Limits to Open Class Performance?

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02 Sep 07
Dedicated to the memory of Dr Paul MacCready

It seems that perfection is attained
Not when there is no more to be added,
But when there is nothing more to be deleted.

At the end of its evolution,
The machine effaces itself.

- Antoine de Saint-Exupery
Intro

- Standard Class
- 15m/Racing Class
- Open Class
- Design Solutions
  - assumptions
  - limiting parameters
  - airfoil performance
  - current trends
  - analysis
- Conclusions
Standard Class

• Q: What is the size limitation in the Standard Class?
• A: 15m span (no flaps)
15m/Racing Class

• Q: What is the 15m size limitation?
• A: 15m span
  (no restriction on flaps)
Open or Unlimited Class

• Q: What is the size limitation on the Open Class?
Open Class Limitation: MASS!

- 650 kg single-place
- 750 kg two-place
- 850 kg two-place w/ motor
Design Solutions

- Assumptions:
  - no active boundary layer control
  - use current technology materials
    fiberglass
    carbon fiber
  - fits within existing rules
  - no variable geometry (camber changing flaps only)
  - no active controls (no unstable designs)
Limiting Parameters

- Reynolds number
  - chord limitations: viscous drag
  - max CL
- Mass increases faster than span - modern materials help
- Still need to fly slow, turn and bank
- Still need to dash fast
Limiting Parameters

• Slow climbing flight requires low wing loading
• High cruise speed requires high wing loading
• Minimum sink requires low speed
• Max L/D balances viscous and induced drag
• Low viscous drag is always desirable
• The ‘best” sailplane will always be versatile

• Note: gains in either induced or viscous drag alone will net only half the gain overall!
• Note: other structural problems (yaw inertia & spins, flutter, static loads integrity)
Airfoil Limitations

• Thickness constraints
• Flaps allow thinner (and lower Cdo) airfoils (with limitations)
• Laminar flow drag bucket is roughly in proportion to thickness (NB: Std Class t/c ~17%; 15m/Open Class t/c ~14%)

• Approximately 60% to 75% of total viscous drag of Open Class designs is airfoil profile drag
Current Trends

• Survey of the Open Class (composites)

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Current Trends (Mass)

- Open Class mass (kg)
Current Trends (L/D)

- Open Class (L/D)
Analysis

- Eta is the performance benchmark
- Near elliptical span load
- 30.9m span
- 710 kg empty
- 70:1 L/D
- Yaw inertia
Design Solutions

- Minimum induced drag for a given span: elliptical span load (or winglets)

- Minimum induced drag for a given structural weight: bell shaped span load (16% greater span and 7% less drag than elliptical - Klein & Viswanathan)
Design Solutions

- Applying bell shaped span load to Eta-class sailplane
- 710 kg We (plus two 70 kg pilots)
- 7% less induced drag
- 16% more span (36m!)
- Max L/D = ~72:1
Design Solutions

• What if we could build a flying wing?
• Decrease viscous drag by 15% (can’t take full credit for 25%)
• Decrease induced drag by 7%
Flying Wing

• Balance between induced and viscous drag gives about 12% total drag decrease
• Optimistic due to additional constraint of pitching moment from wing
• Max L/D = 78:1
• Even if the airfoil Cdo was 40% of the total, & all credit was taken: Max L/D ~ 94:1
Conclusions

- Open Class performance limits (under current rules and technologies) is very close to absolute limits
- Some gains remain to be explored
- Possible gains from unexplored areas, and new technologies, even using existing materials.
References

• Prandtl, Ludwig: "Uber Tragflugel kleinsten induzierten Widerstandes”; Zeitschrift fur Flugtecknik und Motorluftschiffahrt, 28 XII 1932; Munchen, Deustchland.
• Horten, Reimar; and Selinger, Peter; with Scott, Jan (translator): “Nurflugel: the Story of Horten Flying Wings 1933 - 1960”; Weishapt Verlag; Graz, Austria; 1985.
• Klein, Armin and Viswanathan, Sathy; “Approximate Solution for Minimum induced Drag of Wings with a Given Structural Weight”; Journal of Aircraft, Feb 1975, Vol 12 No 2, AIAA.
• Jones, Robert T; “Minimizing Induced Drag.”; Soaring, October 1979, Soaring Society of America. 
• Foley, William; “Understanding the Standard Class”; Soaring, Jan 1975.
• McMasters, John; “Flying the Altostratus”, Feb 1981.
What are we still missing?

Thanks Phil Barnes and Bob Hoey for reminding us…