Wingtip Devices

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March 29th 2004
Outline

- History
- Why do we need or want winglets?
- How do they work?
- Types of wingtip devices
- Design Considerations
- Boeing 737 Case Study
- Conclusions
• 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
In 1977, Learjet Longhorn Model 28/29 had the first winglets ever used on a jet and a production aircraft, either civilian or military.

http://www.larc.nasa.gov
In October 1985 Boeing introduced winglets to 747-400
First commercial Jetliner to incorporate winglets
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?

- 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 aircraft
- To prevent leakage of higher pressure air from underneath the wing

References:
- [www.efluids.com/efluids/gallery/trailing_vortices_2.html](http://www.efluids.com/efluids/gallery/trailing_vortices_2.html)
How does it work?

Winglet

Induced Velocity

In the direction of flight

Planview

Winglet

\[ V \]

\[ V_i \]

\[ \alpha \]
How does it work?

The Resultant Forces

\[ \Delta D = - L_w \alpha_w + D_w \]
\[ \Delta C_D = - \frac{S_w}{S} (C_{Lw} \alpha_w + C_{Dw}) \]
\[ C_{Dw} = C_{Dow} + C_L^2 L_w / (\pi A_w) \]
\[ \Delta C_D = - \frac{S_w}{S} (C_{Lw} \alpha_w - C_{Dow} + C_L^2 L_w / (\pi A_w)) \]
\[ \alpha_w = K C_L \]
\[ C_{Lw} = 2 \pi A_w / (A_w + 2) \alpha_w \]

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

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

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

- 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 ommited
- Toe angle critical to wing loading

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

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 winglet
- Most important 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 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://aerody.org

Upswept & Drooped Tips

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

• 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
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 operates 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
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

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/index.html
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

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