# More innovation using Cradle SC/Tetra and Abaqus for FSI simulations

Yuya Ando
Cradle North America Inc.

# Corporate Profile

CRADLE

***Establishment:*** **March 22, 1984**

***Employees:*** **110+ worldwide**

***Offices:***

**Headquarters:** **Osaka, Japan**

**Branch Offices:** **Tokyo, Japan**

**Dayton, OH USA (Global Business Center)**

**Lyon, France**

**Affiliated:** **Bangalore, India**

**Taipei, Taiwan**

***Distributors:***

- Korea
- China
- Mexico
- France
- Italy
- Hungary
- Turkey
- Spain
- UK

**Headquarters**
**Osaka, Japan**

**Cradle North America, Inc.**
**Dayton, OH**

**Tokyo, Japan**

# Business

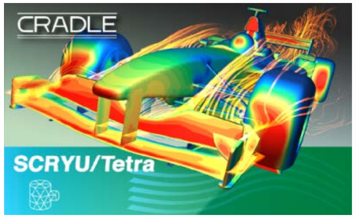
- Software Development
  - CFD software
  - Structural Analysis software (FEA)
  - Data cleaning and modification software
  - Optimization
- Engineering Services
  - Simulation service
  - Consultation
  - Customization
  - Automation

# Products

CRADLE

## CFD

## MAIN INDUSTRIES:



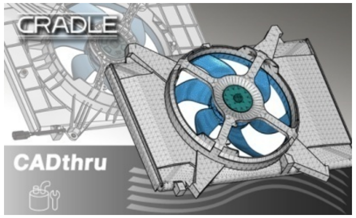

Multi-purpose CFD
Unstructured Mesh
**SC/Tetra**

- Automotive / Aerospace
- Marine / Machinery
- Turbo machinery / chemicals
- Energy / Electrical Appliances


Multi-purpose CFD
Structured Mesh
**scSTREAM**

- Buildings & Architectures
- Civil & Oceanic engineering
- Electronics / Chemical
- Electrical Appliances

## Data Translator and Cleaner




**CADthru**

- Data Translation
- Data Cleaning
- Data Modification

# Awards

- **2002: Won JSME award (The Japan Society of Mechanical Engineering)**


- **2005: Awarded by METI (Ministry of Economy, Trade and Industry of Japan)**
- **2006: Won AEI2006 Tech Awards (Automotive Engineering International)**


- **2007: Certification of Visualization Award (APCOM 2007)**


- **2009: Best CFD Graphics Award (The Japan Society of Fluid Mechanics)**

# Content

1. Introduction to SC/Tetra
2. 2-way FSI simulation using Abaqus and SC/Tetra
3. Validation example
4. FSI simulation of Micro Air Vehicle



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# Content

1. Introduction to SC/Tetra
2. 2-way FSI simulation using Abaqus and SC/Tetra
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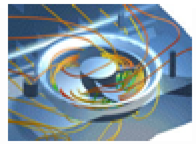
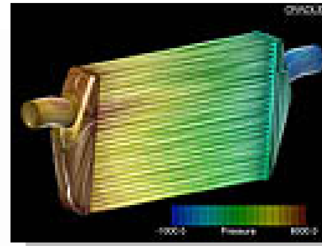
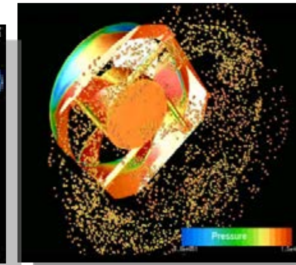
# 1. Introduction to SC/Tetra

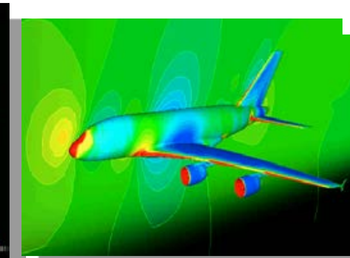
Multi-Purpose CFD Software
with Unstructured Mesh

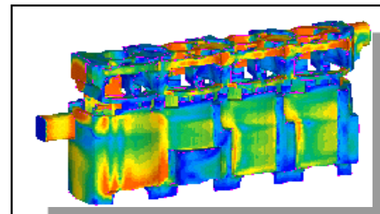
**SC/Tetra**

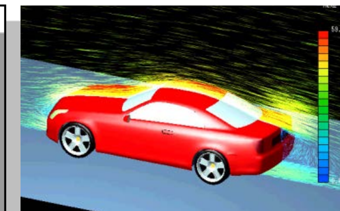












**General:**

SC/Tetra is all-in-one CFD software package consists of

- ***Preprocessor***
- ***Solver (FVM)***
- ***Postprocessor***
- ***Linear structure solver***
- ***Utility tools***

developed not only for CFD experts but also for the design engineers of all the industries.

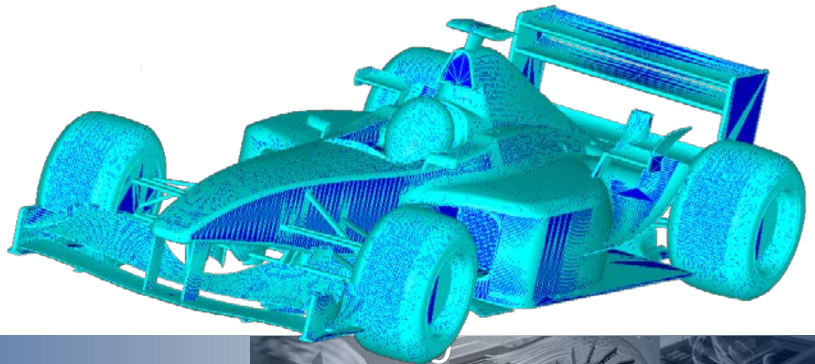
**Concept :**

To provide a practical engineering CFD software as a tool by providing:

- **Ease of use**
- **Computational speed**
- **High accuracy**
- **Low memory consumption**
- **Stability**

# 1. Introduction to SC/Tetra

- **Outstanding Features of SC/Tetra**
  - **User Friendly Interface and Usability**
  - **Fast-Robust-Controllable Mesher**
  - **Low Memory Consumption**
  - **Outstanding Computation Speed and Accuracy**



# 1. Introduction to SC/Tetra

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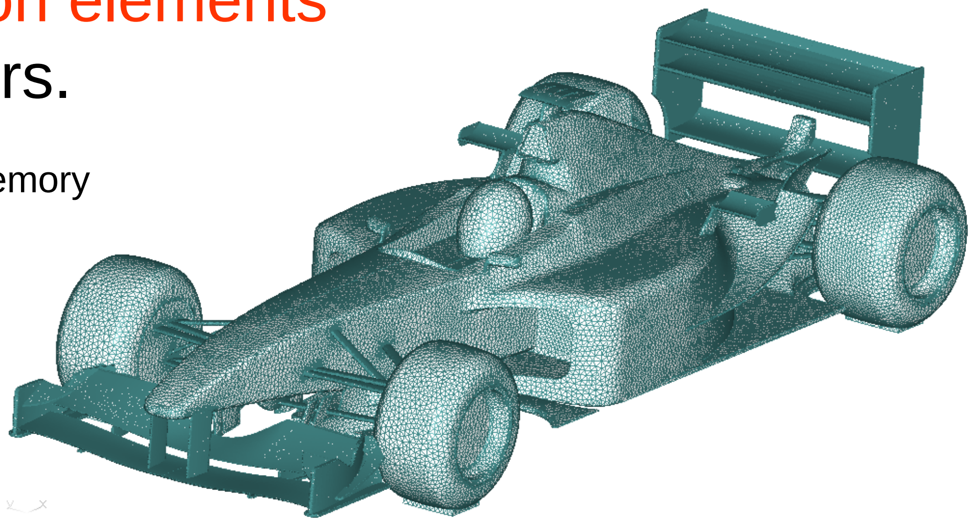
## ❑ Fast-Robust-Intuitive Mesher

***FAST and ROBUST:***

Less than 15 **min.** is required
to generate **15** million elements
including prism layers.

Windows XP x64 edition / 4GB memory
Intel Xeon 5580



Additional functions:

- Smoothing
- Prism layer adjustment (thickness, and No. of layers)
- Internal hexa-mesh
- Sweep mesh

# 1. Introduction to SC/Tetra

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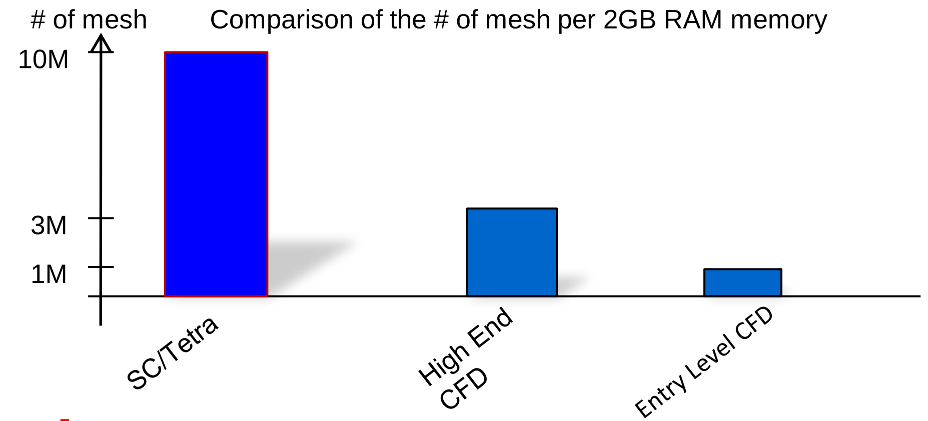
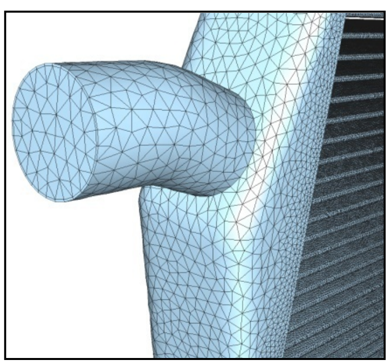
## Low Memory Consumption

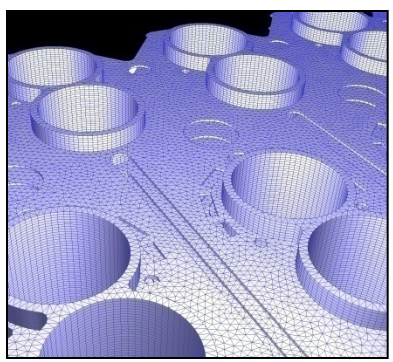
About 5 million elements/1GB!

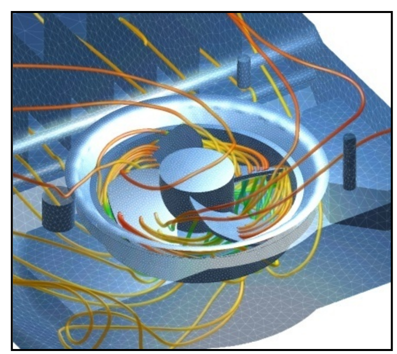
With 2GB : 10 million elements
With 8GB : 40 million elements
With 32GB: 160 million elements
With 64GB:  320 million elements

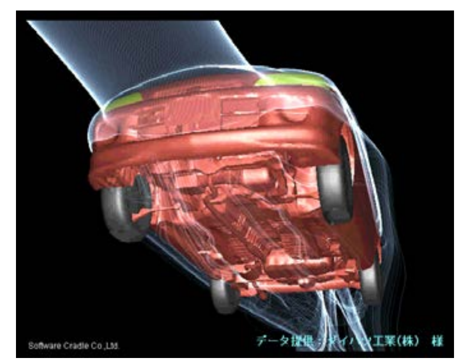



- ***More complicated geometry***
- ***Better accuracy***





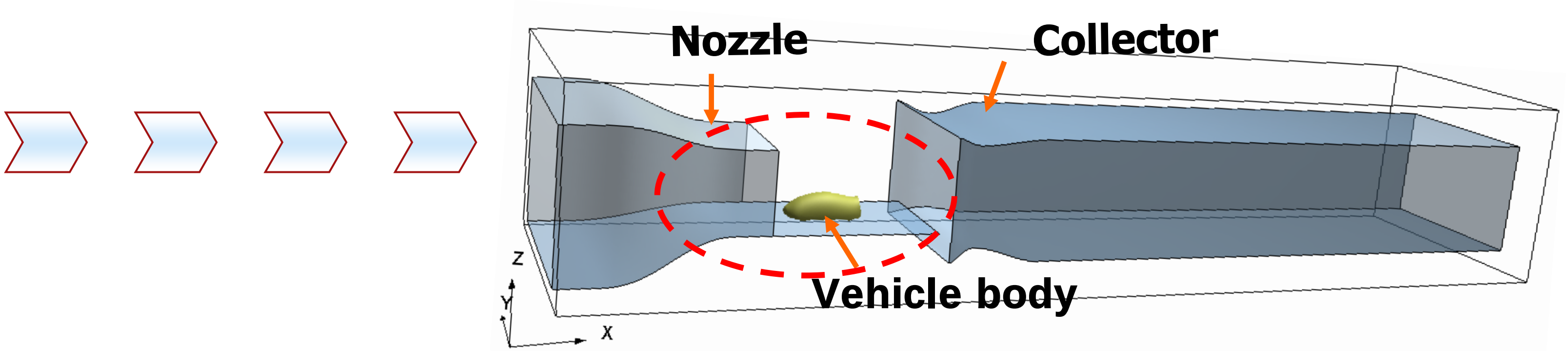


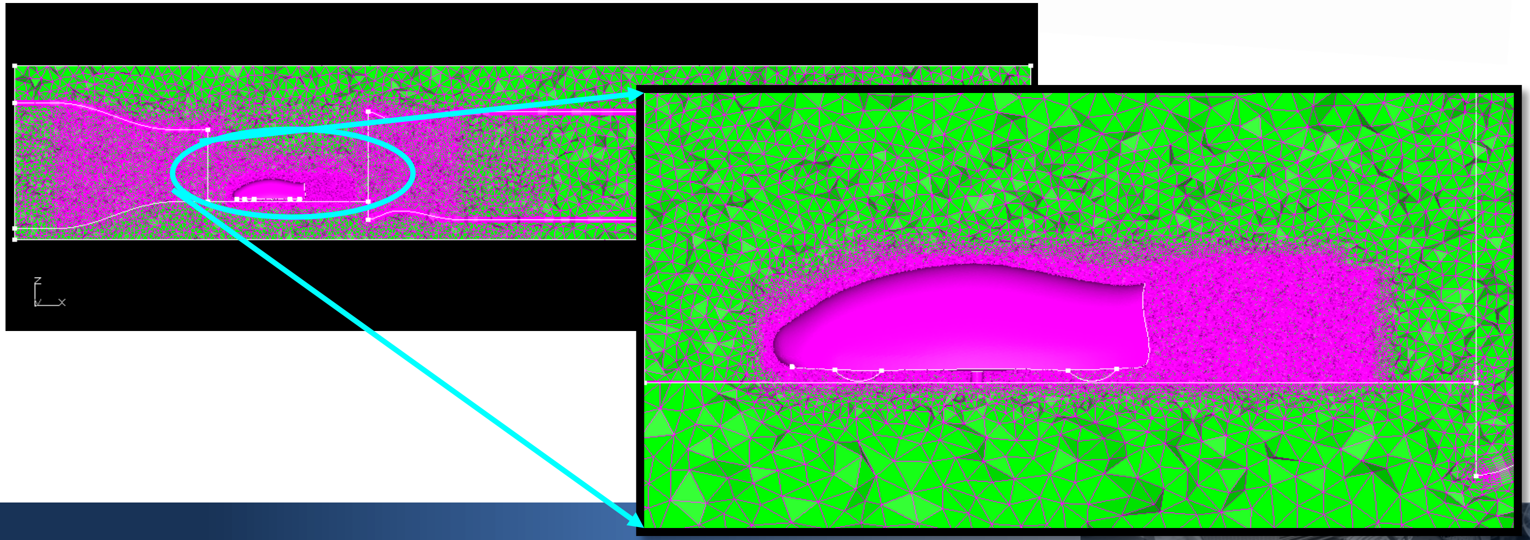


## Outstanding Computation Speed and Accuracy

# Comparison of Commercial CFD software (2006)

* JSAE symposium on Recent Activities in CFD toward Higher Quality, No. 08-06 (2006)



# 1. Introduction to SC/Tetra

## Outstanding Computation Speed and Accuracy

| | $C_D$ | $C_L$ |
|---|---|---|
| Experiments | 0.245 | -0.273 |
| Simulation | 0.247 | -0.275 |
| Difference | <1% | <1% |

[Reference 1] Kumano, T. Et al., Wind Tunnel Testing of a 1/5 Scale Vehicle Model (in Japanese), JSAE symposium on Recent Activities in CFD toward Higher Quality, No. 08-06 (2006).
(Japanese Title: 低C(D)車デザイン模型に基づくCFDベンチマーク )

[Reference 2] Shimano, K. Et al., Wind Tunnel Testing of JSAE Standard Low- aerodynamic-drag Vehicle Body Using 1/5 Scale Model, Review of Automotive Engineering, Vol. 30, No.1, (2009).

# 1. Introduction to SC/Tetra

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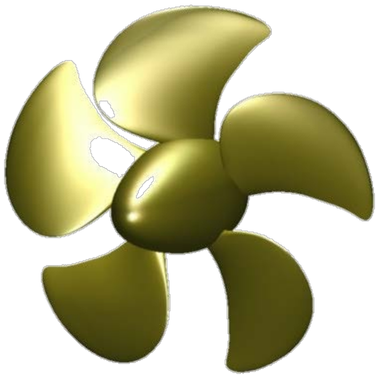
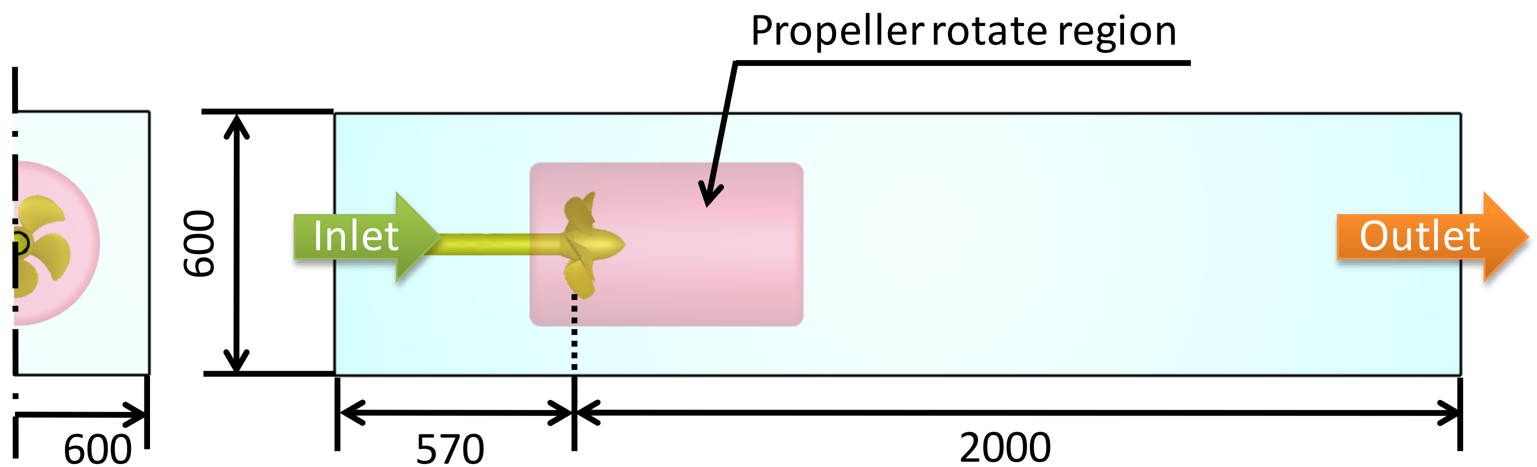
## Outstanding Computation Speed and Accuracy

### Cavitation analysis of PPTC using CFD

*PPTC: Potsdam Propeller Test Case



- Model propeller (Experimental conditions)
  - Diameter： 250 mm
  - Rotation speed： 25 rps
  - Velocity： 6.365・7.927・8.805 m/s
- Computational domain:
  - L×W×H = 600 mm×600 mm×2570 mm



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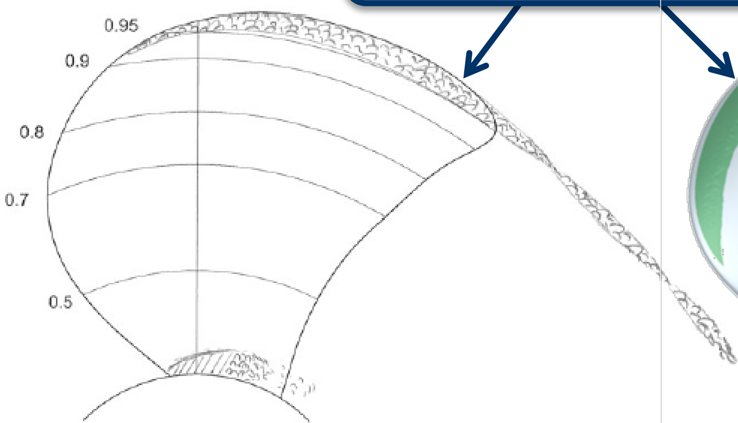
## Outstanding Computation Speed and Accuracy

Comparison of analysis and experimental results

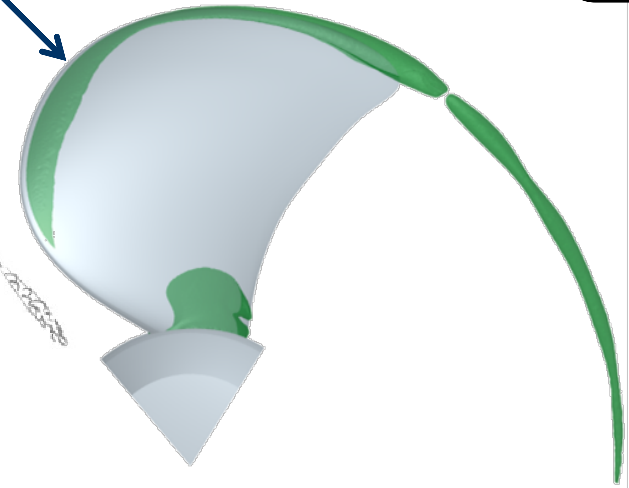
- **J = 1.019 (Velocity = 6.365 m/s) σ = 2.024**

$K_T$ (Thrust coefficient)
Exp : 0.3725
Cal : 0.3750 (+0.67%)

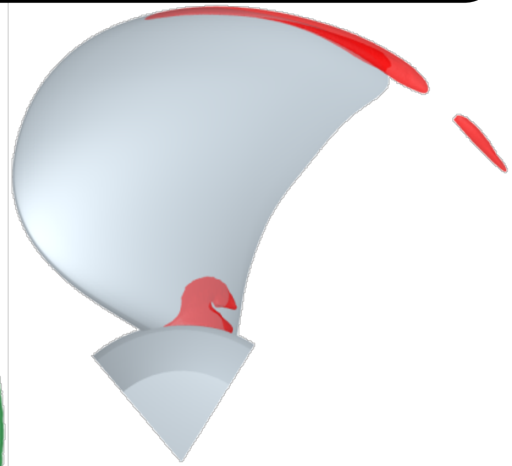
Cavity region




**Sketch (Experimental)**



**Void fraction: 20%**



**Void fraction: 50%**

Fujiyama1, K., Kim, C., Hitomi, D., (2011), Performance and Cavitation Evaluation of Marine Propeller using Numerical Simulations. Second International Symposium on Marine Propulsors (smp‟11), Hamburg, Germany.

# 1. Introduction to SC/Tetra

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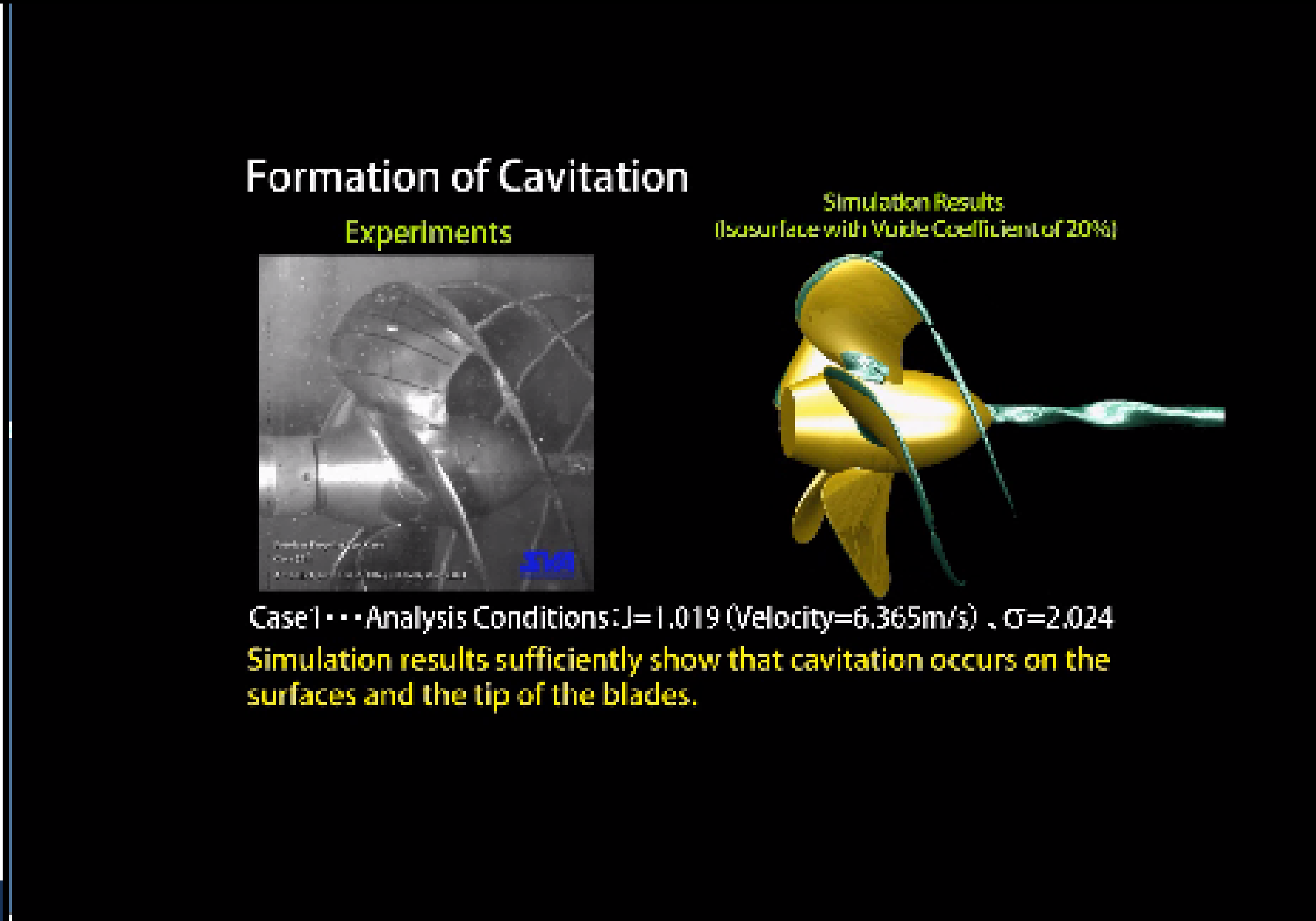
## ❑ Outstanding Computation Speed and Accuracy

$K_T$ (Thrust coefficient) Exp: 0.3725 Cal: 0.3750 (+0.67%)

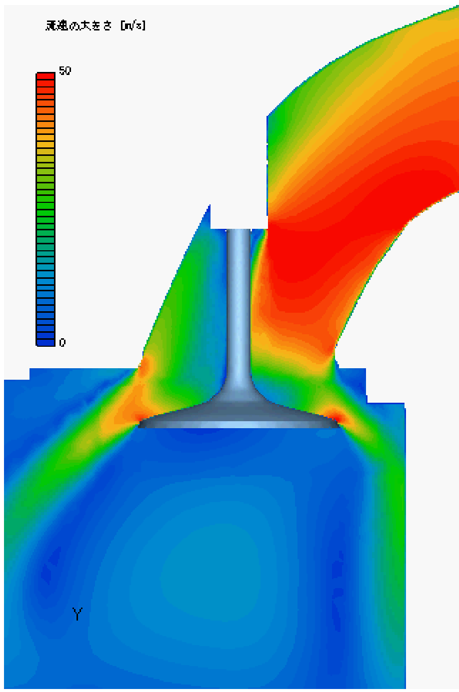


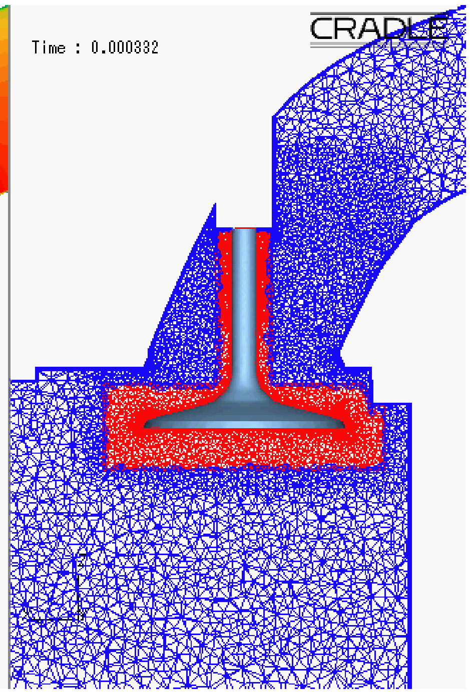
# Unique and Advanced Features of SC/Tetra

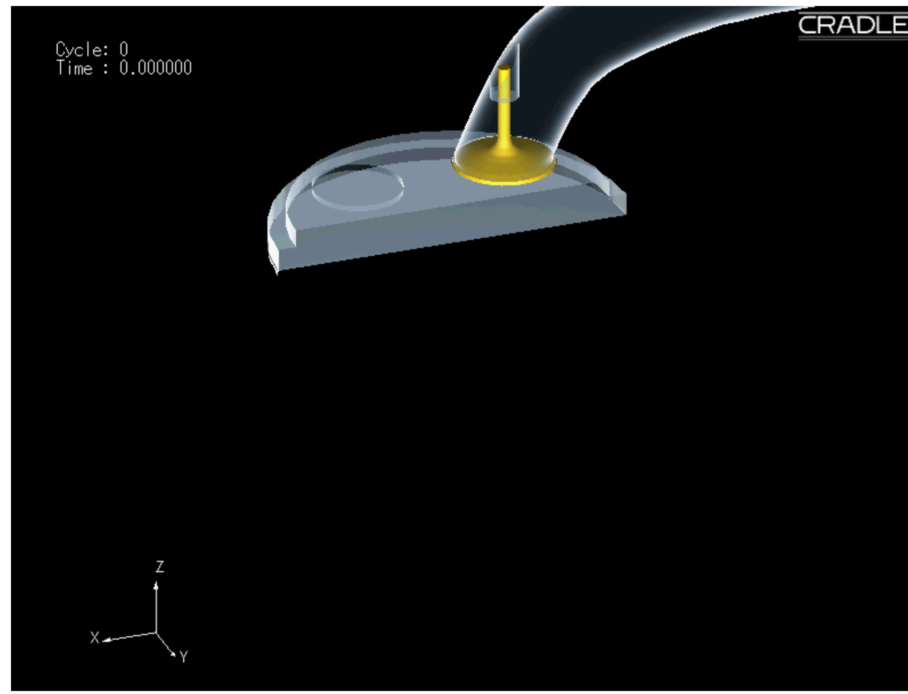
# 1. Introduction to SC/Tetra

## Advanced Motion Handling

***ALE / Passive Motion / Overset Mesh***

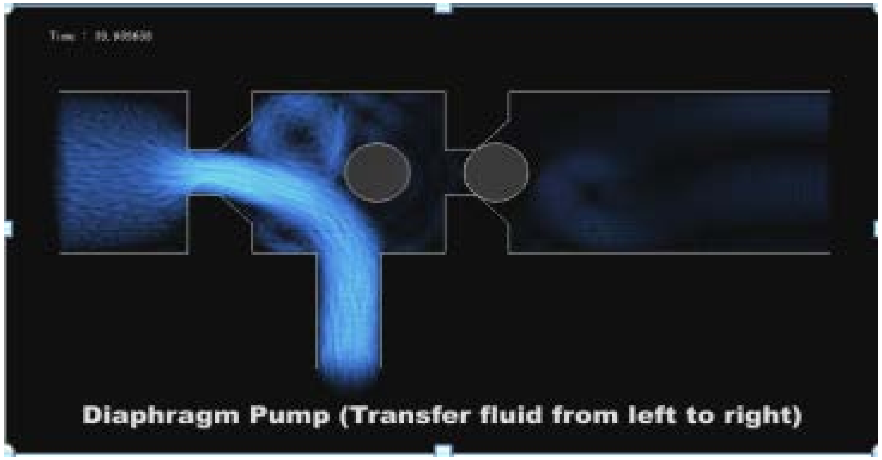


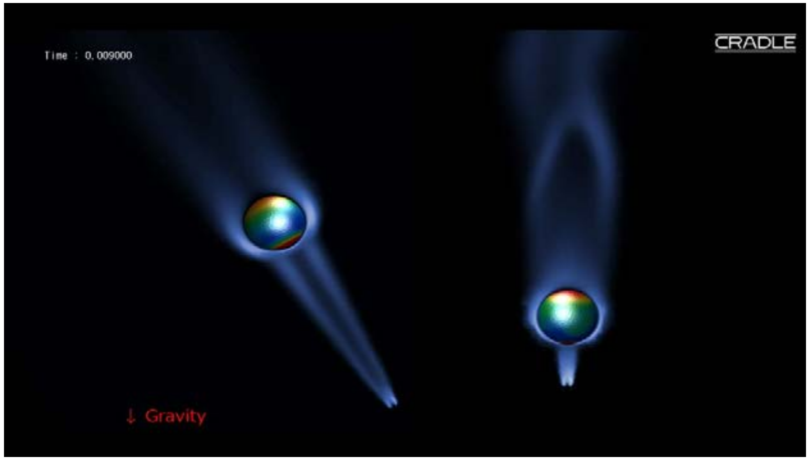



## Advanced Motion Handling

***ALE / Dynamic Motion / Overset Mesh***

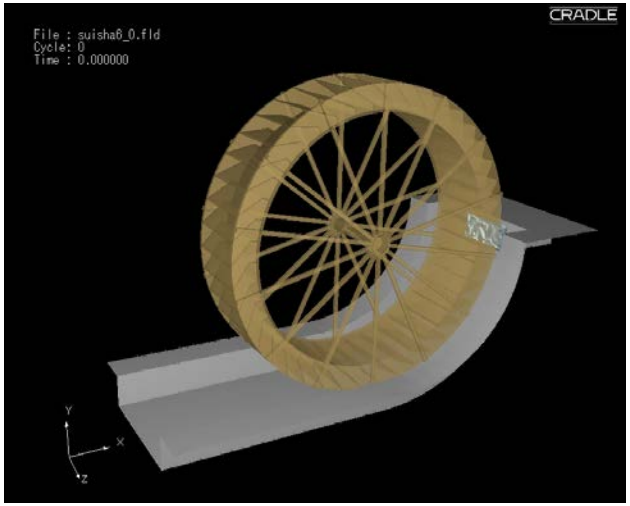


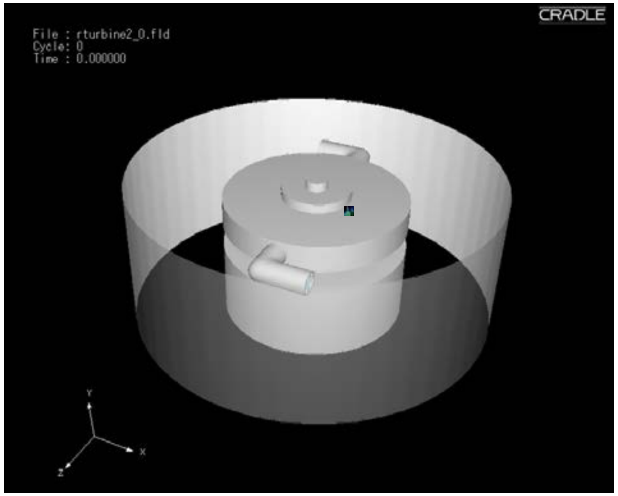



1. Introduction to SC/Tetra

## Advanced Motion Handling

***VOF method with ALE and Dynamic/Passive motion***



# Content

1. Introduction to SC/Tetra
2. 2-way FSI simulation using Abaqus and SC/Tetra
3. Validation example
4. FSI simulation of Micro Air Vehicle

# 2. 2-way FSI simulation using Abaqus and SC/Tetra

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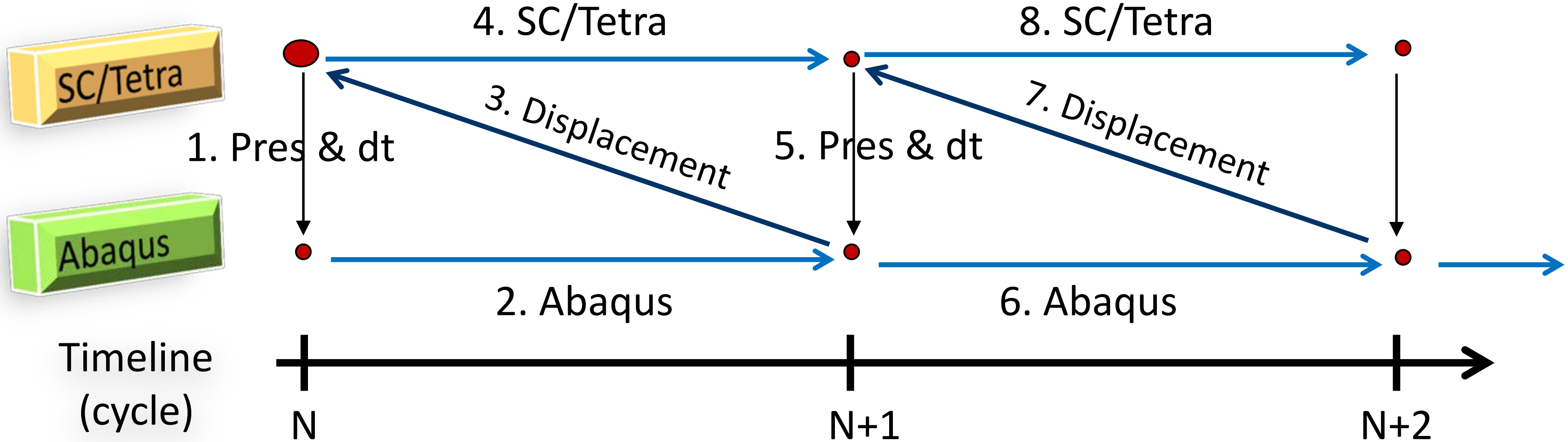
- **Requirements**
  - SC/Tetra V10 and higher
  - SC/Tetra I/F Option for Abaqus
  - Abaqus 6.12 and higher (minimum of 5 tokens)

- **Communication Method:**
  - Using Direct Coupling Interface provided by Abaqus
  - Gauss-Seidel method/Iterative coupling



# 2. 2-way FSI simulation using Abaqus and SC/Tetra

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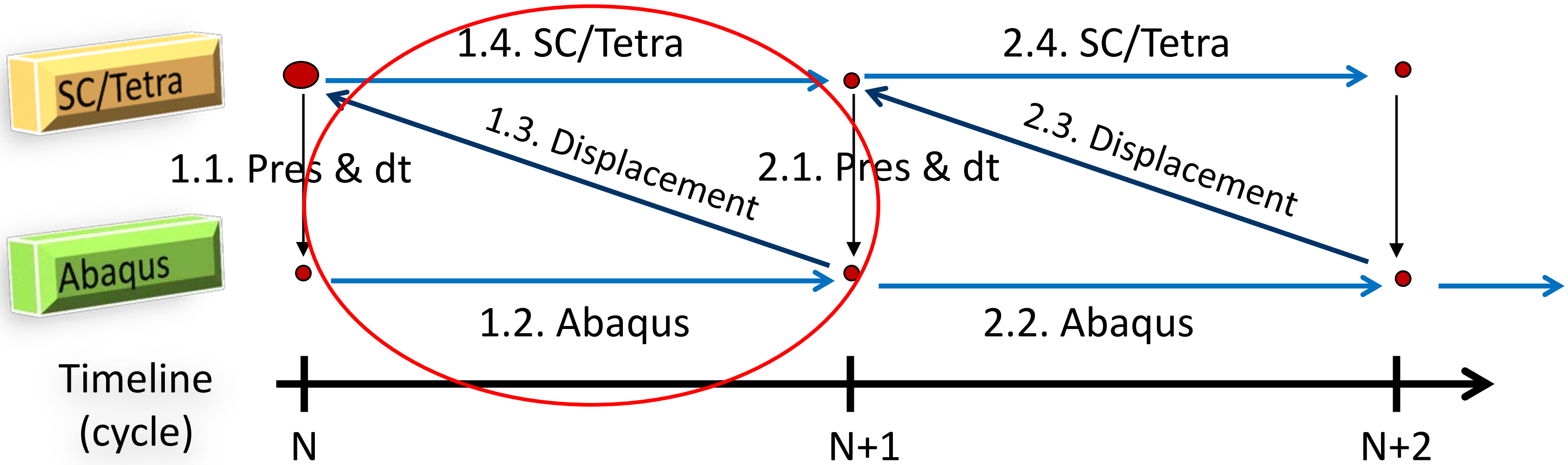
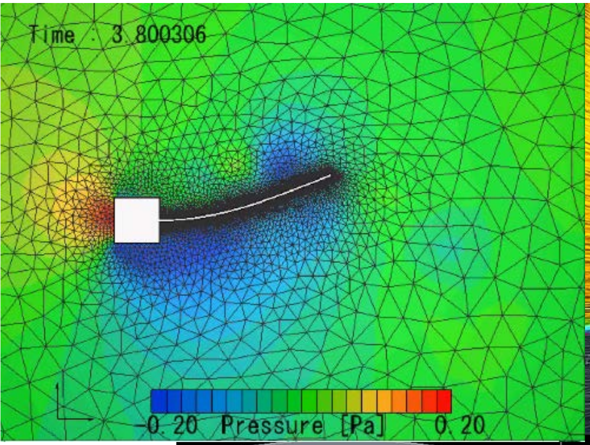
- **Communication Method:**
  - Iterative coupling

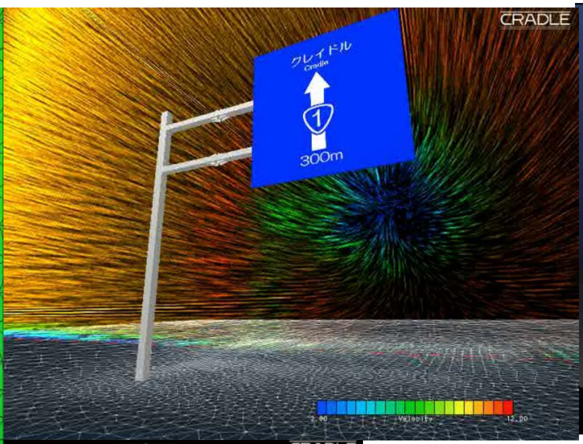


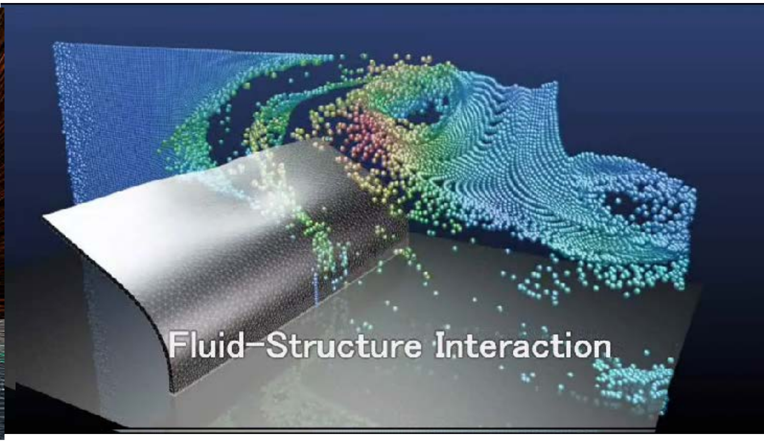
# 2. 2-way FSI simulation using Abaqus and SC/Tetra

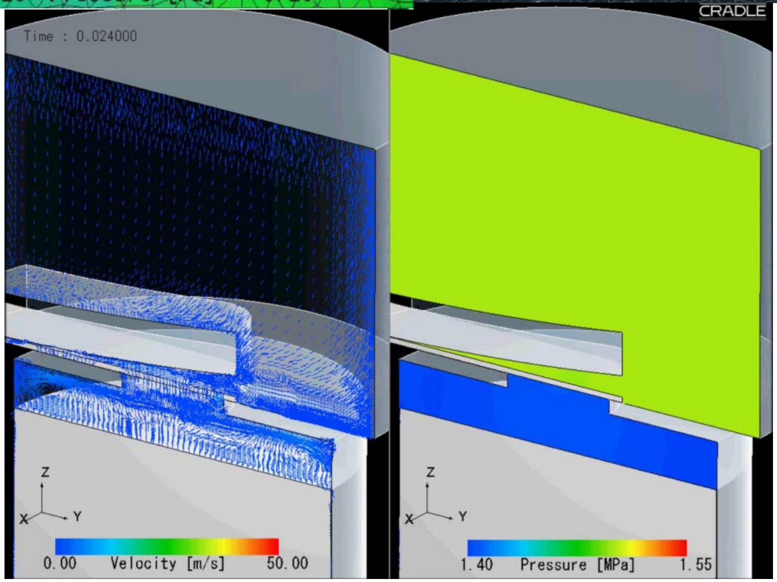
- **Transferable physical properties**
  - From SC/Tetra
    - Pressure (concentrated force vector)
    - Heat Flux
    - Ambient Temperature
  - From Abaqus
    - Displacement
    - Temperature

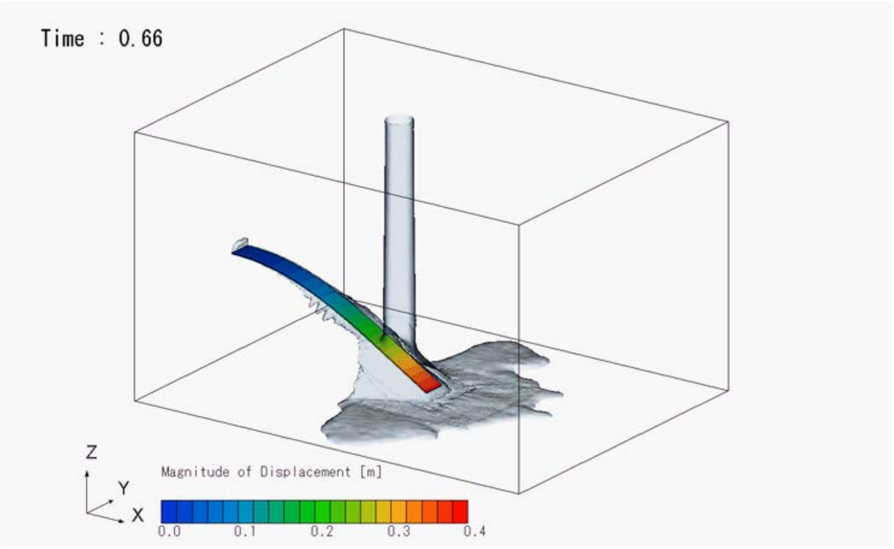
# Examples of 2-Way Fluid Structure Interaction



# Content







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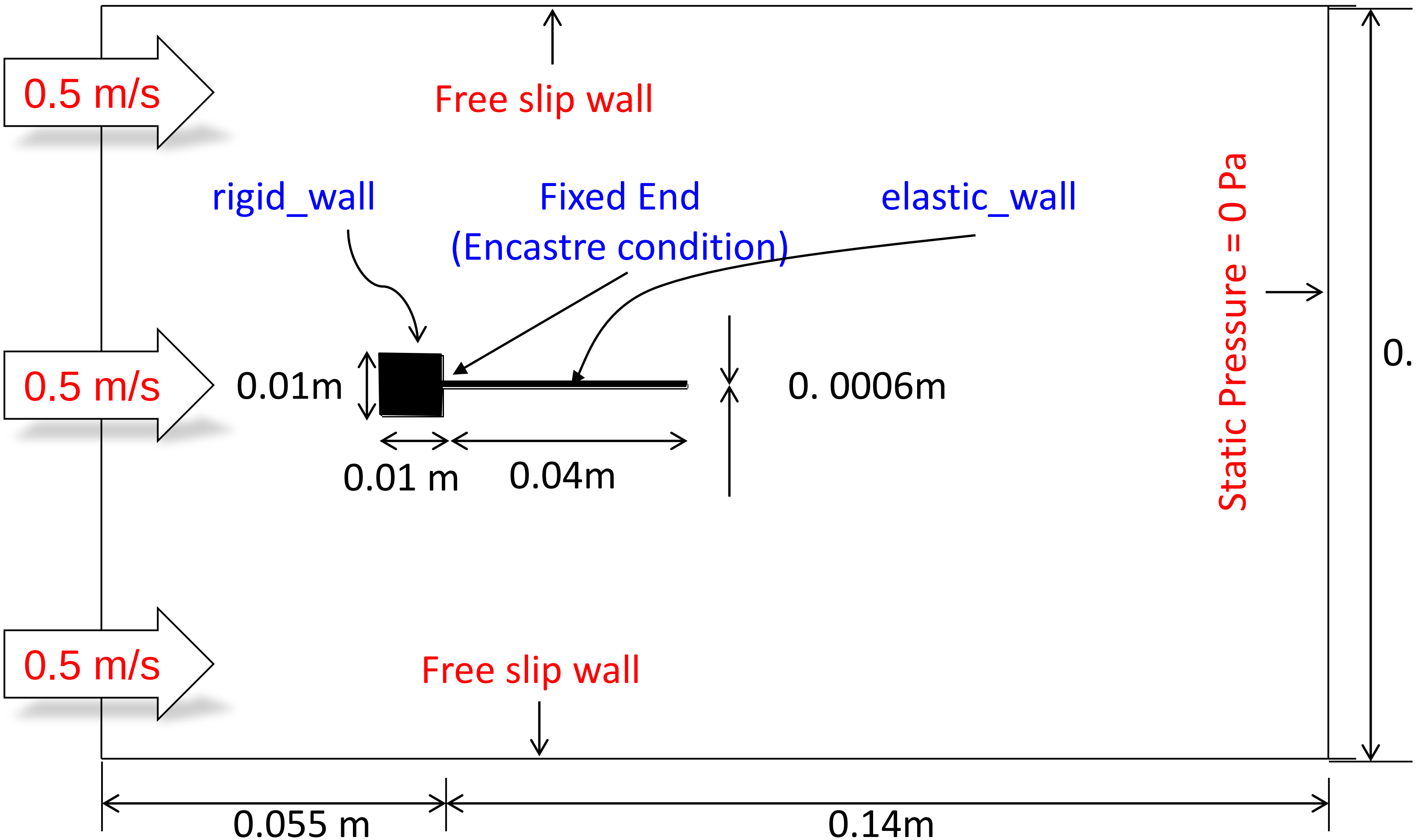
# 3. Validation example

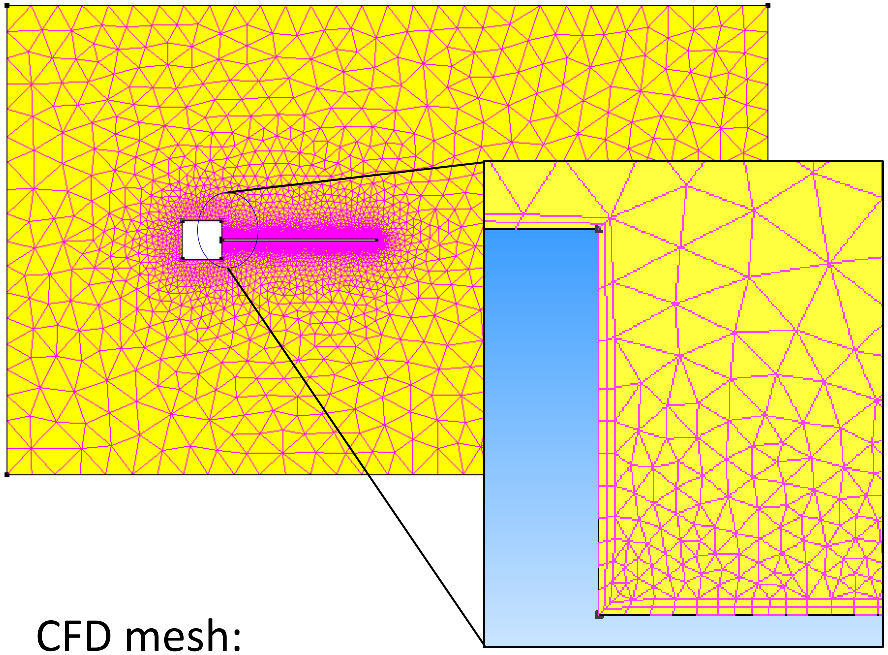
- Vortex–induced oscillations of flexible structure in the wake of a bluff body (Re ~330)



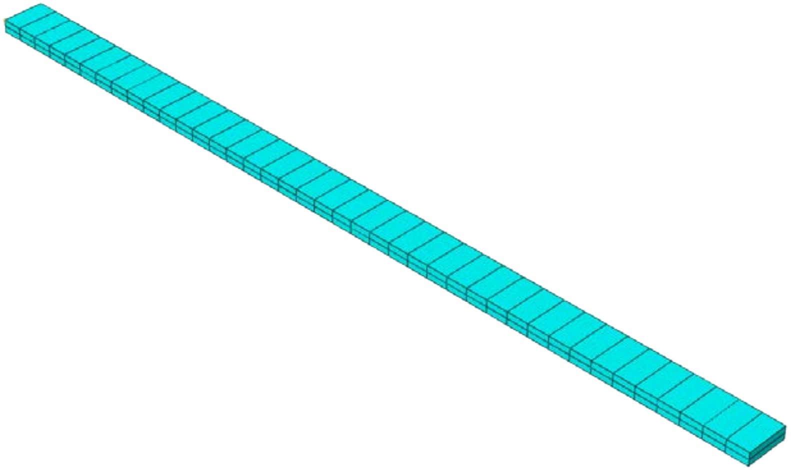

* *Fluid-Structure Interaction Based Upon A Stabilized ALE Finite Element Method*, Wolfgang A. Wall and Ekkehard Ramm , Computational Mechanics, 1998.

# 3. Validation example

- **Mesh in SC/Tetra and Abaqus**



CFD mesh:
Total: about 30k nodes, 44k elements
Smallest octant size: 0.2 mm
Prism layers: 0.1m x 2



Structural mesh:
Total: 246 nodes
(41 nodes x 3 nodes x  2 nodes)

# 3. Validation example

- **Material property**

(SC/Tetra)

Air(20C)

| | | |
|---|---|---|
| Density | ρ | ＝1.206 kg/m3 |
| Viscosity | μ | ＝1.83×10-5 Pa・s |

(Abaqus)

Solid :

| | | |
|---|---|---|
| Density | ρ | ＝100 kg/m3 |
| Youngs Modules | E | ＝250000 Kg/m-s$^2$ |
| Poison Ratio | | ＝0.35 |

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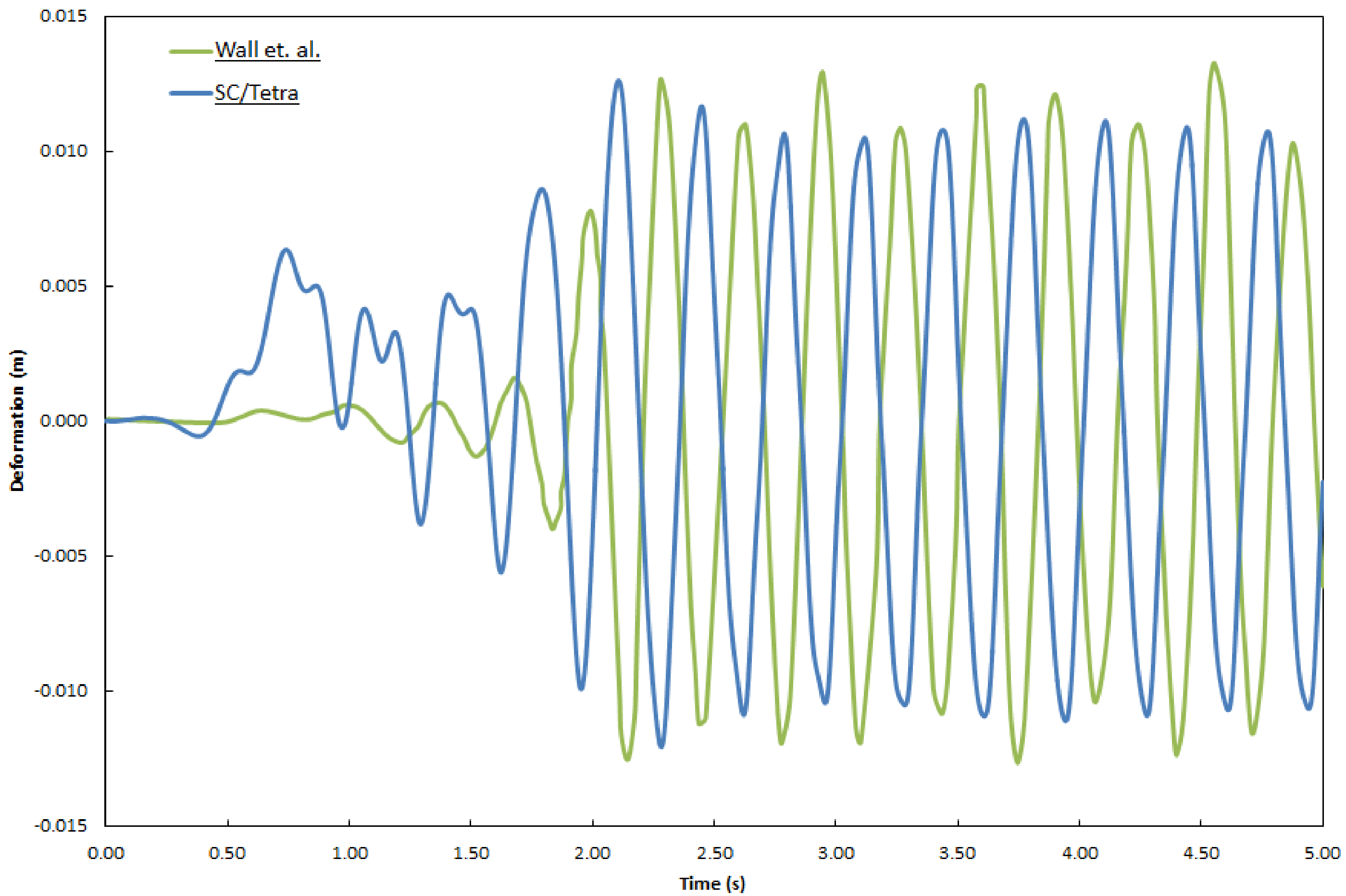
# 3. Validation example

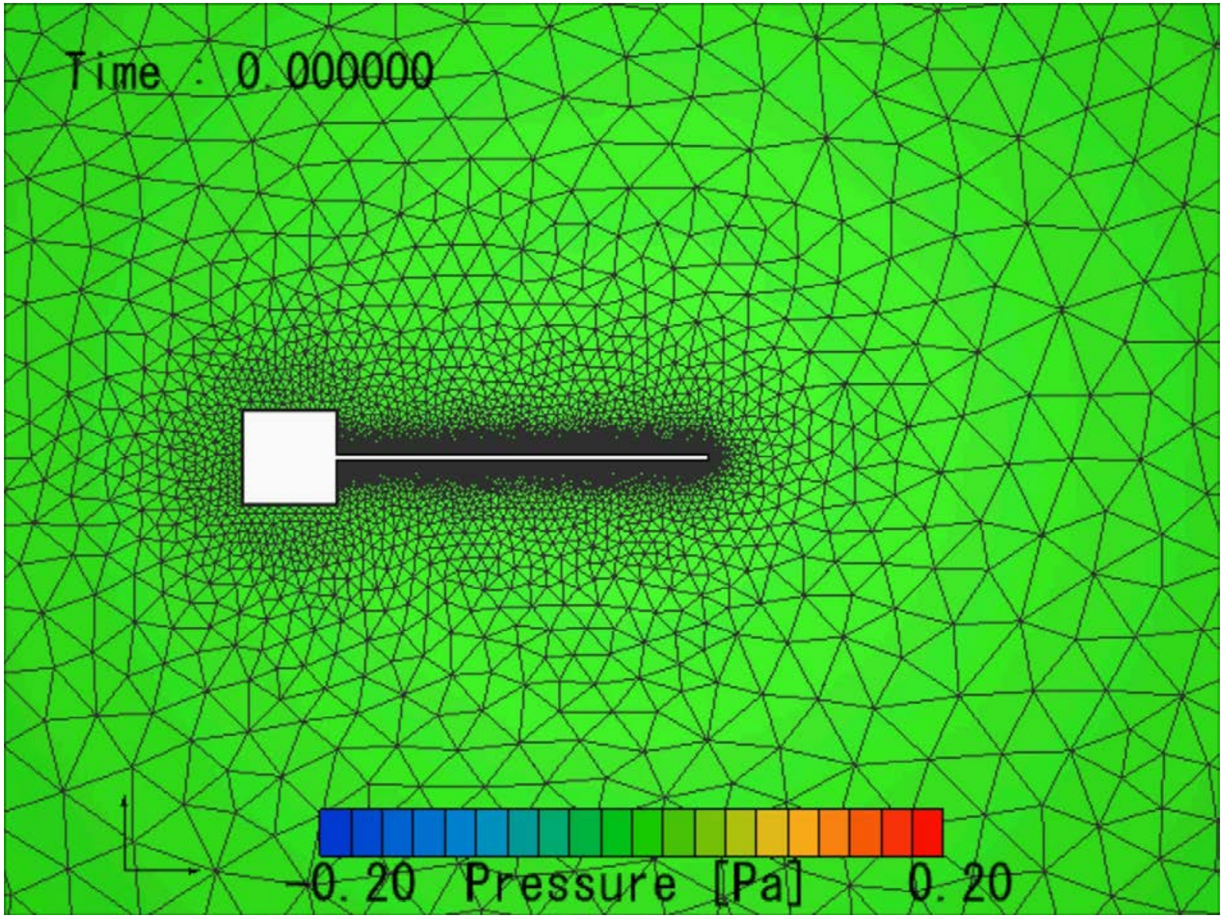
- **Analysis Type**
  - Pseudo 2-D
  - Transient simulation,
    - Initial time step =0.00001
    - CFL number = 1
  - Total simulation time = 5.1 s
    - CFD only simulation t = 0 to t = 0.1s
    - FSI simulation t = 0.1 to t = 5.1s
  - Turbulence model: Standard k-ε

# 3. Validation example




Oscillation time period
Wall et. al. = 0.33 s
SC/Tetra = 0.34 s

# 3. Validation example




Oscillation time period
Wall et. al. = 0.33 s
SC/Tetra = 0.34 s

# 3. Validation example

- **PC Specification**
    - CPU: Intel Core i7 920 3.2GHz
    - RAM: 24.00GB
    - OS: Windows 7 Professional SP1 (64bit)
- **Parallelism**
    - SC/Tetra: 6 cores
    - Abaqus: 1 core
- **Calculation time**
    - Total time: 78 minutes

# Content

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4. FSI simulation of Micro Air Vehicle



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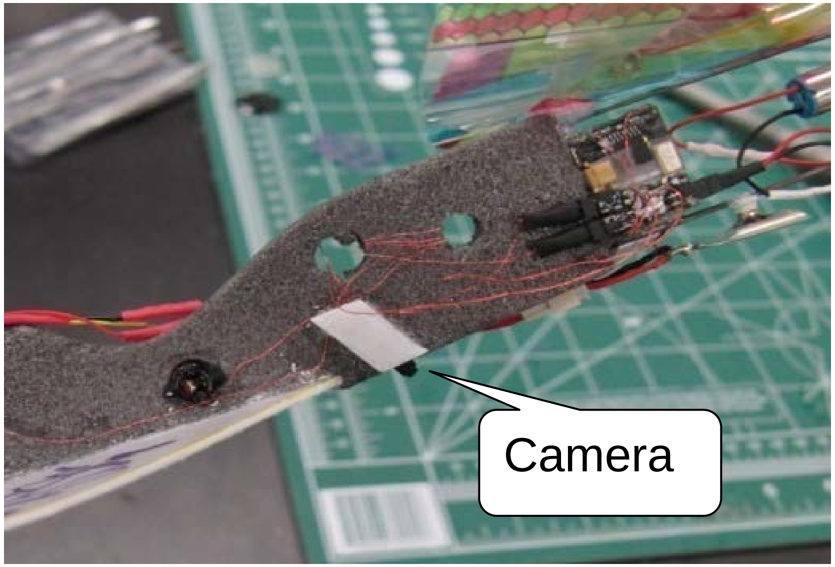
# 4. FSI simulation of Micro Air Vehicle

- **Overview**




- Courtesy of Wright State University

Physical Model

Total weight: 12.56g

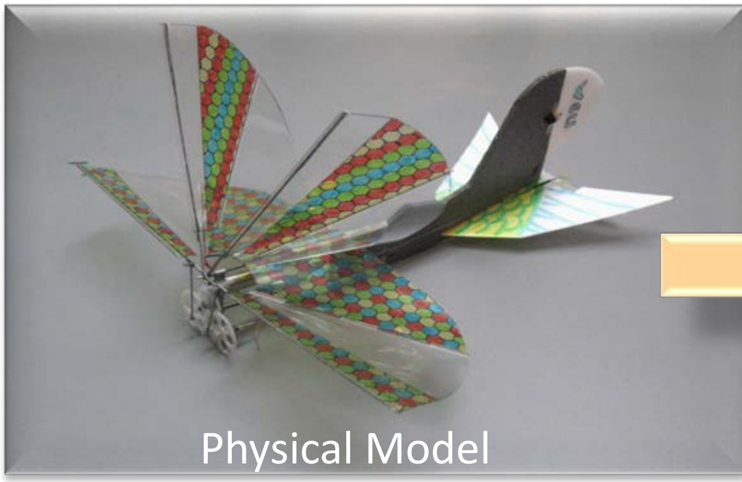
Including 3-channel receiver, Actuator, Motor, Frame, Tail Wings, 2 Drive Gears, Drive Links, Battery, Camera, Camera Battery

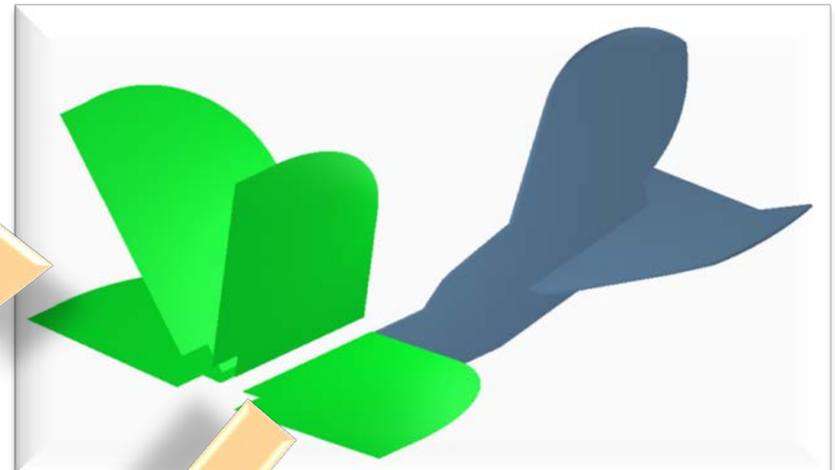
Size :

21 cm x 20 cm x 12cm (span x length x height)

# 4. FSI simulation of Micro Air Vehicle

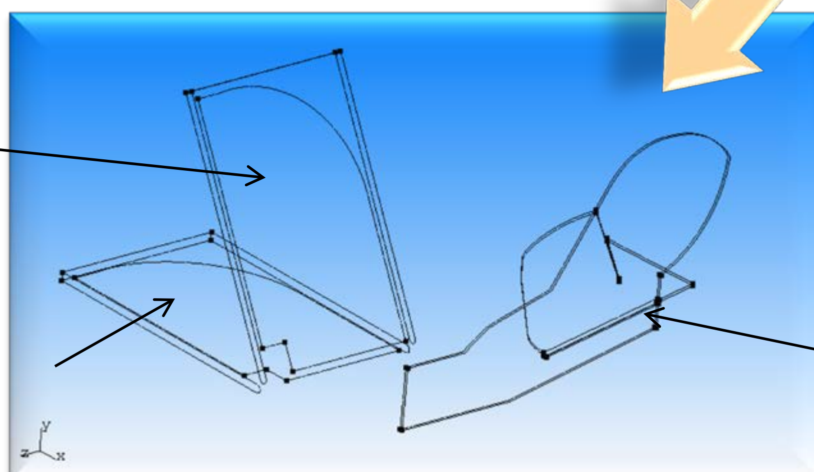
- **Computation Model**



Upper wing
(Slave region1)

Lower wing
(Slave region2 )

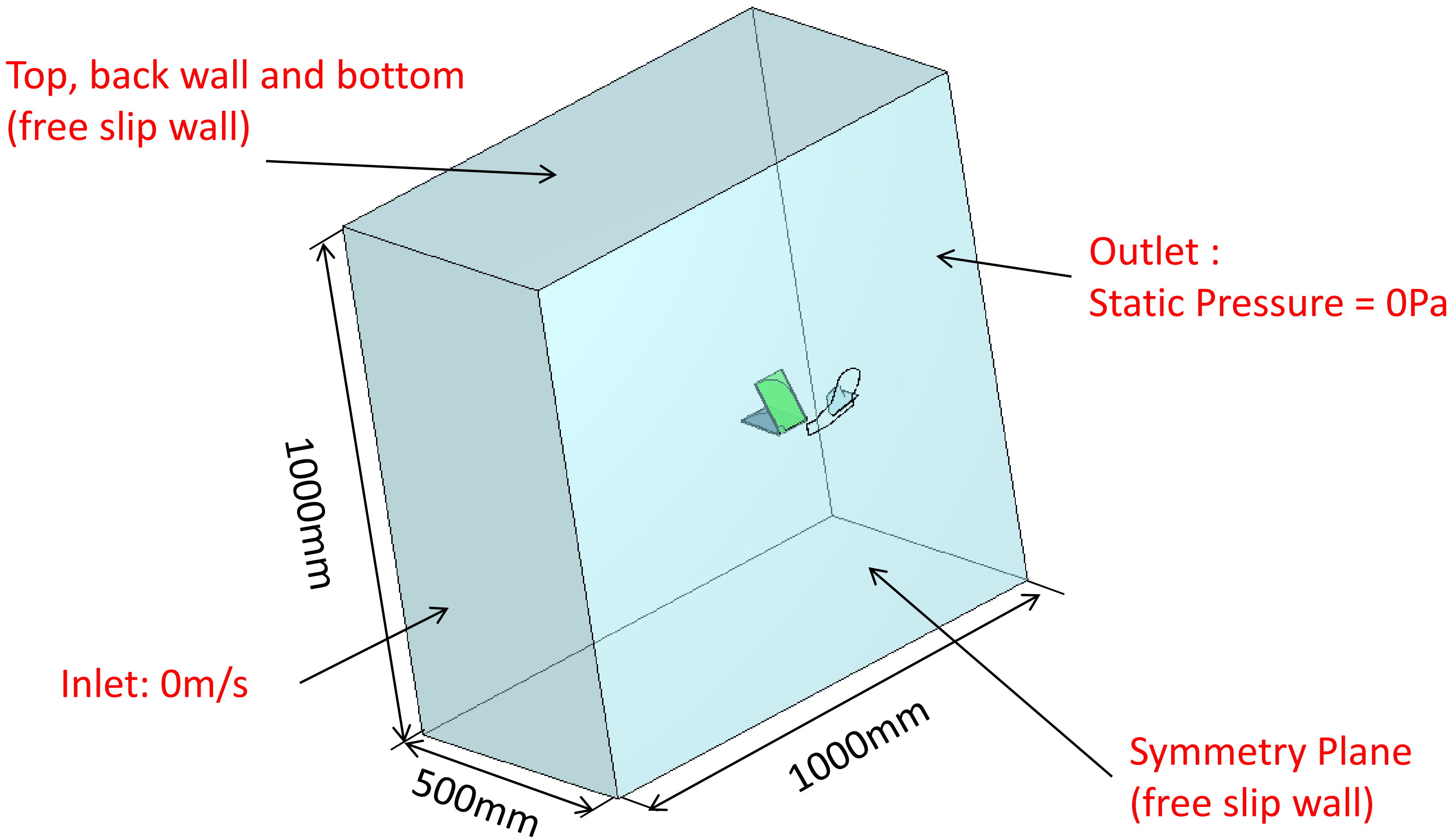


Tail

- ➢ Half model
- ➢ Panel elements for wings
- ➢ Overset mesh for wings

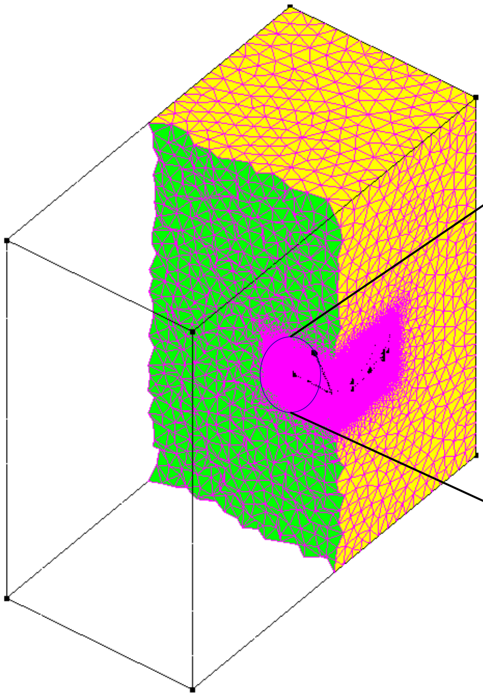
# 4. FSI simulation of Micro Air Vehicle

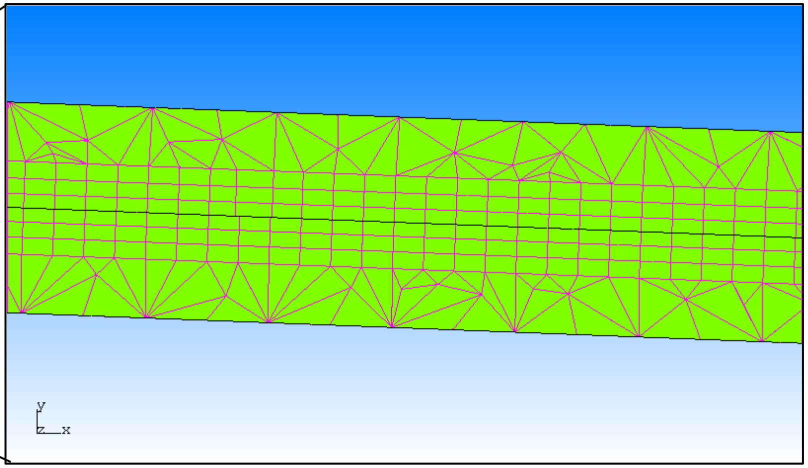
- **Computational Model**



# 4. FSI simulation of Micro Air Vehicle

- **Mesh (SC/Tetra)**
  - 11million elements (2.1 million nodes)
  - Prism layers around the wings: 0.2mm x 3 layers



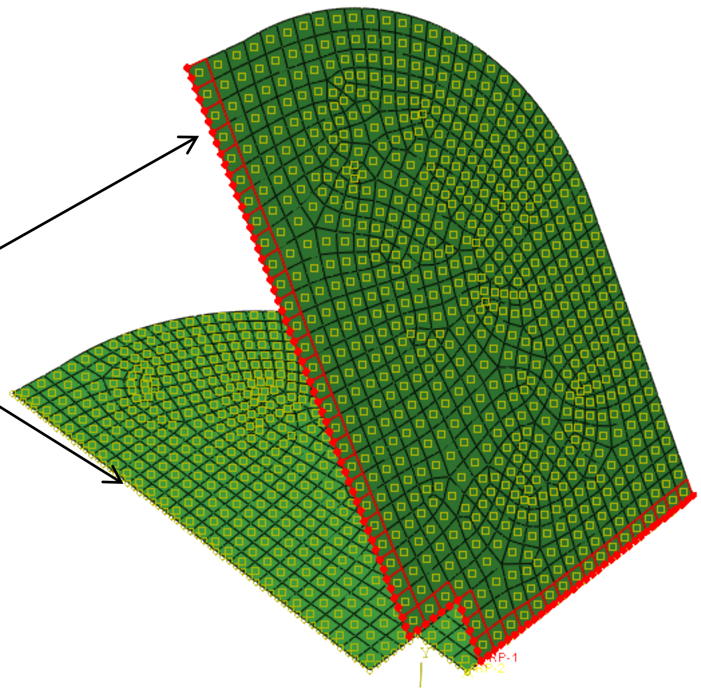


Mesh around the bottom wing

# 4. FSI simulation of Micro Air Vehicle

- **Mesh (Abaqus)**
  - Total number of nodes = 4400
  - Shell elements (numerical thickness: 1mm)

Rigid leading edges
Wing motion is specified to
these leading edges



# 4. FSI simulation of Micro Air Vehicle

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- **Material Property**

(SC/Tetra)

Fluid : Air(20C)

| | | |
|---|---|---|
| Density | ρ | ＝1.206 kg/m3 |
| Viscosity | μ | ＝1.83×10-5 Pa・s |

(Abaqus)

Solid : Plastic(Fe)

| | | |
|---|---|---|
| Density | ρ | ＝1400 kg/m3 |
| Youngs Modules | E | ＝3.1 E09 Kg/m-$s^2$ |
| Poison Ratio | | ＝0.36 |
| Shell thickness of wing | | = 0.001 m |
| | | (real wing is much thinner) |





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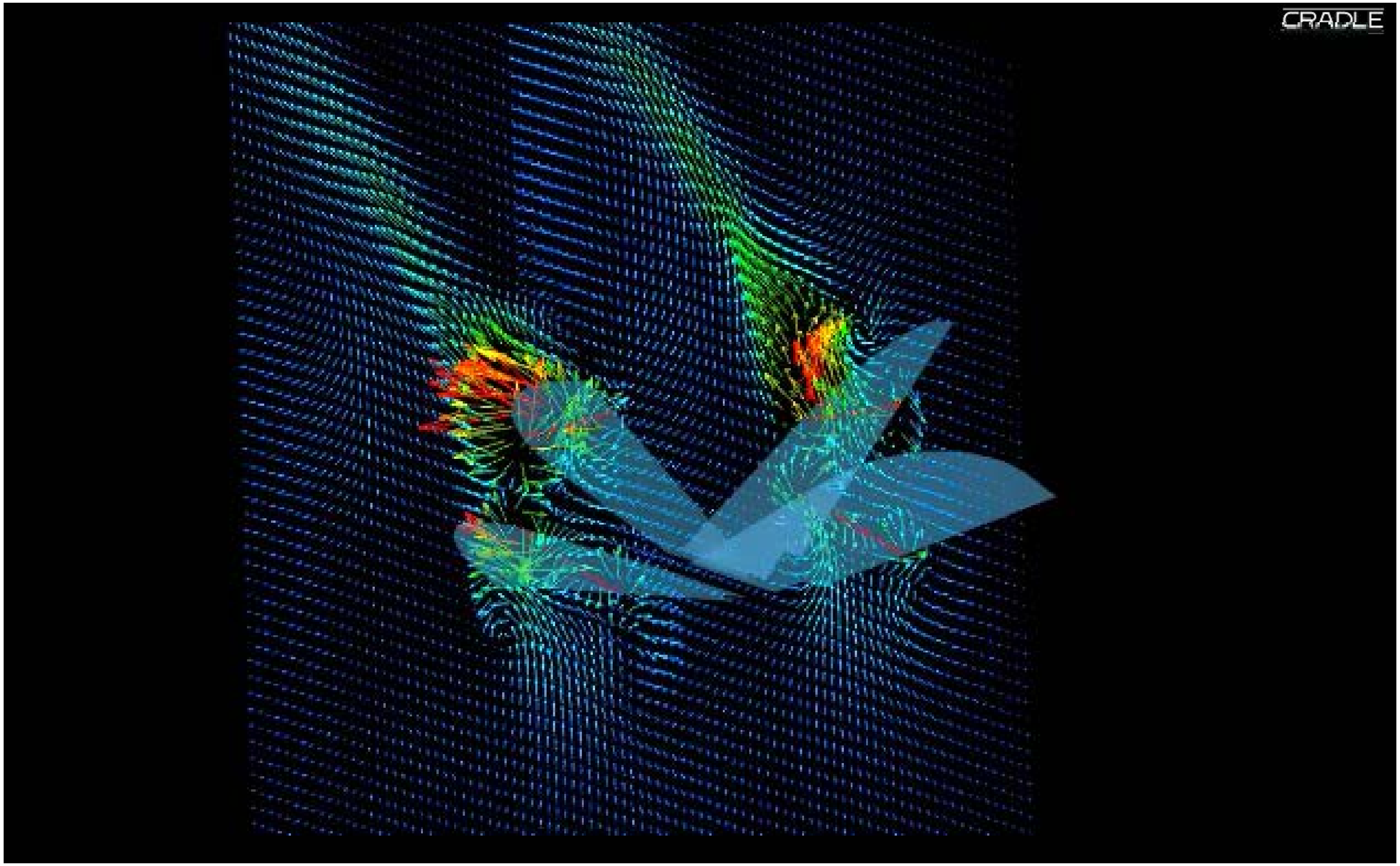
# 4. FSI simulation of Micro Air Vehicle

- **Analysis Condition**
  - Transient simulation,
    - Fixed time step = 0.00001
  - Total simulation time = 1 s
  - Standard k-ε Turbulence model
  - Overset mesh for 2 wings
  - Data exchange at every CFD cycle
  - Wing motion (set in Abaqus)
    - Frequency:16Hz (rigid frame along the leading edge)
    - Amplitude (rotation): 26.4 degree

# 4. FSI simulation of Micro Air Vehicle



# 4. FSI simulation of Micro Air Vehicle

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- **PC Specification**
    - CPU: Intel Core i7 920 3.2GHz
    - RAM: 24.00GB
    - OS: Windows 7 Professional SP1 (64bit)
- **Parallelism**
    - SC/Tetra: 6 cores
    - Abaqus: 1 core
- **Calculation time**
    - Total time: about 20 days



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# 4. FSI simulation of Micro Air Vehicle

# Thank You