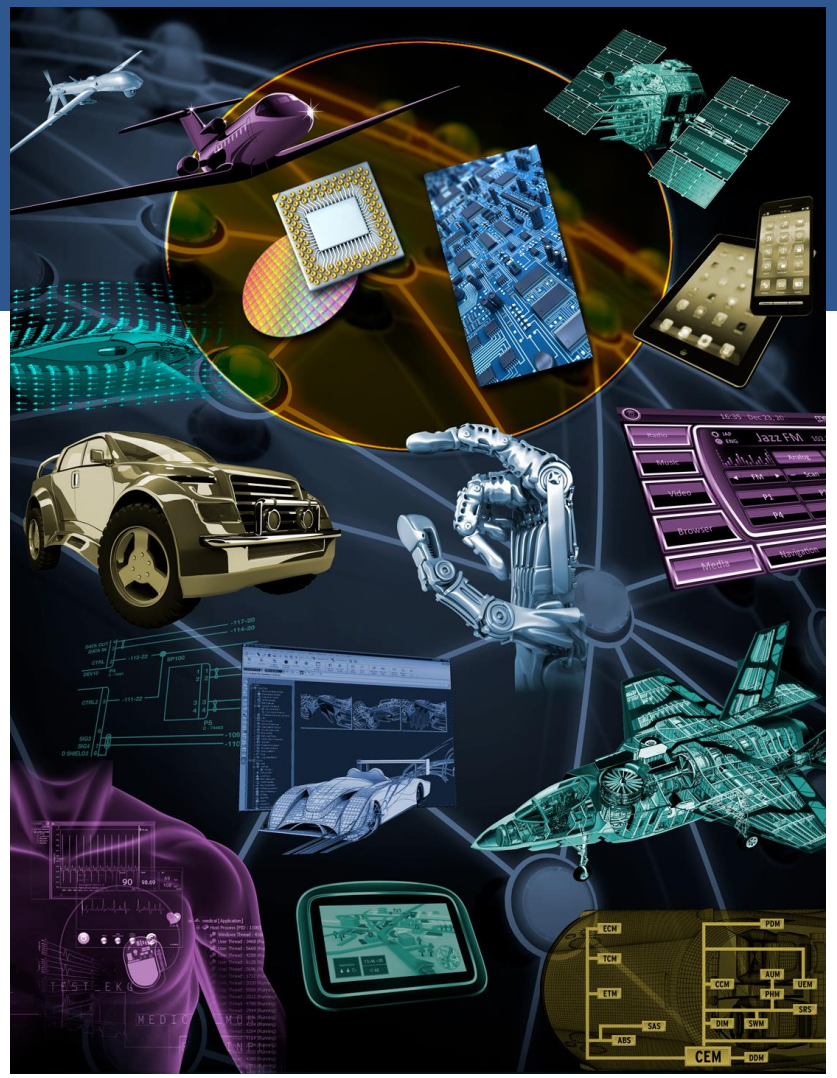

Aerodynamic Analysis of a Red Bull Air Race World Championship Raceplane

Matt Milne

Senior Application Engineer

29th November 2017

Mentor®
A Siemens Business

My Background

Who is this "Matt Milne" guy anyway?

- 1990 – 1994: Air Experience flying with RAF Cadets at school

- 1998: Graduated from "City University" in London with an MEng in Aeronautical Engineering

CITY UNIVERSITY LONDON

- 1998 – 2008: "QinetiQ"
  - Worked in Aerodynamics Group, based at Farnborough
  - Mainly military projects funded by UK MoD, in collaboration with industry e.g. **BAE Systems**, Rolls Royce *et al*
  - Projects include **Eurofighter Typhoon** and **Taranis**
  - Extensive experience of CFD, design optimisation methods and experimental wind-tunnel testing.

- 2008 – Present: "Mentor, A Siemens Business"
  - Based in Hampton Court, London
  - 2008 – 2010: Application Engineer
  - 2010 – 2011: Account Manager
  - 2011 – Present: Application Engineer

Mentor® A Siemens Business

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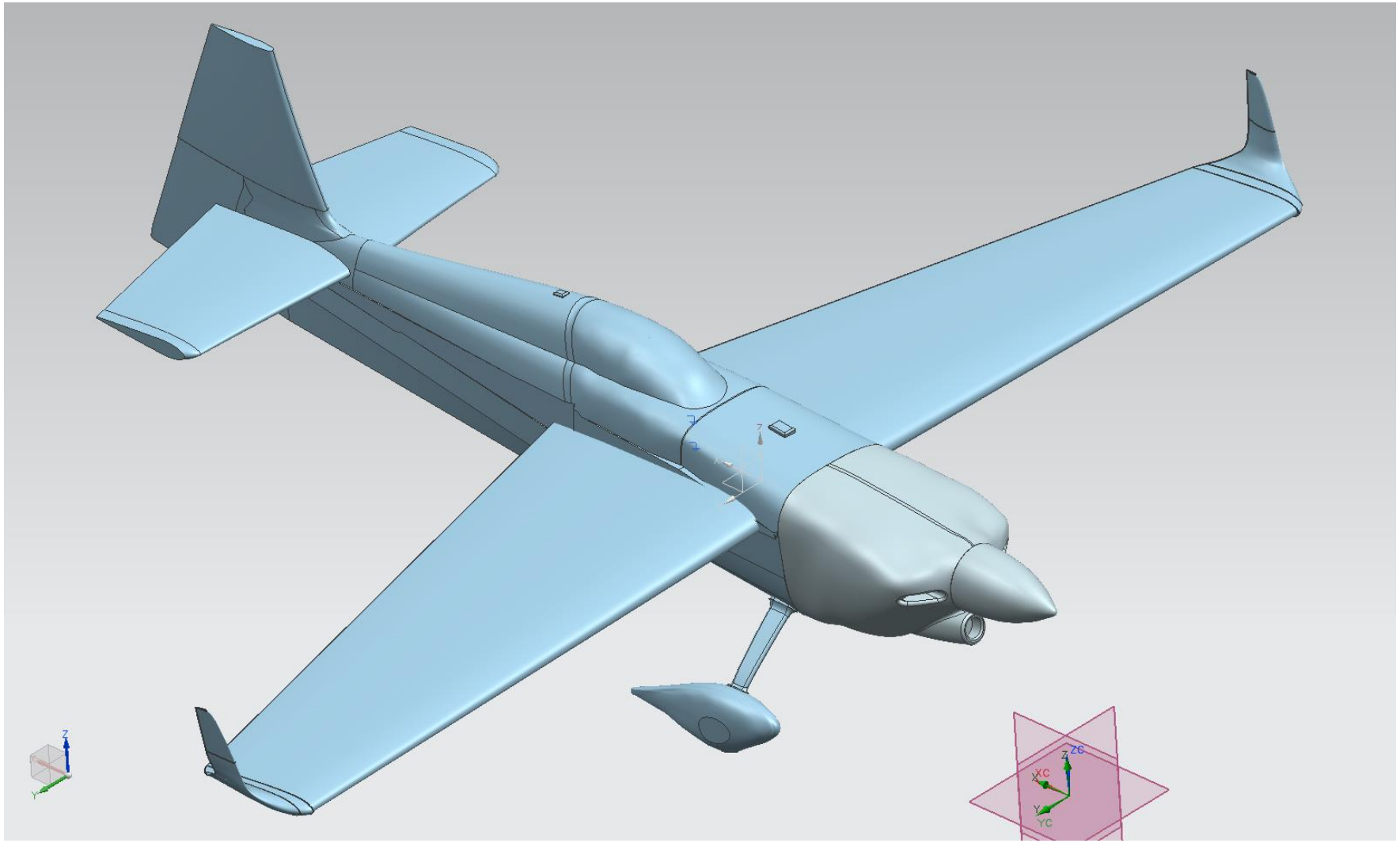
My CFD experience ~1998~2008

- 3D CAD – Surface model, e.g. IGES format
- Use GEMS to simplify and heal 3D CAD
  - Section parts to create rectangular arrays of points for meshing
- Mesh and solve using in-house code (SAUNA)
  - Occasionally used ICEM HEXA for meshing later on
- Typically Euler + wetted area skin friction estimates (robust!)
  - Navier-Stokes + Menter-SST very unstable!
- Developed my own scripts to automate most projects
- But some things were too complex and had to be meshed manually
  - ***2 weeks just to get mesh right on wingtip + sensor pod!!!***
  - ***6 weeks to mesh a complete aircraft (and then the solver didn't work)!!!***
- **Result: Lots of time spent making CFD work; Not enough time spent thinking about aerodynamics!**

CFD 2017: The FloEFD Experience

FloEFD will mesh anything!* (*if it's a solid!)



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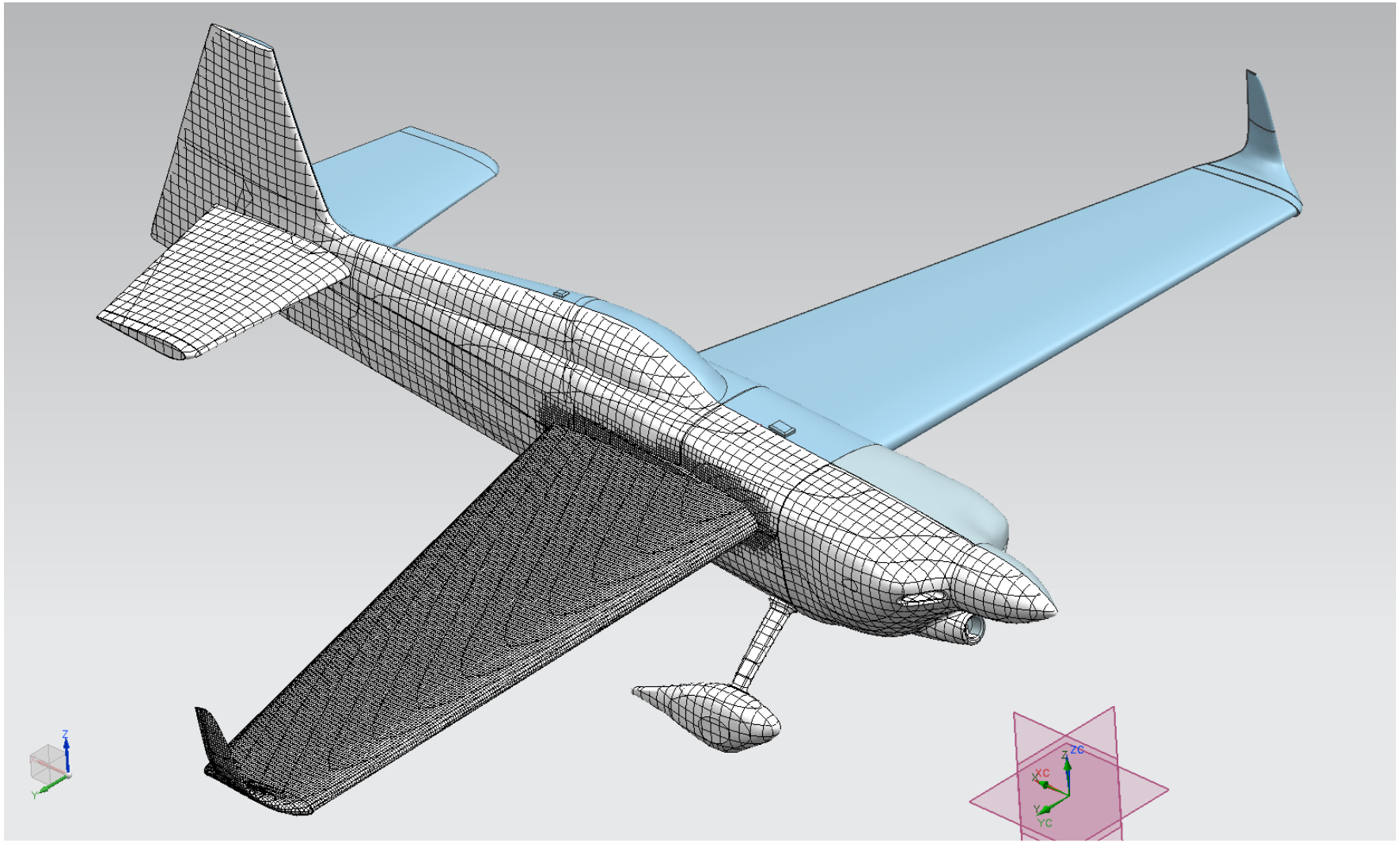

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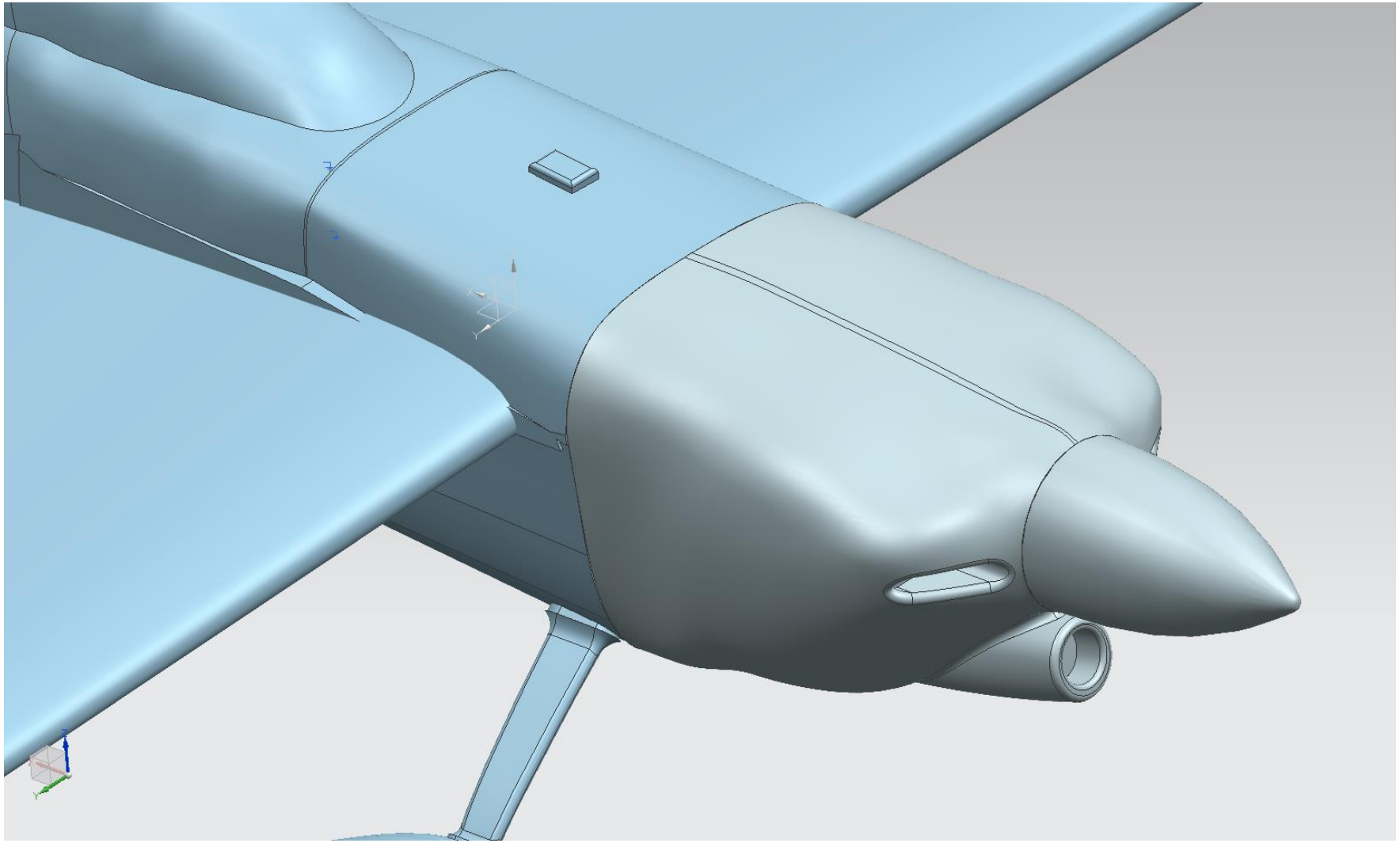

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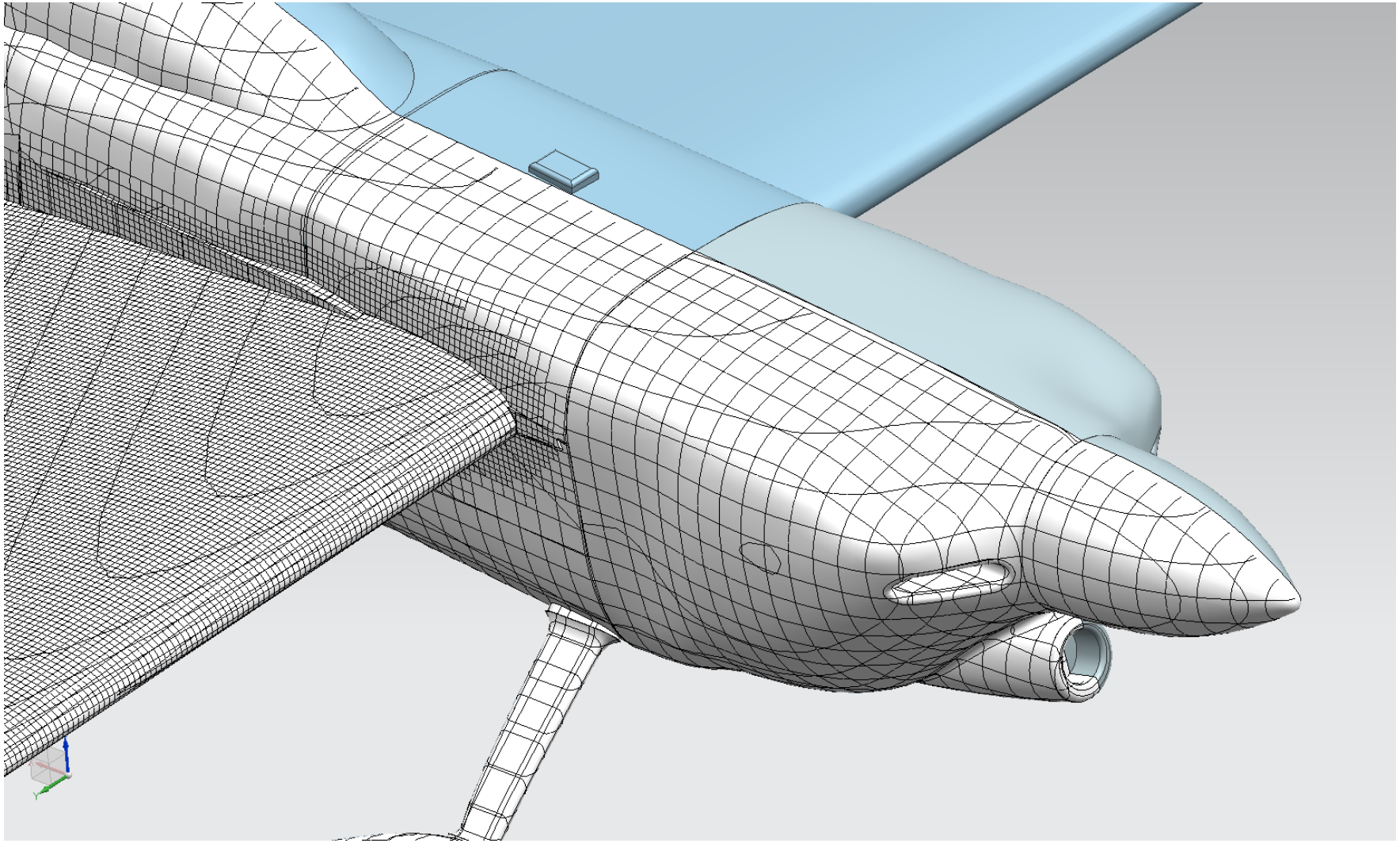

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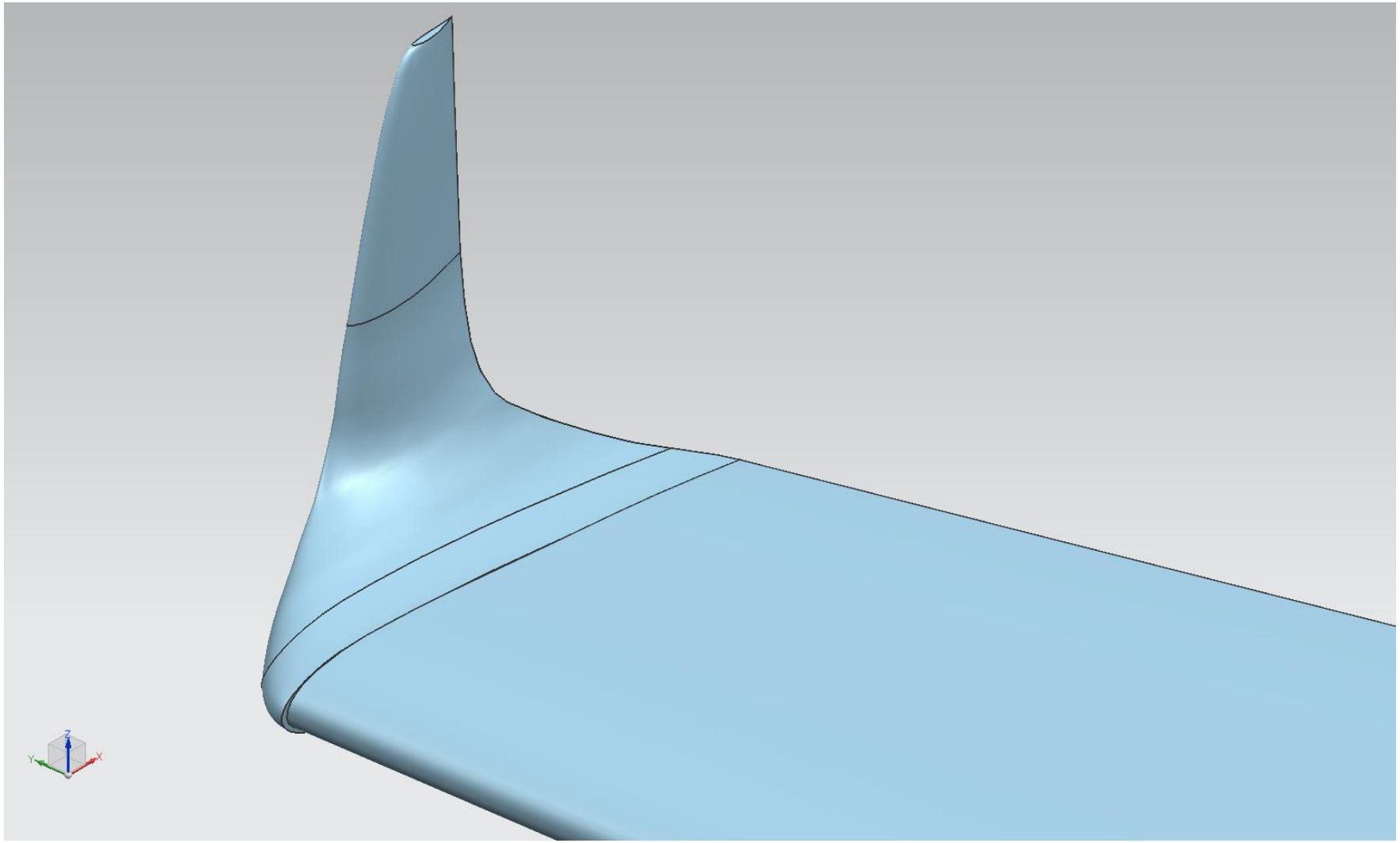

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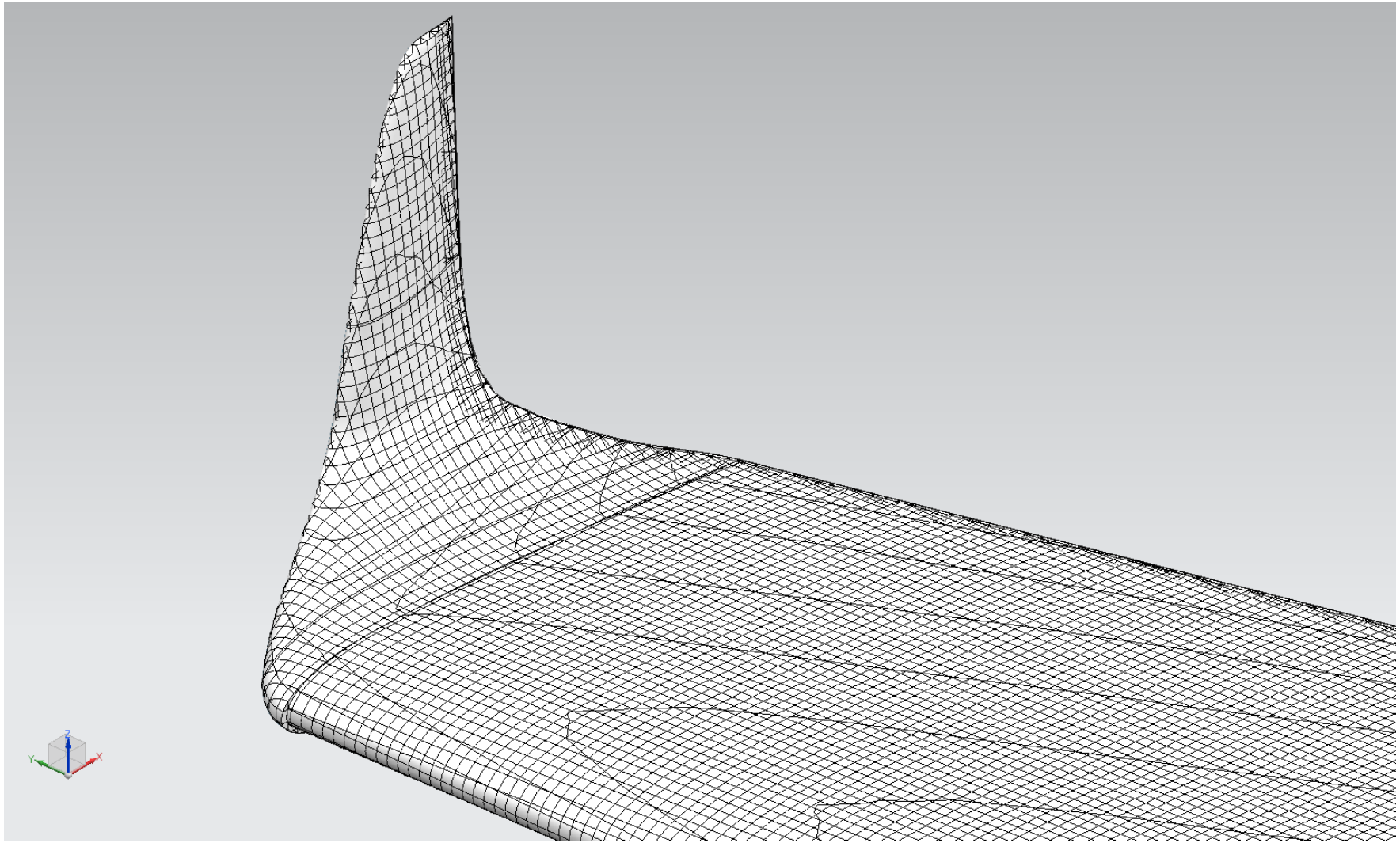
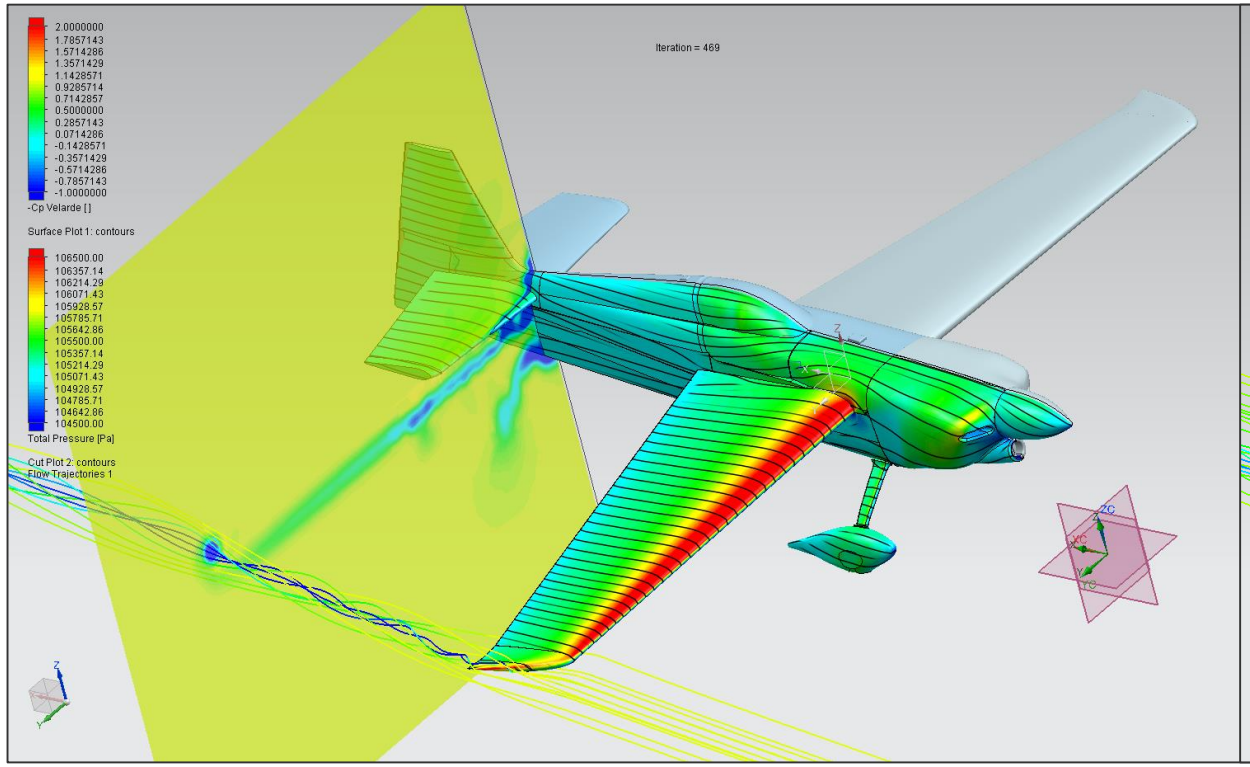
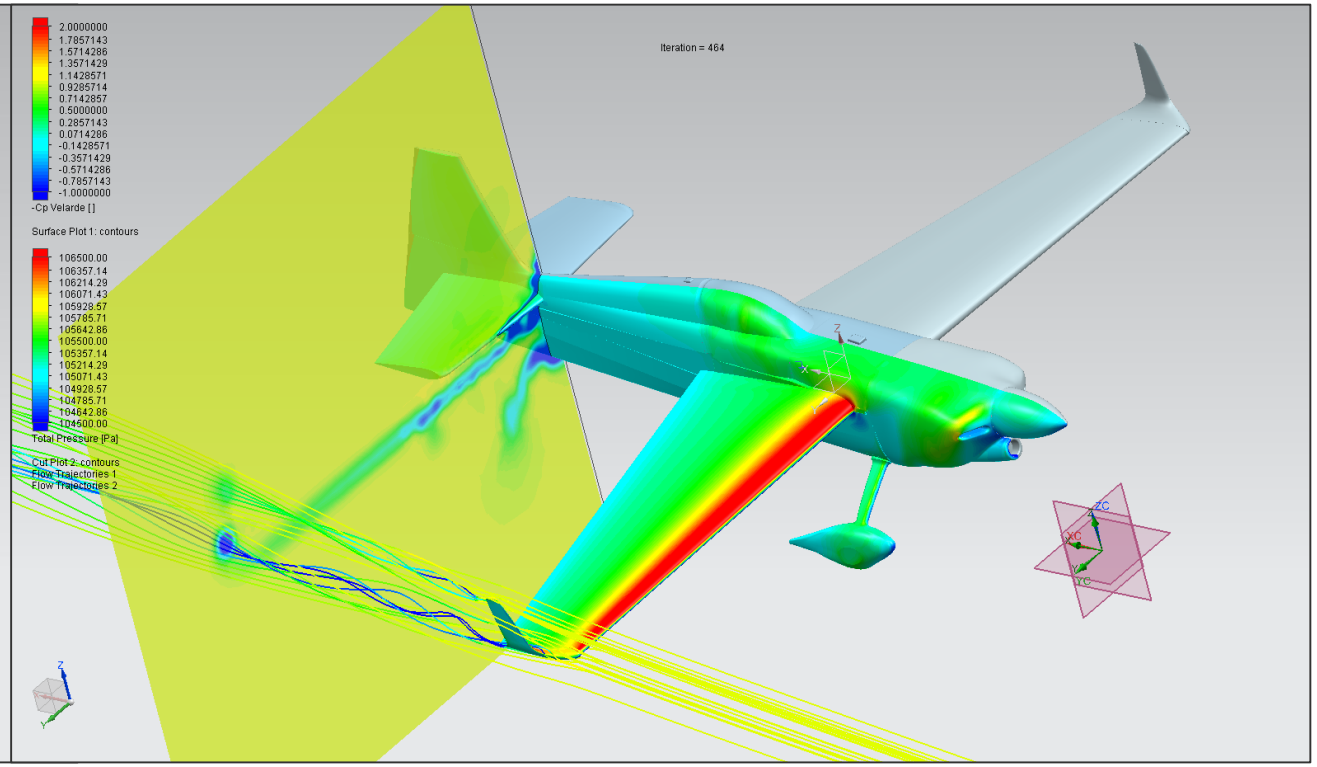


Initial Results: wingtip vs. winglet

- First batch of simulations in January 2017 revealed notable differences in the flow topology between the wingtip compared with the winglet
- ***This was all done in 1 week, and completed before the first race of the season!***



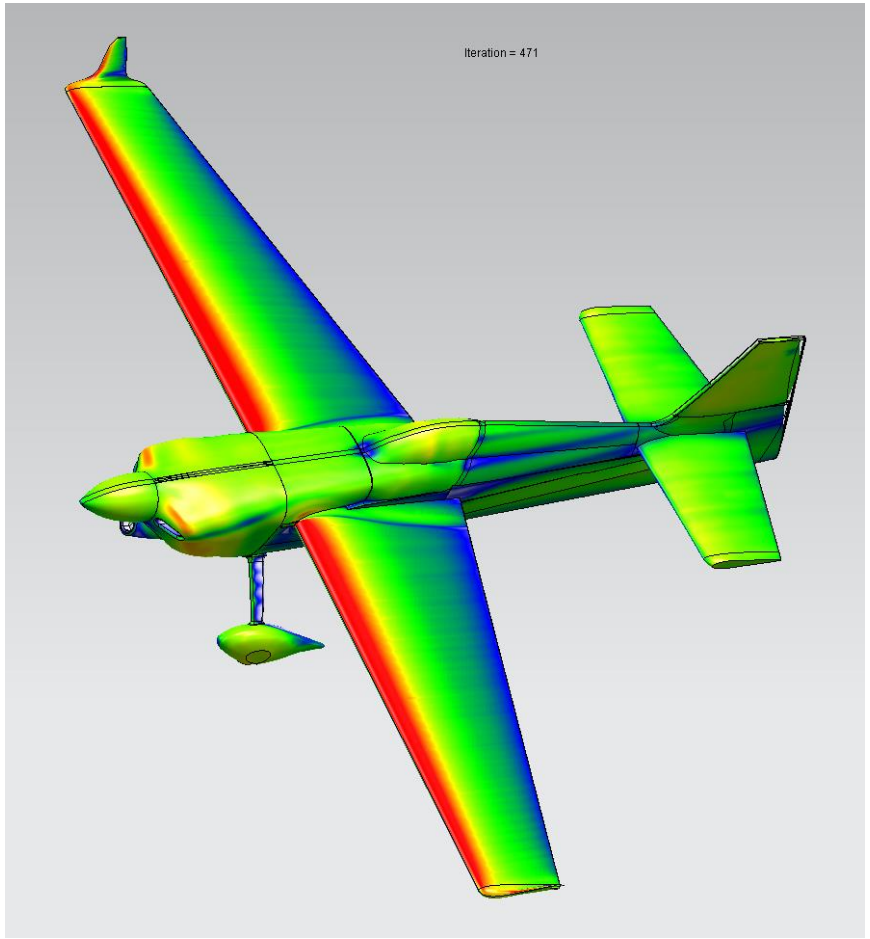


CFD 2017: The FloEFD Experience

- CFD ~1998~2008: Lots of time spent making CFD work; Not enough time spent thinking about aerodynamics!

- CFD 2017: The FloEFD Experience
  - Meshing is something you setup once and then quickly forget about!
  - No solver failures – FloEFD just works

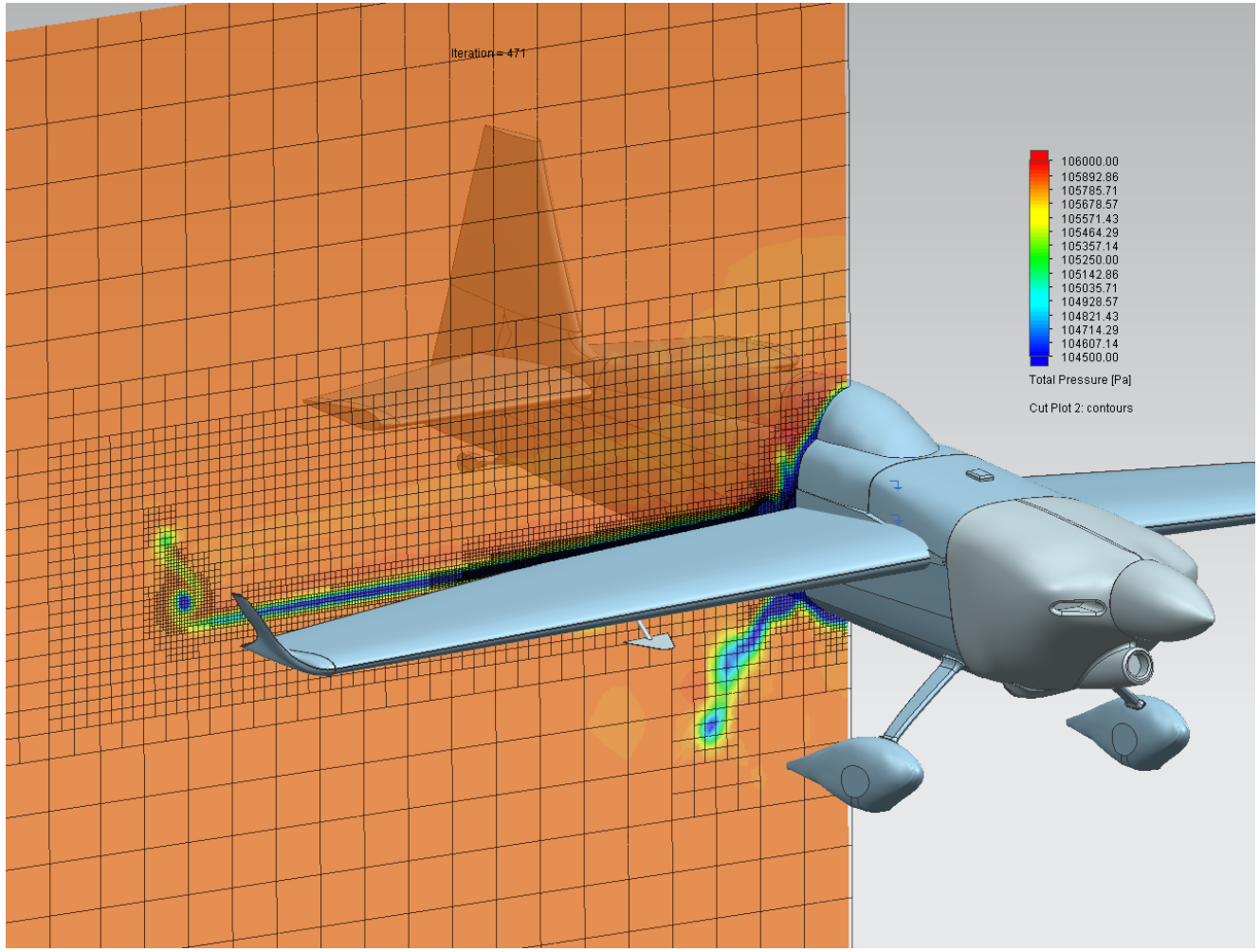
- **Result: In 2017 with FloEFD, CFD just happens → more time to think about aerodynamics!**



Matt’s Tips for External Aero with FloEFD

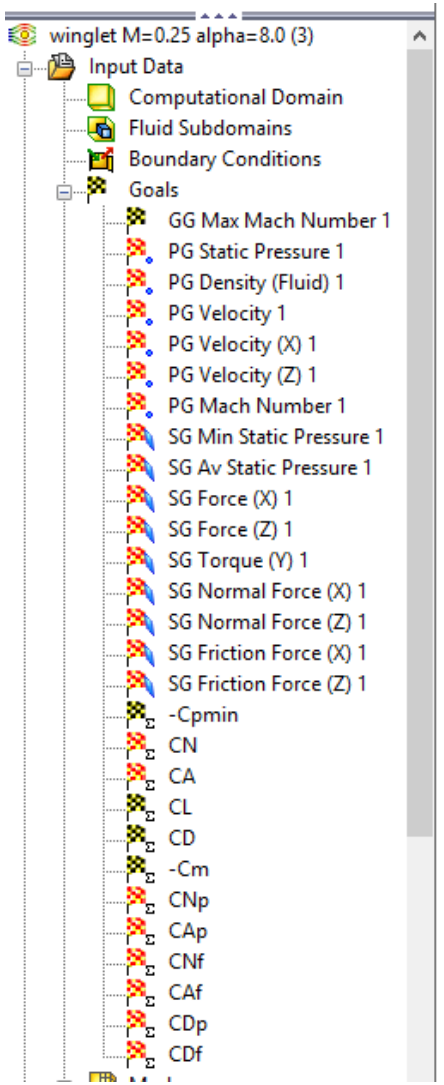
Solution Adaptive Refinement

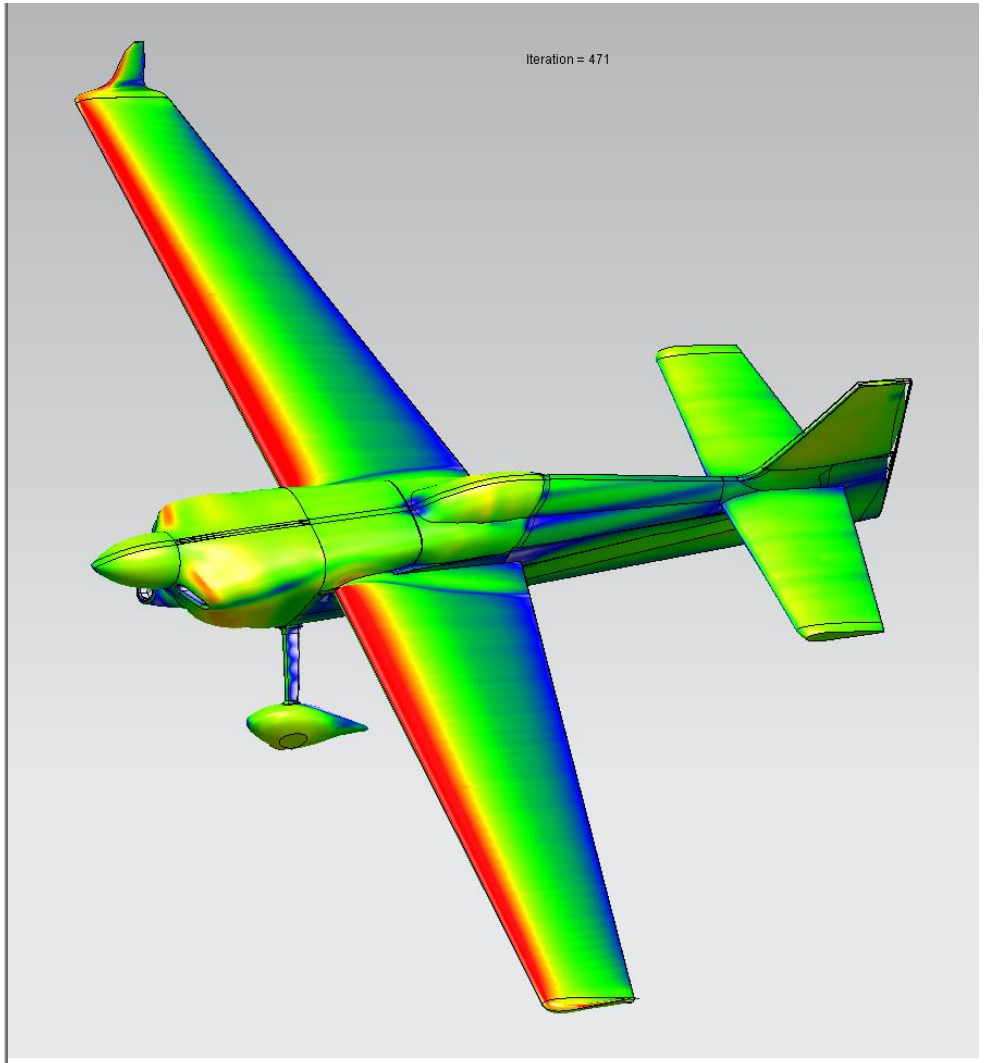
- SAR is essential to get accurate results for aerodynamics
  - ***Must start with a high level of mesh refinement!!!***
  - Otherwise you waste time modelling the "wrong" flow
- Start with Local Initial Mesh:
  - Cuboid/Cylinder/Sphere regions
  - Equidistant refinement
- Use "Calculation Control Options → Refinement" to control refinement in different areas, e.g.
  - More refinement on wings, less on the fuselage
  - Avoid excessive refinement in the wake



Goals

- Lots of goals are needed!!!
  - This ensures the solution is sufficiently converged
- Most are not actually used for convergence
  - Instead they are used to derive equation goals for the quantities we are really interested in
- Do it this way so the numbers we get from FloEFD are exactly what we need to know
  - Little or no further work is required in Excel
- But set convergence tolerances manually
  - Usually the automatic values are OK but for external aerodynamics we need tighter tolerances
  - Also need same tolerance for all flight conditions



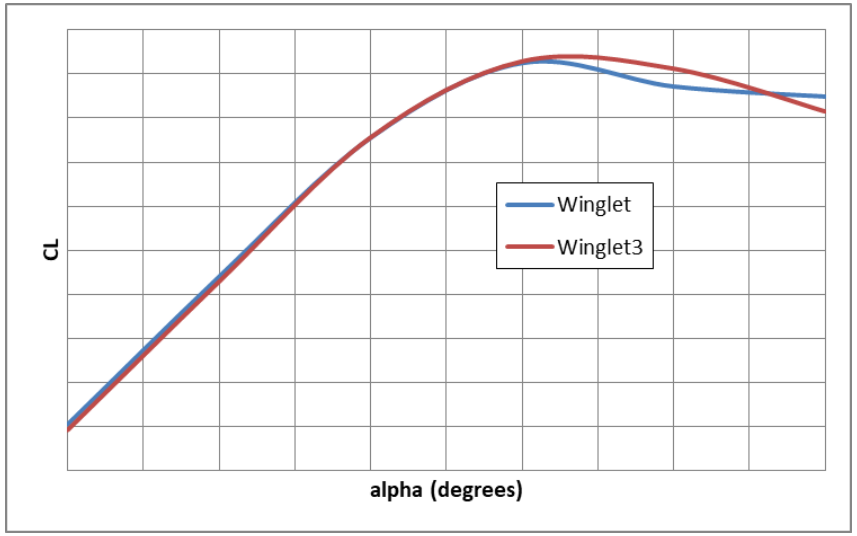


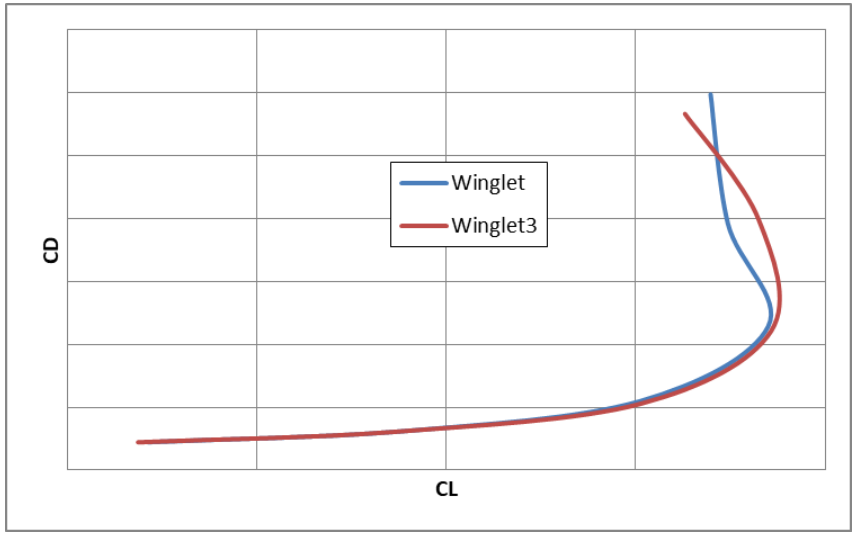
Data Reduction

- Visual results can look cool, but ultimately it is the numerical results that are most important
  - We don't need to see graphical results for every case
  - Instead, unusual numerical results tell us which cases to inspect visually

FloEFD has lots of built-in tools to get the data you need, quickly and easily

- Use "Batch Results Processing" to output numerical results automatically
  - Then use Excel spreadsheet to collate the results for all flight conditions
- Alternatively use FloEFD's built-in "Compare" tool to summarise results, then export to Excel
- You can also use the "Parametric Study" to run lots of different flight conditions and export to Excel at the end

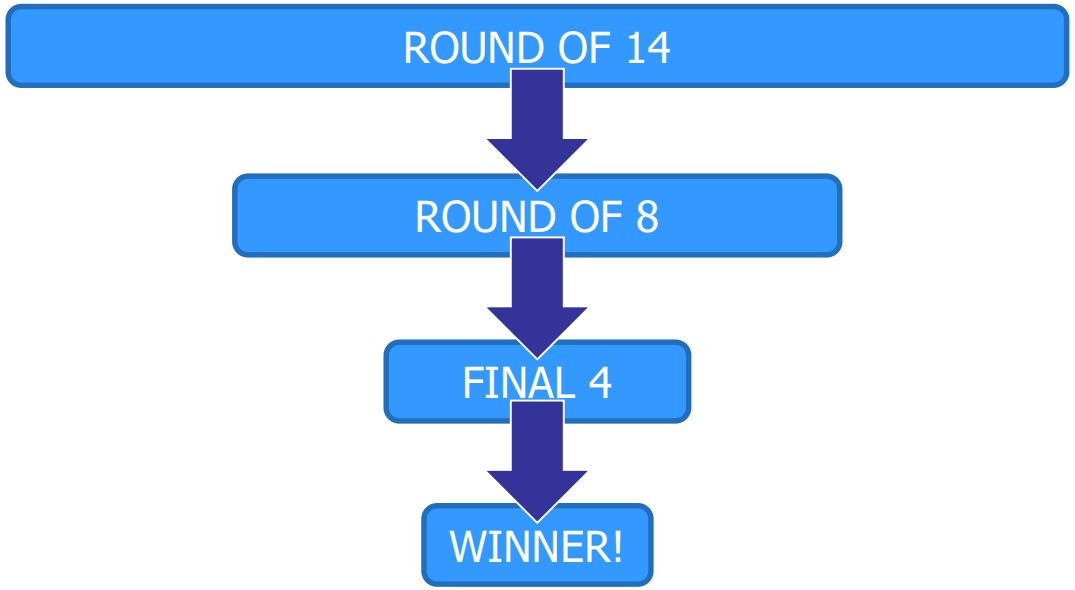




Red Bull Air Race Project

Red Bull Air Race Format

- Not a race like Formula 1 or MotoGP
- More like a knock-out tournament e.g. tennis
- Race Day Schedule:

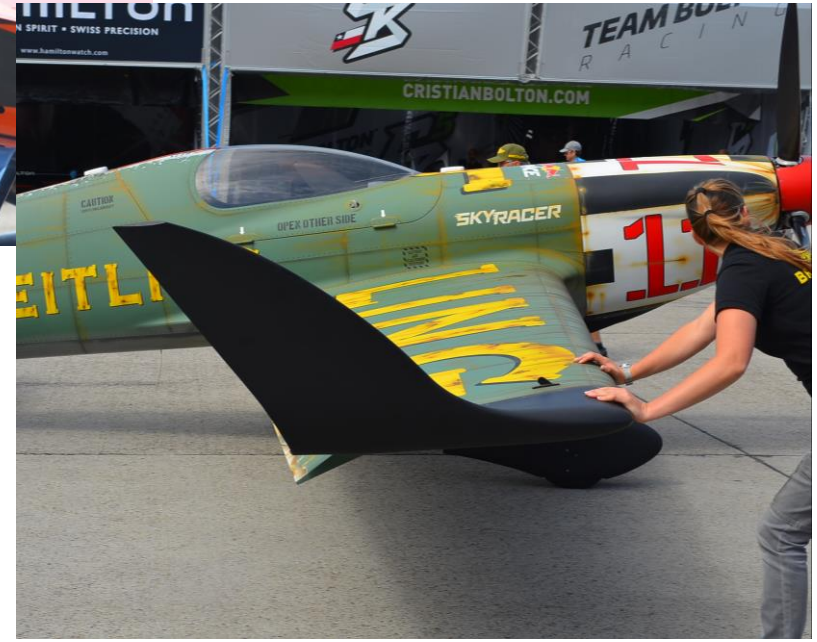


- Most of the time you only have to beat the other guy
  - So even 0.1s or 0.2s can make a ***huge*** difference!

Rules

- Almost all competitors use the same aircraft (Zivko Edge 540)
- All aircraft use the same engine
- Not allowed to modify the engine or propeller
- Otherwise, lots of freedom to change the shape…

Rules



Rules

Rules

Basic Aerodynamics & Winglets

- Classical aerodynamic theory doesn't work so well for novel, stealthy, unmanned aircraft
- But it's still pretty useful for more conventionally shaped race planes!
- Drag is a function of lift, Aspect Ratio (AR) and fudge factor, *e* :

$$C_D = C_{D_{0L}} + \frac{C_L^2}{\pi AR\, e}$$

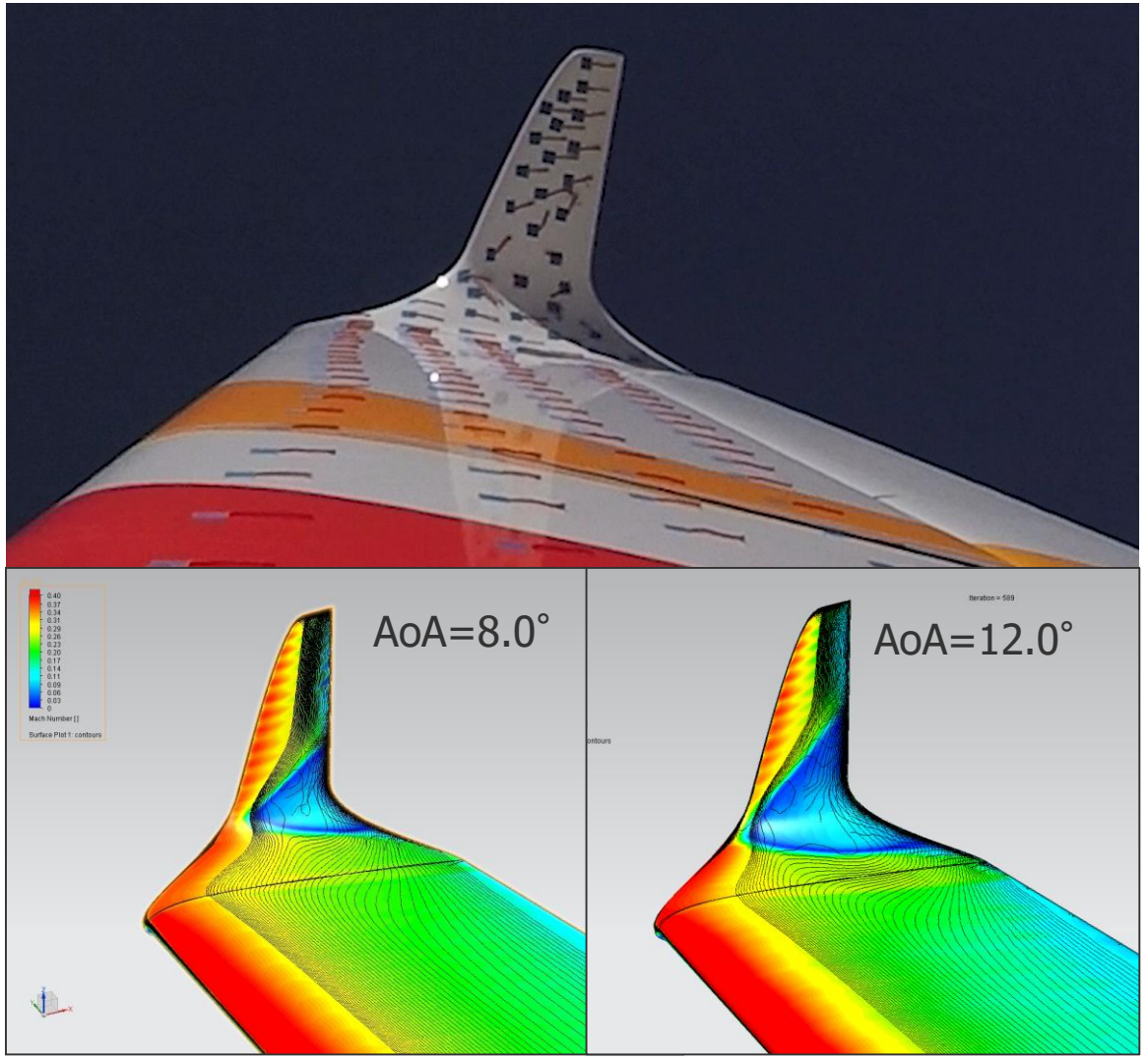
$$\mathrm{AR} = b^2/S = \mathrm{span}^2/\mathrm{area}$$

- Winglets and wingtips work by increasing aspect ratio, and hence reducing the induced drag term

Winglet Optimisation

Winglet Optimisation

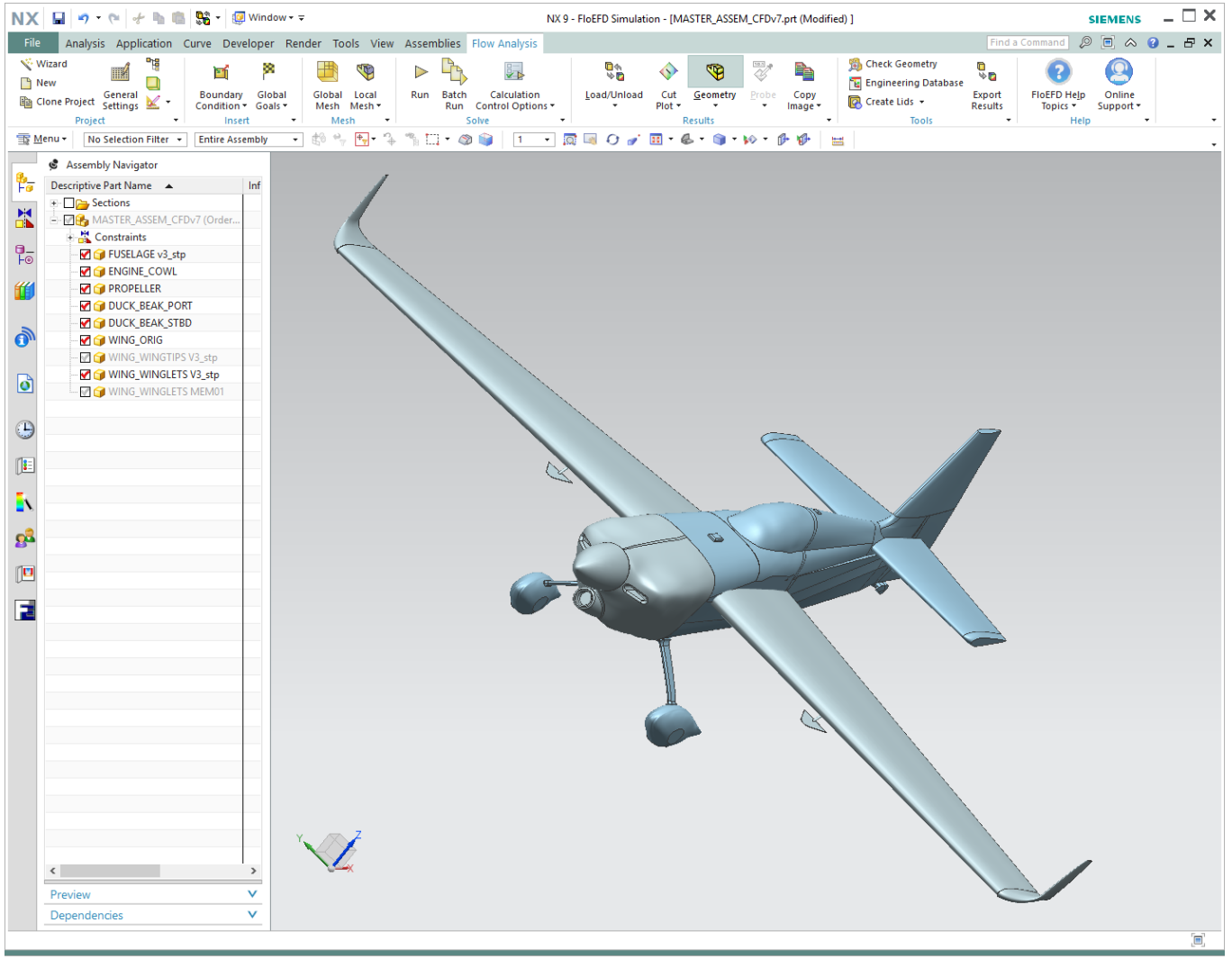
- Early CFD suggested there was an unusual flow separation on the winglet
- But how do we know if this is really correct?
- Subsequent flight tests using flow visualisation tufts seem to indicate similar flow patterns
- Remember - most of the time you only have to beat the other guy
  - 0.1s or 0.2s can make a huge difference!
  - The winglet was an obvious area for redesign and optimisation



Winglet Optimisation

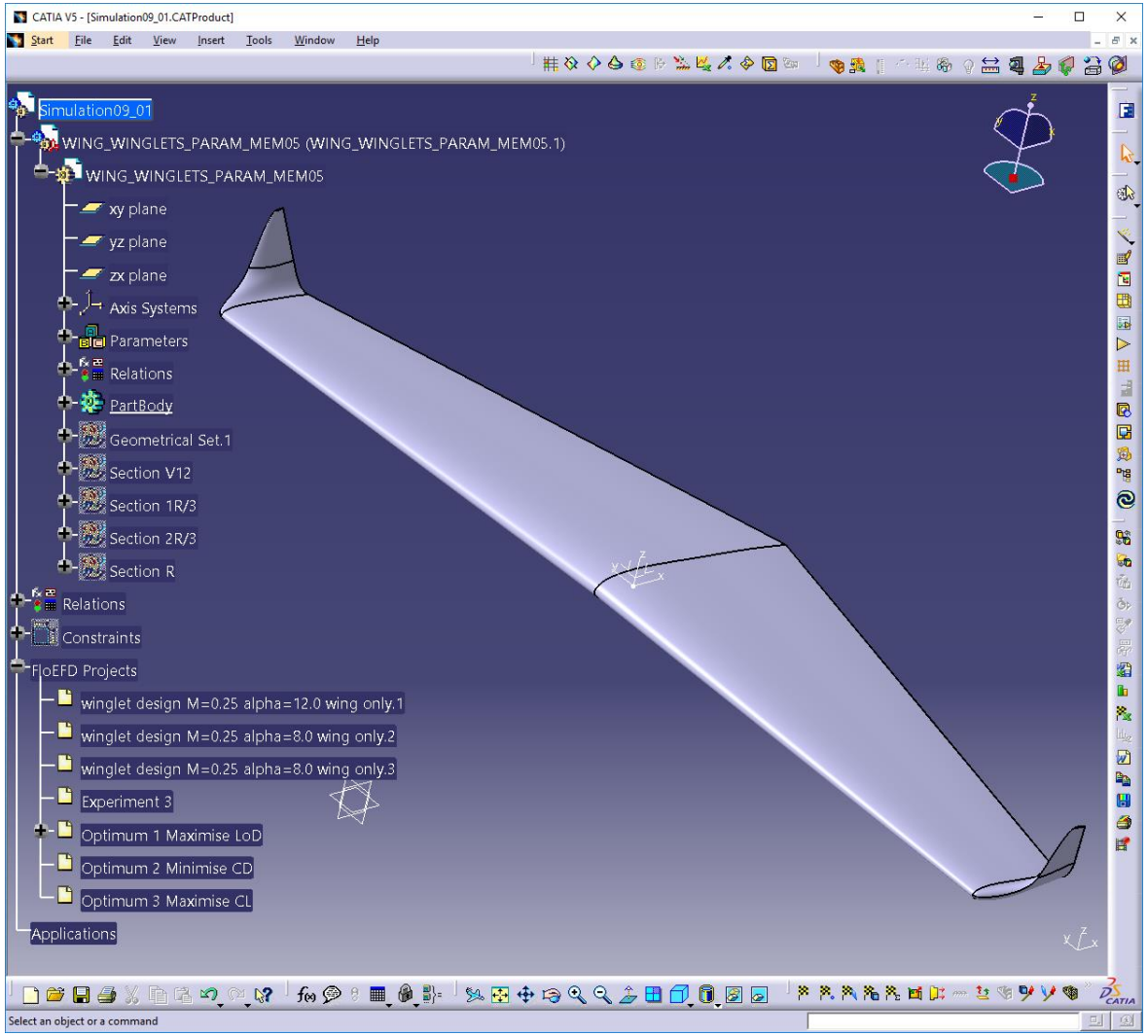
1st Choice of CAD – Siemens NX

- CAD was provided in neutral STEP format so choice of CAD system was arbitrary
- Timescale of this project coincided with Siemens acquisition so decided to use Siemens NX
  - A good opportunity to develop my skills with NX!



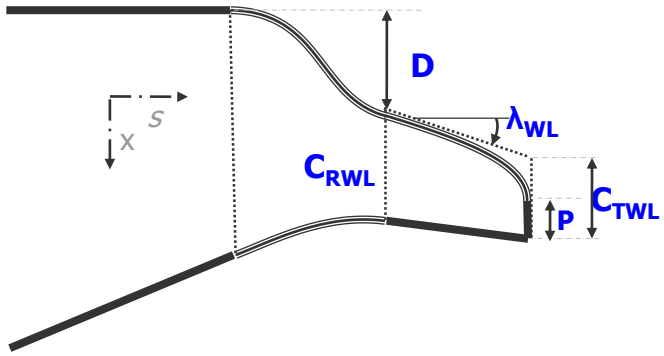
2nd Choice of CAD – Catia V5

- Ideally would have completed all work in NX
  - But I have more experience of parametric design in Catia V5
- To save time, all the parametric design work was done using FloEFD for Catia V5
- Modelled wing-only in Catia (i.e. no fuselage or tail etc)
  - Simplified model
  - => less mesh
  - => shorter run times
  - New designs were verified on full aircraft model using FloEFD for NX

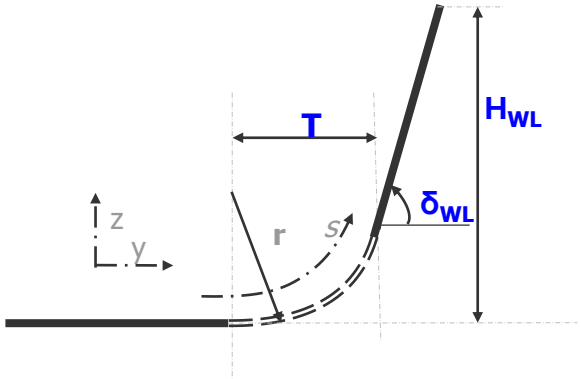


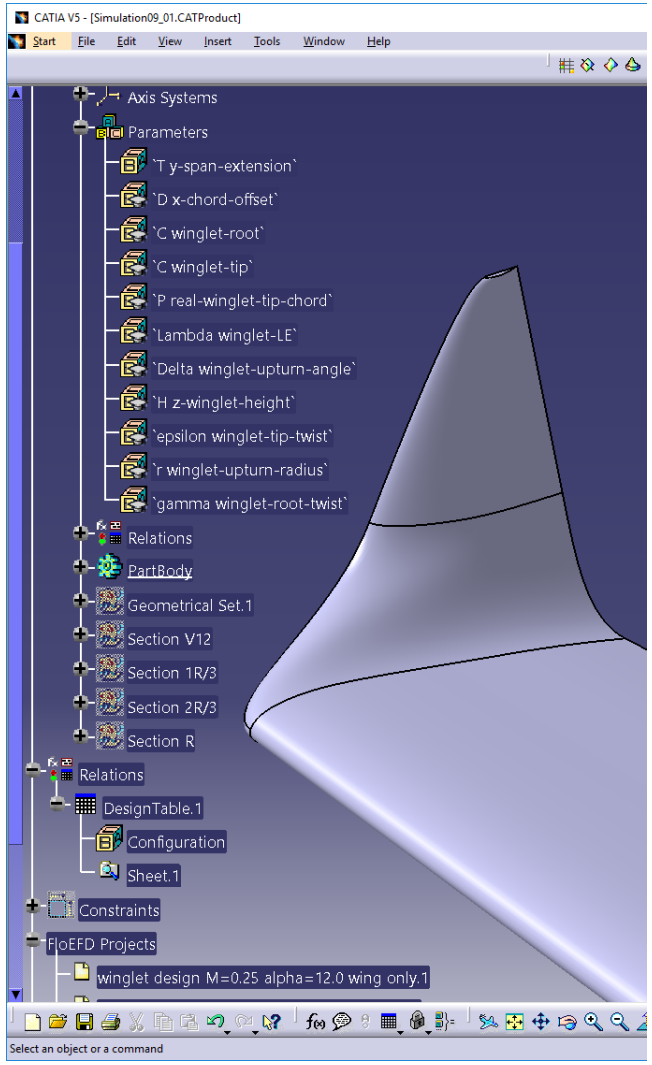
Winglet Optimisation

- Original winglet design/optimisation was done by Composite Works in Spain

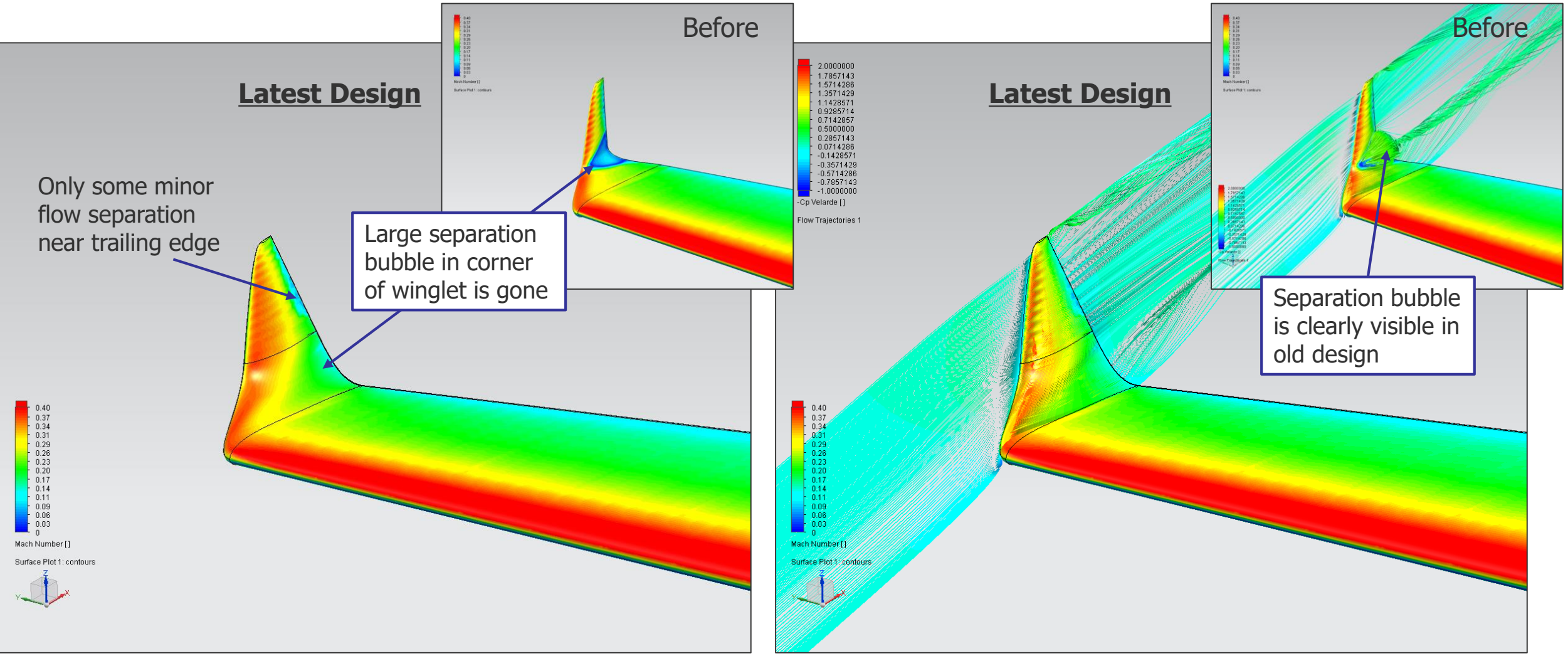


- Parametric model of winglet was rebuilt in Catia V5 using same parametric definition
  - Visual inspection confirmed that it closely matched the original shape

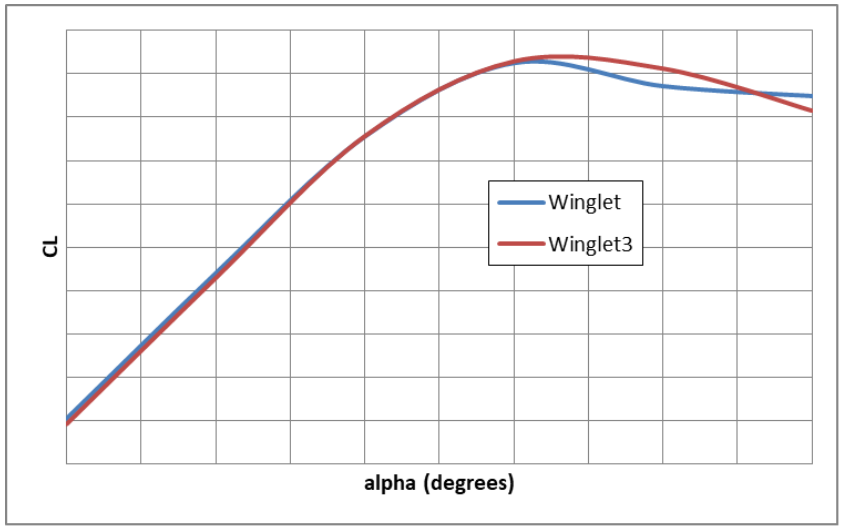


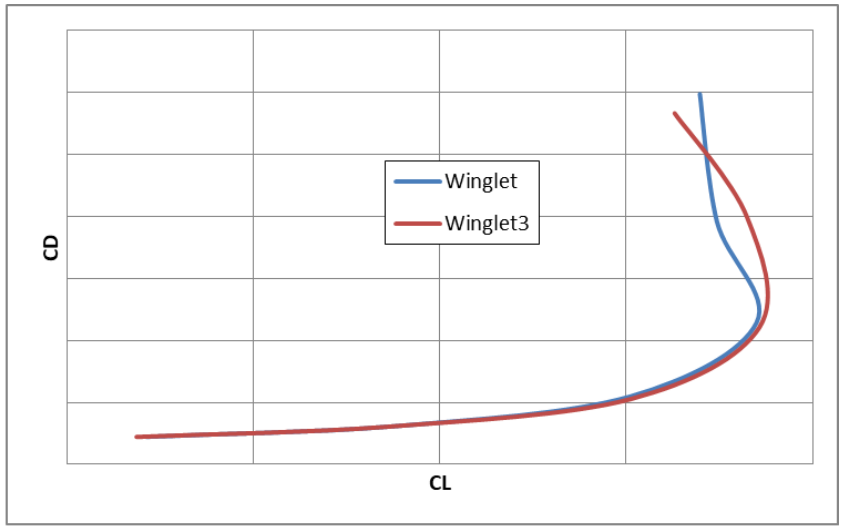


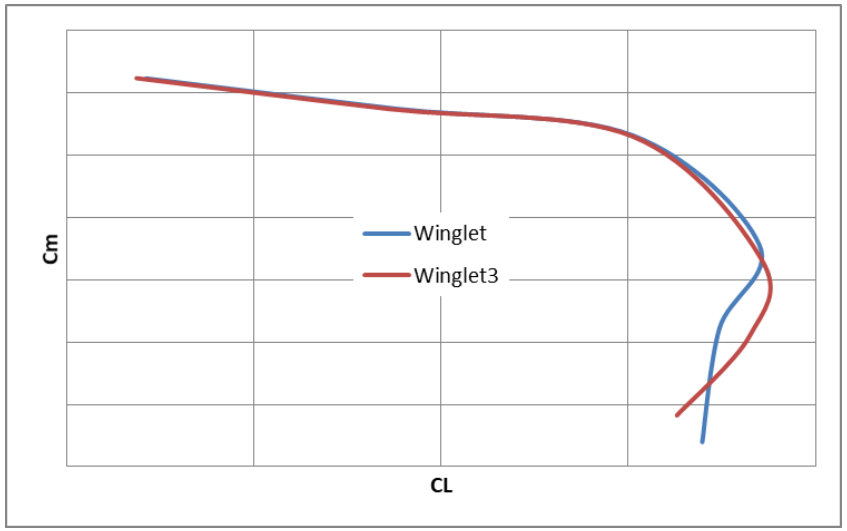
Winglet Optimisation (Maximise L/D @ M=0.25, α=8.0°)

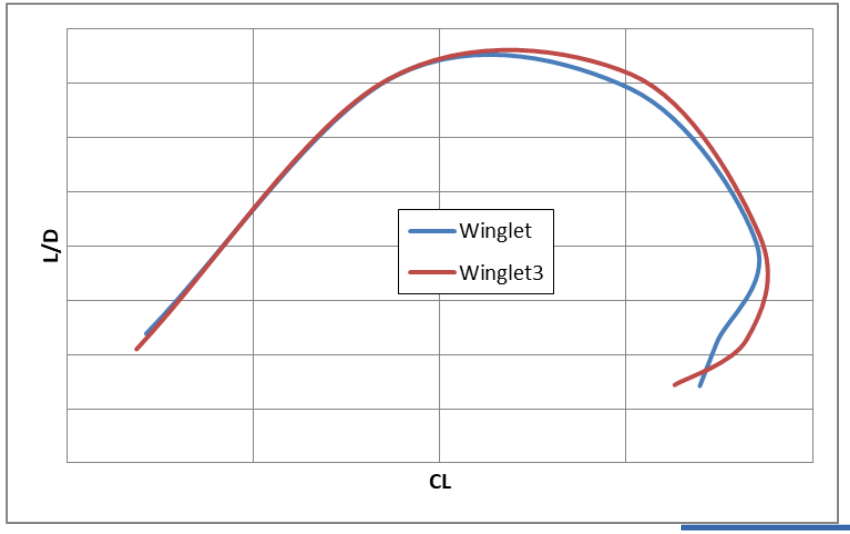


Integrated Forces & Moments









Summary

- L/D is improved around C_L=1.5 (i.e. $\alpha \approx 8.0^\circ$)
- L/D not really affected at lower C_L
- Not clear from these results how this translates into faster time in a race
  - Is it a significant improvement?
  - E.g. 0.1s or 1.0s reduction in lap time?
- Further increase in L/D possible at this design point
- Alternatively we could look for gains at a different design point

Let’s go to Budapest!

Let's go to Budapest!

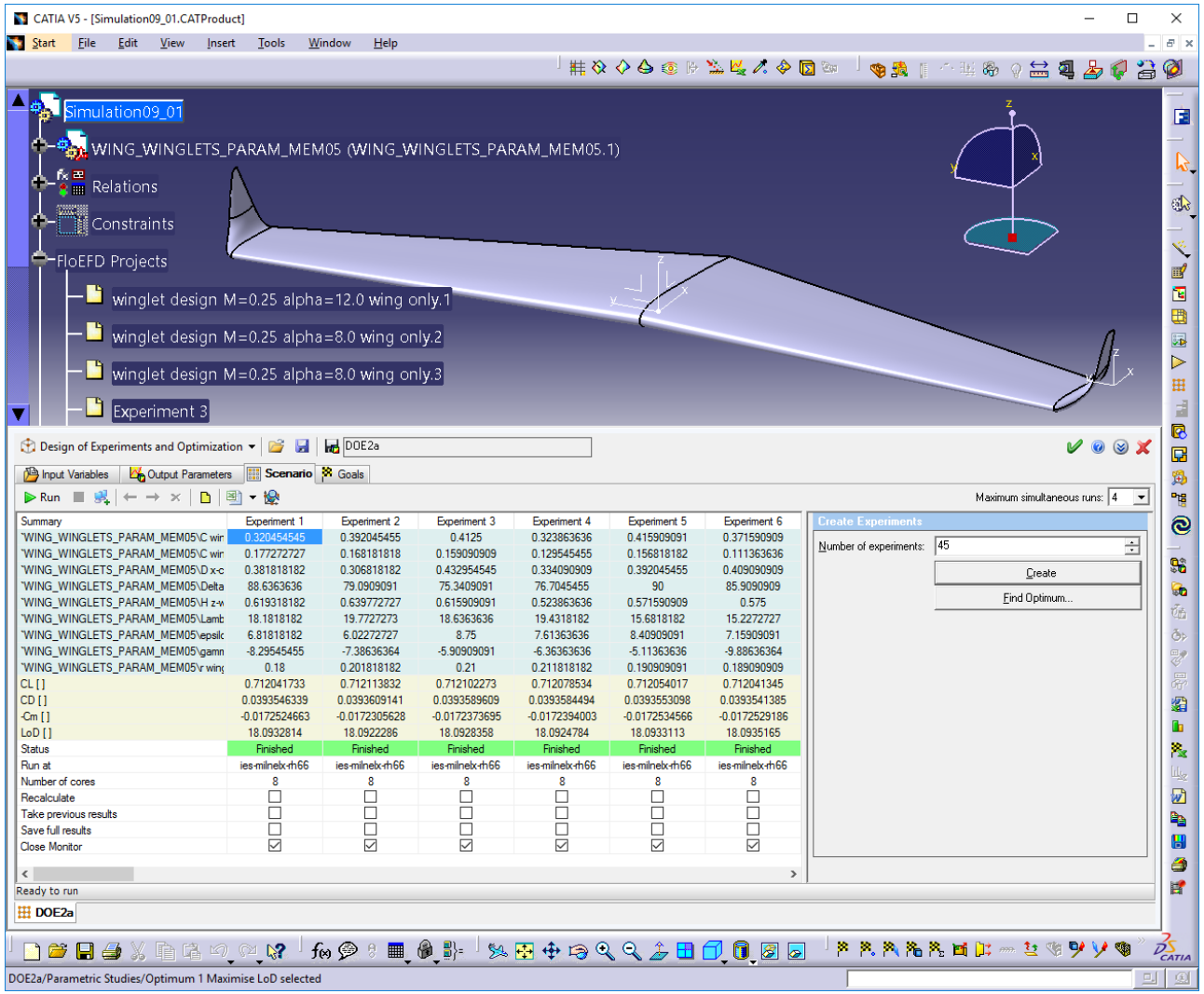
- We arranged to go and visit Team Velarde at the Budapest air race (July 2017)
- Very exciting!
- But also a good change to talk to everyone in the team, understand more about the challenges

DOE & RSM

DOE/RSM

- Design of Experiments & Response Surface Modelling was essential for optimisation studies

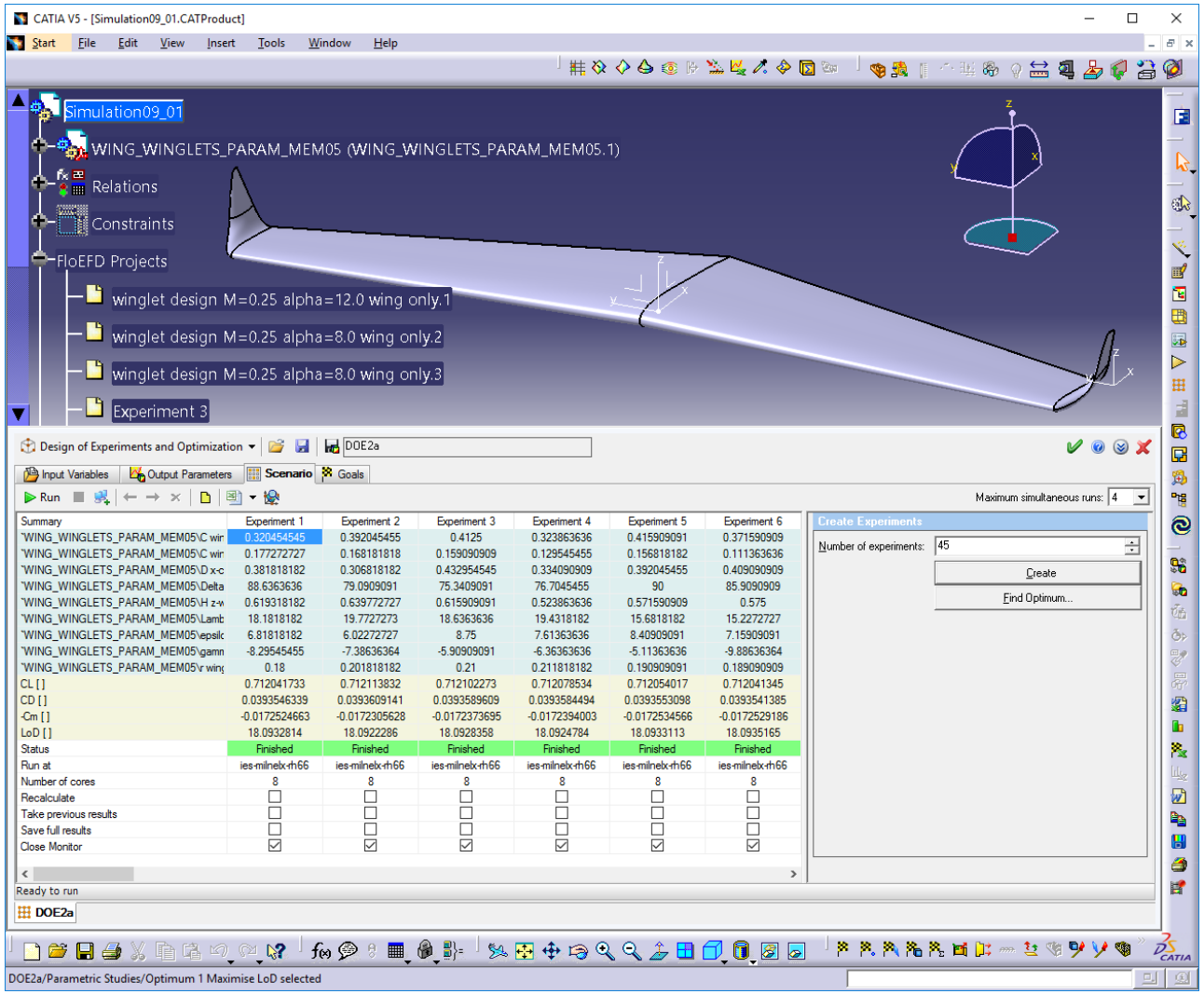
- DOE works by creating a number of "Experiments" within the user specified parameter ranges
  - By default, for N parameters it will do 5N experiments
  - Solve these points then fit an N-dimensional surface through them and find the "optimum"
  - Finally, solve the optimum point to verify it is accurate
  - Run more experiments to improve accuracy of optimum if required



DOE/RSM

- I would estimate using parametric study alone would require at least 5-10x more calculations
  - DOE is computationally much more efficient and can find the optimum design automatically

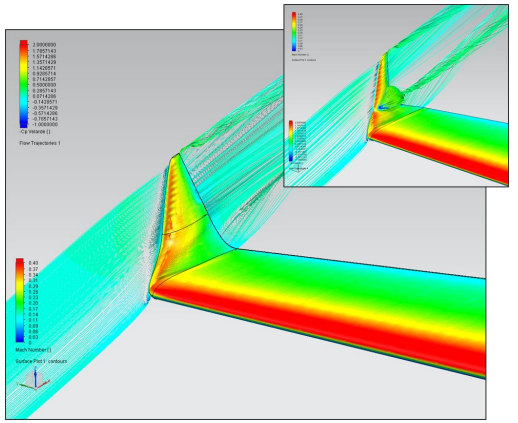
- DOE in FloEFD for Catia V5 is generally pretty robust
  - Some points still occasionally fail to run
  - Failures mainly associated with remote Linux workstation, but also sometimes caused by parametric model not correctly generated (i.e. bad geometry)

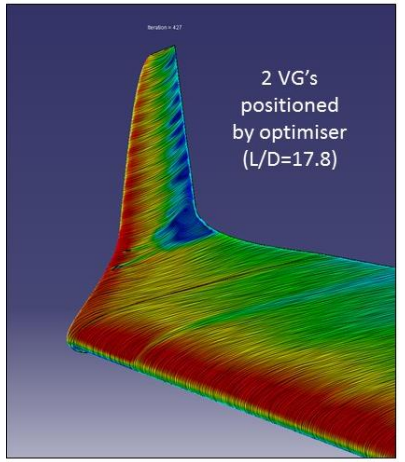


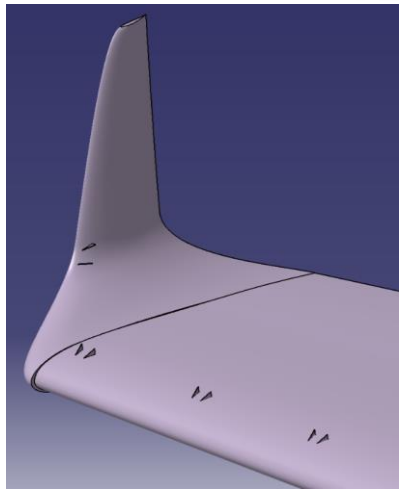
Is it faster?

Is it faster?

- We have already seen that we can change the design…..
  - New winglet, Vortex Generators, etc etc etc
  - Some changes may be low cost, others may be expensive
- We can use FloEFD to predict how this affects aerodynamics…..
  - C_L, C_D, L/D Ratio etc etc etc
- But what does this mean for times during the race?
  - 1.0s? 0.1s? 0.01s?
- We need a way to estimate how changes in C_L, C_D etc affect race times…..
- Then we can make a clearer decision of cost vs. benefit…..







Design Changes & Race Times

- Developed a simple 1D mathematical model to predict change in race time due to improvements found with CFD

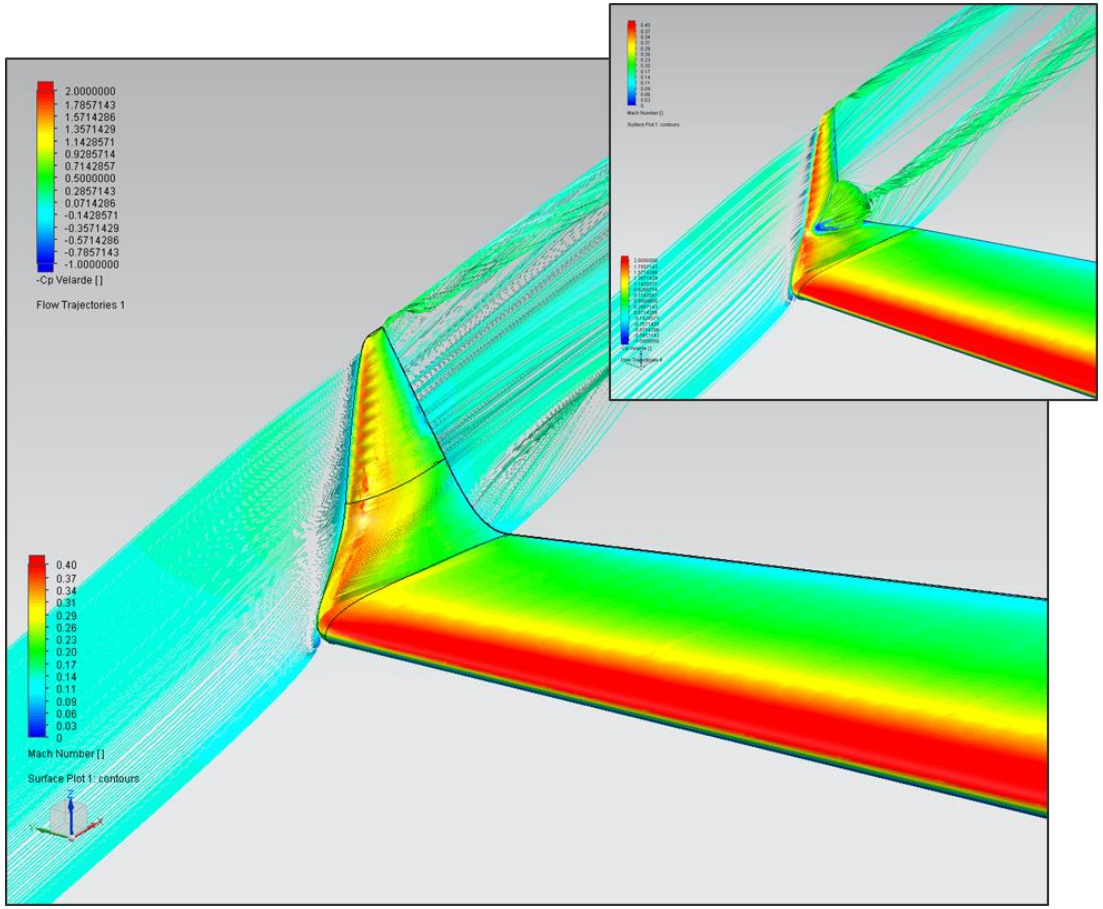
- Uses recorded flight data combined with simply physics:
  - Newton's 2nd law of motion
  - Equations of linear acceleration

Design Changes & Race Times

- Predicted race times for Rounds 1 to 5:
  - Existing Winglet vs. Matt's Proposed New Winglet

Winglet vs. Matt's Proposed New Winglet			
	Time (s)		
	Winglet	New	diff (s)
R1-AbuDhabi R2-SanDiego R3-Chiba R4-Budapest R5-Kazan	***On average ≈0.4s faster!!!***		

- So there could be a significant improvement with a new winglet – ***in theory!***



Summary

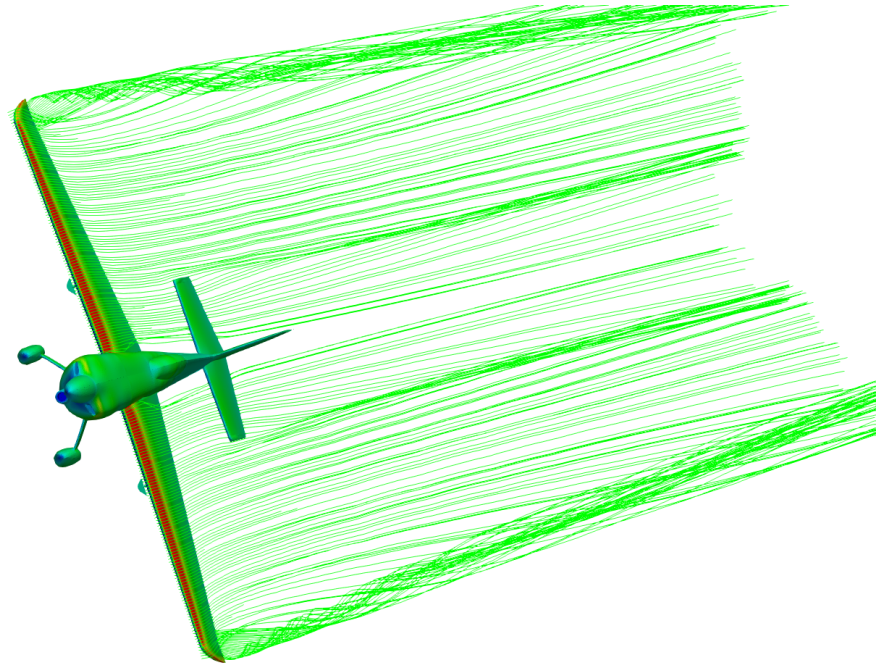
Conclusions

CFD around 2000 was a painful and laborious process:

- Required a lot of time and expertise to get reliable and consistent results

The situation in 2017 is very different:

- Using FloEFD, CFD can now be just another part of the design process
- What used to take 1-2 months can now be done in 1 week
- FloEFD has liberated engineers
- Instead of wasting time making CFD work we can now use our expertise and experience to improve our designs



What next with Team Velarde?

- Results this season include 2nd, 5th, 4th and 3rd place finishes
  - 8th place in the championship (only 2 points behind the 2016 champion!)
  - Congratulations to Juan and the team on this fantastic achievement!
  - A win is not so far away!
- Aerodynamic improvements are possible, as demonstrated using FloEFD
  - Only scratching the surface so far…..
  - Further improvements to winglets are probably possible
  - Other components can also be considered
- **We hope to continue our relationship with Team Velarde in the future!**

Thanks for your attention

Questions?

(or coffee break – it’s up to you ☺)