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Aerodynamic Characteristics of the NACA0018 Airfoil

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Abstract. The NACA0018 is a symmetric four-digit airfoil with a maximum thickness of 18% of the chord. Its geometric simplicity and structural depth make it a common reference section for vertical-axis wind turbines, unmanned aircraft, hydrofoils, and validation of computational fluid dynamics methods. This study examines the airfoil's geometry, pressure distribution, boundary-layer development, drag composition, and stall mechanism, and then evaluates a Reynolds-averaged Navier-Stokes simulation over angles of attack from -2° to 16°. At a chord of 1 m and a freestream velocity of 20 m/s, the chord Reynolds number is approximately 1.37×10^6. The SST k-omega model is used because it combines near-wall resolution with improved treatment of adverse pressure gradients. The computed lift-to-drag ratio reaches a maximum of approximately 49 at 7°, while separation is reported near the upper sweep limit of 16°. The discussion shows that the predicted peak efficiency and stall point depend strongly on transition, surface roughness, near-wall mesh quality, and convergence criteria. The results provide a useful baseline, but quantitative validation against matched-Reynolds-number experiments and a mesh-independence study are required before the data are used for design.

Keywords: NACA0018, symmetric airfoil, computational fluid dynamics, boundary-layer separation, static stall, SST k-omega model

1. Introduction

NACA0018 has zero camber and an 18% thickness ratio. The resulting structural depth suits turbines and hydrofoils, while its analytically defined geometry supports reproducible comparisons [1]. Geometry alone does not determine performance: early NACA tests found changes in lift, drag, and stall as Reynolds number varied [2].

Sheldahl and Klimas compiled symmetric-airfoil force coefficients over 180° for turbine analysis [3]. Timmer demonstrated the influence of free and forced transition on NACA0018 drag and stall [4]. Gerakopulos, Boutilier, and Yarusevych linked lift changes to separation bubbles at Reynolds numbers of 80,000–200,000 [5]. Subsequent shear-layer measurements clarified transition mechanisms that inviscid theory cannot capture [6].

Chinese research emphasizes dynamic-stall measurement and passive control. Meng, Ju, and Yu identify unsteady transition and high-angle separation as validation challenges [7]. Yu's numerical studies show how conventional and serrated trailing-edge devices trade lift enhancement against drag [8, 9].

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Direct comparison with the present calculation is limited by the test conditions. The experiments resolve low-Reynolds-number transition, whereas the flap studies examine modified, three-dimensional geometries. Neither establishes the accuracy of a clean two-dimensional section at the Reynolds number used here. The question is how far their findings remain transferable.

The report interprets a two-dimensional RANS calculation at Re ≈ 1.37 × 10⁶, focusing on aerodynamic mechanisms, turbulence-model limitations, and the evidence needed to validate efficiency and stall predictions.

2. Geometry and governing parameters

2.1. Airfoil geometry

NACA0018 has a straight mean camber line and a thickness ratio t = 0.18. Its upper and lower surfaces follow the symmetric thickness distribution [1]:

$$y_t/c = 5t[0.2969\sqrt{(x/c)} - 0.1260(x/c) - 0.3516(x/c)^2 + 0.2843(x/c)^3 - 0.1015(x/c)^4] \quad (1)$$

Here, x is distance from the leading edge and c is chord length. Thickness provides structural volume, but pressure recovery toward the trailing edge can promote separation and pressure drag.

2.2. Dimensionless quantities and force coefficients

Using the stated density, speed, chord, and viscosity gives:

$$Re_c = \rho U_\infty c/\mu = (1.225 \times 20 \times 1)/(1.79 \times 10^{-5}) \approx 1.37 \times 10^6 \quad (2)$$

Dynamic pressure is $q_\infty = 0.5\rho U_\infty^2 = 245$ Pa. With forces per unit span, $C_L = L'/(q_\infty c)$, $C_D = D'/(q_\infty c)$, and $C_p = (p - p_\infty)/q_\infty$. Comparisons also require matched Reynolds number, roughness, and transition conditions.

3. Aerodynamic mechanisms

3.1. Lift generation and pressure distribution

At zero incidence, symmetry implies approximately zero lift. As incidence increases, accelerated upper-surface flow produces suction. Thin-airfoil theory gives $dC_L/d\alpha \approx 2\pi$ per radian; for an 18%-thick section, however, viscous displacement and separation restrict the accuracy of that estimate.

3.2. Boundary layer, transition, and drag

Drag includes both wall friction and pressure forces. Under adverse pressure recovery, a laminar boundary layer may separate and then reattach after transition. The resulting bubble changes the pressure distribution and lift-curve slope. Although higher Reynolds number can advance transition, its location still depends on turbulence and roughness. Agreement in lift therefore need not imply agreement in drag.

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3.3. Static and dynamic stall

Static stall accompanies extensive separation and loss of suction-side lift; its angle depends on Reynolds number, roughness, turbulence, and blockage. During rapid pitching, delayed separation and a leading-edge vortex can produce transient lift overshoot and hysteresis. Steady angle sweeps cannot capture these dynamic loads [10].

4. Numerical simulation method

4.1. Operating conditions

The simulation conditions are summarized in Table 1.

Table 1. The simulation conditions

Parameter	Value	Role in the analysis
Chord Reynolds number	1.37×10^6	Sets the viscous-flow regime
Air density	1.225 kg/m³	Used in dynamic pressure and forces
Dynamic viscosity	1.79×10^{-5} Pa·s	Used in the Reynolds number
Air temperature	288.15 K	Reference thermodynamic condition
Chord length	1 m	Reference length
Freestream velocity	20 m/s	Mach number is approximately 0.059
Angle of attack	-2° to 16°	Covers attached flow through stall onset

4.2. Domain and boundary conditions

The calculated freestream Mach number is approximately 0.059, supporting an incompressible treatment. The reference boundary arrangement is a velocity inlet, a pressure outlet and a no-slip airfoil. Yu [8] used boundaries 9 chord lengths upstream and 10 chord lengths downstream at Re = 138,000, with a spanwise extent of three serration heights and a mesh of order one million cells. This is a three-dimensional flap configuration. Its domain dimensions provide a comparison, not evidence that the present domain is independent of boundary placement.

4.3. Mesh strategy and near-wall resolution

Drag accuracy depends strongly on near-wall resolution and refinement around the leading edge and wake. Wall-resolved SST generally targets y+ near 1. A stable CL is insufficient. Only when CD, pressure distributions, and separation location also change negligibly under refinement is a claim of grid independence defensible.

4.4. Turbulence and transition modeling

SST blends near-wall k-omega and outer-flow k-epsilon behavior, improving adverse-pressure-gradient predictions [11]. Standard SST does not resolve natural transition. A correlation-based transition model adds intermittency and onset criteria [12]; comparing the formulations would isolate sensitivity to the assumed boundary-layer state.

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4.5. Solver controls and verification

A pressure-based finite-volume method suits this low-speed flow. Falling residuals are only one check; CL and CD must also stabilize. Persistent oscillations near stall may have a physical origin. In that case, time-dependent calculations and time-step checks are needed, with force histories assessed alongside the flow fields [13].

4.6. Published numerical verification data

Rogowski, Śledziewski and Michna [14] report a NACA0018 mesh study in a public preprint. Table 2 records their numerical settings. These are literature values, not measurements from the present calculation.

Table 2. Numerical settings reported by Rogowski et al. [14]

Quantity	Reported value
Nominal mesh	282,934 elements; 285,016 nodes
Airfoil surface nodes	1,669
Near-wall layers	37; growth ratio 1.13
First-layer thickness	5×10^{-6} m
Wall resolution	$y+ \leq 1$ reported for all cases; no full range given
Residual level	10^{-7} reported; not a residual-history dataset
Iterations per time step	Maximum 20
Mesh sensitivity case	Four meshes; stationary airfoil; 8°; Re = 160,000

The preprint reports limited sensitivity beyond its nominal mesh, but does not tabulate complete cell counts and coefficients for all four grids [14]. Its mesh test uses Re = 160,000, compared with approximately 1,370,000 here—a factor of 8.6. The reported y+ ceiling cannot supply a minimum-to-maximum range, nor can these separate calculations establish convergence of the present case.

5. Results and discussion

5.1. Lift, drag, and aerodynamic efficiency

The reported CL/CD maximum is approximately 49 at 7°. At this point, CD/CL ≈ 0.0204: drag is about 2.04% of lift. This is a direct conversion of the reported ratio, not an additional simulation result. It does not determine CL or CD separately. A rising CL/CD curve requires lift to grow faster in relative terms than drag; beyond a smooth maximum, that ordering reverses. The proposed physical explanation is stronger pressure recovery and growing separation, which increase the drag penalty. The location of the peak alone cannot establish the curvature or rate of decline. Without angle-resolved coefficients, neither a fitted lift slope nor an R^2 value can be reported. For scale, the theoretical attached-flow slope of 2π per radian equals approximately 0.110 per degree; this is an ideal reference, not a fit to the present data.

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5.2. Separation and stall interpretation

Separation is reported near 16°, nine degrees above the reported efficiency peak. That interval is not a validated stall margin. The sweep stops at 16°, so no higher-angle points establish a post-peak fall in CL. Pressure recovery offers a plausible explanation for separation, but wall-shear and pressure distributions are needed to locate its onset. In particular, local trailing-edge separation does not by itself identify the maximum of the lift curve.

5.3. Comparison with published work

The low-Reynolds-number measurements [4-6] help interpret transition and separation. Their coefficients cannot be used as direct validation targets, however, unless Reynolds number, turbulence, surface condition, and two-dimensionality are comparable.

At Re = 280,000, Damiola et al. [15] measured markedly different quasi-static lift curves as freestream turbulence changed. With 0.3% turbulence, stall occurred abruptly near 21°; at 8.2%, the stall was gentler and occurred near 23°. The shift was about 2°. Maximum lift also rose by approximately 13%, although Reynolds number remained unchanged. Both the height of the lift peak and the abruptness of stall therefore varied with inflow conditions. These are published experimental results, not points from the present angle sweep.

For the present comparison, the controlled Reynolds number in those tests matters. It shows why attributing a difference in separation angle solely to Reynolds number would be unconvincing. The present Re is approximately 4.9 times their value, but turbulence and transition treatment are also unmatched. Nor are separation onset and lift stall interchangeable criteria. These differences prevent a numerical validation error from being inferred from the angles alone.

5.4. Uncertainty and limitations

The efficiency maximum remains preliminary. This report lacks the present mesh counts, actual y+ distribution, residual and force histories, and a three-grid comparison. The published settings in Table 2 cannot replace those records. Missing angle-resolved CL and CD values also prevent curve fitting or an assessment of peak-location uncertainty. Agreement with the expected aerodynamic trend is therefore a qualitative check.

6. Engineering implications

Symmetry suits reversing turbine loads; thickness supplies stiffness. Neither remove the need for unsteady analysis when incidence changes rapidly. Operation near the reported efficiency peak may reduce power demand, provided that gusts and roughness are allowed for when assessing stall margin. Flap benefits likewise depend on the accompanying drag penalty at the intended Reynolds number [8, 9].

7. Conclusions

The conclusion is as follows:

(1) NACA0018 combines structural thickness with symmetric aerodynamic behavior; transition and separation govern its practical performance.

(2) The reported CL/CD maximum is approximately 49 at 7°. Separation near the 16° sweep endpoint does not establish a precise stall angle.

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(3) Published comparisons demonstrate sensitivity to turbulence and transition, but differences in operating conditions prevent direct quantitative validation.

(4) Actual mesh statistics, y+ distributions, convergence histories, and grid comparisons remain necessary before the reported coefficients support design decisions.

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