

BELLTES ACADEMY

Engineering Mechanics:
Statics & Dynamics

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Section A: Ten Explanations & Examples

Topic 1: Force System Resultants & Vector Algebra

Detailed Explanation: When multiple forces act on a structure, engineers simplify the system by replacing those forces with a single equivalent force (Resultant) and a single twisting effect (Moment) acting at a specific point.

Real-World Example: A Three-Cable Utility Pole. Imagine a telecommunications pole anchored to the ground by three guy wires pulling in different 3D directions. To prevent the pole from collapsing or leaning, structural engineers use 3D Cartesian vectors to calculate the single total resultant pull on the pole cap. This ensures the foundation is anchored to resist that precise directional force.

Topic 2: Equilibrium of Rigid Bodies & Free-Body Diagrams (FBDs)

Detailed Explanation: For a structural system to remain safe, stable, and completely stationary, the sum of all linear pulling forces and all rotational twisting forces must perfectly cancel out to zero.

Real-World Example: A Tower Crane Lifting a Concrete Slab. Before lifting a load, engineers sketch a Free-Body Diagram (FBD)—a drawing isolating the crane from its environment and showing all forces: the weight of the concrete, the heavy concrete counterweights at the rear, the cable tensions, and the reactive forces at the ground foundation. Using the equilibrium equations, they calculate exactly how heavy the counterweight must be to keep the net moment around the base at zero, preventing the crane from tipping forward.

Topic 3: Moments, Torques, and Couples

Detailed Explanation: A moment measures the tendency of a force to cause an object to rotate or bend about a specific axis. A couple consists of two parallel forces that are equal in magnitude, opposite in direction, and do not share a line of action, creating pure rotation without linear movement.

Real-World Example: Using a Lug Wrench to Change a Flat Tyre. When you pull up on one side of a cross-shaped lug wrench and push down on the opposite side with equal force, you generate a force couple. There is zero net horizontal or vertical force pushing on the car wheel bolt (so it won't snap sideways), but the two forces combine to produce a pure torque that breaks the tight lug nut free.

Topic 4: Structural Analysis: Trusses, Frames, and Machines

Detailed Explanation: Trusses are structures composed entirely of two-force members pinned at their ends, meaning every single strut is strictly in pure tension (pulled apart) or pure compression (squashed). Frames and machines contain multi-force members that undergo bending.

Real-World Example: A Steel Railway Bridge. When a massive freight train rolls across a bridge, the load is distributed across a triangular network of steel beams. Designers use the Method of Sections to structurally cut a cross-section of the bridge profile. This determines which diagonal steel beams are under extreme compression (requiring thick columns to prevent buckling) and which are under tension (where thinner steel plates will suffice).

Topic 5: Centroids, Centers of Gravity, and Moments of Inertia

Detailed Explanation: The centroid represents the geometric center of an area. The Moment of Inertia measures a cross-section's physical geometric resistance to bending around a specific axis.

Real-World Example: An Structural Steel I-Beam. The reason floor joists and highway overpasses use I-shaped steel beams rather than solid square blocks is geometric optimization. By pushing the bulk of the material far away from the centroidal axis (forming the top and bottom flat flanges), engineers vastly increase the Area Moment of Inertia. This makes the beam highly resistant to sagging and bending under heavy loads while saving tons of material weight.

Topic 6: Dry Friction

Detailed Explanation: Friction is a tangential retarding force exerted by surfaces in contact, resisting the relative motion between them. Static friction builds up proportionally to match an applied force until it reaches a peak breakdown value (impending motion), at which point the body slips and drops to a lower kinetic friction level.

Real-World Example: A Heavy Wedge Under a House Foundation. Mechanical jacks use steep-angled wedges to level building foundations. By calculating the static friction coefficient between the steel wedge and the concrete foundation, engineers ensure that the system is self-locking. This means the friction force generated by the normal weight of the house pushing down on the wedge is large enough to prevent the wedge from violently shooting back out under load.

Topic 7: Kinematics of Particles (Rectilinear & Curvilinear)

Detailed Explanation: Kinematics tracks the geometry of motion over time without investigating the forces causing it. It bridges the mathematical relationships between position, velocity, and acceleration using calculus derivatives and integrals.

Real-World Example: A Rollercoaster Design. When designing a rollercoaster loop, engineers use curvilinear coordinates to plot the track coordinates. They compute the normal acceleration felt by passengers at the lowest point of the loop. If the radius is too tight or the velocity is too high, the centripetal G-forces could cause riders to pass out, so track geometry is continually adjusted using these calculus derivatives.

Topic 8: Kinetics of Particles: Force and Acceleration

Detailed Explanation: Kinetics introduces the cause of motion. When the forces acting on a particle are unbalanced, the particle accelerates in the direct line of the net resultant force, directly proportional to its mass.

Real-World Example: A Vehicle Roundabout Flyover. When a car navigates a steeply curved highway off-ramp, it experiences an inward centripetal acceleration. Road designers use the kinetics equations to calculate the exact banking angle of the concrete asphalt. By angling the road surface inward, the normal force from the tires helps push the car around the corner, ensuring vehicles do not slide off the wet road during high-speed turns.

Topic 9: Work, Energy, and Momentum Methods

Detailed Explanation: Instead of tracking instantaneous forces second-by-second, these principles look at integrated changes. Work-Energy relates forces acting over a spatial distance to changes in speed, while Impulse-Momentum relates forces acting over a span of time to changes in velocity.

Real-World Example: An Airport Runway Crash Barrier. When designing emergency catch-nets at the end of military runways, engineers do not use $F=ma$ because the stopping force fluctuates wildly as the net stretches. Instead, they use the Work-Energy Principle. They calculate the total kinetic energy of a landing fighter jet and design hydraulic pistons that absorb that exact amount of kinetic work over a safe stopping distance of 50 metres.

Topic 10: Planar Kinetics of Rigid Bodies

Detailed Explanation: Real-world engineering objects cannot be treated as single tiny points. When a force hits a large rigid body off-centre, it undergoes both translation (it flies forward) and rotation (it tumbles or spins). This requires tracking both linear mass and the Mass Moment of Inertia.

Real-World Example: An Aerospace Satellite Deployment. When a satellite unfolds its solar panel wings in space, cold-gas thrusters fire to position it. If a thruster is slightly misaligned from the satellite's exact center of mass, it creates a moment. Aerospace controllers use planar kinetics equations to predict how fast the satellite will rotate and tumble in orbit, ensuring counter-thrusters fire immediately to stabilize the orientation.

Section B: One Hundred Critical Terms

Topic 1 Glossary

• Magnitude

Description: The absolute size, numerical value, or intensity of a force, completely ignoring its direction.

Example: A crane cable pulling upward with a tension force of 50 kilonewtons (kN).

Analogy: The reading on your car's speedometer; it tells you exactly how fast you are going (100 km/h), but it doesn't care if you are driving north, south, or off a cliff.

• Direction

Description: The specific path, line of action, and orientation along which a force points in a coordinate system.

Example: A rocket booster pushing a payload at an angle of 45 degrees relative to the horizon.

Analogy: A compass heading or a GPS navigation arrow guiding you toward a specific destination.

• Resultant Force

Description: A single hypothetical force that perfectly replaces two or more actual forces acting on an object, producing the exact same structural effect.

Example: If two tugboats pull a ship forward, one with 30 kN left and one with 30 kN right, the resultant force is 60 kN straight ahead.

Analogy: A store voucher that combines all your small change into one single card worth R100.

• Cartesian Vector

Description: A method of breaking a single angled force down into three distinct, perpendicular components aligned with the axes of 3D space.

Example: Describing a diagonal cable pull as $F = 3i + 4j + 12k$ kN.

Analogy: Giving someone city directions by saying: 'Walk 3 blocks East, 4 blocks North, and go up 12 floors in the lift.'

• Line of Action

Description: An imaginary infinite straight line extending indefinitely through space along which a force vector is applied.

Example: The straight line passing directly through a taut vertical rope supporting an elevator car.

Analogy: A single, continuous set of train tracks; the train can move anywhere along that line, but it cannot steer left or right off the rails.

• Principle of Transmissibility

Description: A rule stating that the external effect of a force on a rigid body remains identical no matter where you apply it along its line of action.

Example: Pushing a car from the back bumper with 100 N moves it forward exactly the same as hooking a rope to the front bumper and pulling with 100 N.

Analogy: Pushing a friend through a doorway from behind versus standing in front of them and pulling them through by their hands.

• Unit Vector

Description: A vector with a length of exactly one unit that points in a specific direction, used purely to establish orientation without changing a force's size.

Example: A vector $u = 0.6i + 0.8j$ used to align a 500 N cable force in a 2D plane.

Analogy: A miniature signpost hand pointing down a highway; it doesn't add any distance to your trip, it just shows you where to turn.

• Scalar Product (Dot Product)

Description: A mathematical operation that multiplies two vectors to yield a single number, revealing how much they align or the angle between them.

Example: Multiplying a force vector by a displacement vector to calculate the mechanical work done.

Analogy: Comparing two torches shining on a wall; if they point the exact same way, the overlap is bright, but if they are perpendicular, they have zero intersection.

• Vector Product (Cross Product)

Description: A mathematical operation between two vectors that produces a third vector perpendicular to both, directly representing a rotational turning effect.

Example: Crossing a position vector from a hinge with an applied force vector to find the torque vector.

Analogy: Spinning a tabletop globe; your hand moves across the equator (horizontal), but the globe rotates around its vertical axis (perpendicular).

• Coplanar Force System

Description: A situation where all the individual forces acting on a structure lie within a single, flat two-dimensional surface.

Example: All the weight and wind forces acting flatly on a single vertical billboard panel.

Analogy: Crashing two bumper cars together on a perfectly flat theme park floor; all the motion and impacts happen strictly on that flat surface.

Topic 2 Glossary

- **Rigid Body**

Description: A theoretical object that never deforms, stretches, squashes, or changes its shape, no matter how massive the forces applied to it are.

Example: A heavy steel anvil modeled in statics calculations where structural flexing is negligible.

Analogy: A block of solid granite vs a sponge; no matter how hard you squeeze the stone, its internal particles stay in the exact same positions.

- **Free-Body Diagram (FBD)**

Description: A clean, isolated drawing of a single structural component showing every external force, weight, and support reaction acting on it.

Example: Sketching a bridge beam completely detached from its concrete pillars, replacing the pillars with upward arrow forces.

Analogy: An X-ray or a medical cutout diagram that strips away distractions to show exactly where the pressure points are.

- **Static Equilibrium**

Description: A state where an object is completely at rest because all opposing forces and turning moments are balanced to zero.

Example: A book resting motionless on a flat wooden desk.

Analogy: A perfectly balanced see-saw with identical twins sitting at equal distances from the center; it stays dead level and still.

- **Support Reactions**

Description: The resistive forces and moments exerted by brackets, joints, or foundations to prevent a structure from moving when loaded.

Example: A concrete bridge pillar pushing upward with 200 kN to hold up an overhead road deck.

Analogy: Your mattress pushing back up against your body weight at night so you don't sink down onto the floor.

- **Pin Support (Hinge)**

Description: A type of connection that completely prevents a structure from translating sideways or up and down, but allows it to rotate freely.

Example: A standard door hinge that holds the door frame secure but lets the door swing open.

Analogy: A compass needle pinned in the middle; you can't slide the needle off the paper, but it can spin around freely.

- **Roller Support**

Description: A connection that prevents movement in only one direction (usually vertical) while allowing the structure to slide freely horizontally.

Example: The rolling expansion shoes under one end of a long steel highway bridge.

Analogy: A person wearing roller skates; they cannot sink through the concrete floor, but they glide effortlessly forward and backward.

- **Fixed Support (Built-in)**

Description: A heavy, rigid connection that completely locks a beam in place, preventing all horizontal movement, vertical movement, and rotation.

Example: A steel flagpole securely embedded into a thick, solid concrete foundation block.

Analogy: A knife blade stabbed deep into a thick block of wood; you cannot push it sideways, lift it out easily, or tilt it back and forth.

- **Two-Force Member**

Description: A structural component with forces applied at only two pin points, forcing the internal load to act purely along the straight line between those pins.

Example: A single diagonal strut bracing a wall frame against wind loads.

Analogy: A simple piece of rope used in tug-of-war; you can only pull it tight along its length, you can't use it to twist or bend something.

- **Static Indeterminacy**

Description: A structural state where there are more unknown support reactions than available equilibrium equations, making it impossible to solve using basic statics alone.

Example: A long continuous bridge beam supported by five separate pillars instead of just two.

Analogy: Trying to solve a math problem with three missing variables when the teacher only gave you two equations.

- **Constraints**

Description: Physical boundaries, joints, or links that restrict how an object can move through space.

Example: Rail tracks acting as constraints that force a train to travel only along a single path.

Analogy: A dog leash attached to a post; it completely constrains the pet from running beyond a fixed circular radius.

Topic 3 Glossary

- **Moment of a Force**

Description: A mathematical measure of how much a specific force causes a body to bend or rotate around a specific point.

Example: Pressing down on the edge of a spanner to loosen a rusted bolt.

Analogy: Opening a heavy gate; pushing near the outside edge is easy, but pushing right next to the hinge requires immense effort.

- **Moment Arm (Lever Arm)**

Description: The shortest, perpendicular distance measured from the axis of rotation directly to the line of action of the force.

Example: The physical length of a socket wrench handle from the socket to your hand.

Analogy: A playground see-saw; sitting further away from the center pivot gives you a much longer, more powerful lever arm to lift your friend.

- **Couple**

Description: A pair of parallel forces that have identical magnitudes but point in exactly opposite directions, creating pure rotation without pushing the object sideways.

Example: Turning a car steering wheel with both hands—one pulling up, the other pushing down.

Analogy: Opening a bottle of soda; your thumb pushes one way while your index finger pulls the other way to spin the cap without sliding the bottle across the counter.

- **Varignon's Theorem**

Description: A principle stating that the moment of a force about any point is exactly equal to the sum of the moments of its individual component forces about that same point.

Example: Breaking a diagonal force into horizontal and vertical forces to calculate its total twisting effect on a wall bracket.

Analogy: Calculating the total weight of a backpack by weighing the bag and every item inside separately vs weighing the packed bag all at once.

- **Torque**

Description: An alternative engineering term specifically used for moments that cause a structural shaft to twist axially along its length.

Example: A car engine spinning a driveshaft to turn the vehicle's wheels.

Analogy: Wringing out a wet bath towel; your hands twist the opposite ends in circles along the towel's central axis to force the water out.

- **Right-Hand Rule**

Description: A universal visual standard used to determine the vector direction of a moment by curling your right fingers in the direction of rotation; your extended thumb points along the moment vector.

Example: Curling your fingers clockwise around a screw to see that the vector points downward into the wall.

Analogy: Threading a bottle cap; spinning it clockwise ('righty-tighty') drives the cap down onto the bottle neck.

- **Equivalent System**

Description: A simplified arrangement of forces and moments that creates the exact same external physical reaction on a body as a more complex set of forces.

Example: Replacing twenty scattered wind pressures on a building wall with one single force acting right in the middle.

Analogy: Swapping a pocket full of heavy coins for a single neat note.

- **Clockwise Moment**

Description: A rotational effect that twists an object in the same direction as the hands of an analog clock face, traditionally treated as a negative value in standard calculations.

Example: Turning a standard water tap handle to shut off the water flow.

Analogy: Driving a car around a circular roundabout turning consistently to the right.

- **Counter-Clockwise Moment**

Description: A rotational effect that twists an object opposite to the hands of a clock, traditionally treated as a positive value.

Example: Turning a jar lid to open it and break the vacuum seal.

Analogy: Running laps around a standard athletics track, where runners always turn left around the bends.

- **Pure Rotation**

Description: A state of motion where every particle of an object moves in a perfect circle around a fixed axis, with zero linear translation through space.

Example: A desk fan spinning on its highest setting while remaining anchored to a table.

Analogy: A classic playground merry-go-round spinning in place while kids hold on tightly.

Topic 4 Glossary

- **Truss**

Description: A lightweight, rigid framework built entirely from straight, slender bars connected at pinned joints, designed to span long distances efficiently.

Example: The triangular steel web supporting a factory roof or a traditional railway bridge.

Analogy: A skeleton structure built out of drinking straws pinned together with sewing needles into perfect triangles.

- **Method of Joints**

Description: A structural analysis technique where you isolate every single connecting pin one by one to solve for unknown bar forces using simple particle equilibrium.

Example: Isolating the very corner pin of a roof truss to see how much load transfers into the main support wall.

Analogy: Unpicking a knitted jumper stitch by stitch from the outer edge to see how much tension is in each individual thread.

- **Method of Sections**

Description: An analytical shortcut where you conceptually saw an entire truss in half to find the internal forces of specific internal bars using moment equations.

Example: Cutting a bridge truss down the middle to quickly check if the center-most steel beams are safe from snapping.

Analogy: Cutting a layer cake directly down the center to instantly inspect the quality of the internal cream fillings without eating the whole cake.

- **Tension**

Description: An internal structural force that pulls a material apart, stretching it tightly along its axis.

Example: A steel crane cable holding up a heavy steel shipping container.

Analogy: A rubber band being pulled outward by your fingers until it is completely taut.

- **Compression**

Description: An internal structural force that squeezes or squashes a material together, risking structural buckling.

Example: The solid concrete pillars holding up a multi-story parking garage.

Analogy: Stepping flatly onto an empty aluminum soft drink can, squashing it down toward the floor.

- **Zero-Force Member**

Description: A truss beam that carries absolutely zero load under a specific weight configuration, used purely to prevent long beams from buckling or sagging.

Example: A central vertical bar in a roof truss that remains completely unloaded until a heavy storm hits.

Analogy: A backup actor standing silently on a theatre stage; they aren't speaking lines right now, but they keep the scene from looking empty and stabilize the setup.

- **Frame**

Description: A stationary structure containing at least one multi-force member, meaning its beams must resist bending, shear, and twisting, not just pure tension or compression.

Example: The structural skeleton of a modern office building made of rigid concrete beams and columns.

Analogy: A wooden bookshelf; the horizontal shelves bend under the weight of books, meaning they do more than just push or pull at their ends.

- **Machine**

Description: A mechanical assembly containing moving parts designed to alter, magnify, and transmit forces to perform useful work.

Example: A pair of bolt cutters or a hydraulic workshop car jack.

Analogy: A simple nutcracker; you squeeze the handles with a small force, and the internal hinges magnify that pressure to crack open a hard shell.

- **Multi-Force Member**

Description: A structural beam that experiences forces at three or more different locations along its length, inducing internal bending.

Example: A diving board clamped at one end, supported by a pivot in the middle, and stepped on at the tip.

Analogy: Holding a long plastic ruler at both ends and having a friend push down on the exact center until it curves.

- **Planar Truss**

Description: A two-dimensional truss layout where all structural bars and applied loads sit within a single flat plane.

Example: A single vertical triangular truss section running along the side profile of a pedestrian bridge.

Analogy: A flat drawing of a house roof layout sketched out on a sheet of paper.

Topic 5 Glossary

- **Centroid**

Description: The exact geometric center of a shape, calculated as the average position of all the points across its total area.

Example: The exact center point of a flat, uniform cardboard circle.

Analogy: Finding the middle spot of a rectangular table where you can place a single leg to support it evenly.

- **Center of Gravity**

Description: The specific point where the entire total weight of a physical object can be assumed to act, balancing its mass perfectly in a gravitational field.

Example: The point inside an aircraft fuselage where the nose weight perfectly balances the tail weight.

Analogy: Balancing a broom horizontally on your index finger; the exact spot where it doesn't tilt left or right is its center of gravity.

- **Moment of Inertia (Area)**

Description: A geometric property of a cross-section that describes how its material is distributed relative to an axis, dictating its resistance to bending.

Example: A wide steel beam resisting vertical sagging because its material is pushed far from its center.

Analogy: Bending a plastic ruler; it is incredibly easy to bend when flat, but nearly impossible to bend when you flip it sideways on its thin edge.

- **Parallel Axis Theorem**

Description: A mathematical formula used to calculate the moment of inertia of a shape about any axis that runs parallel to its central centroidal axis.

Example: Finding the total bending resistance of a built-up beam consisting of multiple steel plates welded together.

Analogy: Swinging a golf club; swinging it normally around your wrists is easy, but swinging it around your shoulder axis requires much more effort because the club's mass is further away.

- **Radius of Gyration**

Description: An imaginary distance from an axis at which the entire area of a shape could be concentrated into a thin strip while keeping the exact same moment of inertia.

Example: A parameter used by structural engineers to predict when a long steel column will buckle under a building load.

Analogy: Condensing an entire spinning ice skater's body mass into a single thin ring around her axis of rotation.

- **Composite Area**

Description: A complex shape constructed by combining several simple geometric figures like rectangles, triangles, and circles.

Example: An I-beam cross-section, which can be broken down into three simple connected rectangles.

Analogy: Building a toy castle out of standard square, triangular, and cylindrical Lego blocks.

- **First Moment of Area**

Description: A mathematical property calculated by multiplying an area by its distance from a reference axis, used primarily to locate centroids and calculate shear stress.

Example: Calculating how weight distribution affects the internal shear stress inside a wooden floor beam.

Analogy: Balancing a see-saw with multiple children; you must multiply each child's weight by their distance from the center to find the total turning balance.

- **Mass Moment of Inertia**

Description: A physical property that measures a solid object's absolute resistance to changes in its rotational speed around a specific axis.

Example: A heavy steel flywheel slowing down changes in an engine's rotation rate.

Analogy: Spinning around in an office chair; you spin much faster when you pull your arms and legs tight into your chest vs extending them fully outward.

- **Product of Inertia**

Description: A geometric property that measures the asymmetry of an area relative to a set of coordinate axes; it drops to zero if the shape is perfectly symmetrical.

Example: Analyzing the twisting behavior of an asymmetrical L-shaped steel angle beam under load.

Analogy: Driving a car with an unbalanced wheel; if the wheel shape isn't perfectly symmetrical around the axle, it wobbles violently at high speeds.

- **Principal Axes**

Description: The specific orthogonal axes through a shape's centroid where the moment of inertia reaches its maximum and minimum possible values, and the product of inertia is zero.

Example: The vertical and horizontal lines of symmetry through a standard structural I-beam.

Analogy: The spine of a textbook; there is one ideal direction to open and flex the book, and another rigid direction that completely resists bending.

Topic 6 Glossary

- **Static Friction**

Description: The resistive force that opposes the initial boundary movement between two dry, solid surfaces that are completely at rest relative to each other.

Example: The force holding a heavy cardboard shipping box steady on a sloped warehouse ramp.

Analogy: Pushing against a heavy, stationary brick wall; it doesn't budge at first because the microscopic surface ridges are locked together.

- **Kinetic Friction**

Description: The constant resistive sliding force acting between two contacting surfaces once relative sliding motion has already begun.

Example: The continuous dragging force felt as you push a heavy couch across a wooden living room floor.

Analogy: The friction that burns your palms when you slide quickly down a playground fire pole.

- **Coefficient of Static Friction**

Description: A dimensionless number that describes the relative roughness and grip strength between two clean surfaces before sliding occurs.

Example: Rubber on dry concrete has a high coefficient (approx 0.9), while steel on ice has a very low coefficient (approx 0.1).

Analogy: Velcro strips sticking together tightly (high coefficient) vs two smooth bars of wet soap sliding past each other (low coefficient).

- **Impending Motion**

Description: The precise threshold state where an object is on the absolute verge of slipping; static friction has reached its maximum possible capacity.

Example: A car tire just about to break traction and spin wildly during a hard acceleration.

Analogy: A balanced glass sitting on the edge of a table that is tilted so far that the slightest breath of wind will make it slide off.

- **Angle of Friction**

Description: The maximum angle relative to the normal force vector at which the total resultant contact force can act without causing the object to slip.

Example: A mathematical angle used to design self-locking industrial clamps and heavy machinery brackets.

Analogy: Tilting a clipboard with a coin on it; the maximum tilt angle you can reach before the coin slides away is the angle of friction.

- **Normal Force**

Description: The perpendicular support force exerted by a solid surface against any object pressing down or pushing flatly against it.

Example: A table pushing straight up against the flat base of a heavy laptop resting on it.

Analogy: The pressure you feel on the soles of your feet while standing flatly on a solid concrete floor.

- **Self-Locking**

Description: A design property where a mechanical system cannot be forced to slip or move by an external load, because the internal friction scales up to match it.

Example: A standard threaded steel screw holding a heavy picture frame securely in a wall without backing out.

Analogy: A Chinese finger trap puzzle; the harder you try to pull your fingers out, the tighter the mesh grips, preventing escape.

- **Wedge**

Description: A simple, powerful machine consisting of a portable inclined plane used to lift massive weights or split objects apart using high friction forces.

Example: Driving a steel wedge under a heavy industrial generator to level its alignment on a shop floor.

Analogy: Jamming a triangular rubber doorstop firmly under a heavy classroom door to keep it wide open against a draft.

- **Belt Friction**

Description: The exponential friction force that builds up when a flexible rope, cable, or belt is wrapped around a curved drum or pulley wheel.

Example: A mooring rope wrapped three times around a dock bollard to hold a massive cruise ship steady.

Analogy: Wrapping a dog leash once around a park bench post; it allows a small child to hold back a large, pulling dog effortlessly.

- **Slipping vs. Tipping**

Description: A critical engineering analysis determining whether a tall object subjected to a sideways force will slide across the floor first (slipping) or fall over onto its side (tipping).

Example: Designing a tall electrical cabinet to ensure it slides during an earthquake rather than tipping over onto workers.

Analogy: Pushing a tall, slender empty refrigerator box; if you push it near the bottom, it slides, but if you push it at the very top, it flips over.

Topic 7 Glossary

- **Rectilinear Motion**

Description: Linear particle movement that occurs strictly along a single, perfectly straight line path over time.

Example: A drag racing car driving down a straight 400-metre asphalt track.

Analogy: An elevator moving straight up and down inside a vertical high-rise shaft.

- **Curvilinear Motion**

Description: Particle movement that takes place along a curved, non-linear trajectory through a 2D plane or 3D space.

Example: A thrown basketball tracing a smooth parabolic arc through the air toward a hoop.

Analogy: A car driving along a winding mountain pass road with sharp left and right bends.

- **Normal Acceleration**

Description: The component of acceleration that acts perpendicular to a particle's path, pointing directly inward toward the center of curvature, changing its direction.

Example: The sideways force pulling a car passenger inward as the vehicle rounds a sharp highway bend.

Analogy: Swinging a ball on a string; the tension pulling inward on your hand is what constantly bends the ball's path into a circle.

- **Tangential Acceleration**

Description: The component of acceleration that acts parallel to the path of motion, directly changing the linear speed of the particle.

Example: A driver stepping firmly on the accelerator pedal to speed up from 60 km/h to 100 km/h on a straight road.

Analogy: Blowing air directly behind a toy sailboat to make it move faster along its current path.

- **Projectile Motion**

Description: A specialized form of curvilinear motion where a free-falling particle is launched into the air and is acted upon only by downward gravity and forward inertia.

Example: A fired artillery shell traveling through the sky toward a distant target.

Analogy: Squirt gun water arching through the air during a backyard pool fight.

- **Relative Motion**

Description: The mathematical analysis of a particle's movement measured from the perspective of another moving frame of reference.

Example: Calculating how fast a faster train appears to pass a slower train traveling next to it on parallel tracks.

Analogy: Walking forward at 5 km/h down the aisle of a passenger plane that is flying at 800 km/h relative to the ground.

- **Polar Coordinates**

Description: Tracking a particle's position using a radial distance from a central origin combined with an angular rotation measurement.

Example: Tracking a commercial airliner using a rotating sweeping military radar dish at an airport control tower.

Analogy: A lighthouse beam sweeping out across the ocean, locating boats by how far away they are and what angle the light is pointing.

- **Radius of Curvature**

Description: The instantaneous radius of an imaginary perfect circle that matches the curve of a particle's path at a specific point.

Example: Evaluating the sharpness of an F1 racetrack turn to determine safe cornering speeds.

Analogy: Driving along a road; a long, sweeping highway turn has a massive radius of curvature, while a tight cul-de-sac roundabout has a tiny radius.

- **Displacement**

Description: A vector quantity representing the straight-line shortcut distance and direction from a particle's starting position to its final position.

Example: Walking 5 km East, then 5 km West results in a total displacement of exactly 0 km.

Analogy: Flying directly from Johannesburg to Cape Town in a straight line, completely ignoring the twists and turns of the roads down below.

- **Instantaneous Velocity**

Description: The precise vector rate at which an object's position is changing at one exact, infinitesimally small moment in time.

Example: Checking your digital speedometer at the exact millisecond you pass a highway traffic camera.

Analogy: Freezing a movie frame of a speeding bullet; its velocity vector at that exact frozen frame is its instantaneous velocity.

Topic 8 Glossary

- **Newton's Second Law**

Description: The foundation of kinetics, stating that the net unbalanced force vector on a particle is equal to its mass multiplied by its acceleration vector.

Example: A high-powered rocket engine generating thrust to accelerate a heavy satellite into orbit.

Analogy: Kicking a football vs kicking a heavy concrete brick with the same effort; the football flies away quickly because its low mass allows high acceleration.

- **Inertial Reference Frame**

Description: A coordinate system that is completely stationary or moving at a constant speed in a straight line, where Newton's laws hold true without fictitious forces.

Example: Doing physics calculations inside a stationary laboratory building on solid ground.

Analogy: Sitting smoothly in a train cruising steadily at 100 km/h with the blinds closed; coffee sits perfectly still in your cup without spilling.

- **Centripetal Force**

Description: The net inward physical force required to continuously pull a moving object toward the center of a curved path, maintaining its curvilinear motion.

Example: The friction force between a race car's tires and the asphalt that keeps the vehicle turning around a track bend.

Analogy: Holding onto a spinning playground roundabout; your hands must pull inward tightly to keep you from being thrown outward.

- **Mass**

Description: A fundamental scalar property of an object that measures its internal quantity of matter and its absolute physical resistance to being accelerated.

Example: A large lead anvil has a high mass, making it difficult to push or lift regardless of gravity.

Analogy: A fully loaded shopping trolley vs an empty trolley; the loaded trolley requires much more muscle to start moving or stop.

- **Weight**

Description: The downward gravitational force exerted on an object's mass by a planetary body like Earth.

Example: A person weighing 700 Newtons on Earth, but only 115 Newtons when standing on the surface of the Moon.

Analogy: A luggage scale at the airport pulling down on a bag, measuring how intensely Earth's gravity is tugging on the suitcase contents.

- **Equations of Motion**

Description: The set of scalar algebraic equations derived from force/acceleration laws used to solve for unknown structural forces or particle accelerations.

Example: Writing out sum of forces to figure out how fast a heavy block will slide down an inclined ramp.

Analogy: A financial budget spreadsheet where you list all income and expenses to figure out your final bank savings rate.

- **D'Alembert's Principle**

Description: A mathematical formulation that converts a dynamic kinetics problem into a static equilibrium setup by introducing an opposing dynamic inertia term.

Example: Treating an accelerating elevator as a static system by adding a dynamic force to make the equations easier to solve.

Analogy: Leaning your body backward into the wind while walking through a heavy gale to make yourself feel balanced and steady.

- **Unbalanced Force**

Description: A situation where the sum of all external forces acting on an object does not equal zero, forcing the object to accelerate in that direction.

Example: Two people pushing a box from opposite sides, one pushing with 50 N and the other with 20 N.

Analogy: A game of tug-of-war where one team is massive and pulls the rope completely over into their side of the pit.

- **Free Fall**

Description: A state of motion where an object accelerates downward under the sole influence of gravity, with all air resistance and other forces completely omitted.

Example: A heavy steel ball dropped inside a vacuum chamber in a research lab.

Analogy: A skydiver jumping out of a plane at high altitude during the first few seconds before wind resistance builds up.

- **Terminal Velocity**

Description: The constant, maximum speed reachable by a falling object when the upward drag force of air resistance grows to perfectly match its downward weight.

Example: A human skydiver falling chest-to-earth reaching a steady, non-accelerating speed of about 200 km/h.

Analogy: Driving a car with the pedal flat on the floor; eventually, wind resistance matches the engine's power, and the car cannot go any faster.

Topic 9 Glossary

- **Kinetic Energy**

Description: The scalar energy possessed by an object due to its current motion.

Example: A high-speed highway truck carrying an immense amount of destructive kinetic energy due to its large mass and speed.

Analogy: A flying wrecking ball; it has the capacity to smash through a concrete wall purely because it is heavy and moving fast.

- **Potential Energy**

Description: The stored energy an object possesses due to its elevated position or internal physical configuration.

Example: A heavy metal pile-driver weight hoisted up to the top of a construction tower, waiting to be dropped.

Analogy: A stretched archer's bowstring; it holds silent energy ready to shoot an arrow the moment you let go.

- **Work of a Force**

Description: The energy transferred to or from an object when an external force acts along a distance path.

Example: A person pushing a lawnmower 20 metres across a flat grass field.

Analogy: Spending money from your bank account; you do work (spend energy) to move a product from a store shelf to your home.

- **Conservative Force**

Description: A force that does work independent of the path taken; its total work depends only on the starting and ending locations.

Example: Gravity; lifting a box straight up takes the same gravitational work as sliding it up a long, frictionless ramp to the same height.

Analogy: Hiking up a mountain; whether you climb straight up a steep cliff or take a long winding trail, your final change in altitude is identical.

- **Non-Conservative Force**

Description: A force where the total work done depends heavily on the specific path traveled, turning mechanical energy into heat or sound.

Example: Friction; dragging a heavy crate in a wild zig-zag pattern across a room wastes far more energy than sliding it in a straight line.

Analogy: A car's fuel consumption; driving around the block ten times uses up far more petrol than parking immediately, even if you end up in the same driveway.

- **Linear Momentum**

Description: A vector quantity representing the total quantity of motion an object has, calculated as mass times velocity.

Example: A heavy runaway train being nearly impossible to stop quickly, even if it is rolling at a slow walking pace.

Analogy: A heavy rugby player running down the field; they are incredibly difficult to tackle because their combined mass and speed carry immense momentum.

- **Linear Impulse**

Description: The product of an external force multiplied by the duration of time over which it acts, directly causing a change in momentum.

Example: A tennis racket striking a tennis ball, applying a large force over a fraction of a second to reverse its direction.

Analogy: Giving a friend a sudden push on a skateboard to get them rolling down a path.

- **Conservation of Momentum**

Description: A principle stating that the total momentum of an isolated system remains completely constant if no external forces act on it.

Example: Two billiard balls colliding on a pool table; the total momentum before the click equals the total momentum after.

Analogy: Passing a baton in a relay race; the speed of the first runner is transferred directly into the second runner, keeping the momentum moving forward.

- **Coefficient of Restitution**

Description: A scalar ratio between 0 and 1 that measures the bounciness or elasticity of a collision between two objects.

Example: A bouncy golf ball dropped on steel has a high coefficient (approx 0.85), while a lump of wet clay has a coefficient of 0.

Analogy: Dropping a superball on the floor (it bounces nearly all the way back up) vs dropping a ripe tomato (it goes 'splat' and stays flat on the floor).

- **Power**

Description: The rate at which mechanical work is performed or energy is expended over time, measured in Watts or Horsepower.

Example: A sports car engine capable of performing millions of Joules of work per second to accelerate rapidly.

Analogy: Running up a flight of stairs vs walking up the same stairs; you do the exact same amount of total work against gravity, but running requires far more power.

Topic 10 Glossary

- **Mass Moment of Inertia**

Description: A physical quantity that dictates how difficult it is to change a large rigid body's rotational speed around its center of mass.

Example: The heavy, wide steel rotor inside a helicopter engine resisting sudden changes in its RPM.

Analogy: Spinning an open umbrella; it is easy to spin around its handle axis, but incredibly clumsy and difficult to flip end-over-end.

- **Angular Acceleration**

Description: The time rate of change of an object's rotational velocity, measured in radians per second squared.

Example: A circular sawmill blade spinning up from a complete stop to full cutting speed when switched on.

Analogy: Stepping on a car's accelerator pedal while spinning your wheels on ice; the wheels spin faster and faster in circles.

- **Translation**

Description: A type of rigid body motion where every point on the object moves along parallel lines, meaning the object does not rotate or tilt as it travels.

Example: A passenger cabin on a giant Ferris wheel; it moves up, forward, and down, but always stays perfectly upright.

Analogy: Sliding a flat coffee mug carefully across a smooth table without spinning or tilting it.

- **Rotational Kinetic Energy**

Description: The scalar kinetic energy possessed by a large object due to its spinning motion.

Example: A heavy spinning flywheel storing energy in a hybrid bus to help it pull away from stops.

Analogy: A spinning toy top; it looks stationary from a distance, but it contains enough rotational energy to knock over small obstacles.

- **General Plane Motion**

Description: A combination of both translation and rotation occurring simultaneously within a single flat plane.

Example: A bowling ball rolling down a wooden lane; it slides forward while spinning rapidly around its center axis.

Analogy: A coin flipped into the air; it travels forward along a parabolic arc while simultaneously spinning end-over-end.

- **Instantaneous Center (IC)**

Description: An imaginary point about which a rigid body undergoing general plane motion can be assumed to be in pure rotation at one exact instant.

Example: The very bottom point of a car tire where the rubber makes contact with the road asphalt; it is momentarily stationary.

Analogy: Pinning a moving paper map down with one finger; for that brief split-second, the entire map can only pivot around your fingertip.

- **Parallel Axis Theorem (Mass)**

Description: A formula used to calculate an object's mass moment of inertia around any axis that runs parallel to its central axis of gravity.

Example: Calculating the rotational resistance of a heavy vault door pivoting around hinges located at its outer edge.

Analogy: Swinging a baseball bat; swinging it from the handle is much harder than pinning it in the exact middle and spinning it like a propeller.

- **Angular Momentum**

Description: A vector quantity tracking the quantity of rotational motion an object has.

Example: A spinning gyroscope maintaining its vertical alignment in space inside a spacecraft guidance system.

Analogy: A figure skater spinning on ice; pulling her arms inward reduces her inertia, causing her rotational speed to skyrocket to conserve angular momentum.

- **Angular Impulse**

Description: The rotational equivalent of linear impulse, calculated as a torque multiplied by the duration of time it is applied.

Example: A boat propeller gunning its engine for five seconds to spin a heavy ship around in a harbor.

Analogy: Twirling a playground merry-go-round by giving it repeated, timed slaps along its outer rim.

- **Euler's Equations**

Description: The set of fundamental rotational equations that expand Newton's second law to explain how torques cause objects to spin.

Example: Calculating how much engine torque is needed to spin up a massive wind turbine's blades during startup.

Analogy: Figuring out exactly how hard you need to twist a stiff door handle to overcome a rusty internal latch spring.