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:
\[
load \sim Y^{1/2}(1-Y)^{1/2}
\]

Minimum drag equivalent body of revolution:
\[
area \sim Y^{3/2}(1-Y)^{3/2}
\]

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

\[ \frac{C_{D,N}}{C_{D,T}} \]

\[ \tau = \frac{t}{c} \]

\[ \lambda = 60^\circ \]

\[ M_\infty = \sqrt{2} \]
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, \( \mathbf{p} = (r_{le}, X_{up}, \ldots) \)
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%
OOF: CFD ANALYSIS
Inviscid flow results

Chordwise pressure and spanwise load distribution

$M_\infty = 1.41$
$\lambda = 60^\circ$
OFW: CFD ANALYSIS

Inviscid flow results for varying sweep and lift

\[ \lambda = 60^\circ, C_L = 0.145, L/D = 21.3 \]

\[ \lambda = 65^\circ, C_L = 0.122, L/D = 30.3 \]

\[ M_\infty = 1.41 \]
OFW: CFD ANALYSIS

Inviscid flow visualization: isobars

$M_\infty = 1.41$

$\lambda = 60^\circ$
OFW: CFD ANALYSIS

$M_\infty = 1.41$, inviscid flow, variation of sweep angle and lift

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

$\lambda = 65^\circ$
$C_L = 0.122$
$L/D = 30.3$
OFW: CFD ANALYSIS

Inviscid flow quality at design conditions

Isobar distribution visualization on wing surface and along CFD grid surfaces

\[ M_\infty = 1.41, \ \lambda = 60^\circ, \ \text{C}_L = 0.145, \ \text{L/D} = 21.3 \]
OFW: CFD ANALYSIS

Inviscid flow quality at optimum L/D conditions

Isobar distribution visualization on wing surface and along CFD grid surfaces

\[ M_\infty = 1.41, \, \lambda = 65^\circ, \, C_L = 0.122, \, L/D = 30.3 \]
**OFW: CFD ANALYSIS**

Inviscid lift / drag as a function of lift coefficient and sweep angle, $M_\infty = 1.41$

\[ \lambda = 60^\circ \]

\[ C_L = 0.135 \]

\[ \lambda = 68^\circ \]
**VISCOUS EFFECTS**

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

\( M_{\infty} = 1.41, \lambda = 68^\circ \)

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

\[ C_L = 0.24, \ M_\infty = 0.8 \]

\[ C_L = 0.224, \ M_\infty = 1.1 \]

Sweep variation at fixed \( C_L \) and \( M_\infty \)
OBLIQUE FLYING WING

Test case for aerodynamic optimization

\[ M_\infty = 1.41 \]

Design \[ \lambda = 60^\circ \]
- \[ C_L = 0.145 \]
- \[ L/D_{inv} = 21.3 \]

CFL3D Euler analysis

Optimum \[ \lambda = 65^\circ \]
- \[ Re = 3 \times 10^8 \]
- \[ C_L = 0.122 \]
- \[ L/D_{visc} = 17.1 \]
OFW: SHOCK STRUCTURE
Visualization of bow and tail wave system

$M_\infty = 1.41,$
$\lambda = 60^\circ$
SONIC BOOM OF AN OBLIQUE FLYING WING AIRCRAFT

\[ M_\infty = 1.414, \ h = 12.6 \ km \]

Front shock strength \( \Delta p \)
SONIC BOOM OF AN OBLIQUE FLYING WING AIRCRAFT

\[ M_\infty = 1.414, \ h = 12.6 \ km \]

Pressure signature \( \Delta p \) on the ground

\[ \Delta p \ [N/m^2] \]

\[ y \ [km] \]

\[ x - x_o \ [km] \]

\[ -0.25 \]

\[ 0.25 \]

\[ -25 \]

\[ 25 \]
OBLIQUE FLYING WING
Test case for multidisciplinary optimization

Interior structures
Control surfaces
Configuration integration
CONCLUSIONS

Results for candidate OFW:

climb
Mach = 0.8
ML/D = 24.9
sweep = 40°
alitude = 30800 ft

accelerate
Mach = 1.1
ML/D = 23.7
sweep = 56°
alitude = 41300 ft

cruise
Mach = 1.41
ML/D = 24.2
sweep = 65°
alitude = 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.