

Micro-sized Mar Airplane Flight Testing Project

Yugo Suzuki

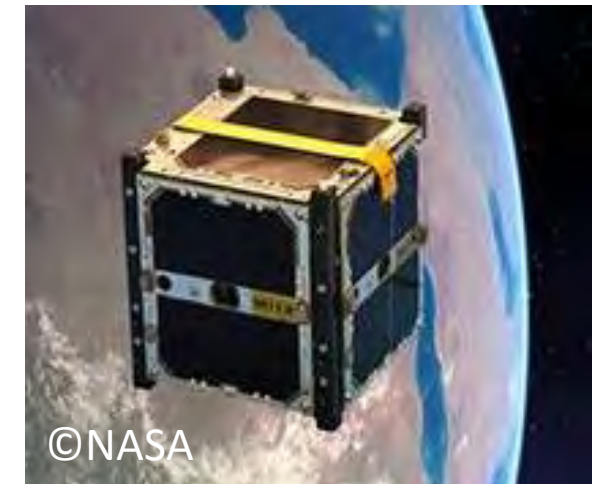
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Tohoku University**

■ Mars Airplane

- ✓ Merit: High mobility
 - Wider range than rovers / No Topographical constraint
- ✓ Challenge: Thin atmosphere
 - ~1 % of Earth's air density (Requires large wing area)
 - Limited launch opportunities → Remains unrealized

■ CubeSat

- ✓ Lightweight, ultra-compact satellite (1 kg, 10×10×10 cm)
- ✓ High availability of launch windows
- ✓ Requires high stowability



Micro-sized Mars Airplane storable in a CubeSat

Micro-sized Mars Airplane, MMA

■ Balancing high stowability and large wing area → Deployable architecture

✓ MMA with inflatable wings

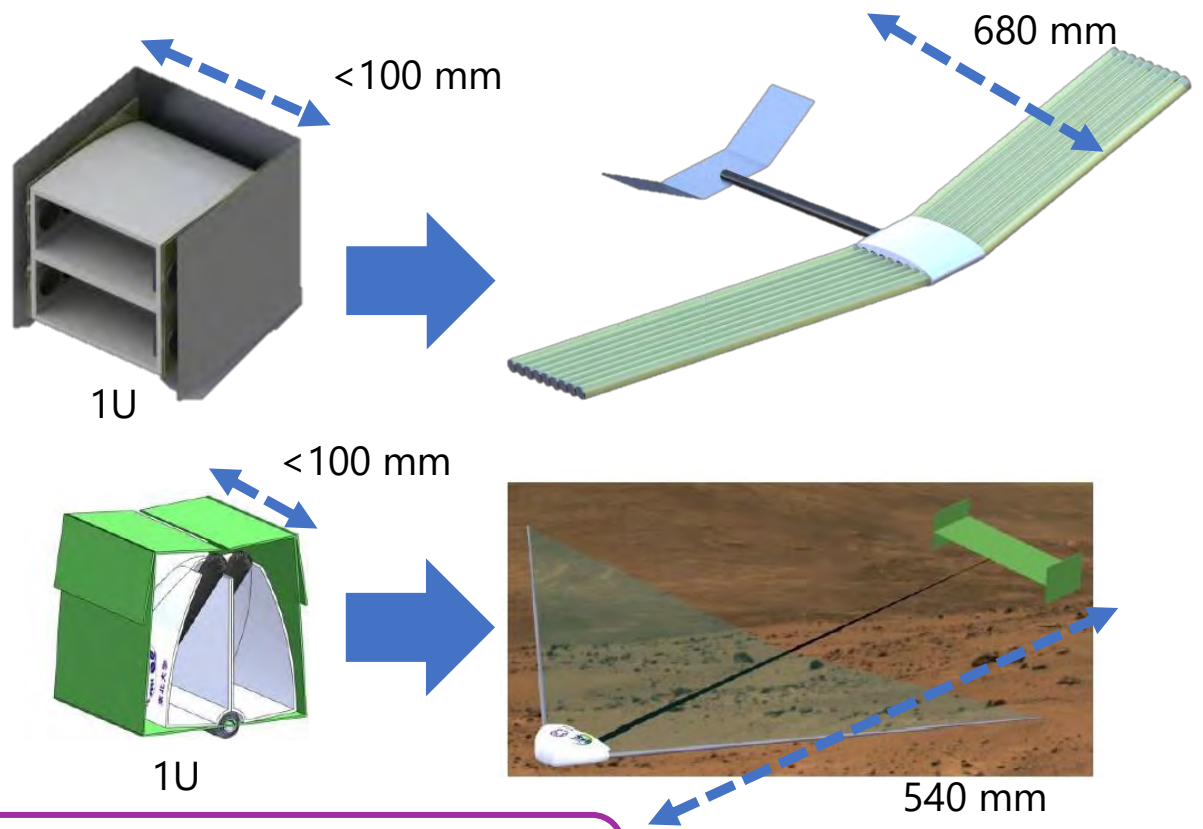
(Mamiya et al. 2019)

- Deployed via gas inflation
- Requires inflation system
- Estimated range: ~34 km

✓ MMA with flexible membrane wing

(Lee et al., 2020)

- Deployed via multi-stage telescopic rods
- Challenge: deployment friction
- Estimated range: ~92 km

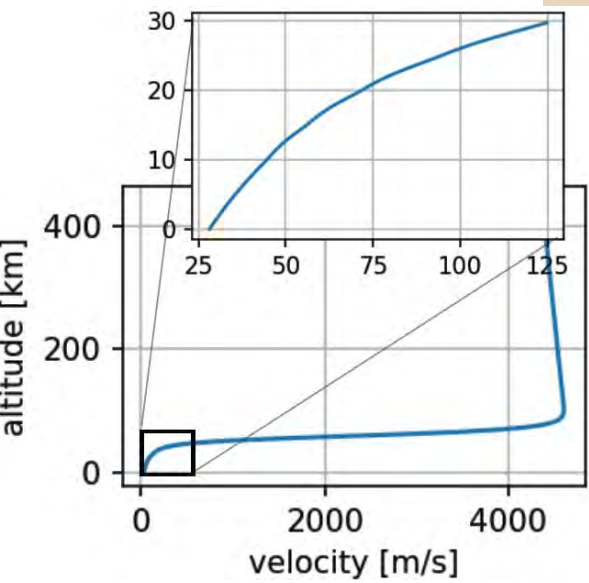
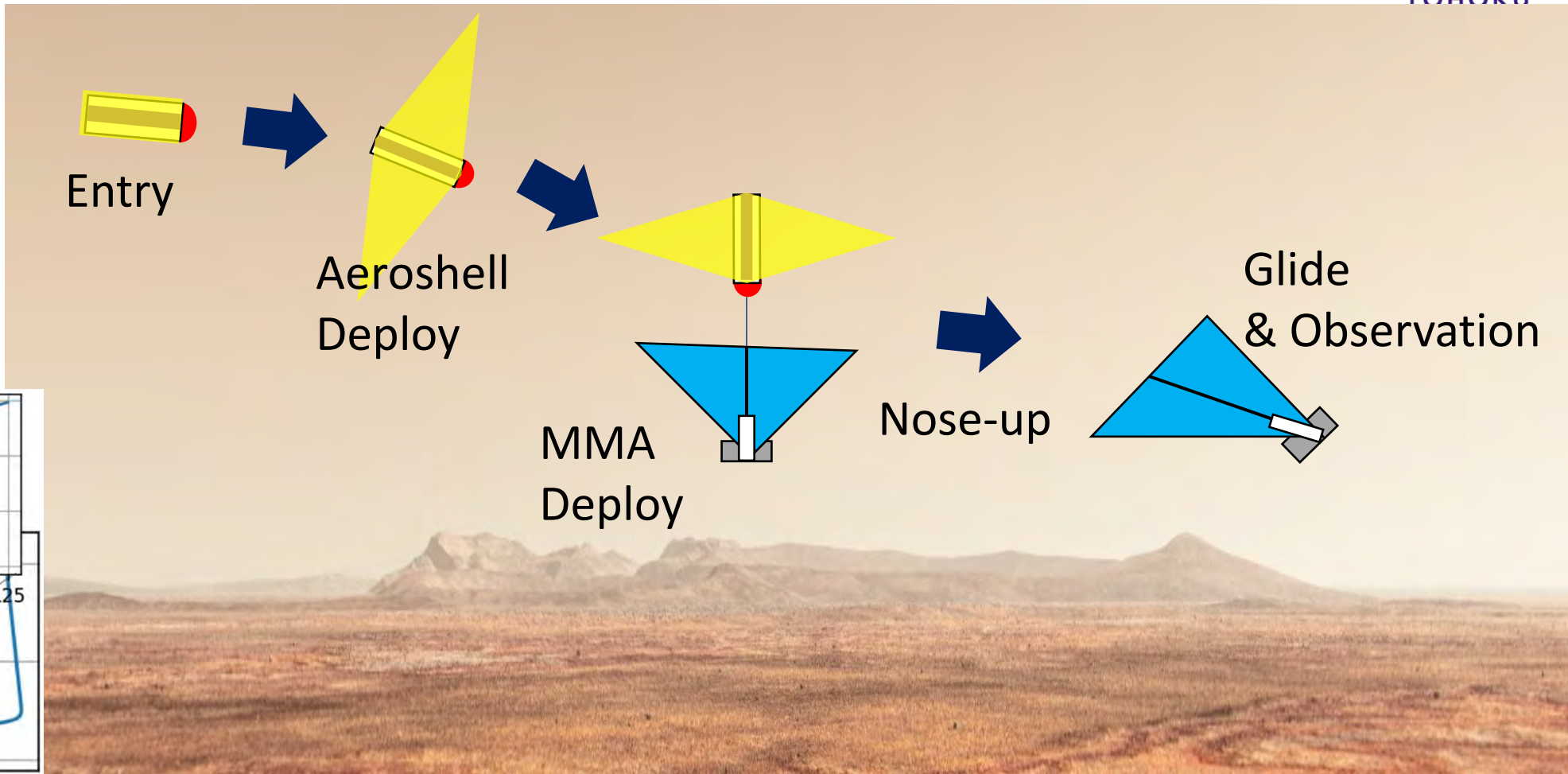
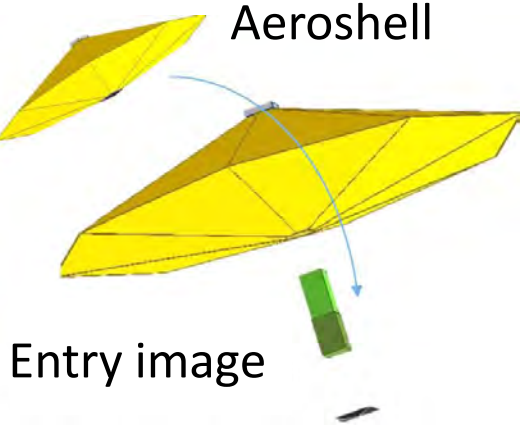


Realizing MMA: Moving beyond conceptual study to flight testing

Conduct flight testing evaluation and aerodynamic measurement of the new design

- ✓ Evaluation of flight performance through flight testing
- ✓ Evaluation of aerodynamic performance through wind tunnel testing

Mission Scenario



✓ Exploration example: RSL (Recurring Slope Line)

Aircraft Concept & Specifications

■ Subsonic gliding

- ✓ Elimination of compressibility effects

■ Flying wing

- ✓ Ensuring wing area & stowability

■ Membrane wings

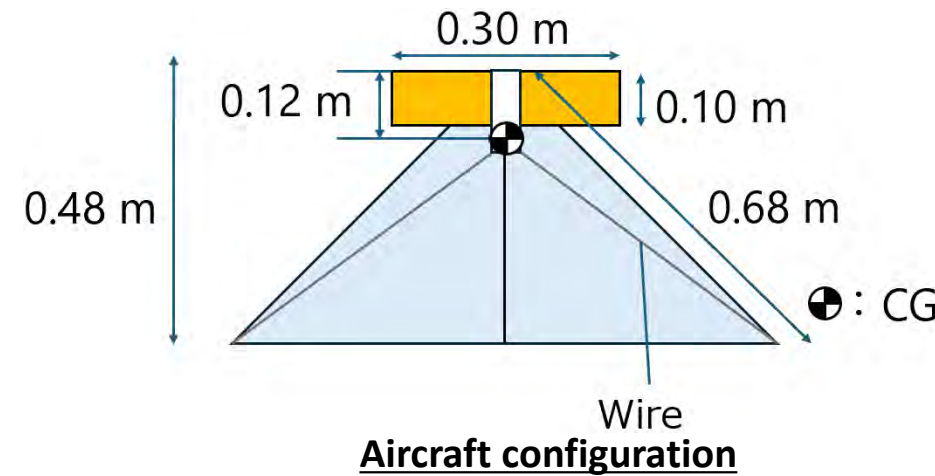
- ✓ Polyimide film
- ✓ Improve stowability

■ Dihedral angle

- ✓ Lateral stability

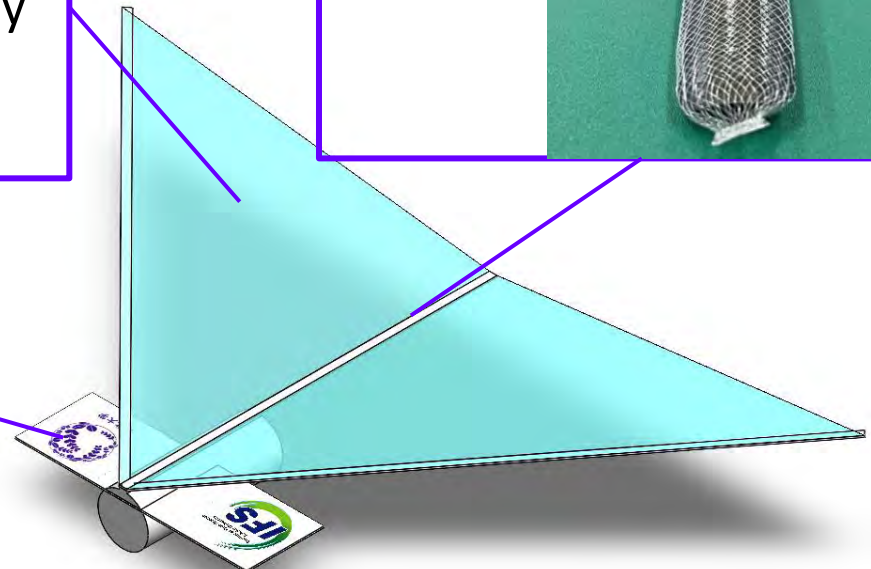
■ CFRP Bi-convex spar

- ✓ Simplified and lightweight structure
- ✓ Self-deployable



Specifications

Main wing area [m ²]	0.23
Canard area [m ²]	0.03
Wingspan [m]	0.96
Total length [m]	0.48
Canard span [m]	0.30
Canard chord [m]	0.10



■ Canard

- ✓ Shares a portion of the lift
- ✓ Pitch control

Outline of the Wind-tunnel Testing



Objective

- ✓ Aerodynamic characterization

Wind-tunnel

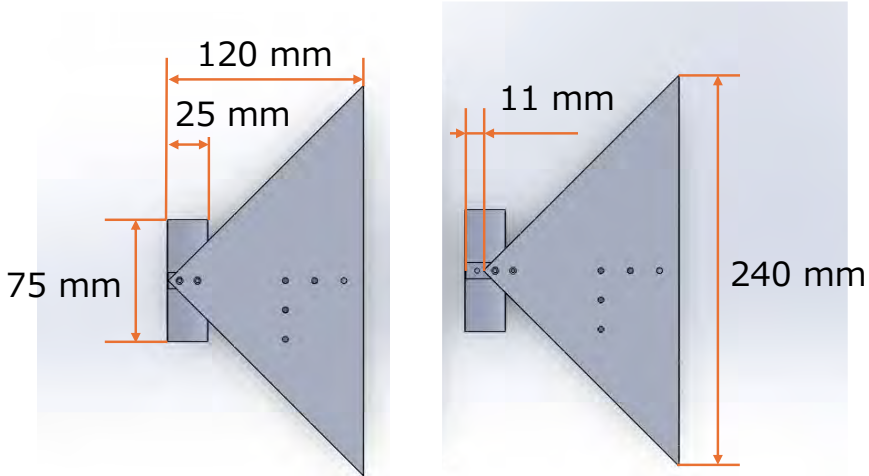
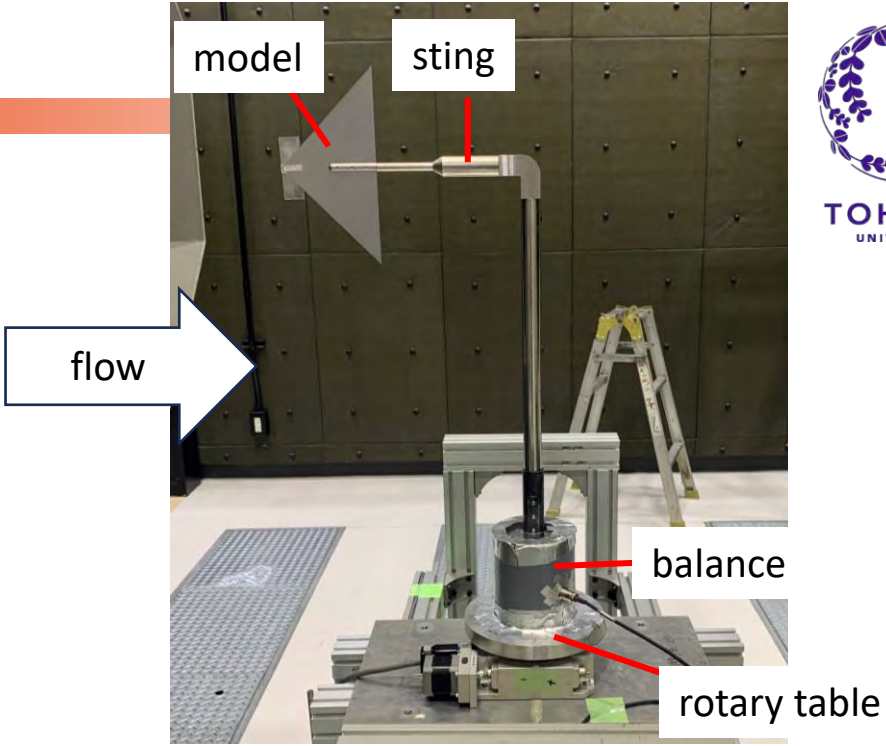
- ✓ Low turbulence wind-tunnel (@IFS, Tohoku univ.)

Measurement items

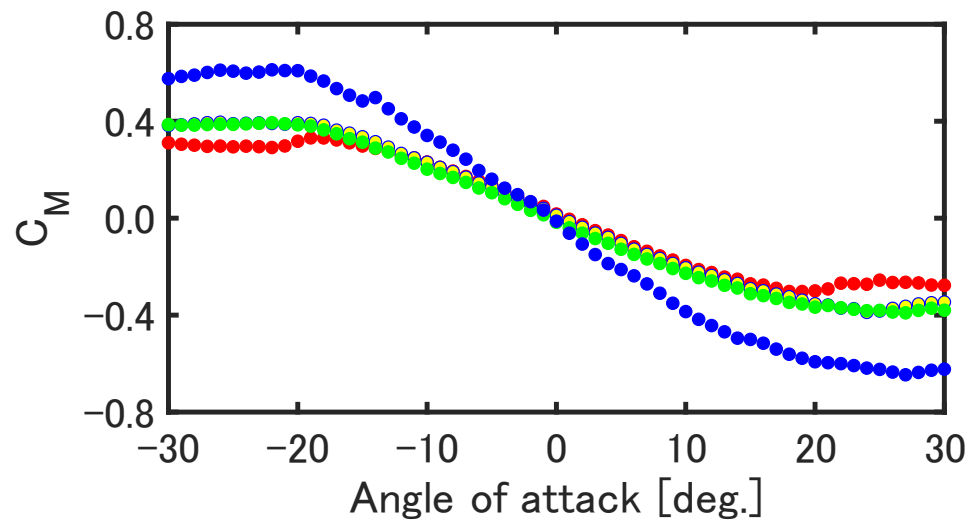
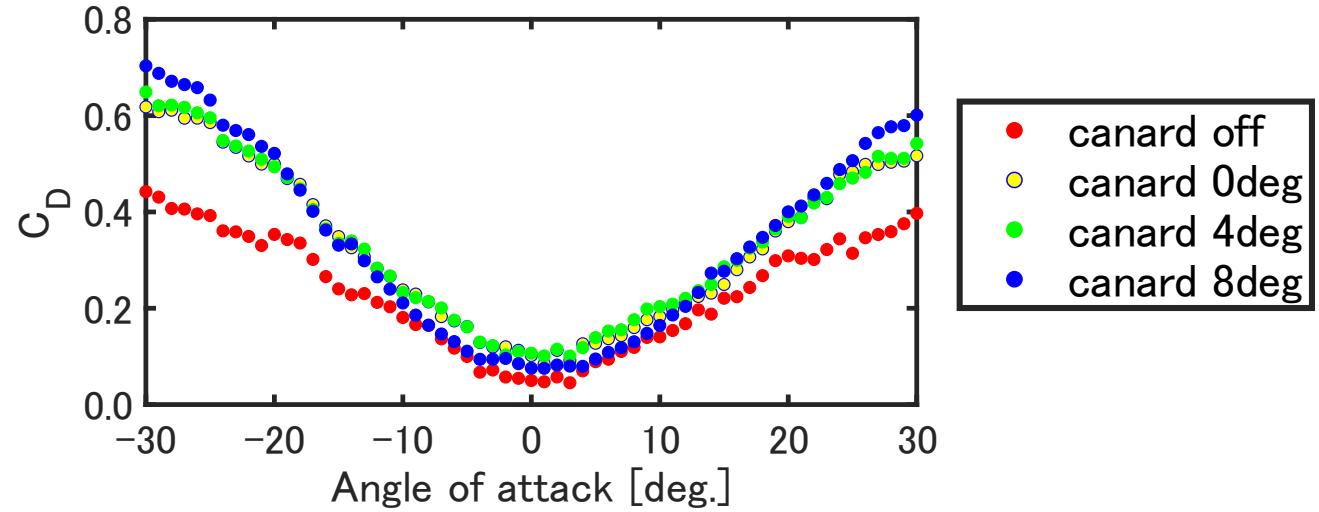
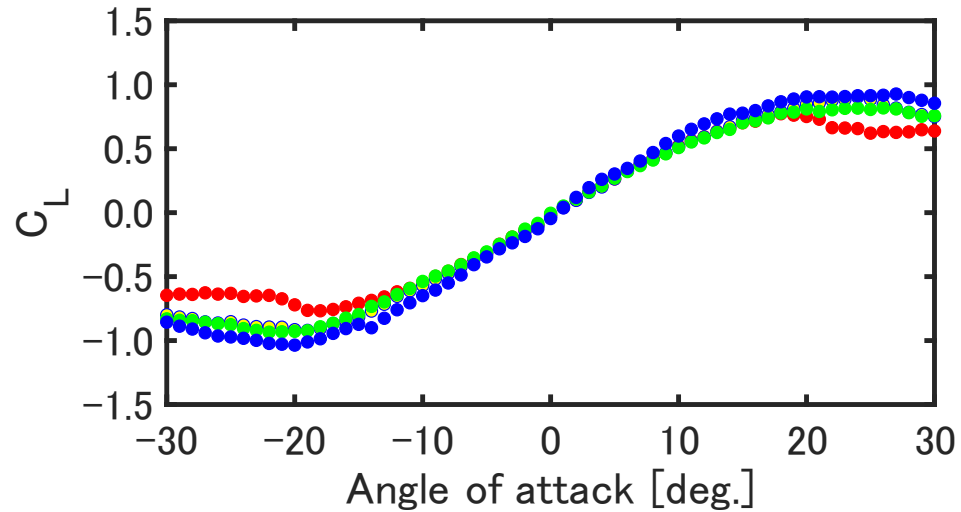
- ✓ Three aerodynamic force components

Experimental condition

Reynolds number [-]	3.0×10^4
Angle of attack [deg.]	-30 – 30
Canard	w/o-canard, 0 deg., 4 deg., 8 deg.
Reference area [cm ²]	144 (Main wing)



■ Comparison by canard setting angle ($Re = 3.0 \times 10^4$)



- ✓ Canard-on configuration
 - Stall delay
 - Increase in C_D
- ✓ The slope of C_M increases at canard 8 deg.
 - Static margin
- ✓ Trim angle of attack
 - **Minor impact of the canard**

Outline of the Flight Testing

■ Objective

- ✓ Evaluation of the proposed aircraft's flight performance

■ Methodology

- ✓ Catapult launch from a gymnasium balcony
- ✓ Launch mechanism: Rubber-band catapult

■ Measurement items

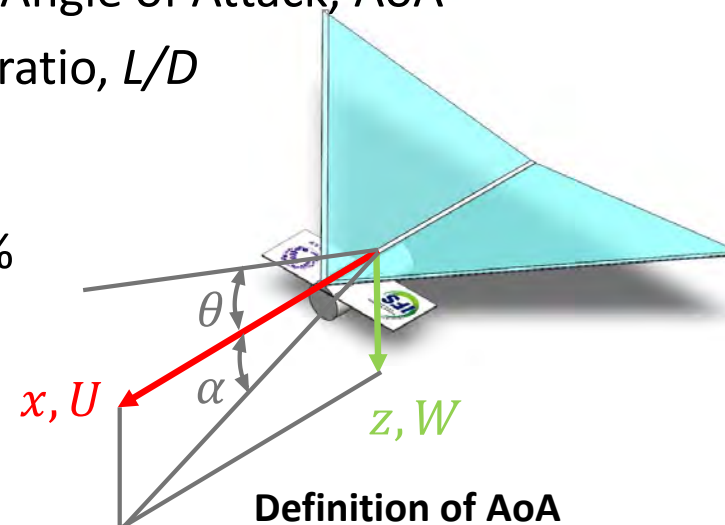
- ✓ 9-axis sensor → Estimation of static stability derivatives
- ✓ Video camera → Estimation of velocity and Angle of Attack, AoA
- ✓ Flight distance → Derivation of Lift-to-Drag ratio, L/D

■ Test cases

- ✓ Center of gravity, CG: 25 % (design CG), 30 %
- ✓ Canard setting angles: 0 deg., 4 deg., 8deg.



Experimental model

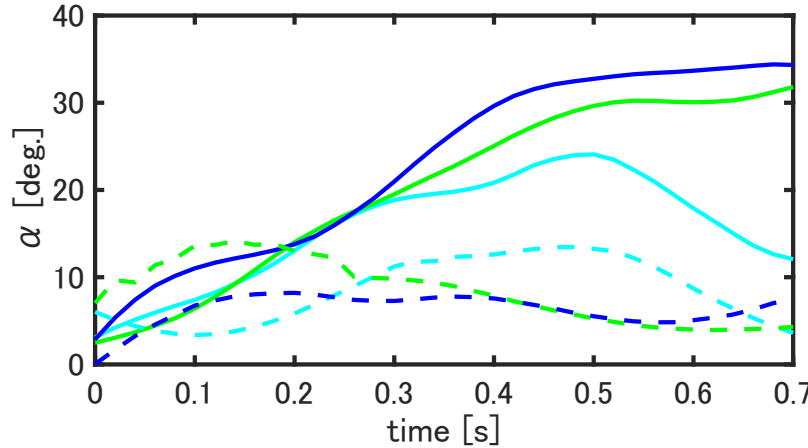
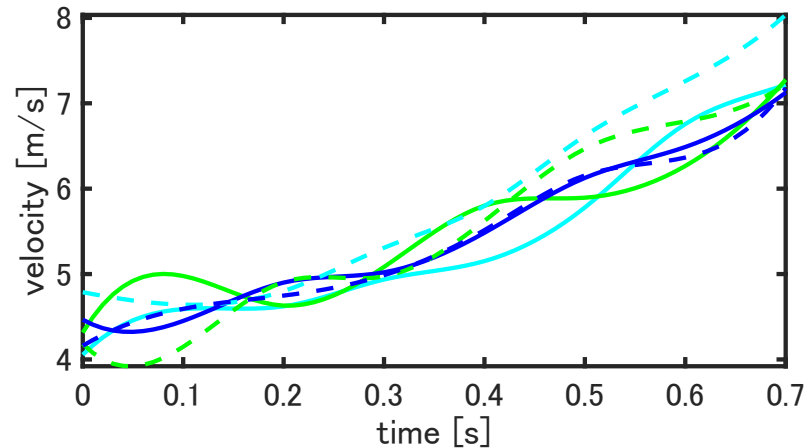


Definition of AoA



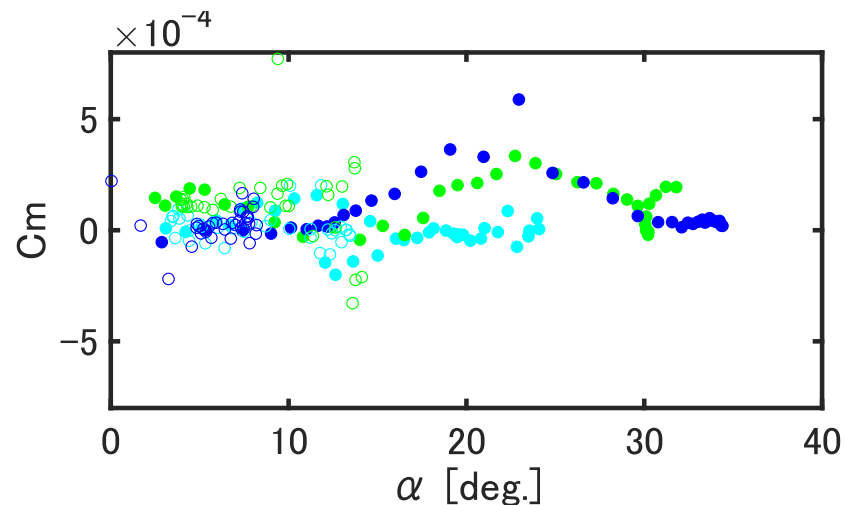
Velocity analysis

Results of velocity analysis



- cg25 0deg - - - cg30 0deg
- cg25 4deg - - - cg30 4deg
- cg25 8deg - - - cg30 8deg
- cg25 0deg ○ cg30 0deg
- cg25 4deg ○ cg30 4deg
- cg25 8deg ○ cg30 8deg

Estimation results of static stability derivative Measured flight distance results



CG position	CG25			CG30		
Canard setting angle [deg.]	0	4	8	0	4	8
Flight distance [cm]	503	561	558	528	439	537
<i>L/D</i>	1.59	1.78	1.77	1.67	1.39	1.70

FY2025 Proposed Configuration



Longitudinal trim optimization

- ✓ Aligning the CP with the CG at the maximum L/D AoA
 ⇒ Enables steady-state gliding at peak aerodynamic efficiency

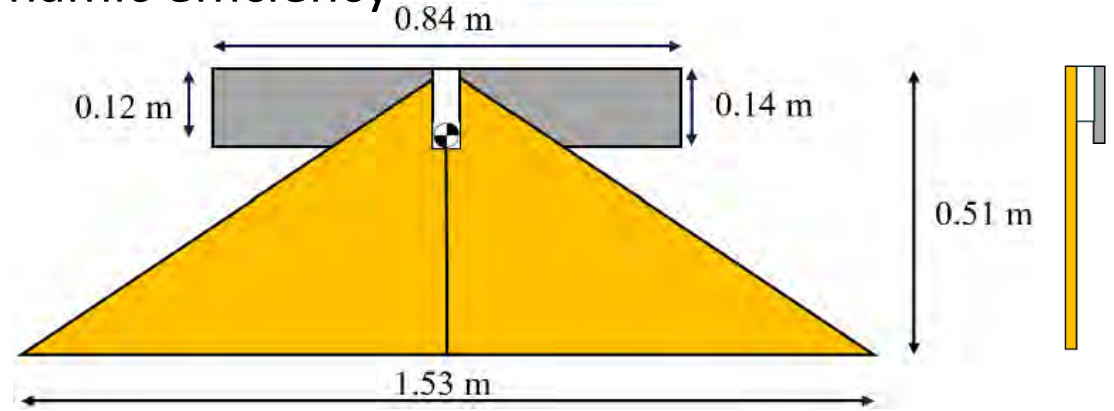
Main wing

- ✓ Flat-plate delta wing ($AR = 6$)
- ✓ Max L/D achieved at AoA = 4.5 deg.
- ✓ CG: $x/c_{root} = 0.24$

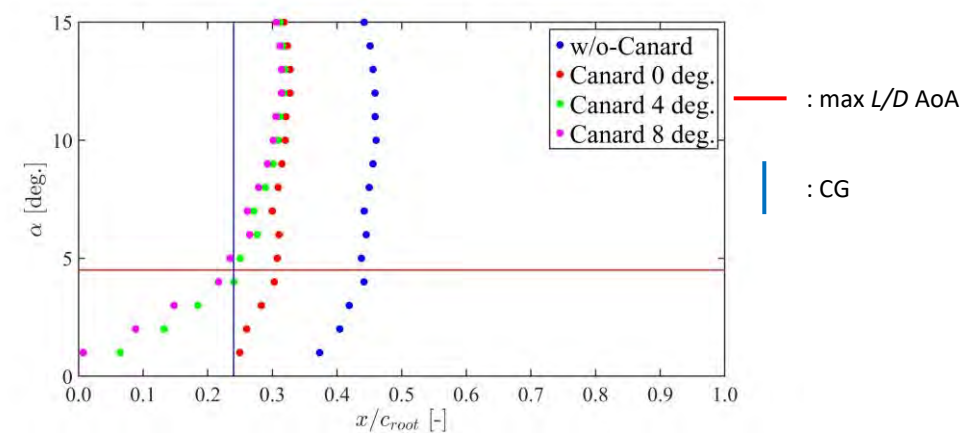
Canard

- ✓ Flat-plate rectangular wing ($AR = 6$)
- ✓ CP: Calculated at $x/c_{root} = 0.23$ (@AoA = 4.5)
- ✓ The minimal gap between CP and CG ensures balanced gliding

Need to assess aerodynamic interaction between the canard and main wing



Aircraft configuration

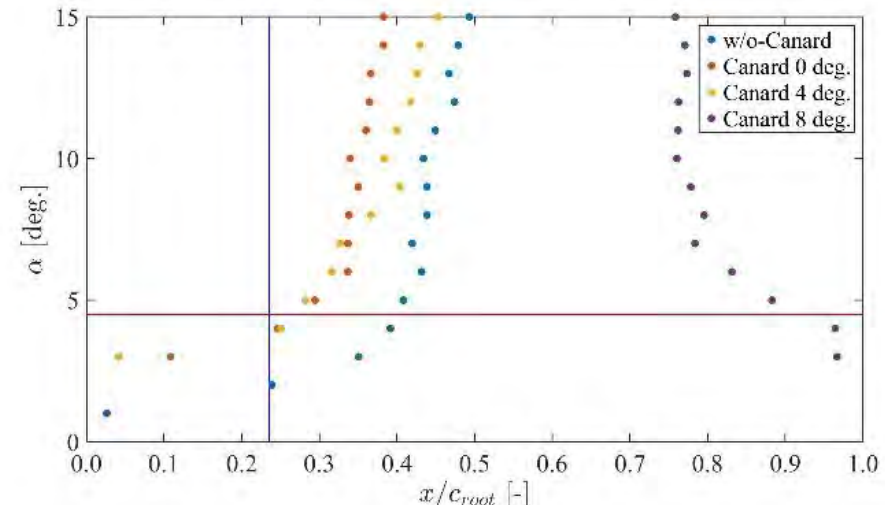
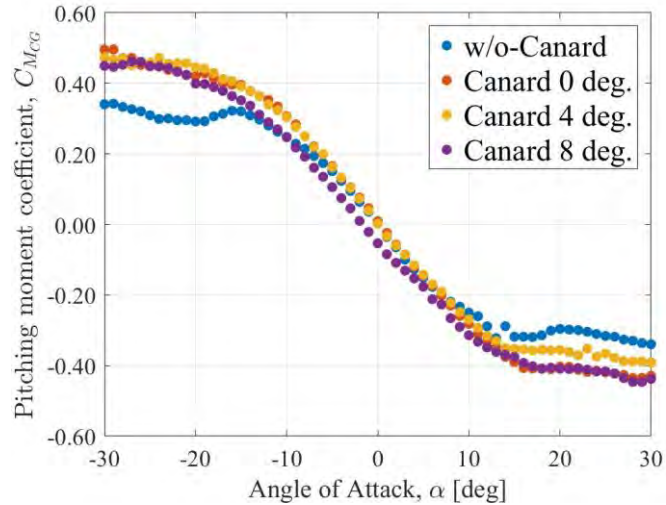
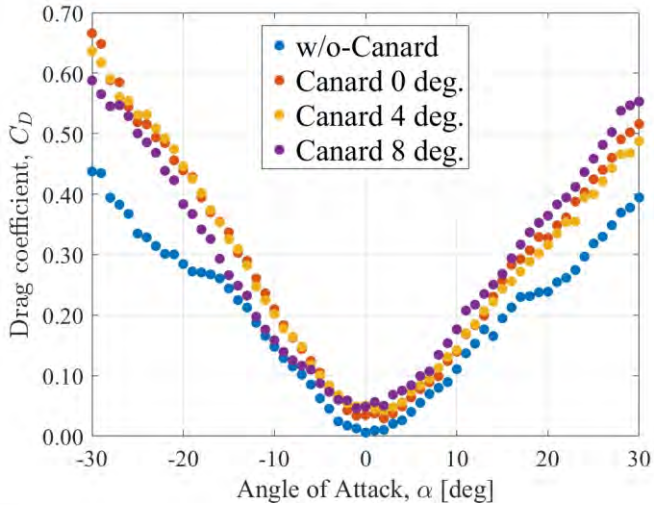
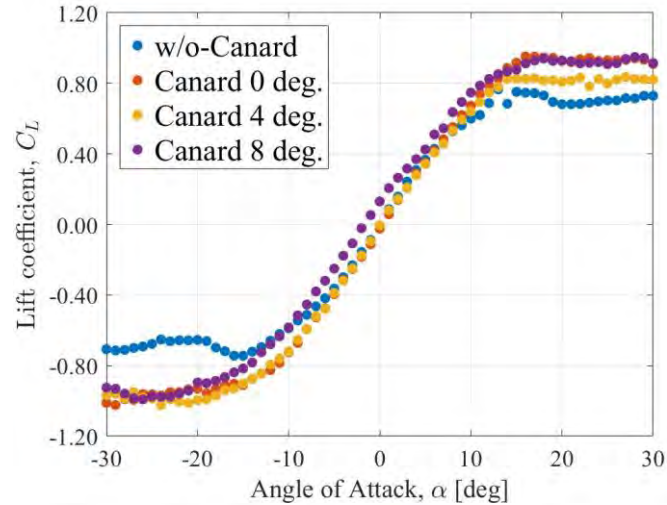


CP migration with respect to AoA

Aerodynamic Characteristics (Wind Tunnel Testing)



■ Comparison by canard setting angle ($Re = 2.2 \times 10^4$)



CP migration with respect to AoA

- ✓ Trim characteristics
 - Reduction in trim AoA at Canard 4 deg. and Canard 8 deg.
- ✓ CP
 - CP migrates aft the AoA increases
 - Anomaly at Canard 8 deg.: exhibits a different trend with extreme aft shift
 - Minimal difference between Canard 0 deg. and Canard 4 deg.
 - ⇒ Low trim control effectiveness

■ Conducted flight testing in a controlled indoor environment

- ✓ CG position is expected to significantly influence the flight attitude
- ✓ The canard setting angle is expected to influence the nose-up authority

■ Conducted aerodynamic measurement for the aircraft with optimized trim characteristic

- ✓ The target trim AoA was not achieved
- ✓ Suggests that canard stall and aerodynamic interference are the primary causes
- ✓ Vertical asymmetry is another potential factor influencing the results

■ Acknowledgment

We would like to express our sincere gratitude to the Boeing Higher Education Program for your generous support.