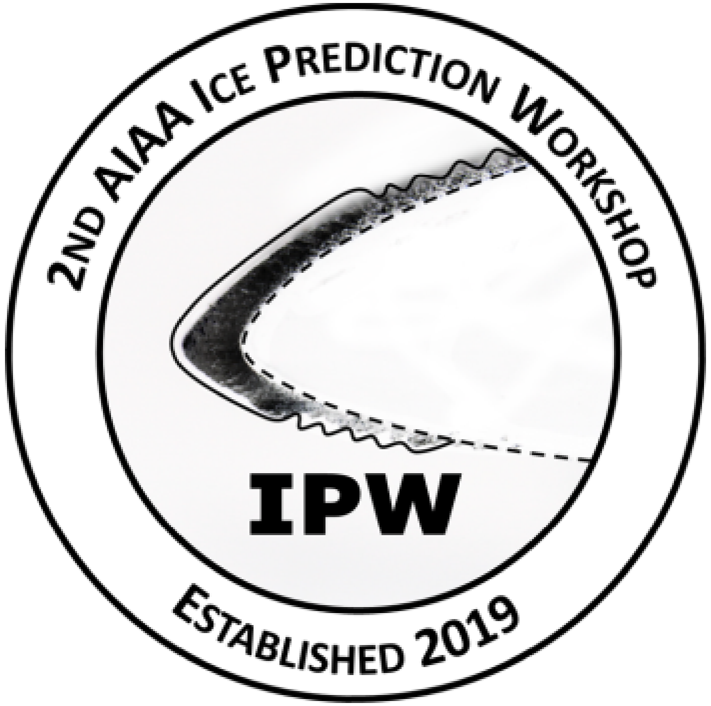

2ND AIAA ICE PREDICTION WORKSHOP
IPW
ESTABLISHED 2019

Ice Prediction Workshop 2

ONERA’s simulations using IGLOO3D

A. Veilleux, E. Radenac, Q. Duchayne

June 23, 2023 – Vienna, Austria

Outline

1. Simulation Process
2. Aerodynamics & Trajectography Outputs
3. Ice shapes
4. Conclusions

Outline

1. **Simulation Process**
2. Aerodynamics & Trajectography Outputs
3. Ice shapes
4. Conclusions

Simulation Process

Computational Method

MESH → Aerodynamics: **CEDRE/CHARME** → Trajectory: **CEDRE/SPIREE** → Ice Accretion: **IGLOO3D**

Mesh

- Cases 1.X (Midspan) and 2.X (Inboard)

  → Structured mesh with gap from the IPW2

- Cases 3.X (RG15)

  → Structured mesh tunnel from the IPW2

Simulation Process

Aerodynamics – CEDRE/CHARME

- Navier-Stokes equations solver
- RANS turbulence model: k-ω SST model, Boussinesq closing
- 2nd order of accuracy in space
- Heat Transfert Coefficient (HTC) on rough-wall

$$h_{tc} = \Phi_w/(T_w - T_r)$$

→ Equivalent sand grain roughness height: $k_s = c/1000$

- Boundary conditions

→Airfoil: imposed temperature $T_{wall} = T_r + 10$ where

$$T_r = T_e\left(1 + Pr^{1/3}\frac{\gamma - 1}{2}M_e{}^2\right)$$

- → Walls: slip conditions

Simulation Process

Trajectography – CEDRE/SPIREE

- Eulerian droplet-trajectory solver
- 2nd order of accuracy in space
- Particle distribution: provided droplet size distributions
- Full deposition
- Schiller and Naumann model for the droplet drag

Ice Accretion – IGLOO3D/MESSINGER3D

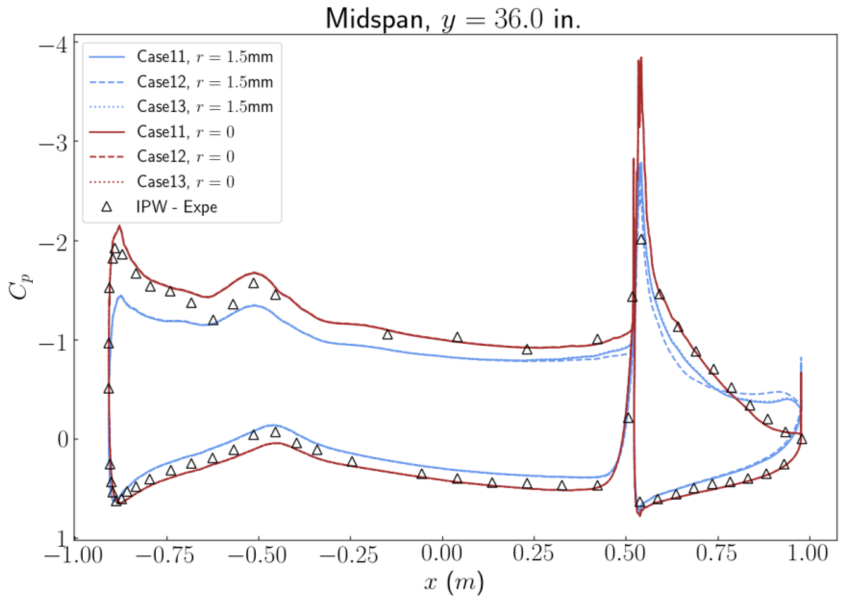
- Messinger balance for ice accretion
- Ice density given by model of Makkonen and Stallabras or constant
- Predictor computations (1-step, no re-meshing)

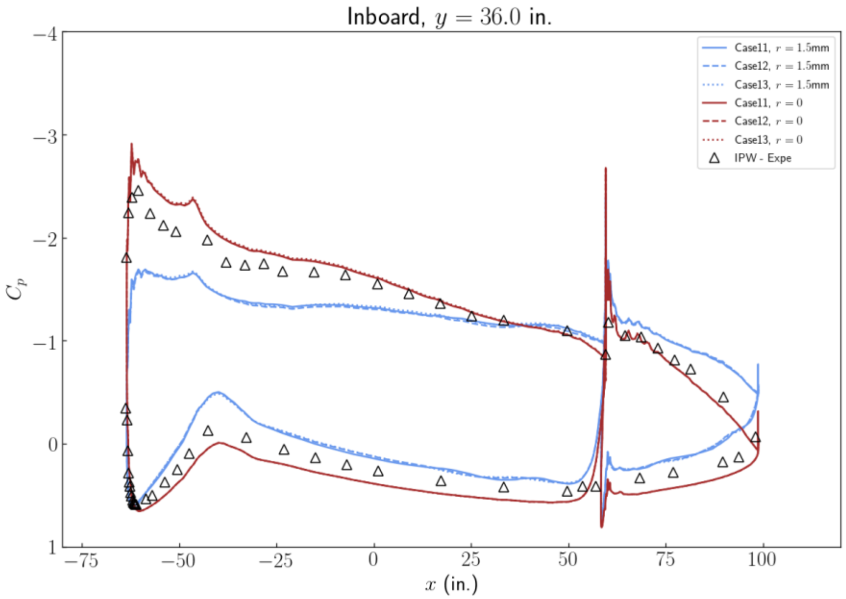
Outline

1. Simulation Process
2. **Aerodynamics & Trajectography Outputs**
3. Ice shapes
4. Conclusions

Aerodynamics & Trajectography Outputs

Impact of the wall roughness on the pressure coefficient





For both the Misdpan and the Inboard:

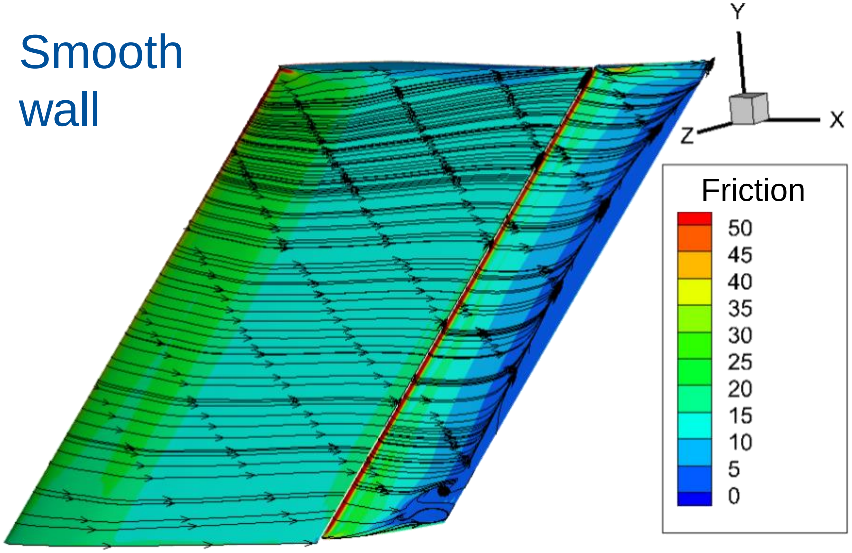
- The pressure coefficient obtained on a smooth wall are in good agreements with the experiments
- Considering a rough-wall leads to a poorer C_p

→ Why is that ?

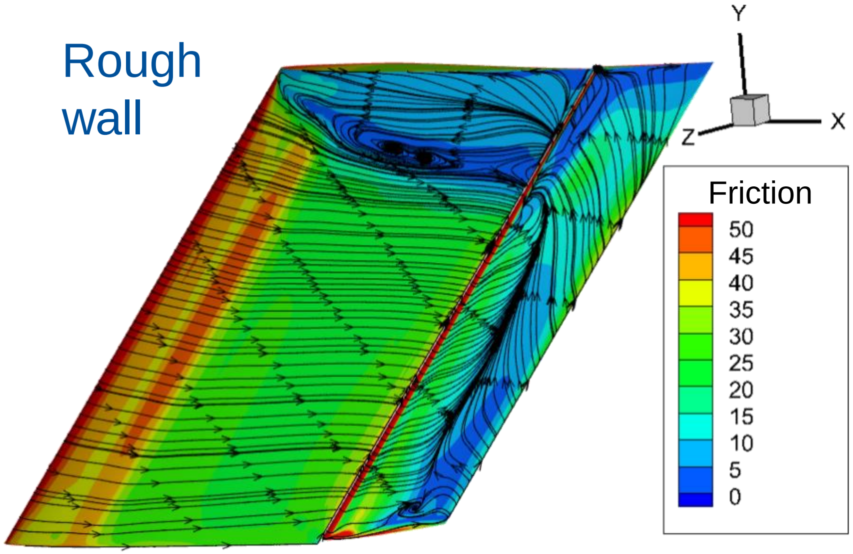
Aerodynamics & Trajectography Outputs

Impact of the wall roughness – Midspan

Smooth
wall



Rough
wall



→ The whole flow structure is modified

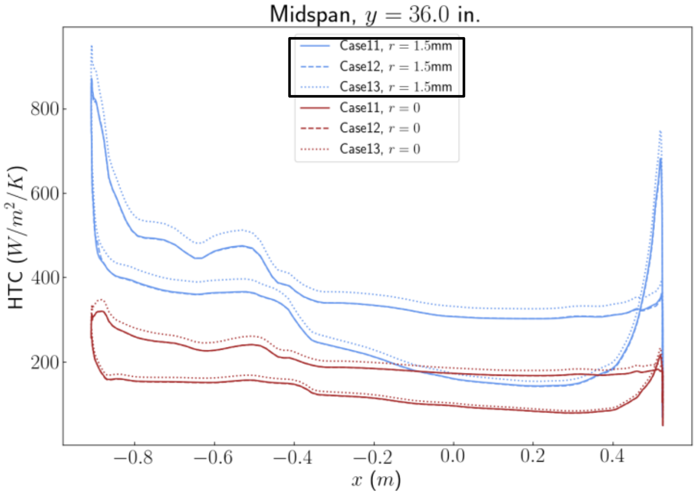
→ The rough-wall model is a priori not the (only) cause of the problem
(past simulations with elsA showed no visible effect of the rough-wall model, cf E. Radenac presentation at SAE 2023).

Aerodynamics & Trajectography Outputs

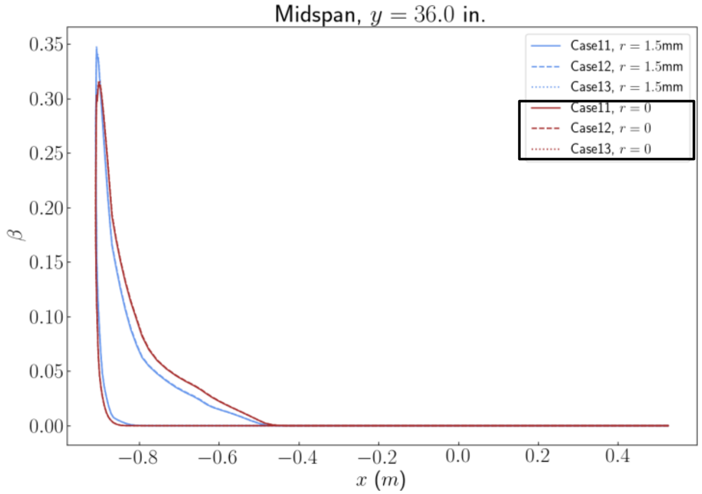
Impact of the wall roughness – Cases 1.X (MIDSPAN)

→ Choice is made to adopt an ‘hybrid’ approach

- Heat Transfer Coefficient is extracted from the rough wall simulation
- The smooth wall simulation is imposed as the aerodynamics field for the trajectory simulation



- A higher HTC is obtained considering a rough airfoil (as expected)

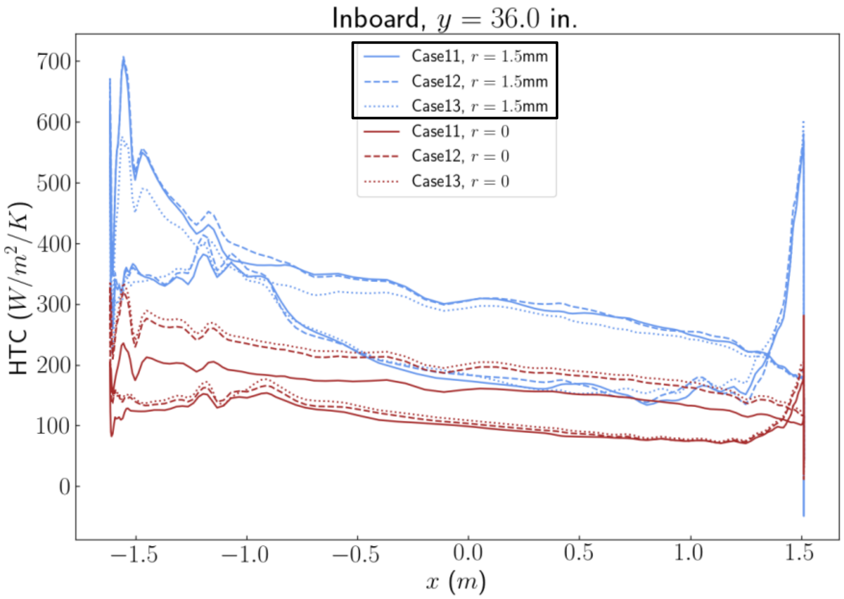


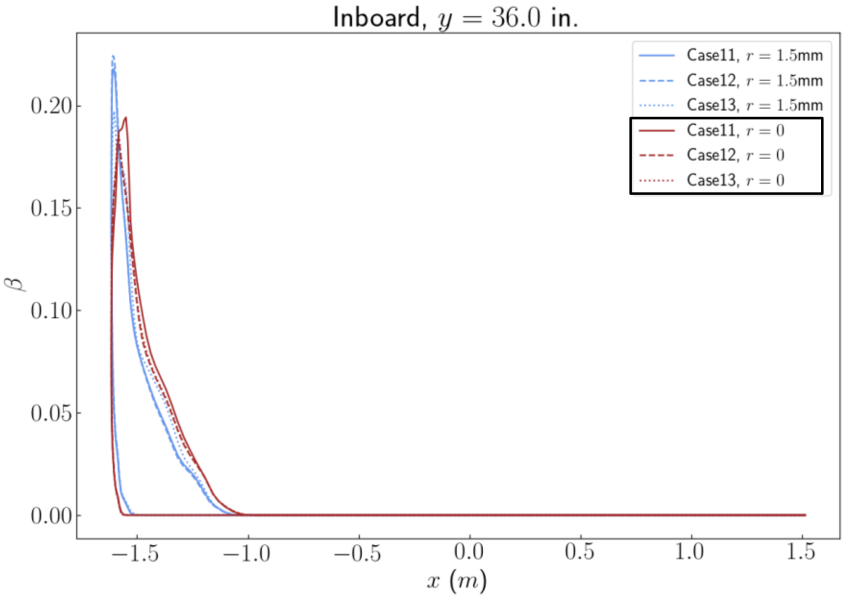
Smooth airfoil leads to

- a higher β on the lower surface
- a smaller one on the upper surface and at the attachment line

Aerodynamics & Trajectography Outputs

HTC and collection efficiency – Cases 2.X (INBOARD)





A higher HTC is obtained:

- Considering rough airfoil

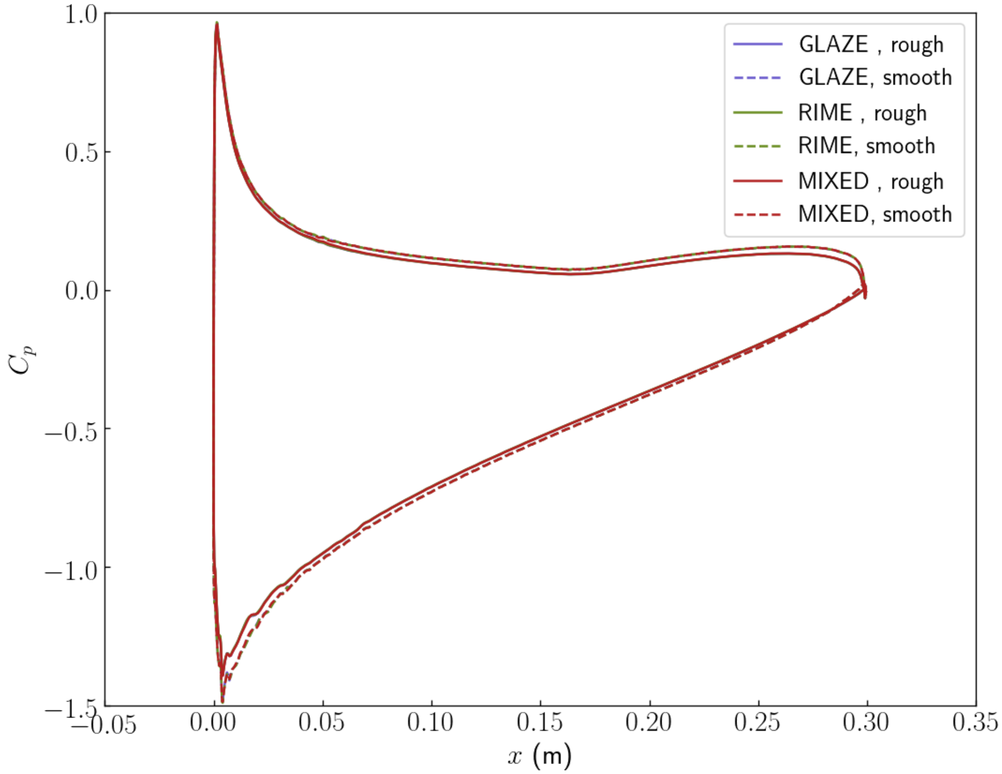
Smooth airfoil leads to

- a higher β on the lower surface
- a smaller one on the upper surface and at the attachment line

Given the discrepancy between cases, results on the inboard seem to be more dependant on the icing conditions

Aerodynamics & Trajectography Outputs

Impact of the wall roughness – Cases 3.X (RG15)

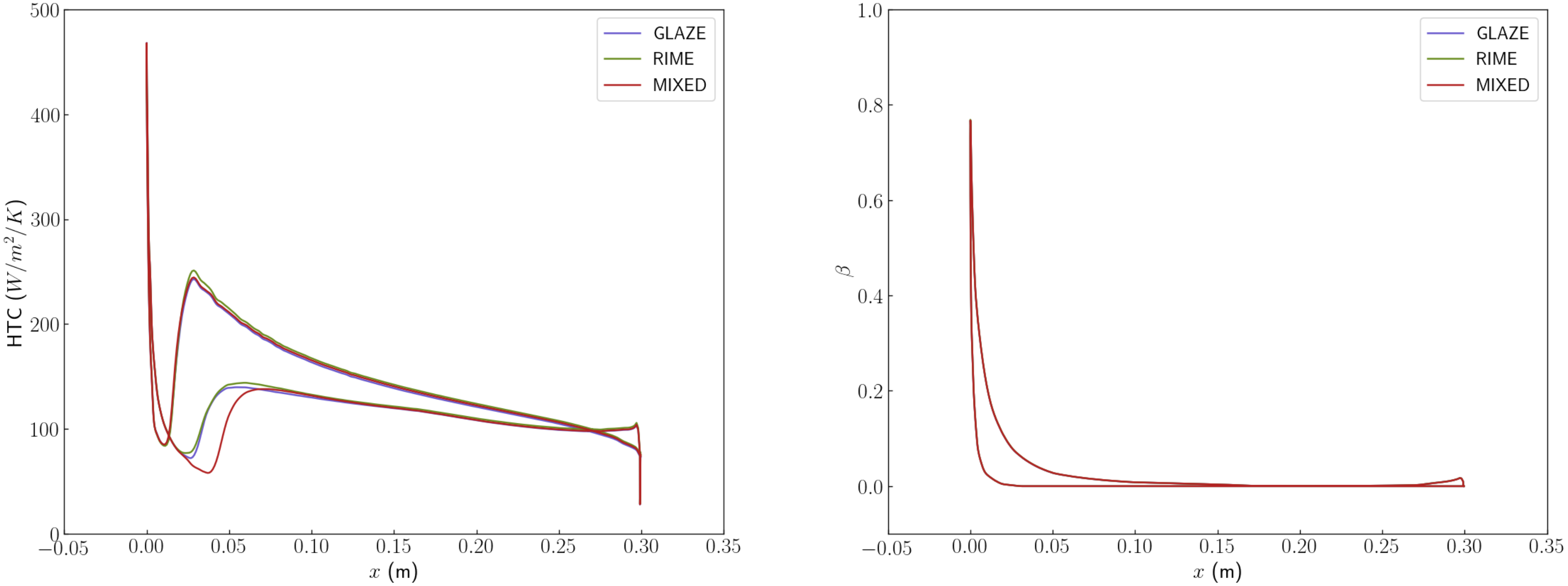


- All conditions lead to the very same pressure coefficient
- Small difference are observed between the rough and smooth pressure coefficients but they remain very close and the flow structure is not modified

→ For the RG15 simulations, both the aerodynamics and trajectory simulations are carried out considering a rough airfoil

Aerodynamics & Trajectography Outputs

HTC and collection efficiency



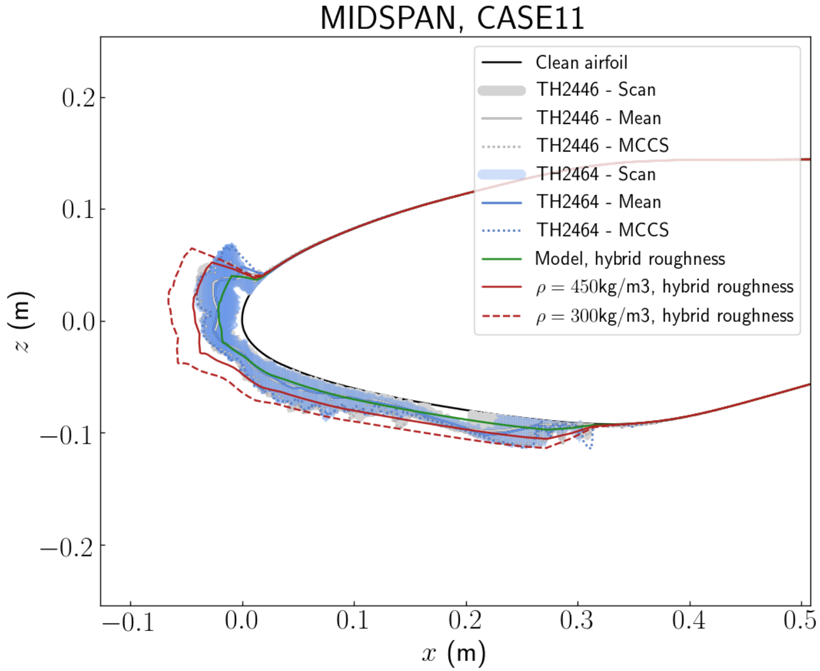
- Same HTC is obtained for the three test case conditions except on the upper surface where the mixed condition leads to a slighlty lower HTC
- No influence of the test case conditions on the collection efficiency

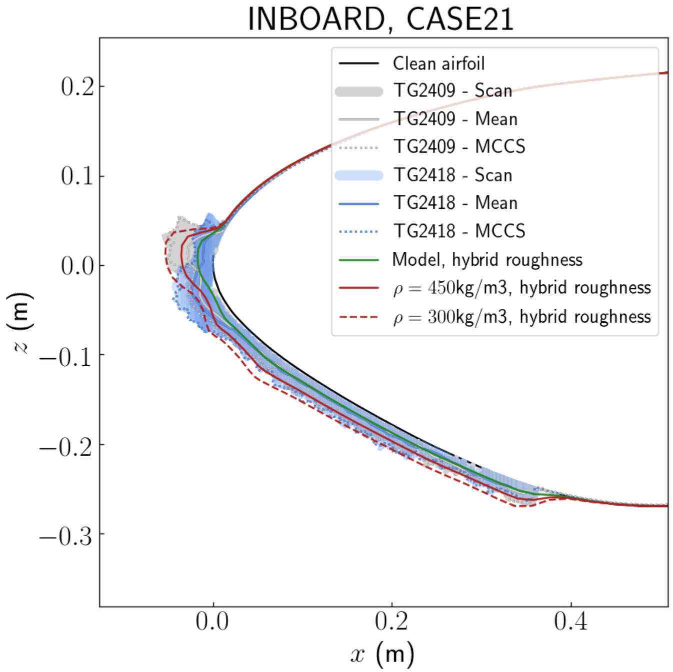
Outline

1. Simulation Process
2. Aerodynamics & Trajectography Outputs
3. **Ice shapes**
4. Conclusions

Ice shapes

Warmer cases

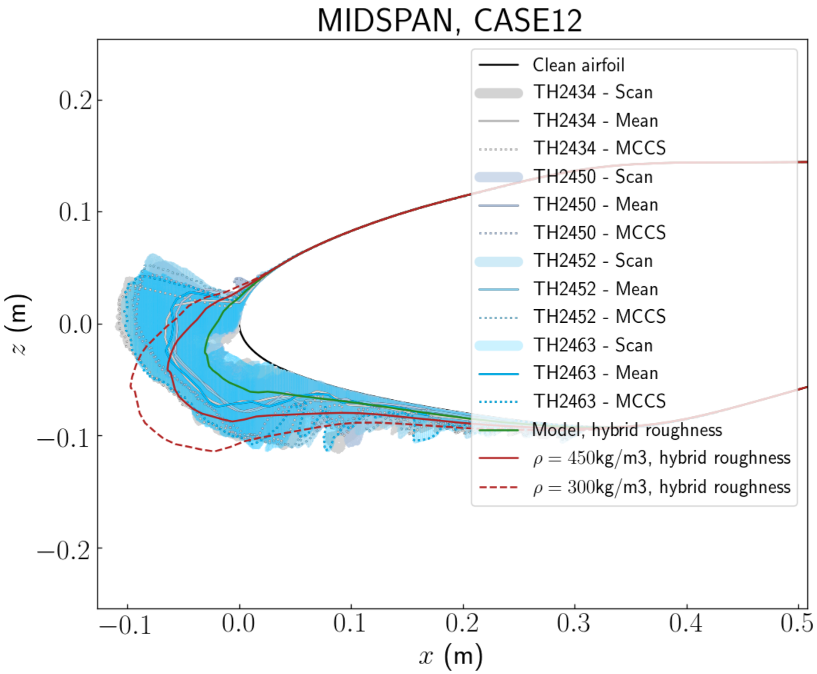


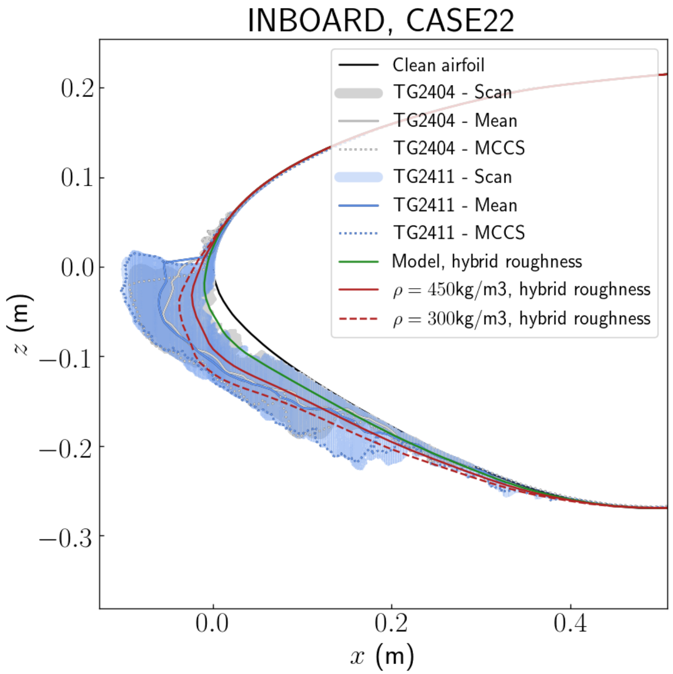


- Proper levels, shapes and ice limits
- MCCS is best predicted for a fixed density
- Mean shape is best predicted with the Makkonen and Stallabras model (MS model) for the ice density

Ice shapes

Maximum scallop cases

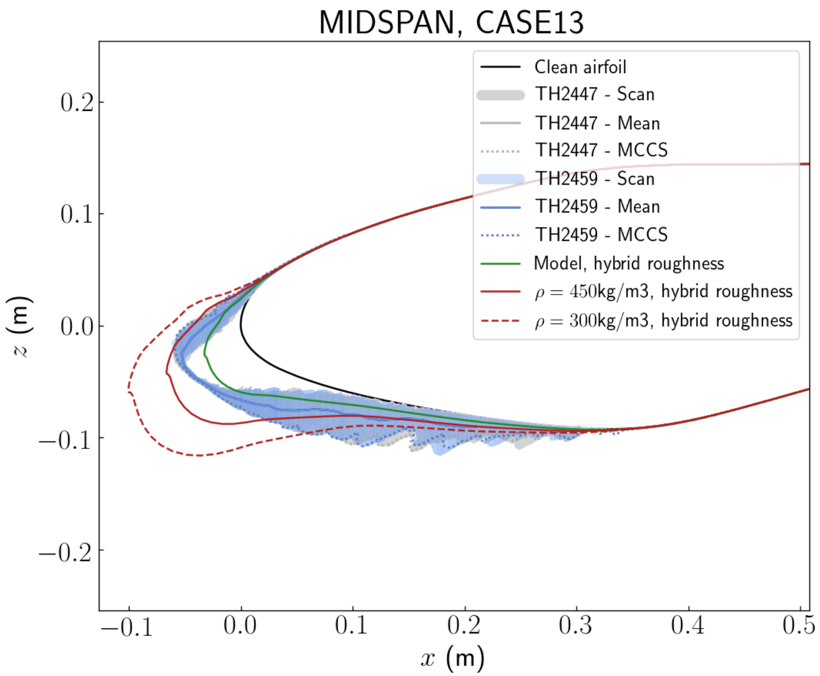

MIDSPAN, CASE12

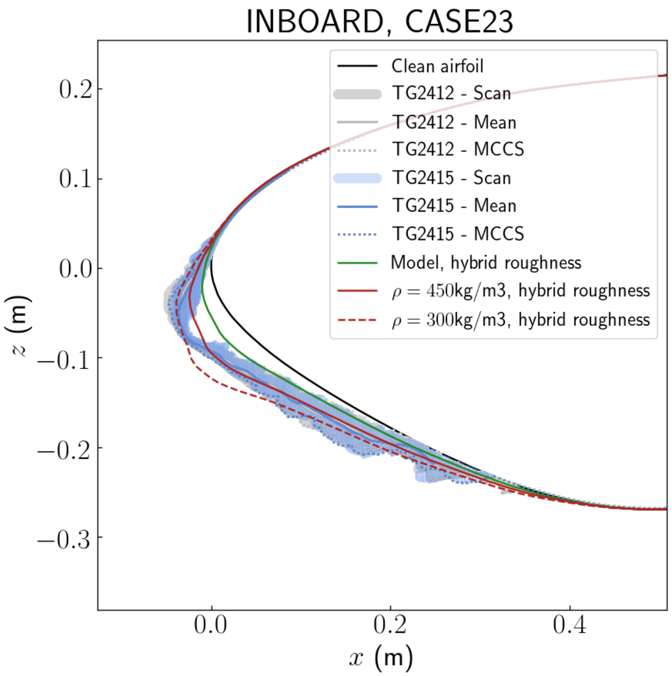

INBOARD, CASE22

- Levels obtained with a fixed density are closer to the (MCCS or mean) experiments than with a modelled density.
- Compared to the MCCS, shapes are not so good…
- Ice limits are rather well predicted
- The ice shape produced with bulk ρ_{ice}=450 kg/m3 (resp. 300 kg/m3) is more representative of the mean ice shape for the midspan (resp. the inboard).

Ice shapes

Rime cases

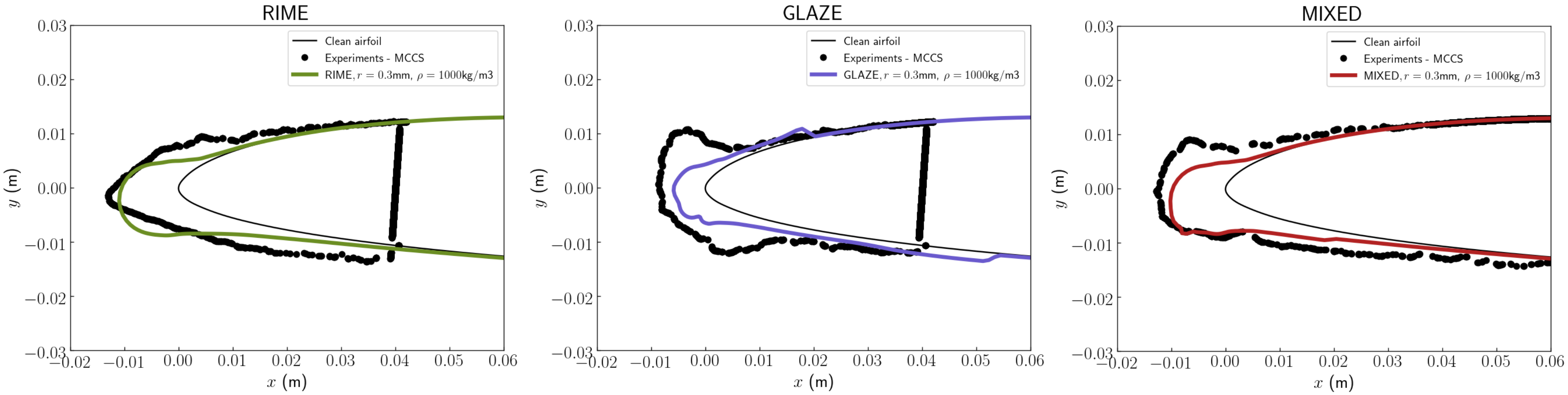




- Ice limits are rather good
- For the midspan, the shape and level obtained when modelling the density are okay at the attachment line but lower elsewhere
- The ice shape obtained with a fixed ice density of 300 kg/m3 for the inboard is better.

Ice shapes

RG15 (3.1, 3.2, 3.3)



All ice shapes were obtained using a modelled density

- Rime: the ice thickness level at the leading edge matches the experiment but the conical shape is not captured
- Glaze: shape and levels are not well represented
- Mixed: levels and shapes are rather good

→ Comparison with results from IGLOO2D must be conducted in the future

Outline

1. Simulation Process
2. Aerodynamics & Trajectography Outputs
3. Ice shapes
4. **Conclusions**

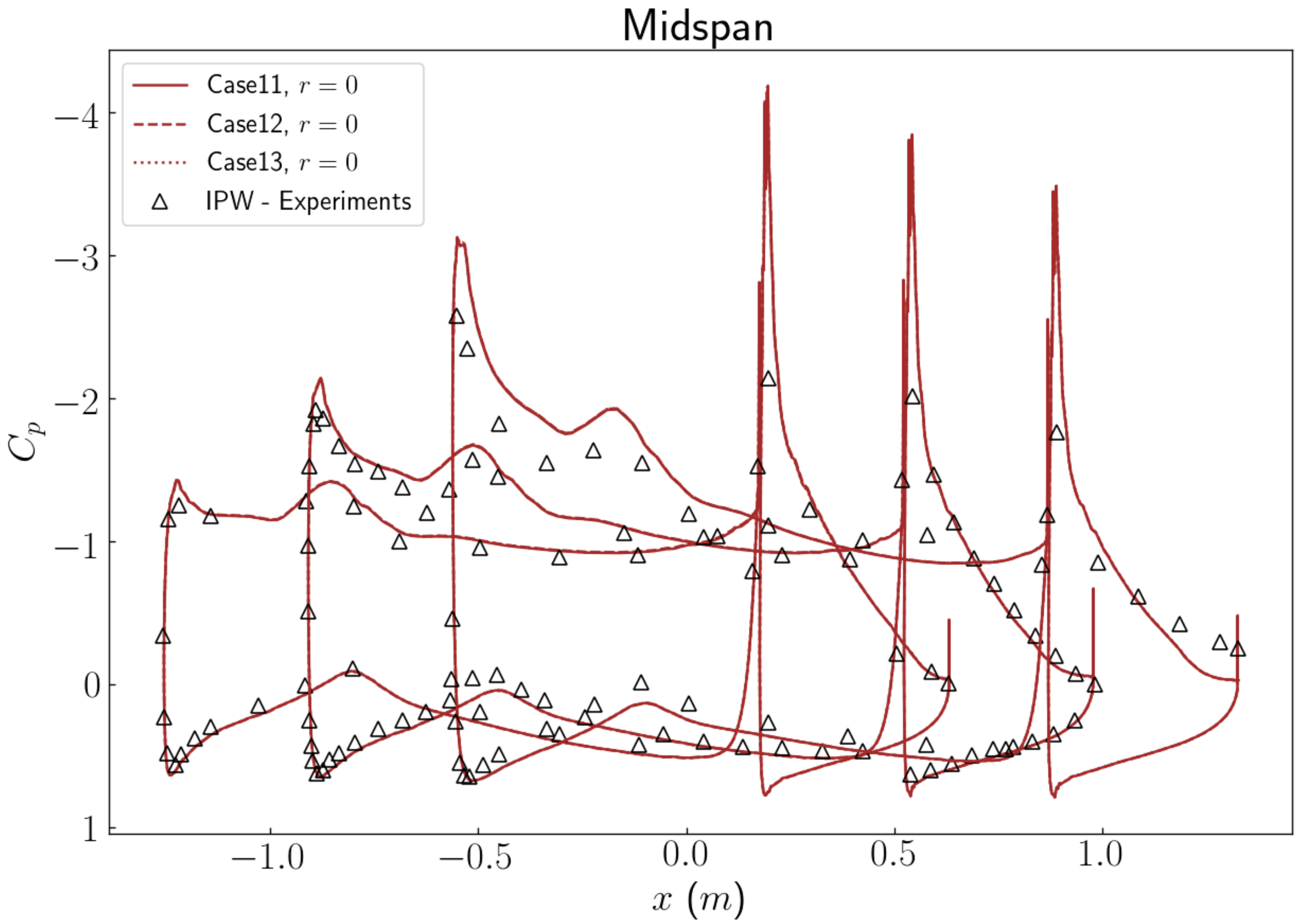
Conclusion

- IGLOO3D was run on all the cases of the IPW2 database.
- Only 1-step simulations were conducted.
- The impact of the ice density modelling was studied. Depending on the conditions, the MS model or the use of a constant ice density can be more representative of the mean or the MCCS, as detailed in the presentation.
- The next step would be to run multi-step simulations

Thank you for your attention! Any questions?

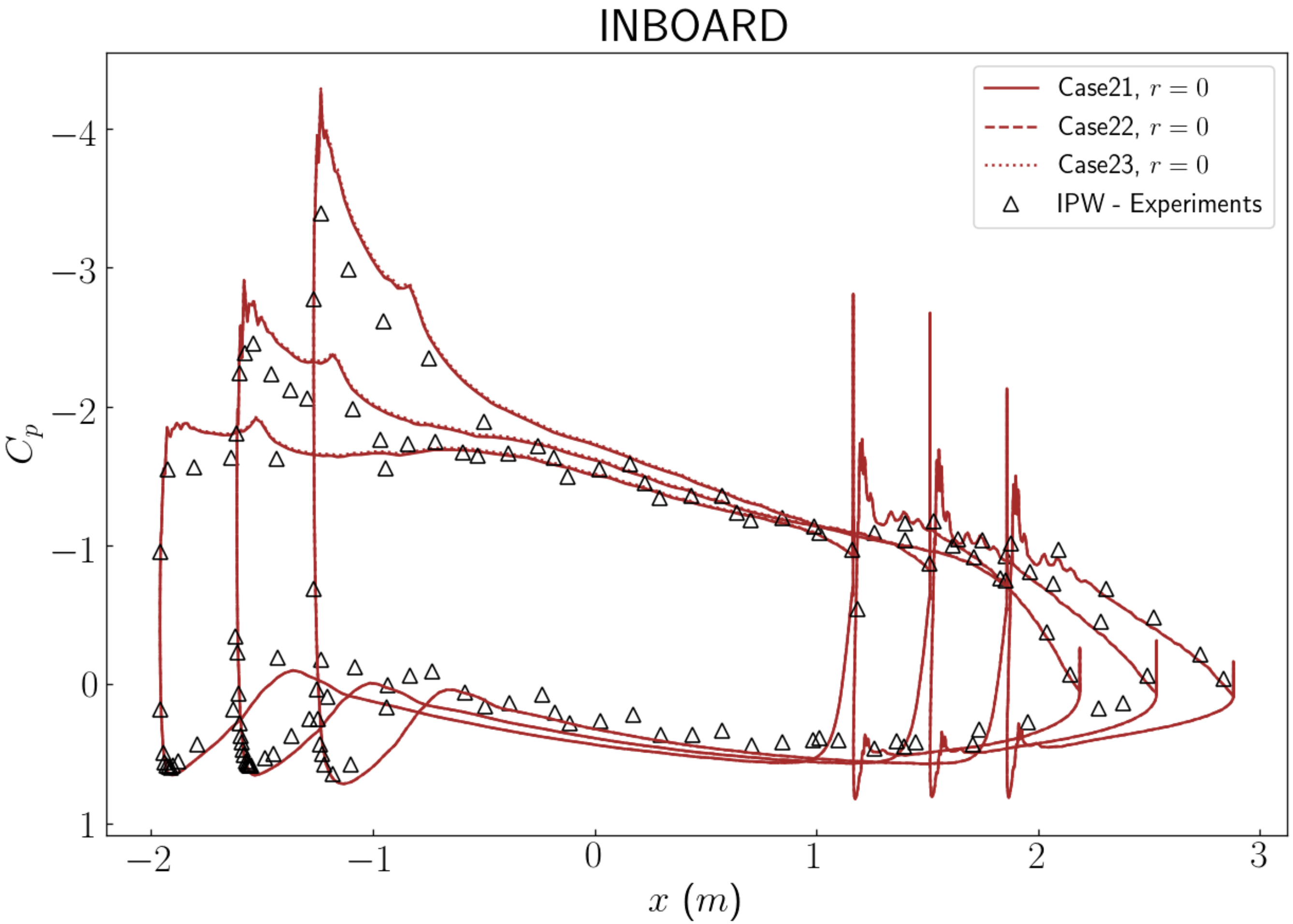
Aerodynamics – Pressure Coefficient

Comparison with experimental data – Cases 1.X (MIDSPAN)



Aerodynamics – Pressure Coefficient

Comparison with experimental data – Cases 2.X (INBOARD)



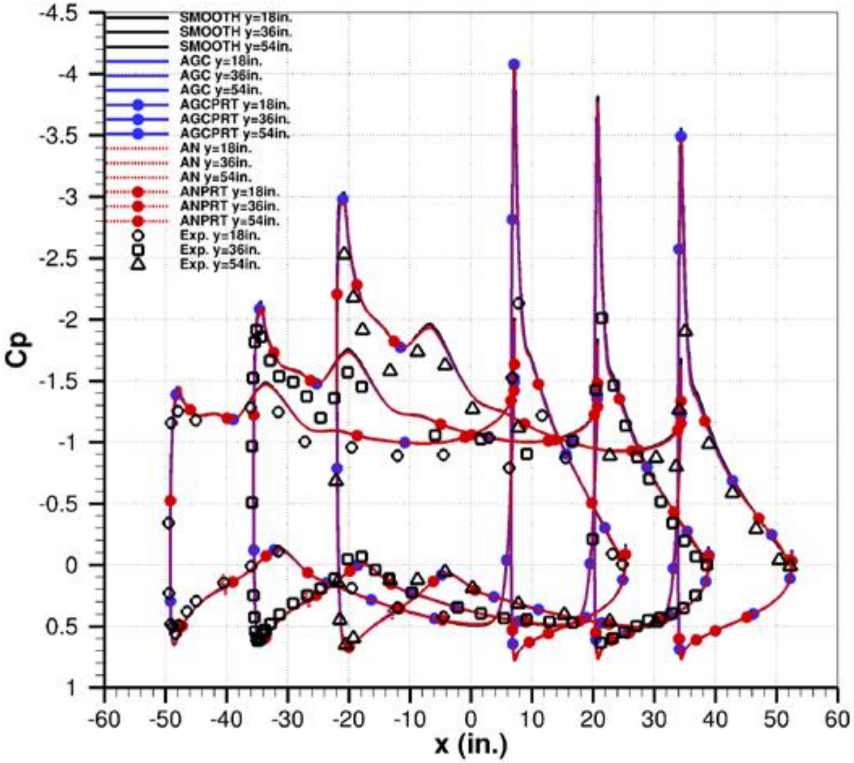
Presentation of the simulations

Numerical strategy for the CRM65 database

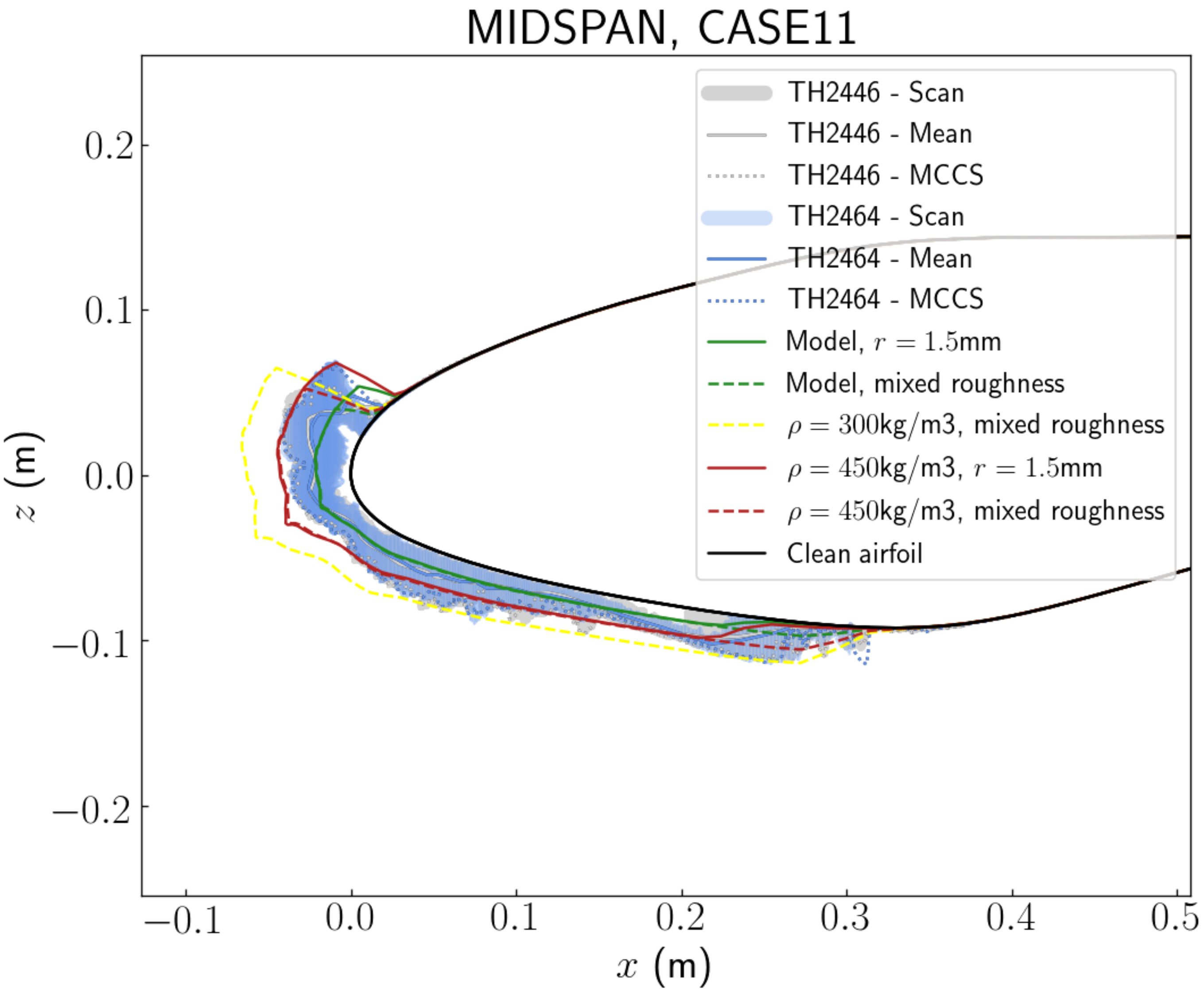
- Effects of our rough-wall modelling on the simulations: rough-wall vs. smooth-wall
  - The rough-wall model is a priori not the cause of the problem

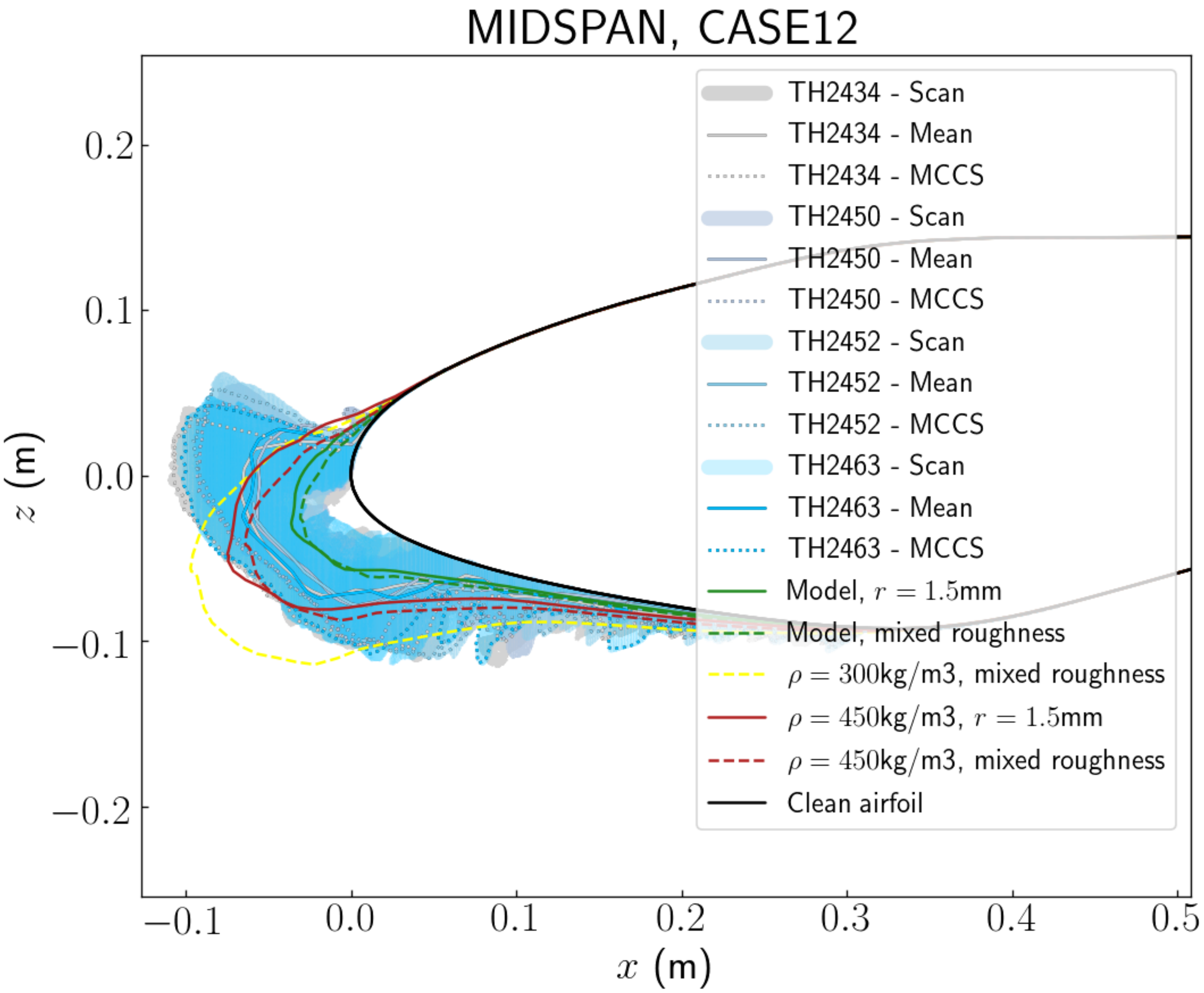
Past simulations with elsA on the Midspan geometry:

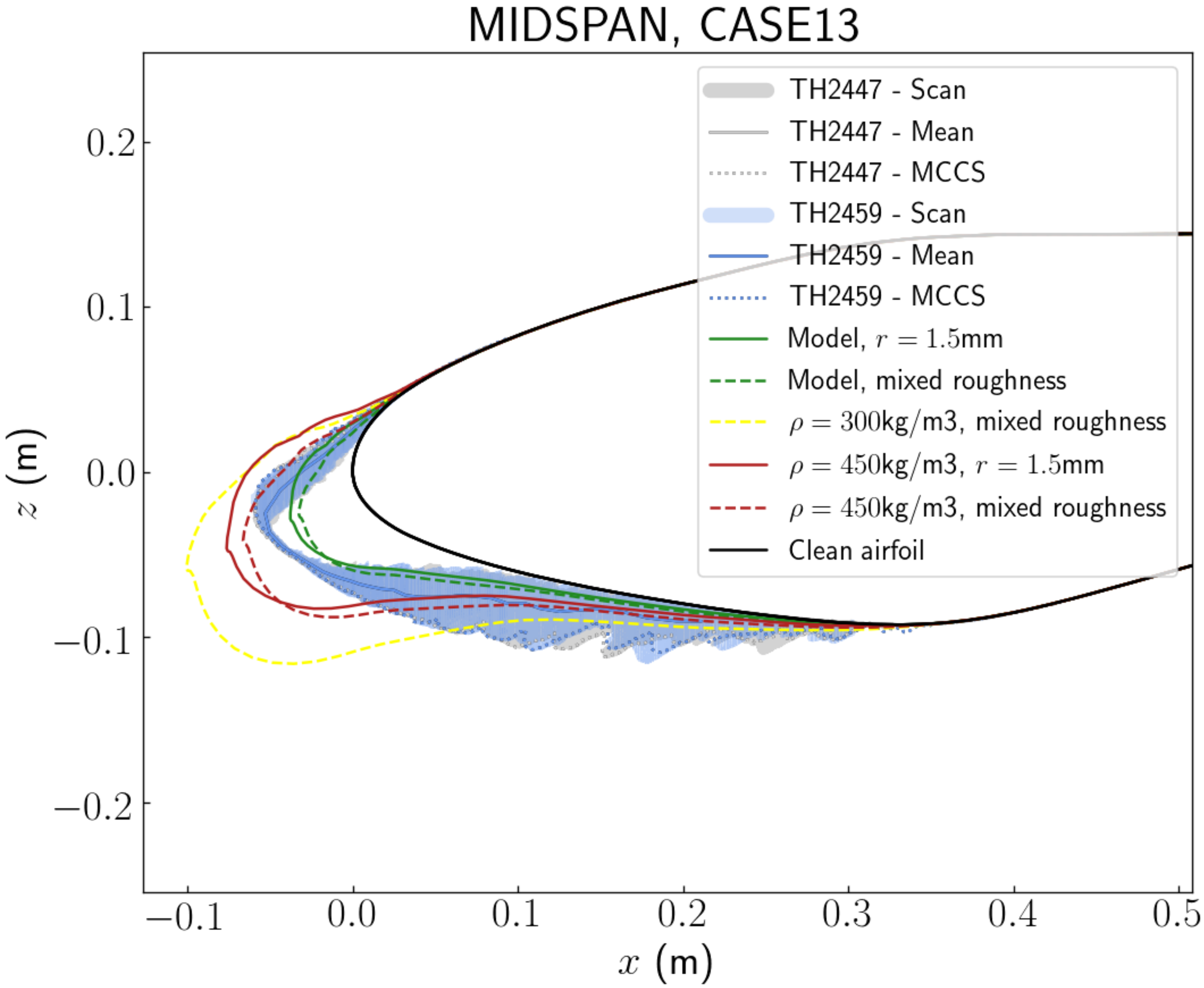
No visible effect of the rough-wall model

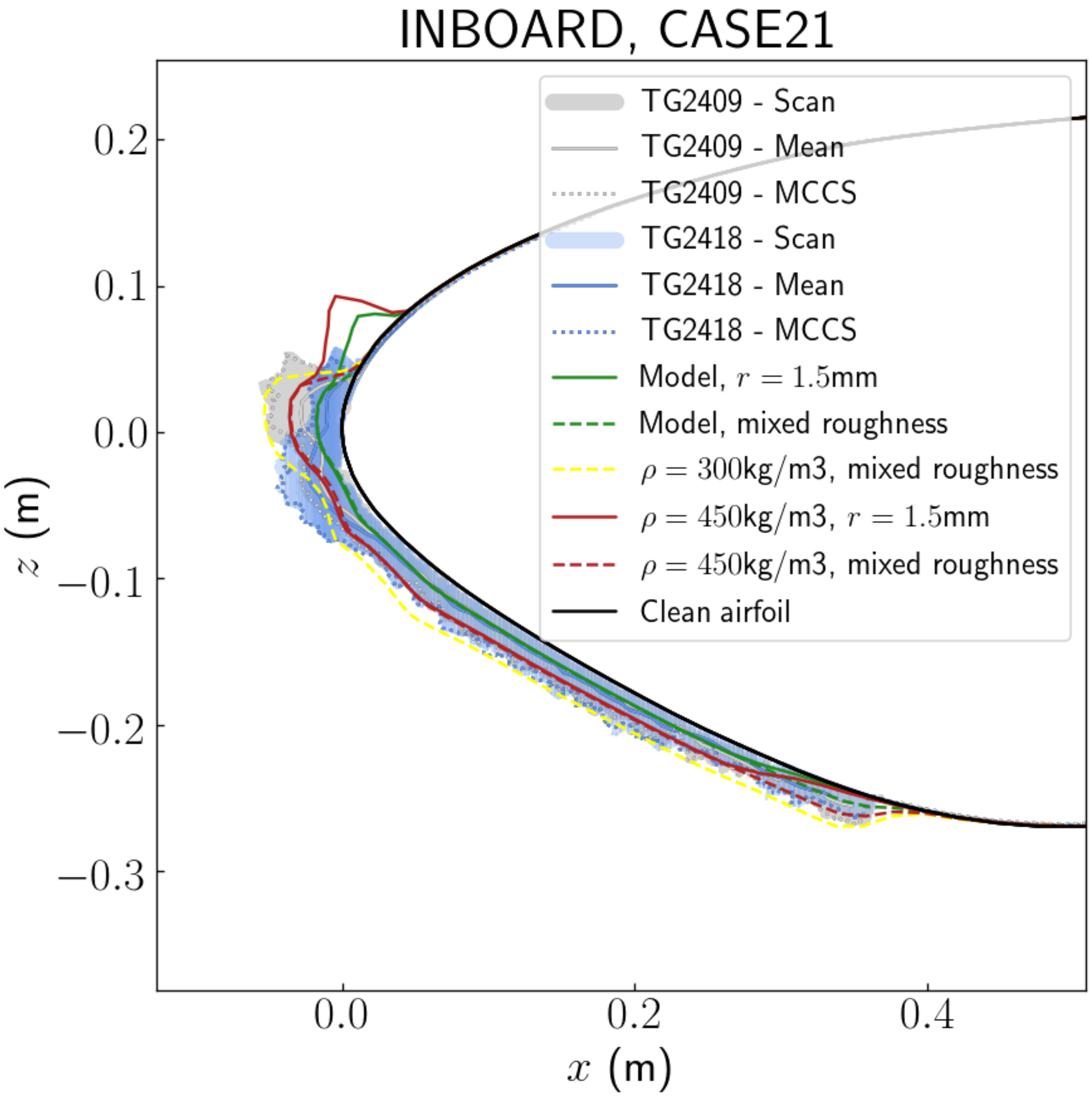


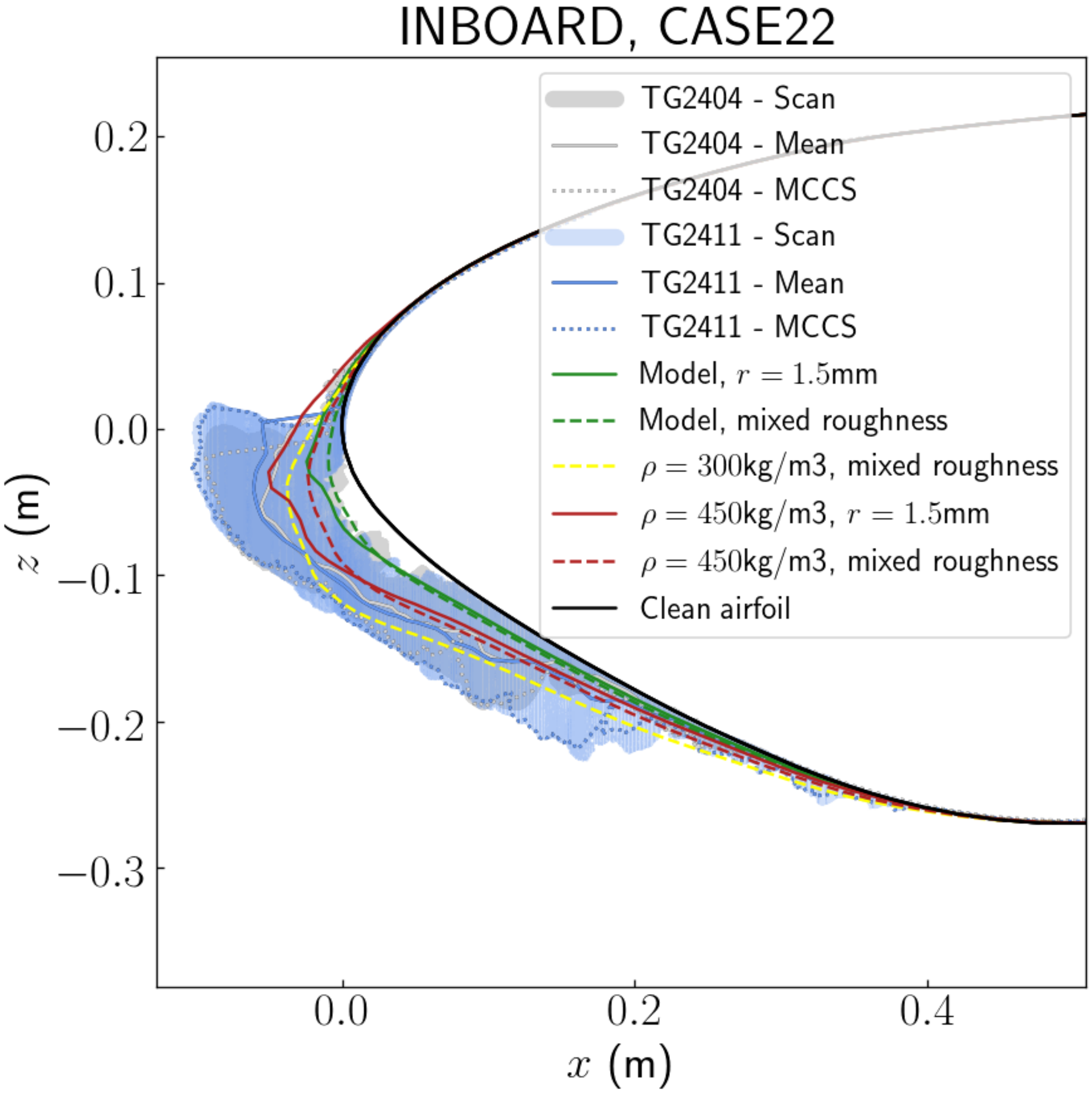
E. Radenac and H. Gaible and H. Bézard and P. Reulet, IGLOO3D Computations of the Ice Accretion on Swept-Wings of the SUNSET2 Database, International Conference on Icing of Aircraft, Engines, and Structures

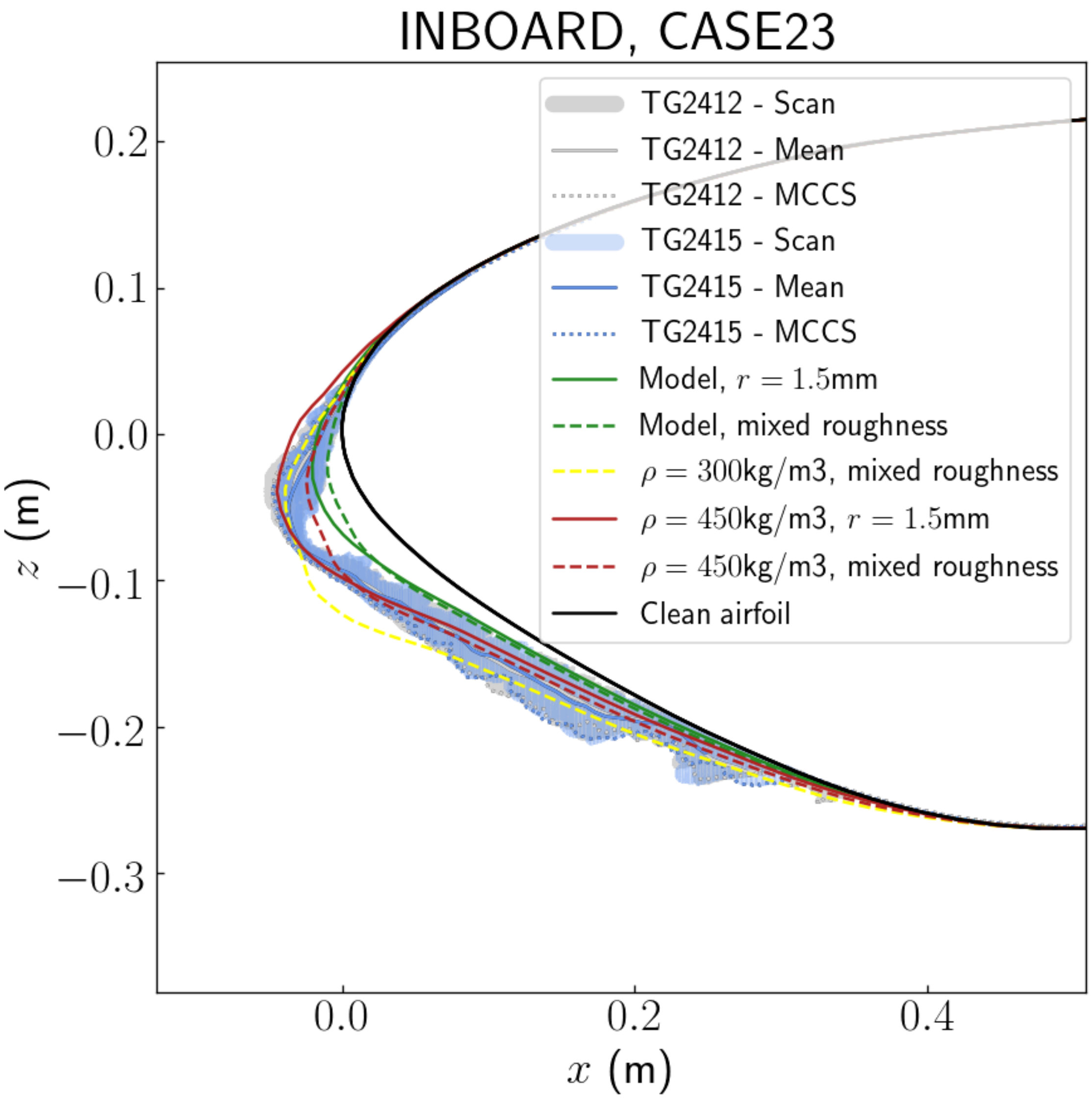

MIDSPAN, CASE11
TH2446 - Scan
TH2446 - Mean
TH2446 - MCCS
TH2464 - Scan
TH2464 - Mean
TH2464 - MCCS
Model, $r = 1.5$mm
Model, mixed roughness
$\rho = 300$kg/m3, mixed roughness
$\rho = 450$kg/m3, $r = 1.5$mm
$\rho = 450$kg/m3, mixed roughness
Clean airfoil
0.2
0.1
0.0
−0.1
−0.2
z (m)
−0.1
0.0
0.1
0.2
0.3
0.4
0.5
x (m)


MIDSPAN, CASE12
TH2434 - Scan
TH2434 - Mean
TH2434 - MCCS
TH2450 - Scan
TH2450 - Mean
TH2450 - MCCS
TH2452 - Scan
TH2452 - Mean
TH2452 - MCCS
TH2463 - Scan
TH2463 - Mean
TH2463 - MCCS
Model, $r = 1.5$mm
Model, mixed roughness
$\rho = 300$kg/m3, mixed roughness
$\rho = 450$kg/m3, $r = 1.5$mm
$\rho = 450$kg/m3, mixed roughness
Clean airfoil
z (m)
0.2
0.1
0.0
−0.1
−0.2
x (m)
−0.1
0.0
0.1
0.2
0.3
0.4
0.5


MIDSPAN, CASE13
TH2447 - Scan
TH2447 - Mean
TH2447 - MCCS
TH2459 - Scan
TH2459 - Mean
TH2459 - MCCS
Model, $r = 1.5$mm
Model, mixed roughness
$\rho = 300$kg/m3, mixed roughness
$\rho = 450$kg/m3, $r = 1.5$mm
$\rho = 450$kg/m3, mixed roughness
Clean airfoil
z (m)
0.2
0.1
0.0
−0.1
−0.2
x (m)
−0.1
0.0
0.1
0.2
0.3
0.4
0.5


INBOARD, CASE21
0.2
0.1
0.0
−0.1
−0.2
−0.3
z (m)
0.0
0.2
0.4
x (m)
TG2409 - Scan
TG2409 - Mean
TG2409 - MCCS
TG2418 - Scan
TG2418 - Mean
TG2418 - MCCS
Model, $r = 1.5$mm
Model, mixed roughness
$\rho = 300$kg/m3, mixed roughness
$\rho = 450$kg/m3, $r = 1.5$mm
$\rho = 450$kg/m3, mixed roughness
Clean airfoil


INBOARD, CASE22
TG2404 - Scan
TG2404 - Mean
TG2404 - MCCS
TG2411 - Scan
TG2411 - Mean
TG2411 - MCCS
Model, $r = 1.5$mm
Model, mixed roughness
$\rho = 300$kg/m3, mixed roughness
$\rho = 450$kg/m3, $r = 1.5$mm
$\rho = 450$kg/m3, mixed roughness
Clean airfoil
0.2
0.1
0.0
−0.1
−0.2
−0.3
z (m)
0.0
0.2
0.4
x (m)


INBOARD, CASE23
TG2412 - Scan
TG2412 - Mean
TG2412 - MCCS
TG2415 - Scan
TG2415 - Mean
TG2415 - MCCS
Model, $r = 1.5$mm
Model, mixed roughness
$\rho = 300$kg/m3, mixed roughness
$\rho = 450$kg/m3, $r = 1.5$mm
$\rho = 450$kg/m3, mixed roughness
Clean airfoil
0.2
0.1
0.0
−0.1
−0.2
−0.3
z (m)
0.0
0.2
0.4
x (m)

Effect of the distribution