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Visualization of Flow-field around a Magnetically-Suspended Model

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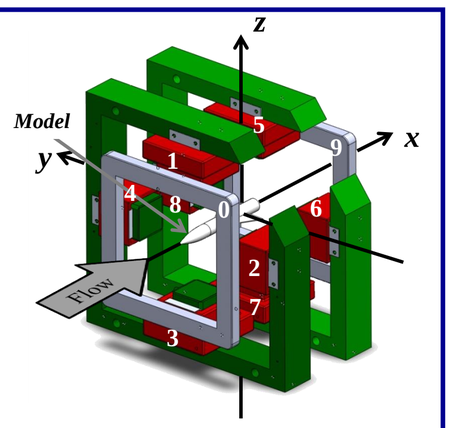
Introduction

Background

Magnetic Suspension and Balance System

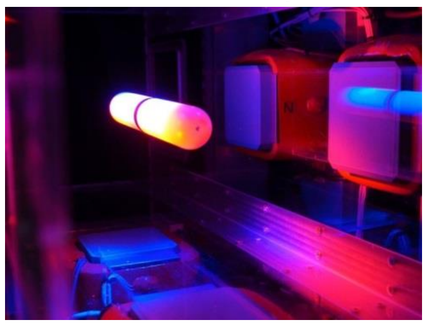
- Test model is levitated by magnetic force.
- Wind tunnel test can be conducted without mechanical support system.
- Aerodynamic forces can be calculated by current flowing through coils.
- The position and attitude of the model for control are obtained by optical sensing system.



0.3m-MSBS coil system

Flow Visualization

- Generally, flow visualization tests are conducted to clarify a flow field in wind-tunnel testing.



Magnetically suspended model in 0.3m MSBS

In MSBS, there are problems for visualization, because optical system of visualization might disturb the position sensing system.

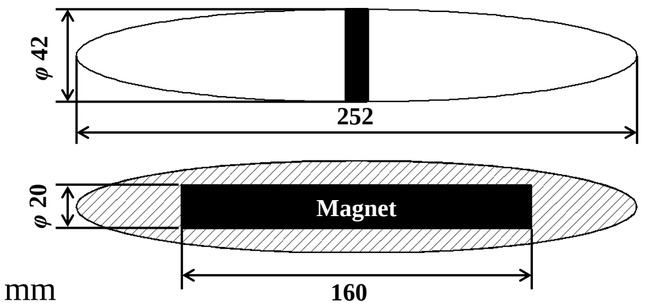
Objective

To develop visualization method for magnetically-suspended model.

Experiments

Test model

- 6:1 Prolate Spheroid
  - ✓ Length : 252 mm
  - ✓ Max diameter : 42 mm
  - ✓ Material : Acrylic plastic
  - ✓ Magnet : Neodymium magnet
  - ✓ Magnet size : φ20 mm × 160 mm
  - ✓ Weight : 602 g

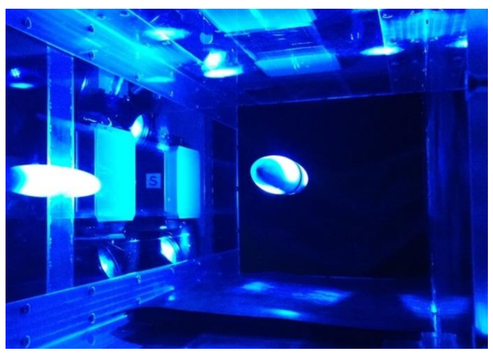


6:1 prolate spheroid model

Test conditions

- Visualization test
  - ✓ Selection of pigments
  - ✓ Levitation test
  - ✓ Application of GLOF for the magnetically suspended model

Flow velocity	*Re* Number	Angle of Incidence	Visualization area
30 m/s	5 x 10^5	0 degree	Trailing end



Levitated model with only blue LEDs

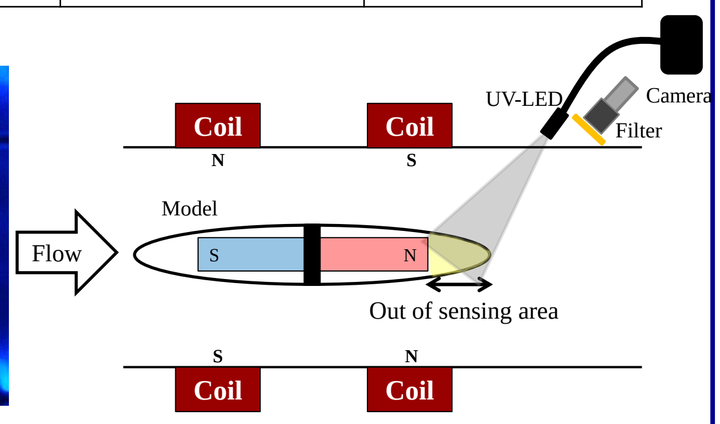
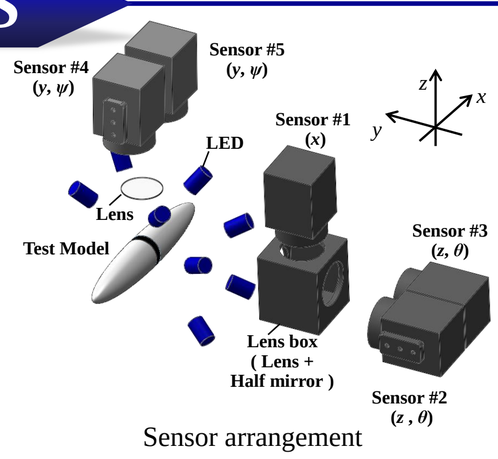


Diagram of optical set-up

Sensing system of the MSBS

The position sensing for control

- The sensing system using CCD line sensor cameras
  - ✓ Detecting the edges and the marker of the model.
  - ✓ The position is measured from two directions, upper and lateral side.
  - ✓ 5 axes (*x*, *y*, *z*, pitch, yaw) can be detected by using 5 CCD cameras.
  - ✓ To decrease interference between sensing system and optical system of visualization, only blue LEDs are used for sensing.



Sensor arrangement

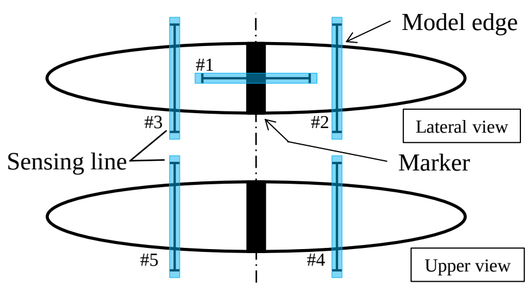


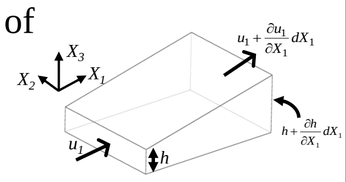
Diagram of detecting area

Visualization method

Global Luminescent Oil-Film Skin-Friction Meter (GLOF method)

T.Liu *et al*, 2008

- Oil doped with luminescent molecules is put on the test model.
- Skin friction can be measured to capture time-changing of emission intensity.



- ✓ Relation equation between time-changing of oil film thickness and skin friction.

$$\frac{\partial h}{\partial t}+\frac{\partial}{\partial X_i}\left[\frac{h^2\tau_i}{2\mu}-\left(\frac{\partial p}{\partial X_i}-\rho g_i\right)\frac{h^3}{3\mu}\right]=0 \quad (i=1,2)$$

X_i : Space coordinates
t : Time
h : Thickness of oil film
τ_i : Frictional stress
μ : Viscosity of oil
p : Pressure
g_i : Gravity force

- ✓ Relation equation between emission intensity and thickness of oil film.

$$I(X_1,X_2)=aI_{ex}(X_1,X_2)h(X_1,X_2)$$

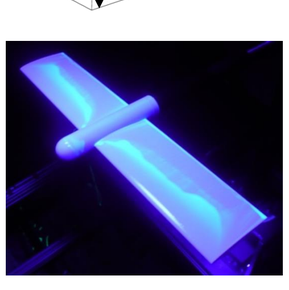
I : Amount of luminescence of oil
I_{ex} : Amount of luminescence of excitation light
a : Constant of proportion

- ✓ Relation equation between skin friction and emission intensity.

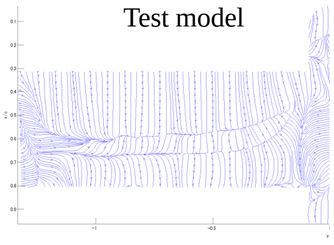
$$\frac{\partial I_r}{\partial t}+\overline{C}_{f1}\frac{\partial I_r}{\partial x_1}+\overline{C}_{f2}\frac{\partial I_r}{\partial x_2}=0$$

$I_r = I/I_{ex}$
$\overline{\boldsymbol{c}}_{\boldsymbol{f}} = \boldsymbol{c}_{\boldsymbol{f}} I_r \lambda a/2\mu$
Terms of pressure gradient and gravity are ignored.

Skin friction is calculated by using “Optical flow” technique. Optical flow can calculate the movement speed of the object on the image.



Test model



Line of frictional stress

Example of the application of GLOF (Surface of wing model)

Experimental Results

Selection of luminescent pigment

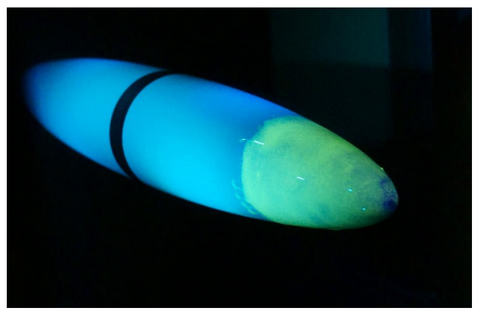
- Necessary conditions
  - ✓ Excitation light source is UV, and sensor LEDs are blue.
  - ✓ Long wavelength emission like yellow or red are needed.

⇨ Pigment with yellow emission was used.

Oil doped with luminescent pigments

Levitation with oil putting and excitation light source

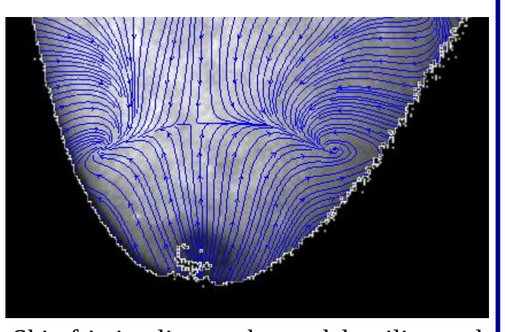
- ✓ Interference between sensor and visualization system was prevented.
- ✓ Levitation was succeeded.



Luminescent oil put on the levitated model

Acquisition of images in wind-tunnel testing

- ✓ Images were acquired under ventilated condition.
- ✓ Skin friction line was obtained by processing images.
- ✓ Separation at trailing end of the model was visualized.



Skin friction line on the model trailing end

Summary

- Levitation succeeded.
- Suitable pigment from the viewpoint of measurement wavelength was selected.
- Acquisition of images under ventilation condition was succeeded.
- Skin friction line were obtained by image processing and separation line was observed.

Future works

- It is needed extension of visualized area.
- Application of other visualization method (PSP, TSP, etc.).