Aerospace Engineering CFD Analysis Template

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Abstract

This template demonstrates computational fluid dynamics (CFD) analysis techniques in aerospace engineering, including NACA airfoil analysis, aerodynamic performance calculations, propulsion system modeling, and flight dynamics simulations.

The template integrates Python computations with LaTeX for reproducible aerospace engineering reports.

Contents

1 Introduction

Computational Fluid Dynamics (CFD) has become an essential tool in aerospace engineering for analyzing complex flow phenomena around aircraft, spacecraft, and propulsion systems.

This template provides a foundation for aerospace engineering reports that combine theoretical analysis with computational results.

2 Aerodynamics Analysis

2.1 NACA Airfoil Geometry

The NACA 4-digit series airfoils are widely used in aerospace applications. For a NACA MPXX airfoil, where M is the maximum camber percentage, P is the position of maximum camber, and XX is the thickness percentage.

NACA 2412 Airfoil Parameters: Maximum camber: 2Maximum thickness: 12Leading edge radius: 0.0720c

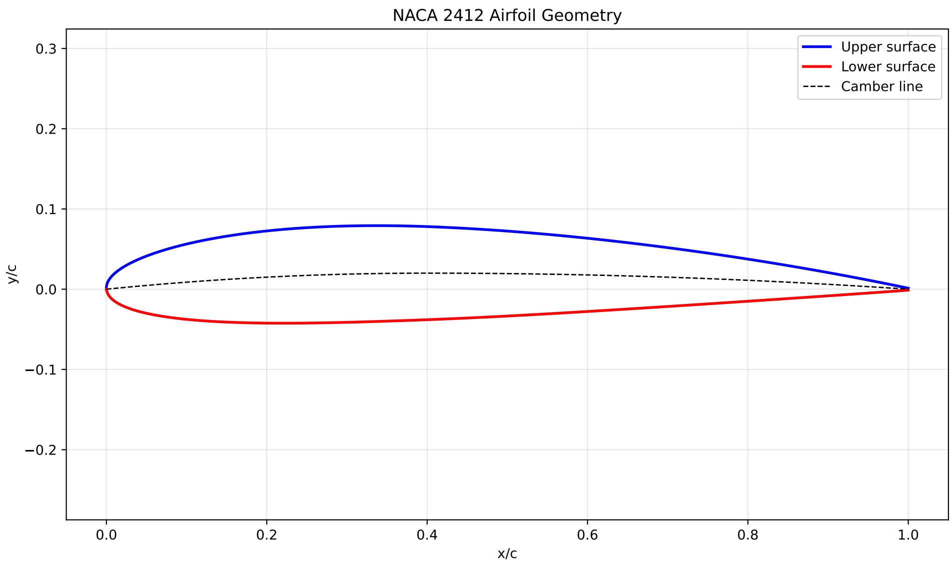

Figure 1: NACA 2412 airfoil geometry showing upper surface, lower surface, and camber line.

2.2 Aerodynamic Performance Analysis

Aerodynamic Analysis Results: Zero-lift angle of attack: -0.00 degrees Lift curve slope: 6.283 per radian (360.0 per degree) At alpha = 5 degrees: CL = 0.549

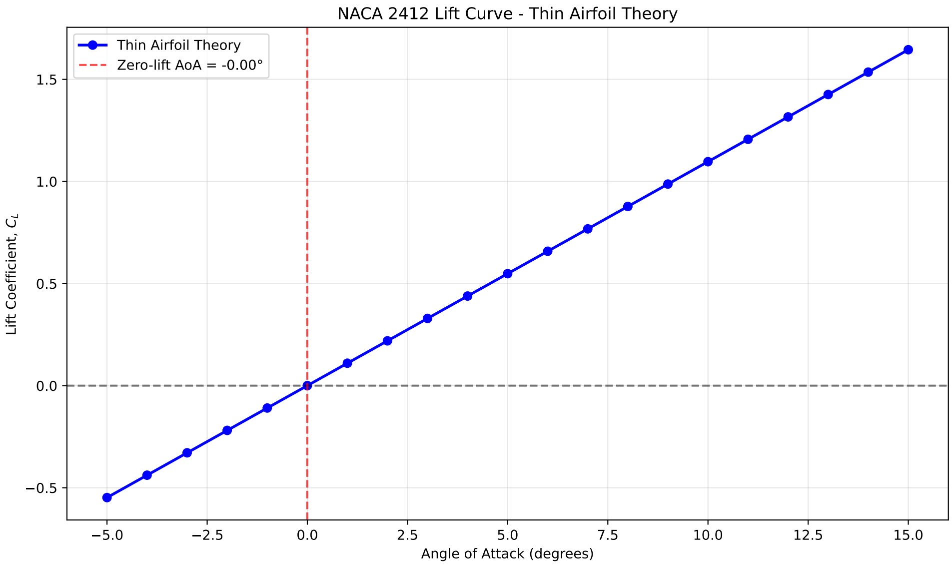

Figure 2: Lift coefficient variation with angle of attack for NACA 2412 airfoil using thin airfoil theory.

3 CFD Analysis Fundamentals

3.1 Governing Equations

The Navier-Stokes equations govern fluid flow in aerospace applications:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{u}) = 0 \tag{1}$$

$$\frac{\partial (\rho \mathbf{u})}{\partial t} + \nabla \cdot (\rho \mathbf{u} \otimes \mathbf{u}) = -\nabla p + \nabla \cdot \boldsymbol{\tau} + \rho \mathbf{f} \tag{2}$$

$$\frac{\partial (\rho E)}{\partial t} + \nabla \cdot ((\rho E + p)\mathbf{u}) = \nabla \cdot (\mathbf{k} \nabla T) + \nabla \cdot (\boldsymbol{\tau} \cdot \mathbf{u}) + \rho \mathbf{f} \cdot \mathbf{u} \tag{3}$$

where ρ is density, $\mathbf{u}$ is velocity vector, p is pressure, $\boldsymbol{\tau}$ is viscous stress tensor, E is total energy per unit mass, and $\mathbf{f}$ represents body forces.

3.2 Dimensionless Parameters

Key dimensionless parameters in aerospace CFD:

Key Dimensionless Parameters in Aerospace CFD: ==================================== Reynolds Number Re Inertial/Viscous forces Mach Number Ma Flow/Sound speed Prandtl Number Pr Momentum/Thermal diffusivity Lift Coefficient C_L Lift/Dynamic pressure Drag Coefficient C_D Drag/Dynamic pressure Pressure Coefficient C_p Local/Dynamic pressure

4 Propulsion Analysis

4.1 Turbojet Engine Performance

Turbojet Performance Summary: Sea level static specific thrust: 772.7 N·s/kg Cruise (Ma=0.8) specific thrust: 352.7 N·s/kg Maximum analyzed Mach: 2.0

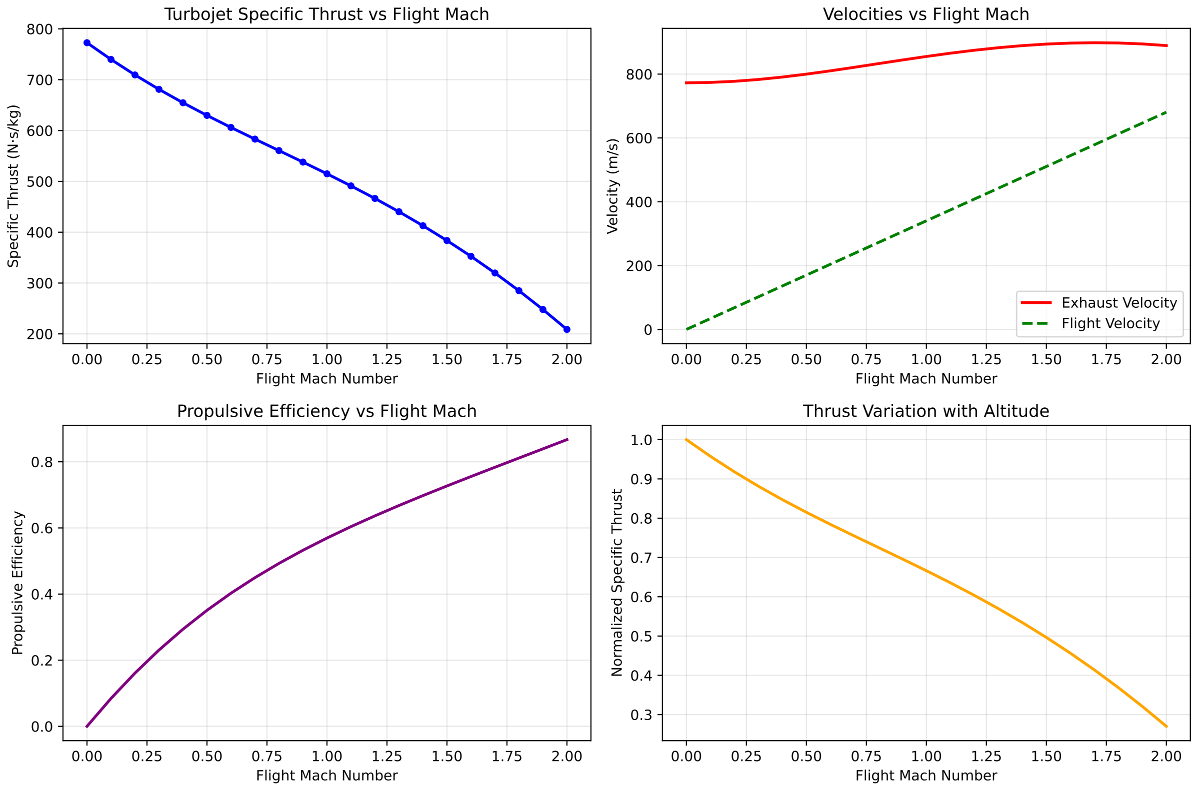

Figure 3: Turbojet engine performance characteristics showing specific thrust, velocities, propulsive efficiency, and thrust variation with flight Mach number.

5 Flight Dynamics

5.1 Aircraft Stability Analysis

Flight Dynamics Analysis: Aerodynamic center: 25.0Stable CG range: 20.0Maximum static margin: 5.0

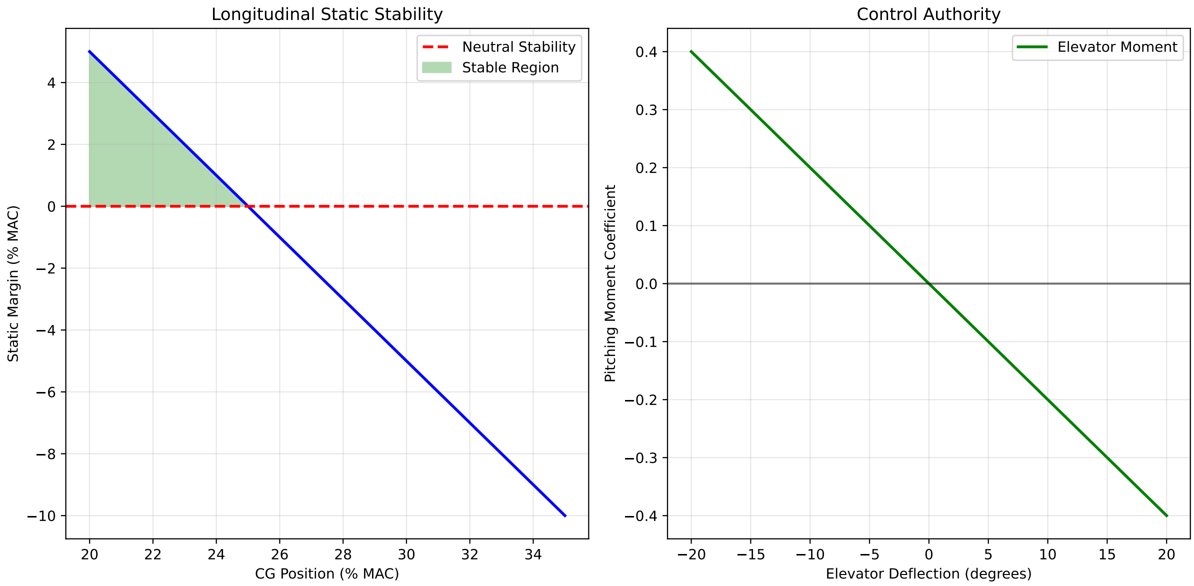

Figure 4: Longitudinal static stability analysis showing static margin variation with CG position and elevator control authority.

6 Computational Methods

6.1 Finite Difference Discretization

For CFD applications, the governing equations are discretized using finite difference, finite volume, or finite element methods. A simple example of finite difference discretization for the 1D heat equation:

$$\frac{\partial T}{\partial t} = \alpha \frac{\partial^2 T}{\partial x^2} \tag{4}$$

Numerical Method Demonstration: Grid points: 50 Time steps: 100 Stability parameter r = 0.025 (should be <= 0.5) Maximum temperature at t=0: 0.995 Maximum temperature at final time: 0.907

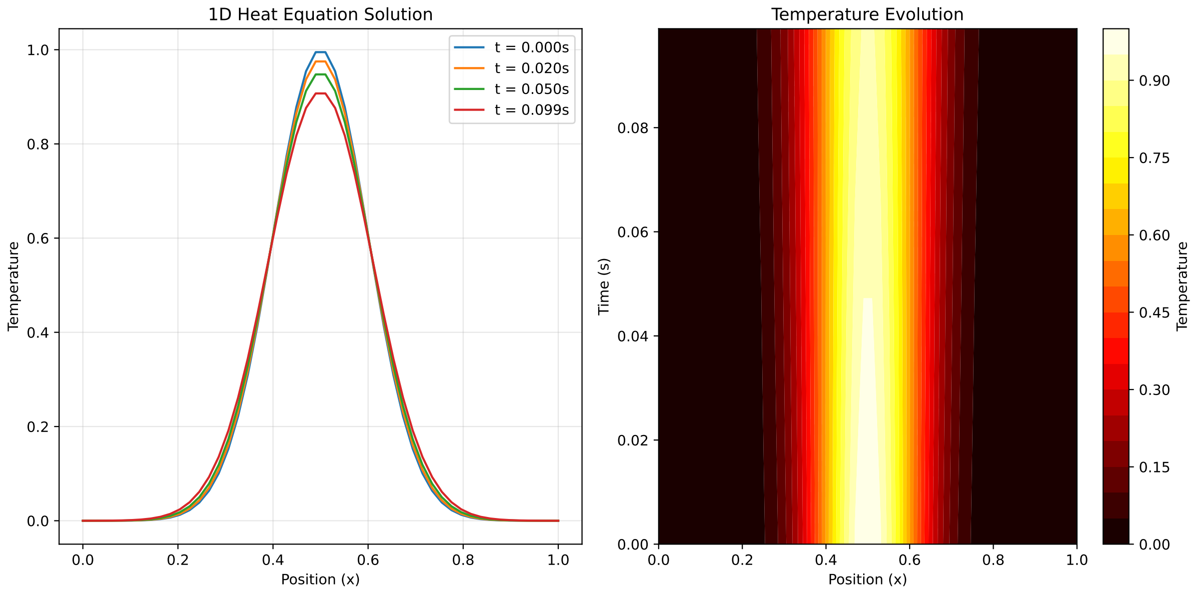

Figure 5: Solution of the 1D heat equation demonstrating finite difference methods commonly used in CFD applications.

7 Conclusion

This template demonstrates the integration of theoretical aerospace engineering concepts with computational analysis using Python and LaTeX. The combination of:

- NACA airfoil geometry generation and analysis
- Aerodynamic performance calculations using thin airfoil theory
- Turbojet engine performance modeling
- Flight dynamics and stability analysis
- Numerical methods for CFD applications

provides a comprehensive foundation for aerospace engineering reports that require both analytical and computational approaches. The PythonTeX integration allows for reproducible results and seamless combination of code, calculations, and professional documentation.

8 References

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3. Etkin, B. and Reid, L.D., *Dynamics of Flight: Stability and Control*, 3rd Edition, Wiley, 1996.
4. Blazek, J., *Computational Fluid Dynamics: Principles and Applications*, 3rd Edition, Butterworth-Heinemann, 2015.