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.

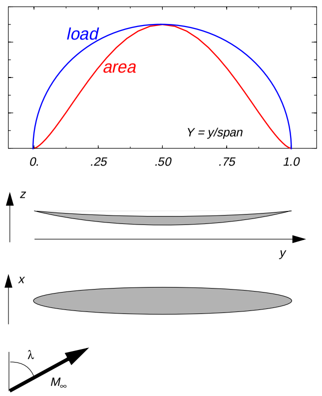
DESIGN TOOLS
Supporting theories and geometry definition

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:

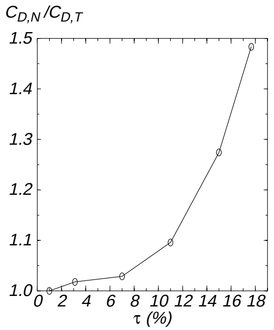
$\boxed{\text{area} \sim Y^{3/2}(1-Y)^{3/2}}$

Baseline shape:

elliptic wing planform,
parabolic bending.

SUPERSONIC THEORY

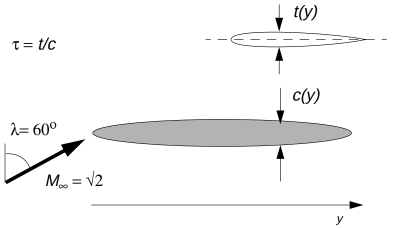
Comparison linear theory vs. CFD results



Elliptic wing, Sears-Haack area distribution:

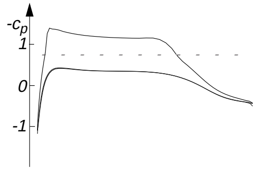
symmetrical airfoil sections

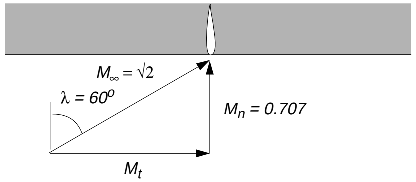
drag coefficients resulting from linear theory and Euler CFD

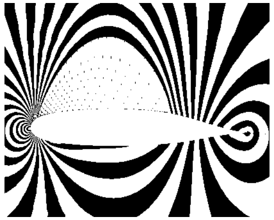


TRANSONIC THEORY

Definition of thick baseline wing sections







Preliminary design: Thick shock-free wing section

Method: Fict. Gas, inviscid flow

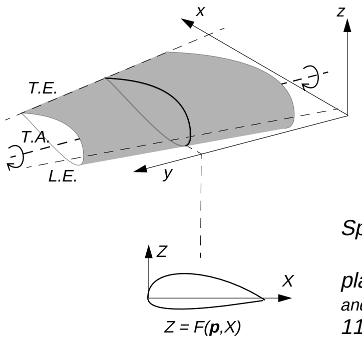
Application of swept wing theory

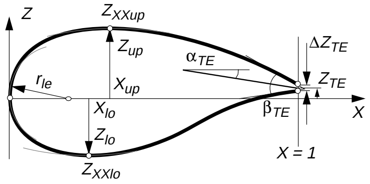
Example: $M_n = 0.707$, $c_l = 0.6$, $\tau = 0.17$

Extraction of geometric parameters for airfoil definition

GEOMETRY GENERATOR

Wing tool with spanwise airfoil variation



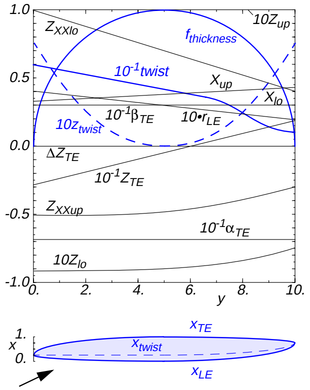


Spanwise definition by shape functions:

planform, twist, dihedral, thickness factor
and
*11 airfoil parameters, **p** = (r_{le}, X_{up}, ...)*

OFW

Spanwise parameter definition



11 airfoil parameters,
6 wing parameters :

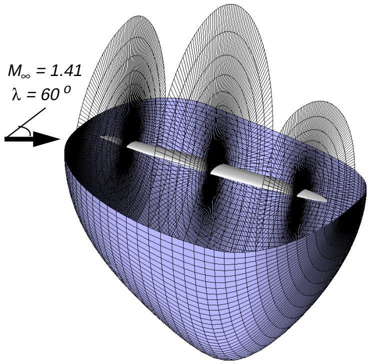
....defined by simple functions along span,

***controlling** linear theories constraints,*

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

NUMERICAL ANALYSIS

Inviscid Flow



Computational grid: O-O, 193 x 41 x 33 pts

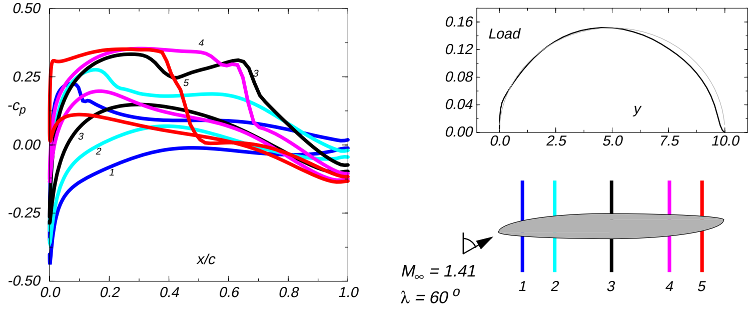
CFD code: CFL3D (Euler version).

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

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

OFW: CFD ANALYSIS

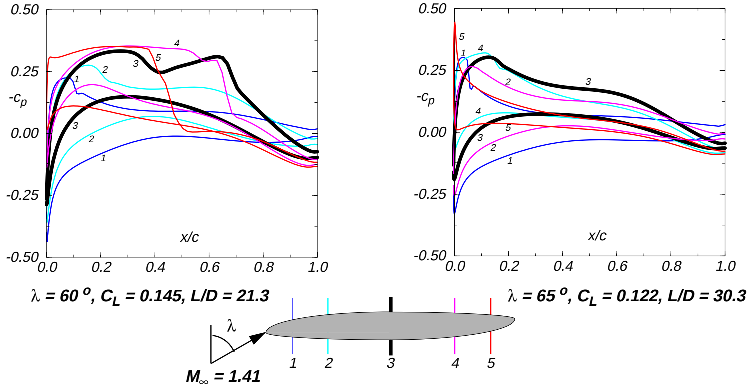
Inviscid flow results



Chordwise pressure and spanwise load distribution

OFW: CFD ANALYSIS

Inviscid flow results for varying sweep and lift

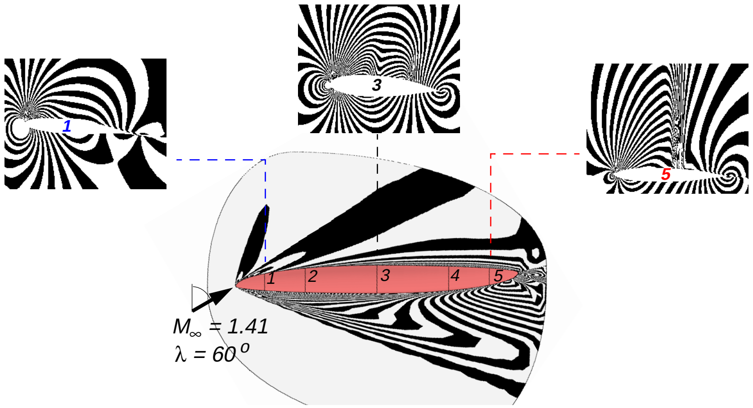


$\lambda = 60^o$, $C_L = 0.145$, L/D = 21.3

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

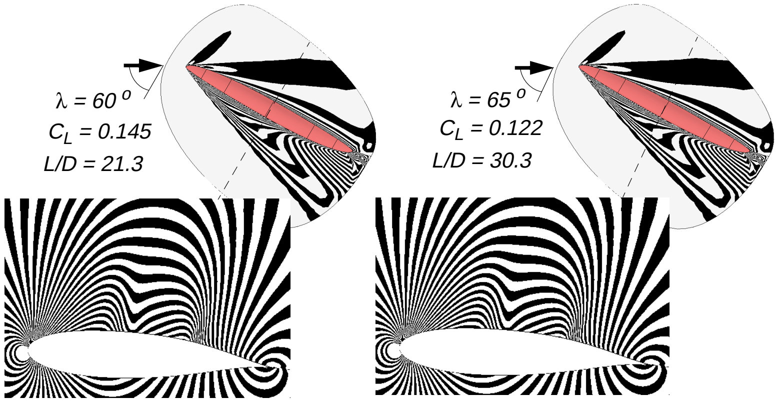
OFW: CFD ANALYSIS

Inviscid flow visualization: isobars



OFW: CFD ANALYSIS

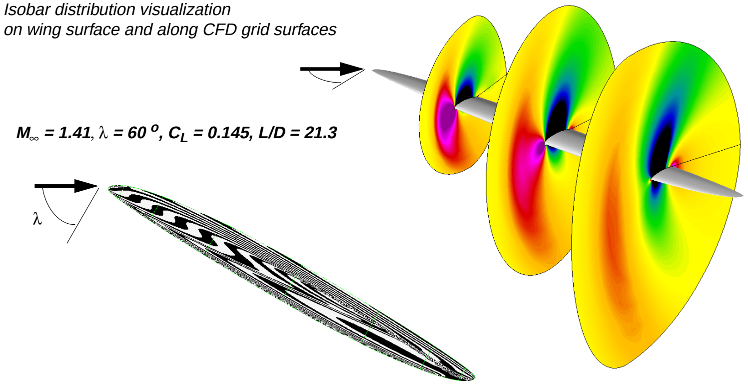
M_∞ = 1.41, inviscid flow, variation of sweep angle and lift



OFW: CFD ANALYSIS

Inviscid flow quality at design conditions

Isobar distribution visualization
on wing surface and along CFD grid surfaces

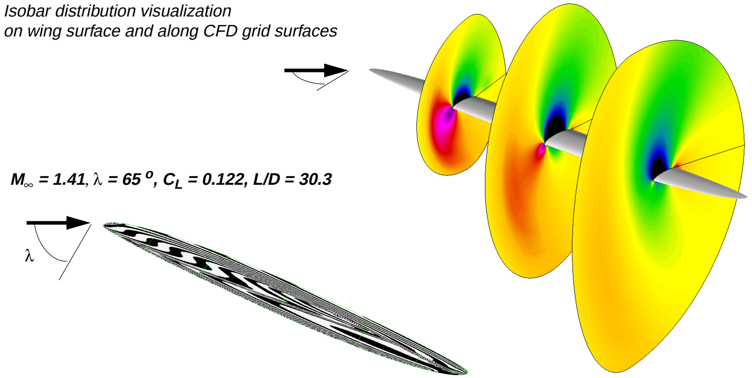


M_∞ = 1.41, $\lambda = 60^o$, C_L = 0.145, L/D = 21.3

OFW: CFD ANALYSIS

Inviscid flow quality at optimum L/D conditions

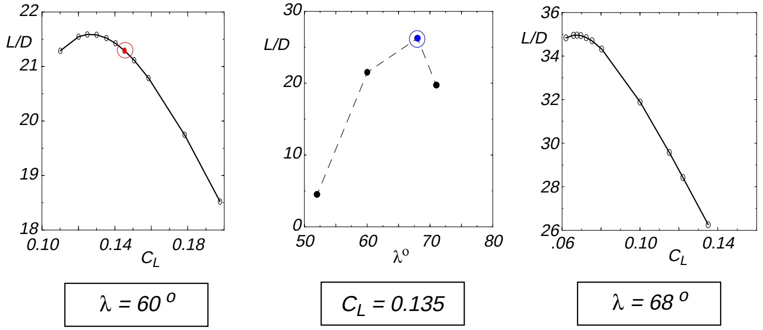
Isobar distribution visualization
on wing surface and along CFD grid surfaces



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

OFW: CFD ANALYSIS

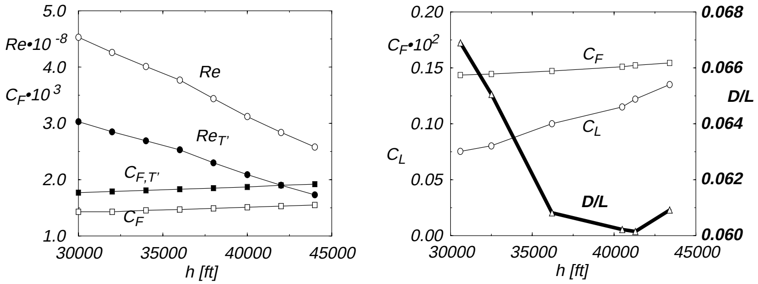
Inviscid lift / drag as a function of lift coefficient and sweep angle, **M_∞** = 1.41



VISCOUS EFFECTS

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

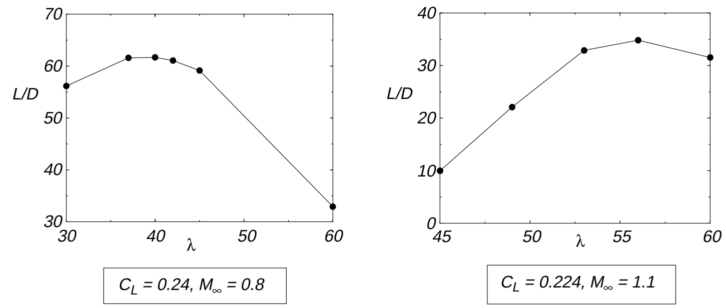
M_∞ = 1.41, λ = 68°



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

OFW: OFF-DESIGN RESULTS

Euler CFD results

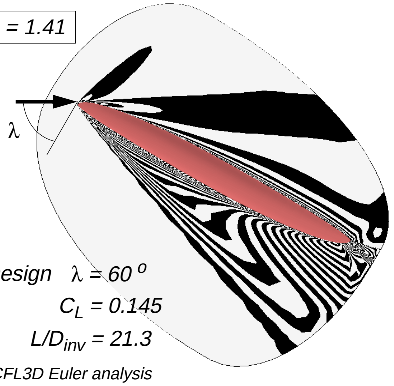


Sweep variation at fixed C_L and M_∞

Oblique Flying Wing

Test case for aerodynamic optimization

M_∞ = 1.41

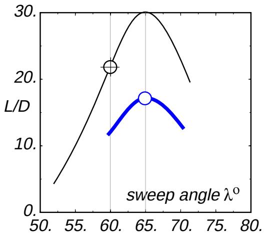


Design λ = 60°

C_L = 0.145

L/D_{inv} = 21.3

CFL3D Euler analysis



Optimum λ = 65°

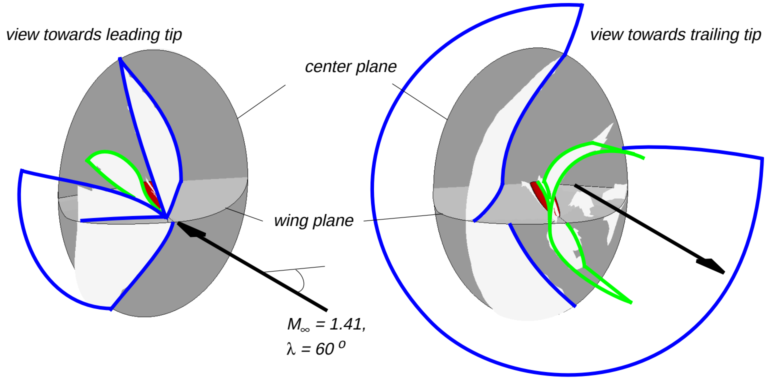
Re = 3 x 10^8

C_L = 0.122

L/D_{visc} = 17.1

OFW: SHOCK STRUCTURE

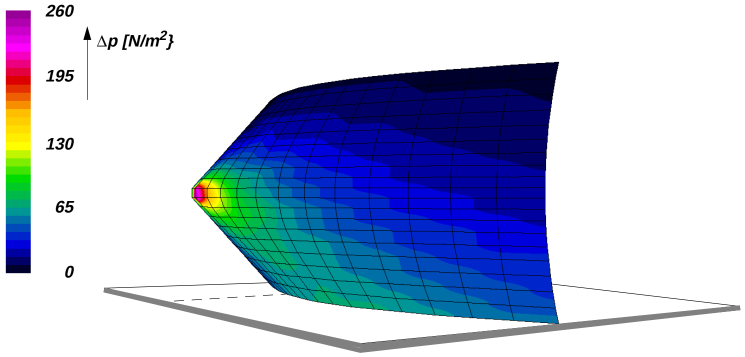
Visualization of bow and tail wave system



SONIC BOOM OF AN OBLIQUE FLYING WING AIRCRAFT

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

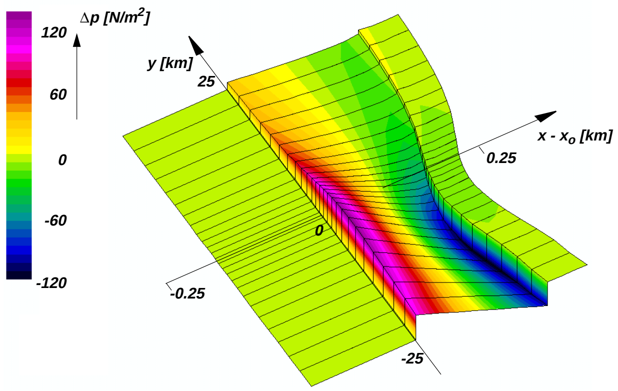
Front shock strength Δp



SONIC BOOM OF AN OBLIQUE FLYING WING AIRCRAFT

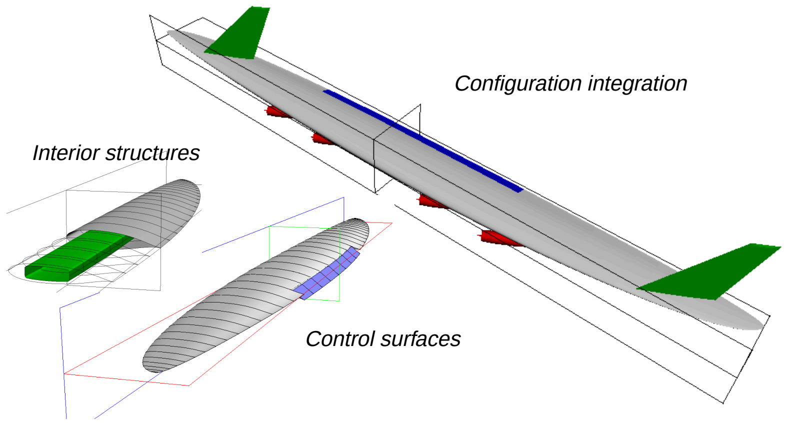
$M_\infty = 1.414$, $h = 12.6$ km

Pressure signature Δp on the ground



OBLIQUE FLYING WING

Test case for multidisciplinary optimization



Configuration integration

Interior structures

Control surfaces

CONCLUSIONS

<u>Results for candidate OFW :</u>

climb →	*accelerate* →	*cruise*
Mach = 0.8	*Mach = 1.1*	*Mach = 1.41*
ML/D = 24.9	*ML/D = 23.7*	*ML/D = 24.2*
sweep = 40^{o}	*sweep = 56^{o}*	*sweep = 65^{o}*
altitude = 30800 ft	*altitude = 41300 ft*	*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.