Limits to Open Class Performance?

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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.

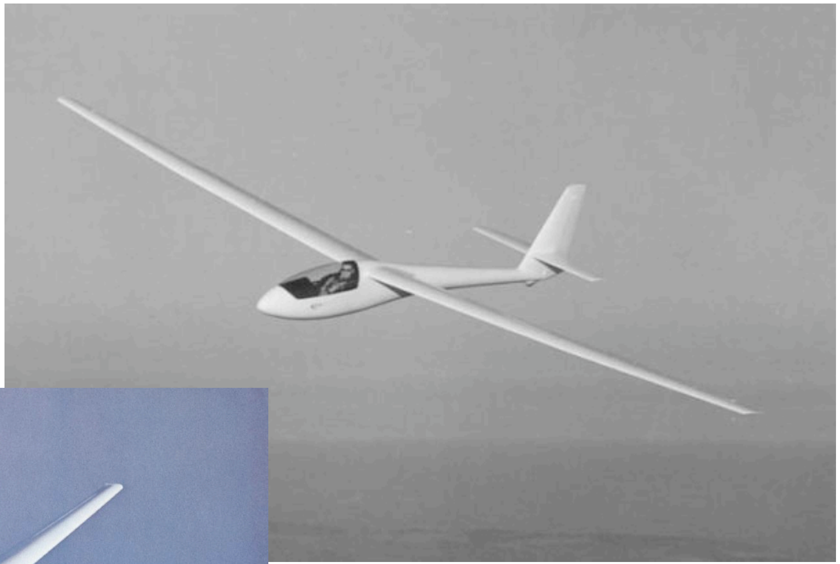
\- Antoine de Saint-Exupery

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

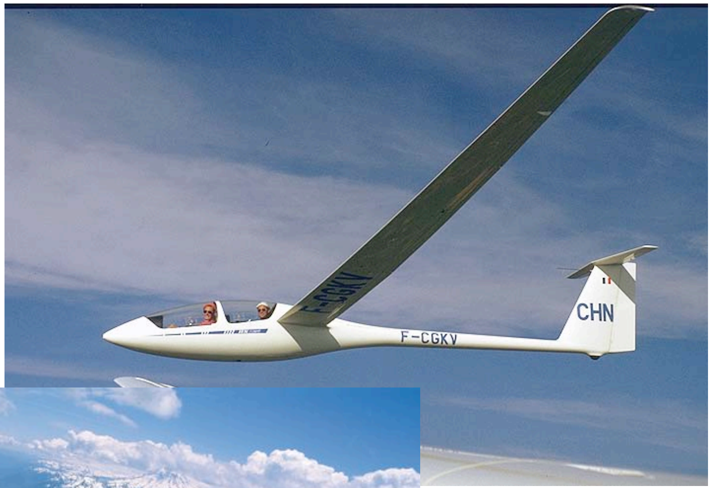
- Q: What is the 15m size limitation?
- A: 15m span
  (no restriction on flaps)

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

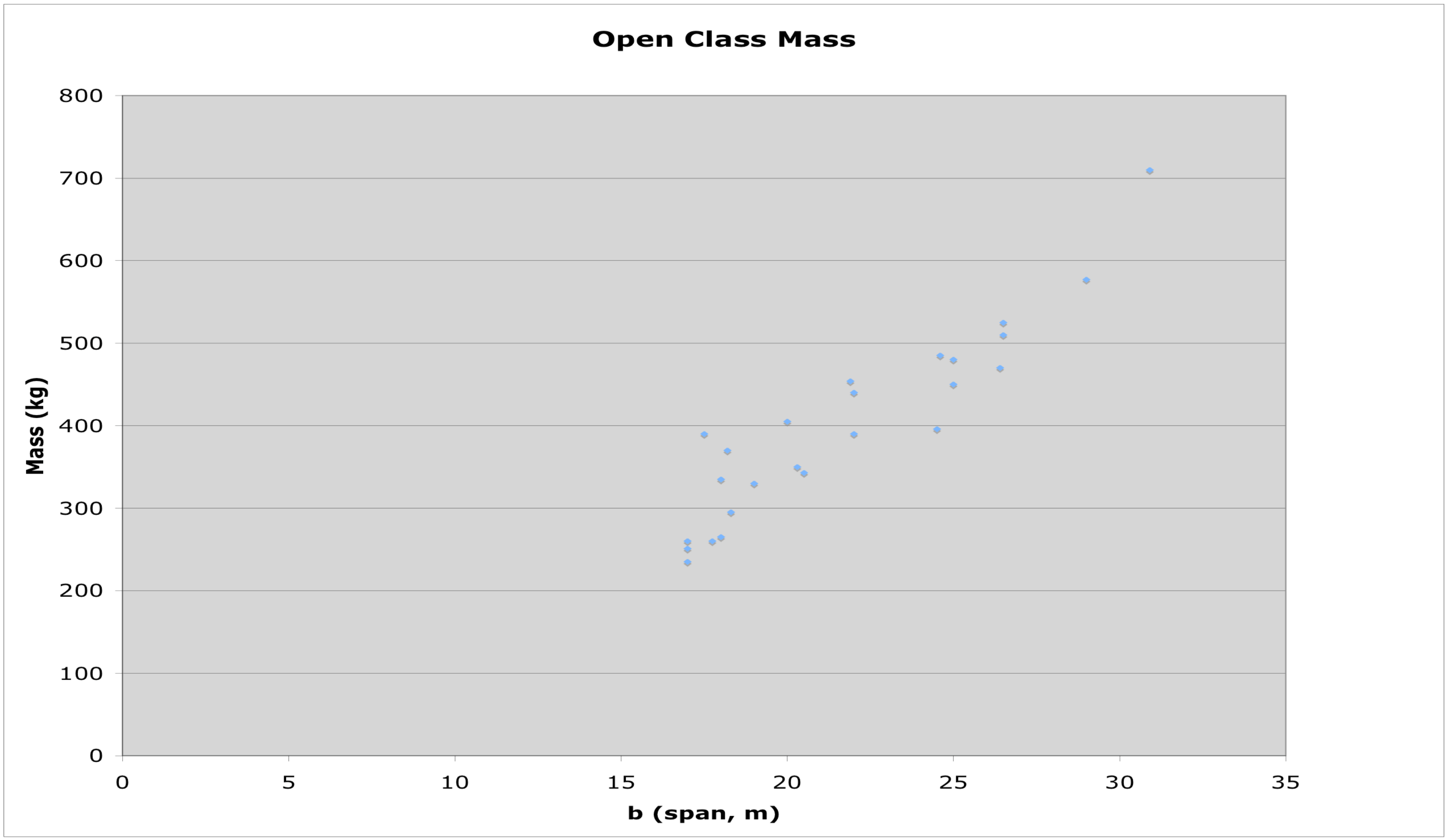
Current Trends

- Survey of the Open Class (composites)

company	model	span	L/D	We
Glasflugel	BS-1	18	44	335
	Kestrel 17	17	43	260
	604	22	49	440
Schempp-Hirth	Cirrus	17.74	44	260
	Nimbus II	20.3	49	350
	Ventus 2C	18	46	265
	Nimbus 3	24.5	58	396
	Nimbus 4	26.4	60	470
Schleicher	AS-W12	18.3	47	295
	AS-W 17	20	48.5	405
	AS-W 22	25	60	450
Akaflieg Braunschweig	SB-10	29	53	577
PZL	Jantar 2	20.5	47	343
MBB	Pheobus C	17	42	235
Slingsby	Kestrel 19	19	44	330
	Kestrel 22	22	51.5	390
Glasar Dirks	DG-202	17	45	251
Applebay	Mescalero	21.9	44	454
Grob	G-103 Twin Astir	17.5	38	390
Schempp-Hirth	Janus	18.2	39	370
	Nimbus 3D	24.6	57	485
	Nimbus 4D	26.5	60	525
Schleicher	AS-H 25	25	57	480
	AS-H 30	26.5	61.8	510
Eta	Eta	30.9	70	710

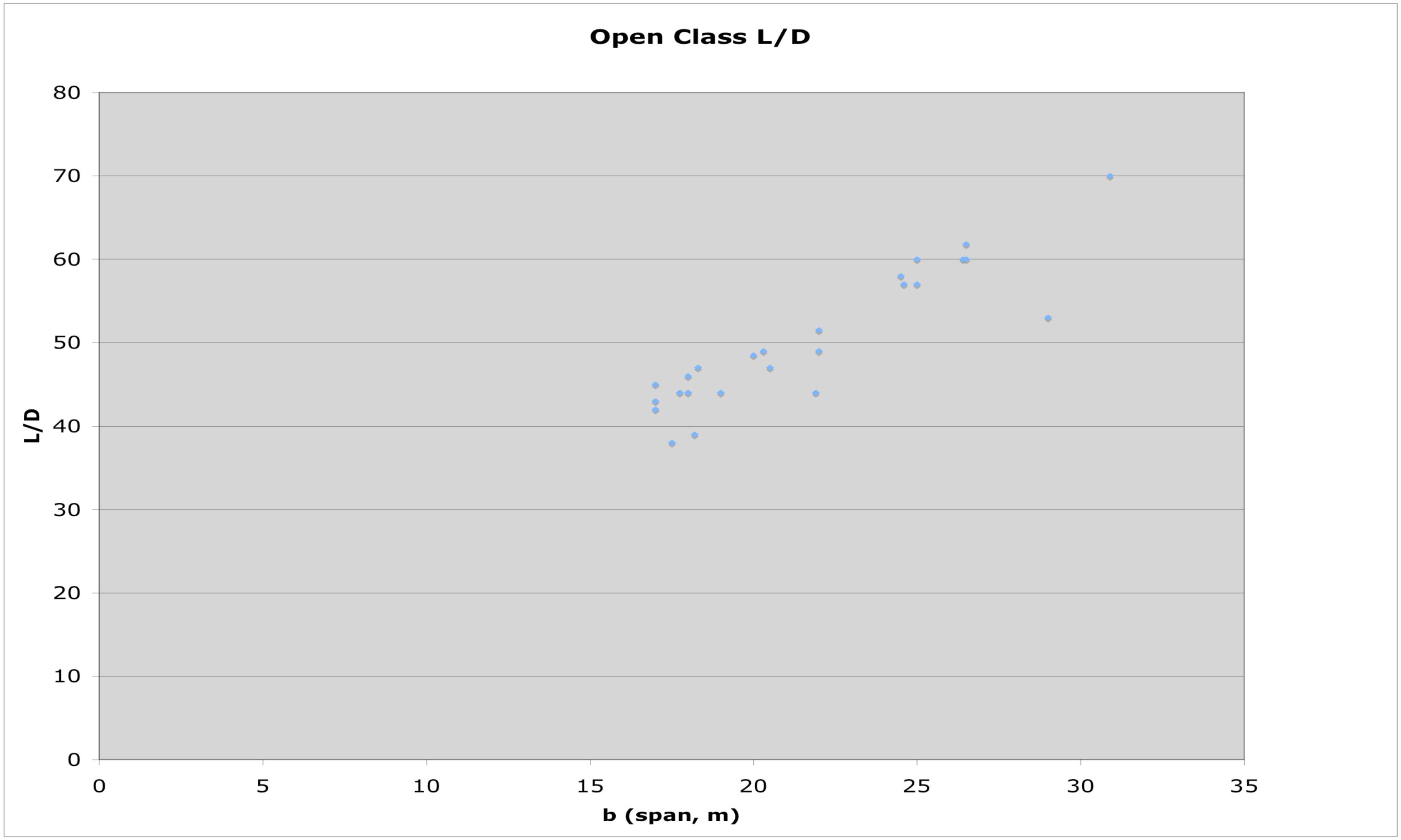
Current Trends (Mass)

- 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

Horten H VI

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

- Anderson, John Jr: “A History of Aerodynamics: and Its Impact on Flying Machines”; Cambridge University Press; Cambridge, United Kingdom.
- Prandtl, Ludwig: “Applications of Modern Hydrodynamics to Aeronautics”; NACA Report No. 116; 1921.
- Munk, Max M.: “The Minimum Induced Drag of Aerofoils”; NACA Report No. 121, 1923.
- Nickel, Karl; and Wohlfart, Michael; with Brown, Eric M. (translator): “tailles Aircraft in Theory and Practice”; AIAA Education Series, AIAA, 1994.
- 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.
- Jones, Robert T.; “The Spanwise Distribution of Lift for Minimum Induced Drag of Wings Having a Given Lift and a Given Bending Moment”; NACA Technical Note 2249, Dec 1950.
- 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.
- Whitcomb, R.T.; “A Design Approach and Selected Wind Tunnel Results at high Subsonic Speeds for Wing-Tip Mounted Winglets,” NASA TN D-8260, July 1976.
- Jones, Robert T; “Minimizing Induced Drag.”; Soaring, October 1979, Soaring Society of America.
- Foley, William; “Understanding the Standard Class”; Soaring, Jan 1975.
- Moffat, George: “New Ships of the 70’s”, Soaring, Feb 1978 and Mar 1978.
- McMasters, John; “Advanced Concepts in Variable Geometry Sailplanes”; Apr 1980, May 1980.
- Chen, M. K. and McMaster, J. H.; “From Paleoaeronautics to Altostratus”, May 1983 & Jun 1983.
- McMasters, John; “Flying the Altostratus”, Feb 1981.
- Wortmann, F. X.; “On the Optimization of Airfoils with Flaps”, Soaring, May 1970.
- Anonymous: “1997 Sailplane Directory”, Soaring , July 1997.
- Simons, Martin; “Sailplanes 1965-2000” Eqip, 2004.
- Coates, Andrew: “Jane’s World Sailplanes and Motor Gliders”, Flying Books, 1978.
- Thomas, Fred: “Fundamentals of Sailplane Design”, College Park Press, 1999.

What are we still missing?

Thanks Phil Barnes and Bob Hoey for reminding us…