Compressor tandem blade: investigation into actuation strategies

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Outline

Swan neck transition LPC to HPC

- LPC: low rotation speed, high $\mathcal{Q}$, high R
- HPC: high rotation speed, low $\mathcal{Q}$, low R

Flow preconditioned by LPC OGV $\alpha_2 = 0°$

- high turning $\Delta\alpha \sim 50°$
- high incidence swing $\Delta i \sim 30°$
- highly 3D end walls

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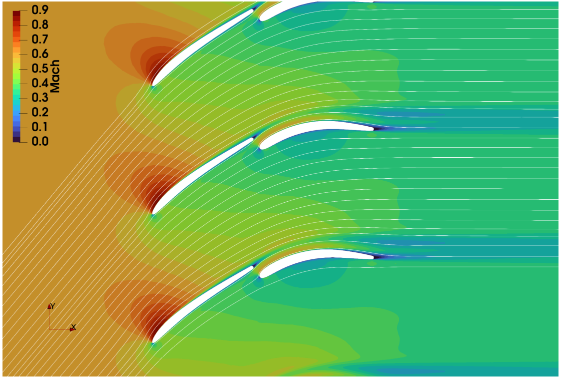
Tandem can obtain high turning $\Delta\alpha$ by

- distributing turning over 2 successive blades
- restarting the boundary layer
- align flow with high turning aft blade
- suction in overlap region increases loading on blades



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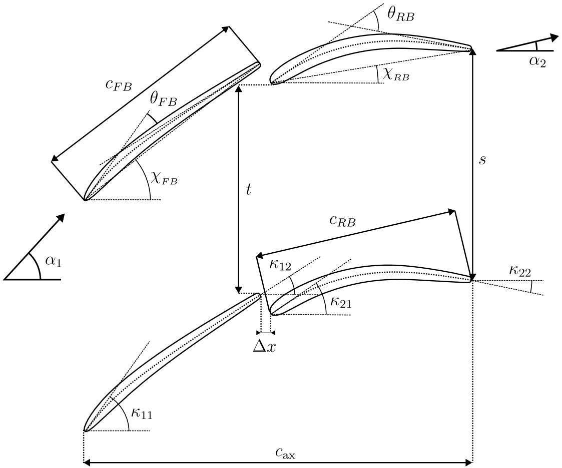
Tandem as OGV studied in project *Wings*

- Safran Aero Boosters, Cenaero and VKI
- Cenaero: parametric optimisation
- starting from "split" single blade
- optimized for ω and π

$$\omega = \frac{p_1^\circ - \widehat{p_2^\circ}}{p_1^\circ - p_1} \qquad \pi = \frac{p_2}{p_1}$$

- $M_1 = 0.6,\ \alpha_1 = 50^\circ,\ Re_{cax} = 550k,\ AVDR = 1$



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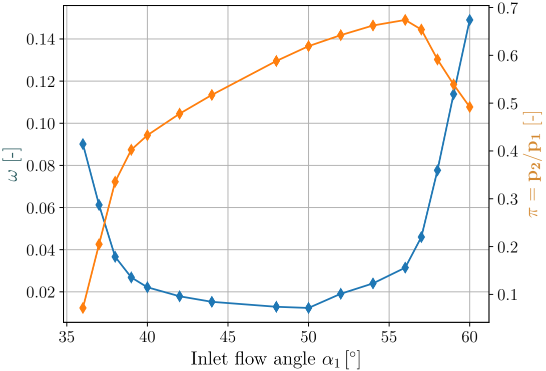

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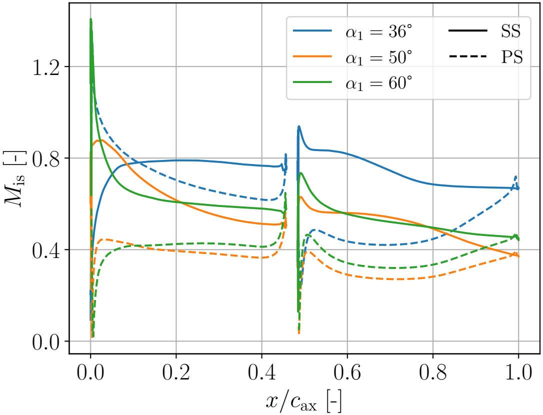

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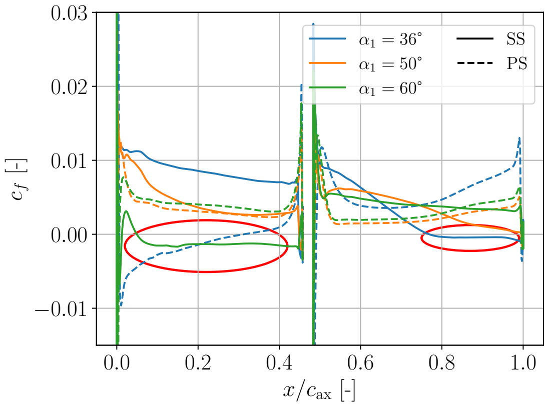

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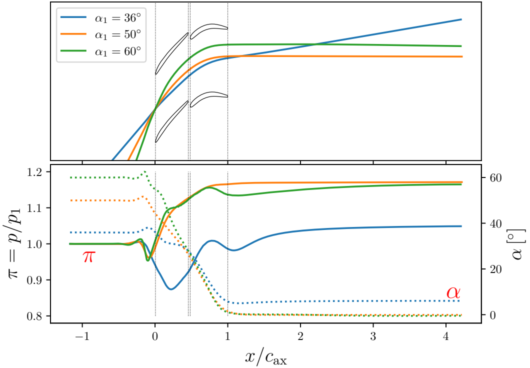
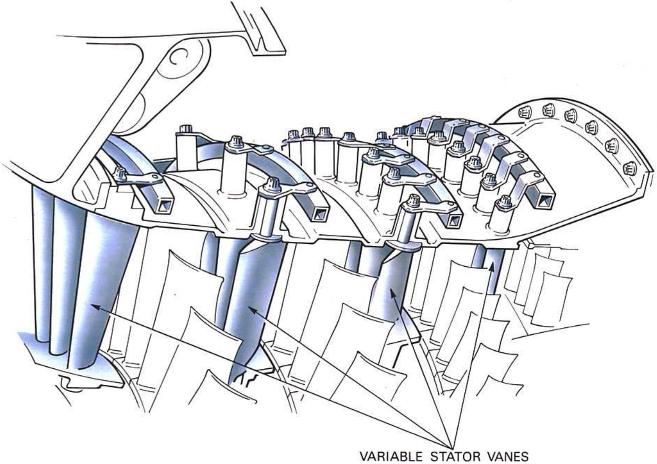


Increasing α_1 range for OGV - variable OGV ?

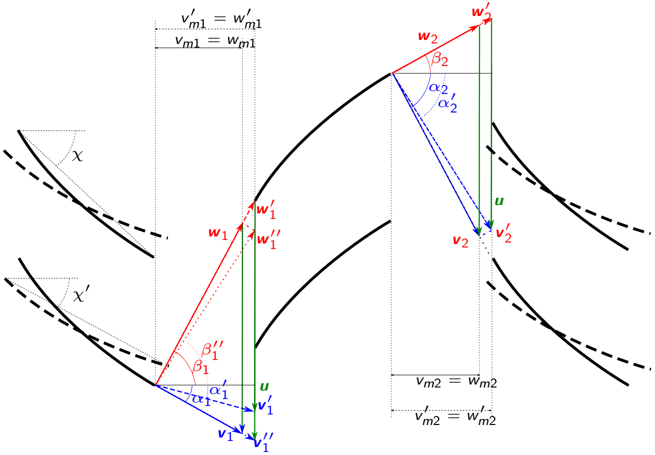
Single blade actuation

- changes both metal angles κ_1 and κ_2



Single blade actuation

- changes both metal angles κ_1 and κ_2
- beneficial for intermediate stator → VSV



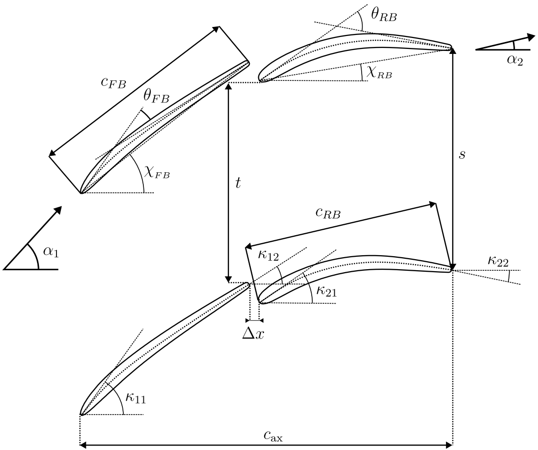
Increasing α_1 range for OGV - variable OGV ?

Single blade actuation

- changes both metal angles κ_1 and κ_2
- beneficial for intermediate stator $\rightarrow$ VSV
- detrimental for OGV/since α_2 should be constant

Tandem : independent actuation possible

- front blade χ_{FB}: **incidence swing** α_1
- aft blade χ_{AB}: adaptation of α_2



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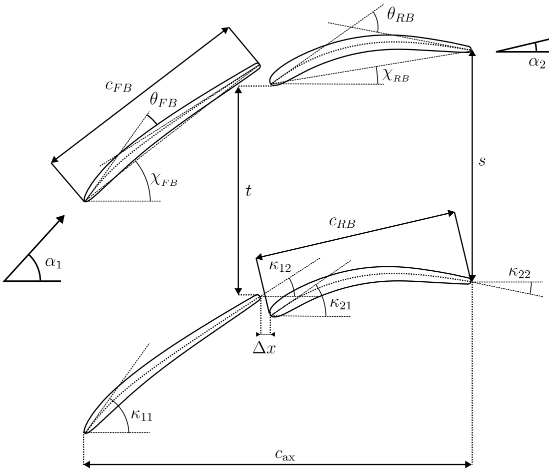
Objective:

- increase α_1 range, keep $\alpha_2 = 0^\circ$ by changing χ_{FB}
- keep airfoils of original tandem
- conditions $M_1 = 0.6$, $Re_{cax} = 550k$, $AVDR = 1$



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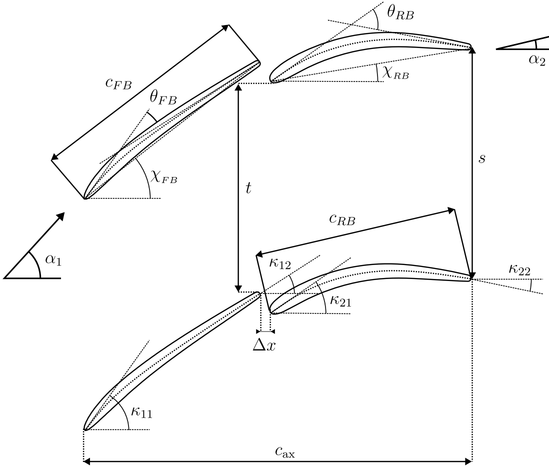
Approach: sweep front blade stagger χ_{FB} for range of α_1

1. align leading edge κ_{11} with α_1
2. χ_{FB} which minimises loss ω
3. χ_{FB} which maximises pressure rise p_2/p_1



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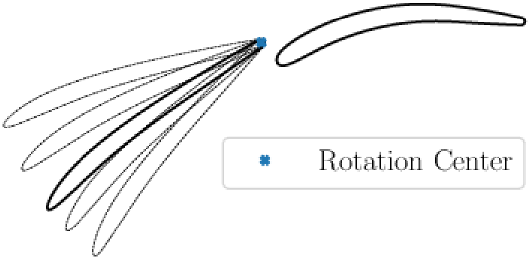
Pivot point

- trailing edge $\rightarrow$ keep interblade space



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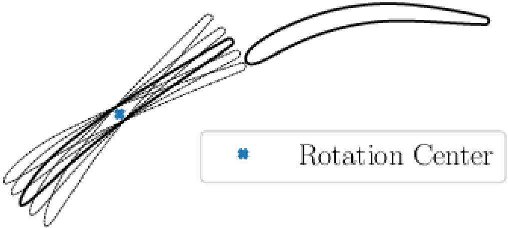
Pivot point

- trailing edge $\rightarrow$ keep interblade space
- mid chord $\rightarrow$ practical configuration for pivot



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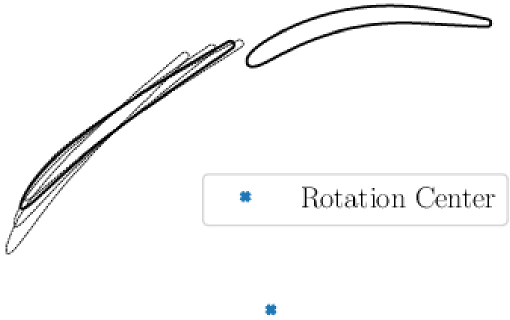
Pivot point

- trailing edge $\rightarrow$ keep interblade space
- mid chord $\rightarrow$ practical configuration for pivot
- tangent $\rightarrow$ keep alignment of camber lines



Proof of concept study
Computational setup

Solver

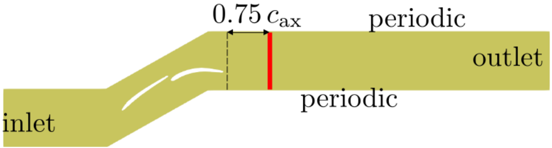
- 2D RANS with AVDR $= 1$
- second order accurate, Roe solver
- SST turbulence model resolved up to wall
- BC inlet: p_1°, T_1° and α_1, outlet adjusted p_2

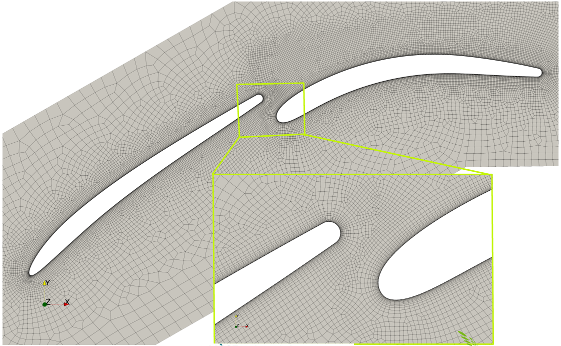
Mesh

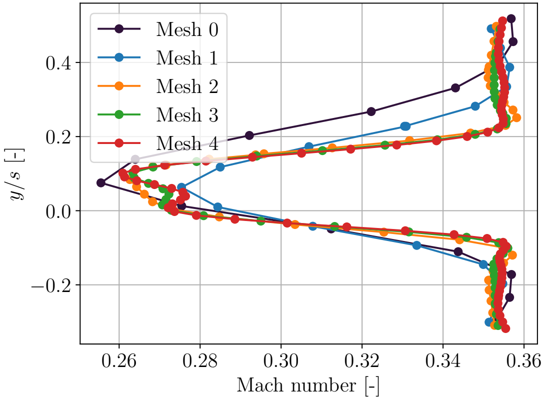
- unstructured in main domain
- extrusion layer near the mesh
- local refinements near LE, TE and in the wakes
- automated generation using python for range of χ_{FB}

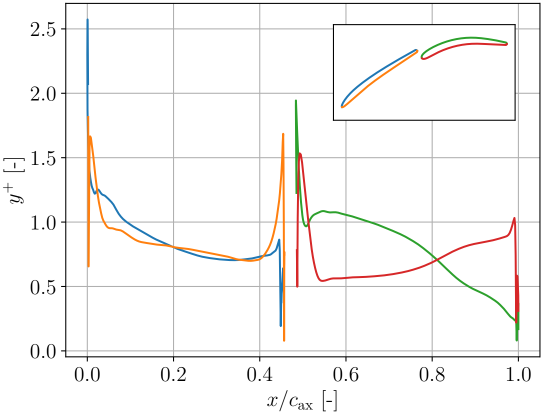
Parametric sweep: embedded loops in python

- sweep over α_1
- for each α_1 sweep over χ_{FB} obtain ω and π
- for each α_1, χ_{FB}, iterate on p_2 to fix $M_1 = 0.6$



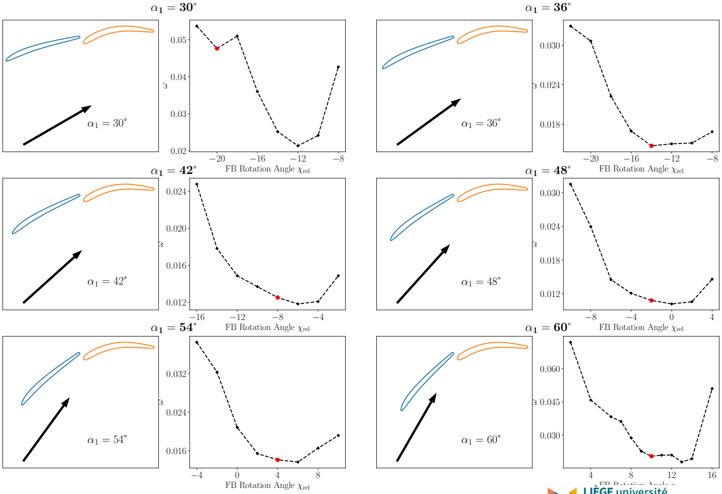



Mesh 0
Mesh 1
Mesh 2
Mesh 3
Mesh 4
y/s [-]
0.4
0.2
0.0
−0.2
0.26
0.28
0.30
0.32
0.34
0.36
Mach number [-]


y^+ [-]
2.5
2.0
1.5
1.0
0.5
0.0
0.0
0.2
0.4
0.6
0.8
1.0
x/c_{ax} [-]

Proof of concept study

Trailing edge pivot - aligned leading edge $\kappa_{11} = \alpha_1$



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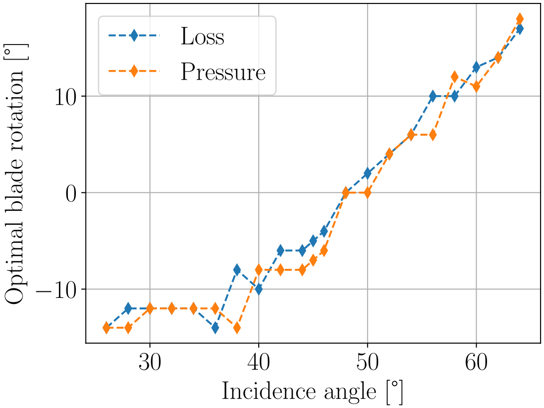
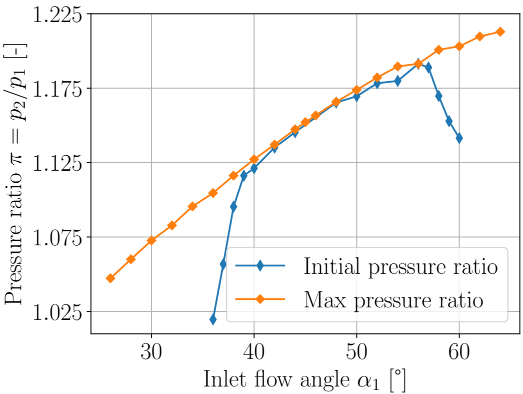
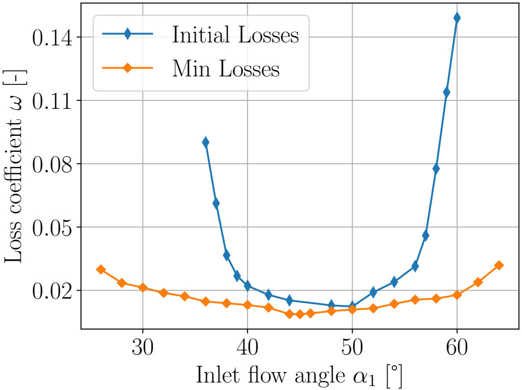
Proof of concept study
Trailing edge pivot - best χ

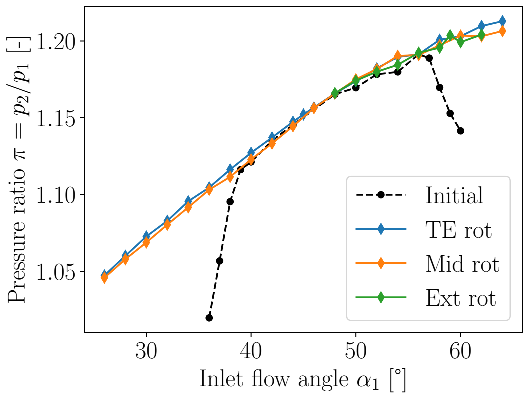


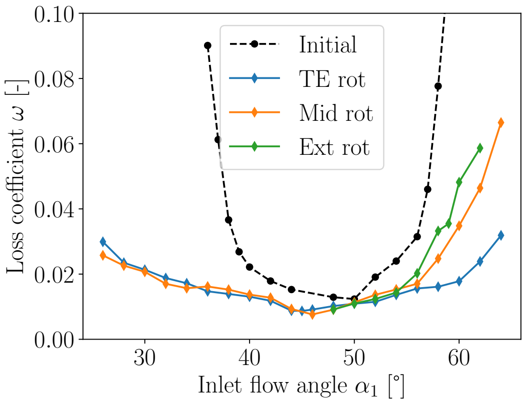
Optimal front blade stagger (very nearly) same for loss and pressure rise





About 20° increase in range obtained



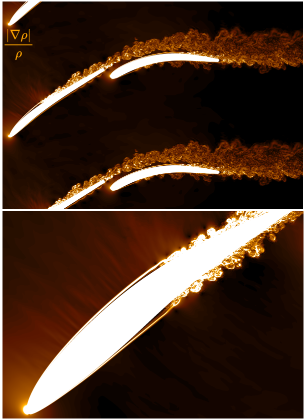


trailing edge pivot best performance without limitations on angle

Concluding remarks

Conclusions

- preliminary study
- large increase of range can be obtained
- leading edge alignment not always optimal
- trailing edge pivot currently best strategy, but probably not very practical



DG/ILES nominal conditions, fixed FB
Dr. Andrea Rocca, ArgoDG (Cenaero)

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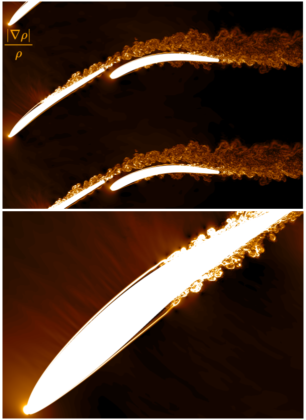
- optimize blade geometry and pivot point conjointly



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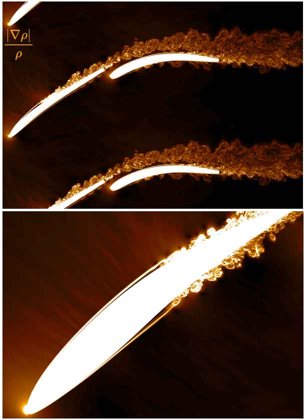

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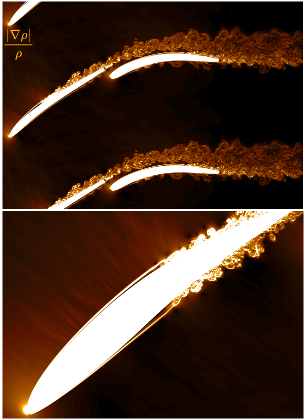
Perspectives - industrialisation

- *optimize shape and pivot for real tandem OGV*
- *investigate scheduling strategy/parameters*



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Acknowledgments

- The tandem geometry used for this study was optimized by Cenaero during the Walloon regional project *Wings*, in a collaborative effort between Safran Aero Boosters, VKI and Cenaero and then made available to ULiège;
- The present research benefited from computational resources made available on Lucia, the Tier-1 supercomputer of the Walloon Region, infrastructure funded by the Walloon Region under the grant agreement n°1910247;
- The tandem blade is currently under further study by ULiège master students T. Dupont, D.A. Dobarro and V. Aslançi, whose efforts are gratefully acknowledged;
- Cenaero, VKI and Safran Aero Boosters are acknowledged for their support and contribution to the evaluation of master students.