3D ISOLATED ROTOR IN HOVER

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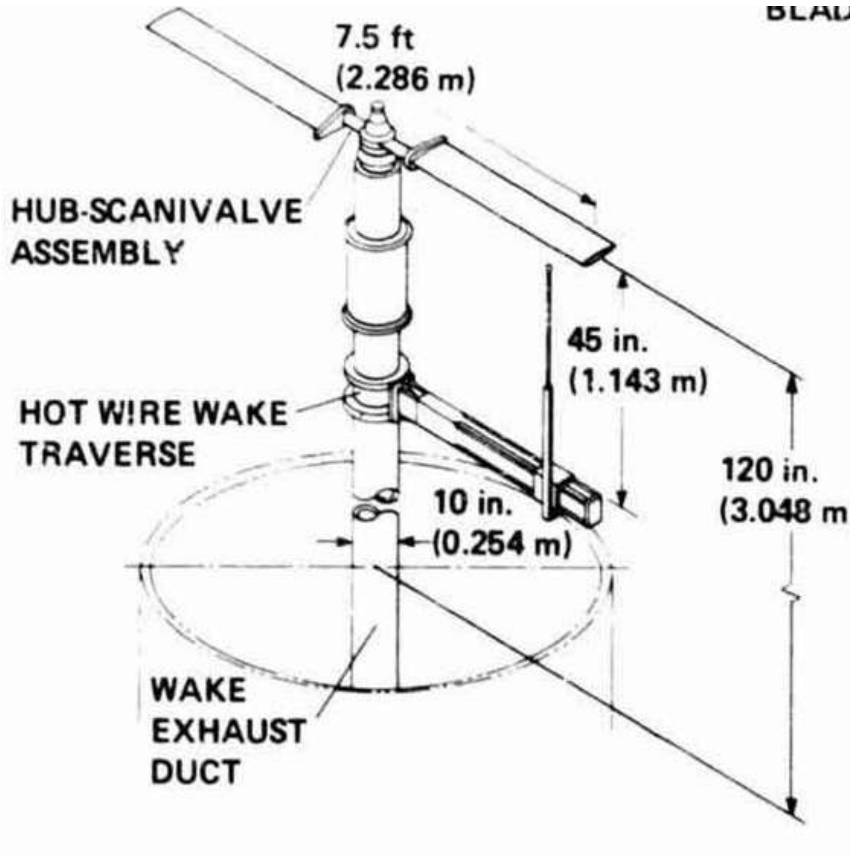
INTRODUCTION

- Rotorcrafts – a unique vehicle with a capability of VTOL
- Many codes developed by institutions and academia. Eg: FUN3D, ROSITA etc.
- Perks of Open-source softwares

REFERENCE EXPERIMENT



- A hallmark experiment by F. X. Caradonna and C.Tung
- Symmetric NACA0012 profile

Features

Chord	*Aspect Ratio*	*Rotor radius*
0.19114 m	*6*	*1.143 m*

DESIGN AND SETUP

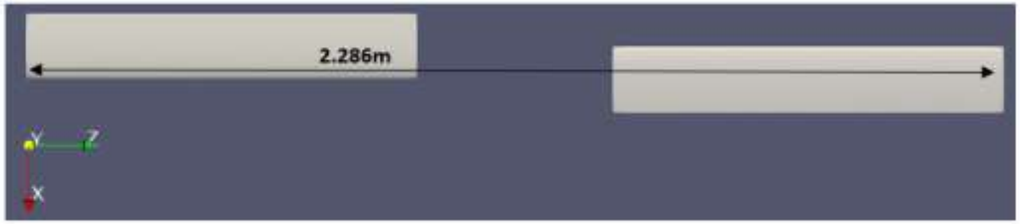
Goal: To computationally reproduce the experiment by
F. X. Caradonna and C. Tung with SU2

Procedure :

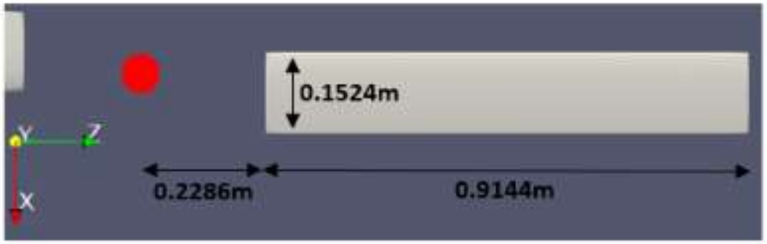
- Mesh generation (Gmsh)
- Mesh convergence
- Verification and Validation of results
- Comparison of Numerical schemes

COMPUTATIONAL MODEL: Problem specifications (1)

- Surface Geometry



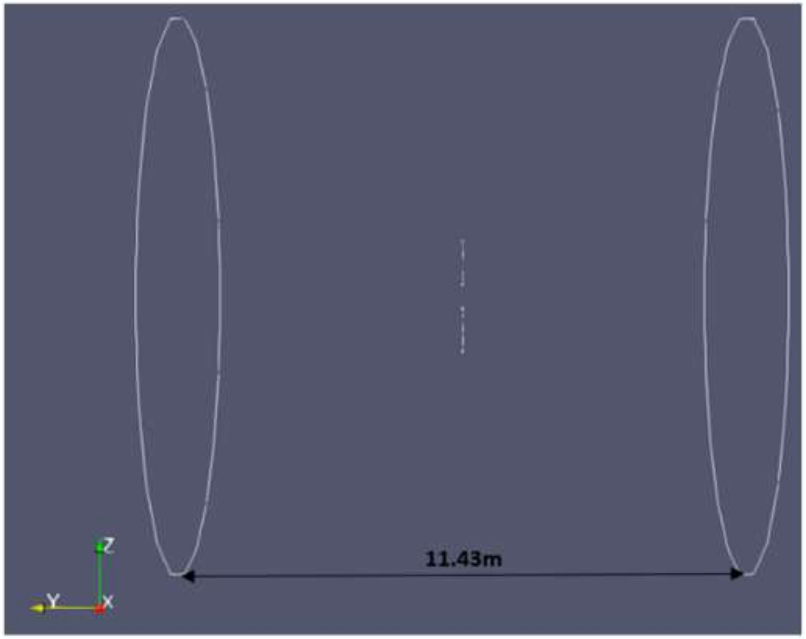
(a) Rotor diameter.



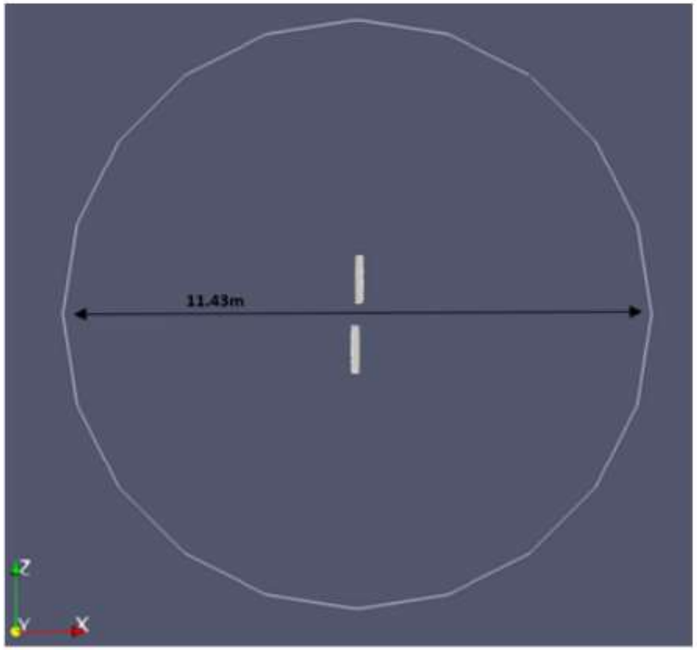
(b) Blade geometry.

COMPUTATIONAL MODEL: Problem specifications (2)

- Farfield Geometry



(a) External boundary height.



(b) External boundary diameter.

COMPUTATIONAL MODEL: Problem specifications (3)

Rotor radius	*Disk Area*	*Aspect Ratio*	*Cutoff Length*	*Blade Length*
1.143 m	*4.104 sq m*	*6*	*0.2286 m*	*0.9144 m*

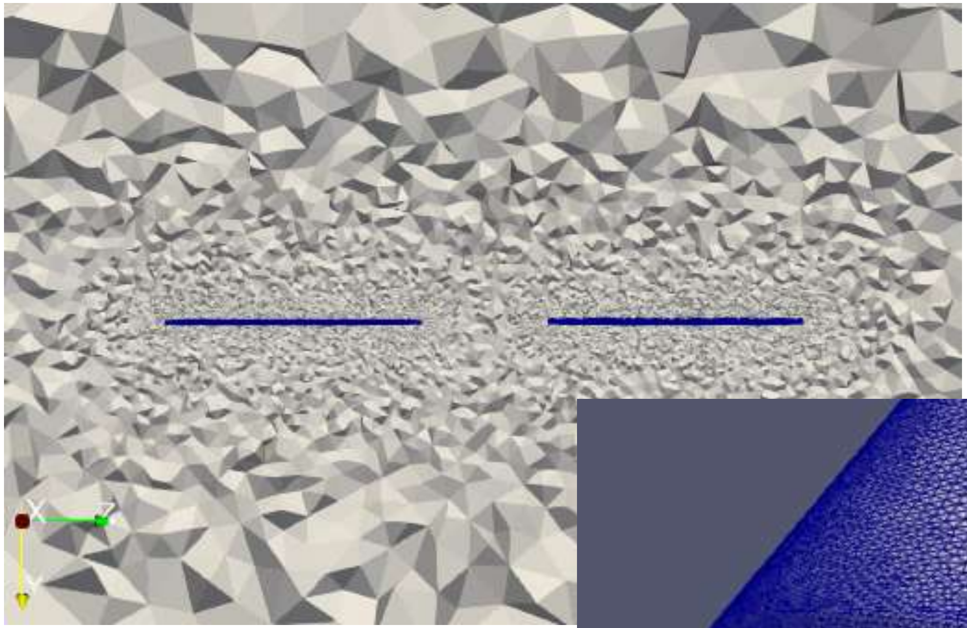
- Free-stream values

Gas constant	$287.058\, ^{Nm}/_{kgK}$
Spec. heat ratio	1.4
Static pressure	$101325\, Pa$
Density	$1.22498\, ^{kg}/_{m^3}$
Temperature	$288.15\, K$
Total energy per unit mass	$206789\, ^{m^2}/_{s^2}$

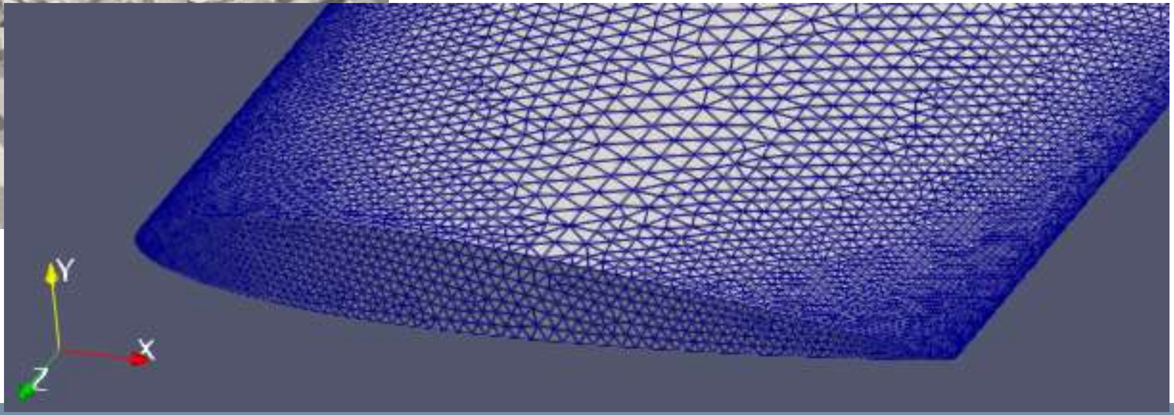
MESH GENERATION

- Surface mesh
- Volume mesh

→ **UNSTRUCTURED**



spanwise mesh section

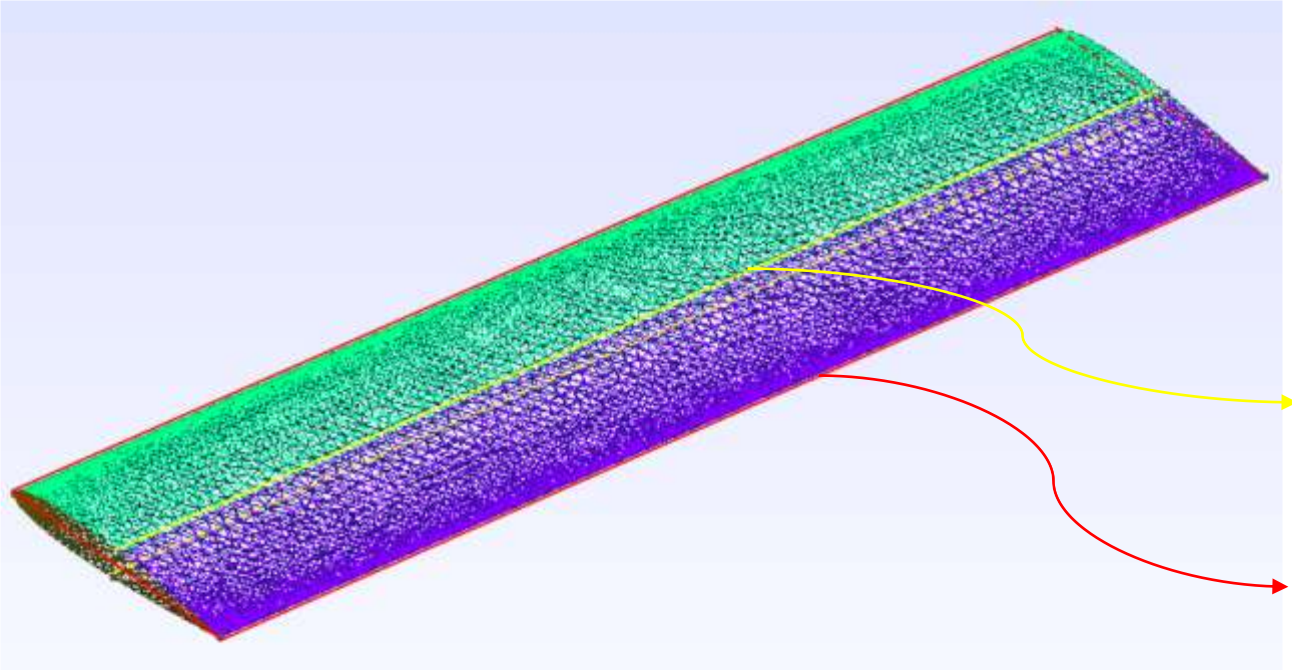


Unstructured blade surface mesh

MESH GENERATION – FIELD MESHING

Parameters $\begin{cases} \text{h} \\ \text{dim} \\ \text{C} \\ \text{N} \end{cases}$ →

reference dimension of surface elements
reference dimension of farfield elements
exponential profile constant
number of spanwise elements at C/2



C/2 lines

Wing planform perimeter

Exponential profile:

$$h - C + e^{F1-\frac{5}{2}}$$

MESH GENERATION – 4 MESHES

$$\text{Parameters}\begin{cases} h \\ dim \\ C \\ N \end{cases}$$

- reference dimension of surface elements
- reference dimension of farfield elements
- exponential profile factor
- number of spanwise elements at C/2

Exponential profile:

$$h - C + e^{F1-\frac{5}{2}}$$

	MESH 1	MESH 2	MESH 3	MESH 4
h	0.0075	0.0055	0.003	0.0025
Dim	2	2	2	2
N	75	105	150	175
C	0.065	0.0775	0.079	0.08
Elements	469804	1476898	2744096	3558951

NUMERICAL IMPLEMENTATION

Numerical approach → Finite Volume Method (FVM)

Governing equations:
COMPRESSIBLE EULER

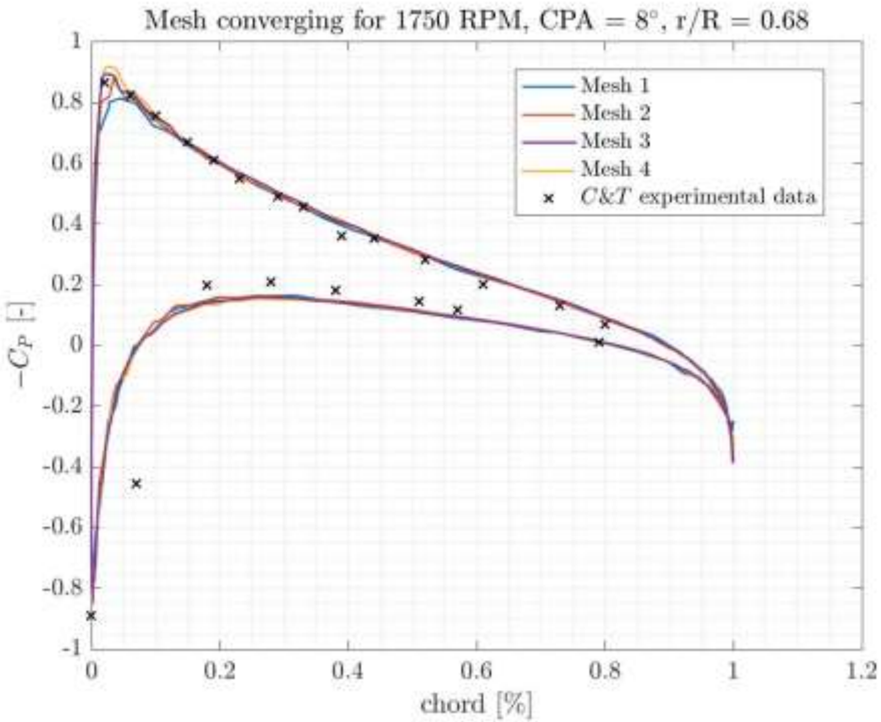
Flight condition:
HOVERING

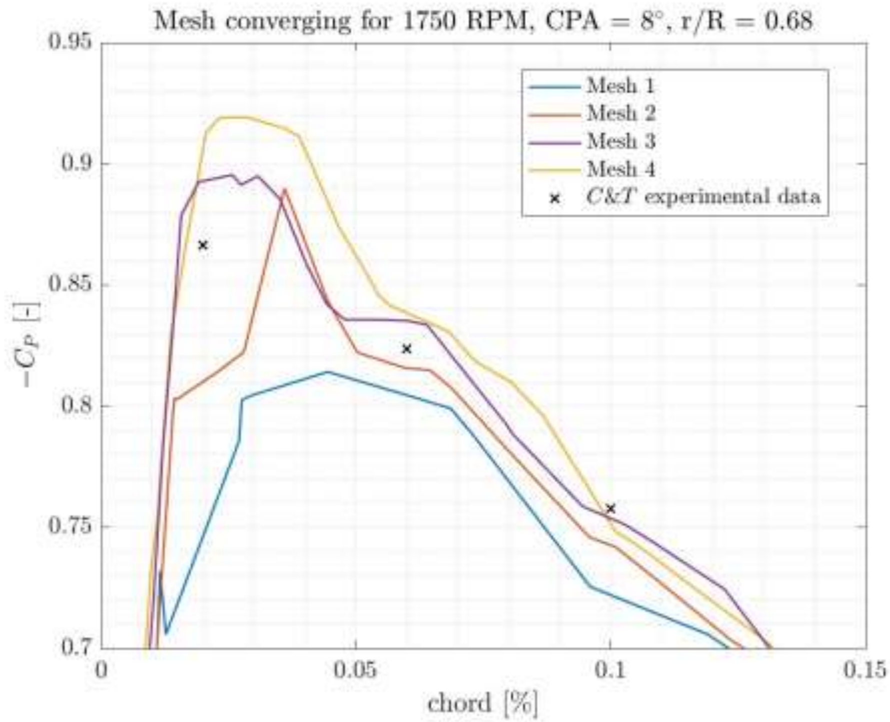
ROTATING FRAME

$$\begin{cases} \nabla \cdot \boldsymbol{F}_r(\boldsymbol{U}) - \boldsymbol{S}_r = 0 & \text{in } \Omega \\ (\boldsymbol{u} - \boldsymbol{u}_r) \cdot \boldsymbol{n}_s = 0 & \text{on } \Gamma_s \\ W_+ = W_\infty & \text{on } \Gamma_\infty \end{cases} \qquad \boldsymbol{F}_r = \begin{Bmatrix} \rho(\boldsymbol{u} - \boldsymbol{u}_r) \\ \rho \boldsymbol{u} \otimes (\boldsymbol{u} - \boldsymbol{u}_r) + \mathcal{I}P \\ E(\boldsymbol{u} - \boldsymbol{u}_r) + P\boldsymbol{u} \end{Bmatrix}$$

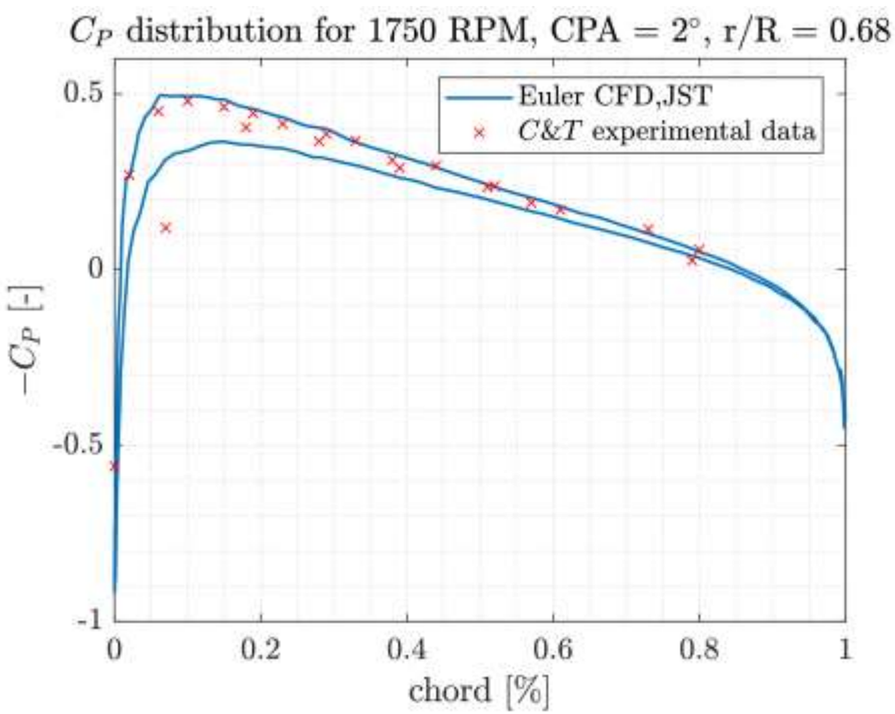
$$\boldsymbol{S}_r = \begin{Bmatrix} S_\rho \\ S_{\rho \boldsymbol{u}} - \rho(\boldsymbol{\omega} \times \boldsymbol{u}) \\ S_E \end{Bmatrix} \qquad \boldsymbol{u}_r = \boldsymbol{\omega} \times \boldsymbol{r}$$

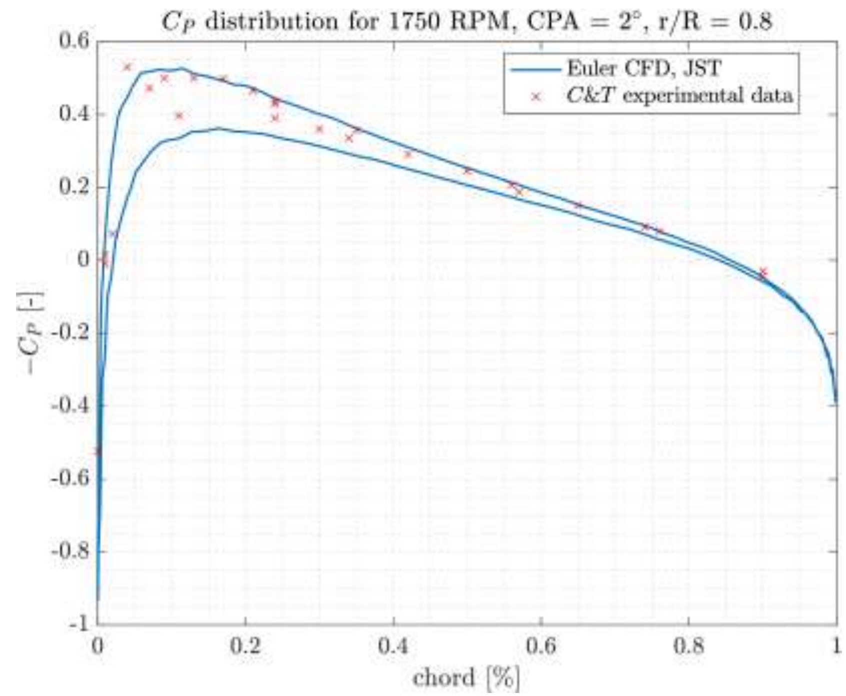
1750 RPM: Mesh Convergence



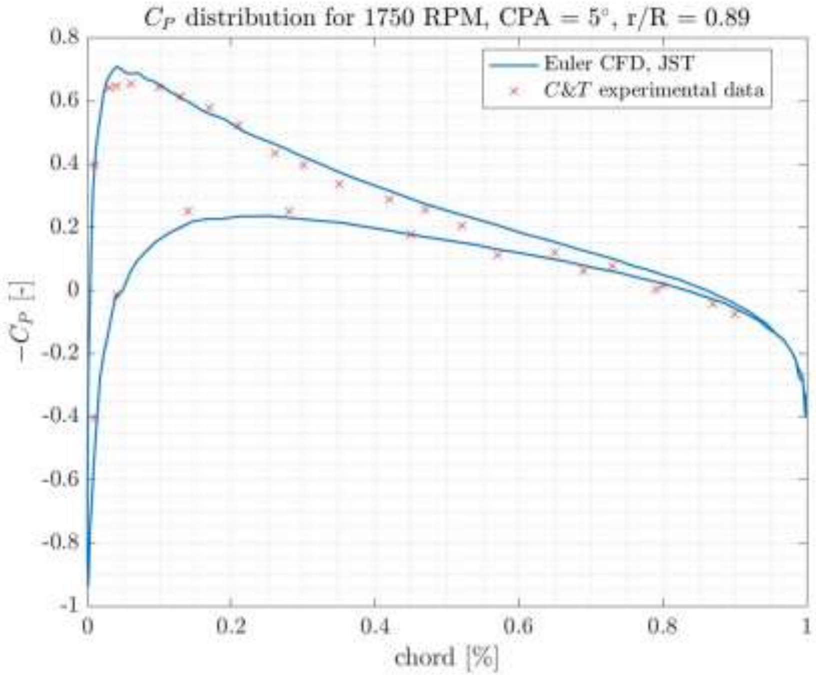


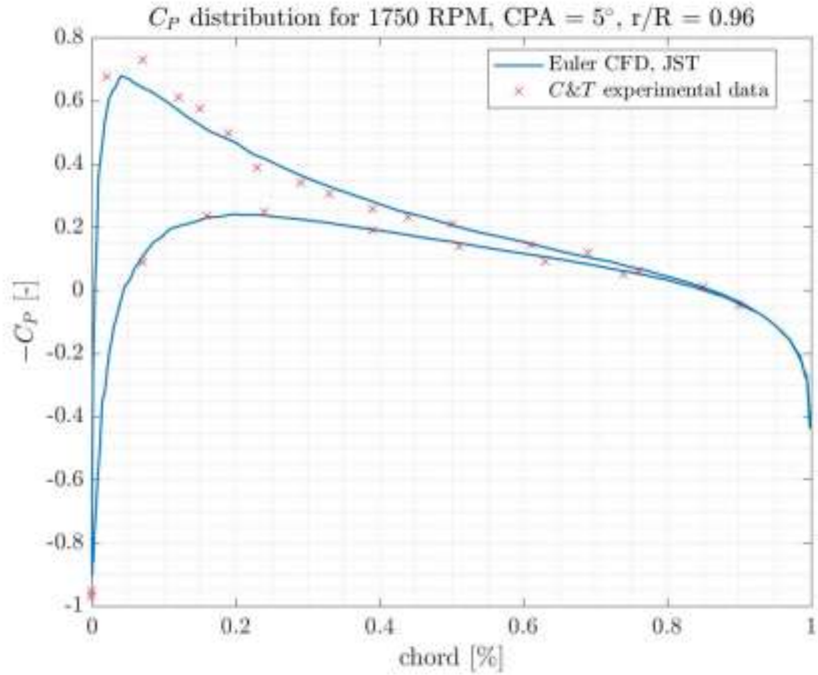
1750 RPM: Cp Plot, 2° CPA



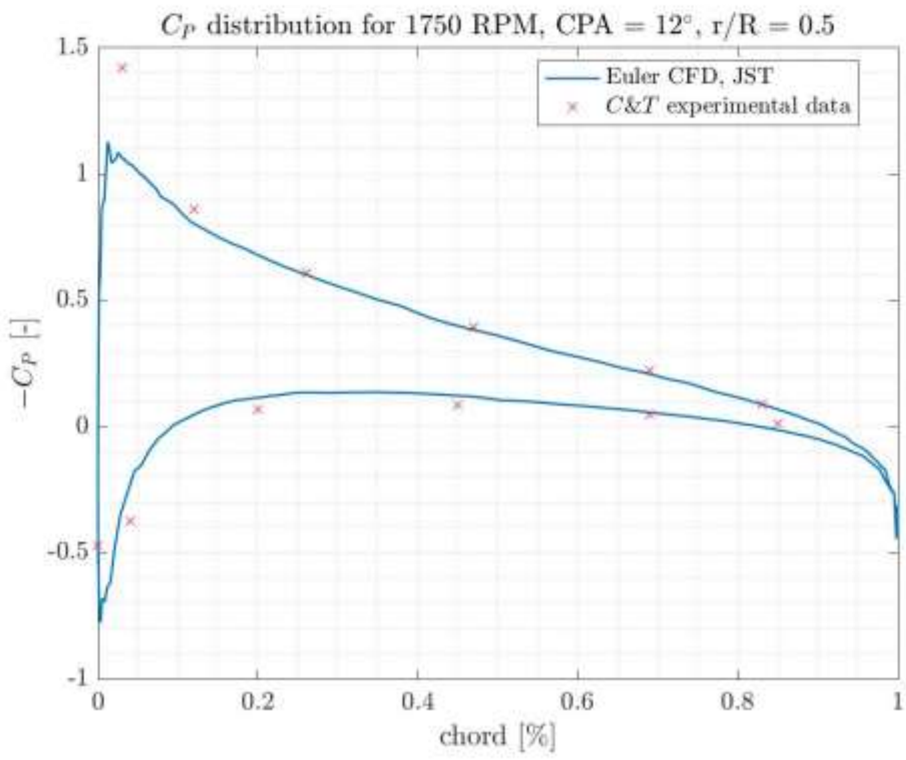


1750 RPM: Cp Plot, 5° CPA

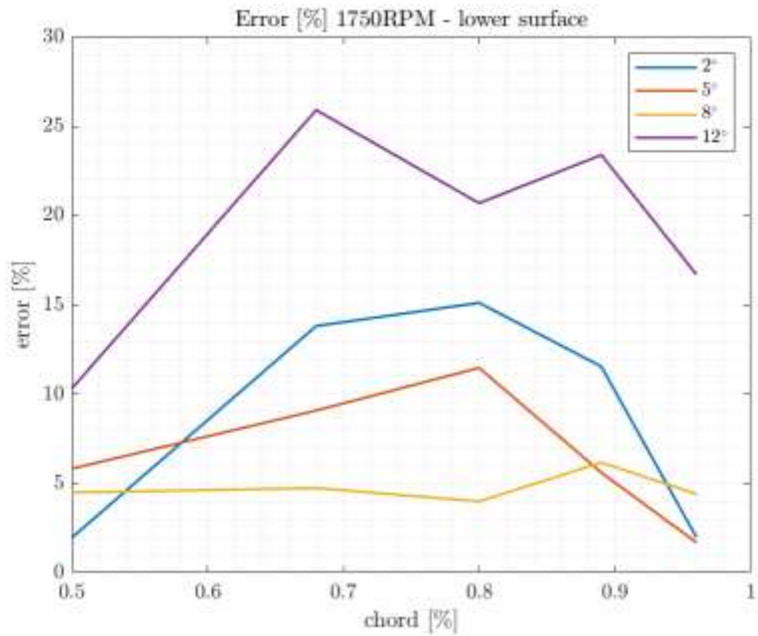


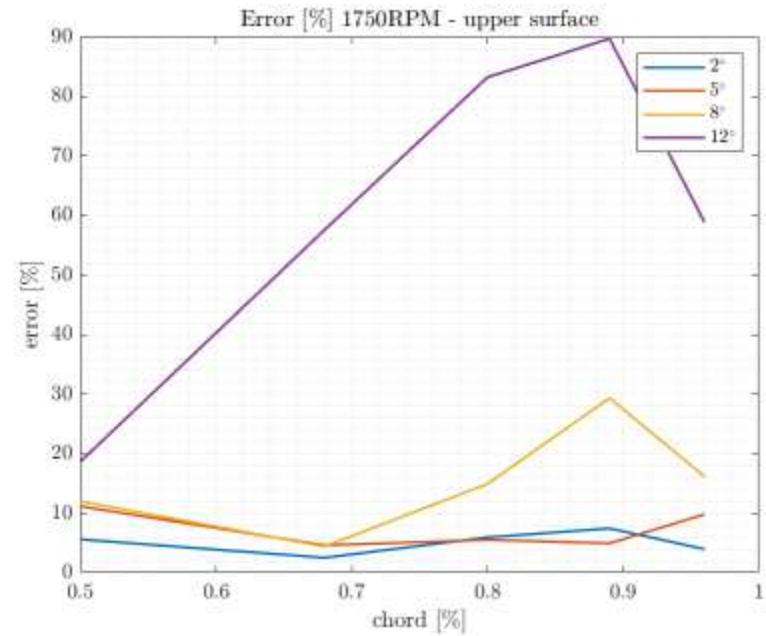


1750 RPM: Cp Plot, 12° CPA

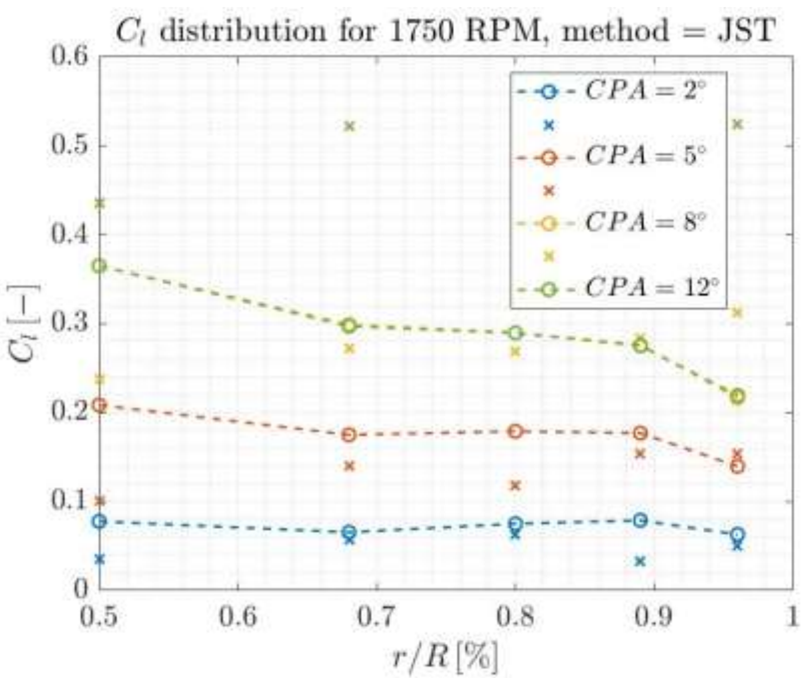


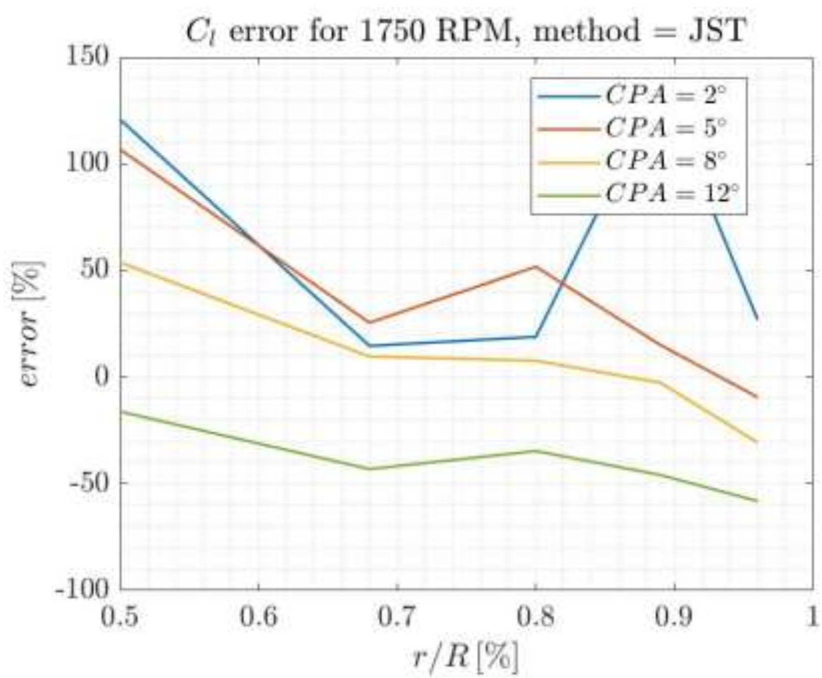
1750 RPM: Cp error %





1750 RPM: Sectional lift coefficient

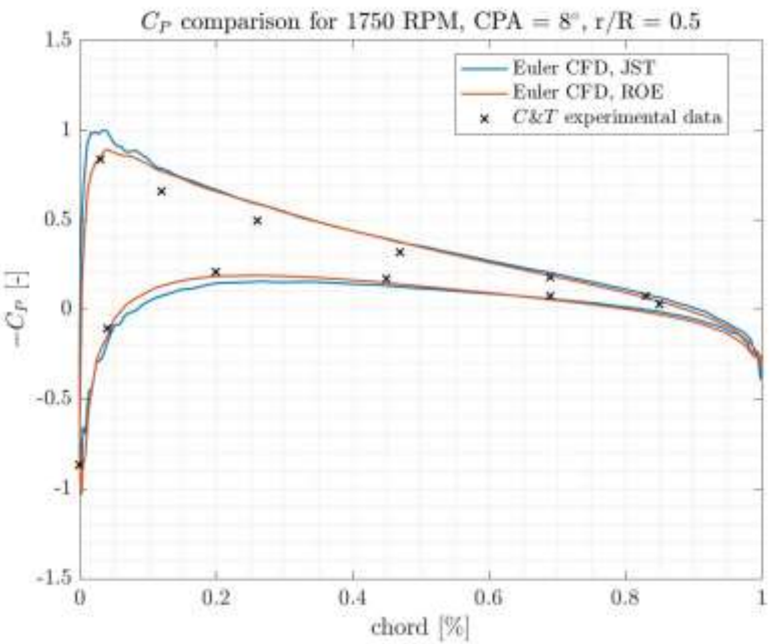


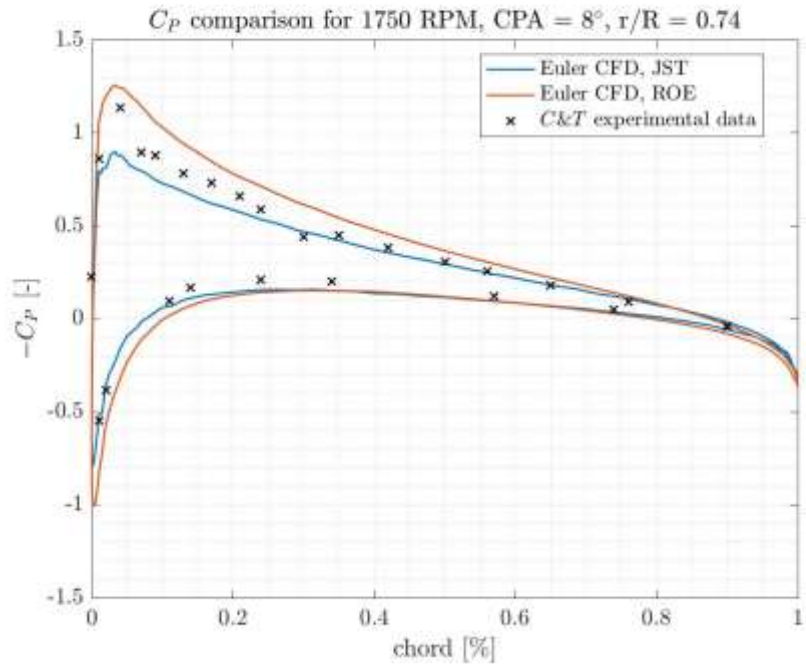


1750 RPM: Thrust Coefficient

	2°	5°	8°	12°
C&T	*NA*	*0.00218*	*0.00455*	*0.00807*
Euler	*0.00103*	*0.00251*	*0.00413*	*0.00418*

1750 RPM: JST vs ROE 2° order (1)





1750 RPM: JST vs ROE 2° order (2)

Sectional lift coefficients

r/R	*0.50*	*0.68*	*0.8*	*0.89*	*0.96*
C&T	*0.2374*	*0.2728*	*0.2690*	*0.2865*	*0.3125*
JST	*0.3566*	*0.2857*	*0.2825*	*0.2735*	*0.2088*
ROE	*0.2831*	*0.3481*	*0.3986*	*0.3832*	*0.2948*

1500 RPM Case

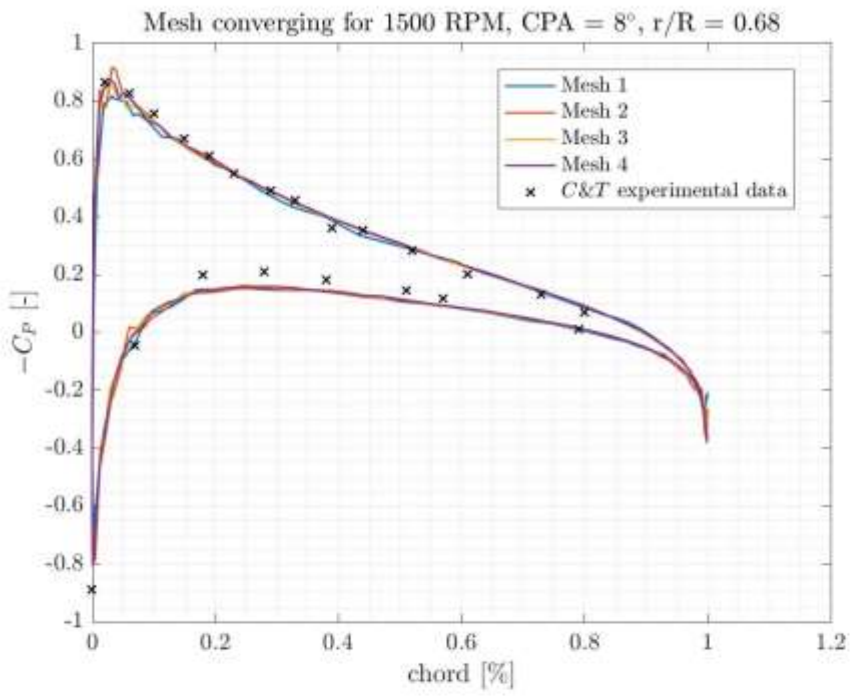
- JST 2nd order

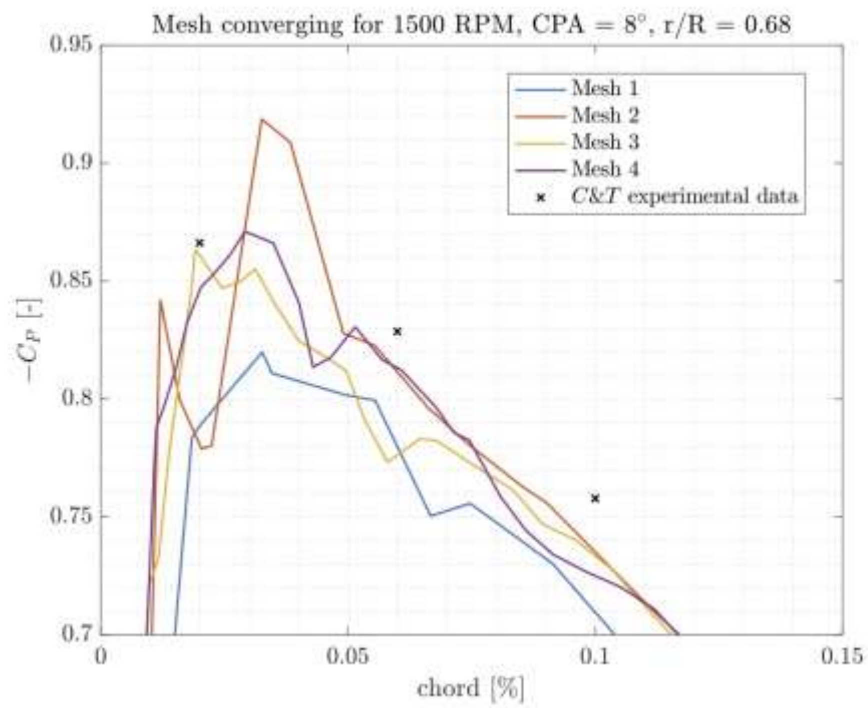
  CPA = 2°, 5°, 8°, 12°

- ROE 1st order

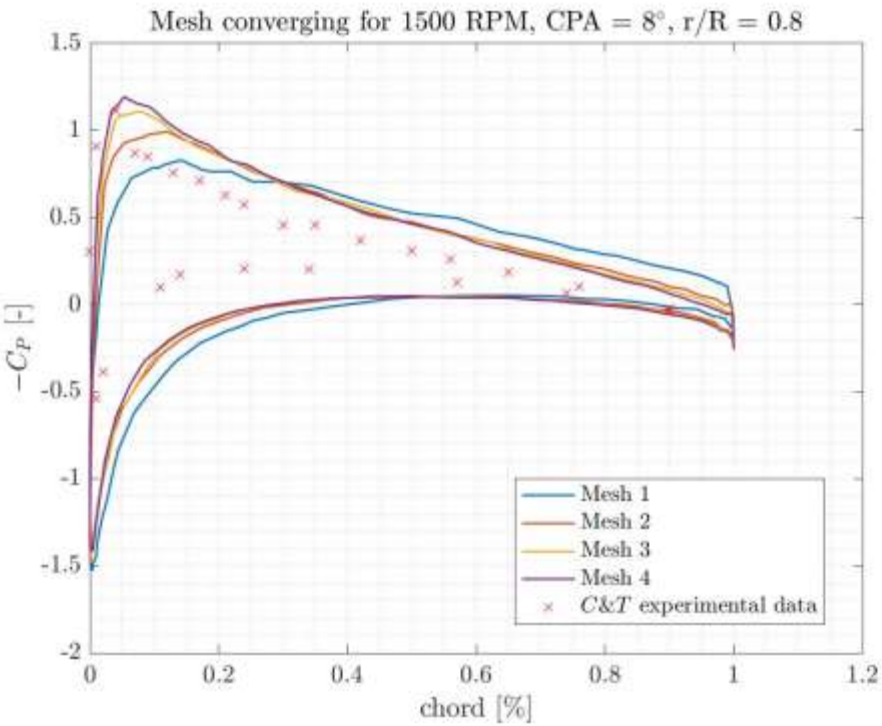
  CPA = 8°

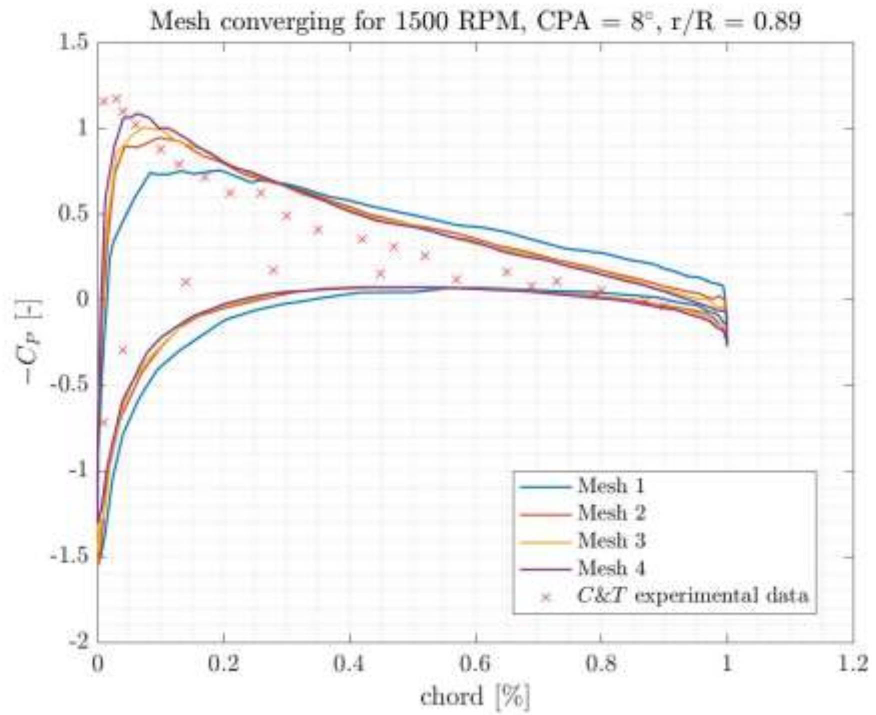
1500 RPM: 2nd order JST, Mesh convergence



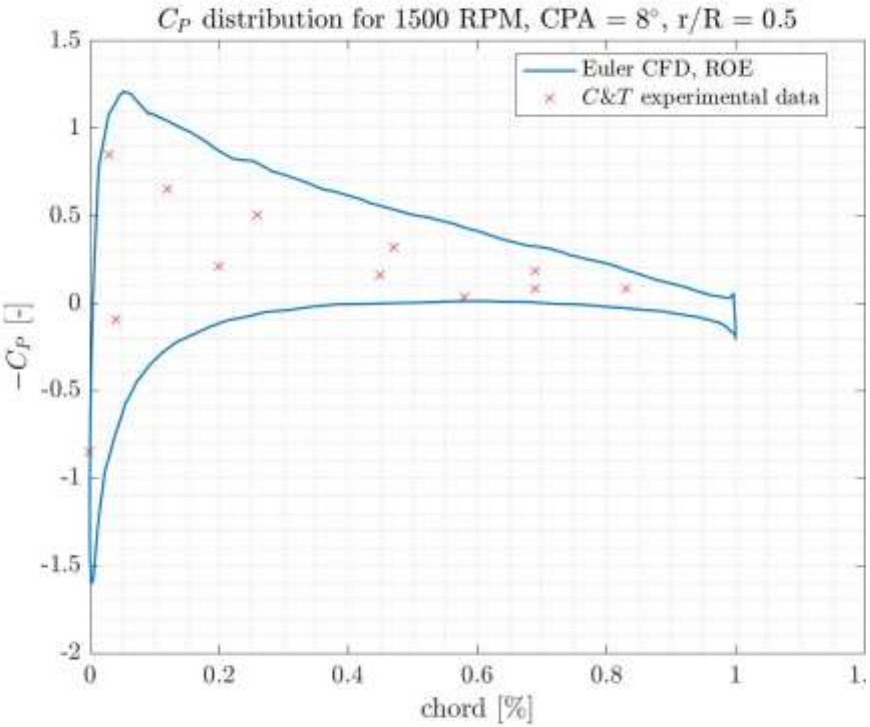


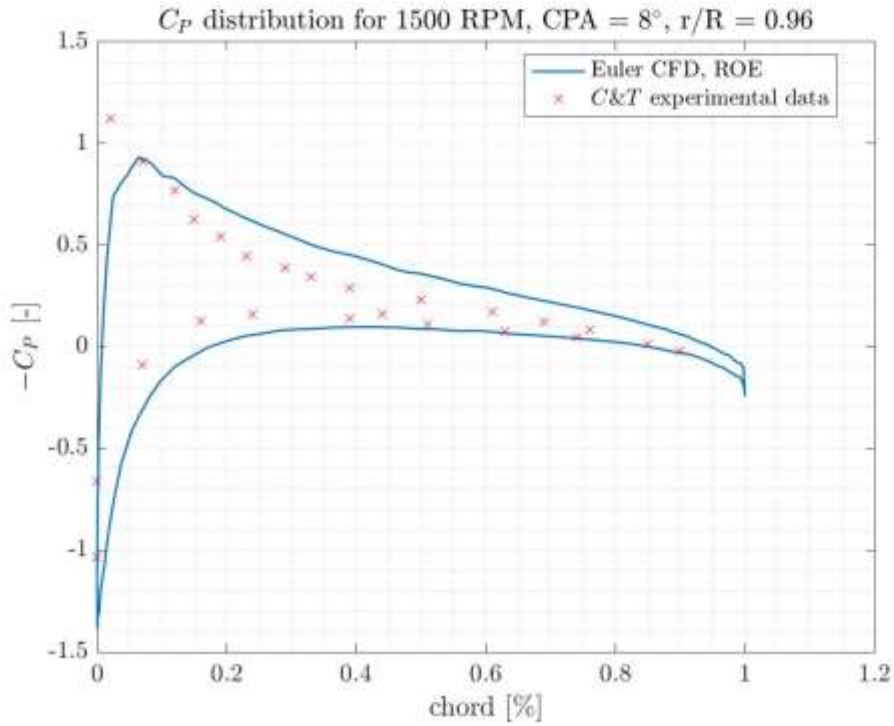
1500 RPM: 1st order ROE, mesh convergence





1500 RPM: 1st order ROE, Pressure coefficient results





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1500 RPM, 1st order ROE, lift and thrust coefficients

CPA = 8°

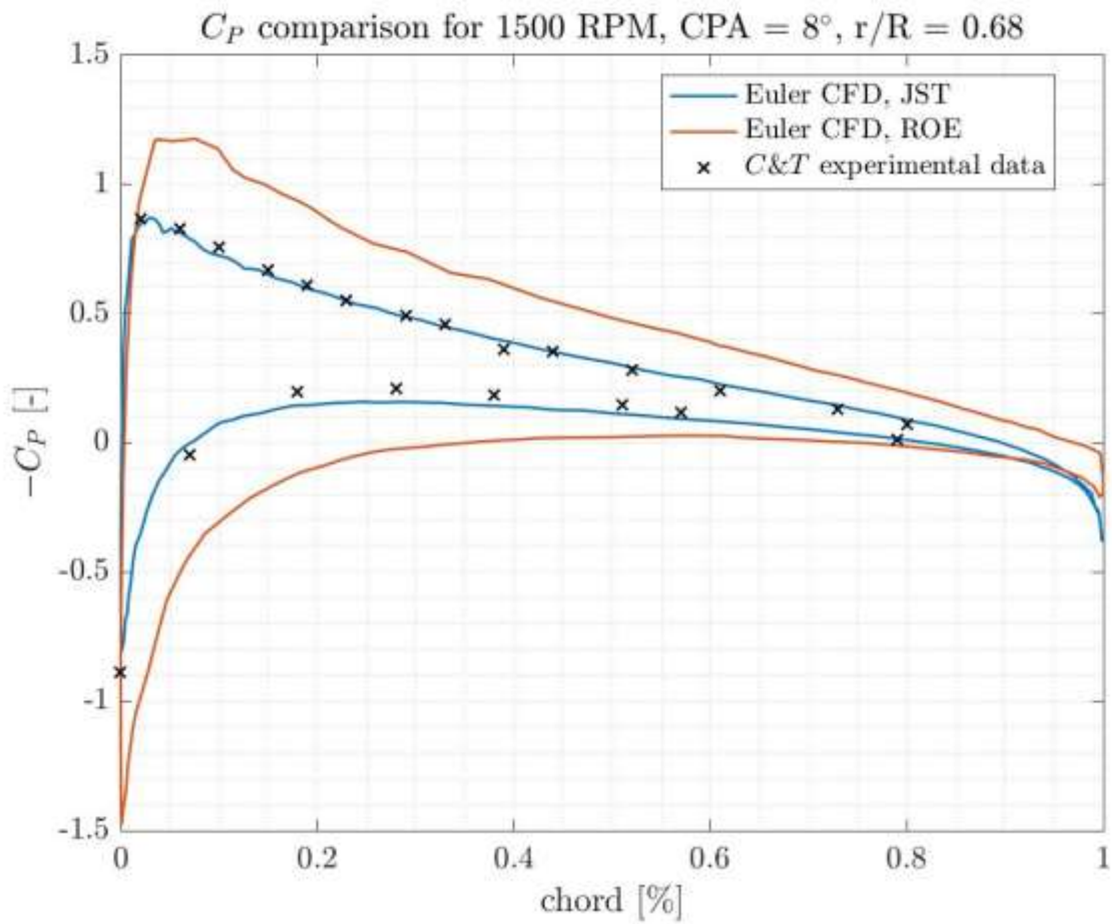
r/R [-]	C&T	CFD	Error [%]
0.50	0.2409	0.6475	169
0.68	0.2638	0.6158	133
0.80	0.2633	0.5738	118
0.89	0.2760	0.5053	83
0.96	0.3052	0.4067	33

Sectional lift coefficient
Comparison CFD results vs. empirical data.

CFD	0.00771
C&T 1750 RPM	0.00459
C&T 1250 RPM	0.00455

Thrust coefficient
Comparison CFD results vs. empirical data.

1500 RPM: 2nd order JST vs 1st order ROE



Conclusions

- Generally most accurate results for small CPAs

- Numerical issues
  - ➢ Strucutred mesh for blades are unfeasible with the meshing software used
  - ➢ Limitated computational power
  - ➢ Problem geometry simplification
  - ➢ Euler numerical scheme not accurate

Thank you for attention!

Aditya Raman

Luca Parisotto

Matteo Freschi

Federico Di Verniere