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Two-dimensional Shock Sensitivity Analysis for Transonic Airfoils with Leading-edge and Trailing-edge Device Deflections

By: Michael Henry
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Outline

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- Objective
- 3-D scenario - separation growth
- 2-D airfoil geometry
- Flow analysis methodology
  - Grid generation
  - FLOMG
  - Turbulence models
- Results for “wing-drop” airfoil
- Comparison with similar airfoil
- Cambered vs. uncambered results
- Conclusions

Objective

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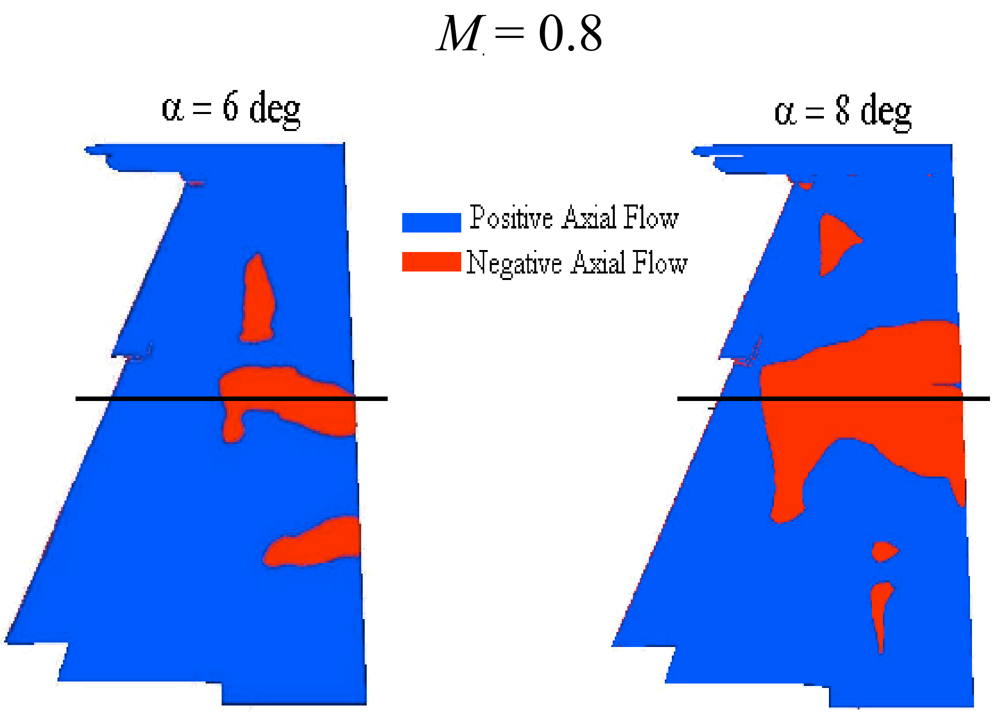
The objective of this study, in consideration of the sudden separation increase involved in wing drop, was to determine if the incorporated 2-D airfoil exhibits abnormal shock sensitivity. The goal was to determine if this particular transonic airfoil is prone to abrupt shock movement, resulting in increased regions of separation.

Three-dimensional Flow

- 3-D data indicates separation jumps forward
- Isobars indicate region of unswept flow



Two-dimensional Airfoil

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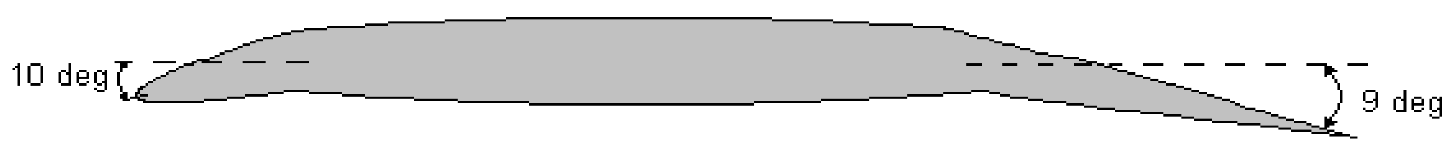
- NACA 65A series airfoil (generated using LADSON)
- t/c = 5.7%
- Leading-edge and trailing-edge deflections



Codes

Provided by Dr. Charlie Swanson of NASA Langley

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- Grid Generating
  - GAIR - defines surface points
  - HYPERG - hyperbolic grid generator
  - PRINTN - organizes points for visualization
- Flow Analysis
  - FLOMG - 2-D flow analysis code using solutions of unsteady Euler or Navier-Stokes equations
    - based on central differencing and Runge-Kutta time stepping
    - multistage scheme with multiple grids
    - multigrid routines adapted from Jameson's Euler code
  - PLTCON - post processing code for visualization in Tecplot®

Grid Specifications

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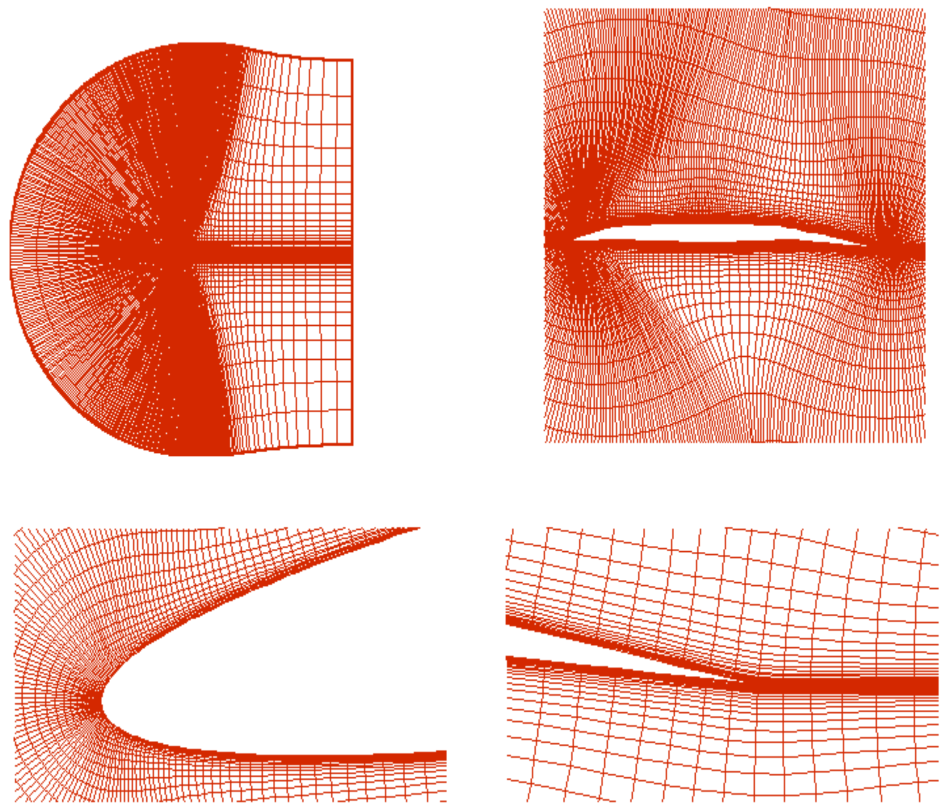
- 480 cells around the airfoil and in the wake
- 64 cells normal to the airfoil surface
- Resolution
  - with this many cells the solution varied little with resolution



Convergence in FLOMG

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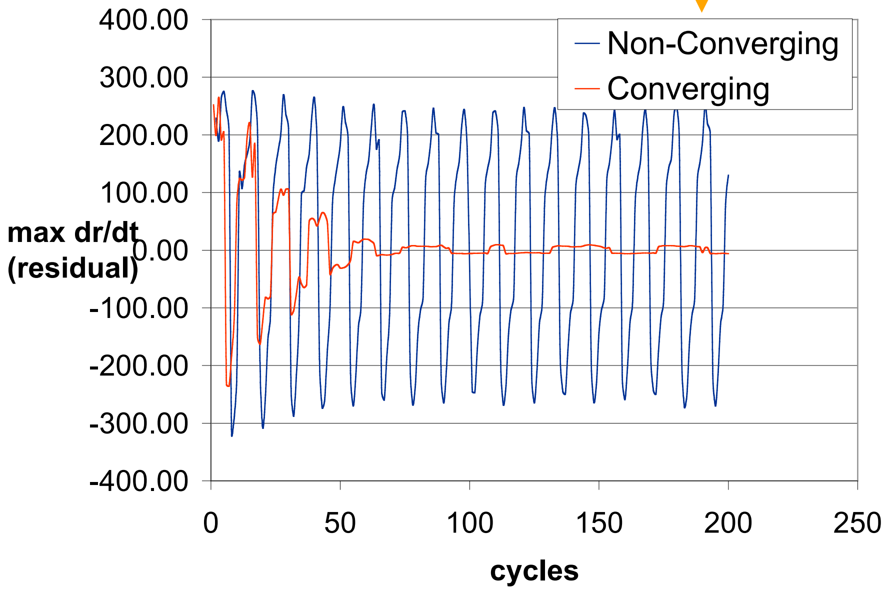
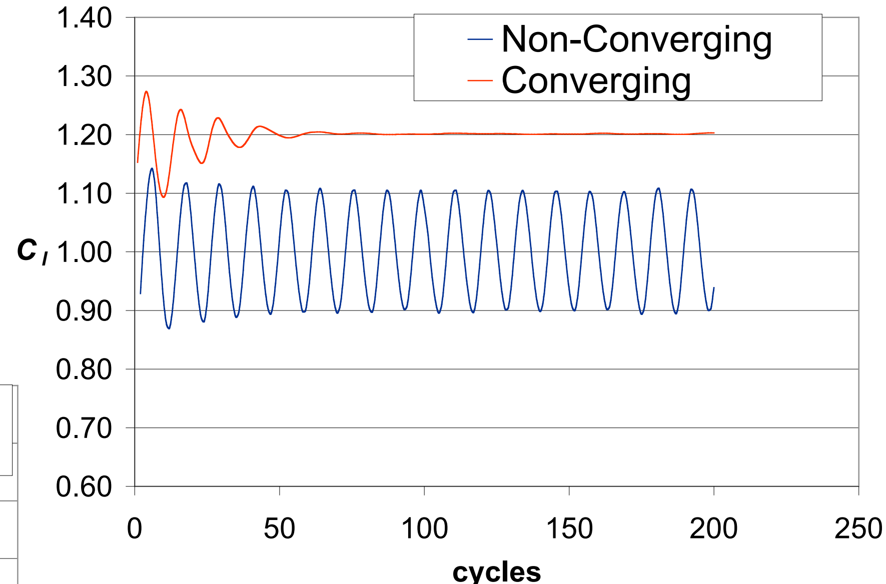
Convergence can be determined by observing the residual





or force coefficients

Turbulence Models

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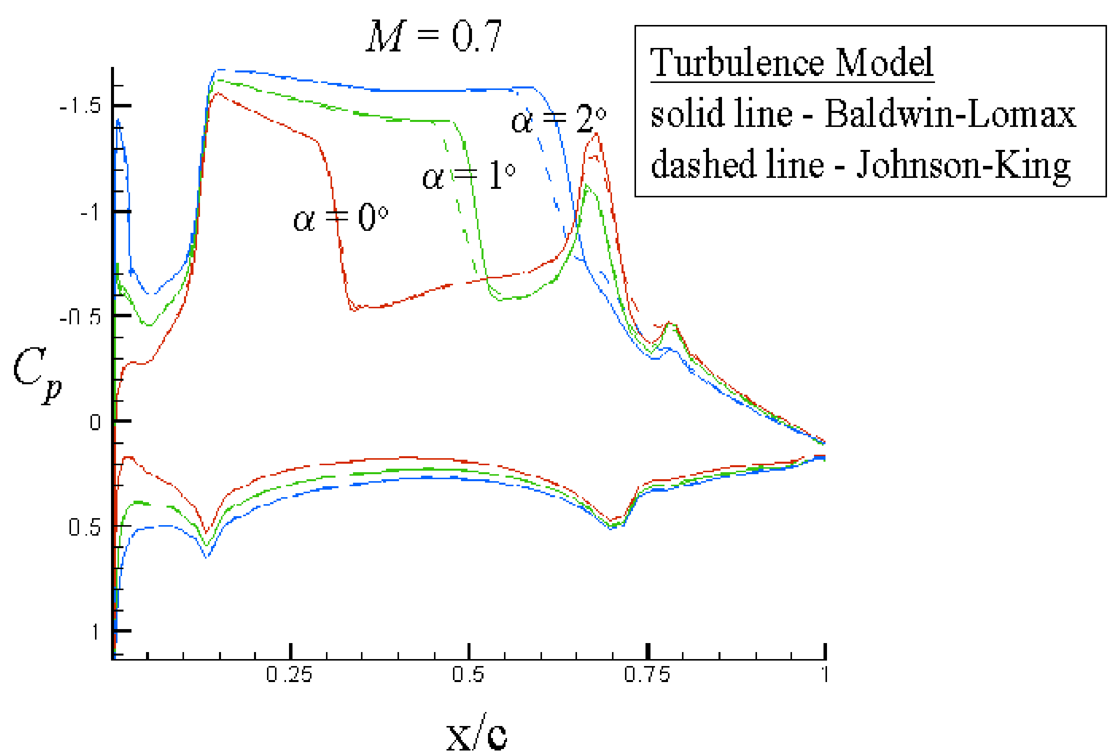
- Two turbulence model options for FLOMG
  - Baldwin-Lomax
  - Johnson-King
- Previous studies favor J-K for pressure calculations
  - Johnson-King results more closely match experimental data
  - Baldwin-Lomax has displayed inaccuracy in predicting the shock location
- Convergence limited with Johnson-King model
  - Results from NACA 65A airfoil failed to converge at higher Mach numbers using Johnson-King turbulence model
  - Baldwin-Lomax model produced converged results for Mach numbers above 0.8.

Turbulence Models cont.

- Data obtained using both turbulence models
- Pattern in shock movement is comparable
- Due to similar shock behavior, the Baldwin-Lomax model was considered adequate for this investigation



Accounting for 3-D Effects

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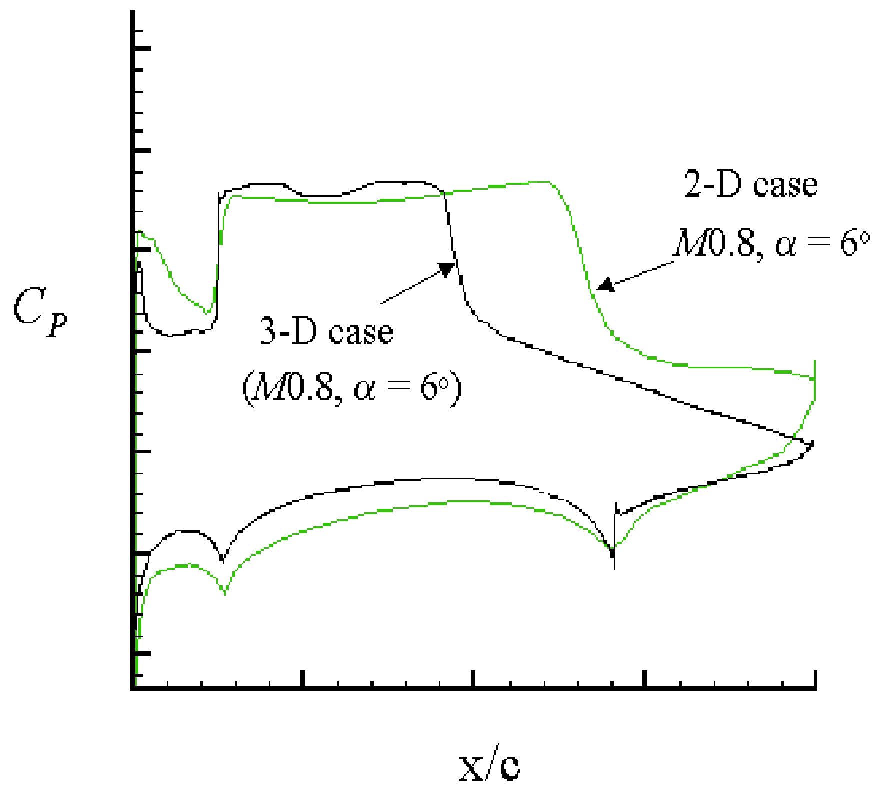
- Can not run 2-D analysis at same conditions as 3-D case
- Matching C_l and pressure distribution requires lower Mach number and AOA
- Adjusted 2-D conditions to operate in vicinity of the 3-D pressure distribution
- For this study:
  - Mach from 0.7 to 0.8
  - AOA from 0° to 2°



Results

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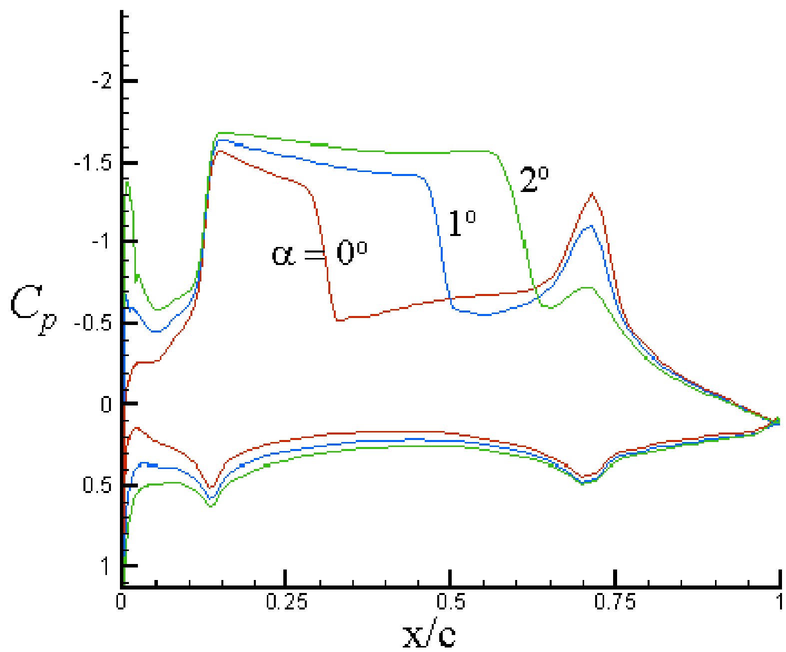
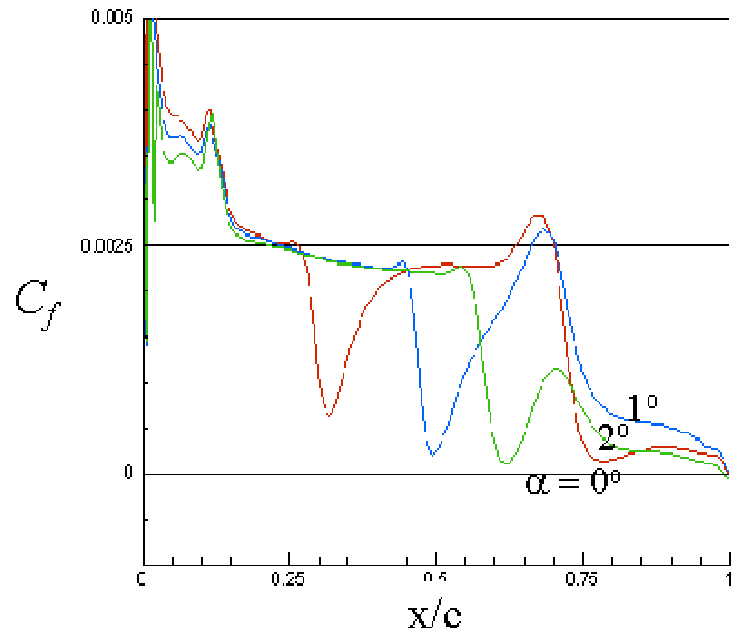
- NACA 65A005.7 airfoil
  - Constant Mach, increasing AOA
  - Constant AOA, increasing Mach
- Airfoil comparison with NACA 65A003.5
  - Constant Mach, increasing AOA
- Device Effectiveness on Shock Movement
  - Comparison between cambered and uncambered NACA 65A005.7

C_P and C_f vs. AOA

NACA 65A005.7

$M = 0.7$, $Re = 22.752$ million





C_P and C_f vs. AOA

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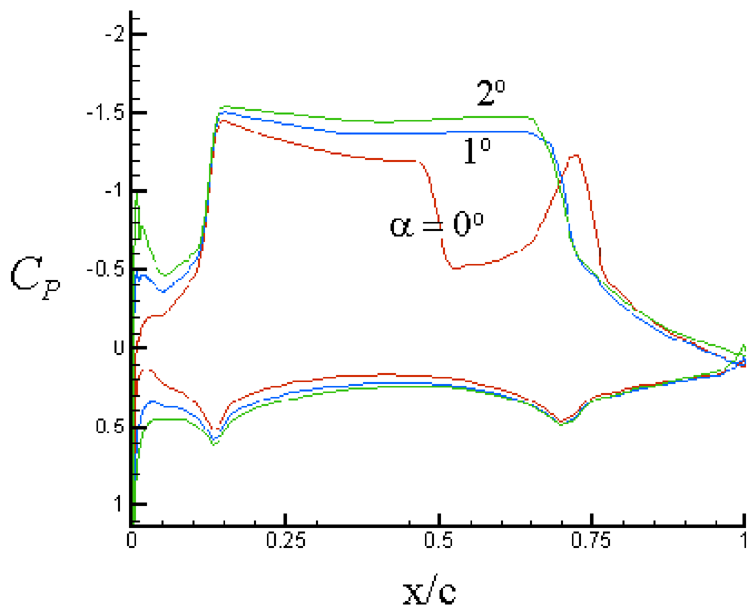
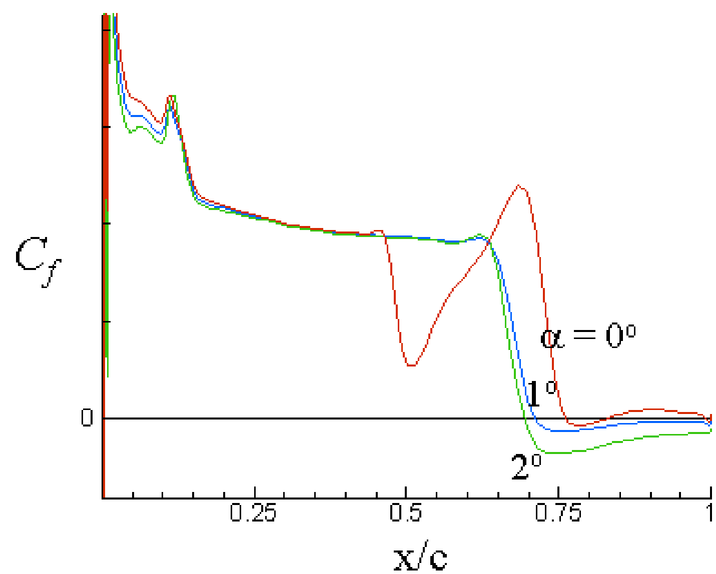
NACA 65A005.7

$M = 0.725$





C_P and C_f vs. AOA

NACA 65A005.7

$M = 0.75$

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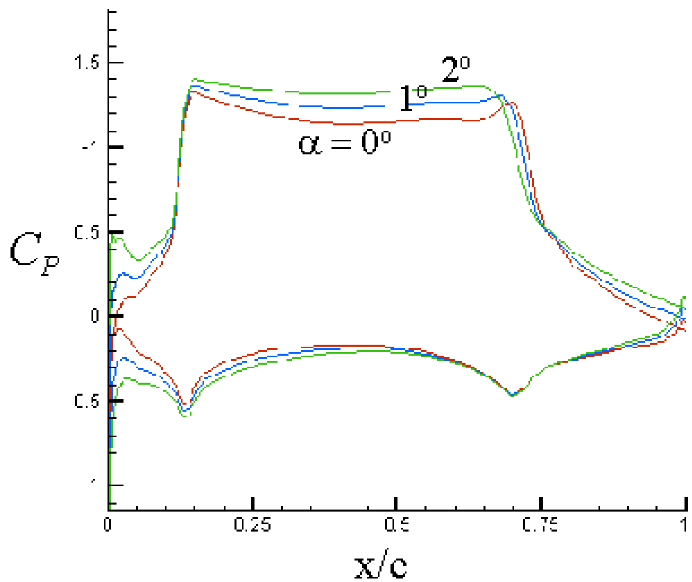

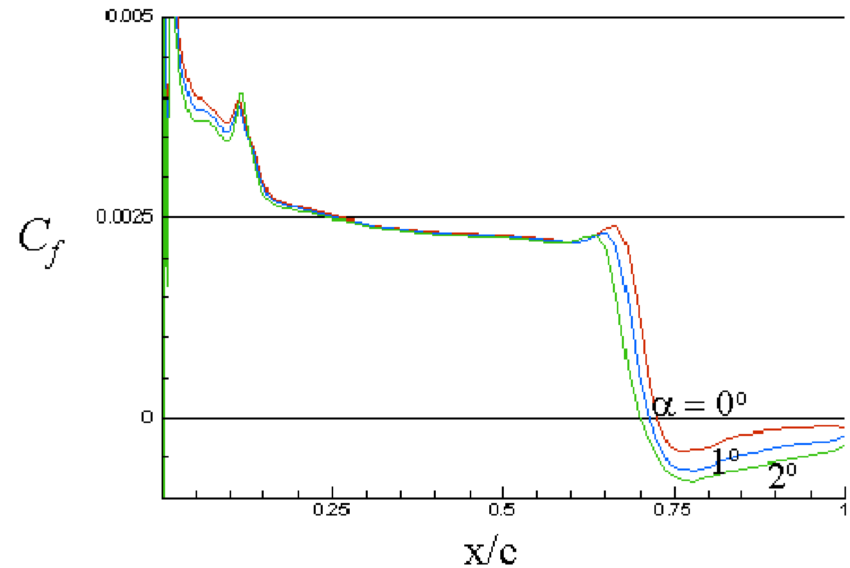

C_P and C_f vs. AOA

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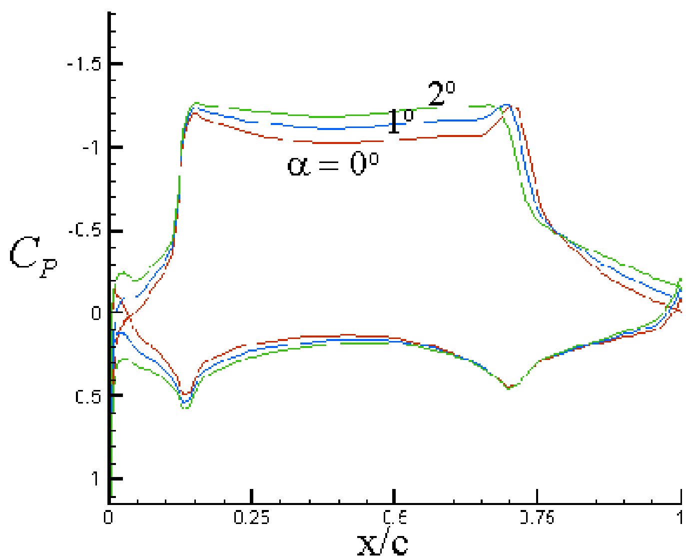
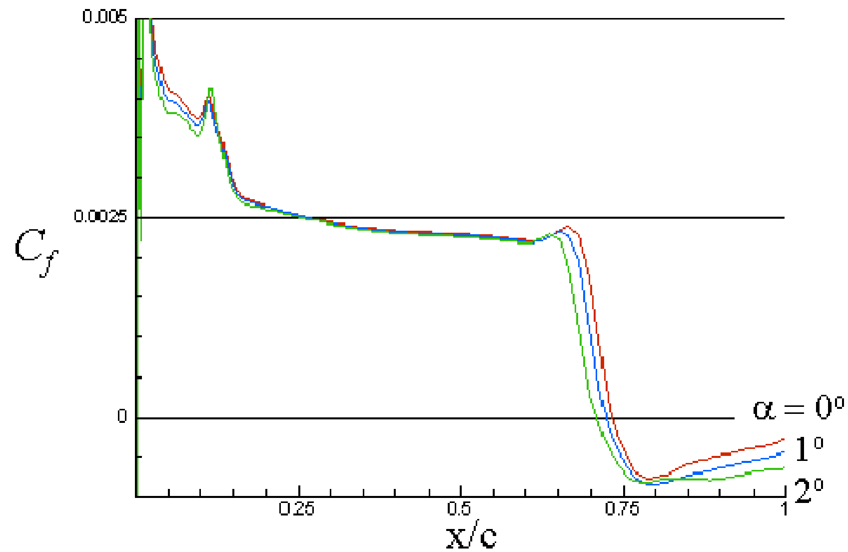
NACA 65A005.7

$M = 0.775$

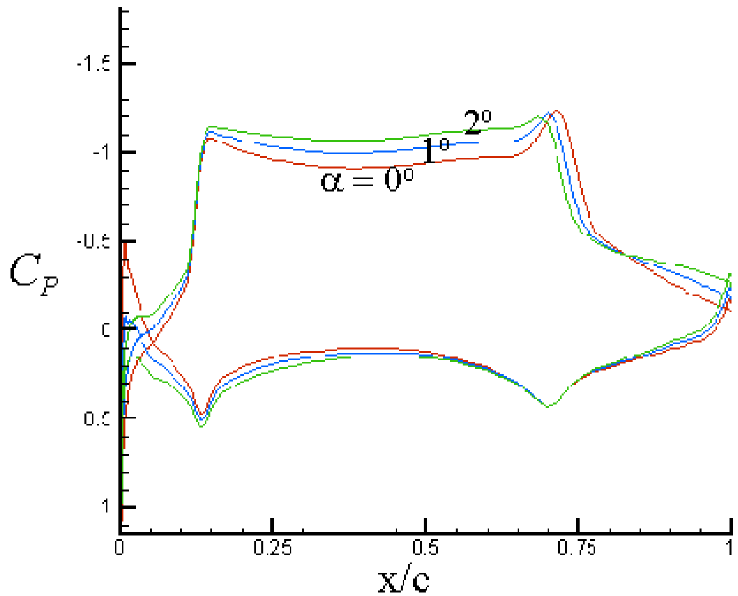


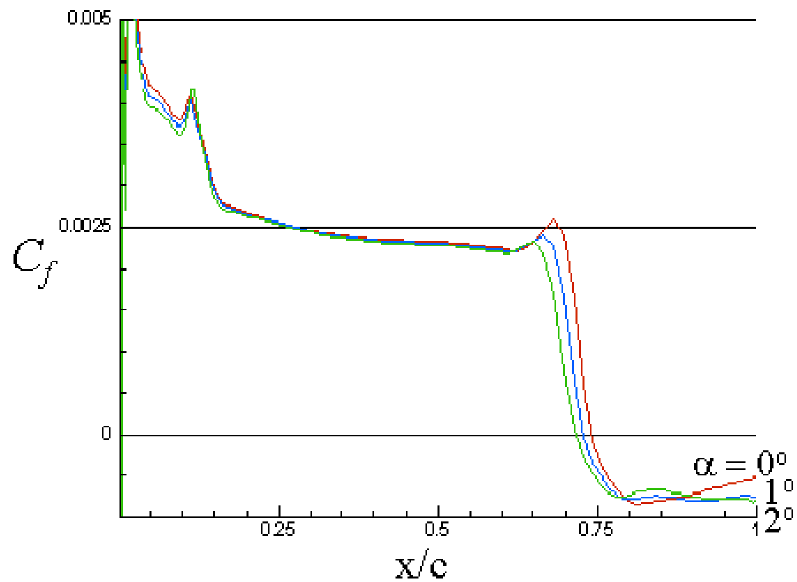


C_P and C_f vs. AOA

NACA 65A005.7

$M = 0.8$





C_P and C_f vs. Mach

NACA 65A005.7

AOA = 0°

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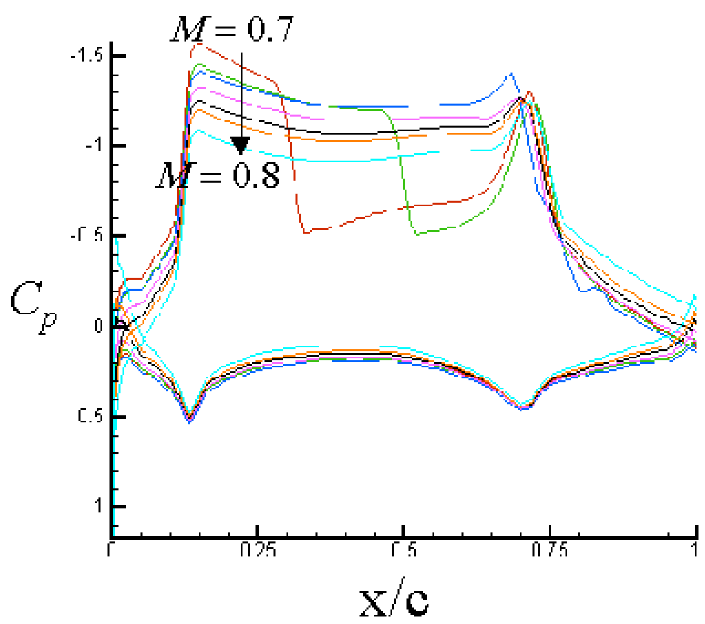
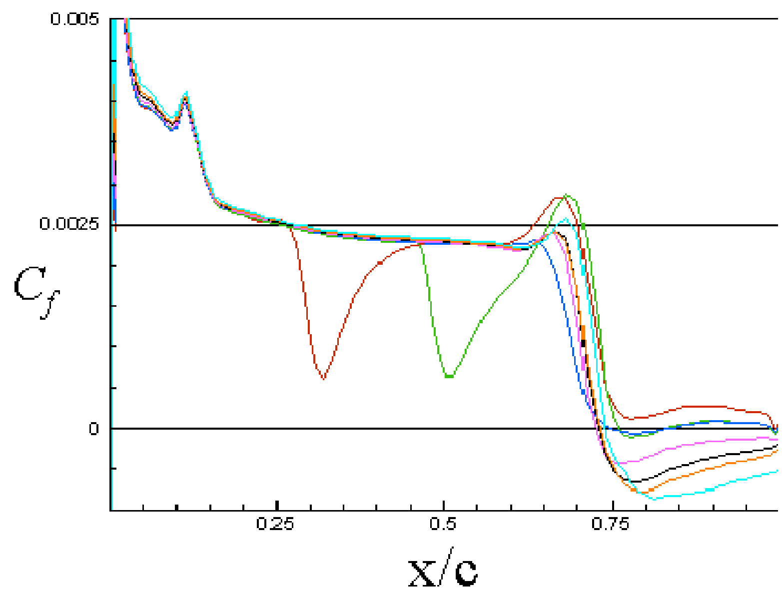
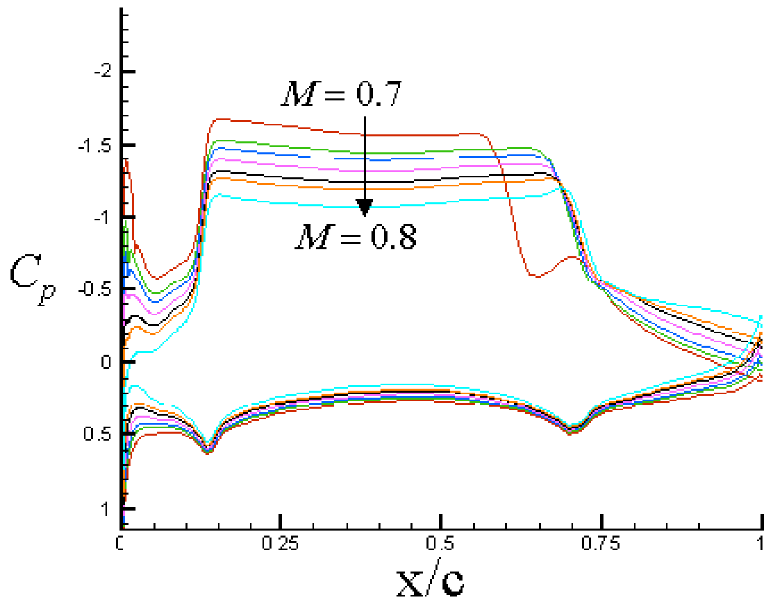


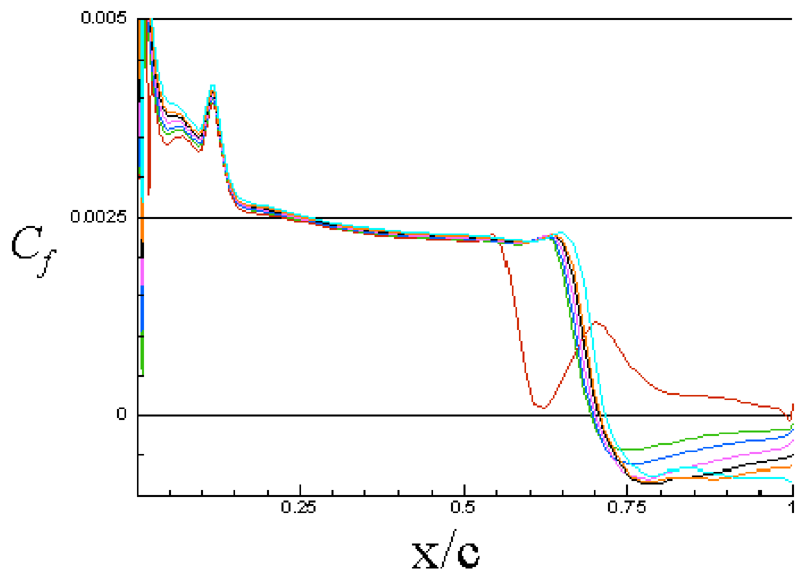


C_P and C_f vs. Mach

NACA 65A005.7

AOA = 2°





Attached and Separated Flow Over the Flap

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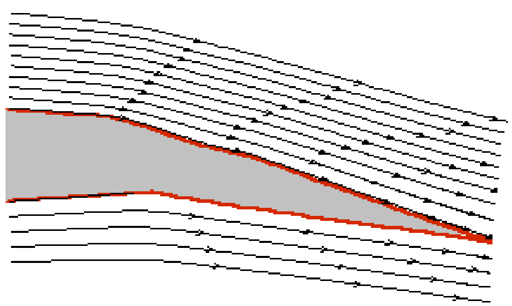
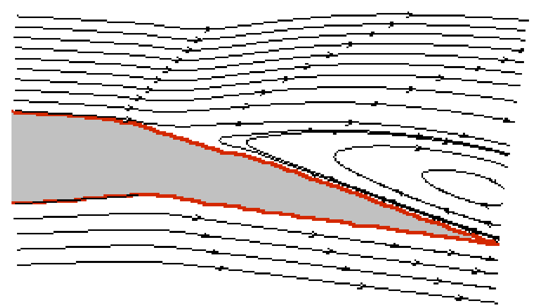
- Skin friction plots show separation occuring at the same location for various conditions
- Streamtraces show the separation region just behind the hinge line
- Flow is pushed upward as the separation region grows

$M = 0.7$
$\alpha = 1^{\circ}$



Attached

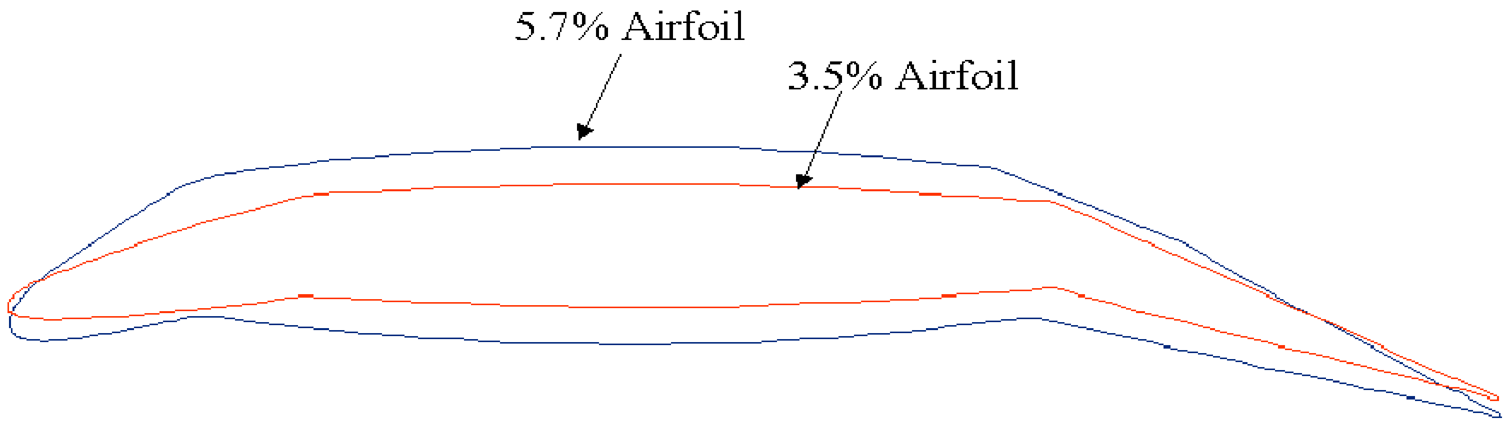
$M = 0.8$
$\alpha = 2^{\circ}$



Separation

Comparative Airfoil

- Data for NACA 65A005.7 is inconclusive
  - No sign of abrupt shock movement
  - Separation confined to trailing-edge flap
- Compare results to similar airfoil from a wing that does not exhibit wing drop characteristics
  - NACA 65A003.5 (t/c = 3.5%)
  - Different device deflections



C_P and C_f vs. AOA

$M = 0.725$

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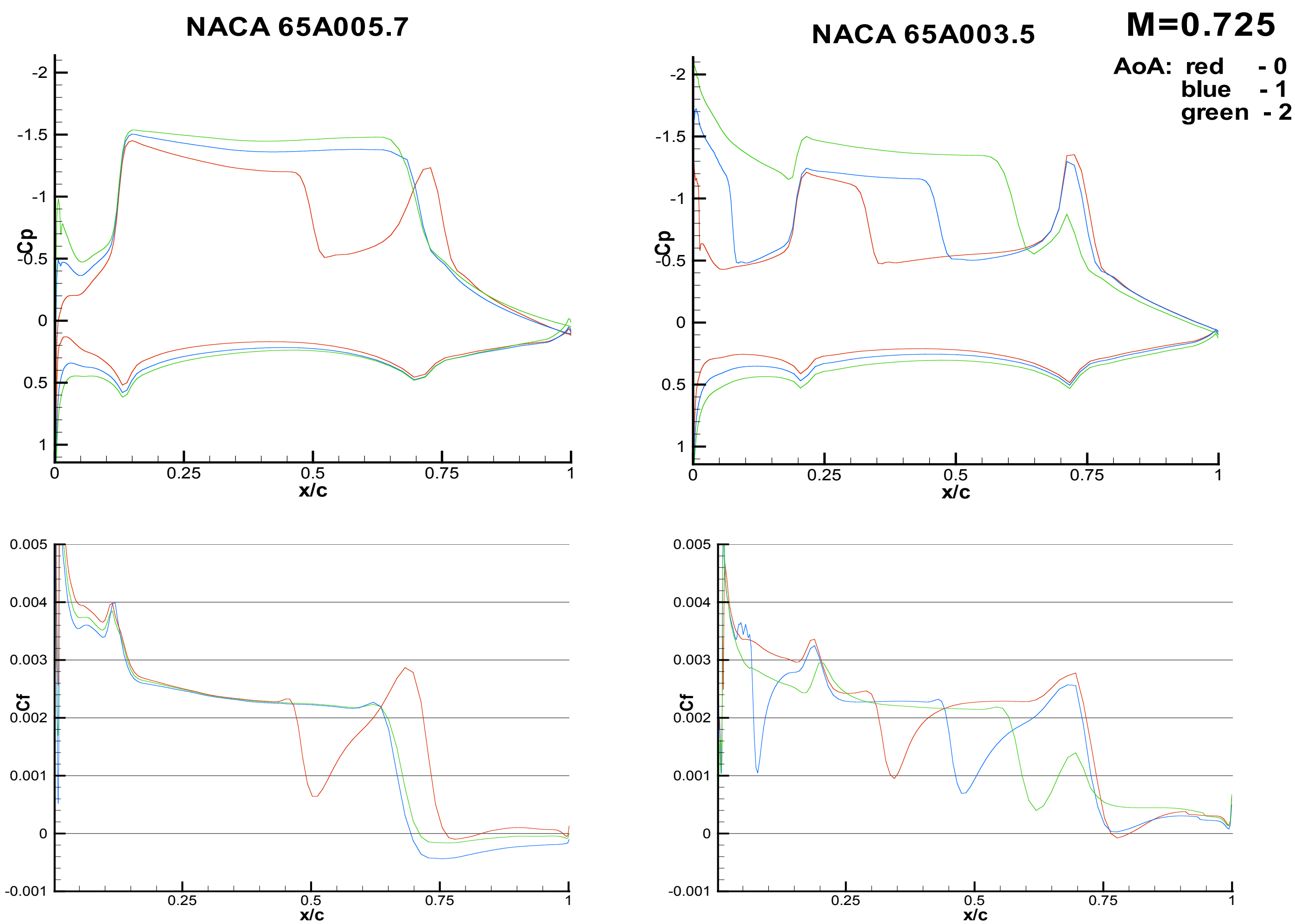

C_P and C_f vs. AOA
$M = 0.75$

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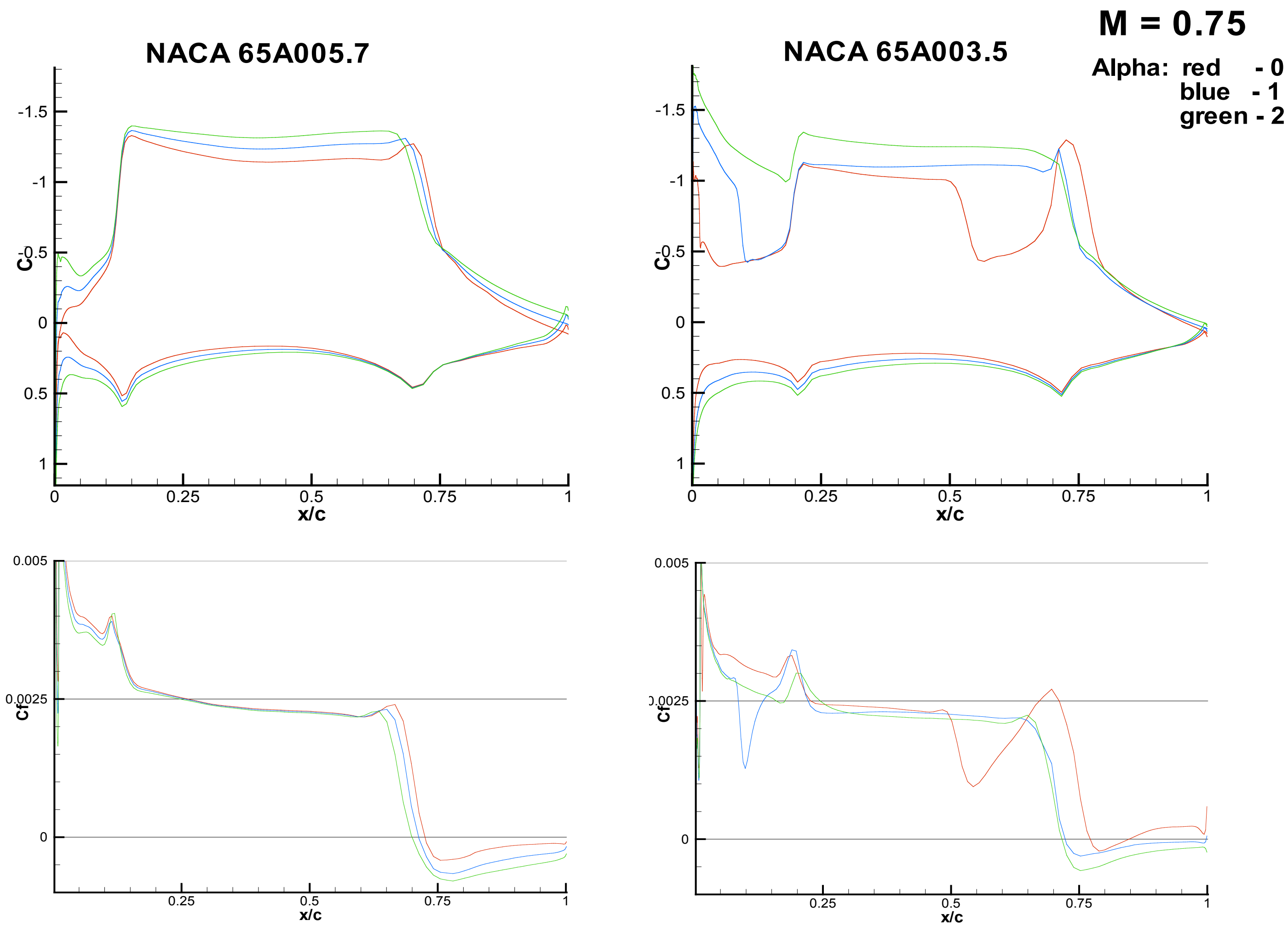

C_P and C_f vs. AOA

$M = 0.775$

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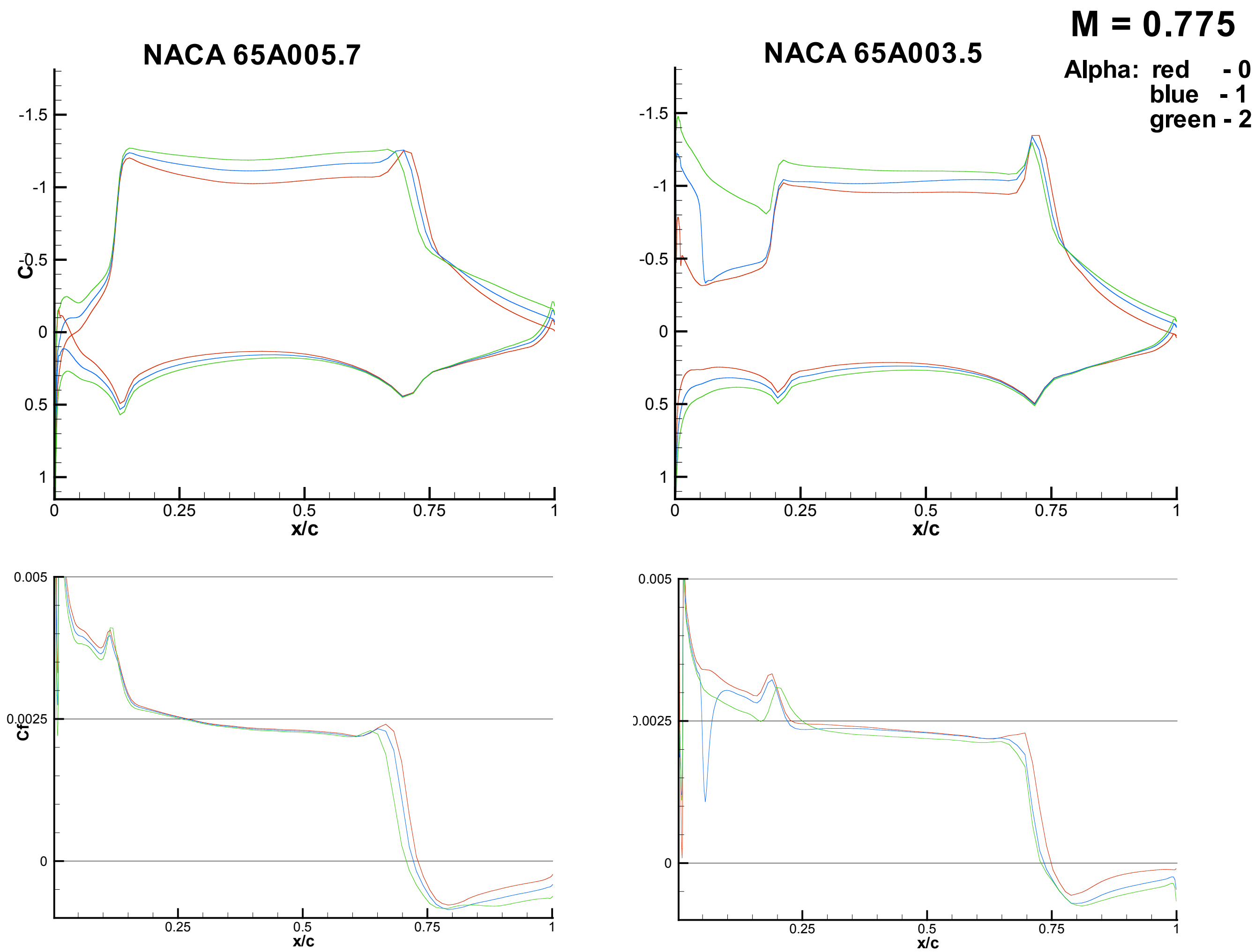


Conclusion for Comparison

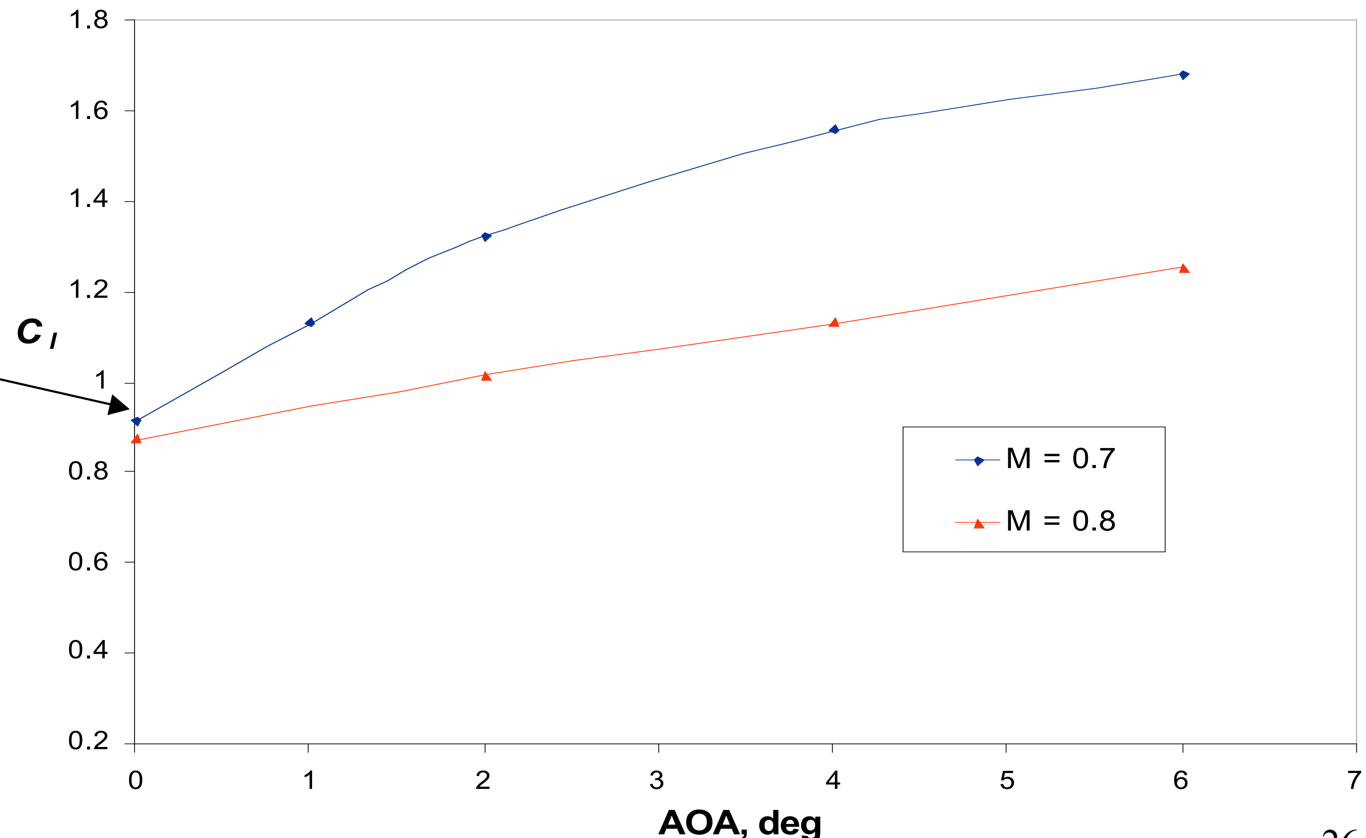
- Behavior of the shock for the two airfoils is similar except that it happens at different Mach numbers. This is most likely the result of the difference in **thickness.**

C_l vs. AOA

NACA 65A005.7

Airfoil is operating at conditions near C_{Lmax}

3-D value



Device Deflection Effectiveness

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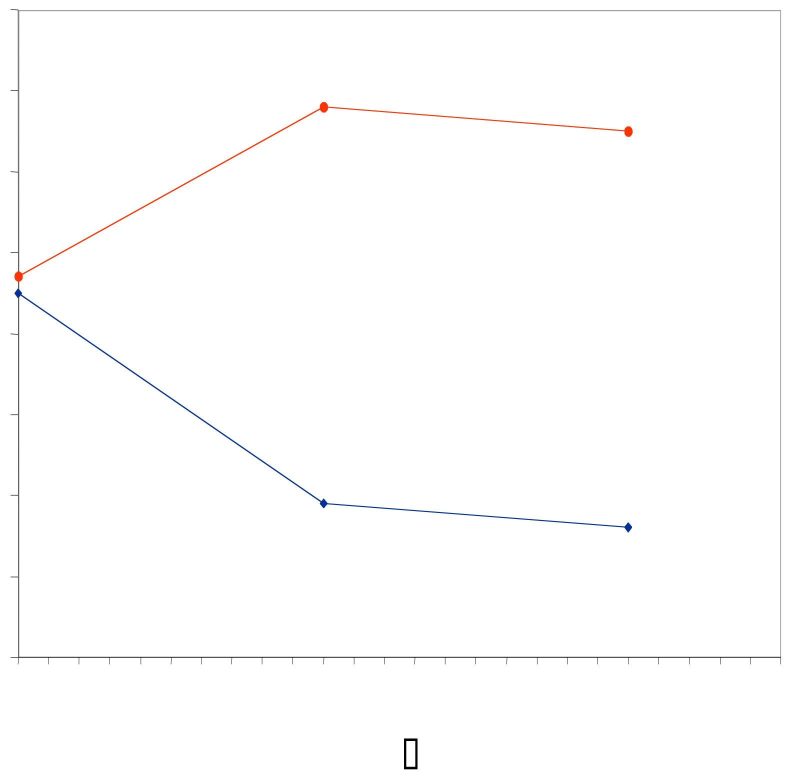
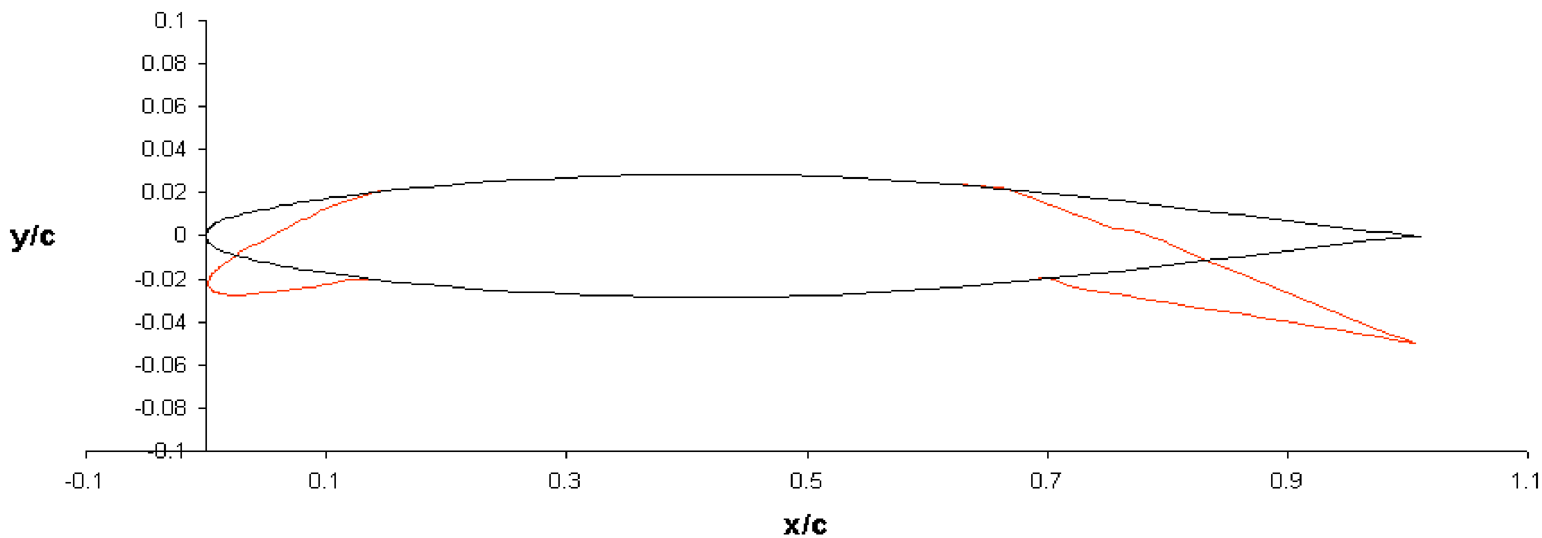
- Shock behavior at hinge line raises curiosity
  - Confines separation to the flap surface
  - Opposes shock behavior of 3-D wing
- Wish to determine the impact of device deflections on shock movement



Cambered and Uncambered Airfoils

- Previous results compared to uncambered (undeflected) NACA 65A005.7 airfoil
- Symmetric airfoil requires higher AOA to produce similar C_l values



C_P and Shock Movement vs. AOA for Symmetric Airfoil

$M = 0.8$

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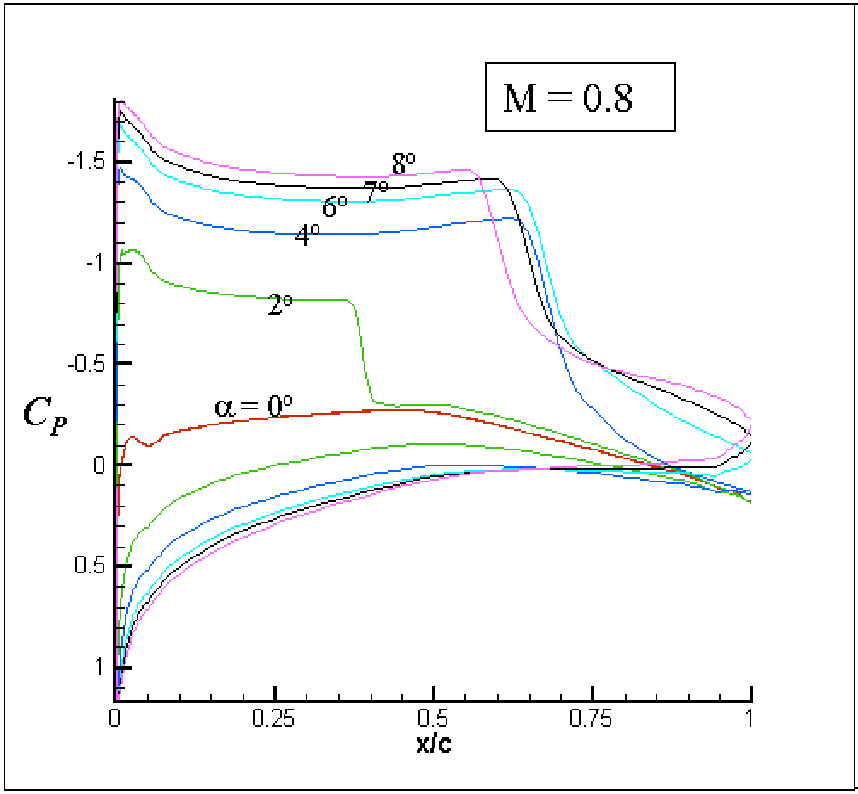
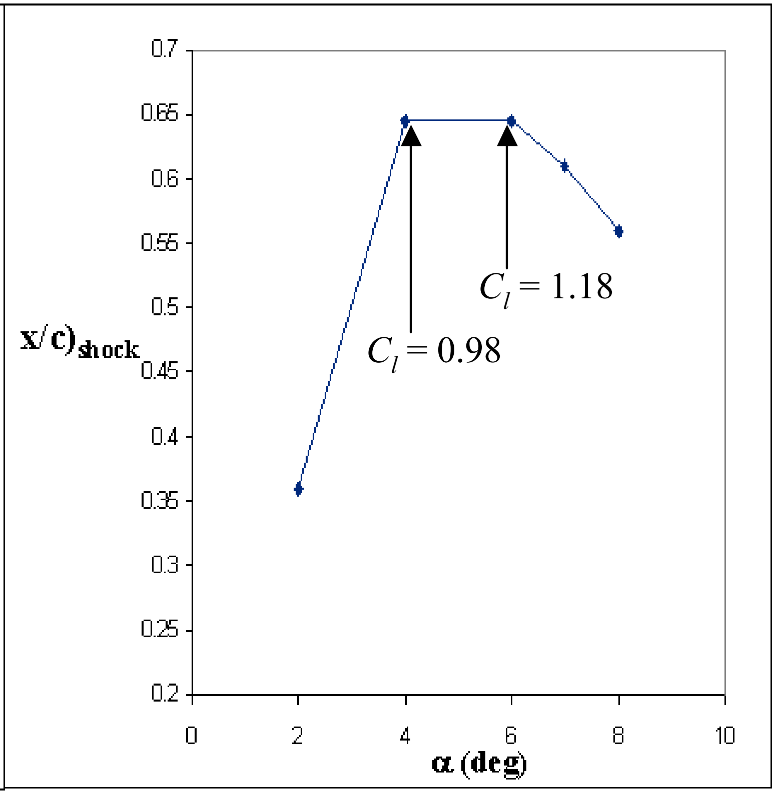
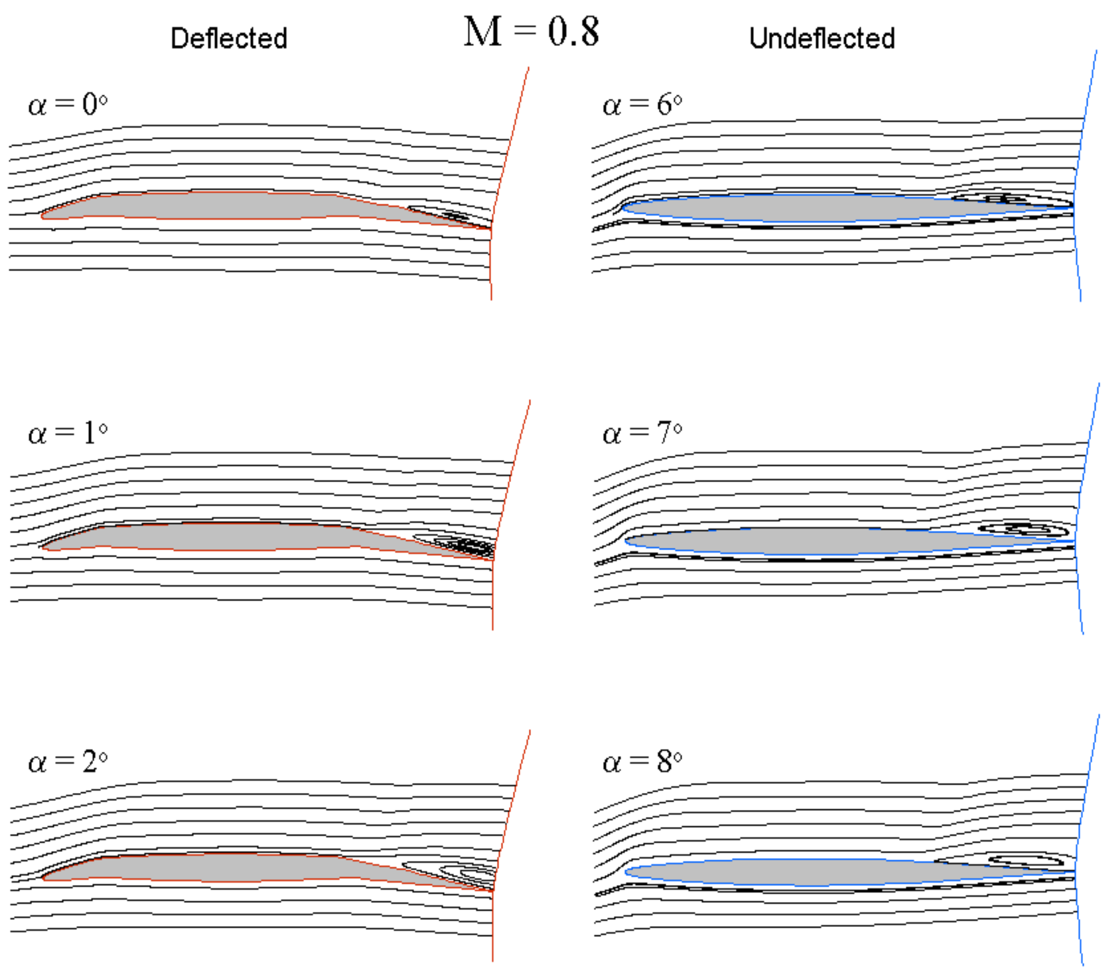




Cambered and Uncambered Streamline Comparison



Conclusions

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- Two-dimensional shock moves in the opposite direction as that of the Three-dimensional wing
  - Separation phenomenon which pushes the shock forward on the 3-D wing is not present on the 2-D airfoil
- Without 3-D effects the separation bubble is confined to the region aft of the hinge line at low AOA's
- The NACA 65A005.7 airfoil does not exhibit any tendency to abrupt shock movement, forward or rearward
- In the 2-D case a deflected trailing edge minimizes the adverse effect of the separation region on the inviscid flow, thus preventing the shock from being pushed forward

- The abrupt shock movement forward is a 3-D effect