could be implemented to better represent real touchdown energy absorption. Enhancing this subsystem would allow the prototype to more closely replicate the load-reduction behavior observed in full-scale aircraft landing gear.

Additional refinement of the kinematic system could also be pursued to reduce friction and misalignment within the pivot joints, particularly in the retraction and extension mechanism. Improving joint geometry and tolerances would lead to smoother motion and more reliable operation throughout repeated cycles.

Experimental testing under repeated loading conditions would provide valuable insight into long-term performance and durability. Cyclic loading tests would help identify wear-related issues, joint loosening, and material degradation, while also validating the failure modes discussed in this report. These tests would strengthen the connection between theoretical design assumptions and observed physical behavior.

Further optimization of material selection and print orientation could be explored to improve structural strength and reduce the risk of layer separation in highly stressed components. Adjustments to wall thickness, infill patterns, and reinforcement at critical joints could significantly enhance the reliability of the 3D-printed parts.

Finally, incorporating basic instrumentation such as displacement sensors or force measurement devices would enable more quantitative evaluation of system performance. This instrumentation would allow direct comparison between analytical predictions and experimental results, providing a stronger foundation for future design iterations.

References

[1] Auten, Donald. “The Impossible Arrested Landing: The F-14 Pilot Who Was Able to Land His Tomcat Aboard USS Enterprise through a Thunderstorm.” *The Aviation Geek Club*, 5 Dec 2023, theaviationgeekclub.com/the-impossible-arrested-landing-the-f-14-pilot-who-was-able-to-land-his-tomcat-aboard-uss-enterprise-through-a-thunderstorm/. Accessed 2 Feb. 2026.

[2] Wikipedia Contributors. “File:F-14 Tomcat with Landing Gear Down.jpg.” *Wikipedia*, Wikimedia Foundation.

[3] N. S. Currey, *Aircraft Landing Gear Design: Principles and Practices*. Reston, VA, USA: American Institute of Aeronautics and Astronautics, 1988.

[4] J. Roskam, *Airplane Design, Part IV: Layout Design of Landing Gear and Systems*. Lawrence, KS, USA: DARcorporation, 1985.

[5] T. H. G. Megson, *Aircraft Structures for Engineering Students*, 6th ed. Oxford, U.K.: Butterworth-Heinemann, 2019.

[6] Federal Aviation Administration, *Advisory Circular 25.473: Landing Load Conditions*. Washington, DC, USA, U.S. Department of Transportation.

[7] J. D. Anderson, *Introduction to Flight*, 8th ed. New York, NY, USA: McGraw-Hill Education, 2016.

[8] I. Gibson, D. W. Rosen, and B. Stucker, *Additive Manufacturing Technologies*, 2nd ed. New York, NY, USA: Springer, 2015.