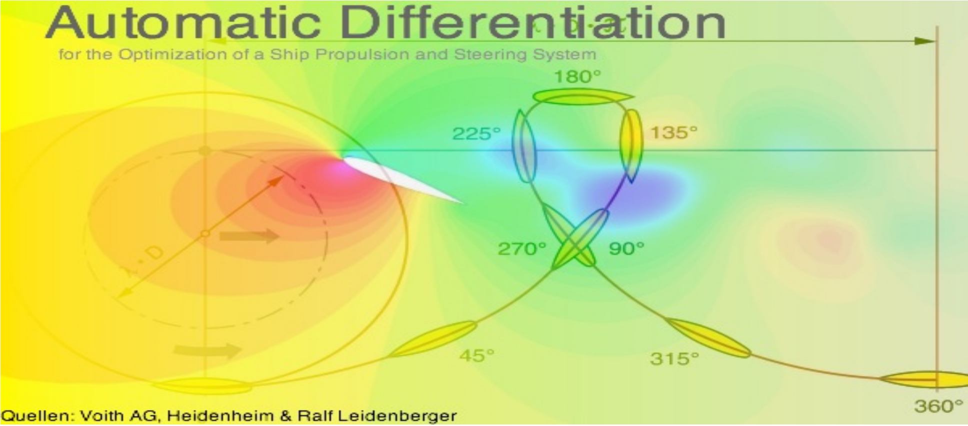
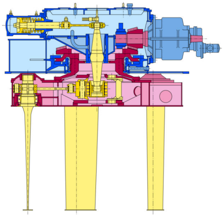


Automatic Differentiation for the Optimization of a Ship Propulsion and Steering System

A joint work with Karsten Urban

Ralf Leidenberger |March 27-29, 2008 |
Faculty for Mathematics and Economics
University of Ulm

Functionality of the VSP

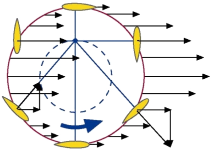


Source: Voith AG, Heidenheim

Functionality

- different angles of attack during one rotation

Functionality of the VSP



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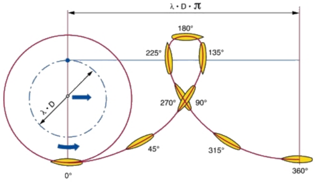
Functionality

- different angles of attack during one rotation
- driving power is resulting force

Functionality of the VSP



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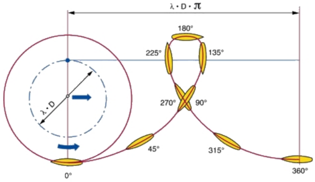
Functionality

- different angles of attack during one rotation
- driving power is resulting force
- enables resulting force in each direction

Functionality of the VSP



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Efficiency of the VSP

$\vec{F} = \int p\vec{\nu}dS$ $\vec{F} = (F_x, M)^T$

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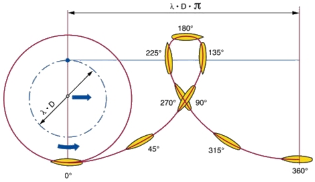

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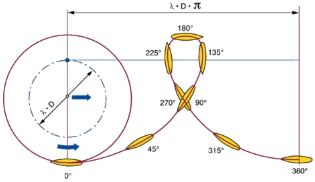
$F_m = \frac{n_f}{2\pi} \int_0^{2\pi} F_x \, d\Theta$ (thrust)

$M_m = \frac{n_f}{2\pi} \int_0^{2\pi} M \, d\Theta$ (driving torque)

Functionality of the VSP



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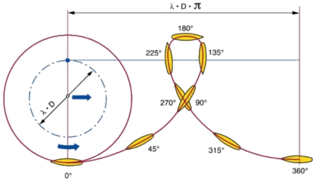
Functionality of the VSP



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k_q dimensionless value of M_m

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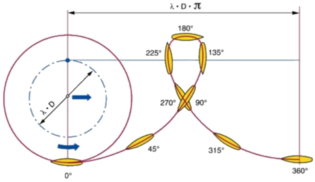

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k_q dimensionless value of M_m

$$\eta := \frac{k_t}{k_q} \frac{J}{2\pi} \tag{1}$$

Optimization Aim

Optimization Targets

- optimize blade angle curve (Sebastian Singer)
- optimize blade profile(Robert Deininger)
- optimize VSP & boat together (Michael Hopfensitz, Juan Matutat)

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- derivative based methods, compute derivatives with AD

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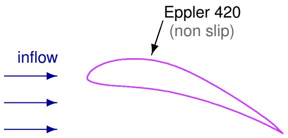
Model Problem

- single blade
- variable angle of attack
- instead of η consider forces in y-direction

Geometry & Optimization Problem

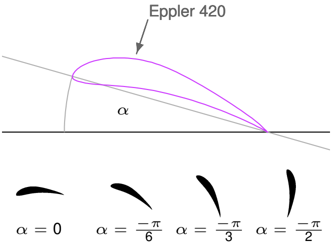


Configuration

- solver: caffa[1]

[1] Computer Aided Fluid Flow Analysis from Ferziger & Peric

Geometry & Optimization Problem



Configuration

- solver: caffa[1]
- angle of attack: α

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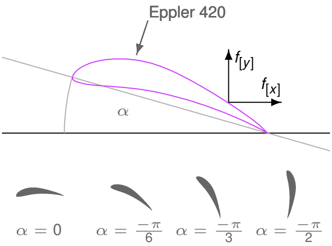
Geometry & Optimization Problem



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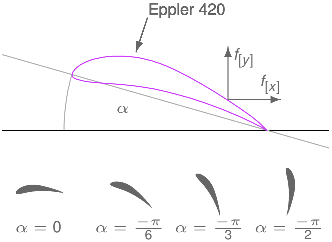

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- $\max\limits_{\alpha \in (0, \alpha_{max})} \{f_{[y]}(\alpha)\}$

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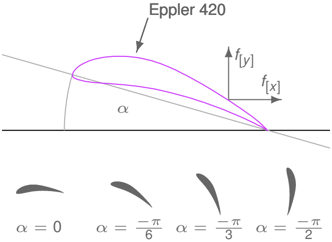

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- $\max_{\alpha \in (0,\alpha_{max})} \{f_{[y]}(\alpha)\}$
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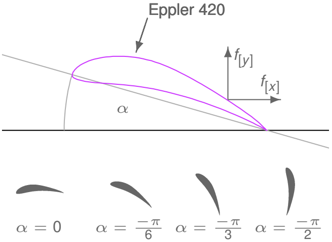

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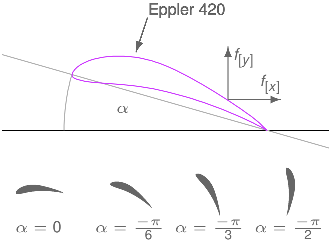

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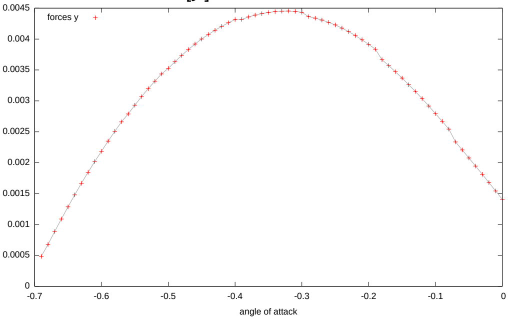
- $\arg\left\{\max\limits_{\alpha \in (0, \alpha_{max})} \{f_{[y]}(\alpha)\}\right\} \Leftrightarrow \arg\left\{f'_{[y]}(\alpha) = 0\right\}$
- Newton-Fixpoint-Iteration: $\Phi_{f_{[y]}}(\alpha_k) = \alpha_{k-1} - \frac{f'_{[y]}(\alpha_{k-1})}{f''_{[y]}(\alpha_{k-1})}$

[1] Computer Aided Fluid Flow Analysis from Ferziger & Peric

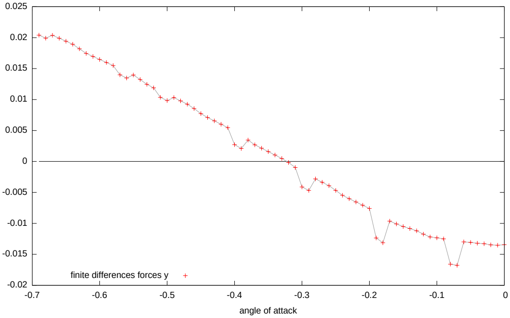
Regularization Effect

Forces: $f_{[y]}(\alpha) \; \forall \; \alpha \in (0, -0.7)$

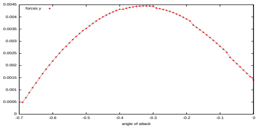


Regularization Effect

Finite Differences (FD): $f'_{[y],FD}(\alpha) = \frac{f_{[y]}(\alpha+h) - f_{[y]}(\alpha-h)}{2h}$

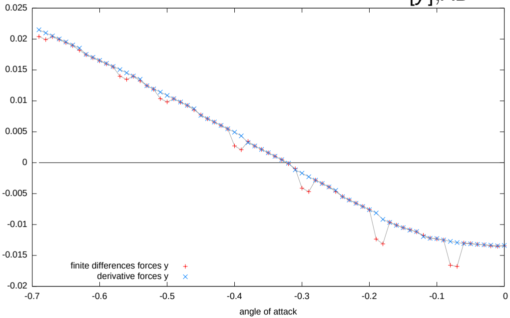


Forces: $f_{[y]}(\alpha)$

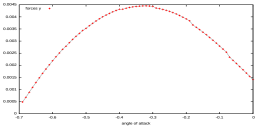


Regularization Effect

Automatic Differentiation (AD): $f'_{[y],AD}(\alpha)$

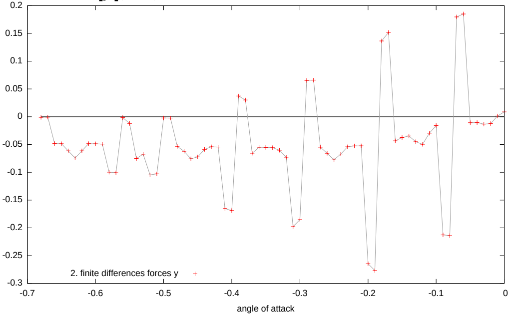


Forces: $f_{[y]}(\alpha)$

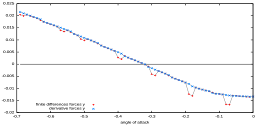


Regularization Effect

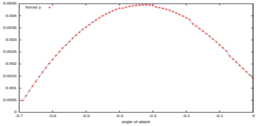
2nd FD: $f''_{[y],FD,FD}(\alpha) = \dfrac{f_{[y]}(\alpha+h) - 2f_{[y]}(\alpha) + f_{[y]}(\alpha-h)}{h^2}$



$f'_{[y],FD}(\alpha)$ & $f'_{[y],AD}(\alpha)$

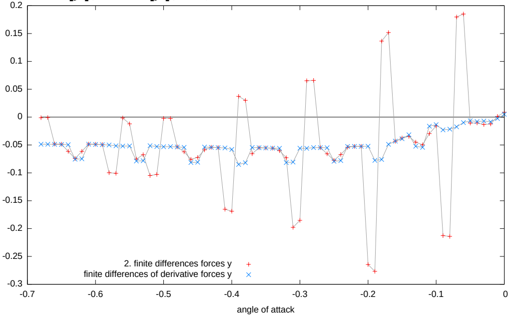


Forces: $f_{[y]}(\alpha)$

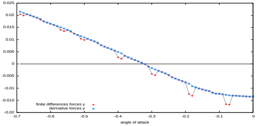


Regularization Effect

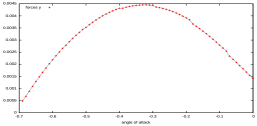
FD of $f'_{[y],AD}$: $f''_{[y],AD,FD}(\alpha) = \frac{f_{[y],AD}(\alpha+h) - f_{[y],AD}(\alpha-h)}{2h}$



$f'_{[y],FD}(\alpha)$ & $f'_{[y],AD}(\alpha)$

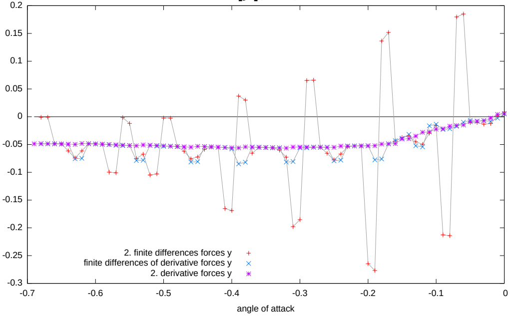


Forces: $f_{[y]}(\alpha)$

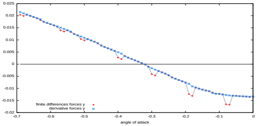


Regularization Effect

2nd AD: $f''_{[y],AD,AD}(\alpha)$



$f'_{[y],FD}(\alpha)$ & $f'_{[y],AD}(\alpha)$



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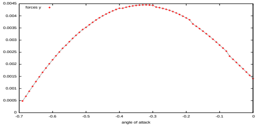
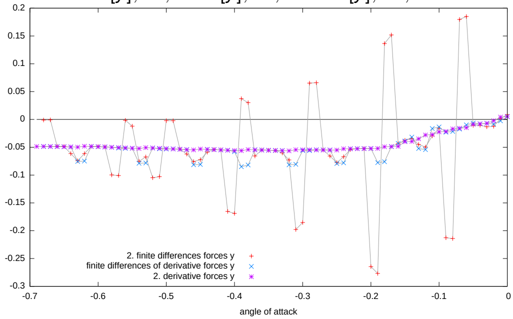
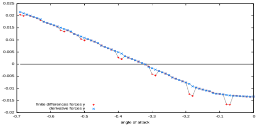


Regularization Effect

$f''_{[y],FD,FD}$, $f''_{[y],FD,AD}$ & $f''_{[y],AD,AD}$



$f'_{[y],FD}(\alpha)$ & $f'_{[y],AD}(\alpha)$



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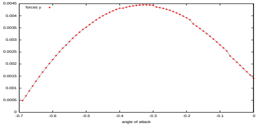
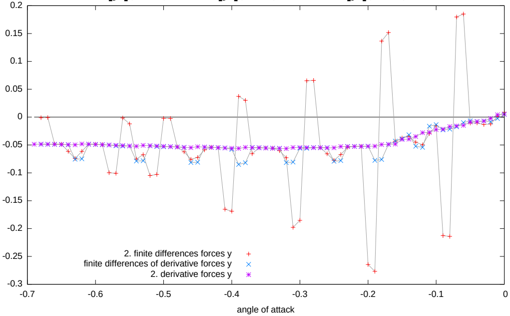


Comments

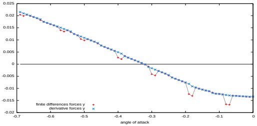
- Justify the application of AD in 2D flow simulation

Regularization Effect

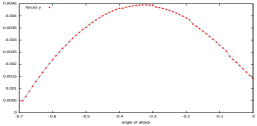
$f''_{[y],FD,FD}$, $f''_{[y],FD,AD}$ & $f''_{[y],AD,AD}$



$f'_{[y],FD}(\alpha)$ & $f'_{[y],AD}(\alpha)$



Forces: $f_{[y]}(\alpha)$



Comments

- Justify the application of AD in 2D flow simulation
- Regularization effect grows from $f'_{[y]}(\alpha)$ to $f''_{[y]}(\alpha)$

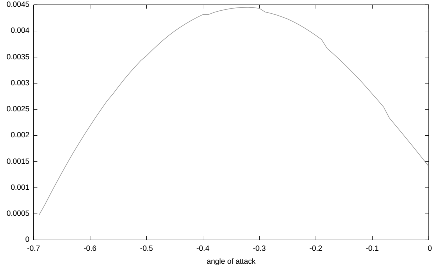
Newton-Fixpoint-Iteration

Angle of attack (AOA) of the profil

Remark

- starting point: $\alpha_0 = -0.03$
- maximum change rate of α: $\alpha_{\Delta,max} = 0.1$ [radian]

Force: $f_{[y]}(\alpha_k)$



Newton-Iterations

It.	AOA: α	$f'_{[y]}(\alpha)$

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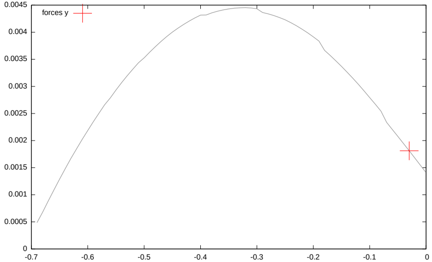

Newton-Iterations

It.	AOA: α	$f'_{[y]}(\alpha)$
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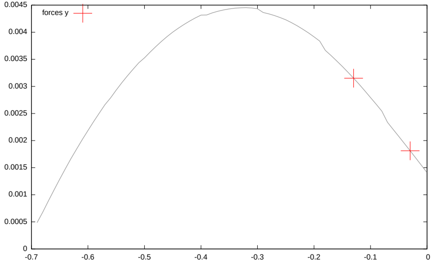

Newton-Iterations

It.	AOA: α	$f'_{[y]}(\alpha)$
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1.	-0.13000000	-0.01114433244

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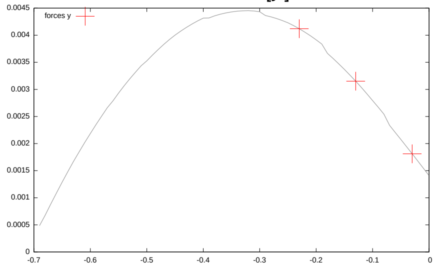

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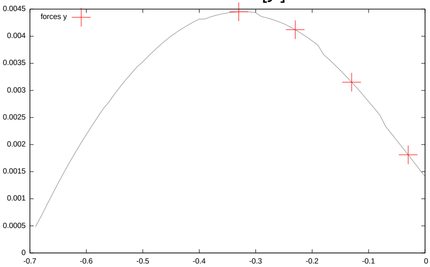

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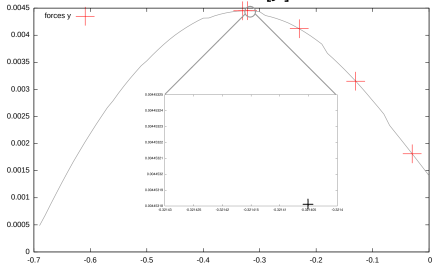

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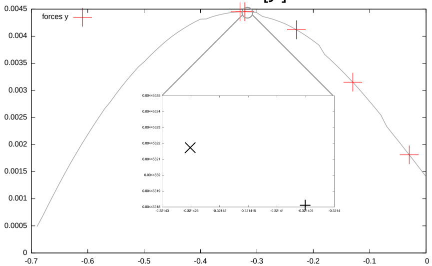
Remark

- starting point: $\alpha_0 = -0.03$
- maximum change rate of α: $\alpha_{\Delta,max} = 0.1$ [radian]

Force: $f_{[y]}(\alpha_k)$



Newton-Iterations

It.	AOA: α	$f'_{[y]}(\alpha)$
0.	-0.03000000	-0.01327457810
1.	-0.13000000	-0.01114433244
2.	-0.23000000	-0.00603337754
3.	-0.33000000	+0.00048255801
4.	-0.32140508	-0.00000113055
5.	-0.32142512	+0.00000008440

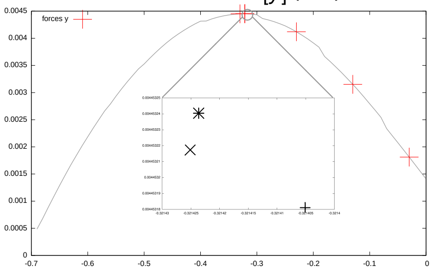
Newton-Fixpoint-Iteration

Angle of attack (AOA) of the profil

Remark

- starting point: $\alpha_0 = -0.03$
- maximum change rate of α: $\alpha_{\Delta,max} = 0.1$ [radian]

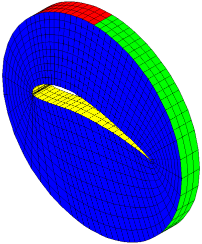
Force: $f_{[y]}(\alpha_k)$



Newton-Iterations

It.	AOA: α	$f'_{[y]}(\alpha)$
0.	-0.03000000	-0.01327457810
1.	-0.13000000	-0.01114433244
2.	-0.23000000	-0.00603337754
3.	-0.33000000	+0.00048255801
4.	-0.32140508	-0.00000113055
5.	-0.32142512	+0.00000008440
6.	-0.32142362	+0.00000007550

Geometry & Simulation Parameters



Boundary-Conditions

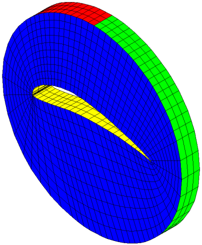
- Red: Inflow
- Green: Outflow
- Blue: Non-reflection
- Yellow: Wall

Simulation Parameters

- solver: Comet[2]

[2] is a commercial software from CD-adapco

Geometry & Simulation Parameters



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Simulation Parameters

- solver: Comet[2]
- no moving grid - grid moving realized with scipt language

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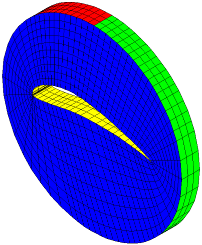
Geometry & Simulation Parameters



Boundary-Conditions

- Red: Inflow
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- Blue: Non-reflection
- Yellow: Wall

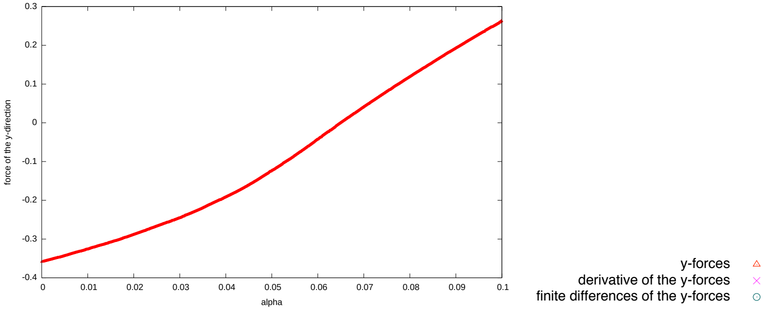
Simulation Parameters

- solver: Comet[2]
- no moving grid - grid moving realized with scipt language
- Idea: variable inflow direction

[2] is a commercial software from CD-adapco

Regularization Effect

Forces: $f_{[y]}(\alpha)$

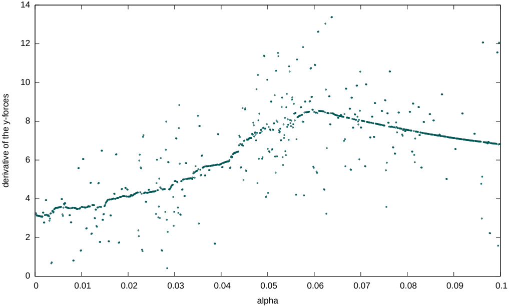


Comments

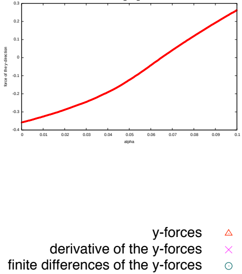
- smooth forces curve

Regularization Effect

FD: $f'_{[y],FD}(\alpha) = \frac{f_{[y]}(\alpha+h) - f_{[y]}(\alpha-h)}{2h}$



Forces: $f_{[y]}(\alpha)$

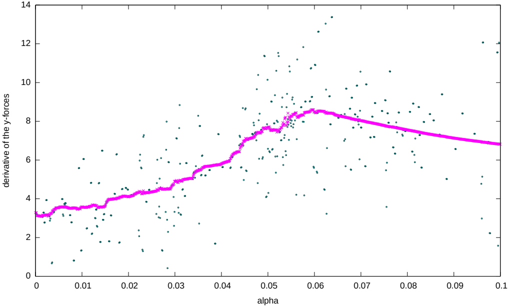


Comments

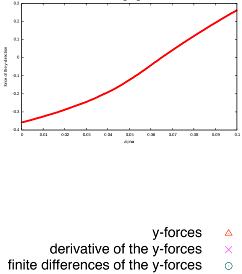
- smooth forces curve
- FD: strong, many outliers

Regularization Effect

AD: $f'_{[y],AD}(\alpha)$



Forces: $f_{[y]}(\alpha)$

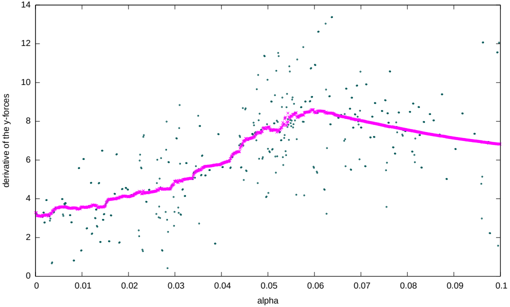


Comments

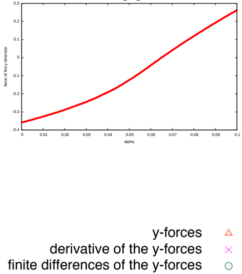
- smooth forces curve
- FD: strong, many outliers
- AD: good regularization effect

Regularization Effect

FD $f'_{[y],FD}(\alpha)$ & AD $f'_{[y],AD}(\alpha)$



Forces: $f_{[y]}(\alpha)$



Comments

- smooth forces curve
- FD: strong, many outliers
- AD: good regularization effect
- justify the application of AD 3D flow simulations

Conclusion & Oulook

Conclusion

- justify the application of AD in 2D & 3D flow simulation
- regularisation effect of AD in 2D & 3D flow simulation
- many *handwork* until a AD simulation runs

Conclusion & Oulook

Conclusion

- justify the application of AD in 2D & 3D flow simulation
- regularisation effect of AD in 2D & 3D flow simulation
- many *handwork* until a AD simulation runs

Outlook

- more complex geometries
- moving grids in 3D (Comet)
- optimization of a full VSP
- more flexible approach of AD

Literature

R. Leidenberger
Automatic differentiation in flow simulation.
diploma-thesis, University of Ulm, 2007.

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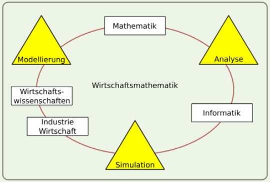

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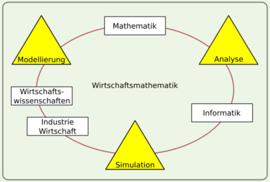

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Thank you for your attention.