Manual Aerodynamic Optimization of Oblique Flying Wing

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INTRODUCTION

Oblique Flying Wing (OFW)

Optimum aerodynamics: Efficient at subsonic, transonic & supersonic Mach numbers by variable sweep.

Optimum structure: Lift is produced where load is located.

Passenger transport: Passenger size defines min. wing section thickness,
Aerodynamics defines min. airfoil chord,
Efficiency defines min. wing span.

Example: ~800 pax OFW with large aspect ratio at Mach ~ 1.4;
Manual optimization for better understanding of aerodynamic phenomena.

DLR

DESIGN TOOLS

Supporting theories and geometry definition

Supersonic aerodynamics:

Area rule (Lomax)

Minimum drag bodies (Sears, Haack, v.Karman)

Transonic aerodynamics:

Supercritical airfoils

Swept wings

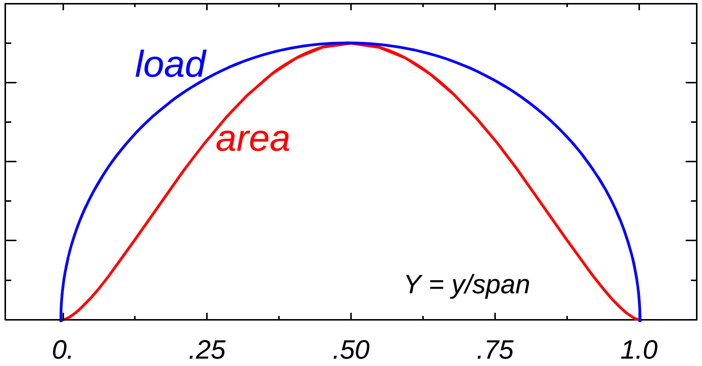
Shape definition:

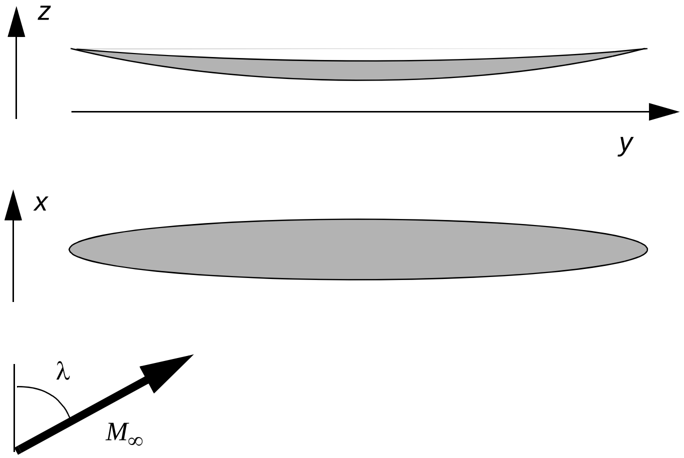
Geometry preprocessor for aerodynamic applications,

Parameter variation tailored by supporting theories.

OFW

Constraints for shape definition





Elliptic lift distribution:

$$\boxed{\text{load} \sim Y^{1/2}(1-Y)^{1/2}}$$

Minimum drag equivalent body of revolution:

$$\boxed{\text{area} \sim Y^{3/2}(1-Y)^{3/2}}$$

Baseline shape:

elliptic wing planform,

parabolic bending.

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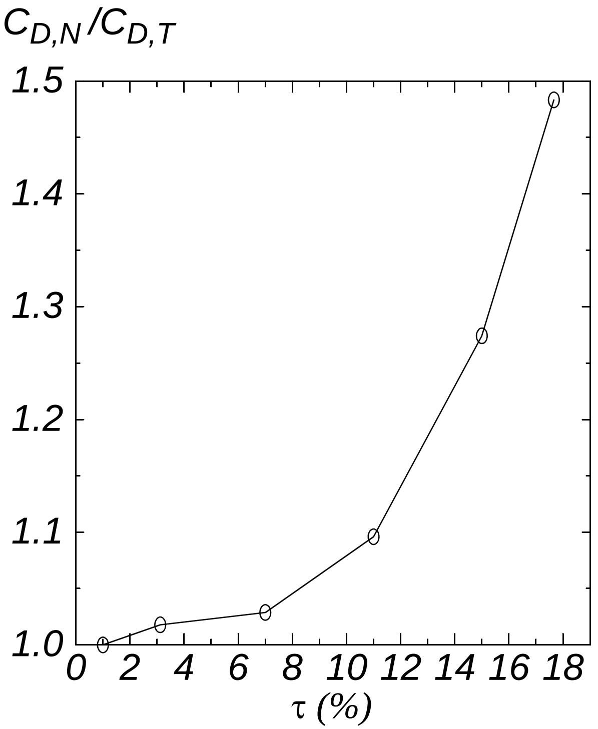
SUPERSONIC THEORY

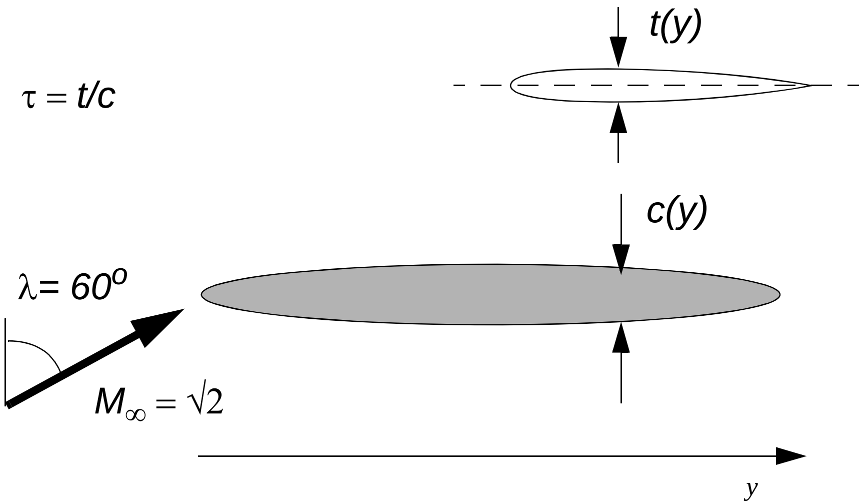
Comparison linear theory vs. CFD results



Elliptic wing, Sears-Haack area distribution:

symmetrical airfoil sections

drag coefficients resulting from linear theory and Euler CFD



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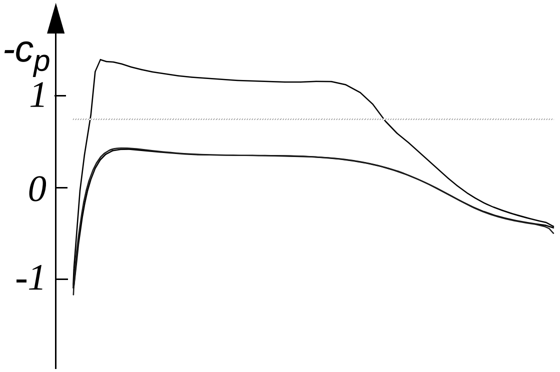
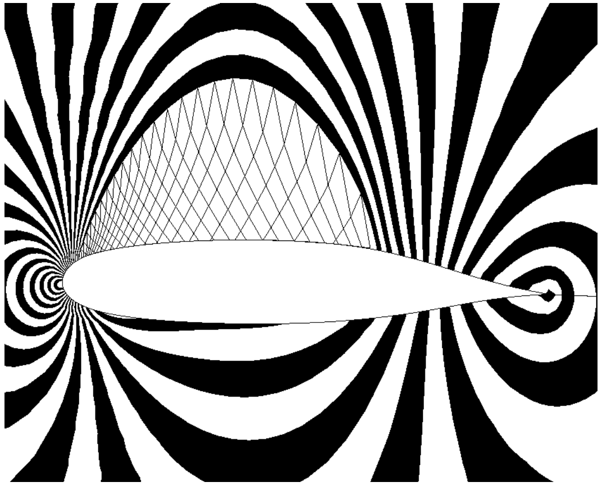
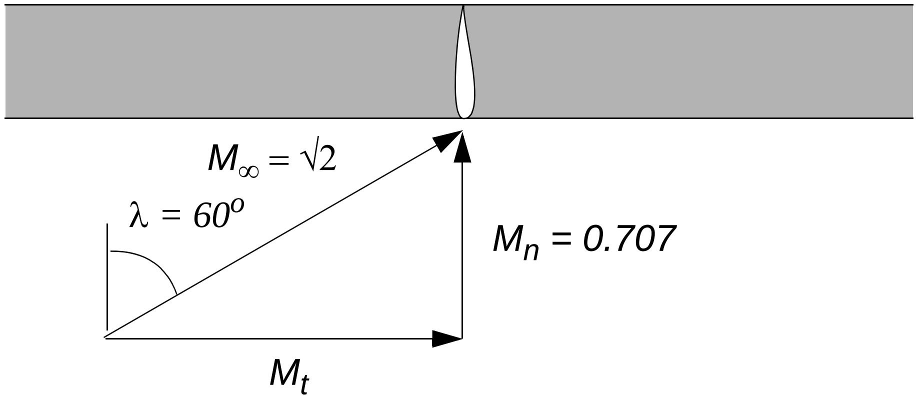
TRANSONIC THEORY

Definition of thick baseline wing sections







Preliminary design: Thick shock-free wing section

Method: Fict. Gas, inviscid flow

Application of swept wing theory

Example: $M_n = 0.707$, $c_l = 0.6$, $\tau = 0.17$

Extraction of geometric parameters for airfoil definition

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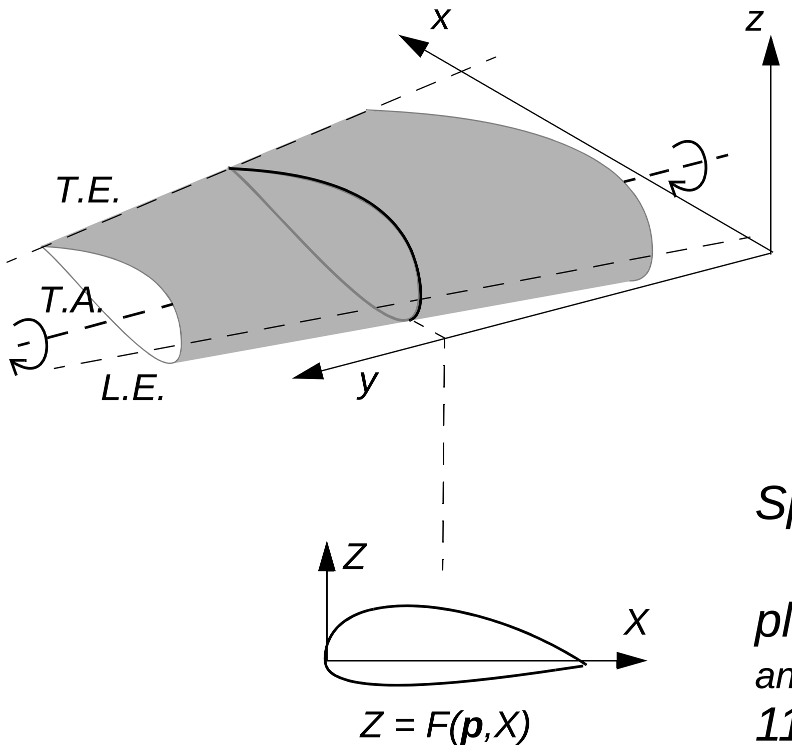
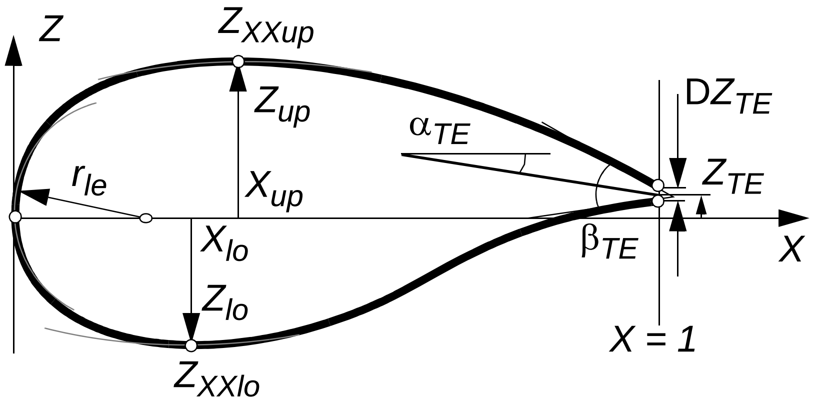
GEOMETRY GENERATOR

Wing tool with spanwise airfoil variation





Spanwise definition by shape functions:

planform, twist, dihedral, thickness factor
and
11 airfoil parameters, $\mathbf{p} = (r_{le}, X_{up}, \ldots)$

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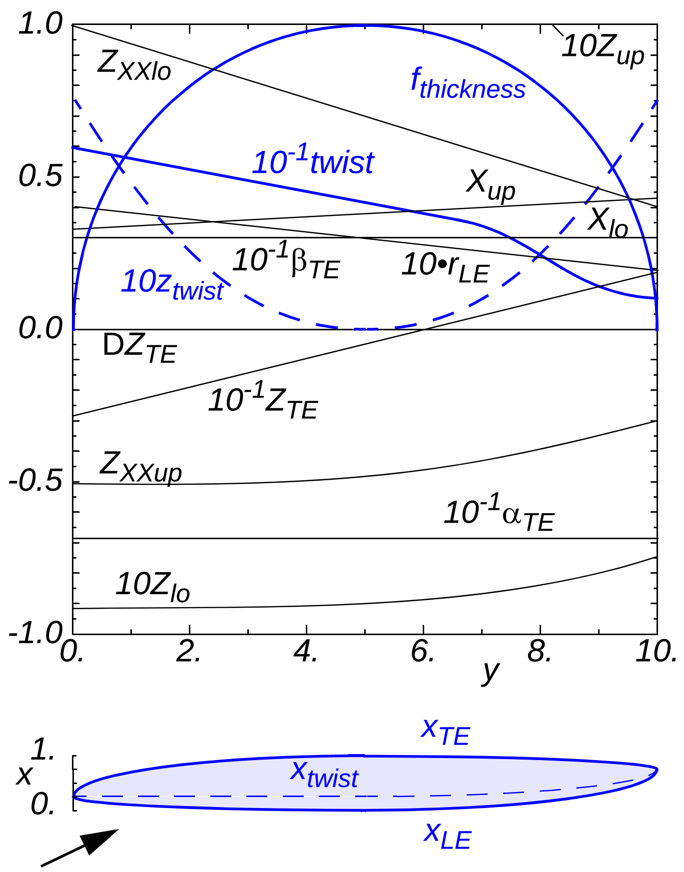
OFW

Spanwise parameter definition



11 airfoil parameters,
6 wing parameters :

....defined by simple functions along span,

***controlling** linear theories constraints,*

***supporting** elliptic load distribution & reduced cross flow shocks*

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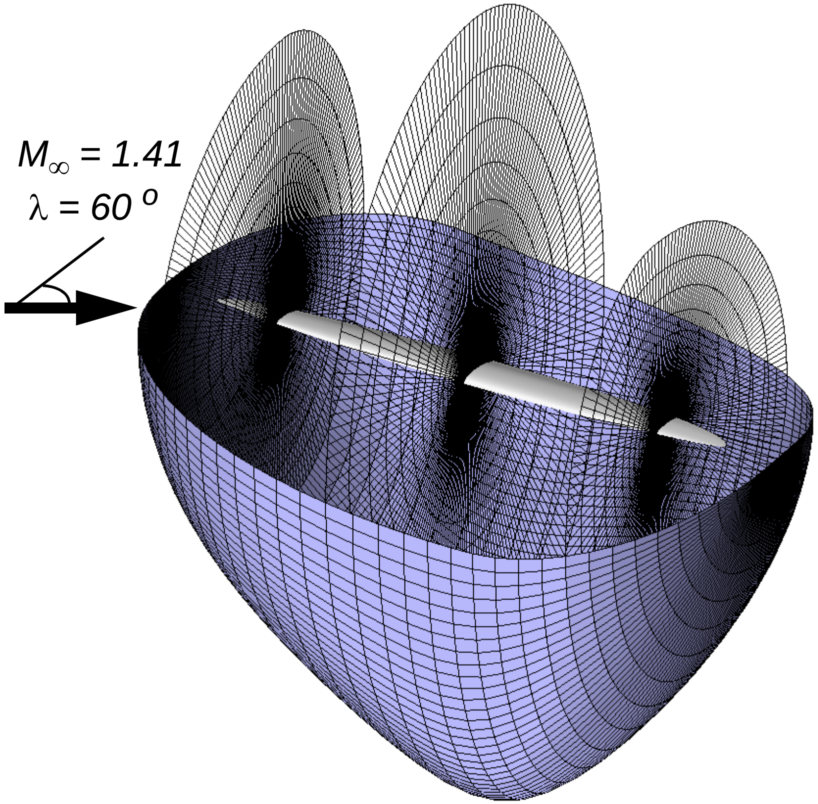
NUMERICAL ANALYSIS

Inviscid Flow



<u>Computational grid:</u> O-O, 193 x 41 x 33 pts

<u>CFD code:</u> CFL3D (Euler version).

<u>Manual optimization process:</u>
analysis runs at design conditions,
check of elliptic load approximation and
sectional pressure distributions,
---> selected parameter adjustments.

<u>Improvements after 22 runs:</u>
L/D from 14 to 21.3
section thickness from 17 to 19%

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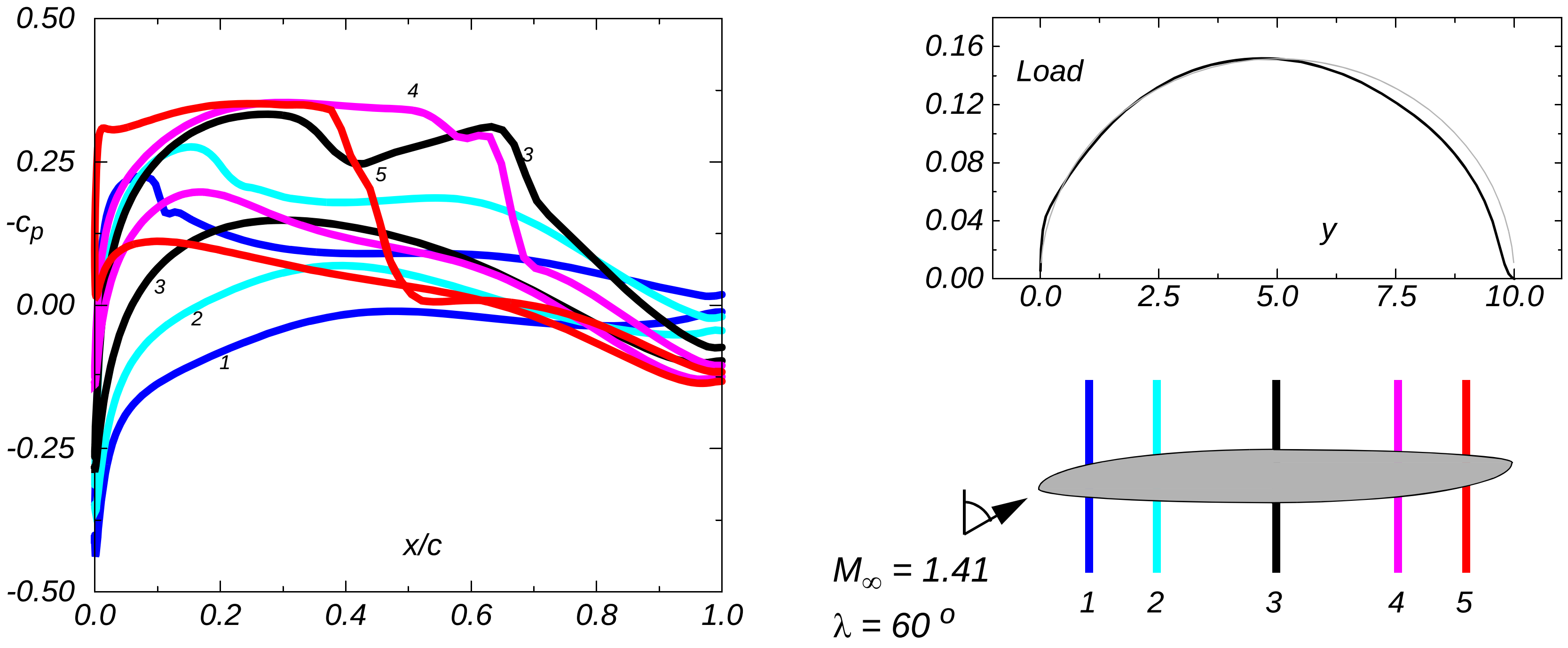
OFW: CFD ANALYSIS

Inviscid flow results



Chordwise pressure and spanwise load distribution

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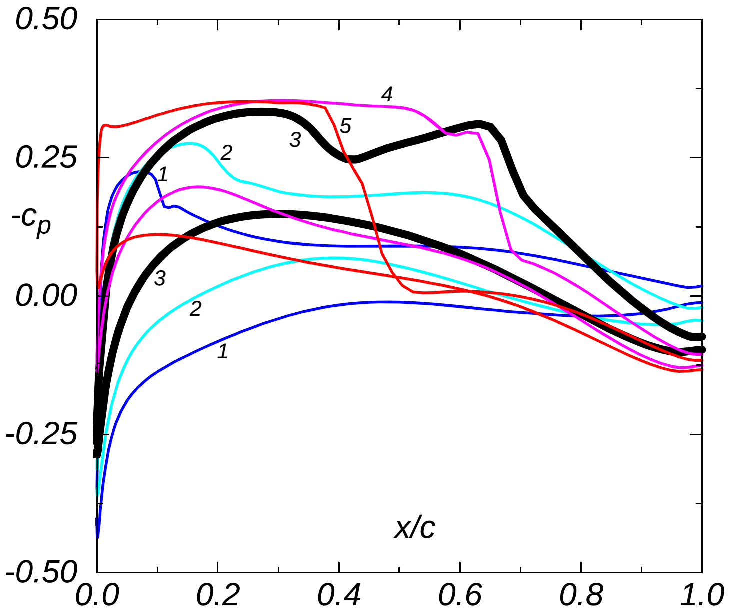
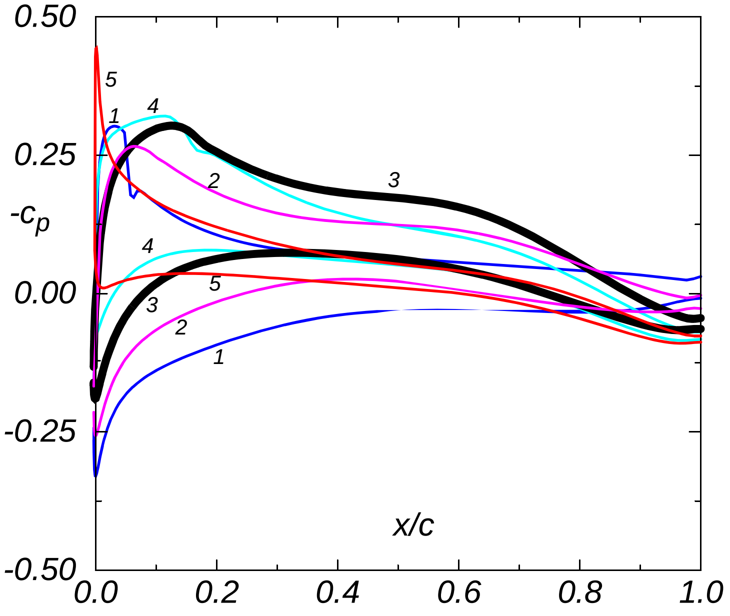
OFW: CFD ANALYSIS

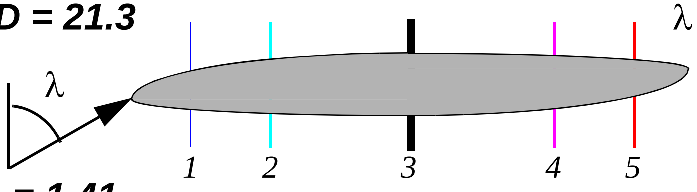
Inviscid flow results for varying sweep and lift



λ = 60 °, C_L = 0.145, L/D = 21.3



λ = 65 °, C_L = 0.122, L/D = 30.3



M_∞ = 1.41

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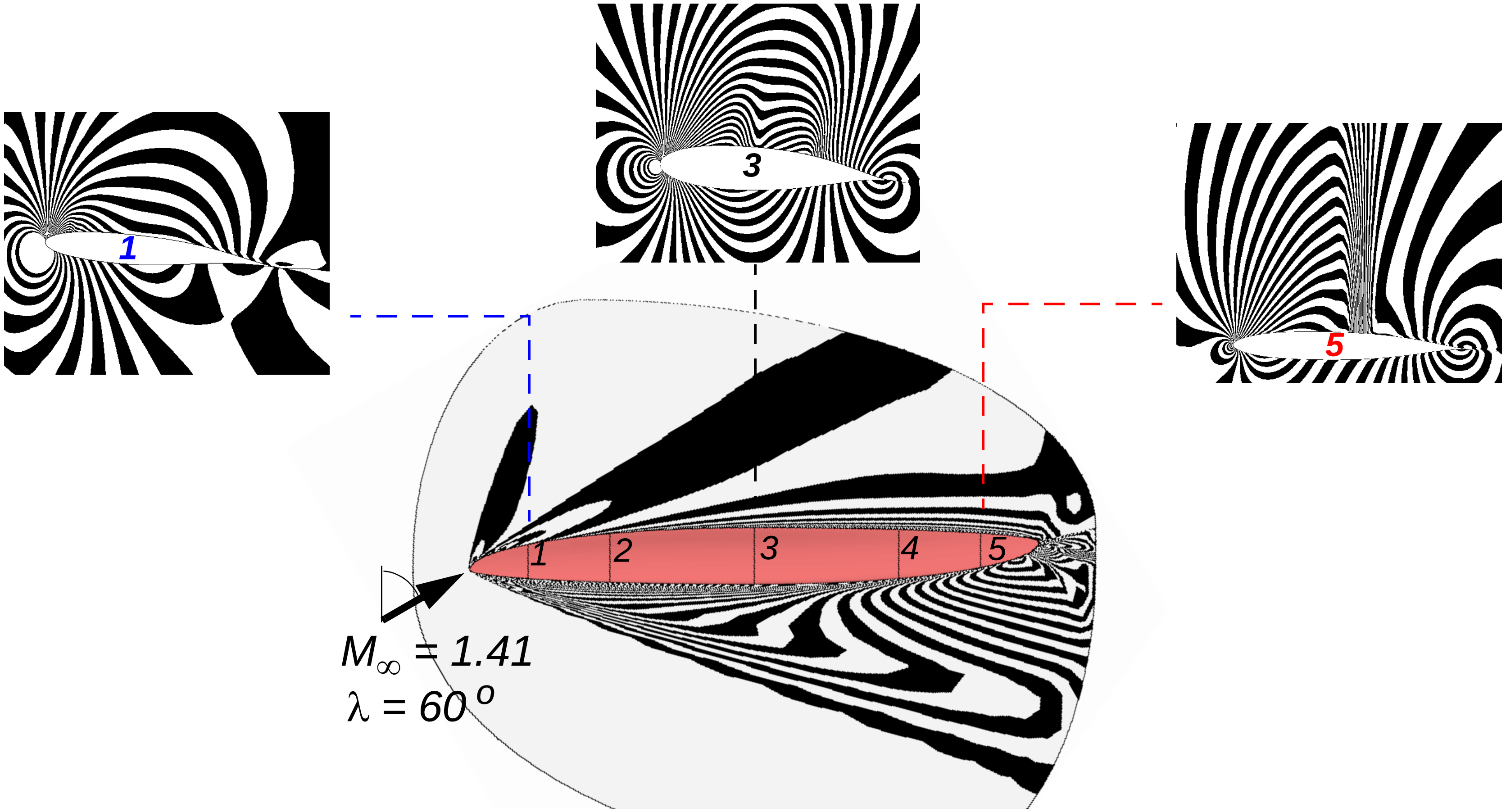
OFW: CFD ANALYSIS

Inviscid flow visualization: isobars



$M_\infty = 1.41$

$\lambda = 60^o$

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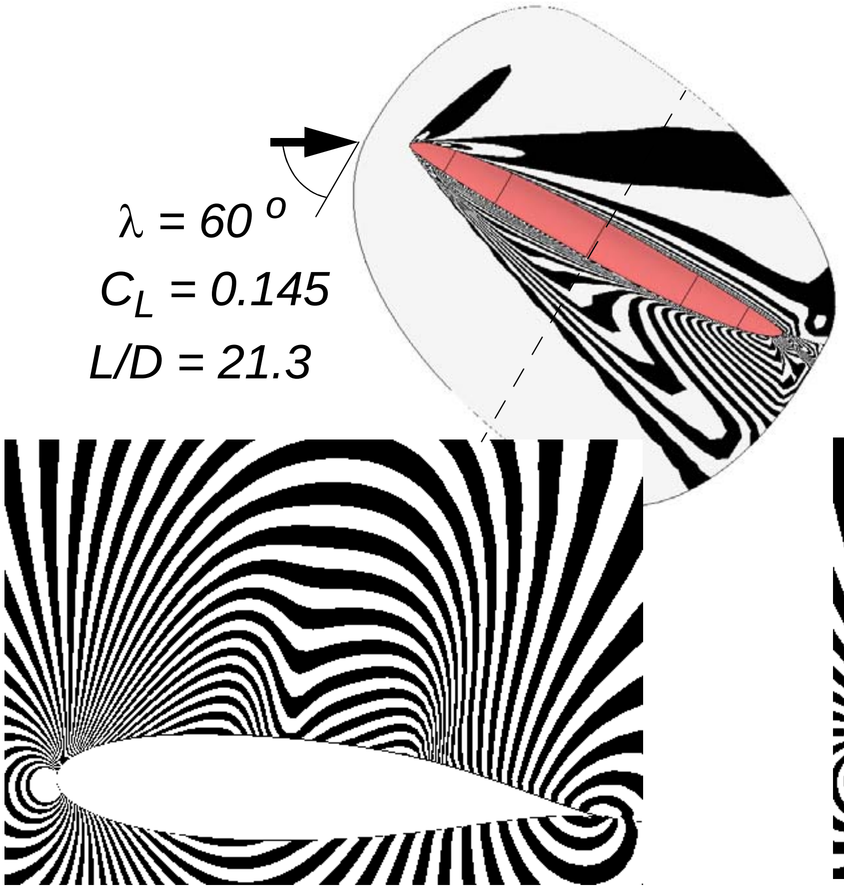
OFW: CFD ANALYSIS

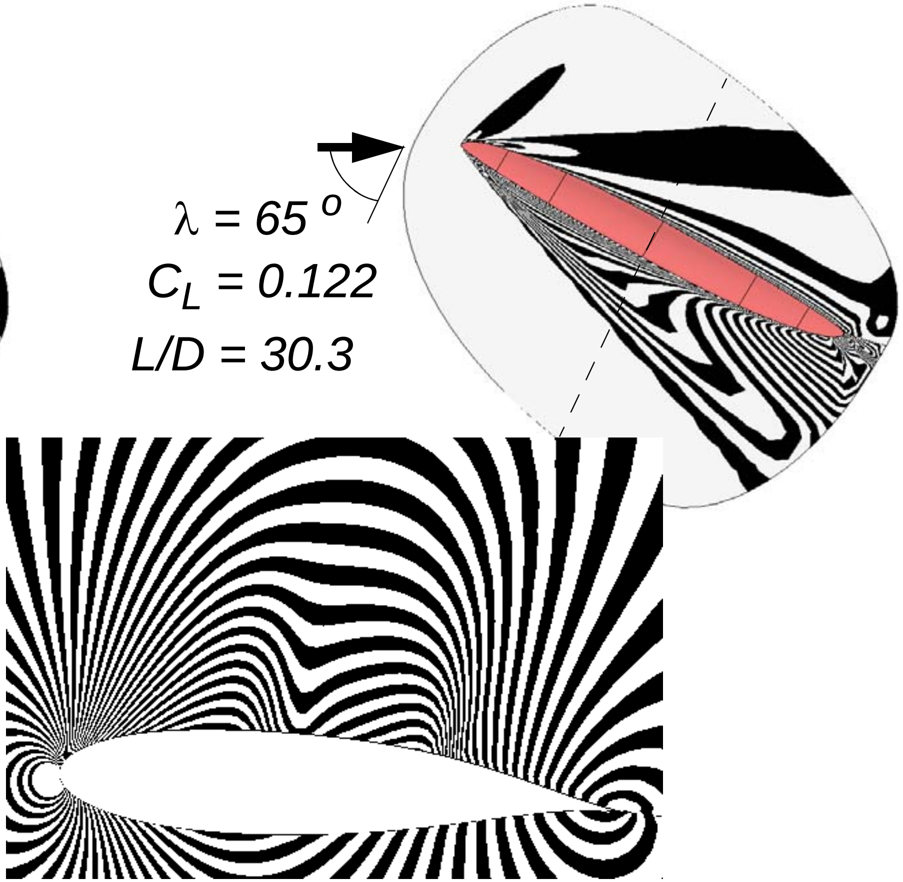
M_∞ = 1.41, inviscid flow, variation of sweep angle and lift



$\lambda = 60^o$

$C_L = 0.145$

$L/D = 21.3$



$\lambda = 65^o$

$C_L = 0.122$

$L/D = 30.3$

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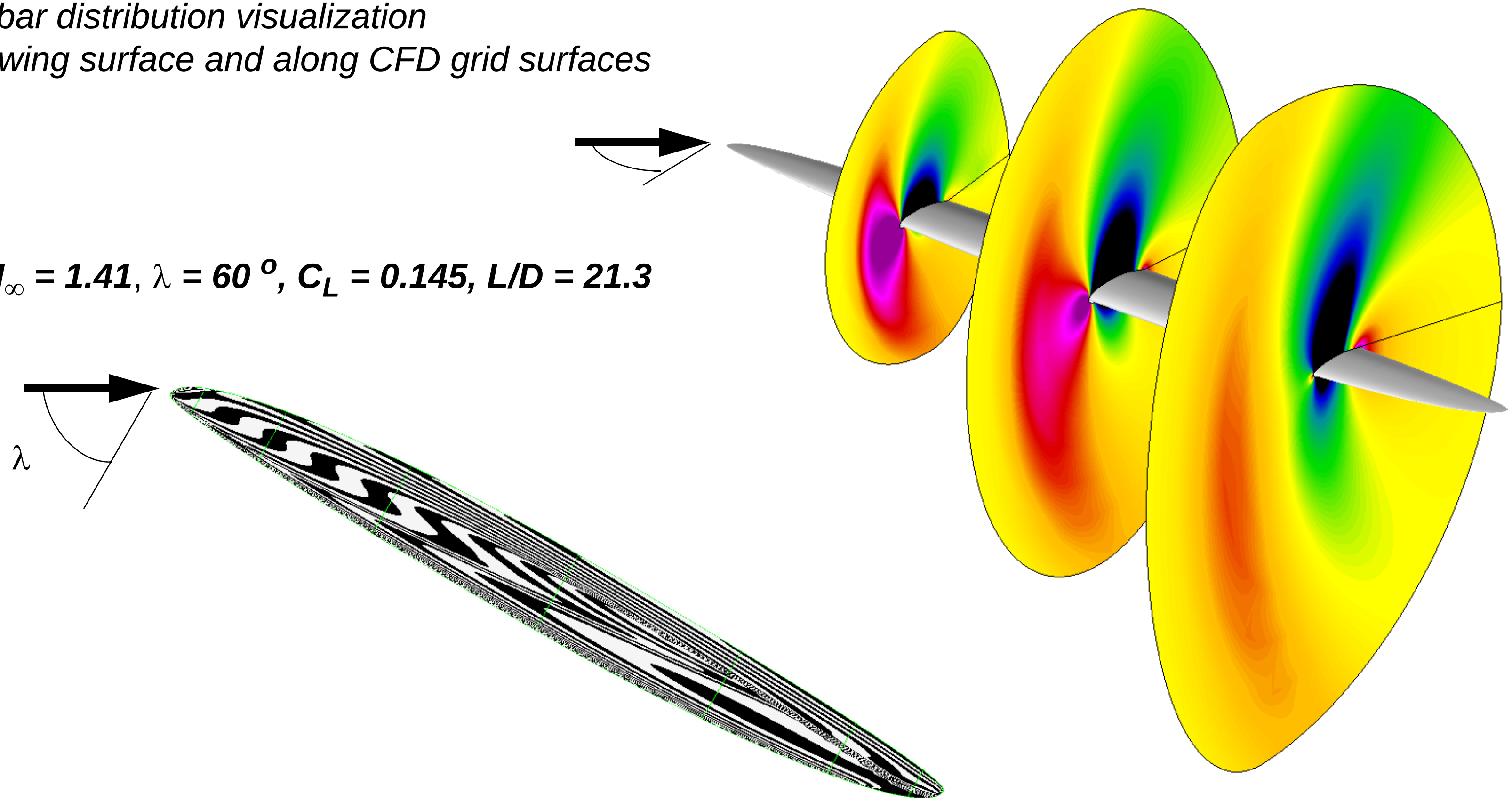
OFW: CFD ANALYSIS

Inviscid flow quality at design conditions

Isobar distribution visualization
on wing surface and along CFD grid surfaces

$M_\infty = 1.41$, $\lambda = 60^o$, $C_L = 0.145$, $L/D = 21.3$



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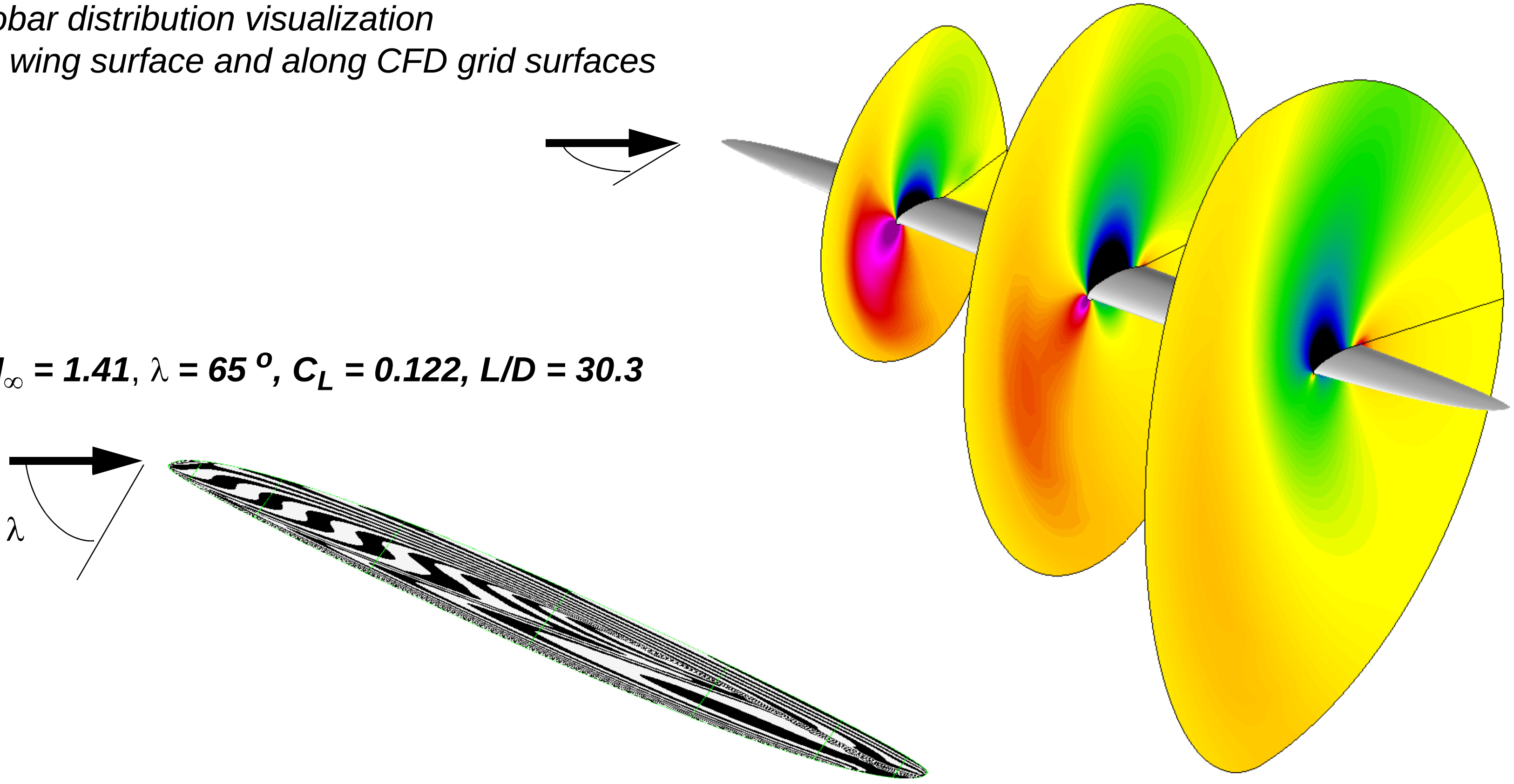
OFW: CFD ANALYSIS

Inviscid flow quality at optimum L/D conditions

Isobar distribution visualization
on wing surface and along CFD grid surfaces



$M_\infty = 1.41$, $\lambda = 65^o$, $C_L = 0.122$, $L/D = 30.3$

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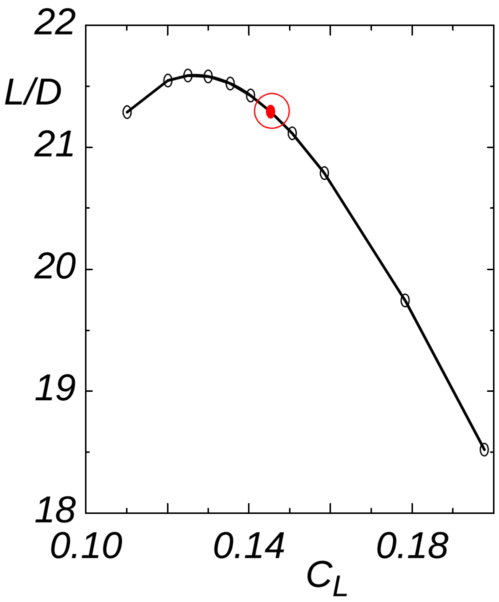
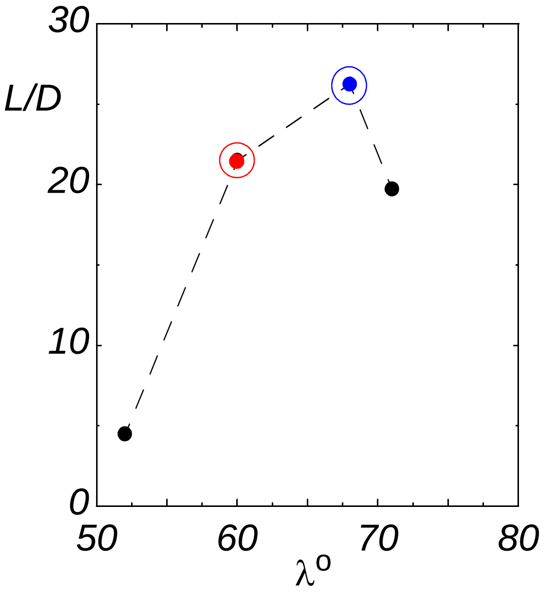
OFW: CFD ANALYSIS

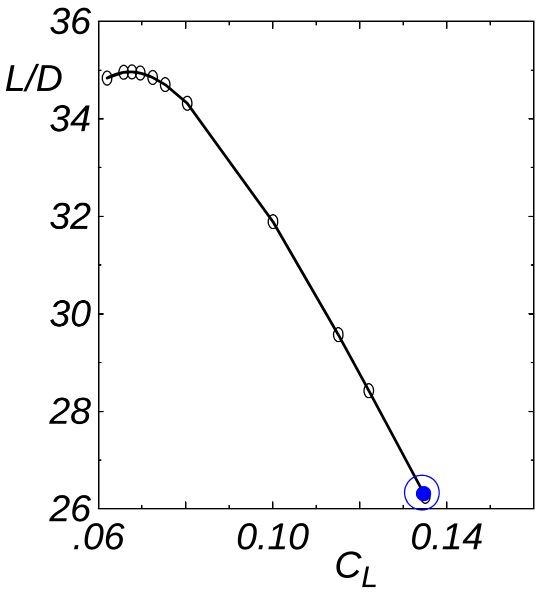
Inviscid lift / drag as a function of lift coefficient and sweep angle, $\mathbf{M}_\infty = 1.41$



$\lambda = 60^o$



$C_L = 0.135$



$\lambda = 68^o$

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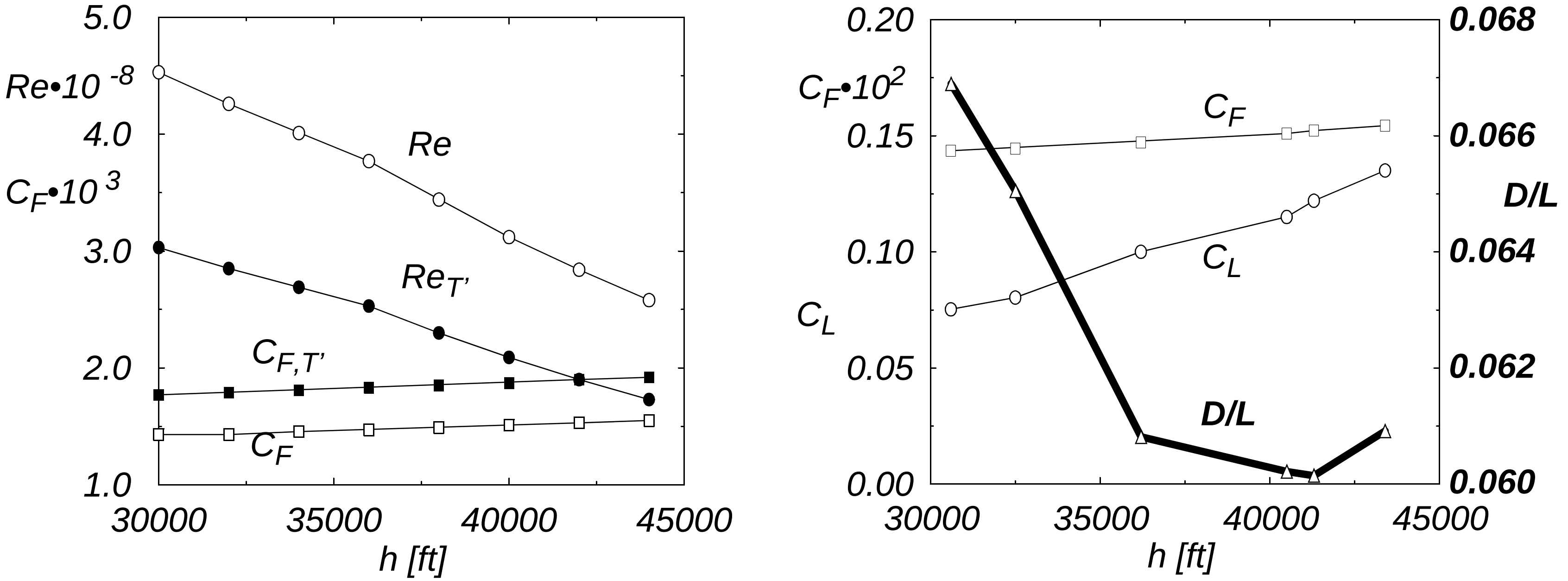
VISCOUS EFFECTS

$$\text{Drag} = \text{Lift}\ \{ (D/L)_{inviscid} + 2\, C_F / C_L \}$$

$M_\infty = 1.41,\ \lambda = 68^o$



Reynolds number, skin friction coefficient, lift coefficient and drag-to-lift ratio as a function of flight altitude (linear theory)

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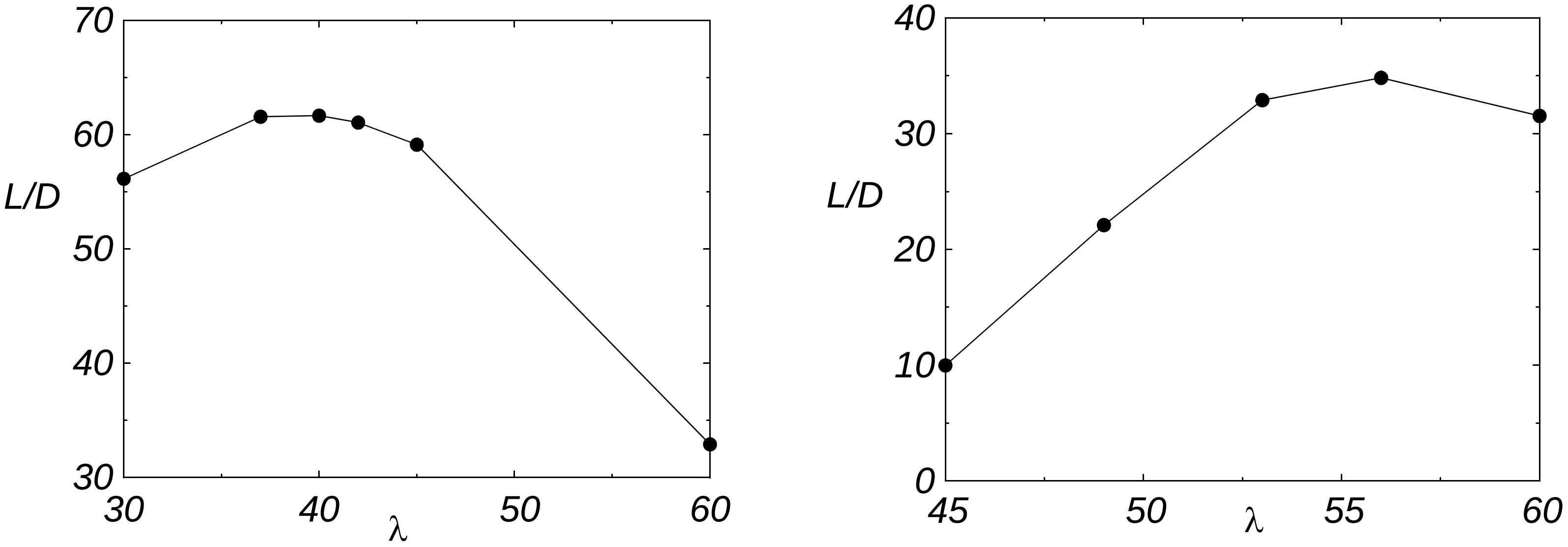
OFW: OFF-DESIGN RESULTS

Euler CFD results



$C_L = 0.24, M_\infty = 0.8$

$C_L = 0.224, M_\infty = 1.1$

Sweep variation at fixed C_L and M_∞

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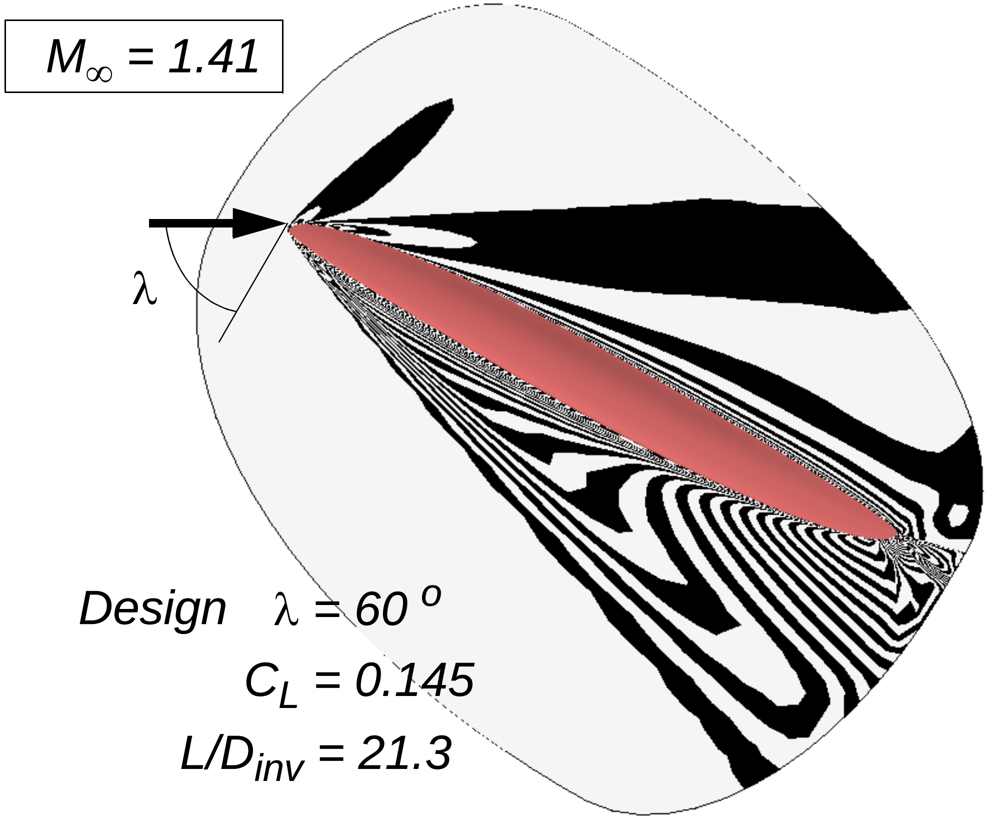
OBLIQUE FLYING WING

Test case for aerodynamic optimization

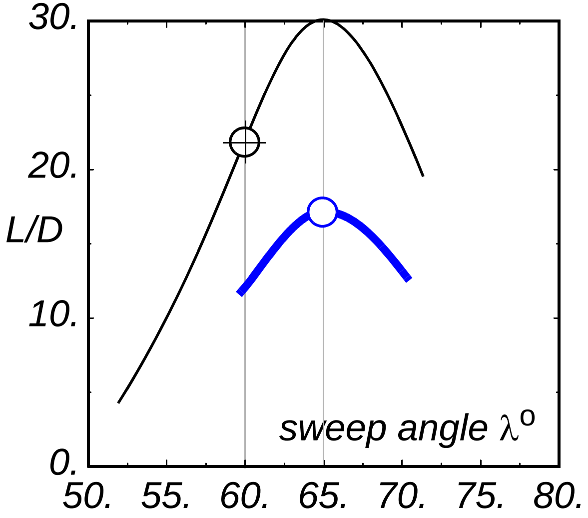


Design $\lambda = 60^o$

$C_L = 0.145$

$L/D_{inv} = 21.3$

CFL3D Euler analysis



Optimum $\lambda = 65^o$

$Re = 3 \times 10^8$

$C_L = 0.122$

$L/D_{visc} = 17.1$

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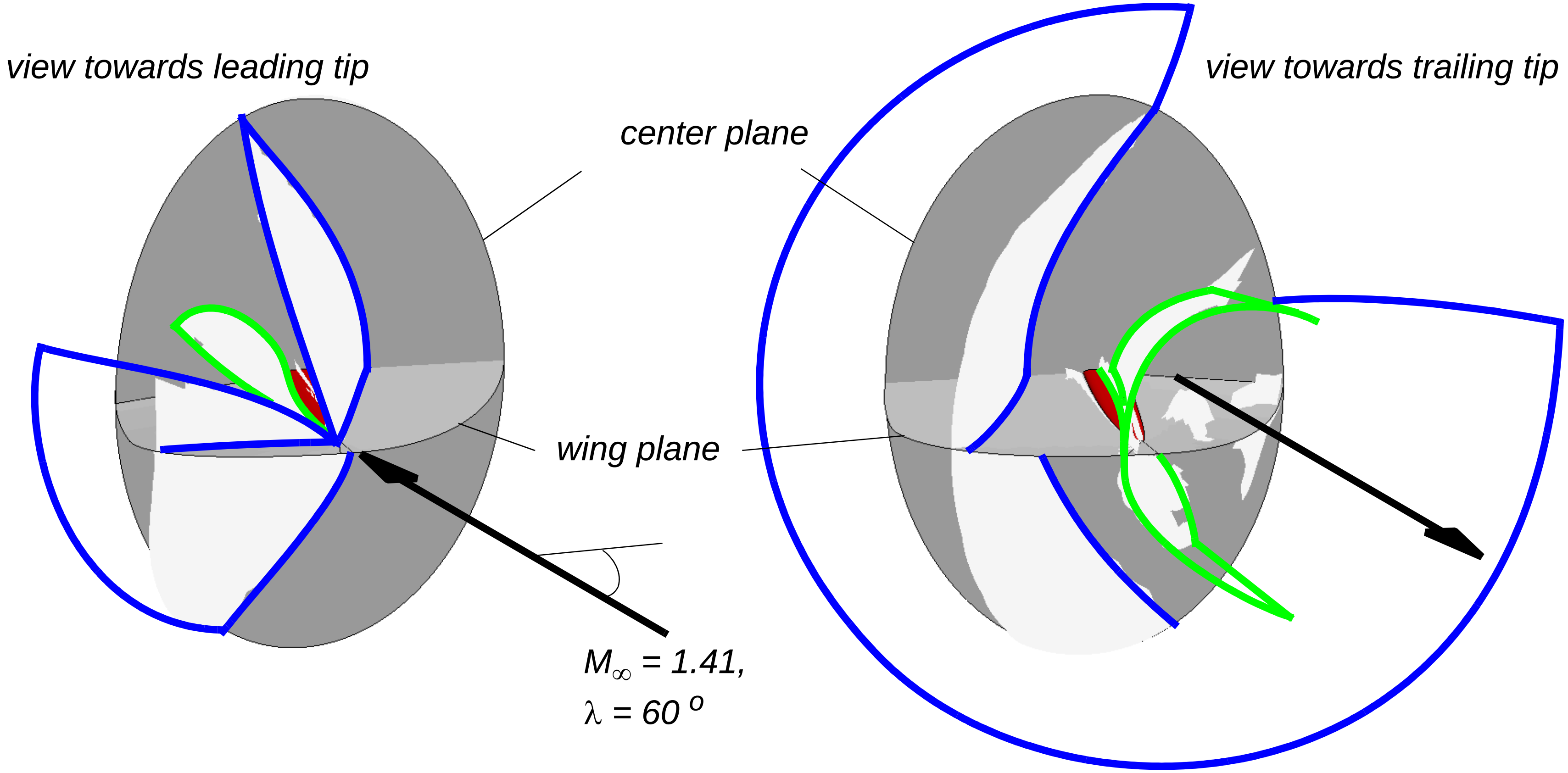
OFW: SHOCK STRUCTURE

Visualization of bow and tail wave system



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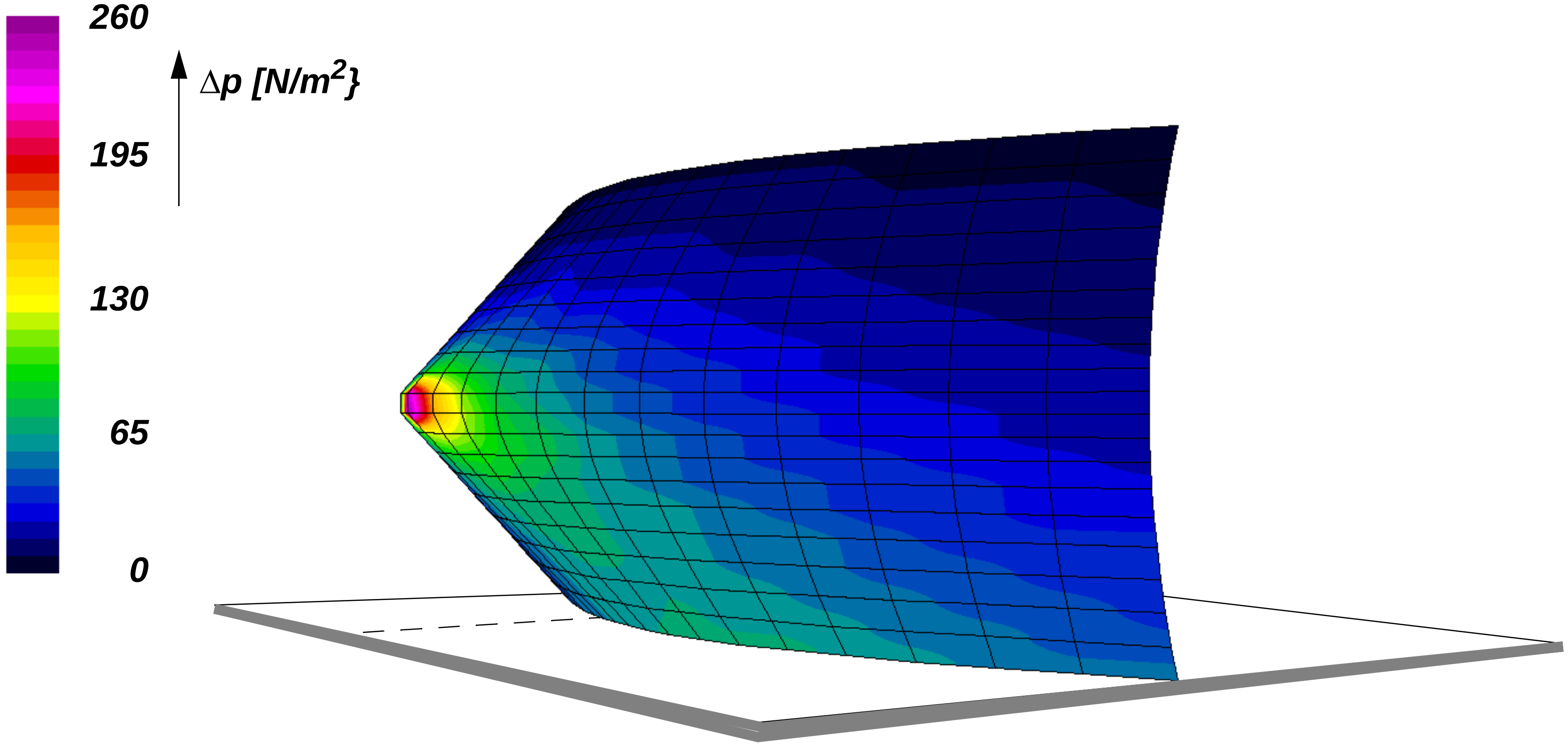
SONIC BOOM OF AN OBLIQUE FLYING WING AIRCRAFT

$M_\infty = 1.414$, $h = 12.6$ km

Front shock strength Δp



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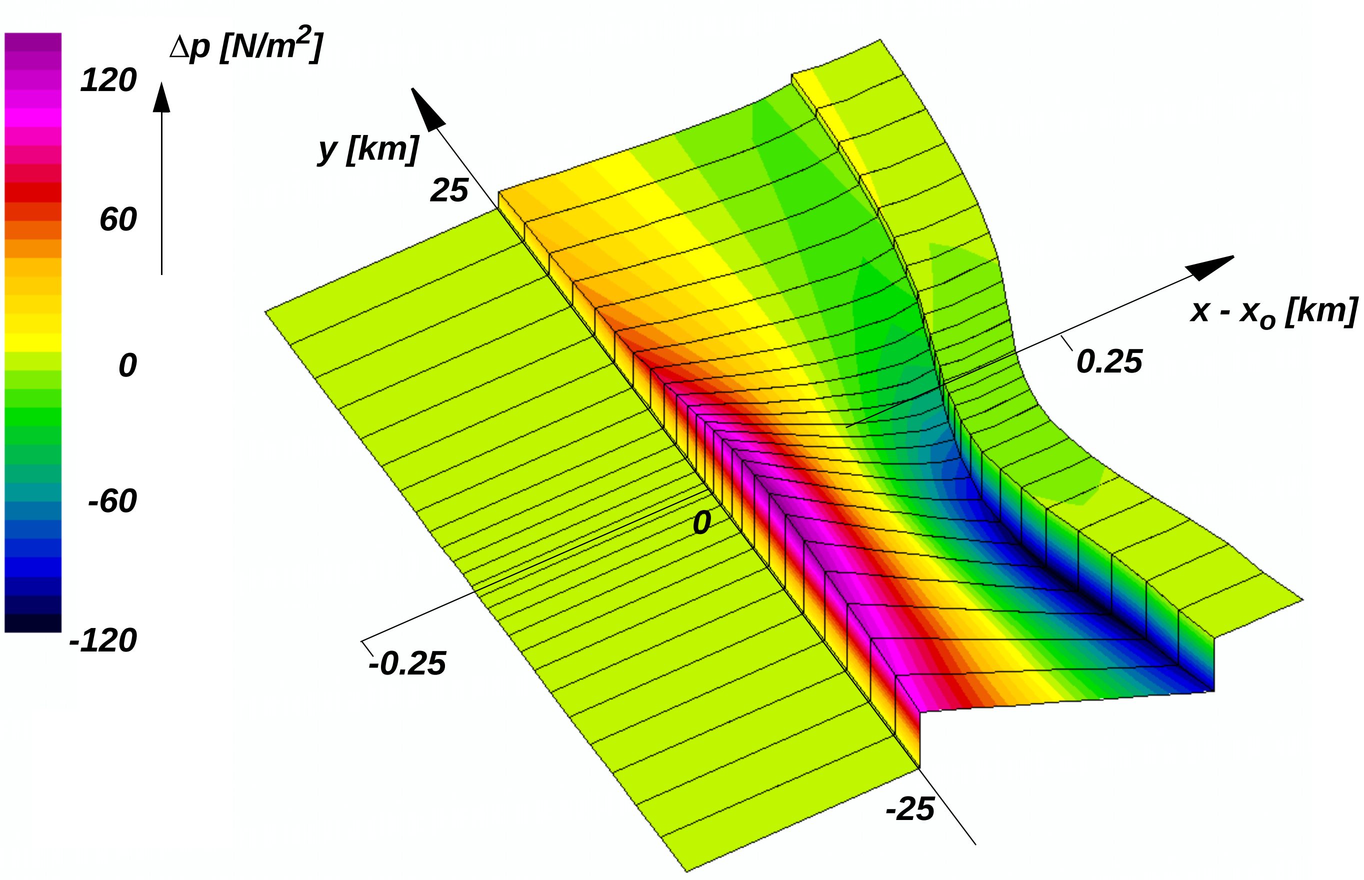
SONIC BOOM OF AN OBLIQUE FLYING WING AIRCRAFT

$M_\infty = 1.414$, $h = 12.6$ km

Pressure signature Δp on the ground



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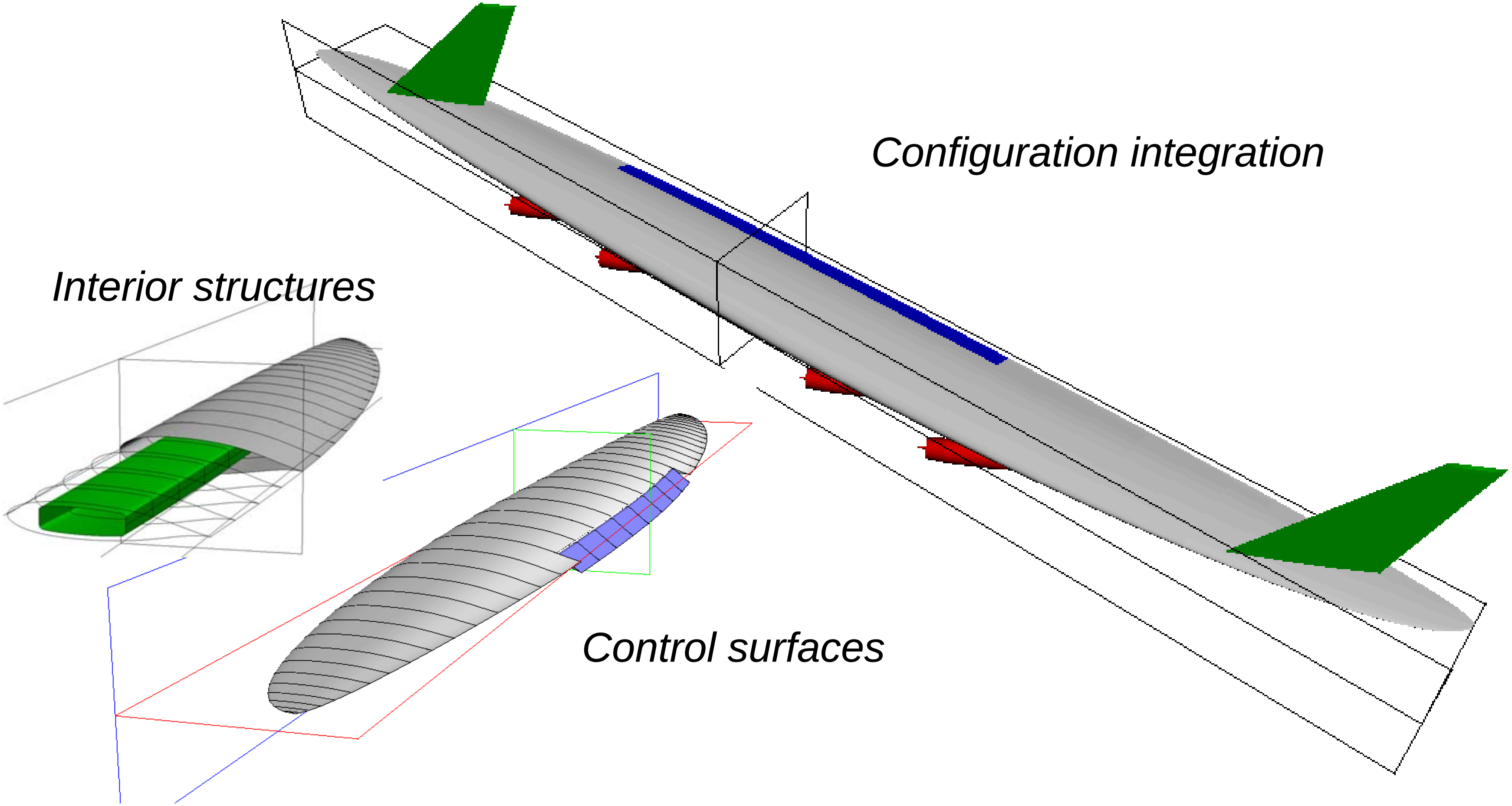
OBLIQUE FLYING WING

Test case for multidisciplinary optimization



Configuration integration

Interior structures

Control surfaces

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CONCLUSIONS

Results for candidate OFW :

climb
Mach = 0.8
ML/D = 24.9
sweep = 40 ^{o}
altitude = 30800 ft

accelerate
Mach = 1.1
ML/D = 23.7
sweep = 56 ^{o}
altitude = 41300 ft

cruise
Mach = 1.41
ML/D = 24.2
sweep = 65 ^{o}
altitude = 41300 ft

Results for systematic design tools development:

A manual design and optimization exercise for a novel HSCT configuration,
providing
parameter identification for notable aerodynamic performance improvements.