Wind Energy Denmark 2018

Winglets

Reduction of induced drag on low aspect ratio wing by alteration of wingtips

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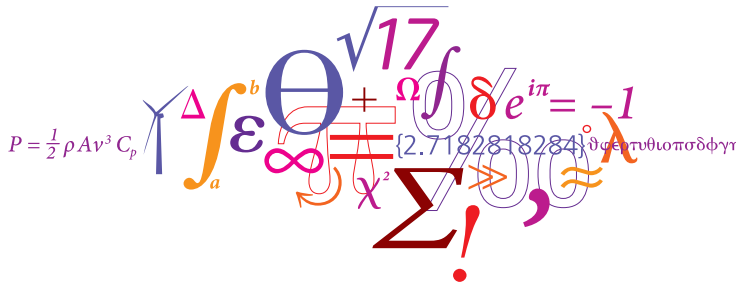

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Department of Wind Energy

Background
The Druine Turbulent

(Source: Erik Frikke, Vamdrup 1985.)

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The Druine Turbulent

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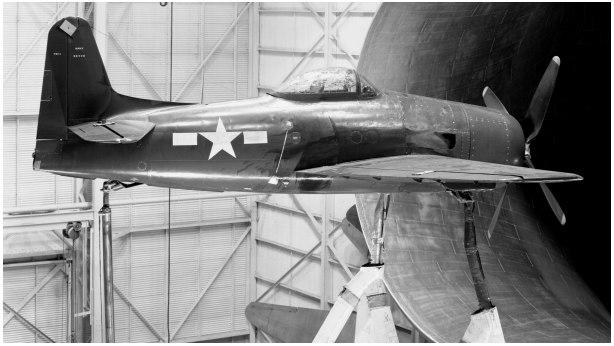
Druine Turbulent

• Ultralight aircraft. Gross weight:	260 kg
• Cruise speed:	120 km/h
• Wingspan:	6.55 m
• Aspect Ratio:	5.65

Problem
Induced Drag

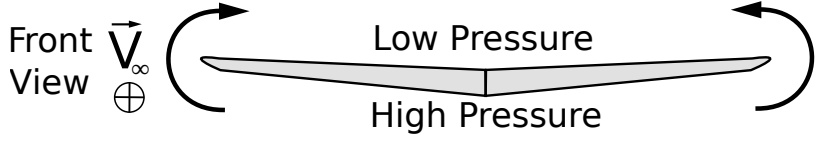


(Source: nasa.gov, *F8F-1 Bearcat*, Langley 1946.)

(Source: nasa.gov, *P-51B Mustang*, Ames 1943.)

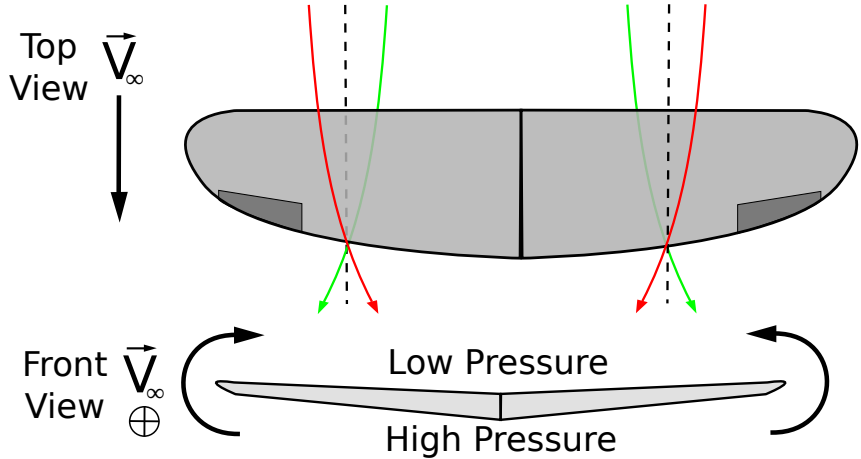
Problem
Induced Drag (2)

- Drag due to lift.
- Spanwise pressure gradient.

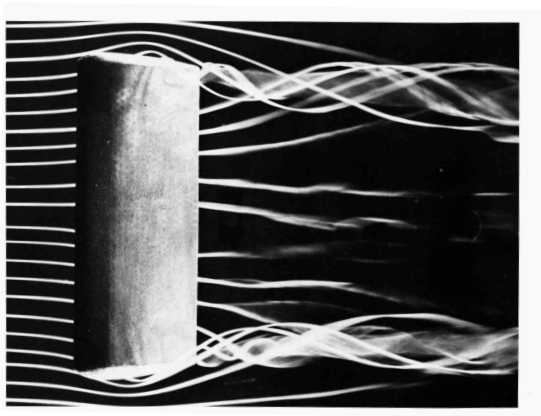


Problem
Induced Drag (2)

- Drag due to lift.
- Spanwise pressure gradient.
- Vortex formation.
- Tip vortices and downwash.



Problem
Induced Drag (3)

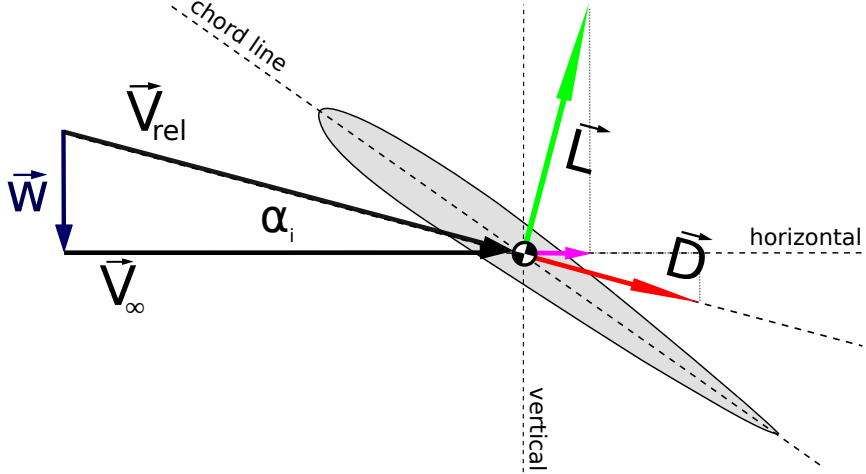


(Source: Van Dyke, *Album of Fluid Motion*, 1982.)

(Source: Unknown, *Tu-95/114 Aircraft*.)

Problem
Induced Drag (4)

- Downwash, w
- Induced AOA, α_i
- Rotation of aerodynamic force



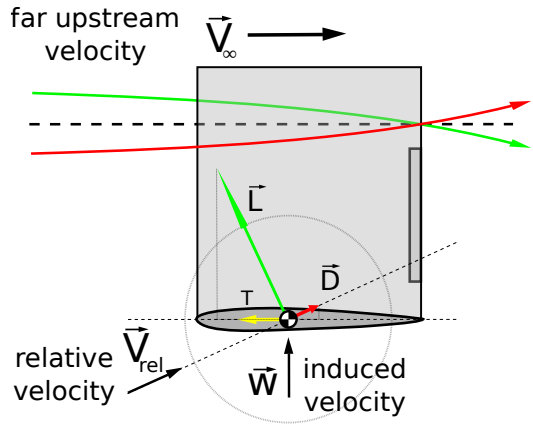
Solution
Winglets

(Source: nasa.gov, *KC-135* winglet prototype, Dryden 1979.)

(Source: nasa.gov, *KC-135*, Dryden 1979.)

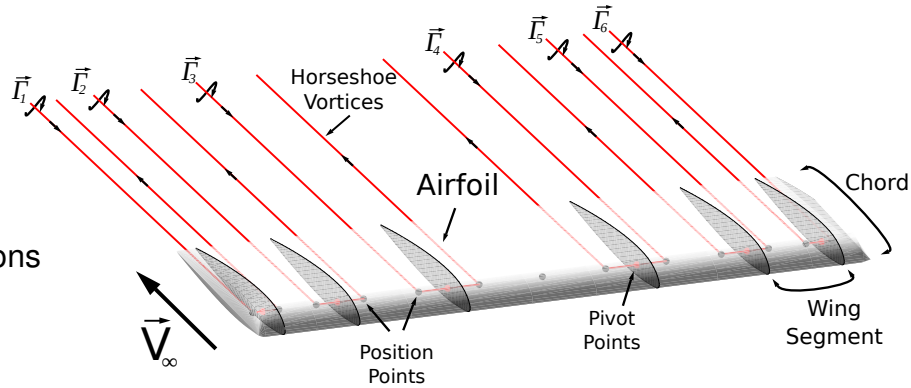
Solution
Winglets (2)

(Source: nasa.gov, *KC-135* winglet prototype, Dryden 1979.)



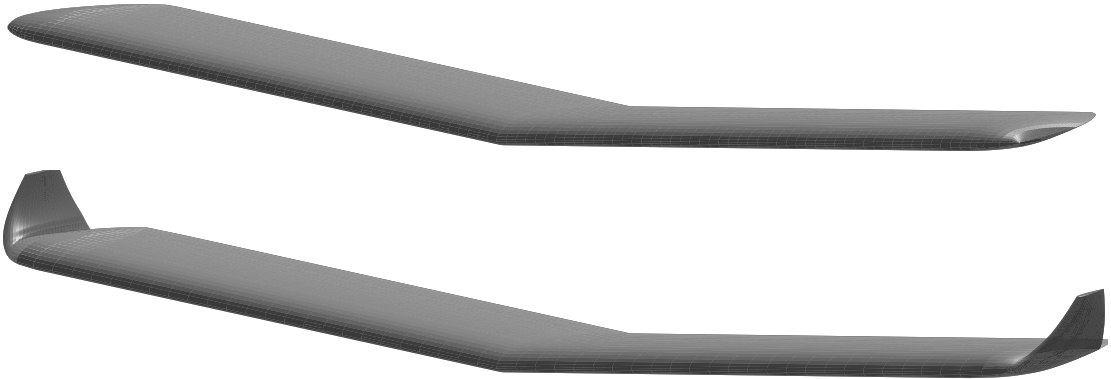
Prandtl's Lifting-line Theory
Preliminary Design

- Lanchester 1907.
- Potential flow.
- Kutta-Joukowski Theorem
- Lift distributions on 3D wing-configurations



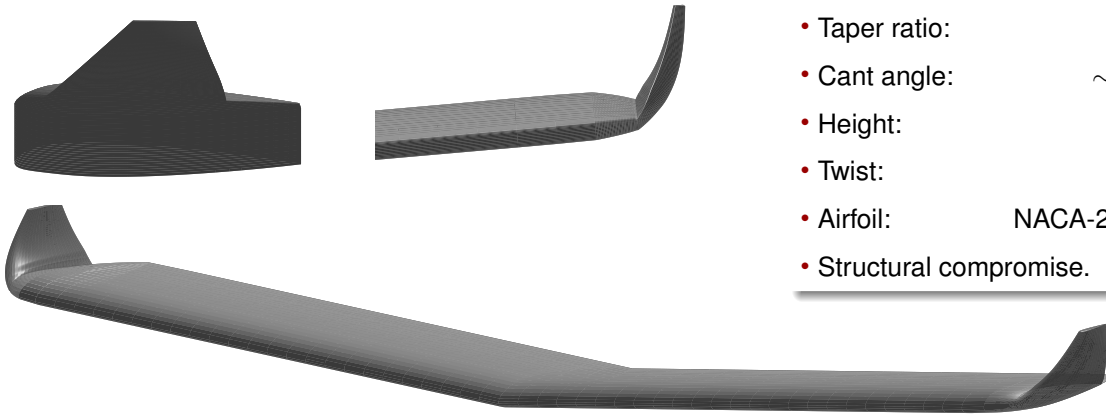
(Literature: "Fundamentals of Aerodynamics", *Anderson.* "Low-speed Aerodynamics", *Katz/Plotkin.*)

Upgraded Wing Configuration
Winglets



(CAD Software: Matlab)

Upgraded Wing Configuration
Winglets



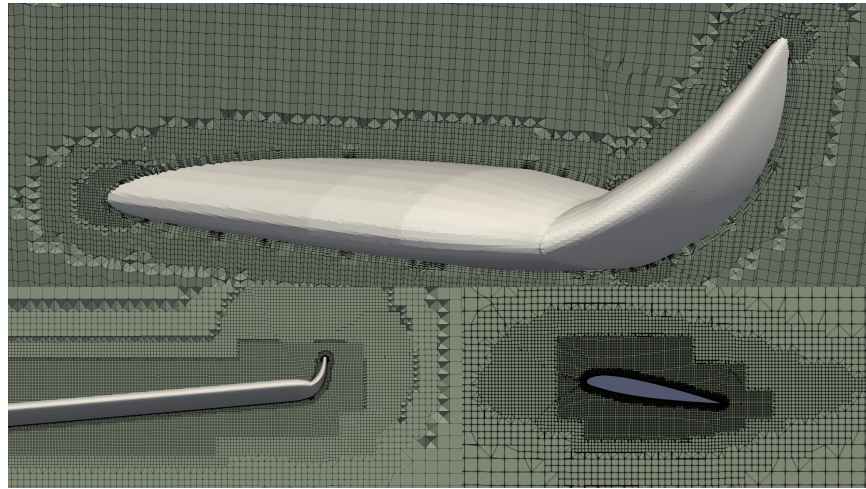
Properties

- Taper ratio: 1/2
- Cant angle: $\sim 60\ ^\circ$
- Height: c/3
- Twist: $\sim 5^\circ$
- Airfoil: NACA-23012
- Structural compromise.

(CAD Software: Matlab)

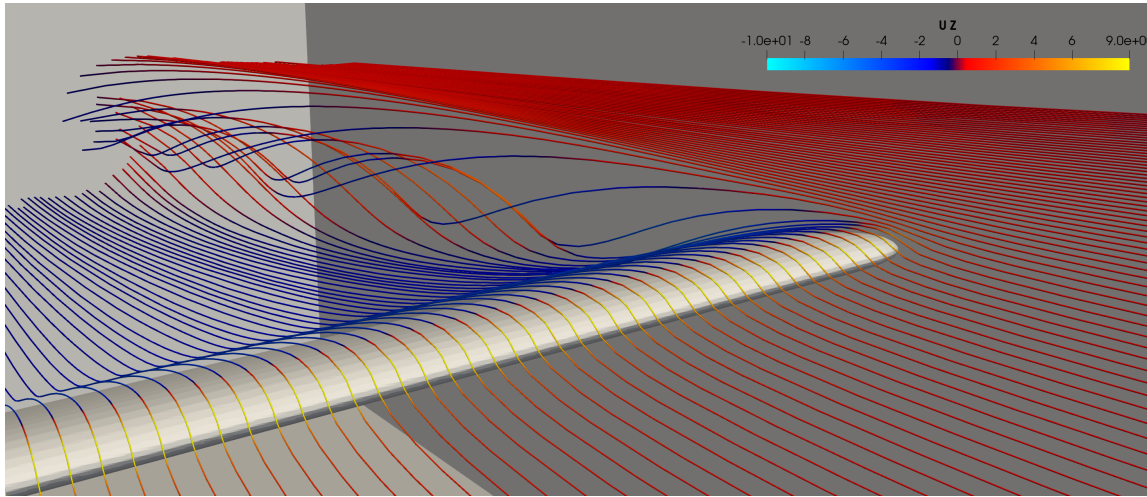
CFD Analysis
Final Design

- Steady state simulation.
- k-ϵ turbulence.
- Re $\approx 10^6$

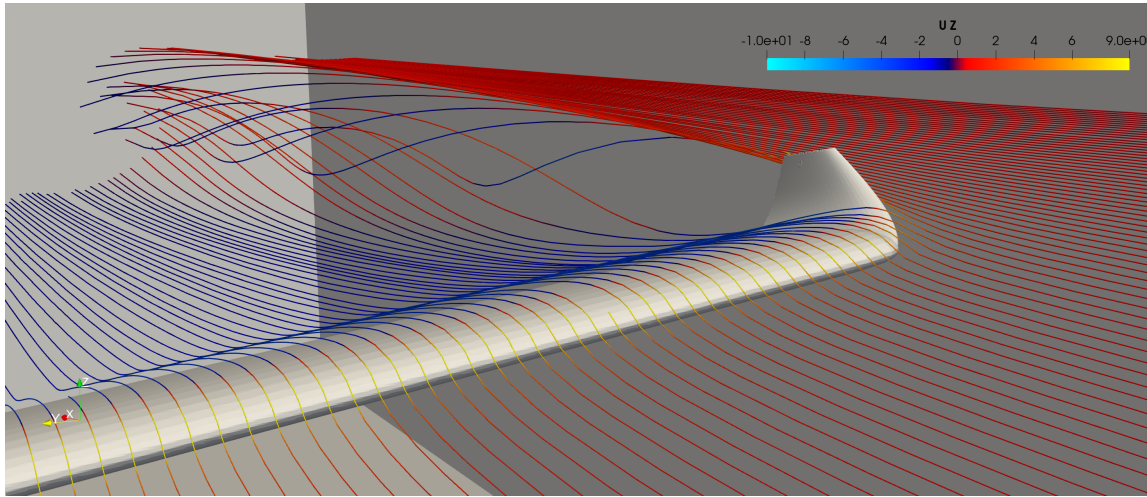


(CFD Software: OpenFOAM, Star-CCM+, ParaView)

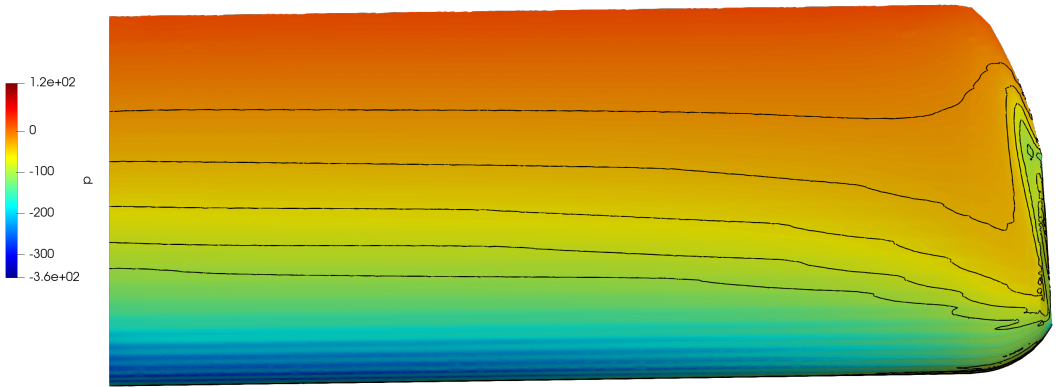
CFD Analysis
Streamlines - Standard Wing Configuration



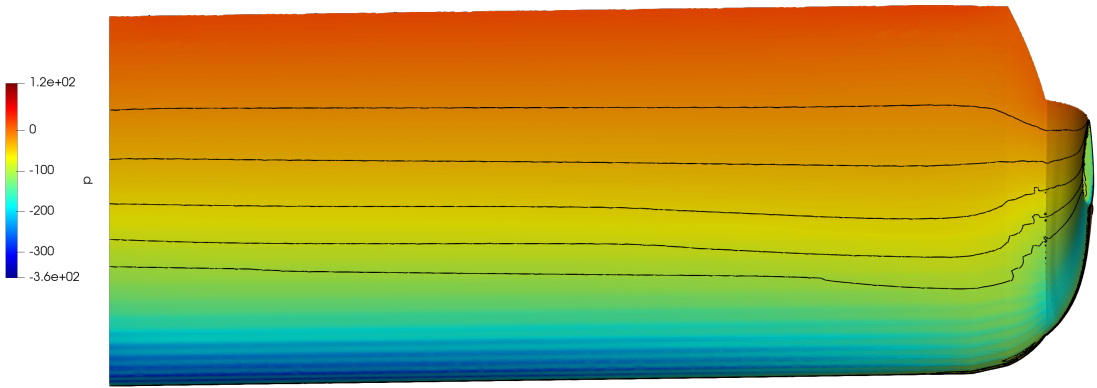
CFD Analysis
Streamlines - Upgraded Wing Configuration



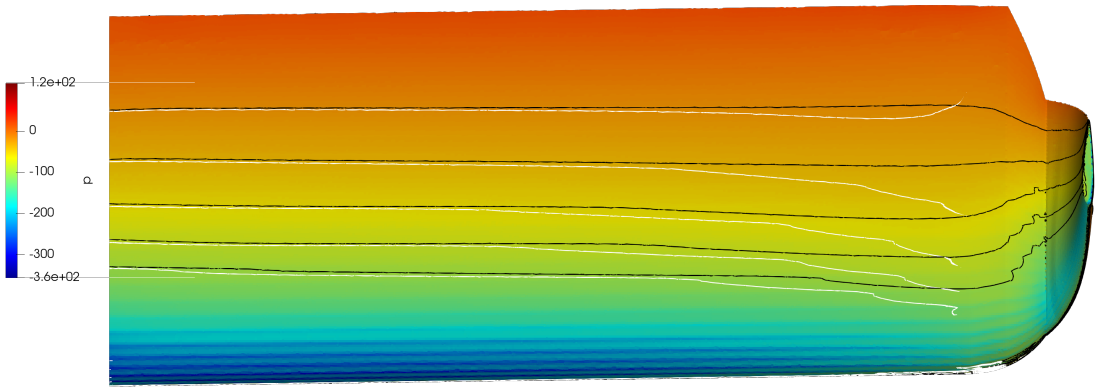
CFD Analysis
Pressure Distribution - Standard Wing Configuration



CFD Analysis
Pressure Distribution - Upgraded Wing Configuration

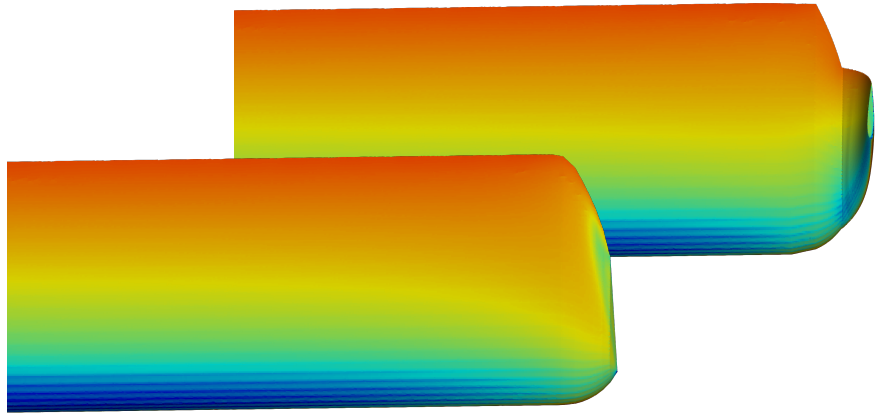


CFD Analysis
Pressure Distribution - Upgraded Wing Configuration (2)



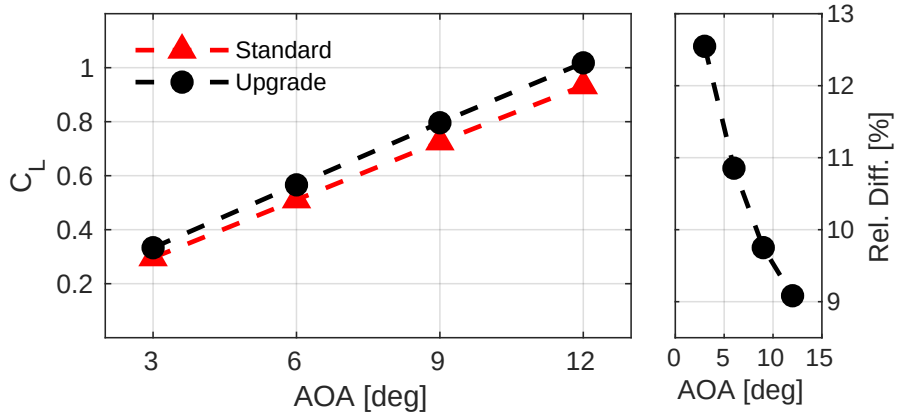
CFD Analysis
Pressure Distribution

- Improved spanwise pressure gradient.
- Weak loads on winglet.
- No disturbance of aileron area.



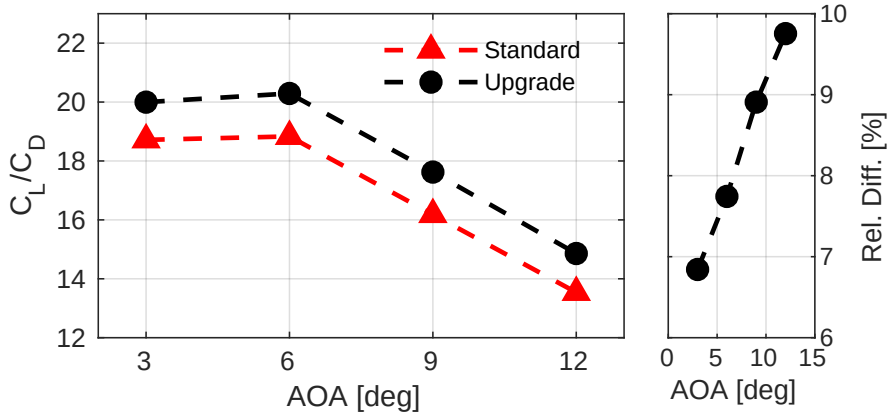
CFD Analysis
Comparison - Lift

- Improvement increases with AOA.
- Relative improvement of about 9 to 13 percent.
- Better take-off and landing.



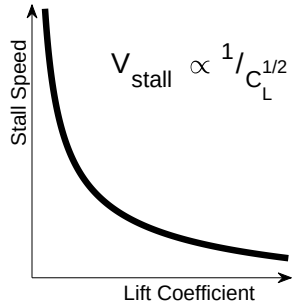
CFD Analysis
Comparison - Aerodynamic Efficiency

- Relative improvement increases with AOA.
- Relative improvement of about 7 to 10 percent.
- Better overall flight efficiency.



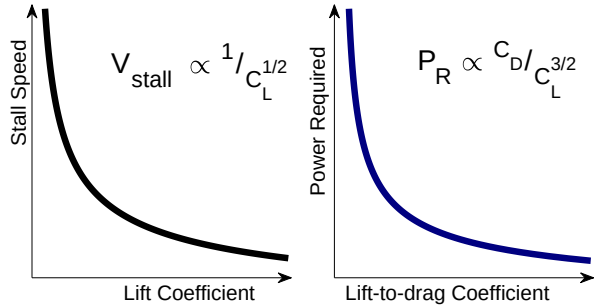
Evaluation of Results
Aircraft Performance

- Take-off and landing ✓



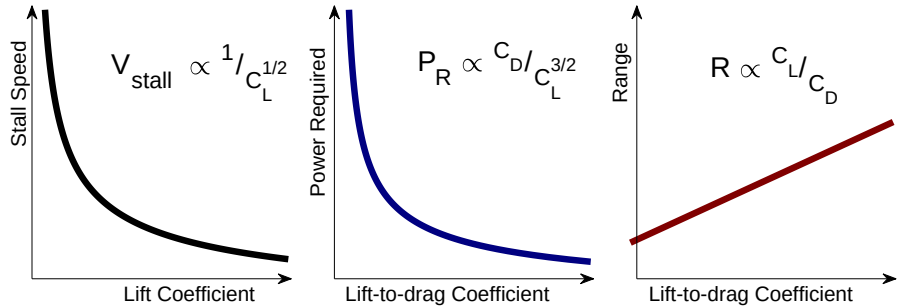
Evaluation of Results
Aircraft Performance

- Take-off and landing ✓
- Shaft power required ↓



Evaluation of Results
Aircraft Performance

- Take-off and landing ✓
- Shaft power required ↓
- Range ↑



Final Notes
Aerodynamics and Winglets

- Aerodynamics discipline is complex.
- Unique design for each application; Reynolds and Mach number ranges.
- Modern technology; CFD is very accessible, fly-by-wire computers, exotic materials, ect.
- Traditional wing design complemented by modern tools.

(Source: pixabay.com)

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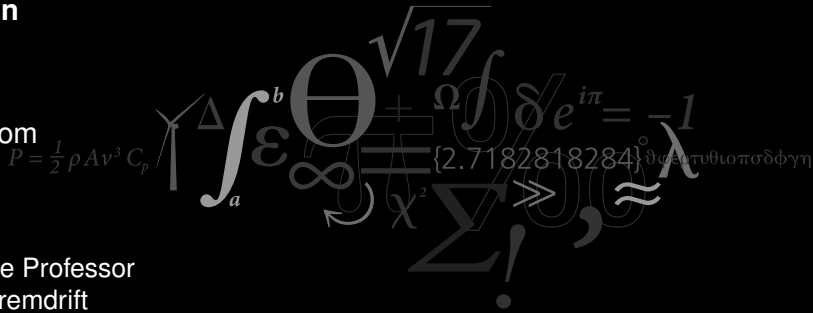

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