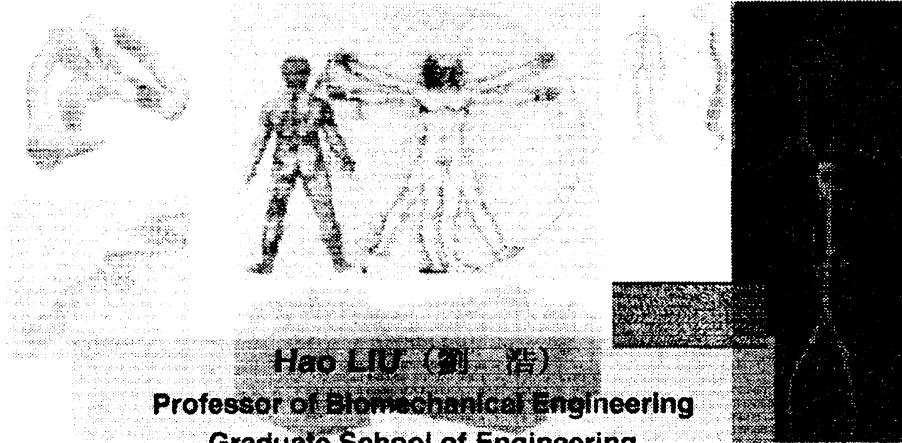


Computational biomechanics: from animal locomotion to the cardiovascular system



Hao LIU (劉 浩)

Professor of Biomechanical Engineering
Graduate School of Engineering
Chiba University, JAPAN

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Why Computational Biomechanics Physiom of Circulatory system

Biological systems and hence biomechanics are, in general, "complex systems", which need to be modeled as realistically as possible so that we can avoid some pitfalls.



An 'alive' CVS modeling for the whole body

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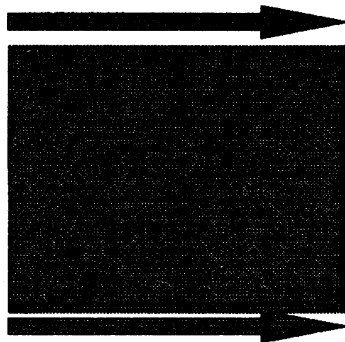
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FOUR Dynamic Phenomena in Insect Flight

Force generation
mechanisms



Flight control
mechanisms



@Complicated wing
kinematics

@Unsteady aerodynamics in
terms of vortex dynamics

@Low Res < 10^4

@Conventional 'quasi-
steady' theory never works

@Multi-body Dynamics with
6DOF

@High freq. 20~1000Hz

@Dynamic flight stability

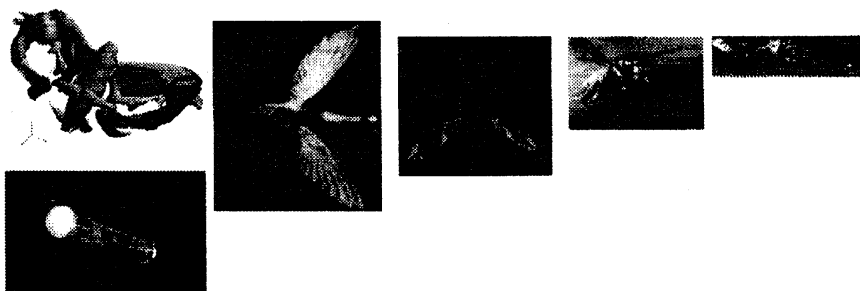
@Maneuverability

**Four Dynamics, large-scale simulation on flight dynamics,
aerodynamics, structural dynamics, and thermodynamics**

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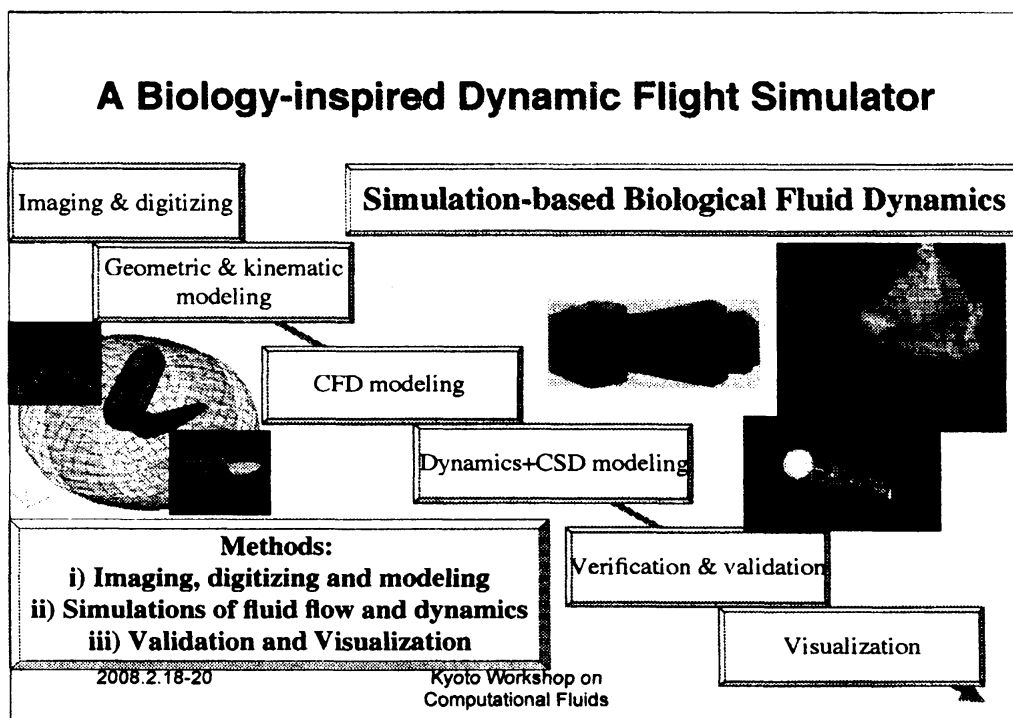
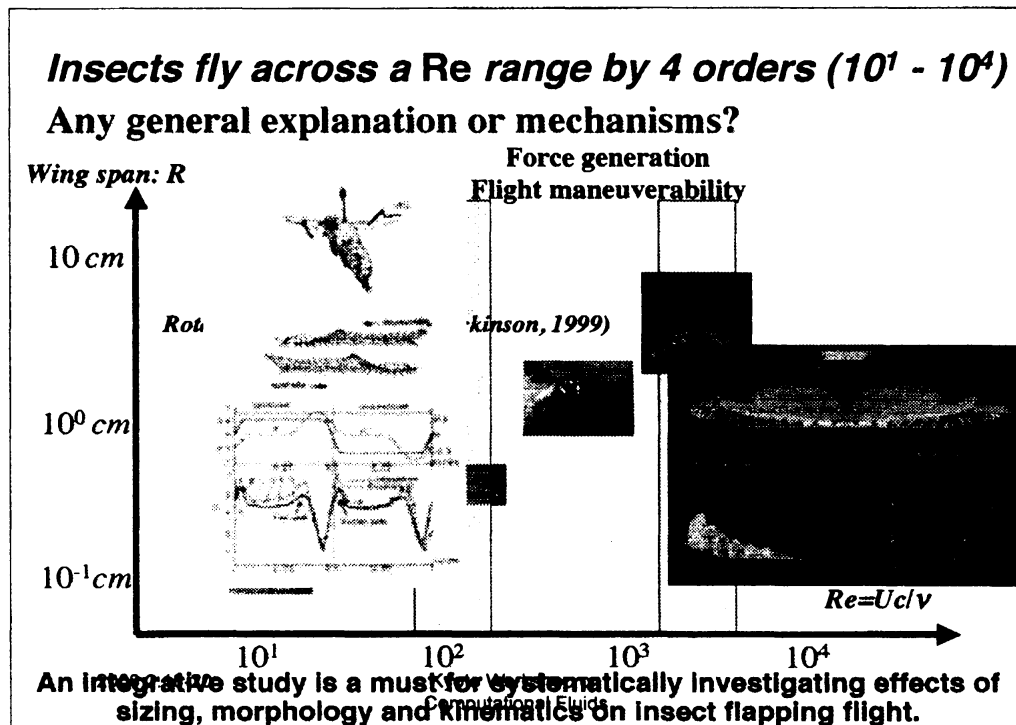
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Novel Mechanisms in Insect Flapping Flight



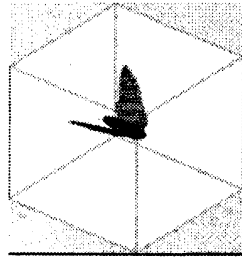
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A Biology-inspired Dynamic Flight Simulator continued

Aerodynamics

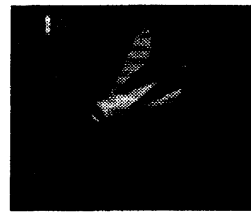
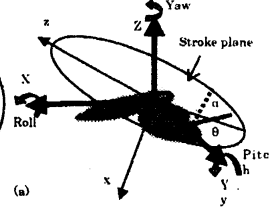
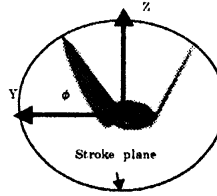


Flight dynamics

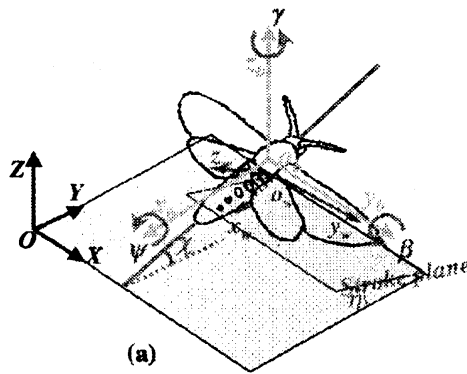
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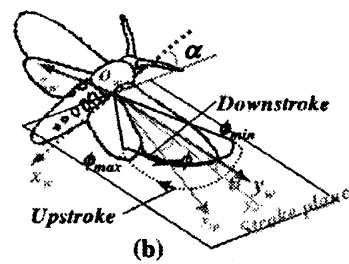
Energetics: Force, Moment and Power



Pressure-gradient, Centrifugal, and Coriolis forces



(a)

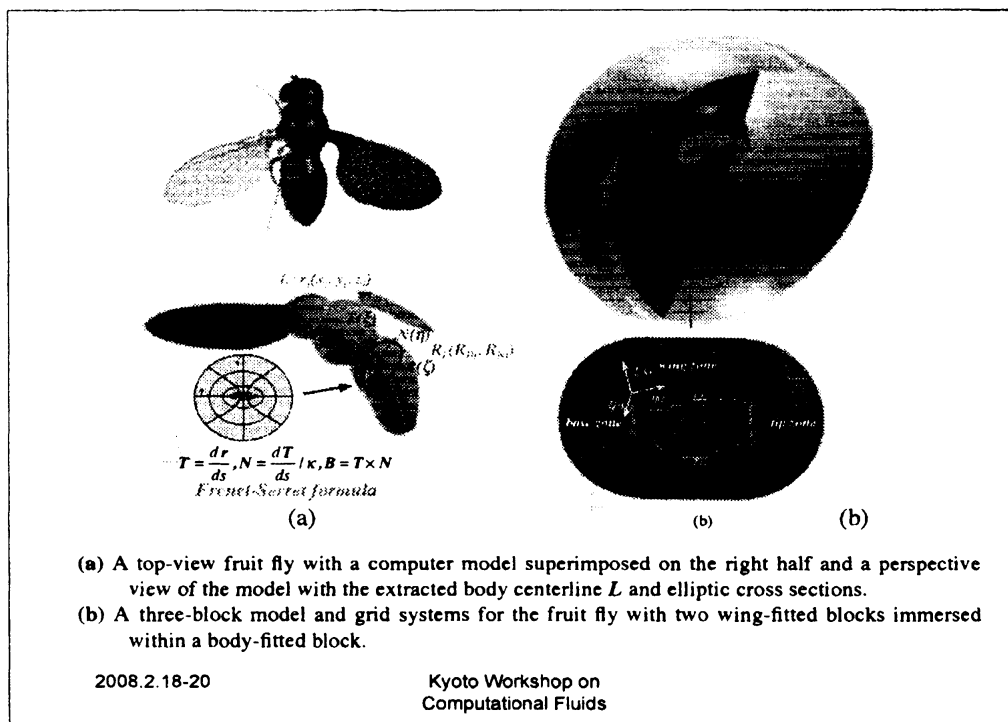


(b)

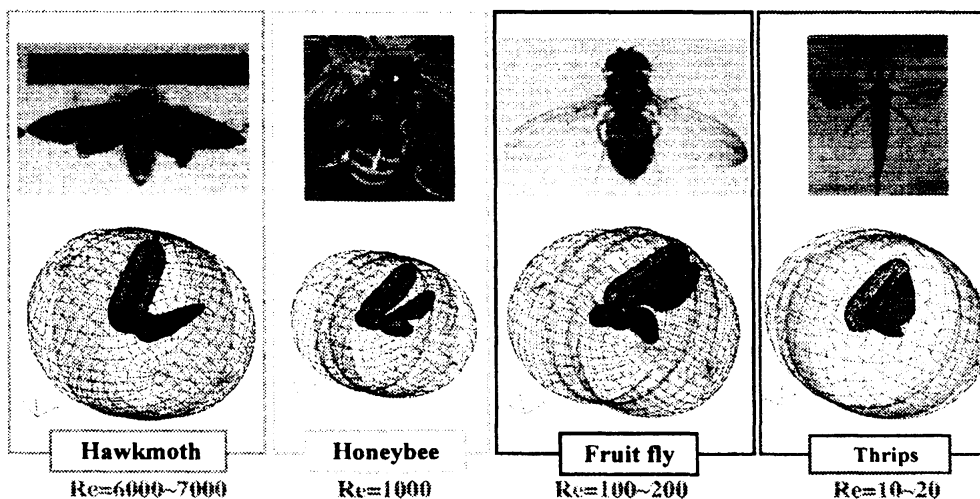
- (a) Three systems: wing-fixed system (x_w, y_w, z_w), the body-fixed system (x_b, y_b, z_b), and the global system (X, Y, Z); the stroke plane angle η and the body angle χ ; the angles of pitch β , roll ψ , and yaw γ with respect to the body-fixed system.
- (b) Wing position parameters within the stroke plane: the wingtip path, the positional angle ϕ , the elevation angle θ , and the angle of attack α .

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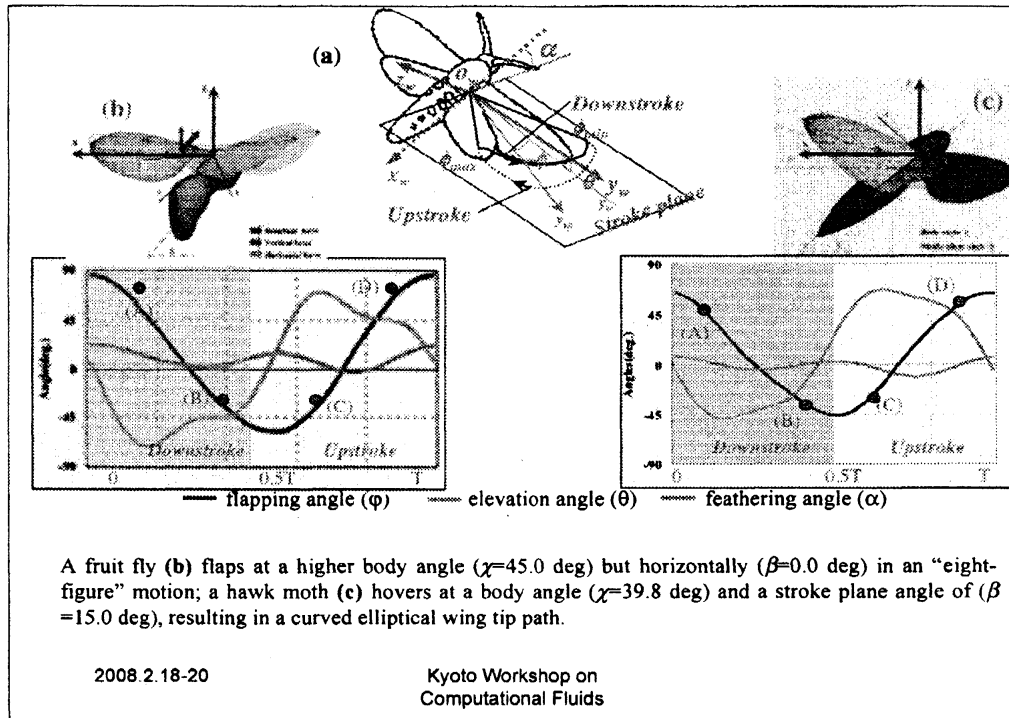
Morphological models of four typical insects over a wide range of Re s of $O(10^1)$ to $O(10^4)$



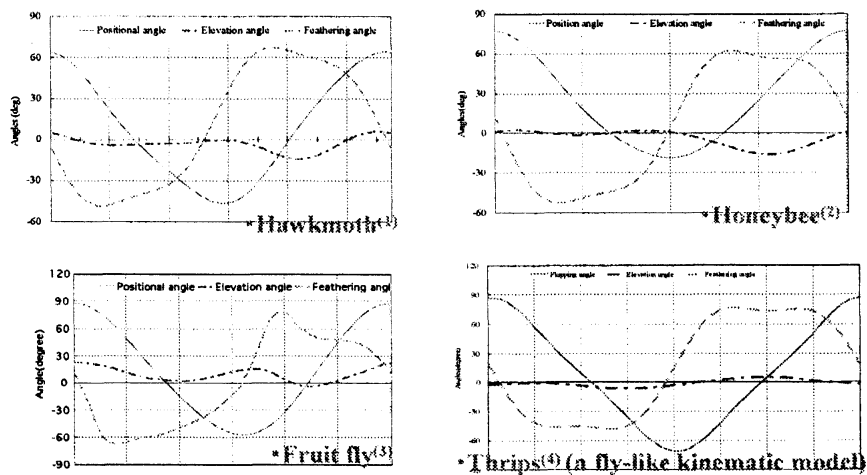
Hawkmoth: wing(45×45×31), body(45×43×95) Honeybee: wing(45×45×31), body(45×45×95)
Fruit fly: wing(45×45×31), body(45×47×95) Thrips: wing(45×45×45), body(51×51×95)

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Outer-boundary : 2008.2.18-20



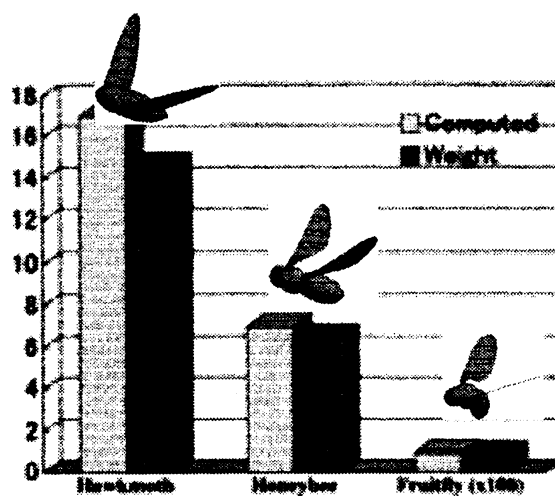
Kinematic models of four typical insects



- (1) A.P. Willmott., et al, *JEB*; 200 2705-2722 (1997)
 (2) D.L. Altshuler., et al, *PNAS*; vol.102; no.50; 18213-18218 (2005)
 (3) N.S. Fry, et al, *JEB*; 208, 2303-2318 (2005)
 (4) F.O. Lehmann, et al, *JEB*; 208, 3075-3092, (2005)

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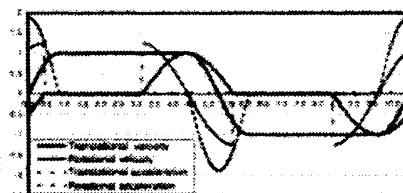
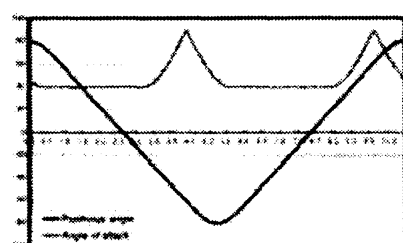
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Weights and computed lift forces (mN) in hovering flights of hawkmoth, honeybee and fruitfly.

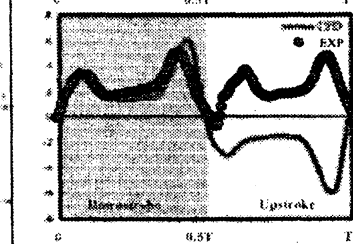
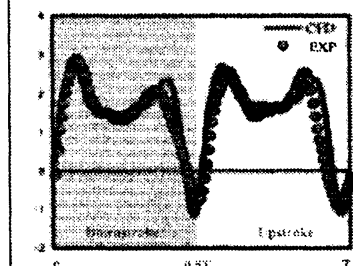
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(a)

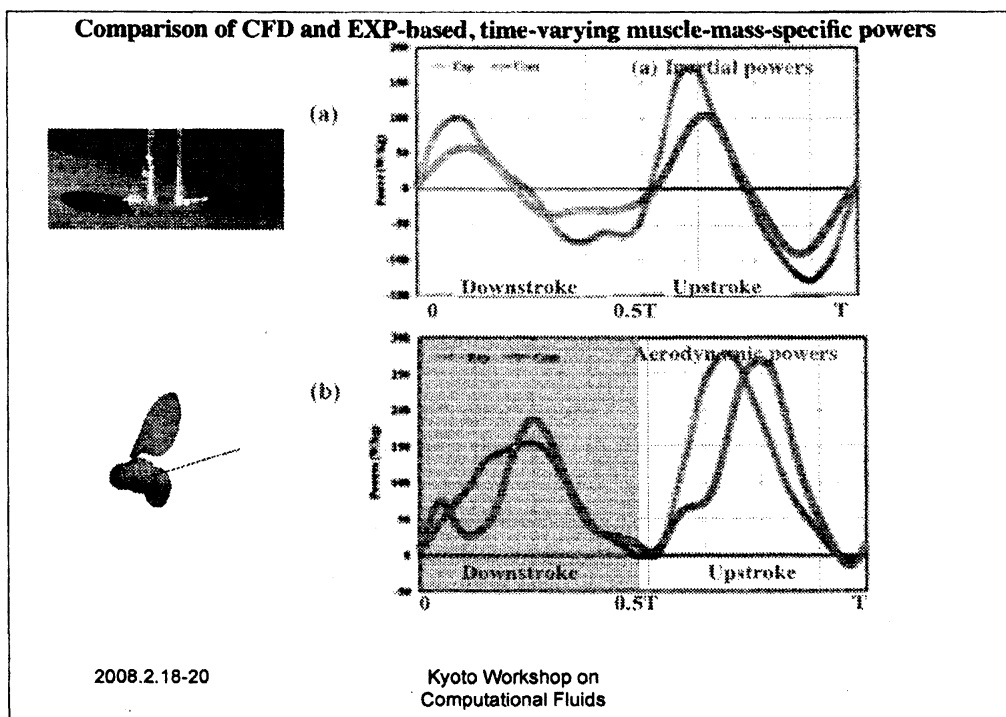
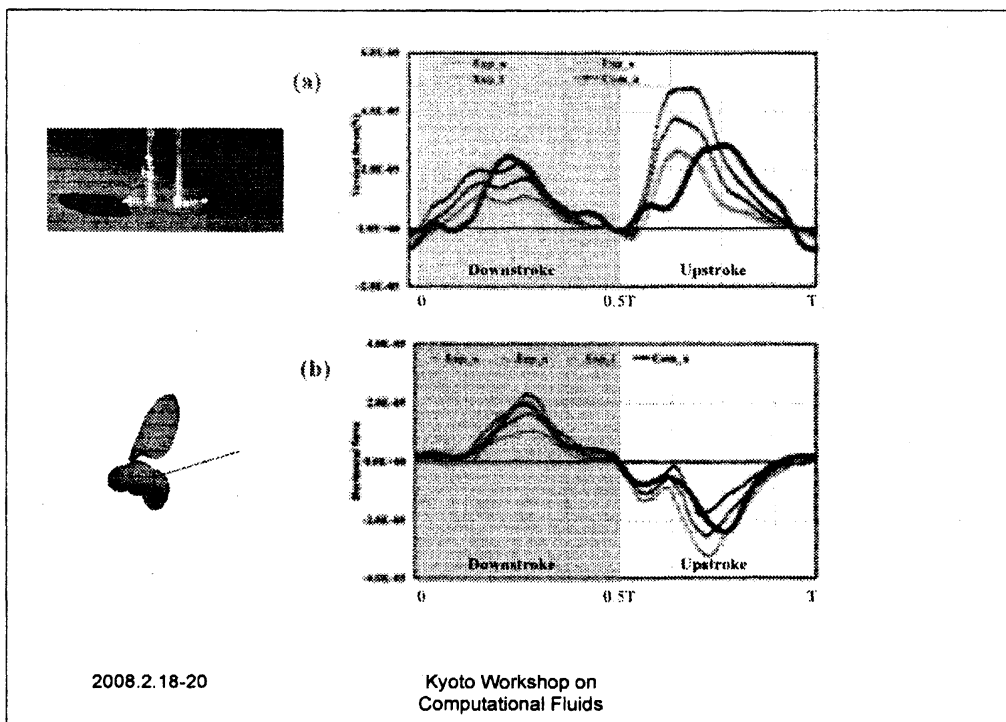
(a) Idealized wing movements of translation and rotation (angles, velocities and accelerations). (b) Time course of lift and drag force coefficients compared with EXPs

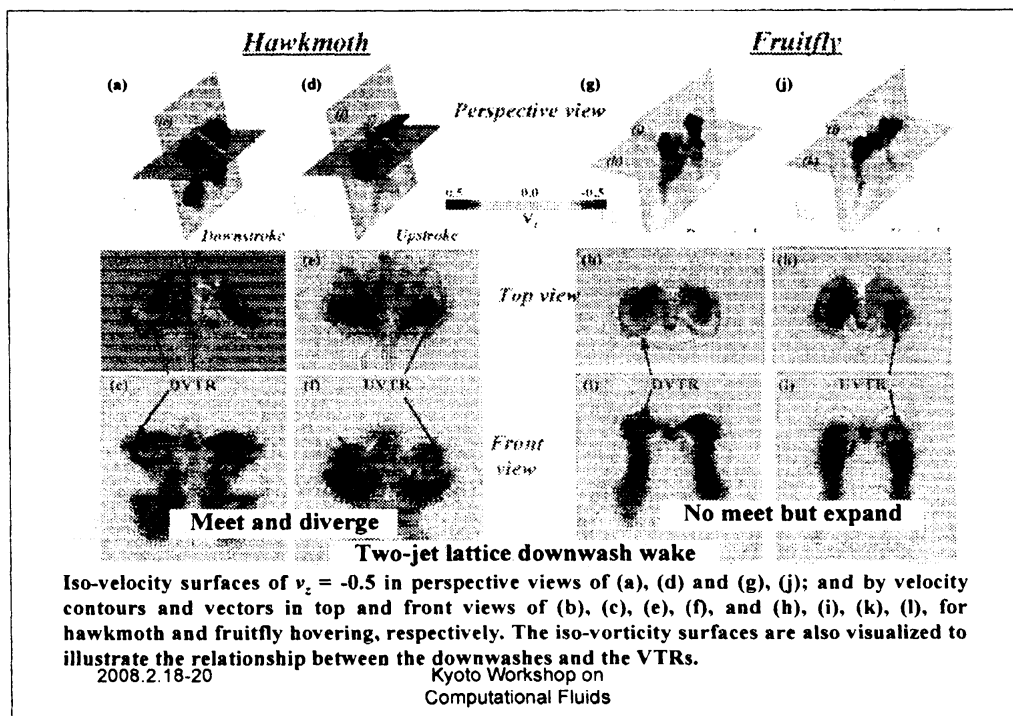
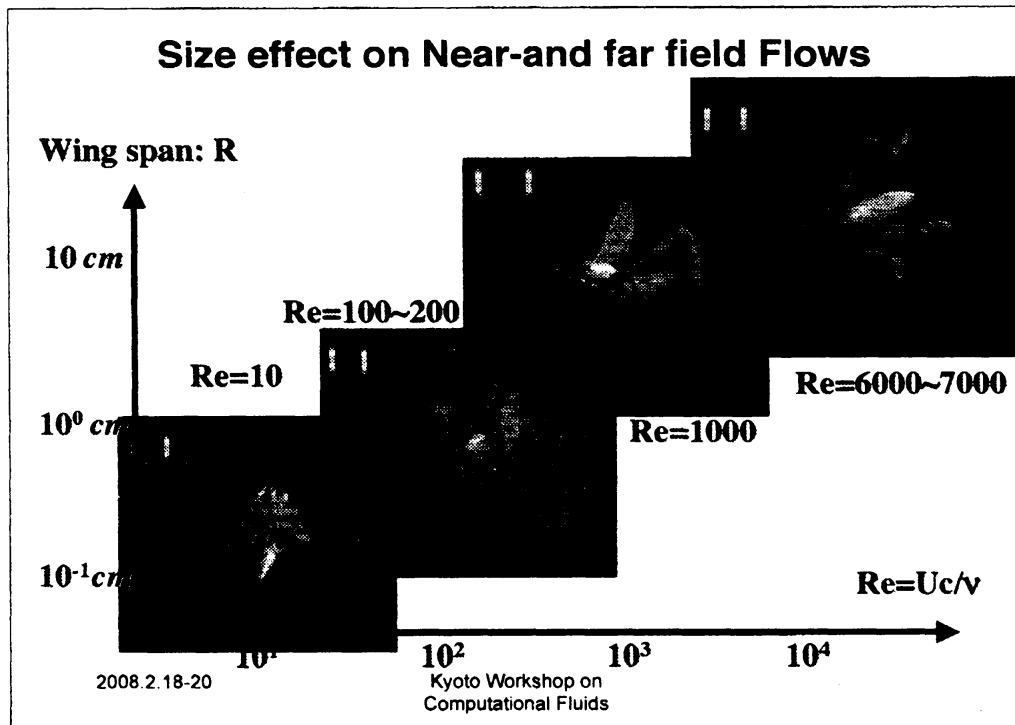


(b)

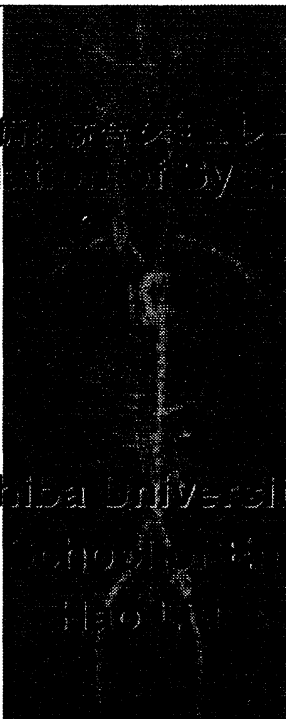
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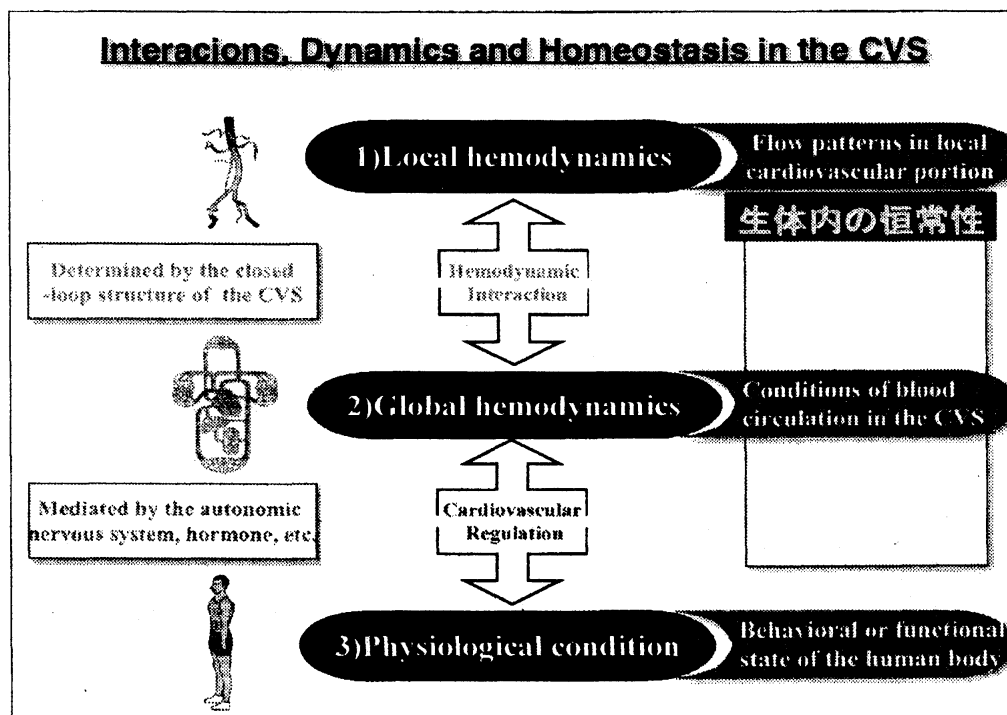


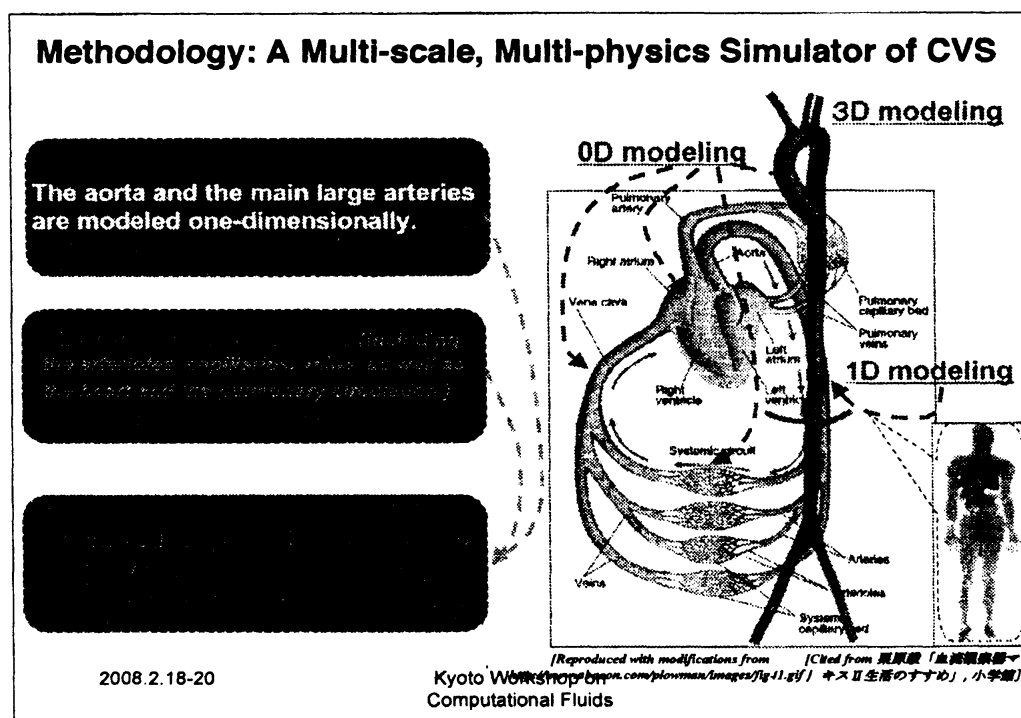
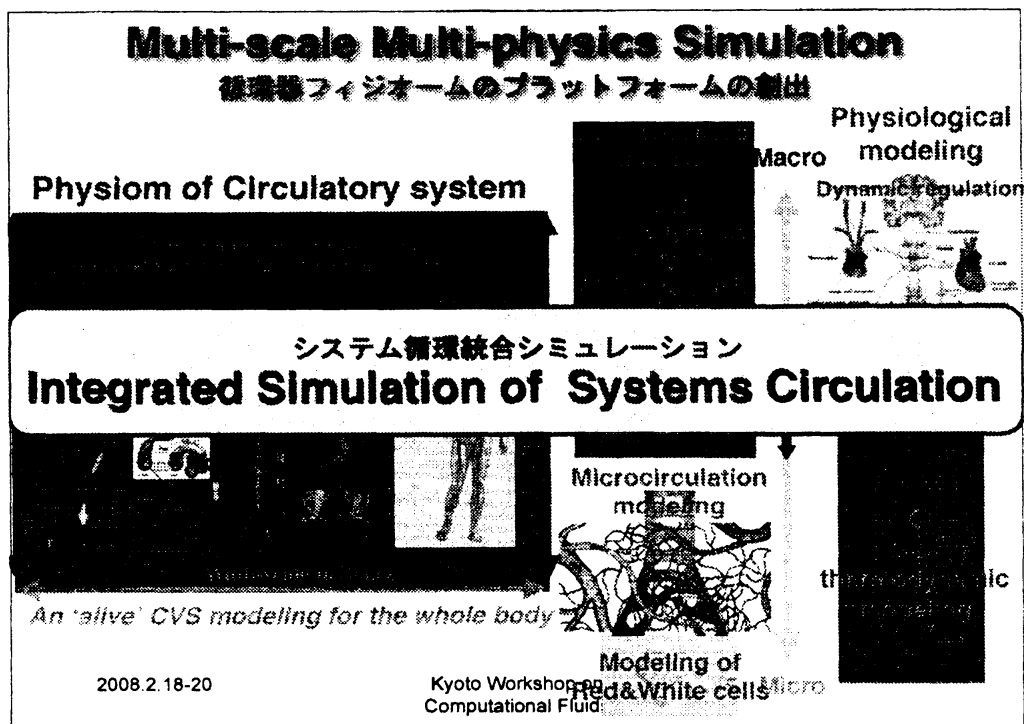
システム統合が人体のシミュレーション
Integrated Simulation of Systems Circulation



Chiba University
Graduate School of Engineering

2008.2.18-20



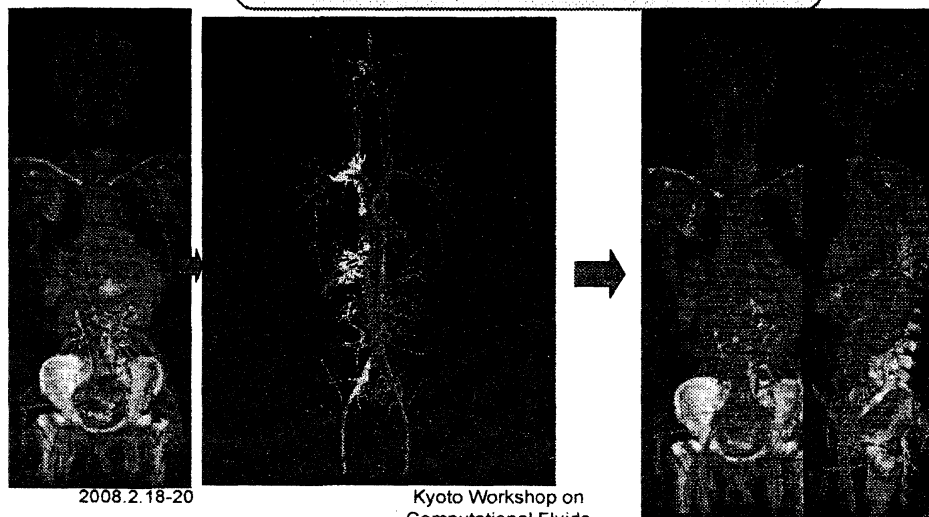


A prototype, anatomically realistic arterial-and venous -tree model

A Global Arterial- and Venous-Tree model

A VHP-based prototype model (A:266; V:117)

A CT/MRI-based, individual model

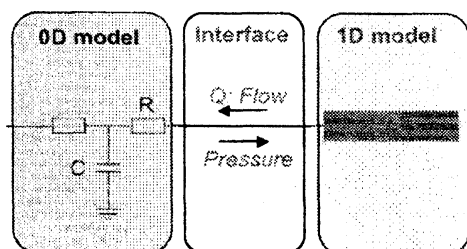


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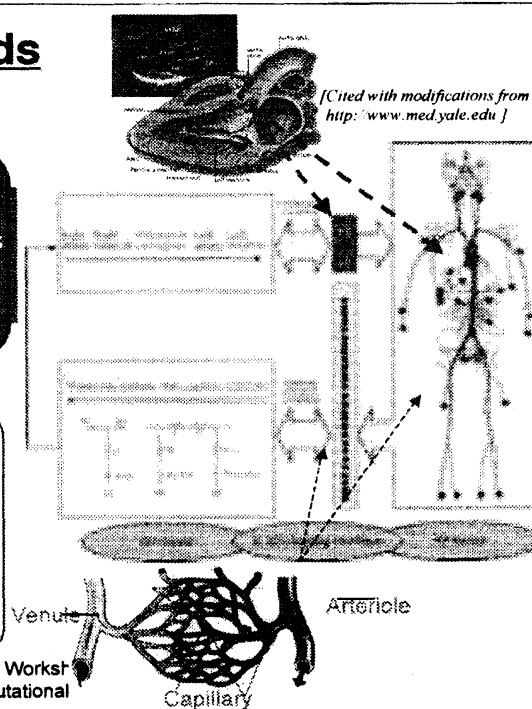
0-1D coupling methods

0-1D coupling is implemented at the aortic inlet and the distal ends of the large arteries via pressure-flow exchange.

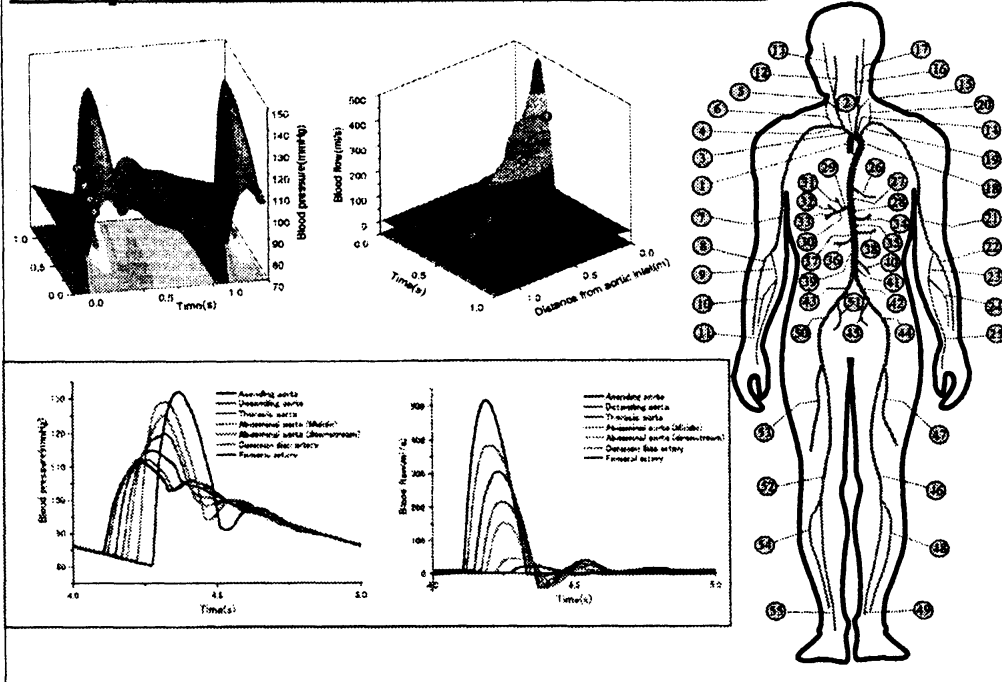


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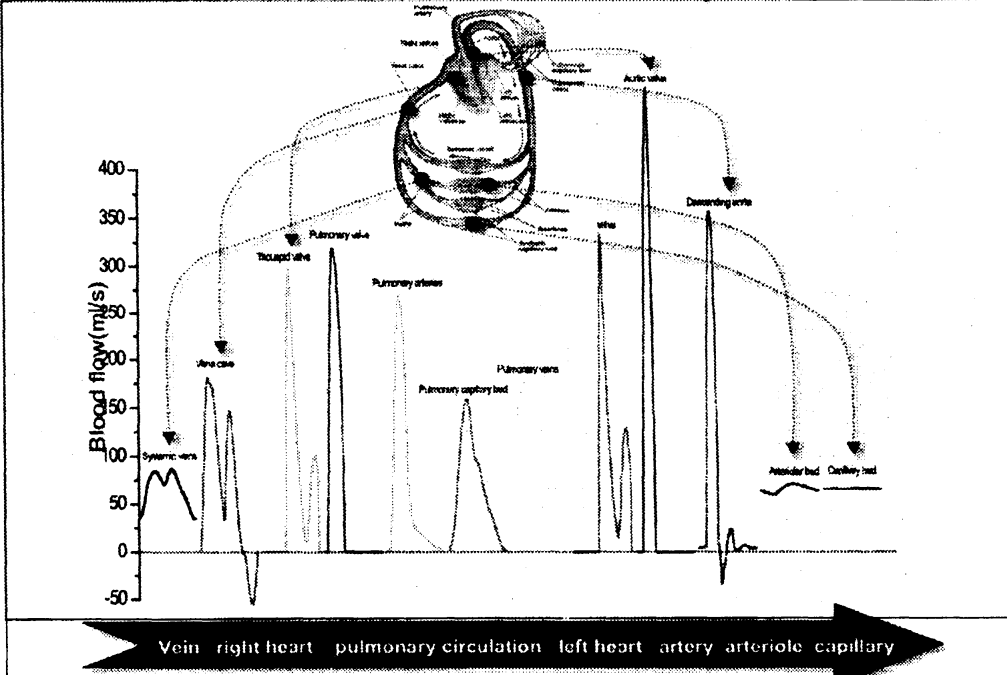
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Computational



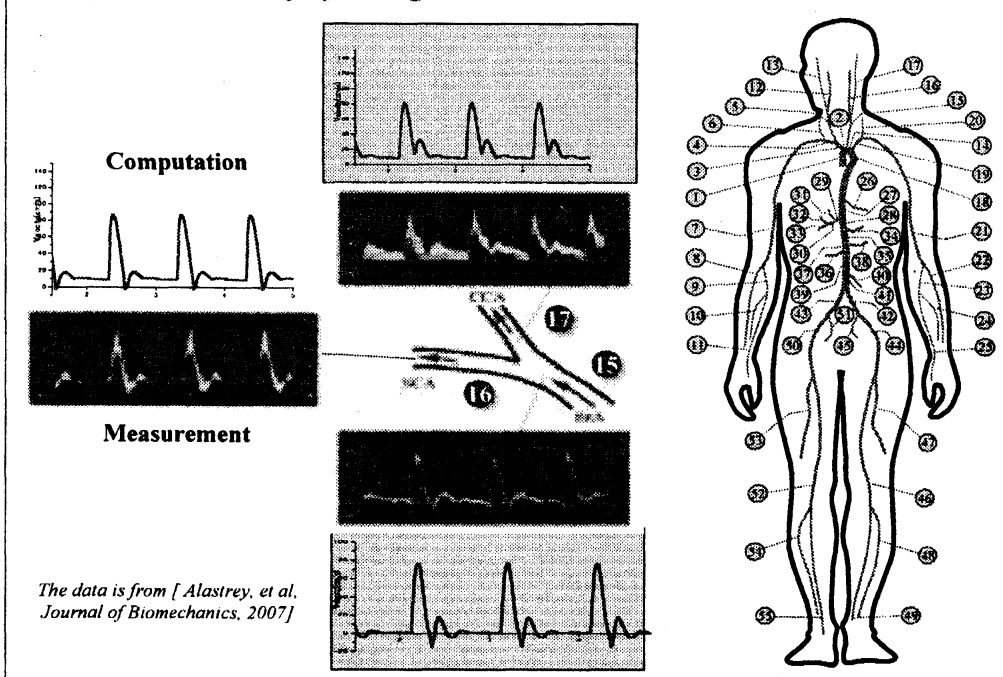
Blood pressure/flow waveforms in the arterial tree



Flow waveforms in the whole cardiovascular system

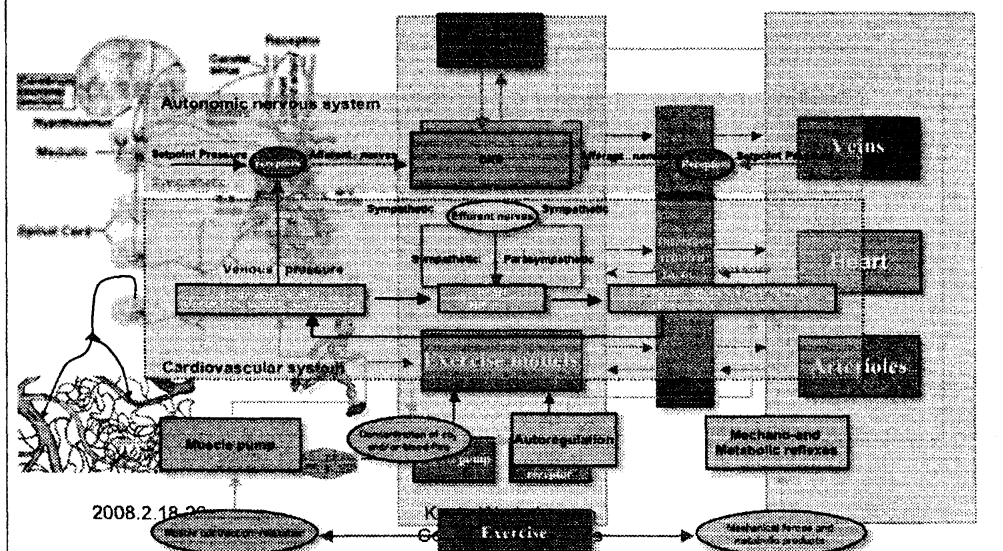


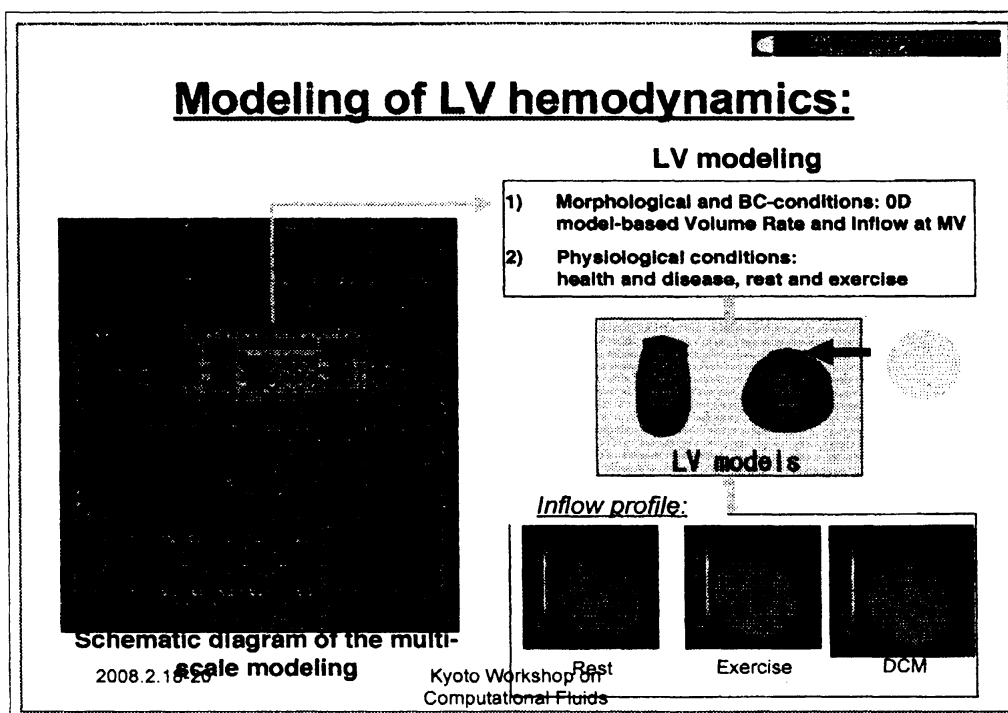
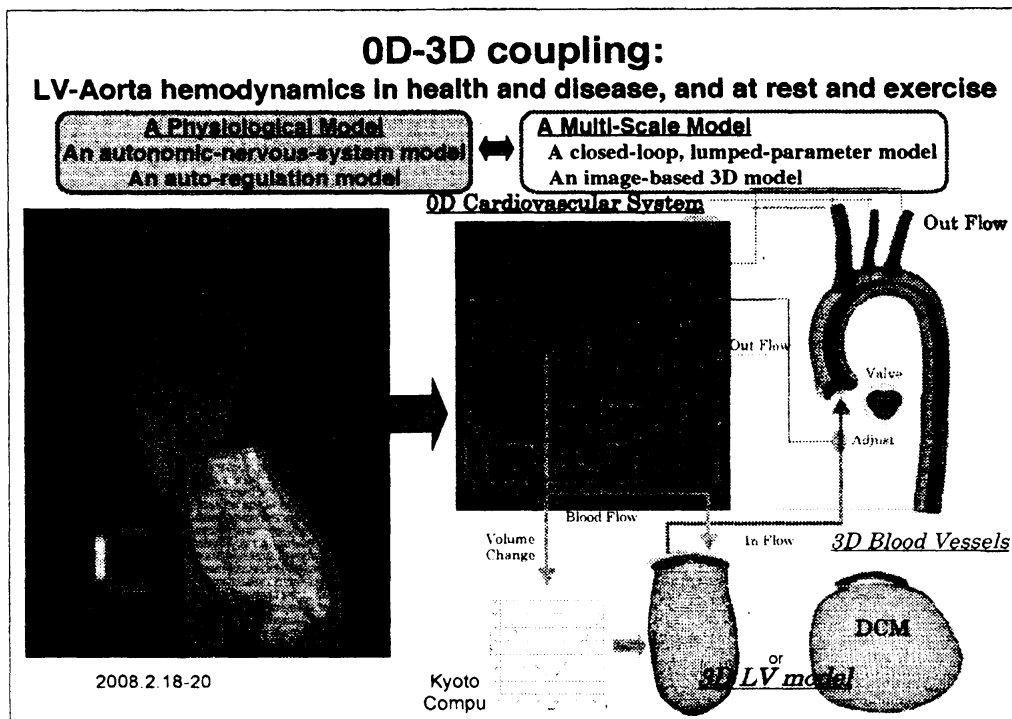
Comparison with physiological data



ANS Modeling

Physiological models and their coupling with 0D model





LV hemodynamics: DCM

National University Corporation
Kyoto University



The vortex ring in the vicinity of ventricle apex persists almost a whole cardiac cycle, especially the presence of the vortex ring in systole is thought to dissipate the contraction energy of ventricle thus compromising the ventricular pumping function.

Summary:
Enlargement of the ventricle
Spherical transformation of the ventricular shape

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An integrated LV-AA-model:

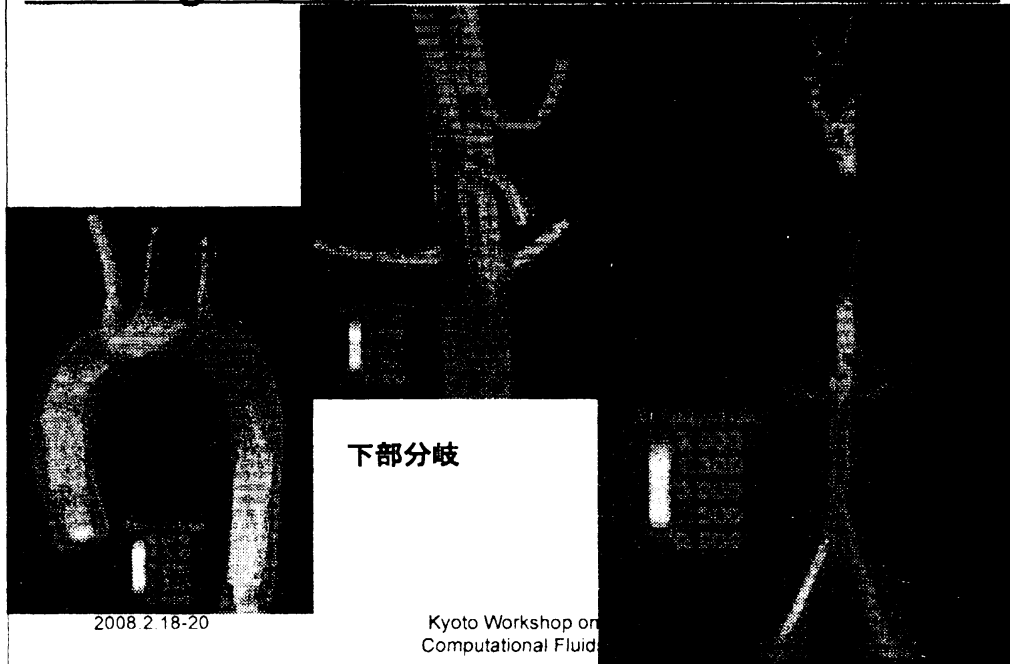
National University Corporation
Kyoto University



Rest **Exercise** **DCM**

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An integrated LV-AA-Multi-Bifurcation model:

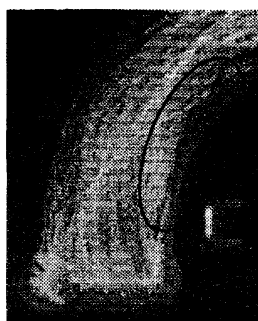


血管壁ずり応力分布



Influence of valsalva sinus

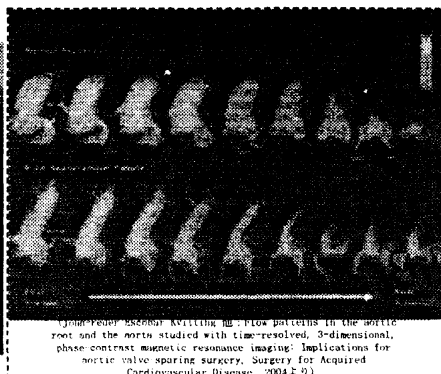
MRA measurement



With sinus



Without sinus



The valsalva sinus seems to stabilize the vortex flow in the Asc. A.

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Influence of valsalva sinus

Measured

Computed



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Future Directions

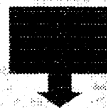
- **Physically, it should be integrated.**
Multi-scale and multi-physics over a huge range on an order of 10^9
- **Computationally, it must be large-scale.**
Parallelization and grid computing
- **In interdisciplinary, it should merge with experiments.**
Systematic verification & validation,
in vivo and *in vitro*

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A universal rule in biological systems:

Local Worse, Global Best!



**Toward 'Computational'
System Biomechanics**

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