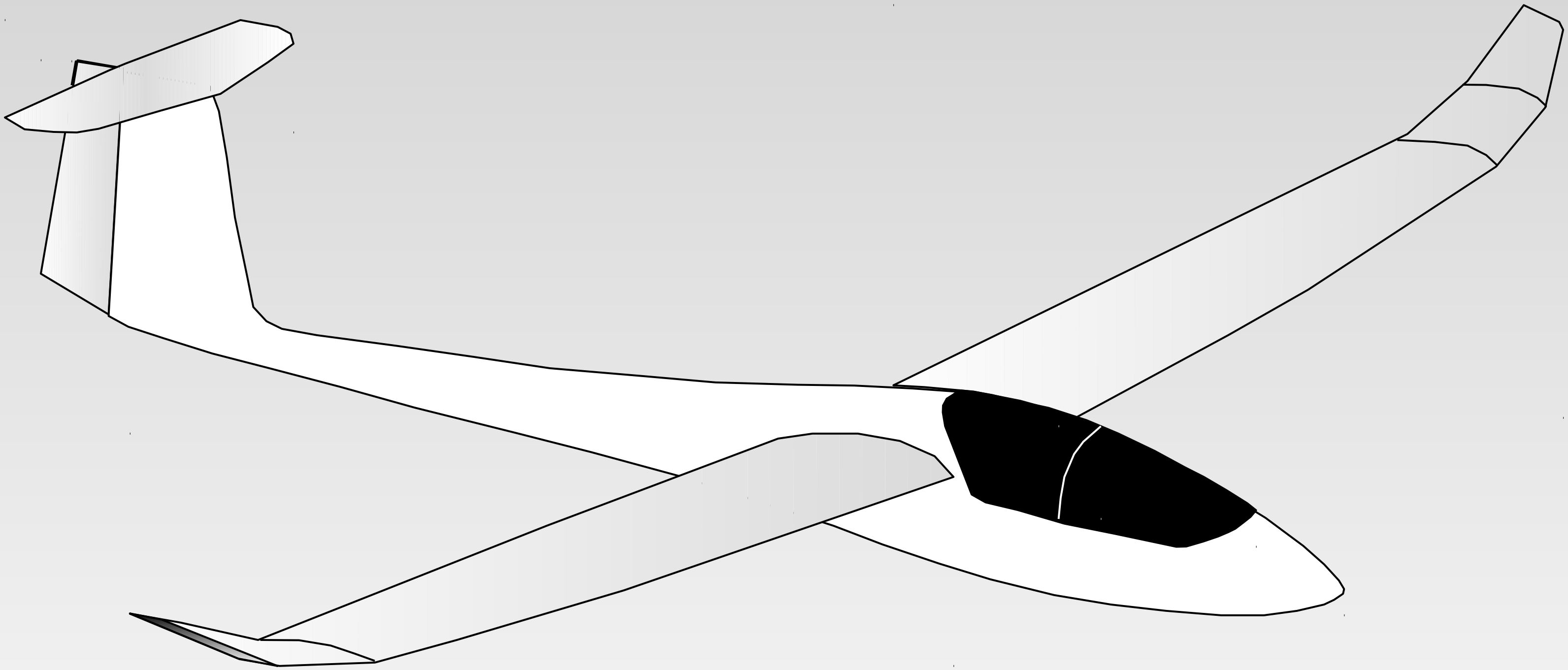
F.A.Q : Why do I get the message "Point is out of the flight envelope ?"



About viscosity

- The error message is indirectly a consequence of the fluid's viscosity, so that's a good point to start

- The air in which the plane flies is viscous ; its viscosity is characterized by
  - The dynamic (absolute) viscosity : μ [kg/m/s]
  - or by the kinematic viscosity : ν [m^2/s] or [centistokes]

- Both constants are linked by : $\mu = \rho.\nu$

  where ρ is the fluid's density [kg/m^3]

The Reynolds Number in general

$$Re = \frac{CV}{\nu}$$

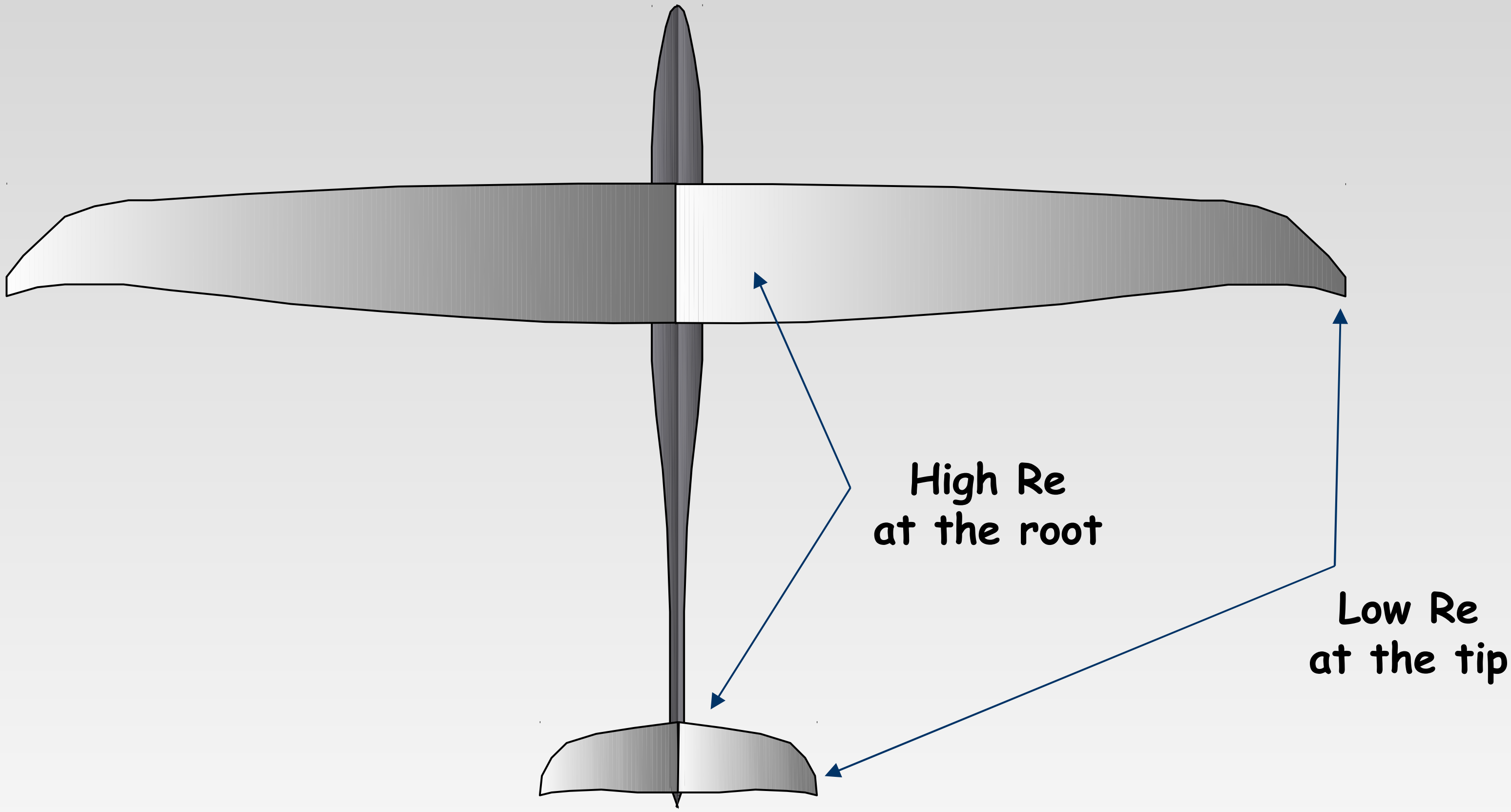
- With C being a reference length
- V is the fluid's freestream speed
- ν is the fluid's kinematic viscosity

The Reynolds Number **Re** :

- is a dimensionless coefficient
- is a measure of the ratio of inertia forces to viscous forces : the greater the speed, the lower the impact of viscous forces

The Reynolds model applied to an aircraft

- The usual reference length C is the local chord
- Hence, the Re Number depends on the span location



Induced drag and viscous drag

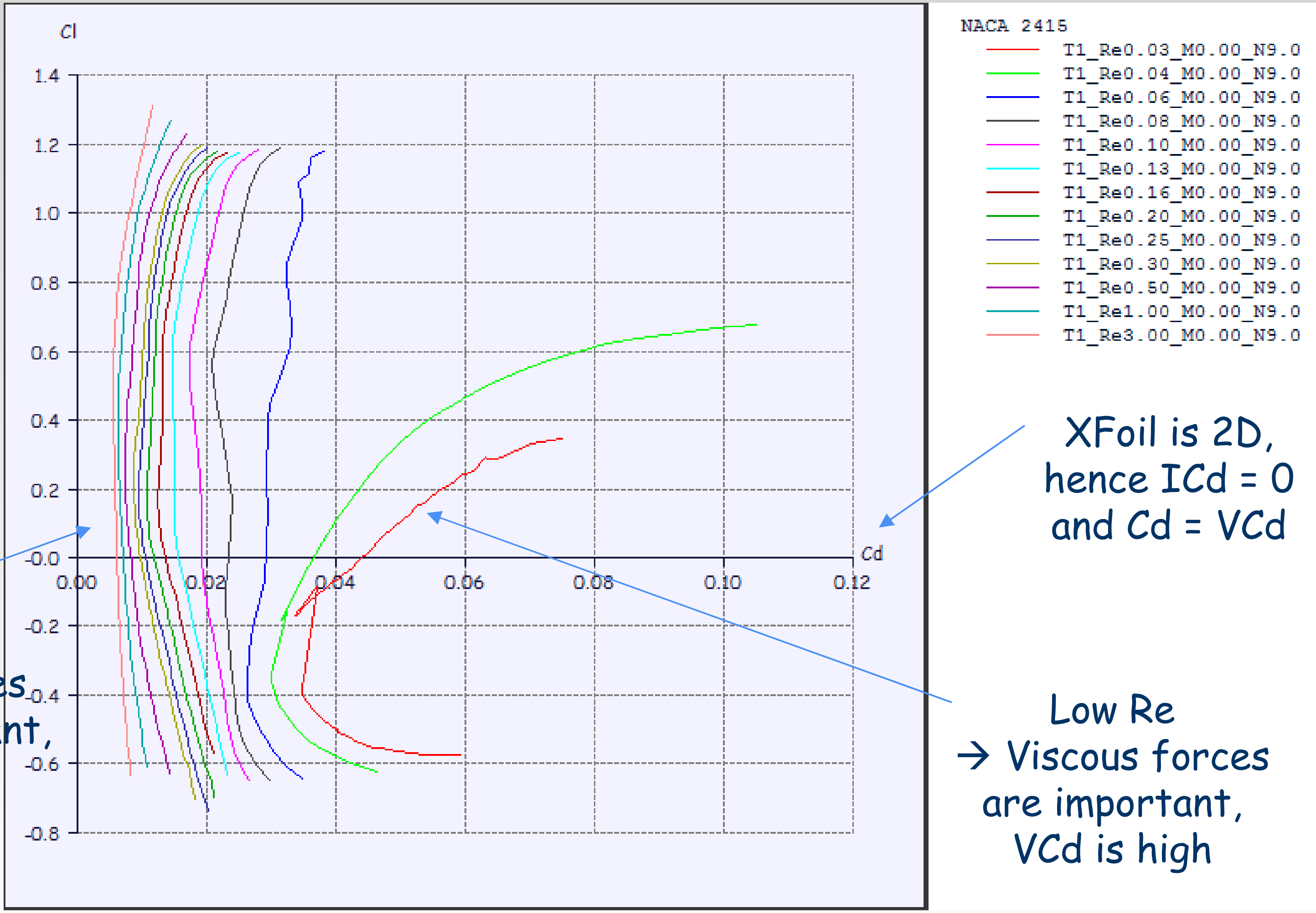
- The induced drag is related to the kinematic energy given by the plane to the fluid, and depends on the plane's speed : Induced Drag = $\frac{1}{2}$ ρ S V^2 ICd
  - ICd does not depend on the plane's speed

- As can be guessed, the viscous drag is a result of the fluid's viscosity : Viscous Drag = $\frac{1}{2}$ ρ S V^2 VCd
  - VCd depends on the plane's speed, and therefore on the Reynolds Number

We illustrate this graphically in the next slide

The viscous drag coefficient VCd

- It would be easier if VCd did not depend on Re, like ICd, but that is not the case. It can be seen by running a batch analysis with XFoil



High Re,
→ Inertia forces are more important,
VCd is low

XFoil is 2D,
hence ICd = 0
and Cd = VCd

Low Re
→ Viscous forces are important,
VCd is high

Viscous and non-viscous behaviour

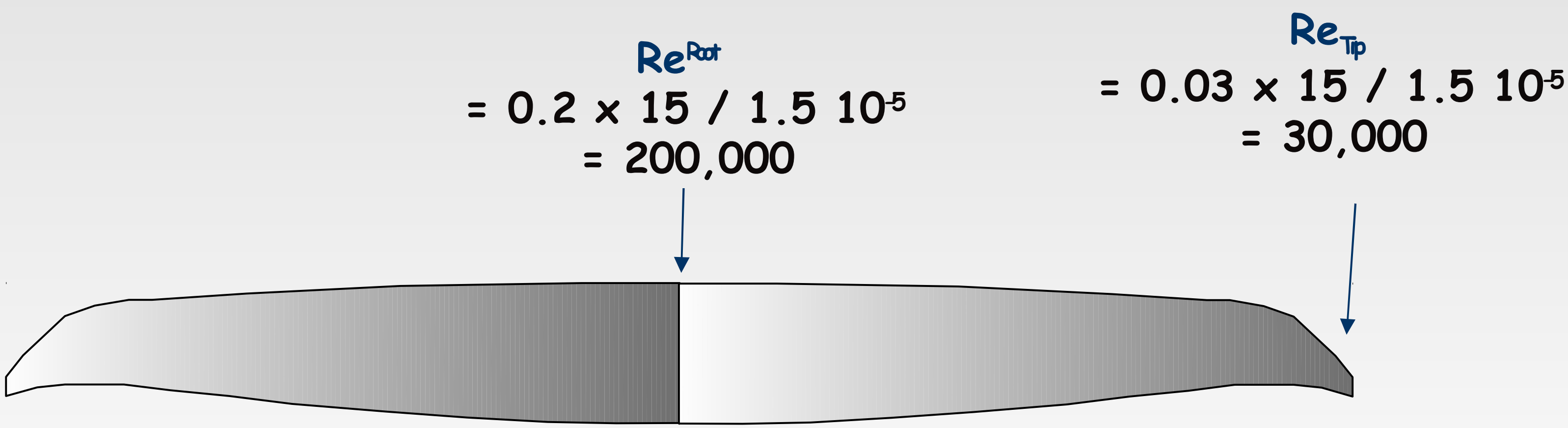
- The classic (linear) LLT, the VLM, and the 3D panel methods are derived from non-viscous (inviscid) assumptions for the fluid
- Therefore the results from these methods
  - ignore the viscous drag
  - are independent of speed
- Unfortunately, for the size and speed of our model aircraft, the viscous drag cannot be ignored
- Since there is no adequate theory to take into account viscosity in 3D analysis for the Re numbers of our model aircraft, we extrapolate it from 2D

Not really satisfactory,
but is the best we can do ☹

An example

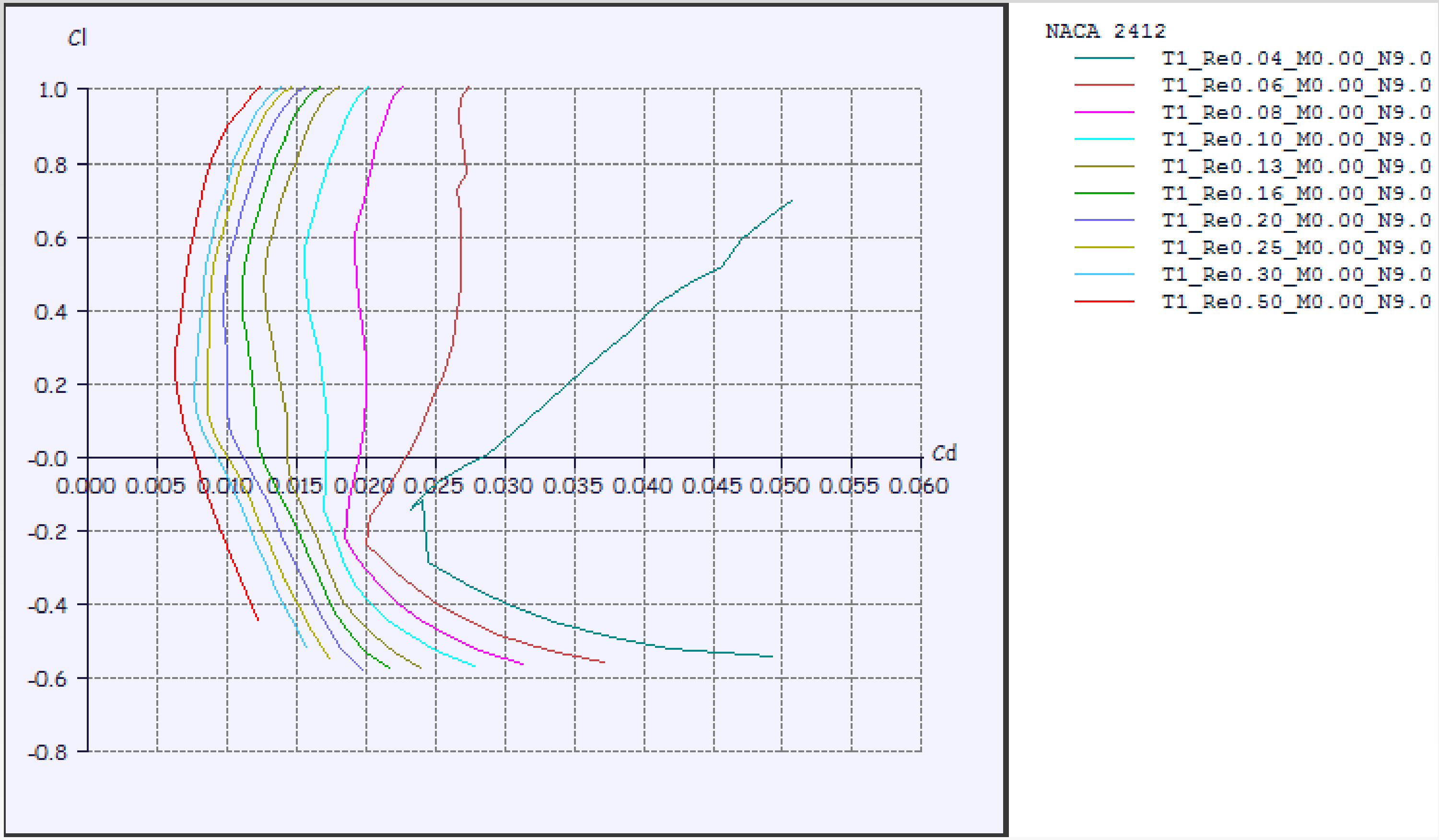
Consider a wing with span	1 500 mm
The airplane flies at	15 m/s
The root chord is 200 mm =	0.20 m
The tip chord is 30 mm =	0.03 m
The air's kinematic viscosity is ν =	$1.5\ 10^{-5}\ m^2/s$

The foil is the NACA 2412 for the whole span



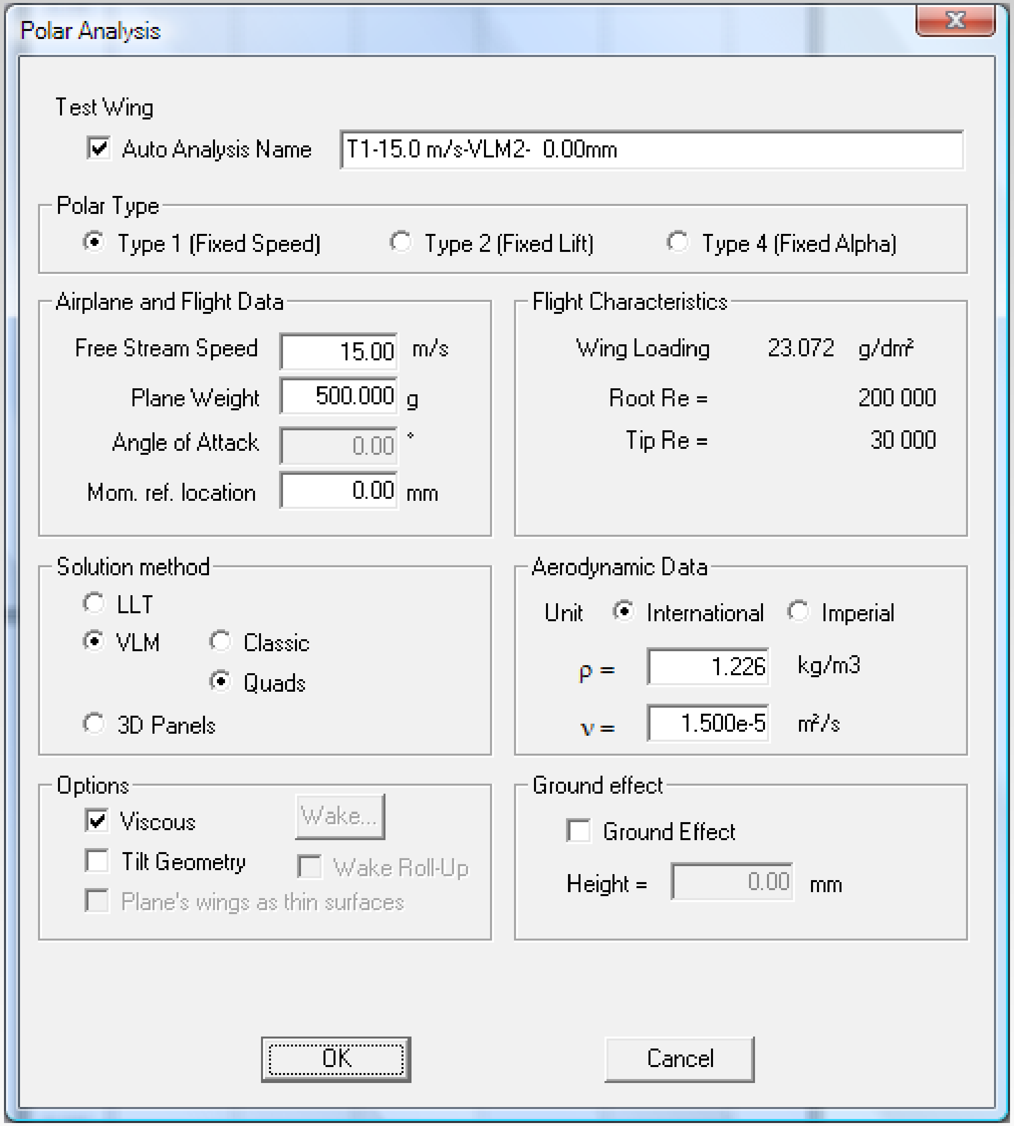
First we generate the viscous polars for the foil

This is done in the "Application/XFoil Direct Analysis" menu, using the "Polars/Run Batch Analysis command"



Our foil polar mesh runs from Re=40 000 to Re=500 000

Next we analyze the wing



We generate a polar analysis

And we launch the analysis for α=1°

Results

- Unfortunately, nothing is generated : why ?
- The error messages showed up too fast to read during the analysis, so we call the XFLR5.log file from the "Operating Point" menu

Note : the ".log" file extension is usually associated by default to the notepad, check the association if nothing shows up

```
Test Wing
July 25, 2008  at  20:27:04
___________________________________
   Solving the problem...

      Creating the influence matrix...
      Solving the linear system...
      Calculating the vortices circulations...


      ...Alpha=1.00
        Calculating induced angles...
        Calculating aerodynamic coefficients...
         Calculating wing...
       Span pos =   -679.00 mm,   Re =    36 786,   Cl =   0.25 is outside the flight envelope
       Span pos =    679.00 mm,   Re =    36 786,   Cl =   0.25 is outside the flight envelope
```

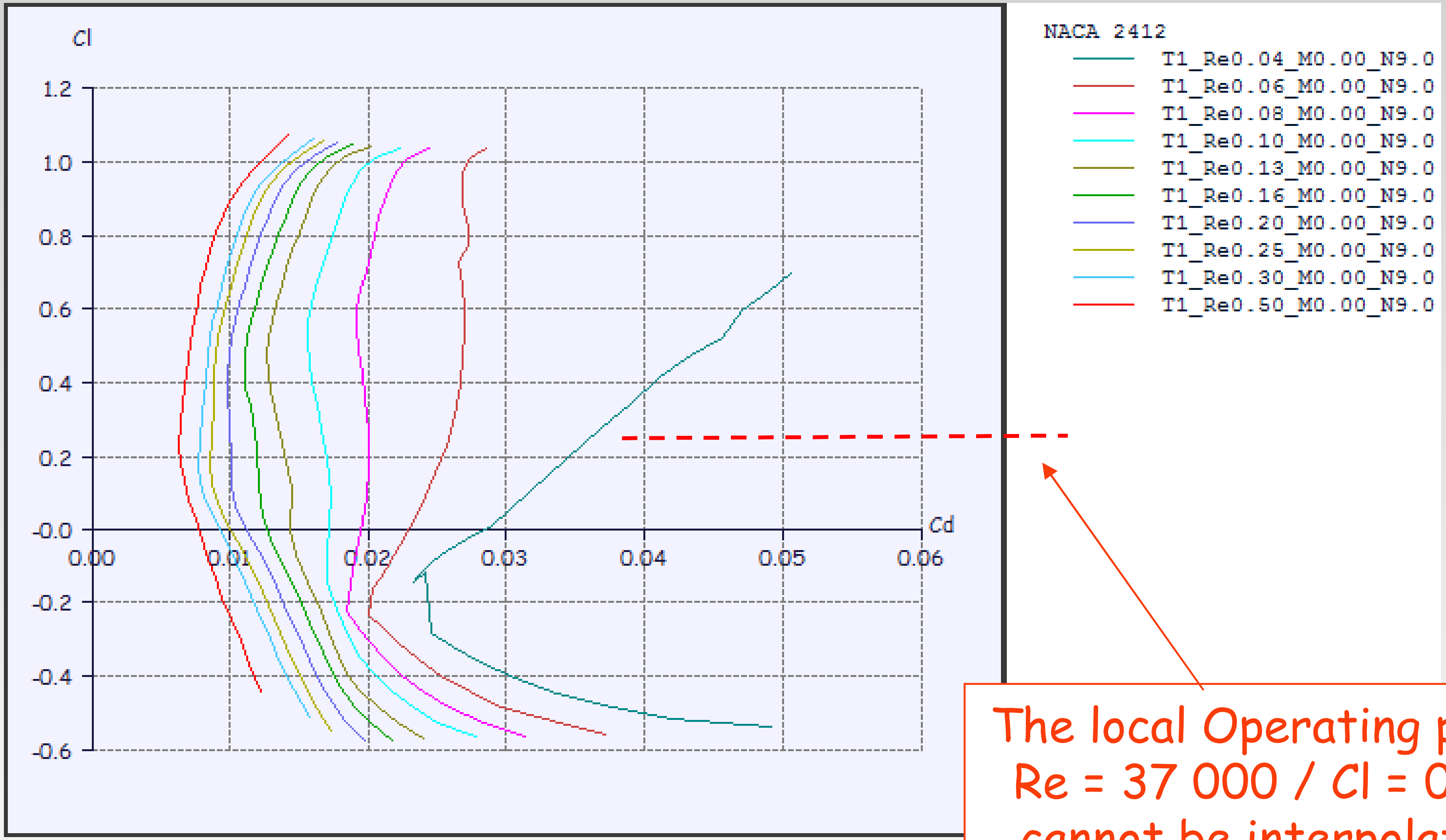
The interpolation fails

We have a problem at the tip

The calculated Re at 15 m/s is less than the min value of the polar mesh, which is 40 000

We illustrate this graphically in the next slide

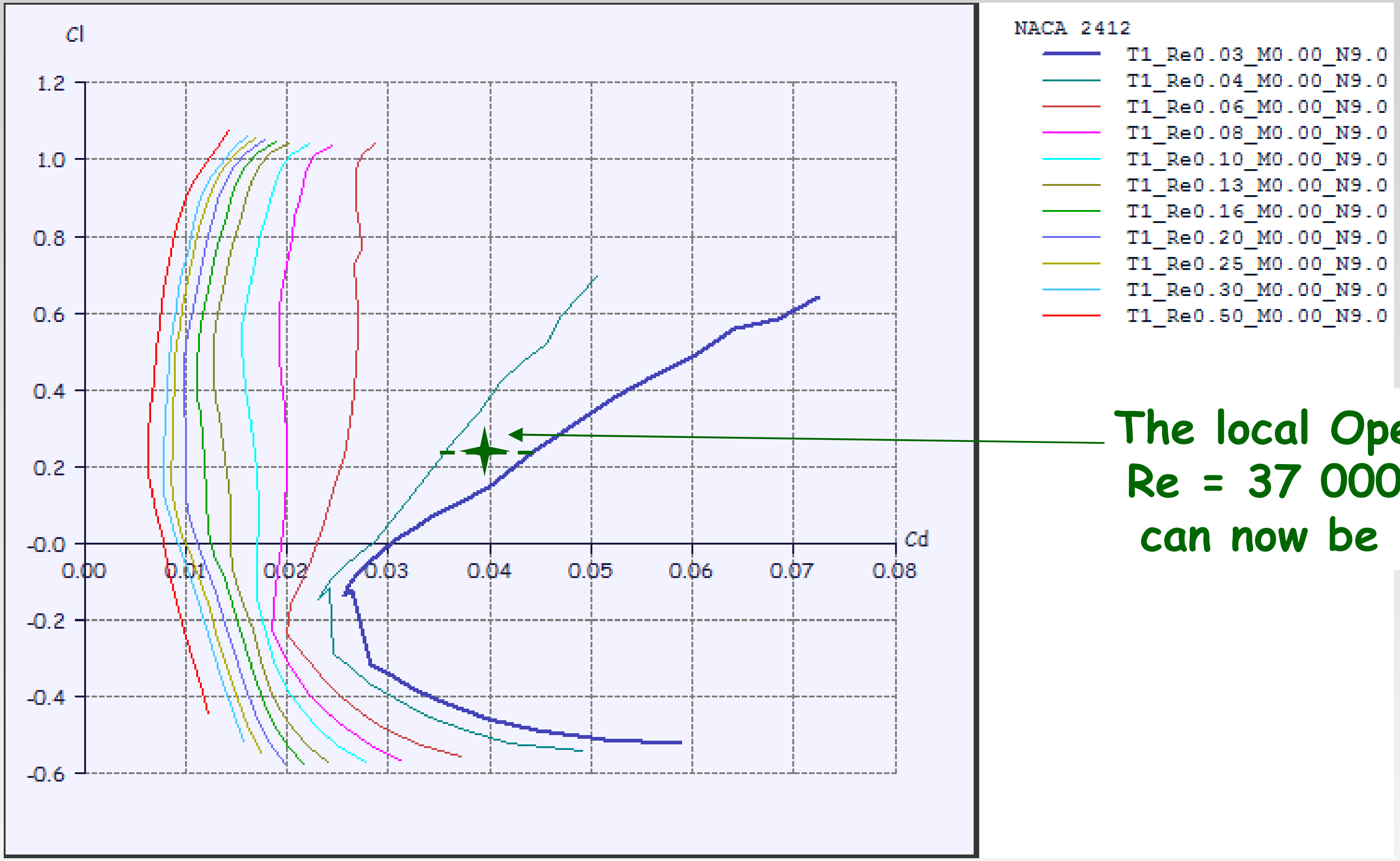
Interpolating from 2D results at tip chord



The local Operating point
Re = 37 000 / Cl = 0.25
cannot be interpolated

The Fix

We extend the polar mesh down to Re =30 000



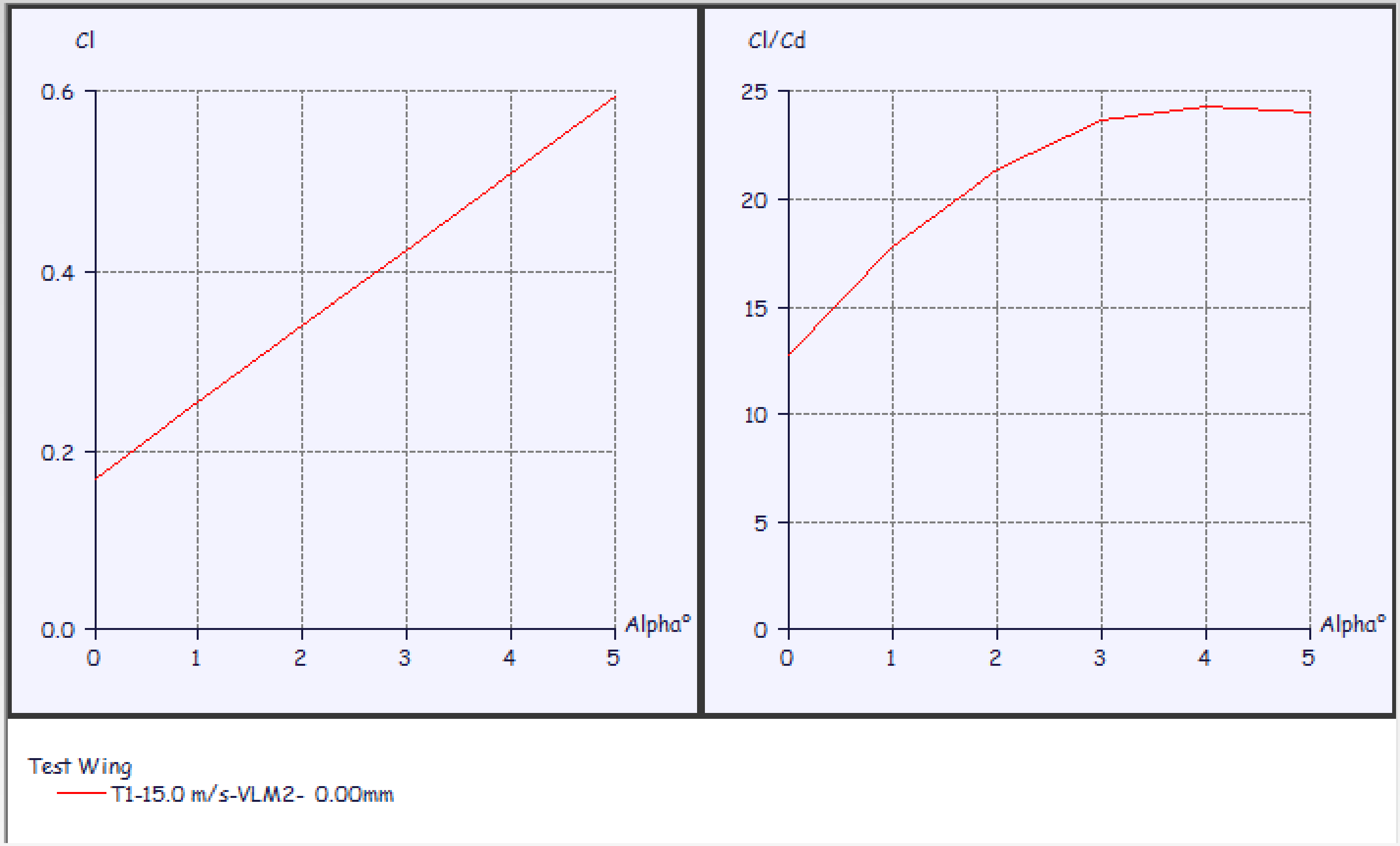
The local Operating point Re = 37 000 / Cl = 0.25 can now be interpolated

No more issue for α = 1°

… so we boldly run an analysis from α = 0° to α = 10°

Wing Analysis Results from $\alpha = 0°$ to $\alpha = 10°$

Unfortunately, the analysis does not run higher than $\alpha = 5°$: why ?



We check again the log file

Using the log file information

```
Test Wing
July 25, 2008  at  20:45:17

___________________________________

   Solving the problem...

      Creating the influence matrix...
      Solving the linear system...
      Calculating the vortices circulations...
      ...Alpha=0.00
        Calculating induced angles...
        Calculating aerodynamic coefficients...
         Calculating wing...

[…]

      ...Alpha=6.00
        Calculating induced angles...
        Calculating aerodynamic coefficients...
         Calculating wing...
       Span pos =   -679.00 mm,  Re =    36 786,  Cl =   0.65 could not be interpolated
       Span pos =    679.00 mm,  Re =    36 786,  Cl =   0.65 could not be interpolated
```

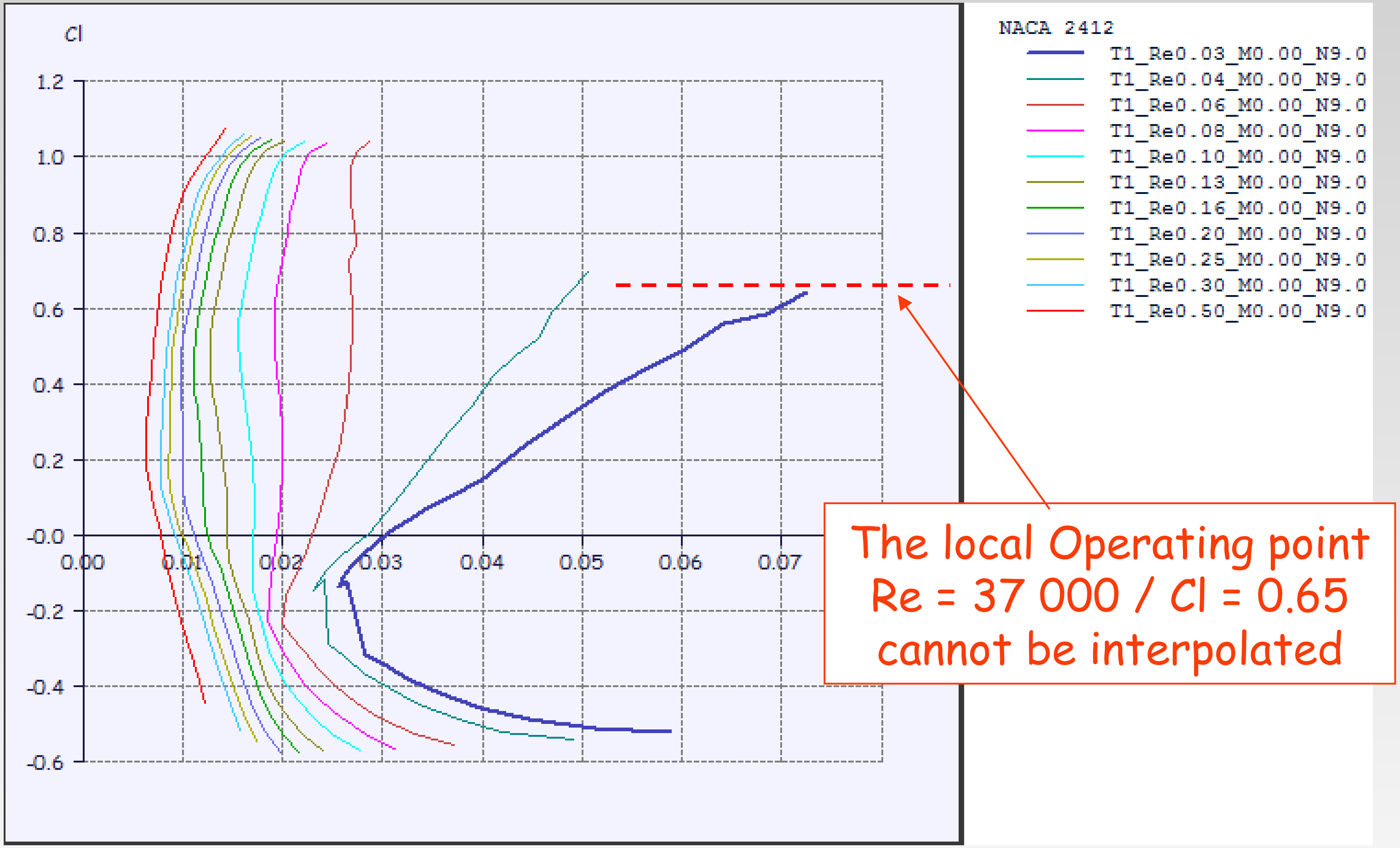
Unfortunately the foil's Type 1 polar mesh does not extend to Cl=0.65 for Re=30 000 : the interpolation fails

The problem is still at the tip

The Re is OK

We illustrate this graphically in the next slide

Interpolating from 2D results at high incidence



The fix

- We try to extend the foil polar mesh at high a.o.a for Re = 30 000 to achieve Cl values higher than 0.65

- Two possibilities :
  1. The XFoil analysis converges for Re =30k and Cl>0.65
     → we have fixed the issue and may run the wing analysis with success
  2. The XFoil analysis does not converge
     →we have reached the limits of the 2D approximation for the viscous drag ;

In fact, the approximation is most probably quite questionable long before this point is reached

In the hope that this helped !

☺