Lesson 27: Wings at Transonic Speed

The original DC-8 reflection plane model, in the VT WT Lab

An advanced Douglas transport WT Model, also in the VT WT Lab
The Swept Wing – A Major Advance

From Aerodynamics for Naval Aviators by Hurt
The original swept wing model carved by George Shairer

Picture of B-52 made in Dayton Hotel over a weekend by Boeing engineers

picture taken by Mason at the Museum of Flight, Seattle, WA
The problem of transonic wing design


Remember the importance of good straight isobars!
The Standard Transonic Test Case: the ONERA M6 Wing

A standard way to look at your results

The wing is symmetrical with no twist: note the unsweep of the shock and the build up of the pressure peak at the tip
Comparison: computations to data for the ONERA M6

\[ \frac{y}{b/2} = 0.655 \]

\[ \frac{y}{b/2} = 0.800 \]

Note double shock, rarely captured in computations

Viscous Effects Still Important

Lockheed Wing A

From NASA CR178156, Oct. 1986

\[ \frac{y}{(b/2)} = 0.50 \]

\[ \frac{y}{(b/2)} = 0.70 \]
How to use advanced airfoil capability in wing design

TWO WAYS OF USING SUPERCritical AIRFOIL

STRAIGHT WINGS

INCREASING M_Cruise

ΔM = 15%

Δt/c = 42%

CONVENTIONAL

SUPERCritical

WIND-Tunnel DATA

Flight DATA

PROJECTED

Re-winged T-2 Buckeye

Whitcomb’s original (pre-1st oil embargo) idea: increase speed
Ways to use Advanced Aerodynamics
Frank Lynch’s Wing Chart

Instead of higher speed for same sweep and max thickness

\[
\Delta C_{DC} \quad \text{CONVENTIONAL} \quad \text{SUPERCRITICAL}
\]

For energy efficiency

Reduce sweep

For similar \( M_0 \)
- Reduces weight
- Improved high-speed post-buffet flight characteristics
- Improved low-speed performance

Increase thickness

For similar \( M_0 \)
- Reduces weight
- Increases fuel volume
- Increases \( C_{L_{\text{max}}} \)

Increase aspect ratio

- Reduced cruise drag
- Improved low-speed performance

Korn Eqn and Simple Sweep Theory
- a sort of Poor Man’s method (no CFD) -

Extend Korn to swept wings using simple sweep theory

\[ M_{dd} = \frac{\kappa_A}{\cos \Lambda} - \frac{(t / c)}{\cos^2 \Lambda} - \frac{c_l}{10 \cos^3 \Lambda} \]

and then use Lock’s approximation:

\[ C_{D_{Wave}} = 20(M - M_{crit})^4 \quad M > M_{crit} \]

where using: \( \frac{\partial C_D}{\partial M} = 0.1 \), \( \frac{\partial C_D}{\partial M} = 0.1 = 80(M - M_{crit})^3 \)

so that we find \( M_{crit} \):

\[ M_{crit} = M_{dd} - \left(\frac{0.1}{80}\right)^{1/3} \]

Remember this is only a rough approximation!
Transonic Drag Rise Estimate: B747

Example computed by Joel Grasmeyer, $\kappa_A = 0.89$

So how do you design the wing?

- Set the spanload in an MDO trade
- Linear theory gives a good first guess for the twist distribution
- Design the airfoils in 2D to start, and place in wing
- Finally, full 3D nonlinear analysis and design
- Special attention to root and tip mods to maintain isobar sweep
- Well known considerations:
  - Viscous effects are important
  - You must also model and include the fuselage
  - Need to address off design: buffet onset and overspeed
Jameson Wing Design for the MD-12

COMPARISON OF CHORDWISE PRESSURE DISTRIBUTIONS
MPX5X WING-BODY
REN = 101.00, MACH = 0.860

Solution 1
Upper-Surface Isobars
(Contours at 0.05 C)

X / C
95.6% Span

X / C
99.1% Span

X / C
60.8% Span

X / C
9.6% Span

X / C
29.2% Span

X / C
4.3% Span

SYMBOL SOURCE ALPHA CL CD
SYN107P DESIGN 40 2.094 0.610 0.01126

Off Design Characteristics of the Jameson Wing

Transonic Transport Wing Design
Other Lessons learned at Boeing

• You can increase the root thickness w/o a drag penalty
• Nacelle/pylon wing interference can be done with CFD with almost no penalty
Real Current Example, The A-380

Quarter Chord Sweep: 33.5°
Aspect Ratio: 7.67
Root chord: 0.132 t/c
Tip chord: 0.087 t/c

From *Aerodynamic Design of Transport Aircraft*, Ed Obert, Delft Press, 2009
A-380 Thickness and Twist Distributions

- a rare find -

Note: “jig shape” means before the change in twist due to aerodynamic load

Finally: the fuselage can effect drag

Another Whitcomb Contribution: Fuselage Area Addition

Low mounted wing, $C_L = 0.3$

High mounted wing, $C_L = 0.3$

Adding a fuselage bump reduces drag slightly above $M = 0.85$: the Boeing 747 used this idea, it was supposed to cruise at $M = 0.90$

From Whitcomb NACA TN 4290, June 1958.
Fighter Wings: A more complicated story


Rather than cruise, fighter wings have to consider supersonics and low speed speed maneuvering as well as transonic cruise and maneuver
An Example: the F-15 - Design Points

17 Design points
C - cruise ($\leq L/D_{\text{max}}$)
M - maneuvering ($> L/D_{\text{max}}$)

(8) ♦ Maximum power $P_S$ points
(5) □ Mil power $P_S$ points
(1) △ Buffet onset $G$ load
(3) ○ Maximum mach points

F-15 Wing Evolution

The wing has conical camber: hard to see in streamwise section cuts

Drag from Larry Niedling, “The F-15 Wing Development Program”, AIAA Paper 80-3044
Example of attached flow fighter design

Grumman proposed HiMAT, \( M = 0.90 \)

Hybrid Wings: the F-16 and F-18

A combined low aspect ratio strake and a traditional wing

From *Modern Combat Aircraft Design*, by Klaus Huenecke, 1987
Fighter Wings – Drag: Hybrid Wing Vortex Flow Effects Compared to Attached Flow Concepts

Vortex flow concepts have an advantage at high $C_Ls$
To Conclude

• We’ve given a broad overview
  – Stressed the fundamental physics and issues

• Thousands of papers written on
  – Computational analysis methods
  – Design and optimization methods
  – Applications and design concepts

• You are prepared to start contributing