DS airfoil selection

considering multidisciplinary criteria

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Here is an attempt to read Xfoil results with a multidisciplinary point of view, in order to select the best airfoil for reaching high speed in DS.

1 DSing context

1.1 DS mechanism

While DSing, the glider extract energy from atmosphere by using tilted lift as a thrust component (see Ref [1], [2]) :

Lift is the engine of DS.

The importance of lift must not be forgot in the airfoil selection process, particularly for initiating DS.

1.2 What does limit speed in DS

There are many source of speed limitation :

- Structural bending strength of wing
  G-loads encountered while DSing can be HUGE. Basic structural strength of the wing is a very crude but real limit to airspeed.
  Related topics : airfoil thickness, building technology
- Drag
  Drag is the force that consumed energy along the path.
  While extracting energy, max efficiency is reach for the best L/D. For ballistic & transition phases of the path, D is to be minimized.
  Related topics : minimum drag of the airfoil, drag rise with C_L, drag of fuselage, interference drag.

- Actual path performed

Actual speed is highly linked to the ability of the pilot to reach accurate position in the mountain airflow while DSing. A lack of confort/precision in handling may limit the maximum airspeed.
Related topics : general handling, stability, hinge moment and servo capability

- "Tuck under" phenomenon

This is the main current issue about very high speed : pitch authority disappears. Although not fully understood, it is likely that tuck under is causes by aero-elastic problem on tails, elevator servo overloading and stability issue.
Related topics : stability, hinge moment and servo capability.

In order to maximise speed, we have to minimize the impact of all this speed limiting effects as a whole thing.

2 Reading airfoil results

2.1 Evaluated airfoils

From a drag point of view at low CL, the thinner the airfoil the best. In real life thickness of airfoil is directed by wing bending consideration, for a given material.
Current empirical process for DS glider using carbon fibre construction seems to have converge to relative thickness around 8%. Airfoil selected have thickness close to this mean value.

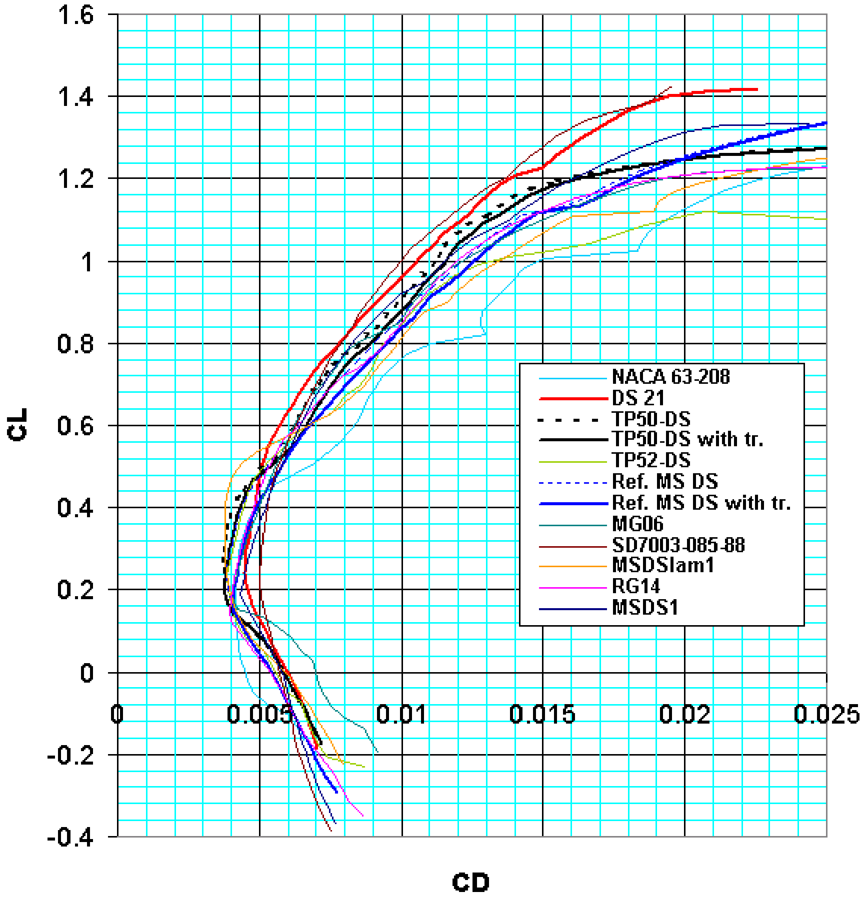
Here are the airfoils tested

Name	Comment
Naca 63208	Reference laminar airfoil (expérimental data available)
DS21	Equipped the current record holder (309Mph)
RG14	Airfoil with "good reputation at high speed".
SD7003	Airfoil with "good reputation at high speed", very relevant at low Re.
MG06	Airfoil with good handling reputation, very relevant at low Re with flaps. Flaps extend greatly performance.
TP50DS (& TP52DS)	New design from Thierry Platon, for DS use
MS DS1	Personal design, with low Cm constraint
MS DSlam	Personal designs with low CDmin constraint
Ref MS DS	Personal designs, the most satisfactory

Reference values
Current record speed record was measured around 300mph (ground speed), that is about 500km/h. With a typical chord around 20cm and a speed of 400km/h, Reynolds number is about Re=1 500 000. Will will retain this value for the Xfoil computations.

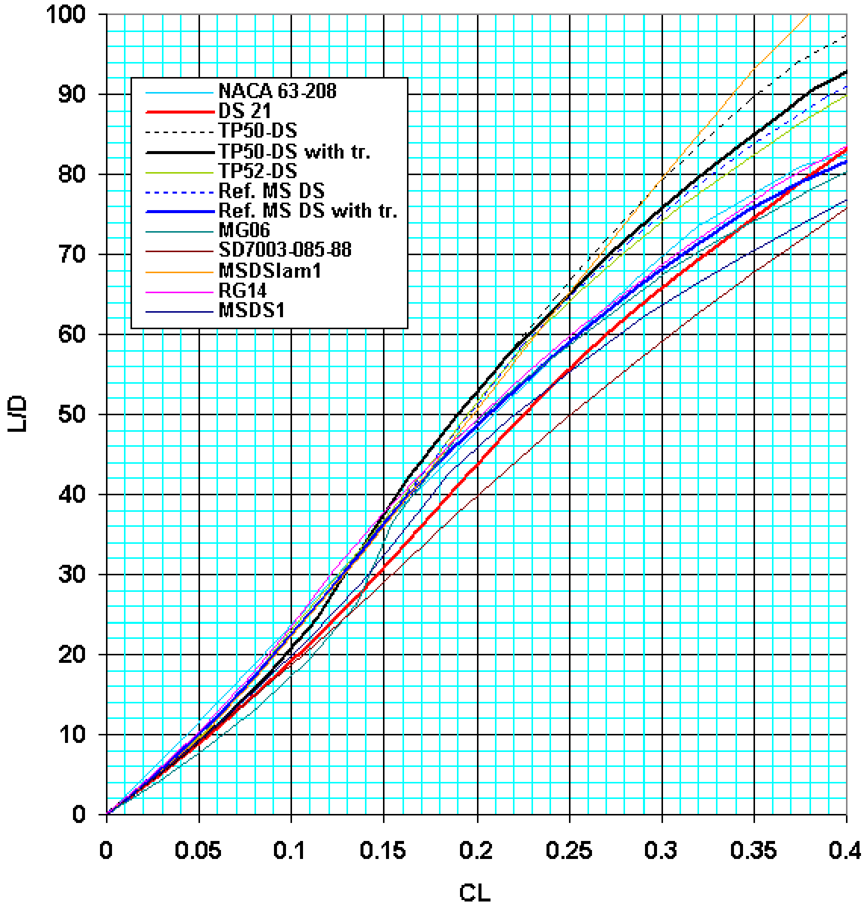
2.2 *Performance : Drag & L/D consideration*

Overview on CL-CD polars



Name	Comment
Naca 63208	Good Cdmin. Very wavy drag to lift curve at CL over 0.4 : sign of bad adaptation to low Re. Lack of CLmax
DS21	Not good at CDmin. Best CD to CL curve above CL=0.5 Great max lift
RG14	Good Cdmin. Very wavy lift to drag at CL over 0.4 : sign of bad adaptation to low Re. CLmax correct
SD7003	Poor Cdmin. Very wavy lift to drag at CL over 0.4 : sign of bad adaptation to low Re. Good CLmax
MG06	Poor Cdmin. Bad CD at low CL if no flap used (LE design) Lack of CLmax
TP50DS	Best Cdmin. CD to CL curve robust to transitioning (See stability concern) Clmax correct
TP52DS	Good Cdmin. Small gain at low CL compared to TP50DS Lack of CLmax
Ref MS DS	Cdmin Correct Small gain at low CL compared to TP50DS Lack of CLmax
MSDSlam	Best Cdmin. Wavy drag to lift curve at CL over 0.6 Lack of CLmax
MSDS1	Good Cdmin. Small gain at low CL compared to TP50DS Lack of CLmax

L/D in the low CL DS range



Name	Comment
Naca 63208	Best in L/D at very low CL
DS21	Low values of L/D in the plotted CL range
RG14	Best in L/D at CL around 0.10-0.15, mean values above
SD7003	Lowest values of L/D in the plotted CL range – Flaps deflection may help
MG06	Lowest values of L/D under CL=0.15, correct above
TP50DS	Best in L/D around CL=0.2 – robust to transitioning.
TP52DS	Better in L/D than TP50DS under CL=0.15, lower above.
Ref MS DS	Good in L/D under 0.15
MSDSlam	Good in L/D all over plotted range
MSDS1	Poor in L/D for higher CL values

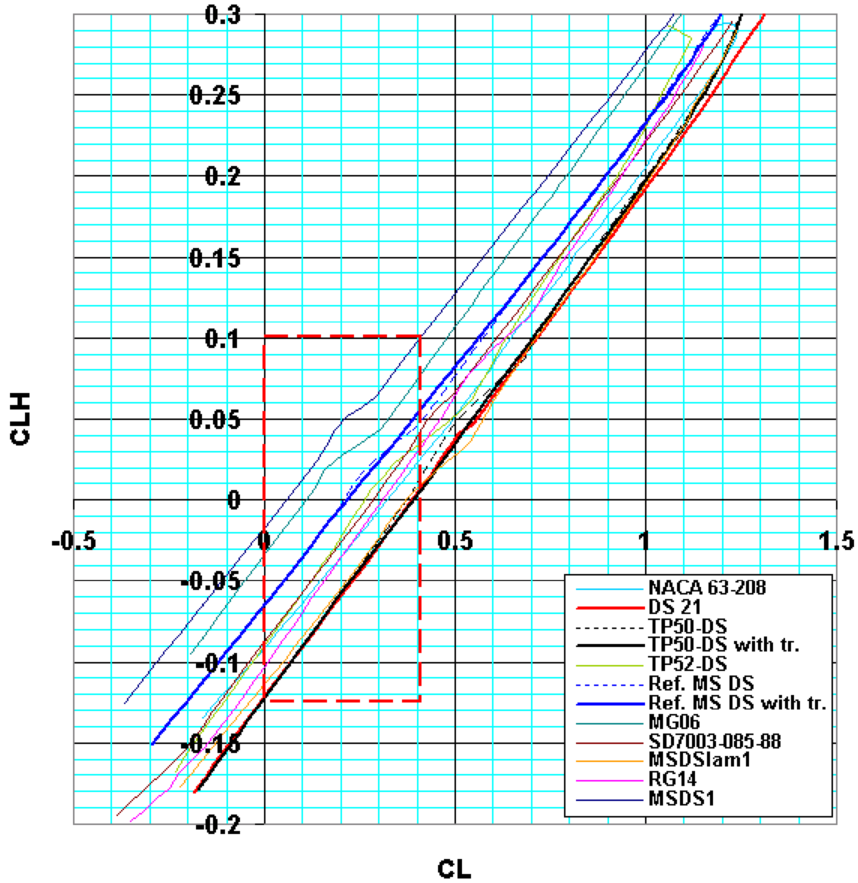
2.3 Tail loading consideration

With a typical CG location corresponding to an effective "mean static margin" around 8%, load on the horizontal tail can be computed.

- Negative values for CLH (lift downward) causes downward bending of the rear fuselage, hence divergent aero elastic behaviour (prone to tuck under).
- Positive values for CLH (lift downward) causes upward bending of the rear fuselage, less prone to tuck under behaviour (pitch up under load).

Tail load is a relevant issue for very high speed (high dynamic pressure), for which

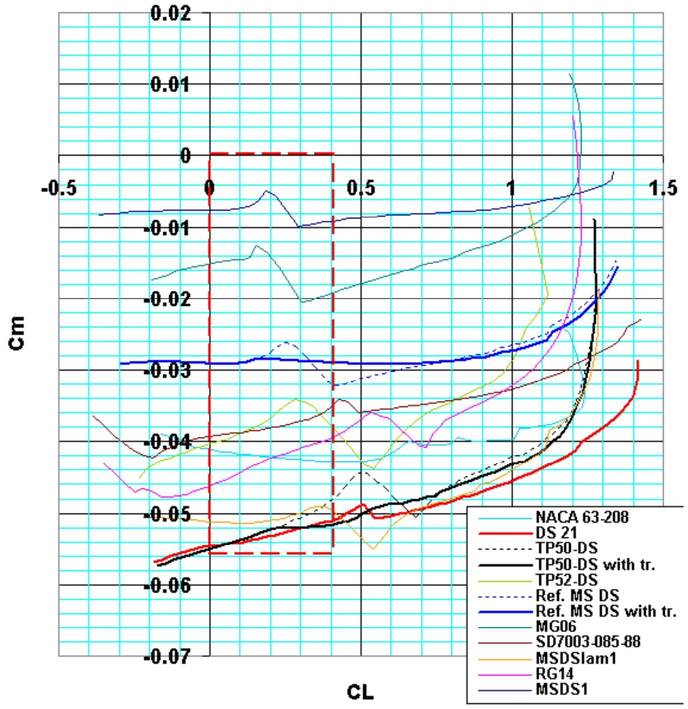
NB : 8% static margin corresponds to a CG located around 38% of MAC with Vh=0.45.



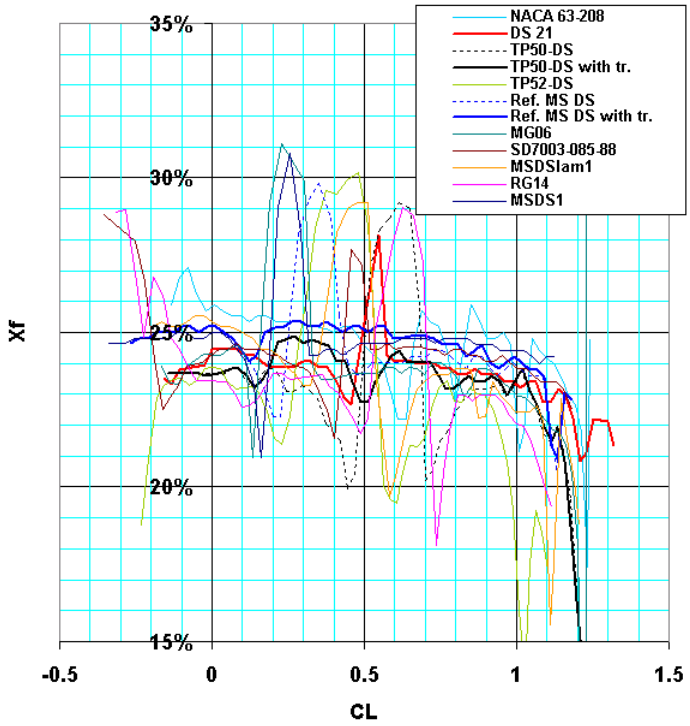
Name	Comment
Naca 63208	Negative tail loading for most of high speed CL range
DS21	The most negative tail loading for most of high speed CL range
RG14	Rather negative tail loading for speed CL range
SD7003	Rather negative tail loading for speed CL range
MG06	Rather positive tail loading for high speed CL range
TP50DS	The most negative tail loading for most of high speed CL range
TP52DS	Rather negative tail loading for most of high speed CL range.
Ref MS DS	No tail bending in the middle of high speed CL range
MSDSlam	The most negative tail loading for most of high speed CL range
MSDS1	Positive tail loading for most of high speed CL range

2.4 Longitudinal stability consideration

Cm –CL curve



Aerodynamic centre location (theory : 25%)

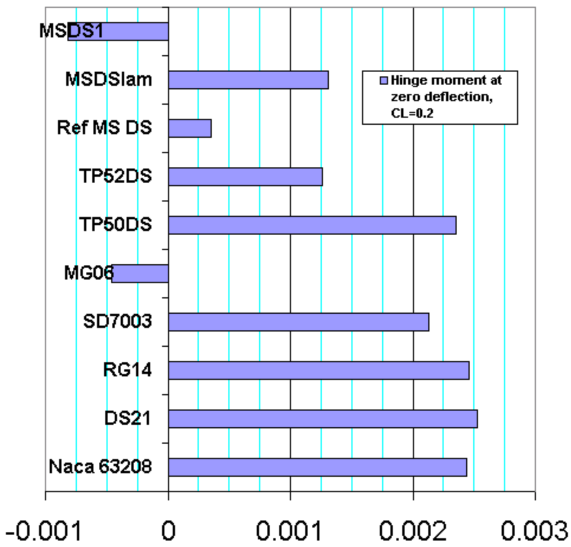


Name	Comment
Naca 63208	Very regular Cm CL curve : little movement of Aerodynamic centre.
DS21	Very regular Cm CL curve : little movement of Aerodynamic centre, over the high speed CL range (CL>0.5)
RG14	Step in Cm CL curve, over the high speed CL range (CL>0.5)
SD7003	Very regular Cm CL curve : little movement of Aerodynamic centre at the end of the high speed CL range (CL>0.4)
MG06	Step in Cm CL curve, in the middle of high speed CL range (CL=0.2 – 0.3)
TP50DS	Step in Cm CL curve, at the end of high speed CL range (CL=0.2 – 0.3) Cured by transitioning BL.
TP52DS	Huge step in Cm CL curve, at the end of high speed CL range (CL=0.2 – 0.3)
Ref MS DS	Step in Cm CL curve, at the end of high speed CL range (CL=0.2 – 0.3) Cured by transitioning BL
MSDSlam	Step in Cm CL curve, at the end of high speed CL range (CL=0.2 – 0.3) Cured by transitioning BL
MSDS1	Step in Cm CL curve, in the middle of high speed CL range (CL=0.2 – 0.3)

2.5 Zero deflection aileron hinge moment

Hinge moment was evaluated from Xfoil, for CL=0.2. Flap was supposed to occupy 20% of local chord.

Only zero deflection hinge moment coefficient Chm0 is presented : it corresponds to the load the servo will sustain with no deflection, when resting.
The gradient in hinge moment coefficient with deflection is supposed to be the same for any airfoil, the hinge location being given.



Load on the servo is obtained as follows :

$$\text{Hinge moment at zero deflection} = Chm0*0.5*L*C^2*V^2$$

L : length of aileron (spanwise)
C : chord of the airfoil

Example : For L=0.4m, C=0.2m, V=100m/s (360km/h)
Cmh0=0.00250 : Hinge moment at zero deflection = 2.5kg.cm
Cmh0=0.00035 : Hinge moment at zero deflection = 0.35kg.cm

Name	Comment
Naca 63208	Rear loading produces high hinge moment value
DS21	Rear loading produces high hinge moment value
RG14	Rear loading produces high hinge moment value
SD7003	Rather high hinge moment value
MG06	Low negative hinge moment values
TP50DS	Rear loading produces high hinge moment value
TP52DS	Medium hinge moment values
Ref MS DS	Low hinge moment values
MSDSlam	Medium hinge moment values
MSDS1	Reflex load produces negative hinge moment value : some positive flap setting could be added with less hinge moment.

3 Conclusions

Here is a table that summarize all this study.

My choice would be either :

- TP50DS for an extreme design, with special care on the tail assembly and longitudinal command. Transition could cure some problems.
- Ref MSDS with transition for a less extreme performance, but with much more confort and robustness

Evaluation of the current DS record holder should also be considered, talking about which criterion is the most important.

	Performance			Handling and robustness		
Name	**Minimum drag**	**Max lift**	**L/D low CL**	**Tail loading**	**Stability aspect**	**Hinge moment**
Naca 63208	😐	☹	😐	😐	☺	☹
DS21	☹	☺	☹	☹	☺☺	☹
RG14	😐	😐	😐	😐	😐	☹
SD7003	☹	☺	☹	☺/😐	☺	☹
MG06	😐	☺	😐	☺/😐	☹	☺
TP50DS	☺	😐	☺	☹	😐	☹
TP50DS with Tr	☺	😐	☺	☹	☺	☹
TP52DS	☺	☹	☺	☺/😐	☹	😐
Ref MS DS	☺	😐	☺	☺	☹	☺
Ref MS DS with Tr	😐	😐	😐	☺	☺	☺
MSDSlam	☺	😐/☹	☺	☹	😐	😐
MSDS1	☹	☺	☹	😐	😐	☺

Reference

[1] "Wind energy extraction for sailplane models" Scherrer M
http://perso.wanadoo.fr/scherrer/matthieu/aero/publication.html
[2] "Dynamic soaring" Foucher JL http://perso.wanadoo.fr/dsjlf/
[3] TP airfoils : Platon T