# Predictive Model for Automotive Fan Performance using Thin Airfoil Theory: Update Meeting

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# *Challenges*

- Implementation of body forces in new CFD packages

- Need to account for losses through fan to predict flow rate accurately – simple loss model must be added to Hall et al. approach

- Model may need modification for low blade counts typically found in automotive fans

# Focus of Last Meeting: 2D Basic Body Force in OpenFOAM

| Major Activity | Mo 1 | Mo 2 | Mo 3 | Mo 4 | Mo 5 | Mo 6 | Mo 7 | Mo 8 | Mo 9 |
|---|---|---|---|---|---|---|---|---|---|
| Build simple grids for testing body force model (OpenFOAM) | | | | | | | | | |
| Implement body force model into OpenFOAM, including debugging for simple flat plate blades where solution can be analytically estimated | | | | | | | | | |
| Build model of fan test facility with fan of interest (body force model – OpenFOAM; model with fan blades – OpenFOAM and StarCCM+) | | | | | | | | | |
| Implement simple loss model for fan based on local deviation (body force) | | | | | | | | | |
| Verify model performance in OpenFOAM by comparing results for fans previously modelled within the applicant's research group using other software | | | | | | | | | |
| Carry out simulations for fan of interest (body force model + model with fan blades) and compare to existing experimental data (OpenFOAM and StarCCM+) | | | | | | | | | |

# OF Impl. Completed & Validated, Fan Test Model Ready

Past ← → Future

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# BF + Bladed CFD Starting Soon, Loss Model Work Moved Back

Past — Future

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# *Key Messages*

- Implementation of body force model for 3D applications in OpenFOAM complete

- Model validated with results from Ansys CFX

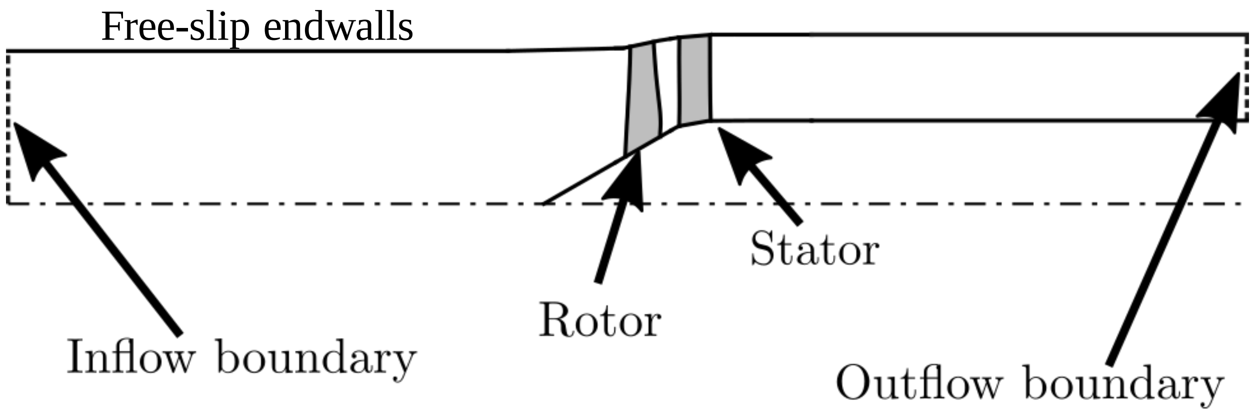
- Computational domain for the Pacifica fan test complete – ready to move on to body force and bladed CFD

# Whittle Fan - Test Case to Assess 3D Model Implementation

- Same low-speed fan modelled by Hall et al. (2017), Defoe et al. (2018)

- Experimental facility at the Whittle Lab, U. of Cambridge – relevant publications 2014-2017

- Ansys CFX results available for design flow coefficier $\phi = \frac{\dot{m}}{\bar{\rho}^M A_1 U_{mid}} = 0.50$



# CFD Cases Similar but not Identical

- CFX: compressible (but Mach<0.3 everywhere)
  - Inlet: total pressure/temperature/velocity direction
  - Outlet: static pressure – set to yield desired mass flow rate
- OpenFOAM: incompressible
  - Inlet: velocity inlet (sets volume flow)
  - Outlet: static pressure (sets total pressure level)

# CFD Solvers Work Differently – Leads to Differing Grids

- CFX is a node-centered code: data is stored at the corners of cells

- OpenFOAM is a cell-centered code: data is stored at cell centres

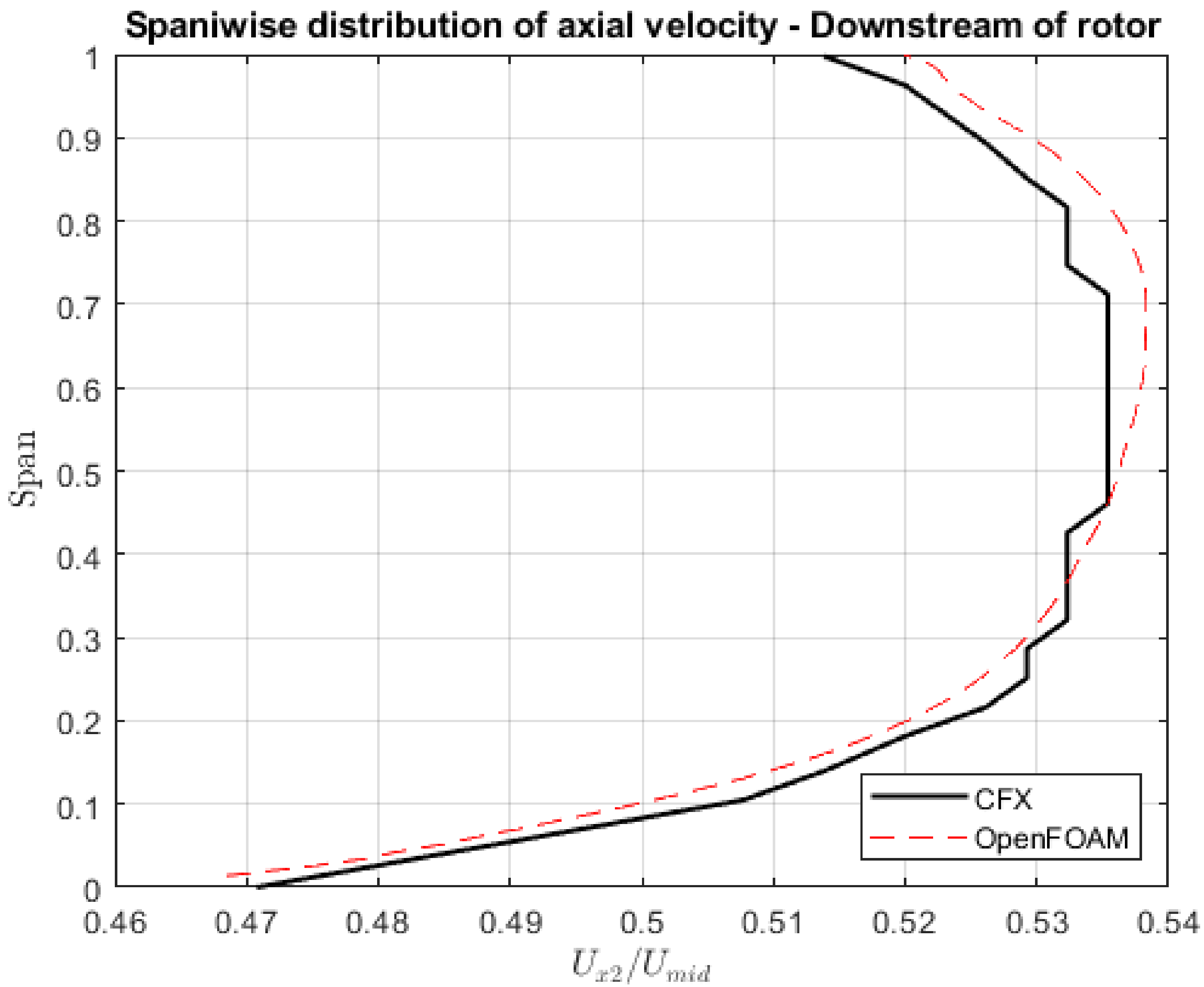
- Means that grid-independent solutions may not be the same, and may occur on different grids

- CFX results confirmed to be grid-independent for OVERALL STAGE performance

- OpenFOAM results checked for convergence of radial profiles

- Led to a grid 9X finer than that used in CFX

# Mass Flow Distributions Similar at Rotor Exit

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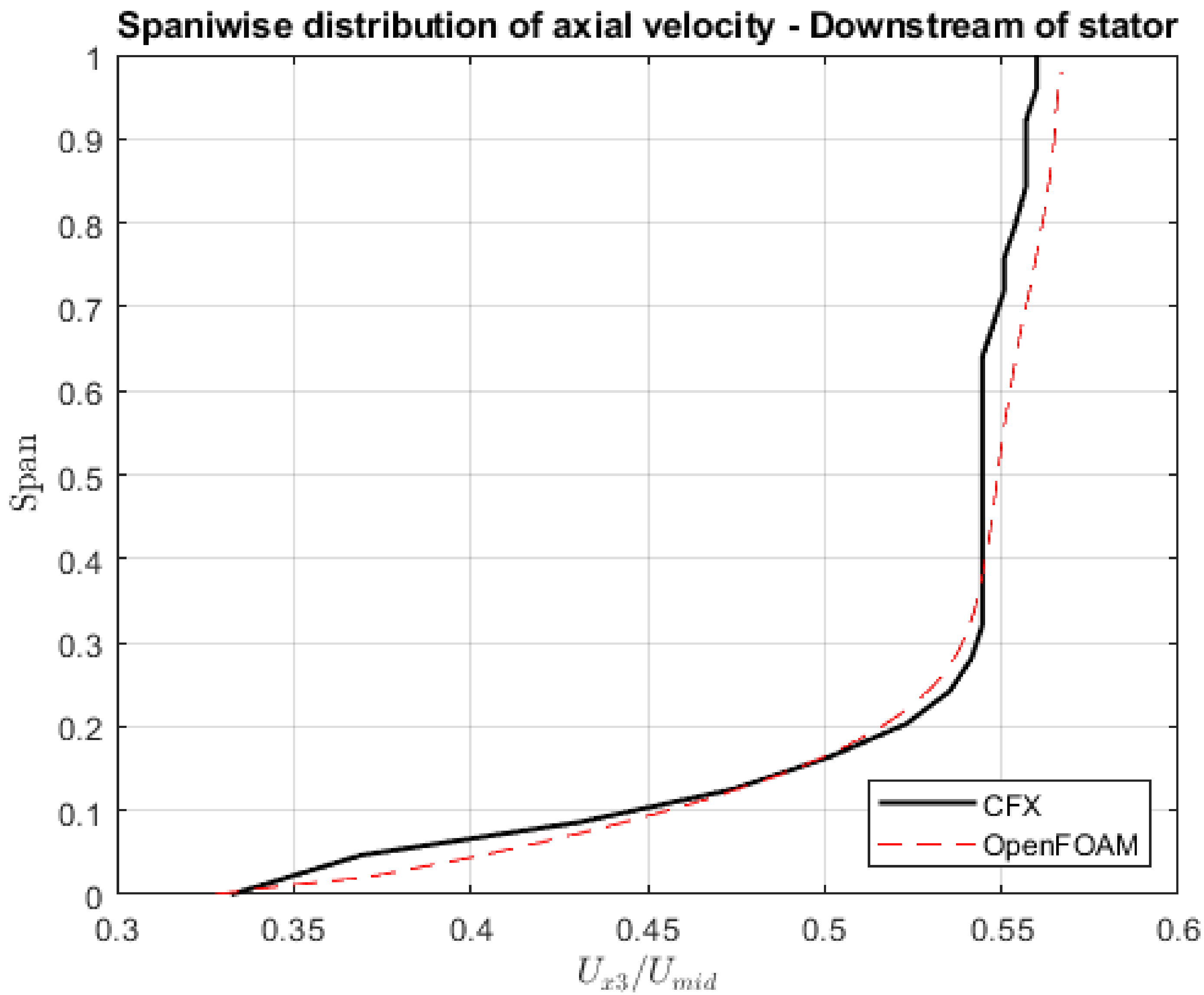
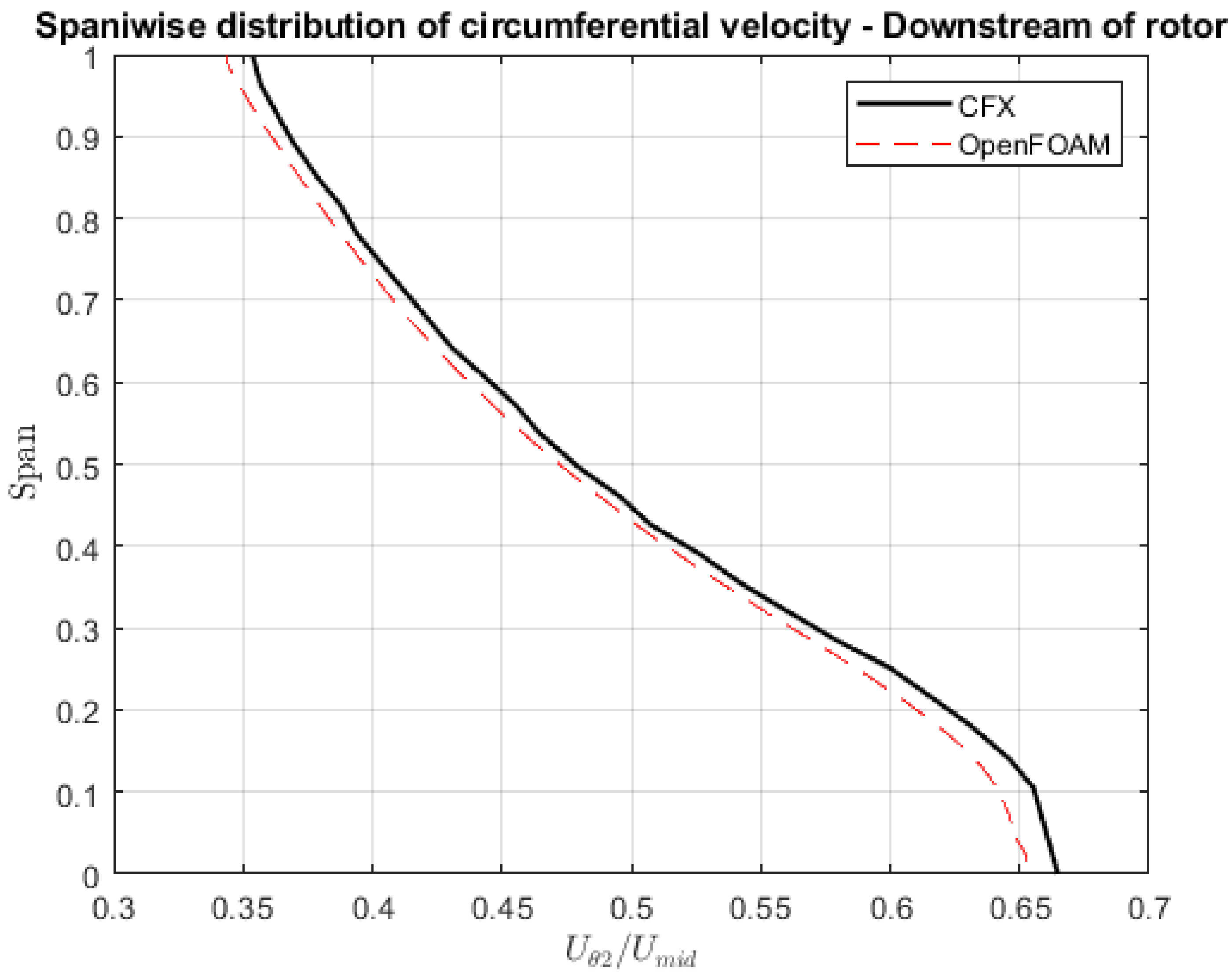
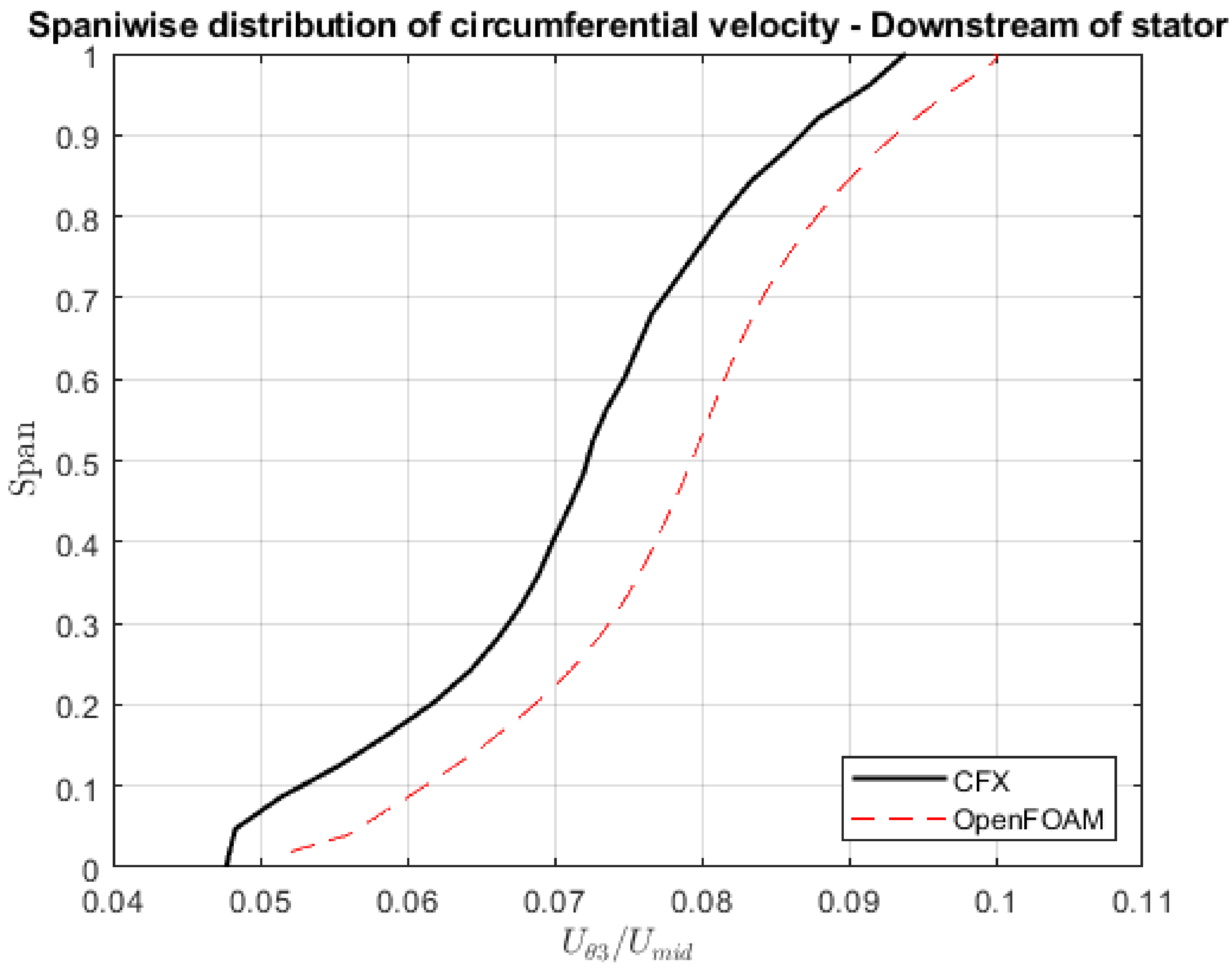
# Mass Flow Distributions Similar at Stator Exit



# OF Predicts Slightly Lower Flow Turning at Rotor Exit



# OF Stator Again Eliminates Less Swirl than CFX

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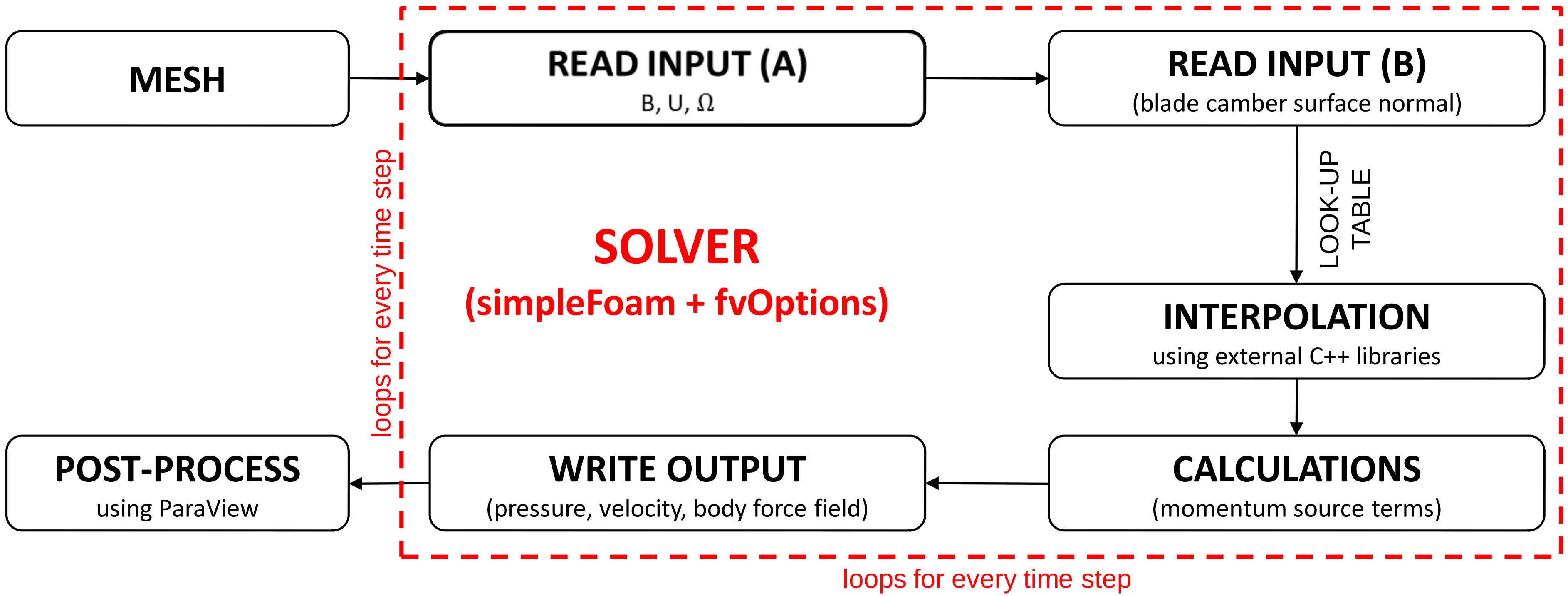
# OF Yields a More Accurate Total Pressure Rise Coefficient

# Challenges with Previous BF Implementation



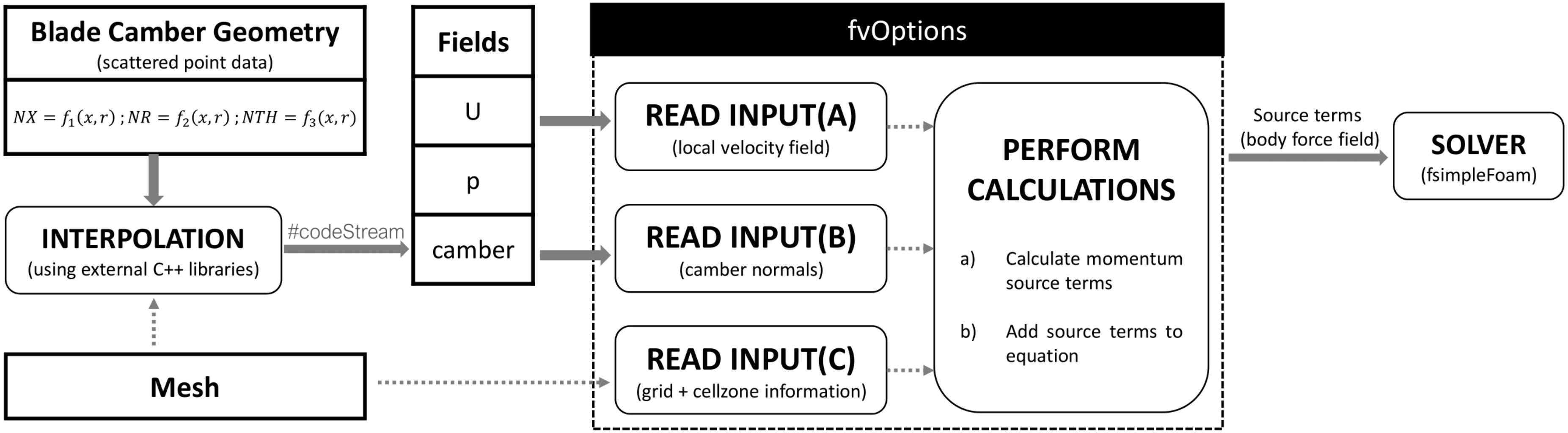

**Three biggest challenges:**

1. Distinguishing b/w cell zones with & without turbomachinery
2. Moving `NX, NR, NTH` interpolation code out of `fvOptions`, but within the OpenFOAM framework
3. Minimizing memory use & redundant calculations

# Improved OF BF Impl. Speeds up Calculation ~100X

**New features:**

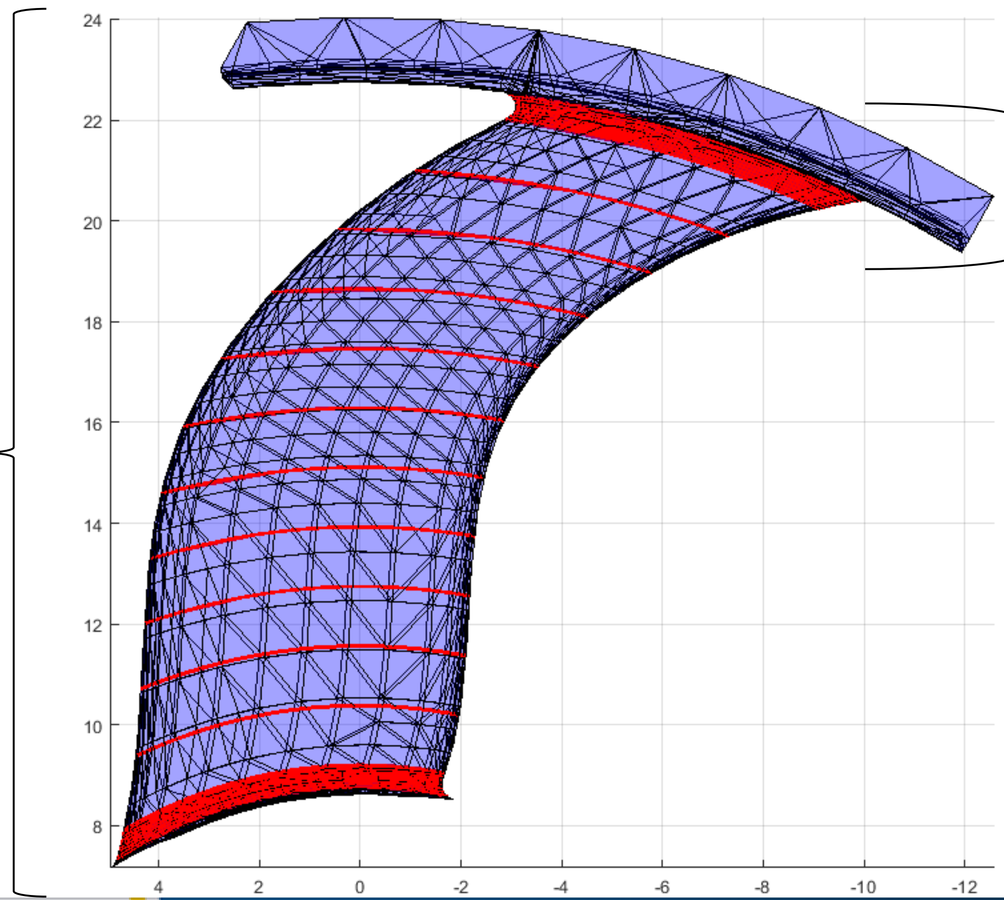
1. BF calculations for specific `cellZone`s only
2. Separate `camber` field defined – requires solver recompilation (`fsimpleFoam`)
3. Interpolation performed only once, defined as initial field setting for `camber`



# Extracting Pacifica Blade Geometry – Very Time-consuming

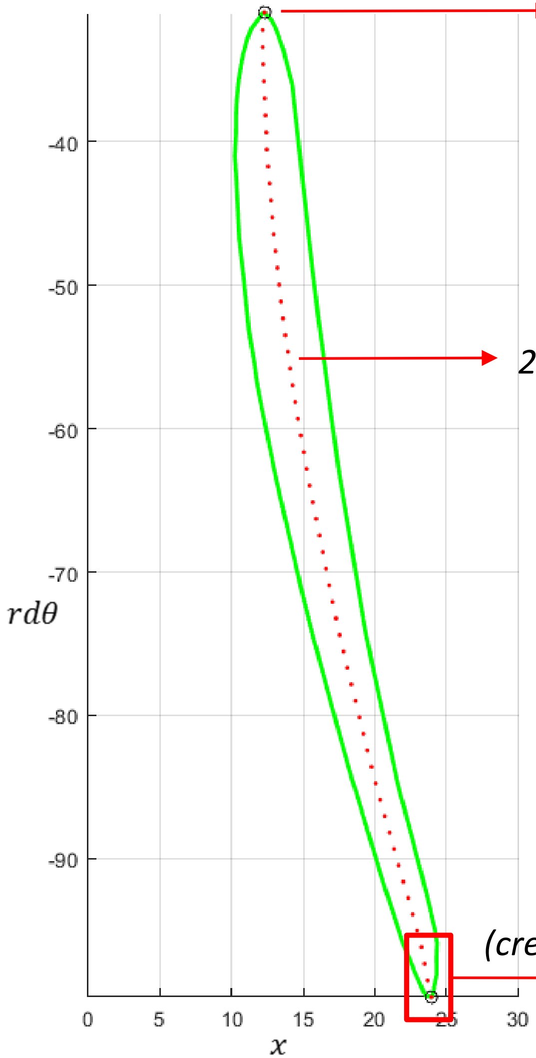
- **Challenge**: Accurately capture complex blade shape with twist and fillets
- **Solution:** Extract a high no. of profiles from .stl file, makes manual cleanup difficult

*Blade profiles extracted at different radii*




*Higher no. of profiles near the hub/tip to capture fillet*

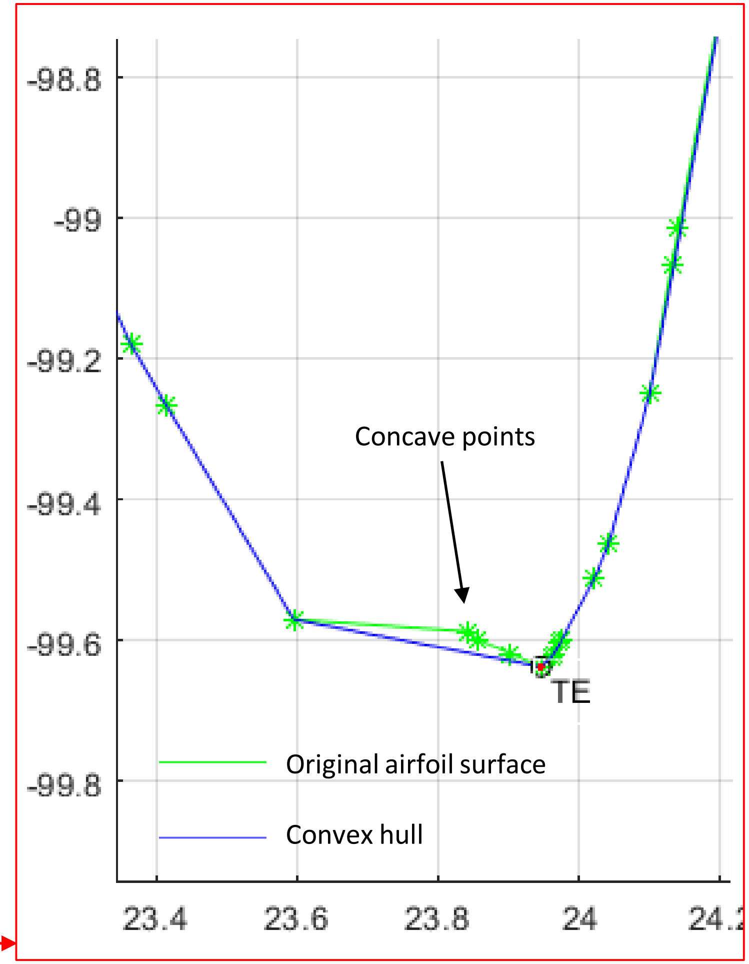
# Generating Clean Airfoil Profiles for TurboGrid – Challenges




*1. Estimation of LE-TE (a critical choice)*

*2. Highly curved camber line (mean camber estimate inaccurate)*

*3. Uneven TE problem (creates negative mesh volumes)*

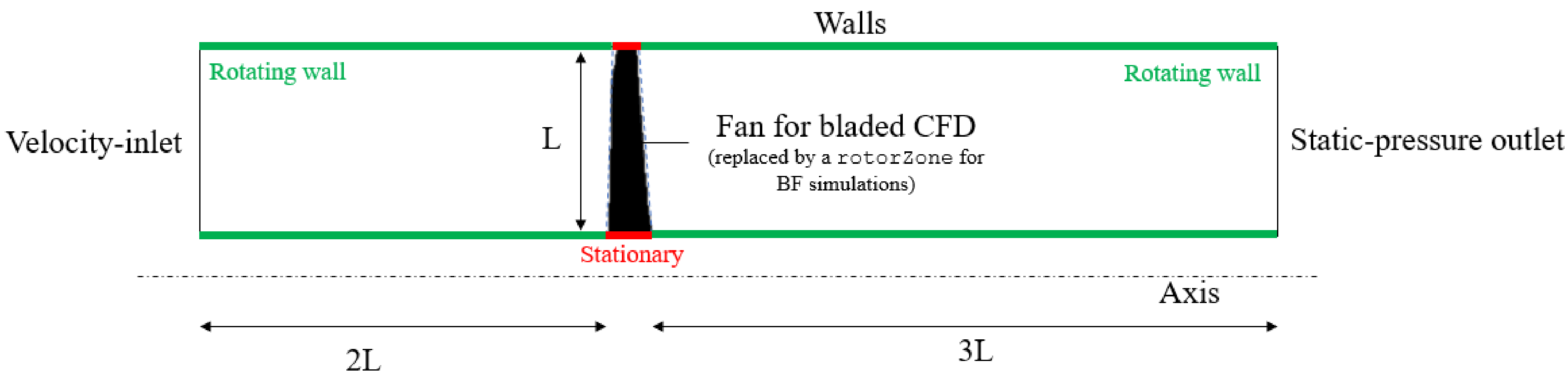


# *Profiles Cleaned - Keeping Accuracy and Efficiency in Mind*

- **Estimation of LE/TE:**
  - By definition, the two most distant points on an airfoil profile
  - Generated using rotating calipers algorithm
- **Extracting camber line:**
  - Mean camber line is first approximation
  - Iteratively find a line with equal perpendicular distances from suction and pressure surfaces.
- **Uneven TE problem:**
  - TE neighboring region replaced by a convex hull

# Pacifica Computational Domain & Boundary Conditions

- Different grids to be created for bladed and BF simulations
- Boundary conditions:
  - Inlet: velocity inlet (set to achieve target mass flow rate)
  - Outlet: static pressure (sets total pressure level)



# CFD Simulations To Assess Accuracy of Blade Loading Model

| SOLVER / TYPE OF SIMULATION | OpenFOAM | Star-CCM+ |
|---|---|---|
| Single blade, single passage model | 1. Free-slip blade walls<br>2. No-slip blade walls<br>(compared to experimental data) | 1. Free-slip blade walls<br>2. No-slip blade walls<br>(compared to OF simulations for solver validation) |
| Body force model | 1. W/o loss model<br>(compared to free-slip bladed CFD to assess model accuracy)<br>2. W/ loss model<br>(implemented if needed) | For later … |

# Resources needed from FCA

- StarCCM+ for CFD of fan test facility model with blades, simulated in StarCCM+
- Spend time on-site with ARDC staff to help Palak set up computations in Star-CCM+
- Post-processing – Information needed about measurement plane locations for pressure rise for provided experimental data

# Back To Key Messages

- Activities re-shuffled but project timeline essentially on schedule
- Body force model completely implemented, optimized and validated
- Pacifica computational domain for bladed CFD ready in TurboGrid