Wingtip Devices

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Outline

- History
- Why do we need or want winglets?
- How do they work?
- Types of wingtip devices
- Design Considerations
- Boeing 737 Case Study
- Conclusions

Winglets Short History

- Frederick W. Lanchester patented the endplate concept in 1897 (England)
- Theoretical investigations by Weber in 1954 indicated a beneficial effect on both lift and drag characteristics.
- From 1974 to 1976 Richard T. Whitcomb evaluated and tested winglets concepts extensively. (NASA)

http://www.larc.nasa.gov and http://aerodyn.org

Learjet Model 28/29 (1977)

- In 1977, Learjet Longhorn Model 28/29 had the first winglets ever used on a jet and a production aircraft, either civilian or military

Boeing 747-400 (1985)

- In October 1985 Boeing introduced winglets to 747-400
- First commercial Jetliner to incorporate winglets

McDonnell Douglas MD-11 (1990)

- In December 1990 McDonnell Douglas included the winglet concept in its design for the MD-11
- Built on development experience gained in NASA ACEE Program to design winglets for the MD-11.

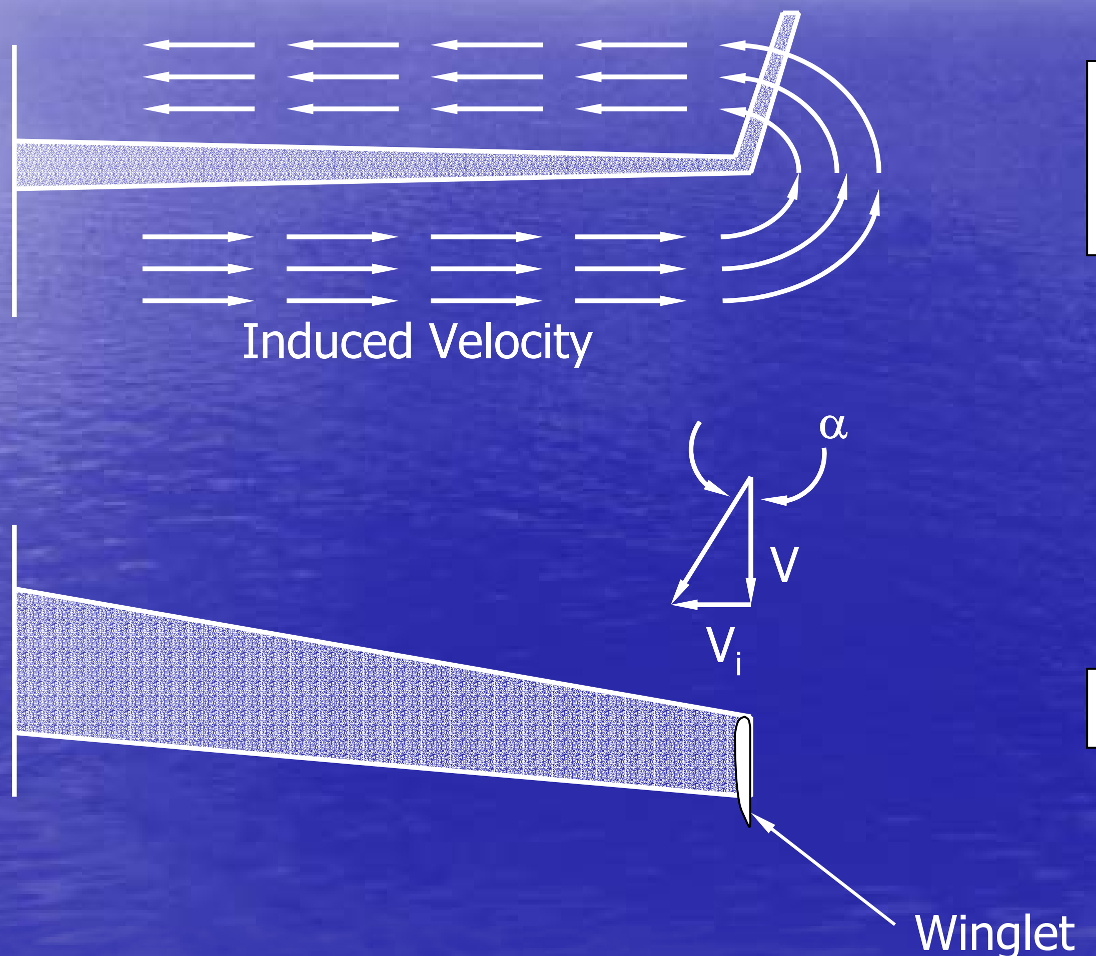
Why do we need them?

www.efluids.com/efluids/gallery/trailing_vortices_2.html

http://www.efluids.com/efluids/gallery/c17vortices_1.html

- Wingtip vortices reduce the aircraft performance by reducing the effective angle of attack of the wing through the induction of downwash
- Impact on fuel burn
- Vortices from large aircraft are dangerous for small aicraft
- To prevent leakage of higher pressure air from underneath the wing

How does it work?

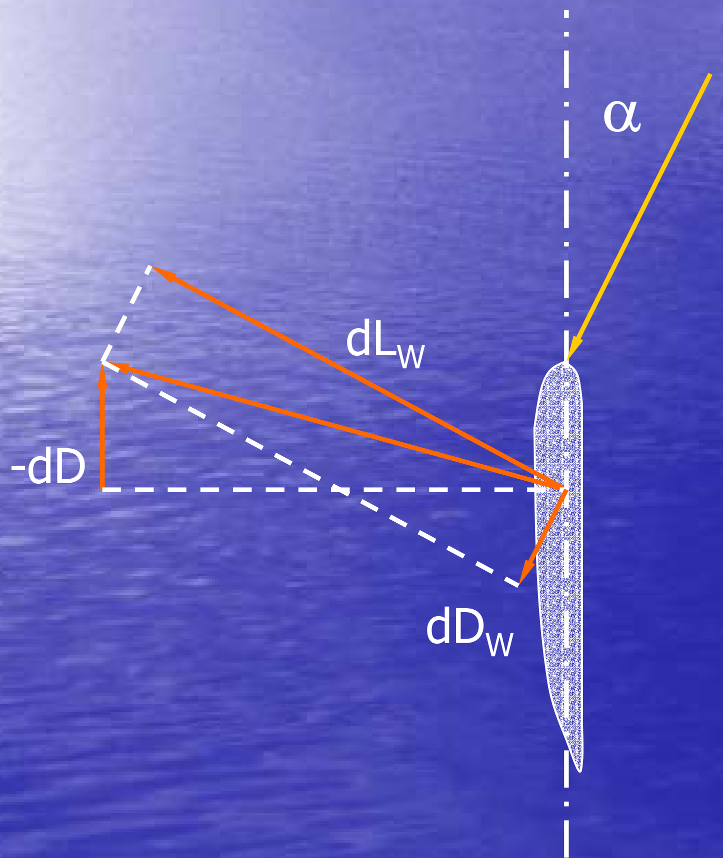


In the direction of flight

Planview

How does it work?

The Resultant Forces



$$\Delta D = -L_w \alpha_w + D_w$$

$$\Delta C_D = -\, S_w/S\,(C_{Lw}\alpha_w + C_{Dw})$$

$$C_{Dw} = C_{Dow} + C_L{}^2 L_w/(\pi A_w)$$

$$\Delta C_D = -\, S_w/S\,(C_{Lw}\alpha_w - C_{Dow} + C_L{}^2 L_w/(\pi A_w))$$

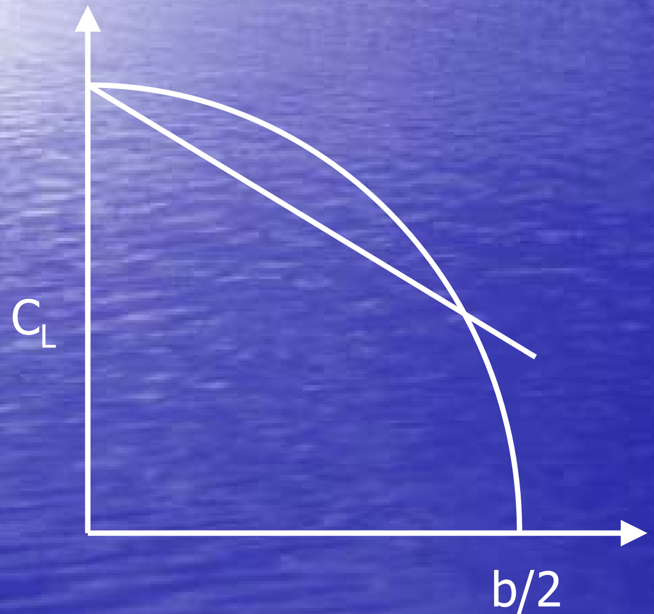
$$\alpha_w = KC_L$$

$$C_{Lw} = 2\pi A_w/(A_w + 2)\alpha_w$$

$$\Delta C_D = -\, S_w/S[2\pi(A_w/(A_w + 2))^2 K^2 C_L{}^2 - C_{Dow}]$$

McCormick, B. W. Aerodynamics, Aeronautics, and Flight Mechanics. John Wiley and Sons, Inc. Toronto, 1995.

Flow Mechanism



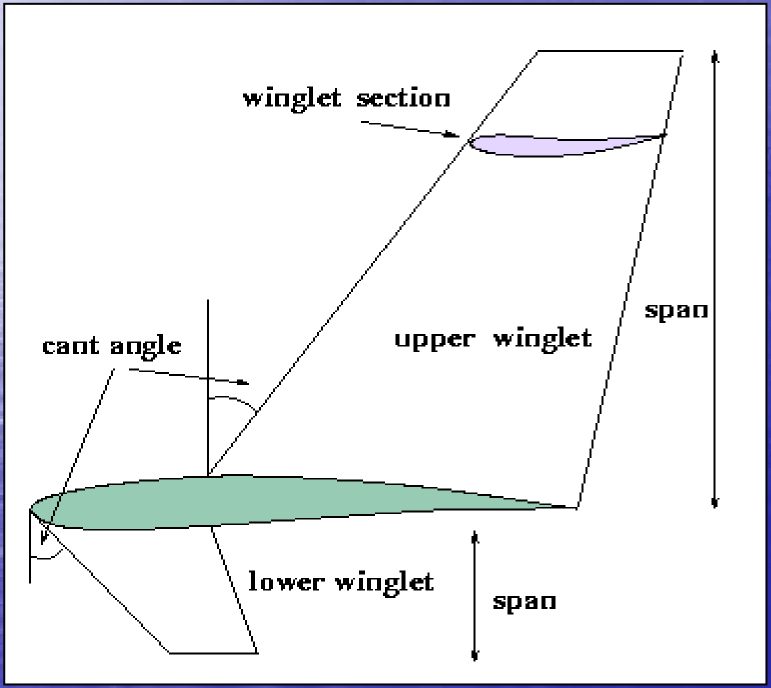
- Alters the spanwise distribution of circulation along the wingspan
- Allows for an increase in tip loading
- Reduction in C_D increases linearly with C_L^2
- At low C_L values, C_D will be increased by the addition of a winglet
- High aspect ratio winglets are desirable

McCormick, B. W. Aerodynamics, Aeronautics, and Flight Mechanics. John Wiley and Sons, Inc. Toronto, 1995.

Types of wingtip devices

- Endplates
- Classic Winglet (Whitcomb)
- Blended Winglet
- Hoerner Tips
- Upswept and Drooped Tips
- Wing Grid
- Sail Tips
- Spiroid Tips
- Tip Turbines

Classic Winglet



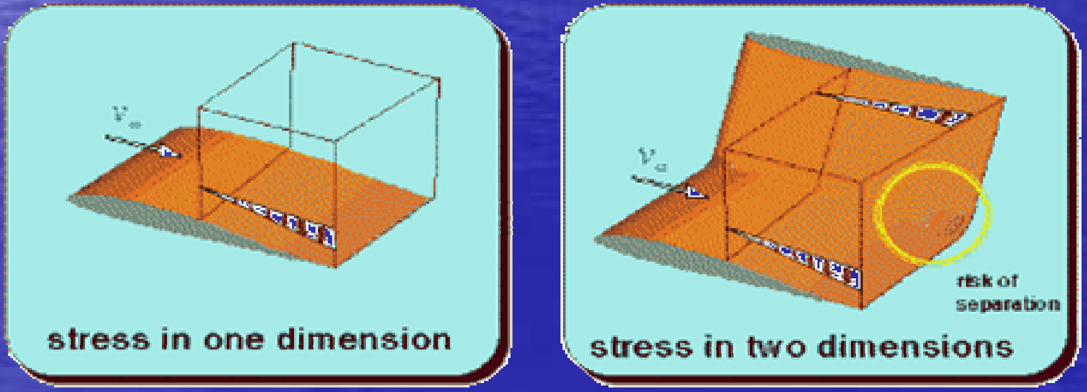
http://www.aerodyn.org/Drag/tip_devices.html

- Defined by Whitcomb
- Upper winglet begins at max thickness
- Same sweep as wing
- Span equals wing tip chord
- Higher camber than wing
- Lower winglet contributes little to drag
- Lower winglet often ommitted
- Toe angle critical to wing loading

Raymer, Daniel P. Aircraft Design: A Conceptual Approach, Third Edition. Reston: AIAA, 1999. p. 164-166.

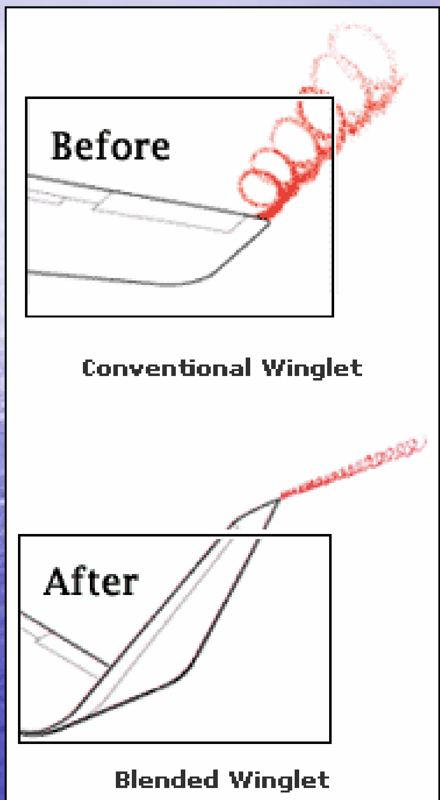
Winglet Connection

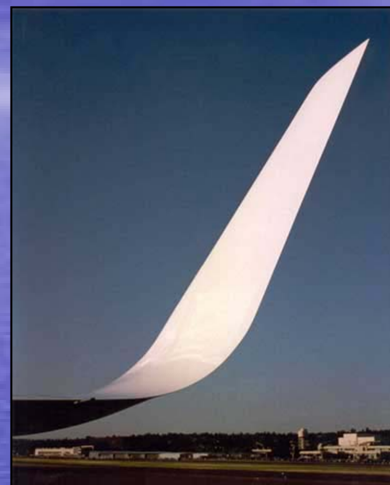
- Sharp, Rounded, and Downstream
- Two pressure rises must be overcome at junction
- Sharp connection leads to separation
- Smooth reduces pressure effects
- Downstream winglet shift decouples pressure rises



http://www.mh-aerotools.de/airfoils/winglets.htm

Blended Winglet

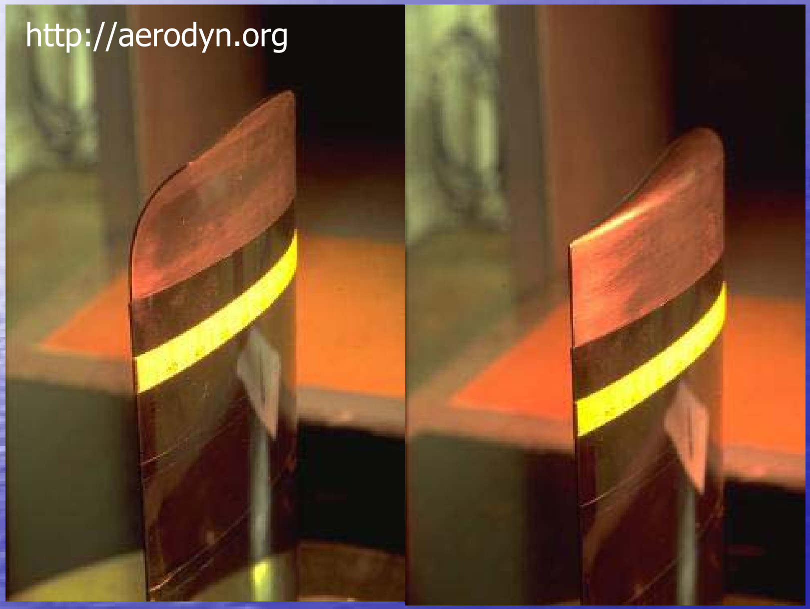




- Developed by Aviationpartners
- Greatly reduces the adverse flow conditions at winglet junction
- Defined by a large transition radius coupled with a smooth chord variation
- High AR blended winglet can be up to 60% more effective than a conventional winlget
- Most imporant parameter in design is the ratio of winglet high to wing span – optimum value must be found

http://www.aviationpartners.com/gulfstream/gulf_tech.html

Hoerner Tip

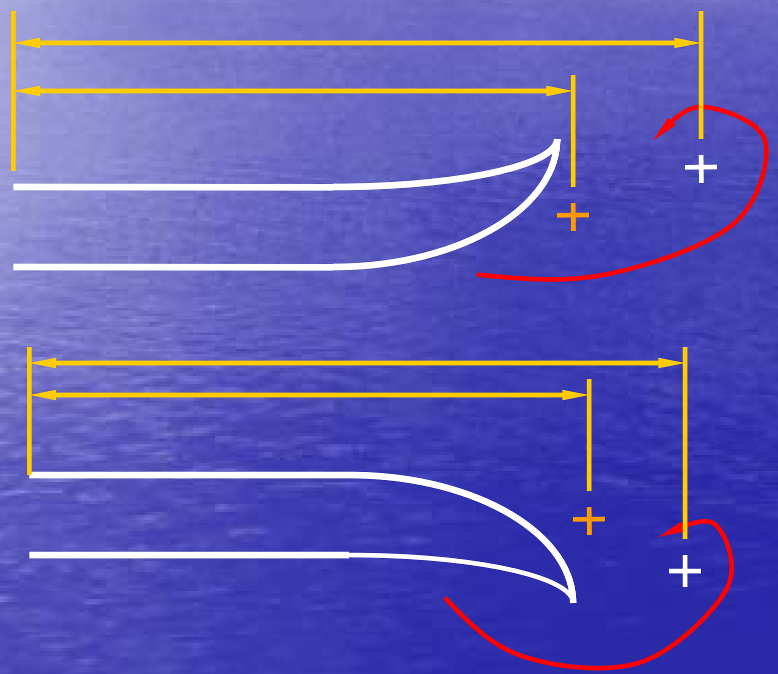


- Hoerner tips are crescent-shaped geometries with a slight upward feathering
- Promote a better diffusion of the tip vortex
- Slightly better than conventional round tips

http://aerodyn.org

Raymer, Daniel P. Aircraft Design: A Conceptual Approach, Third Edition. Reston: AIAA, 1999.

Upswept & Drooped Tips



- Similar to Hoerner Tips but curve either up or down to increase the wing's effective span

Raymer, Daniel P. Aircraft Design: A Conceptual Approach, Third Edition. Reston: AIAA, 1999.

Wing grids

http://www.winggrid.ch/

http://www.winggrid.ch/

- The circulation is taken over by the winggrid along the chord of the main wing.
- The segmented circulation is transferred to the end of the winggrid, increasing the far field vortex spacing
- The lift distribution on several winglets results in a reduction of the far field vortex energy

Wing grids (cont'd)

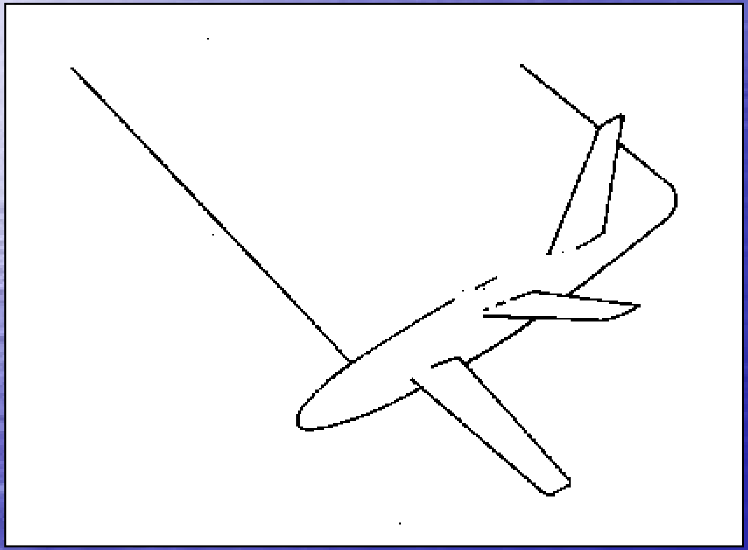
- Induced drag is reduced by the winggrid up to 60%, that corresponds to span efficiencies of up to over 3.0, that means that total drag can be reduced up to 50% depending on velocity and design.

- The winggrid has two distinct operating regimes:

  1) Below a critical angle of attack (above a specific design speed) span efficiency is between 2.0 and 3.0 with full winggrid effect.

  2) Above a critical angle of attack (below a specific design speed) the effect of reduced induced drag fades out, the winggrid perates as a slit wing with very high stall resistance.

Sail Tips

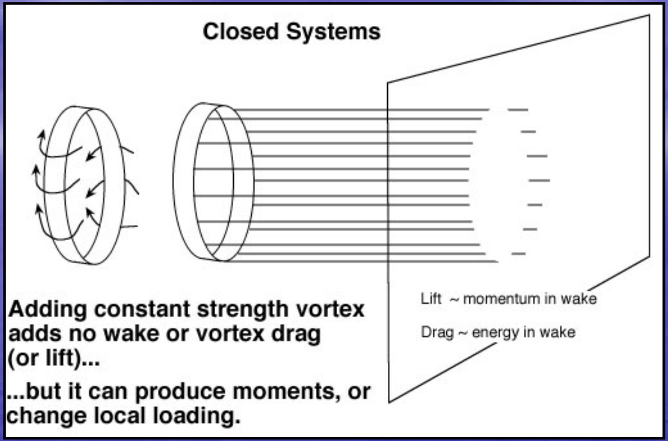


- Developed by John Spillman (1978)
- Defined by multiple high AR lifting elements at several dihedral angles
- More complex
- Benefits from reduced transonic and viscous interactions at intersection
- Number of surfaces could be investigated to find optimum value

Kroo, Ilan Drag due to Lift: Concepts for Prediction and Reduction Annual Review of Fluid Mechanics. March 2001 33:587-617

Wingtip Devices

Spiroid Tips



- Developed by Aviationpartners
- Eliminates concentrated wingtip vortices (Dr. L. Gratzer)
- Vorticity is gradually shed from the trailing edge
- Extensive optimization necessary
- Flutter concerns
- Cut fuel consumption 6-10% compared to conventional tip

http://aero.stanford.edu/Reports/Nonplanarwings/ClosedSystems.html (This is Ilan Kroo's Website)
http://www.aviationpartners.com/company/concepts.html

Tip Turbines

- Developed by James Patterson (1985)
- Reduce the strength of the vortices
- Recover energy required to overcome the drag
- It is estimated that a similar system on Boeing 747 would result in the recovery of 400HP

Smith, H. The Illustrated Guide to Aerodynamics Tab Books, Inc. Pennsylvania, 1985
Kroo, Ilan Drag due to Lift: Concepts for Prediction and Reduction Annual Review of Fluid Mechanics. March 2001 33:587-617

Design Considerations

So why don't all aircraft have winglets???

- Trade-off analysis – extensive optimization
- Reduce induced drag
- Effective increase in AR without span extension – good if you're already at limit
- Increased parasite drag
- Increased weight
- Increased cost
- Flutter

Boeing 737 Case Study

- Only upper winglet with 8 ft height
- 4 ft root chord with 2 ft tip chord (Taper Ratio=0.5)
- Added approximately 5 ft to span
- Each winglet is 180 lbs and a total of 480 due installation structure
- Structural strengthening required

http://www.boeing.com/commercial/737family/winglets

Wingtip Devices

Boeing 737 Case Study

- Increasing max payload by 6000 lbs
- Added 130 nautical miles of range
- Reduced fuel on flights over 1000 nautical miles.
- Lower engine maintenance costs
- Less emissions
- Better takeoff capabilities
- Aesthetically pleasing

http://www.boeing.com/commercial/737family/winglets/
http://www.b737.org.uk/winglets.htm

Conclusions

- Can effectively reduce the induced drag and realize performance benefits:
  - Decreased fuel burn
  - Increased Range
  - Less noise
  - Shorter span if integrated in original design
  - Look snazzy - marketability
- Significant optimization is necessary
- Flutter Considerations
- Additional weight
- Can be expensive

References

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13. http://www.winggrid.ch/
14. http://aerodyn.org
15. http://www.larc.nasa.gov

No Winglets?

Don’t worry, there are always ejection seats…just ask this guy