

Winglets

(It's all about controlling the flow field)

Bill Kuhlman

With thanks to Wayne Duncan for asking the question

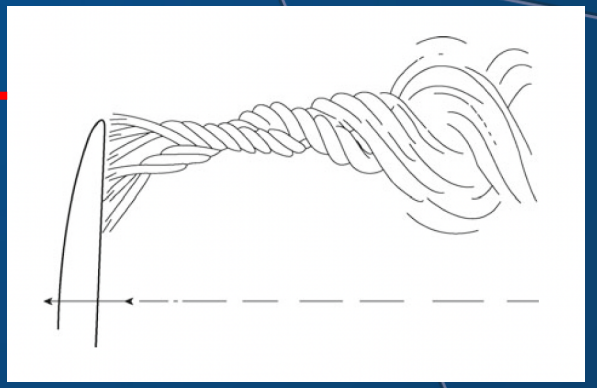
What are “winglets”?

Winglets are...

- relatively small aerodynamic devices
- installed at the tips of a wing
- designed to improve wing efficiency by changing the flow field around the wing
  - reducing induced drag
  - enhancing lift
  - producing induced thrust (?)

A brief history of winglets

1897: Frederick W. Lanchester



1897 & 1905: John J. Montgomery

1918: Prandtl's Lifting Line Theory

1920-1930s: Simple wing tip devices

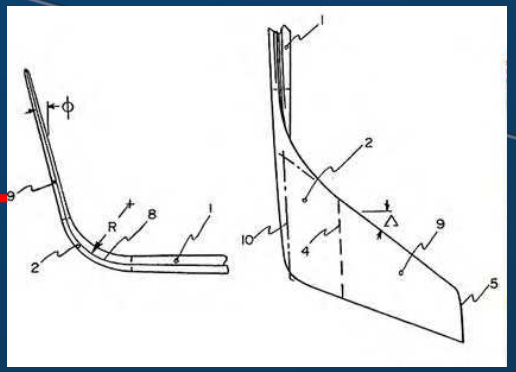


1976: Dr. Richard T. Whitcomb (NASA)

1980s: Boeing and Airbus

1987-2000s: Dr. Mark Maughmer

1994: Gratzer's blended winglet



2024: Active winglets patented

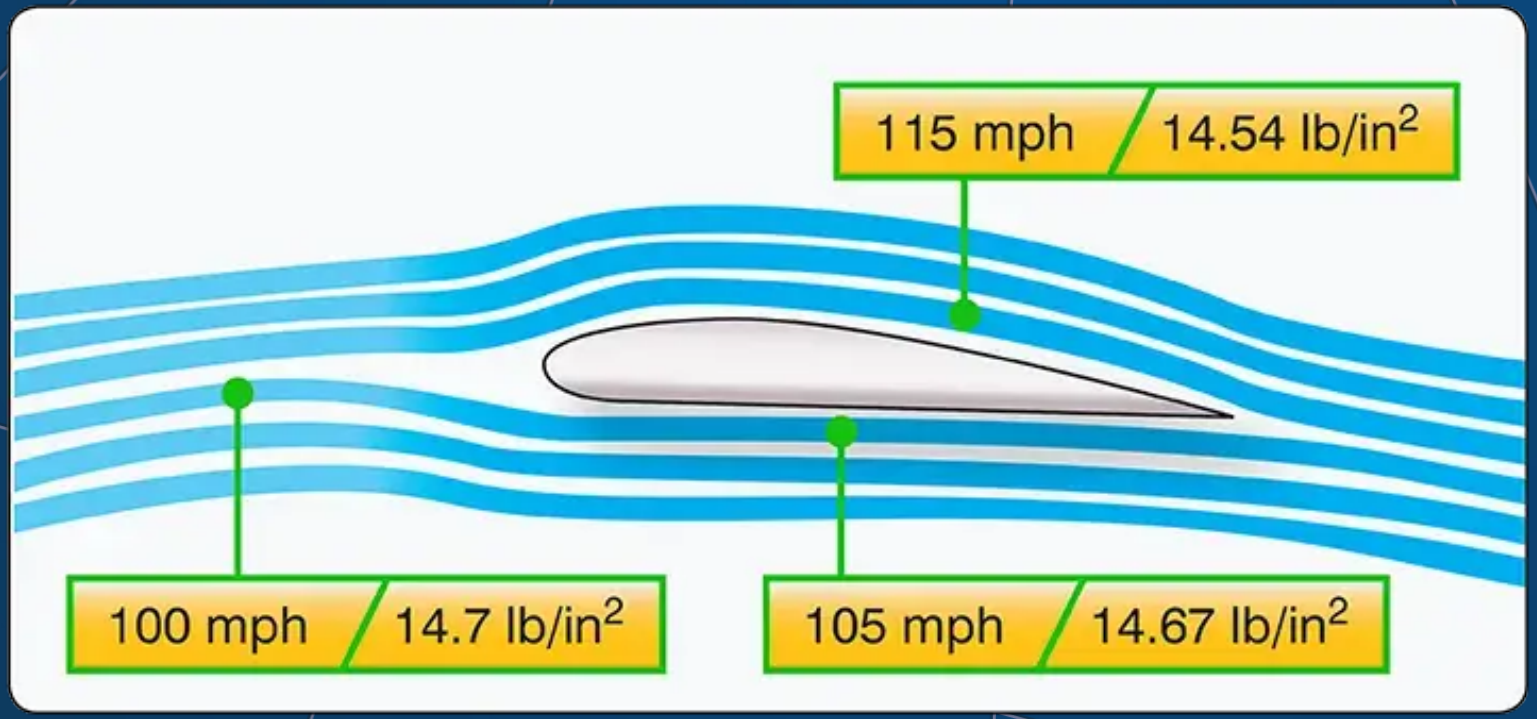
Visualizing the flow around a section

Prandtl's Historic Flow Visualization Film

- Approach of a hydrofoil (film camera traveling)
- The start-up vortex of a hydrofoil (film camera stationary)
- Vortex formation of an airfoil that accelerates a short distance and then stops again (film camera stationary)

Anfahrt
eines Tragflügels
(Filmkamera mitfahrend)

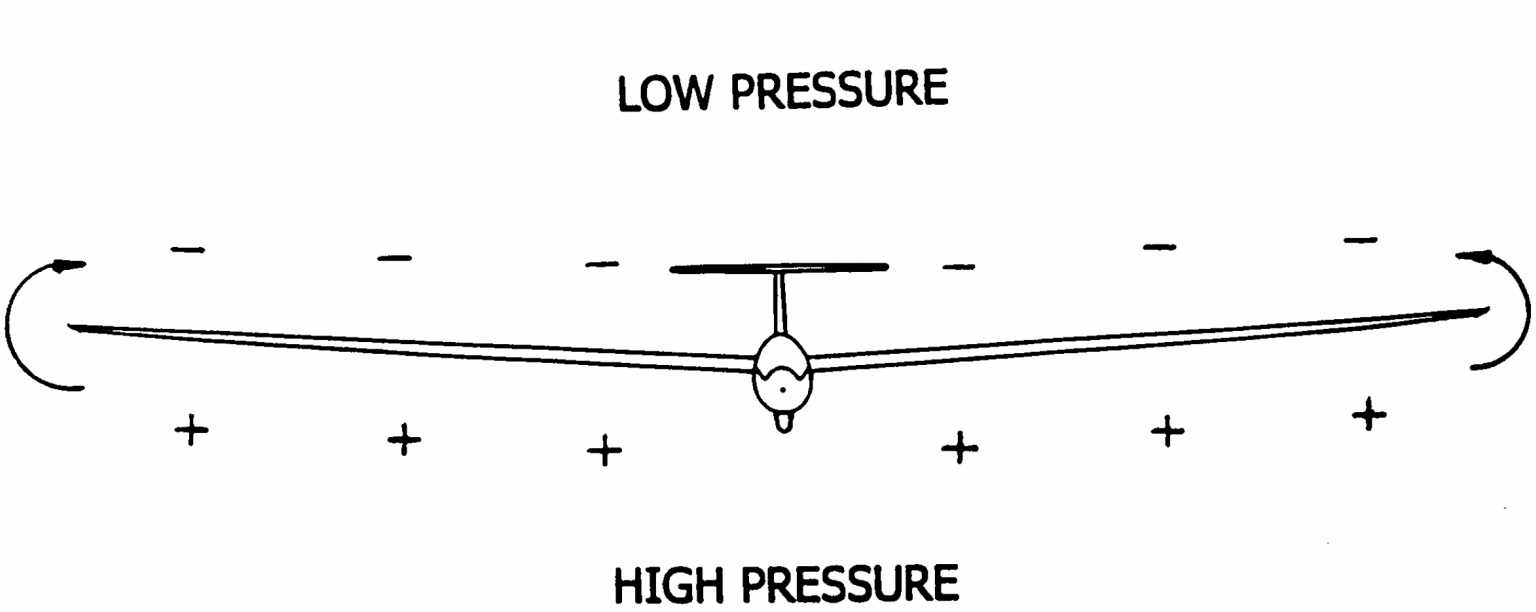
Circulation



- Air accelerates differentially as it flows around wing
- Average air velocity around wing is 110mph
- 115mph - 110mph = +5mph (toward trailing edge)
- 105mph - 110mph = -5mph (toward leading edge)
- Flow can be visualized as a bound vortex around the wing

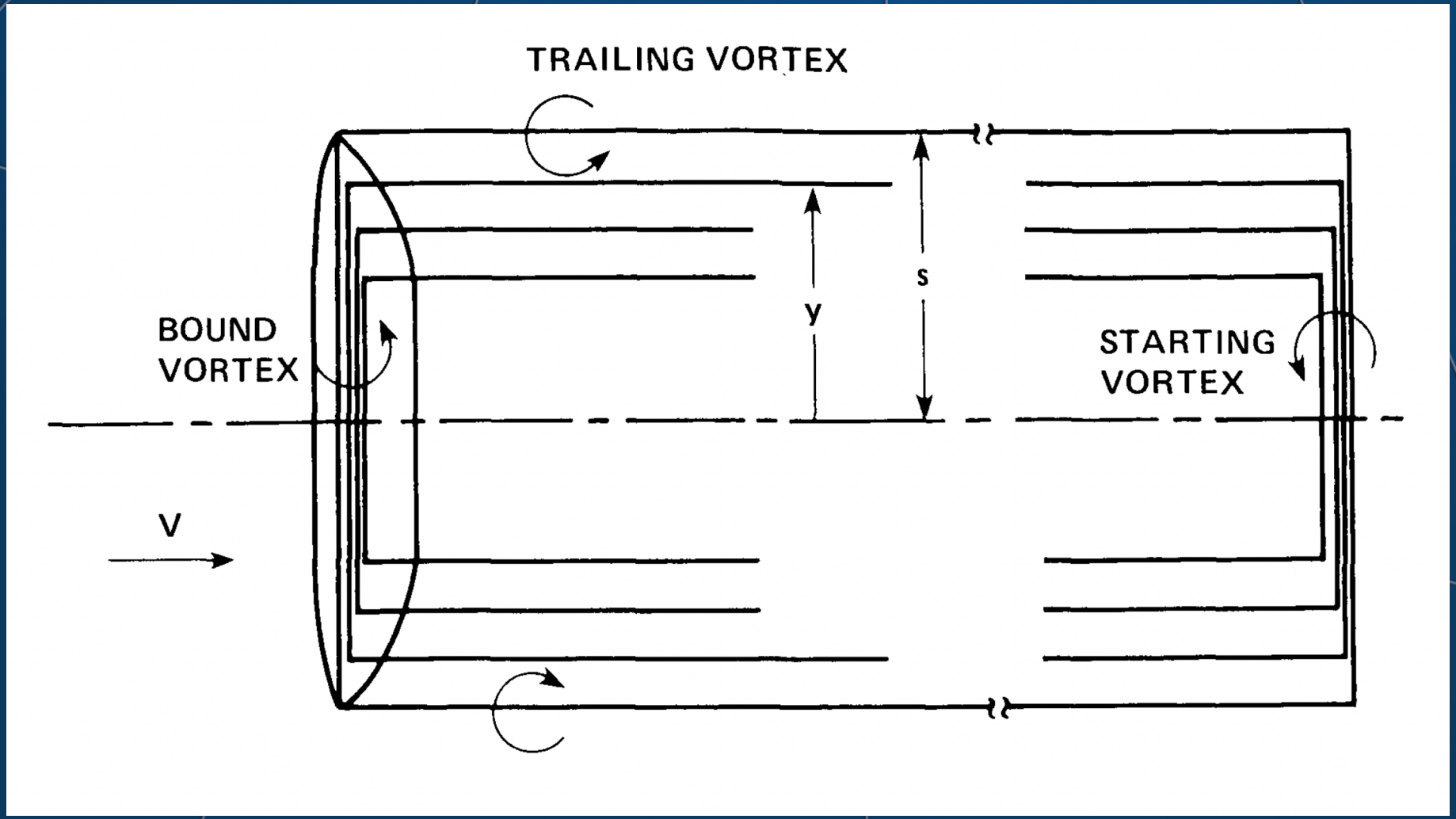
Generalized spanwise flow

- The flow around a wing from high to low pressure areas

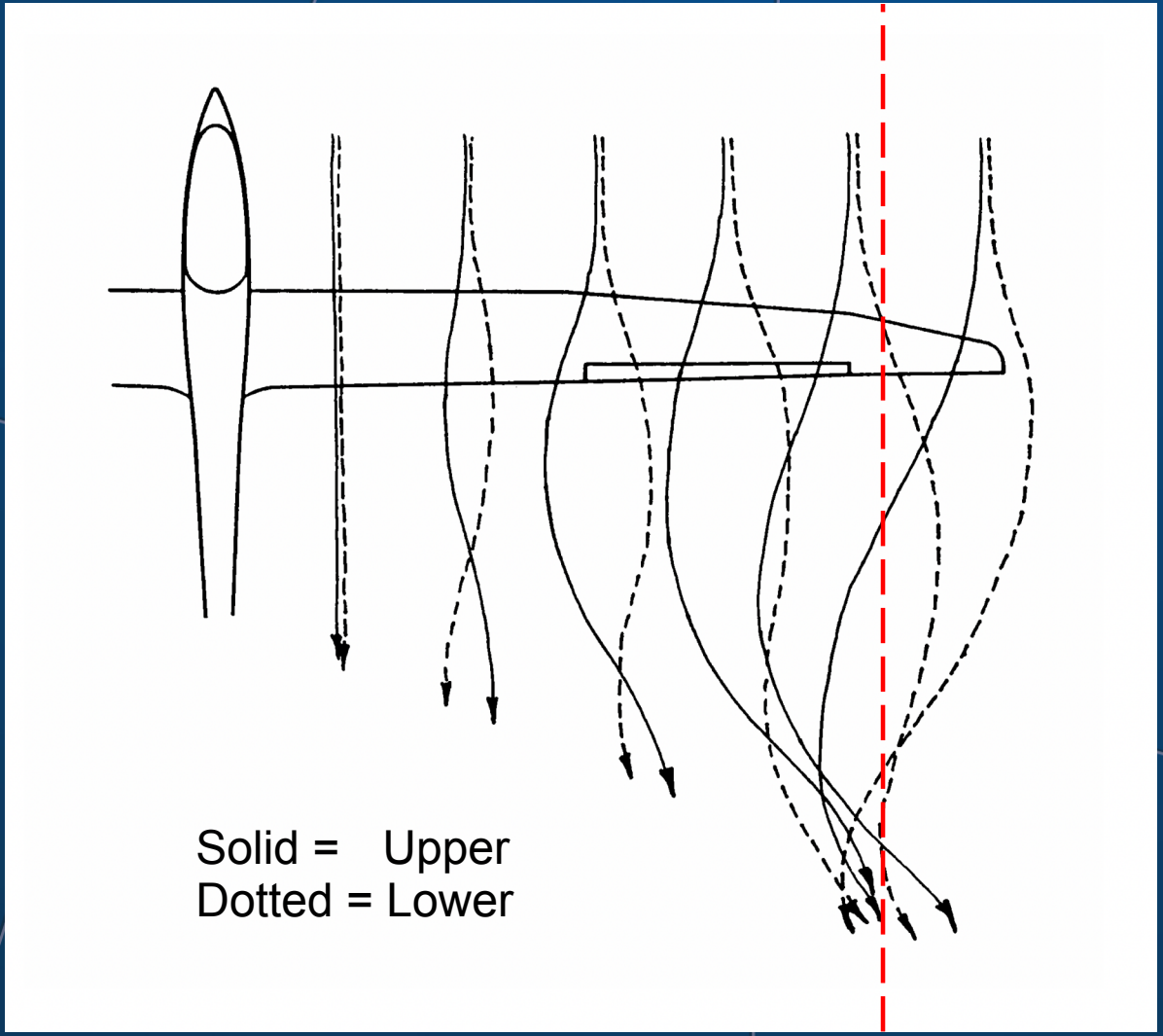


The flow field around a wing

- Creation of three vortex fields



Airflow over a sailplane wing

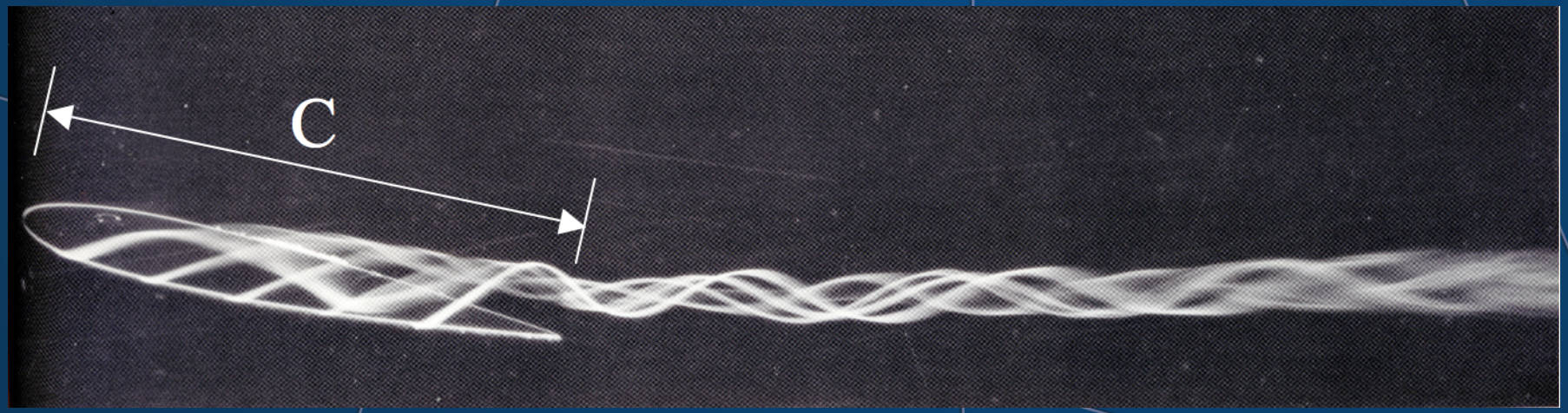


Visualizing the formation and behavior of the trailing vortex

- As viewed from the side
- As viewed from above
- As viewed from the rear
- As viewed in 3D (CFD)
- Real life examples

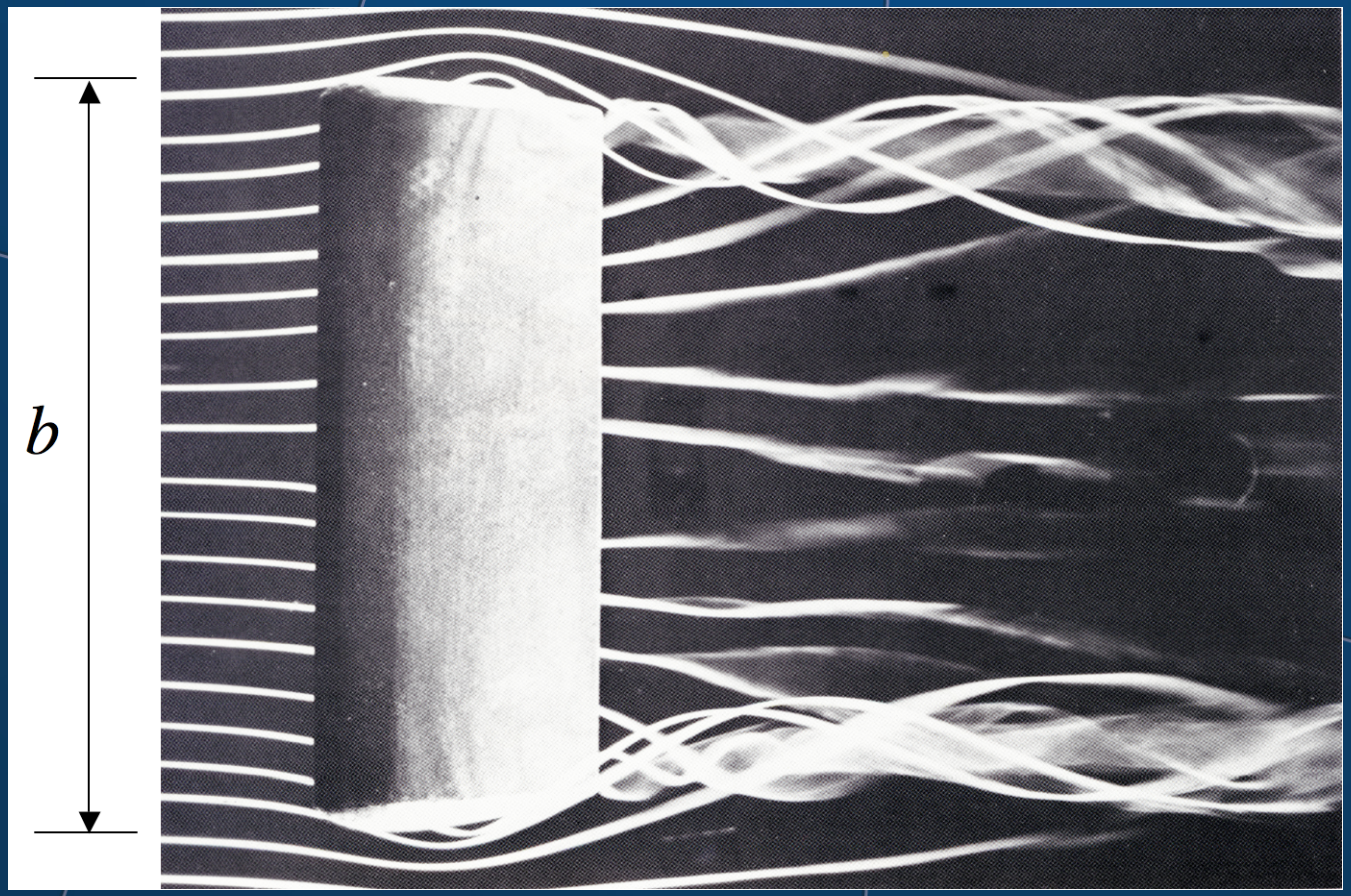
Wing viewed from the side

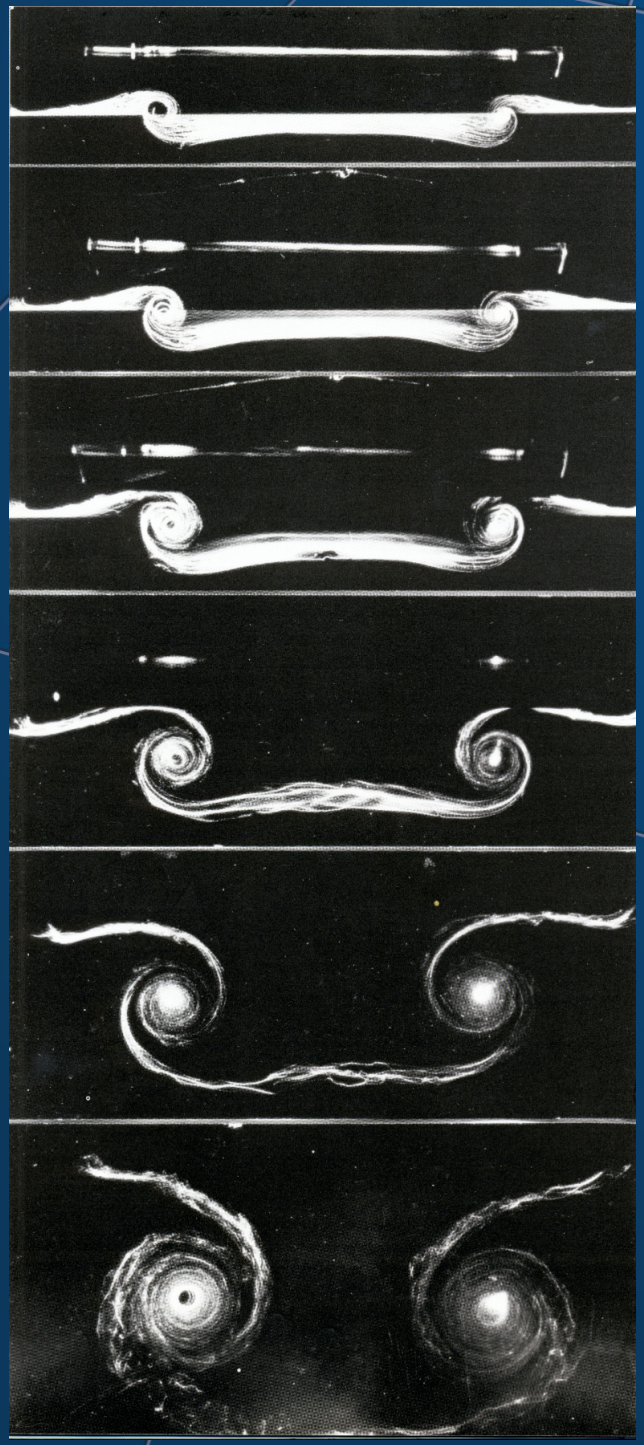
Streamlines are from lower surface only



Wing viewed from above

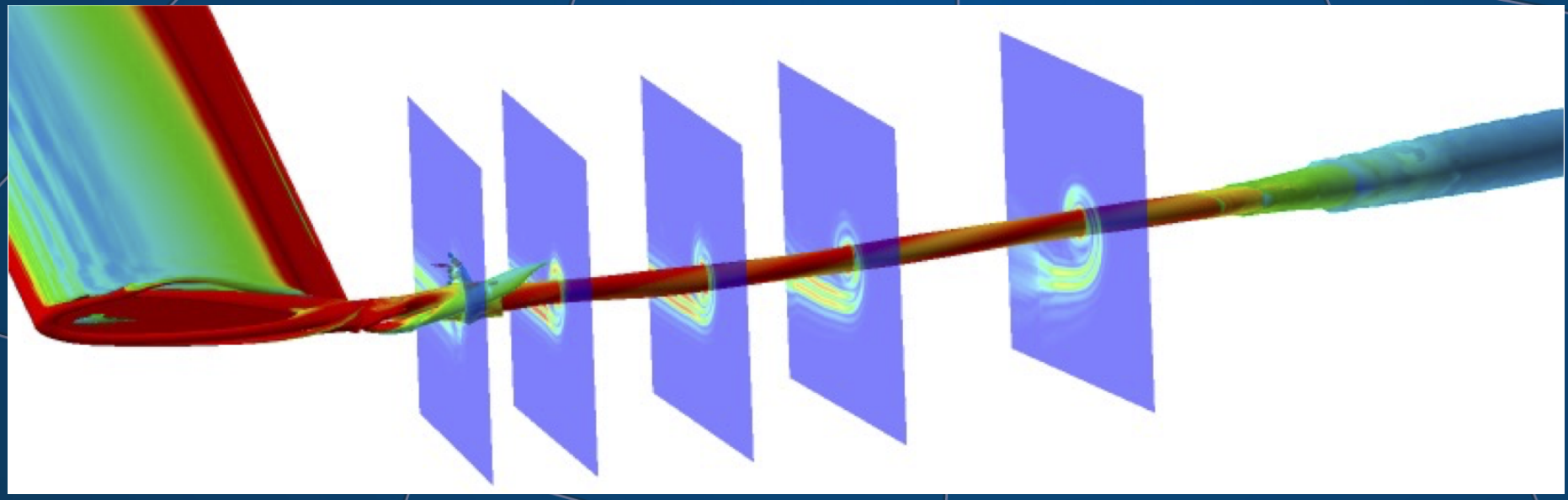
Streamlines are from lower surface only





Wing from rear

Streamlines are from lower surface only



Wingtip vortex roll-up

Visualizing the trailing vortex

- Colored smoke
- Flying through a cloud
- Condensation in a humid environment



Wing tip vortex from a crop duster





The vortex field



Wingtip vortices from an F-35A Lightning II

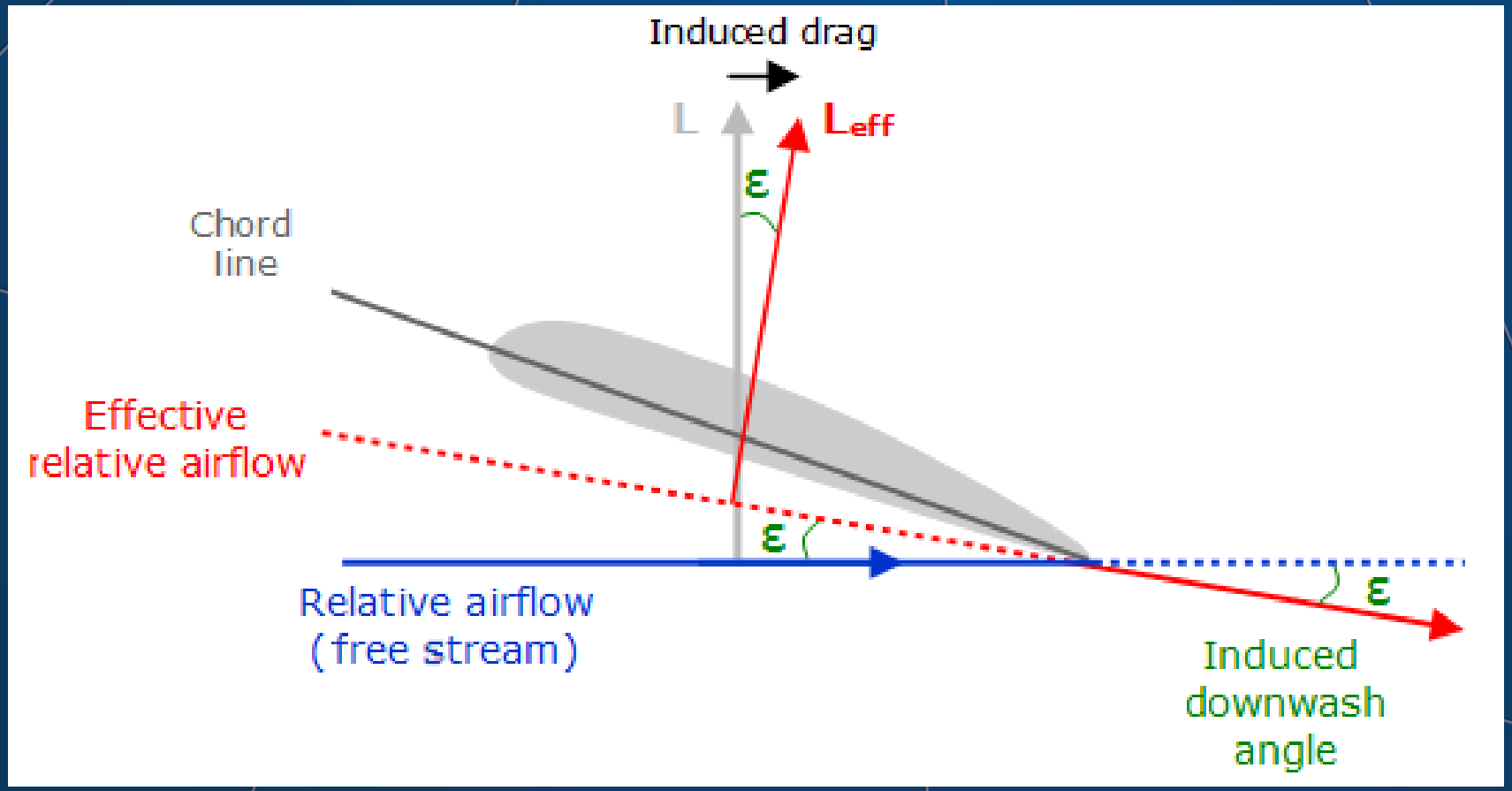


Wingtip vortices from an F-35A Lightning II

About Induced Drag

- What is induced drag?
  Simply put, induced drag is drag due to lift
- What is the source of induced drag,
  i.e., how is it generated?
- What is the relationship between
  induced drag and the strength of
  wing tip vortices?

The production of induced drag



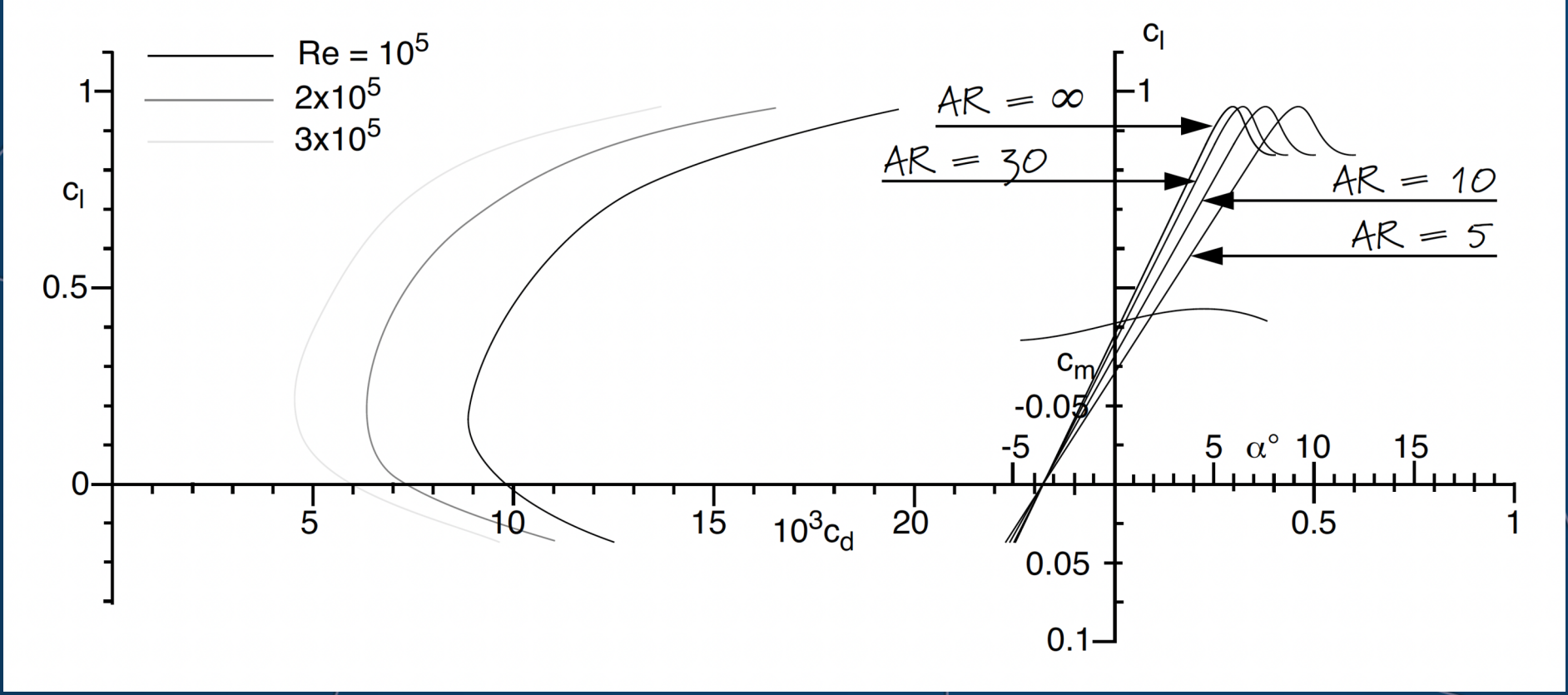
Induced drag and wing tip vortices

- Induced drag is proportional to the strength of wing tip vortices
- A smaller vortex does not indicate a weaker vortex
- Wings with a high aspect ratio exhibit
  - weaker wing tip vortices
  - less downwash
  - and a reduction in induced drag

Methods of modifying the flow field to reduce induced drag

- Increase aspect ratio by reducing chord and/or by increasing span (but this increases the root bending moment)
- Simple methods for controlling the flow around the wing tip
- Whitcomb winglet for KC-135 tanker
- Examples of winglet evolution

Increase the aspect ratio



- Decrease chord, retain span
- Increase span, retain chord

A method for increasing the span without changing the root bending moment

R.T. Jones

- Increases span
- Wing area remains the same
- Modifies the load distribution
- No change in root bending moment
- Changes downwash pattern to trapezoid
- Decreases induced drag (15% increase in span gives 15% reduction in induced drag)

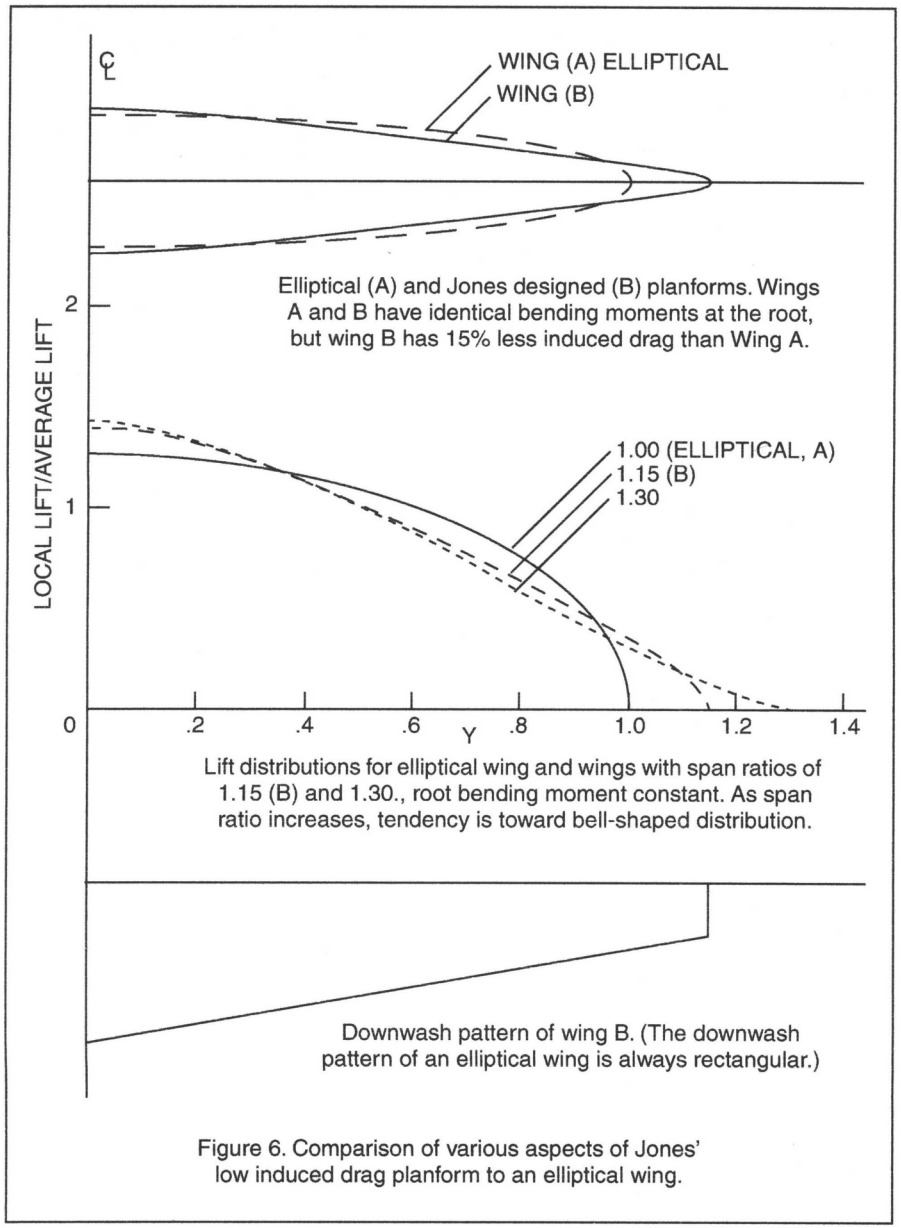


Figure 6. Comparison of various aspects of Jones' low induced drag planform to an elliptical wing.

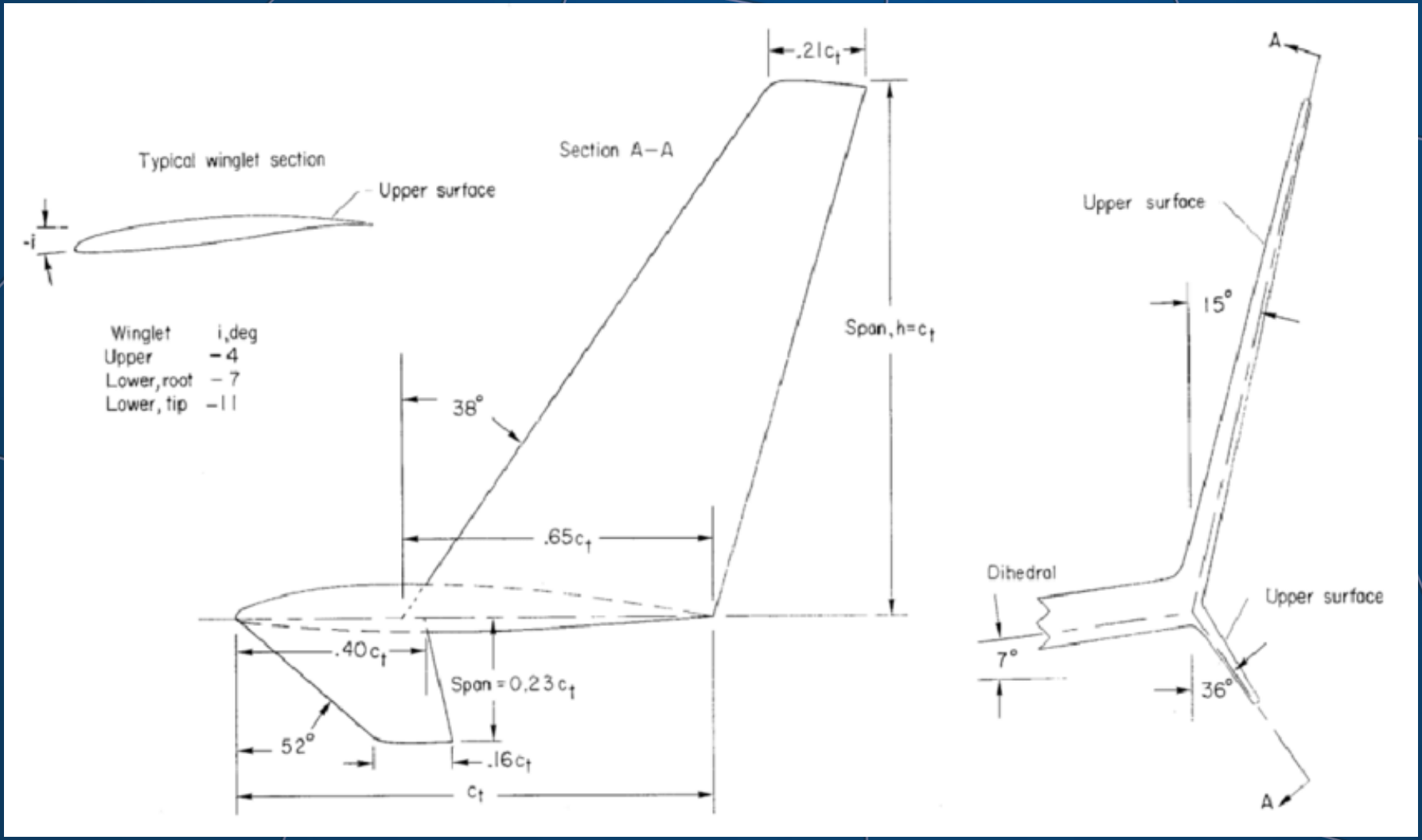
Simple devices for reducing cross-span flow



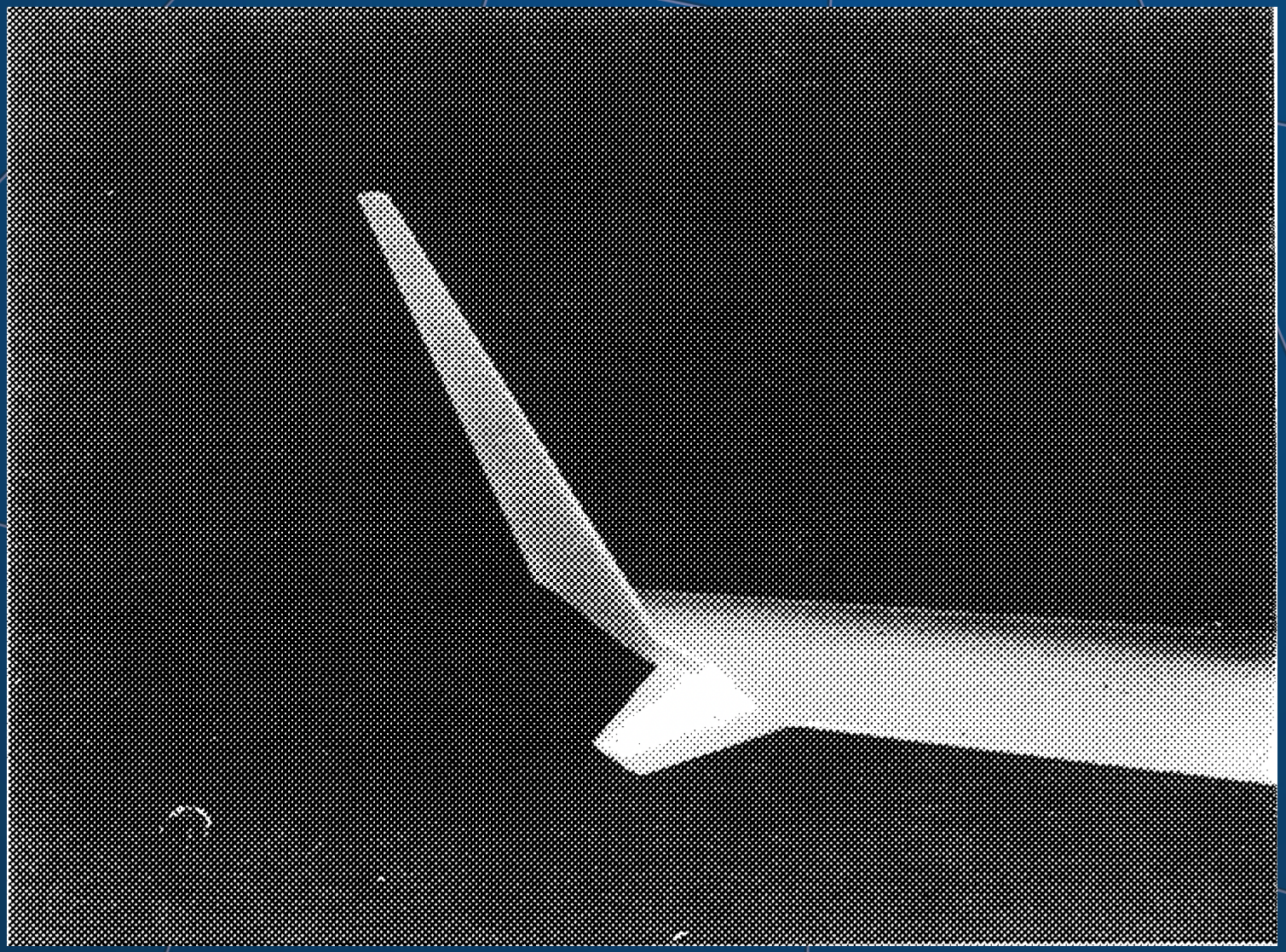
Basic endplate (Republic SeaBee)



Tip fence (Airbus 380)

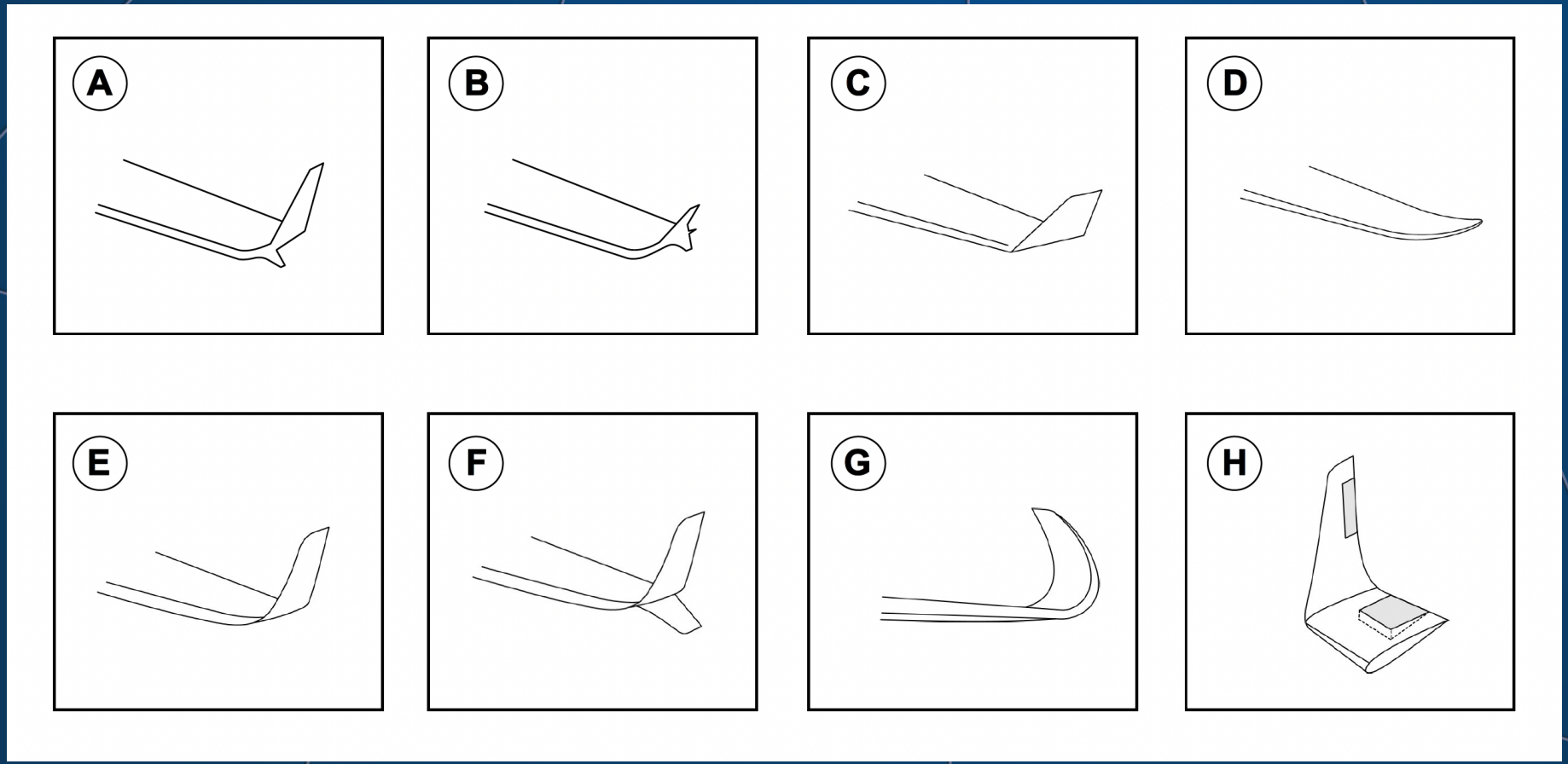


Winglet geometry, Richard T. Whitcomb,1976
Specifically designed for the KC-135 tanker
Lower winglet is set to LE inward, upper winglet is set to LE outward



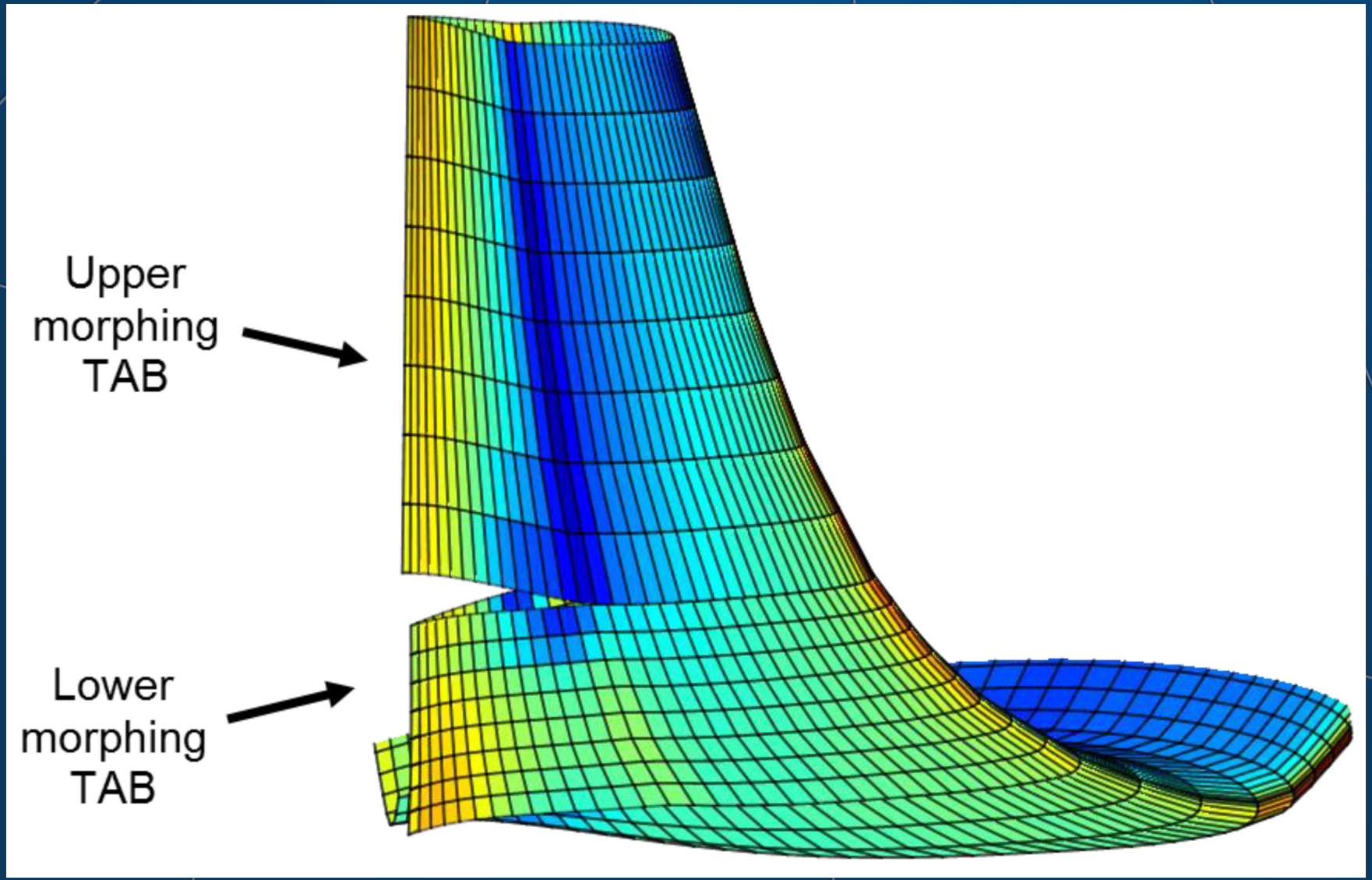
Wind tunnel model of KC-135/Whitcomb winglet

The evolution of winglet design

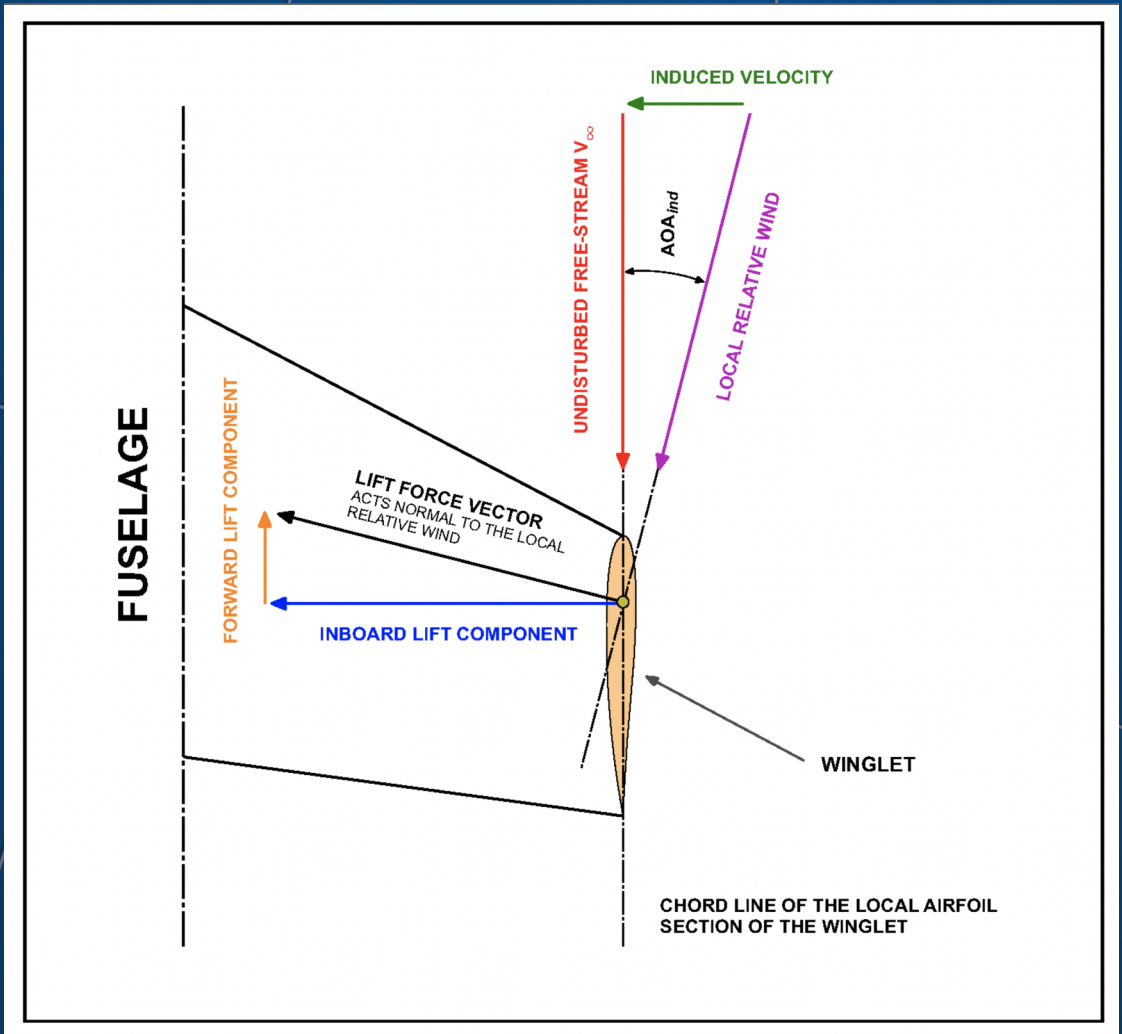


(A) Whitcomb winglet, (B) Tip fence, (C) Canted winglet, (D) Raked wingtip
(E) Blended winglet, (F) Blended split winglet, (G) Sharklet, (H) Active winglet

Illustration of an active winglet



A winglet myth



What winglets actually do

- Increase the effective span
- Reduce the strength of the trailing vortex
- Reduce induced drag
- Decrease wing downwash

- Result: “2 - 1 - 3”

Winglet design considerations

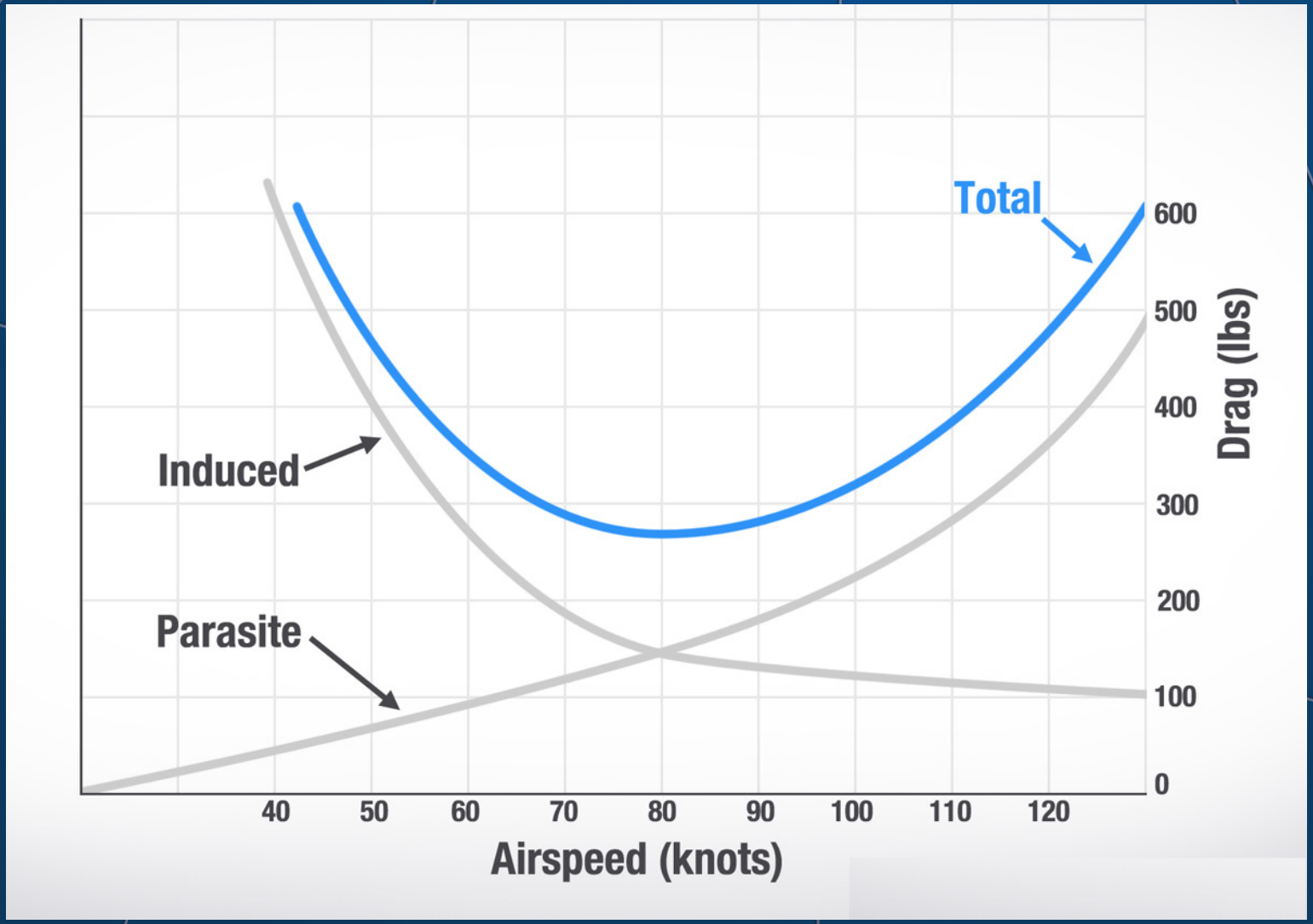
Drag issues:

- The contribution of induced drag
- The contribution of profile drag

Geometry issues:

- Airfoil considerations
  - Operational AoA
  - Reynolds number
- Chord distribution and height
  - Velocity vs loading
  - Chord distribution should be elliptical
  - Reduction of induced versus profile drag
- Sweep, twist, and toe angle
  - Increasing sweep increases load
  - Toe angle is related to loading on the wing
  - Twist related to local airflow

The crossover point



Performance with & without winglets, ASW-19 (15m/49.2')

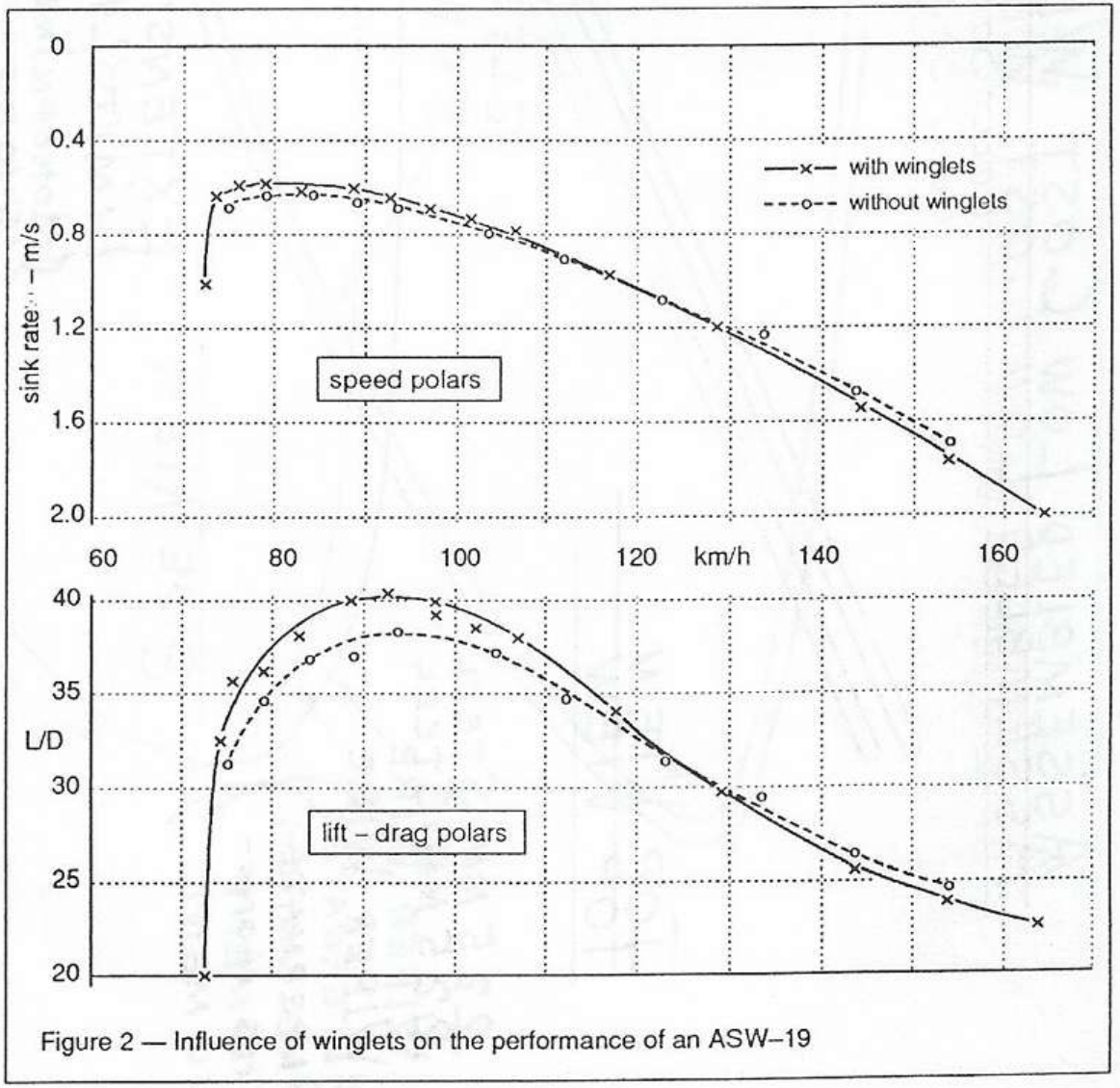
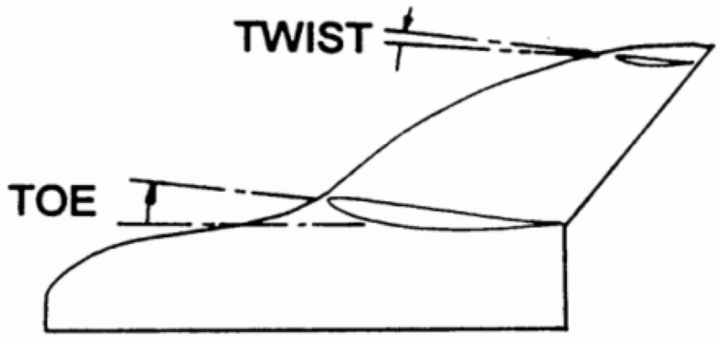


Figure 2 — Influence of winglets on the performance of an ASW–19

Sink rate is lower below ~120km/h, ~72mph

L/D is higher below ~125km/h, ~75mph

Basic winglet geometry (Maughmer)

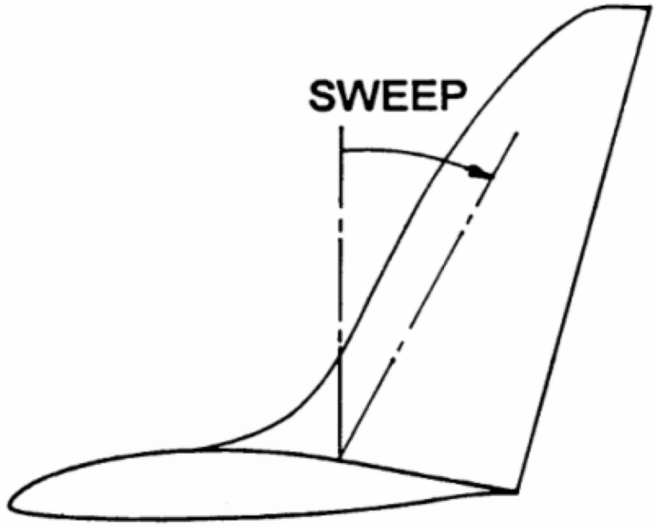


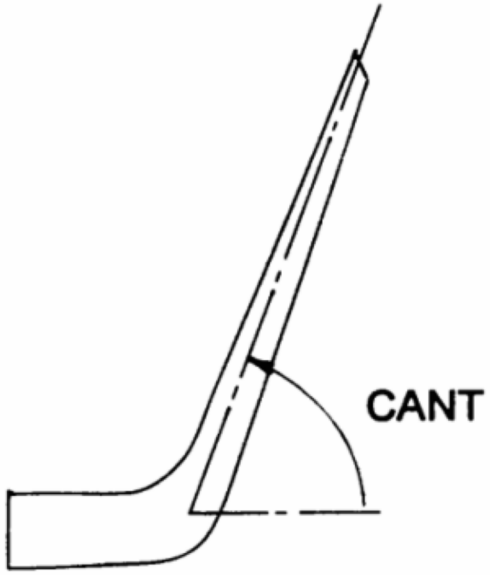
AIRFOIL

WINGLET HEIGHT

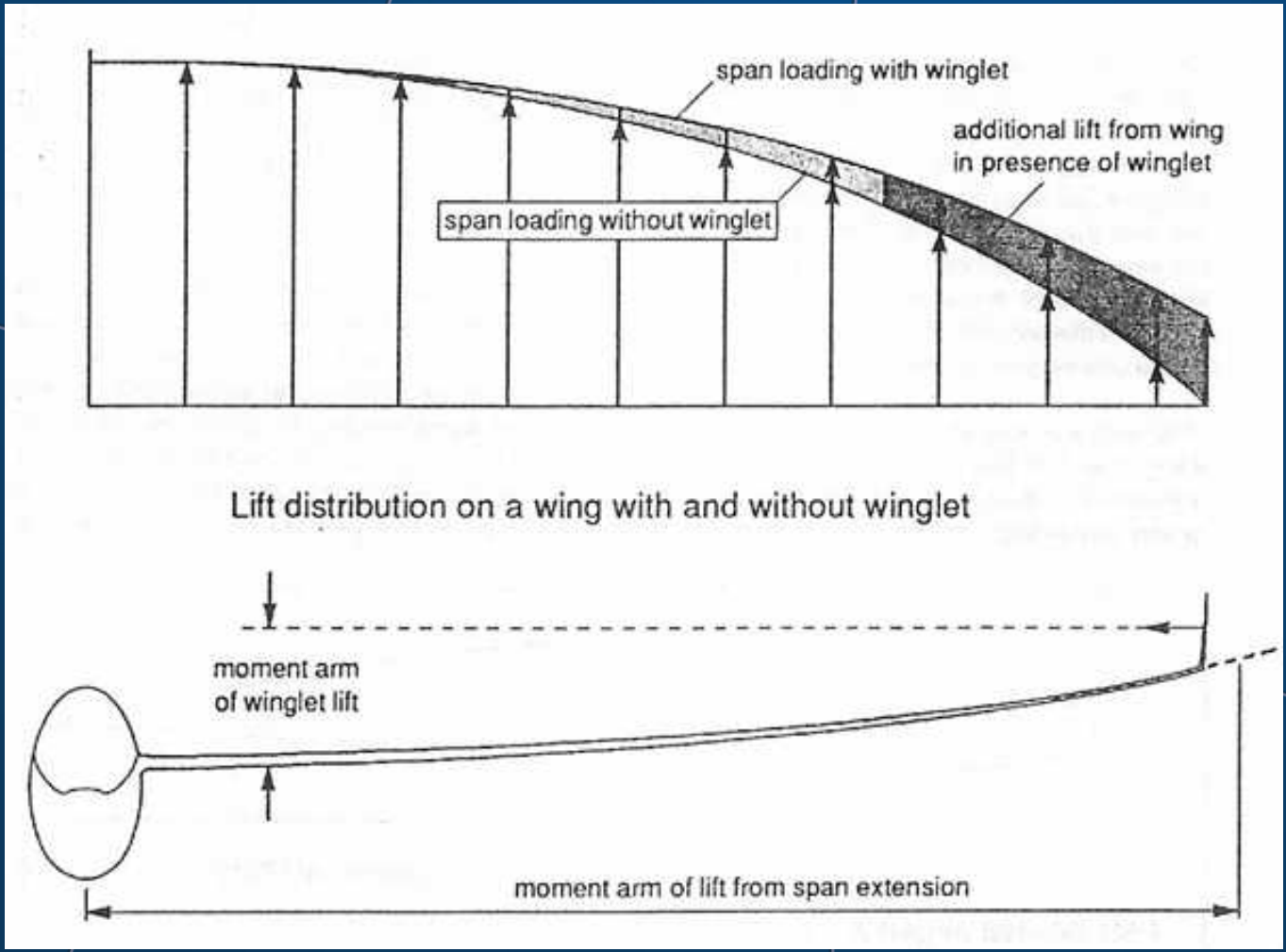
CHORD DISTRIBUTION

WINGLET-WING RADIUS





Effect of winglet on wing bending



- Airfoil considerations
  - Operational AoA
  - Reynolds number

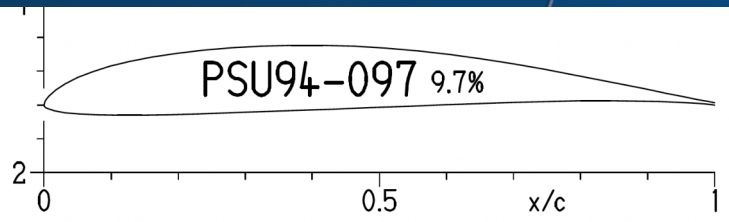


Fig. 10 Comparison of measured design point pressure distributions at $R = 1.0 \times 10^6$ to inviscid theory.

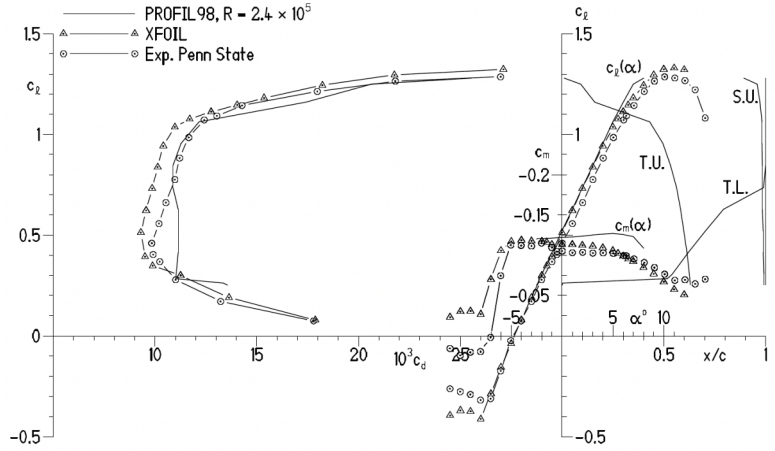


Fig. 11 Comparison of theoretical and experimental section characteristics for $R = 2.4 \times 10^5$. 240k

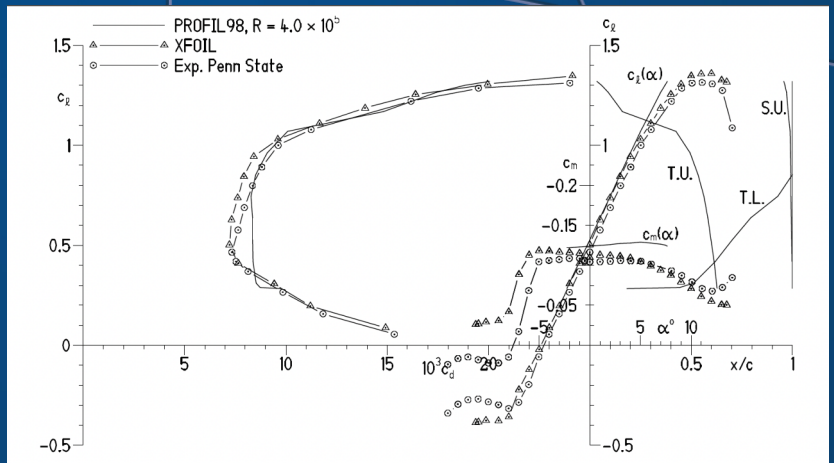


Fig. 12 Comparison of theoretical and experimental section characteristics for $R = 4.0 \times 10^5$. 400k

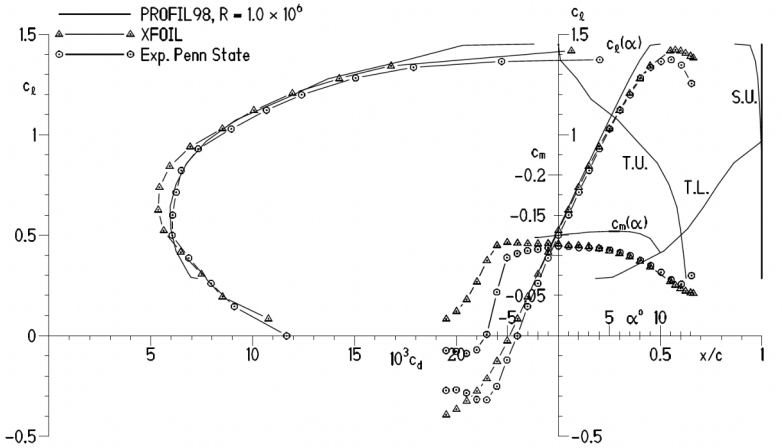
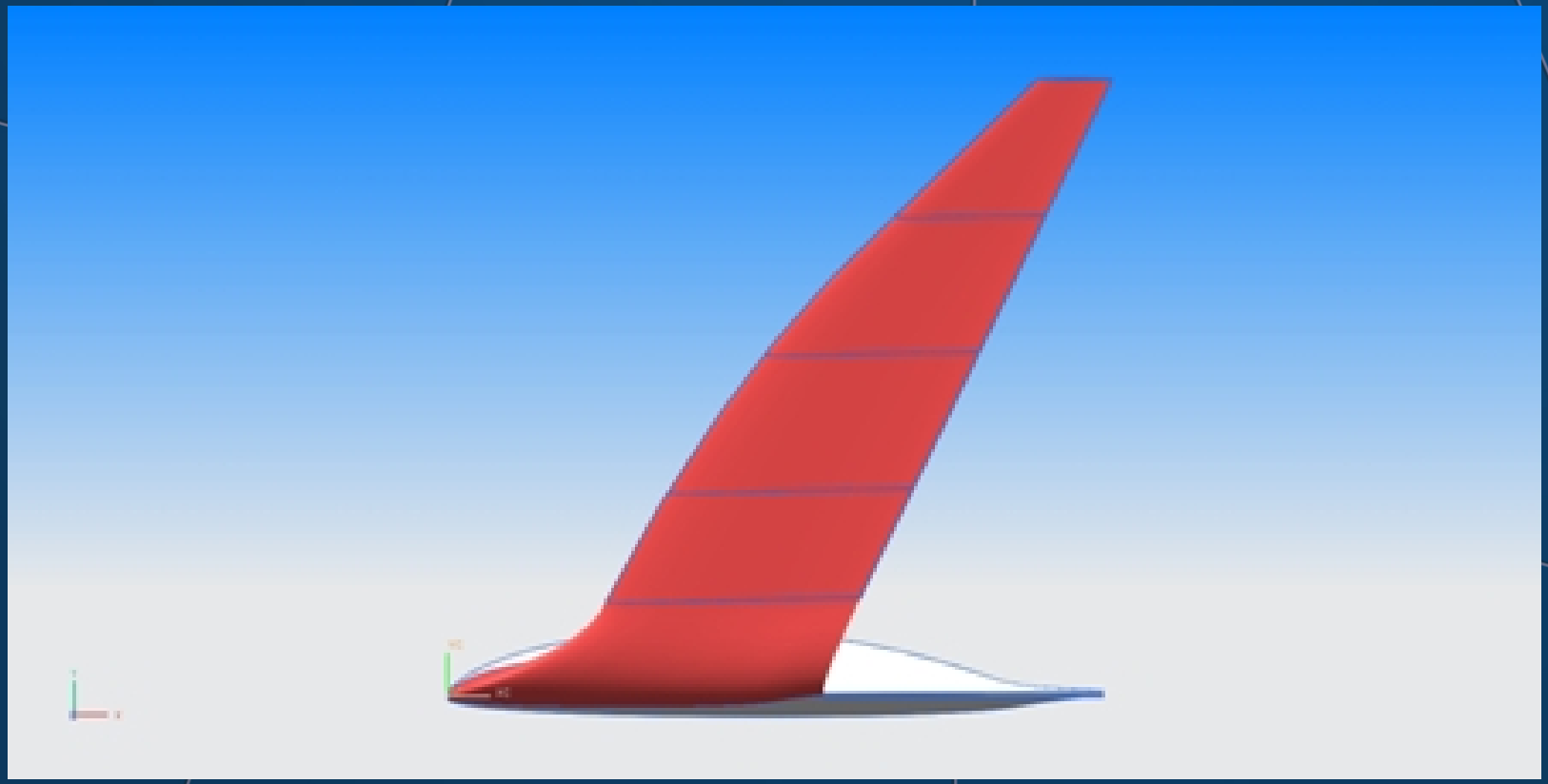
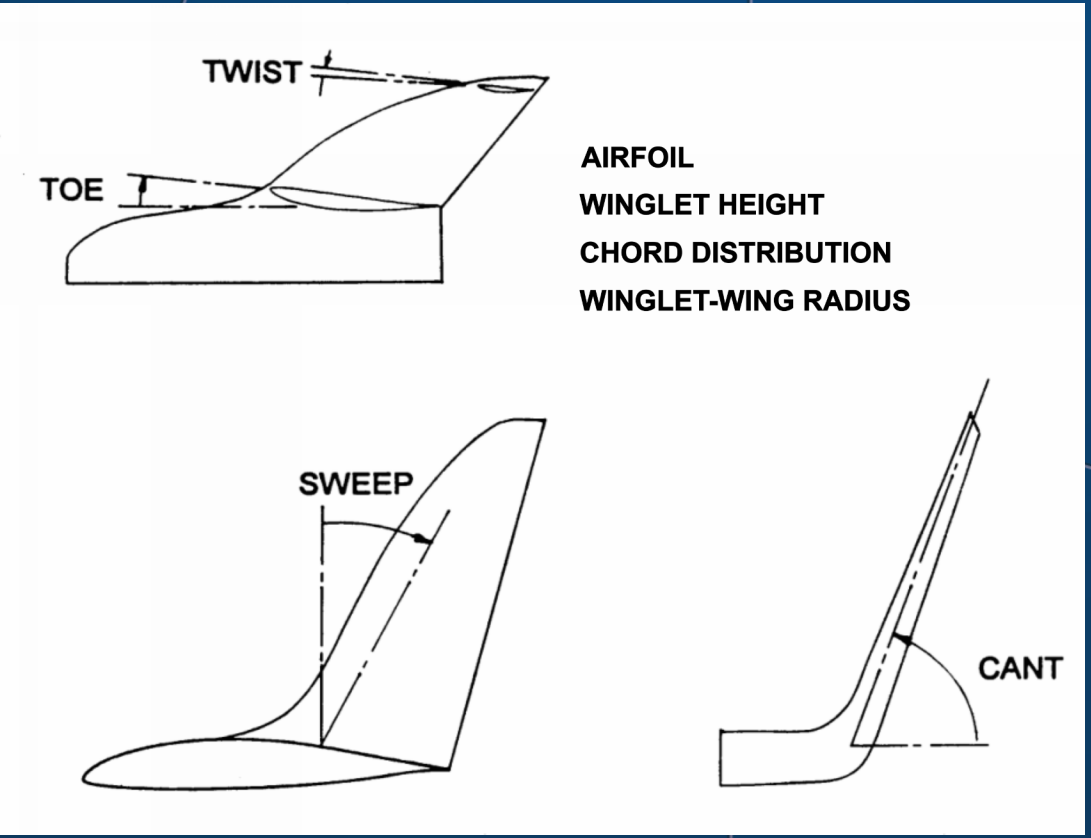


Fig. 13 Comparison of theoretical and experimental section characteristics for $R = 1.0 \times 10^6$. 1000k

- Chord distribution should be elliptical
- Height is related to aspect ratio and load on the wing
- Increasing sweep increases the load on the wing



- Toe angle, twist, cant and wing-winglet radius
  - Toe angle is related to loading on the wing
  - Twist should be related to the local airflow
  - Cant affects wing bending moment and span
  - Radius between wing and winglet



Thinking about winglet parameters

These eight variables are inter-related, and changes to the wing coefficient of lift will affect all to some extent.

Task goals, flight regimes, and the percent of time spent in each flight regime need to be evaluated, potentially with a weighted system, to determine if the addition of winglets will be advantageous.

This leads to some generalized rules for winglet viability.

Some cases may, however, require counterintuitive thinking.

General rules and exceptions

- If span is limited, use winglets
- If span is not limited, extend span

- But there are exceptions…

If span is limited, use winglets

Full size competition sailplanes are racing machines.

* Competition goal is to traverse *distance* between points A and B in shortest *total time*.

* Wing operates at low Re and high C_L conditions in thermals, and time in thermals is minimized.

* Wing operates at high Re and low C_L conditions between thermals, and speeds are maximized.



Schempp-Hirth Ventus 2ax 15m/49.2′ sailplane with blended winglets



Experimental winglets on a Schempp-Hirth 15m/49.2′ Discus 2

If span is not limited, increase span

+ Increases aspect ratio to improve efficiency
+ Moves the trailing vortex further outboard
+ Increases lift and reduces downwash

- Increases weight
- Increases root bending moment

* And there are exceptions

If span is not limited, extend span

EXCEPTION

Eta 30.9m/101.4′ Open Class (unlimited span) sailplane uses winglets to improve aileron authority in thermal flight.

AR = 51.3

Glide ratio = 70:1

Min sink rate = 1.3′/sec

Vmax, maneuvering = 180km/h, 112mph

Vmax = 280 km/h, 170mph





Self-powered Eta at takeoff showing wing bending



Eta in thermal

General “winglet rules” for RC sailplanes

Thermal Duration:
Span limited, use a well-designed winglet
Span unlimited, a well-designed winglet is an option

FAI F3B (Multi-task — Speed, Distance, Duration)
Span unlimited, but winglets are not recommended

Cross-country (FAI F3H) and GPS Triangle Racing:
Span unlimited, a well-designed winglet is an option

Slope Racing (F3F):
- Span unlimited, winglets are not recommended!

Question to be answered…
- Is the task defined predominantly by duration
- or by speed?

A quick review…

- *Winglets modify the flow field to decrease the wing downwash and thus reduce induced drag. This is evidenced by weaker and typically smaller vortices coming off the end of the wing.*

- *To be effective, winglets must be designed to operate efficiently over as much of the coefficient of lift range as possible and at velocities below that at which the cross-over point occurs.*

FINIS