Expanded 1-Month CFD Solver & MDO Project Plan

1) Overall scope & tech stack

- Language: C++17 (good perf, CGNS API, easy bindings).
- Libraries: CGNS C API (mesh IO), NLopt or Pagmo (optim), Eigen (linear algebra for convenience), tinyyaml/CLI11 (config/CLI), matplotlib-cpp or CSV dump + Python for plots.
- Post: ParaView/Tecplot for contours; Python for Cp / objective history charts.
- Build: CMake; unit tests via Catch2 (lightweight).

2) Week 1 — Foundation setup (mesh, CGNS, baseline Euler solver)

Goal: Read a CGNS mesh, run a steady 2D compressible Euler solver, validate on an oblique shock over a wedge.

2.1 Mesh & geometry (CGNS)
- Create meshes in Gmsh (airfoil + combustor duct).
- Export to CGNS, keep boundary tags (`farfield`, `wall`, `inlet`, `outlet`).
- CGNS reader: read coords, connectivity, BCs. Build cell-centered storage, compute metrics (area, normals, centroids).

2.2 Governing equations (Euler, 2D)
- State: $U = [\rho, \rho u, \rho v, E]$.
- Flux via Riemann solver.
- Numerics: HLLC Riemann, MUSCL+limiter, TVDRK3 time march, local dt by CFL.
- BCs: inflow/outflow, slip wall, farfield.
- Validation: Wedge shock angle vs oblique-shock theory.

Deliverable: residual plots, shock contours, pressure line probe.

3) Week 2 — Project 1: Non-reacting airfoil MDO

Goal: Black-box shape optimization: minimize drag with lift constraint.

Geometry parameterization
- Bézier control points or Hicks–Henne bumps.
- Remesh each design in Gmsh to avoid mesh morphing.

CFD black-box objective
- Inputs: design vector → geometry → mesh → solver.
- Outputs: CL, CD.
- Objective: $J = CD + \mu[\max(0, CLreq - CL)]^2$.

Optimizer
- NLopt or Pagmo, 3–5 vars, derivative-free (COBYLA, ISRES, etc).
- Bounds on geometry.
- Cap ~50–100 evals.

Deliverables
- Cp curves, Mach/pressure contours, optimization history, report with drag reduction vs baseline.

4) Week 3 — Project 2 start: Reacting-flow extension

Goal: Extend solver to multi-species Euler + 1-step chemistry.

Governing equations
- Species mass fractions Y_s, source terms from Arrhenius law.
- Thermo: cp(T), γ(T) from mixture.

Numerics
- Operator splitting: Euler convection + chemistry ODE per cell.
- Integration: backward Euler or sub-cycled explicit.

Validation case
- Supersonic duct with side injector.
- Expect shock/flame interaction, T rise, total pressure loss.

Deliverable: species/T/Mach fields, residual plots, physical sanity check.

5) Week 4 — Project 2 MDO (reacting combustor)

Goal: Optimize combustor design variables for efficiency/thrust.

Design variables
- Wall divergence angle, injector location/angle, fuel rate, cavity length.

Objective & constraints
- Maximize efficiency or thrust.
- Minimize total pressure loss (penalty).
- Constraints: max wall heat flux, static pressure limits.

Optimization loop
- Budget: 5–10 evaluations.
- Reuse optimizer structure from Project 1.
- Deliverables: contours, efficiency history, comparison with baseline.

6) Code architecture

```
/cfd
/mesh // CGNS reader, BC maps
/numerics // Riemann, reconstruction, time integrators
/euler // non-reacting solver
/reacting // multi-species + chemistry
/io // CGNS writers, CSV/VTK exporters
/mdo // optimizer bindings, geometry
/utils // logging, timers
main.cpp // CLI entry point
```

Configs via YAML (flow inputs, CFL, chemistry, optimizer).

7) Implementation details & guardrails

Riemann + reconstruction
- HLLC robust for shocks, Roe optional.
- Limiters: Venkatakrishnan, ensure positivity.

Convergence & efficiency
- CFL ramping, restart/warm-start, coarse mesh to fine.

Robustness
- Enforce positive ρ, p, Y_s.
- Chemistry: cap T and enforce sum(Y_s)=1.

8) Minimal day-by-day milestones

D1–2: CGNS reader, mesh/BC check.
D3–4: HLLC+MUSCL+RK3, uniform flow test.
D5: Wedge shock validation.
D6–8: Airfoil parametric + optimizer wiring.
D9–10: Run airfoil optimization, report.
D11–13: Reacting extension + duct injector case.
D14: Combustor MDO run (5–10 evals), final report.

9) Deliverables

- Codebase (solver + optimizer scripts).
- Configs (.geo, .yaml).
- Plots: Cp curves, contours, optimization history.
- Reports: Airfoil (Proj 1), Combustor (Proj 2).