Liikenteen turvallisuusvirasto

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Frostwing Preliminary Results

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Vastuullinen liikenne.
Yhteinen asia.

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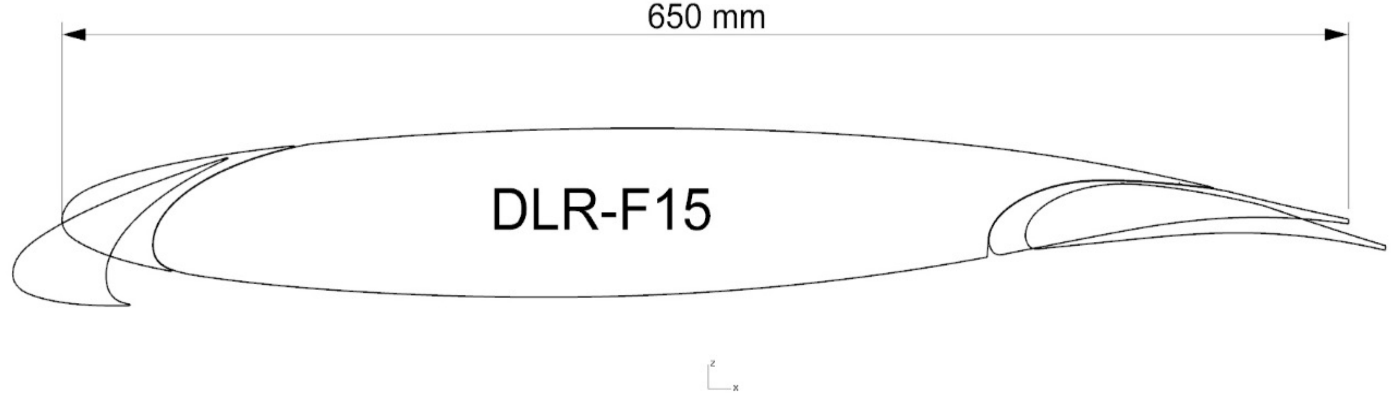
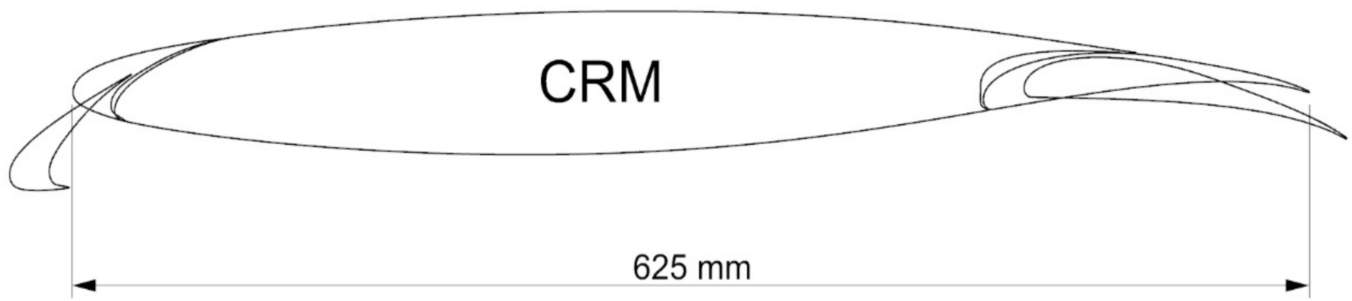
2D Wing Section Models



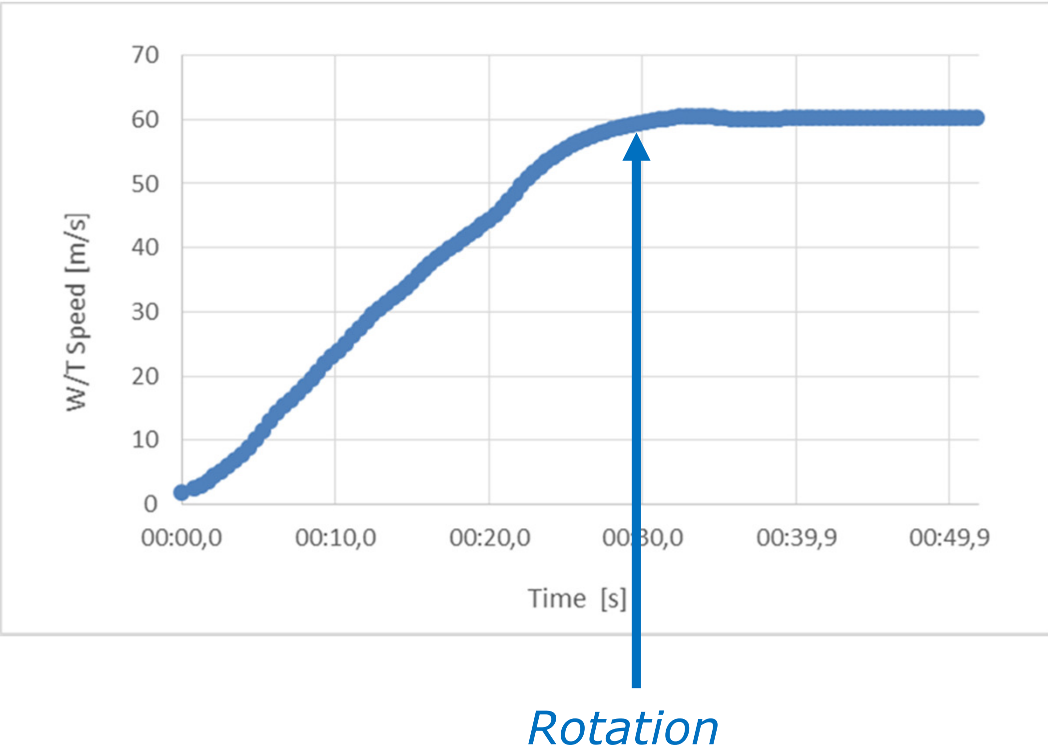
DLR-F15
W/T tests
2012-2014.
(IW-project)



HL-CRM Mod.
W/T tests
started 2016

W/T Measurement program

W/T speed and AoA sequence



Wing section	Slat/Flap angle	Ground Roll α	Ground Roll C_l	α at V_2	C_l at V_2
DLR – F15	S11˚ /F5˚	0˚	0.51	8.0˚	1.28
CRM	S22˚/F10˚	0˚	0.52	9.2 ˚	1.50

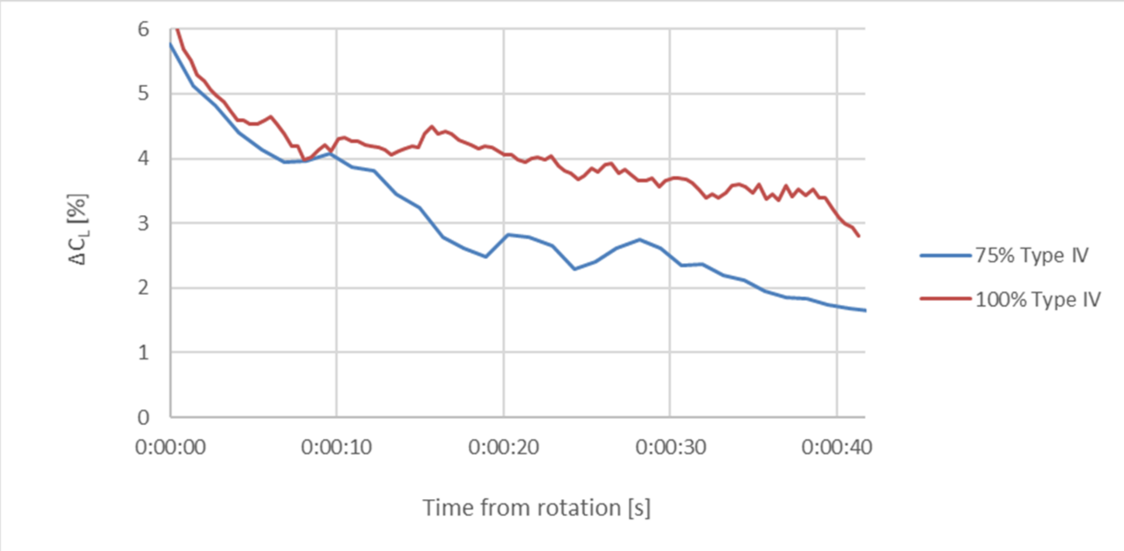
V_2 = 60 m/s, rotation 3°/s

Aerodynamic forces measured

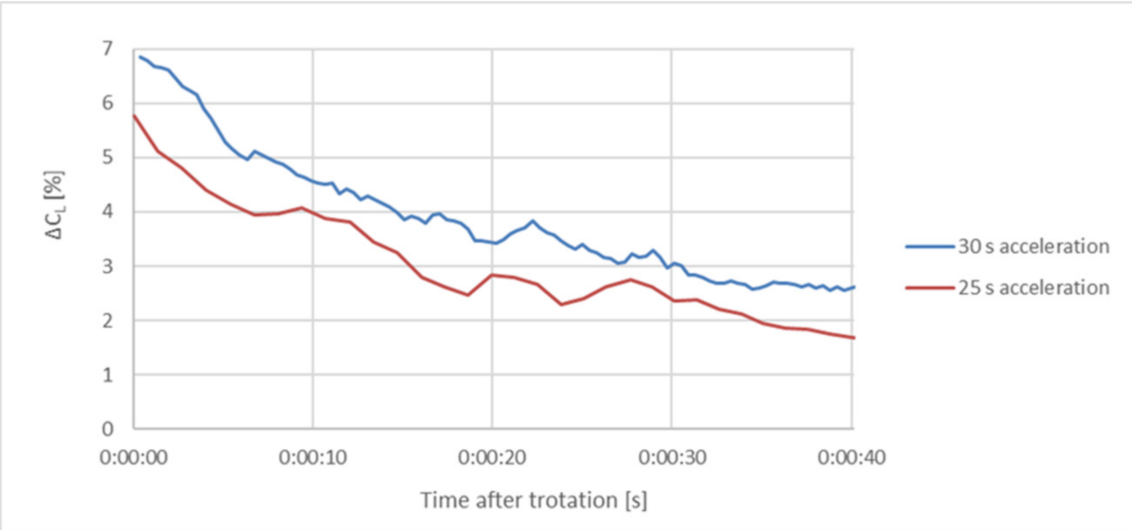
B/L rake only for CRM

Fluid/Frost behavior video taped

Fluid Test Results – ΔC_L [%] in time

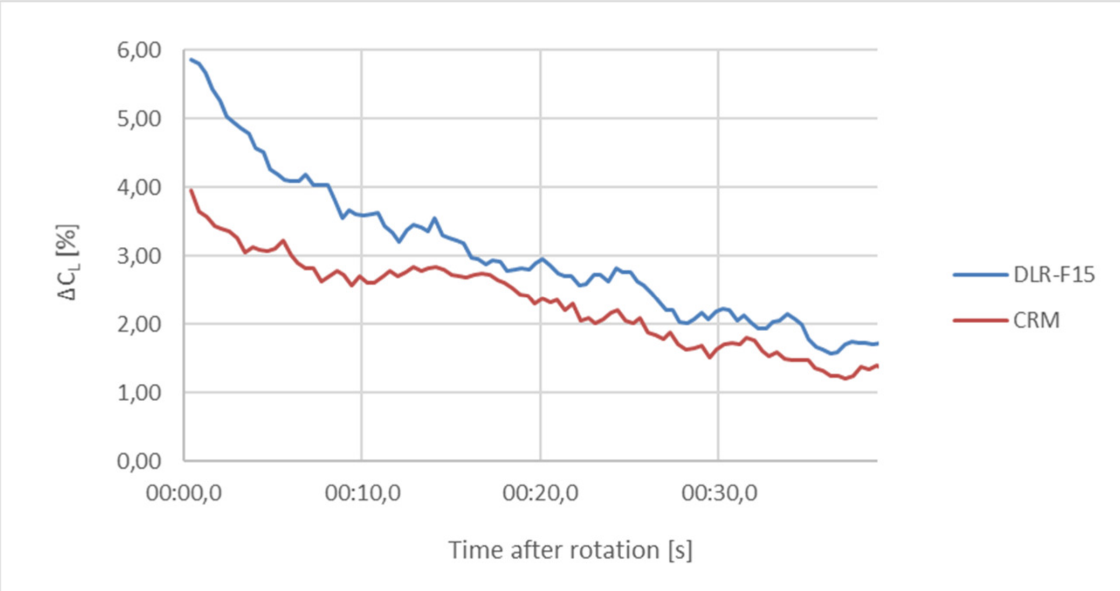


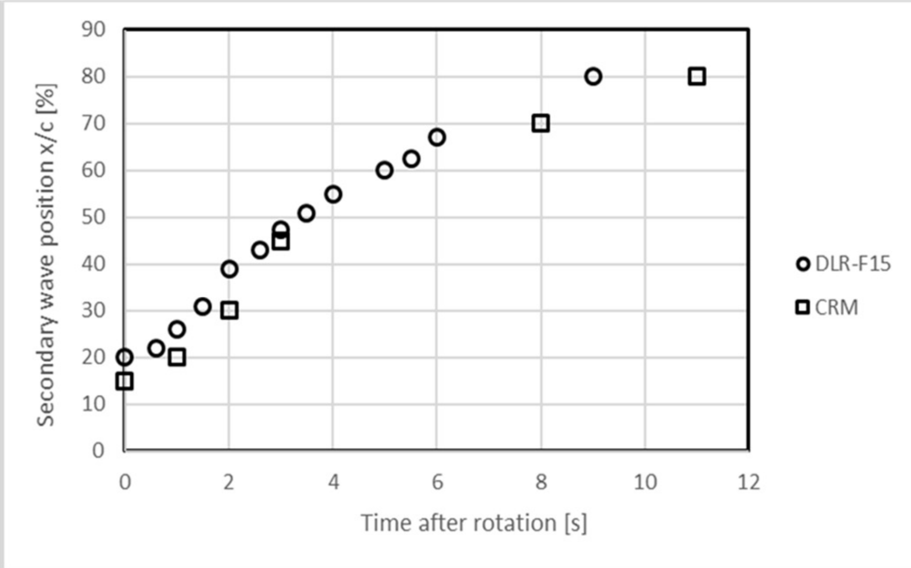
Lift degradation from uncontaminated wing section in time after rotation
DLR-F15, ambient T= -3°C
Diluted TIV
ΔC_L "hangs" quite high after rotation 30-40 s



Acceleration time has a simple time shifting effect on fluid induced lift degradation
DLR – F15

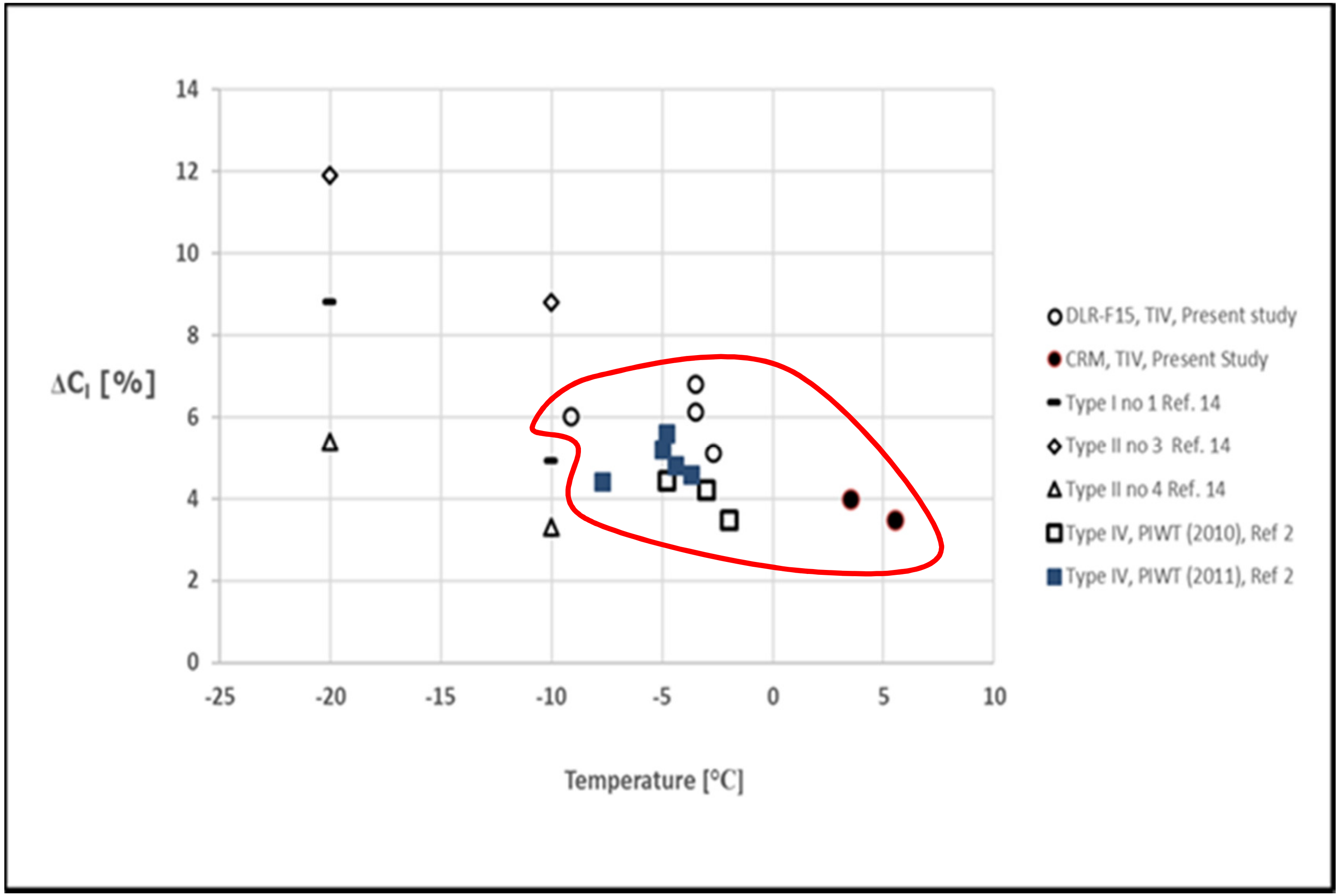
Fluid Test Results – ΔC_L [%]





The differences between the 2 wing sections tested are most probably due to different secondary waves. Further evidence by tests where the secondary wave effects were isolated (restricted fluid application, closed and sealed slat). Further tests indicated secondary wave contribution in the lift loss to be dominant

Fluid Test Results – ΔC_L [%]



ΔC_L immediately after rotation

Several studies

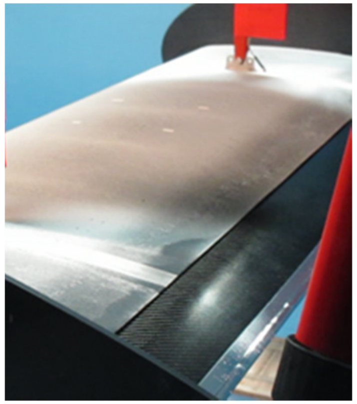
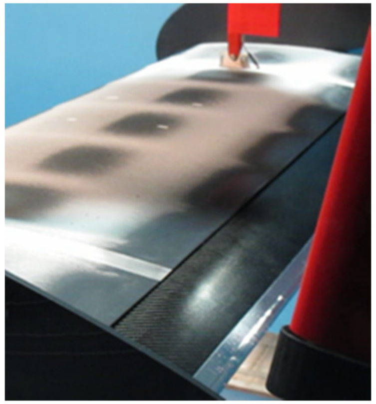
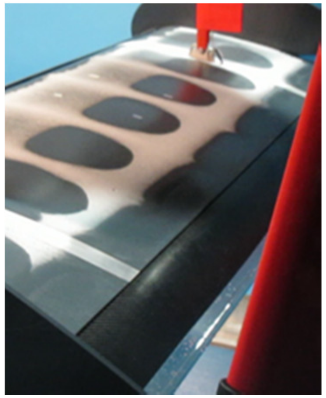
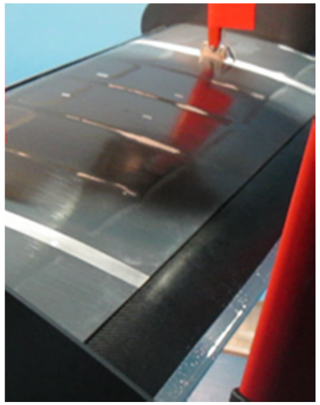
Cases isolated by red line: equivalent TIV fluid

CSFF W/T Test Results

W/T speed and AoA sequence and measurements identical to fluid tests

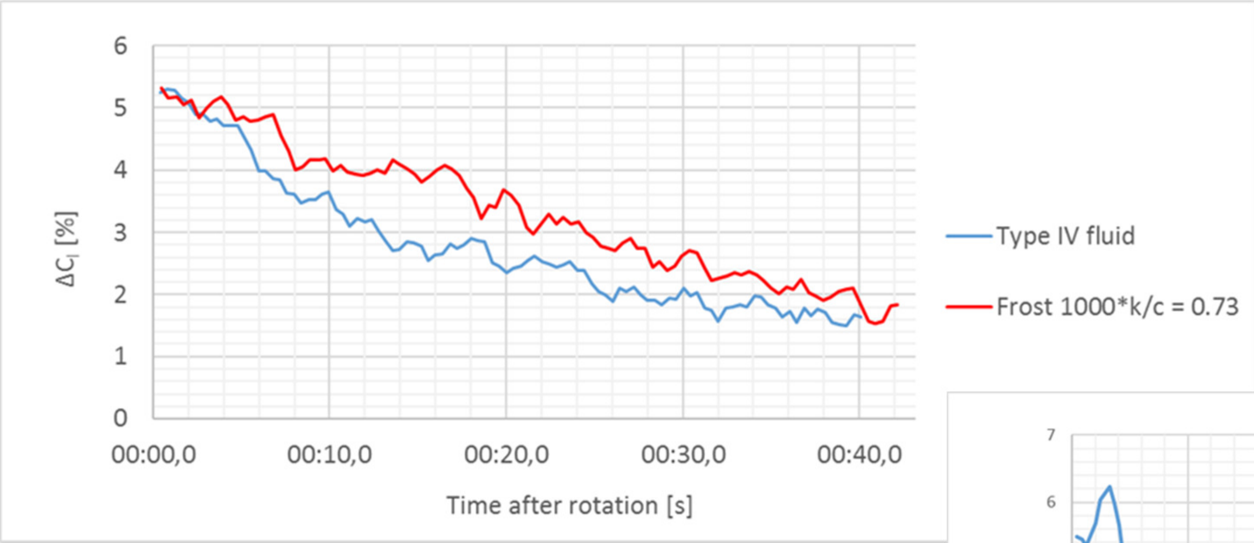
17 different frost cases - thickness variation:
$k/c = 0.14 * 10^{-3}$ to $3.60 * 10^{-3}$

Real frost – not sandpaper roughness → transient effects

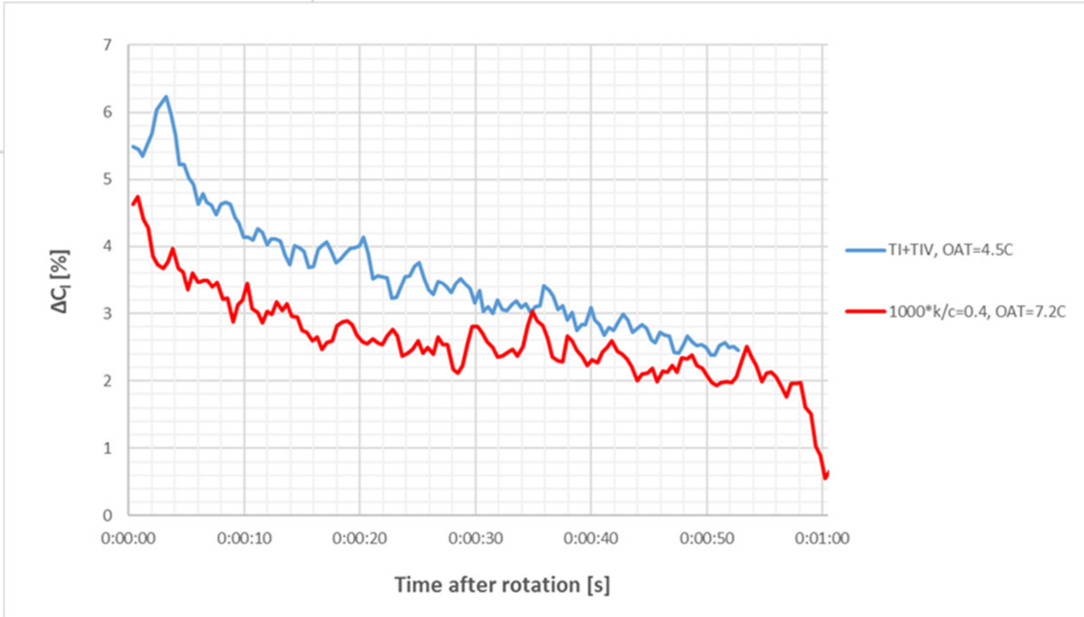





AoA=0º / U=38 m/s   AoA=0º / U=57 m/s   AoA=9.2º / U=60 m/s   30 s after rotation
Ambient T = 7.2 ˚C and initial frost thickness $k/c = 0.41\ 10^{3}$

CSFF vs. Fluids: Lift Loss Transiency

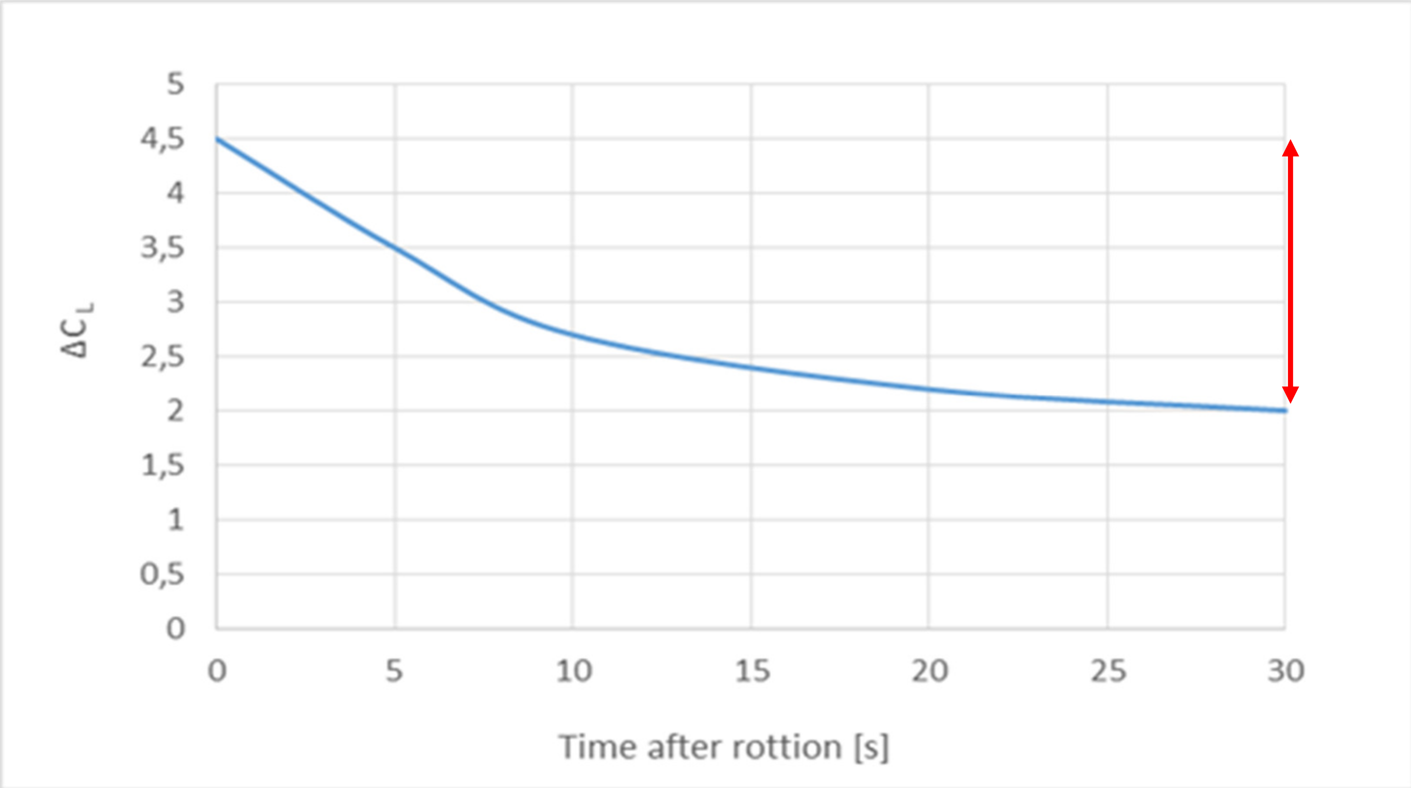


DLR-F15



CRM

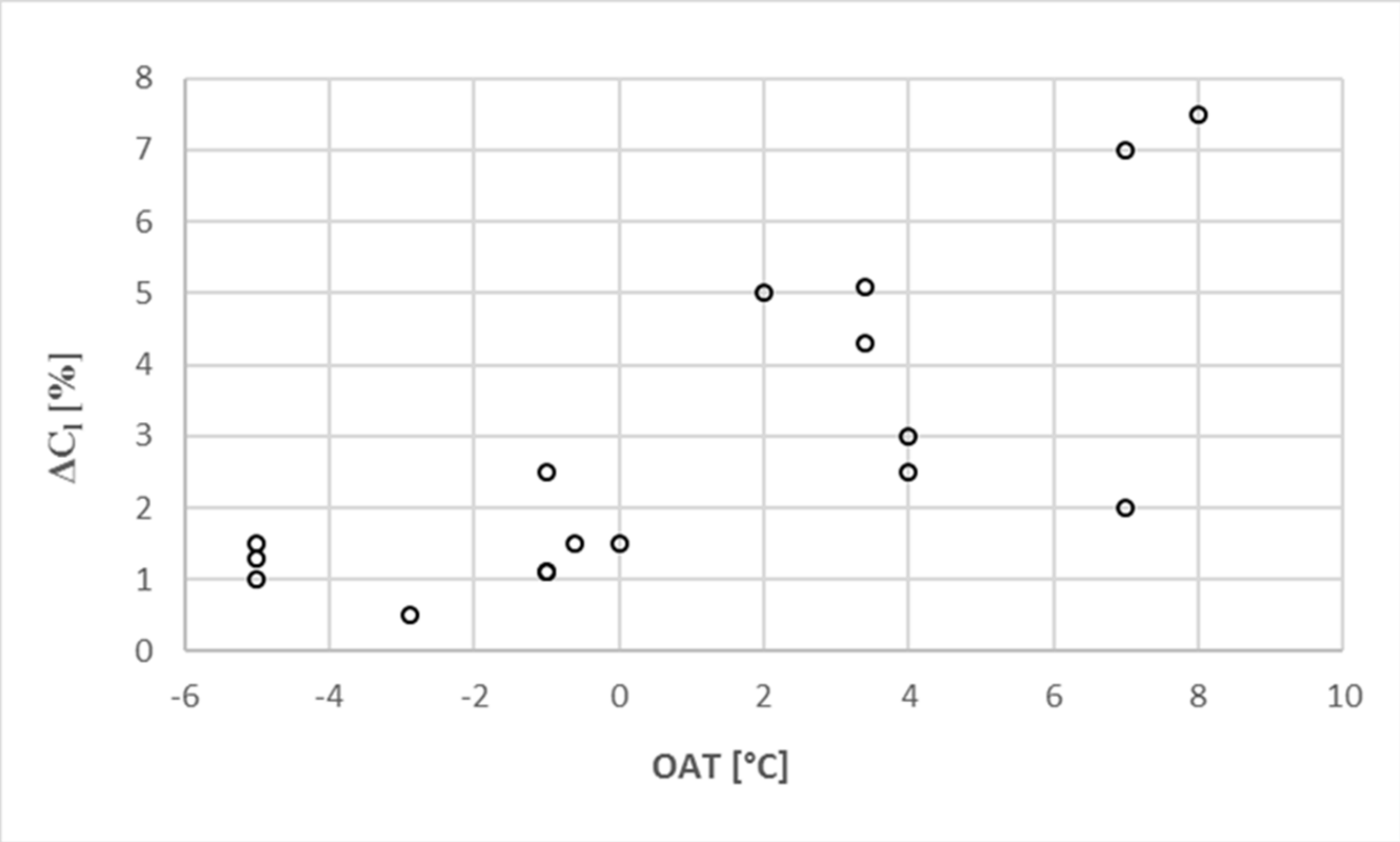
CSFF Lift Loss Recovery



Lift recovery in 30 s

Lift degradation [%] in time after rotation

CSFF Lift Loss Recovery



The variation of lift coefficient recovery with air temperature after the first 30 s from rotation for a Cold Soaked Fuel Frost

Lift loss recovery (30 s after rotation) variation with ambient temperature
Note:
scatter at higher temperatures are due to effects during take-off roll phase

CFD Studies

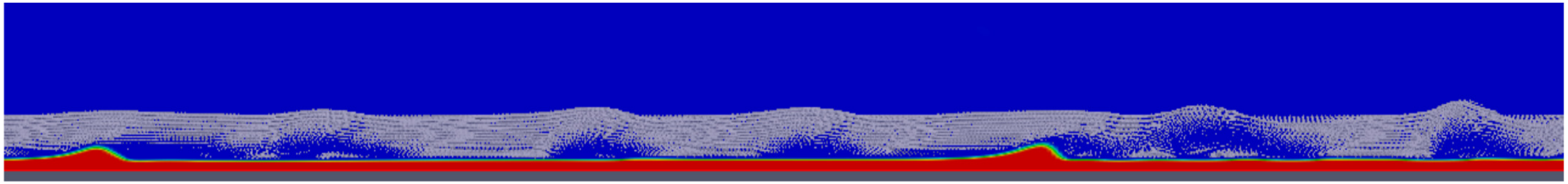
- *Objective: study the possibility to estimate the fluid loss in time computationally without experiments*
- *A flat plate with a fluid layer in an accelerating airstream*
- *If the preliminary studies were successful there will be a theoretical method available to study the effects of fluid properties (density, viscosity and surface tension) on the fluid loss rate and FPET B-L displacement thickness*

CFD Studies

- *Due to limited time/resources a 2D flat plate model was chosen*
- *Code applied: OpenFoam*
- *2 solvers available for 2-phase flow in OpenFoam code:*
  - *multiphaseEulerFoam*
  - *multiphaseInterFoam supports Non-Newtonian viscosity models, better stability, allows either LES or RANS turbulence models → this solver was selected*
- *2D grid for 0.6m long flat plate: 165 000 cells - recent trials with 1.8m flat plate with 480 000 cells*
- *Initial time step for 2D simulations $5*10^{-6}$ s → 5 second simulation for a 0.6m flat plate takes 2 weeks with 2 CPUs.*

CFD Studies

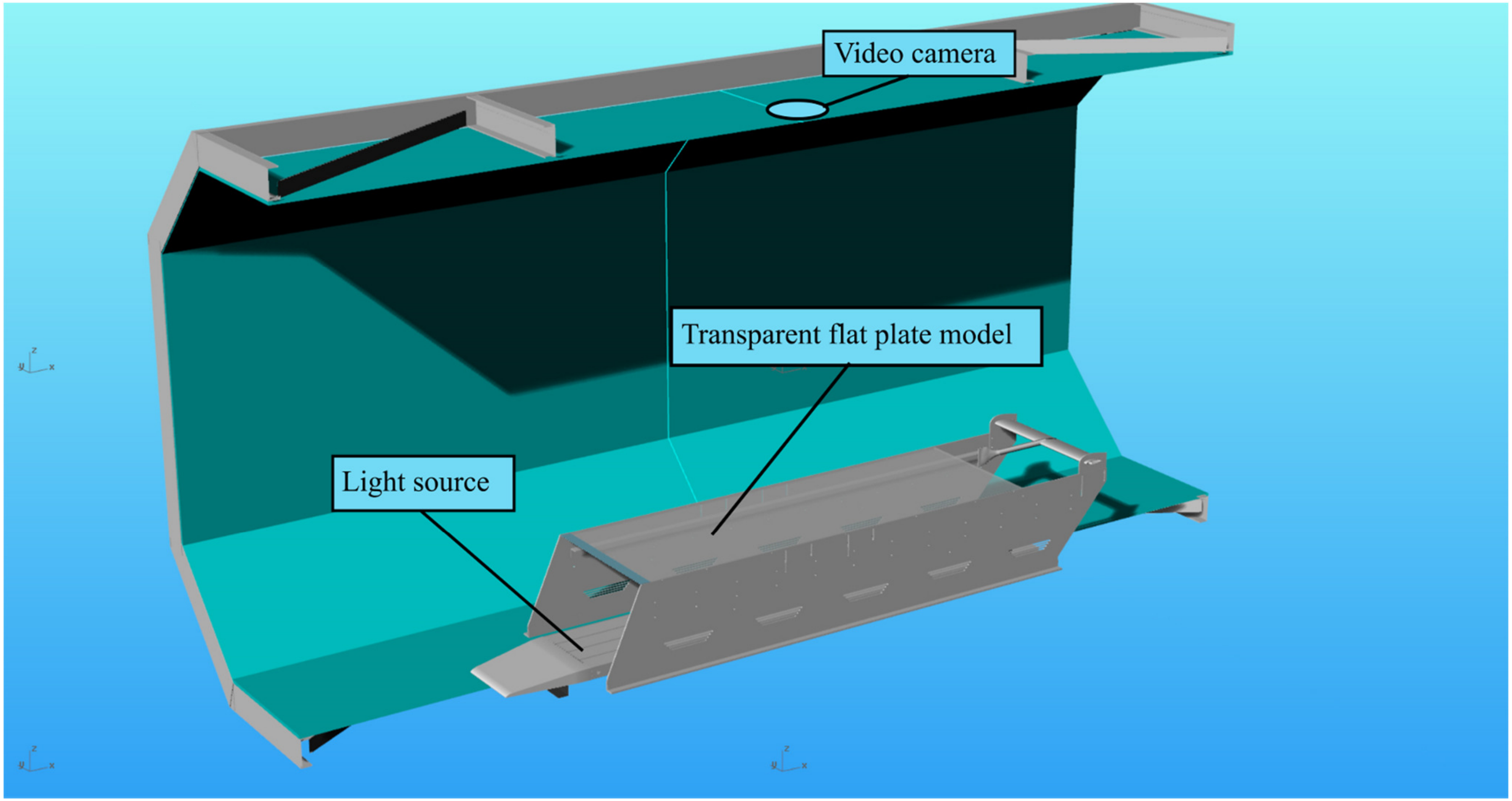
Type I fluid (100 %) in airstream of 17 m/s – note airstream eddies



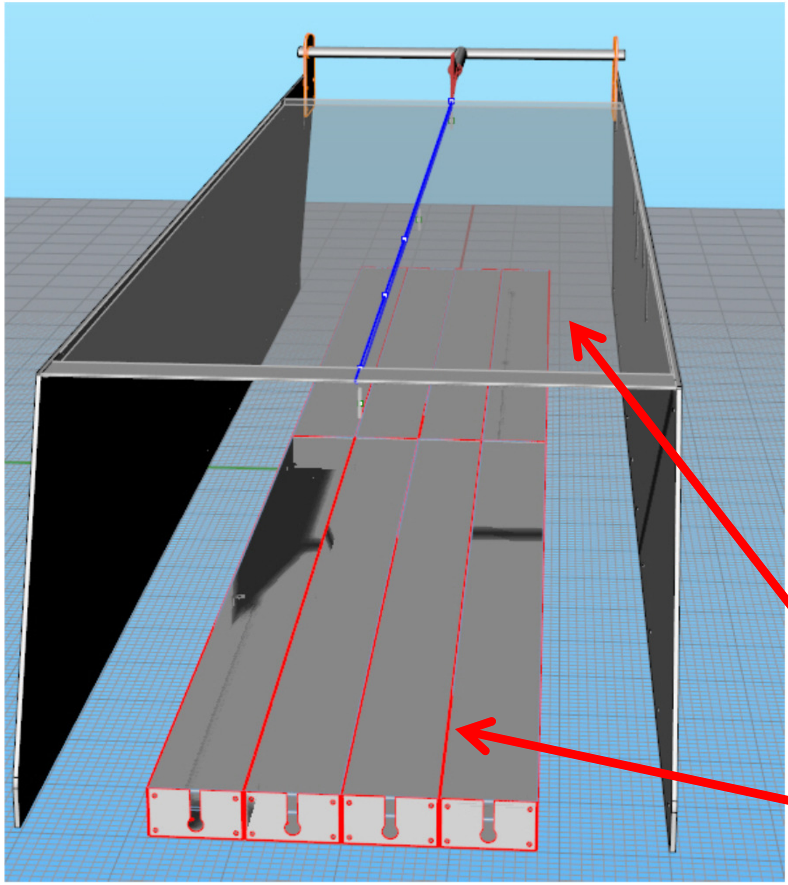
To catch the effects of these eddies LES – turbulence model was chosen though it is considered essentially a 3D turbulence model

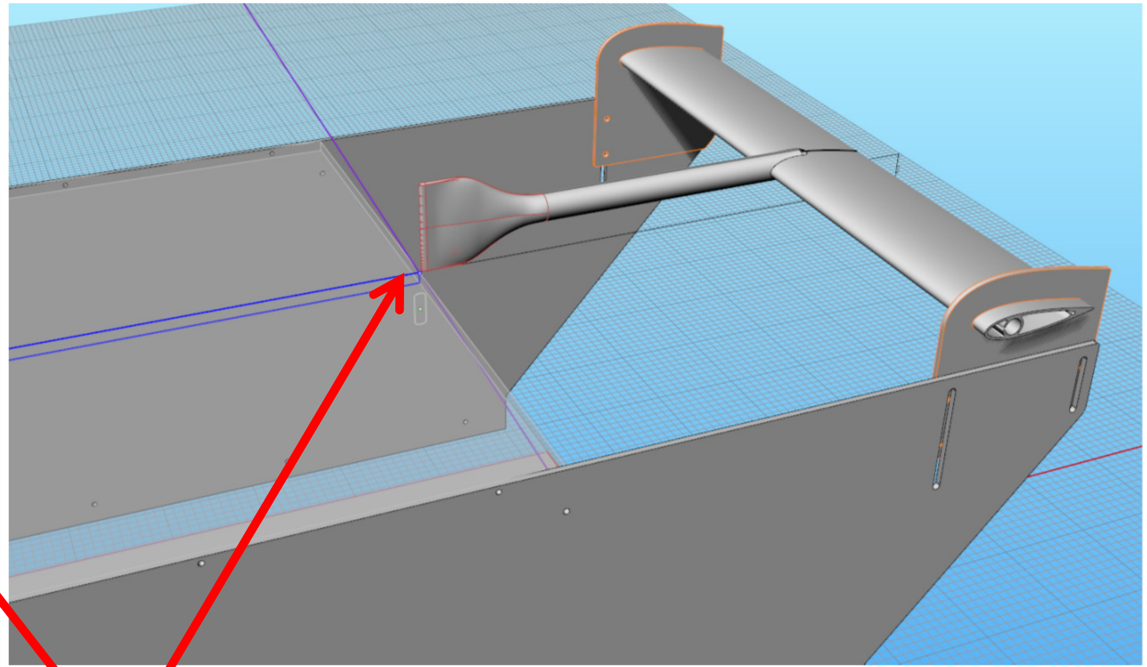
Selection was motivated by a fairly good 2 dimensionality of the waves according to W/T tests

Flat Plate W/T Tests to Evaluate CFD Calculations



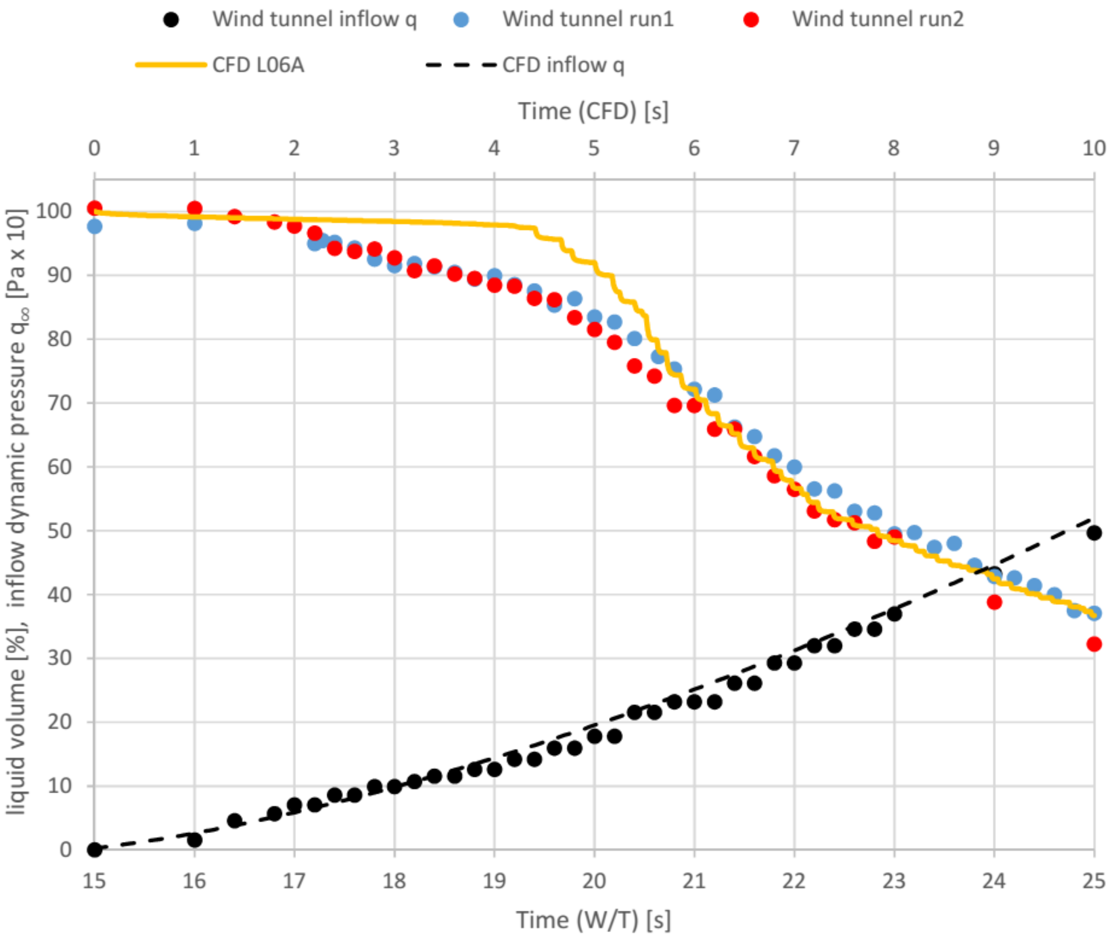
Flat Plate Wind Tunnel Model





- Pitot – Static Rake
- Transparent flat plate - PMMA (acrylic)
- Distributed LED-light sources

CFD Results Compared to Measurements



0.6 m Flat plate

Total fluid volume variation and W/T kinetic pressure variation in time

CFD Studies - Continuation

- *Preliminary studies for Non-Newtonian fluids (TIV) have appeared challenging – at least for OpenFoam code. Needs more basic research*
- *Now in process TI fluids on a 1.8m flat plate and calculations for fluids at lower temperatures (-6 to -10° C) and higher viscosities (35 mPas to 170 mPas)*