GETTING HYBRID ELECTRIC

Aerodynamic Investigation of a Propeller-Driven Transport Aircraft with Distributed Propulsion within the Imothep Project / ECCOMAS 2024

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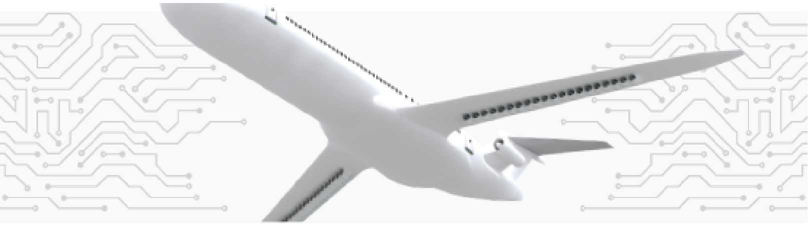
IMOTHEP in a nutshell

Project Coordination
ONERA
THE FRENCH AEROSPACE LAB



Project acronym & title
IMOTHEP – Investigation and Maturation of Technologies for Hybrid Electric Propulsion

Starting date
01/01/2020

Duration
48 months

33 partners
(including European and international partners)

Call/Topic
H2020-MG-2019-SingleStage-INEA / LC-MG-1-7-2019 Future propulsion and integration: towards a hybrid/electric aircraft (InCo flagship)

GA Number
875006

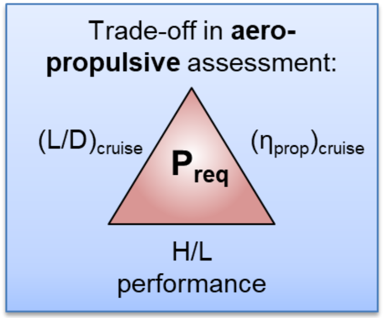
Grant/Budget
10.4 M€
of EU funding

11 countries

ONERA THE FRENCH AEROSPACE LAB · AIRBUS · CIRA Centro Italiano Ricerche Aerospaziali · DLR · LEONARDO AIRCRAFT
CHALMERS · Łukasiewicz Institute of Aviation · INCAS · ITP Aero · nlr
University of Strathclyde Glasgow · Politecnico di Bari · University of Nottingham UK | CHINA | MALAYSIA · EUROCONTROL
SAFRAN · Avio Aero · UP · AIT · GKN AEROSPACE
MTU Aero Engines · Bauhaus Luftfahrt Neue Wege · UNIVERSITÉ DE LORRAINE · ISAE SUPAERO · KIT
NRC·CNRC

Motivation & Objectives

- Reduce aviation's climate impact
  - Hybrid electric propulsion
- IMOTHEP's top level goals:
  - Building the overall European development roadmap for HEP
  - Achieving a key step in assessing potential benefits of HEP for emissions reductions of commercial aircraft
- Aero-propulsive integration essential for overall assessment
  - Investigation of aerodynamic aspects of regional propeller-driven transport aircraft with distributed propulsion
    - Propeller design*
    - Basic sensitivity studies to assess effects on
      - Aero-propulsive efficiency ("direct" efficiency improvements)
      - Potential of lift augmentation ("indirect" efficiency improvements)
    - Integration design & performance assessment



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*see: Y. Maldonado, F. Tong-Yette, L. Delcambre and B. Rodriguez, "Propeller predesign for distributed propulsion architectures," in *3AF - Towards Sustainable Aviation Summit*, Toulouse, 2022

Content

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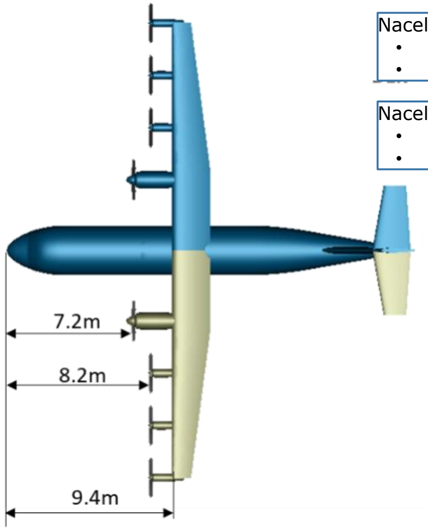
Concept / Geometry

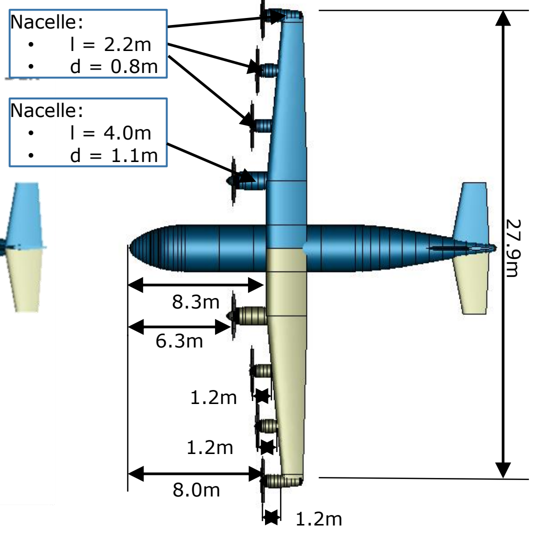
- Short range regional aircraft
- «Plug-in-hybrid» with range-extender
- Overall aircraft design within IMOTHEP*
- Aero studies based on three different design loop stages
- Detailed aerodynamic high-lift design (**single slotted drop-hinge flaps, no l.e. device**) considering kinematics

TLARS	
Payload	40 PAX (4240 kg)
Range (Design / Typical)	600 nm / 200 nm
Cruise Mach number	0.4
Cruise Altitude	20000 ft
TOFL @ SL,ISA	1100 m
Approach Speed	115 kts

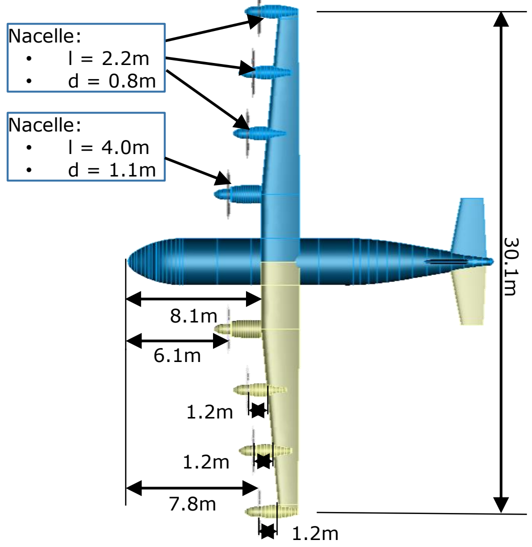
Loop 0 design*



Loop 1 design*



Loop 1.5 design*



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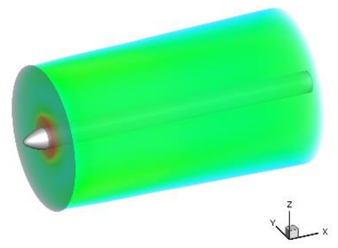
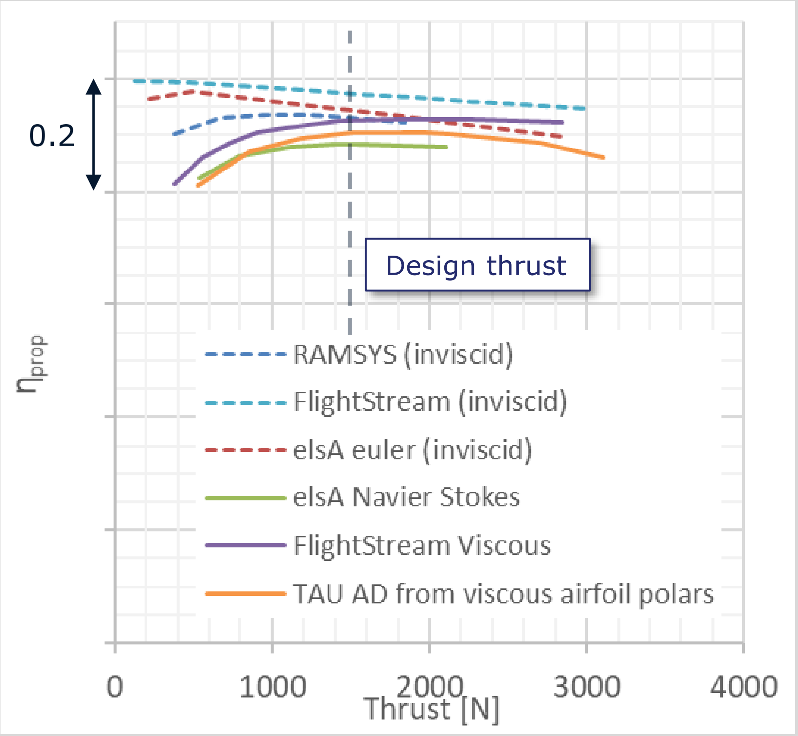
*see Atanasov, G.: „IMOTHEP Plug-In Hybrid-Electric Aircraft Concept: REG-RAD"

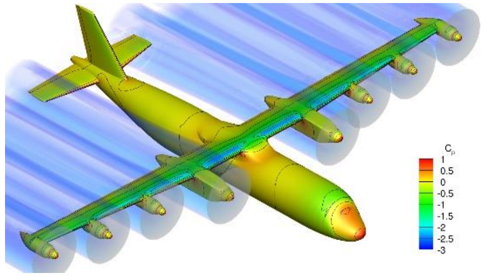
Comparison of Numerical Methods



- Utilization of methods with varying fidelity within studies
  - Mi-Fi (Unsteady): RAMSYS, FlightStream
  - Hi-Fi (RANS): elsA, TAU (w/ actuator disk)
- Isolated Propeller:
  - Viscous codes all reflect similar trend for $\eta_{p(T)}$
  - Larger discrepancies for inviscid codes



Comparison of Numerical Methods



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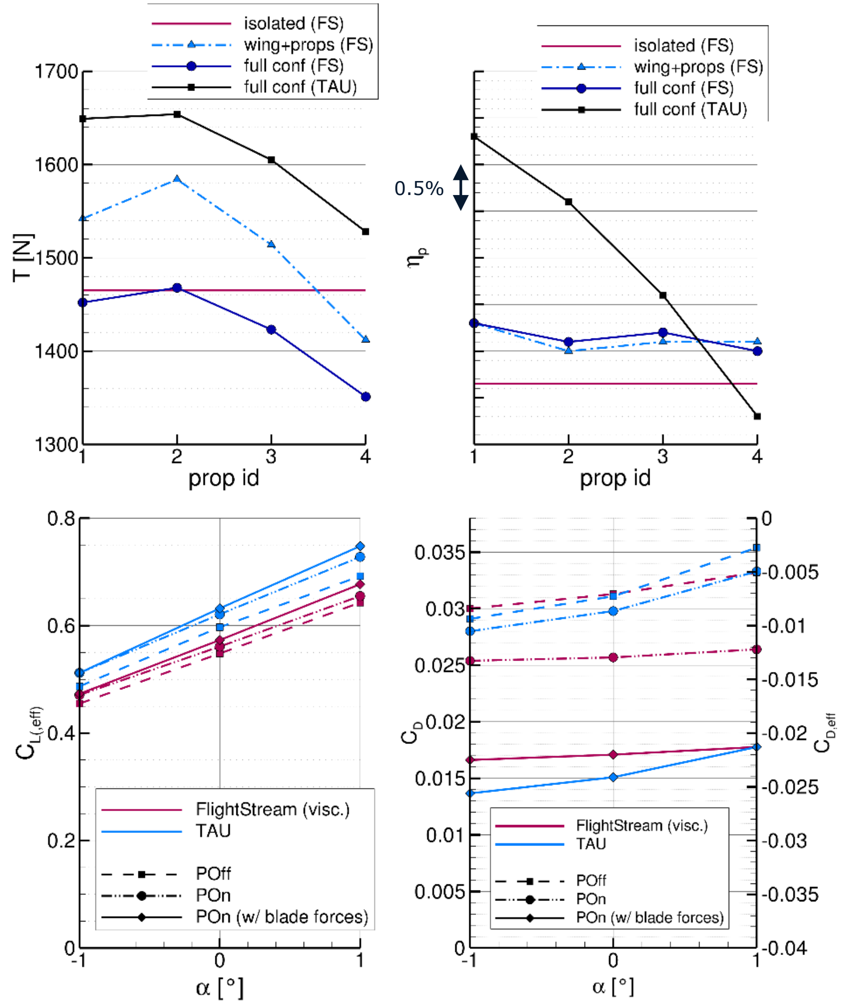
- Isolated Propeller:
  - Viscous codes all reflect similar trend for $\eta_{p(T)}$
  - Larger discrepancies for inviscid codes
- Installed Propeller:
  - Installation effects on propellers:
    - Thrust: Trends agree well between FlightStream (MiFi) & TAU (RANS), higher offset with “full conf”
    - η_{prop}: Disagreement in trend
  - Installation effects on wing:
    - Airframe coefficients: Generally good agreement in trends with offsets



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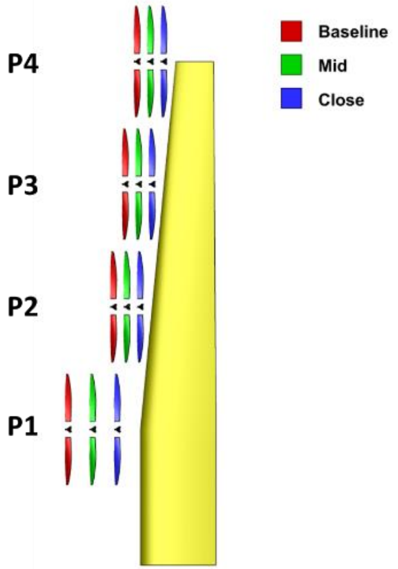
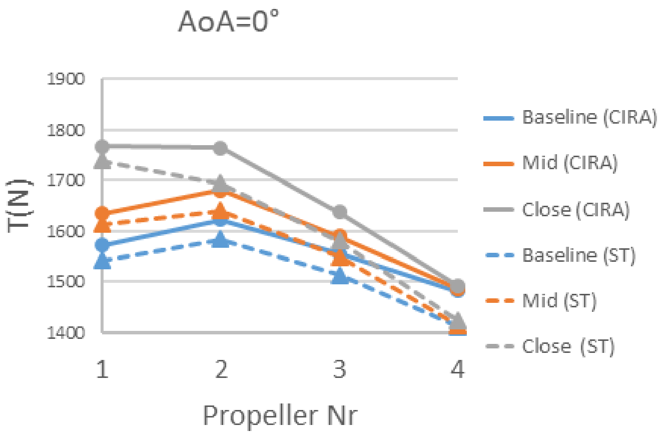
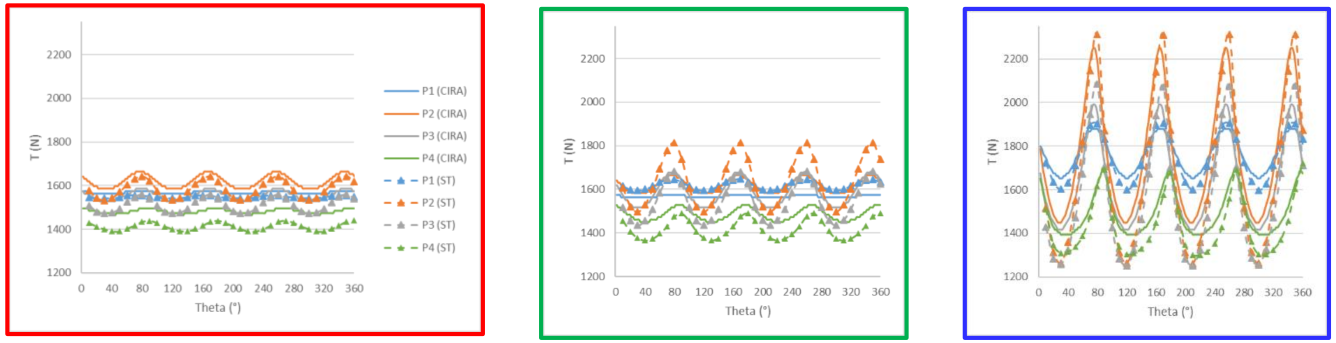
Propeller Position: Cruise Flight

- Results based on MiFi methods:
  - Good agreement between CIRA's and Safran Tech's methods
- Impact of streamwise propeller position:
  - Reduced prop-wing distance:
    - Increased thrust / prop efficiencies
    - Stronger thrust / torque oscillations





Reduced prop-wing distance / stronger oscillations



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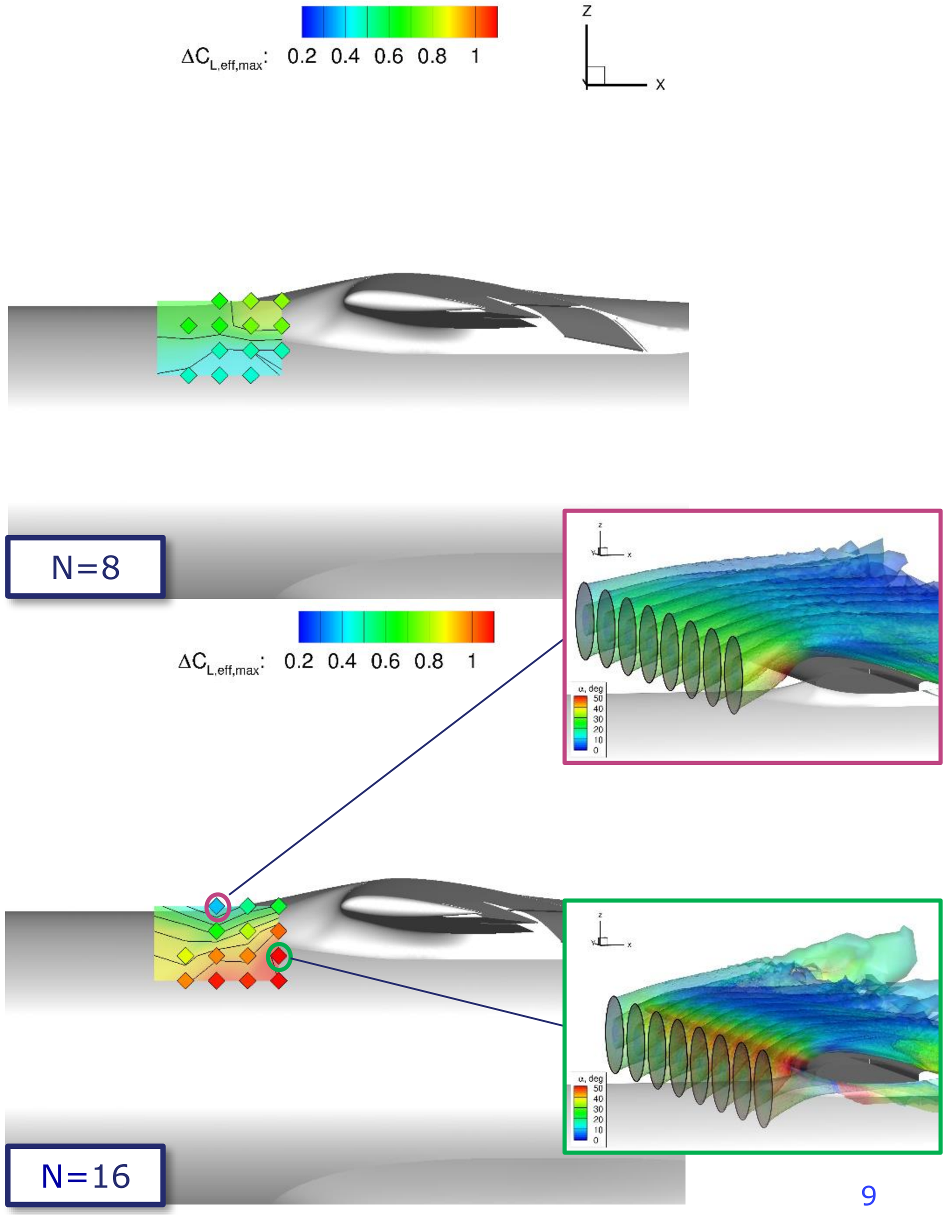
Propeller Position: High-Lift

Increase in maximum effective lift coefficient

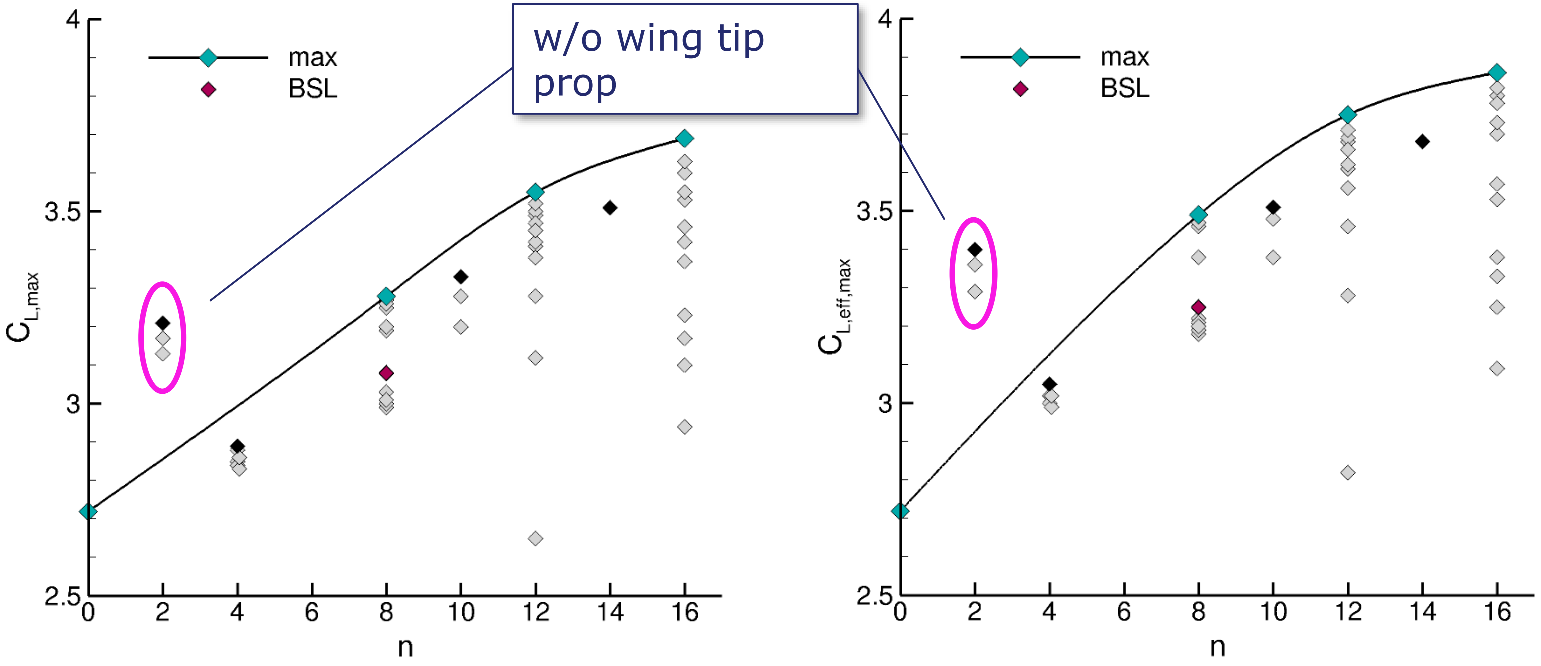
- Results based on RANS computations
- Impact of propeller position:
  - Modest impact for moderate number of props (n) / large D_p
  - Significant impact on $\Delta C_{L,max}$ for highly distributed props /small D_p
    - Best low speed performance achieved at rather unfavorable propeller positions w.r.t. cruise performance



Propeller Count: High-Lift

Maximum lift coefficient

Maximum effective lift coefficient



- $\Delta C_{L,eff,max}$ strongly dependent on propeller positions
- Maximum (effective) lift coefficient ($C_{L,eff,max}$) increases with number of propellers (n) (up to $\Delta C_{L,eff,max}$ = 1.14 (+42%)). Curve flattens at large n (most likely) due to low D_{prop}/c_{ref} ratios
- 2 prop. configuration achieves favorable $\Delta C_{L,eff,max}$ but certification requirements have to be kept in mind

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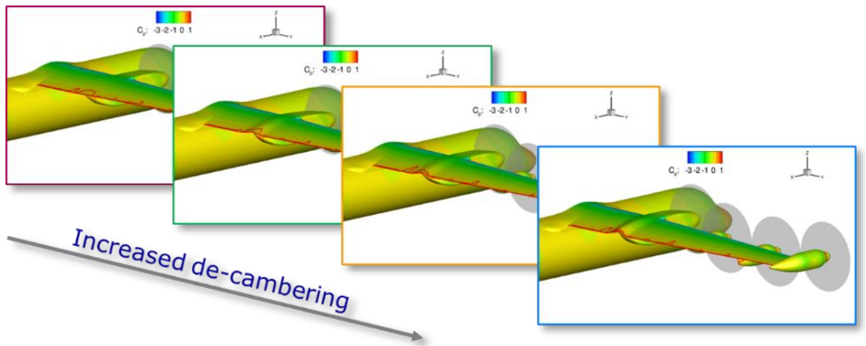
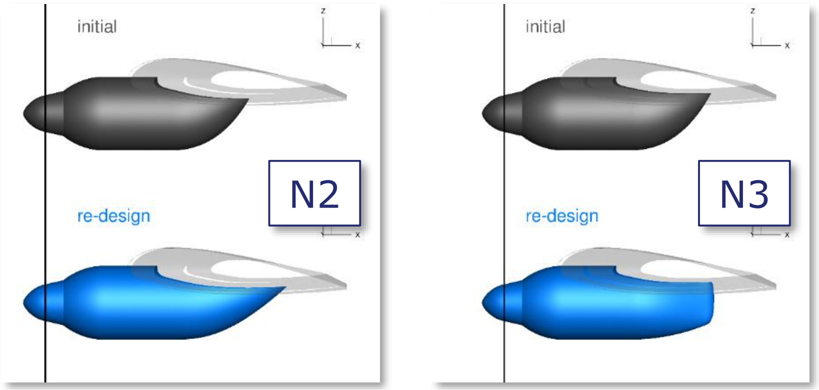
Propulsor Design / Integration

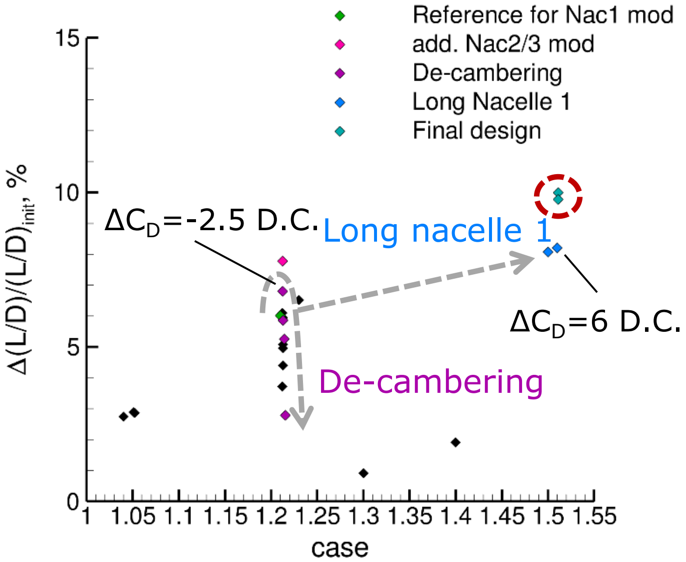


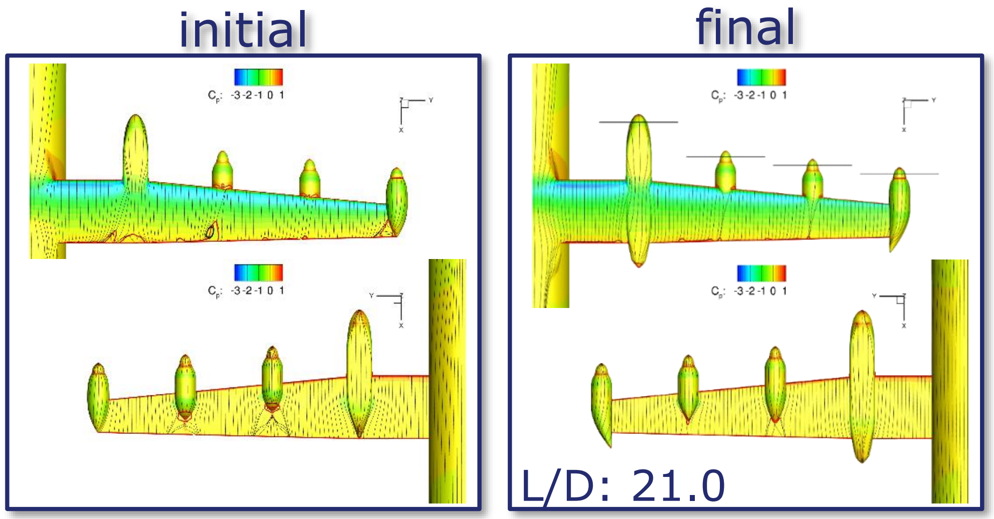
Cruise Flight

- Large nacelles due to OAD requirements (accommodation of landing gear, gas turbine, batteries, etc.)
- Nacelle design with focus on performance in cruise flight (mid cruise: M=0.4, $C_{L,MCR}$=0.7974)
- Improvement in aerodynamic efficiency by approx. 10 %
- Reduction in required propulsive power by 6 %



Aerodynamic Efficiency





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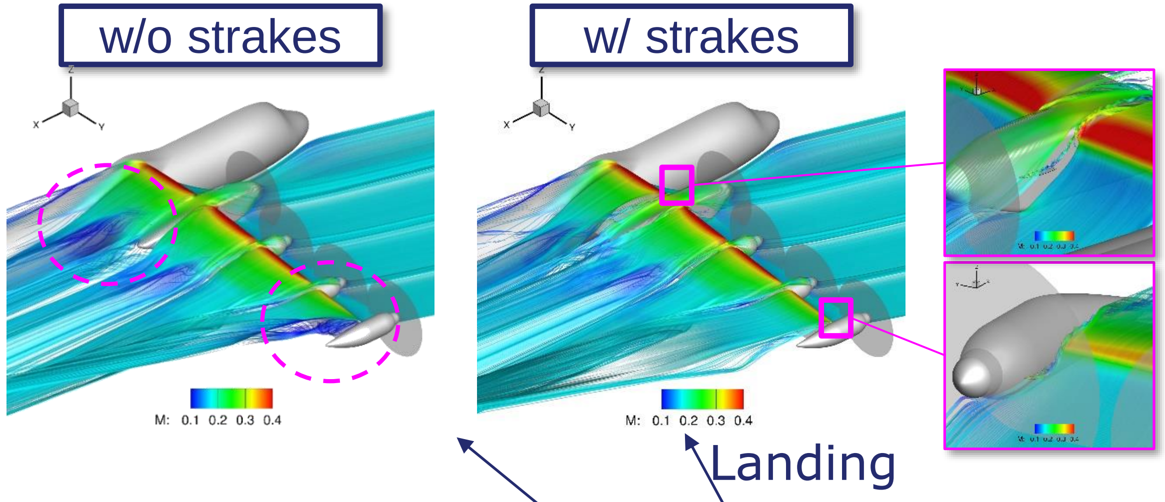
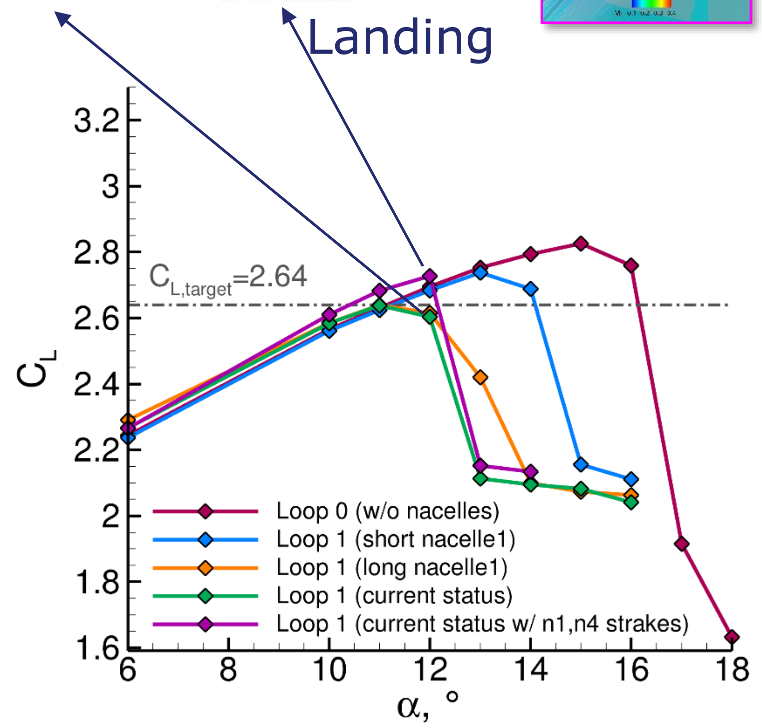
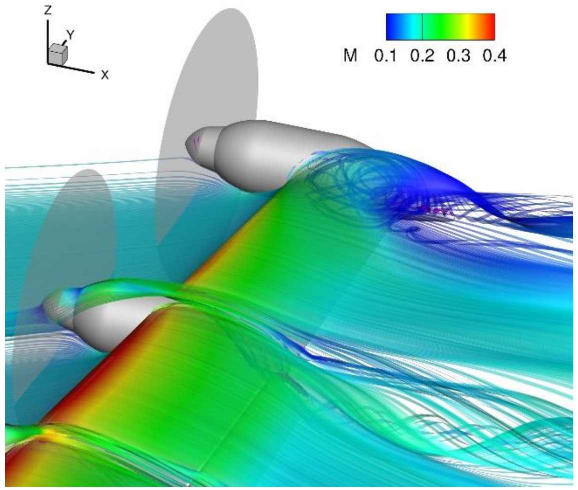
Propulsor Design / Integration

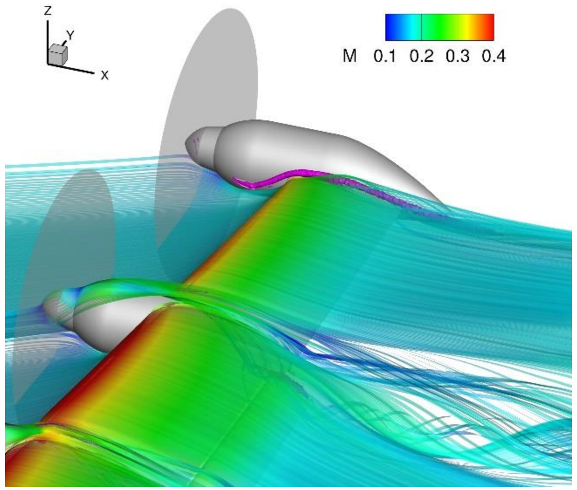
Low Speed

- High-lift performance degraded due to “long nacelle”
  - Reduction in H/L device surface size
- Delay of flow separation due to nacelle 1 & 4 strake ($\Delta C_{L,max}$=0.09)









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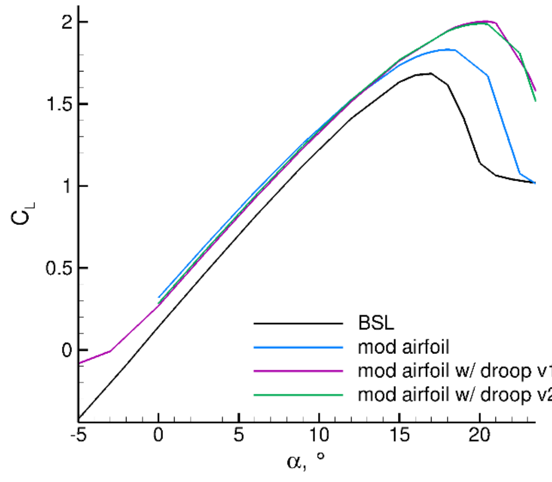
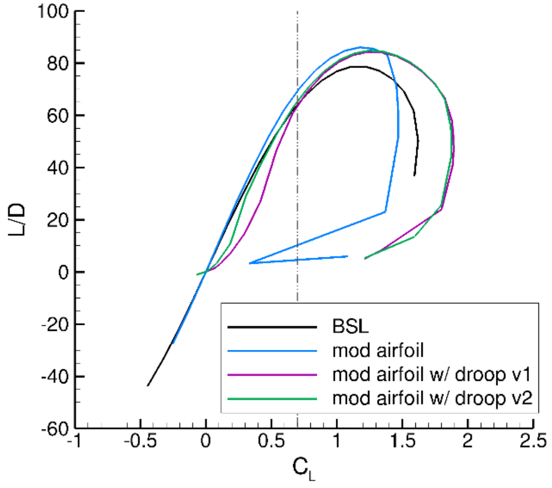
Propulsor Design / Integration

Low Speed

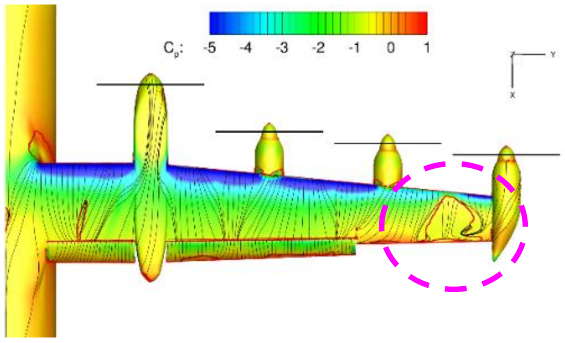
- O/B flow separation promoted by propeller slipstream
- Optimization of O/B airfoil with droop
  - Objectives: Increase α_{max} in low speed while maximizing L/D in cruise flight
  - Wing integration:
    - Improved stall pattern
    - Drag penalty (≈3 d.c. due to airfoil mod. + 4 d.c. with additionally modified twist distribution) in cruise flight based on preliminary lifting line assessment



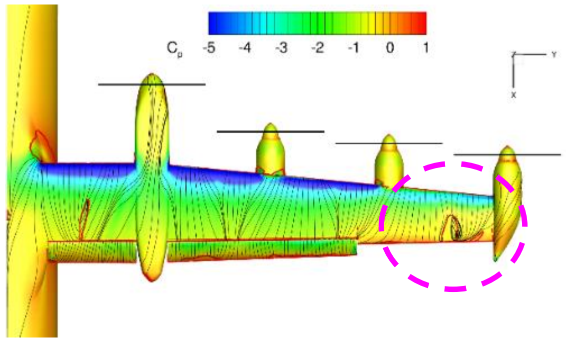


Take-Off: α=9°:

Baseline



Modified airfoil v2



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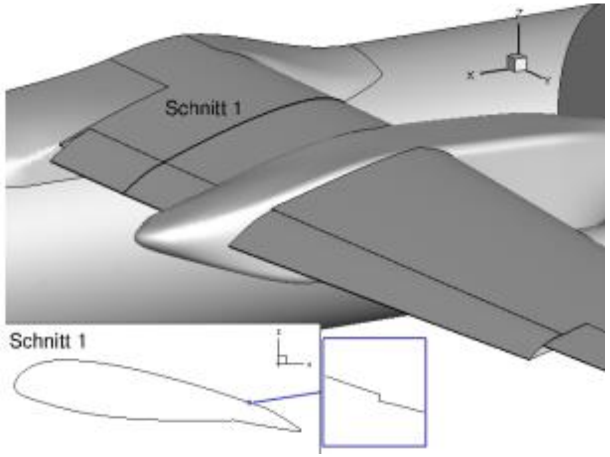
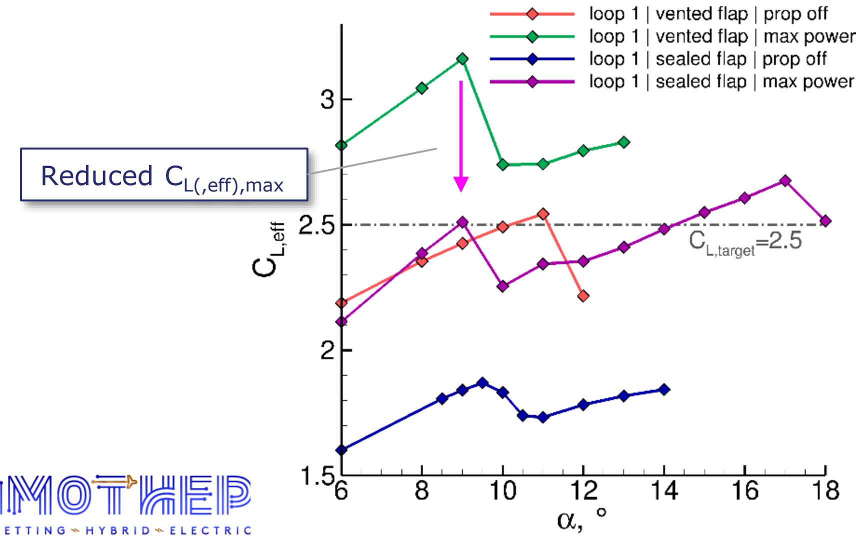
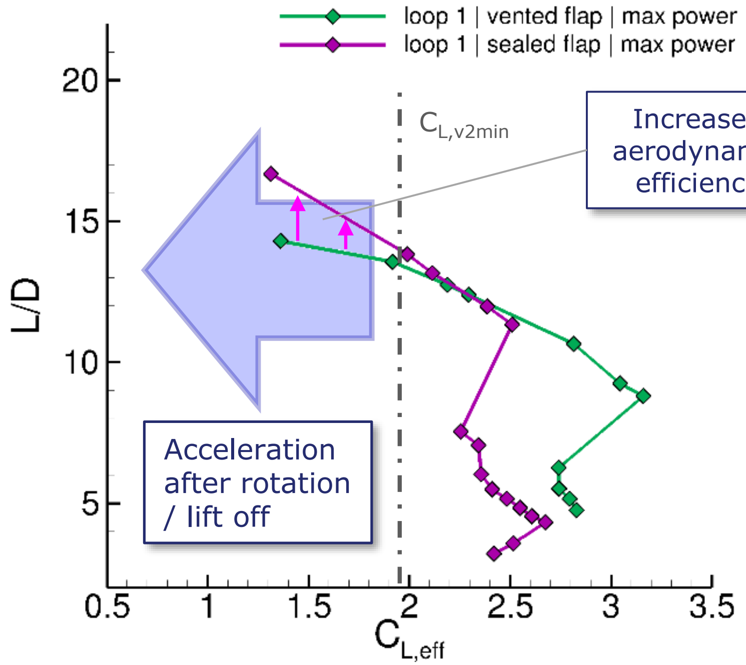
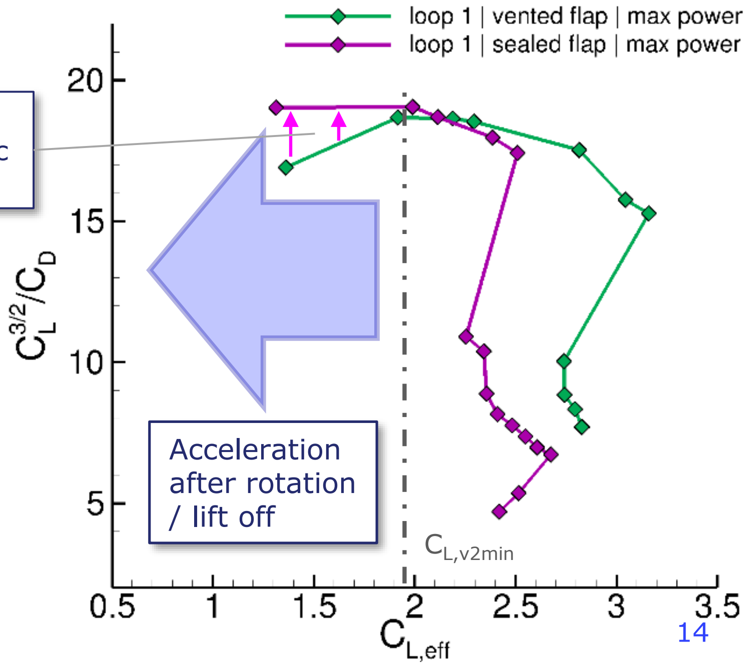
Take-Off Performance

- Improve take-off performance by trading excessive $C_{L,eff,max}$ for better climb ratio
- Modified high-lift design with sealed flap in take-off
- $C_{L,max}$ target still achieved
- $\Delta L/D=+3.9\%$, $\Delta CL^{3/2}/CD=+2\%$ @ $C_{L,v2min}$
- $\Delta L/D=+15\%$, $\Delta CL^{3/2}/CD=+12\%$ @ $C_L=1.37$
- Further potential to increase performance









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Summary / Conclusion

- MiFi tools: Suitable to estimate trends under cruise flight conditions and efficient way to analyze transient effects
- Streamwise propeller positions affect magnitude of load oscillations and lift augmentation potential in low speed
- Propeller count:
  - High count: **Large lift augmentation potential** (up to $\Delta C_{L,eff,max}$ = 1.14 (+42%)) but at the cost of unfavorable vertical propeller position w.r.t. cruise flight performance*
  - Lower propeller count: Less potential, more **robust against (vertical) propeller position***
- Nacelles can have a meaningful impact on performance (cruise & low speed) due to their size and position and may have to be counter-acted by mitigation strategies (propeller position, strakes, …)
- DP may promote tendencies of O/B flow separation
- Potential to trade excessive $C_{L,eff,max}$ in take-off for improved climb-ratio

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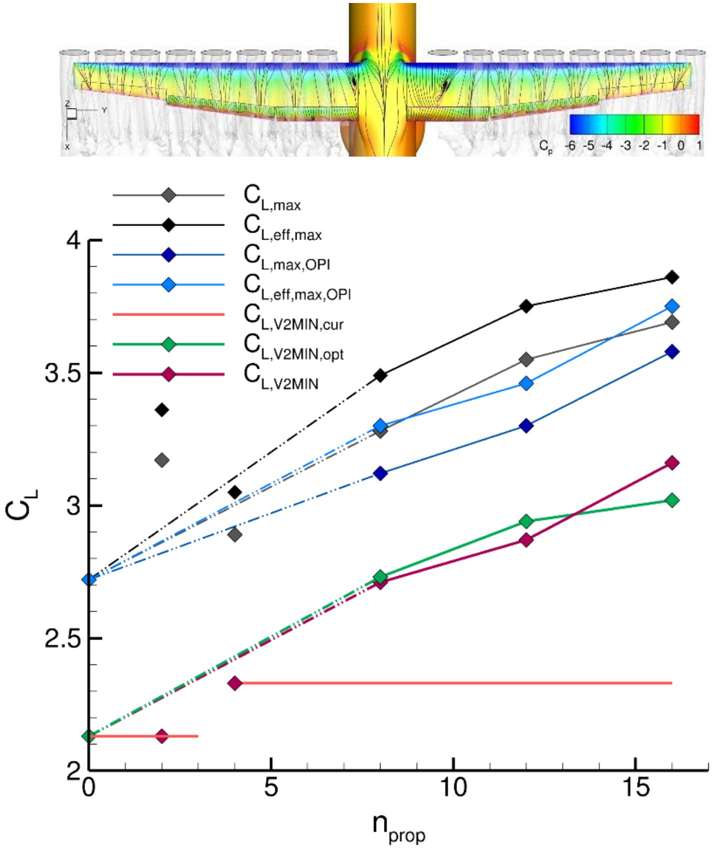
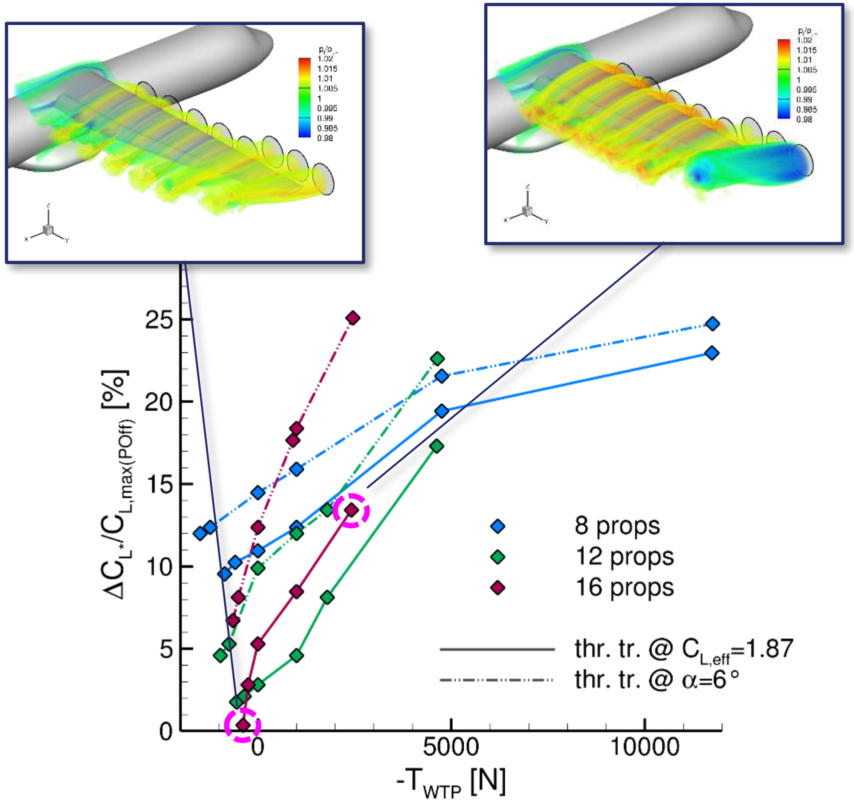
*see D. Keller, Aerodynamic Investigation of the High-Lift Performance of a Propeller-Driven Regional Transport Aircraft with Distributed Propulsion, J. Phys. Conf. Ser. 2526 (2023)

Current Work

- Impact of propulsor failures
- Lift augmentation potential in approach/landing





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Thank you for your attention!

https://www.imothep-project.eu

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