




Mechanical Engineering in the Aerospace & Marine Sector

An Introductory Lecture for First-Year ME Students

 Course: Introduction to Mechanical Engineering
 Duration: 1 Hour |  B.Tech – Year 1

Lecture Roadmap & Learning Outcomes

Design Thinking across the skies and seas — a 1-hour journey

01

Empathize

Global & India
aerospace + marine
challenge

02

Define

ME's role in both
sectors

03

Ideate

Core technologies —
flight & propulsion

04

Prototype

Marine systems &
advanced engineering

05

Test

Case studies,
sustainability & careers

 *Outcome: Understand how ME fundamentals power aircraft, spacecraft, ships, and submarines*

Introduction to Mechanical Engineering/Role in Aerospace &
Marine

EMPATHIZE – Aerospace & Marine: The High-Stakes Sectors



Industries where engineering failure is never an option

\$430B+

Global aerospace
market (2024)

\$180B+

Global shipbuilding
& marine market

₹1 Lakh Cr

India aerospace
defence target by 2025

- Aerospace: Every aircraft component is life-critical — engineering tolerances and quality standards are the strictest in any industry
- Marine: 90% of global trade travels by sea — shipping, naval, and offshore engineering underpin world commerce
- India's space economy target: \$44 billion by 2033 (currently \$8.4B) — ISRO, DRDO, and 140+ private space startups
- Indian Navy: 3rd largest in Asia; Cochin Shipyard building INS Vikrant — India's first indigenous aircraft carrier
- Both sectors require ME graduates who master aerodynamics, propulsion, structures, materials, and systems engineering

India's Aerospace & Marine Landscape

A rapidly expanding ecosystem across defence, space, civil aviation, and shipbuilding

AEROSPACE

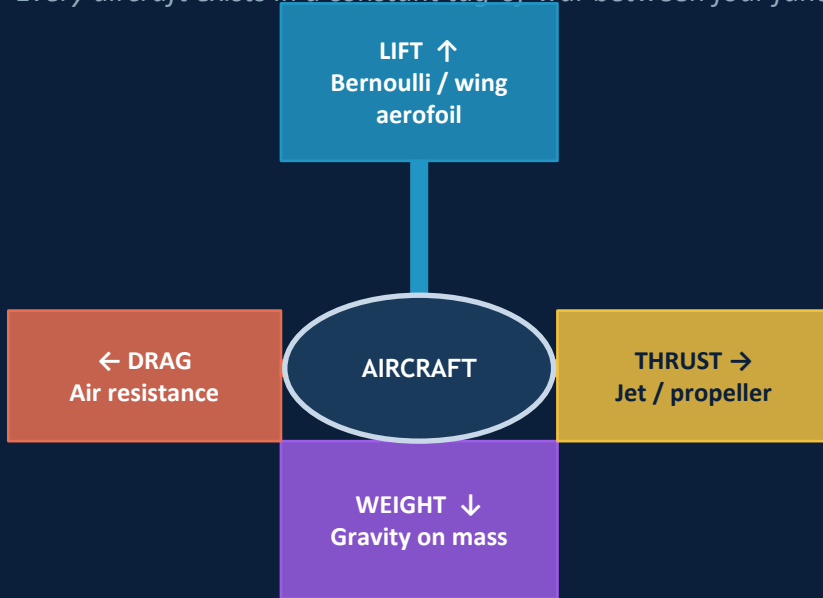
- ISRO: 100+ successful missions; PSLV world record — most reliable launch vehicle
- HAL: Tejas LCA, ALH Dhruv helicopter, Hawk trainer; 70+ aircraft types produced
- DRDO: Astra missile, Brahmos supersonic cruise missile, GSAT satellites
- Private Space: Agnikul, Skyroot, Pixxel, Dhruva Space — 140+ startups, \$3B+ funding
- Civil Aviation: IndiGo, Air India MRO market ₹26,000 cr; growing at 8% p.a.

MARINE

- Indian Navy: 150+ warships; \$10B+ modernisation programme underway
- Cochin Shipyard: INS Vikrant (45,000 tonne aircraft carrier); largest shipyard in India
- Mazagon Dock (MDL): Submarines, destroyers (P15B Visakhapatnam class)
- NIOT (National Inst. of Ocean Technology): Deep-sea mining, AUVs, Samudrayaan manned submersible
- Offshore & Ports: ONGC offshore platforms; Sagarmala Project — 575 port projects ₹6 lakh cr

DEFINE – The Four Forces of Flight

Every aircraft exists in a constant tug-of-war between four fundamental forces



- **LIFT:** Wing aerofoil, Bernoulli's principle, angle of attack — Fluid Mechanics + CFD
- **DRAG:** Streamlining, boundary layer control — reduce fuel burn by 5–15%
- **THRUST:** Jet engines (Brayton cycle), propellers, rockets — Thermodynamics + Propulsion
- **WEIGHT:** CFRP + Ti alloys — lightest structure that can survive all flight loads
- **L/D Ratio:** Boeing 787 L/D \approx 21 — the key efficiency metric every aero ME optimises

Aircraft Structures – Engineering

Extreme Lightness & Strength

A commercial aircraft must survive 90,000+ flight cycles over 30 years

- Semi-monocoque fuselage: Skin + frames + stringers carry loads together — aluminium alloy or CFRP panels riveted/bonded
- Wing box: Primary structural element carrying bending + torsional loads; spars, ribs, skin — critical fatigue design
- Materials hierarchy: 2024-T3 Al alloy → 7075 Al alloy → Ti-6Al-4V → IM7/8552 CFRP — each 2× stronger/lighter
- Damage Tolerance: Aircraft designed to fly safely with detectable cracks — NOT designed to be crack-free
- Fatigue Analysis: Goodman diagram, S-N curves — Boeing 737 Max wing designed for 75,000 flight cycles
- Finite Element Analysis (FEA): Virtual stress simulation of entire airframe before first metal is cut

Aircraft Load Types

Bending

Wing lifts fuselage upward in flight — massive bending moment at wing root

Torsion

Aileron deflection twists the wing — spiral failure mode if not designed for

Pressurisation

Cabin pressurised to 0.75 atm — 500 MPa hoop stress on fuselage skin

Thermal

Supersonic aircraft skin heats to 120°C+ — thermal expansion stresses

Fatigue

Pressurisation cycle every flight — millions of stress reversals over lifetime

IDEATE – Jet Engines & Aerospace Propulsion



The Brayton cycle transforms fuel into thrust — the most demanding heat engine ever built



Turbofan bypass ratio (BPR): GE9X on Boeing 777X = 10:1 — 65% of thrust from cold bypass air, fuel burn -20%

- Turbine Blade: Spins at 10,000–16,000 RPM, 1600°C inlet temperature (above melting point of blade alloy!) — film cooling holes save it
- Turbine Efficiency: Thermal efficiency 40–50%; LEAP/GE9X use ceramic matrix composites (CMC) to run even hotter
- Rocket Propulsion: Liquid engines (LOX/LH2 or LOX/kerosene); thrust-to-weight ratio >100 — ISRO VIKAS engine, SpaceX Merlin
- Ramjet / Scramjet: Air-breathing supersonic propulsion — Brahmos uses ramjet; DRDO HSTDV tested scramjet at Mach 6
- Electric Propulsion: Distributed electric fans for urban air mobility (UAM); eVTOL startups like Joby, Archer, and India's ePlane

Aerodynamics & Computational Fluid



Dynamics (CFD)

Understanding airflow is the foundation of aircraft, rocket, and turbine design

- Aerofoil Geometry: Chord, camber, thickness ratio, leading-edge radius — each parameter tunes lift, drag, and stall behaviour
- Reynolds Number ($Re = \rho VL/\mu$): Governs flow regime — laminar (smooth) vs turbulent (chaotic); determines drag coefficient
- Boundary Layer: Thin layer of slow-moving air near surface — separation causes stall; turbulators and vortex generators delay it
- Supersonic Flow: Shock waves form when flow $>$ Mach 1; normal, oblique, Prandtl-Meyer expansion — compressible flow theory
- CFD (ANSYS Fluent / OpenFOAM): Solve Navier-Stokes equations numerically on a mesh of millions of cells
- Wind Tunnel Testing: Physical validation; India's NAL 1.2m tunnel and DRDL hypersonic tunnel used for aircraft/missile testing

Key Aerodynamic Metrics

Mach 0.85

Typical cruise speed of commercial jets

CL \approx 0.5

Cruise lift coefficient (Boeing 787)

L/D \approx 21

Lift-to-drag ratio
787 Dreamliner

Mach 3.2

SR-71 Blackbird max — world fastest aircraft

Re $>$ 10^7

Wing chord Reynolds number in cruise

Spacecraft & Launch Vehicle



Engineering

From launch pad to orbit — ME systems that defy gravity



Launch Vehicle Structures

Monocoque shell, propellant tanks (LOX/LH2 at -253°C), inter-stage separation — extreme thermal and pressure loads



Propulsion Systems

Liquid, solid, and hybrid rocket motors; ISRO VIKAS (25 kN), CE-20 cryogenic engine for GSLV Mk III



Thermal Protection

Re-entry heat shield: ablative PICA (Phenolic Impregnated Carbon Ablator) or TPS tiles — survives 1650°C



Attitude Control

Reaction Control System (RCS) thrusters, reaction wheels, gyroscopes — keep satellite pointed precisely



Satellite Structures

CFRP honeycomb sandwich panels; deployed solar arrays; vibration isolation for sensitive instruments



Space Environment

Vacuum, atomic oxygen, thermal cycling (-180°C to $+150^{\circ}\text{C}$), radiation — all stress ME systems

ISRO's PSLV has successfully launched 440+ satellites from 36 countries — the world's most reliable launch vehicle

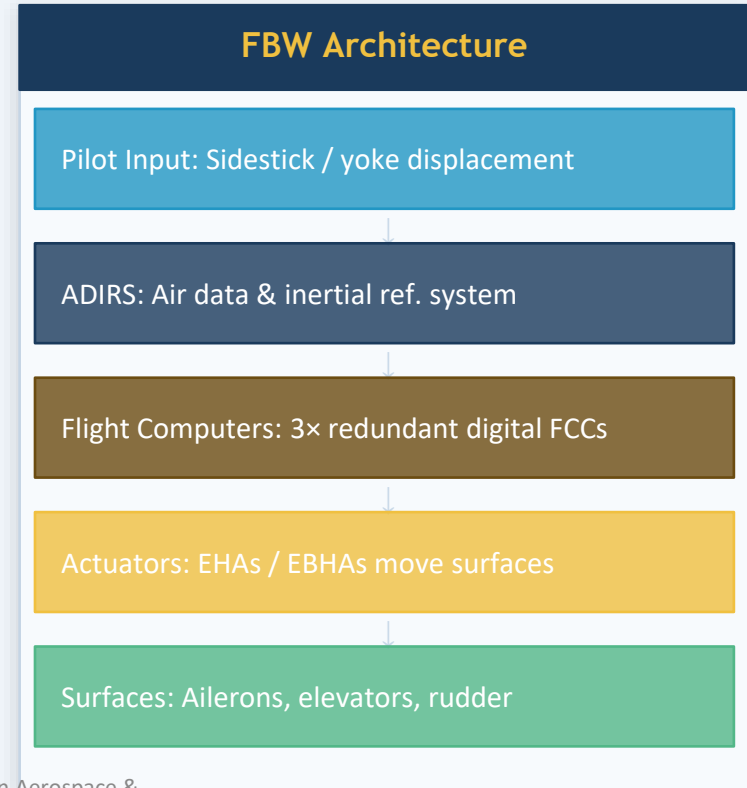
Introduction to Mechanics: Engineering Roles in Aerospace & Marine

Aircraft Systems Engineering — Fly-By-Wire & Avionics



Modern aircraft are flying computers — ME integrates structure, actuation, and control

- Fly-by-Wire (FBW): Pilot inputs converted to electrical signals → flight computers → hydraulic/electric actuators on control surfaces
- Hydraulic Systems: 3000–5000 psi systems move control surfaces, flaps, landing gear, brakes — ME designs all actuator cylinders
- Landing Gear: Energy absorption via oleo-pneumatic shock struts; wheel brakes reach 400°C; tyre pressure 200 psi
- Environmental Control System (ECS): Bleed air from engines pressurises and conditions cabin; heat exchangers, valves, ducting
- Ice Protection: Engine bleed air or electric heating on wing leading edges — critical for safety in icing conditions
- Fuel Systems: Integral wing tanks; fuel as heat sink for hydraulic fluid; fuel density affects CG and structural loads



PROTOTYPE – Marine Engineering Fundamentals



Ships operate on the same physics principles as aircraft — but in water, 800× denser than air

Buoyancy & Stability

- Archimedes' Principle: Buoyant force = weight of displaced water
- Metacentric height (GM): >0 for stability; GM ≈ 0.5–2.0 m for cargo ships
- Free surface effect: Liquid cargo sloshing reduces GM — stability hazard
- INS Vikrant GM designed for survivability in 45° flooding conditions

Resistance & Propulsion

- Hull resistance: Frictional + wavemaking + form drag — Froude number governs wavemaking
- Ship speed vs power: $P \propto V^3$ — doubling speed needs 8× the engine power
- Propeller: Converts shaft torque → thrust; Ka-Wageningen B-series; cavitation limit
- Fixed vs Controllable Pitch Propeller (CPP) — manoeuvrability vs efficiency trade-off

Structural Integrity

- Hull girder bending: Wave sagging and hogging loads — steel plates welded into box girder
- Plate thickness: 12–25 mm steel for bulk carriers; higher-strength AH36/DH36 steel grades
- Fatigue: Stress concentrations at hatch corners, bilge keels — class society rules (Lloyd's, DNV)
- Corrosion: Cathodic protection (zinc anodes); paint systems; ballast tank coatings

Marine Propulsion – Engines That Move the World's Cargo



The marine diesel engine is the largest and most fuel-efficient internal combustion engine ever built

- Two-stroke marine diesel: MAN B&W 12G95ME — 107,390 kW (144,000 HP); 91% thermal efficiency at optimal load
- Diesel-Electric: Diesel generators power electric motors; precise speed control; used in cruise ships, icebreakers
- Gas Turbine (COGAG/COGOG): Naval vessels use Rolls-Royce MT30 or GE LM2500 — 36 MW; high power-to-weight ratio
- Nuclear Propulsion: Naval submarines/carriers (USS Nimitz class, INS Arihant) — 30-year fuel life, unlimited range
- Azipod Propulsion: Electric motor inside 360° rotating pod replaces rudder — ABB units on cruise ships and icebreakers
- LNG Propulsion: Liquefied natural gas reduces SO_x by 99%, NO_x by 85% — Maersk, MSC converting fleets to LNG

Propulsion Comparison	
Slow 2-stroke diesel	BSFC: 155 g/kWh η : 51%
4-stroke medium speed	BSFC: 185 g/kWh η : 46%
Gas turbine (naval)	BSFC: 250 g/kWh η : 32%
Nuclear steam turbine	Virtually unlimited range
LNG dual-fuel diesel	-25% CO ₂ vs HFO
Hydrogen fuel cell	Zero emissions; in trials

Submarines & Underwater Vehicles

Engineering machines that survive crushing ocean pressure — 600 bar at 6,000 m depth

- Pressure hull: Circular cross-section distributes hydrostatic pressure uniformly; HY-80/HY-100 steel — 5–10× stronger than structural steel
- Dive & surface: Variable Ballast Tanks (VBT) flood with seawater to dive; Main Ballast Tanks (MBT) blow with compressed air to surface
- Hydrostatic pressure: 1 atm per 10 m depth; at 300 m (submarine combat depth) = 30 atm or 3 MPa pressure on every surface
- Propulsion (conventional): Diesel-electric — diesels charge batteries on surface/snorkel; batteries drive electric motors submerged
- AIP (Air Independent Propulsion): Fuel cell or Stirling engine; eliminates need to snorkel — INS Kalvari (Scorpène) uses MESMA or battery
- AUV / ROV: Autonomous/remotely operated underwater vehicles — ISRO's Samudrayaan, oil platform inspection, deep-sea cable laying

Ocean Depth & Pressure

0 m | 1 atm | Sea surface

200 m | 21 atm | Continental shelf

300 m | 31 atm | Sub combat depth

800 m | 81 atm | DSV crush depth

4000 m | 401 atm | A... ..

Offshore & Ocean Engineering

Extracting energy and resources from the ocean — some of the harshest engineering environments on Earth



Offshore Platforms

Fixed jacket platforms (< 500 m), semi-submersibles, FPSO vessels — ONGC Bassein Field, Mumbai High



Mooring & Risers

Dynamic mooring systems anchor floating platforms; flexible risers carry oil from seabed to surface



Offshore Wind

Monopile, tripod, and floating foundations; India's 37 GW offshore wind potential in Gujarat and Tamil Nadu



Pipeline Engineering

Subsea pipelines laid by J-lay and S-lay vessels; internal corrosion, pig inspection, repair clamps



Wave & Tidal Energy

Wave energy converters (OWC, attenuators); tidal barrages and tidal stream turbines; NIOT test sites



Ocean Thermal Energy

OTEC uses temperature gradient between surface (27°C) and deep (5°C) ocean; NIOT's 1 MW OTEC plant trial

Advanced Materials – The Backbone of Extreme Engineering



Both sectors push materials science to absolute limits — temperature, pressure, fatigue, and corrosion

CFRP (Carbon Fibre)

✈️ 787 fuselage, Tejas wing, A350 primary structure — 5× stronger than steel at 20% weight

⚓ Ship superstructures, masts, fast patrol boats, submarine fairings, racing yacht hulls

Nickel Superalloys

✈️ Turbine blades & discs at 1600°C — Inconel 718, René 88DT; single crystal casting

⚓ Marine gas turbine hot sections, nuclear reactor core components, submarine shafting

Titanium Alloys

✈️ Airframe bulkheads, landing gear, engine nacelles — Ti-6Al-4V; 56% of F-22 structure

⚓ Submarine pressure hull fittings, seawater piping, propeller shafts, ROV frames

Aluminium Alloys

✈️ Legacy fuselage, wing ribs, spars — 2024-T3, 7075-T6; replaced by CFRP in new aircraft

⚓ Superstructures, deck plating on naval vessels; reduces topside weight, lowers CG

- Ceramic Matrix Composites (CMC): GE LEAP turbine shrouds run 300°C hotter than metal — 1/3 the weight; DRDO developing for AMCA engine

Digital Engineering – Simulation Before Steel



Modern aerospace and marine design is 80% digital simulation and 20% physical testing



CFD (Fluent/OpenFOAM)

Solves Navier-Stokes equations on millions-cell mesh; aircraft drag, ship resistance, propeller flow, gas turbine combustion



FEA (ANSYS/NASTRAN)

Structural stress, vibration, fatigue, and thermal analysis; full airframe or ship hull modelled with millions of DOF



MBD (Adams/LMS)

Multi-body dynamics simulates landing gear drop, rotor blade dynamics, propeller shaft vibration — before prototyping



Digital Twin

Real-time virtual replica of aircraft/ship in operation — GE Aviation's Digital Twin monitors 40,000+ engines in service



Mission Simulation

6-DOF flight mechanics, orbit mechanics, re-entry simulation — ISRO simulates full Chandrayaan trajectories digitally



Topology Optimisation

Altair HyperWorks, SIMULIA Tosca — remove material where stress is low; creates organic lattice structures impossible to design manually

TEST — India's Landmark Aerospace & Marine Achievements



Engineering milestones that define India's strategic and technological capability



ISRO Chandrayaan-3 — Moon South Pole Landing (2023)

First nation to successfully soft-land on Moon's south pole; LVM3 launch vehicle; 3.84 lakh km journey • ME systems: Vikram lander propulsion (throttle-able 800N engines), heat shield, landing legs designed for uneven terrain • Pragyan rover 6-wheel rocker-bogie: ME design for mobility on unknown regolith surface



HAL Tejas MK-1A — India's Indigenous Fighter Aircraft

AESA radar, glass cockpit, FBW — 83 aircraft order worth ₹48,000 crore; Indian Air Force's backbone programme • ME content: CFRP airframe (45% by weight), EJ200 engine (Mk2), landing gear, hydraulic systems, thermal management • NAL-designed composite wing with bonded ribs — no fasteners through primary structure



INS Vikrant — India's First Indigenous Aircraft Carrier

45,000 tonne displacement; 262 m length; 76% indigenous content; built at Cochin Shipyard over 13 years • ME systems: 88 MW combined diesel and gas turbine (CODAG) propulsion; 4 shafts; 28-knot top speed • Structural challenge: 2,100 compartments; DMR-249A indigenous shipbuilding steel developed by SAIL for this vessel

Global Benchmarks – World-Class Aerospace & Marine ME

Engineering achievements that define what is possible



Airbus A350 XWB

53% CFRP by weight; Trent XWB engines; 25% better fuel burn than A340; 5,000+ parts fewer than A380 — design efficiency benchmark



SpaceX Falcon 9 (Reusable)

First orbital-class rocket booster to land vertically and re-fly 19 times; Merlin 1D engines at 845 kN; ME innovation that halved launch costs



Maersk Triple-E class ships

400 m length; 18,000 TEU capacity; waste heat recovery system; 35% lower CO₂ per container than previous class — scale + efficiency



DSV Limiting Factor (Triton)

Reached deepest point on Earth — Challenger Deep (10,924 m); titanium pressure sphere; 1,100 bar external pressure —



extreme ME

Each of these engineering feats was designed, built, and operated by mechanical engineers using the exact principles you will study

Sustainability — Decarbonising the Skies & Seas

Aviation accounts for 2.5% and shipping 2.9% of global CO₂ — both sectors face net-zero mandates



Sustainable Aviation Fuel (SAF)

Bio-based or e-fuels drop into existing jet engines; -80% lifecycle CO₂; IATA target: 65% of aviation fuel by 2050



Hydrogen Aviation

Airbus ZEROe — H₂ combustion or fuel cell; zero CO₂; ME challenge: cryogenic tanks, -253°C, 4x volume of Jet-A



Electric Aircraft

All-electric (< 1 tonne payload, < 500 km); Joby Aviation, Lilium eVTOL; distributed electric propulsion



Green Shipping Fuels

Ammonia, methanol, LNG, hydrogen — Maersk has 12 methanol-ready ships; MOL testing ammonia propulsion



Hull Optimisation

Air lubrication systems (Silverstream): Air bubbles under hull reduce friction 5–8%; FLNG Prelude uses this



IMO 2050 Strategy

Net-zero GHG from shipping by 2050; EEDI/CII regulations; ME engineers redesigning entire propulsion systems

Career Pathways – ME in Aerospace & Marine



The most technically prestigious — and globally mobile — careers in engineering

Aerospace Structural Engineer

 HAL / DRDO / Airbus / Boeing GE

 ₹8-24 LPA

Propulsion / Engine Engineer

 GTRE / Safran / Rolls-Royce / GE

 ₹10-30 LPA

Naval Architect / Marine Eng.

 MDL / CSL / L&T Shipbuilding

 ₹7-20 LPA

Spacecraft / Systems Engineer

 ISRO / DRDO / Skyroot / Agnikul

 ₹8-22 LPA

Offshore / Subsea Engineer

 ONGC / Shell / TechnipFMC / Baker

 ₹12-40 LPA

MRO / Technical Services

 Air India / IndiGo / ST Engineering

 ₹7-18 LPA

 GATE score → HAL / ISRO / DRDO PSU | DGCA AME licence → Aircraft Maintenance Engineering | Class IV CoC → Merchant Navy

Introduction to Mechanical Engineering / Role in Aerospace & Marine

MIND MAP – ME in Aerospace & Marine Engineering

