RUSSIAN HELICOPTERS

ОБЪЕДИНЕННАЯ ПРОМЫШЛЕННАЯ КОРПОРАЦИЯ ОБОРОНПРОМ

Evdokimov I.E.
Ivchin V.A.

APPLICATION OF GENETIC METHODS FOR SURROGATE MODELLING AND AIRFOIL SHAPE OPTIMIZATION

23rd September 2014

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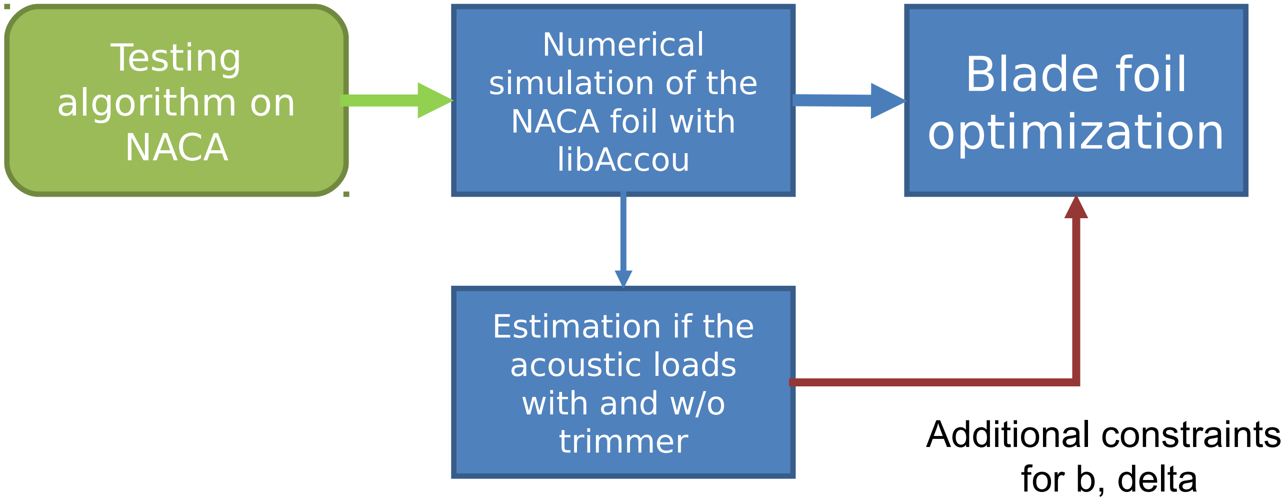
STAGES AND PURPOSES

Main purpose is to find optimal geometry for airfoil trimmer (length- b, angle - delta)



Testing algorithm on NACA:

- obtain information about proper numerical schemes used to simulate airfoil with trimmer from experimental data for airfoils without trimmers

- compare simulation data for NACA with trimmer with experimental data for special helicopter airfoil, also with trimmer (comparing moment characteristics is the most important topic here)

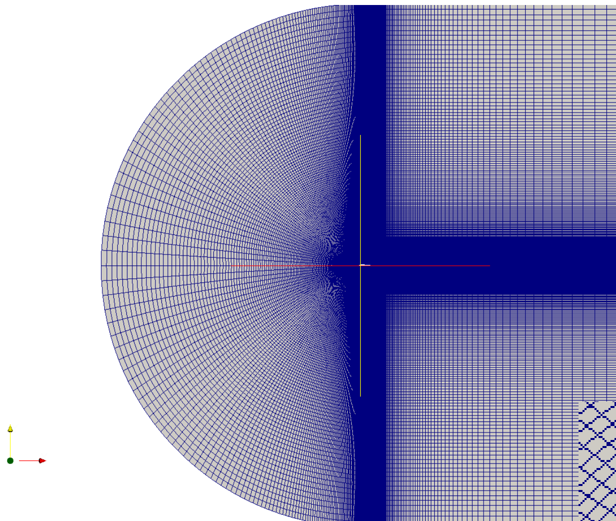
- Validation

Validation

Numerical schemes requirement (by priority):

- Stability
- Fast convergence
- Accuracy in Cx, Cy, Mz

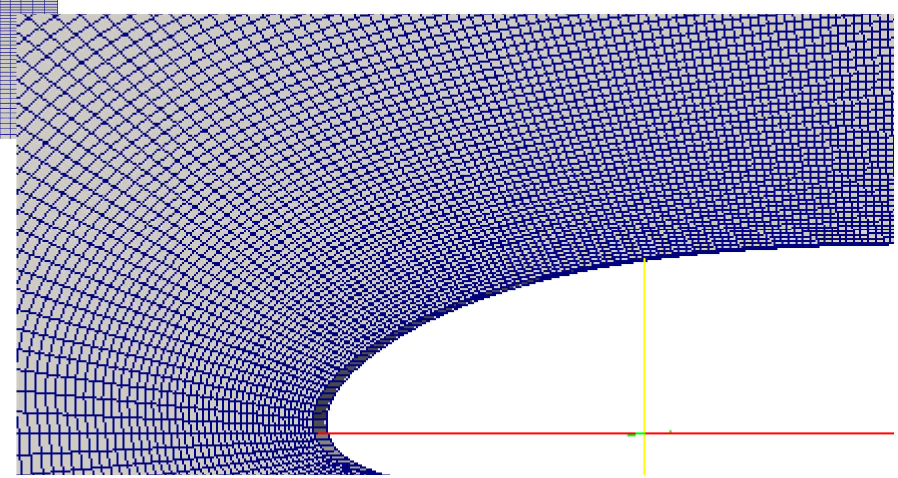
Mesh:



C – mesh with BC of types:

1.Freestream

2.Inlet-outlet



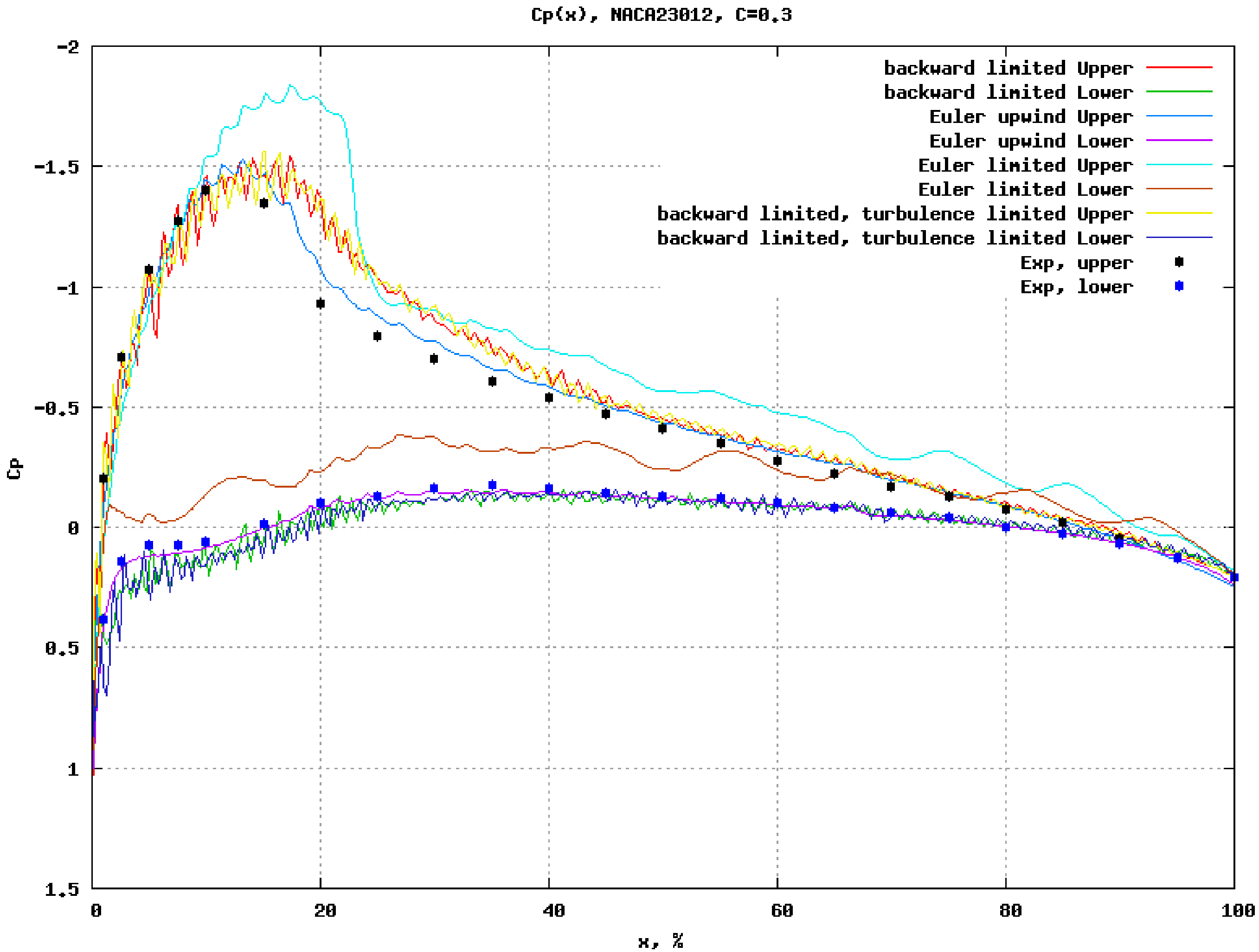
Solvers:

1.sonicFoam

2.RhoCentralFoam

y+<100, wallFunctions

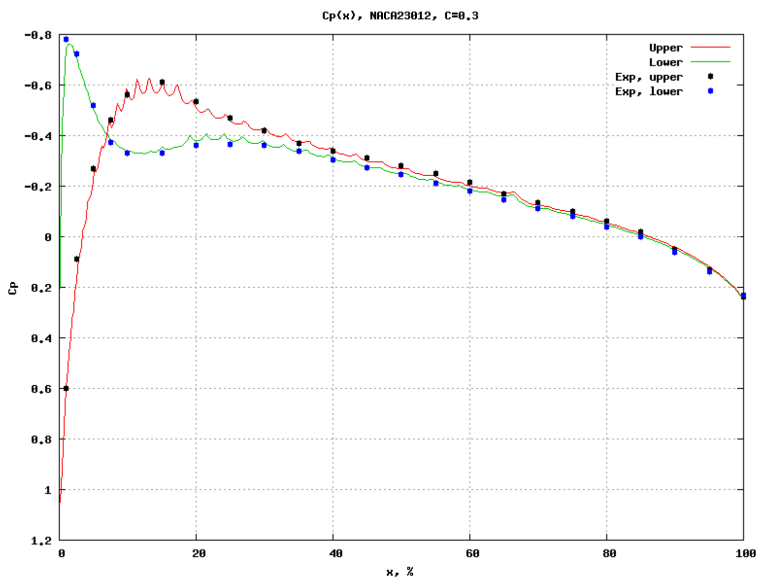
Validation



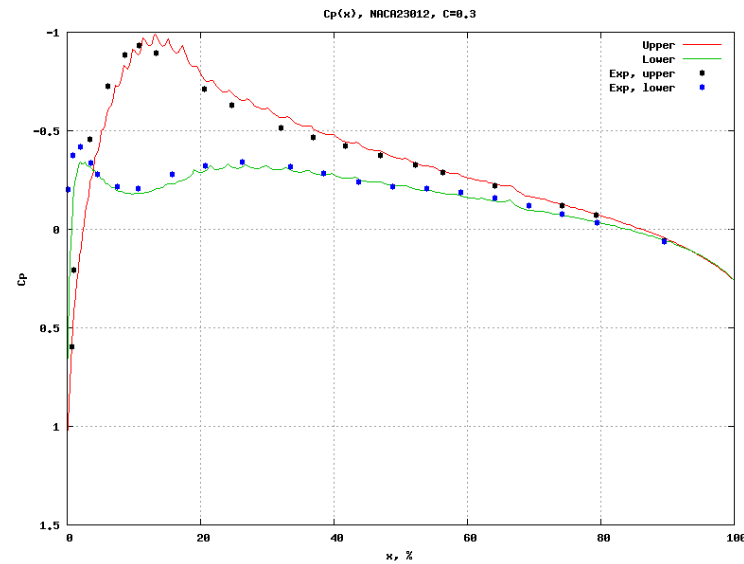
sonicFoam, M = 0,6 ; *Alpha* = 3°

fvSchemes configuration:

- solver - *sonicFoam*;
- *div*(*phi;U*) - Gauss linearUpwindV grad(U);
- *div*(*phid; p*) - Gauss blended 0.5;



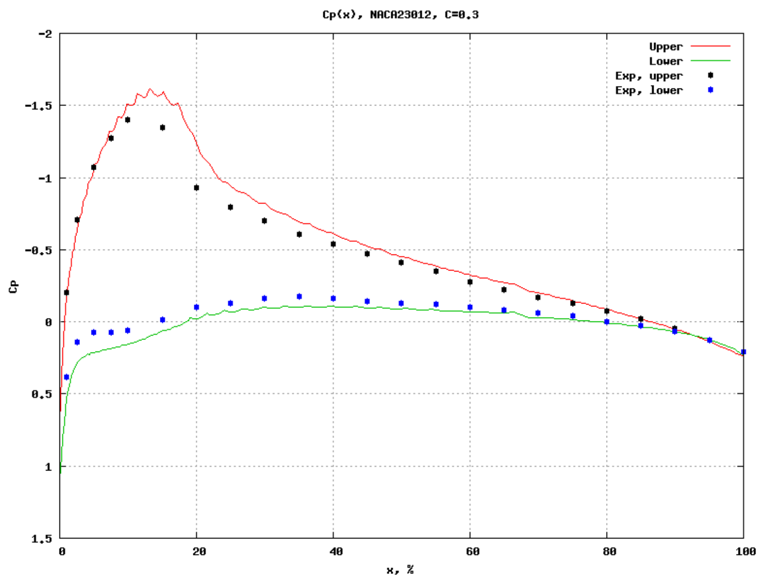
sonicFoam, *M* = 0,6 ; *Alpha* = -1,2°



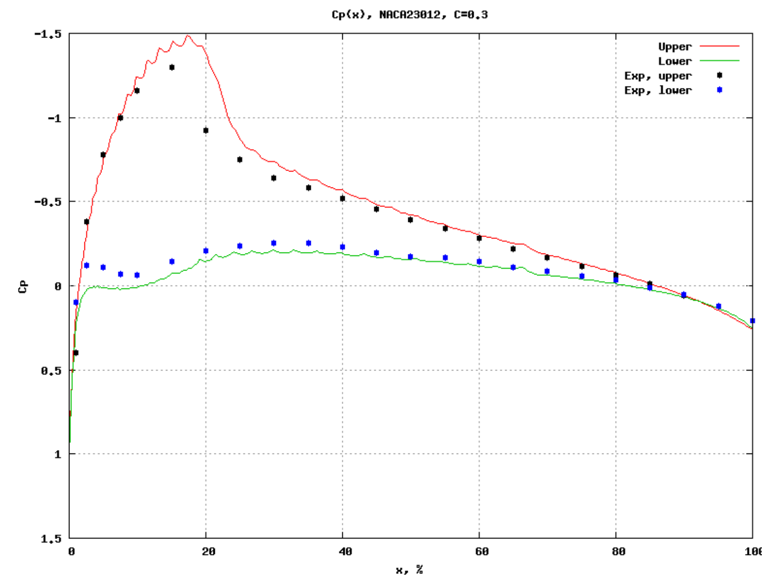
sonicFoam, *M* = 0,6 ; *Alpha* = 0,17°

Gorsky I.P., The investigation of the pressure distribution on the wing's foils at the high speed, TZAGI works: 1946.

Validation



sonicFoam, M = 0,6 ; *Alpha* = 1,67°



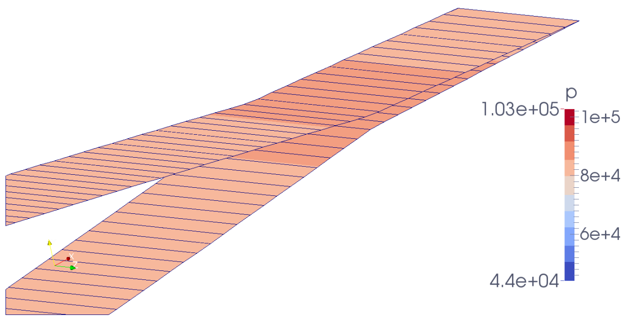
sonicFoam, M = 0,6 ; *Alpha* = 3°

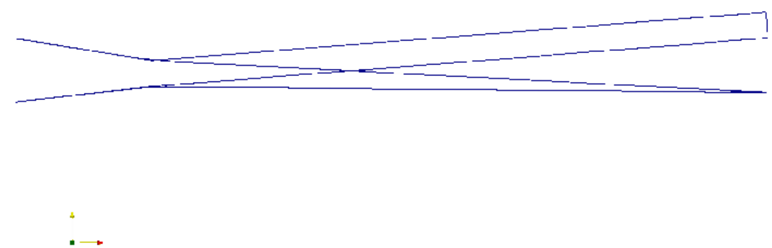
```
ddtSchemes
                    backward
divSchemes
                    div(phi,U)      Gauss linearUpwindV grad(U);

                    div(phi,k)      Gauss upwind;
                    div(phi,omega)  Gauss upwind;
                    div(phid,p)     Gauss blended 0.5;
```

Gorsky I.P., The investigation of the pressure distribution on the wing's foils at the high speed, TZAGI works: 1946.

Implementations of the trimmer at the end of the foil:

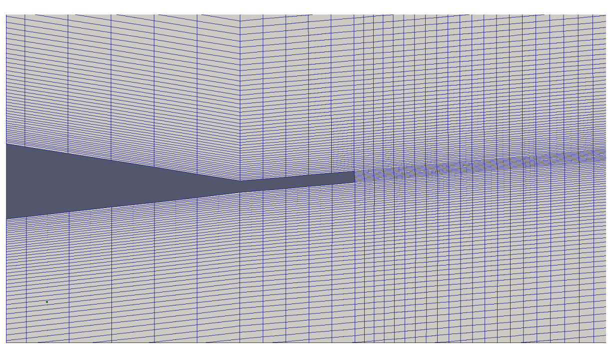
Sharp edge

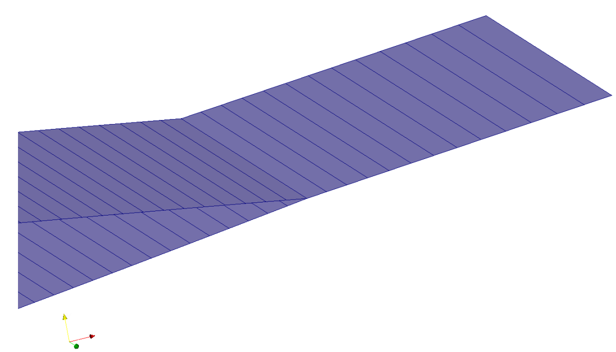




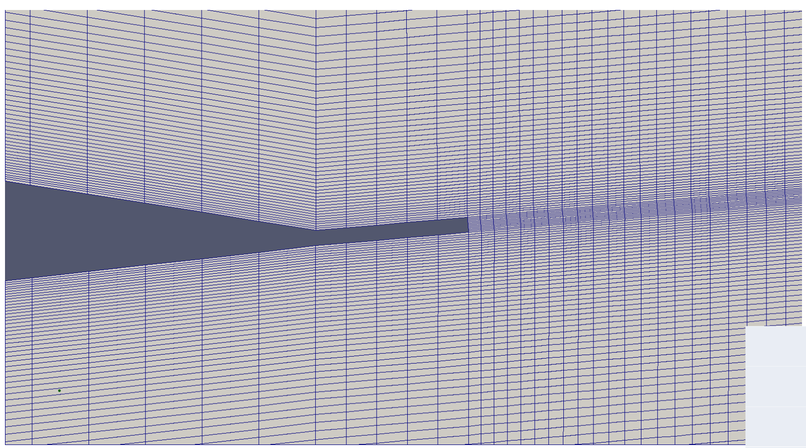
Thick edge

“Baffle”



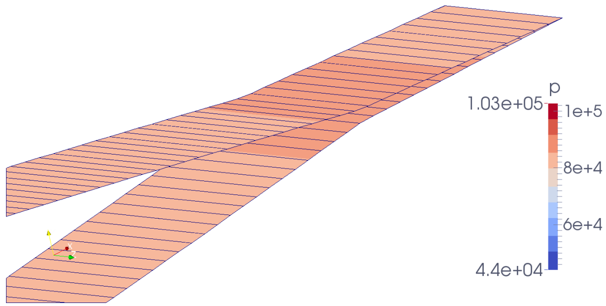


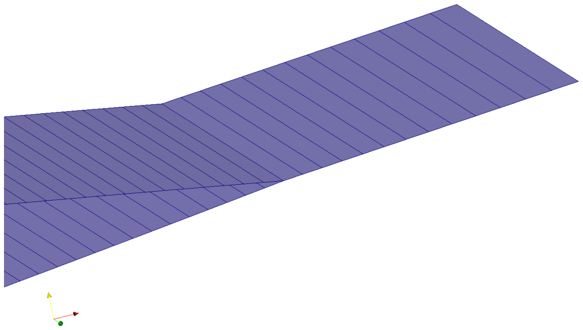
- According to simulation results, the case with “thick” trimmer does not produce any changes in Mz.
- The reason was not investigated

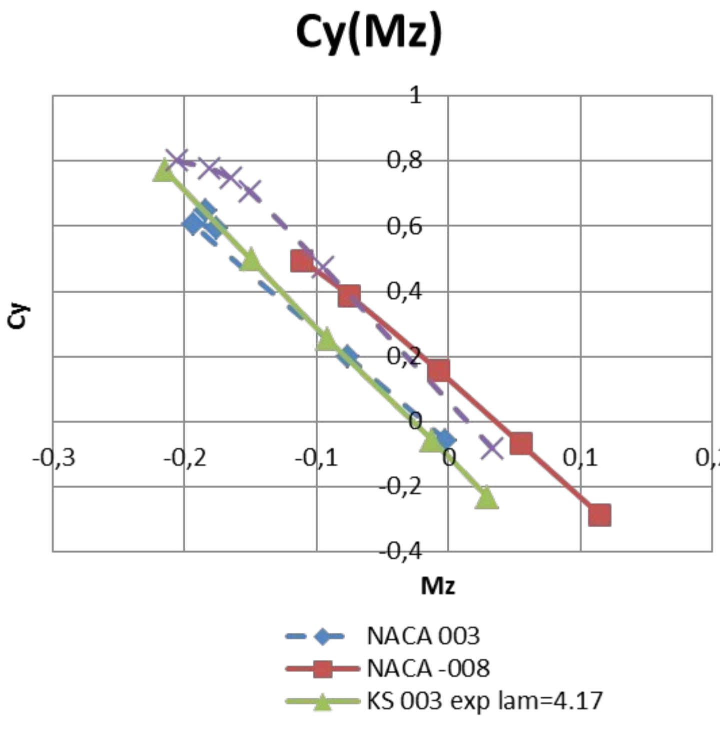


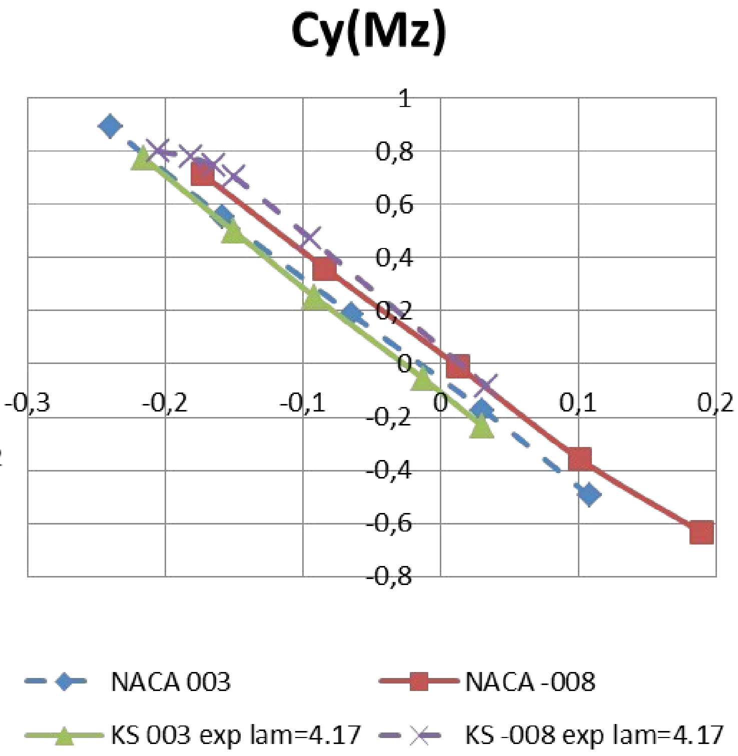
	r	delta	alpha	Mz
1	18	1,75	-5	0,1248365
2	18	1,75	-2,5	0,121256
3	18	1,75	0	0,1221417
4	18	1,75	2,5	0,1221133
5	18	1,75	5	0,1220588

Validation

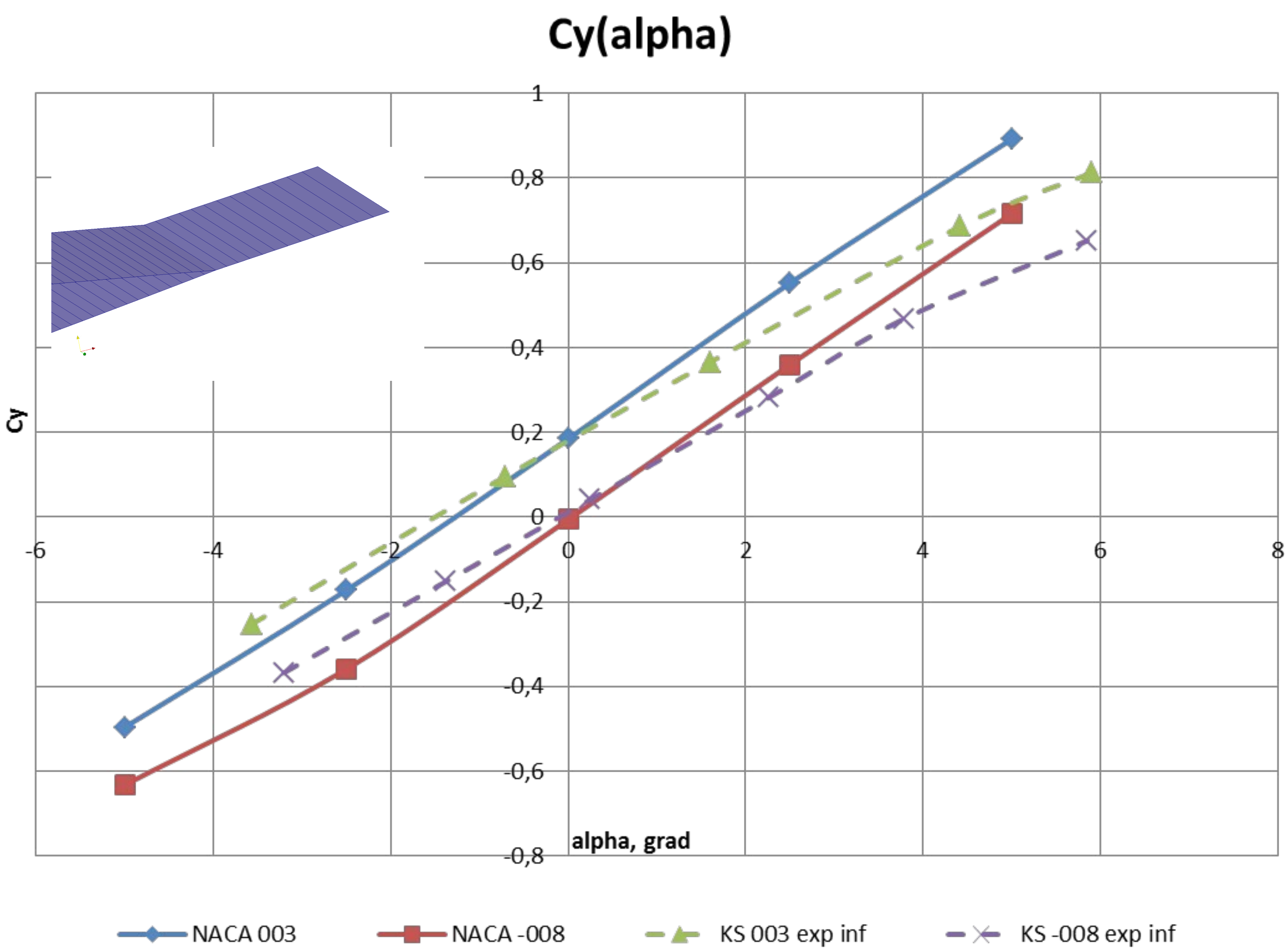

p
1.03e+05
1e+5
8e+4
6e+4
4.4e+04




Cy(Mz)
Cy
Mz
NACA 003
NACA -008
KS 003 exp lam=4.17


Cy(Mz)
NACA 003
NACA -008
KS 003 exp lam=4.17
KS -008 exp lam=4.17

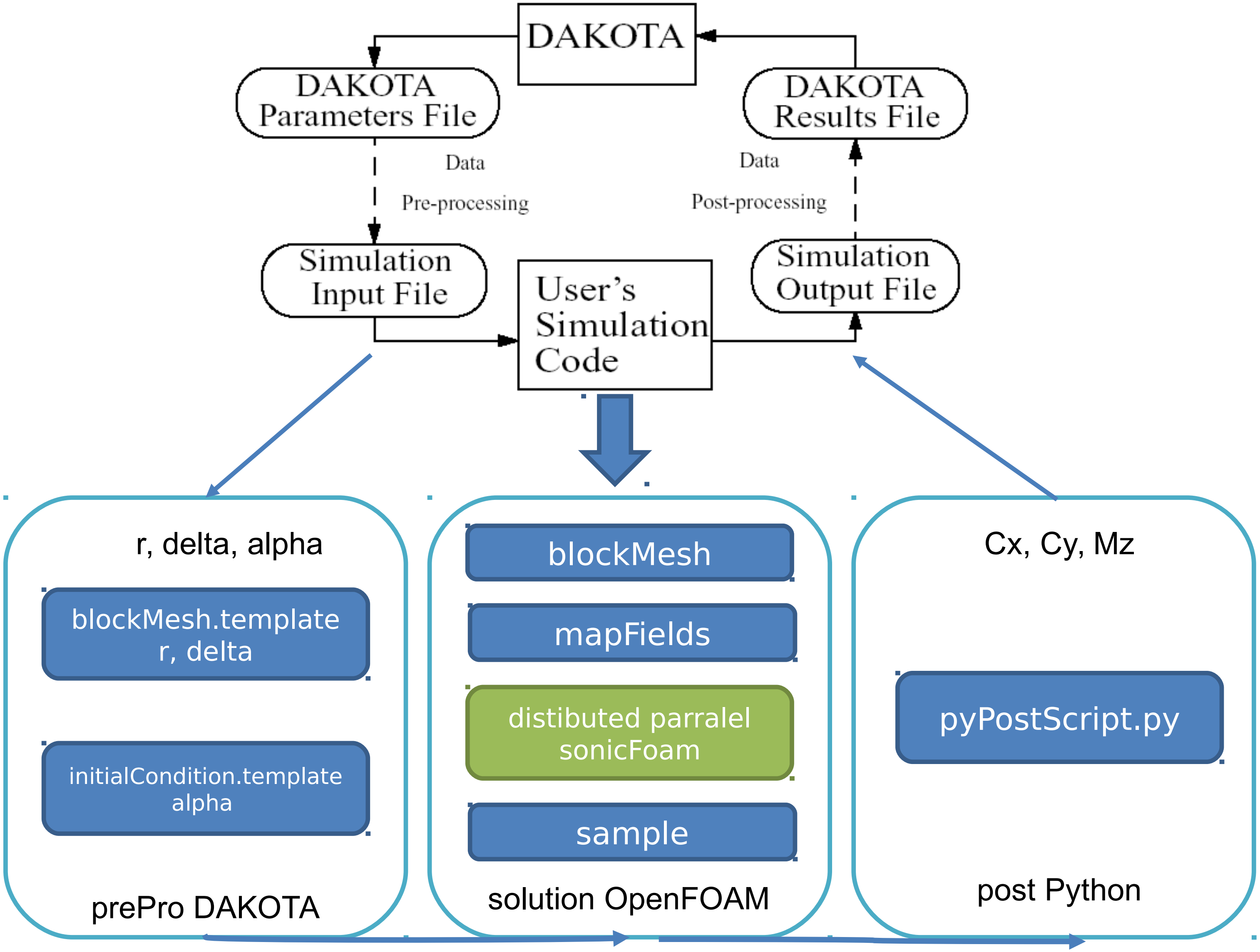
Validation



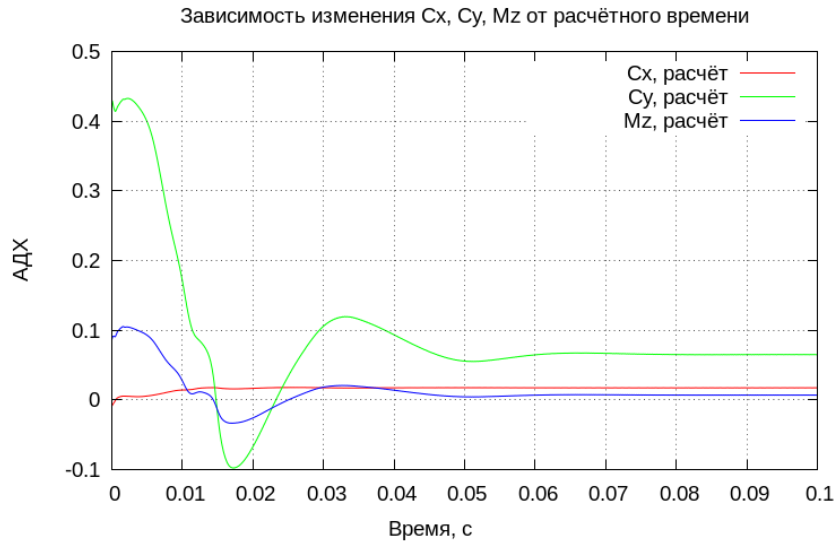
Full name of the TZAGI foil, «ВП6₀-1,7-0-0-35-12КС»

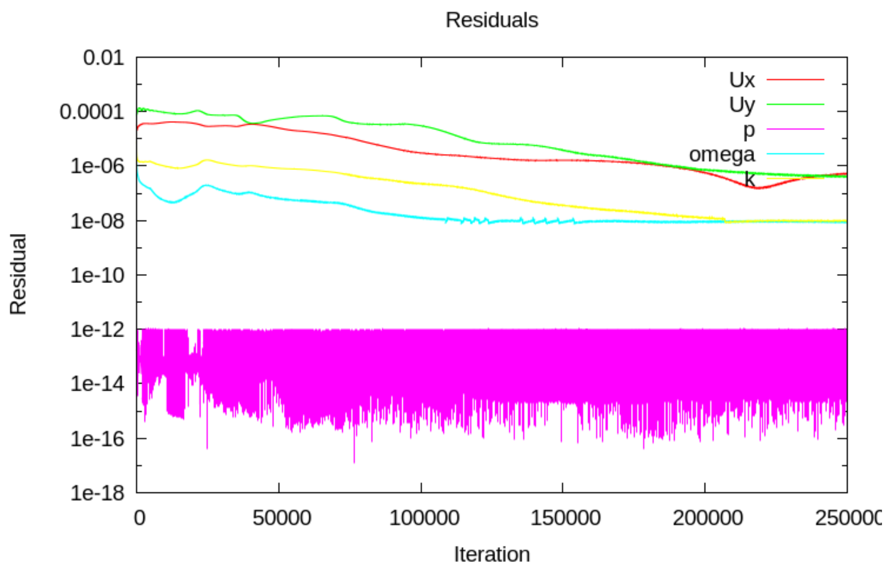
- Optimization case

Workflow


DAKOTA
DAKOTA Parameters File
DAKOTA Results File
Data Pre-processing
Data Post-processing
Simulation Input File
User's Simulation Code
Simulation Output File
r, delta, alpha
blockMesh.template r, delta
initialCondition.template alpha
prePro DAKOTA
blockMesh
mapFields
distibuted parralel sonicFoam
sample
solution OpenFOAM
Cx, Cy, Mz
pyPostScript.py
post Python

Workflow





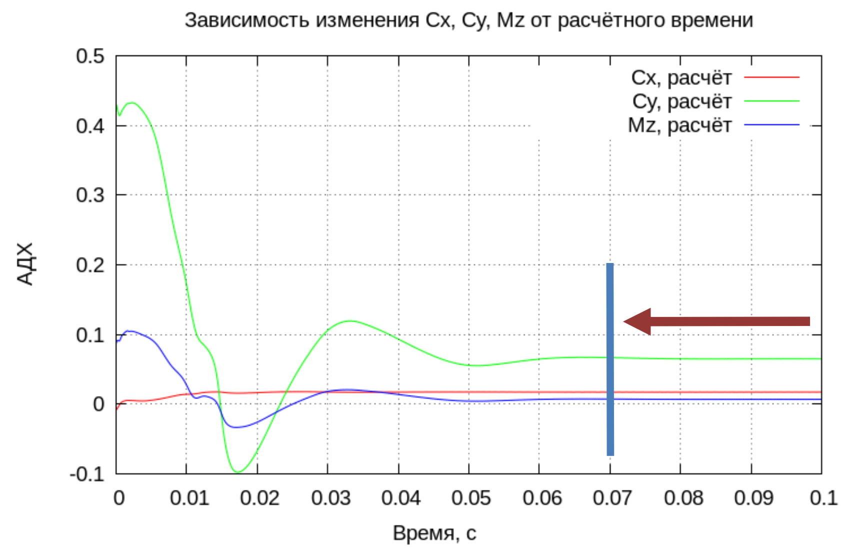
19 points – DACE (LHS)
45 points – sampling (r - var, delta – var, alpha – var)

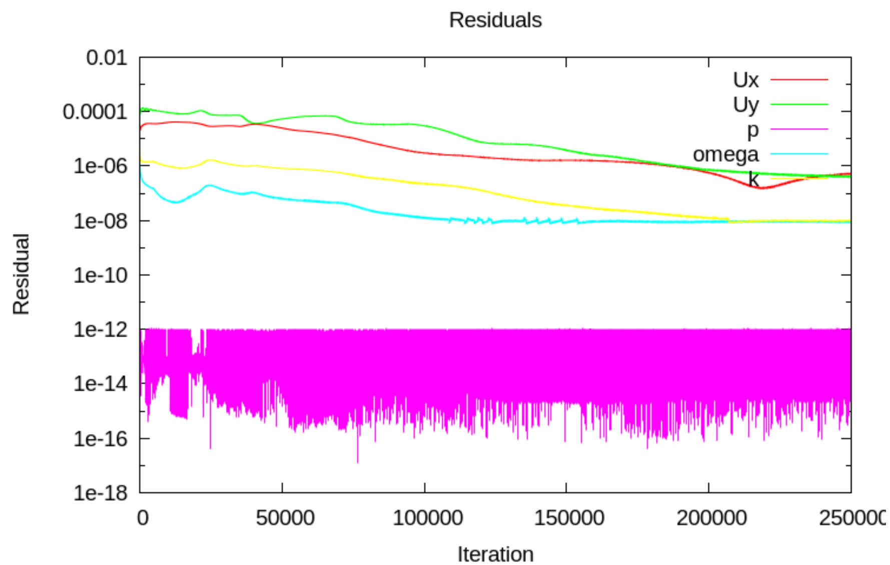
DACE:
5<r<30
-8<delta<8
-2.5<alpha<2.5

Sampling:
r = 9; 18; 36
delta = -4,5; 1,75; 6,25
alpha = -5; -2,5; 0; 2,5; 5

Time ~7 days, 24 cores

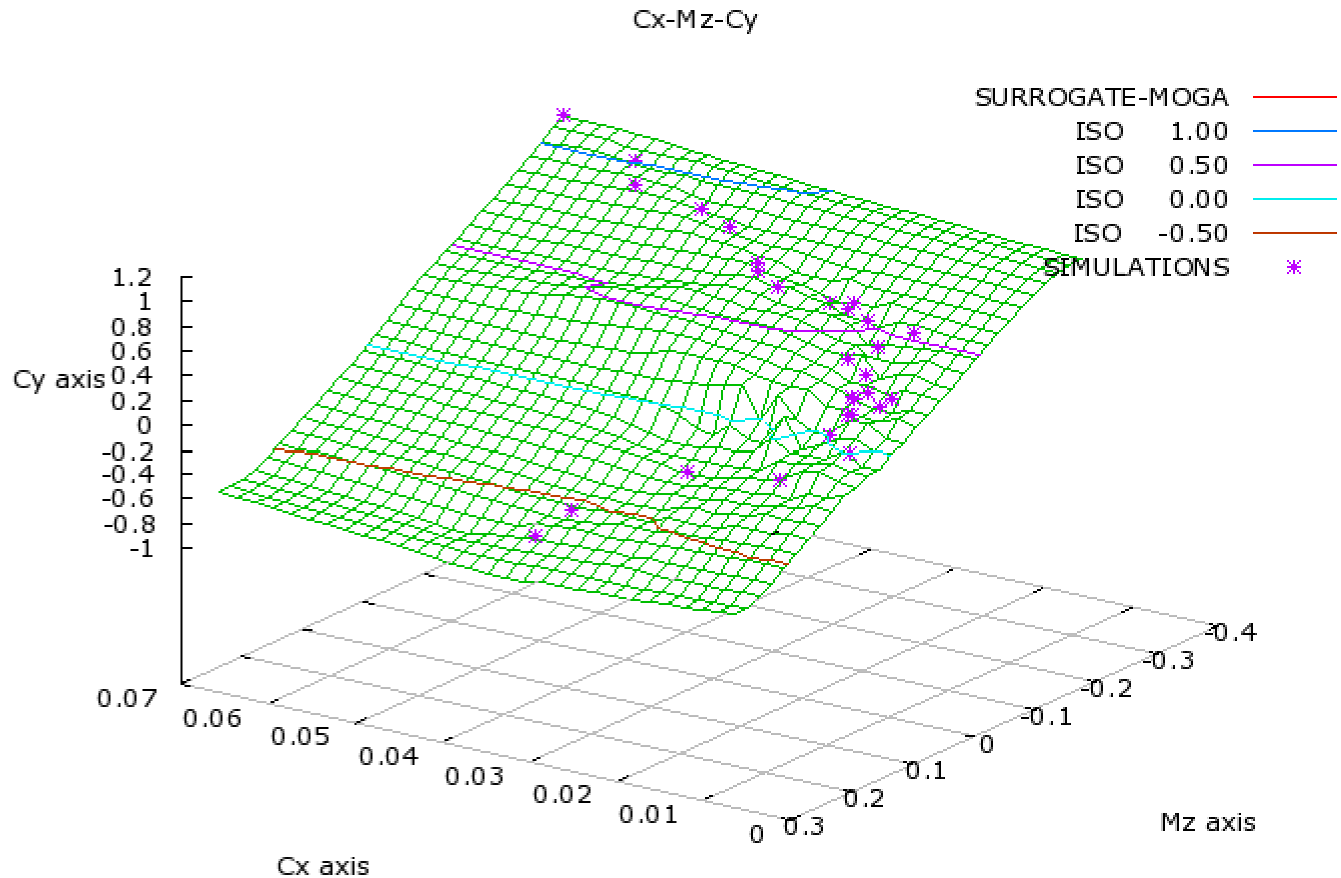
Workflow





Optimal end of simulation

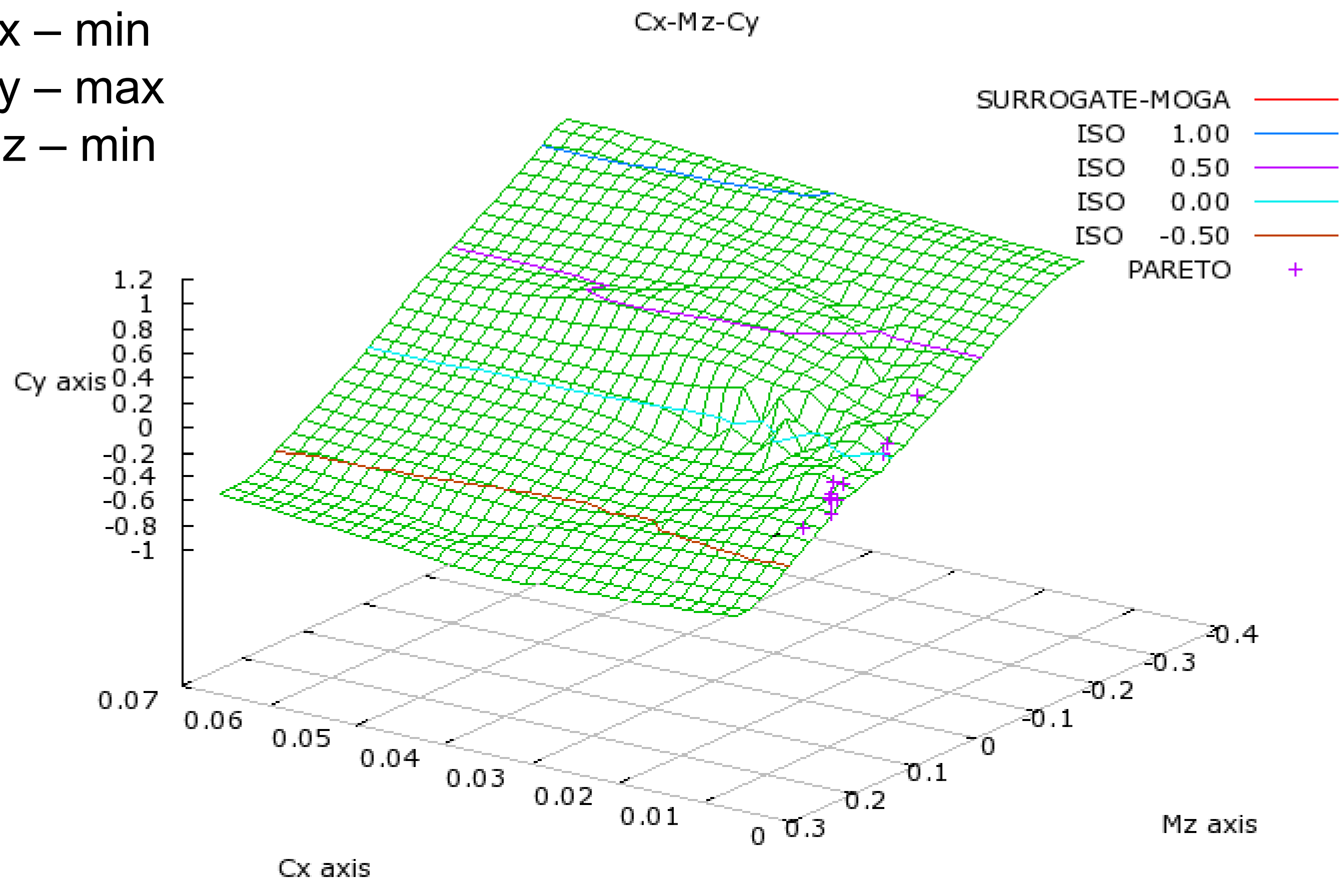
Optimization results



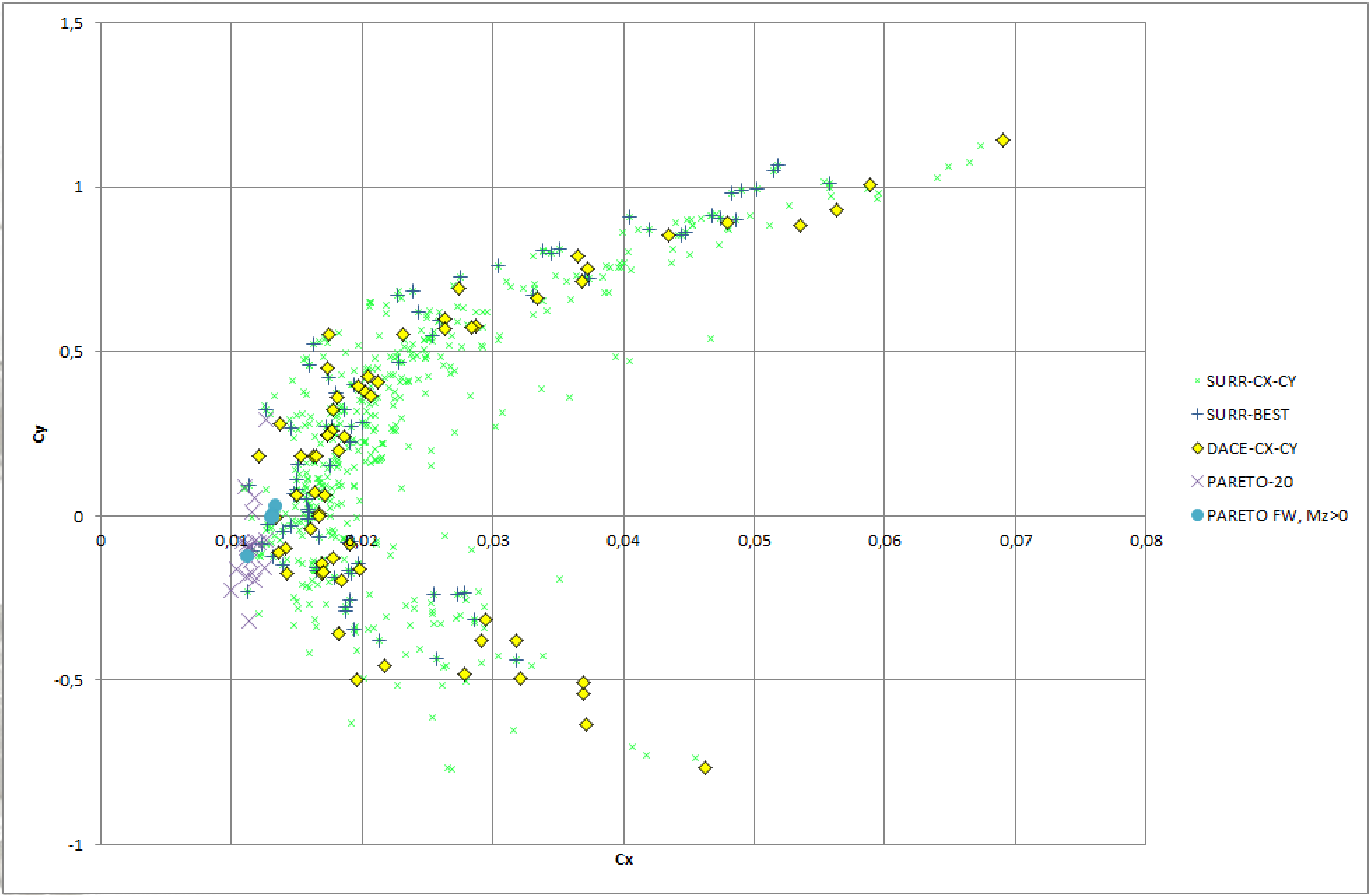
Surface extrapolated by the points of the surrogate model and original simulations poins

Optimization results

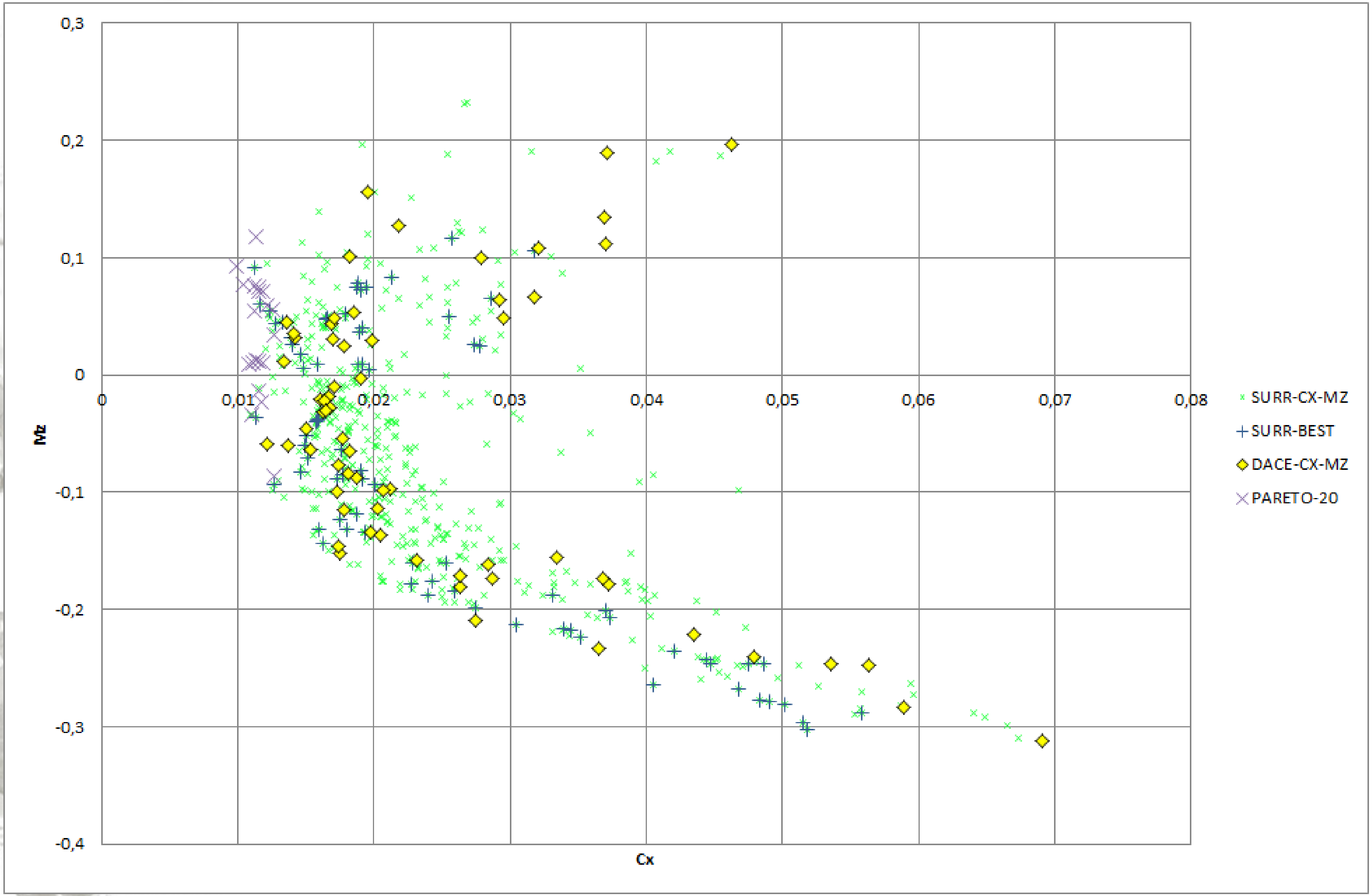
Surrogate model response surface and pareto-set points
-2<alpha<2,
Objectives:
Cx – min
Cy – max
Mz – min



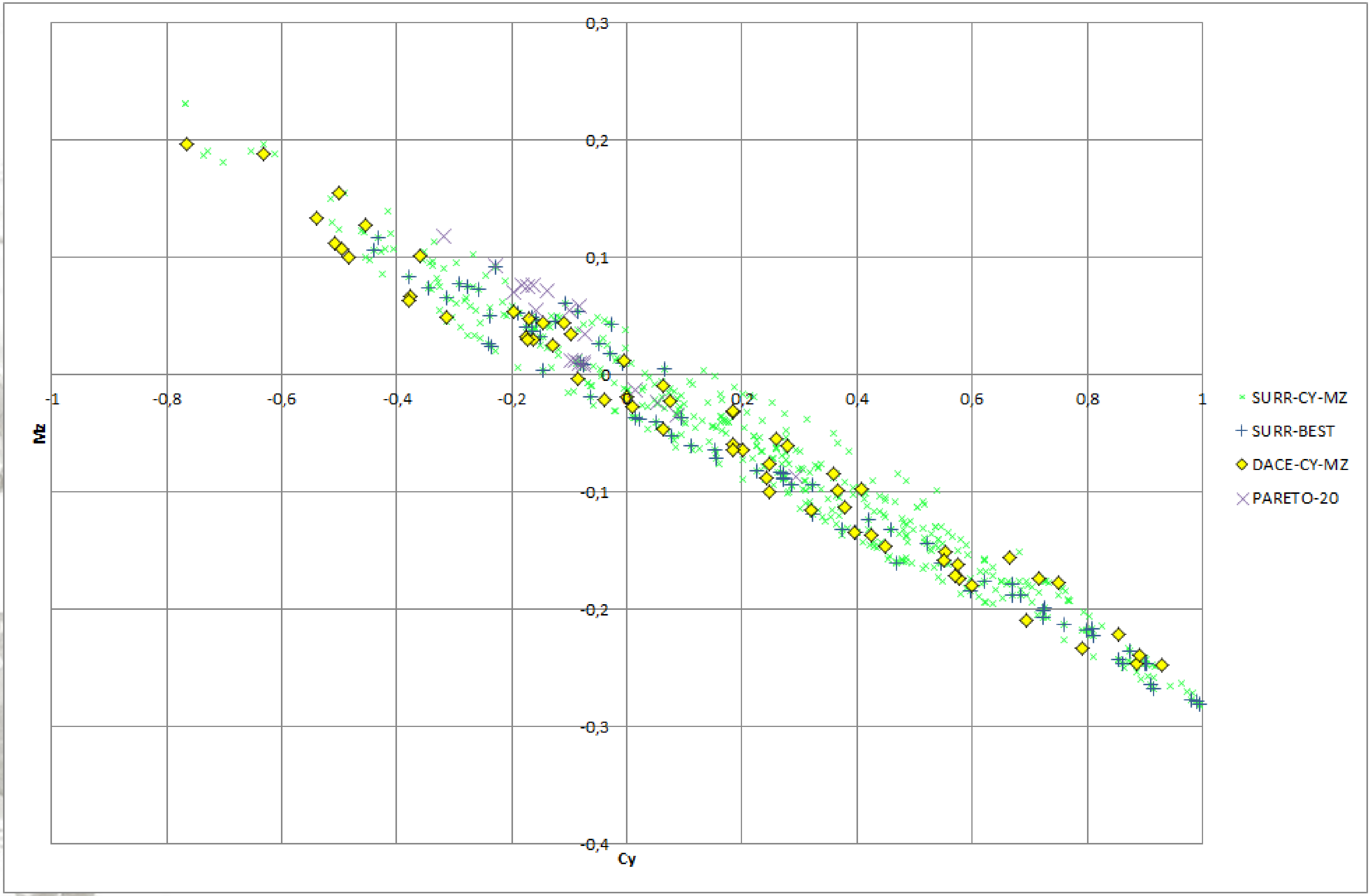
Optimization results



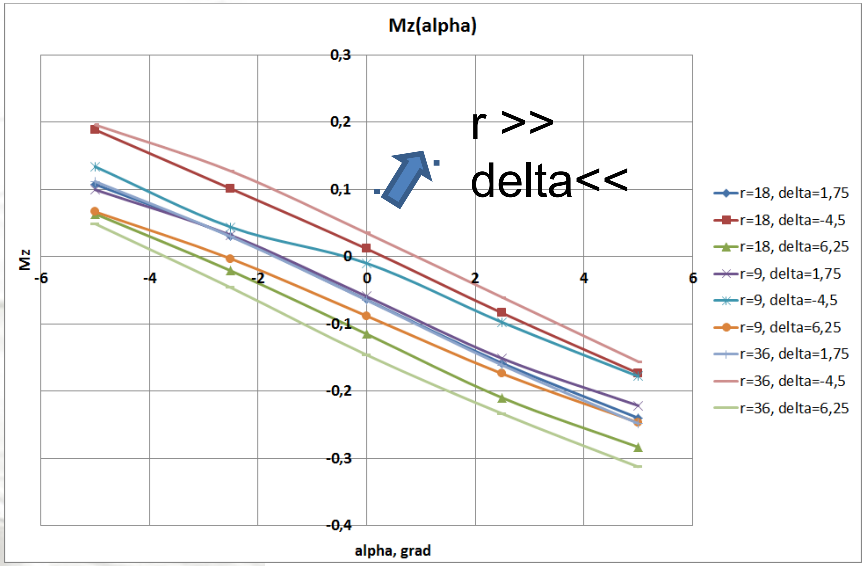
Optimization results

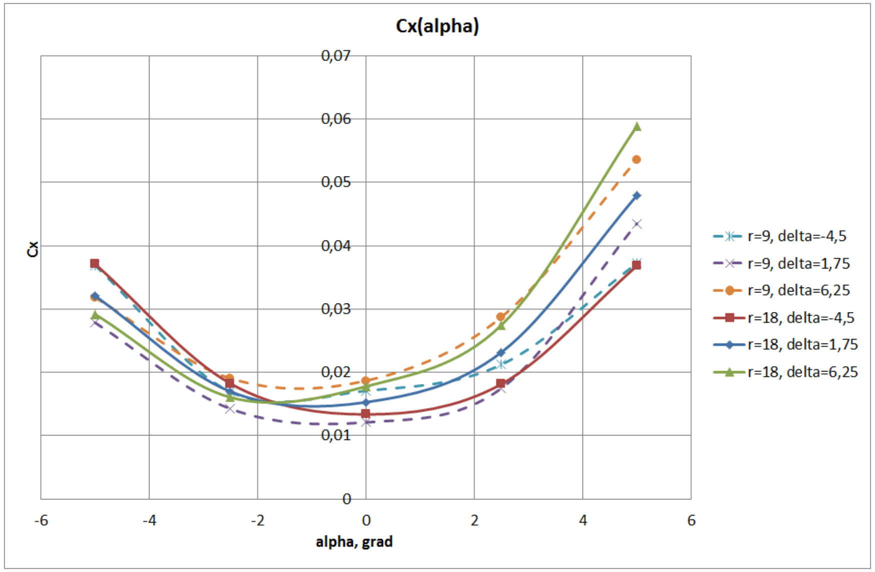


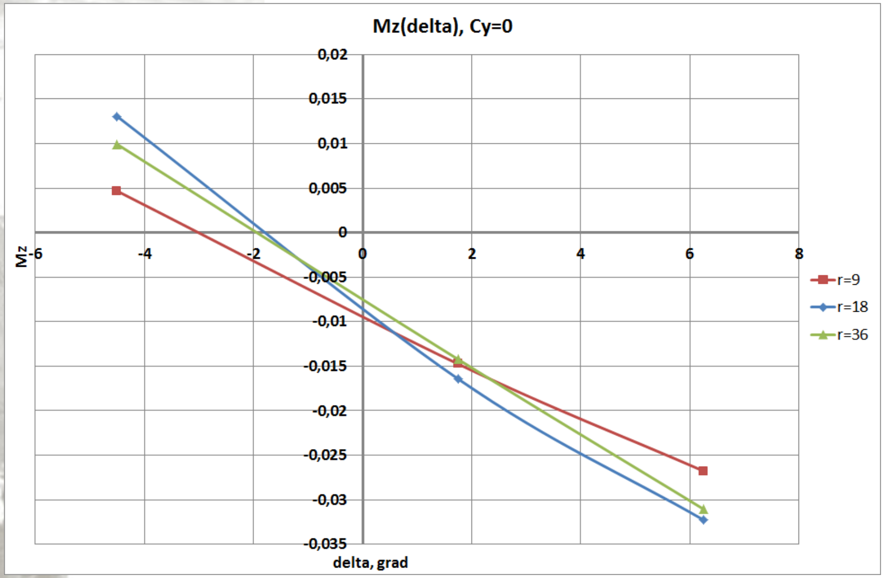
Optimization results

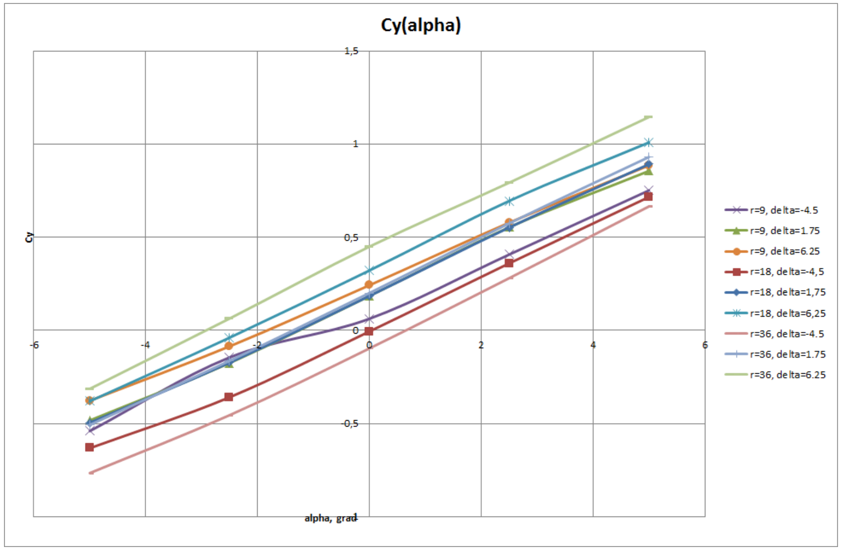


Optimization results

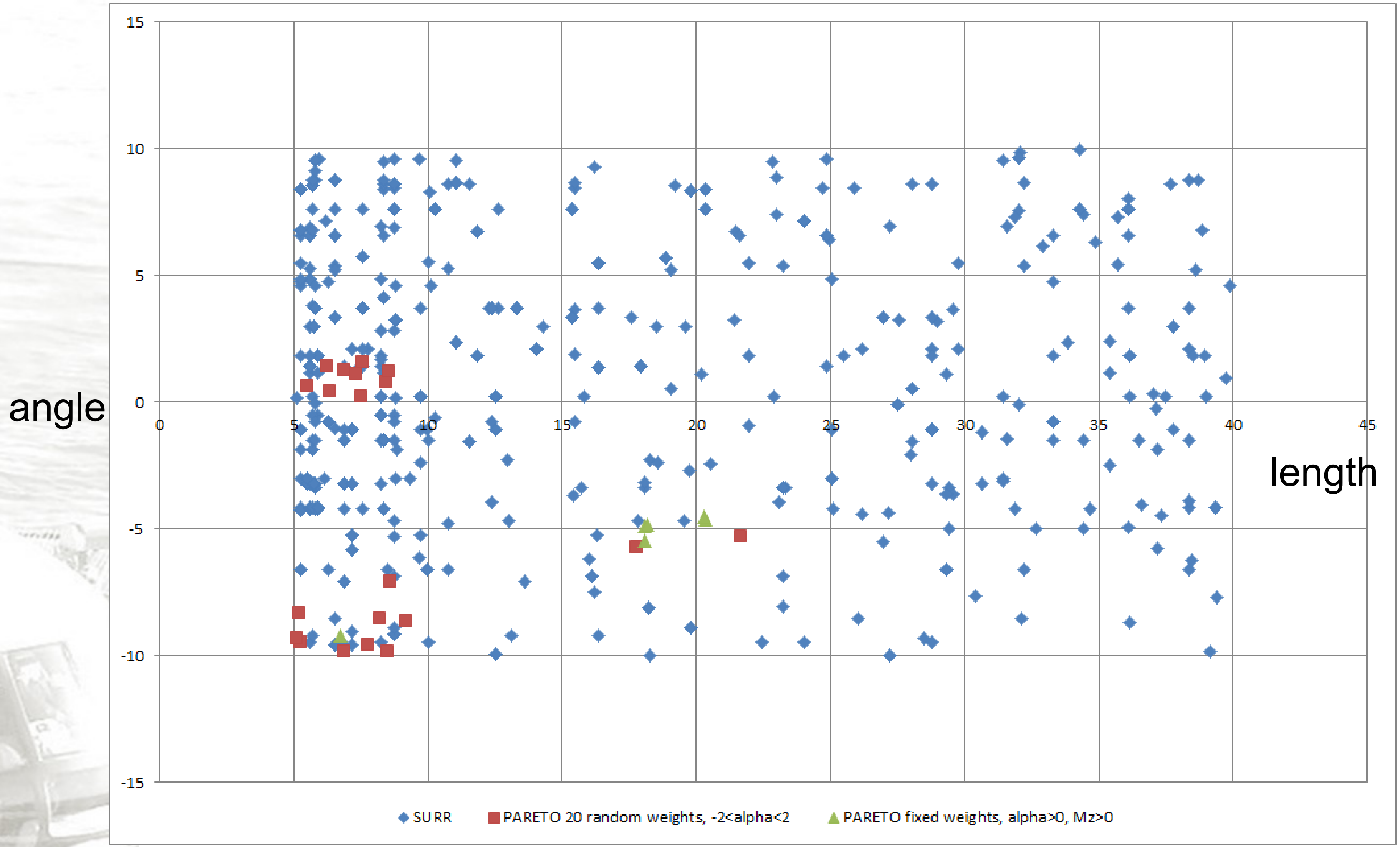




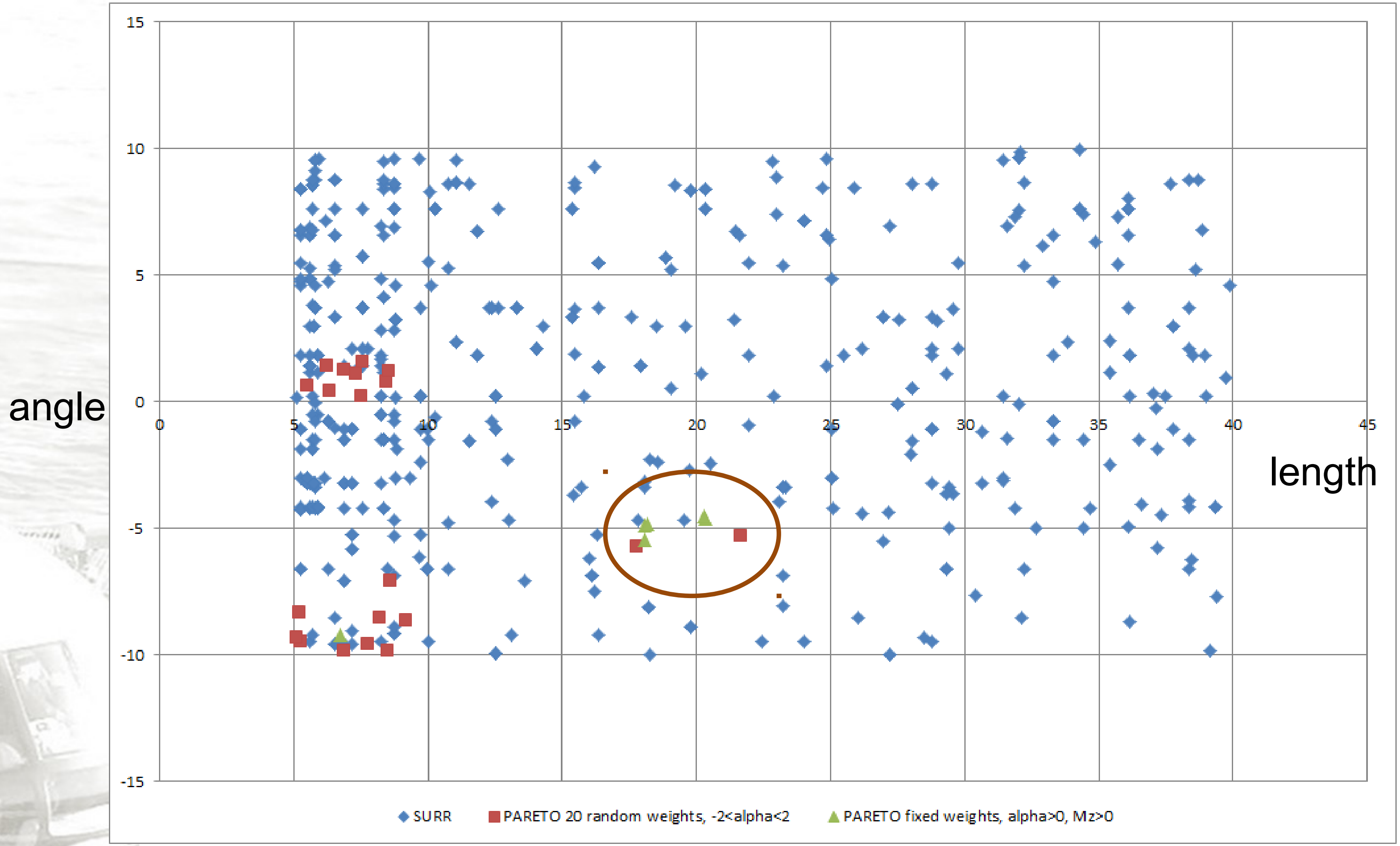




Optimization results



Optimization results



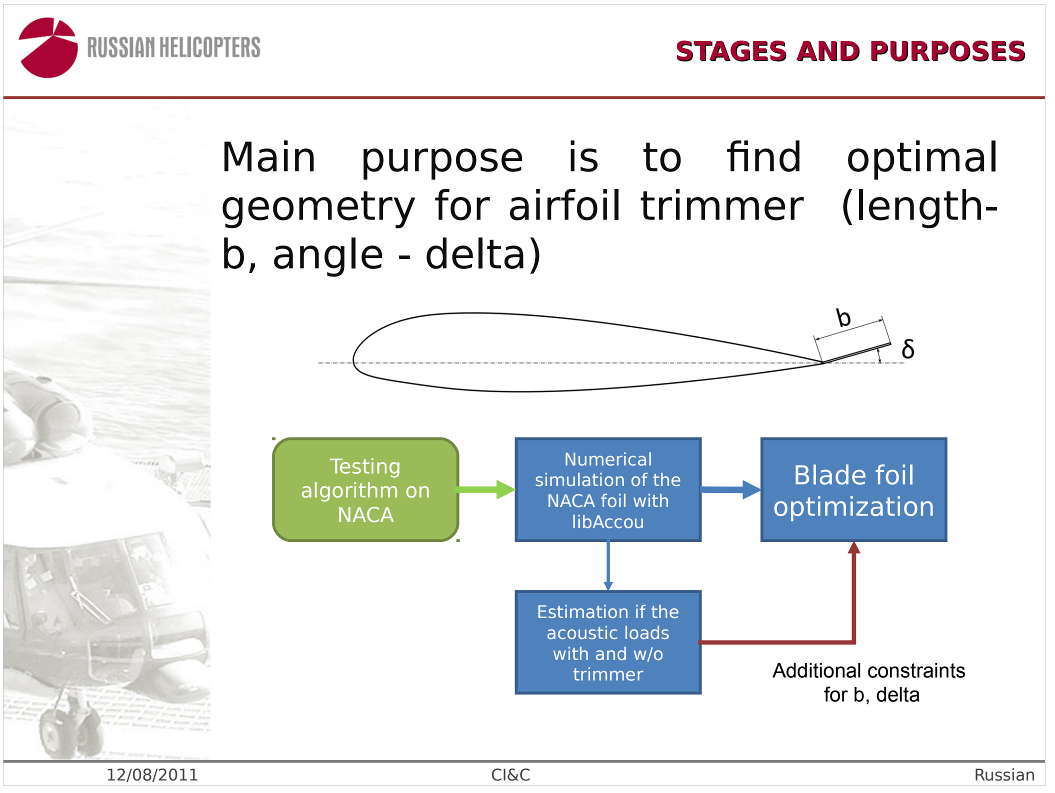
Thank You!

Good day!

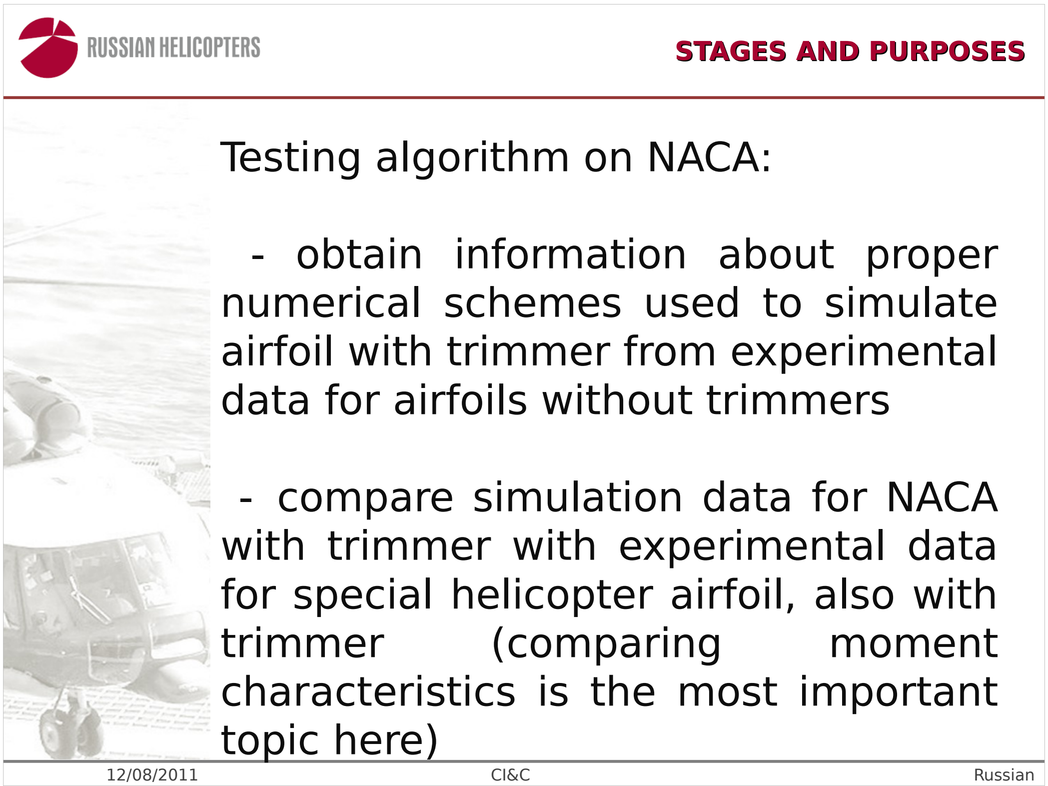
I want to bring to your attention a presentation about An application of the genetic[dʒɪˈnɛtɪk] methods [ˈmɛθəd] and surrogate [ˈsʌrəɡət] modelling for airfoil shape optimization. By authors Ilya Evdokimov and Valeryi Ivchin.

I'm sorry for my english, it is my first presentation on foreign language.

You can ask me about everything at the end and i will try to explain.



Main purpose is to find optimal length [lɛŋ(k)θ] and angular ['æŋgjʊlə] position of the new helicopter airfoil trimmer. All work was devided on three parts: 1. Algorithm testing on well-known NACA – airfoil, 2. Noise numerical simulation using OpenFOAM library libAcou developed in ISP RAS and Kurchatov's Institute. On this stage we obtain constraints for the third stage for optimisation of the helicopter's airfoil to minimize moments and possible acoustic penalties ['pɛn(ə)ltɪ].



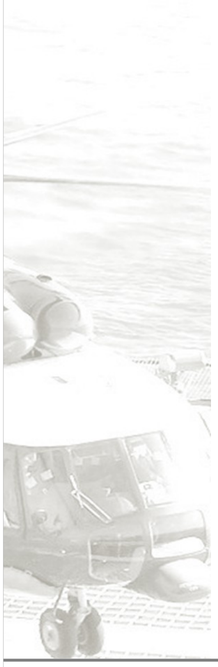
On the first stage, which is discussed today, we have had two tasks [tɑːsk]:

First task.

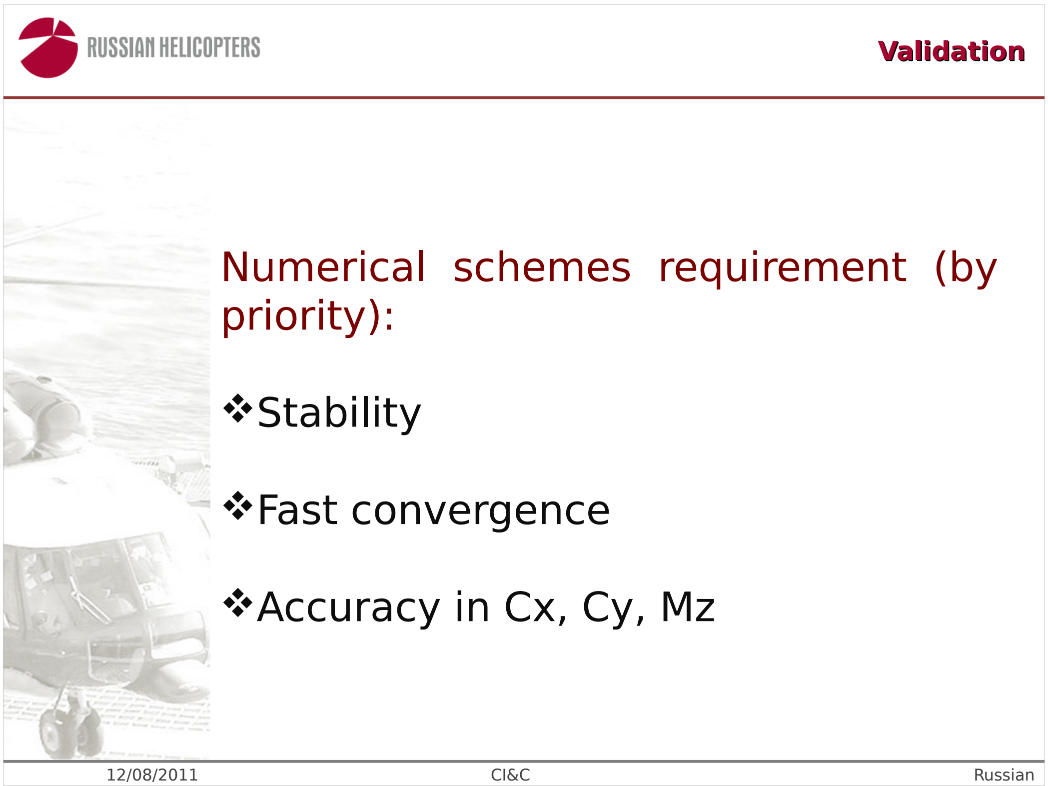
obtain information about proper numerical schemes used to simulate airfoil with trimmer from experimental data for airfoils without trimmers

The second one

compare simulation data for NACA with trimmer with experimental data for special helicopter airfoil, also with trimmer (comparing moment characteristics is the most important topic here)



- Validation

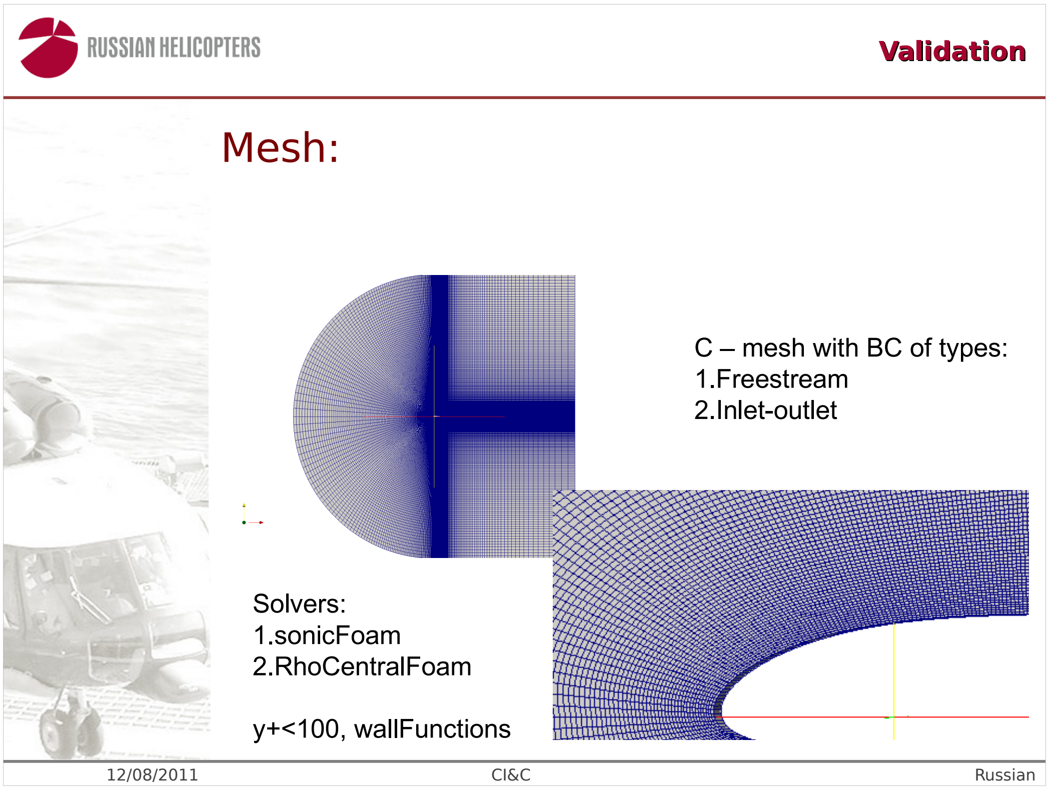


Time and computation consuming [kənˈsjuːmɪŋ] optimization calcultaions need particular approach for setting up numerical schemes. Thus [ðʌs] we have looked over few different schemes implemented in OpenFOAM. Ideal combination of the numerical schemes should provide furher properties:

Outstanding stability

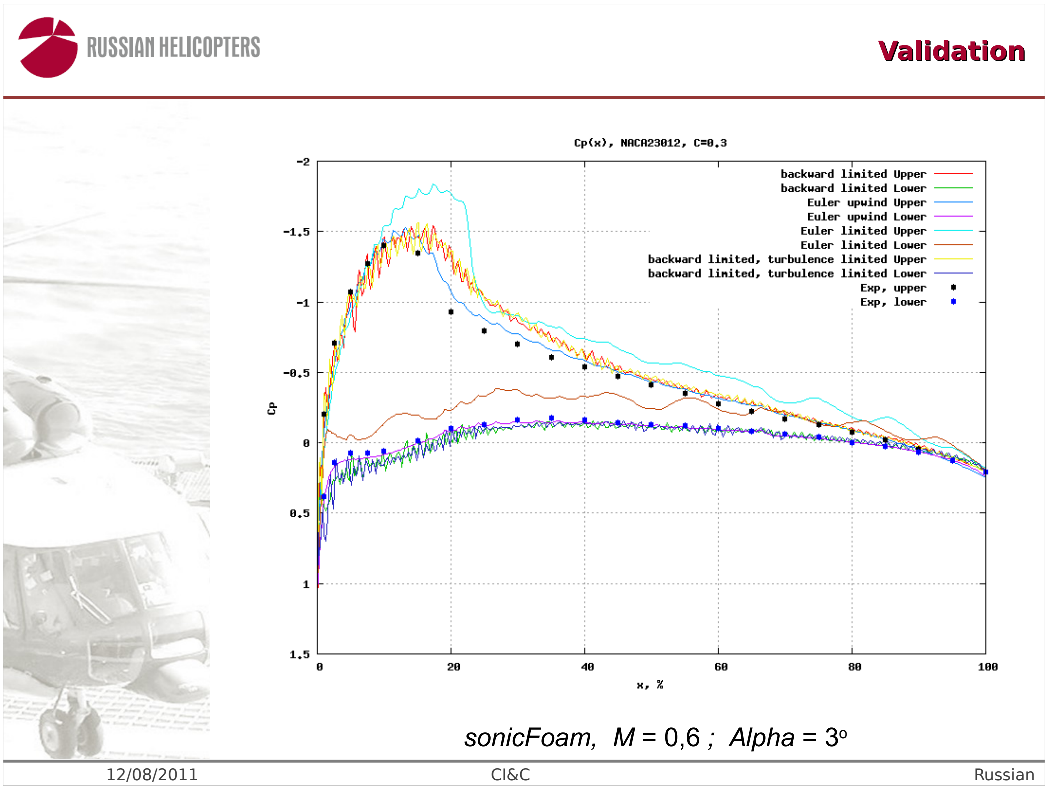
Fast convergence

Accuracy in Cx, Cy, Mz



We have used C-type 2-dimensional hexahedra [hɛks-] meshes with up to four houndred thousand elements. The mesh had 1 element along Z-axis.

We have tested two types of boundary conditions Freestream and inlet-outlet which means using fixedValue and zeroGradient types for velocity and pressure at the inlet and vise-versa at the outlet.



Here are different results for different numerical schemes. In the legend at first place showed time derivative terms scheme, devergence terms scheme and then turbulence k and omega scheme if it's not an upwind scheme.

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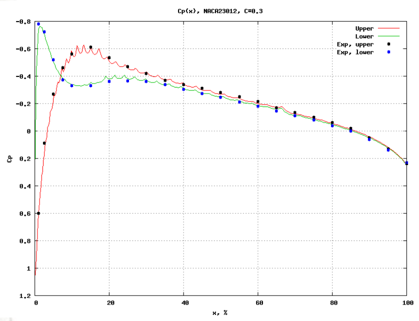
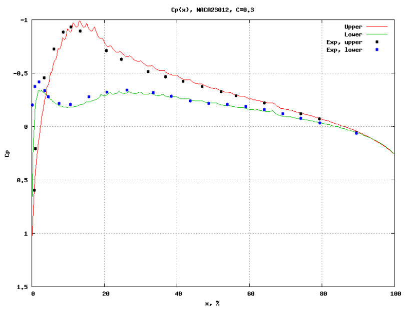
Validation

fvSchemes configuration:

- solver - *sonicFoam*;
- *div*(*phi;U*) - Gauss linearUpwindV grad(U);
- *div*(*phid; p*) - Gauss blended 0.5;



sonicFoam, *M* = 0,6 ; *Alpha* = -1,2°



sonicFoam, *M* = 0,6 ; *Alpha* = 0,17°

Gorsky I.P., The investigation of the pressure distribution on the wing's foils at the high speed, TZAGI works: 1946.

12/08/2011 CI&C Russian

On this slide you can see simulation and experimental results for the hand-picked numerical schemes of the divergence terms.

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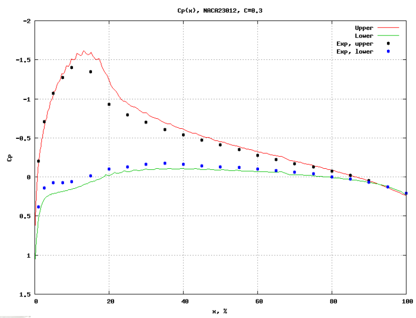
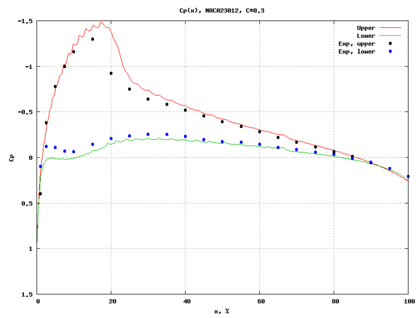
Validation



sonicFoam, *M* = 0,6 ; *Alpha* = 1,67°



sonicFoam, *M* = 0,6 ; *Alpha* = 3°

```
ddtSchemes
                    backward
divSchemes
                    div(phi,U)     Gauss linearUpwindV grad(U);

                    div(phi,k)     Gauss upwind;
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```
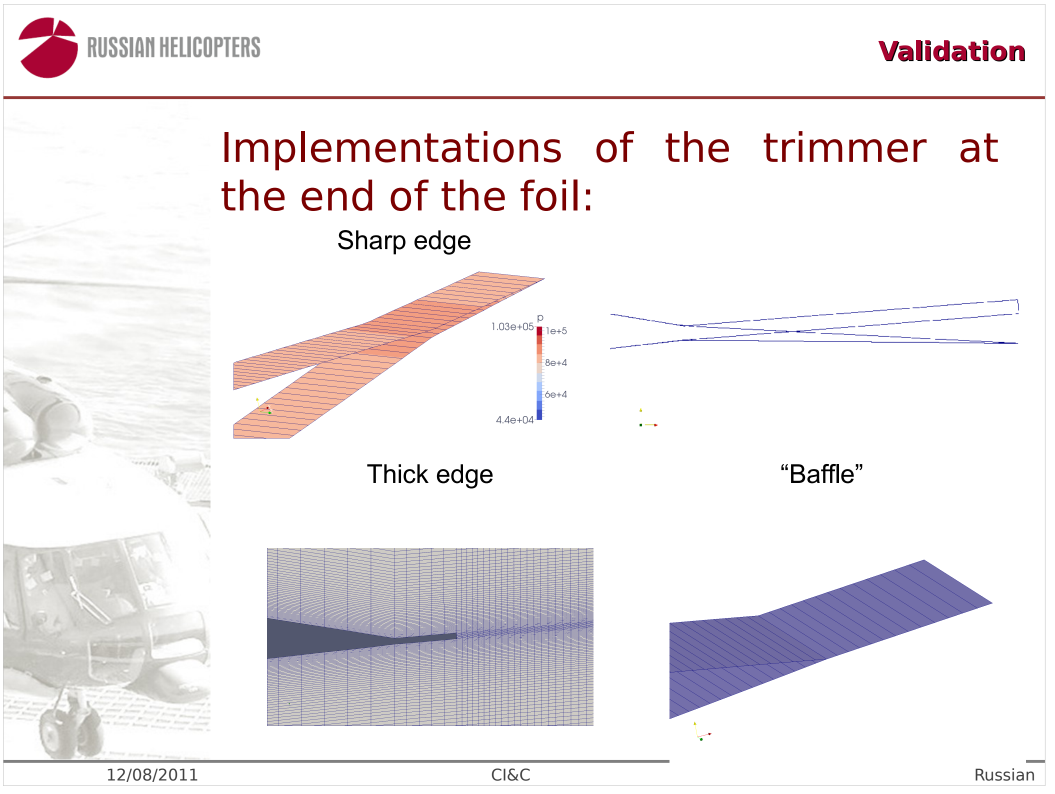

Gorsky I.P., The investigation of the pressure distribution on the wing's foils at the high speed, TZAGI works: 1946.

12/08/2011 CI&C Russian

Error increasing when angle becomes bigger, but this combination of the schemes allows us fastest and the most stable simulations on the angle of attack up to 5 grads. We can achive better accuracy using another schemes for divergence terms with first order Euler scheme for time derivatives but in this way we should use more processors or reserve additional computation time for simulations switching schemes from 1st order to 2st order despite interpolation.



After standard tests on well-known NACA — profile, we have validated OpenFOAM on the case of airfoil with trimmer.

We have investigated three different models of trimmer:

1. sharp tail
2. Thick tail
3. Baffle trimmer — only faces of the cells between neighbour [ˈneɪbə] blocks.

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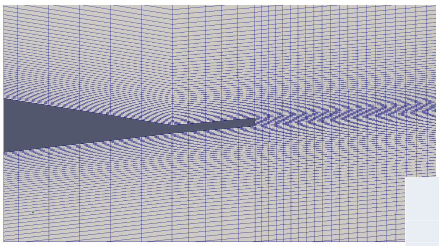
Validation

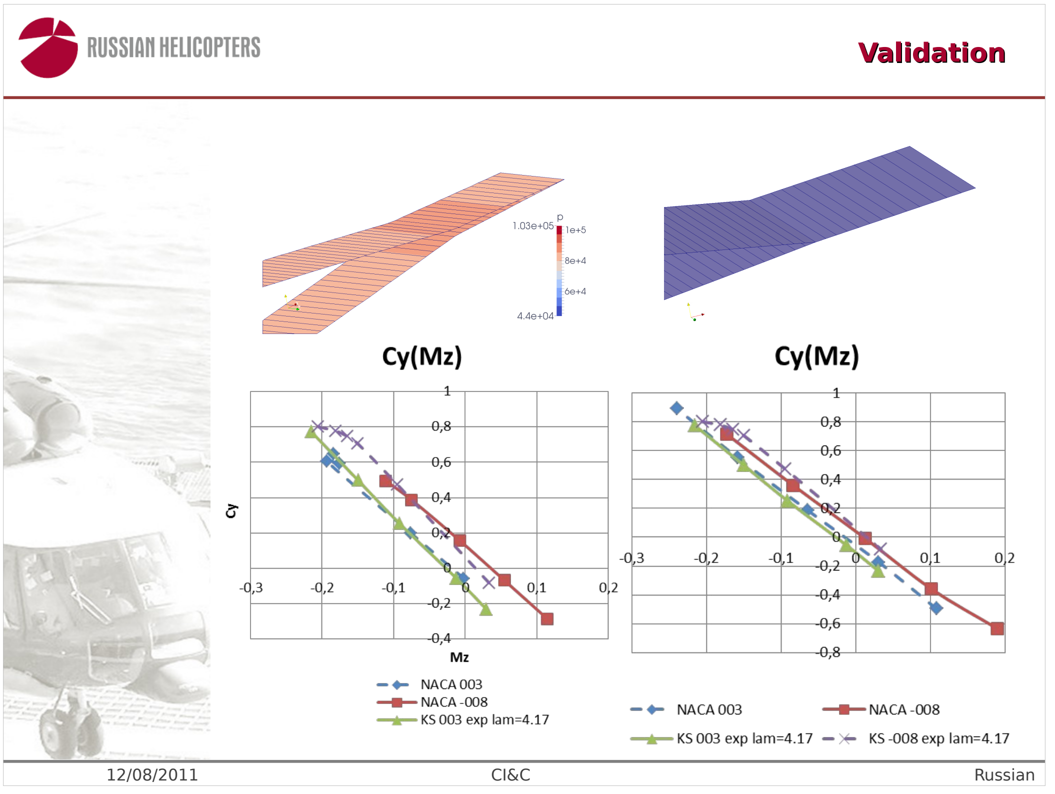
- According to simulation results, the case with “thick” trimmer does not produce any changes in Mz.
- The reason was not investigated



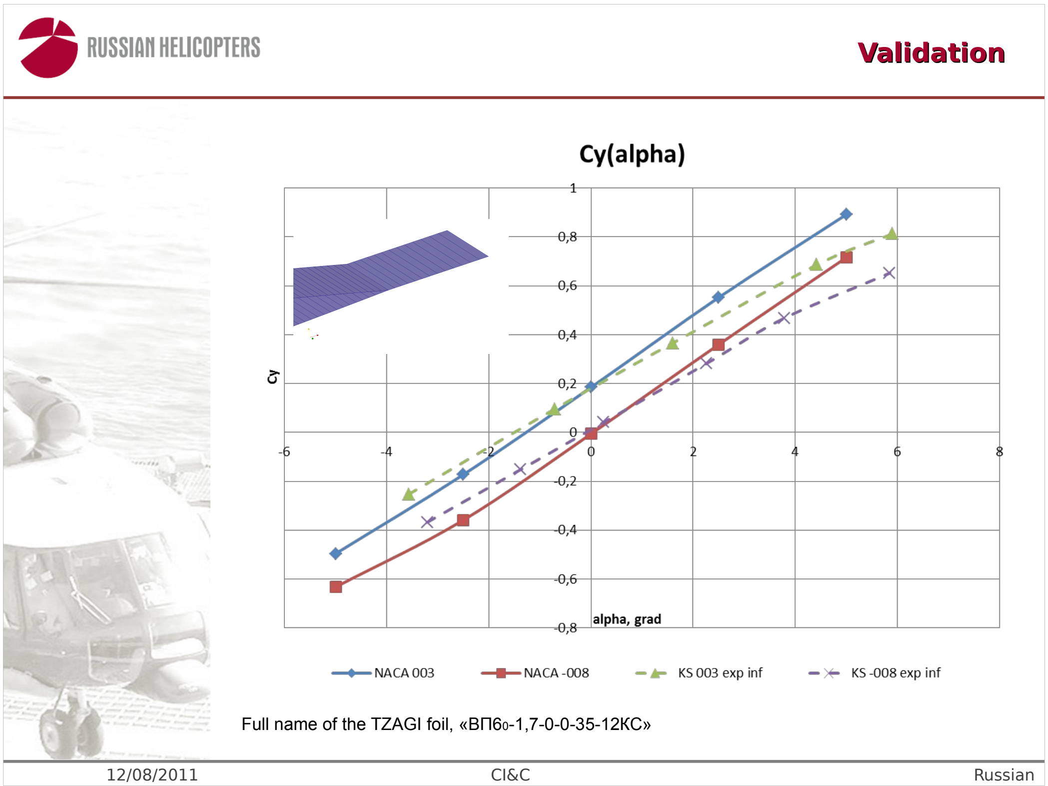
	r	delta	alpha	Mz
1	18	1,75	-5	0,1248365
2	18	1,75	-2,5	0,121256
3	18	1,75	0	0,1221417
4	18	1,75	2,5	0,1221133
5	18	1,75	5	0,1220588

The simulation of the «thick» trimmer was not satisfied Us, the aerodynamical moment did not change across angles of attack.

Despite this model have had outstanding stability and Fast convergence, all results were culled [kʌl].

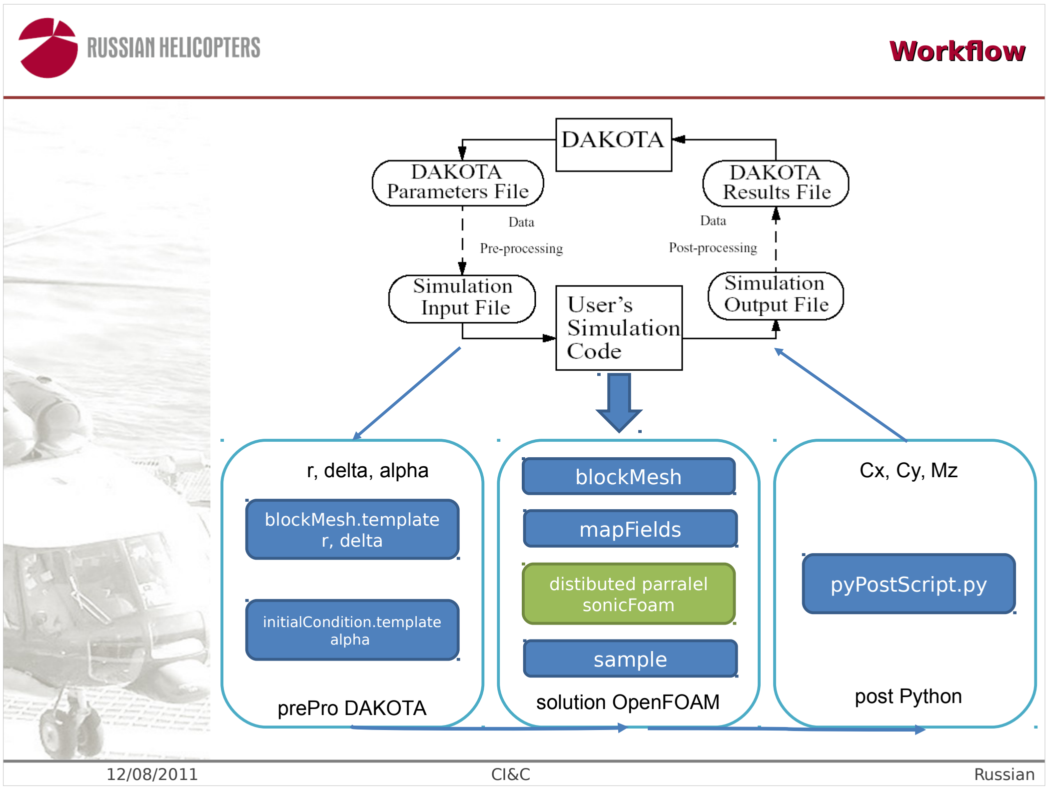


For sharp tail we have mediocre results close to the experimental results for helicopter foil with trimmer. Baffle trimmer showed the best results.
Here is the most important characteristics for our Optimisation the lift coefficient as an funtion and Moment as an argument.



Here we can see pretty good quality correspondence in aerodynamic Lift coefficient despite different foils.

- Optimization case



We used toolkit DAKOTA for optimization. For meshing and
Boundary conditions input OpenFOAM file the templates
were created. Postprocessing was a bit tricky and specially
Developed python script was used with OpenFoam utility Sa

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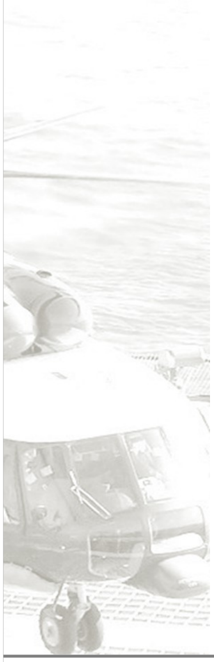
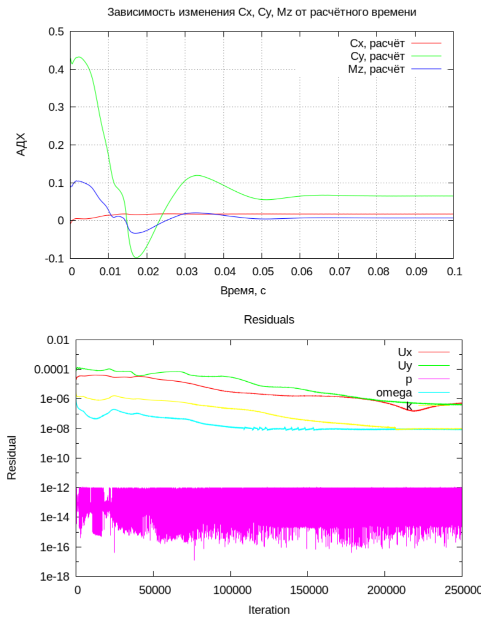
Workflow





19 points – DACE (LHS)
45 points – sampling (r - var, delta – var, alpha – var)

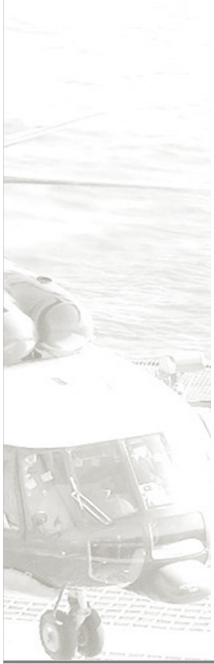
DACE:
5<r<30
-8<delta<8
-2.5<alpha<2.5

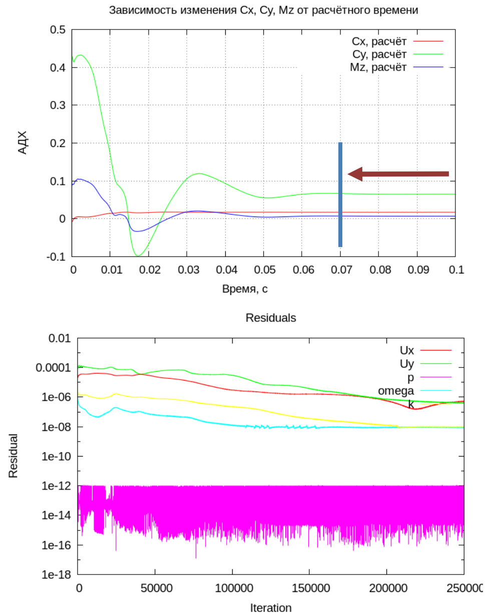
Sampling:
r = 9; 18; 36
delta = -4,5; 1,75; 6,25
alpha = -5; -2,5; 0; 2,5; 5

Time ~7 days, 24 cores

For surrogate model we used Design of Computational Experiments methods and 19 points were generated. 45 Points of validation case were also useful for our corellation model.

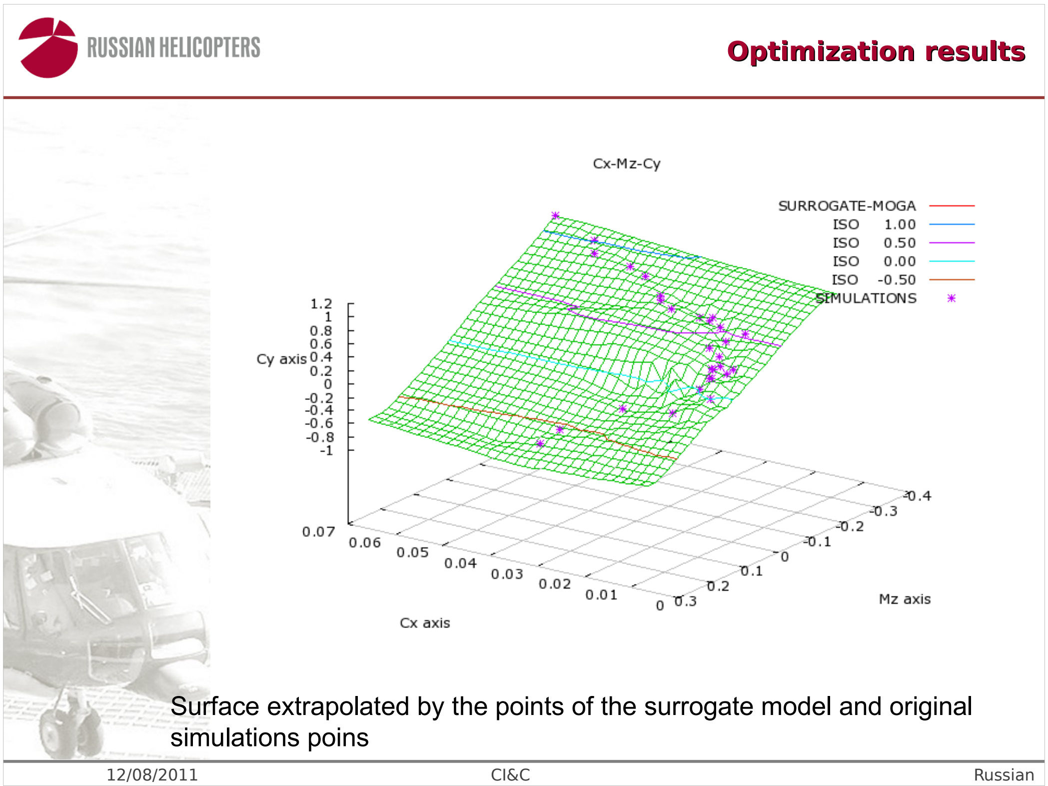
Workflow



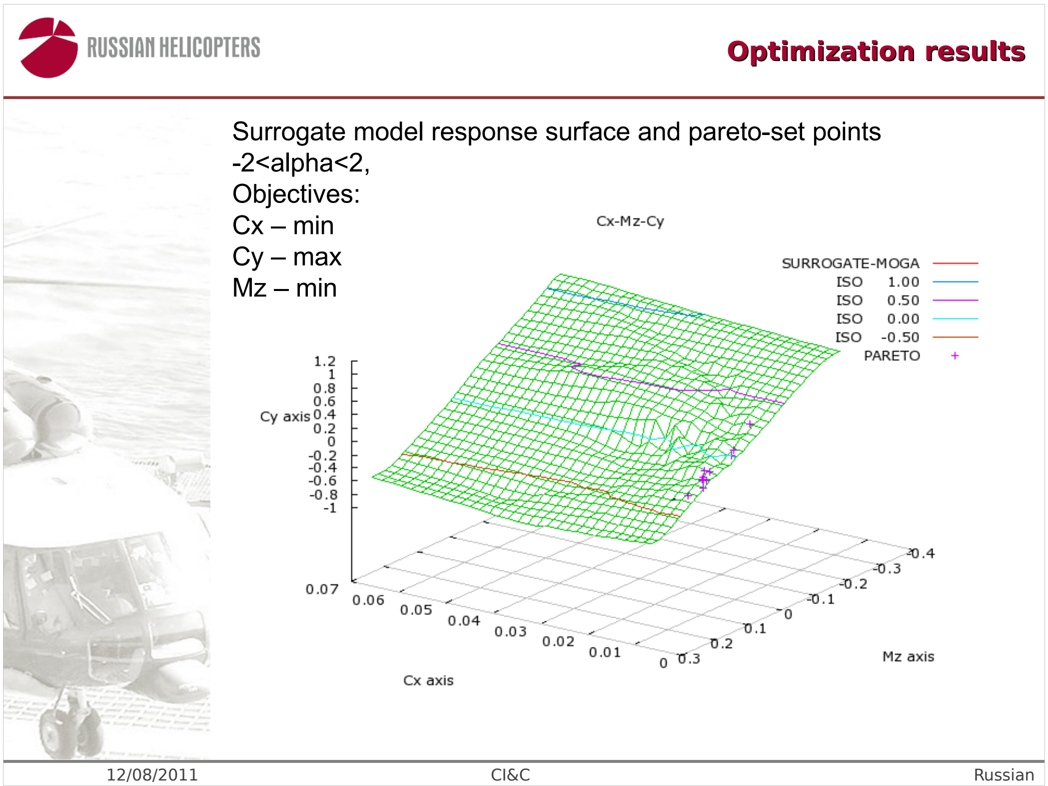


Optimal end of simulation

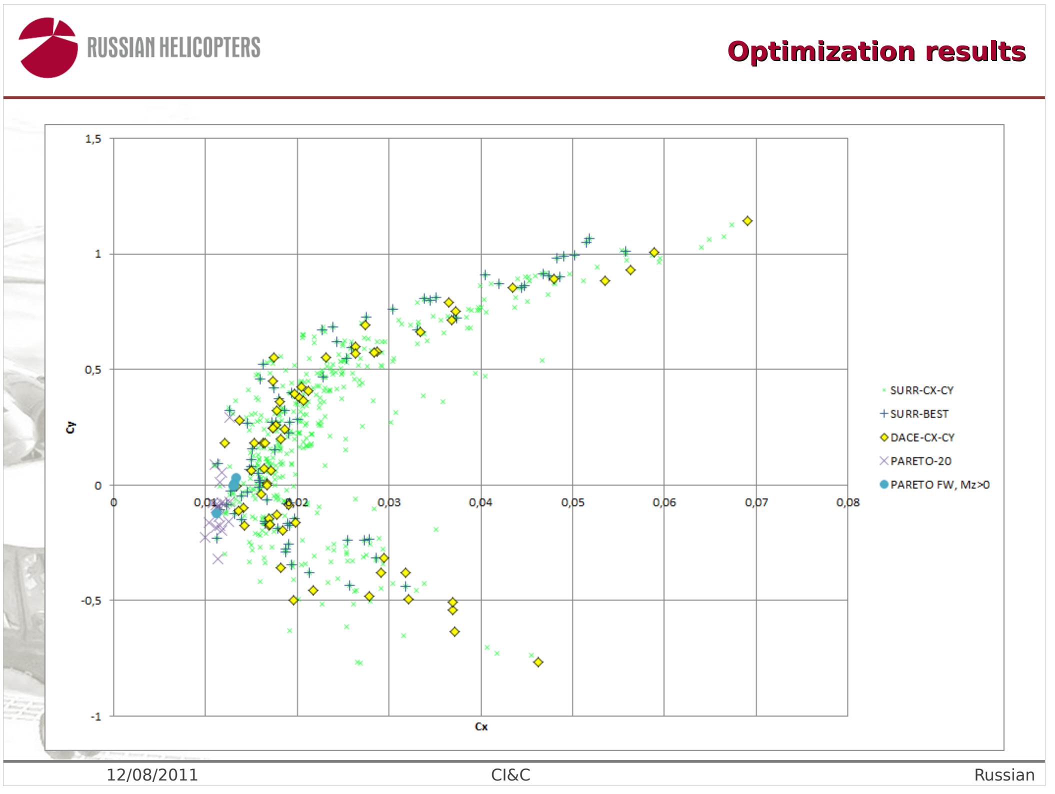
For decreasing of the whole optimization consumed time We little bit short every case calculation time to 0,07 c. We can see that RMS and aerodynamical coeffitients Convergence are good in that way.



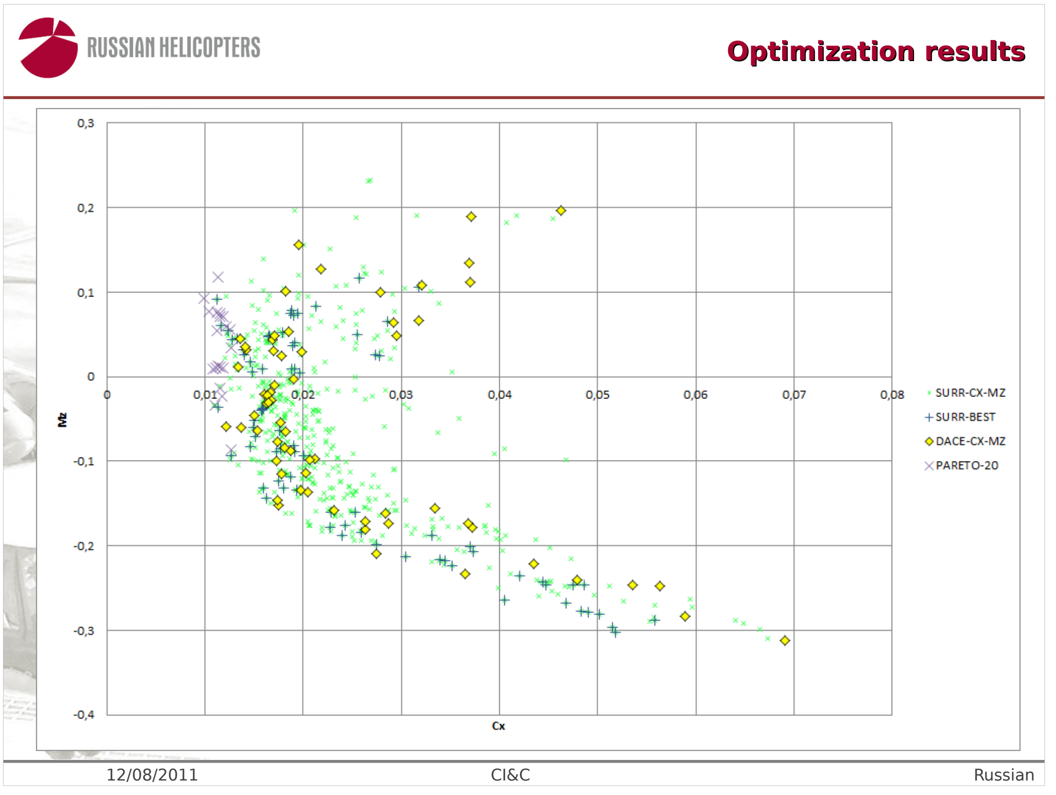
Here is response surface and original simulations points.



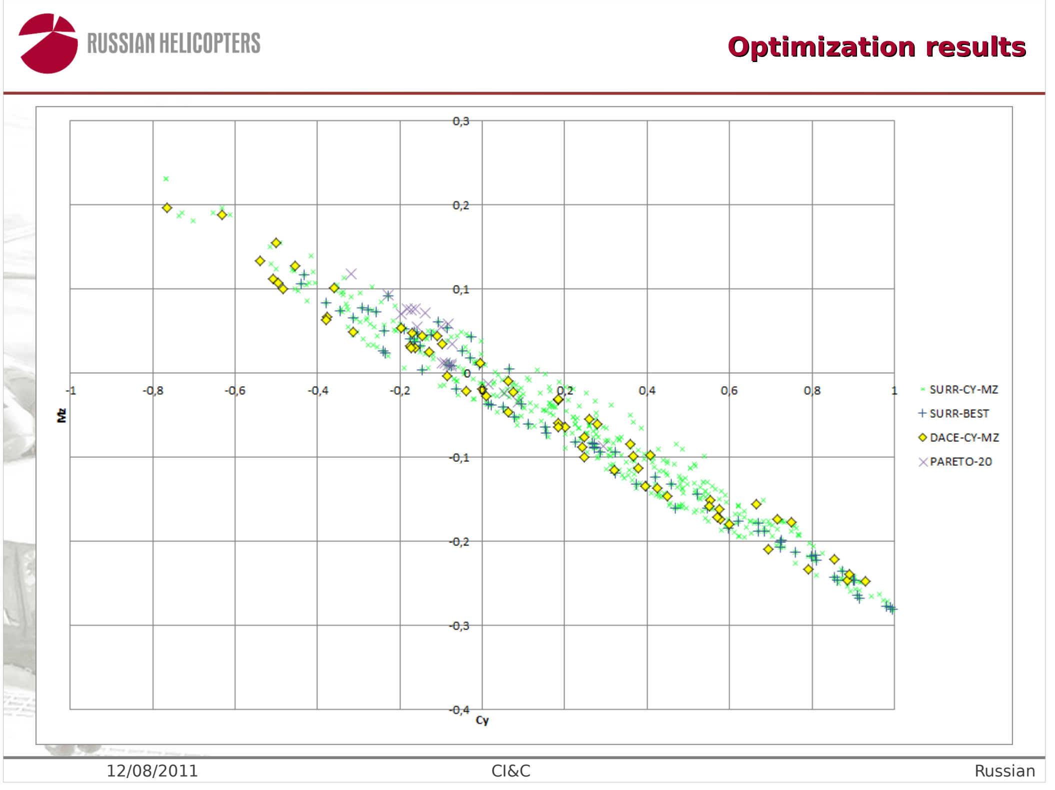
And here added pareto-set points. On the further slide they will be showed better.



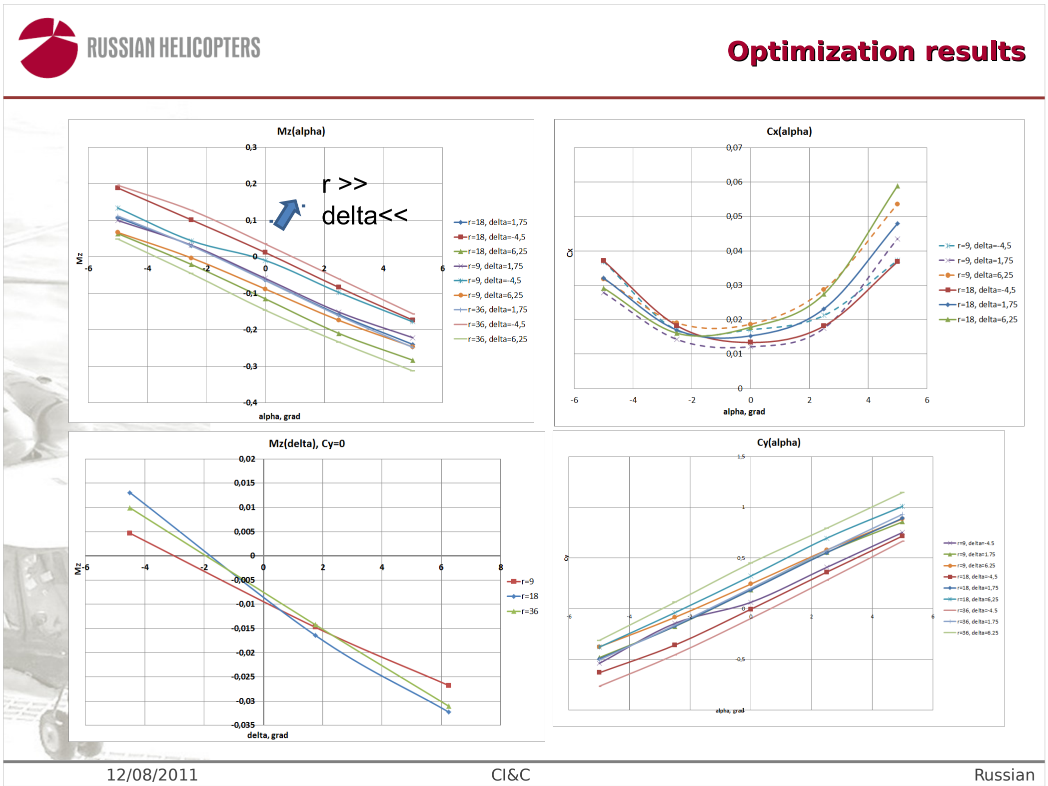
On this slide we can see set of points generated by surrogate model under control of genetic algorithm MOGA of DAKOTA toolkit, set of the best points from Different populations and set of pareto points obtained With two different approaches. The first one was automat generated twenty sets of random weighting factors. And second one — user set of weighting factors.



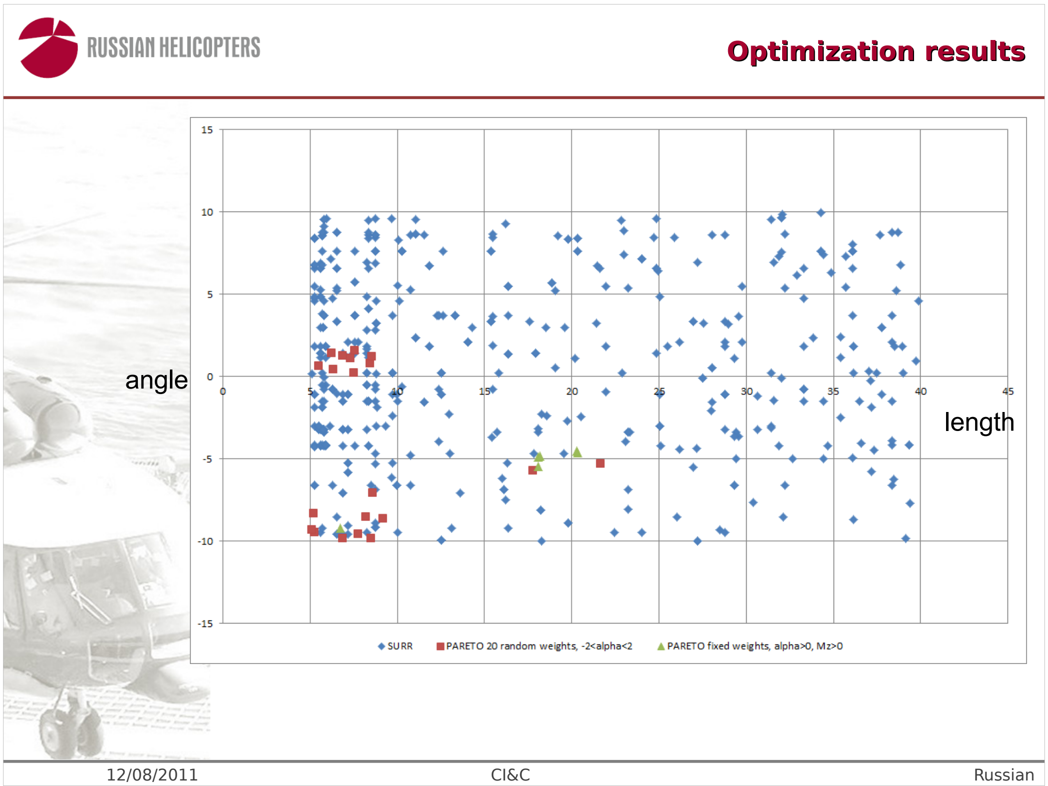
On this slide two axis graph with moment as X and Drag coefficient as Y



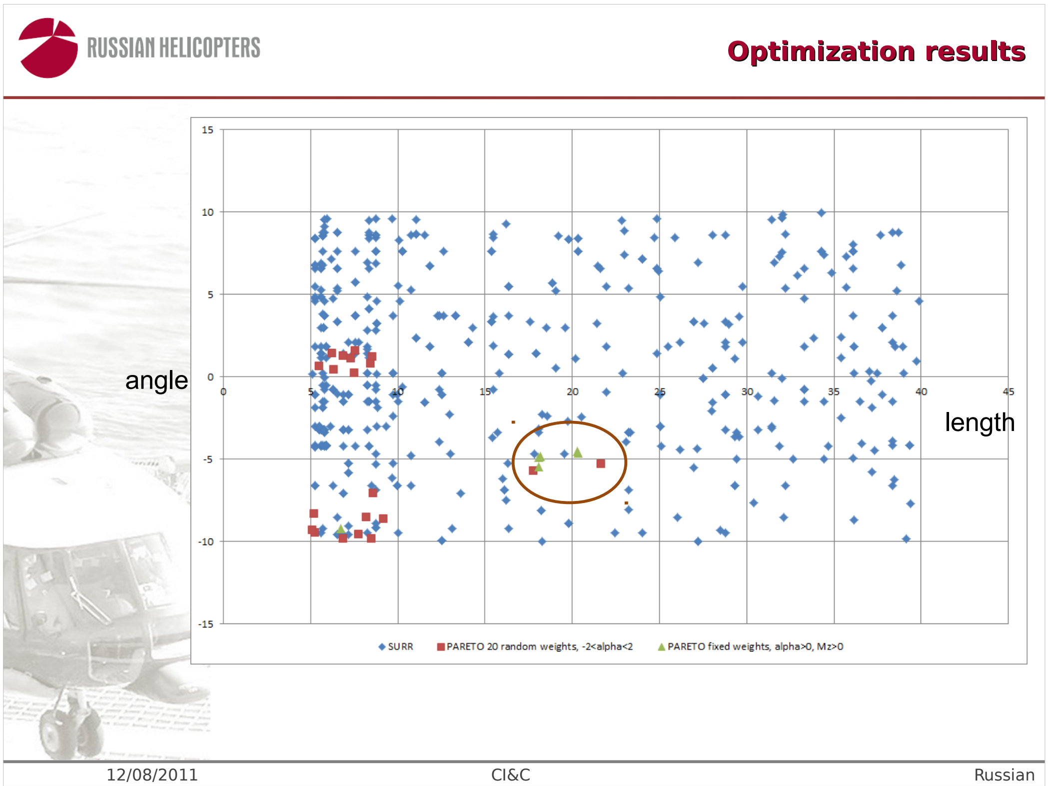
And the most important graph show us points with different Moment coefficient and lift coefficient as X and Y respectively Despite very sophisticated algorithms, it's not clear what really Happens when we using DAKOTA and trying to minimize or Maximize three objective functions. So let's do it manually.



Some cases used to validate our algoritm are also useful To make conclusion about proper length and angular Position of the trimmer to minimize moment at certain Angles of attack. At the first graph line of the moment moves higher right when angle less than zero.The length Could be different, this dependence much weaker.



The optimisation points distribution shows us three Regions of the optimal points we have found by genetic Algoritm and pareto-strategy with genetic algorithm as a method.



And the red circle is what engineer could find from Graphs manually.

Other points could show hidden alternatives althougth They are based on different weigth factors for the three objective function.This information could be useful for engineer and could be used for another models. For example adding mach number to surrogate modell may be used for simplified models of helicopter blade.

Also additional acoustic simultions will provide additional Constraints.

Thank You!