Frostwing Preliminary Results

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CONTENTS

- 2D Wing Section Model W/T Tests
  - Fluid Tests
  - CSFF Tests

- CFD Studies and Flat Plate W/T Tests
  - CFD Modeling of a Flat Plate with a Fluid layer
  - Flat Plate Tests in Wind Tunnel
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**

$V_2 = 60 \text{ m/s}, \text{ rotation } 3^\circ/\text{s}$

**Aerodynamic forces measured**

**B/L rake only for CRM**

**Fluid/Frost behavior video taped**

<table>
<thead>
<tr>
<th>Wing section</th>
<th>Slat/Flap angle</th>
<th>Ground Roll $\alpha$</th>
<th>Ground Roll $C_1$</th>
<th>$\alpha$ at $V_2$</th>
<th>$C_1$ at $V_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>DLR – F15</td>
<td>S11°/F5°</td>
<td>0°</td>
<td>0.51</td>
<td>8.0°</td>
<td>1.28</td>
</tr>
<tr>
<td>CRM</td>
<td>S22°/F10°</td>
<td>0°</td>
<td>0.52</td>
<td>9.2°</td>
<td>1.50</td>
</tr>
</tbody>
</table>
Fluid Test Results – $\Delta C_L [%]$ in time

Lift degradation from uncontaminated wing section in time after rotation DLR-F15, ambient $T= -3 ^\circ C$

$\Delta C_L$ “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 – $\Delta C_L [%]$

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 – $\Delta C_L$ [%]**

$\Delta C_L$ 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:

\[ k/c = 0.14 \times 10^{-3} \text{ to } 3.60 \times 10^{-3} \]

Real frost – not sandpaper roughness → transient effects

\[ \text{AoA}=0^\circ / U=38 \text{ m/s} \quad \text{AoA}=0^\circ / U=57 \text{ m/s} \quad \text{AoA}=9.2^\circ / U=60 \text{ m/s} \quad 30 \text{ s after rotation} \]

Ambient \( T = 7.2 \ ^\circ \text{C} \) and initial frost thickness \( k/c = 0.41 \times 10^3 \)
**CSFF vs. Fluids: Lift Loss Transiency**

- **DLR-F15**

- **CRM**

15.5.2017
CSFF Lift Loss Recovery

Lift degradation [%] in time after rotation

Lift recovery in 30 s

Liikenteen turvallisuusvirasto
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

The variation of lift coefficient recovery with air temperature after the first 30 s from rotation for a Cold Soaked Fuel Frost
**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 $5 \times 10^{-6}$ s → 5 second simulation for a 0.6m flat plate takes 2 weeks with 2 CPUs.
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)