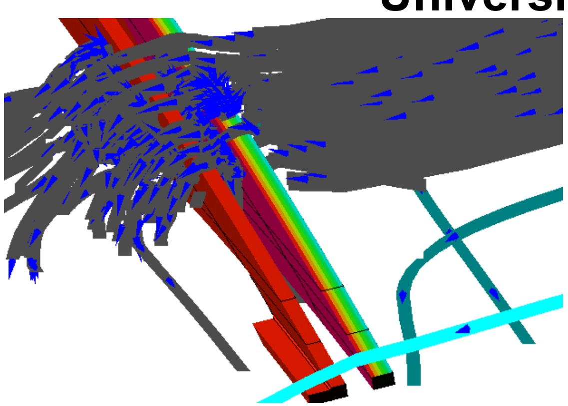
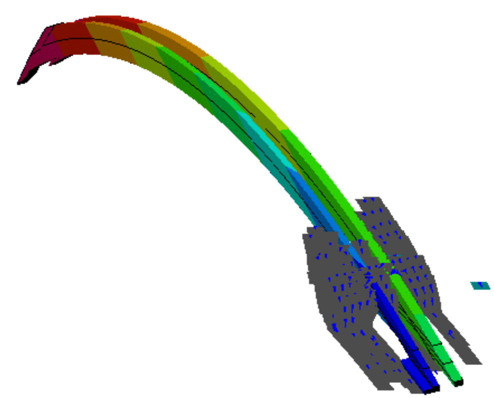
Numerical Simulation of Flow, Pressure and Motion of Front Back Fingers in a Two Rows Finger Seal

M.J. Braun, Dept. of Mechanical Engineering
University of Akron, mjbraun@uakron.edu

V.V. Kudriavtsev, CFD Canada,
vvk@cfdcanada.com

F.K. Choy Dept. of Mechanical Engineering
University of Akron, mjbraun@uakron.edu





ABSTRACT

- This proposal fits within the programmatic long-term development direction for turbine engine seals of the Seal Team of the Mechanical Component Branch.

- The intended work concerns the further development of the Finger Seal concept which is a compliant passive-adaptive seal meant to mitigate (and eventually replace) the shortcomings of the entire class of rigid seals used today (labyrinth, honeycomb, mechanical face seals) in the gas turbines and compressors.

GOALS

- **First,**

  we are aiming at developing a fully integrated numerical 3-D model, which couples the hydrodynamic fluid model (Navier-Stokes based) to the solid mechanics code that models the compliance of the fingers.

  The coupled codes that feedback in an iterative mode, will allow the full simulation of the passive-adaptive properties of this innovative seal.

- **Secondly**,

  experimentally, we shall test alternative models of finger seals in an effort to better understand their sealing and lifting properties, as well as guide and validate the code numerical development.

In Year II, in collaboration with the Seal Team of the Mechanical Components Branch, we shall extend the University of Akron based experimental program to the High Temperature Test Rig at NASA Glenn Research Center. This will allow moving our technology readiness level from a room temperature laboratory environment (TRL-4) to the high temperature, engine relevant environment (TRL-5).

NUMERICAL SIMULATION COMPONENT MODULES

⇨**Mechanical model of the single finger and assembly of fingers**. This model will entail the generation of a finite element based code that will simulate the stiffness and damping of the element as it is subject to engine environment pressures (high and low side), hydrodynamic pressures at the finger foot/shaft interface, and Coulomb friction between the two rows of fingers.

⇨)**Hydrodynamic fluid model**. This model has to simulate the hydrodynamic lifting effects on the finger seal, as well as the primary and secondary leakages as they occur between the fingers and at the shaft/finger foot interface. We intend to use an already existing numerical package and tailor it to the particular needs of the project.

NUMERICAL SIMULATION COMPONENT MODULES

⇨)**Solid/fluid Interaction with the Dynamics module.** Through the implementation of a) and b) we shall obtain a fully interactive model that will model the interaction between finger mechanics and the 3-D fluid hydrodynamic behavior In this context we shall generate a complete pressure map of the hydrodynamic pressures ensuing under the finger pad footprint. All external body forces acting on the finger will be accounted for, in this model.

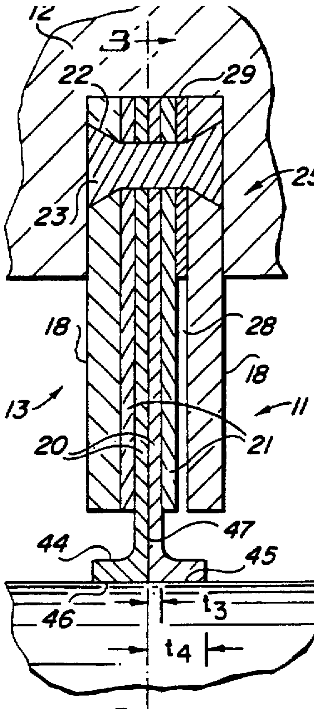
⇨)**Simplified spreadsheet design.** With a), b) and c) implemented we project the possibility that a detailed parametric run will allow creation of a database that can be used for the creation of a simplified calculation methodology that will use a spreadsheet format, without any further need of 3-D calculations.

EXPERIMENTAL PROGRAM

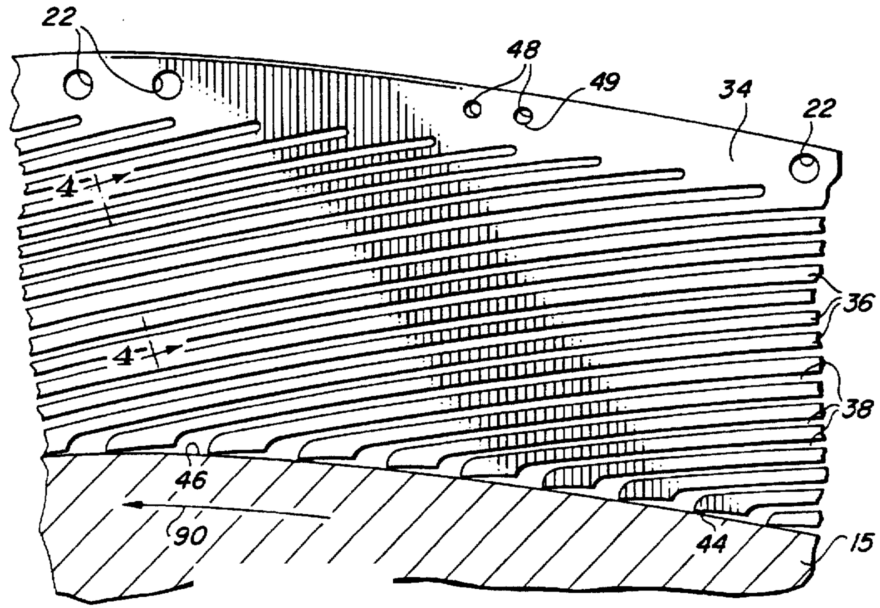
⇨The Tribology Laboratory at the University of Akron possesses a high-speed rig that can be run up to 15,000 rpm. The rig contains all necessary controls and data acquisition system for measuring pressures, temperatures, rotor orbits. The spindle is mounted in cantilever and allows installation of a slip ring at its axial end.

- full pressure and temperature maps
- identification of lift-off and torque characteristics
- high speed visualization of the finger motion and subsequent leakage patterns
- identification of the physics of finger lift-off
- flow visualization of flow patterns before and after finger seal pad lift-off
- effects on sealing efficiency and seal hydrodynamics when
- spiral grooves are etched in the shaft
- grooves are etched on the seal footpads.
- effect of eccentric rotor on seal performance

GEOMETRY OF THE FINGER



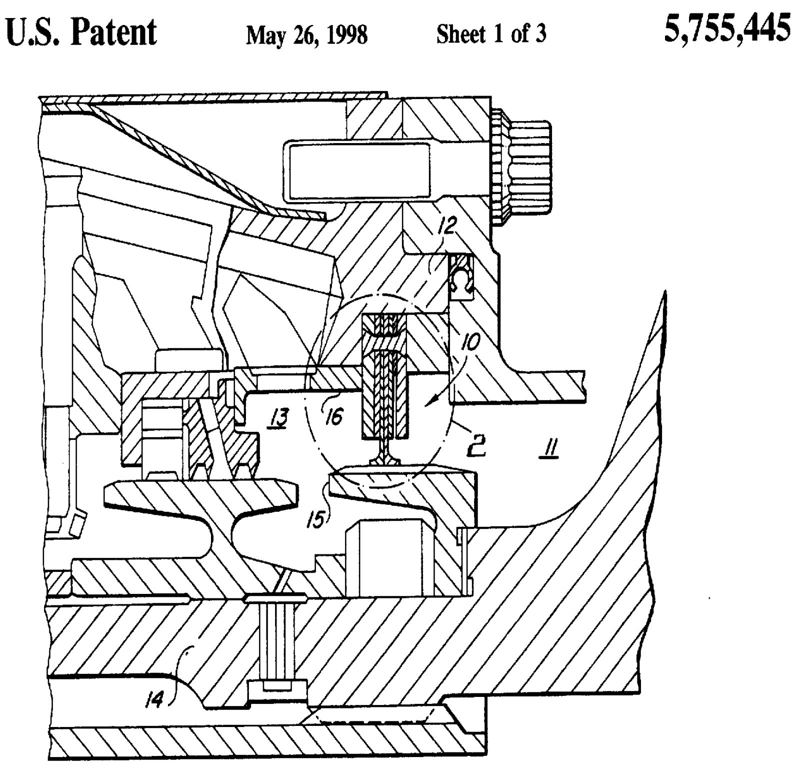
4a)



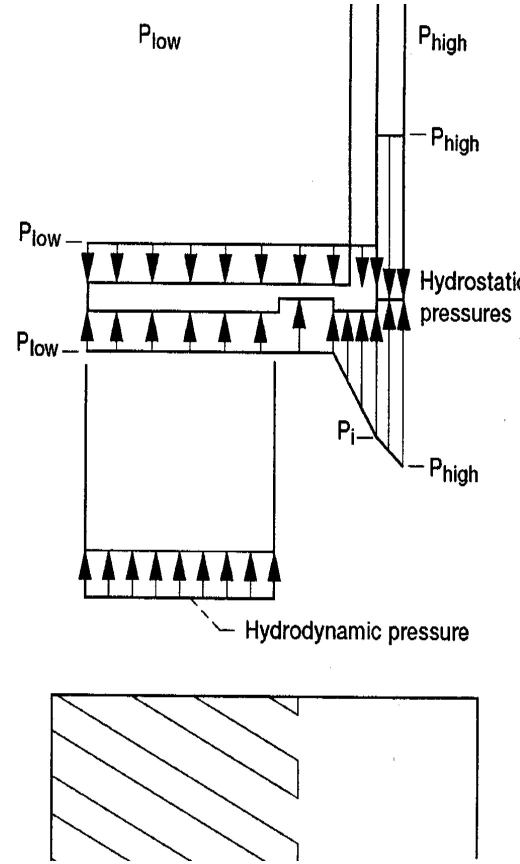
4b)

Seal Two row Configuration with Wide Finger Pads. Cross Section and Side View of the Seal (U.S. Patent No. 5,755,445)

Typical application and Free Body Diagram



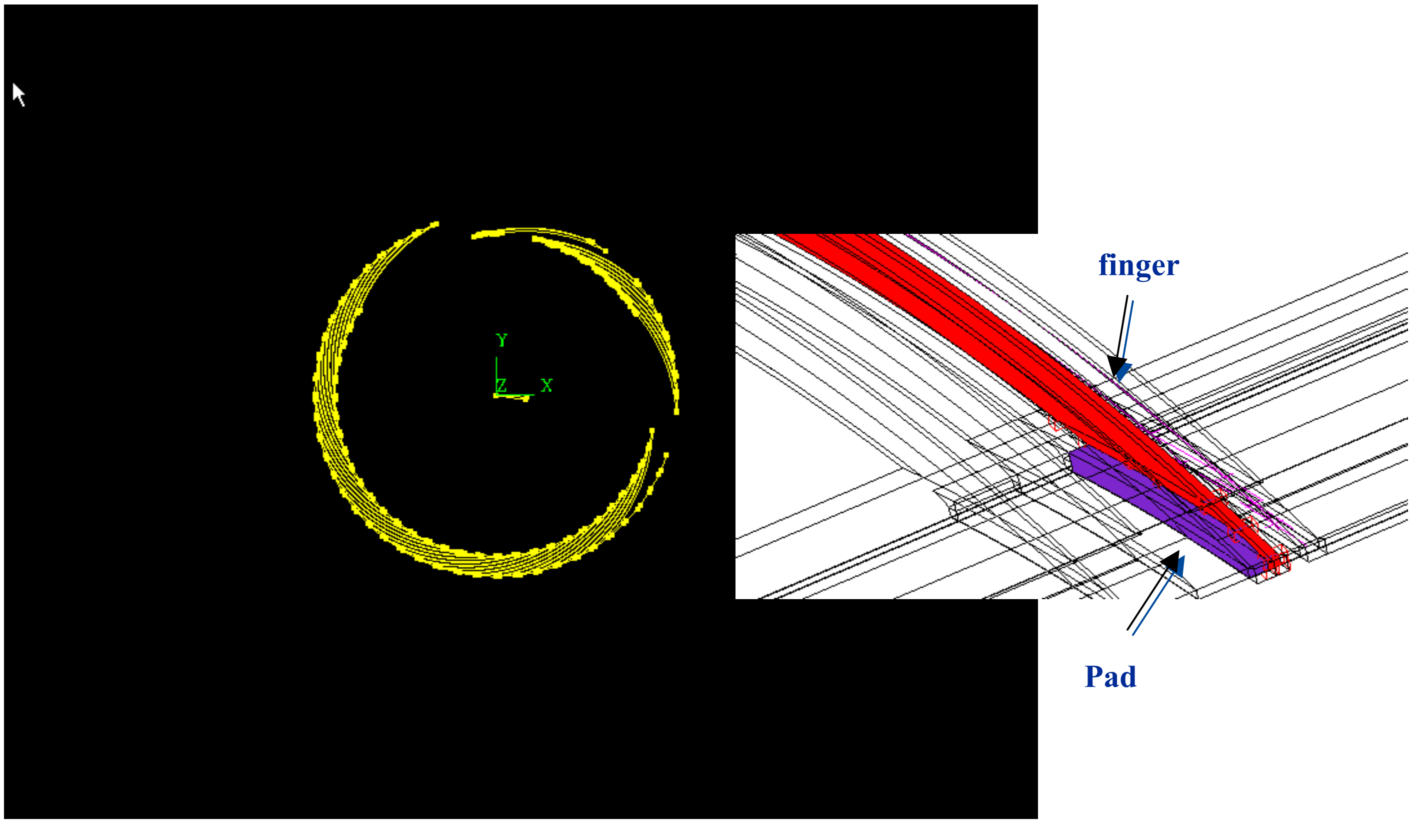
Typical Application of the Finger Seal presented on previous slide (U.S. Patent No. 5,755,445)



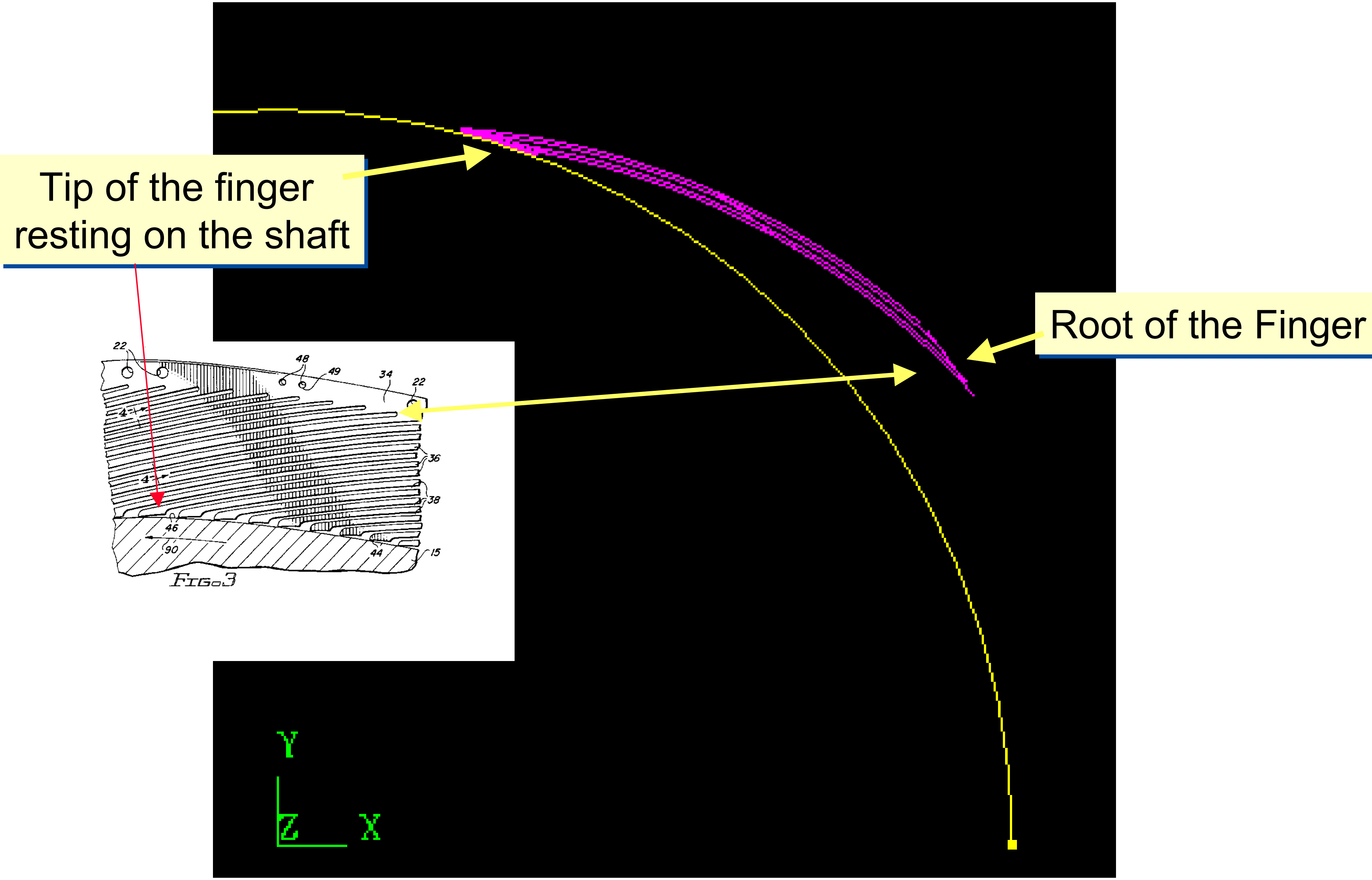
Single Finger as a Free Body Diagram and Geometrical Changes Proposed For Better Wear Behavior

Compliant Fingers Discretization

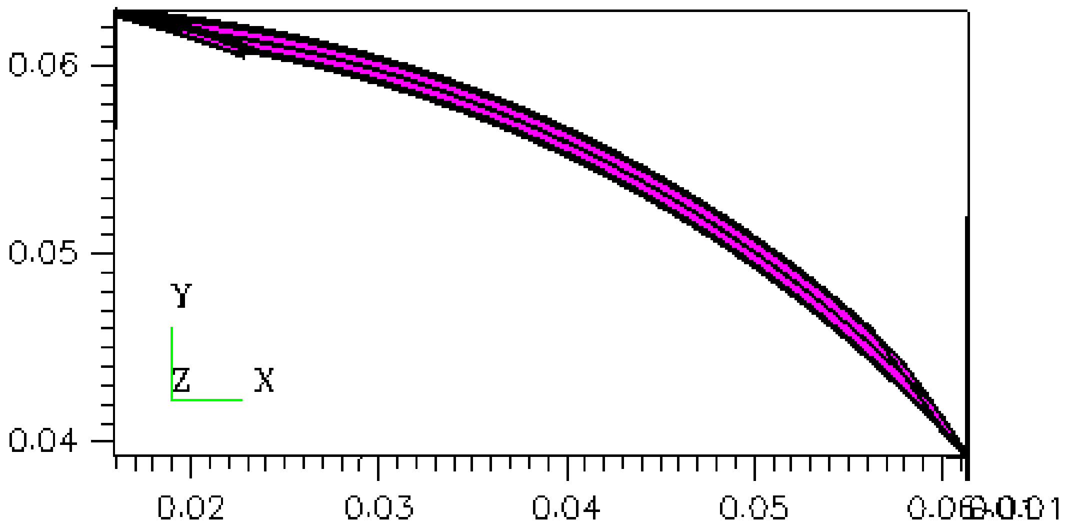
Assembly of 72 fingers along the circumference



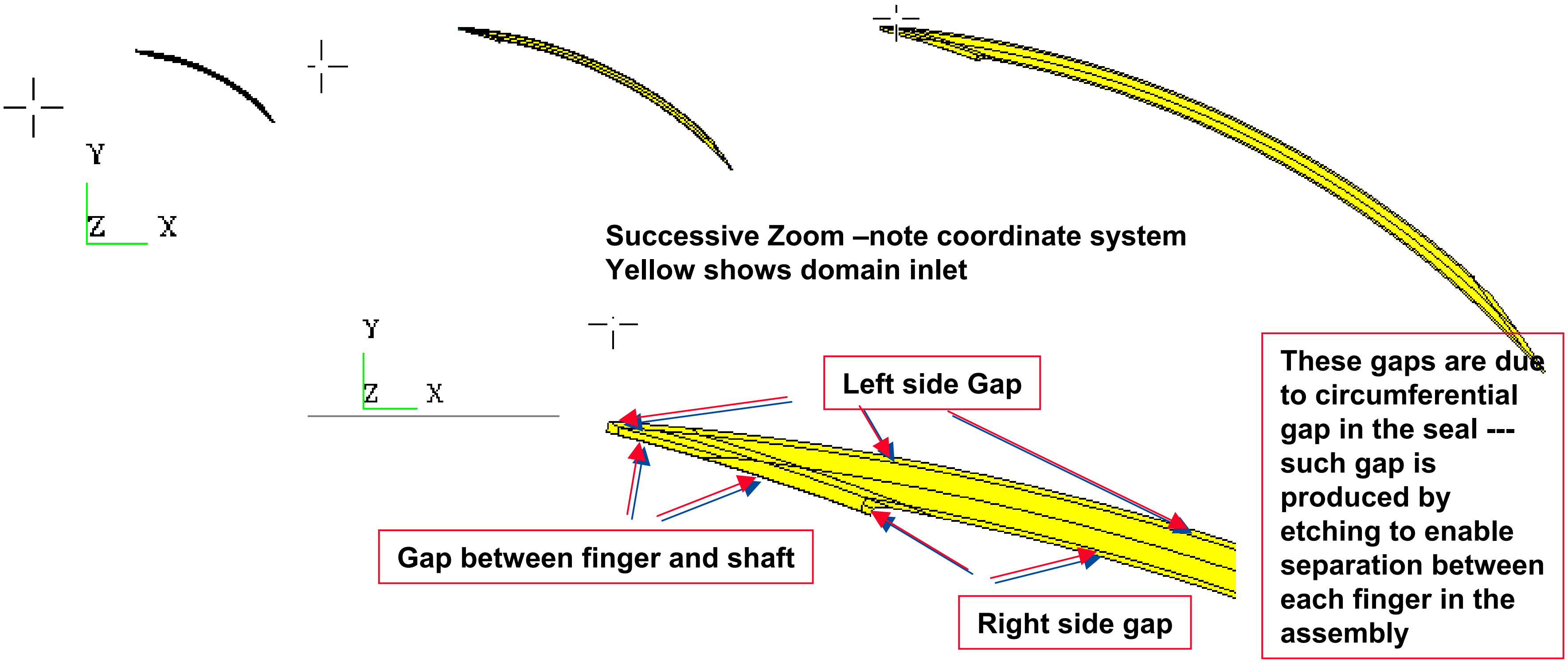
Single Finger Resting on the Shaft



Front View– Geometry, single finger

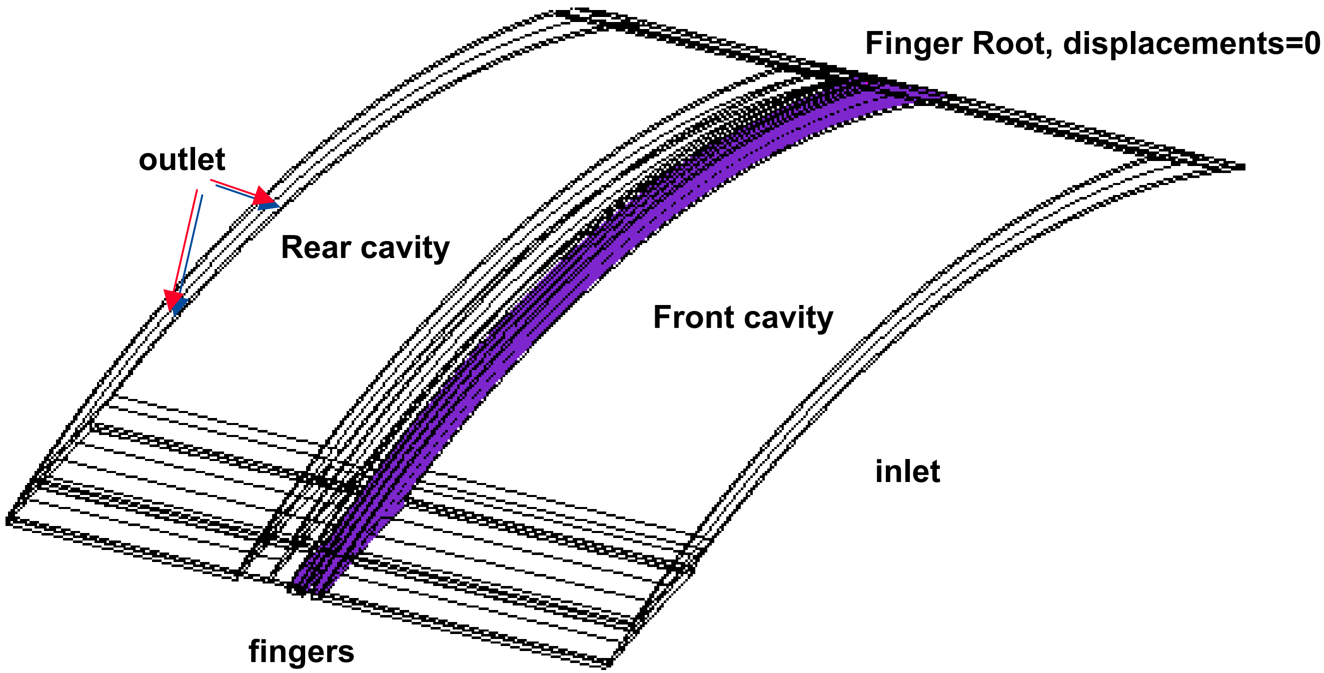


Front View Sequence –One Finger

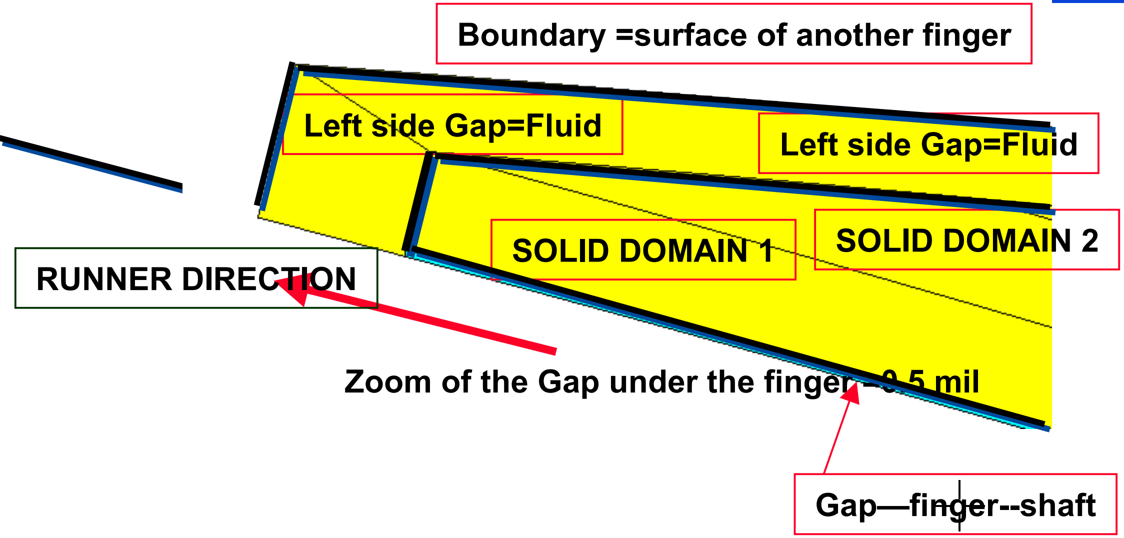


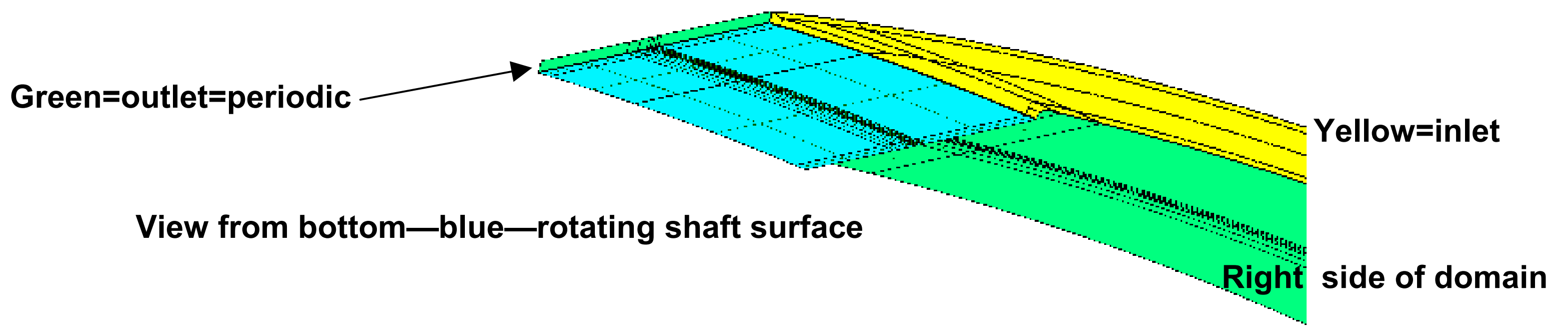
This slide shows one finger out of 72 located along the circumference. Z is axis along the shaft.

3d of computational domain

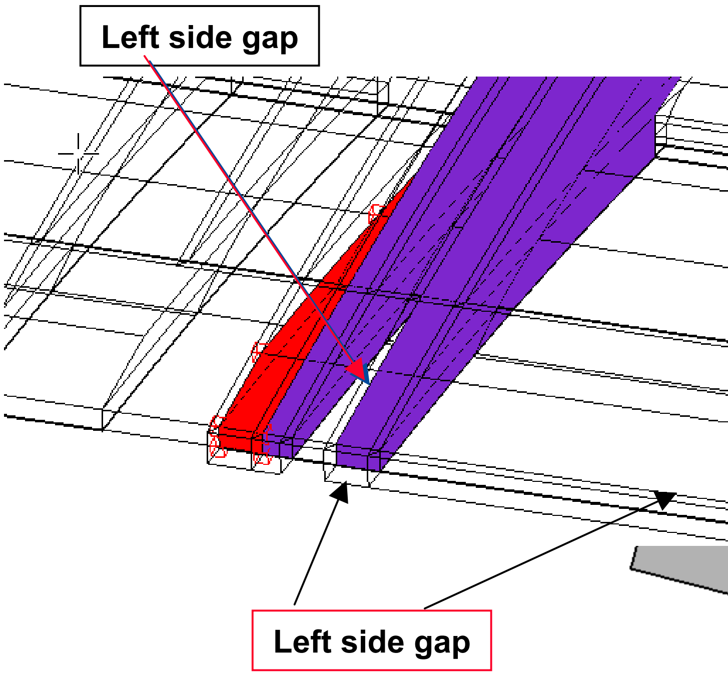


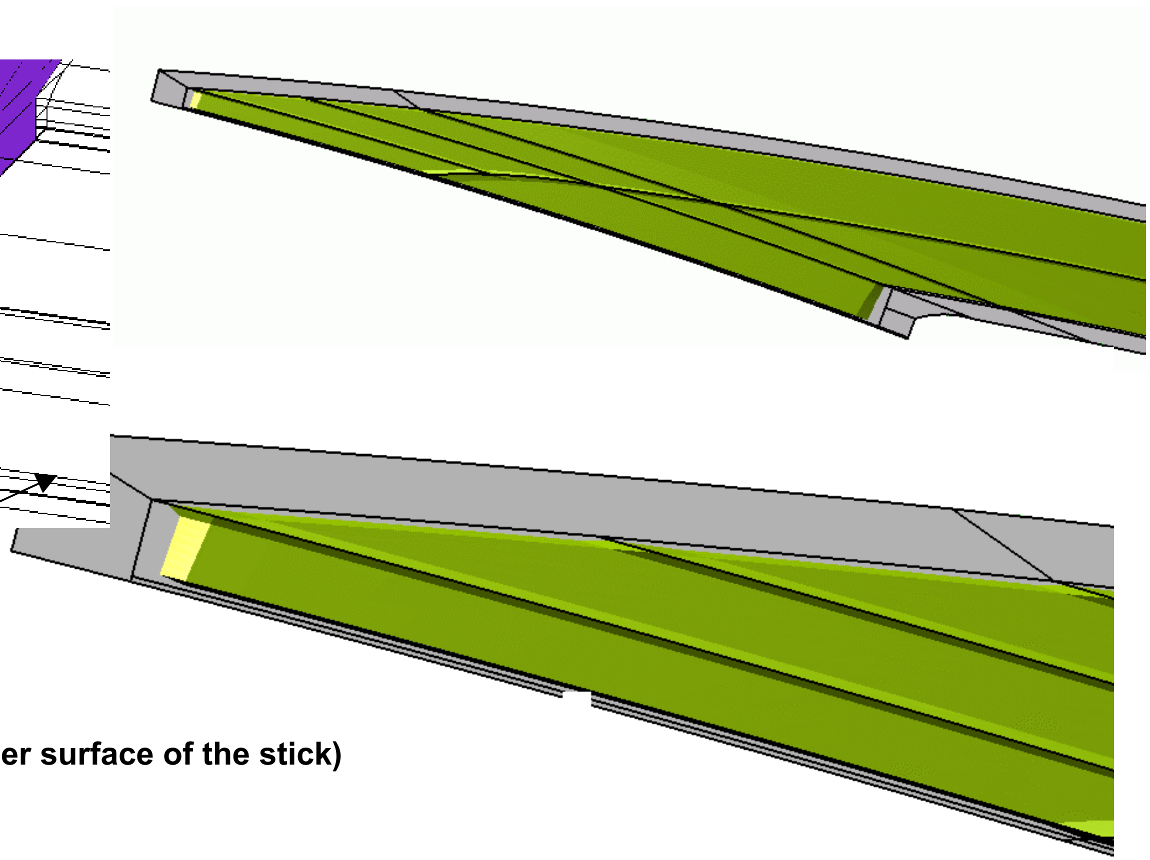
Domains identification and 3d view of the runner





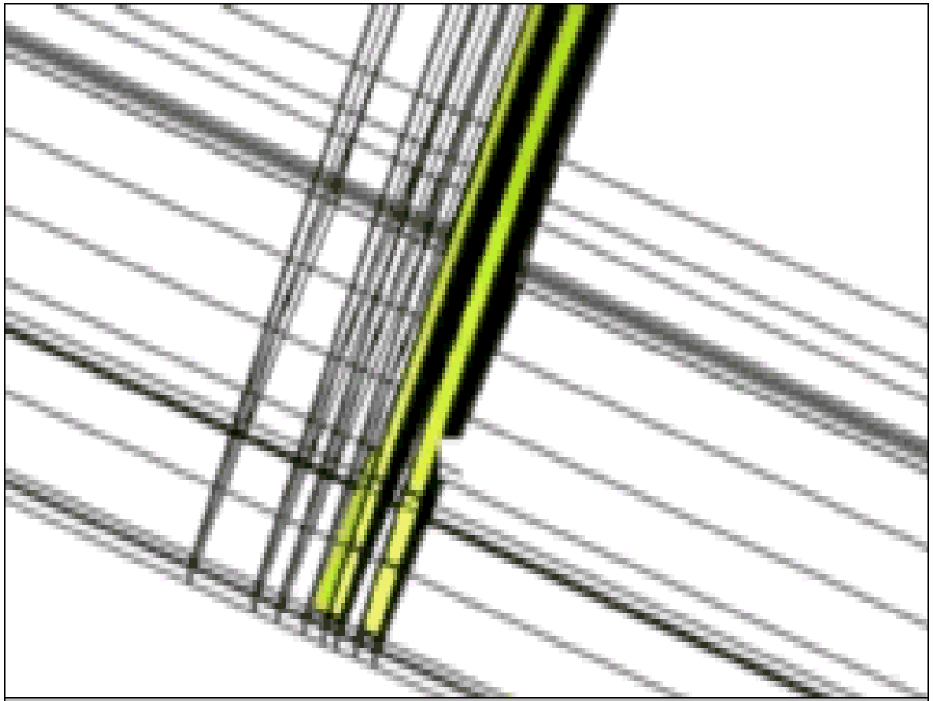
Details of the computational grid





Rear Finger(red shows extended slider surface of the stick)

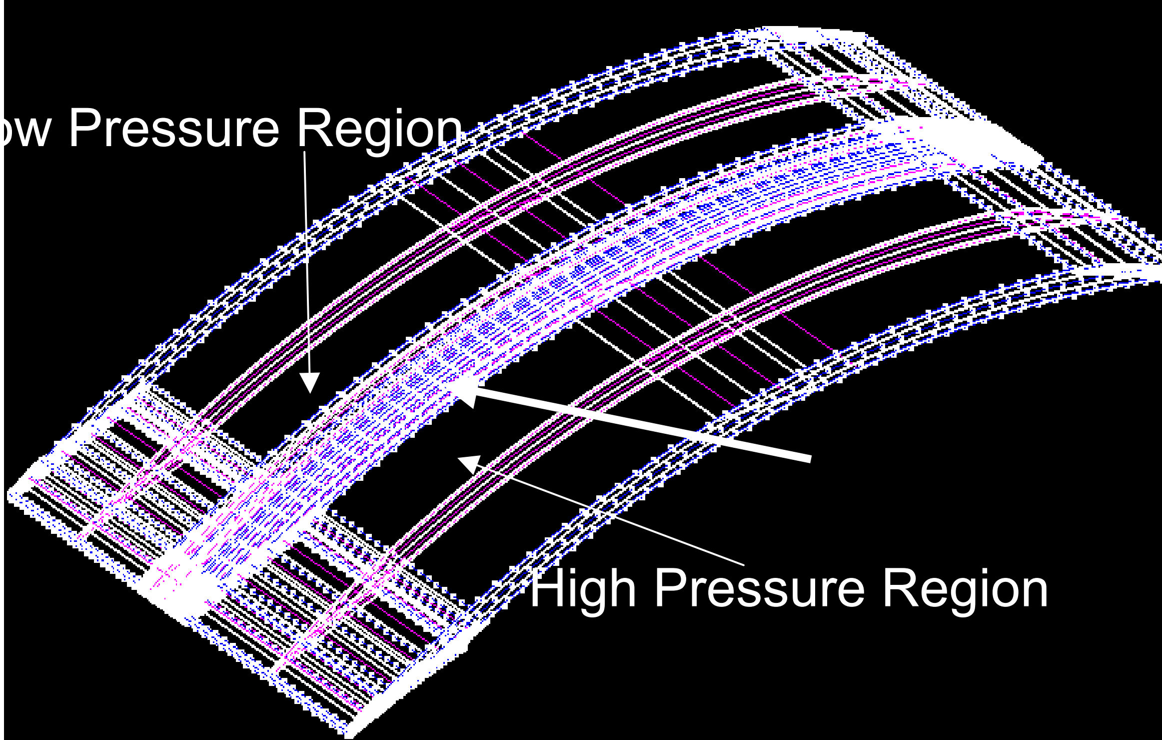
In line finger 3-D dimensional view the computational grid

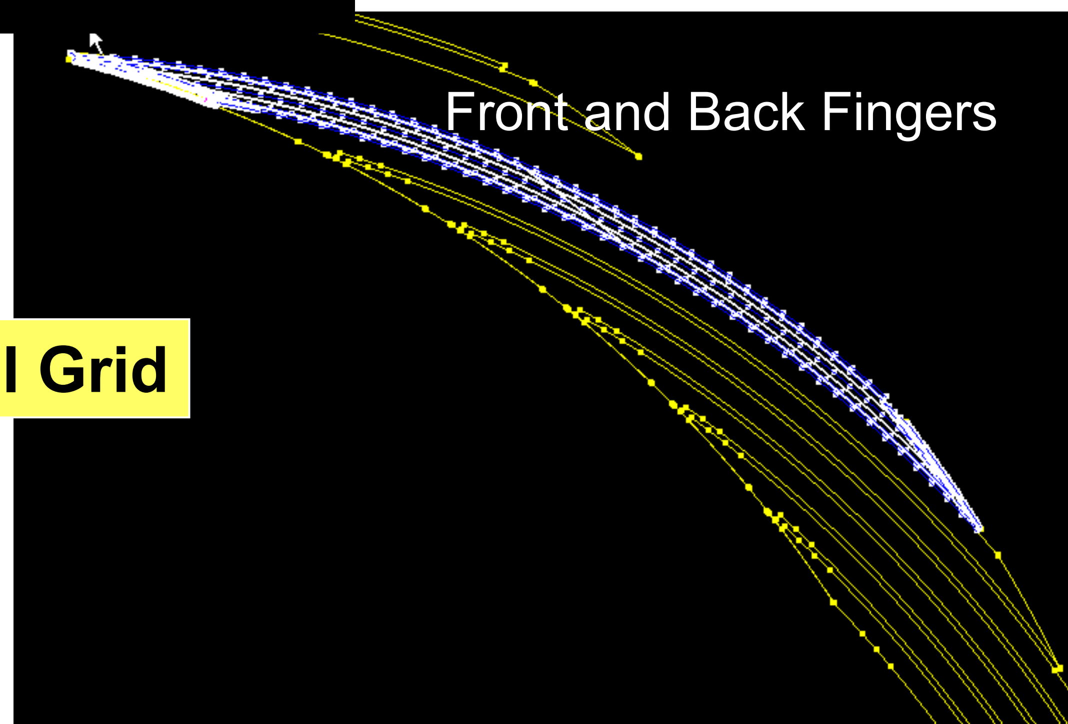


two finger geo a.avi

This short clip shows the domains of the front high pressure finger and and the low pressure finger behind it from different angles for a better geometrical understanding

Grid Details





Full Domain Computational Grid

FEMSTRESS--for FINGER DEFORMATION

CFD CANADA

-)**Mechanical model of the single finger and assembly of fingers**.. FEMSTRESS is used for static and transient structural analysis, for both linear and nonlinear problems. The module is coupled with the other modules of CFD-ACE+ (flow, thermal, electrostatics, etc.) for multidisciplinary analyses. It uses a Fast and Efficient Vector Sparse Solver (VSS).

- In the fluid solid interaction proposed by this study a two-way coupling will be utilized to proliferate shape changes due to deformation into computational flow domain. In this case for the flow within the finger seal domain, grid deformation and stress modules will be simultaneously activated, pressure forces integrated on all fingers, finger deflections will be calculated on each iteration and corresponding geometry/grid changes will be implemented.

CFD-ACE+ for Fluid Simulation

⇨ **Hydrodynamic fluid model**. **The computational engine used is CFD-ACE+, which is a product of CFD Research Corporation of Huntsville/Alabama.** CFD-ACE+ supports structured, unstructured polyhedral, hybrid (structured/unstructured) moving grids and non-matching grid interfaces. It consists of pre-processor for grid generation (CFD-GEOM), GUI Module for model setup (CFD-GUI) and post-processor CFD-VIEW.

⇨**Special features** that make CFD-ACE+ and FEMSTRESS especially suitable for our purposes are:

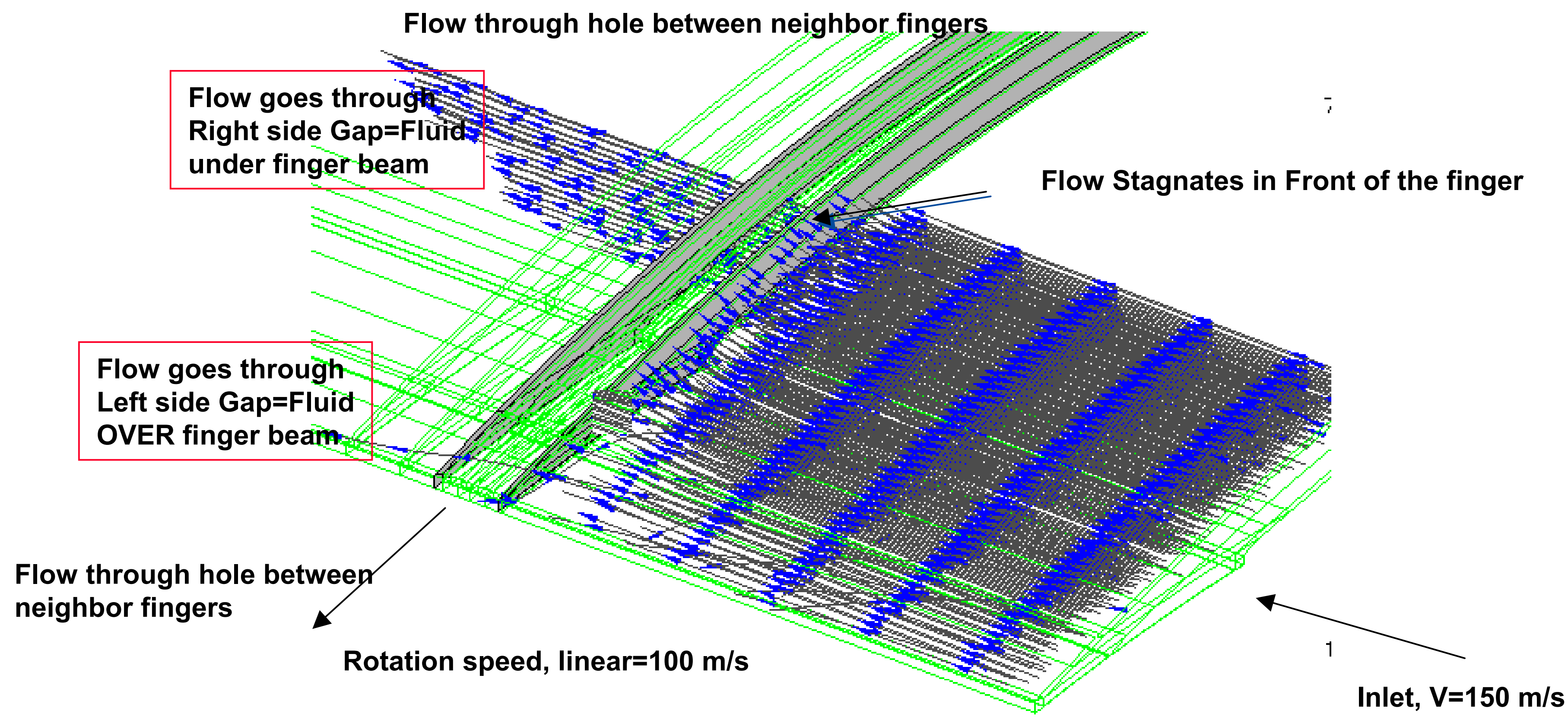
- coupled flow-structure interaction for steady-state and transient flow regimes
- solver stability which allow highly stretched nodes required for thin-film resolution
- ability to solve leakage flows in full Navier-Stokes formulation
- configurable GUI which allows creation of application specific templates/tools

RESULTS

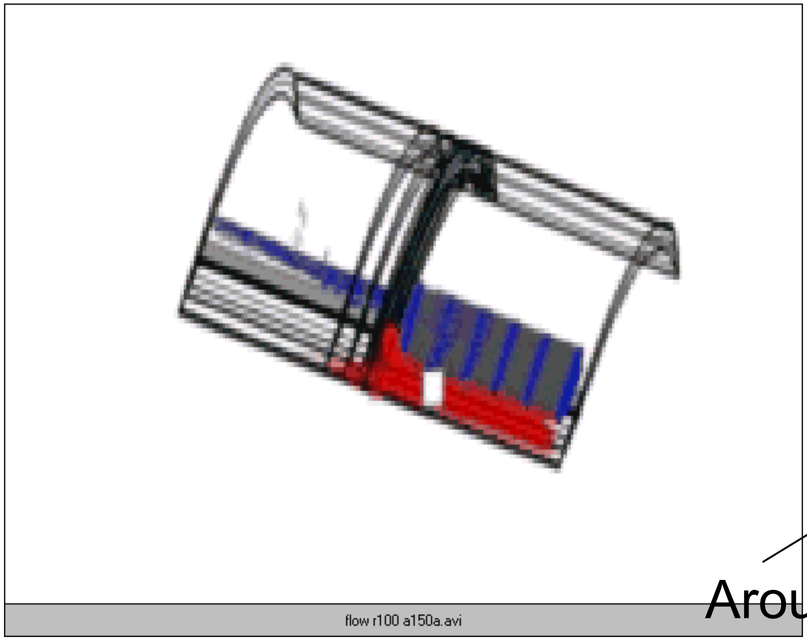
- Flow in the Front Cavity
- Flow About the First Finger
- Flow in the Inter-Cavity First/Second Finger
- Flow Past The Second Finger (2nd Cavity) and Under the Pad
- Pad Motion
- Pressure Maps

3D Example Solution (no deformation)

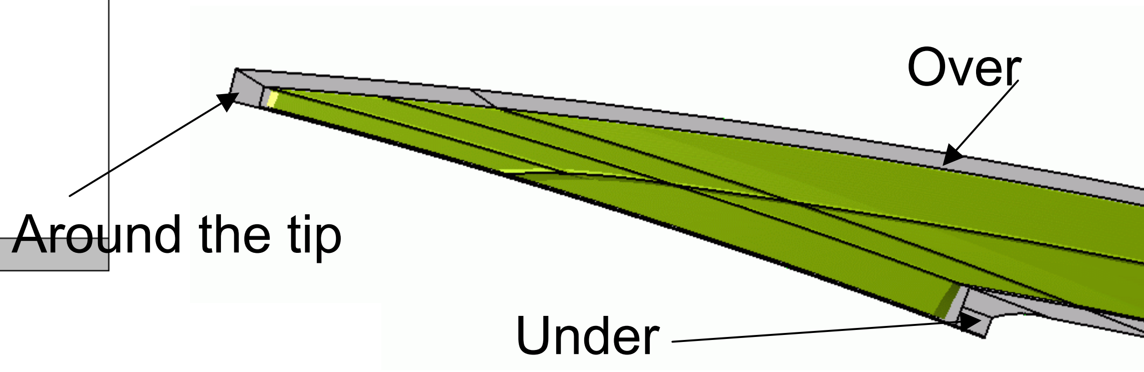
HIGH VELOCITY CASE –rotational flow is swung by axial

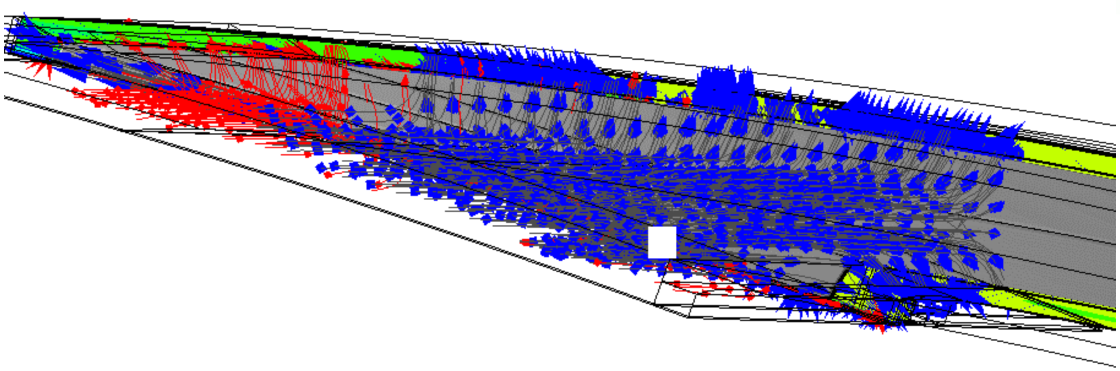


Flow in and around the Finger seal
Vshaft=125 m/s, V inlet=100 ms –no def



One can notice the blue arrows representing mostly flow over and under the finger , while the red arrows represent the flow around the tip of the finger throught he gap left between two consecutive fingers.



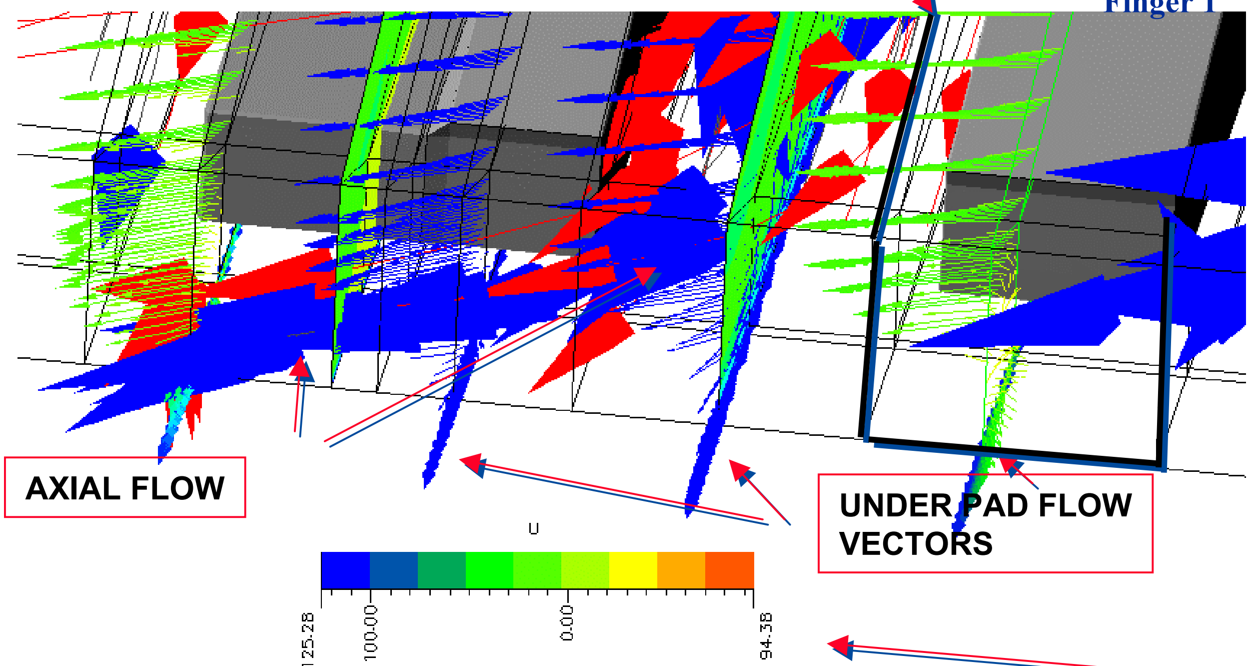


Flow in and around the Finger seal-Details
Vshaft=125 m/s, V inlet=100 ms –no def

NEXT “circumF” finger outlineAXIAL FLOW

Finger 2 and pad

Finger 1



AXIAL FLOW

ROTATIONAL

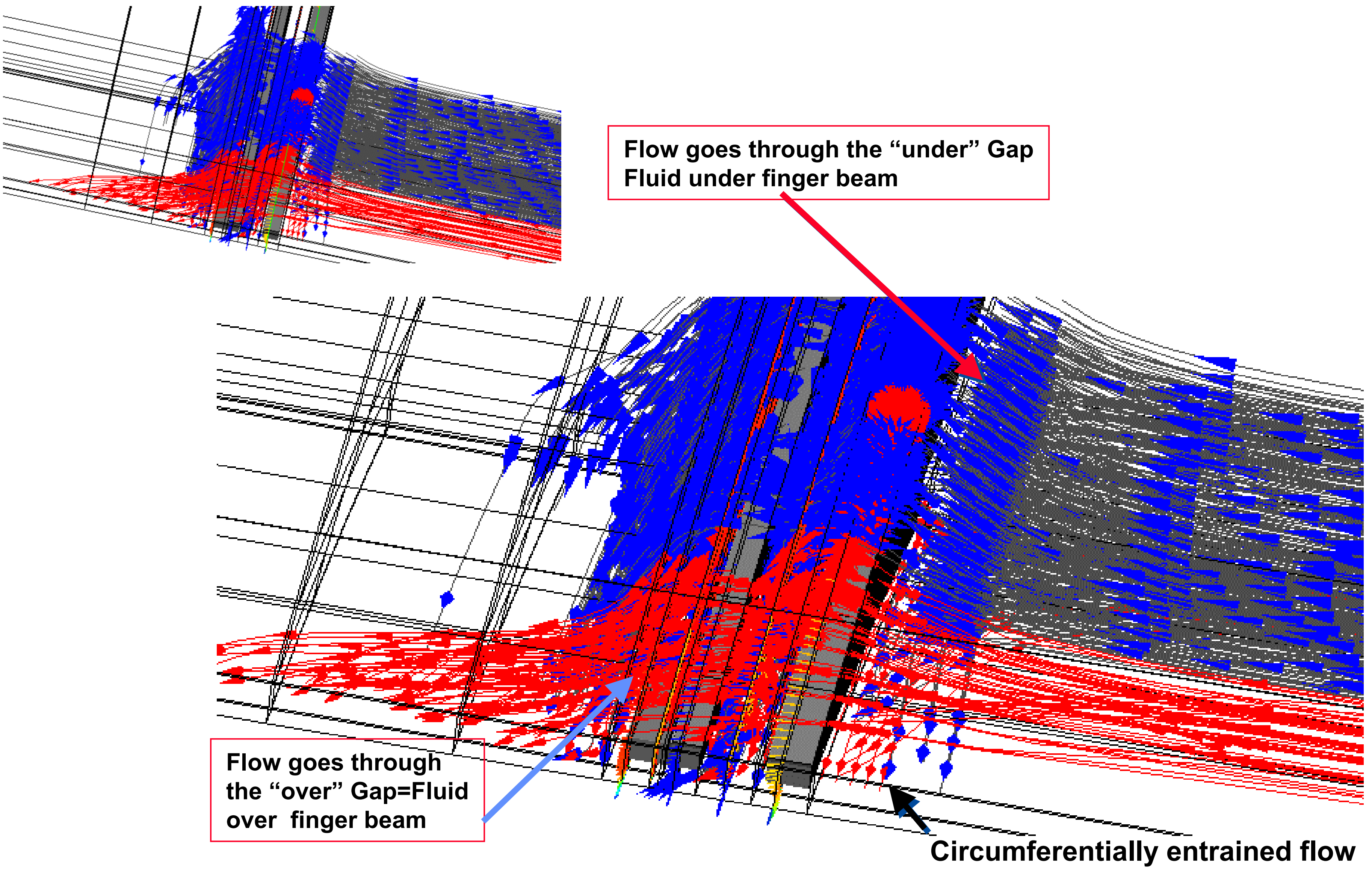
AXIAL FLOW

UNDER PAD FLOW VECTORS

Notice that rotational flow in the gap (circumferential) is unaffected by flow through the seal.

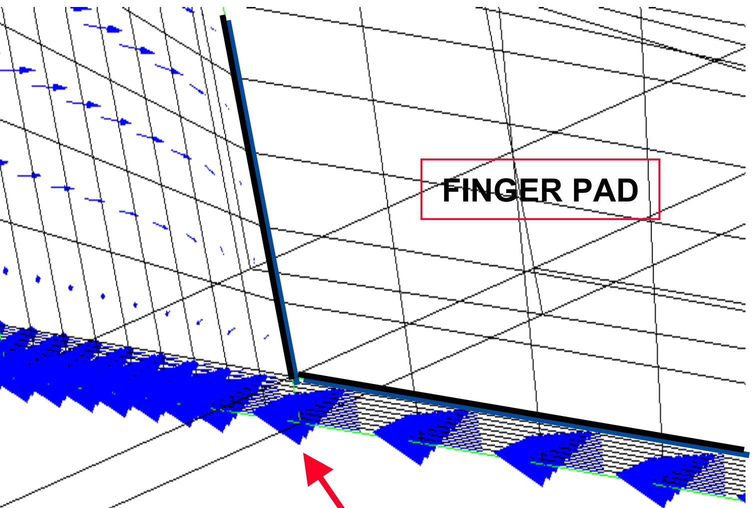
AXIAL FLOW—MAINLY IN THE “CIRCUMFERENTIAL GAP BETWEEN FINGERS---NOT UNDER THE PAD

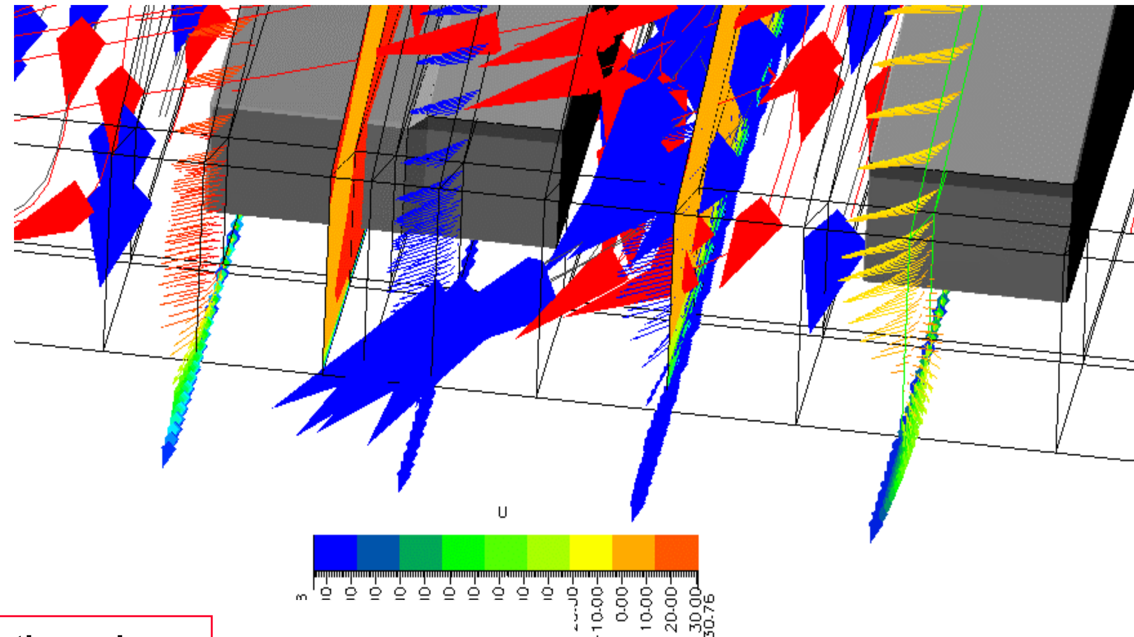
3-D flows, Vshaft=125 m/s, V inlet= 50 ms no finger deformation



Details of the Flow at the tip of the finger
Vshaft=100 m/s, V inlet= 50 m/s

CFD CANADA

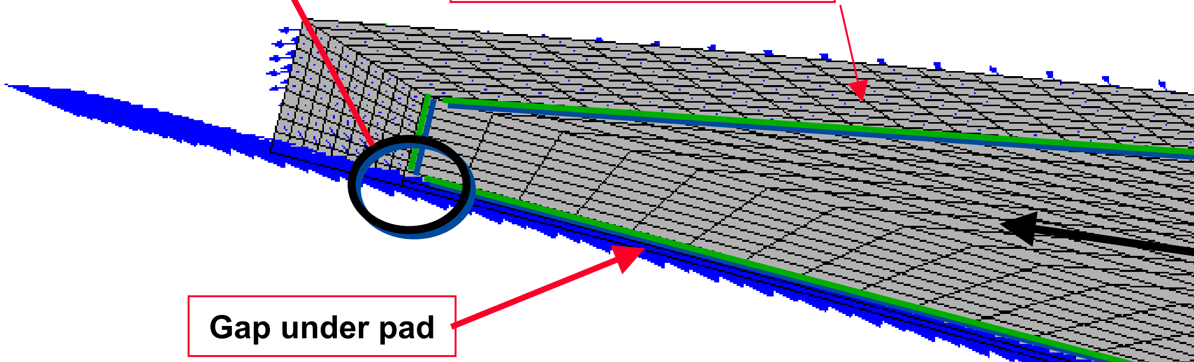




Flow detail at the tip of the finger

Flow goes through "over" Gap
Fluid over finger beam

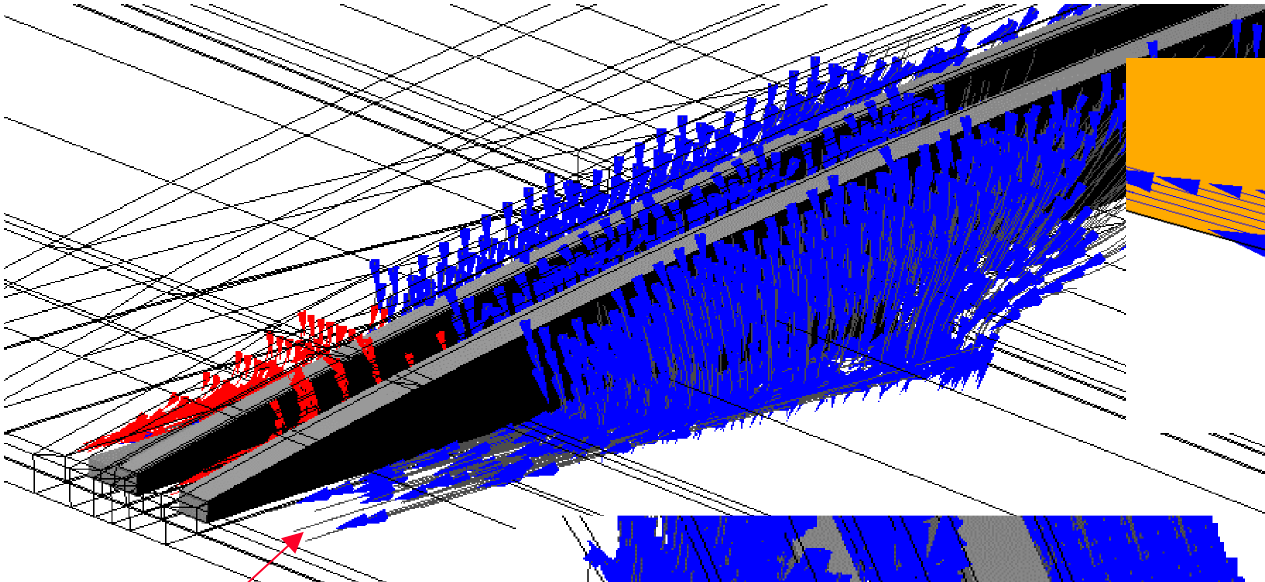
Rotational component in the gap is unaffected by axial flow around the finger



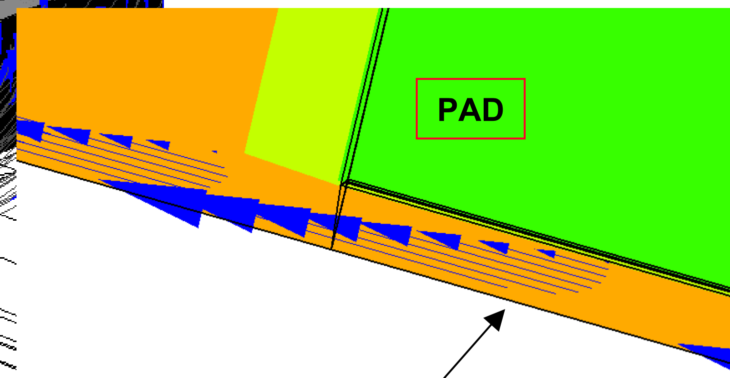
Finger Domain

Gap under pad

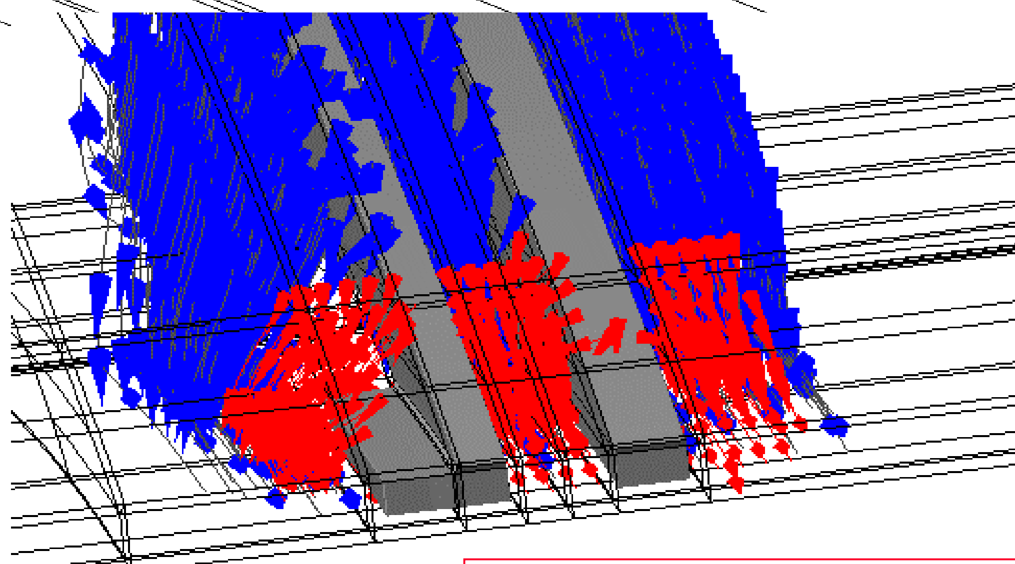
Rotational Dominated Flow
Vshaft=100 m/s, V inlet= 1 m/s, no def



Strong Flow in the circumferential direction
Side view



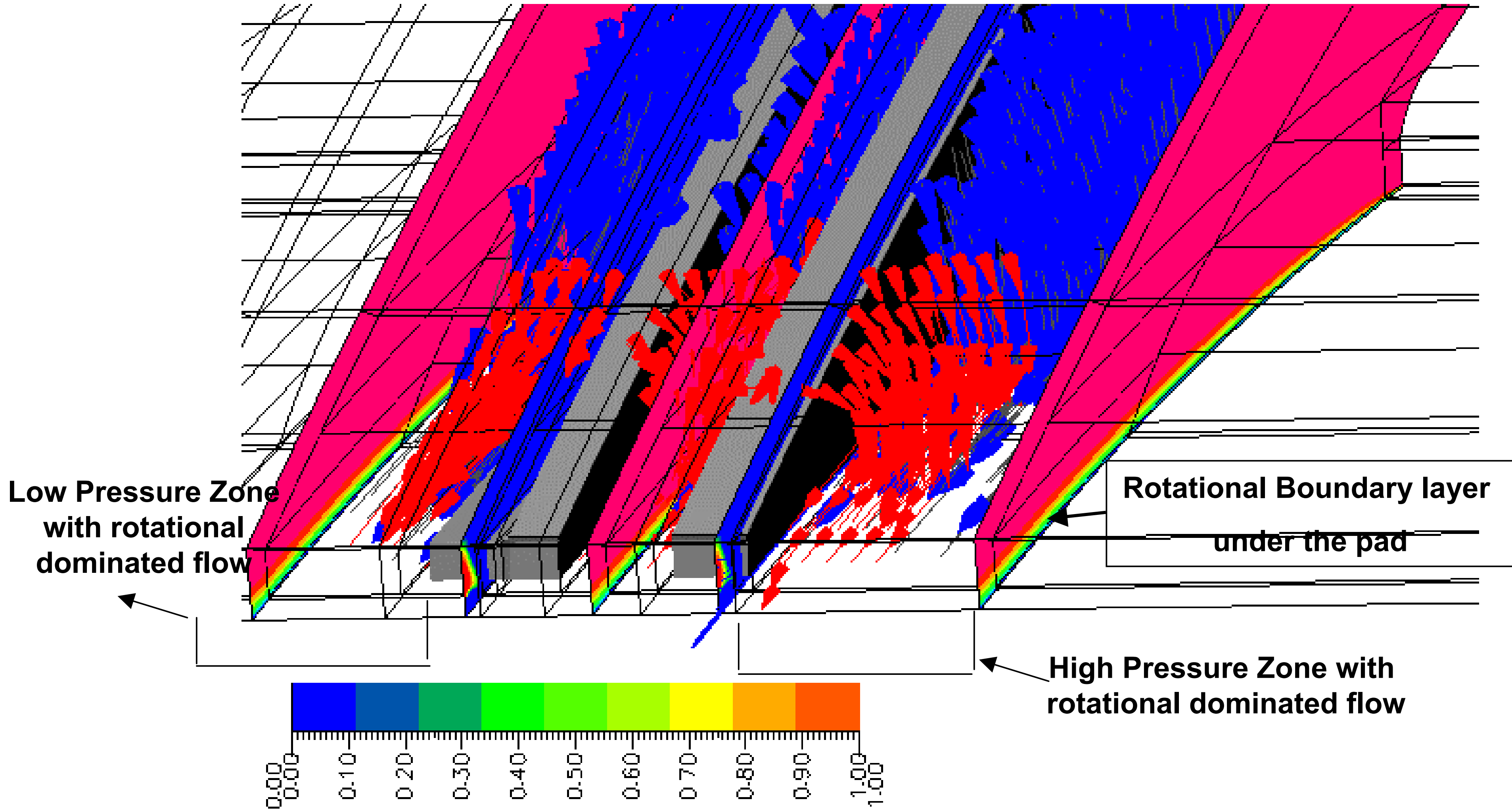
Flow in the Gap



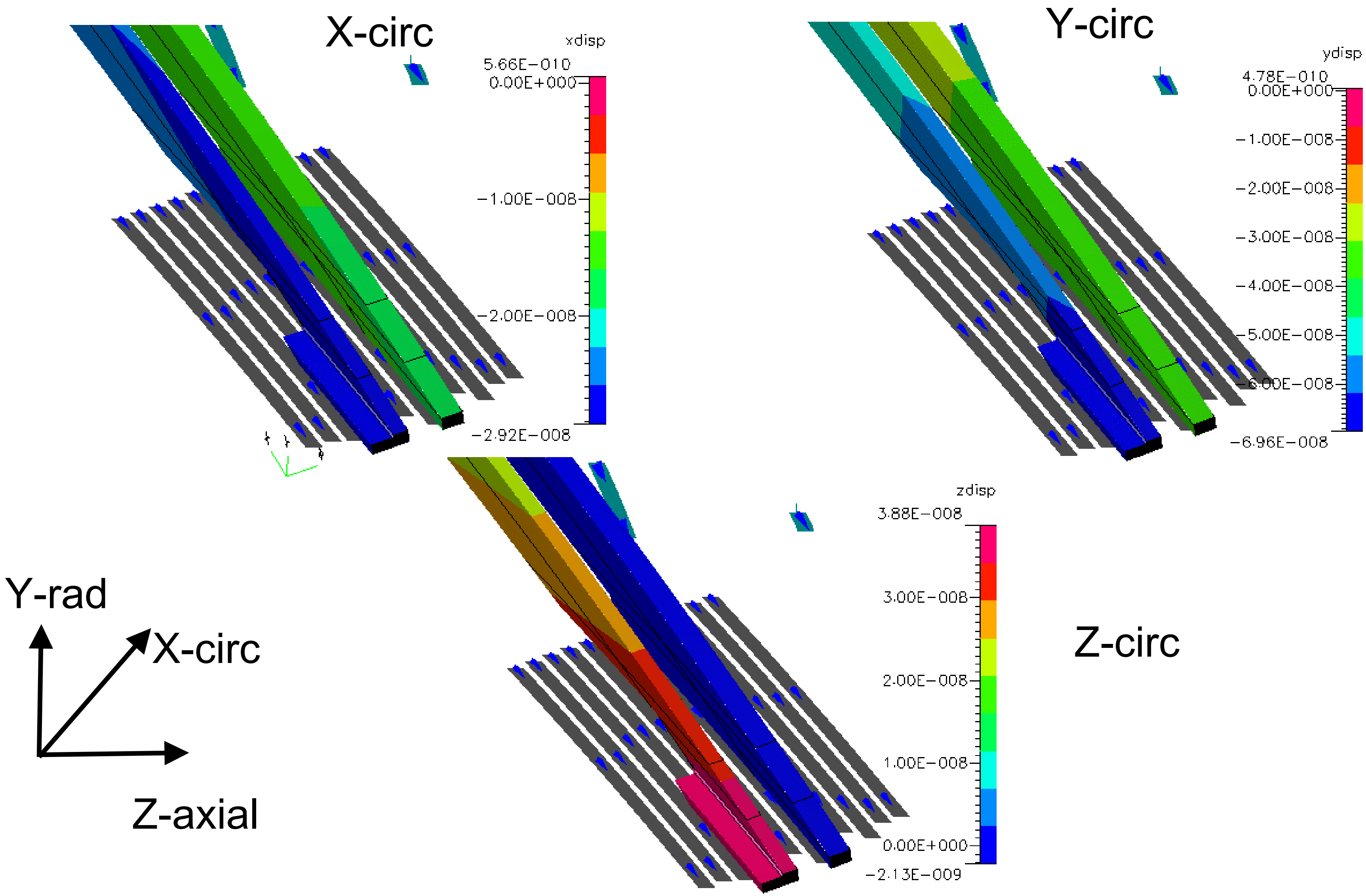
Fingers Assembly and Flow Front View
Arrows pointing at us showing strong rotational (circumferential) flow

Rotational Dominated Flow-Cross Sections

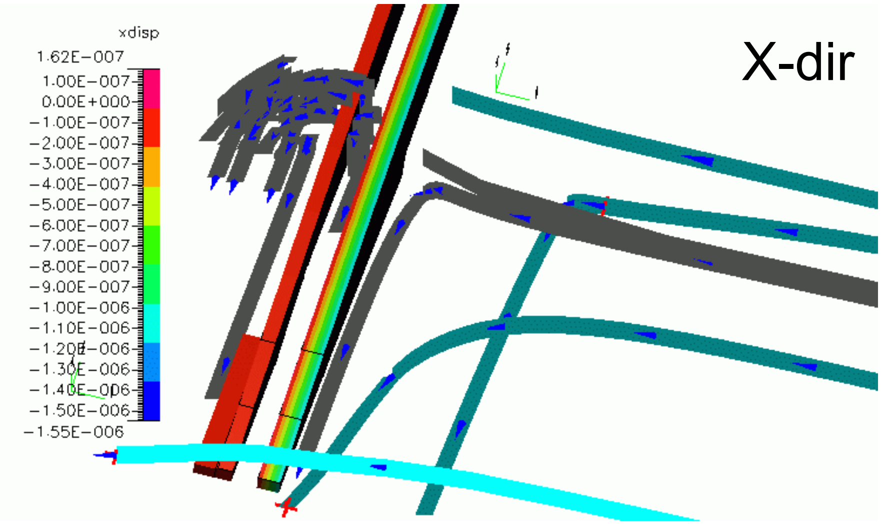
Vshaft=100m/s ; Vaxial=1m/s

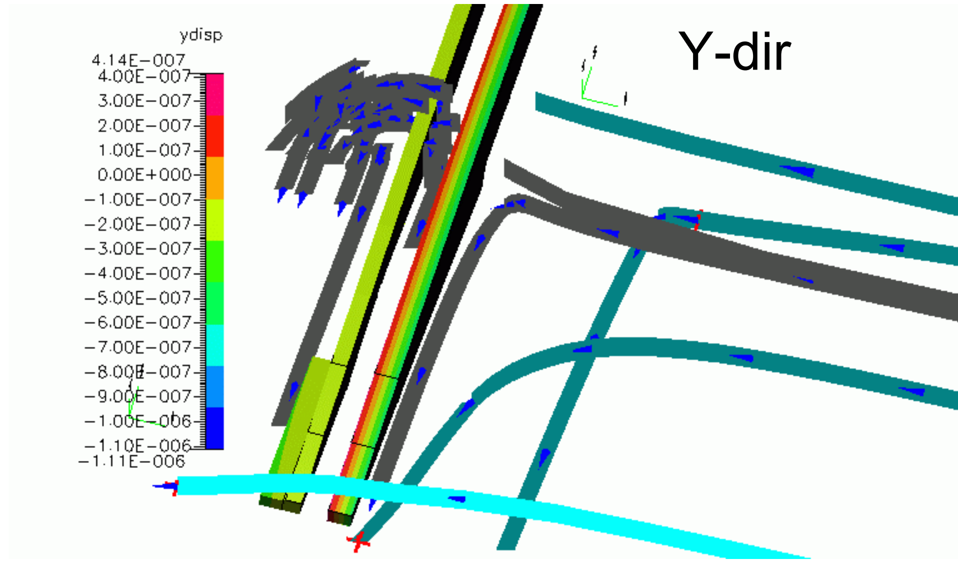


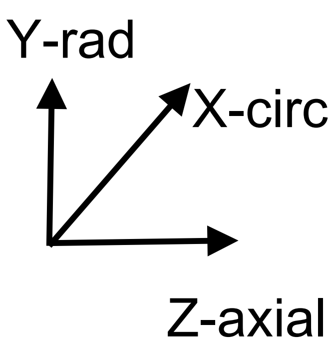
Color Coded displacements and Streamlines
Vshaft=100 m/s, V inlet= 1 m/s

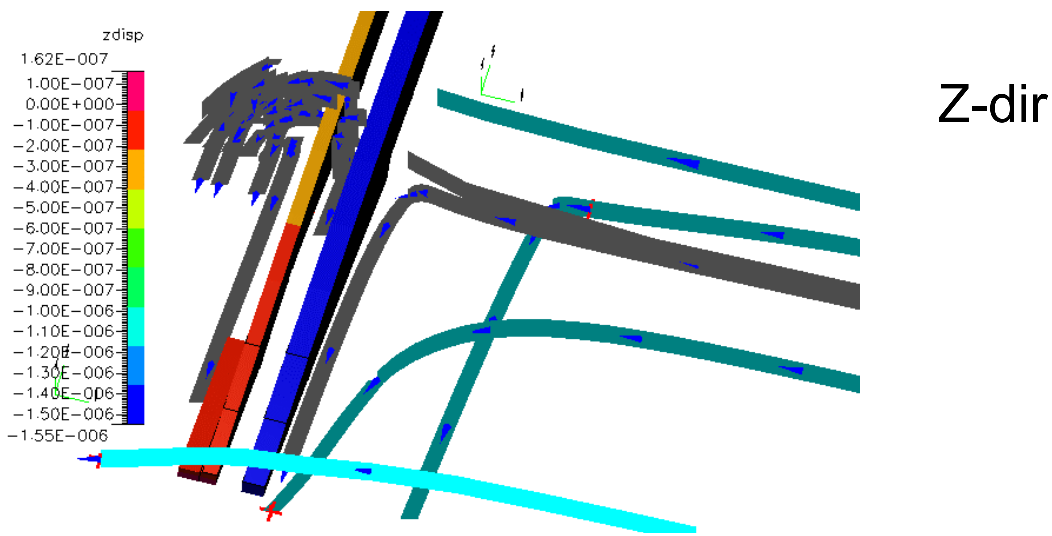


Color Coded displacements and Streamlines
Vshaft=100 m/s, V inlet= 50 ms

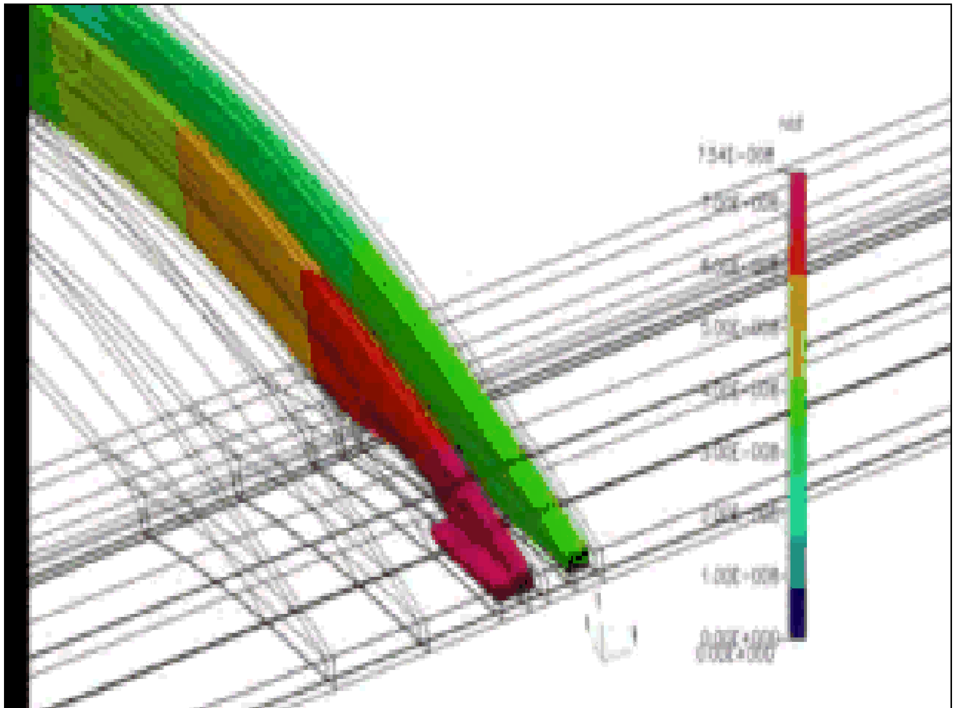








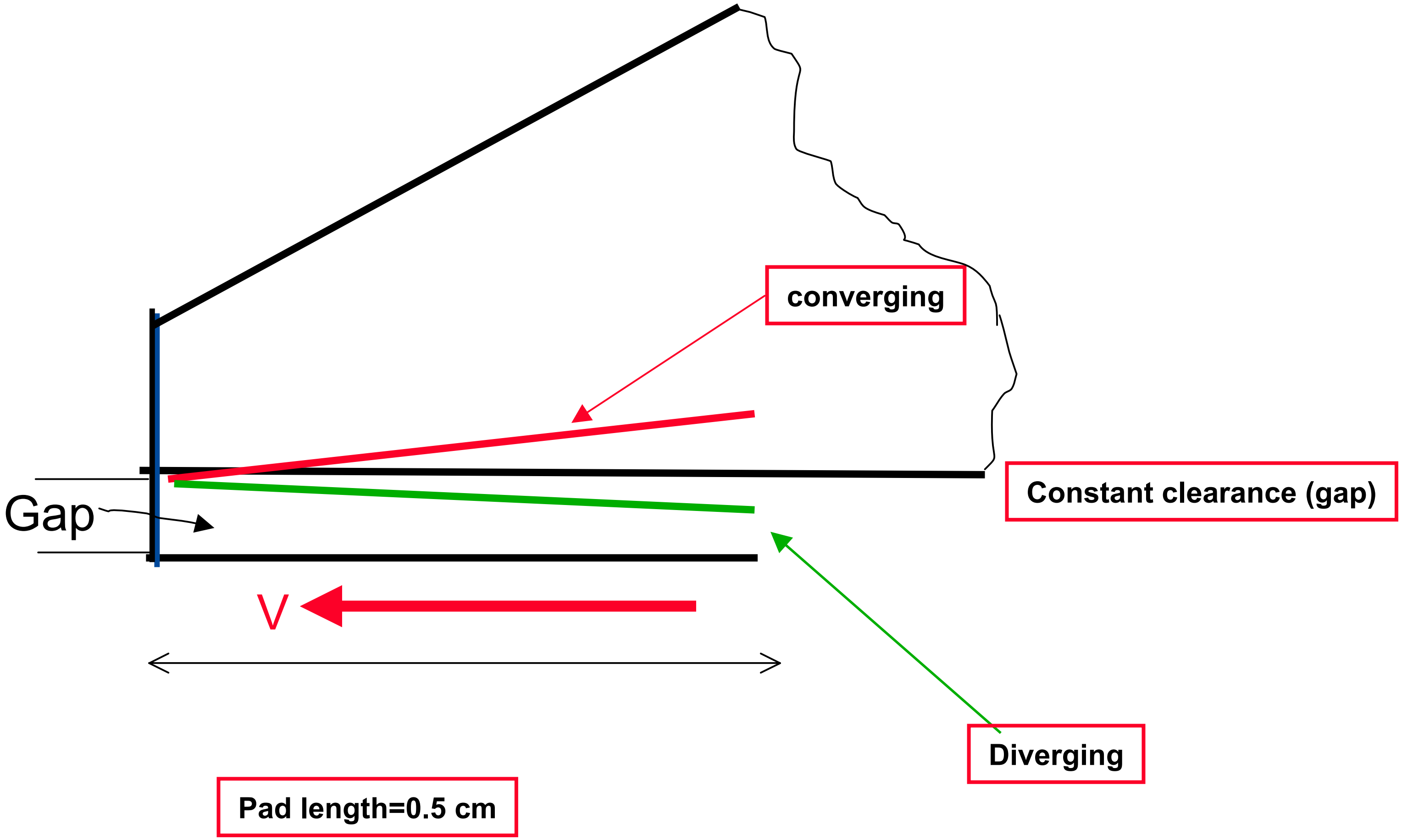
Deformations of the Fingers in 3-D environment



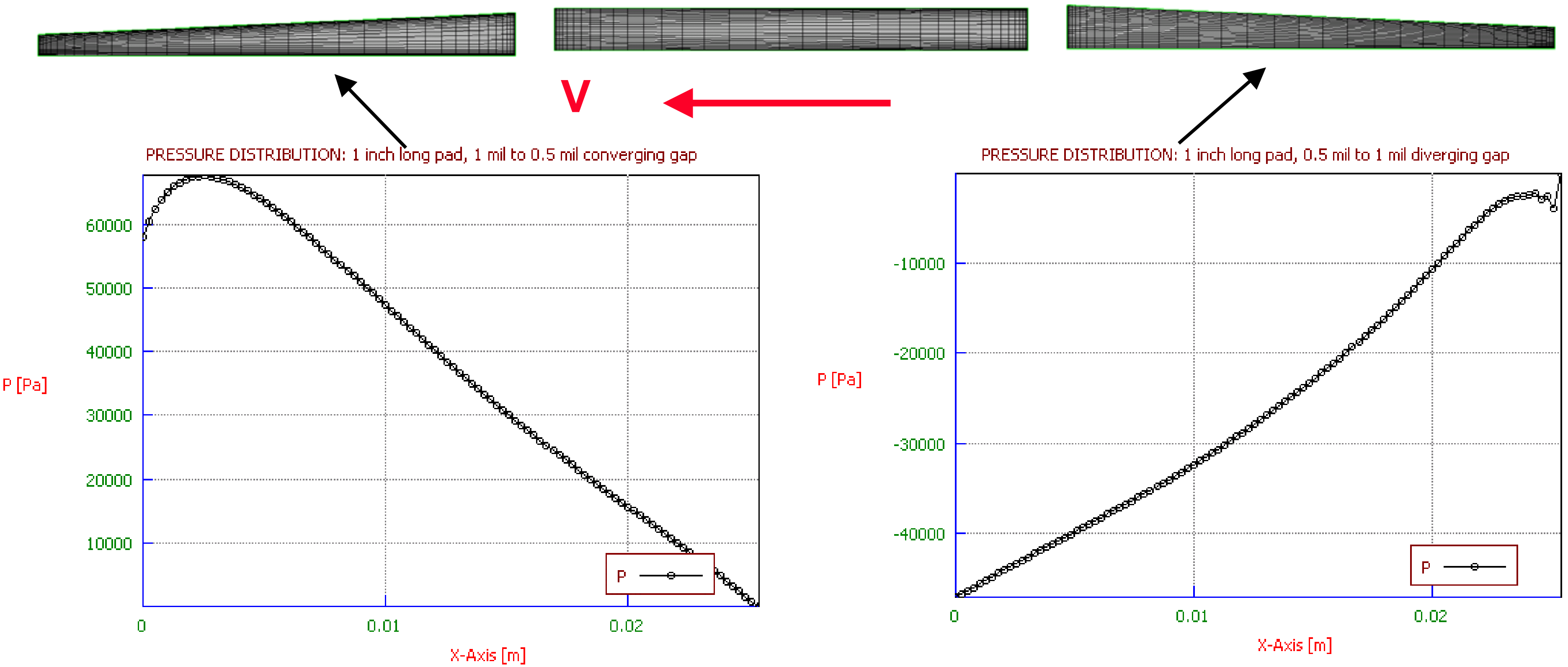
finger motion.avi

Brown-Red spectrum represents displacements in the positive direction while dark green to blue colors represent displacements in the negative direction

2-D Pressure Distributions for Characteristic Gap



Pressure profiles in the Finger gap



Conclusions

- Good insights into flow formation, finger motion, pressure development.
- Proper software well chosen. FEMSTRESS + CFD ACE+
- A LOT MORE WORK TO DO.