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A Comparison of Various Wingtip Devices

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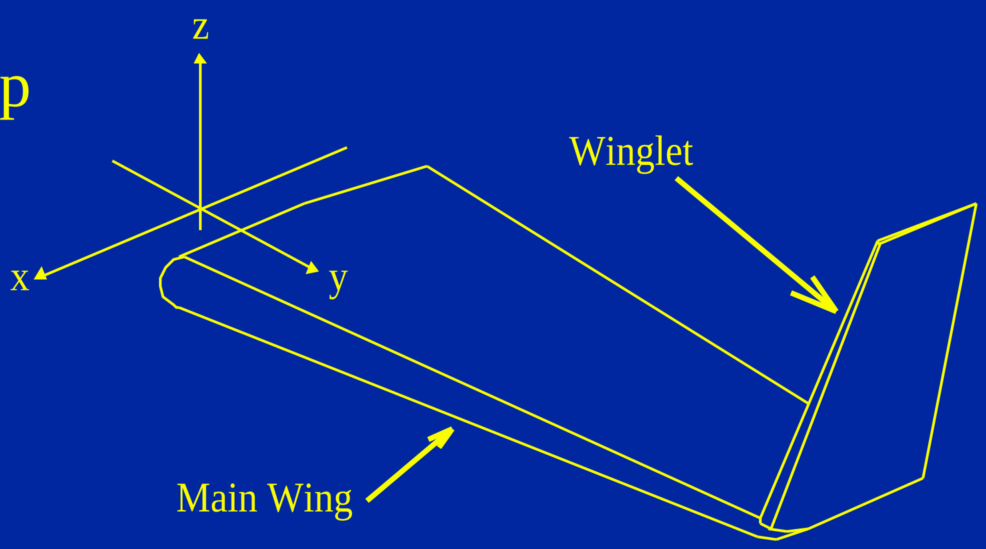
The birds knew it all along...

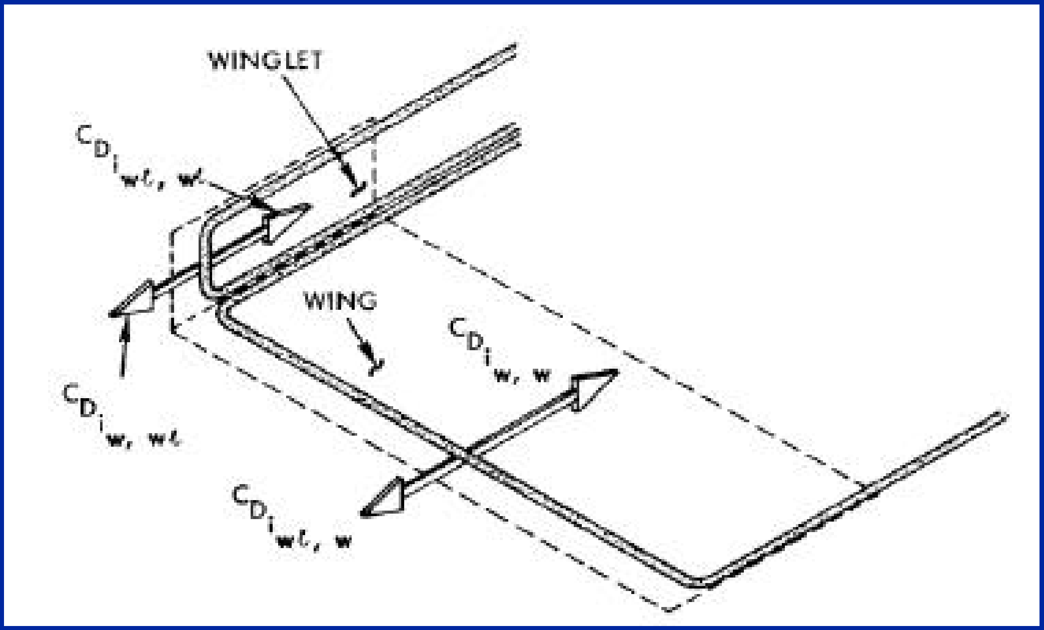
What is a Winglet?

- Small inclined wing at tip
- Whitcomb
- Reduce Induced Drag
- Improve Aesthetics (Marketability)
- Used in a Number of Commercial Transports and Business Jets



How do winglets work?

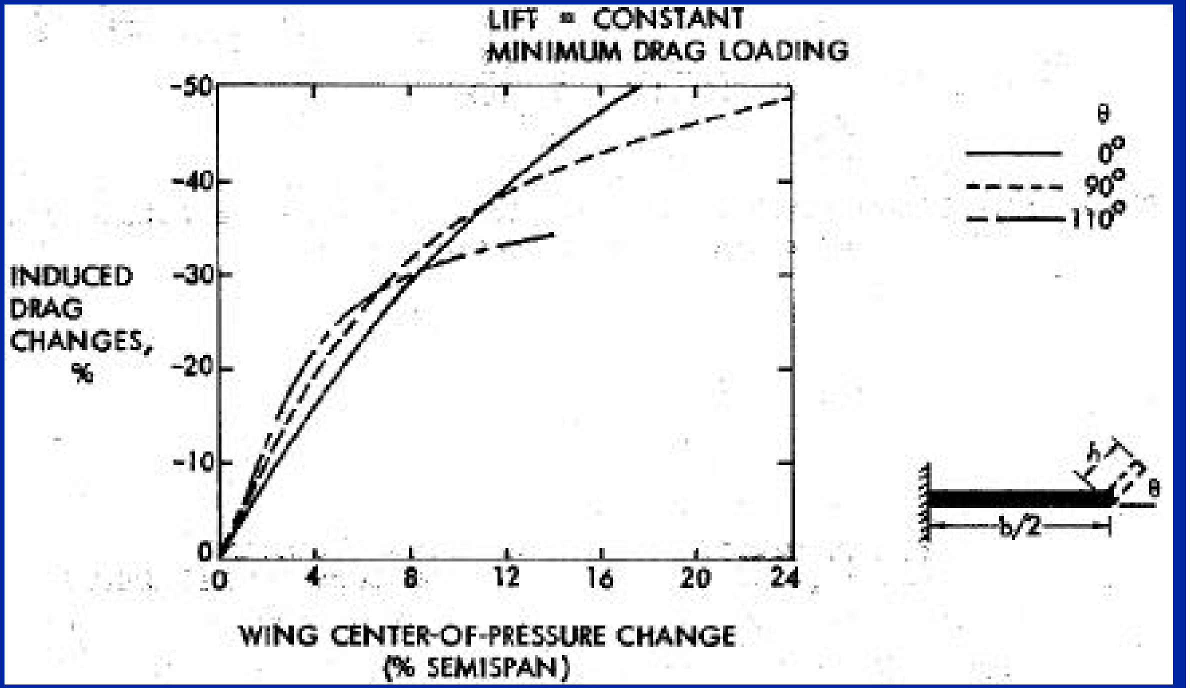
- Drag on Wing due to Wing
- Thrust on Wing due to Winglet
- Drag on Winglet due to Winglet
- Thrust on Winglet due to Wing



Blackwell, James A., "Numerical Method to Calculate the Induced Drag or Optimum Loading for Arbitrary Non-Planar Aircraft," NASA SP-405.

Configuration Trade-Offs

- Reduce Center of Pressure Shift by Using Winglets
- Outboard Shift in Center of Pressure = Increased Wing Weight



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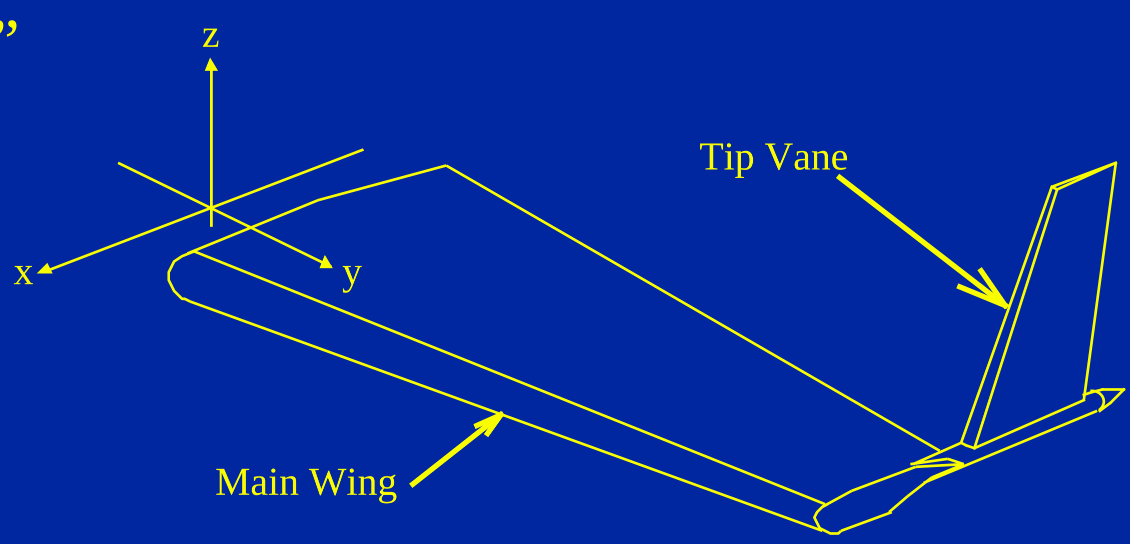
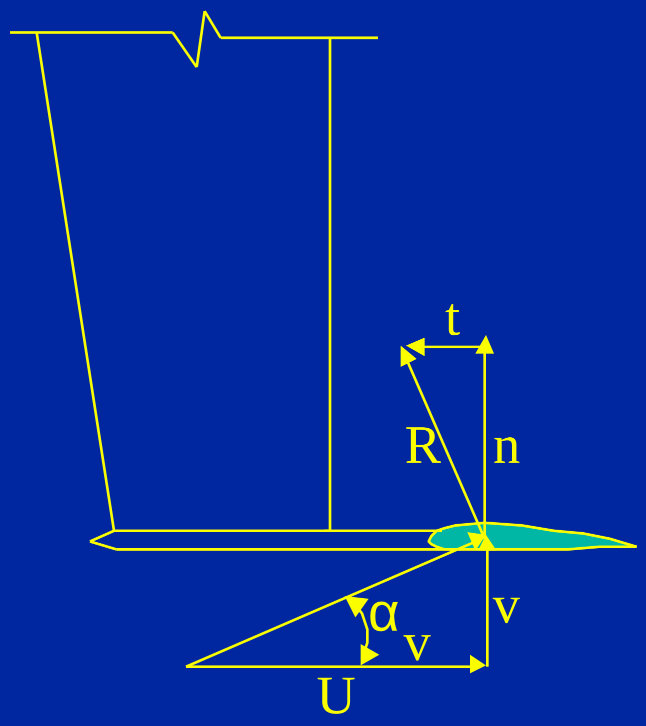
Tip Vanes

- Winglet positioned aft on boom
- Developed by J.E. Hackett
- “Vortex Diffuser Vane” (VDV)



How the Vane Works

- Idea slightly different from plain winglet
- Larger “v” component
- Effect of cant on bending moment

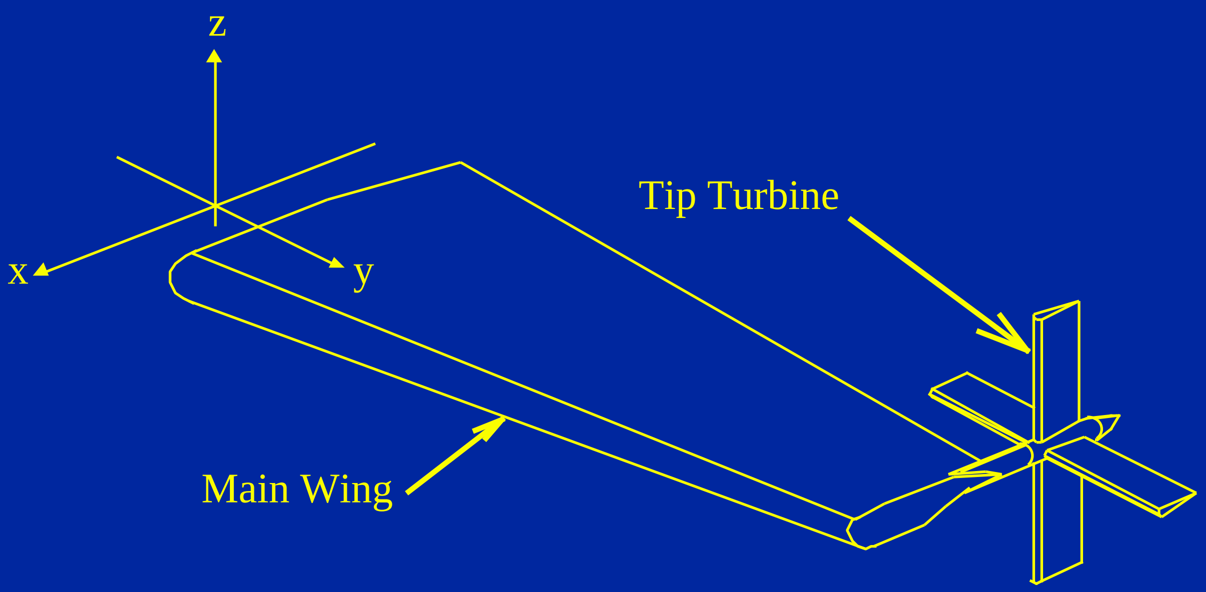


More Considerations

- Tested on the “Thrush” agricultural aircraft.
- Reduced vortex entrainment of spray
- Reduced drag
- Stability Issues
  - Can decrease Dutch Roll damping
  - Not as bad as a pure winglet

Tip Turbines

- Rotating
  - Electrical power
- Non-Rotating
  - Reduction in vortex strength



Design Considerations

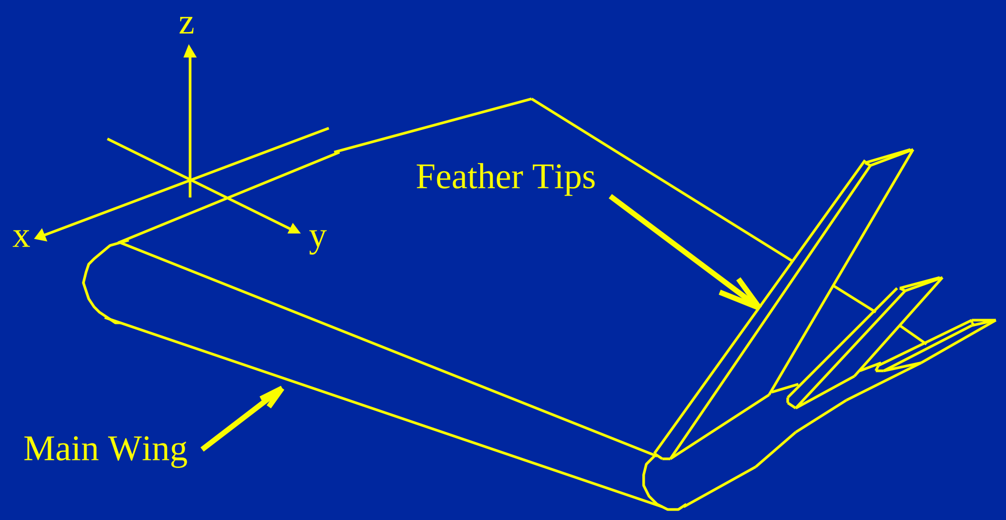
- In general
  - Breakeven lift coefficient about 0.35
  - Blade taper increased drag reduction
  - Adding camber improves drag reduction
  - Pitching moment increased at zero lift
- Rotating Blades
  - Increased induced drag

Testing

- Piper PA-28
  - Tested by NASA
  - Drag reduction
  - Optimized turbine blade design

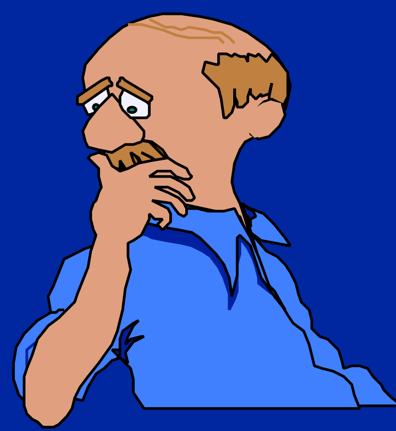
Tip Sails or Feather Tips

- First investigated by J. J. Spillman at the Cranfield Institute of Technology
- Theoretical and experimental research also performed at NASA and Lockheed-Georgia



Tip Sail Design Philosophy

- Tip sails "unwind" the wingtip vortex, like stators in a fan
- Each surface can be better matched to the local flow direction
- Multiple wingtip surfaces help to prevent separation
- Greater efficiency with more sails—similar to multi-element airfoils for high lift systems
- Break-even C_L is lower for tip sails than for winglets



Experimental Results

- Which aircraft have tip sails been tested on?
  - Wind tunnel: BAE Jetstream (twin-engine turboprop)
  - Flight test: Paris MS 760 (small jet)
- Experimental results
  - Reduction in induced drag
  - Higher than expected parasite drag due to separation
    - Blamed on poor tip sail design
  - Wake effects with addition of tip sails
    - Maximum vortex intensity is reduced by 25%
    - Maximum vortex intensity is delayed from 400 m to 700 m behind aircraft (6.5 sec to 11.3 sec)

Configuration Geometries

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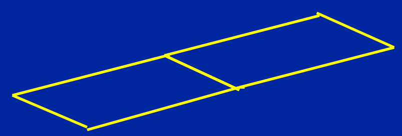
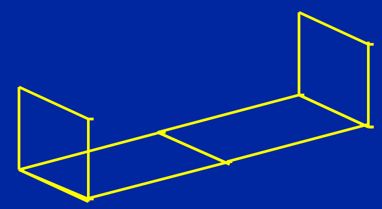


Plain Wing

1.43



Winglet

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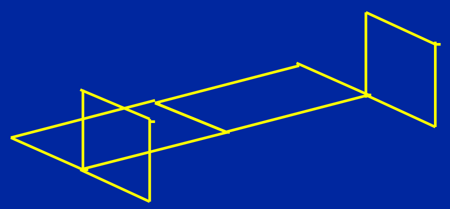

Tip Vane

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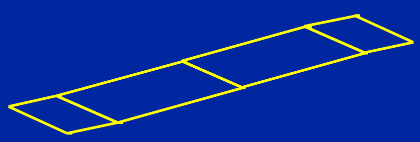
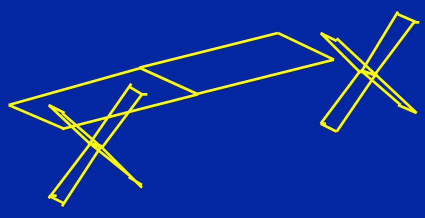


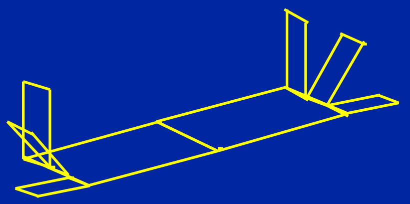
Wingtip Extension

2.33



Tip Turbine

2.28

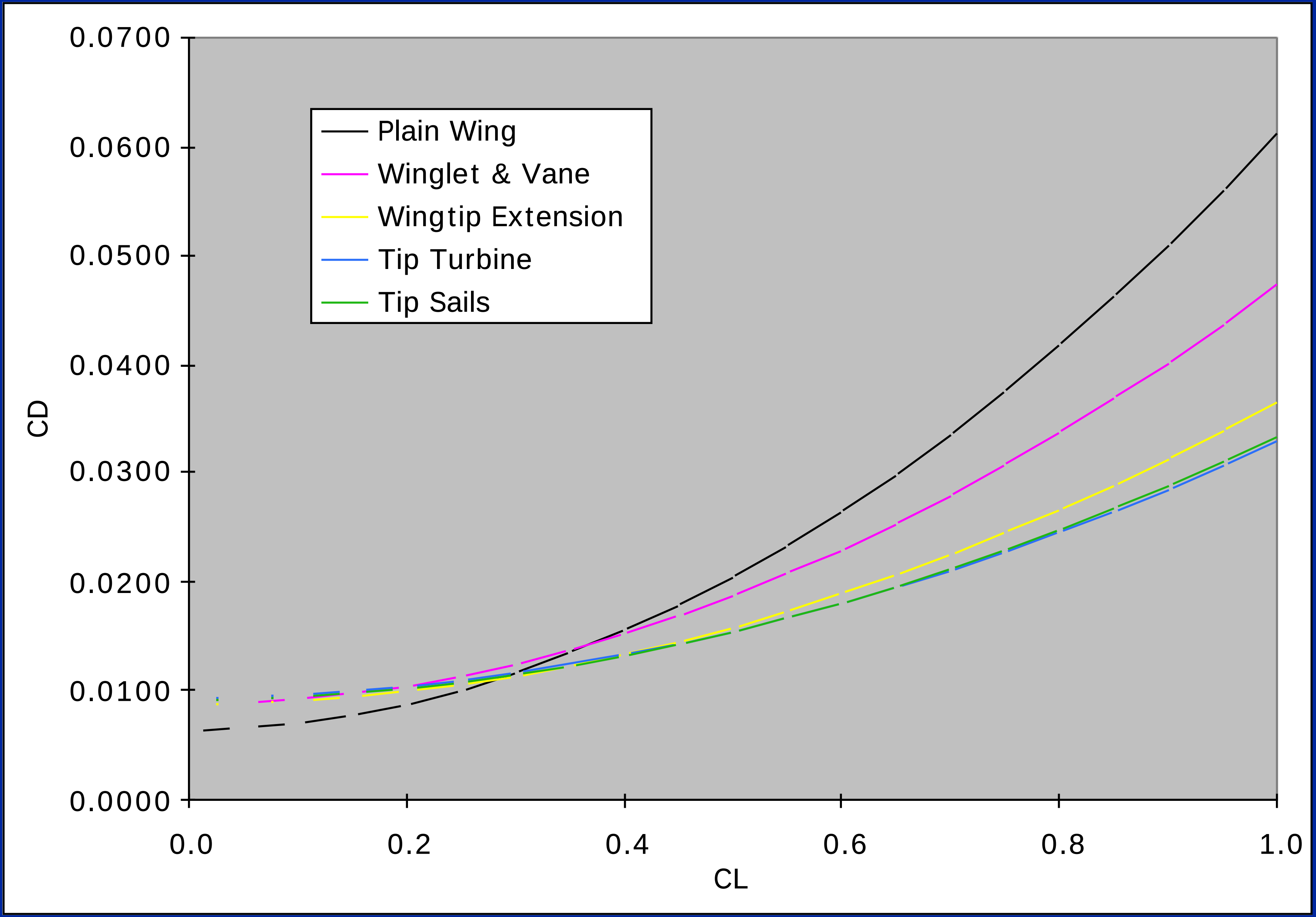


Tip Sails

Drag Estimation Methodology

- Assumptions
  - Span = 50 ft., Aspect Ratio = 8, height/span = 0.2
  - Wing t/c = 0.12, tip device t/c = 0.10
  - M = 0.6, altitude = 20,000 ft.
  - Reference area = constant = 416.5 ft^2
  - Fully turbulent flow for all surfaces
  - Interference drag not included
- Analysis codes
  - Trefftz plane calculation for minimum induced drag
  - Program FRICTION for friction and form drag

Drag Polars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Plain Wing
Winglet & Vane
Wingtip Extension
Tip Turbine
Tip Sails

Conclusions

- No free lunch!
  - Induced drag is reduced 3-6%, but only at the cost of increased parasite drag, increased trim drag, and increased weight, manufacturing complexity, and expense
- A wingtip extension has a higher span efficiency than a winglet
- Tip sails and tip turbines have higher span efficiencies than wingtip extensions
- Wingtip extensions, tip sails, and tip turbines have a lower break-even C_L

Recommendations

- Potential applications
  - Good for span-limited, fuel-volume limited, or climb-driven missions
  - Also good for add-ons to existing aircraft, since the root bending moment does not increase significantly
- Must look at interference drag and multidisciplinary ripple-through effects for a true comparison
- Must examine the feasibility of designing shapes to achieve the optimum load distribution without separation losses

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