

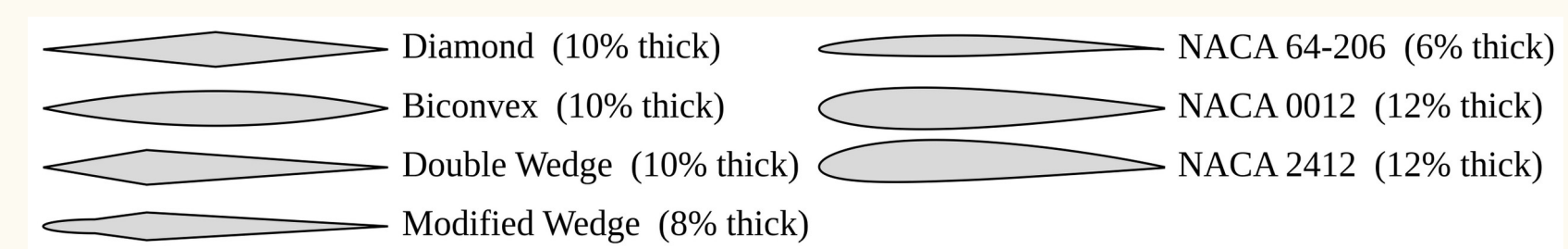
Abstract

Seven supersonic airfoil sections were compared at Mach 1.2–3.0 using inviscid simulations in the open-source SU2 code (560 cases). Forces were checked against an exact theory and across three grid sizes, and the three sharp-nosed sections were then reshaped by a gradient-based optimizer at constant lift. Drag fell 11.5–18.9% at Mach 1.2 but only 0.25–5.84% at Mach 1.5–3.0, with every gain confirmed on finer grids. Rounding a sharp nose reduced the lift-to-drag ratio by up to 37%.

Introduction

Above the speed of sound, most of an airfoil's drag comes from the shock waves its shape creates. Classical theory favors thin, sharp sections but breaks down where the shock detaches: near Mach 1 and ahead of rounded noses (5). Comparisons also often use a single grid and average lift-to-drag ratio (L/D) near zero lift, where small errors dominate.

Question: Which airfoil performs best at equal lift, and how much can reshaping reduce its drag?



The seven sections compared, with thickness ratios.

Methods

Flow model. Two-dimensional, steady, inviscid (friction-free) simulations in SU2 8.4.0 (1) at Mach 1.2, 1.5, 2.0, 2.5 and 3.0 and angles of attack -5° to 10° ; one solver configuration for all 560 cases.

Checks. Three grid sizes (52k–207k cells) for every section (4); sharp-section forces compared with shock-expansion theory for the 161 attached-shock cases.

Ranking. L/D at a fixed lift coefficient of 0.15, averaged over Mach number. Sections count as separated only if their gap is larger than their combined grid-to-grid variation.

Optimization. For the Diamond, Biconvex and Double Wedge, ten smooth bump functions (3) reshape the surface and a gradient-based optimizer (SLSQP) minimizes drag at a lift coefficient of 0.15, held to within 10^{-8} by trimming the angle of attack, with thickness and area kept at or above baseline. The gradients come from an adjoint solver (2), checked against finite differences, and every final design was re-solved on finer grids.

Cutting Drag at Supersonic Speeds

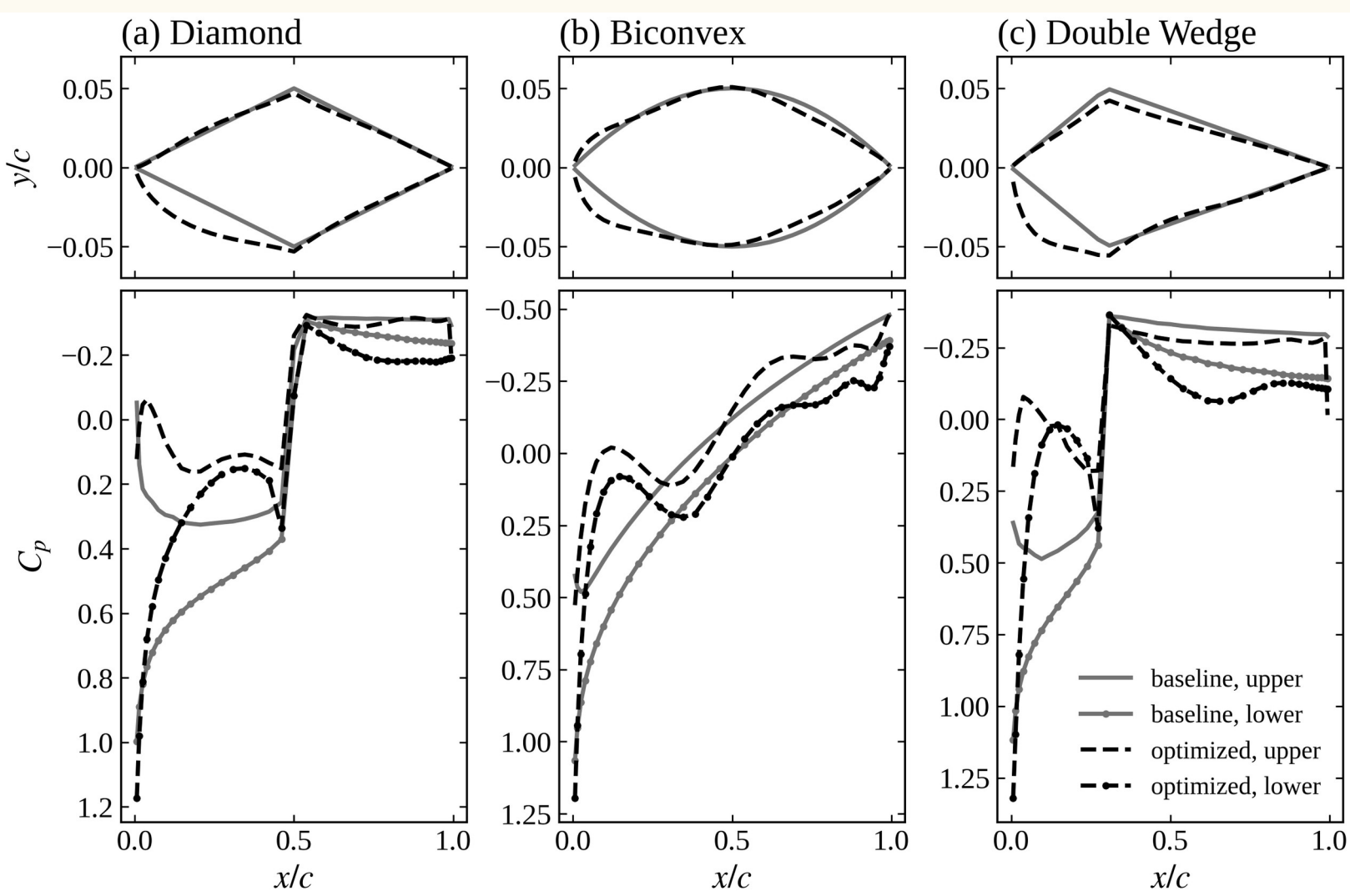
Airfoil Comparison and Adjoint Shape Optimization in SU2

Khushal Gogada

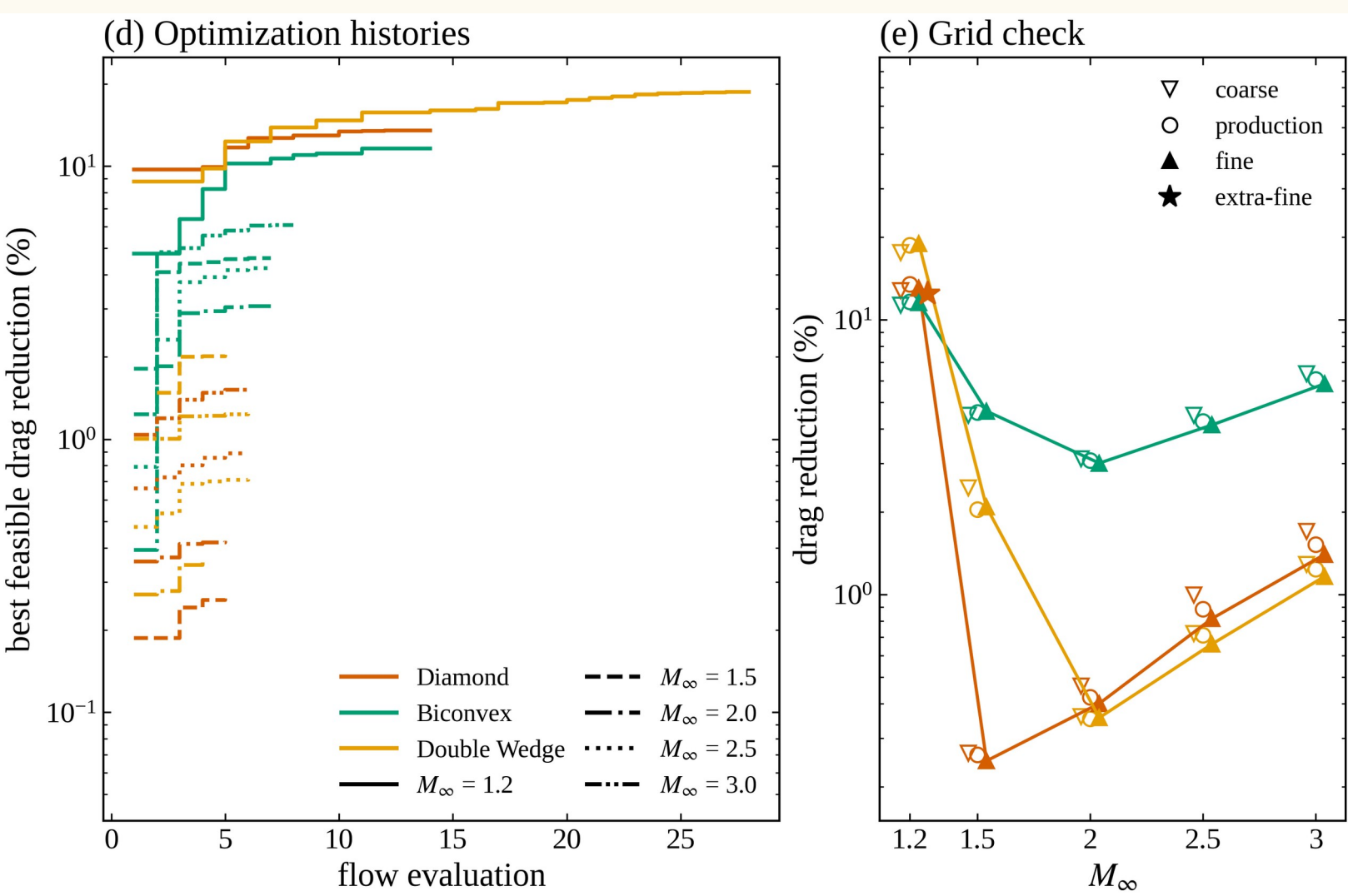
Drag reduction was greatest at Mach 1.2

At Mach 1.2, drag fell by **11.5–18.9% at equal lift** (Biconvex 11.5%, Diamond 12.4%, Double Wedge 18.9%), raising L/D 13–23%: the optimizer pushed the lower nose down, weakening the compression behind the detached bow shock. At Mach 1.5–3.0 the gains were only 0.25–5.84%. All 15 optimizations converged.

CFD matched shock-expansion theory within 1.39% in drag (maximum over the 161 attached-shock cases), and L/D varied by 0.62–2.12% between grids, depending on section.



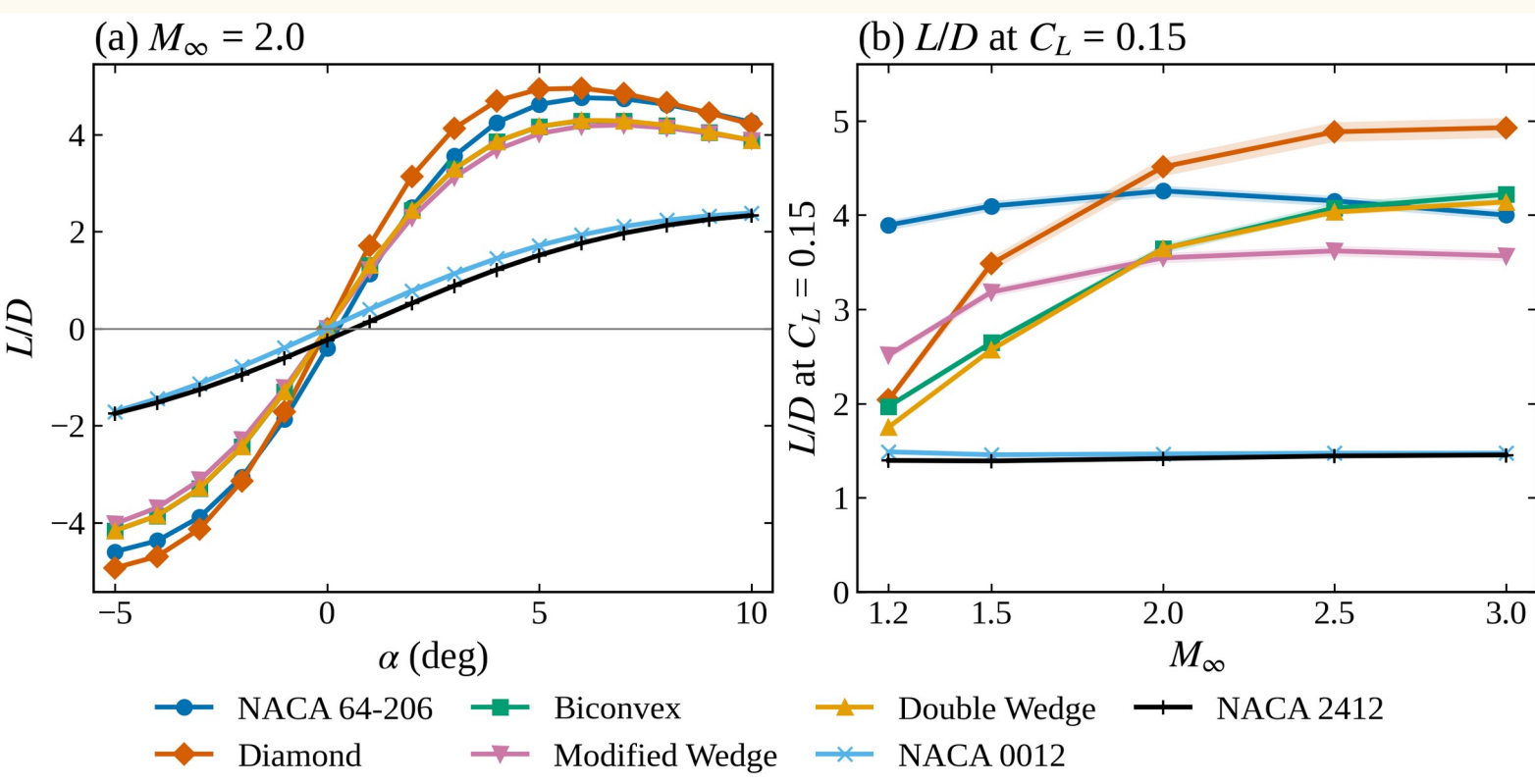
Baseline (grey) and optimized (dashed) shapes and surface pressures at Mach 1.2.



Drag reduction per flow evaluation (d) and final reductions re-solved on up to four grids (e).

Discussion

No single section wins: the thin NACA 64-206 leads at Mach 1.2–1.5, the Diamond at Mach 2.0–3.0, and averaged over Mach the two cannot be told apart within grid variation. The small gains above Mach 1.5 agree with linear theory, which already makes the Diamond the lowest-drag shape for its thickness. Rounding the Double Wedge nose at fixed thickness cut L/D by 8–37% at Mach 2–3; an entropy-flux estimate attributes 53–88% of the added drag to the strong shock ahead of the blunt nose.



L/D versus angle of attack at Mach 2 (a) and at fixed lift across Mach (b); bands show grid spread.

Conclusion

Within the tested shapes and constraints, optimization reduced drag by 11.5–18.9% at Mach 1.2 and 0.25–5.84% at Mach 1.5–3.0, at equal lift. The strongest gains occurred at Mach 1.2. These two-dimensional, inviscid results motivate further testing with viscosity and three-dimensional effects.

References

1. Economou TD, Palacios F, Copeland SR, Lukaczyk TW, Alonso JJ. SU2: an open-source suite for multiphysics simulation and design. AIAA J. 2016;54(3):828–46.
2. Albring TA, Sagebaum M, Gauger NR. Efficient aerodynamic design using the discrete adjoint method in SU2. AIAA Paper 2016-3518.
3. Hicks RM, Henne PA. Wing design by numerical optimization. J Aircr. 1978;15(7):407–12.
4. Celik IB, Ghia U, Roache PJ, Freitas CJ, Coleman H, Raad PE. Procedure for estimation and reporting of uncertainty due to discretization in CFD applications. J Fluids Eng. 2008;130(7):078001.
5. Liepmann HW, Roshko A. Elements of gasdynamics. New York: Wiley; 1957.