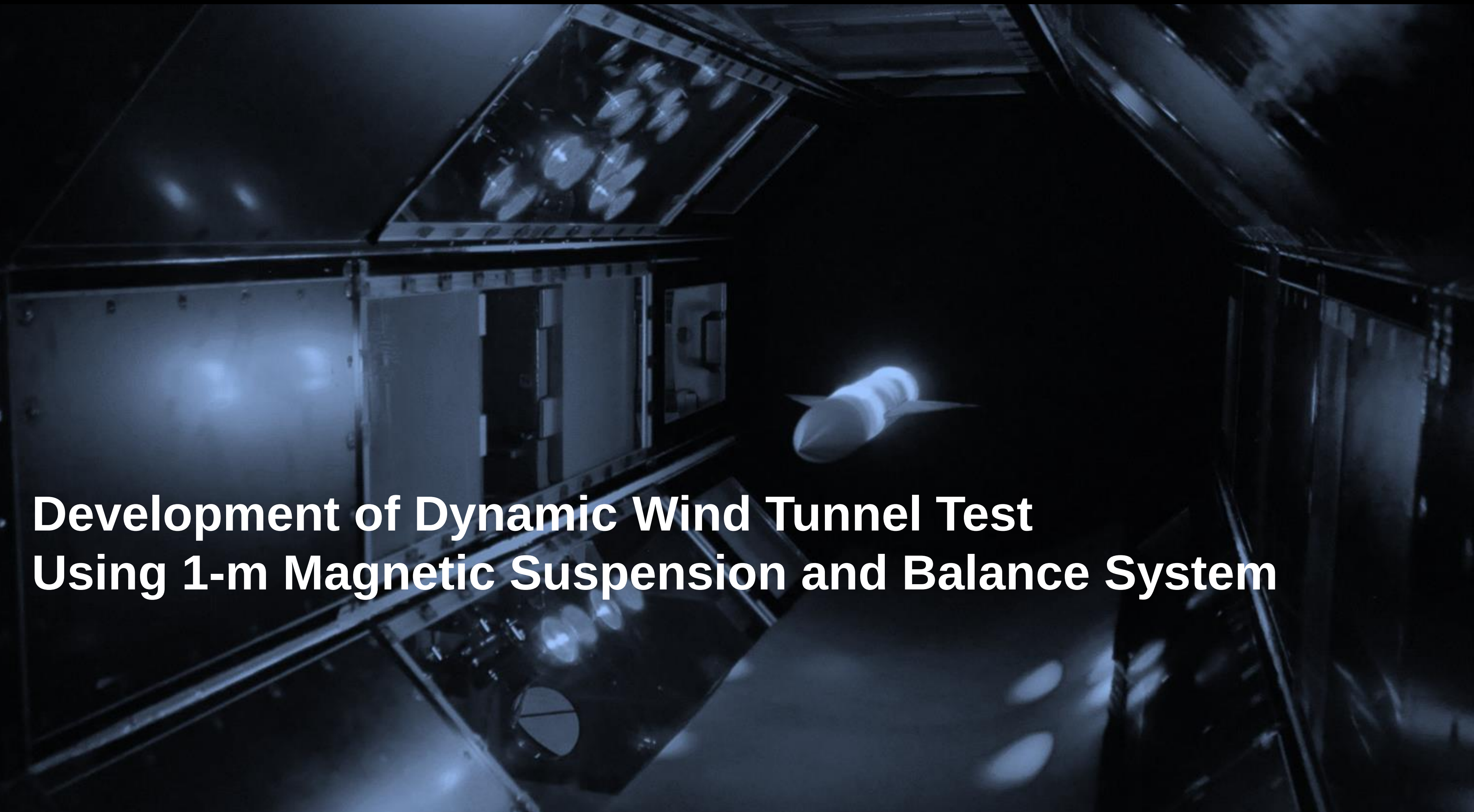
Boeing Higher Education Program Debriefing Meeting
January 21st, 2019, @Boeing Japan, Tokyo



Development of Dynamic Wind Tunnel Test Using 1-m Magnetic Suspension and Balance System

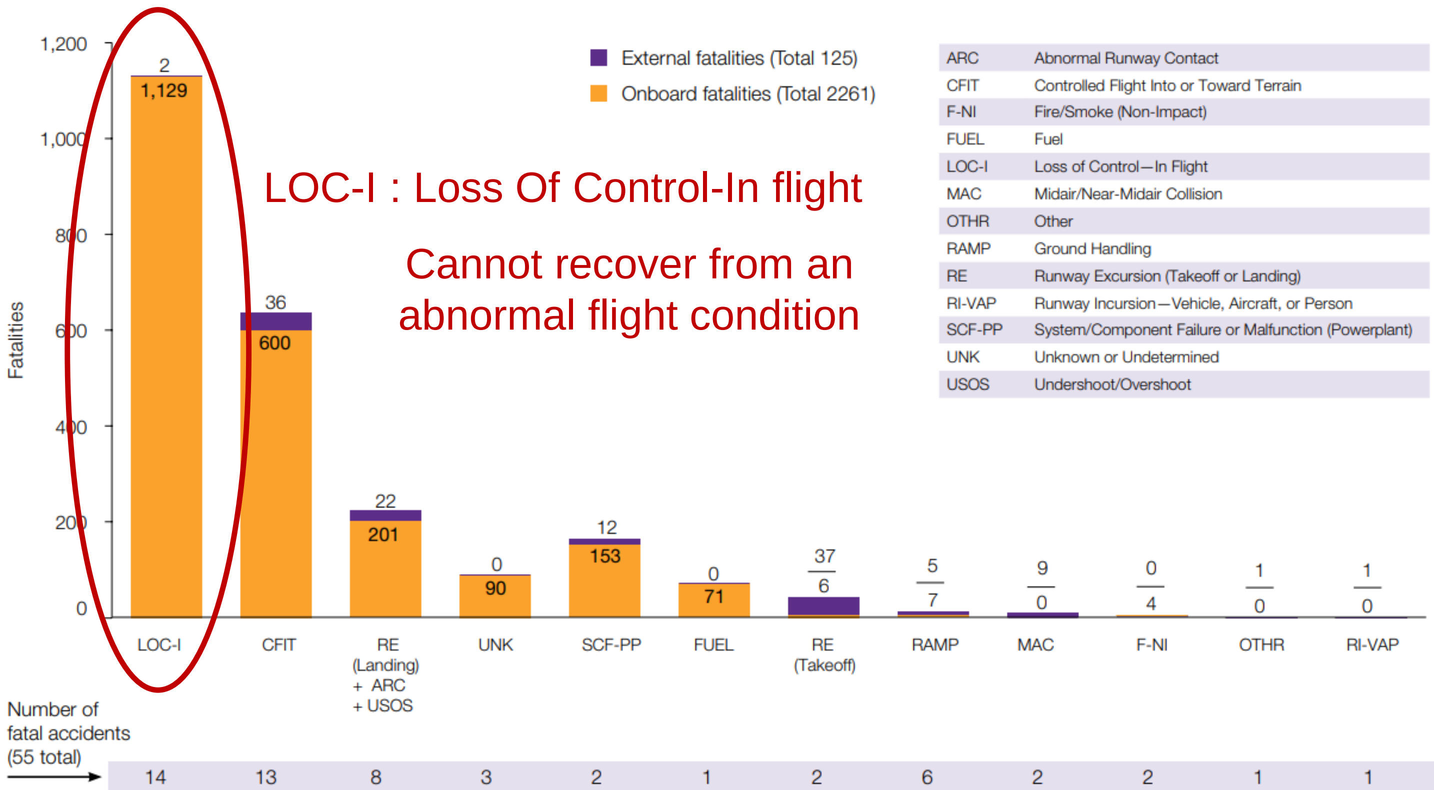
Shogo Oyama, Kasumi Sasaki, Hiroki Senda

Graduate School of Engineering, Tohoku University

Aiming for Safety Flight

Fatalities by CICTT Aviation Occurrence Categories

Fatal Accidents | Worldwide Commercial Jet Fleet | 2008 through 2017



ARC	Abnormal Runway Contact
CFIT	Controlled Flight Into or Toward Terrain
F-NI	Fire/Smoke (Non-Impact)
FUEL	Fuel
LOC-I	Loss of Control—In Flight
MAC	Midair/Near-Midair Collision
OTHR	Other
RAMP	Ground Handling
RE	Runway Excursion (Takeoff or Landing)
RI-VAP	Runway Incursion—Vehicle, Aircraft, or Person
SCF-PP	System/Component Failure or Malfunction (Powerplant)
UNK	Unknown or Undetermined
USOS	Undershoot/Overshoot

Note: Principal categories as assigned by CAST.
For a complete description of CAST/ICAO Common Taxonomy Team (CICTT) Aviation Occurrence Categories, go to www.intlaviationstandards.org.

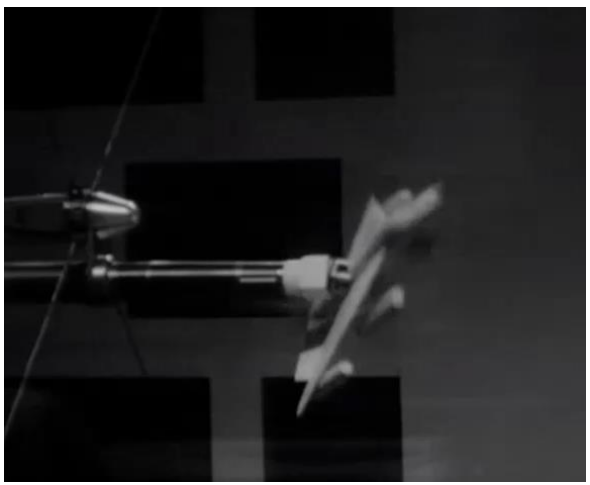
22 | 2017 STATISTICAL SUMMARY, OCTOBER 2018

The Boeing Company, 2018.

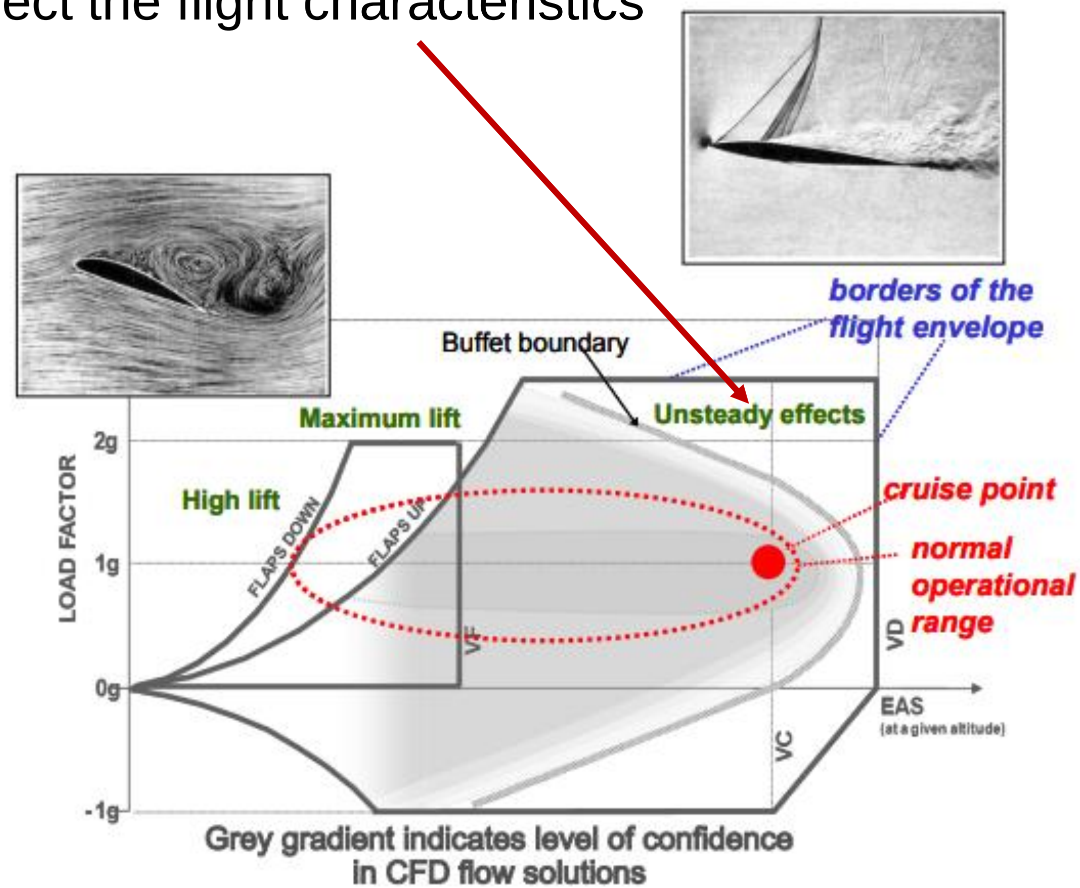
Modeling the extreme flight condition

= Near or outside of the edge of the flight envelope

Unsteady aerodynamics affect the flight characteristics



NASA Langley (from YouTube), 1960.



Kroll N. et al., 2012.

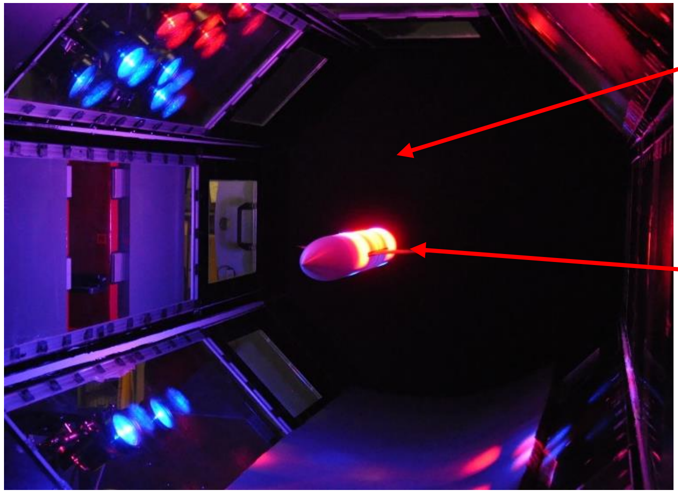
Issues of dynamic wind tunnel

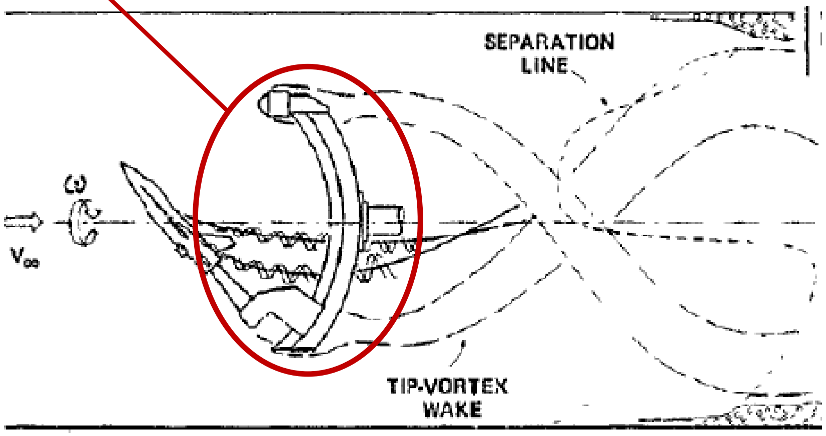
❶ Complicated support mechanism
or limit the motion degrees-of-freedom

❷ Interference with flow stream
or apply the correction (very hard)

D. D. Victory, et al., 2014.

MSBS : Magnetic Suspension and Balance System

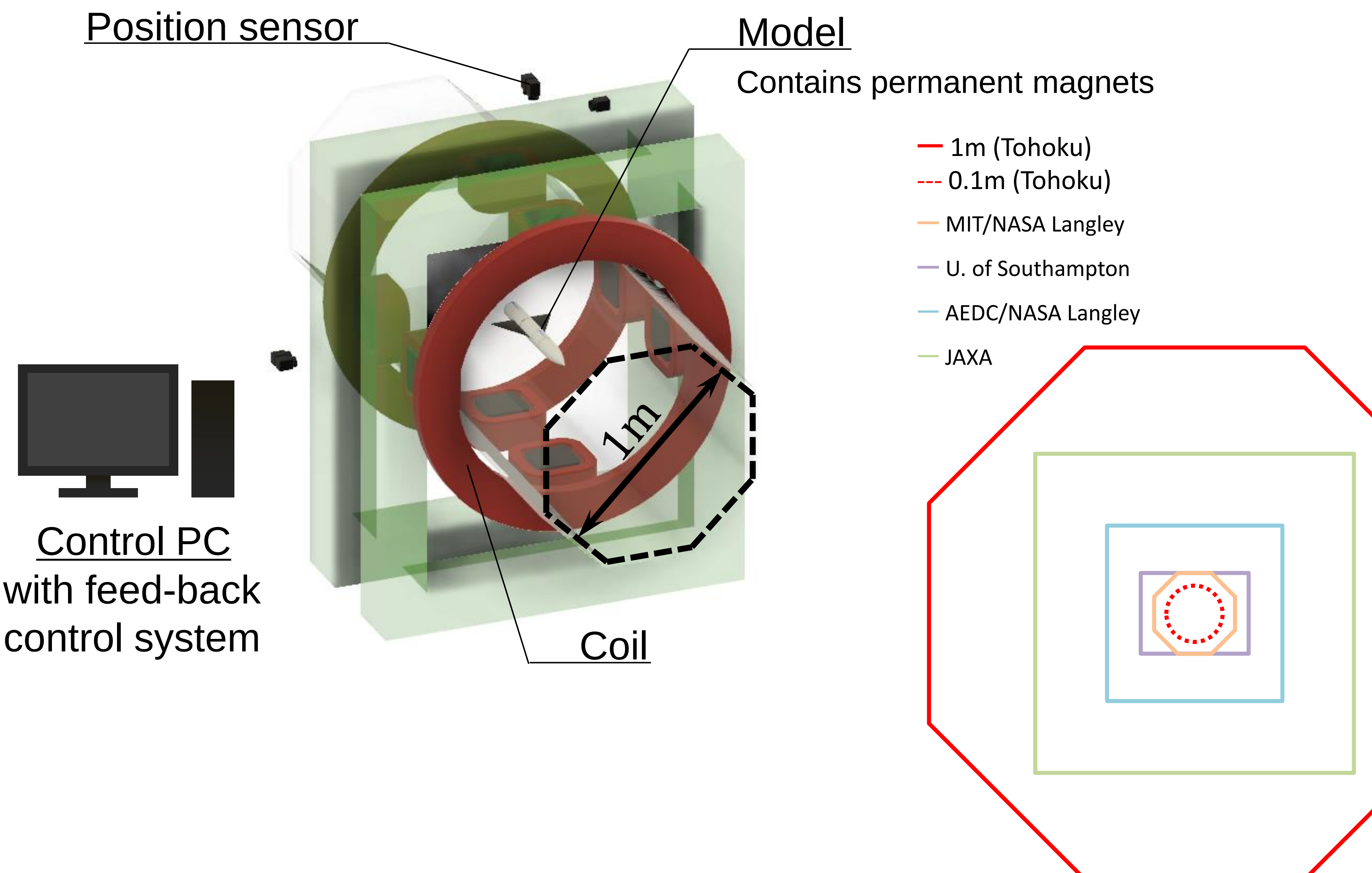




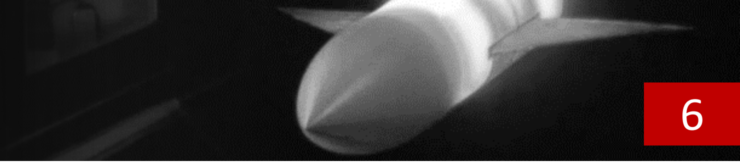
M. E. Beyers, et al., 1993.

MSBS can perform the wind tunnel tests without mechanical interference

1-m MSBS : The largest MSBS in the world



What function is required?



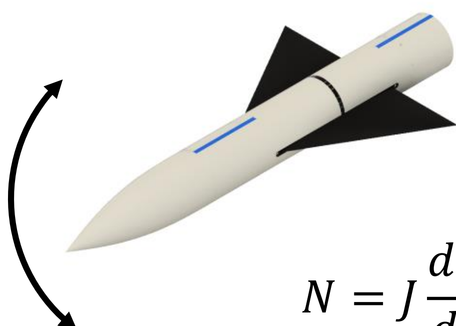
❶ Make a motion

➡ Considering a simple forced-oscillation test

❷ Measure an unsteady aerodynamic force

➡ Validating with inertial force

$\theta(t)$



$$N = J\frac{d^2\theta}{dt^2}$$

Inertial torque

Goal of the study

Our goal

Performing a dynamic wind tunnel test using 1-m MSBS

- Evaluation of the motion accuracy
- Validation of the force evaluation accuracy
- Dynamic wind tunnel at simple flight condition
- Dynamic wind tunnel at extreme flight condition

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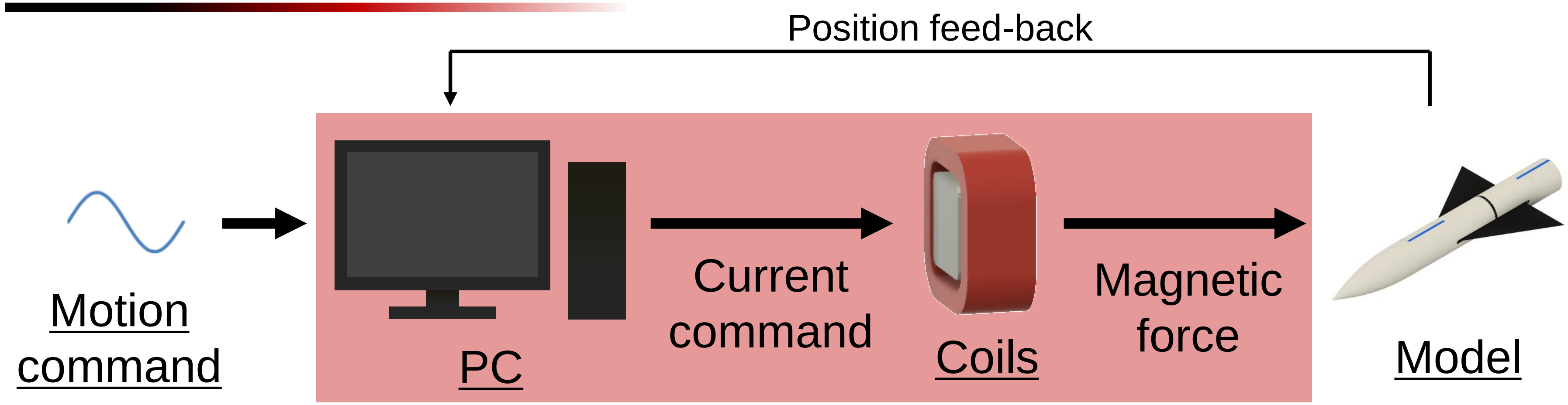
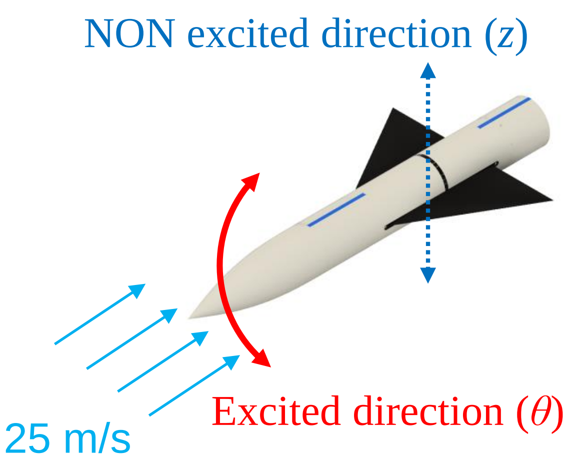
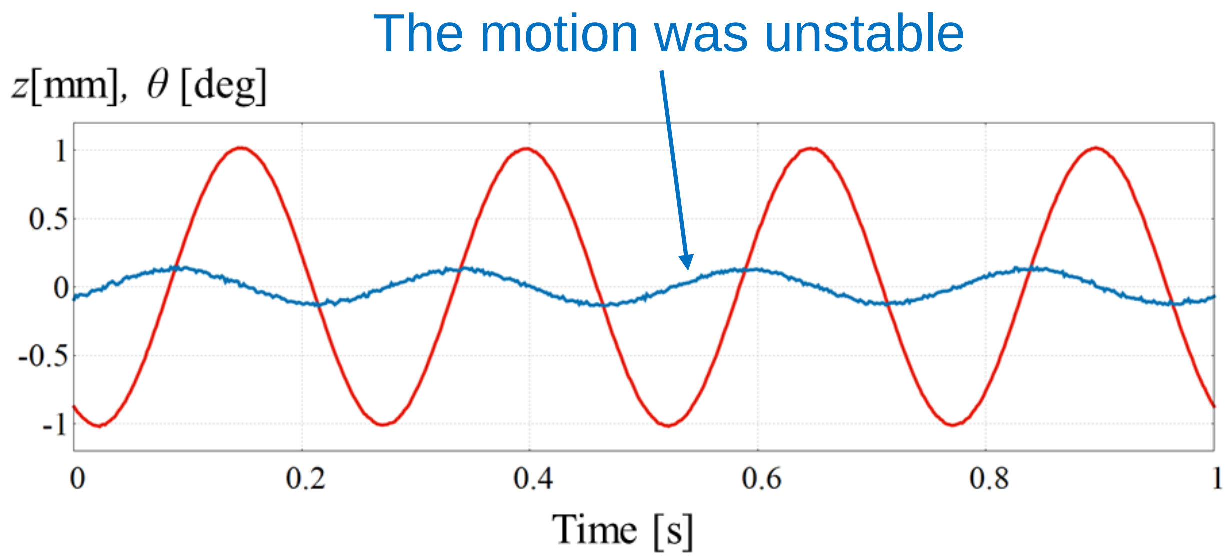
Motion Accuracy

How to excite the model:



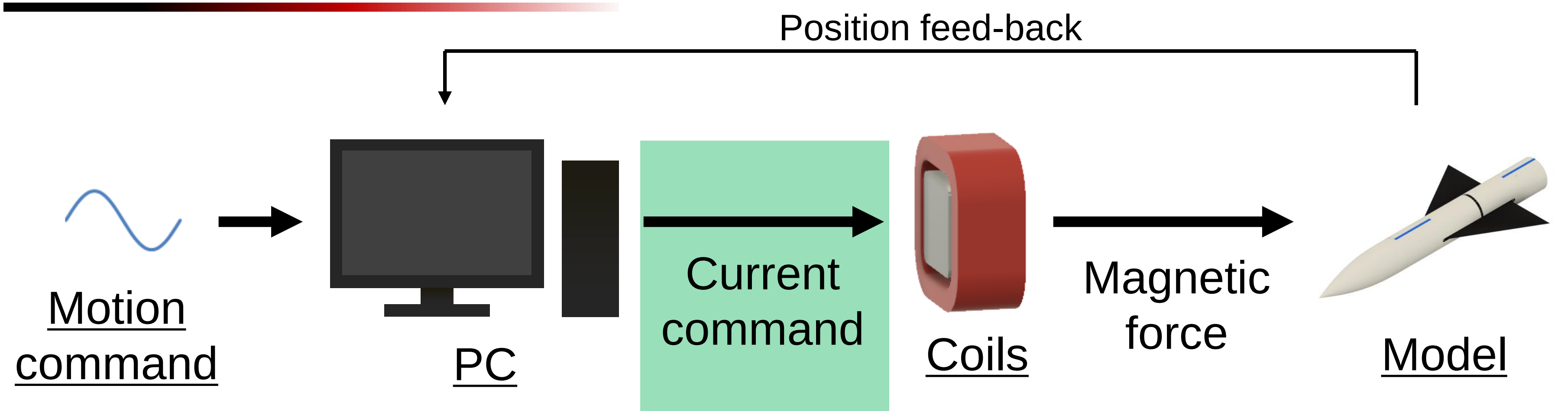
Delay of control system





Motion Accuracy

How to excite the model:



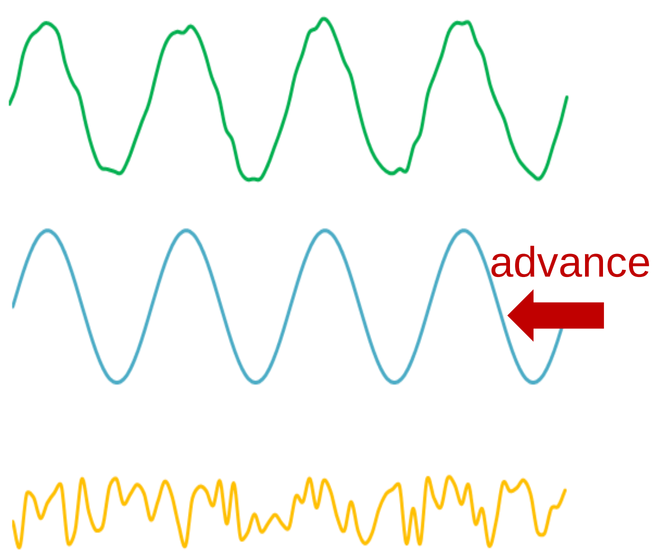
Noisy wave

=

Sinusoidal wave

+

noise

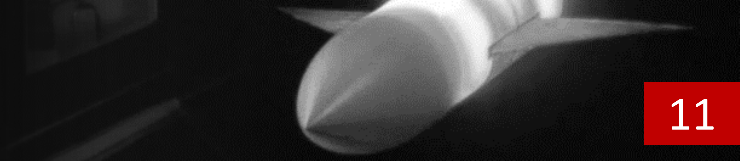


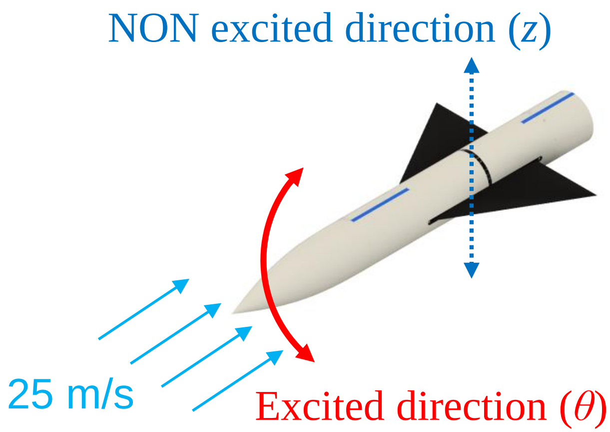
Decided by feed-back control with phase delay

Input this “bias” signal as a sinusoidal function with phase advance

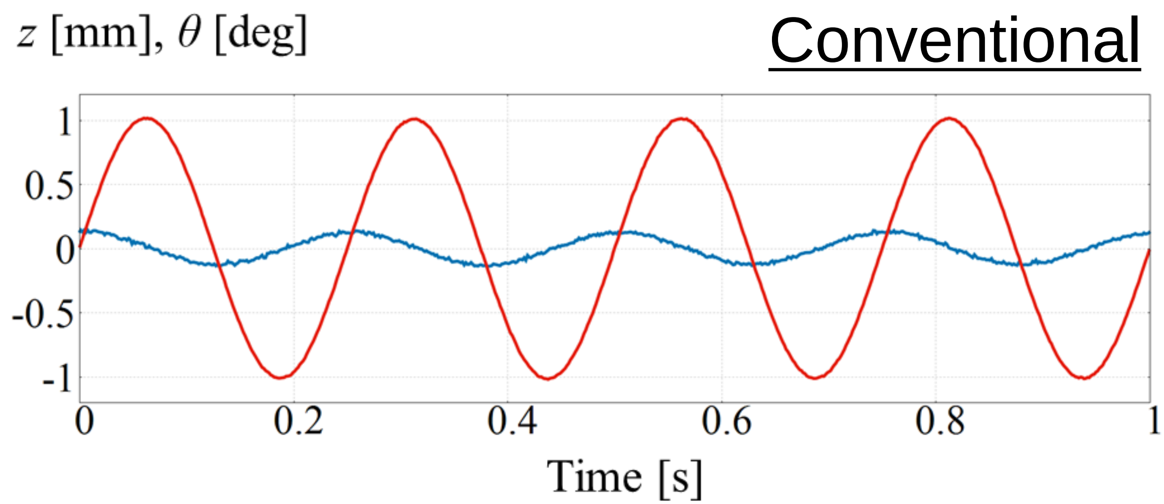
Input by feed-back control with minimum amplitude

Motion Accuracy

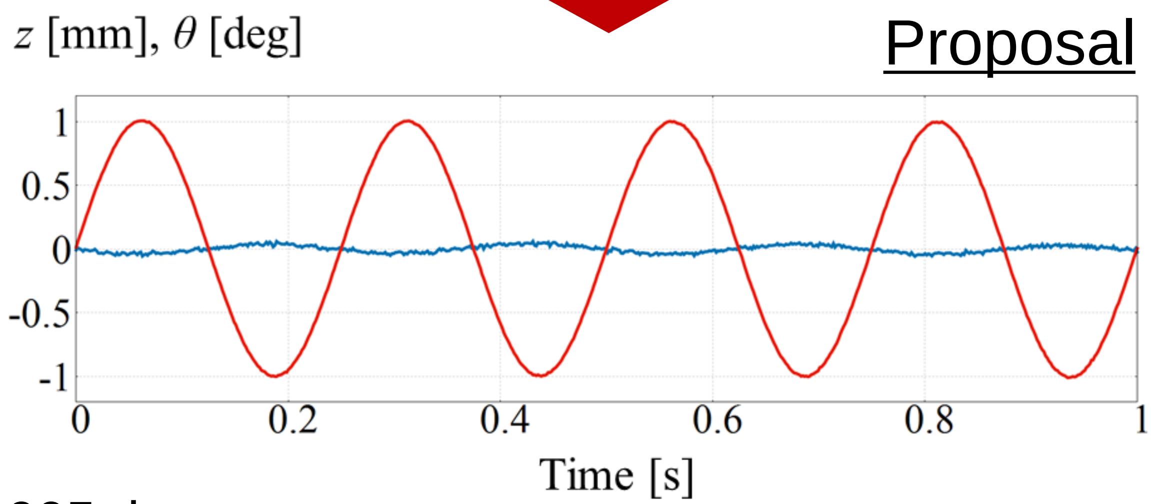




Conventional



Proposal



Angles of attack error < 0.005 degrees

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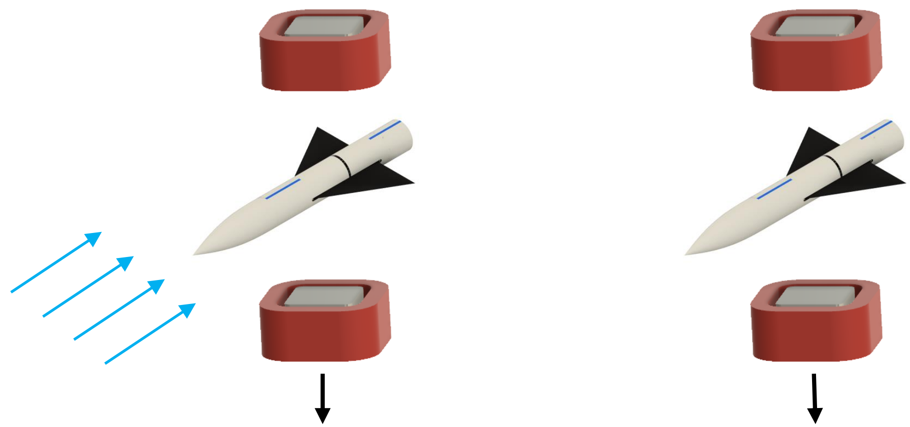
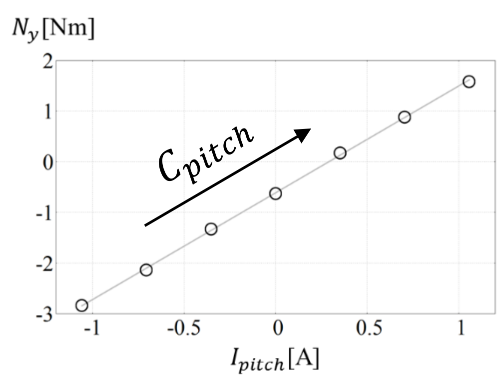
Force Measurement Accuracy

How to measure the aerodynamic force:



$$N = (I_{wind-on} - I_{wind-off}) \times C$$

Aerodynamic moment — Coil current — Coefficient



$$N_y = C_{pitch} I_{pitch}$$

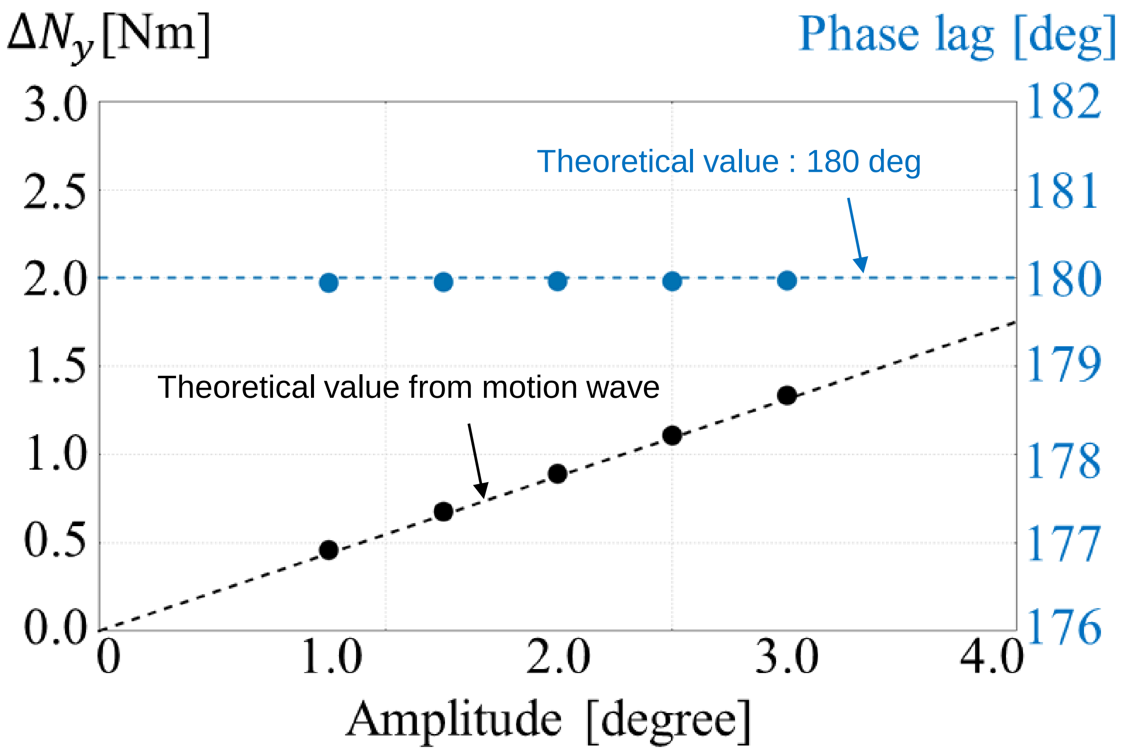
$$N_y(t) = \alpha C_{pitch} I_{pitch}(t + \tau)$$

Gain change — Phase delay

Force Measurement Accuracy

Validation with Inertial torque

Coil current and inertial torque (4Hz)



Maximum error <u>amplitude : 2.4 %</u>

<u>phase lag : 0.1 degree</u>

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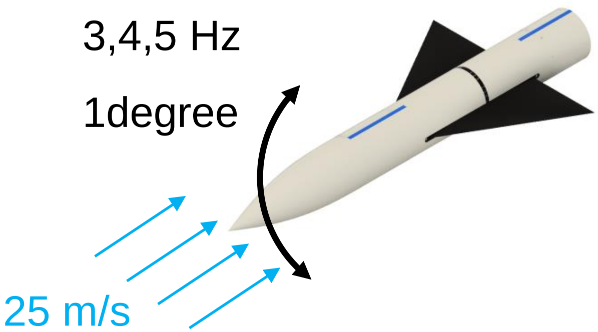
Wind tunnel in simple flight condition

Test condition

AGARD-B winged model



Condition	Value
Oscillatory direction	pitch
Free stream velocity [m/s]	25
Reynolds number (based on m.a.c.)	2.9×10^5
Oscillation frequency [Hz]	3, 4, 5
Oscillation center AoA [deg]	0.0
Oscillation amplitude [deg]	1.0
Reduced Frequency	0.065 ~ 0.109

Evaluated flight parameter

Measurement object :

Motion $\theta(t) = \theta_0 \sin(2\pi f t)$

Aerodynamic moment $N_y(t) = N_{y0} \sin(2\pi f t + \tau)$

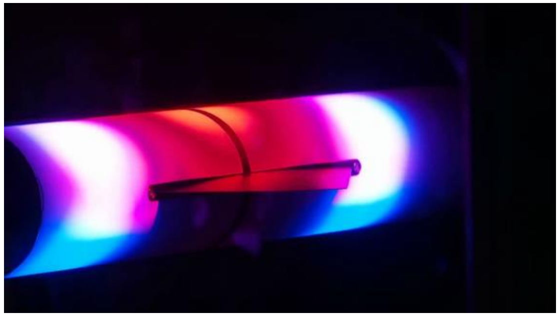
Stability derivatives :

Static stability $C_{m\alpha}$
(Also obtained by static test)

Dynamic stability $C_{m\dot{\alpha}} + C_{mq}$

Wind tunnel in simple flight condition

Stability derivatives evaluation



Condition		$C_{m\alpha}$ [/deg]	$C_{m\dot{\alpha}} + C_{mq}$ [/rad]
Present	3 Hz	0.010 $\pm$0.000	-0.9 $\pm$0.5
	4 Hz	0.010 $\pm$0.000	-0.8 $\pm$0.2
	5 Hz	0.010 $\pm$0.000	-1.0 $\pm$0.1
	Static	0.010 $\pm$0.000	-
DATCOM		0.008	-1.1

DATCOM : a computer-based evaluation

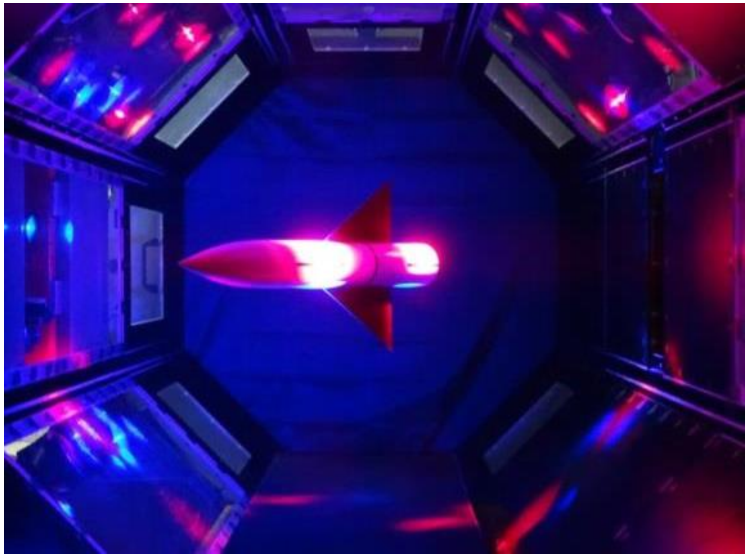
❶ Static stability agreed well between dynamic and static tests

➡ The dynamic wind tunnel was performed appropriately

❷ Dynamic stability approximately agreed each other

➡ Aerodynamic stability evaluation in unsteady flight condition is available

Future plan suggestion



H. Senda, et al. (2018)

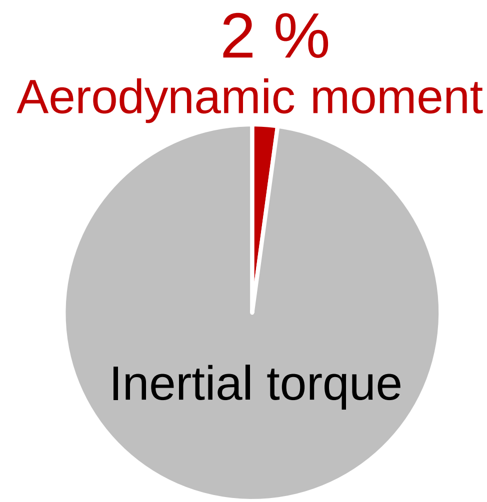
- Evaluation of the motion accuracy
- Validation of the force evaluation accuracy
- Dynamic wind tunnel at simple flight condition
- Dynamic wind tunnel at extreme flight condition

Future plan suggestion

Issues to make this study practical

❶ Perform the dynamic wind tunnel with :

- a) High angles of attack
- b) Large amplitude and frequency

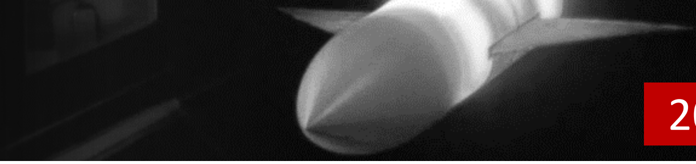


Torque of wind-on condition (4 Hz)

❷ Upgrade the model to lightweight

❸ Perform the test with realistic shaped model

Summary



Development of dynamic wind tunnel technique using 1-m MSBS :

Motion accuracy

- Error of AoA : within 0.005 deg

Unsteady force evaluation accuracy

- Error of evaluation : within 2.4 % in amplitude, 0.1 degree in phase

Dynamic wind tunnel

- Evaluated dynamic stability agreed well with estimated value

Unsteady aerodynamic measurements using 1-m MSBS are feasible.

Thank you for listening!