A TUTORIAL FOR XFLR5 – VERSION 1

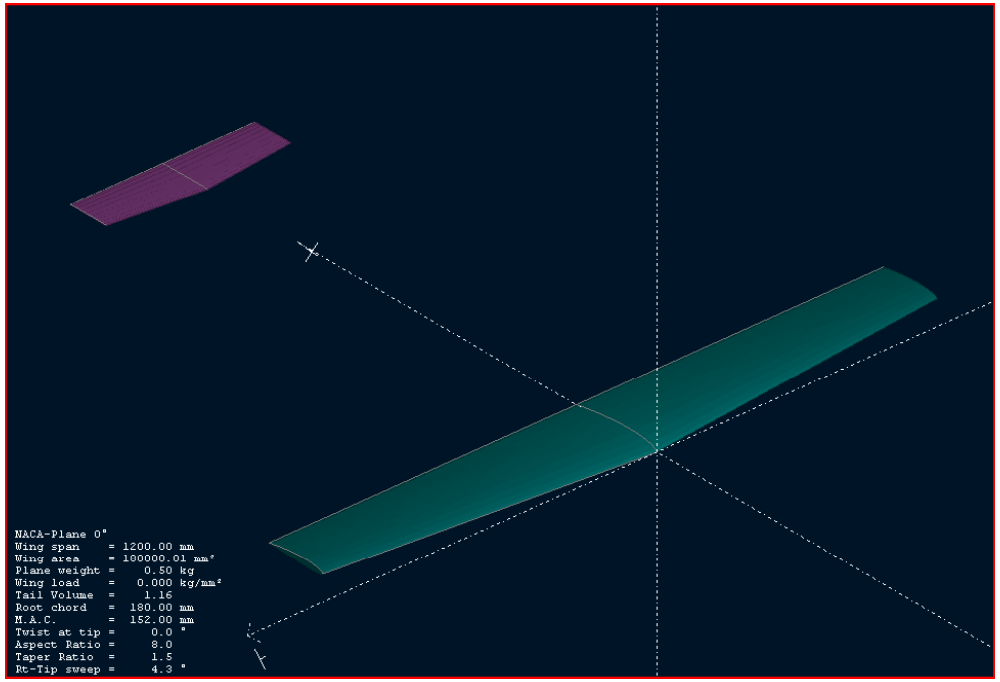
http://www.mjw.co.at

mjw@mjw.co.at

The Airplane

- Main-Wing Wingspan: 1200mm
- Main-Wing Root-Chord: 180mm
- Main-Wing Tip-Chord: 120mm (offset 60mm)
- Main-Wing Dihedral: 0°
- Main-Wing Area: 180 000 mm^2

- Elevator Wingspan: 360mm
- Elevator Root-Chord: 100mm
- Elevator Tip-Chord: 80mm (offset 20mm)
- Dihedral: 0°
- LE Position: 1000mm
- Elevator area: 34 200 mm^2



Total Weight: 500g

It looks stupid? Maybe, but we should look on the physics, not the art! ☺

Geometric Results

- Main-Wing Area: 0.3m^2
- Main-Wing M.A.C.:152mm
- Aspect Ratio: 13.3
- Main-Wing NP Position: 64.10mm from LE
- CG @ SM 5%: 56.5mm from LE
- CG @ SM 10%: 48.9mm from LE
- CG @ SM 20%: 33.7mm from LE

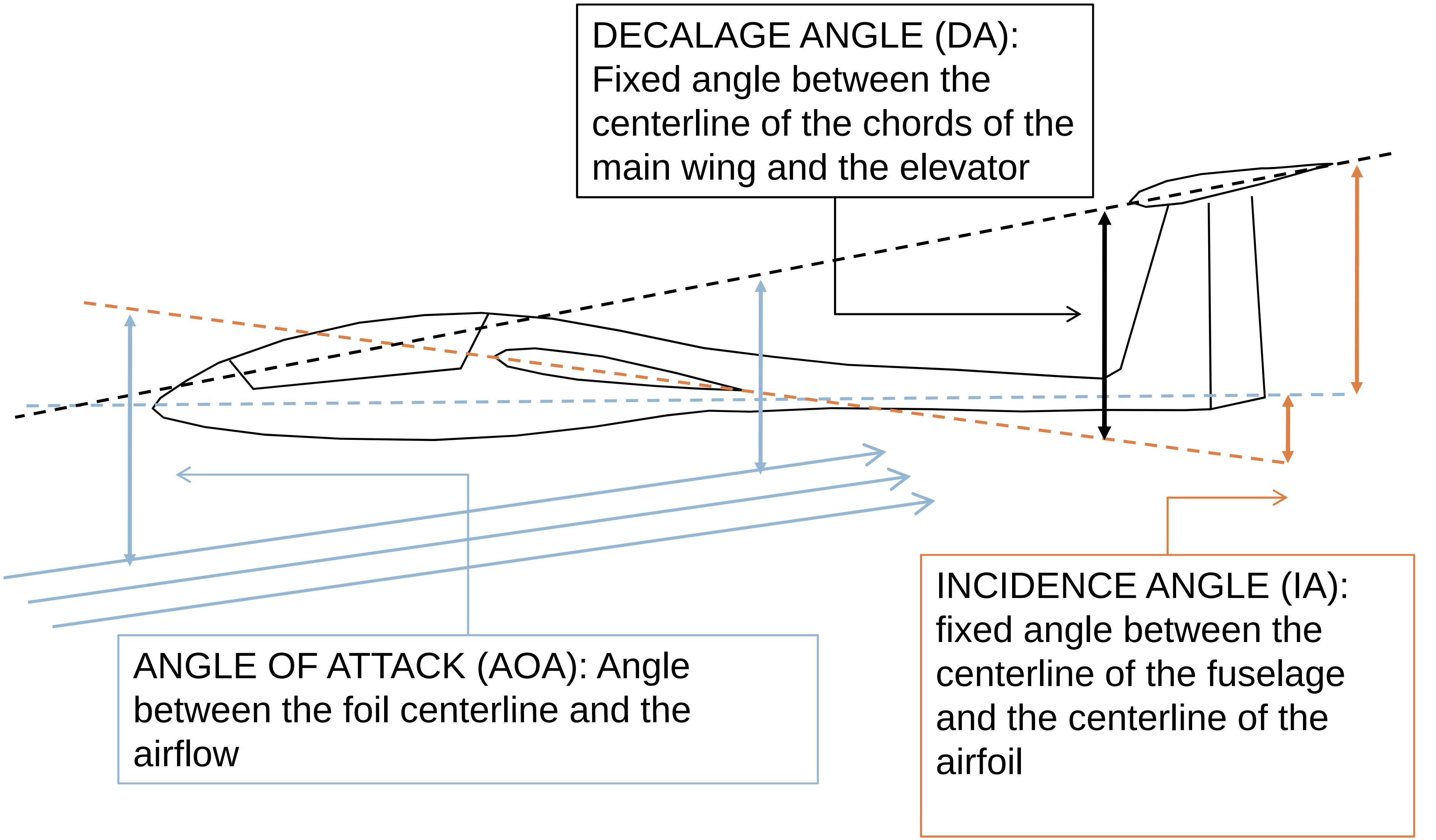
$$SM = \frac{X_{NP} - X_{CG}}{M.A.C.} ==> X_{CG} = X_{NP} - (SM * M.A.C.)$$

The Profiles

- HQ/W 3/8:
  - thickness 10% @ 31%
  - Camber 3% @ 45%
- NACA 2410
  - Thickness 10% @ 28%
  - Camber 2% @ 38%
- MH 32 10%
  - Thickness 10% @ 28%
  - Camber 2.4% @ 42%

- For the Elevator we use a NACA 0004 4% @ 30%

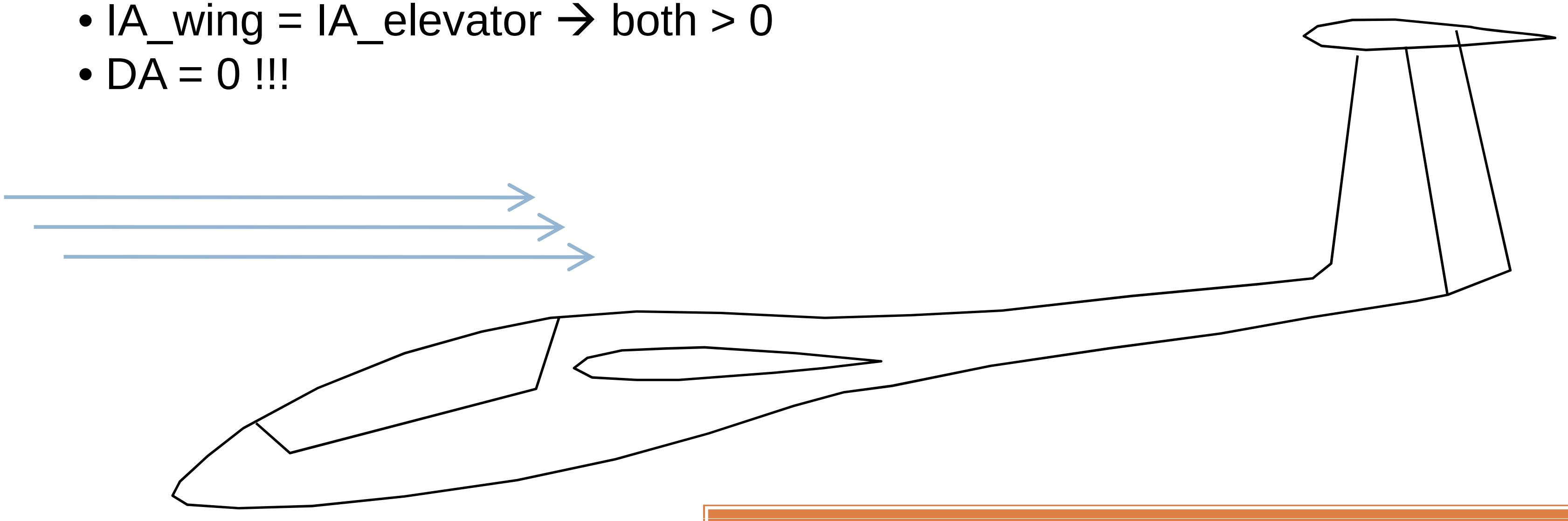
Angle Definitions



IA, DA, AoA example

In this „funny case“ we have:

- AoA = 0
- IA_wing = IA_elevator → both > 0
- DA = 0 !!!



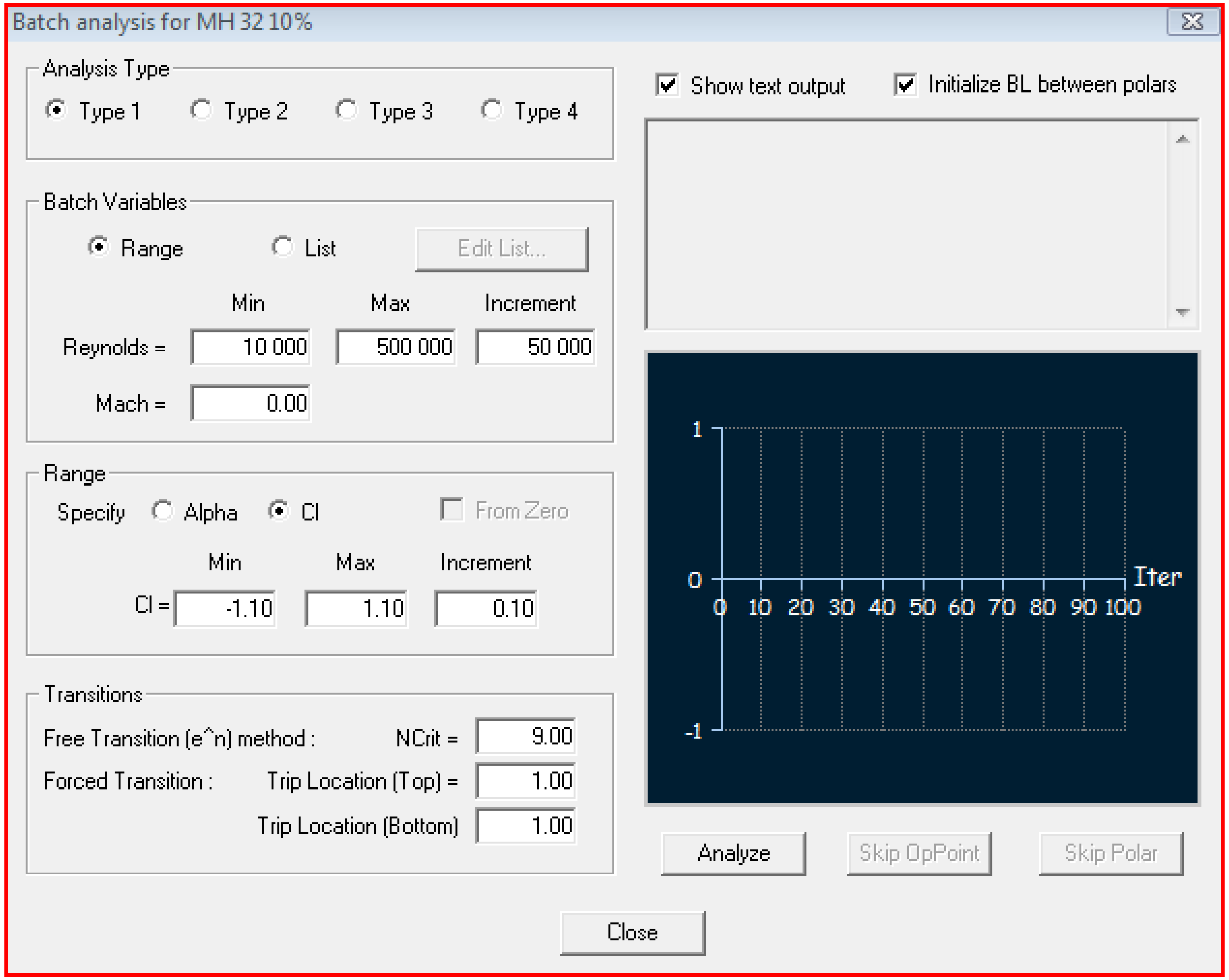
Note: This „funny“ plane can fly, even though it looks „stupid“!

Be careful with AoA, IA and DA!

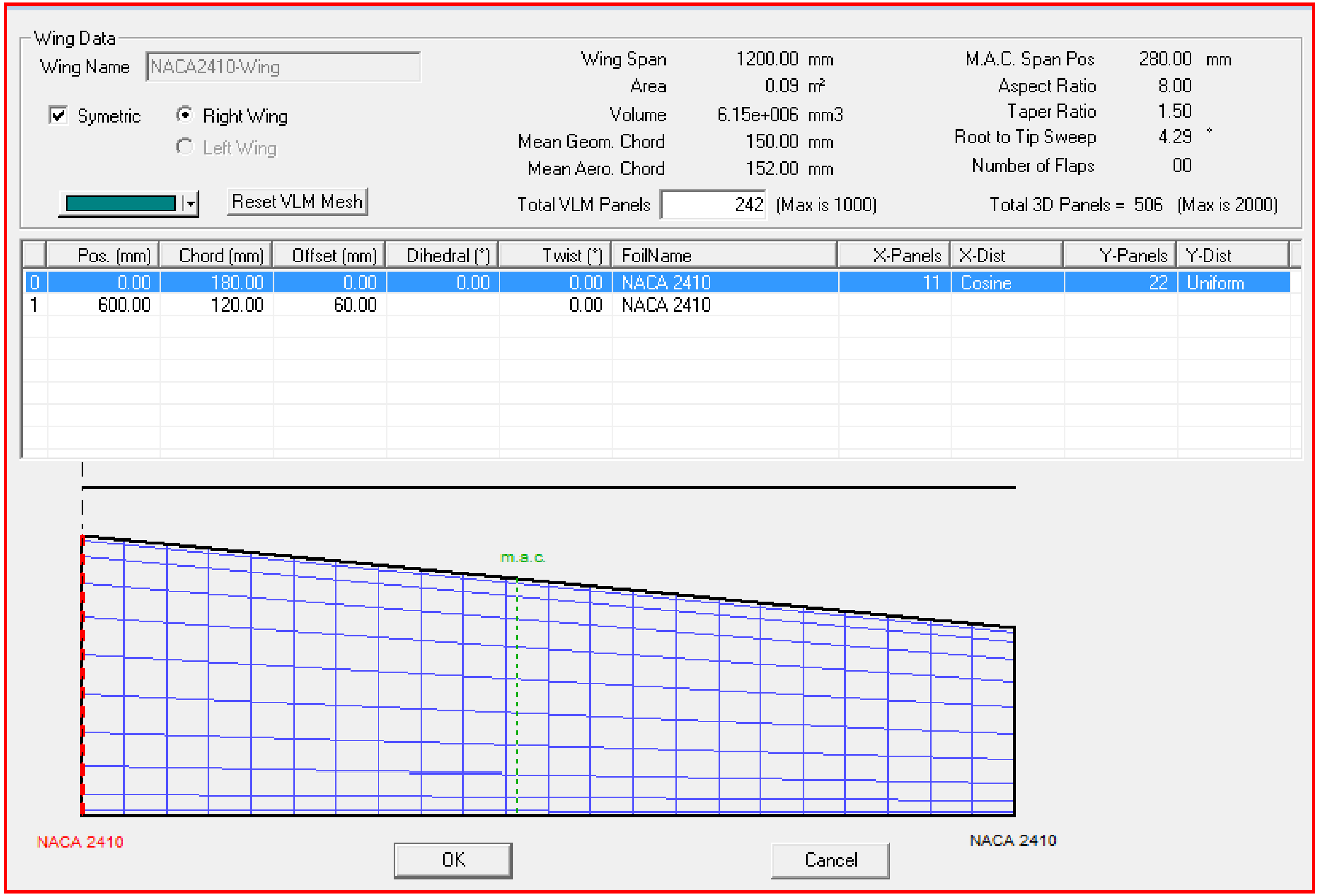
- AoA, IA and DA are so often messed and mixed up that the world is full of mistakes. Please, please, please always use the right names for the right things when you talk about aerodynamics. You do yourself and others a favour! THX ☺

Direct Analysis – Batch mode

For all airfoils we do a direct analysis using the batch mode over the rage of Re numbers from 10000 to 500000.



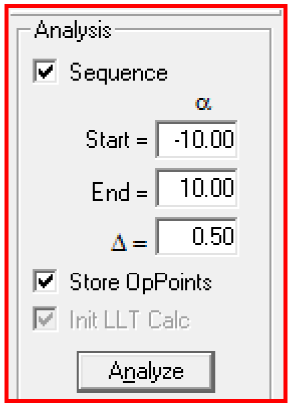
Define the main wing

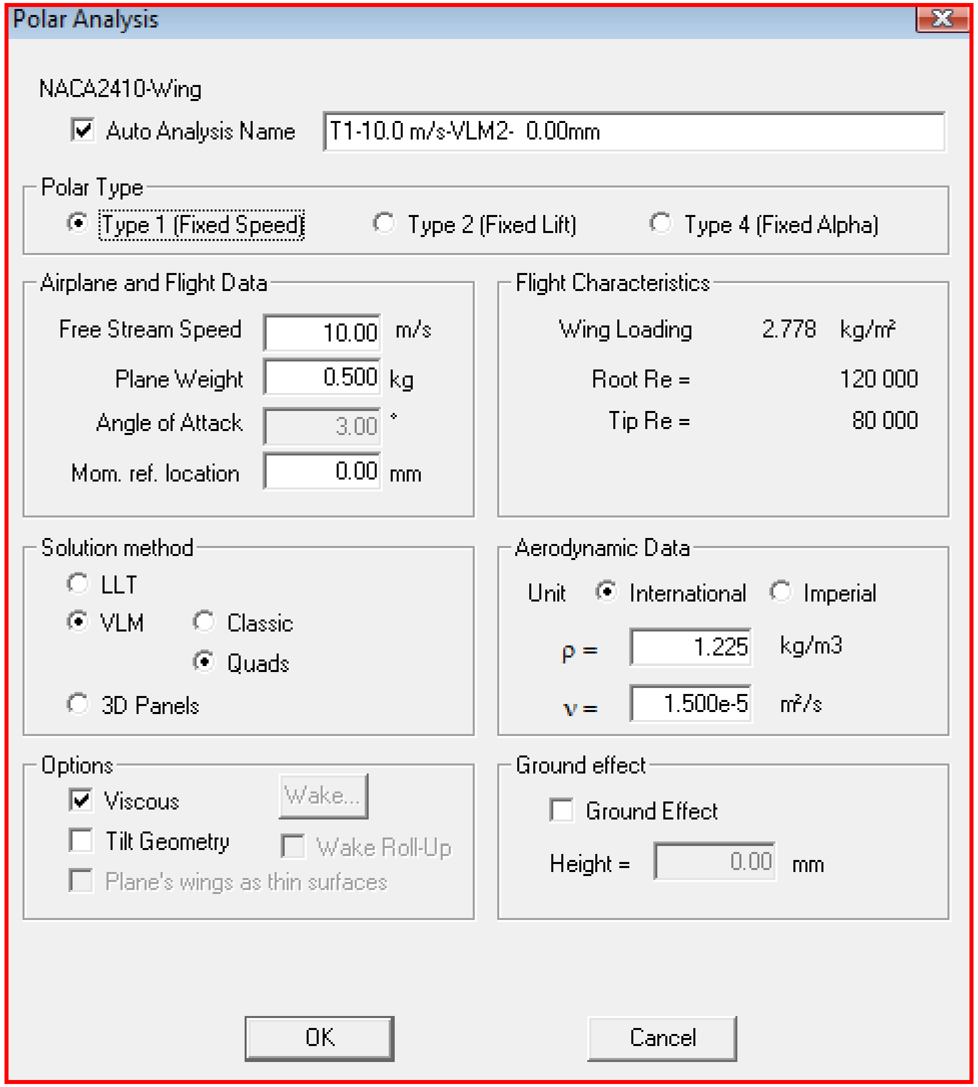


Analysis of the wing

We start our analysis by just looking at the main-wing alone. For this we dial in a Fixed Speed of 10m/s. Since we have no idea for the position of the COG (mom.ref.location) we set it to 0mm.

After this we start the calculation by doing a sequence analysis for AoA starting from -10° to 10° with a step of 0.5°





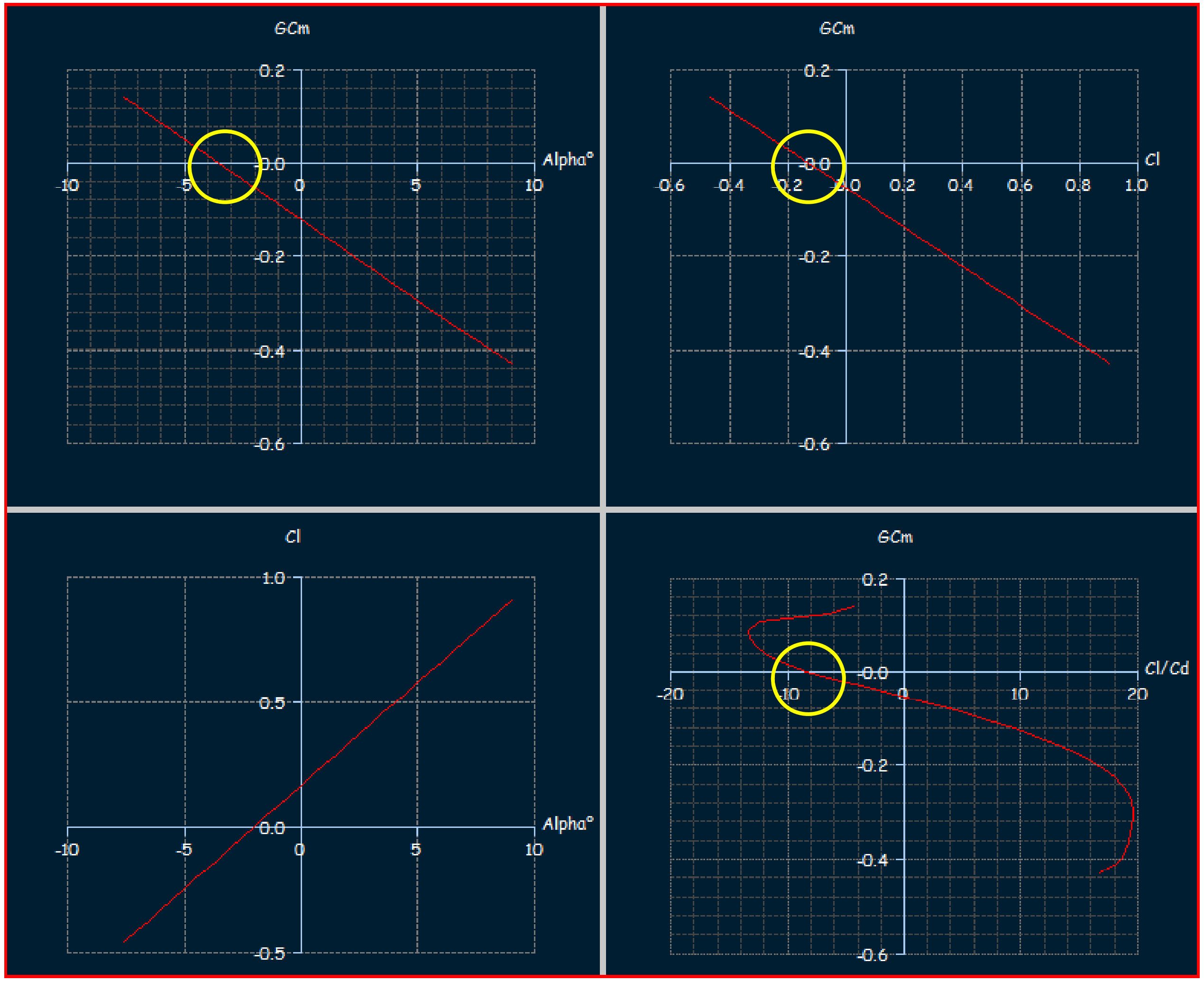
The first results

First we look at the functions of GCm (global pitching-moment) vs. AoA (alpha), Lift (cl) and Glide Ratio (Cl/Cd). Why GCm? Because GCm=0 means that the wing is in balance (→ no moment)

All we search now is: When is GCm = 0?
GCm = 0 when:

- alpha ~= -3.5°
- Cl ~= -0.1
- Cl/Cd ~= -9

Since Cl < 0 for the balance state this wing does not fly. Lets try to dial in a new position of the COG. If we place it exactly on the neutral-point NP the theorie says we should have a constan GCm on whatever AoA (alpha) we use. Let‘s check this!

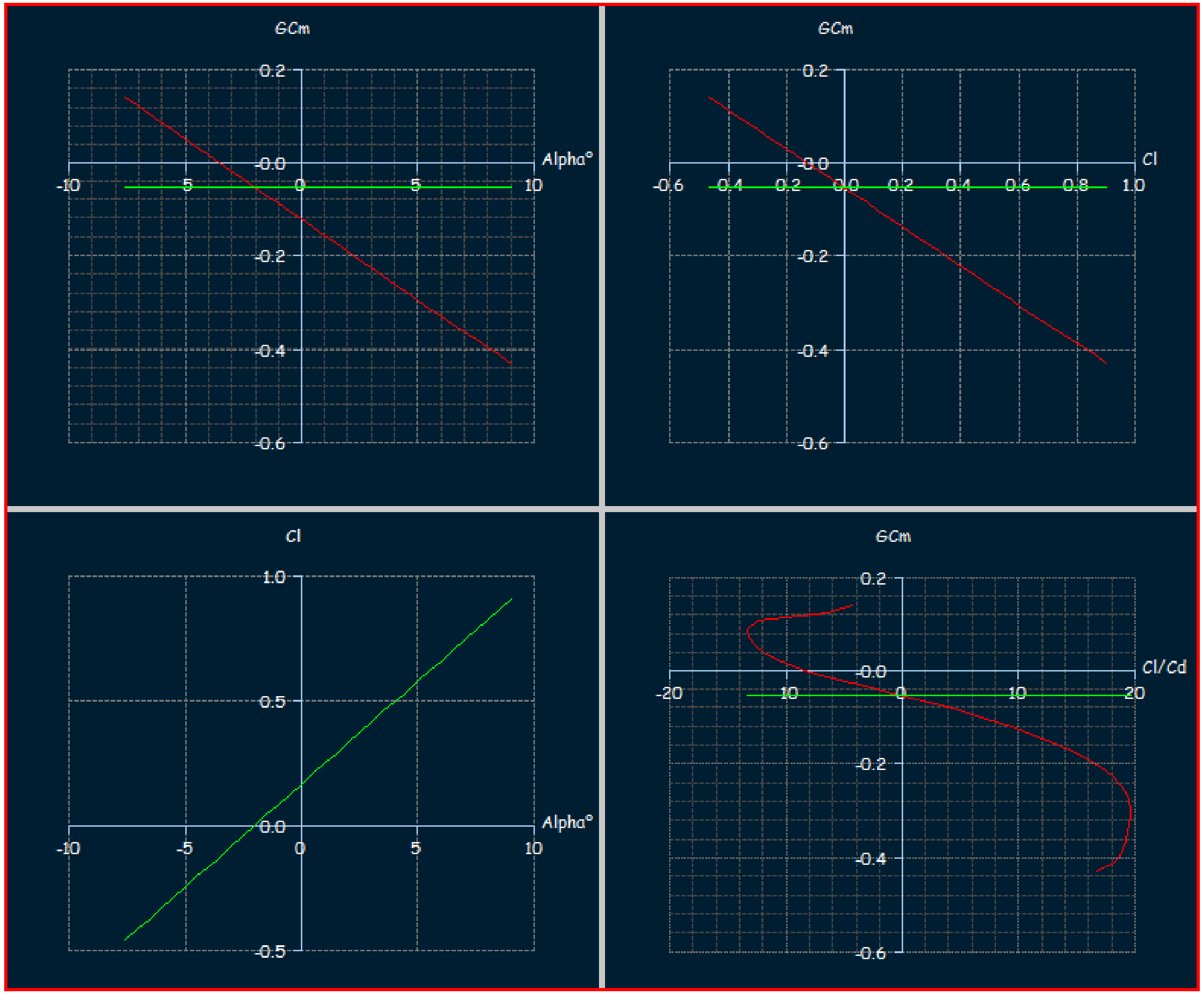


COG @ NP – The results

The new calculations are in green.

In the first graph we see what theorie tells us: if we place the COG on the NP, whatever AoA we choose the pichting moment does not change. So the NP form the geometric calculations is correct! But does this wing fly?

To fly we need a Cl > 0. The lower left graph shows us Cl vs. alpha. As you notice this is the same as before. So the position of the COG does not change the Cl vs. alpha function!
So CL is >0 for alpha > -2.5°.
For any AoA > -2.5 we have positiv lift, but we are not balanced! Look at graph top left: GCm is always < 0! In the top right graph the green line never crosses the x-axis (Cl) so there is never a balanced state! This wing is unable to fly by its own.
Lets move the COG to the place we found from geometric calculations for a SM of 10%

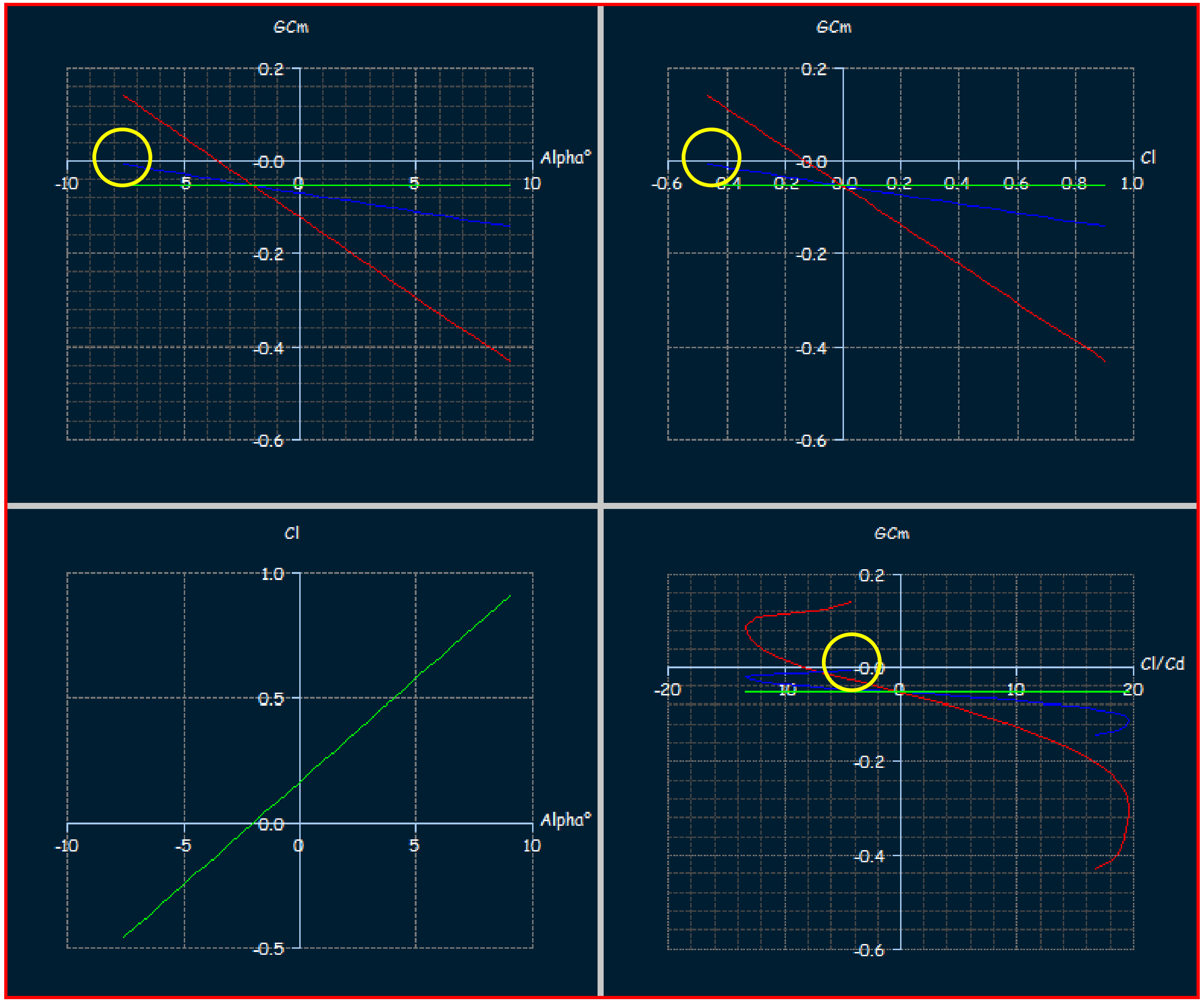


Moving the COG to SM=10%

The new calculation is in blue.

We see that the results fall between the COG@0mm (red) and COG@NP (green) lines. Again we look for the GCm = 0 values of alpha, Cl and Cl/Cd. Sad but true, there is no positiv lift (Cl) for a balanced state (Cl ~= -0.5). Are we out of luck? Whats wrong? We moved the COG in front of the NP and have a good SM of 10%!

Lets see what we have leared from moving the COG around and take a very close look at the GCm vs. Alpha and GCm vs. Cl graph.



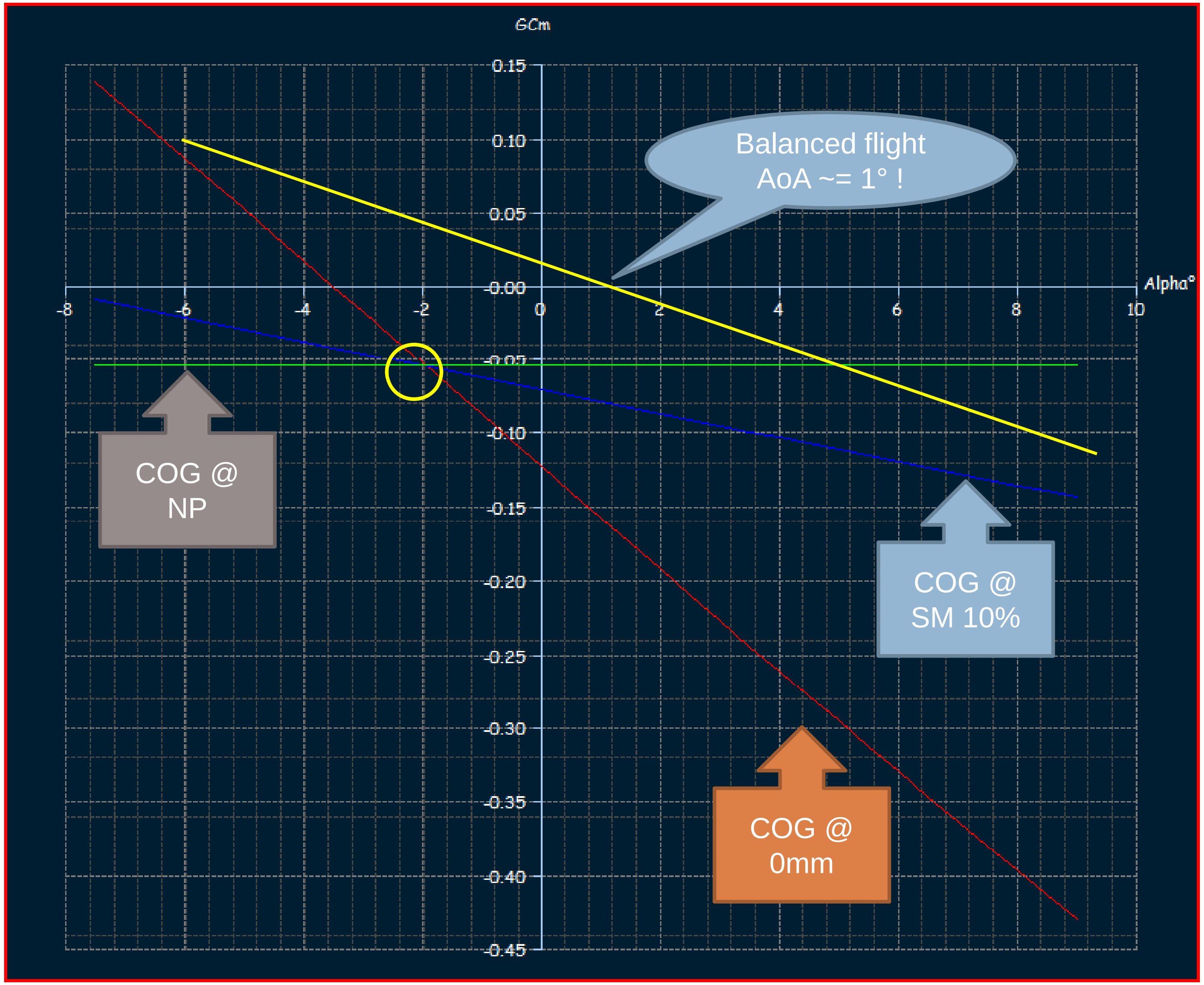
GCm vs. alpha

Lets answer some questions:

Q: What happens if the AoA (alpha) goes up?
A: If the COG is not at the NP the GCm becomes much more negativ. The more we move the COG to the NP the less steeper the slope is. The steeper the slope the more „nose“ down moment.

Q: What is this special point (yellow circle) where all lines cross whatever COG position we choose?
A: The position of this point is the so called Zero-Lift-Angle and Zero-Lift-Moment. For this Airfoil the Zero-Lift-Angle is -2° and the Zero-Lift-Moment is ~= -0.05

Q: What would be a „good“ function of GCm vs. alpha?
A: The YELLOW line.
Q: Why is this „good“?
A: 1) The line is not as steep as the COG@0mm line and it is not constant. 2) We need the GCm vs. Cl graph for more!



GCm vs. Cl

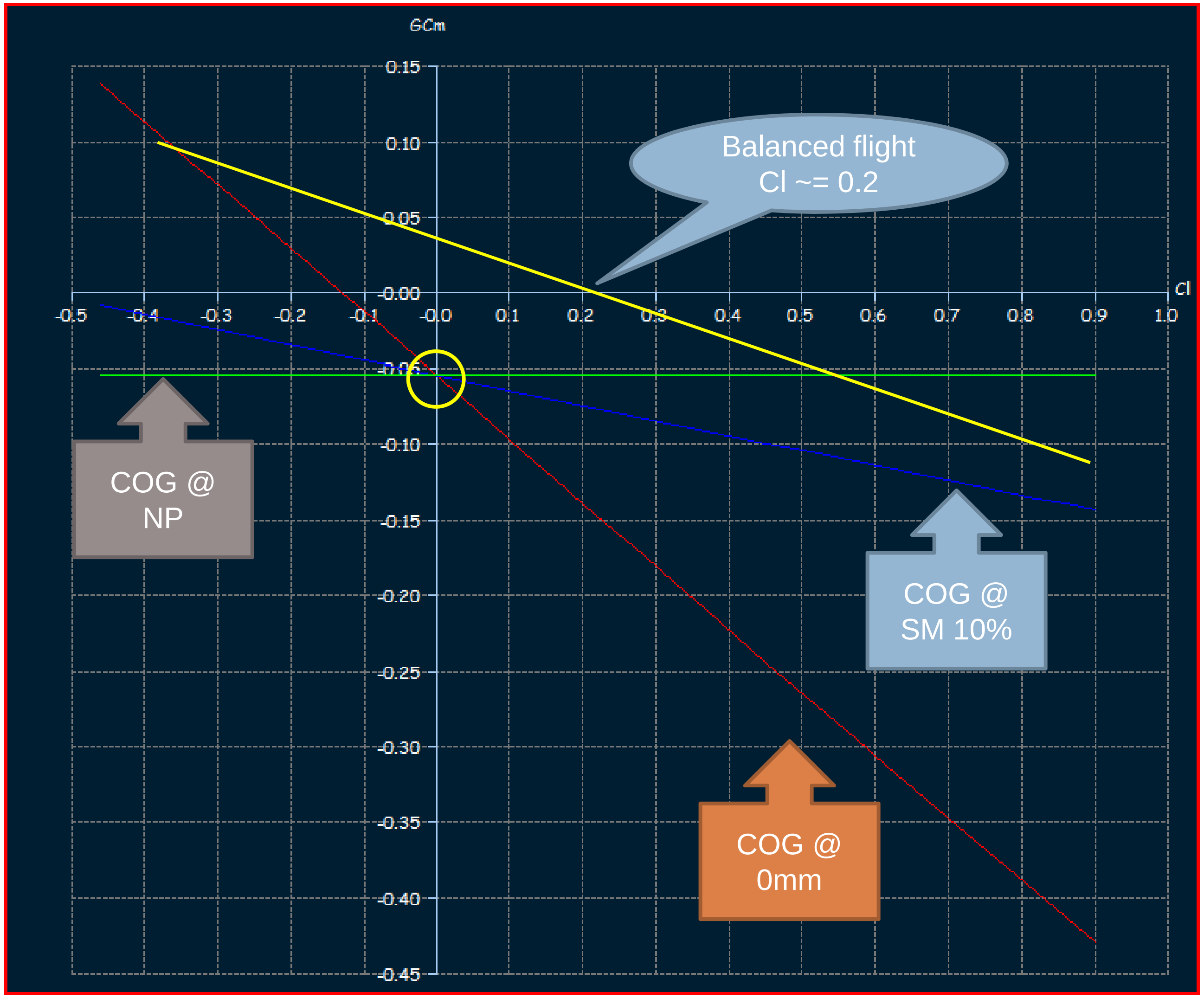
We see here that whatever COG position we choose the balanced state (GCm=0) always gives us a negative lift Cl<0.

The yellow lines is an example of a „good" function of GCm vs Cl → we want positiv lift for the balanced state GCm=0

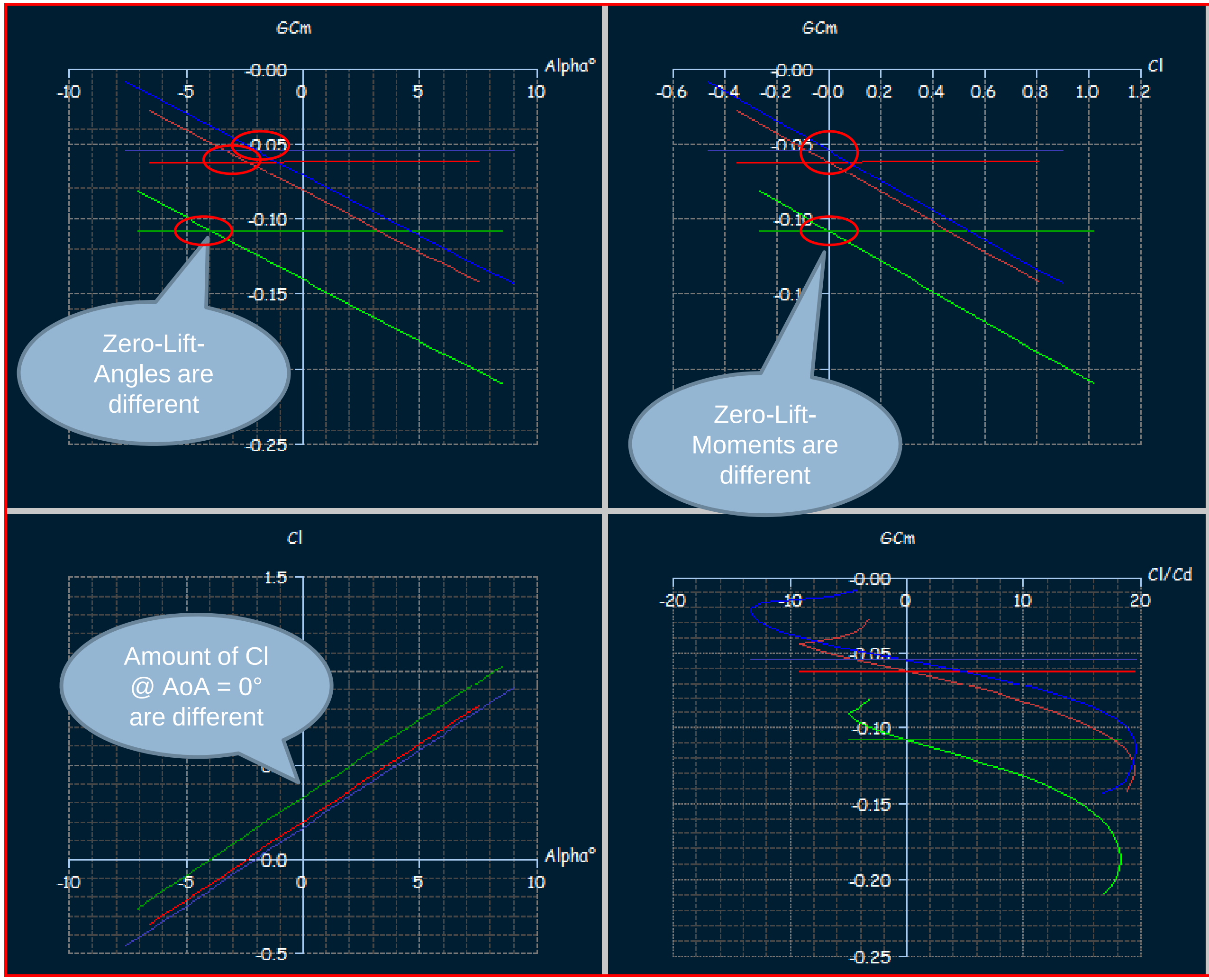
The yellow circles markes again the Zero-Lift-Moment. Now we understand why it is the so called Zero-Lift-Angle. For Cl=0 the moment GCm is ~= -0.05

The „shocking" experience now is that we can never reach the yellow curve by moving the COG since all curves go trough the spot marked by the yellow circle (Zero-lift-moment). Even when we change the speed of the airflow nothing changes (you can try that!).

What happens if we change airfoil? Since the position of the NP depends only on the geometry the position of COG @ SM 10% does not change. Lets see what are the results for the different foils.



Different foils – same wing



HQW-Wing
T1-10.0 m/s-VLM2- 48.90mm
T1-10.0 m/s-VLM2- 64.10mm

MH-Wing
T1-10.0 m/s-VLM2- 48.90mm
T1-10.0 m/s-VLM2- 64.10mm

NACA2410-Wing
T1-10.0 m/s-VLM2- 48.90mm
T1-10.0 m/s-VLM2- 64.10mm

The slopes of all curves for COG@SM 10% are the same. The only differences are:
•The Zero-Lift-Angles are different
•The Zero-Lift-Moments are different
•The amount of lift for a given AoA are different.

The important things are:
•The NP depends only on the geomery, the calculation confirms this
•The slopes of all curves are the same. That means that a change in the AoA has the same amount „correcting force“ for whatever foil we use. (but the absolute values of the moments are different!)

Changeing the foil is like moving one set of cuves around.

What we have learned now

- The NP depends on the geometry. (at least it looks so!)
- By changing the foil we can „move“ the graphs around.
- Changing the COG position changes only the slope but the Zero-Lift-Angle and Zero-Lift-Moment stay the same.

→ Great, but the wing still does not fly!!!

What can we do now?!?

- ➔ We choose a „better“/“other“ profile.
- ➔ We „invent“/“add“ something.
- ➔ We change the geometry.

- We do not want to change geometry, because the plane/wing looks so cool! ☺

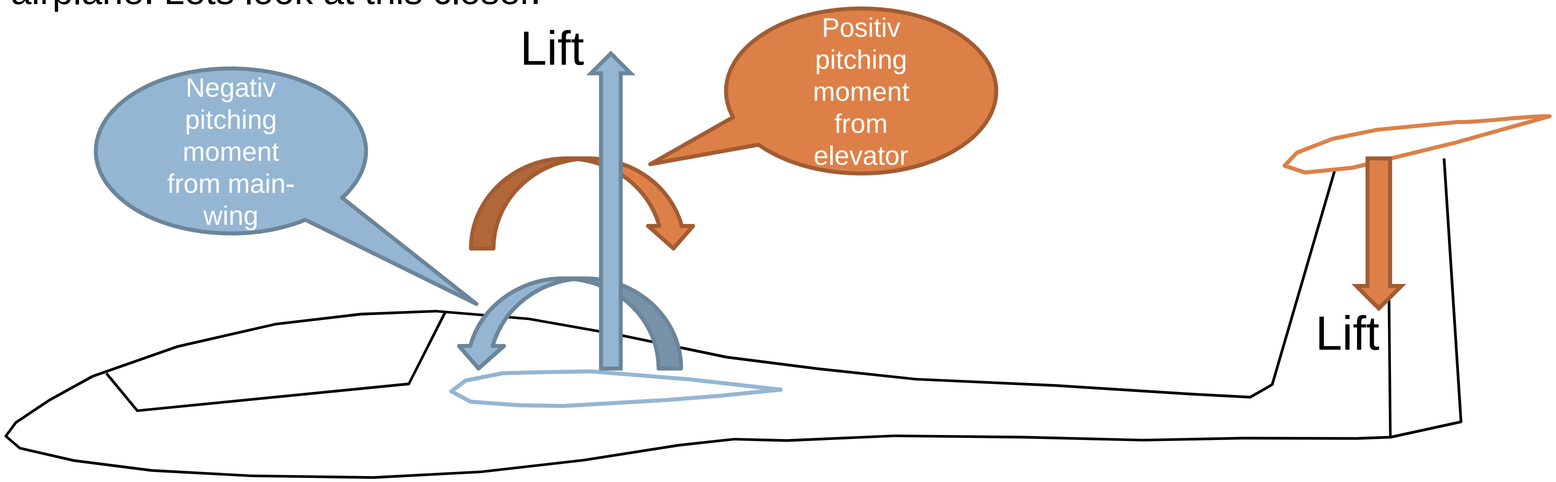
Howto change the profile?!

- When we look at the graphs we see that we have too much negativ GCm for a given AoA and always negativ lift. What we need is more positiv GCm to shift the curve „up“ on the GCm axis!

➔ We need an airfoil that has a positiv lift for the balance GCm = 0 . Those foils are called „S-profiles“ or „self-stable-profiles“. We look at them later.

We add something...

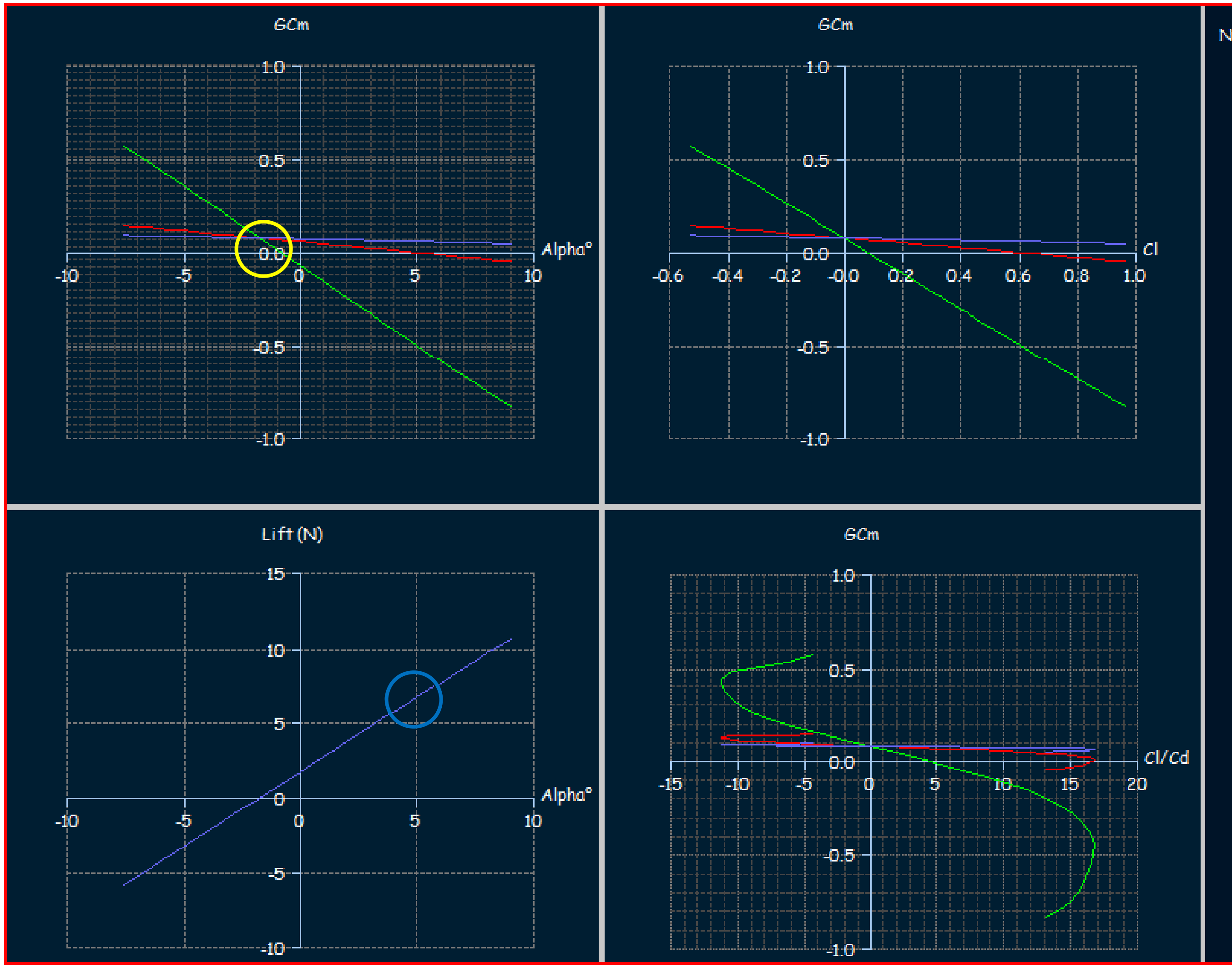
- Since we need a „Force“ that produces a positiv moment we add a simple elevator to our airplane. Lets look at this closer.

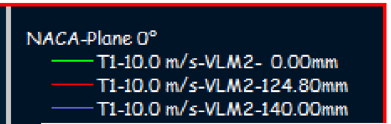


To compensate the negativ pitch-moment of the main-wing we add an elevator. Since the elevator is an airfoil it produces lift. We want to compensate the pitch moment so we need „negativ“ lift on the elevator. To do so we choose a negativ AoA (better IA).

The question now is: What is the IA of the elevator? Since a moment is defined by force * length (distance of the elevator from the LE of the main-wing) we must be very careful by choosing the IA because the elevator itself is an airfoil!

NACA2410 wing with 0° elevator





We start our calculation again with a fixed speed of 10m/s.
First we use a COG postion of 0mm (green curve).
Since now we have an additional airfoil (the elevator) we must now find the global NP for the whole airplane! We can no longer use the one of the main wing! So we start „guessing" and finally find a global NP (GNP) of about 140mm. (blue curve)

Since we want a SM 10% we calculate it and this gives us a COG @ SM 10% at a position of 124.8mm.

The results with the COG @ 124.8mm gives us the red curve. As with the wing alone we have a fixed point (yellow circle)

This plane flies! Why? For the GCm = 0 we have an AoA ~= 5° and a lift of Cl ~= 0.6 . Our plane weights 0.5kg so we need at least 5N of force to make it fly. At the balance AoA we have about 6N (blue circle)!

What have we done? What happened that it flies now?!

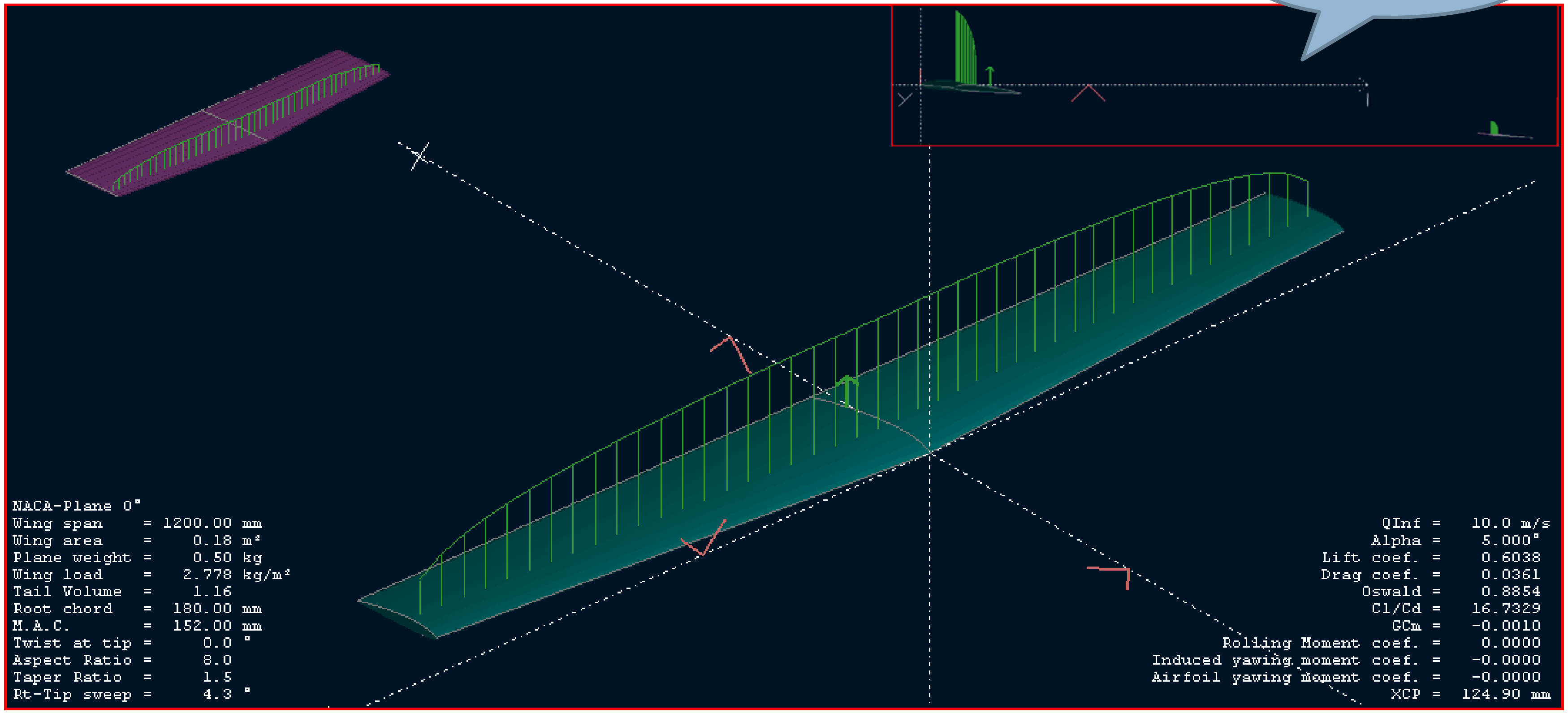
Why it flies....

- The elevator manages it to produce some kind of moment (with its lift) that compensates the negativ moment of the main wing.
- So we get a positiv lift Cl>0 for a balanced GPm = 0
- The „strange“ thing is the high AoA for GPm = 0. Lets take a look at the lift distributions.

Local Lift – Bad looking plane

Here we see the lift distribution among the main-wing and the elevator at an AoA of 5° which is the balanced flight (GPm=0). What we see is a little strange: Both wings produce an uplift! So how can this system be stable? Well, we should not forget that we moved the COG to 124.8mm. A COG of 124.8 only at the main wing is a unstable position so the moment is positiv! That means we need a negativ compensation from the elevator!

On the Sideview you see the airplane with the stable AoA from the side. This doesnt look good but it flies!



What now?!

- We can try to change the IA of the elevator...
- Since the moment of the elevator is force*distance we could try to
  - Reduce the sice of the elevator
  - Move it closer to the main wing
- We could change a higher SM to move the balance AoA closer to 0 → not a good idea since we want to control the plane and fly acrobatics ☺
- We could change the airfoil, but what if we already build it? So we keep it!

Performance?

- Before we start to arguee about the balance AoA of 5°, the strange elevator and the messed up moments, lets look at the performance of this airplane.
- The first analysis told us that it flies, but we dont know how „good“, how „fast“ and if its a thermal floater or a slope-combat beast.

➔ Lets do some performance analysis

Performance analysis

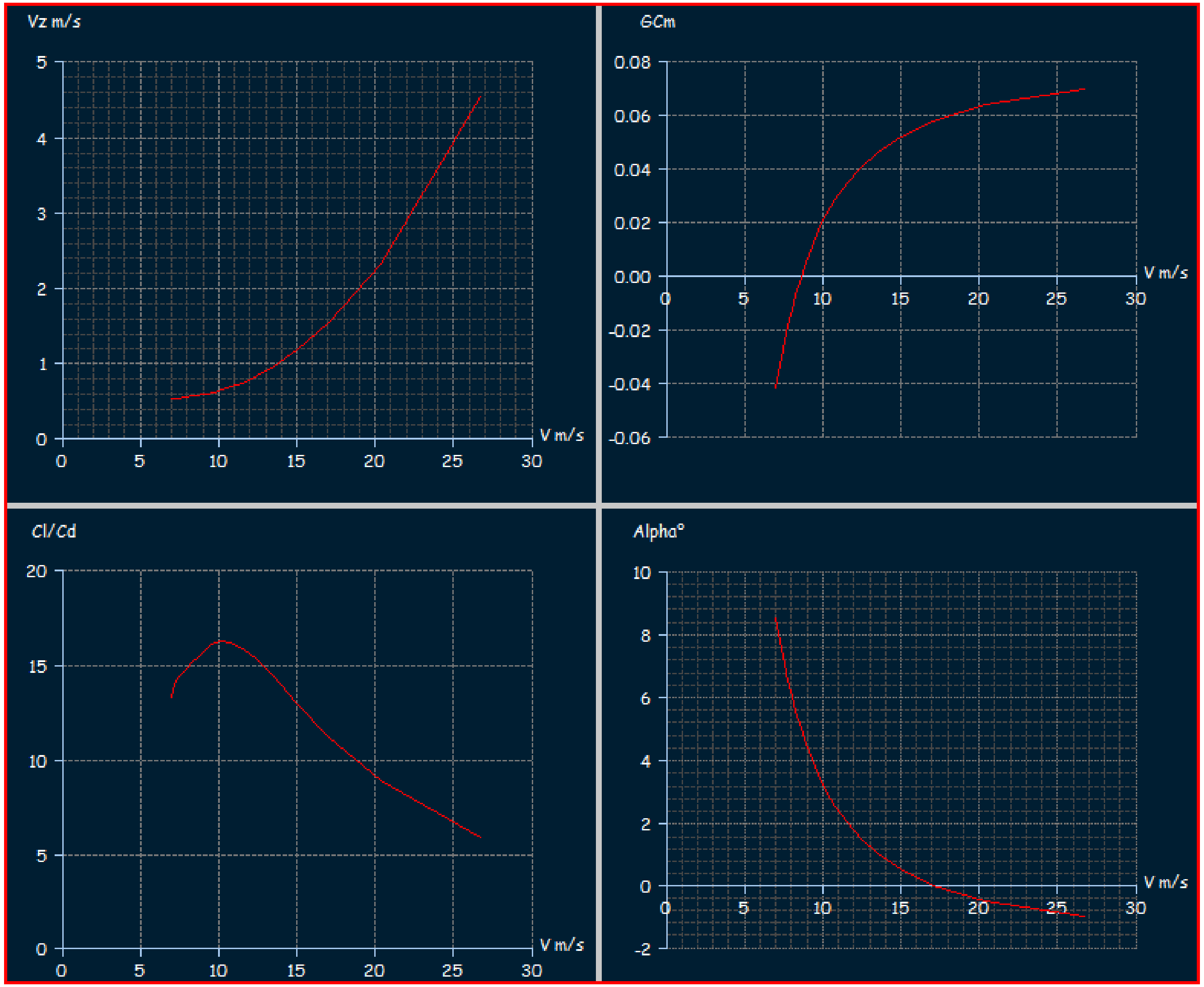
For getting this graphs we have chosen the „fixed lift“ method. Using this calculation method XFLR5 changes the speed and AoA so that the required lift force for the airplane (0.5kg → 5N force) is always achieved.

Vz vs V
In this graph we can see the sinking speed versus the flying speed. As you see there is no minimum in this graph. When we fly at 7m/s the sink speed is ~0.5m/s. If we fly slower we will fall from the sky.

GCm vs V
This is a very important graph. It shows us the speed where the airplane flies in balanced condition. Its about 8 m/s. So we now know how fast the plane wants to fly!

Cl/Cd vs V
The maximum is at ~10m/s and the ratio is ~16. So we must fly 10m/s to fly as far as possible!

Alpha° vs V
This shows us the AoA for a given speed. If we fly ~17m/s the AoA is 0°.



Good or bad airplane?

- When the plane flyies at the balanced speed (trim speed) of ~8m/s the sink speed Vz is ~0.6m/s. So we need an „slope upwind“ or „thermal upwind“ of only 0.6m/s to make this plane fly! → trim speed = 8m/s
- The best Cl/Cd ratio of ~16 is at a speed of ~10m/s. So if we need/want to go as far as possible we must choose this speed. → max distance speed = 10m/s
- There is no miniumum in the Vz curve so all we know is that going slower than 7m/s is dangerous!
- The slope of AoA vs V changes very rapidly. If we dial in an AoA of 0° we fly ~17m/s . As we dial in 2° we must slow down to ~11m/s to keep a balanced state otherwise we are unstable.

→ Since the trim speed 8m/s, the max distance speed 10m/s and the „minimum“ sink speed close to 7m/s are all very close together we can say that this airplane is a „slow floater“. Its very sensitive to AoA changes and going fast without re-trimming causes serious problems!

But i want a fast slope-glider!

- Ok, we have seen that the first attemt wasnt that bad. We now try to optimize the plane to become a fast slope-glider. Lets sum up what we must change.
- Trim speed must be faster
- Balance AoA should be „smaller“

We start by optimizing the elevator and make it ~1/10 of the size of the main wing.

A new elevator is born!

- The original elevator was 34 200 mm^2. We want to size it down to ~1/10 of the main wing area which is 180 000 mm^2. So the new area of the elevator should be ~18 000 mm^2
- We keep the LE position of the elevator at 1000mm. The new geomety of the elevator is:
- → Root Chord: 100mm
- → Tip Chord: 80mm offset 20mm
- → Wingspan: 202mm
- → Total aera is now: 18180 mm^2

➔ Lets start the calculation over again!

First results...a few hours later

- After changeing the elevator size we must recalculate the NP of the whole airplane.
- After this we choose a COG @ 10% SM (NP ~98mm → COG @ SM 10% = 82.80mm) and see that we dont reach a good balance AoA so we need more „positiv moment“.
- So we use a IA of -1° on the elevator → now its better!

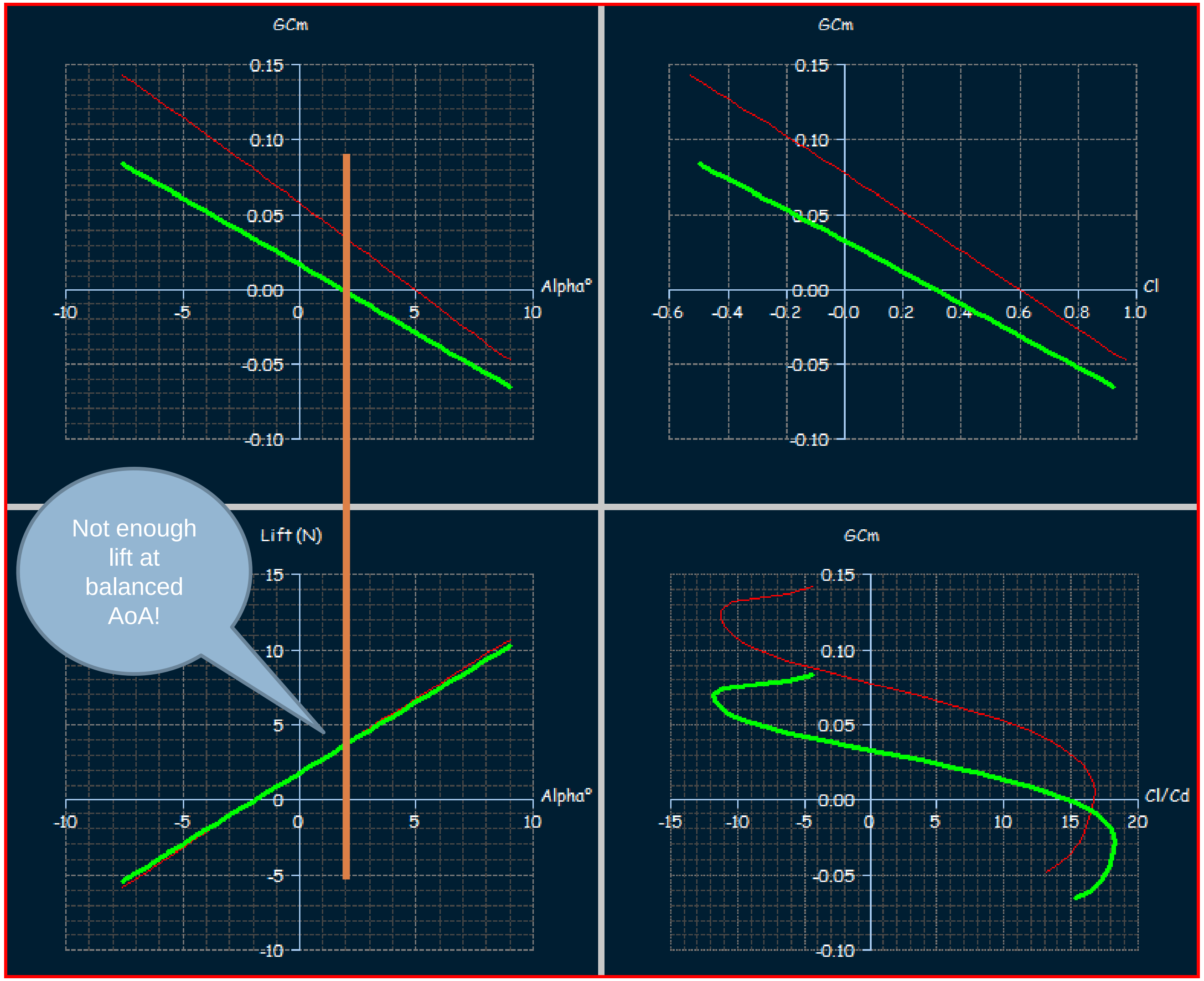
→ Lets take a look at the results

Introducing the new elevator

The new calculation are the green lines. The red lines are the old ones.

Nice isnt it? A lower AoA @GPm = 0 and almost the same slope! The balance AoA is now 2°

Wow, we did it? Did we? Well, we are not producing enough lift at the balance AoA but we are very close! Lets look at the performance.



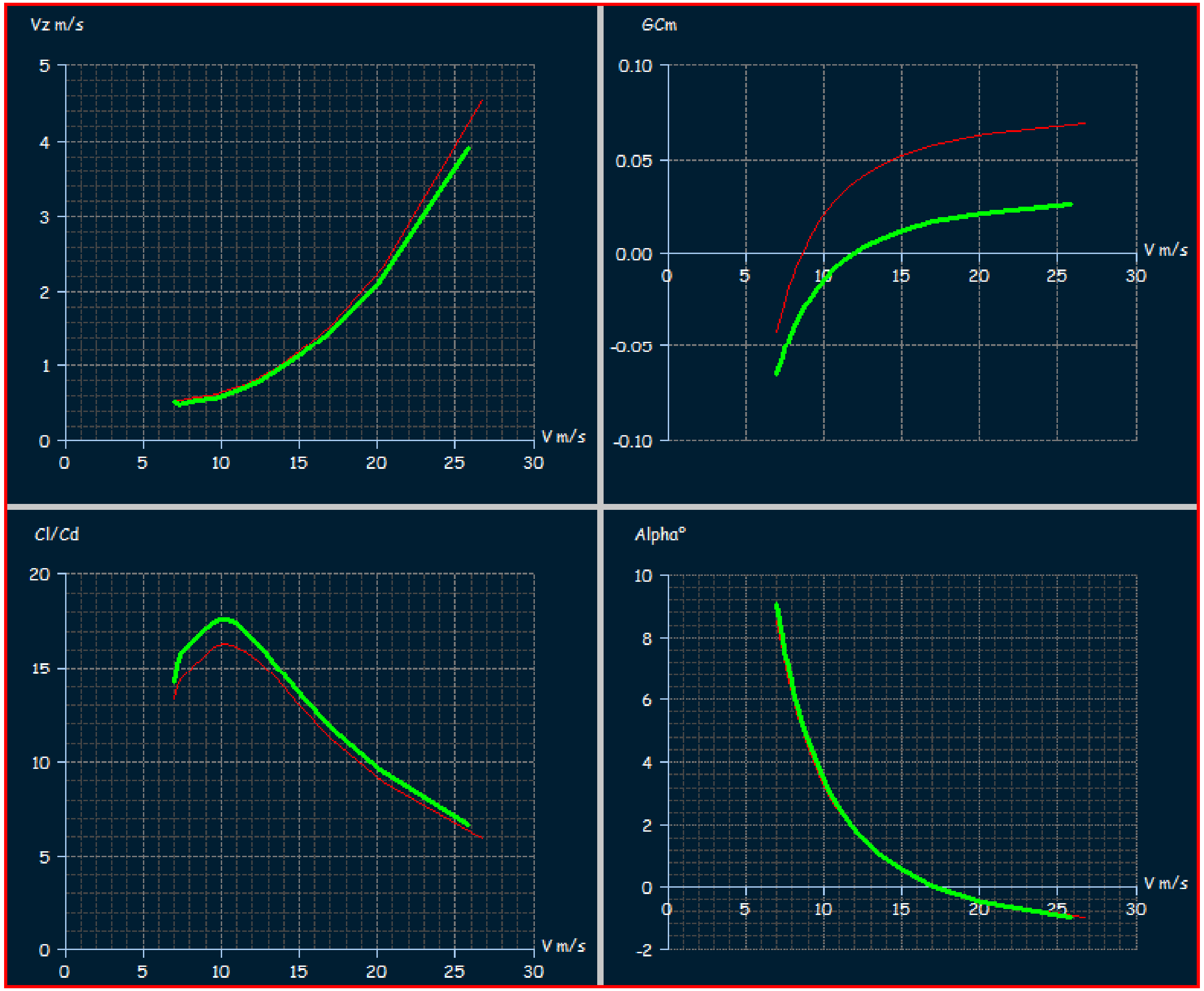
Better performance?

Vz vs V
Almost the same!

GPm vs V
Wow, the trim-speed is now at 12m/s!

Cl/Cd vs V
Higher ratio at the same speed as before! This is a better glider!

Alpha° vs V
Almost the same!



So? Is it better?

- Yes, much better, but far from perfect!
- The Cl/Cd ratio is better and the plane can now go faster.
- The balance AoA does not bring enough lift so we always have to „pull up“ to keep on „floating“ but we can go much faster → more a slope machine! But we can „fix“ that: just build the model with less weight!!!!! ☺
- So what to do to make it „perfect“? → Redesign it! ☺

Common mistakes

„I was told the profile XYZ123 is the best! Why does it suck so much in XFLR5?“

A: Do you use the profile within the right wing geometry with the right boundary condition it was made for?

Common mistakes:

- → Using a profile that was designed for high aspect ratios on short and deep wings
- → Using the profile at the wrong Re numbers
- → Doing some „modding“ of a profile just because it looks „better“
- → Making a wing design by artists and not by technicians
- → Using a profile on a self-design airplane just because it „goes good“ on another airplane that is „almost“ the same

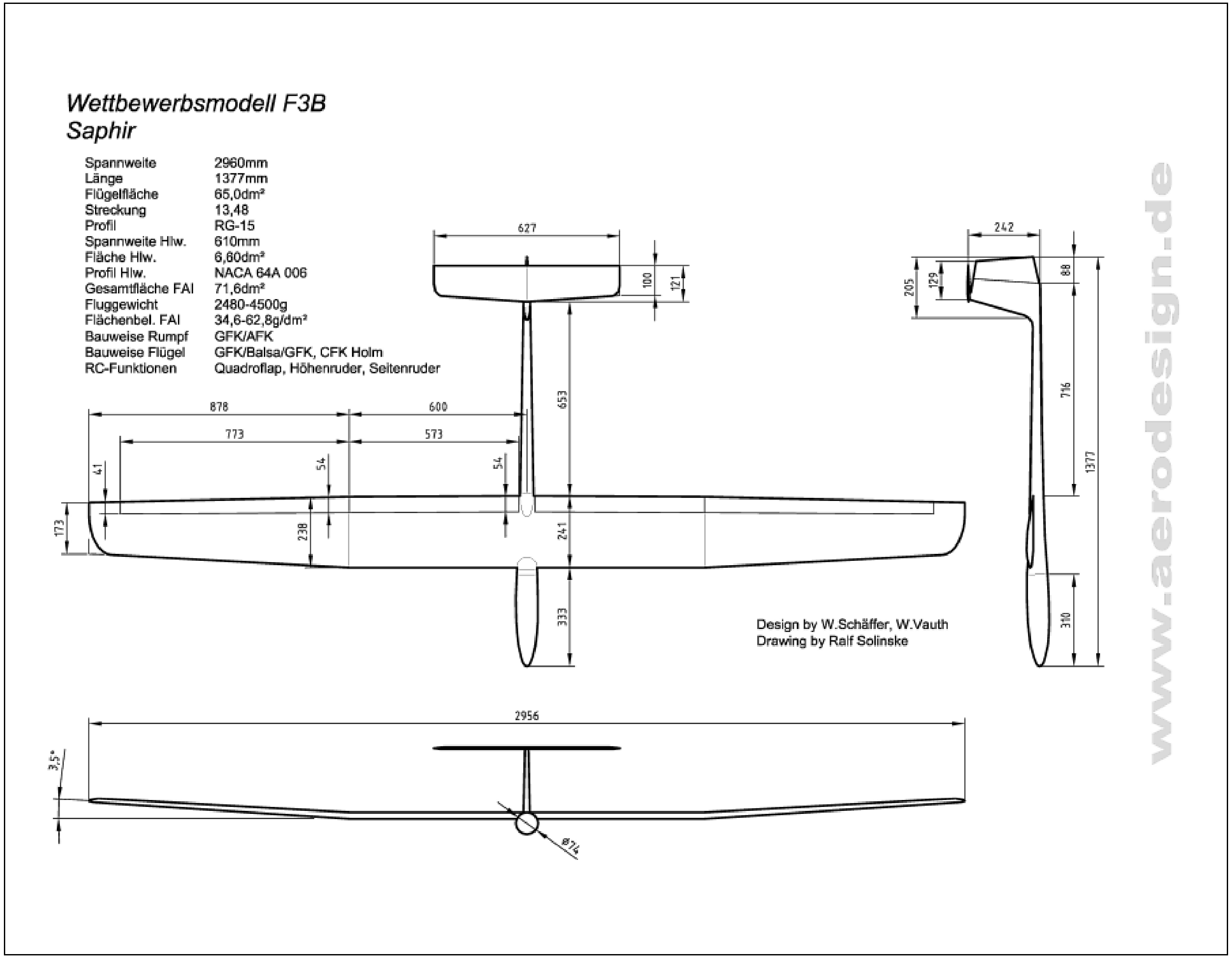
What about the other profiles?

- If you took a very close look at the analysis you see that the NACA 2410 and the MH32 have always been very close. This is not a random result. The NACA2410 is/was used for more than 30 on all kind of airplanes.
- The HQ/W 3/8 is for „bigger“ models and designed for the use of flaps.

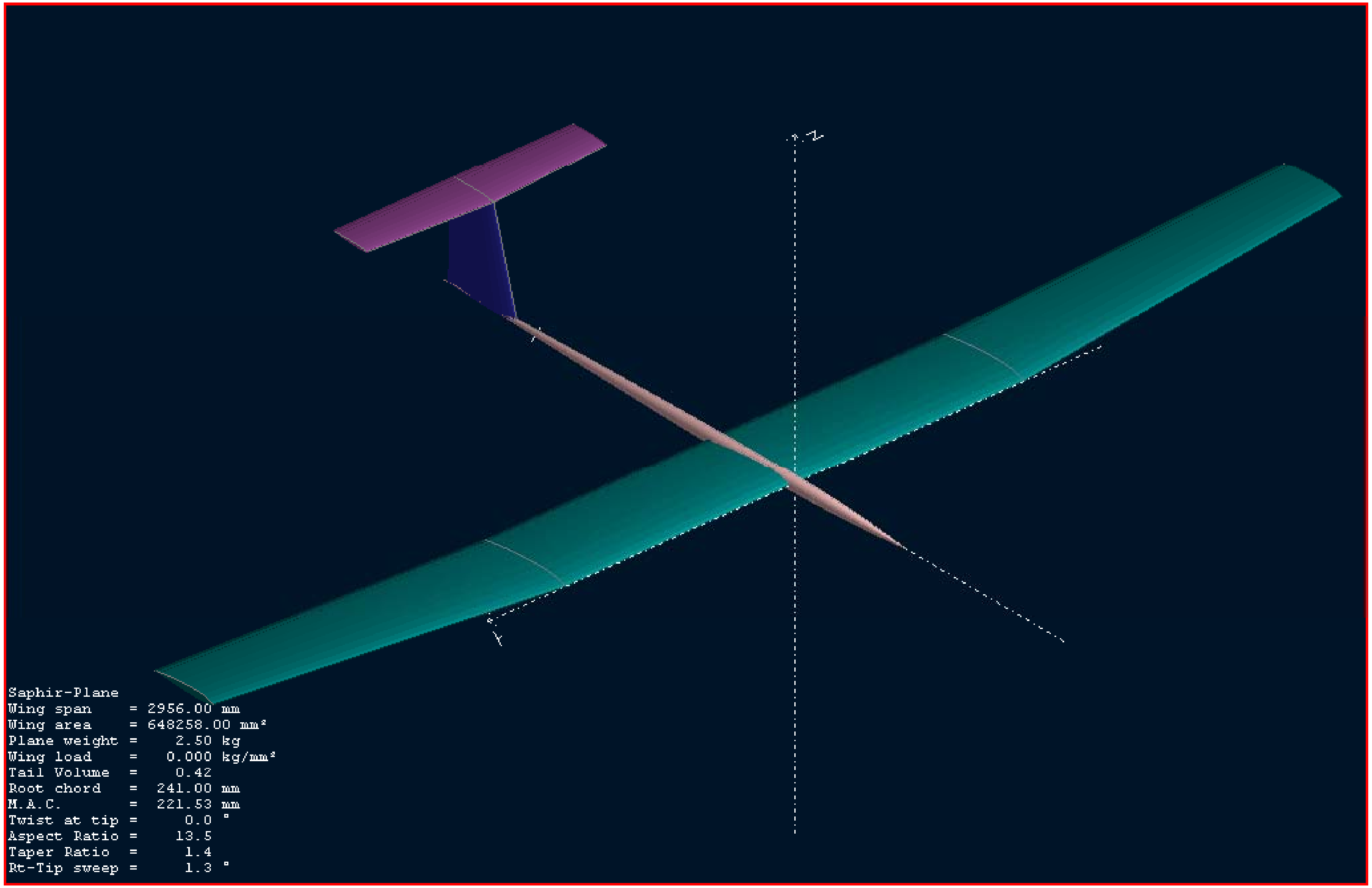
→ What would be a good profile?

→ Depends on the geometry. Lets try a good airplane and compare the results !

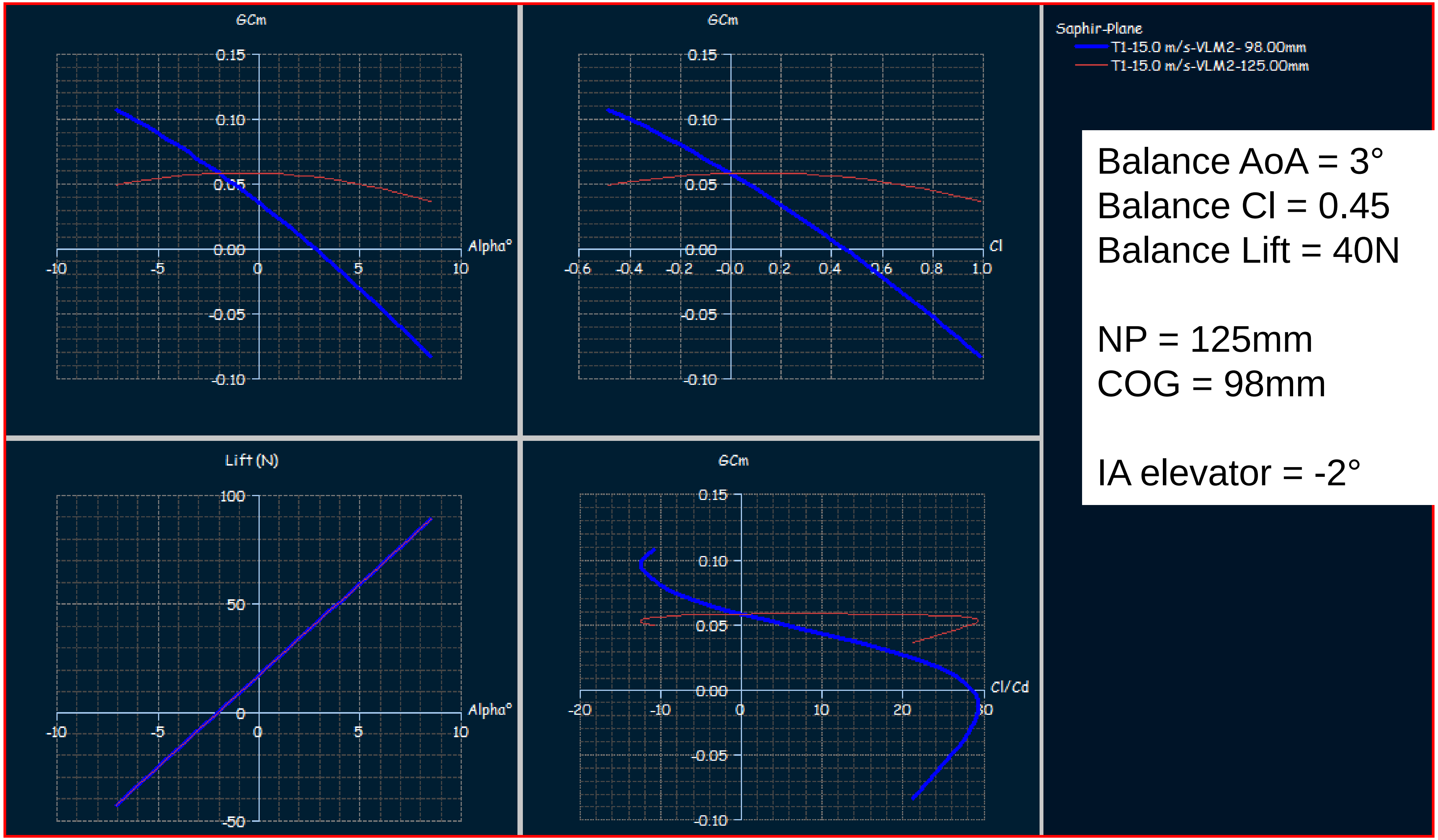
Saphir – A glider



Saphir in XFRL5



XFLR5 results - Stability



Balance AoA = 3°
Balance Cl = 0.45
Balance Lift = 40N

NP = 125mm
COG = 98mm

IA elevator = -2°

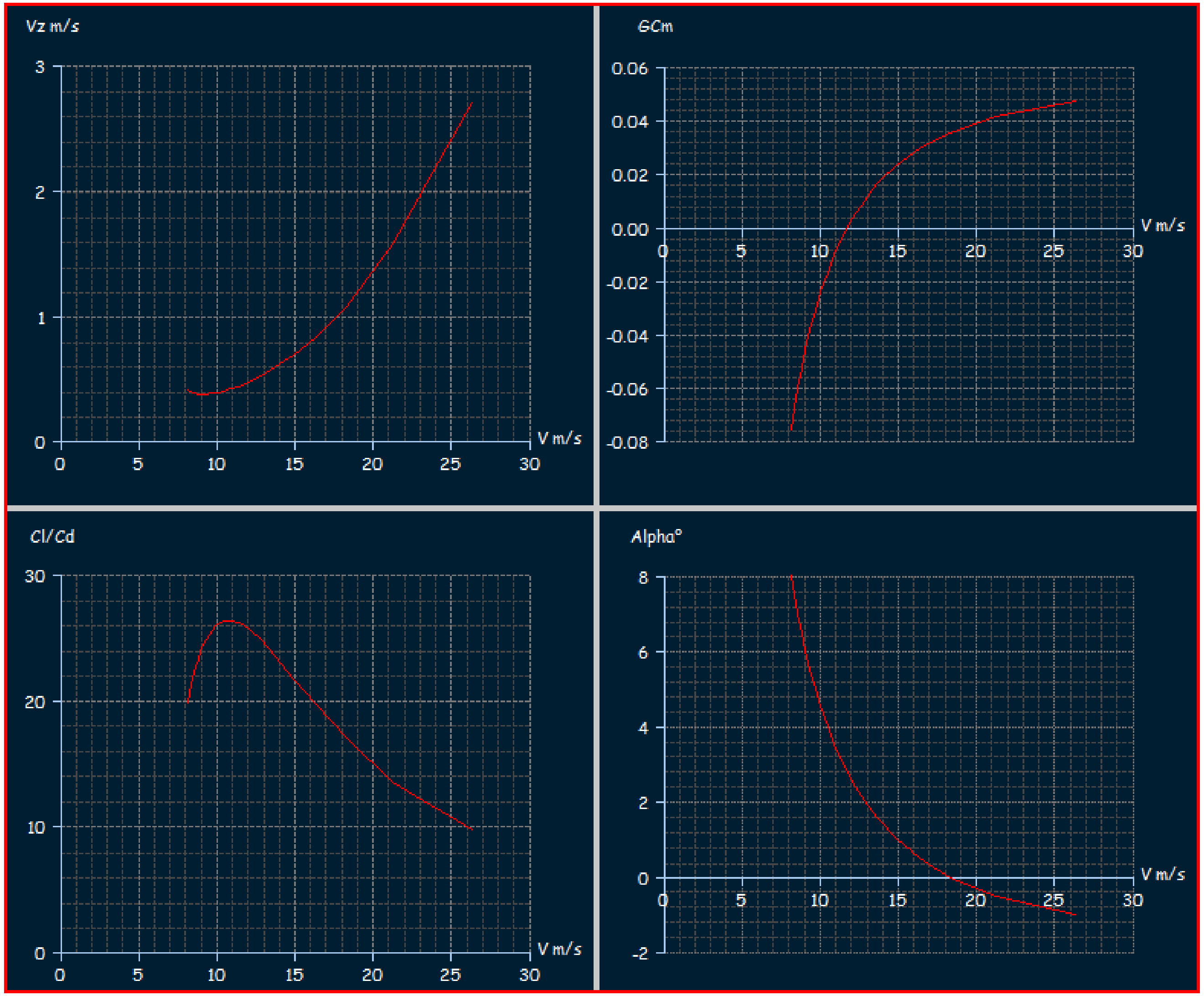
XFLR5 - Performance

Min sink rate of 0.4m/s @ 9m/s

Trim-Speed ~11.5m/s

Max Cl/Cd 26 @ 11m/s

„Stall Speed“ ~8m/s



Lets compare

- Our plane:
  - Trim-Speed: ~12m/s
  - Trim AoA: ~2°
  - Max Cl/Cd ~18 @ 10m/s
  - Min sink rate ~ 0.5m/s @ 7m/s
- Saphir:
  - Trim-Speed: ~11.5m/s
  - Trim AoA: ~3°
  - Max Cl/Cd ~ 26 @ 11m/s
  - Min sink rate ~ 0.4m/s @ 9m/s

➔ Saphir glides much better max Cl/Cd is much higher!

➔ Which one is better? This is part of another analysis ☺