

MECHZONE

VOL 3 • ISSUE 1 • MAY 2023

MAY
2023

INSIDE THIS ISSUE

Turbomachinery: Fluid Mechanics of Pumps, Fans & Compressors
Vibration Analysis: Fundamentals and Industrial Significance
Precision Machining: Modern Cutting Tool Technologies
Design of a Solar-Electric Hybrid Vehicle — Our S4 Project
Stress Analysis of a Pressure Vessel: From Theory to FEA My
Training at HAL Bangalore — An S7 Internship Account

May 2023 · Vol 3 · Issue 1

FACULTY ARTICLES

Turbomachinery Fundamentals: The Fluid Mechanics of Pumps, Fans and Compressors	<i>Dr. Vidya Chandran · Associate Professor</i>	03
Vibration Analysis: Why Machines Talk and How Engineers Listen	<i>Mr. Sanju A C · Assistant Professor</i>	07
Precision Machining: Modern Cutting Tool Technologies and Their Impact	<i>Dr. Anjana Vishwanath · Assistant Professor</i>	11

STUDENT ARTICLES

Designing a Solar-Electric Hybrid Vehicle — Our Mini-Project Journey	<i>Sanjay Krishna E. (S8 ME)</i>	15
Stress Analysis of a Pressure Vessel: From Hand Calculation to FEA	<i>Govind T V (S6 ME)</i>	19
Inside HAL Bangalore: What My S7 Internship Taught Me	<i>Harikrishnan T P (S8 ME)</i>	23

EDITORIAL BOARD — MECHZONE MAY 2023

Role	Name	Position
Editor-in-Chief	Dr. Rag R L	Head
Faculty Editor	Dr. Gibin George	Associate Professor
Student Editor	Sanjay Krishna E	S8 ME
Student Editor	Vinay P Mony	S8 ME
Student Editor	Govind T V	S6 ME
Student Editor	Alen Bijan	S6 ME
Student Editor	Vishnu Valsan	S6 ME
Student Editor	Thushar Shaiju	S6 ME

From the Editor's Desk

MechZone—the annual technical magazine of the Department of Mechanical Engineering at SCMS School of Engineering and Technology—returns with Volume 3, continuing our tradition of documenting the department's academic, research, and innovation journey. As we release this volume, we also mark another year of learning, discovery, and collaboration. The close of the academic year offers an opportunity to reflect on accomplishments, celebrate new ideas, and recognize the dedication of our faculty, students, alumni, and industry collaborators. MechZone serves as a record of this collective effort while inspiring the next generation of engineers to pursue innovation with purpose.

This issue features insightful faculty contributions spanning diverse areas of mechanical engineering. Readers will explore advances in turbomachinery and fluid mechanics, developments in vibration analysis and condition monitoring, and emerging trends in advanced manufacturing and precision machining. Our student contributors continue to demonstrate exceptional creativity and technical competence. Their projects, design innovations, internship experiences, and research initiatives reflect the hands-on learning environment that defines our department.

Dr. Rag R L

Editor-in-Chief, MechZone 2023

Professor & Head, Dept. of Mechanical Engineering, SSET

Vision and Mission of the Institute

Vision

To be a centre of excellence in providing technical education in harmony with the changing global order.

Mission

To offer technology related education of exceptional quality to students by developing their total personality with due emphasis on ethical values and preparing them to meet the growing challenges of the industry and human society.

Vision and Mission of the Department

Vision

To be a centre of excellence in Mechanical Engineering recognized for its quality education, innovative research and social outreach programs.

Mission

1. Provide excellent student-centric education generating high calibre graduates to face global challenges.
2. Maintain state-of-art facilities for faculty and students to learn, research and disseminate knowledge.
3. Emphasize on collaborative technology-transfer encouraging innovations for the benefit of society.

FACULTY ARTICLE

Turbomachinery Fundamentals: The Fluid Mechanics of Pumps, Fans and Compressors

From water supply pumps to jet engines — the unifying fluid mechanics that governs every turbomachine, and why every mechanical engineer must understand it.

Dr. Vidya Chandran · Associate Professor, Department of Mechanical Engineering

Turbomachines are everywhere. The centrifugal pump lifting drinking water to Kochi's overhead tanks, the axial fan circulating air in SCMS SET's laboratories, the turbocharger compressing air into a diesel truck's engine, the gas turbine powering NTPC's Kayamkulam plant, the jet engine propelling an Air India aircraft from Kochi to Mumbai — all are turbomachines, and all obey the same fundamental fluid-mechanical principle: Euler's turbomachinery equation. Understanding this equation is not merely academic; it is the key to reading a pump curve, diagnosing a compressor surge, and designing a fan blade.

A turbomachine transfers energy between a fluid and a rotating element — the impeller or rotor. In pumps, fans, and compressors, energy flows from rotor to fluid (work input machines); in turbines, energy flows from fluid to rotor (work output machines). The specific work $W = u_{c_{u2}} - u_{c_{u1}}$ where u is blade speed and c_u is the tangential component of absolute velocity — a relationship that elegantly captures the geometry of the velocity triangle as the foundation of all turbomachinery design.

The Four Fundamental Turbomachine Families

1

Centrifugal Pumps and Fans

The dominant workhorse of fluid handling. Fluid enters axially, is accelerated radially by the rotating impeller, and exits at high velocity through the volute or diffuser. Specific speed $N_s = N\sqrt{Q}/H^{3/4}$ determines the impeller geometry: low $N_s \rightarrow$ radial (high head), high $N_s \rightarrow$ axial (high flow). India's pump industry, worth Rs. 18,000 crore in 2023, is built almost entirely on centrifugal machines.

2

Axial Flow Machines

Propellers, axial fans, and axial compressors operate by accelerating fluid parallel to the rotation axis through aerofoil-section blades. Multi-stage axial compressors in jet engines can achieve pressure ratios above 40:1 across 18-22 stages — each stage adding 1.3-1.5:1. Blade stall and rotating stall are the critical instability modes that turbine engineers devote careers to avoiding.

3

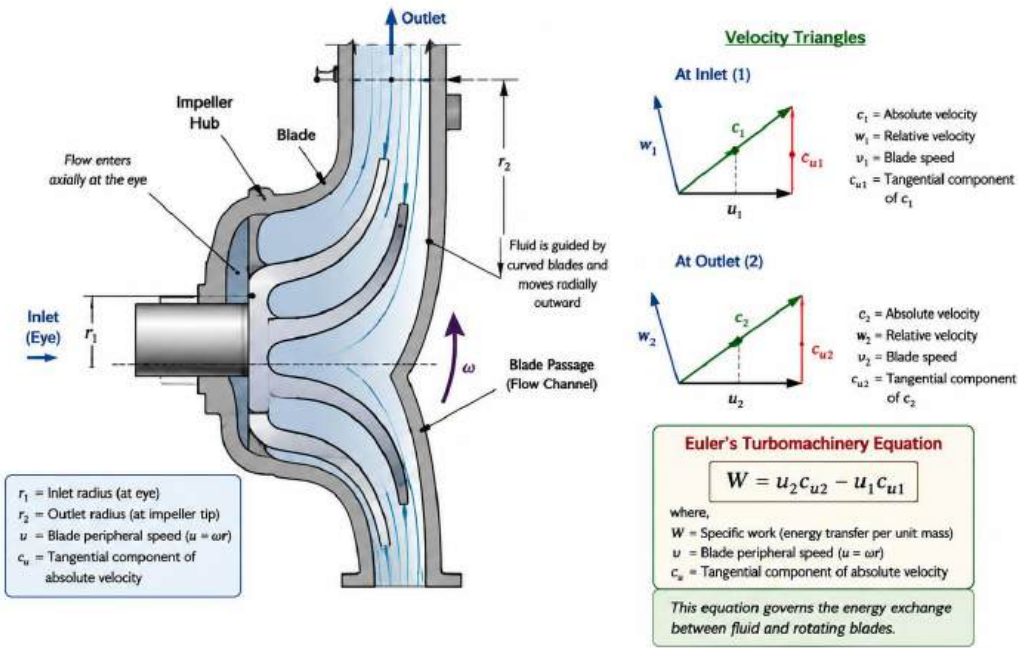
Mixed-Flow Machines

A compromise between centrifugal and axial geometries, mixed-flow machines are used where intermediate specific speeds are required. Common in large cooling water pumps for thermal power stations and in low-head, high-flow irrigation applications where axial would cavitate and centrifugal would be inefficient.

4

Positive Displacement vs. Turbomachinery

Unlike turbomachines, positive displacement devices (reciprocating pumps, gear pumps) deliver a fixed volume per cycle, independent of pressure. They excel where high-pressure precision is needed — hydraulic presses, fuel injection systems — but cannot match turbomachines for high-flow, continuous-duty applications.



The Pump Characteristic Curve and System Matching

A centrifugal pump's performance is characterised by its H-Q curve: the relationship between head H and flow rate Q at constant speed. This curve falls with increasing flow due to internal losses. The system curve — $H_{\text{system}} = H_{\text{static}} + kQ^2$ — rises with flow due to pipe friction losses. The operating point is the intersection of these two curves, and selecting a pump whose best efficiency point (BEP) lies close to this intersection is the central task of pump selection.

Pump Type	Specific Speed (N_s)	Typical Head (m)	Typical Flow (m^3/hr)	Typical Efficiency
Radial / centrifugal	10–70	10–1000	5–500	70–90%
Mixed flow	70–170	5–30	100–5000	80–88%
Axial	170–400	0.5–5	1000–100,000	82–90%
Regenerative (peripheral)	8–30	50–3000	0.5–50	25–55%
Multi-stage centrifugal	10–60	100–5000	10–500	72–88%

Table 1 — Turbomachine classification by specific speed and performance range.

Cavitation: The Silent Killer of Pumps

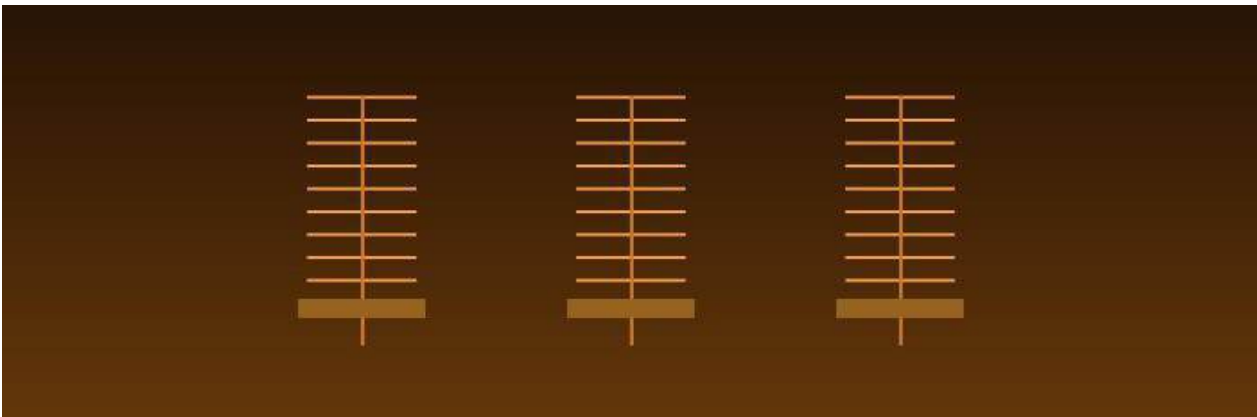
When the local static pressure in a pump falls below the vapour pressure of the liquid, vapour bubbles nucleate. As these bubbles travel into higher-pressure regions, they collapse violently — releasing pressure pulses that can erode impeller material at rates exceeding 1 mm/year in severe cases. The Net Positive Suction Head available (NPSH_A) must exceed the NPSH required (NPSH_R) by a margin of at least 0.5–1.0m. In India's agricultural pump sector, cavitation due to improperly designed suction systems is estimated to cause Rs. 500 crore in premature pump replacements annually.

"Every pump curve tells a story. The engineer who can read it — BEP, NPSH, shut-off head, power consumption at part load — has a fundamental advantage in every fluid system they will ever design."

Vibration Analysis: Why Machines Talk and How Engineers Listen

Every rotating machine generates a unique vibration signature. Learning to read that signature is the difference between preventive maintenance and catastrophic failure — and it is one of the most underrated skills in mechanical engineering.

Mr. Sanju A C · Assistant Professor, Department of Mechanical Engineering



Spring-mass-damper systems representing single-degree-of-freedom oscillators: the mathematical foundation of all vibration analysis, from simple beams to complex rotor-bearing systems.

Vibrations are information. Every time a rotating machine deviates from smooth, periodic motion, it encodes that deviation in its vibration signal — a message written in frequency and amplitude that trained instruments can read and trained engineers can interpret. The discipline of vibration analysis sits at the intersection of classical mechanics, signal processing, and mechanical intuition, and it is the engine of the billion-dollar condition monitoring industry.

Fault Frequencies in Rotating Machinery

Fault	Dominant Freq.	Signature
Mass imbalance	1× running speed	Large 1× peak
Shaft misalignment	2× running speed	Elevated 2× & 3×
Bearing inner race	BPFI formula	Sideband modulation
Bearing outer race	BPFO formula	Regular impacting
Gear mesh fault	Z × RPM/60	Gear mesh sidebands
Resonance	Natural freq. f_n	Amplitude peak at f_n

The fundamental model is the single degree of freedom (SDOF) system: a mass m , spring k , and damper c . Its equation of motion

$$m\ddot{x} + c\dot{x} + kx = F(t),$$

yields the natural frequency $\omega_n = \sqrt{k/m}$, the damping ratio $\zeta = c/(2\sqrt{km})$, and the complete dynamic response to any forcing function $F(t)$. This model, extended to multi-DOF systems and continuous structures, underlies every vibration calculation in structural and mechanical engineering.

ISO 10816-3: Vibration Severity

Zone	RMS Velocity (mm/s)	Assessment
A (new machine)	2.3	Acceptable
B (acceptable)	2.3 – 4.5	Long-term operation OK
C (alert)	4.5 – 11.2	Restricted operation
D (danger)	≥ 11.2	Shut down immediately

Free, Forced, and Resonance

Free vibration occurs at natural frequencies when a system is disturbed without sustained external forcing — a plucked string, a struck bell, a shaft struck by a sudden torque spike. Forced vibration occurs under sustained periodic excitation; when the excitation frequency approaches a natural frequency, amplitude grows dramatically — resonance. For lightly damped systems ($\zeta < 0.1$), resonant amplification factors of 5-50× are common. Resonance is not always catastrophic — musical instruments depend on it — but in machinery it is almost always destructive.

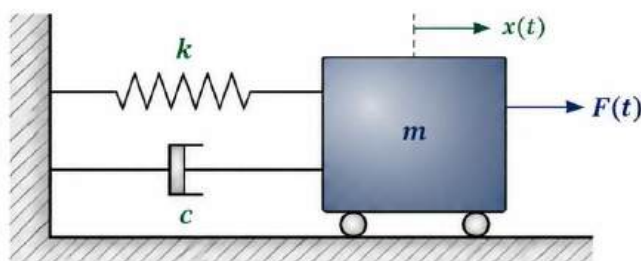
Fast Fourier Transform: The Engineer's Microscope

The FFT algorithm — Cooley and Tukey's 1965 masterpiece of computational efficiency — transforms a time-domain vibration signal into its frequency spectrum in $O(N \log N)$ operations rather than the $O(N^2)$ of the direct DFT. This computational breakthrough made real-time vibration monitoring economically viable and is the foundation of every modern vibration analyser. The resulting spectrum — amplitude versus frequency — is the primary diagnostic tool: each peak corresponds to a physical excitation source whose frequency can be predicted from the machine's geometry and speed.

At SCMS SET, our vibration lab houses a portable FFT analyser (Fluke 810) and an 8-channel data acquisition system (NI CompactDAQ) for student experiments. In the S5 vibration elective, students characterise the natural frequencies of a multi-rotor shaft system using experimental modal analysis — excitation by impact hammer, response measurement by accelerometers, and curve-fitting using the Circle-Fit method to extract modal parameters.

Vibration in Kerala's Industries

Kerala's industrial base — paper mills (Perumbavoor), rubber processing (Kottayam), cashew processing, and electronics manufacturing (Kochi's infopark industrial units) — all operate rotating machinery that benefits from condition monitoring. The MSME sector's reluctance to invest in vibration monitoring (typical instrument cost: Rs. 1.5-8 lakhs) leaves significant preventive value untapped. Low-cost MEMS accelerometer-based monitoring (cost: Rs. 2,000-15,000 per point) is rapidly making the economics accessible even for small units.



Natural Frequency (Undamped System)

$$\omega_n = \sqrt{\frac{k}{m}} \text{ rad/s}$$

$$f_n = \frac{1}{2\pi} \sqrt{\frac{k}{m}} \text{ Hz}$$

Damping Ratio

$$\zeta = \frac{c}{2m\omega_n}$$

- $\zeta < 1$ Underdamped
- $\zeta = 1$ Critically damped
- $\zeta > 1$ Overdamped

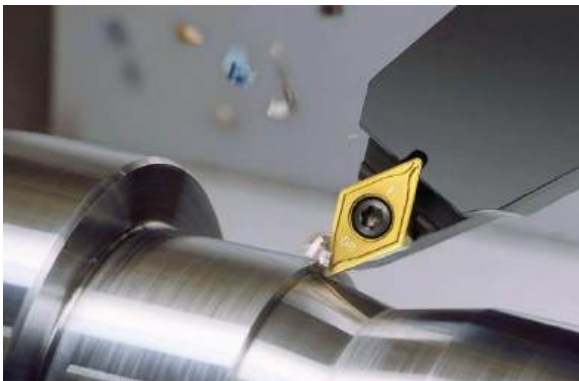
Equation of Motion

$$m\ddot{x} + c\dot{x} + kx = F(t)$$

- m = Mass (kg)
- c = Damping coefficient (N·s/m)
- k = Spring stiffness (N/m)
- x = Displacement (m)
- $F(t)$ = External force (N)

Role in Vibration Analysis

- Models the dynamic behavior of a wide range of mechanical systems.
- Basis for understanding resonance, transient response, and stability.
- Extended to multi-degree-of-freedom systems for complex structures and machines.



CNC turning operation: carbide insert tool engaging a steel workpiece. The chip geometry, cutting forces, and tool wear rate are governed by cutting speed, feed, depth of cut, and tool material properties.

FACULTY ARTICLE

Precision Machining: Modern Cutting Tool Technologies and Their Impact on Indian Manufacturing

From carbide inserts to CBN, from dry cutting to minimum quantity lubrication — the cutting tool revolution that is reshaping productivity across India’s engineering manufacturing sector.

Dr. Anjana Vishwanath · Assistant Professor, Department of Mechanical Engineering

Cutting tools are the most consumable, most critical, and most under-appreciated element of any machining operation. A Rs. 200 carbide insert removed after 15 minutes of cutting is not a cost — it is an investment that just produced Rs. 8,000 worth of machined product. Understanding tool geometry, material, coating, and wear mechanism is the foundation of productive, economic machining, and it is a foundation that many engineering curricula barely touch.

The Three Tiers of Cutting Tool Materials

Tool Material	Properties	Speed & Use
HSS (M2, M42)	60-65 HRC with TiN. Tough, regrindable. Good for complex profiles and interrupted cuts.	30-60 m/min Drills, taps, form tools
Cemented Carbide (WC-Co, ISO P/M/K)	1400-1800 HV hardness. TiAlN/TiSiN coatings extend life 3-8x. Most widely used tool material.	100-500 m/min Turning, milling, boring
CBN and PCD (Superhard tools)	CBN: hardened steel above 45 HRC. PCD: aluminium and CFRP. Near-zero wear. Cost 10-50x carbide.	200-1000 m/min Hard turning, composites

Tool Material	Properties	Speed & Use
HSS (M2, M42)	60-65 HRC with TiN. Tough, regrindable. Good for complex profiles and interrupted cuts.	30-60 m/min Drills, taps, form tools
Cemented Carbide (WC-Co, ISO P/M/K)	1400-1800 HV hardness. TiAlN/TiSiN coatings extend life 3-8x. Most widely used tool material.	100-500 m/min Turning, milling, boring
CBN and PCD (Superhard tools)	CBN: hardened steel above 45 HRC. PCD: aluminium and CFRP. Near-zero wear. Cost 10-50x carbide.	200-1000 m/min Hard turning, composites

Taylor's Tool Life Equation and Its Modern Extensions

F.W. Taylor's 1907 tool life equation $VT^n = C$ remains the cornerstone of machining economics. Here V is cutting speed, T is tool life in minutes, n is the Taylor exponent (typically 0.1-0.4 for carbide), and C is the cutting speed for 1-minute tool life. The equation encapsulates a crucial trade-off: higher cutting speed means shorter tool life, but also faster material removal — the optimum speed for minimum cost per part is not the lowest speed but a balance point that engineers calculate using Gilbert's economic tool life criterion.

Work Material	Tool Material	V (m/min)	f (mm/rev)	Taylor n	Tool Life T (min)
C45 steel (230 HB)	Uncoated WC-Co	120	0.25	0.25	15-25
C45 steel (230 HB)	TiAlN coated	240	0.30	0.28	18-30
Stainless 316L	TiSiN coated	150	0.20	0.22	12-20
Aluminium 6061	Uncoated WC-Co	500	0.40	0.45	60-120
Titanium Ti-6Al-4V	WC-Co (fine grain)	60	0.15	0.20	8-15
Hardened steel 60HRC	CBN (low content)	150	0.10	0.50	20-40

Indicative Taylor tool life parameters for common work-tool combinations.

Minimum Quantity Lubrication: The Sustainable Cutting Trend

Conventional flood cooling uses 20-200 litres/hour of cutting fluid. MQL (Minimum Quantity Lubrication) delivers 20-200 mL/hour of vegetable oil mist directly to the cutting zone — a 99% reduction in coolant consumption. Studies from our manufacturing lab confirm that MQL achieves equivalent or superior surface finish (R_a 0.8-1.2 μ m) compared to flood cooling for steel turning, with 15-20% improvement in tool life due to reduced thermal shock. With cutting fluid disposal costs in India's precision machining sector estimated at Rs. 45-80/litre, the economic case for MQL adoption is compelling.



Model of the solar-electric hybrid vehicle (SolarMech Mk.1, SCMS SET). 450W solar array roof, 48V/20Ah LFP battery, 500W BLDC rear hub motor, tubular steel chassis.

STUDENT ARTICLE

Designing a Solar-Electric Hybrid Vehicle from Scratch

How S6 students designed a solar-assisted electric vehicle, got their chassis calculations wrong twice, learned what 'safety factor' actually means under load, and ended up with something that moves.

Sanjay Krishna E · S8 Mechanical Engineering

We proposed the solar-electric vehicle as our S6 mini-project in June 2022, and our guide's first response was: 'What is your total vehicle mass budget?' We had not calculated it. That conversation set the tone for the next four months — every assumption we made had to be quantified, every estimate had to become a calculation, and every calculation had to be verified.

SOLARMECH MK.1 — DESIGN SPECIFICATION	
Vehicle type	Solar-electric hybrid, 2-seat
Overall dimensions	2,800 × 1,200 × 1,400 mm (L×W×H)
Chassis	AISI 1020 ERW steel tube, 38×2mm, TIG welded
Total vehicle mass (loaded)	280 kg (driver + passenger + systems)
Solar array	3× 150W monocrystalline panels (450W total), roof-mounted
Battery	48V / 20Ah LFP (LiFePO4), BMS protected, 960 Wh
Drive motor	500W BLDC rear hub motor, 48V nominal
Transmission	Direct drive (hub motor, no gearbox)
Max speed	45 km/h (governor limited, road legal)
Range (battery only)	38 km at 30 km/h constant

Range (solar + battery)	55 km (8-hour day, Kerala irradiation)
Brakes	Mechanical disc, front and rear, 160mm rotor
Suspension	Fixed axle front; trailing arm rear with coil spring
Fabrication cost	Rs. 38,500 (materials + bought-out components)

The Chassis Calculation That Failed Twice

Our first chassis design used 25×1.5mm ERW tubes in a ladder frame, sized for the static load of 280 kg on the critical cross-member. What we forgot: a vehicle experiences dynamic loads. Hitting a 50mm bump at 30 km/h imposes approximately 3G vertical acceleration — an effective load of 840 kg on a frame designed for 280 kg. Dr. Sanjay pointed this out during the first design review, and we redesigned to 38×2mm tubes with a triangulated subframe — the design in our specification above.

Our second mistake was ignoring torsional stiffness. A vehicle chassis must resist the twisting moment applied when one wheel hits a bump that the other does not. Our ladder frame had essentially zero torsional stiffness, producing a body twist of 42mm at the windshield pillar under a 200N·m torque — sufficient to pop a windscreen. Adding a diagonal X-brace reduced this to 7mm, within acceptable limits.

"Every wrong calculation taught us something that the correct one never would. After redesigning the chassis twice, we understood structural mechanics in a way no textbook had managed."

Energy Budget: The Calculation That Drove Every Decision

Driving resistance power $P = (C_r \cdot m \cdot g \cdot v + 0.5 \cdot \rho \cdot C_D \cdot A \cdot v^3)$ determines how much power the vehicle needs at any speed. At 30 km/h: rolling resistance power = $0.015 \times 280 \times 9.81 \times 8.33 = 344 \text{ W}$; aerodynamic drag power = $0.5 \times 1.2 \times 0.45 \times 1.44 \times 8.33^3 = 158 \text{ W}$; total = 502 W. Our 500W motor is just sufficient at 30 km/h. The 450W solar array under Kerala conditions (4.5 peak sun hours) generates 2,025 Wh/day — enough to sustain 30 km/h operation for approximately 4 hours, with the remainder stored in the battery.

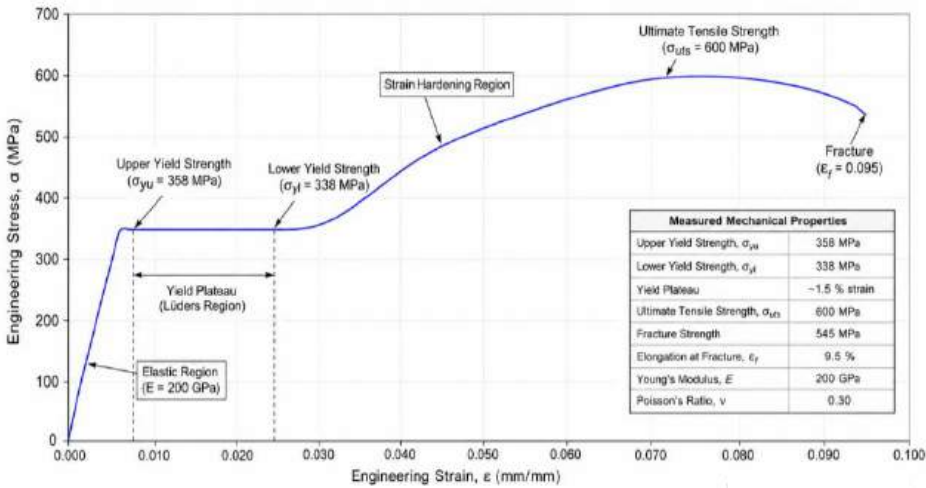


STUDENT ARTICLE

Stress Analysis of a Pressure Vessel: From Hand Calculation to Finite Element Analysis

An S6 project that set out to verify thin-shell theory using FEA and discovered that the agreement was excellent — until the nozzle junction, where theory and simulation diverged dramatically and instructively.

Govind T V · S6 Mechanical Engineering



Experimentally characterised stress-strain curve for ASTM A516 Gr.70 pressure vessel steel. Note the well-defined yield plateau: a critical feature for elastic design of vessels under Internal pressure.

Pressure vessels are among the most safety-critical components in engineering: failures can be catastrophic, and design codes — ASME Section VIII Div.1 and Div.2, IS:2825 — are meticulous. My S6 project analysed a horizontal cylindrical vessel (2 m length, 600 mm diameter, 8 bar design pressure) using three approaches: thin-shell theory, ASME code equations, and ANSYS finite element analysis.

Thin-Shell Theory: The Baseline

For a thin-walled cylinder under internal pressure p , the hoop stress $\sigma_\theta = pD/(2t)$ and longitudinal stress $\sigma_L = pD/(4t)$. For our vessel at design pressure 8 bar: $\sigma_\theta = 0.8 \times 600 / (2 \times 8) = 30 \text{ MPa}$; $\sigma_L = 15 \text{ MPa}$.

The von Mises equivalent stress

$$\sigma_{eq} = \sqrt{(\sigma_\theta^2 - \sigma_\theta \cdot \sigma_L + \sigma_L^2)} = 25.98 \text{ MPa}.$$

With A516 Gr.70 yield strength of 260 MPa and ASME allowable of 138 MPa (at room temperature), the safety factor is 5.3, deliberately high for a new vessel under static loading.

Analysis Summary

Location	Thin-Shell	ANSYS FEA	
Cylinder shell	30.0 MPa	31.2 MPa	+4.0%
Flat end cap (centre)	—	28.4 MPa	n/a
Nozzle (far from jn.)	30.0 MPa	31.8 MPa	+6.0%
Nozzle junction (SCF)	30.0 MPa	89.4 MPa	+198%
Support saddle	—	18.6 MPa	n/a

The Nozzle Junction Revelation

At the shell-nozzle junction, the FEA predicts 89.4 MPa — nearly 3× the nominal hoop stress. This stress concentration (SCF ≈ 3.0) is invisible to thin-shell theory, which assumes uniform membrane stress. The ASME code handles it through area replacement rules and reinforcement pad requirements — but only FEA reveals the actual stress distribution in the transition zone.

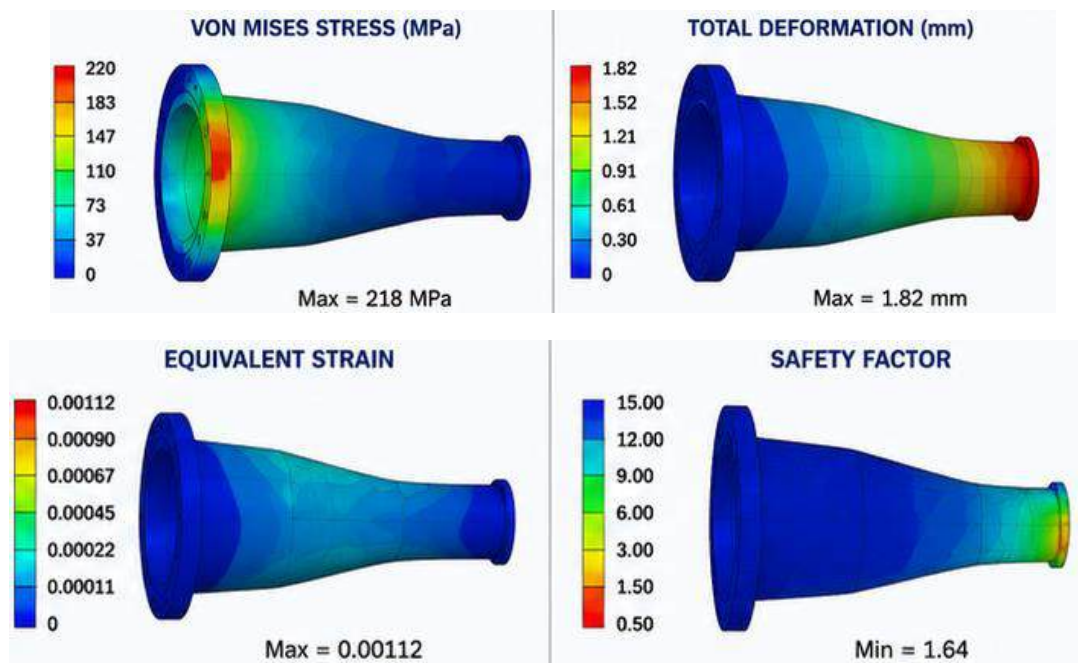
ASME Div.1 adds corrosion allowance (1.5 mm), weld joint efficiency ($E = 1.0$ for full RT), and thinning tolerance, resulting in a minimum required wall thickness of 9.3 mm — we specified 10 mm.

What the FEA Taught That Theory Could Not

The 198% stress concentration at the nozzle junction was the most important finding of my project — and it is entirely absent from thin-shell theory. ASME addresses it through the Area Replacement Method: the material removed by the nozzle opening must be compensated by adding reinforcement in a prescribed zone around the opening. My FEA of the reinforced nozzle reduced the peak stress from 89.4 MPa to 52.1 MPa — still above the nominal 30 MPa, but within the ASME limit of $1.5\times$ allowable for local membrane plus bending stress.

The lesson I take from this project: hand calculations are essential for preliminary sizing, code checks, and sanity verification. FEA is essential for understanding what actually happens at geometric discontinuities. Using one without the other is incomplete engineering — and in a safety-critical vessel, incomplete engineering can be lethal.

"Thin-shell theory tells you what happens in the middle of the vessel. FEA tells you what happens at the nozzle — and that is almost always where vessels actually fail."



STUDENT ARTICLE

Inside HAL Bangalore: What My S7 Internship Taught Me About Aerospace Manufacturing

Six weeks at Hindustan Aeronautics Limited — producing aircraft that national security depends on, to tolerances that leave no margin for the word 'close enough'.

Harikrishnan T P · S8 Mechanical Engineering



Bangalore's aerospace corridor houses HAL's Aircraft, Engine, Helicopter, and MRO divisions, making it India's most concentrated aerospace manufacturing hub.

HAL does not look the way you expect. There are no dramatic runway views from the manufacturing floor, no aircraft silhouettes framed in hangar doors like a film poster. What you find instead when you pass through the security gate is something more interesting: building after building of systematic, methodical, highly controlled precision manufacturing — people and processes working together to produce aircraft components to tolerances measured in hundredths of a millimetre, in materials that forgive nothing.

I was placed in the Aircraft Division's Sheet Metal Department under Mr. Rajagopalan, a senior production engineer with 22 years in aerospace forming. My project was to document and analyse the forming process for titanium fuselage panels on the LCA Tejas — specifically, to understand why springback in Ti-6Al-4V press-braked panels had been causing fitment issues during final assembly.

The Titanium Springback Problem

Springback is the elastic recovery of a metal after forming: the pressed shape partially returns toward its original flat geometry upon tool release. For mild steel, springback is 2-4°; for aluminium, 5-8°; for Ti-6Al-4V, it can be 10-20° for simple bends, and the high variability between batches makes it particularly challenging to control. The HAL team was over-bending by an empirically determined amount — but batch-to-batch variations in tensile properties caused fitment tolerances to be exceeded 12% of the time.

My contribution was modest but concrete: I set up a correlation analysis between the incoming material's yield strength (from mill certificates) and the observed springback angle for 24 panel batches over three months. The Pearson correlation coefficient was 0.78 — strong enough to justify a yield-strength-adjusted overbend factor. Implementing this reduced out-of-tolerance panels from 12% to 4.5%.

A Tolerance That Put Everything in Perspective

On my third week, I watched an inspector measure a fuselage frame with a coordinate measuring machine to a tolerance of ± 0.05 mm over a 1.2 metre span. When I asked why the tolerance was so tight, he said: 'The skin panels that fasten to this frame come from a different building. If we are off by 0.15mm, they don't fit. If they don't fit, we either scrap a Rs. 28-lakh panel or we accept a fastener hole that is loaded eccentrically. Over 8,000 flight hours, an eccentrically loaded fastener is a fatigue crack waiting to happen.' I have never looked at a tolerance callout the same way since.

What Six Weeks at HAL Permanently Changed

1 Tolerances are not constraints — they are decisions

Every tolerance on every drawing represents a conscious decision about how much variation can be absorbed by the system. At HAL, I learned to ask 'why is this tolerance this tight?' before I asked 'how do I achieve this tolerance?' The first question leads to better designs; the second leads only to more expensive manufacturing.

2 First Article Inspection changes how you think about design

FAI (First Article Inspection) requires 100% dimensional verification of every feature on the first part produced to a new drawing. Going through an FAI at HAL — 340 individual measurements on a single formed panel — made me realise that every feature I put on a drawing will eventually be measured by someone. Designing with that consciousness produces cleaner, more inspectable parts.

3 The relationship between material properties and process outcomes

In university, material properties are data to look up and use in equations. In aerospace manufacturing, they are variables that change batch to batch, temperature to temperature, and direction to direction in anisotropic materials. Learning to treat materials as statistical distributions rather than fixed constants is one of the most important shifts in thinking for an engineer moving from academia to industry.

4 Patience is a technical skill

Aerospace manufacturing is slow by design. An LCA Tejas airframe has a production lead time measured in months. The first time you watch a machinist take three passes where one would work just to ensure dimensional stability before the finishing cut, you understand that impatience is a quality risk — and quality risk is a safety risk.

"Every tolerance on a drawing represents a decision about how much variation the system can absorb. At HAL, I learned to design tolerances, not just comply with them."



MECHZONE

mechzonesset@gmail.com · <https://scmsgroup.org/sset>
A Publication of the Dept. of Mechanical Engineering

— Accredited by —



NBA
NATIONAL BOARD
of ACCREDITATION



SCMS SCHOOL OF
ENGINEERING & TECHNOLOGY
Vidya Nagar, Palissery, Karukutty, Ernakulam - 683576, Kerala, India.
www.scmsgroup.org/sset