清華大學 清华学堂钱学森班
Tsien Excellence in Engineering Program

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Date of Birth: 1997/03 **Websites**: ResearchGate, Google Scholar; Group, LinkedIn; Gitee

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Education Background

- **2019/08-2025/07** ***Doctor of Philosophy*** Tsinghua University Department of Engineering Mechanics
  - **Major**: Power Engineering and Engineering Thermal Physics (Admission by Recommendation)
  - **Field of Research:** Electrokinetic transport in liquid-liquid multiphase flow (**Supervisor**: Prof. Moran Wang)
  - **Dissertation**: Spontaneous charging and electrokinetic multiphase flow of immiscible liquid-liquid interface
  - **Applications**: Enhanced oil recovery with low-salinity waterflooding, Electrolyte filling in rechargeable batteries
- **2018/10-2019/01** ***Visiting Student*** Purdue University School of Mechanical Engineering
  - **Project:** Optimization of the pillar array distribution for rare cell analysis (**Supervisor:** Prof. Steven T. Wereley)
  - **Applications**: Reaction efficiency enhancement in point-of-care fluidics for rare cell analysis
- **2015/08-2019/07** ***Bachelor of Engineering*** Tsinghua University Department of Engineering Mechanics
  - **Major**: Theoretical and Applied Mechanics (Tsien Excellence in Engineering Program, TEEP) (Ranked 6/29, GPA 3.78/4.00)
  - **Field of Research:** Hydrodynamic effect in low-temperature electron transport (**Supervisor**: Prof. Moran Wang)
  - **Thesis:** Electron hydrodynamics in micro/nanoscale low-dimensional materials
  - **Applications**: Super-ballistic electron transport in 2D materials, Thermal management of electronic devices

Research Experiences

Research Interests

- Electrokinetic flows, micro-/nano-fluidics, complex flows
- Hydrodynamic effect in electron and phonon transport
- Kinetic modeling and multiscale simulation of multiphysical transport

Research Projects (See Supplementals for more)

- **2019-2025** ***Doctoral dissertation***, also supported by NSFC & NKRD Tsinghua University
  - Project: Electrokinetic multiphase flow in porous media & Multiphysical microflow simulation software development
- **2021/07-08** Internship (in Company) DORIGHT
  - Project: Review and simulation of flow and heat transfer in a high-temperature air preheater with helical baffles
- **2017-2019** ***Bachelor's thesis*** & Open Research for Innovative Challenges TEEP
  - Project: Mechanism of electron transport in two-dimensional materials based on electron hydrodynamics
- **2018-2019** Senior Undergraduate Research Fellowship Purdue University - TEEP
  - Project: Optimization of the pillar array distribution for rare cell analysis in point-of-care diagnostics
- **2018/07-08** Internship (in Institute) Beijing CSRC
  - Project: Implementation of Zoltan interface for mesh partitioning in high-precision CFD software
- **2017-2018** Advanced Placement Course (Finite element method) TEEP
  - Project: Development of complex elements and multifunctional finite element programs for cable-stayed bridges

Possible Engagement

- **Physico-chemical hydrodynamics**: electrochemical energy conversion, soft matter, collective behavior of living matter
- **Quantum hydrodynamics in solids**: vortex hydrodynamics in electron transport, odd viscosity of electron fluid

Other Experiences

Academic Skills

- **Theoretical kinetic modeling**: electron-phonon transport in solids, ion-fluid coupling transport in electrolyte solutions
- **Algorithm development**: particle mesoscopic methods (LBM), PDE solvers (DOM, FVM/FEM); in Matlab/Fortran/C
- **Numerical simulation**: COMSOL, ANSYS Fluent, ABAQUS, OpenFOAM; AutoCAD, SolidWorks, Origin, ParaView
- **Experiment platform setup**: microfluidic measurement system, including design, fabrication, test and data processing
- **Engineering system design**: optimization of complex bridge / heat exchangers, electrical and control system in CMG

Academic Experiences

- 2021-2023/Fall, Teaching Assistant of *Heat and Mass Transfer* (Prof. Moran Wang), Tsinghua University
- 2018/07, Participant (1/40) in Airbus Airnovation Summer Academy, Cranfield University (UK)

Social Practices and Hobbies

- 2020/11, Technology Industry Survey of Hangzhou, TEEP, Tsinghua University
- 2017-2018/Winter, Industrial Survey of Hong Kong/Singapore, Student Association for Sci & Tech, Tsinghua University
- **Hobbies**: Music (Violin, Piano, Chorus), Sports (Badminton, Table tennis), Reading (Sci-Fi, Sci-Tech history)

Honors & Awards

In Research+

- 2024.08 Tsinghua Doctoral Travel Grant for International Conferences (Top-Tier)
- 2023.06 Tsinghua Doctoral Travel Grant for International Conferences (Grade A)
- 2019.07 Tsinghua “Future Scholar” Scholarship
- 2019.07 Bachelor’s Thesis with Honor (both in Tsinghua, and in Beijing)
- 2018.02 Honorable Mention in the Mathematical Contest in Modeling (MCM, held by SIAM)

In Education+

- 2023.12 Excellent Teaching Assistant (Eng. Mech. Dept.)
- 2021.12 Tsinghua Excellent Mentor for Undergraduate
- 2021.12 Tsinghua Comprehensive Excellence Scholarship (1st Prize)
- 2019.07 Tsinghua Outstanding Graduate (Bachelor)
- 2016.10 National Scholarship
- 2015.10 Tsinghua Xuetang Scholarship (Outstanding Innovative Talent Cultivation Program)

Supplemental materials

A. List of Publications

B. Project Details

A. List of Publications

Publications in Journal (first author)

1. **Y.F. Huang** and M. Wang*. Solvent mixing and ion partitioning effects in spontaneous charging and electrokinetic flow of immiscible liquid-liquid interface. *Physical Review Fluids*, **9**: 103701, 2024 (Editors' Suggestion)
2. **Y.F. Huang**, M. Wang*. Merging of mechanics and mathematical physics: a brief discussion on similarity method. *Mechanics in Engineering*, **46**: 868-875, 2024 [in Chinese; education]
3. A. Alizadeh[#], **Y.F. Huang**[#], F.L. Liu, H. Daiguji, M. Wang*. A streaming-potential-based microfluidic measurement of surface charge at immiscible liquid-liquid interface. *International Journal of Mechanical Sciences*, **247**: 108200, 2023
4. X. Ran[#], **Y.F. Huang**[#], M. Wang*. A hybrid Monte Carlo-discrete ordinates method for phonon transport in micro/nanosystems with rough interfaces. *International Journal of Heat and Mass Transfer*, **201**: 123634, 2023
5. **Y.F. Huang** and M. Wang*. Nonnegative magnetoresistance in hydrodynamic regime of electron fluid transport in two-dimensional materials. *Physical Review B*, **104**: 155408, 2021
6. **Y.F. Huang**. Relationship between the two loci of instant center of rigid body in plane motion. *Mechanics in Engineering* **3**: 306, 2017 [in Chinese; education]
7. **Y.F. Huang** and M. Wang*. Review of spontaneous charging and electrokinetic flow at liquid-liquid interface (I): physical picture and typical phenomena. *ACIS* (in preparation)
8. **Y.F. Huang** and M. Wang*. Review of spontaneous charging and electrokinetic flow at liquid-liquid interface (II): theory, simulation and experiment. *ACIS* (in preparation)
9. **Y.F. Huang** and M. Wang*. Enhanced streaming potential and effective viscosity within electrolyte-solution-infused surface by surface conduction effect. *PRF* (in preparation)
10. **Y.F. Huang** and M. Wang*. Electrophoresis of small droplets with non-polarizable interface regulated by charge relaxation effects. *PRF* (in preparation)
11. **Y.F. Huang** and M. Wang*. Hydrophobic and impurity effect in surface charging and contact angle of nonpolar oil. *Langmuir* (in preparation)

Publications in Journal (others)

12. Z.G. Tian, **Y.F. Huang**, M. Wang*. Analytical solution of inertia effect in high-speed flows through disordered porous media. *Physical Review Fluids*, In Press, 2024
13. B. Liu, **Y.F. Huang**, M. Wang*. Physics and modeling of phonon wave behaviors in nanoscale heat conduction. *Chinese Journal of Computational Physics*, In Press, 2024 [in Chinese]
14. Q.Q. Li, G. Yang, **Y.F. Huang**, X.K. Lu, J. Min and M. Wang*. Lattice Boltzmann method for particulate multiphase flow system. *International Journal of Mechanical Sciences*, **273**: 109217, 2024
15. Y.R. Li, **Y.F. Huang**, X.K. Lu, M. Wang*. Criterions of distribution transitions in dispersed multiphase systems based on an extended lattice model. *Langmuir*, **39**: 17021, 2023
16. W. Liu, **Y.F. Huang**, M. Wang*. Extended space charge in electroconvective flow near ion-selective surfaces. *IJMS* (under review)
17. W. Liu, **Y.F. Huang**, M. Wang*. Instability and scaling transition triggered by strong capacitive charging in induced-charge electro-osmosis. *PRX* (under review)
18. M.B. Zhang, Z.G. Tian, **Y.F. Huang**, M. Wang*. Flow regimes and criterions of gas flow in porous media by experiments. *IJMS* (under review)
19. X.K. Lu, Q.Q. Li, G. Yang, **Y.F. Huang**, M. Wang*. Inertial accumulation effect on microgel particle transport and preferential flow control in disordered media. *JFM* (under review)

Conferences

1. **Y.F. Huang**, W. Liu, M. Wang*. Electrokinetic multiphase flow at spontaneously charged liquid-liquid interface: a diffuse interface model with adsorption-induced interface charge (Oral & Long abstract). *ICTAM 2024*. Daegu, Korea. 2024.08
2. **Y.F. Huang**, A. Alizadeh, F.L. Liu, M. Wang*. Measurement of surface charge at immiscible liquid-liquid interface using streaming-potential-on-microfluidics (Oral). *InterPore 2023*. Edinburgh, UK. 2023.05
3. **Y.F. Huang**, M. Wang*. Measurement of liquid-liquid interfacial charge based on streaming potential (Oral). *NCFluid 2022*. Xi’an, China. 2022.11 [in Chinese]
4. **Y.F. Huang**, M. Wang*. Hydrodynamics of low dimensional electron transport at micro-nanoscales (Oral & Paper). *CCTAM 2019*. Hangzhou, China. 2019.08 [in Chinese]

Patents (Chinese)

1. M. Wang, **Y.F. Huang** and F.L. Liu. A method and apparatus for measuring the charge density at the liquid-liquid interface, patent number ZL 2021 1 1448254.6, authorization number CN 114216950 B, 2024.
2. M. Wang, **Y.F. Huang**. A method, device, and system for in-situ measurement of the charge density at the immiscible liquid interface, application number 012434465, 2024.

Software copyrights (Chinese)

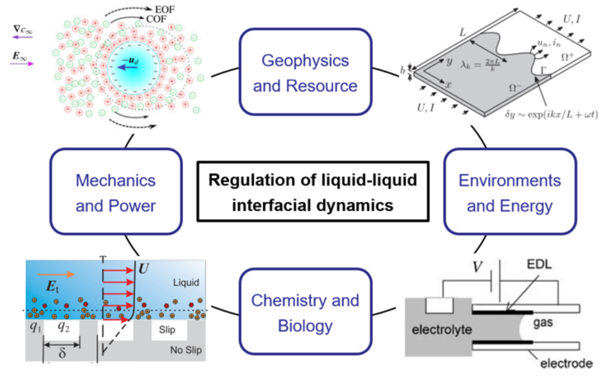
3. M. Wang, G, Yang, H.Y. Chen, and **Y.F. Huang**. Multi-physics, multi-phase, multi-scale flow simulation software (μ^3-Flows), registration number 2024SR0160474, 2024.

B. Project Details

Doctor dissertation (RETURN): Spontaneous charging and electrokinetic multiphase flow of immiscible liquid-liquid interface (I)

Motivation: mechanism & description of electrokinetics at soft liquid-liquid interface

Background



∇c_∞
E_∞
EOF
COF
$-u_d$
L
U, I
u_n, i_n
Ω^+
b
y
$\lambda_k = \frac{2\pi L}{k}$
x
Γ
Ω^-
U, I
$\delta y \sim \exp(ikx/L + \omega t)$
E_t
U
Liquid
q_1
q_2
Slip
δ
No Slip
V
EDL
electrolyte
gas
electrode

Geophysics and Resource

Mechanics and Power

Regulation of liquid-liquid interfacial dynamics

Environments and Energy

Chemistry and Biology

Physical model

$$\nabla^2 n_k + \nabla \cdot \left(n_k \nabla \frac{z_k e\varphi + \Delta G_k(\phi)}{k_B T}\right) = 0$$

$$\nabla \cdot (\varepsilon \nabla \varphi) = -\rho_e + \rho_{\text{fix}}, \qquad \rho_e = \Sigma_k z_k e n_k$$

$$n^{(w)}_{+/-,\infty} = n^{(w)}_\infty \qquad \varphi^{(w)}_\infty = 0\ \text{V}$$

$$\Delta G_k^{(a)}(\phi) = \begin{cases} \Delta G_k^{(a)} & -d_{\text{ad}} < x < d_{\text{ad}} \\ 0 & |x| \geq d_{\text{ad}} \end{cases}$$

$$\Delta G_k^{(t)}(\phi) = \begin{cases} \Delta G_k^{(t)} & x > d_{\text{ad}} \\ 0 & x < d_{\text{ad}} \end{cases}$$

$$\frac{\partial \phi}{\partial t} + \boldsymbol{u} \cdot \nabla \phi = \nabla \cdot M \nabla \mu_\phi$$

$$\nabla_n \mu_\phi = 0, \nabla_n \phi = |\nabla \phi| \cos\theta$$

$$\rho \frac{\partial \boldsymbol{u}}{\partial t} + \rho \boldsymbol{u} \cdot \nabla \boldsymbol{u} = -\nabla p + \nabla \cdot \mu \nabla \boldsymbol{u} + \boldsymbol{F}_{\text{st}} + \boldsymbol{F}_{\text{e}}$$

$$\boldsymbol{F}_{\text{st}} = \mu_\phi \nabla \phi, \boldsymbol{F}_{\text{e}} = \rho_e \boldsymbol{E} - \frac{1}{2} E^2 \nabla \varepsilon$$

$$\boldsymbol{E} = -\nabla \varphi_{\text{surf}} + \boldsymbol{E}^{\text{ind}}_{\text{ext}}, \nabla \cdot \left(\sigma \boldsymbol{E}^{\text{ind}}_{\text{ext}}\right) = 0$$

$$\lambda_{\text{D}}^{(w)} \simeq 10\ \text{nm}$$

$$\varepsilon^{(o)}/\varepsilon^{(w)} = \varepsilon_r < 1$$

$$\varepsilon(\phi) = \varepsilon^{(i)} V_{\text{f}}^{(i)}$$

$$d_{\text{ad}} = \sqrt{2}\ \text{nm}, \rho_{\text{fix}} = \sigma_{ll}/d_{\text{ad}}$$

$$n^{(o)}_{+/-,\infty} = n^{(w)}_\infty \exp\left(-\frac{\Delta G_+^{(t)} + \Delta G_-^{(t)}}{2 k_B T}\right)$$

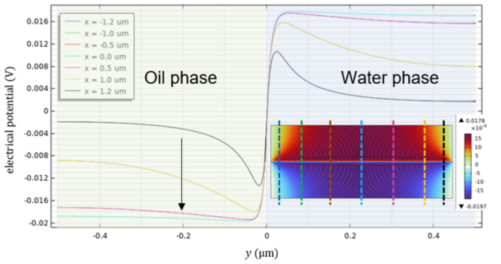
$$M = \chi \varepsilon_{\text{pf}}^2$$

$$\mu_\phi = \Lambda\left[-\nabla^2 \phi + \frac{(\phi^2 - 1)\phi}{\varepsilon_{\text{pf}}^2}\right]$$

$$\mu^{(o)}/\mu^{(w)} = \mu_r, \rho^{(o)}/\rho^{(w)} = \rho_r$$

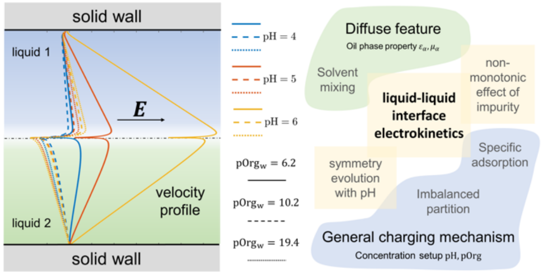
$$\mu(\phi) = \mu^{(i)} V_{\text{f}}^{(i)}, \rho(\phi) = \rho^{(i)} V_{\text{f}}^{(i)}$$

$$E_{\text{ext}} \ll E_{\text{surf},\perp}$$



$$\frac{\partial n_i}{\partial t} + \nabla \cdot \left(n_i \boldsymbol{u} - \bar{D}_i \left(\nabla n_i + n_i \nabla \ln \gamma_i^\phi\right) - \frac{z_i e \bar{D}_i}{k_B T} n_i \nabla \varphi\right) = 0,\ \gamma_i^\phi := \exp\left(\frac{\Delta g_i(\phi)}{k_B T}\right)$$

Flow mechanism



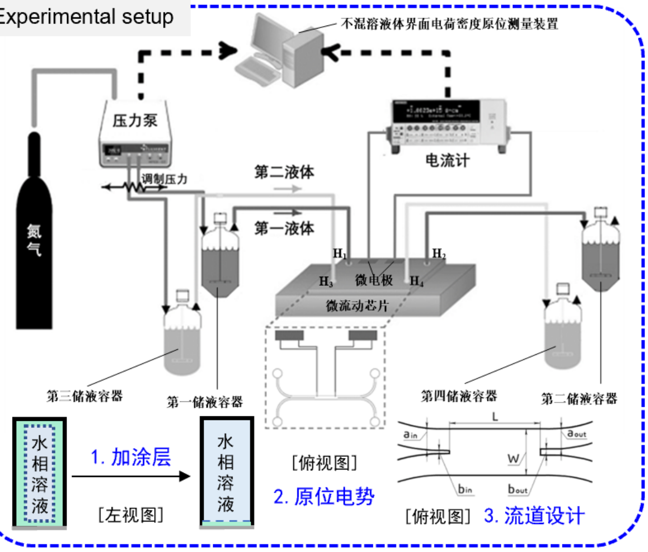
solid wall
liquid 1
E
liquid 2
velocity profile
solid wall
pH = 4
pH = 5
pH = 6
$\text{pOrg}_w = 6.2$
$\text{pOrg}_w = 10.2$
$\text{pOrg}_w = 19.4$
Diffuse feature
Oil phase property $\varepsilon_\alpha, \mu_\alpha$
Solvent mixing
liquid-liquid interface electrokinetics
non-monotonic effect of impurity
symmetry evolution with pH
Specific adsorption
Imbalanced partition
General charging mechanism
Concentration setup pH, pOrg

Y.F. Huang and M. Wang*. *Physical Review Fluids* (in press); Software copyrights * 1 (μ^3-Flows)

Doctor dissertation: Spontaneous charging and electrokinetic multiphase flow of immiscible liquid-liquid interface (II)

Motivation: to overcome limitations of traditional droplet electrophoresis method

Experimental setup



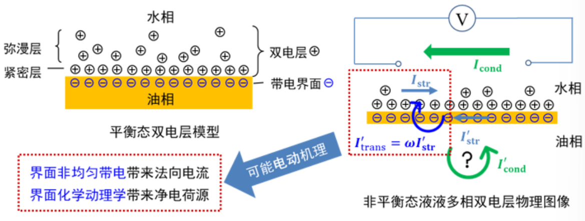
不混溶液体界面电荷密度原位测量装置
压力泵
氮气
调制压力
第二液体
第一液体
电流计
H_1
H_2
H_3
微电极
H_4
微流动芯片
第三储液容器
第一储液容器
第四储液容器
第二储液容器
水相溶液
1. 加涂层
水相溶液
[左视图]
[俯视图]
2. 原位电势
L
a_{in}
a_{out}
W
b_{in}
b_{out}
[俯视图]
3. 流道设计

Principles for two-phase

$$\varepsilon \zeta_{s-l}^{\text{sing}} = \mu_w s_{w,0} \left(\frac{d\phi}{dp}\right) \xrightarrow{\text{形式类比}} \varepsilon \zeta_{\text{eff}}^{\text{two-ph}} = \mu_w s_{\text{eff}} \left(\frac{d\phi}{dp_w}\right)$$

速度放大因子　　速度剖面系数　　固液界面贡献

$$\zeta_{\text{eff}}^{\text{two-ph}} \simeq \underbrace{\left[(1-\omega)\frac{\beta}{\lambda} - \alpha_{\partial,z\sim 0}\right]\zeta_{l-l}}_{\text{液液界面等效}\zeta\text{电位 }\zeta_{l-l}^{\text{eff}}} + \underbrace{\left(1 + 3\alpha_{\partial,z\sim W/2}\right)\zeta_{s-l}}_{\text{固液界面等效}\zeta\text{电位 }\zeta_{s-l}^{\text{eff}}}$$



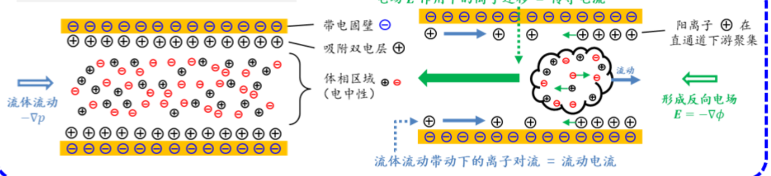
水相
弥漫层
紧密层
双电层⊕
带电界面⊖
油相
平衡态双电层模型
V
I_{cond}
I_{str}
水相
$I'_{\text{trans}} = \omega I'_{\text{str}}$
I'_{str}
?
I'_{cond}
油相
可能电动机理
非平衡态液液多相双电层物理图像

界面非均匀带电带来法向电流

界面化学动理学带来净电荷源

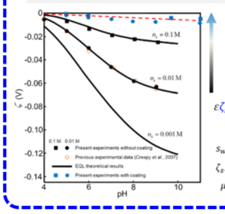
极化系数：界面对流电流对水相流动电流的额外贡献，在萃取中常见

Principles for single phase



带电固壁 ⊖
吸附双电层 ⊕
体相区域 ⊕ ⊖
（电中性）
流体流动
$-\nabla p$
电场 E 作用下的离子迁移 = 传导电流
阳离子 ⊕ 在直通道下游聚集
流动
形成反向电场
$E = -\nabla\phi$
流体流动带动下的离子对流 = 流动电流

Experimental results



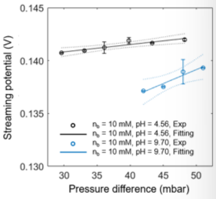
经聚合物涂层后，固液界面带电量被削弱约80%

$$\varepsilon \zeta_{s-l} = \mu_w s_{w,0} \left(\frac{d\phi}{dp}\right)$$

$s_{w,0}$ - 体相溶液电导率

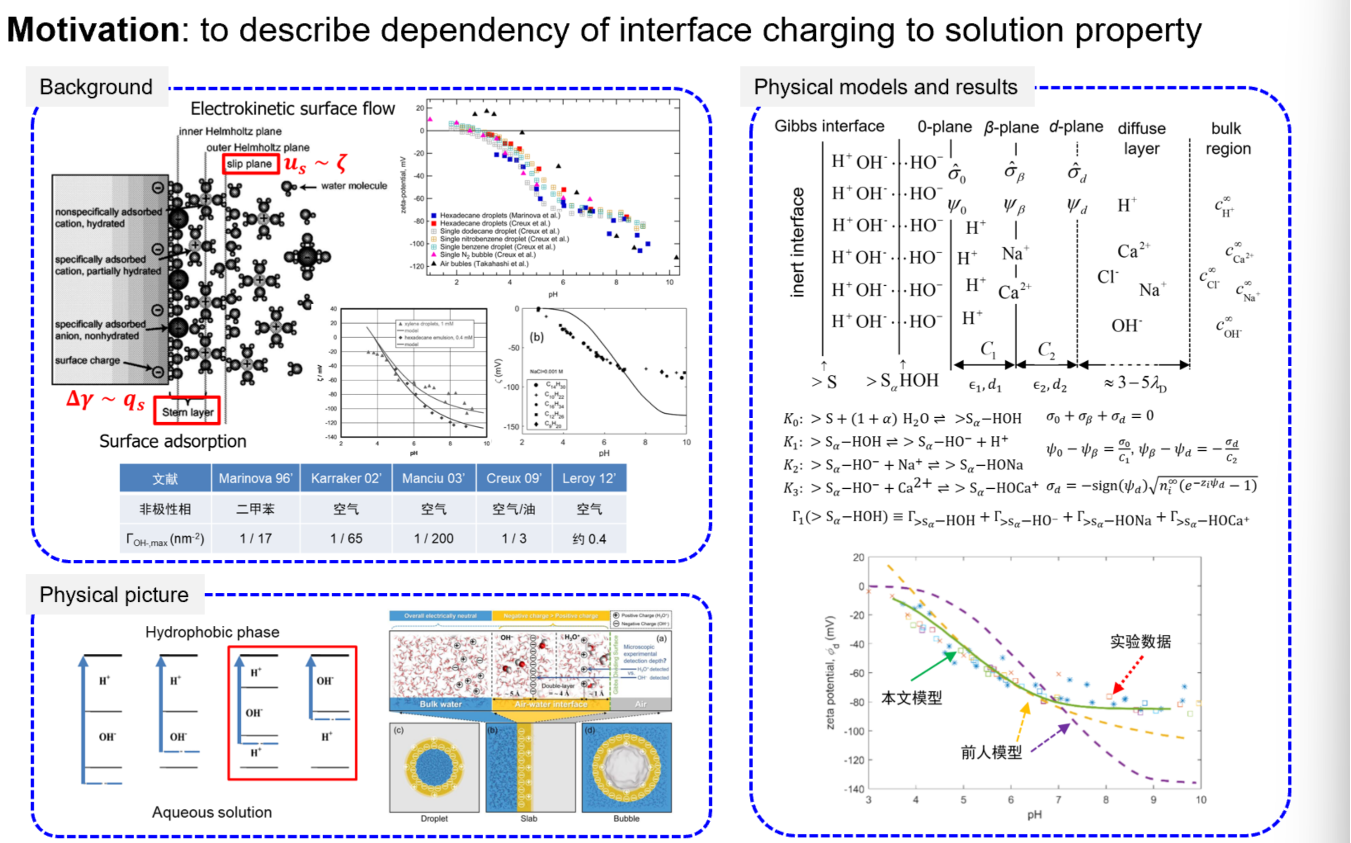
ζ_{s-l} - 固液界面ζ电位

μ_w - 动力粘度系数



A. Alizadeh#, **Y.F. Huang**#, … and M. Wang*. *International Journal of Mechanical Sciences*, **247**: 108200, 2023; Patents * 2

Doctor dissertation: Spontaneous charging and electrokinetic multiphase flow of immiscible liquid-liquid interface (III)



Motivation: to describe dependency of interface charging to solution property

Background

Electrokinetic surface flow
inner Helmholtz plane
outer Helmholtz plane
slip plane
$u_s \sim \zeta$
water molecule
nonspecifically adsorbed cation, hydrated
specifically adsorbed cation, partially hydrated
specifically adsorbed anion, nonhydrated
surface charge
$\Delta\gamma \sim q_s$
Stern layer
Surface adsorption
zeta-potential, mV
pH
Hexadecane droplets (Marinova et al.)
Hexadecane droplets (Creux et al.)
Single dodecane droplet (Creux et al.)
Single nitrobenzene droplet (Creux et al.)
Single benzene droplet (Creux et al.)
Single N₂ bubble (Creux et al.)
Air bubles (Takahashi et al.)
xylene droplets, 1 mM
model
hexadecane emulsion, 0.4 mM
ζ / mV
(b)
ζ (mV)
NaCl=0.001 M
C₁₄H₃₀
C₁₀H₂₂
C₁₆H₃₄
C₁₂H₂₆
C₉H₂₀

文献	Marinova 96’	Karraker 02’	Manciu 03’	Creux 09’	Leroy 12’
非极性相	二甲苯	空气	空气	空气/油	空气
$\Gamma_{OH-,max}$ (nm^{-2})	1 / 17	1 / 65	1 / 200	1 / 3	约 0.4

Physical picture

Hydrophobic phase
H⁺
OH⁻
Aqueous solution
Overall electrically neutral
Negative charge > Positive charge
Positive Charge (H₃O⁺)
Negative Charge (OH⁻)
(a)
OH⁻
H₃O⁺
Microscopic experimental detection depth
Bulk water
Air-water interface
Air
(c)
(b)
(d)
Droplet
Slab
Bubble

Physical models and results

Gibbs interface
0-plane
β-plane
d-plane
diffuse layer
bulk region
inert interface
σ_0
σ_β
σ_d
ψ_0
ψ_β
ψ_d
H⁺ OH⁻ ··· HO⁻
H⁺
Na⁺
Ca²⁺
Cl⁻
OH⁻
$c^\infty_{H^+}$
$c^\infty_{Ca^{2+}}$
$c^\infty_{Cl^-}$
$c^\infty_{Na^+}$
$c^\infty_{OH^-}$
C_1
C_2
$>S$
$>S_\alpha HOH$
ϵ_1, d_1
ϵ_2, d_2
$\approx 3-5\lambda_D$

K_0: $>S + (1+\alpha)\,H_2O \rightleftharpoons\ >S_\alpha{-}HOH$

K_1: $>S_\alpha{-}HOH \rightleftharpoons\ >S_\alpha{-}HO^- + H^+$

K_2: $>S_\alpha{-}HO^- + Na^+ \rightleftharpoons\ >S_\alpha{-}HONa$

K_3: $>S_\alpha{-}HO^- + Ca^{2+} \rightleftharpoons\ >S_\alpha{-}HOCa^+$

$$\sigma_0 + \sigma_\beta + \sigma_d = 0$$

$$\psi_0 - \psi_\beta = \frac{\sigma_0}{c_1},\ \psi_\beta - \psi_d = -\frac{\sigma_d}{c_2}$$

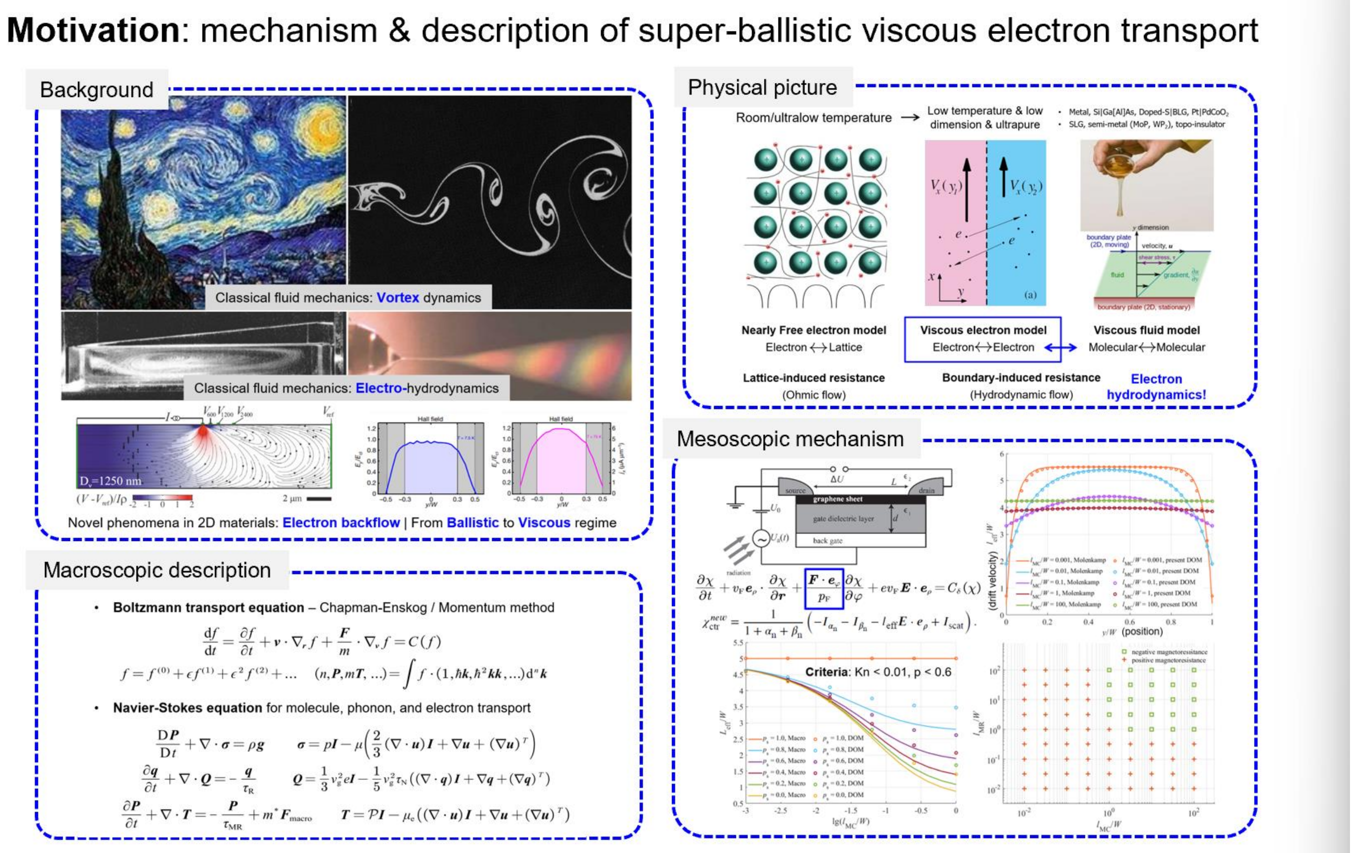
$$\sigma_d = -\mathrm{sign}(\psi_d)\sqrt{n_i^\infty(e^{-z_i\psi_d} - 1)}$$

$$\Gamma_1(>S_\alpha{-}HOH) \equiv \Gamma_{>S_\alpha-HOH} + \Gamma_{>S_\alpha-HO^-} + \Gamma_{>S_\alpha-HONa} + \Gamma_{>S_\alpha-HOCa^+}$$

zeta potential, ϕ_d (mV)
pH
实验数据
本文模型
前人模型

Y.F. **Huang** and M. Wang*. *Langmuir* (in preparation)

Undergraduate thesis (RETURN): Electron hydrodynamics in micro/nanoscale low-dimensional materials



Motivation: mechanism & description of super-ballistic viscous electron transport

Background

Classical fluid mechanics: **Vortex** dynamics

Classical fluid mechanics: **Electro-**hydrodynamics

D_ν=1250 nm
$(V-V_{ref})/I\rho$
2 µm
Hall field
y/W

Novel phenomena in 2D materials: **Electron backflow** | From **Ballistic** to **Viscous** regime

Physical picture

Room/ultralow temperature →
Low temperature & low dimension & ultrapure
Metal, Si|Ga[Al]As, Doped-S|BLG, Pt|PdCoO₂
SLG, semi-metal (MoP, WP₂), topo-insulator
$V_x(y_1)$
$V_x(y_2)$
e
(a)
y dimension
boundary plate (2D, moving)
velocity, u
shear stress, τ
fluid
gradient
boundary plate (2D, stationary)

Nearly Free electron model Electron ↔ Lattice	Viscous electron model Electron ↔ Electron	Viscous fluid model Molecular ↔ Molecular
Lattice-induced resistance (Ohmic flow)	Boundary-induced resistance (Hydrodynamic flow)	**Electron hydrodynamics!**

Macroscopic description

- **Boltzmann transport equation** – Chapman-Enskog / Momentum method

$$\frac{\mathrm{d}f}{\mathrm{d}t} = \frac{\partial f}{\partial t} + \boldsymbol{v}\cdot\nabla_{\boldsymbol{r}} f + \frac{\boldsymbol{F}}{m}\cdot\nabla_{\boldsymbol{v}} f = C(f)$$

$$f = f^{(0)} + \epsilon f^{(1)} + \epsilon^2 f^{(2)} + \ldots \qquad (n, \boldsymbol{P}, m\boldsymbol{T}, \ldots) = \int f\cdot(1, \hbar\boldsymbol{k}, \hbar^2\boldsymbol{kk}, \ldots)\,\mathrm{d}^n\boldsymbol{k}$$

- **Navier-Stokes equation** for molecule, phonon, and electron transport

$$\frac{\mathrm{D}\boldsymbol{P}}{\mathrm{D}t} + \nabla\cdot\boldsymbol{\sigma} = \rho\boldsymbol{g} \qquad \boldsymbol{\sigma} = p\boldsymbol{I} - \mu\left(\frac{2}{3}(\nabla\cdot\boldsymbol{u})\boldsymbol{I} + \nabla\boldsymbol{u} + (\nabla\boldsymbol{u})^T\right)$$

$$\frac{\partial\boldsymbol{q}}{\partial t} + \nabla\cdot\boldsymbol{Q} = -\frac{\boldsymbol{q}}{\tau_R} \qquad \boldsymbol{Q} = \frac{1}{3}v_g^2 e\boldsymbol{I} - \frac{1}{5}v_g^2\tau_N((\nabla\cdot\boldsymbol{q})\boldsymbol{I} + \nabla\boldsymbol{q} + (\nabla\boldsymbol{q})^T)$$

$$\frac{\partial\boldsymbol{P}}{\partial t} + \nabla\cdot\boldsymbol{T} = -\frac{\boldsymbol{P}}{\tau_{MR}} + m^*\boldsymbol{F}_{macro} \qquad \boldsymbol{T} = \mathcal{P}\boldsymbol{I} - \mu_e((\nabla\cdot\boldsymbol{u})\boldsymbol{I} + \nabla\boldsymbol{u} + (\nabla\boldsymbol{u})^T)$$

Mesoscopic mechanism

ΔU
L
ϵ_2
source
drain
graphene sheet
U_0
gate dielectric layer
d
ϵ_1
$U_a(t)$
back gate
radiation
L_{eff}/W
(drift velocity)
y/W (position)
l_{MC}/W = 0.001, Molenkamp
l_{MC}/W = 0.01, Molenkamp
l_{MC}/W = 0.1, Molenkamp
l_{MC}/W = 1, Molenkamp
l_{MC}/W = 100, Molenkamp
l_{MC}/W = 0.001, present DOM
l_{MC}/W = 0.01, present DOM
l_{MC}/W = 0.1, present DOM
l_{MC}/W = 1, present DOM
l_{MC}/W = 100, present DOM
L_{eff}/W
p_s = 1.0, Macro
p_s = 0.8, Macro
p_s = 0.6, Macro
p_s = 0.4, Macro
p_s = 0.2, Macro
p_s = 0.0, Macro
p_s = 1.0, DOM
p_s = 0.8, DOM
p_s = 0.6, DOM
p_s = 0.4, DOM
p_s = 0.2, DOM
p_s = 0.0, DOM
$\lg(l_{MC}/W)$
negative magnetoresistance
positive magnetoresistance
l_{MR}/W
l_{MC}/W

$$\frac{\partial\chi}{\partial t} + v_F\boldsymbol{e}_\rho\cdot\frac{\partial\chi}{\partial\boldsymbol{r}} + \boxed{\frac{\boldsymbol{F}\cdot\boldsymbol{e}_\varphi}{p_F}}\frac{\partial\chi}{\partial\varphi} + ev_F\boldsymbol{E}\cdot\boldsymbol{e}_\rho = C_\delta(\chi)$$

$$\chi_{ctr}^{new} = \frac{1}{1+\alpha_n+\beta_n}\left(-I_{\alpha_n} - I_{\beta_n} - l_{eff}\boldsymbol{E}\cdot\boldsymbol{e}_\rho + I_{scat}\right).$$

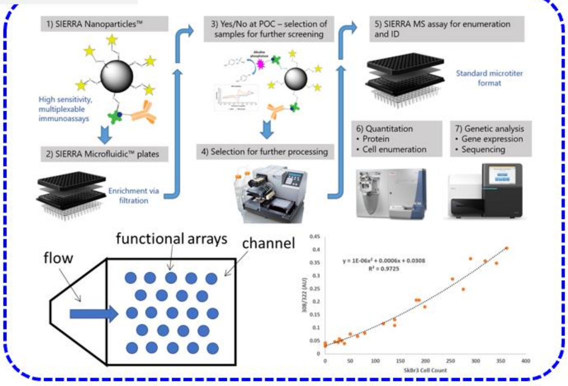
Criteria: Kn < 0.01, p < 0.6

Y.F. **Huang** and M. Wang*. *Physical Review B*, **104**: 155408, 2021; Bachelor thesis with honor

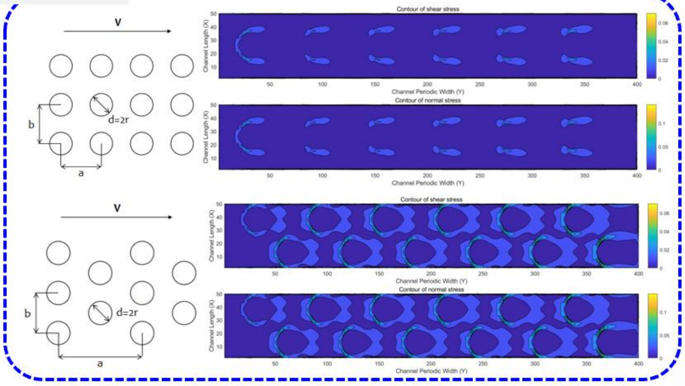
TEEP-SURF (RETURN): Optimization of the pillar array distribution for rare cell analysis in point-of-care diagnostics

Motivation: to achieve better reaction efficiency by optimizing pillar array structure

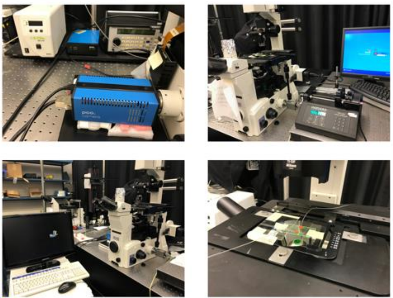
Background

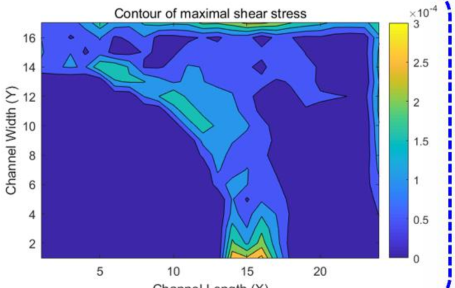

1) SIERRA Nanoparticles™
High sensitivity, multiplexable immunoassays
2) SIERRA Microfluidic™ plates
Enrichment via filtration
3) Yes/No at POC – selection of samples for further screening
4) Selection for further processing
5) SIERRA MS assay for enumeration and ID
Standard microtiter format
6) Quantitation
• Protein
• Cell enumeration
7) Genetic analysis
• Gene expression
• Sequencing
functional arrays
channel
flow
y = 1E-06x² + 0.0006x + 0.0308
R² = 0.9725
308/322 (AU)
SkBr3 Cell Count

Simulation



Experiments



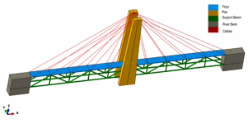


TEEP-APC (RETURN): Development of complex elements and multifunctional finite element programs for cable-stayed bridges

Motivation: to incorporate elements and functions into prescribed C++ program

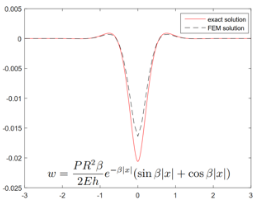
Problem description

- 扩展后的STAP++程序必须能够求解给定的桥梁问题（同时包括杆单元、梁单元、六面体实体单元和板单元），并用ABAQUS进行验证


Floor
Pier
Support Beam
River Bank
Cables

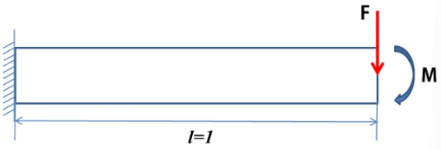
- 除以上基本要求外，各组可以自行选择增加其他功能，包括但不限于分片应力恢复(SPR)、稀疏求解器、半带宽优化、无限单元、超级单元、过渡单元、模态分析、动力学响应分析和弹塑性杆单元等。

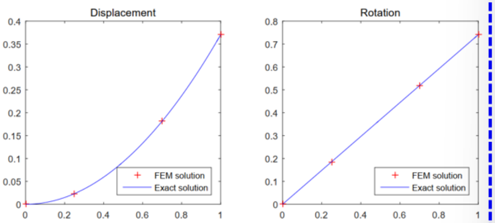
Shell element



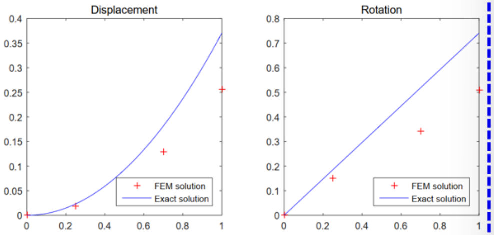
$$w = \frac{PR^2\beta}{2Eh} e^{-\beta|x|}(\sin\beta|x| + \cos\beta|x|)$$

Timoshenko beam element





Patch test: selective reduced integration



Patch test: accurate integration

Group report

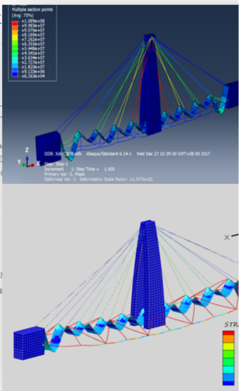
经过一个月的的努力，经历了 9 次每周五
设例会以及若干次不定期讨论，在小组成员
配合下，本组顺利地完成了大作业的任务。
以 STAP++ 程序为主进行展示。

算例的具体描述与测试结果如下 [1]：

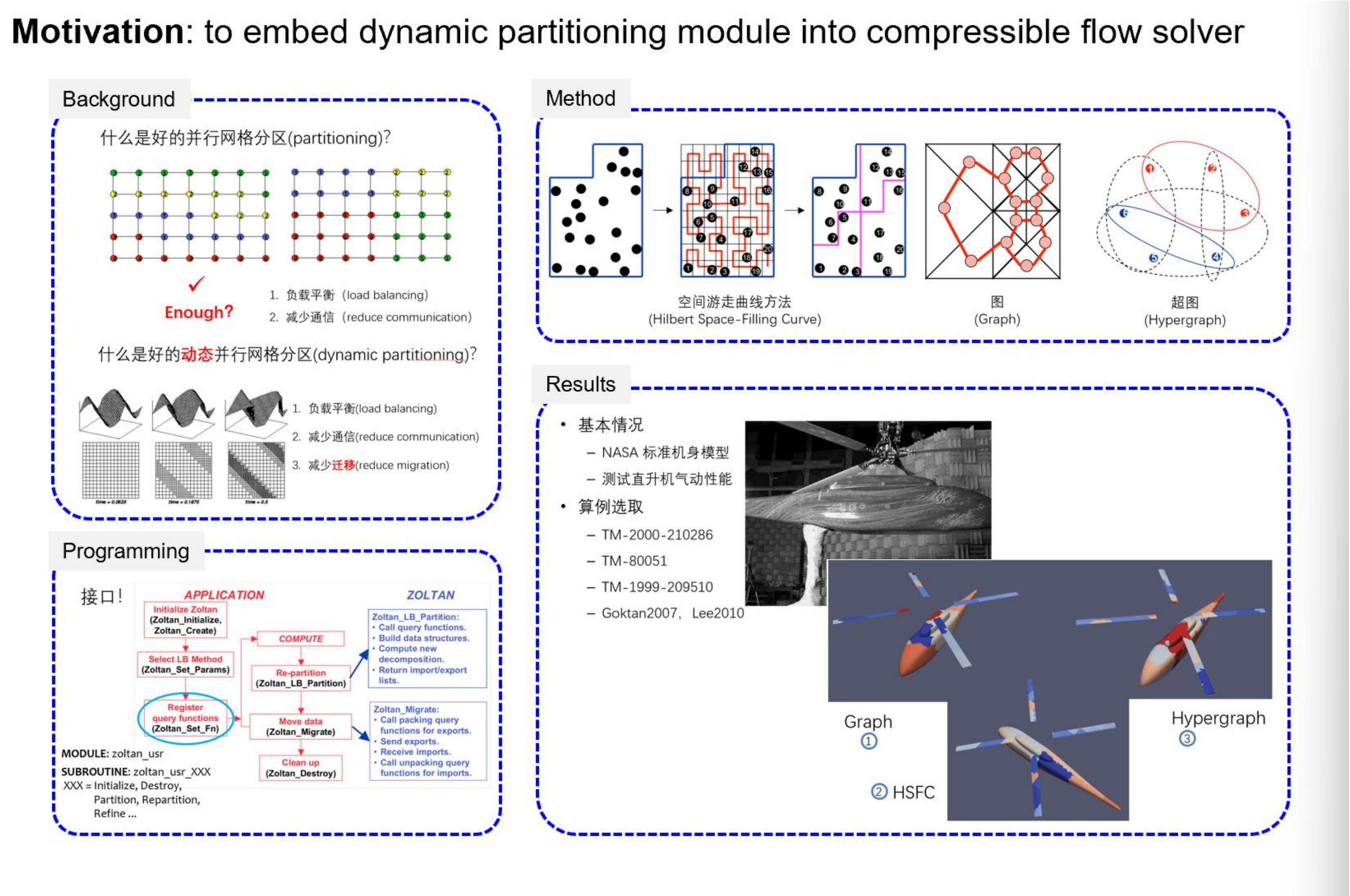
算例	$NumNode$	$NumEle$	$S4R$	$C3D8R$	$B31$	$T3D2$	t_{min}/s
1	4.16E3	2.88E3	4E2	1.76E3	7.04E2	20	0.27
2	3.72E4	3.04E4	2.5E3	2.65E4	1.35E3	20	2.35
3	\	2.33E5	1E4	2.2E5	2.7E3	20	25.0
4	1.91E6	1.81E6	4E4	1.76E6	5.42E3	20	3131

[1] 环境：CPU: intel xeon cpu e5-2620 v4，2.10Hz，16核；内存: 64G；操作系统: win10；MSVC

- 前后处理
  - 前：Python 开发；DOF 自动适配
  - 后：Tecplot 作图；基于 8H 的 SPR 功能
- 单元构造
  - 基本单元：杆单元^{Bar}, 六面体实体单元^{8H}, 欧拉梁^{Beam},
  - 其他单元：平面单元$^{3T, 4Q, 9Q}$, 纯弯板^{Plate}, 铁木辛柯梁
  - 扩展单元：过渡单元^{5Q}, 无限单元^{InfEle}
- 求解器
  - LDLT 求解器
  - PARDISO®稀疏求解器
- 模态分析



Internship-CSRC (RETURN): Implementation of Zoltan interface for mesh partitioning in high-precision CFD software



Motivation: to embed dynamic partitioning module into compressible flow solver

Background

什么是好的并行网格分区(partitioning)?

✓

Enough?

1. 负载平衡（load balancing)
2. 减少通信（reduce communication)

什么是好的动态并行网格分区(dynamic partitioning)?

1. 负载平衡(load balancing)
2. 减少通信(reduce communication)
3. 减少迁移(reduce migration)

Programming

接口!

MODULE: zoltan_usr

SUBROUTINE: zoltan_usr_XXX

XXX = Initialize, Destroy,
Partition, Repartition,
Refine ...

Method

空间游走曲线方法
(Hilbert Space-Filling Curve)

图
(Graph)

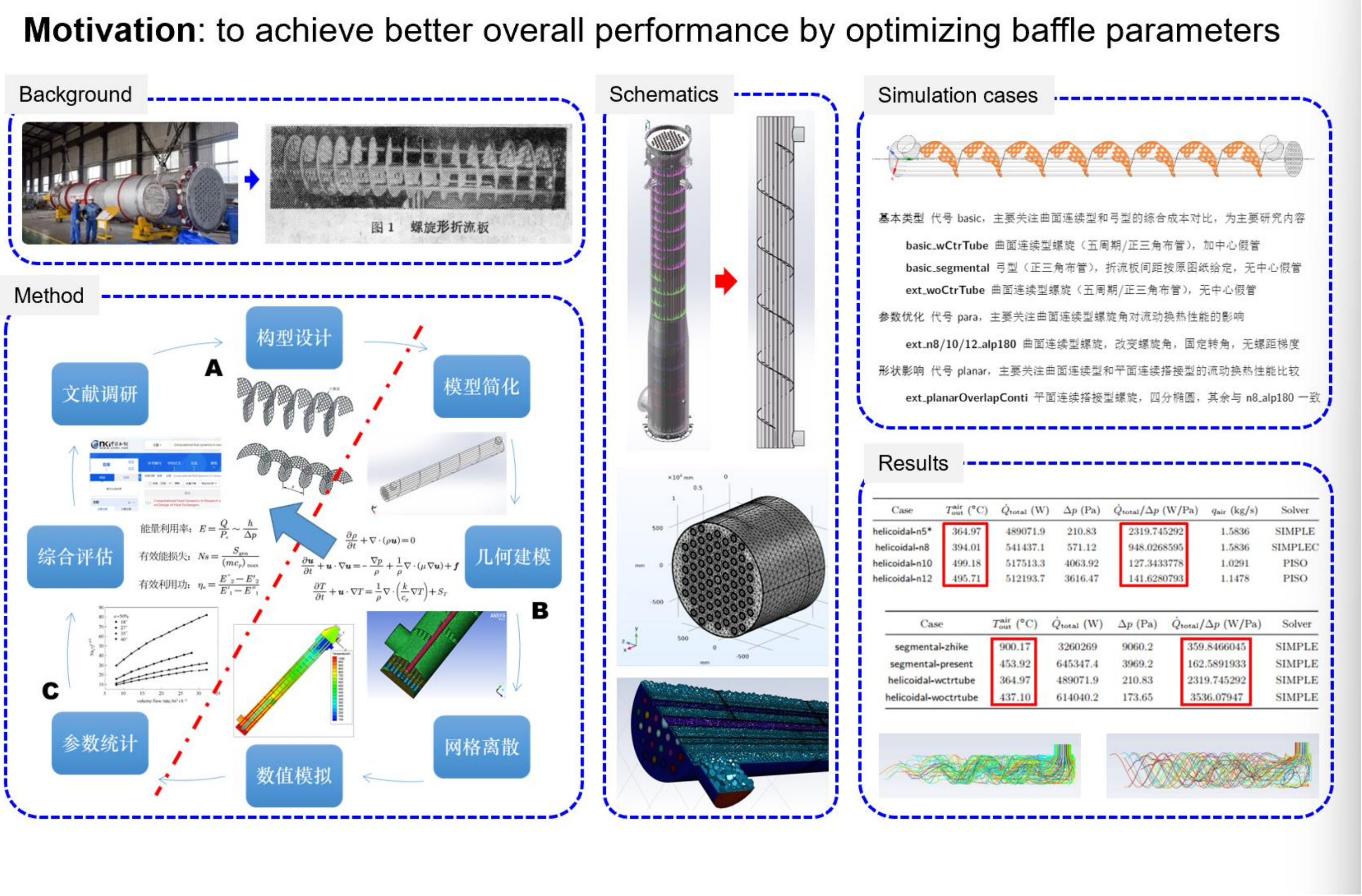
超图
(Hypergraph)

Results

- 基本情况
  - NASA 标准机身模型
  - 测试直升机气动性能
- 算例选取
  - TM-2000-210286
  - TM-80051
  - TM-1999-209510
  - Goktan2007，Lee2010

time = 0.0625
time = 0.1875
time = 0.5
APPLICATION
ZOLTAN
Initialize Zoltan (Zoltan_Initialize, Zoltan_Create)
Select LB Method (Zoltan_Set_Params)
Register query functions (Zoltan_Set_Fn)
COMPUTE
Re-partition (Zoltan_LB_Partition)
Move data (Zoltan_Migrate)
Clean up (Zoltan_Destroy)
Zoltan_LB_Partition:
• Call query functions.
• Build data structures.
• Compute new decomposition.
• Return import/export lists.
Zoltan_Migrate:
• Call packing query functions for exports.
• Send exports.
• Receive imports.
• Call unpacking query functions for imports.
Graph ①
② HSFC
Hypergraph ③

Internship-DORIGHT (RETURN): Simulation of flow and heat transfer in a high-temperature air preheater with helical baffles



Motivation: to achieve better overall performance by optimizing baffle parameters

Background

图 1　螺旋形折流板

Schematics

Method

文献调研　构型设计　模型简化　几何建模　网格离散　数值模拟　参数统计　综合评估

能量利用率：$E=\frac{Q}{P_e}\sim\frac{h}{\Delta p}$

有效能损失：$Ns=\frac{S_{\rm gen}}{(mc_p)_{\max}}$

有效利用功：$\eta_e=\frac{E''_2-E'_2}{E'_1-E''_1}$

$$\frac{\partial\rho}{\partial t}+\nabla\cdot(\rho\boldsymbol{u})=0$$

$$\frac{\partial\boldsymbol{u}}{\partial t}+\boldsymbol{u}\cdot\nabla\boldsymbol{u}=-\frac{\nabla p}{\rho}+\frac{1}{\rho}\nabla\cdot(\mu\nabla\boldsymbol{u})+\boldsymbol{f}$$

$$\frac{\partial T}{\partial t}+\boldsymbol{u}\cdot\nabla T=\frac{1}{\rho}\nabla\cdot\left(\frac{k}{c_p}\nabla T\right)+S_T$$

Simulation cases

基本类型　代号 basic，主要关注曲面连续型和弓型的综合成本对比，为主要研究内容

basic_wCtrTube 曲面连续型螺旋（五周期/正三角布管），加中心假管

basic_segmental 弓型（正三角布管），折流板间距按原图纸给定，无中心假管

ext_woCtrTube 曲面连续型螺旋（五周期/正三角布管），无中心假管

参数优化　代号 para，主要关注曲面连续型螺旋角对流动换热性能的影响

ext_n8/10/12_alp180 曲面连续型螺旋，改变螺旋角，固定转角，无螺距梯度

形状影响　代号 planar，主要关注曲面连续型和平面连续搭接型的流动换热性能比较

ext_planarOverlapConti 平面连续搭接型螺旋，四分椭圆，其余与 n8_alp180 一致

Results

Case	$T_{\rm out}^{\rm air}$ (°C)	$\dot{Q}_{\rm total}$ (W)	Δp (Pa)	$\dot{Q}_{\rm total}/\Delta p$ (W/Pa)	$q_{\rm air}$ (kg/s)	Solver
helicoidal-n5*	364.97	489071.9	210.83	2319.745292	1.5836	SIMPLE
helicoidal-n8	394.01	541437.1	571.12	948.0268595	1.5836	SIMPLEC
helicoidal-n10	499.18	517513.3	4063.92	127.3433778	1.0291	PISO
helicoidal-n12	495.71	512193.7	3616.47	141.6280793	1.1478	PISO

Case	$T_{\rm out}^{\rm air}$ (°C)	$\dot{Q}_{\rm total}$ (W)	Δp (Pa)	$\dot{Q}_{\rm total}/\Delta p$ (W/Pa)	Solver
segmental-zhike	900.17	3260269	9060.2	359.8466045	SIMPLE
segmental-present	453.92	645347.4	3969.2	162.5891933	SIMPLE
helicoidal-wctrtube	364.97	489071.9	210.83	2319.745292	SIMPLE
helicoidal-woctrtube	437.10	614040.2	173.65	3536.07947	SIMPLE