Progress Report supported by Boeing Higher Education Program
- Graduate Student Project -

Evaluation of Supersonic Wind Tunnel Testing using a Magnetic Suspension and Balance System – Wing Model –

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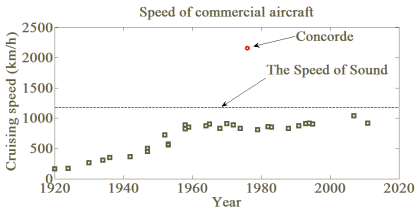
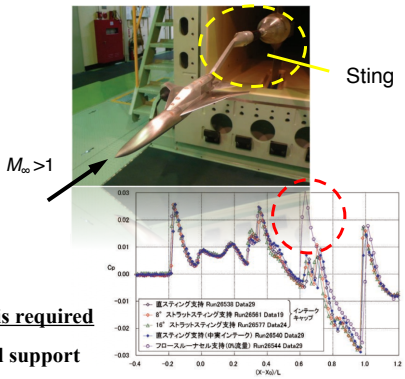
Background ～SuperSonic Transport～

Possibility of wind tunnel by magnetic support





Support Interference

出典：牧野 好和, 野口 正芳, “静粛超音速研究機基本設計 低ブーム確認超音速風洞試験”,2010.

- ❒ Implementation Issues for SST
  - ➢ Reduction of Sonic Boom
    - Near-field pressure measurement/evaluation is required
  - ✓ Conventional wind tunnel tests using mechanical support

⇩

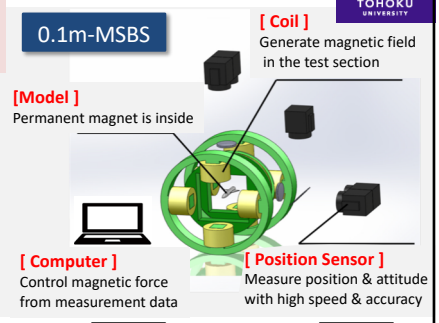
Support Interference between support mechanism & wake flow

⇒ Obstruction of high precision measurement for near-field pressure waveform occurs

Wind tunnel with no influence of support interference is promising

Background ～Magnetic Suspension and Balance System～

Support a model by interaction
between a permanent magnet and magnetic field



Feature

- No support interference
- Force evaluation by magnetic force
  (Balance function)

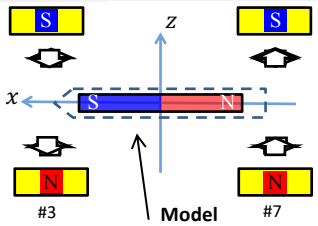
Especially, with 0.1 m – MSBS

- Magnetic suspension at high dynamic pressure

Current status

- Magnetic suspension at supersonic range
  by 6-axis control using wing models is not performed

➡ Controlling roll axis & adjustment of test conditions are required



Establishment of supersonic wind tunnel technique
with wing model with no support interference

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Objective

Establishment of supersonic wind tunnel test technique with wing model by 0.1 m - MSBS

1. Construction of test environment at supersonic range by 6-axis control
2. Wind Tunnel Test

   Target1 Verification of 6-axis control technique

   Target2 Wing model

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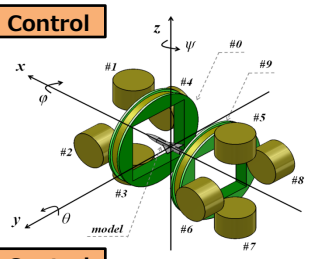
Control by magnetic force

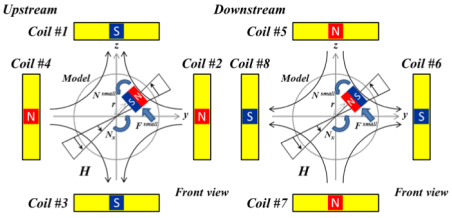
5-axis Control



Coil current's Combinations

I_{drag}	$(I_{\#0} + I_{\#9})/2$
I_{side}	$(I_{\#2} + I_{\#4} + I_{\#6} + I_{\#8})/4$
I_{lift}	$(I_{\#1} + I_{\#3} + I_{\#5} + I_{\#7})/4$
I_{pitch}	$(I_{\#1} + I_{\#3} - I_{\#5} - I_{\#7})/4$
I_{yaw}	$(I_{\#2} + I_{\#4} - I_{\#6} - I_{\#8})/4$

6-axis Control



Combination of model magnets

Combination of roll axis control current

I_{roll}	$-(I_{\#2} - I_{\#4} - I_{\#6} + I_{\#8})/4$
	$(I_{\#1} - I_{\#3} - I_{\#5} + I_{\#7})/4$

- ✓ Magnetic field is formed in three dimensions
- ✓ Rolling moment is generated by arranging small magnets around each 45 deg.

Control & evaluate each axis by coil current's combinations

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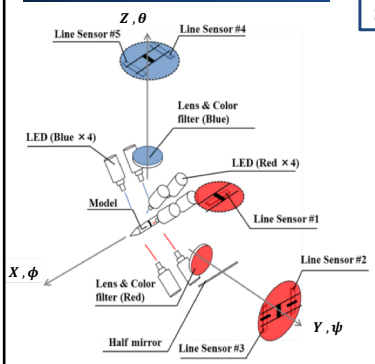
Position & attitude angle measurement

Sensor arrangement layout

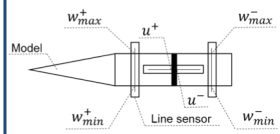


Measurement range

x, y, z	±3 mm
θ, ψ	±3 deg.
ϕ	±5 deg.

Sensor Detection

$x, y, z, \theta, \psi - axis$



$$x_{count} = -\frac{u^{\#1}_{max} + u^{\#1}_{min}}{2} + r\psi$$

$$y_{count} = -\frac{w^{\#2}_{max} + w^{\#2}_{min} + w^{\#3}_{max} + w^{\#3}_{min}}{4}$$

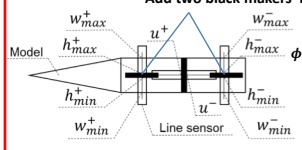
$$z_{count} = -\frac{w^{\#4}_{max} + w^{\#4}_{min} + w^{\#5}_{max} + w^{\#5}_{min}}{4}$$

$$\theta_{count} = -\frac{w^{\#4}_{max} + w^{\#4}_{min} - w^{\#5}_{max} - w^{\#5}_{min}}{4u_0}$$

$$\psi_{count} = -\frac{w^{\#2}_{max} + w^{\#2}_{min} - w^{\#3}_{max} - w^{\#3}_{min}}{4u_0}$$

$\phi - axis$

Add two black makers for controlling roll angle



$$\phi_{count} = -\left(\frac{h^{\#2}_{max} + h^{\#2}_{min} + h^{\#3}_{max} + h^{\#3}_{min}}{4r}\right) - \left(\frac{w^{\#2}_{max} + w^{\#2}_{min} + w^{\#3}_{max} + w^{\#3}_{min}}{4r}\right)$$

Change of ϕ count depends on modell radius,
The smaller model diameter, the more difficult it is to measure

Edge of model surface & black marker are detected,
Position & attitude angle are measured.

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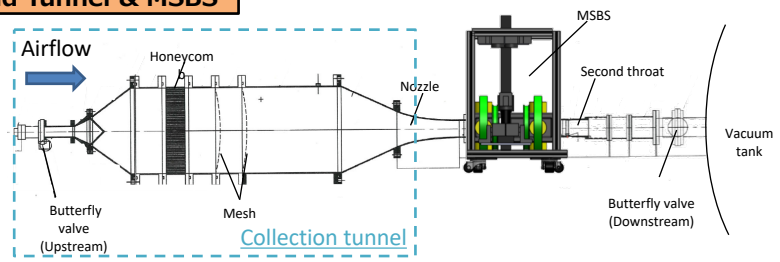
Experiment System & Condition

Wind Tunnel & MSBS



Suction type supersonic wind tunnel
with collection tunnel
Designed Mach number 1.7
Test section diameter 85 mm
Flow Time About 4 sec

・Collection tunnel reduces initial total pressure
→ It can reduce Starting load
・Adjust the upstream butterfly valve's opening
→ It can adjust total pressure during steady stete

Condition

Condition1

Reynolds number 1.4×10^6

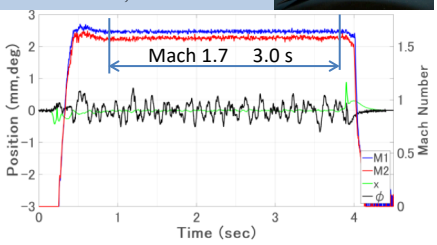
Condition2

Reynolds number 7.3×10^5

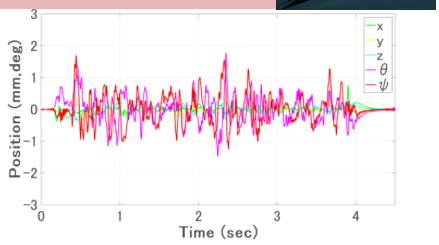
Wind Tunnel Testing -Target1-

6-axis control

Length φ10 × 80 mm
Material SUS, Resin



5-axis control



・5-axis vs. 6-axis control
Difference of displacement
→ Due to the difference in model weight & inertia moment

・Control current of ϕ axis was Max 3.12A
Coils #1 ~ #8 can output 15A steady → Sufficiently controllable

・Displacement of ϕ axis was Max 0.7 deg
→ Sufficient magnet force support accuracy was confirmed

Maximum displacement during air flow

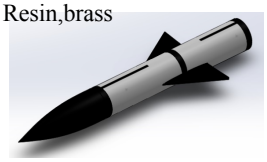
Control	6-axis	5-axis
x [mm]	-0.07	-0.17
y [mm]	-0.21	-0.33
z [mm]	-0.27	-0.33
θ [deg]	1.38	1.79
ψ [deg]	-1.41	1.56
ϕ [deg]	0.7	

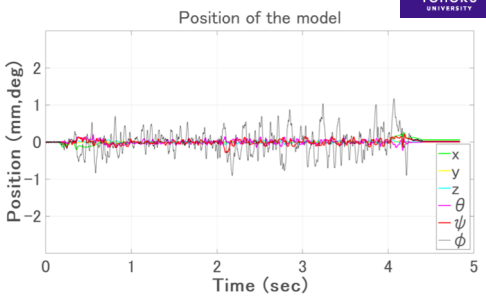
6-axis control technique which performs wind tunnel tests
by suppressing rotation of the model was verified

Wind Tunnel Testing -Target2-

Specifications refer to AGARD-B

- Span Length 33 mm (3/4 span length)
- Full length φ11 × 93.5
- Material Resin,brass





Maximum displacement during air flow

x [mm]	-0.19
y [mm]	0.03
z [mm]	0.07
θ [deg]	-0.23
ψ [deg]	-0.28
ϕ [deg]	1.18

- Compared to Target1, displacement other than ϕ axis was small because of the small Reynolds number test.
- Due to this test added wings, rotation of ϕ axis increased.

Test using 3/4 span length model of AGARD-B could be performed up to Re 7.3×10^5 .

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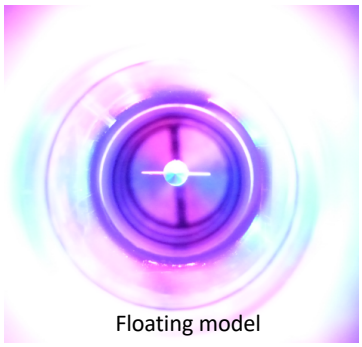
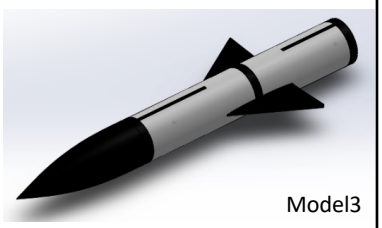
Wind Tunnel Testing -Target2-

Test Scene



Floating model



Model3

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Conclusions

Establishment of supersonic wind tunnel test technique with wing model by 0.1 m - MSBS

- **Axisymmetric model**

  6-axis control technique which performs wind tunnel tests by suppressing rotation of the model was verified.

- **Wing model**

  Test using a 3/4 span length model of AGARD-B could be performed up to Re 7.3×10^5 .

Future work

- **Supersonic wind tunnel test with AGARD-B model**
- **Near-field pressure measurement**

Thank you for your attention