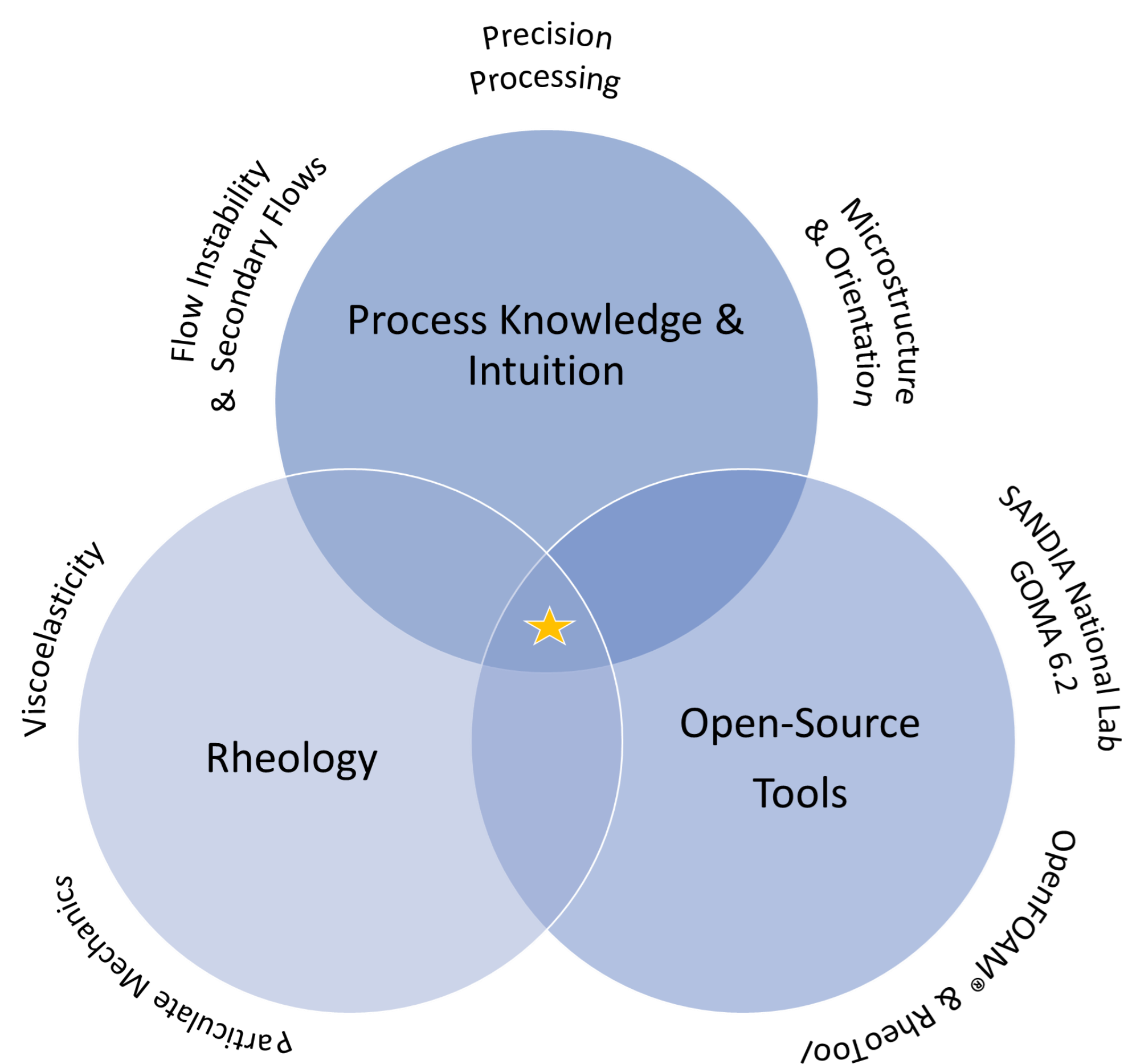# EXPLORING SECONDARY FLOWS WHILE BUILDING HIGH FIDELITY TOOLS FOR COMPLEX VISCOELASTIC BEHAVIOR IN PRECISION MANUFACTURING

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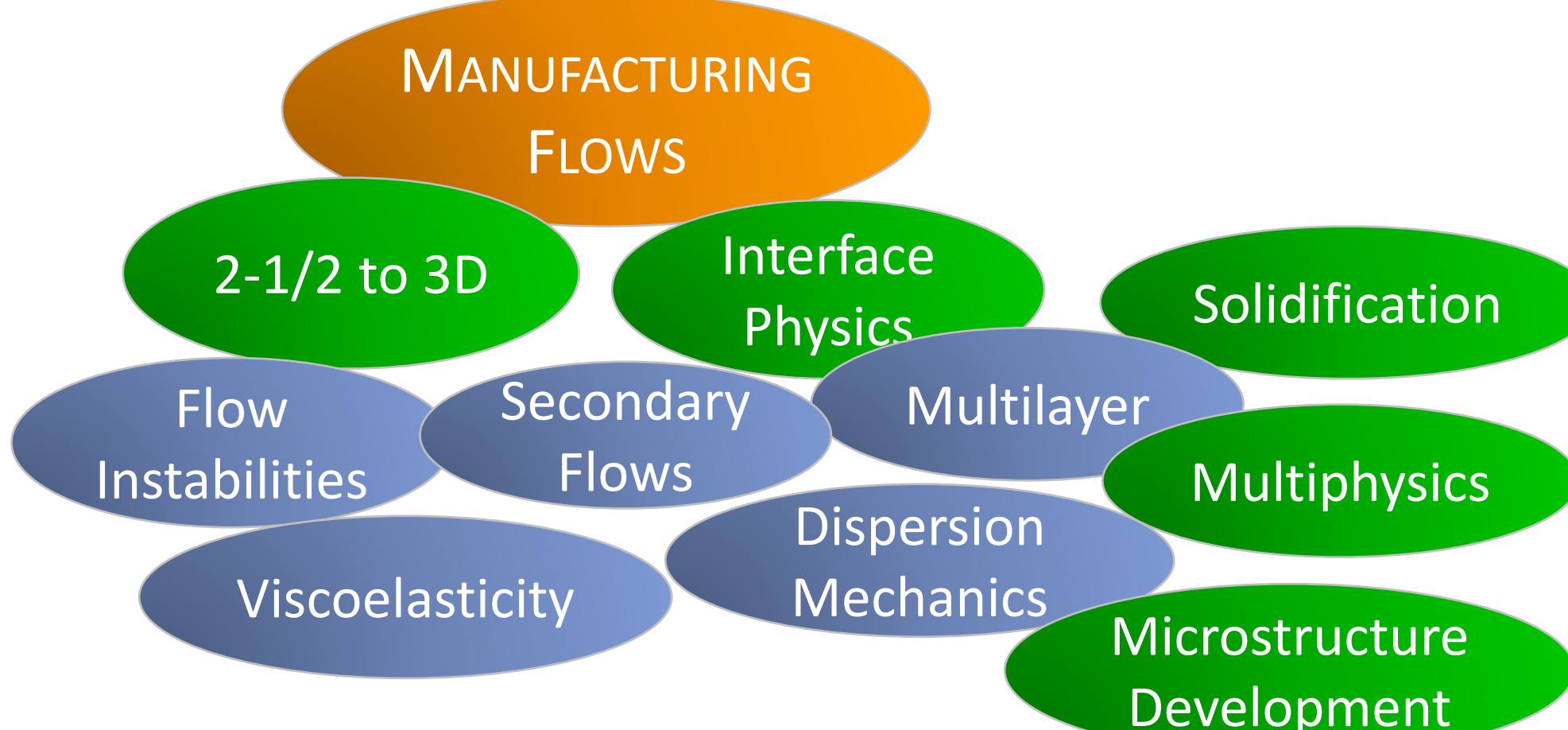
BUILDING AN OPENSOURCE BRIDGE

These examples are offered as a means of bringing fundamental rheology knowledge to process practitioners where it can be combined with experiential process knowledge to accelerate high-fidelity manufacturing.

The computational model bridge between rheological research and manufacturing process design advantageously becomes an integral part of the iterative procedure of model hypothesis and verification towards customized knowledge discovery for optimal process design, operability, and window of control information.
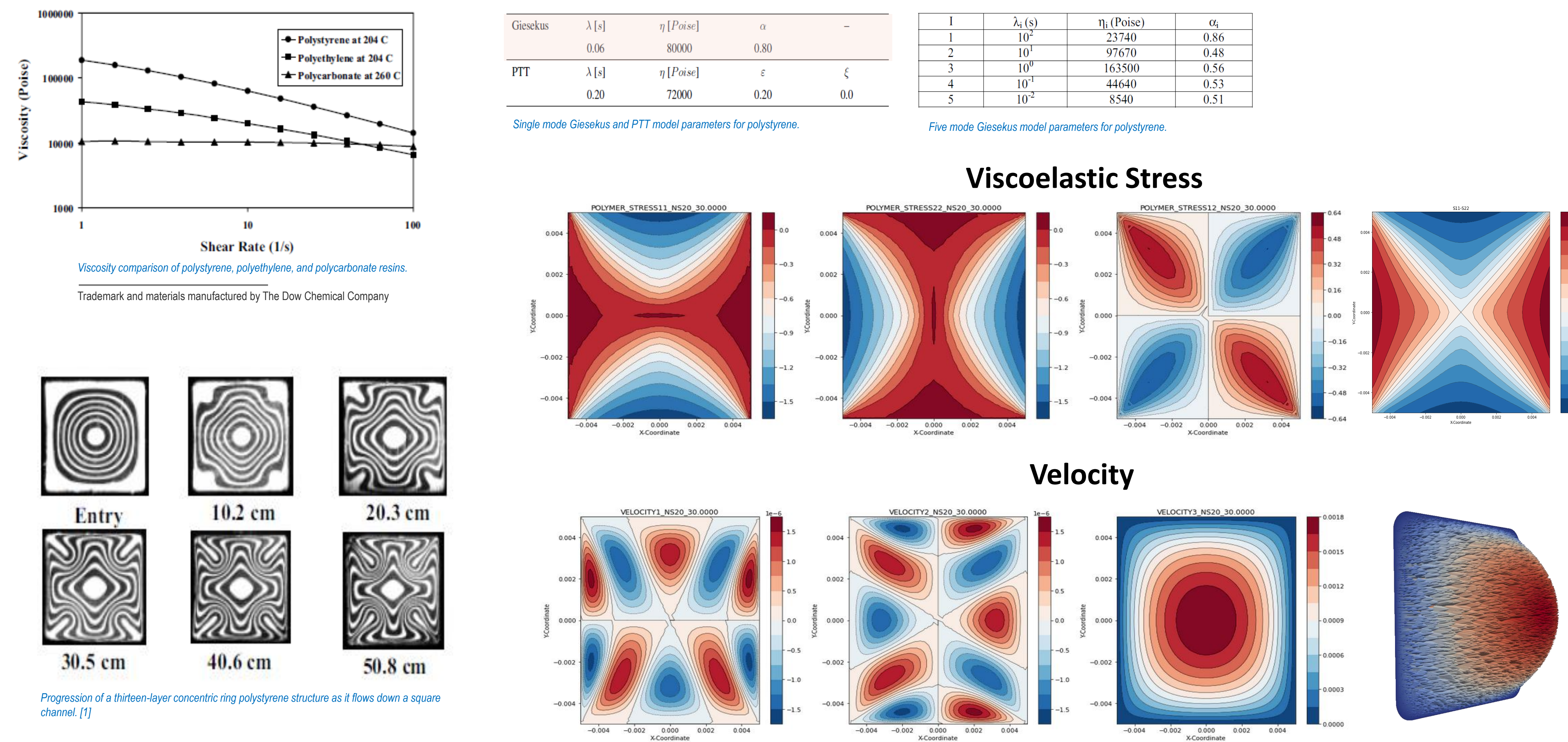
Precision Processing

Flow Instability & Secondary Flows

Microstructure & Orientation

Process Knowledge & Intuition

SANDIA National Lab GOMA 6.2

Viscoelasticity

Rheology

Open-Source Tools

OpenFOAM® & RheoTool

Particulate Mechanics

PRECISION PROCESSING FOR MANUFACTURING FLOWS

Possible Applications:
Multilayer Extrusion Fidelity
Mixing/Polymer Extrusion
Coating Flow Instability Mitigation
Particle Manipulation
Solidification/Microstructure Development
??

MANUFACTURING FLOWS

2-1/2 to 3D
Interface Physics
Solidification
Flow Instabilities
Secondary Flows
Multilayer
Multiphysics
Viscoelasticity
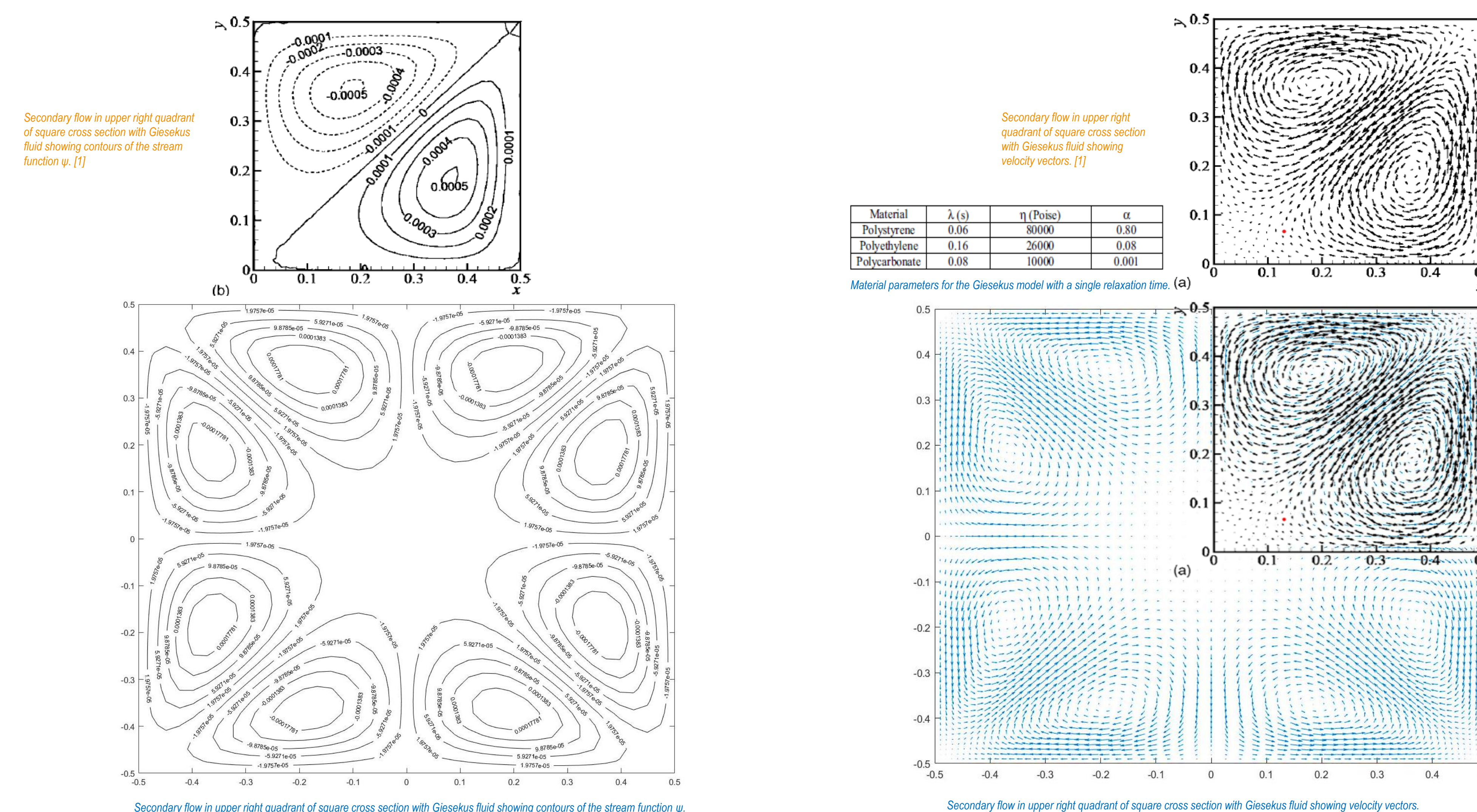Dispersion Mechanics
Microstructure Development

INTRODUCTORY EXAMPLE: SECONDARY FLOWS IN SQUARE DUCTS

Secondary flows driven by viscoelasticity in irregular ducts are revisited with the aim of creating effective tools for multilayer extrusion. Efficient 2.5D calculations of single and multi-mode Giesekus and Phan-Thien-Tanner (PTT) constitutive models detail the development of corner flows in rectangular channels; with the capacity to explore full 3D simulations. This is a starting example in the building of these tools upon high fidelity open-source codes in providing key information for process development and design.

Viscosity comparison of polystyrene, polyethylene, and polycarbonate resins.
Trademark and materials manufactured by The Dow Chemical Company

Giesekus	λ [s]	η [Poise]	α	–
	0.06	80000	0.80	
PTT	λ[s]	η [Poise]	ε	ζ
	0.20	72000	0.20	0.0

Single mode Giesekus and PTT model parameters for polystyrene.

I	λ_i (s)	η_i (Poise)	α_i
1	10^1	23740	0.86
2	10^1	97670	0.48
3	10^2	163500	0.56
4	10^3	44640	0.53
5	10^3	8540	0.51

Five mode Giesekus model parameters for polystyrene.

Viscoelastic Stress

POLYMER_STRESS11_NS20_30.0000   POLYMER_STRESS22_NS20_30.0000   POLYMER_STRESS12_NS20_30.0000

Velocity

VELOCITY1_NS20_30.0000   VELOCITY2_NS20_30.0000   VELOCITY3_NS20_30.0000

Entry   10.2 cm   20.3 cm
30.5 cm   40.6 cm   50.8 cm

Progression of a thirteen-layer concentric ring polystyrene structure as it flows down a square channel. [1]

LDPE Streamline Comparison

Secondary flow in upper right quadrant of square cross section with Giesekus fluid showing contours of the stream function ψ. [1]

Secondary flow in upper right quadrant of square cross section with Giesekus fluid showing velocity vectors. [1]

Material	λ_i (s)	η (Poise)	α
Polystyrene	0.06	80000	0.30
Polyethylene	0.16	26000	0.08
Polycarbonate	0.08	10000	0.001

Material parameters for the Giesekus model with a single relaxation time.

Secondary flow in upper right quadrant of square cross section with Giesekus fluid showing contours of the stream function ψ.

Secondary flow in upper right quadrant of square cross section with Giesekus fluid showing velocity vectors.

2-½ D SECONDARY FLOW STUDY PROGRESSION

Square Channel Secondary Flow

✓ Giesekus
✓ PTT
• FENE-P
• Pom-Pom
• …

Single & Multimode Viscoelasticity

$$v_{x,y,z}(x,y) \; ; \; \frac{\partial \boldsymbol{v}}{\partial z} = 0 \; ; \; \frac{dP}{dz}$$

Effect of Rounded Corners

Multiple Layers
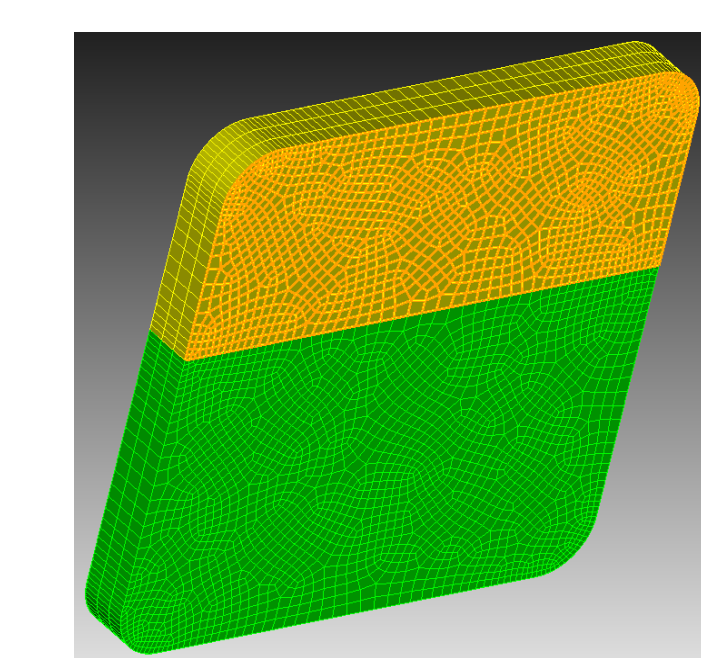
IN PROGRESS:
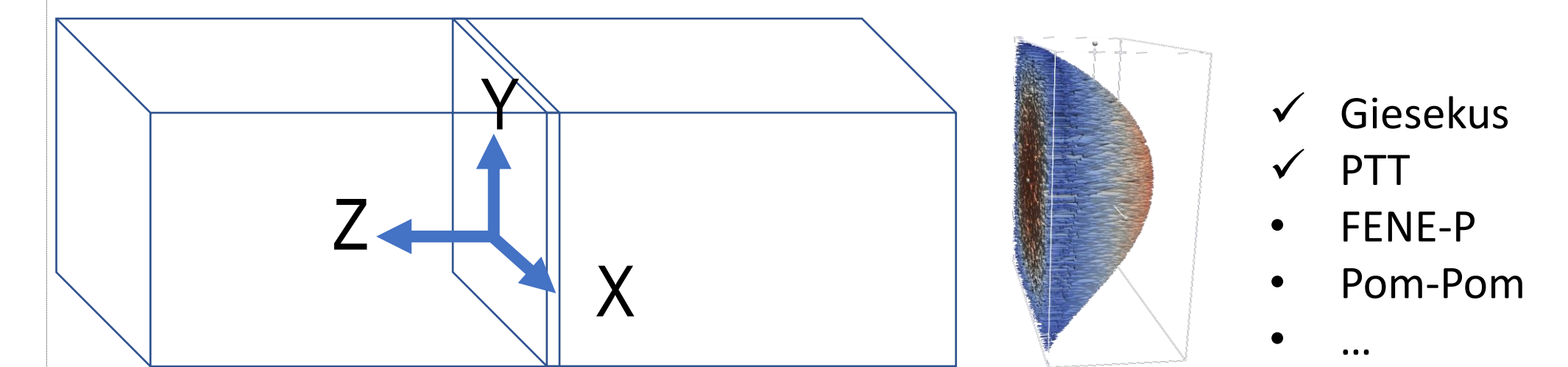Compare Level Set Interface with Deformed Geometry Remeshing

Rolling Coating Bank

REFERENCES

1. Yue, Dooley, and Feng, "A general criterion for viscoelastic secondary flow in pipes of noncircular cross section," J. Rheol. 521, 315-332 (2008).
2. Holmes, Favero, and Osswald, Modeling Viscoelastic Secondary Flows in Three-Dimensional Noncircular Ducts,", PE&S 52(8), 1715-1723 (2012).
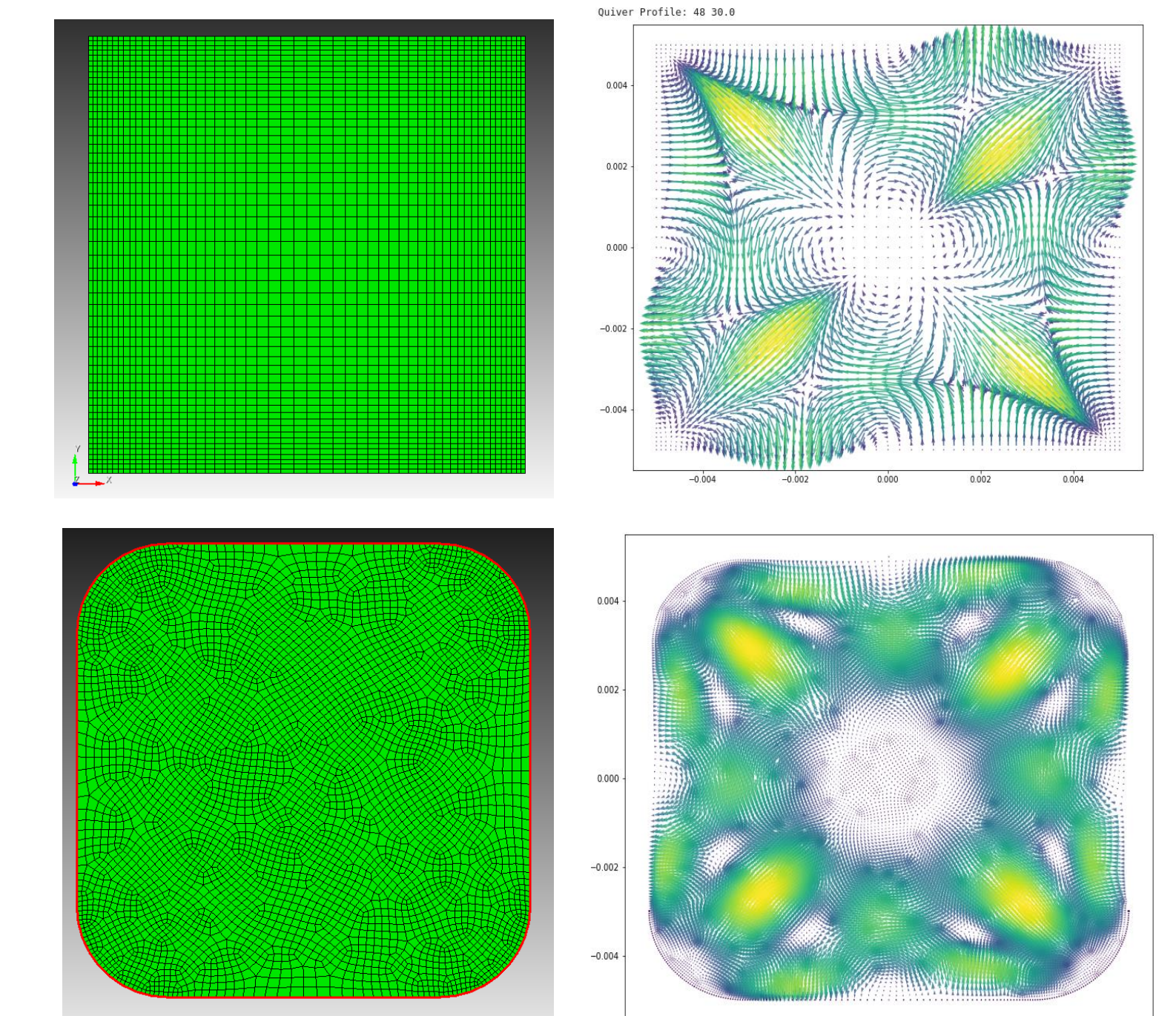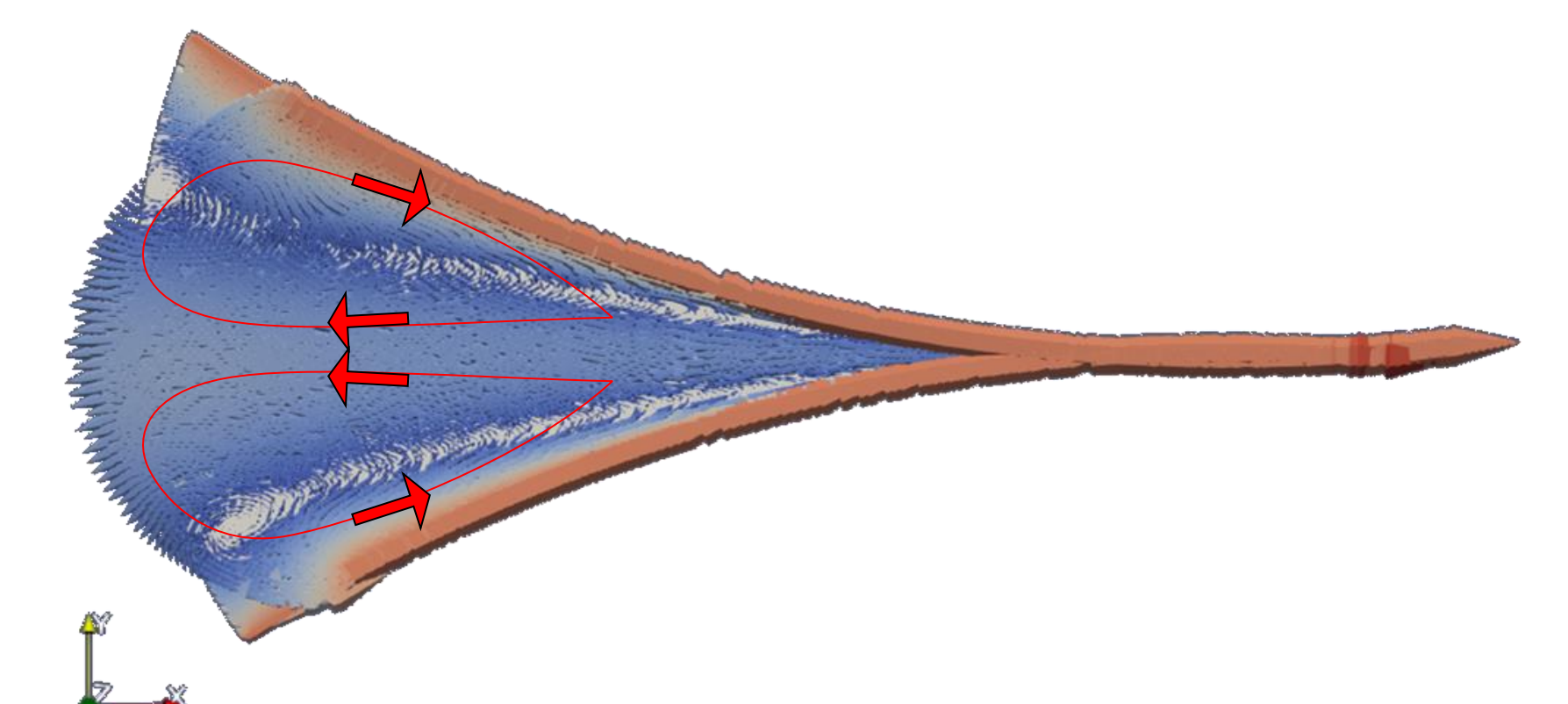
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