FMC Project ideas

1 The Coandă Effect and Jet Attachment

Concept: A fast jet follows a curved surface due to entrainment and pressure gradients—illustrating boundary-layer and momentum conservation effects.

Core Theory: From momentum flux balance,

$$\rho U_j^2 A_j \approx \rho U_s^2 A_s + \int (p - p_\infty)\, dA,$$

where jet curvature is maintained by a pressure drop on the wall side.

Demo Setup:

- Hair dryer or compressed-air can
- Curved surface (spoon, bottle)
- Threads or smoke for flow visualization

Observe: Jet deflection and adherence to curved surface; estimate deflection angle vs. curvature radius.

Extension: Show lift on a curved plate using the same jet to illustrate circulation and Bernoulli pressure difference.

2 Vortex Rings and Smoke Rings

Concept: A vortex ring moves due to its self-induced velocity, representing coherent vorticity transport.

Core Theory: For circulation Γ and radius R,

$$U \approx \frac{\Gamma}{4\pi R}\left[\ln\left(\frac{8R}{a}\right) - \frac{1}{4}\right],$$

where a is the core radius.

Demo Setup:

- Cardboard box or plastic tub with circular hole
- Rubber membrane (balloon or elastic sheet)
- Smoke or fog for visualization

Observe: Formation and travel of rings; estimate speed vs. diameter.

Extension: Compare with vortex rings in water using dye injection.

3 Rayleigh–Taylor Instability

Concept: A heavy fluid over a lighter one becomes unstable under gravity, forming finger-like plumes.

Core Theory: Linear growth rate:

$$\sigma^2 = gk\frac{\rho_1 - \rho_2}{\rho_1 + \rho_2}, \quad k = \frac{2\pi}{\lambda}.$$

Demo Setup:

- Transparent tank (10–15 cm wide)
- Bottom: fresh water; top: dyed saltwater
- Optional barrier to start experiment cleanly

Observe: Development of plumes and interpenetrating fingers.

Extension: Record video to estimate growth rate vs. wavelength.

4 Rayleigh–Bénard Convection

Concept: Buoyant convection occurs when heating from below overcomes viscous and diffusive damping.

Core Theory: The Rayleigh number controls onset:

$$Ra = \frac{g\beta \Delta T h^3}{\nu\kappa} \gtrsim 1708.$$

Demo Setup:

- Shallow transparent tray (1–2 cm deep)
- Dyed water or light oil
- Gentle heat source (warm plate or water bath)

Observe: Hexagonal convection cells or rising plumes.

Extension: Measure onset ΔT and estimate Ra_c.

5 Gravity Currents and Hydraulic Jumps

Concept: Density or velocity discontinuities lead to fronts and jumps described by shallow-water theory.

Core Theory: Jump condition:

$$Fr_1^2 = \frac{u_1^2}{gh_1} = \frac{(h_2 - h_1)^2}{4h_1h_2}.$$

Demo Setup:

- Shallow tray or flume
- Gate release for dyed water or saltwater
- Camera for side recording

Observe: Front speed, depth ratio, and jump position.

Extension: Vary density or gate height; test Froude-number scaling.

6 Capillary and Marangoni Effects

Concept: Surface-tension gradients drive motion along an interface (e.g., soap or camphor boats).

Core Theory: Balance of interfacial stress:

$$\nabla_s \gamma = \mu \frac{\partial u_t}{\partial n}.$$

A gradient in $\gamma(T, c)$ drives tangential flow.

Demo Setup:

- Petri dish or bowl of water
- Paper or plastic boat with soap/camphor at stern
- Food dye to trace surface flow

Observe: Self-propelling motion, surface spreading, and flow symmetry.

Extension: Vary temperature or surfactant concentration to study speed dependence.