Exploration of a Slotted Airfoil Laminar-Flow-Control Concept

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NASA Aeronautics Research Institute

Objectives

SNLF Airfoil, S414

To better understand the aerodynamics and explore the practicality of the Slotted, Natural-Laminar-Flow (SNLF) airfoil concept via wind-tunnel tests.

To compare the SNLF concept with Laminar-Flow Control (LFC) using suction.

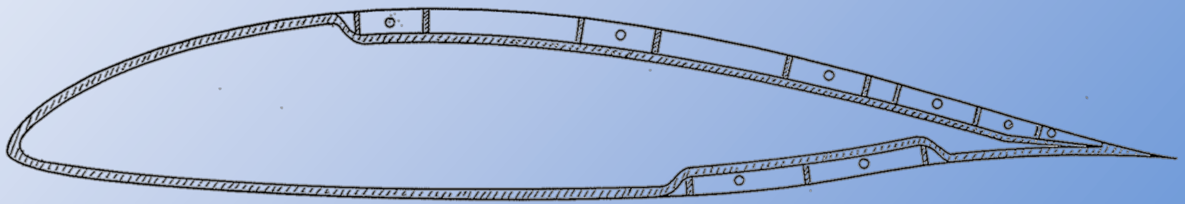
To develop and validate design tools for both SNLF and LFC airfoils.

Motivation

Recent reawakened interest in laminar-flow technologies owing to rising fuel costs.

Provide data to better to assess the practicality of the SNLF concept.

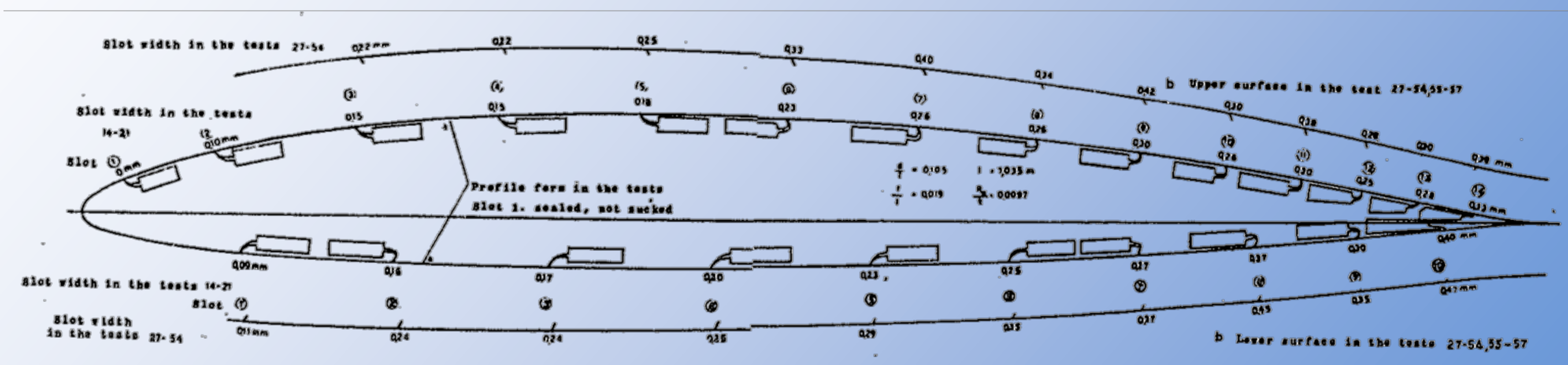
Drag reduction potential without the complexities of active LFC approaches such as suction.



DLR LFC (Suction) Airfoil

Innovation

Passively achieve drag reductions roughly equivalent to LFC concepts without power, complex active mechanisms, and extensive ducting.



Pfenninger, Zurich, 1946
Slot Suction, R = 1.0 to 6.0 million

Technical Approach

Explore the effect of different positions and deflections of the aft element of the S414 SNLF airfoil.

Examine high-lift behavior as well as aileron/flap viability.

Measure the drag penalty associated with the aft element mounting brackets.

Validation of theoretical design and analysis tools.

Comparison of the SNLF and LFC concepts.

Impact

If found practical, the SNLF airfoil concept could have a major impact on laminar-flow wing design for many different categories of flight vehicles.

The SNLF concept promises performance benefits comparable to LFC, but with less complexity and lower cost

Penn State Low-Speed, Low-Turbulence Wind Tunnel

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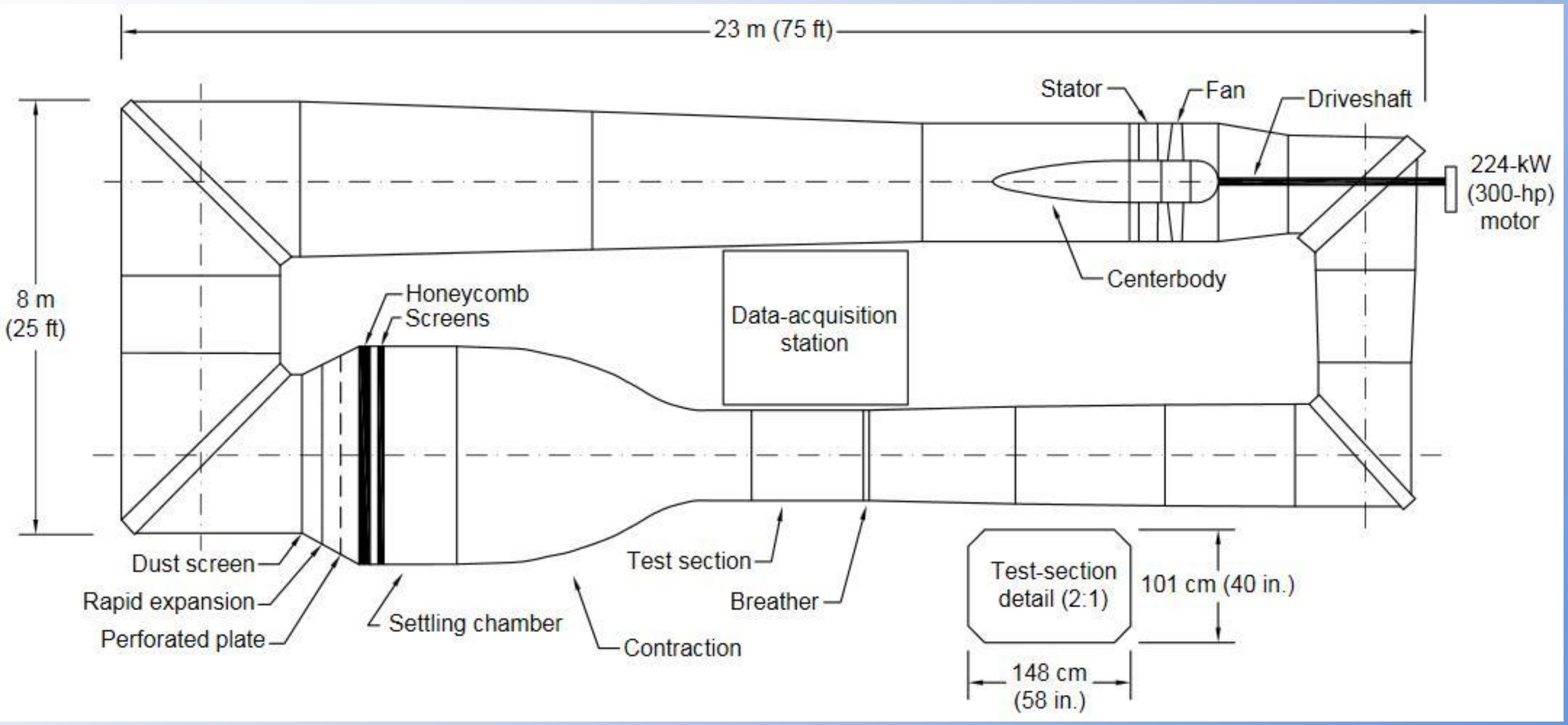
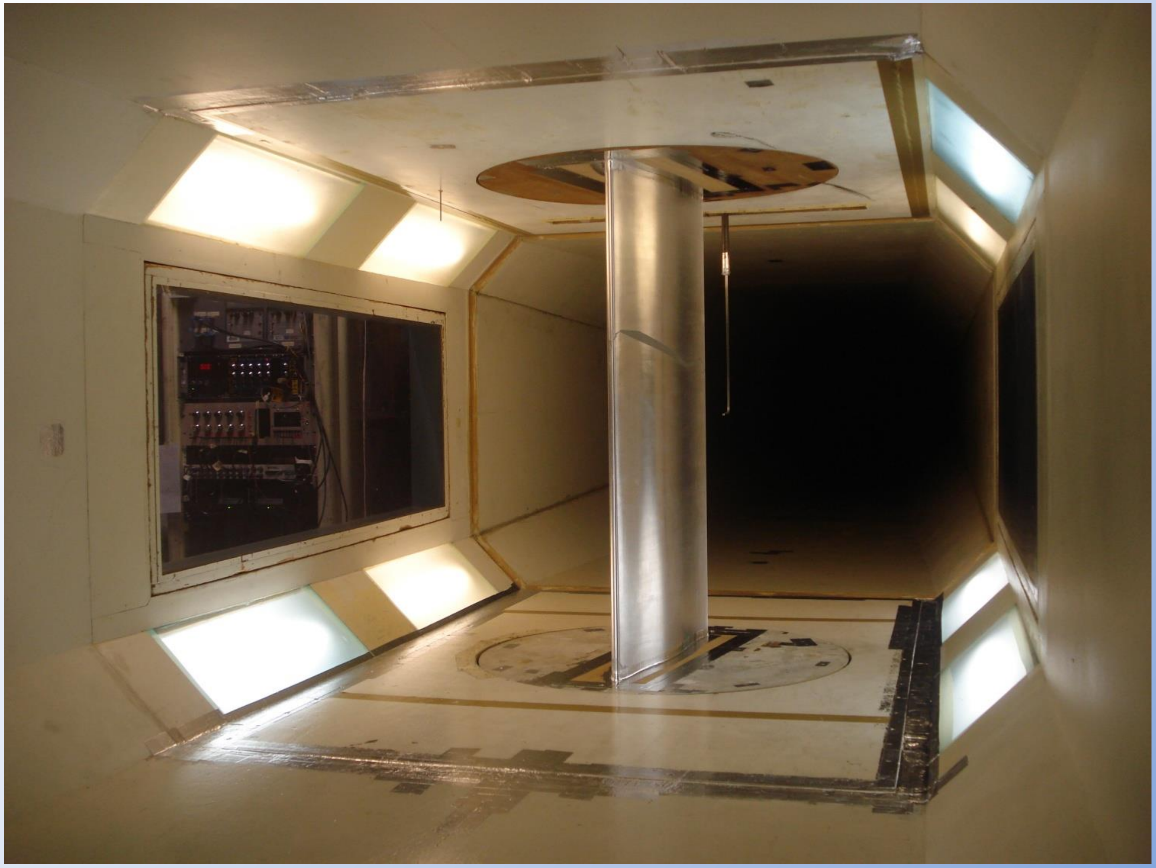


Penn State Low-Speed, Low-Turbulence Wind Tunnel



Test Section Size
3.3 ft by 5.0 ft
Max Test Speed
220 ft/sec
Reynolds Numbers
0.06 to 2.0 million
Turbulence Intensity
below 0.045%

Qualification of the Penn State Low-Speed, Low-Turbulence Wind Tunnel - Comparison w/ NASA Langley Low-Turbulence Pressure Tunnel

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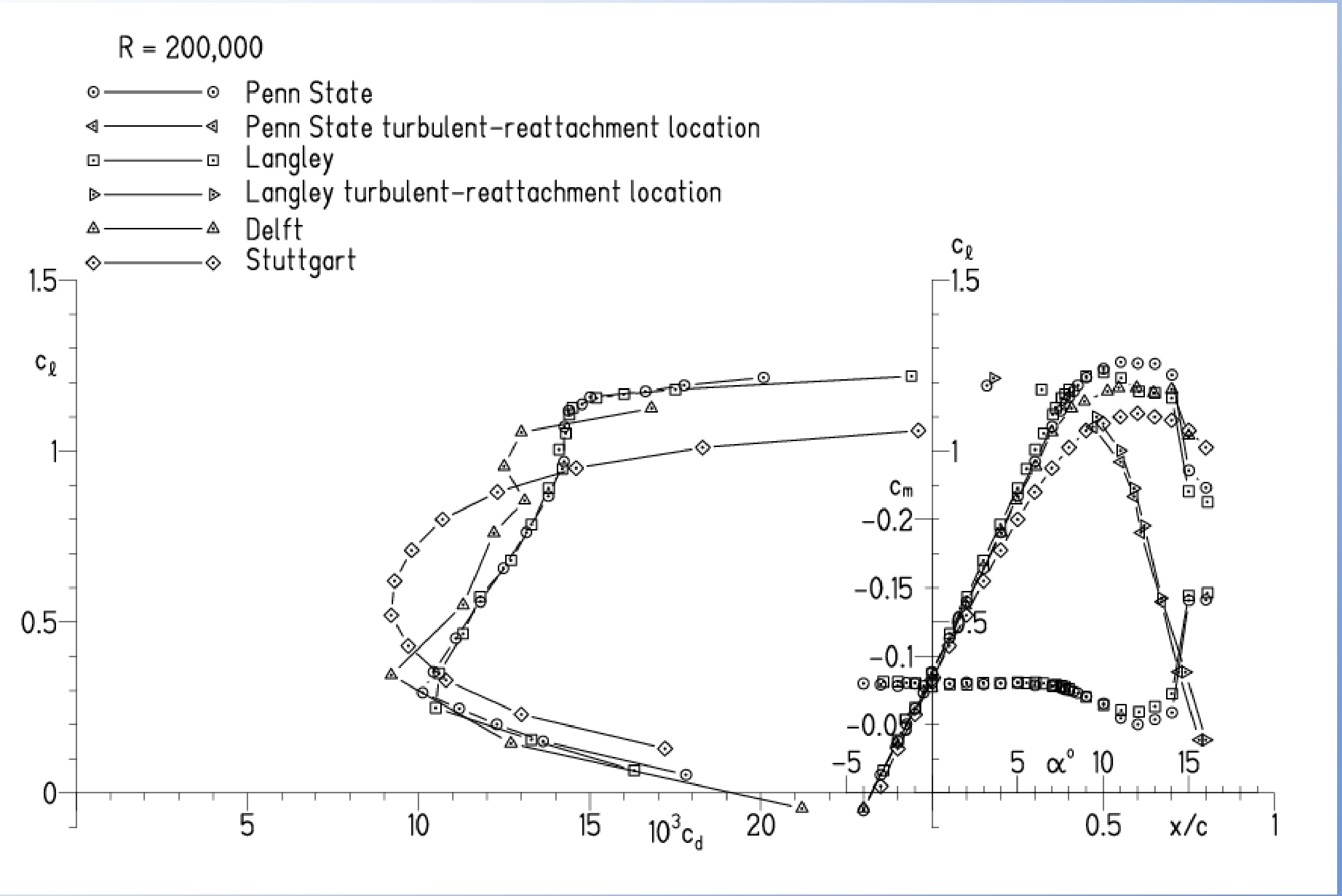

Excellent agreement: R = 60,000 to 460,000

Qualification of the Penn State Low-Speed, Low-Turbulence Wind Tunnel - Comparison w/ TU Delft Low-Speed Tunnel

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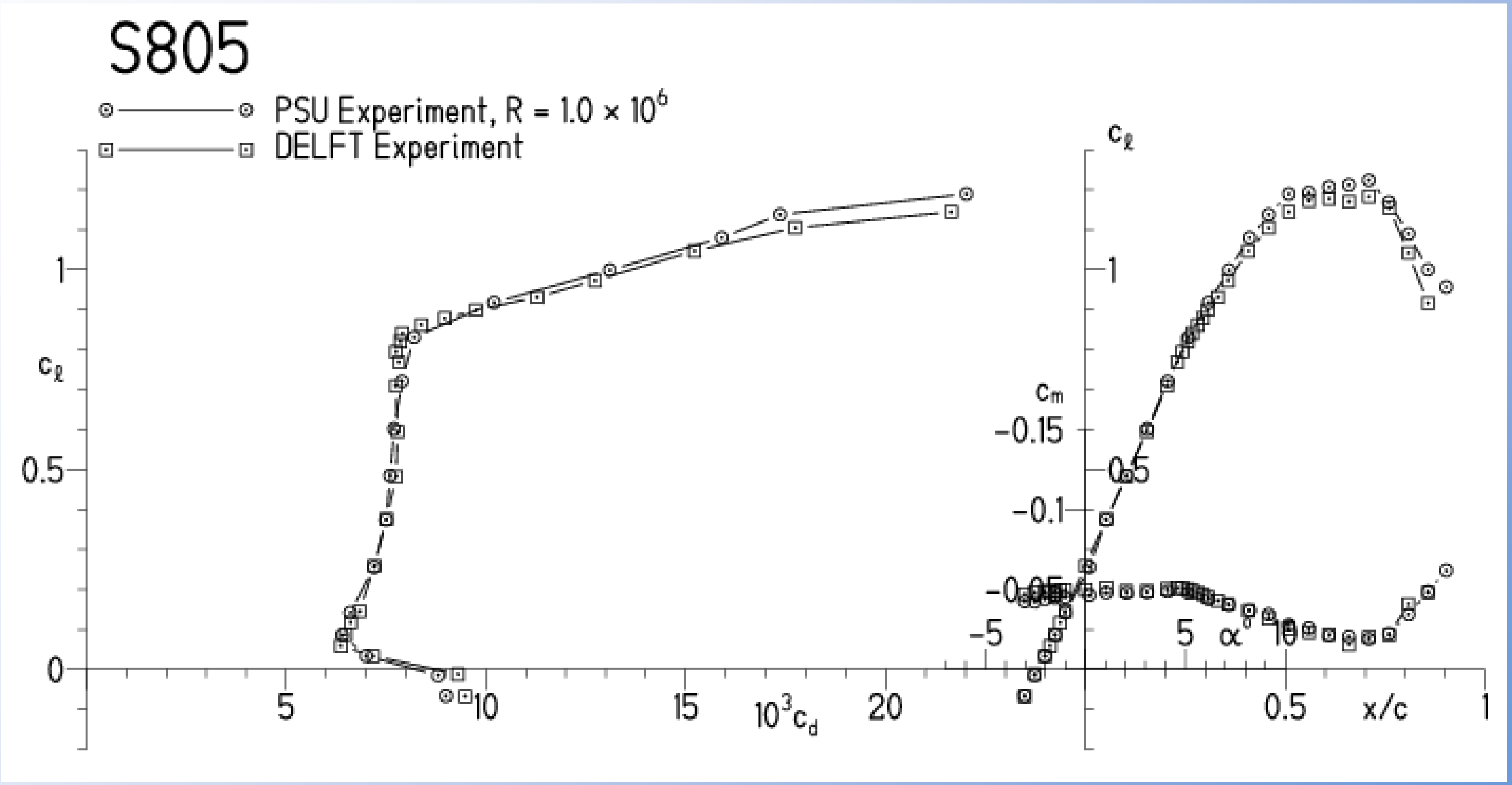

Excellent agreement: R = 700,000 to 1,500,000

SNLF Airfoil Model

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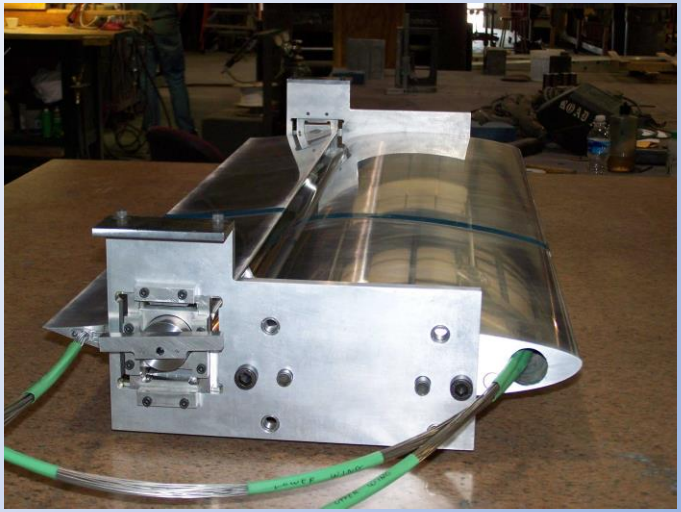

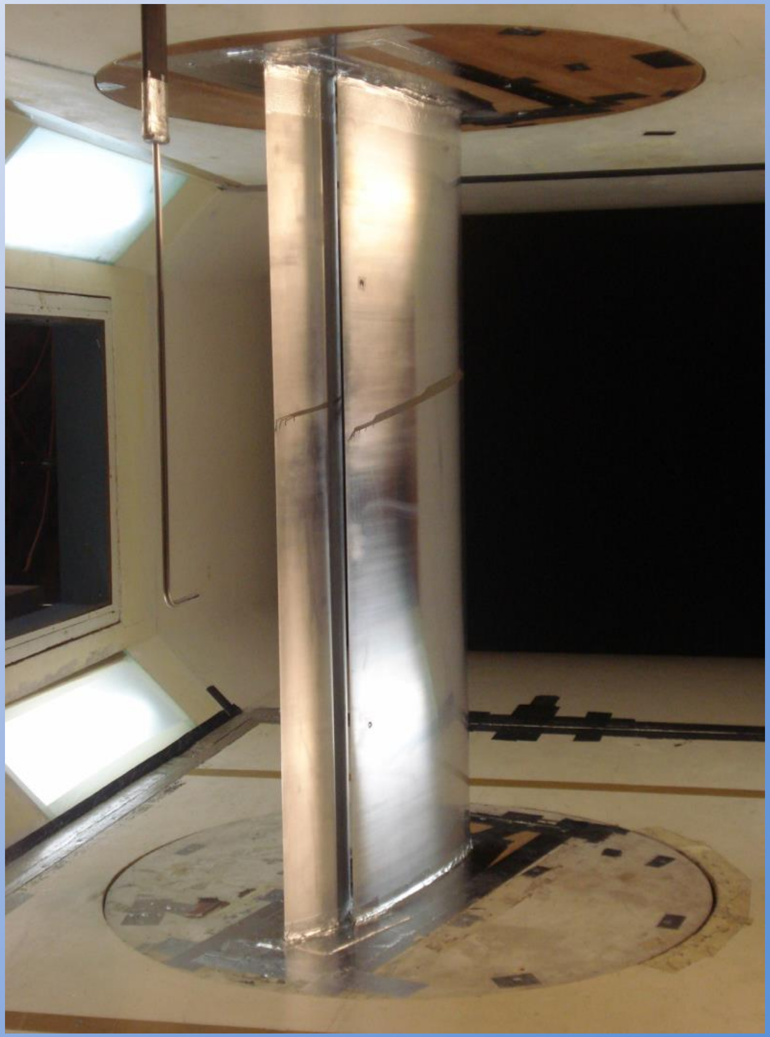

Baseline Aerodynamic Characteristics 2009 and 2013

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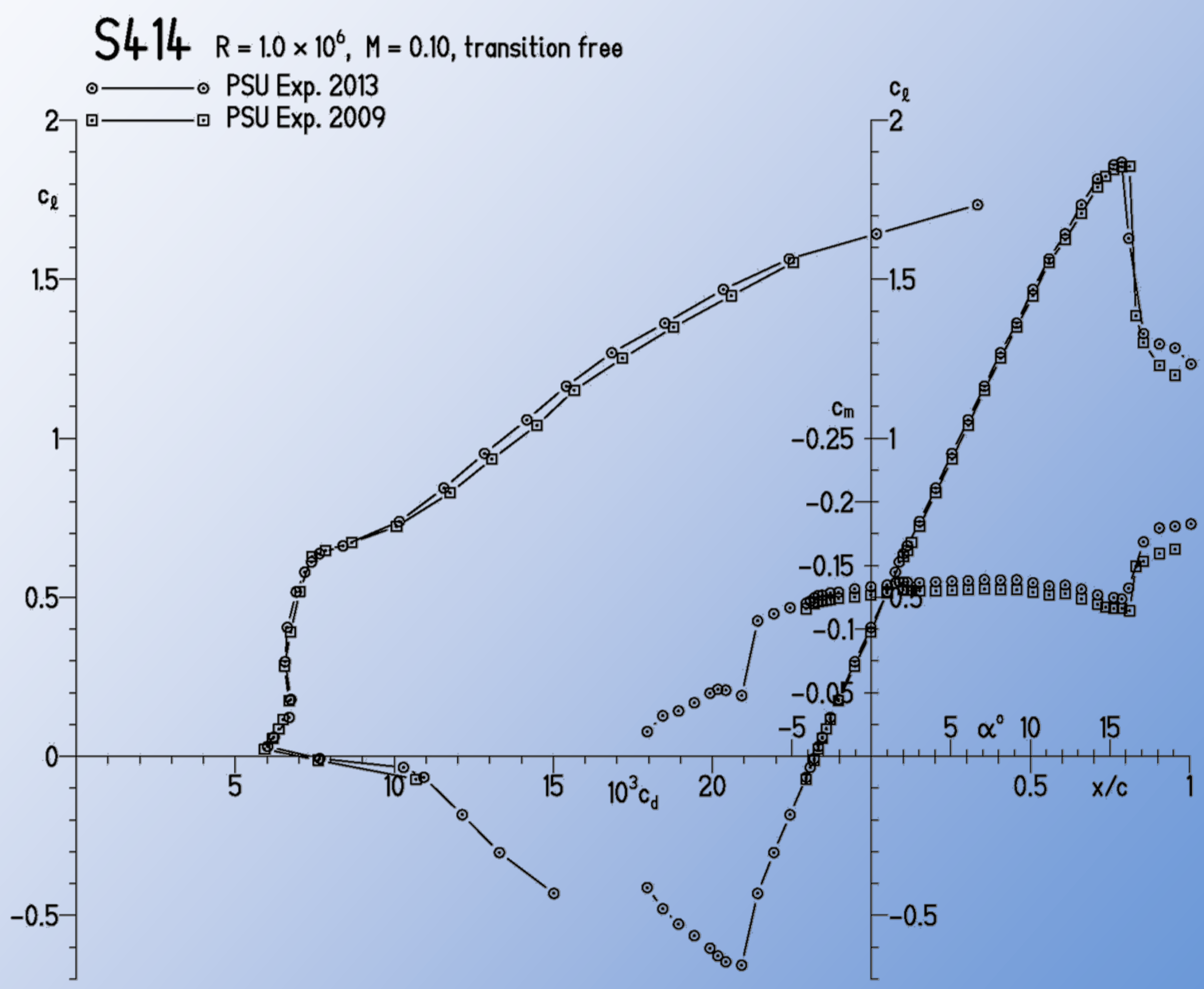
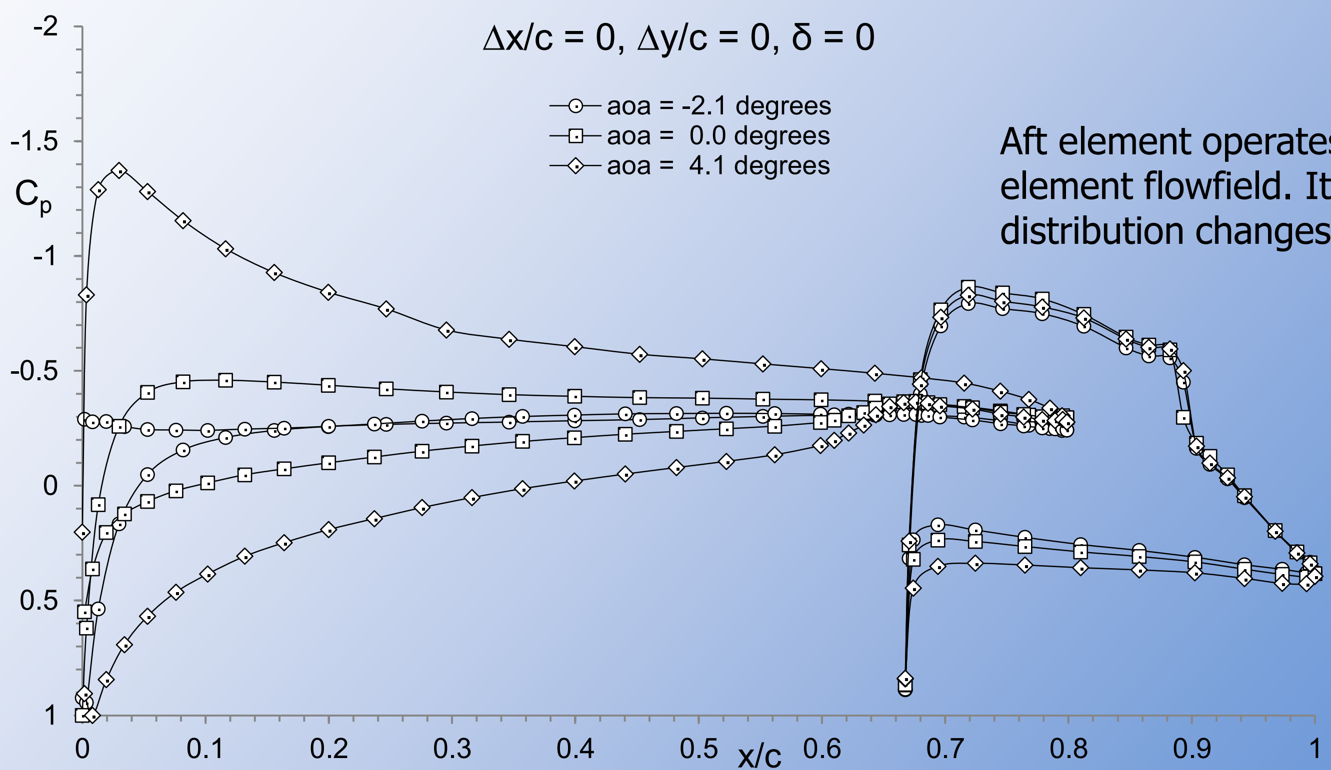


Baseline Pressure Distributions



Aft element operates in fore element flowfield. Its pressure distribution changes very little.

Baseline Pressure Distributions

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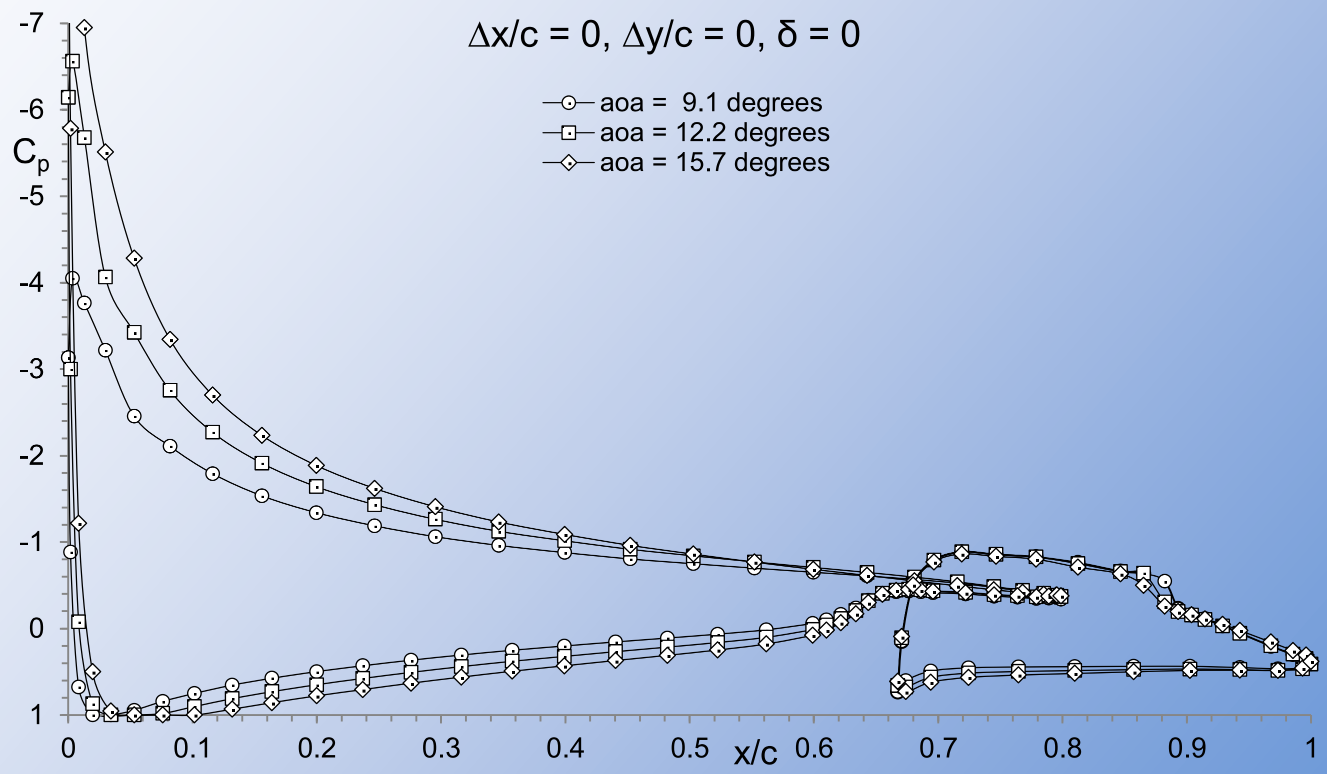

Aft Element Position and Deflection Schedule

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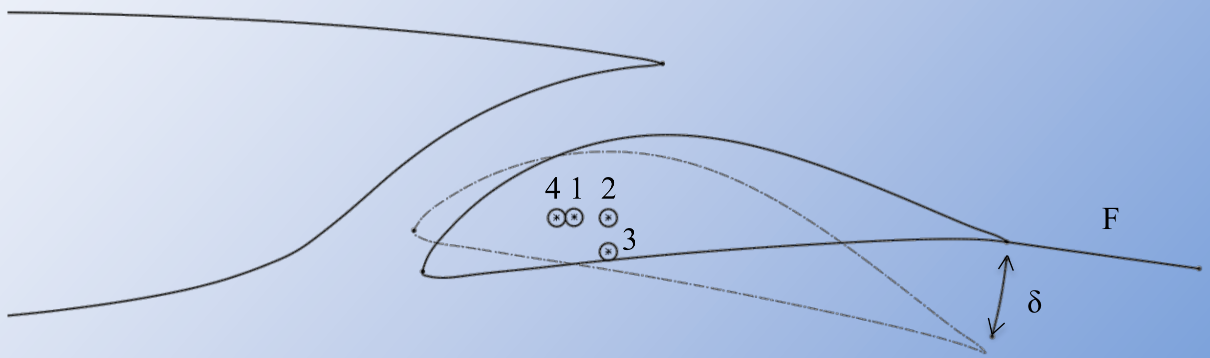
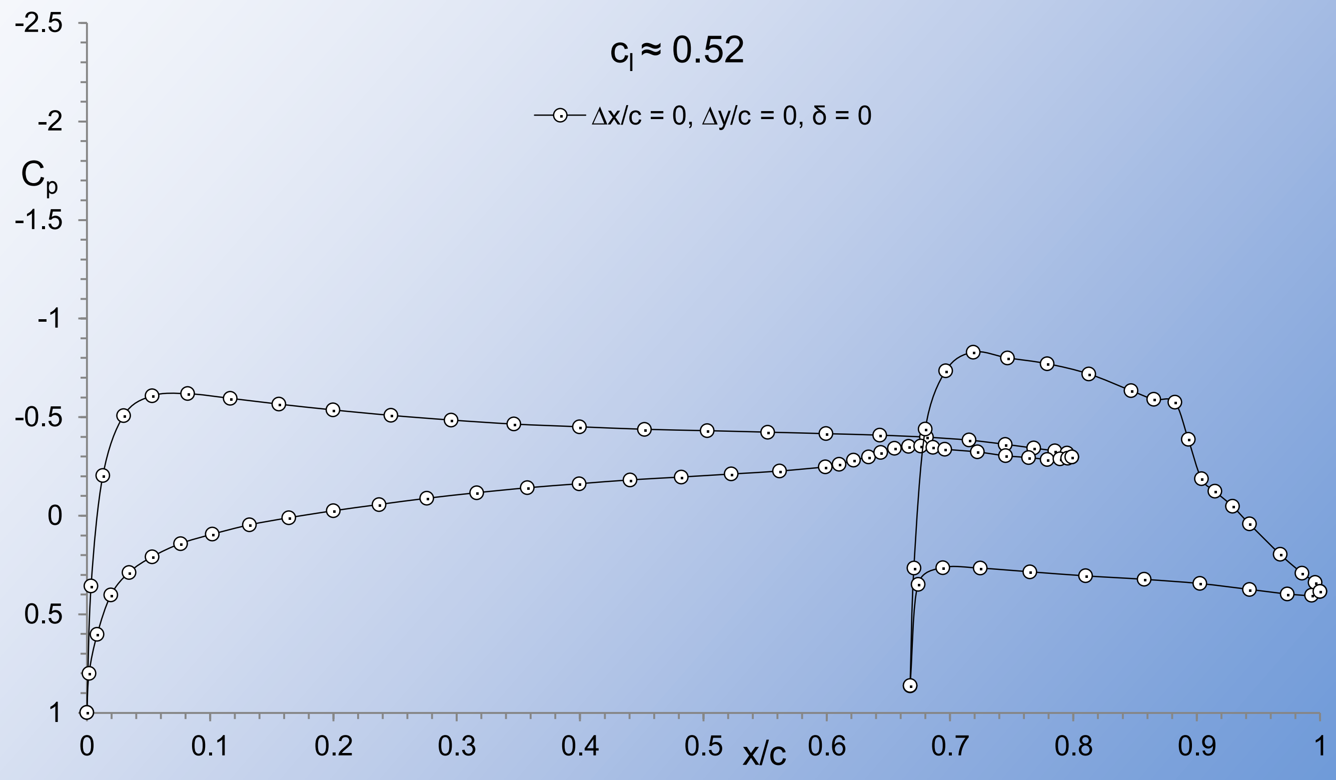
Position	δ							F		
1	0	1	5	10	-5	-10	-15			
1+F	0							3.5	22.5	17
2	0	5	10							
3	2	5								
4	0									



Baseline Pressure Distributions

NASA Aeronautics Research Institute



Pressure Distributions

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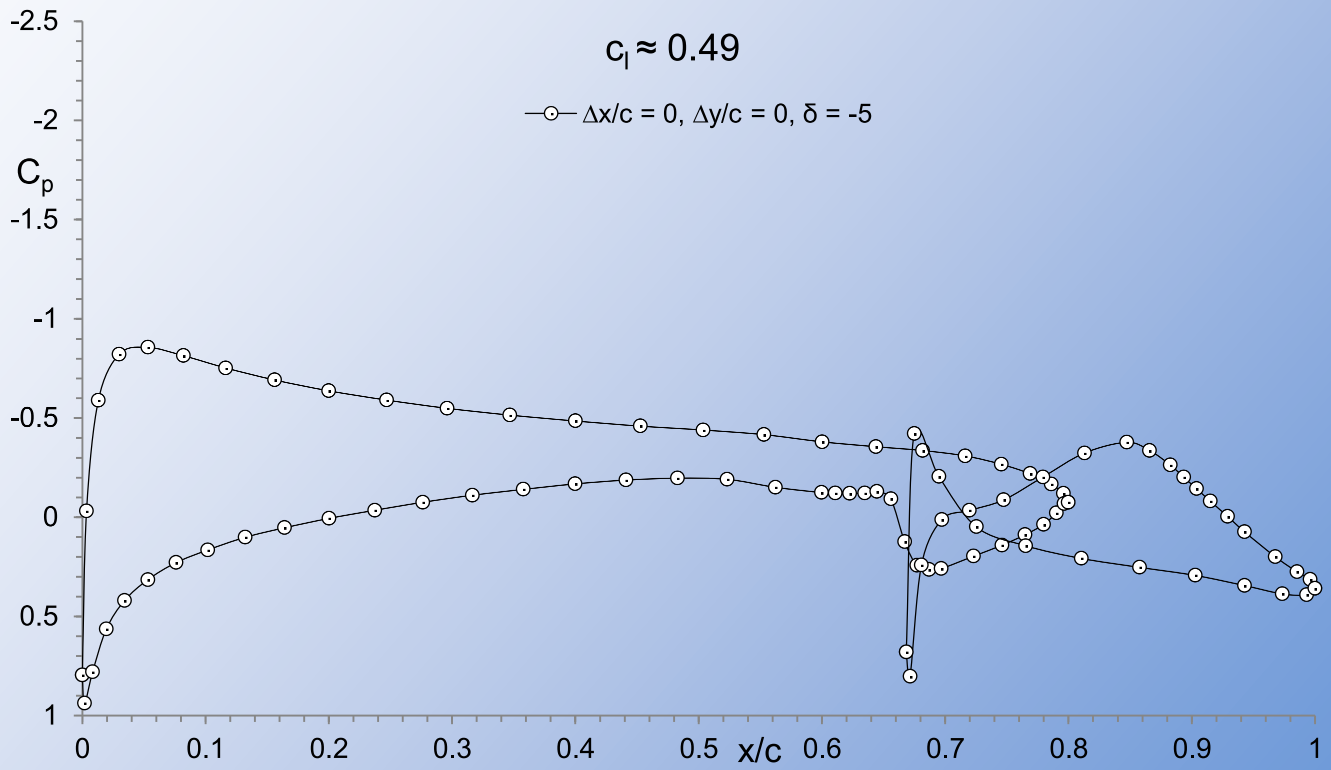

Pressure Distributions

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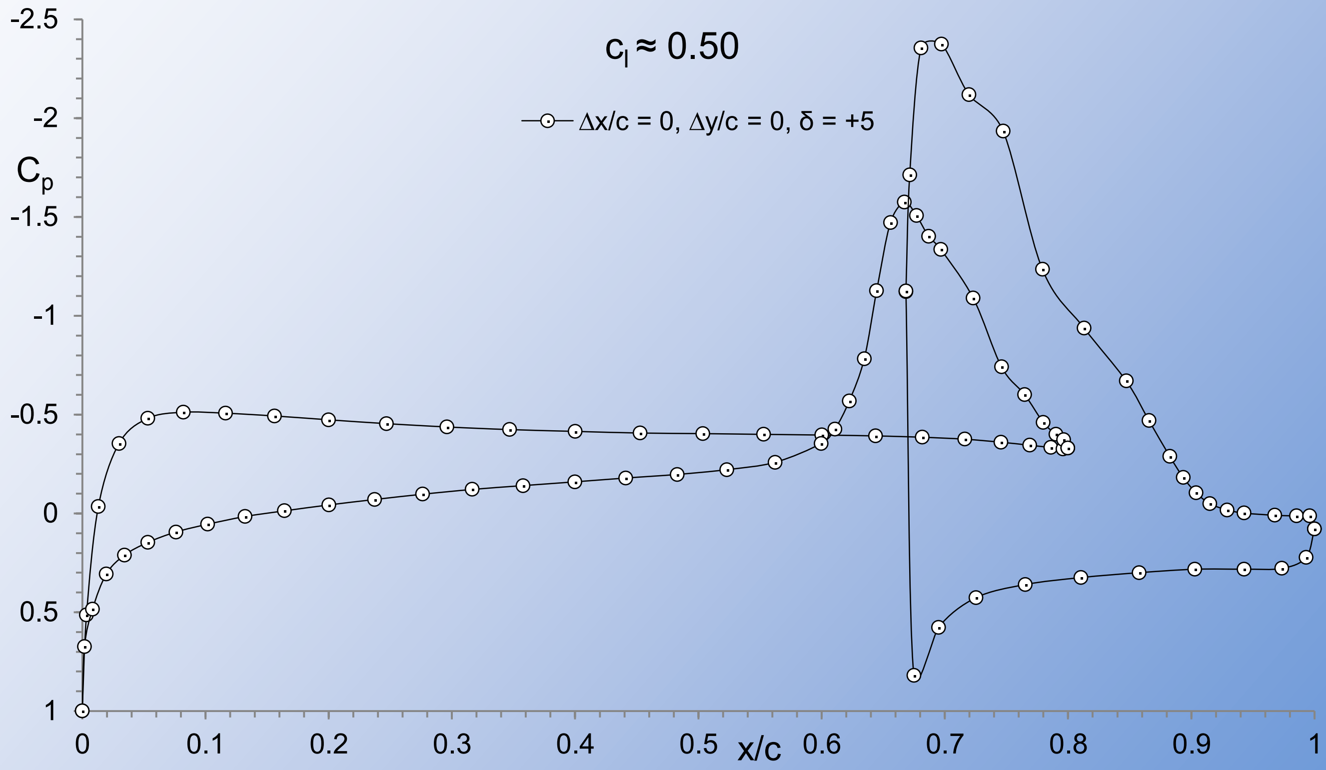

Aerodynamic Characteristics

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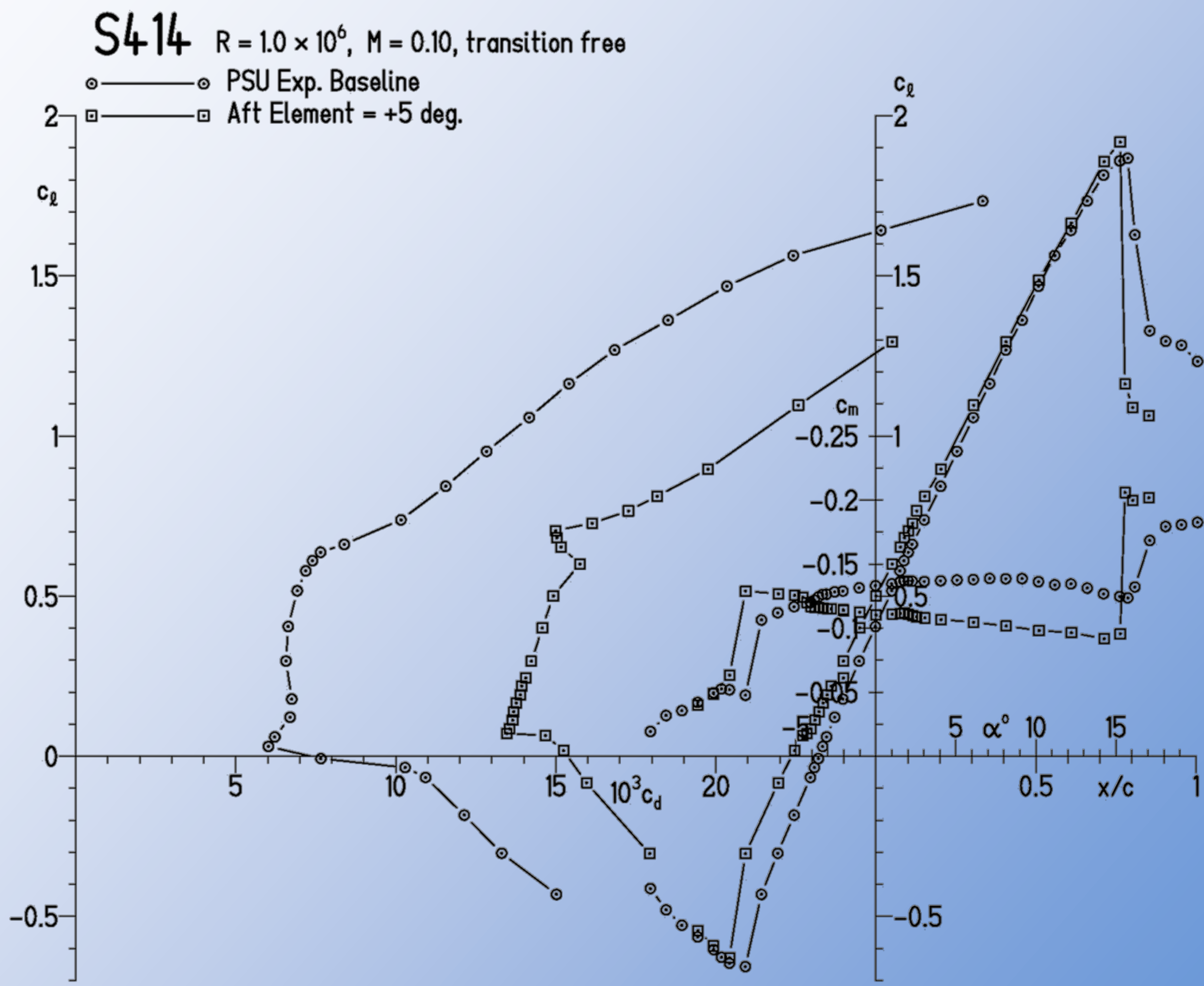
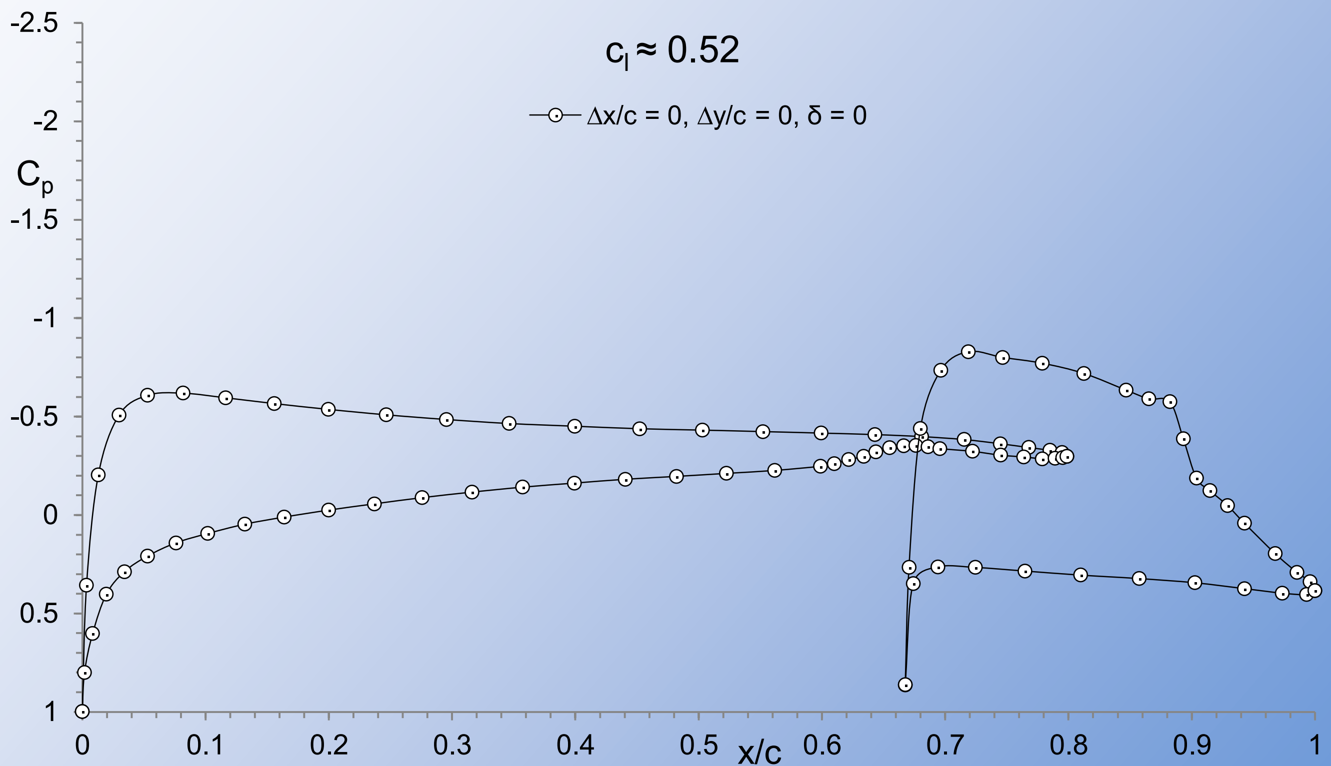
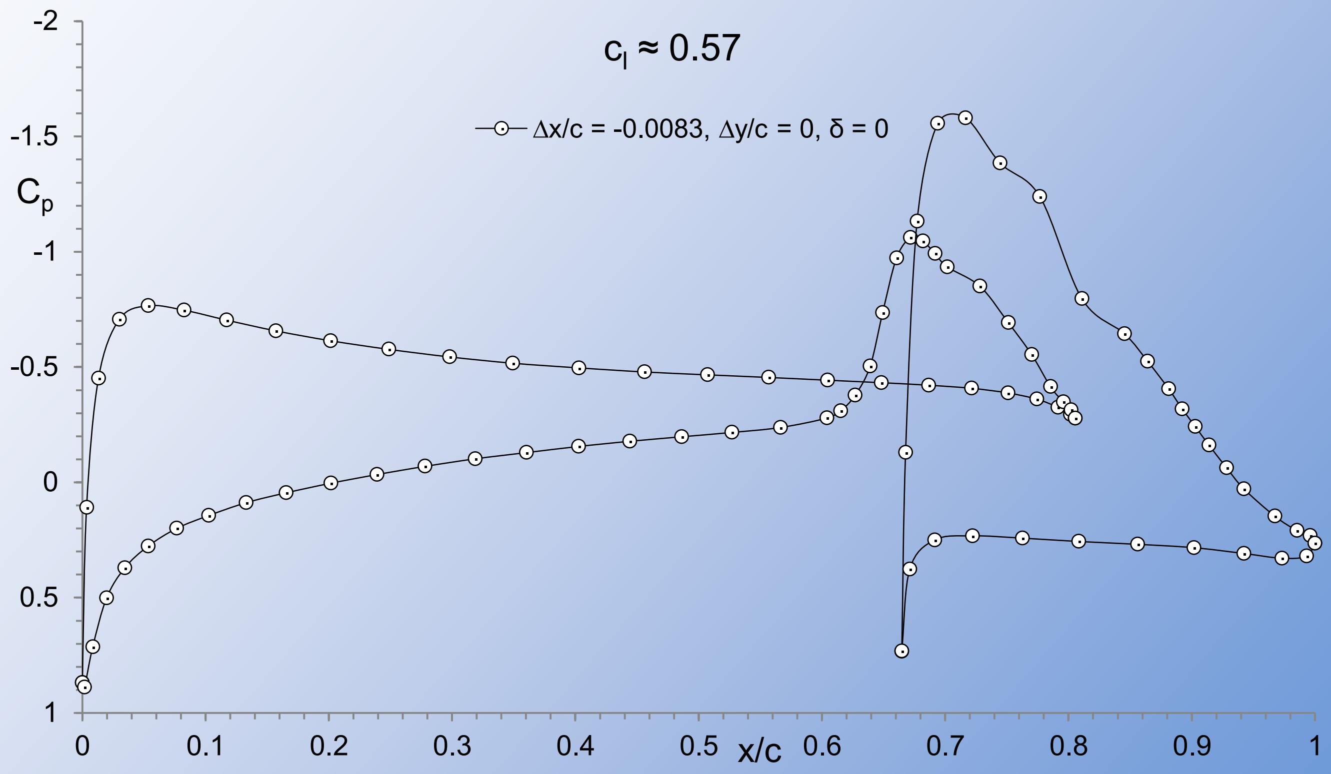


Baseline Pressure Distributions

NASA Aeronautics Research Institute

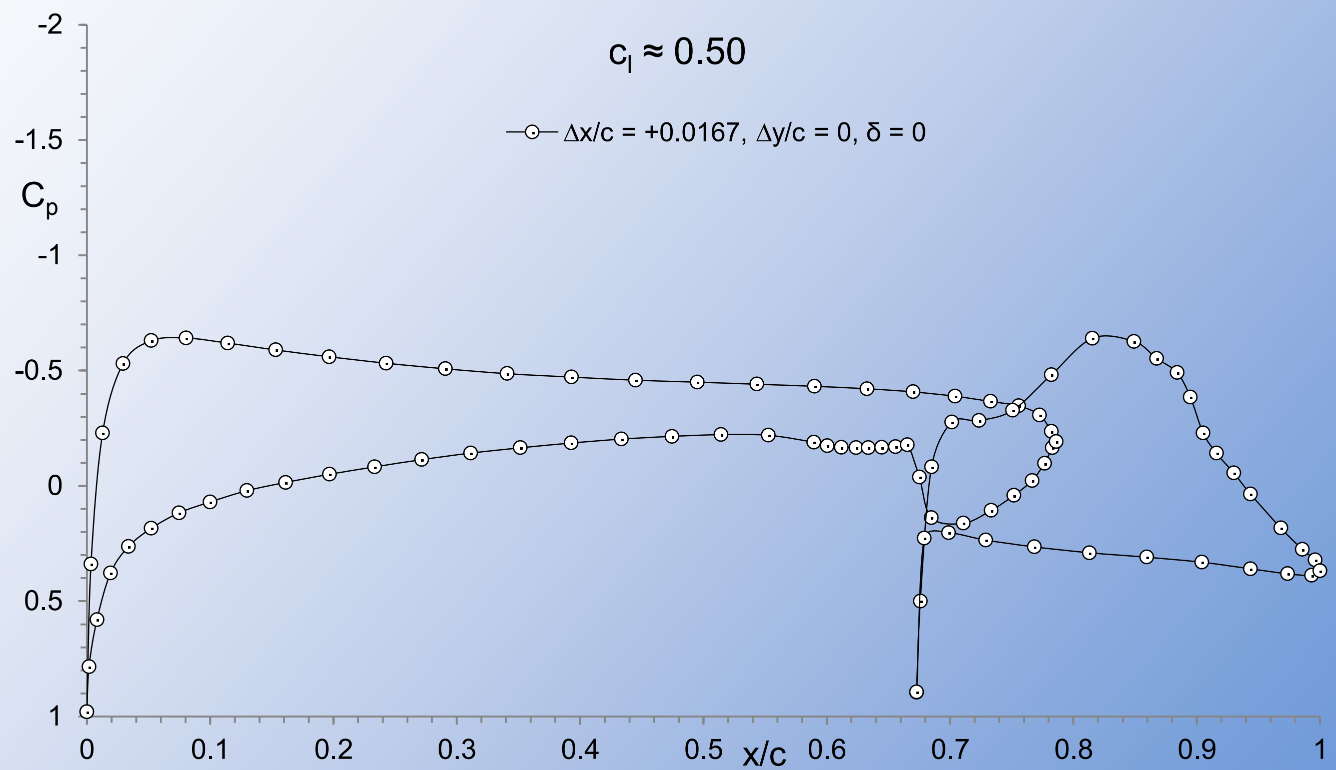


Pressure Distributions

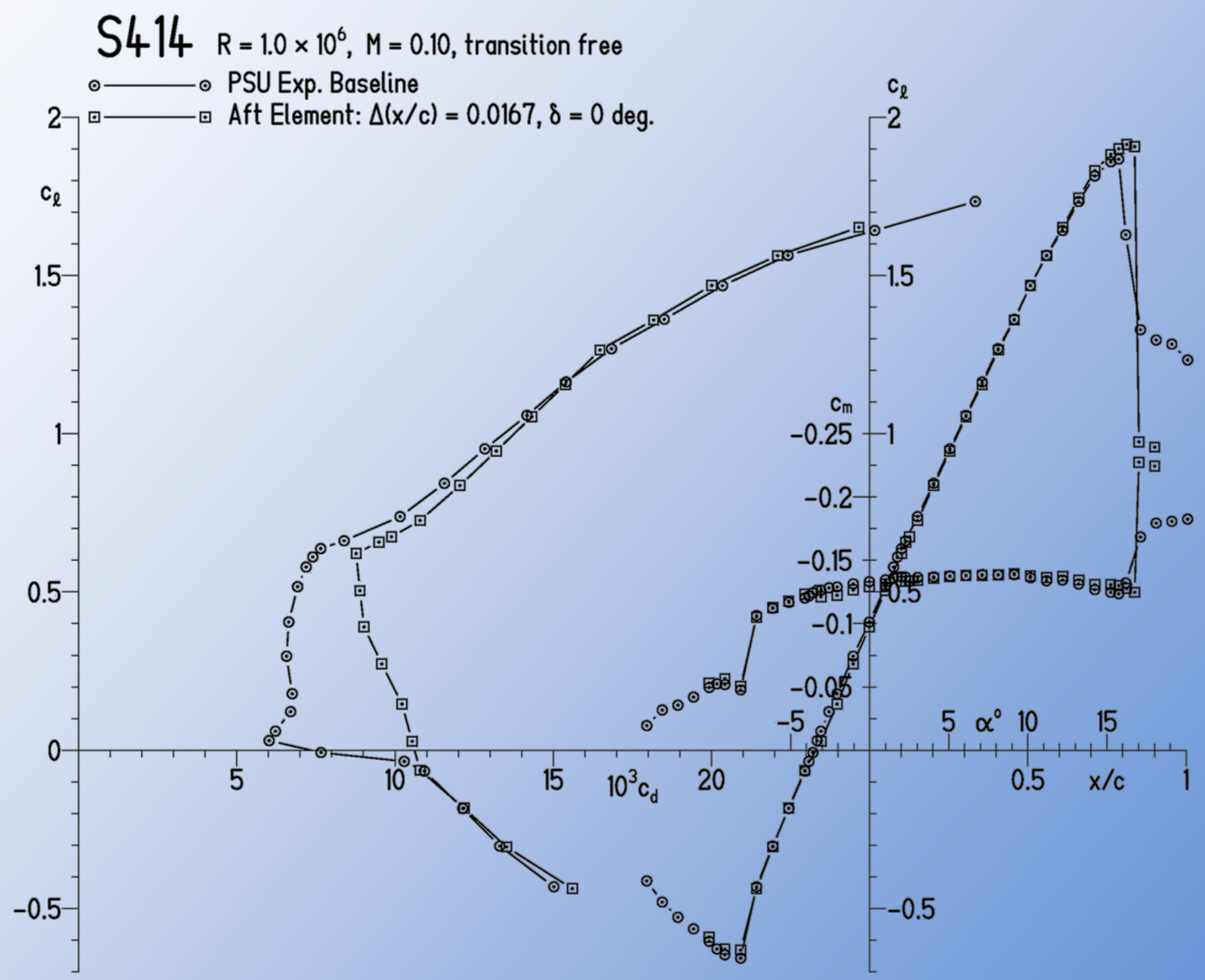


Pressure Distributions

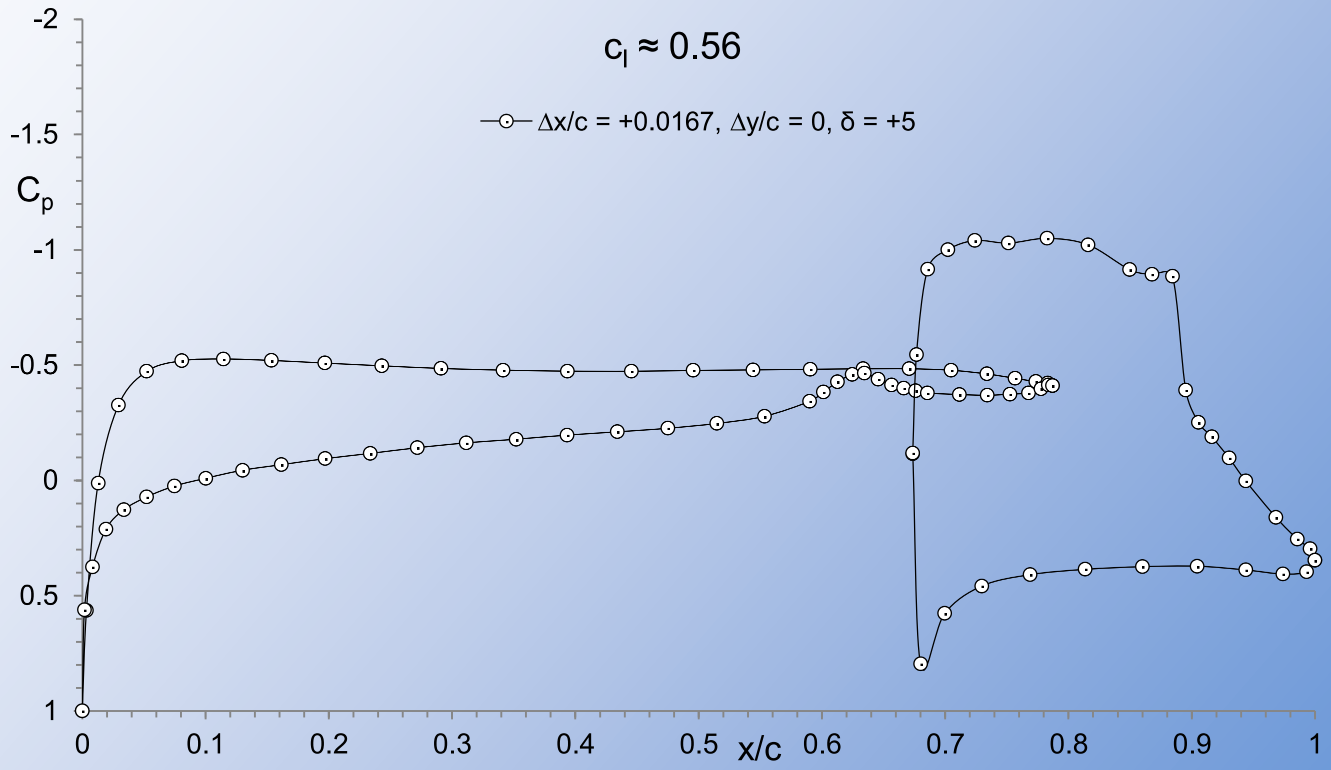
NASA Aeronautics Research Institute



Aerodynamic Characteristics



Pressure Distributions



Aerodynamic Characteristics

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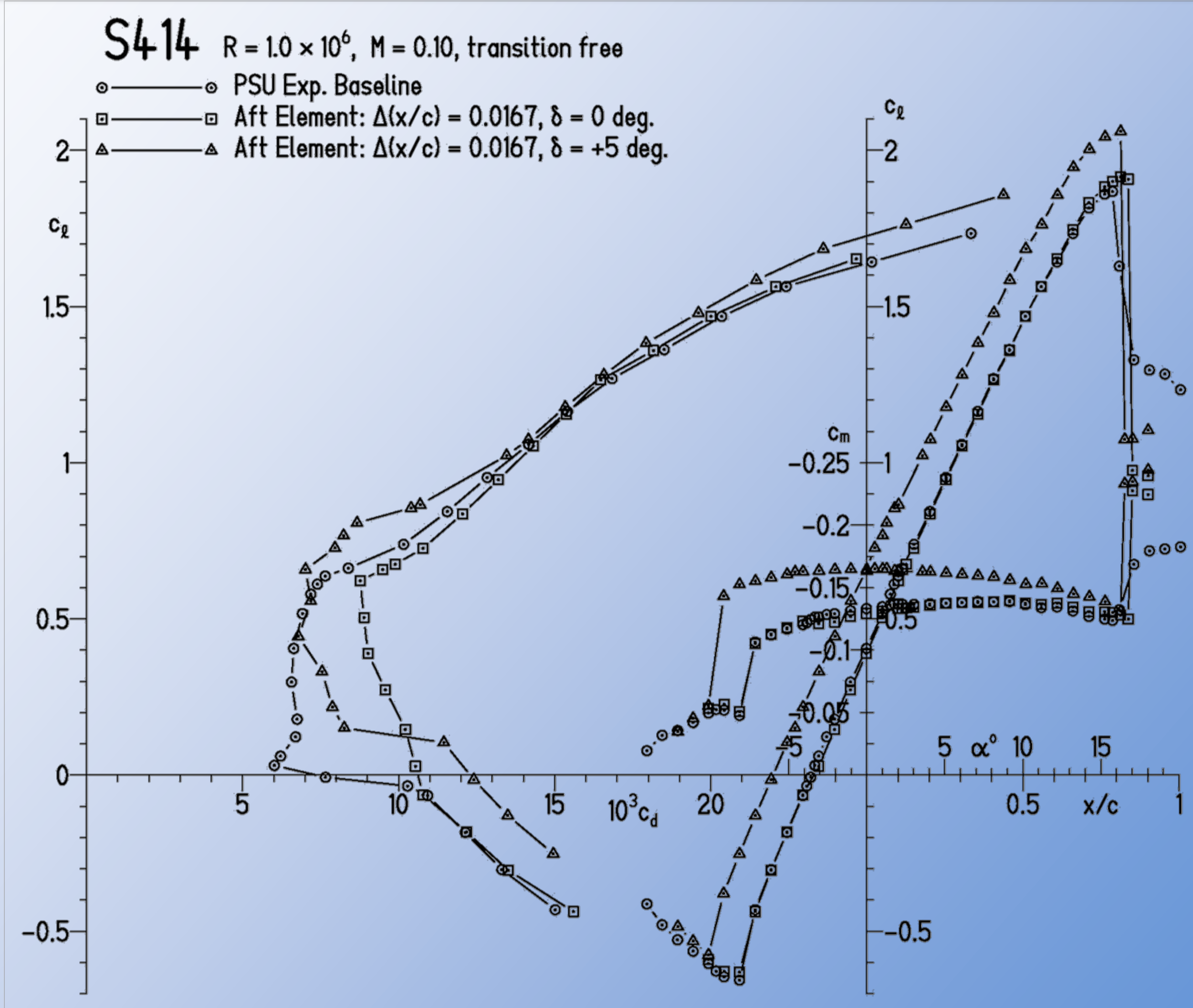


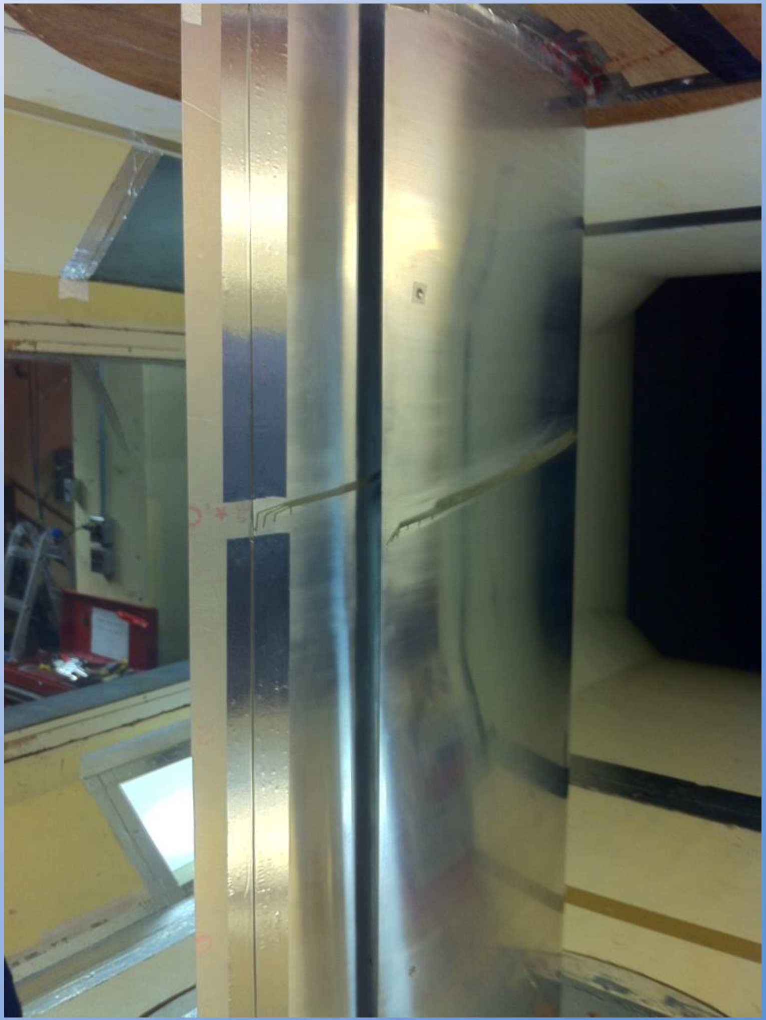
Tab Simulating a Simple Flap

Tab was taped on aft element.

Tab chord was 10% of total airfoil chord, 30% of aft-element chord.

Deflections of -17, 0, 3.5, 22 degrees.

No pressure orifices on tab.



Aerodynamic Characteristics- Tab Simulating a Simple Flap

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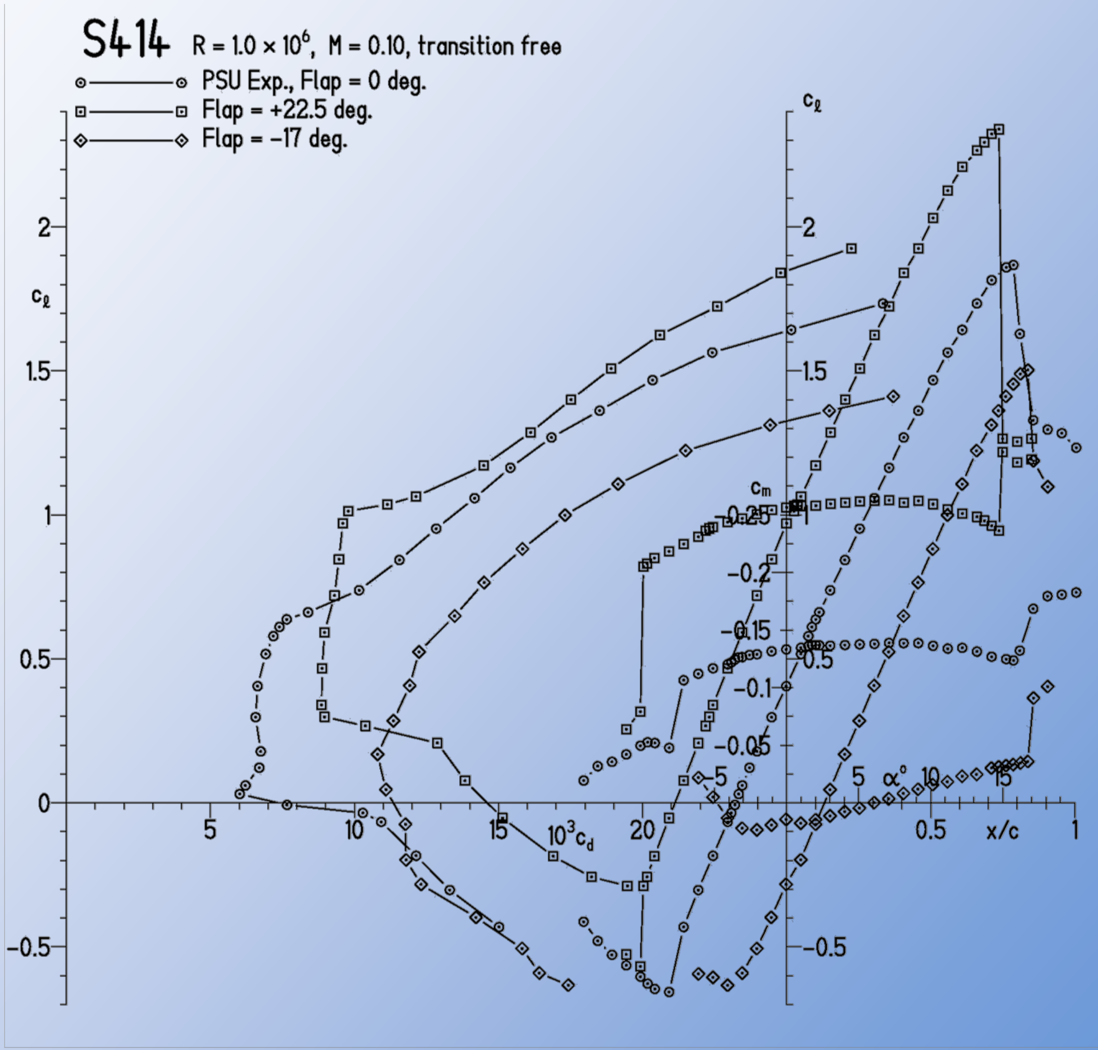
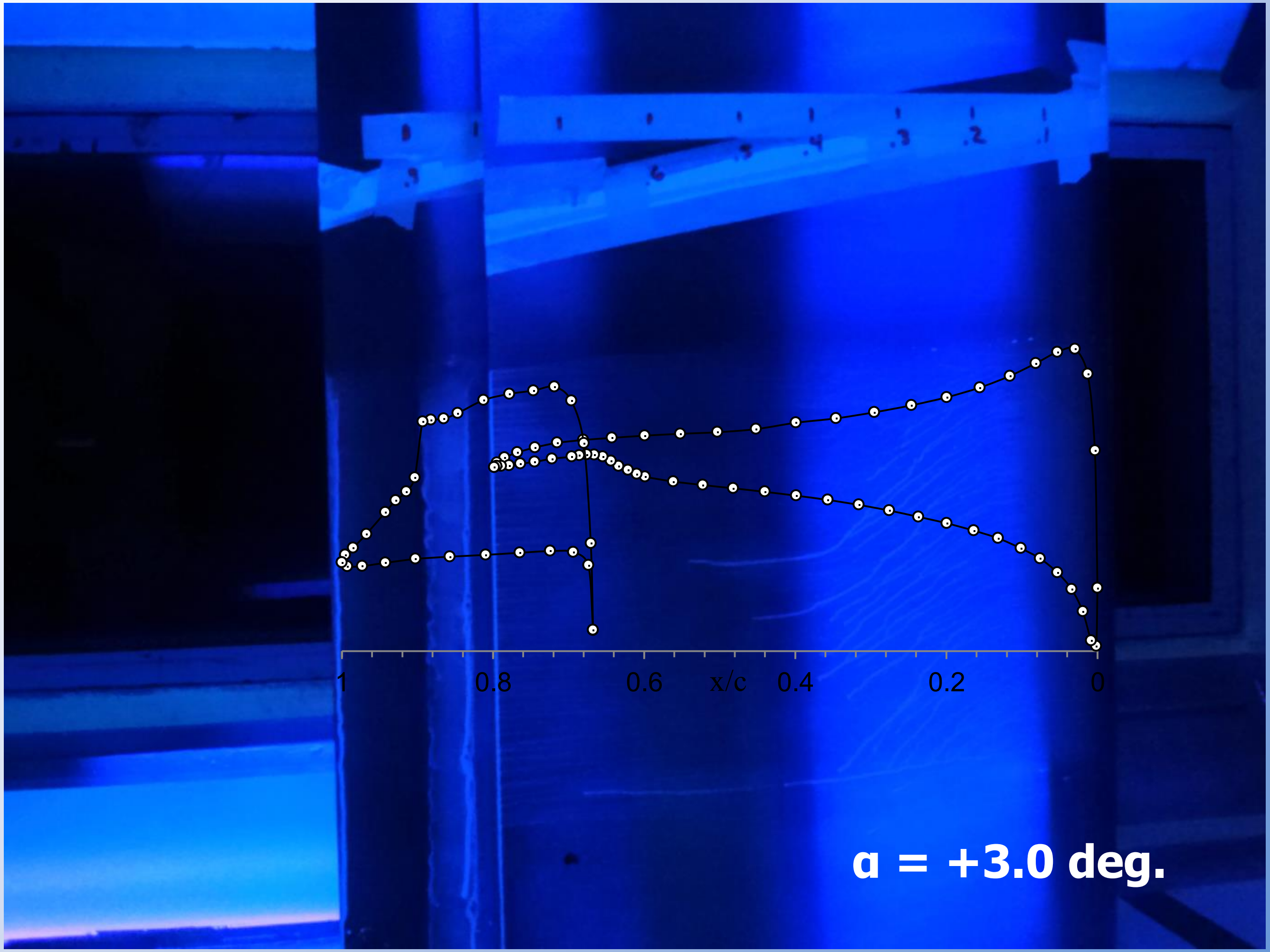


Fluorescent Oil Flows



Aft Element Mounting Bracket

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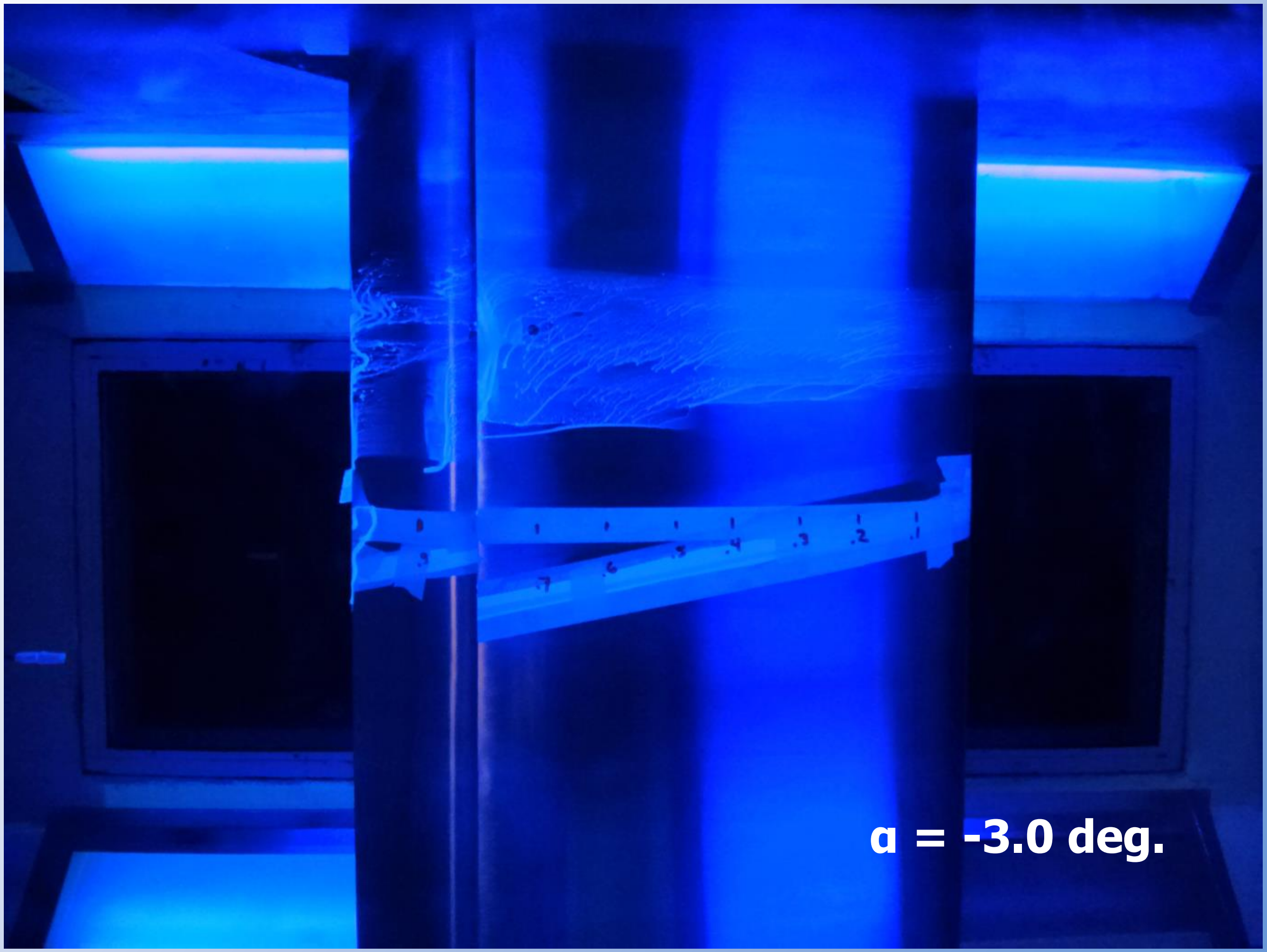

Baseline Pressure Distributions
Theory vs. Experiment

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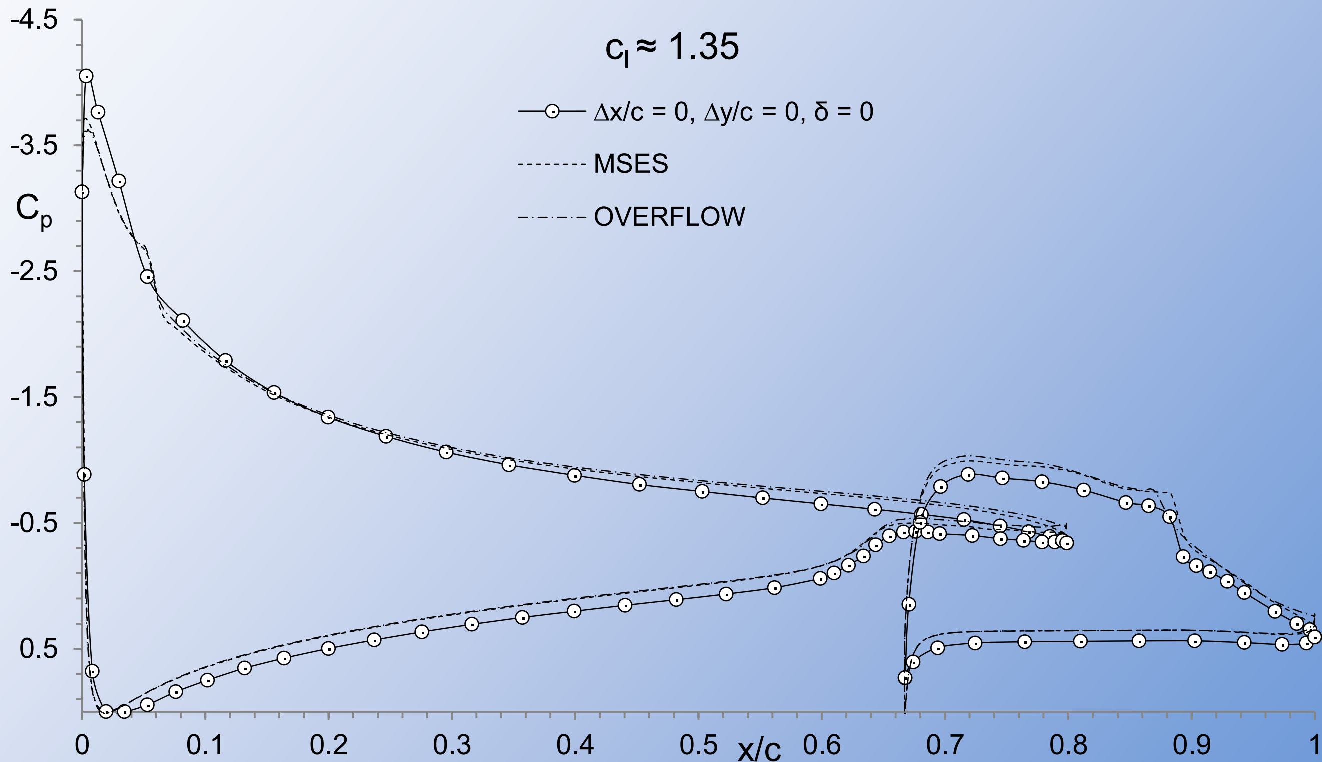

Aerodynamic Characteristics Theory vs. Experiment

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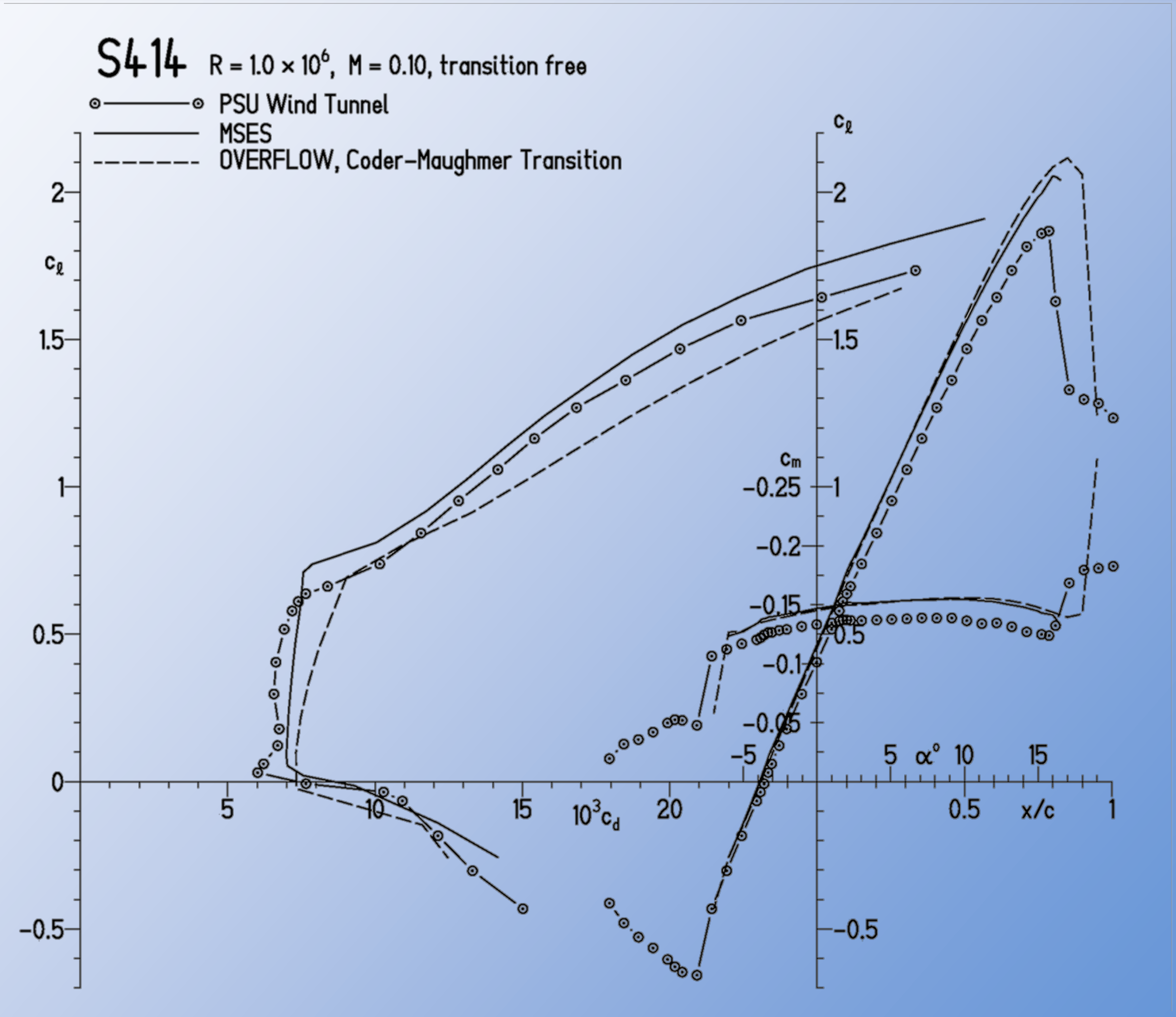

DLR LFC (Suction) Airfoil

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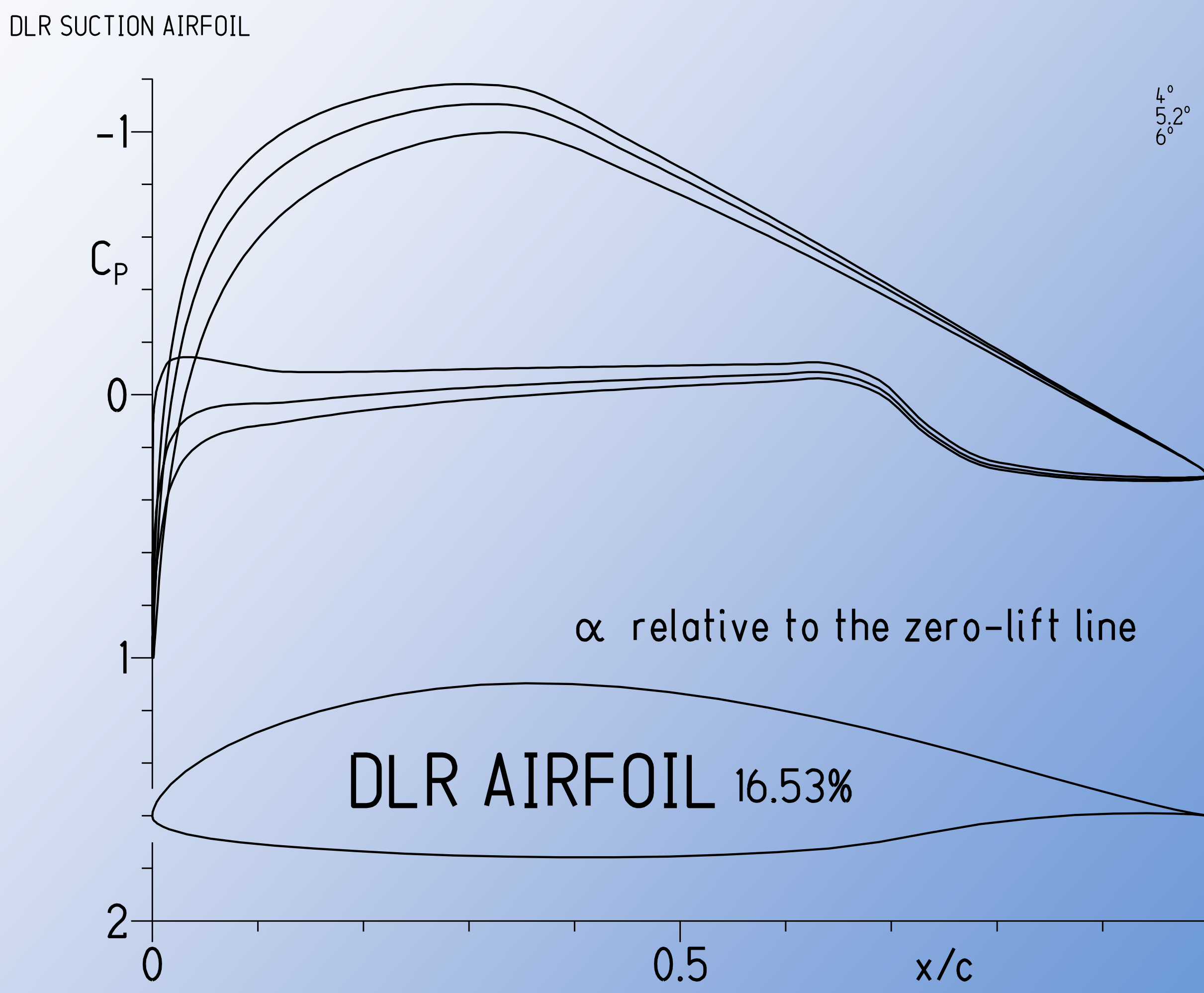
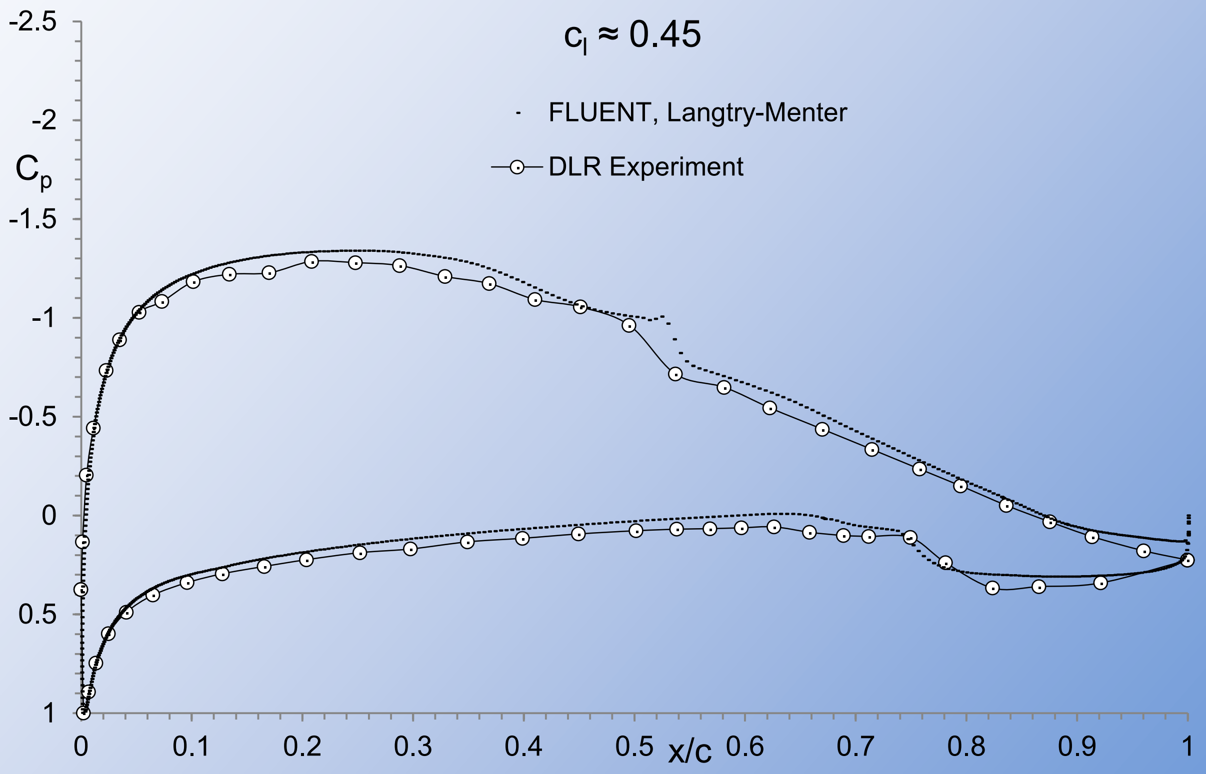


Suction Airfoil Pressure Distribution



DLR LFC (Suction) Airfoil

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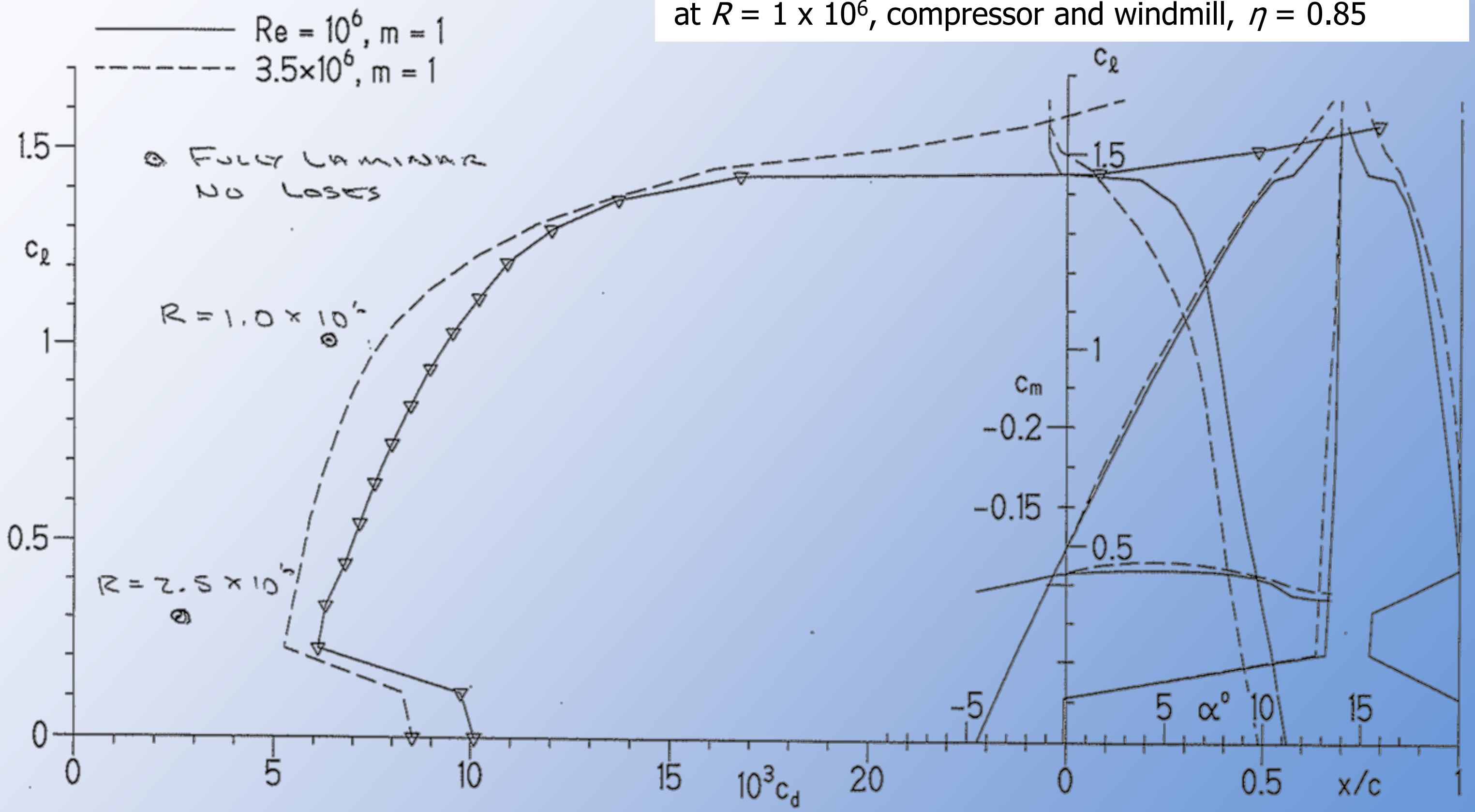
At $c_l = 0.5$, Pfenninger gives the losses as 0.0007 at $R = 1 \times 10^6$, compressor and windmill, $\eta = 0.85$



Conclusions

SNLF concept works

Theory is reliable except for maximum lift and stall characteristics

While scheduling of aft element for ailerons/flaps is possible, a simple flap/aileron on aft element seems more suitable

Aft element mounting bracket drag is not excessive

S414 stall characteristics are undesirable

DLR LFC airfoil wind-tunnel data have been compared with results from theoretical methods used for design

The LFC airfoil design methodology is being complimented with an analysis method (modified MSES)

Next steps

Design a new SNLF airfoil based on understanding gained during Phase I, including improved stall characteristics

Conduct wind-tunnel investigation to validate codes and determine maximum lift and stall characteristics, which are beyond current theoretical capabilities

Perform design studies to explore Reynolds and Mach number limits of SNLF applications

Refine and validate LFC design methodologies; design new LFC airfoil to same specifications as new SNLF airfoil

Perform conceptual design studies of an unmanned air vehicle with both SNLF and LFC airfoil concepts to determine practical issues and potential benefits

Dissemination of Results

Coder, J.G., Maughmer, M.D., and Somers, D.M., "Theoretical and Experimental Results for the S414, Slotted, Natural-Laminar-Flow Airfoil," submitted for publication, *Journal of Aircraft*, Aug. 2013.

Coder, J.G., Maughmer, M.D., and Somers, D.M., "Theoretical and Experimental Results for the S414, Slotted, Natural-Laminar-Flow Airfoil," AIAA Paper 2013-2655, 31st AIAA Applied Aerodynamics Conference, San Diego, CA, June 24-27, 2013.

Maughmer, M.D., "The Theoretical and Experimental Exploration of a Slotted, Natural-Laminar-Flow Airfoil Concept," Symposium for Sailplane Development, Technical University Braunschweig, Nov. 21 -22, 2013.