CFD High Lift Prediction Workshop

HiLiftPW-3
JSM wind tunnel experiment Overview

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Outline

- **JSM wind tunnel experiment**
  - Overview
  - Influence of standoff height
  - Influences of HLDs support brackets
  - Slat Static Pressure Tubes treatment
  - Flap Static Pressure Tubes treatment
- **Data for HiLiftPW-3**
  - Conditions for HiLiftPW-3
  - CAD model modification
  - Forces, Moment Data
  - Pressure Coefficient Data
  - Oil Flow Images
  - Transition Information

JSM Overview (1/2)

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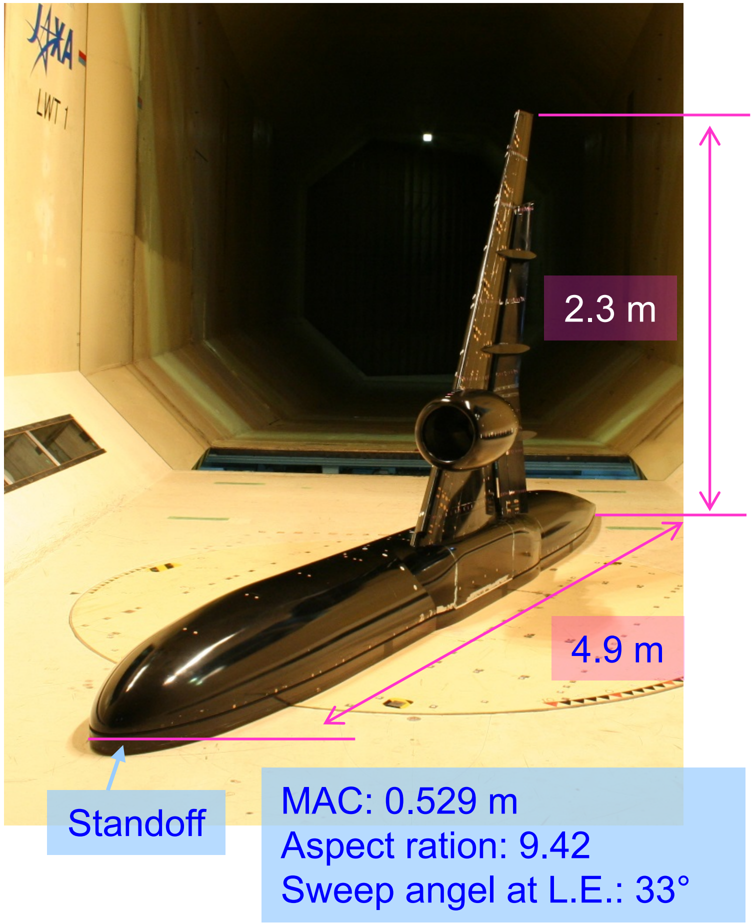
- **JSM** **J**axa highlift configuration **S**tandard **M**odel
  - Tested in 2005 ~ 2009
- **Model specification**
  - 17% of assumed aircraft (100 PAX)
  - 90% span slat
  - Inboard single- or double-slotted flap
  - Outboard single-slotted flap
  - Cylindrical fuselage
  - Pylon-mounted nacelle
  - FTFs
  - No trip dot
- **Test facility**
  - 6.5m by 5.5m JAXA low-speed wind tunnel (JAXA-LWT1)
    - Closed-circuit, atmospheric pressure
  - Estimated* tunnel turbulence intensity was
    Tu = 0.16 percent (via 2003 JAXA study)

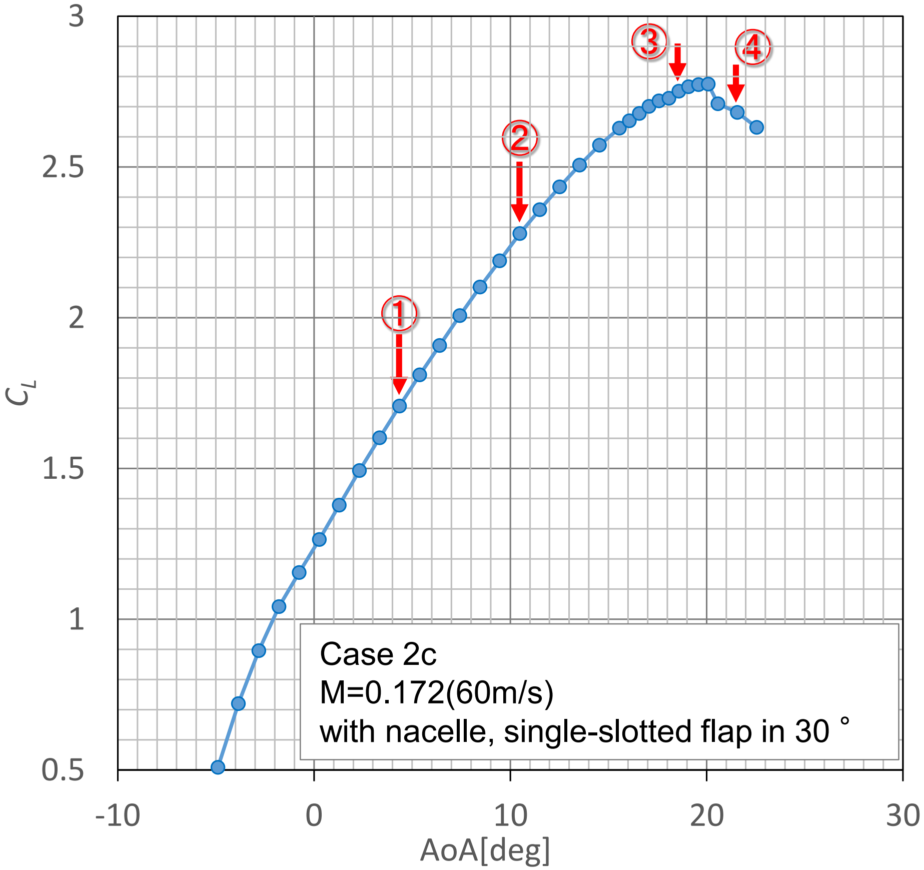


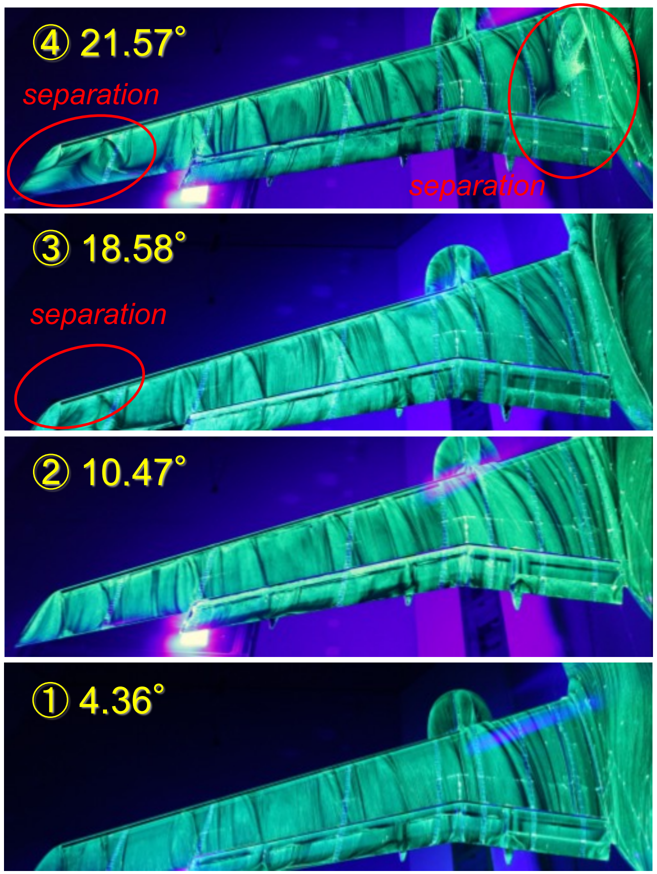
JSM Overview (2/2)

- **Measurements**
  - Forces and moments (5-components balance)
  - Surface pressure distributions (456-taps on mainly 7-sections)
  - Surface flow pattern (oil-flow visualization)
  - Boundary layer transition location (china-clay visualization)
  - Model deformation (optical stereo measurement with target markers)
- **Tested cases in WTT**
  - High-lift setting effect
    - ✓ Flap deflection study
      - Inboard single- or double-slotted flap: 30° or 35°
      - Outboard single-slotted flap: 30° or 35°
    - ✓ Slat/flap position effect
  - Nacelle on/off effect
  - Nacelle chine effect
  - Influence of standoff height

Basic characteristics

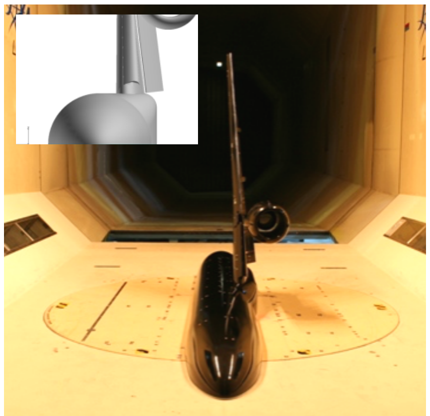
- Laminar separation bubbles locate on the flap surface.
- Flow separation in the tip region occurs at higher AoA.
- Stall is caused by large separation in the wing-root region.



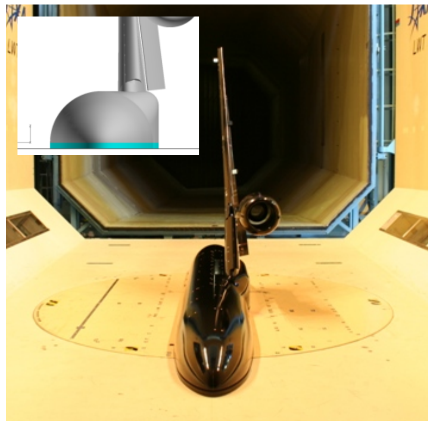


Influence of Standoff Height

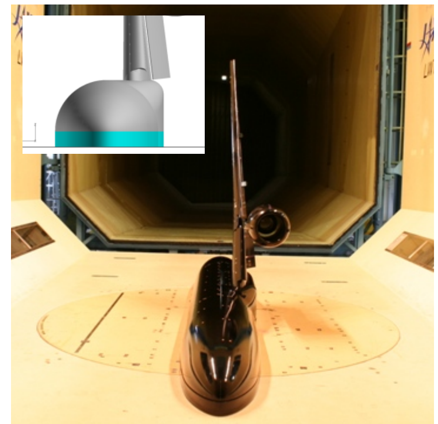
- A standoff height of 60 mm (≈ twice of the displacement thickness) was selected based on wind tunnel tests and extensive CFD studies.



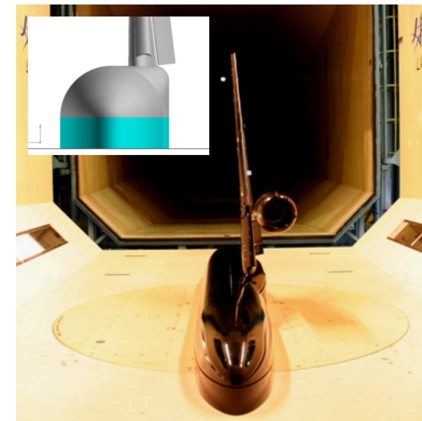
Without standoff



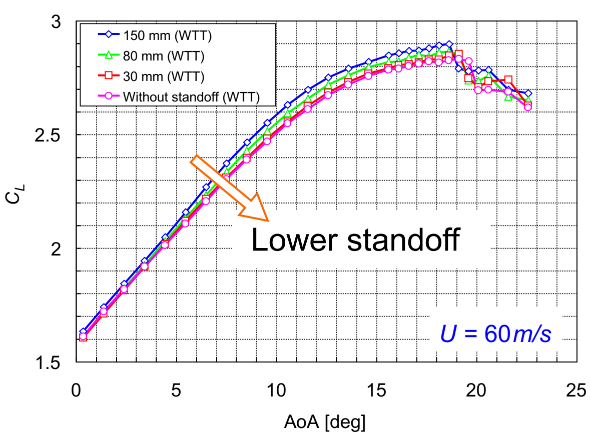
30 mm
(≈ B.L. displacement thickness)

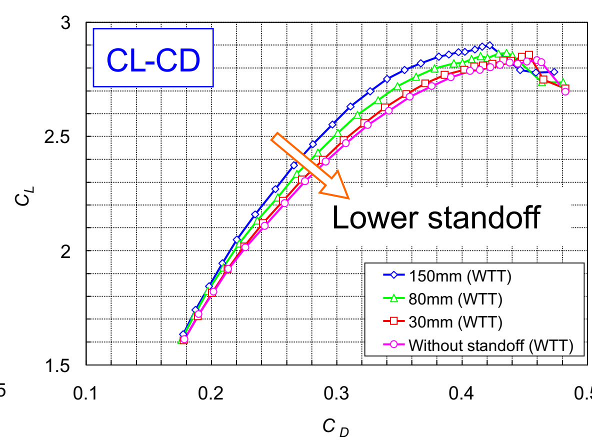


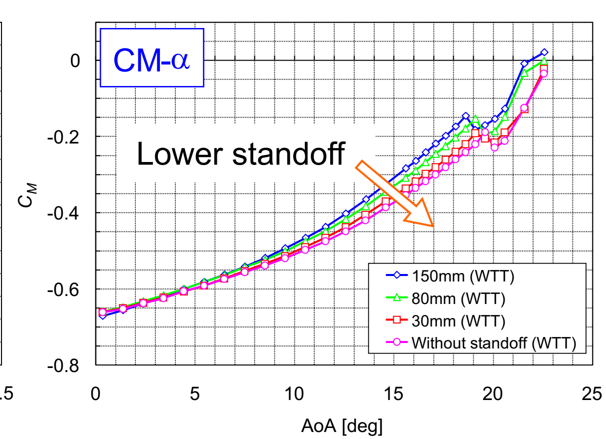
80 mm



150 mm
(≈ 99% B.L. thickness)







Influences of HLDs support brackets

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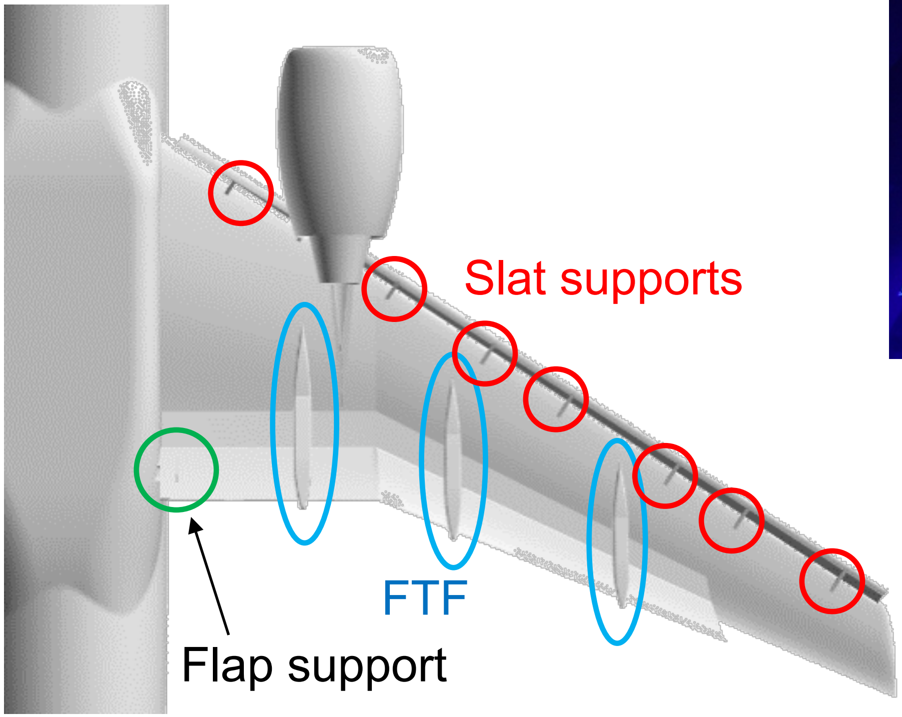
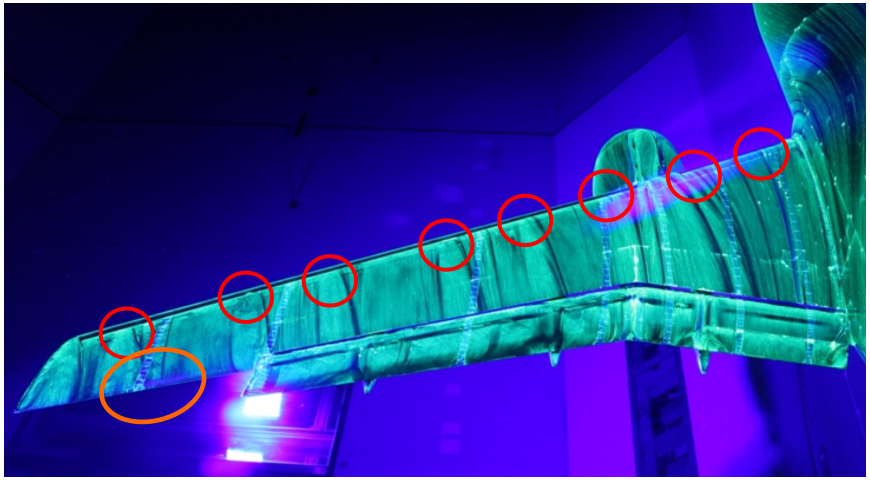
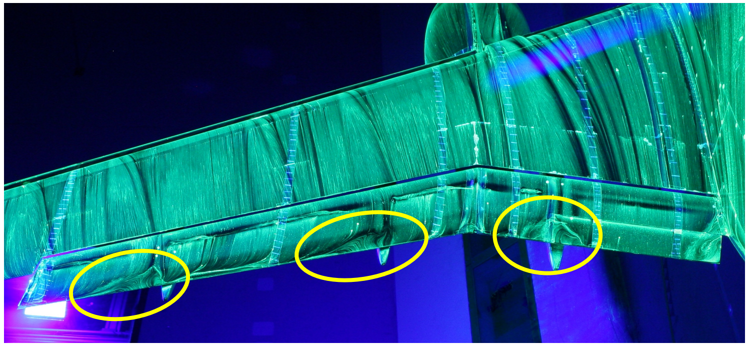
- Flow separation near wing tip appears due to slat support
- Slat support causes flow separation on the main wing near the wing-tip
- Local flow separation appears on flap due to FTF

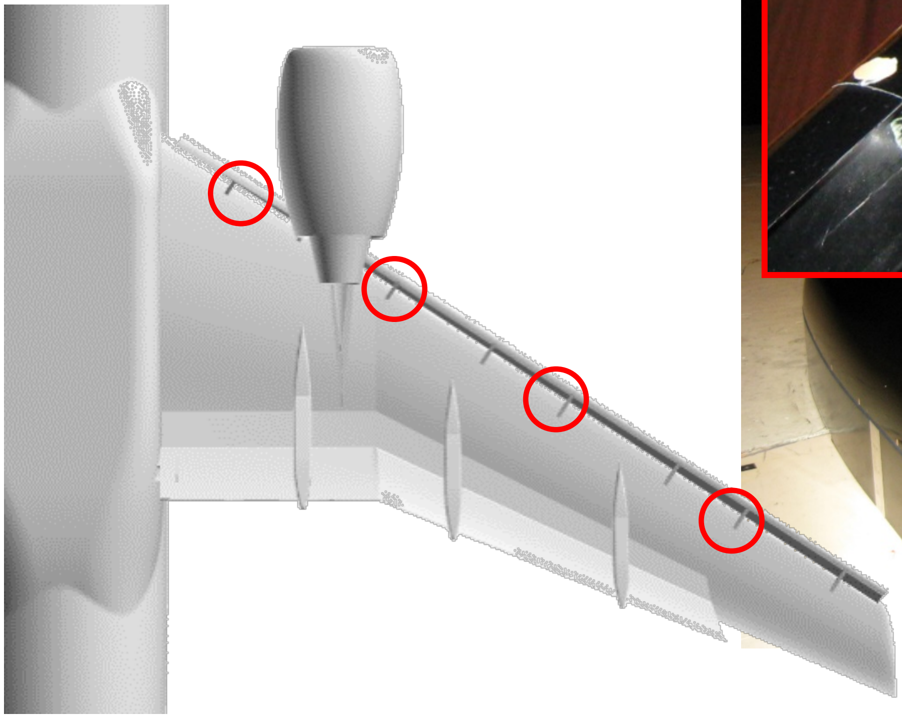


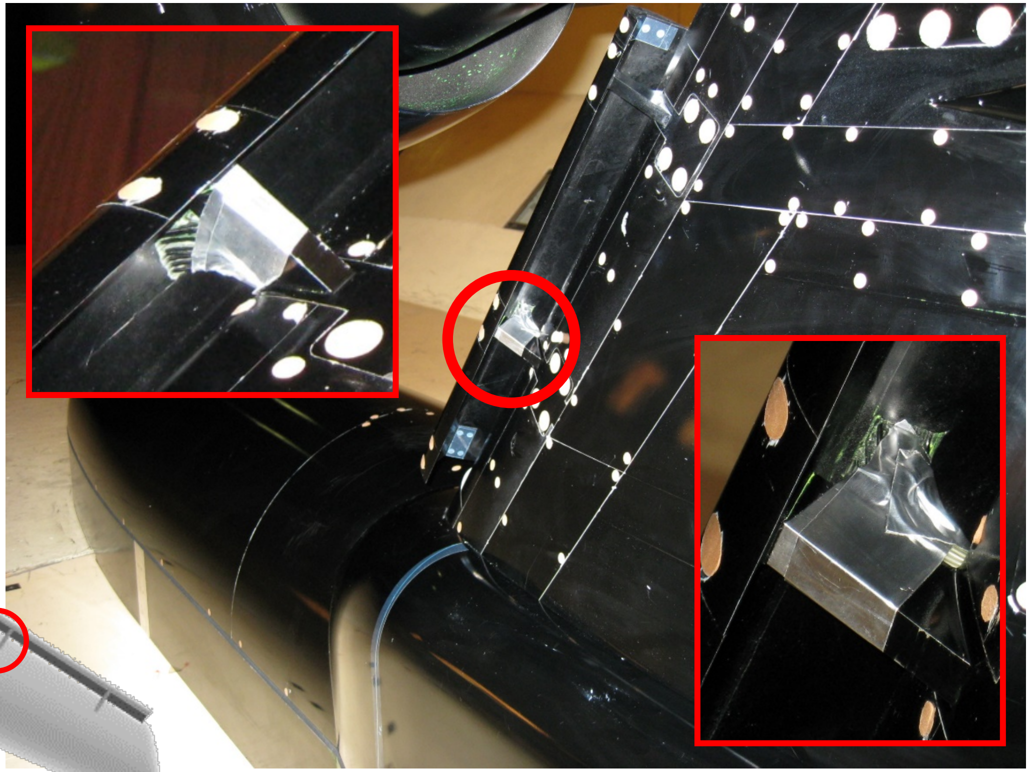




Slat Static Pressure Tubes

- Pulled in the main wing along the slat supports circled by red
- Wrapped by aluminum tape
- Tubes are not included in the CAD model this time





Flap Static Pressure Tubes

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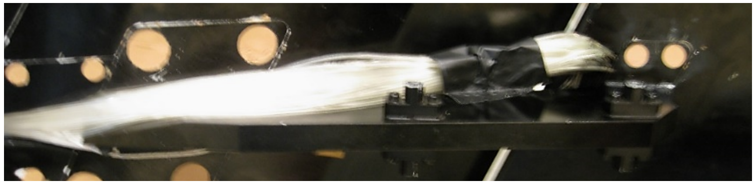
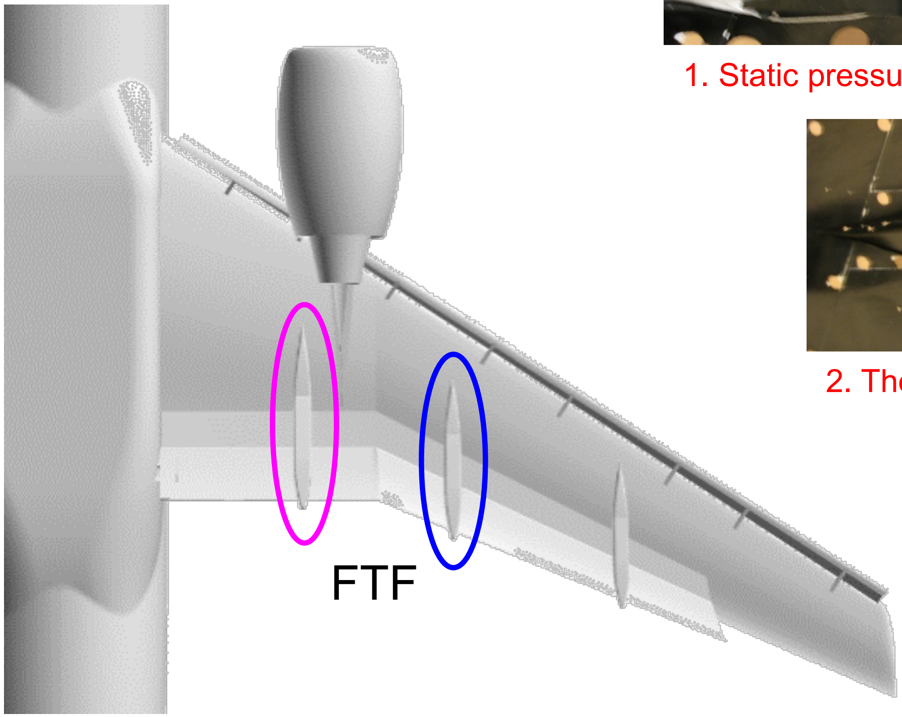
- Pulled in the main wing along flap supports #1 (magenta) and #2 (blue)
- Covered by FTFs
- Tubes are not included in the CAD model this time.



1. Static pressure tubes for flap are pulled in main wing along flap supports.

2. The flap support and static pressure tubes are covered by FTF.

3. Protruded pressure tubes are covered by tape.



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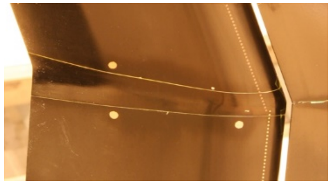
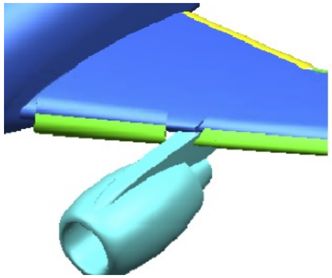
  - Pressure Coefficient Data
  - Oil Flow Images
  - Transition Information

Conditions for HiLiftPW-3 Data

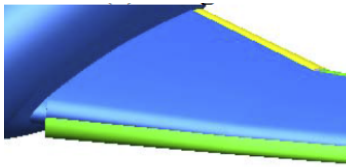
- Re = 1.93 million per MAC(mean aerodynamic chord)
- M = 0.172 (60 m/s)
- Nacelle-on/off configurations with minimal standoff effect
  - Flap
    - ✓ Inboard/outboard single-slotted flaps with 30° deflection
    - ✓ 35° deflection & inboard double-slotted flap induced larger flow separation over the flap and it caused large scattering of CFD in a 2006 workshop in JAPAN.
    - ✓ Gap between the flaps was continuously connected.
  - Slat
    - ✓ Nominal 25° deflection setting for both nacelle on/off configurations



Flap gap connection



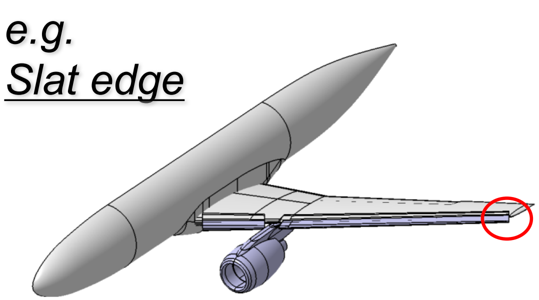
Case 2c: Nacelle-on

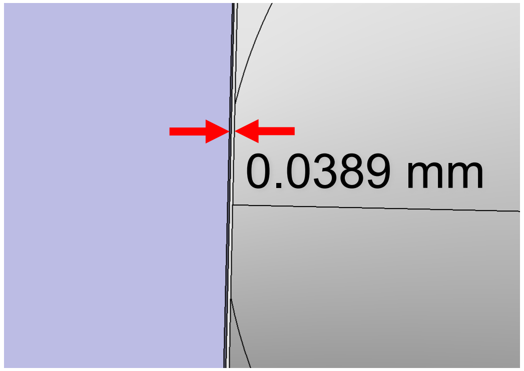


Case 2a: Nacelle-off

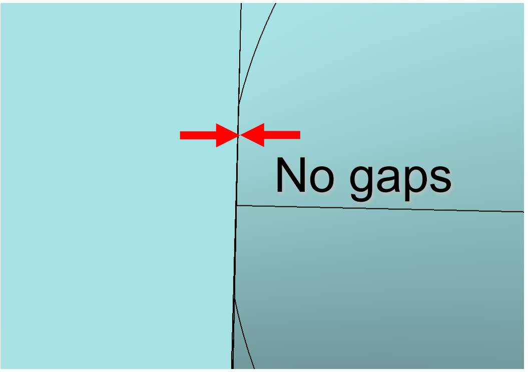
CAD Model Modification

- As-built CAD model provided by JAXA was modified for CFD studies by HiLiftPW-3 committee.
  - To fill small gaps and smooth out small bumps in junctions between parts.
  - Detail information is shown in the Appendix





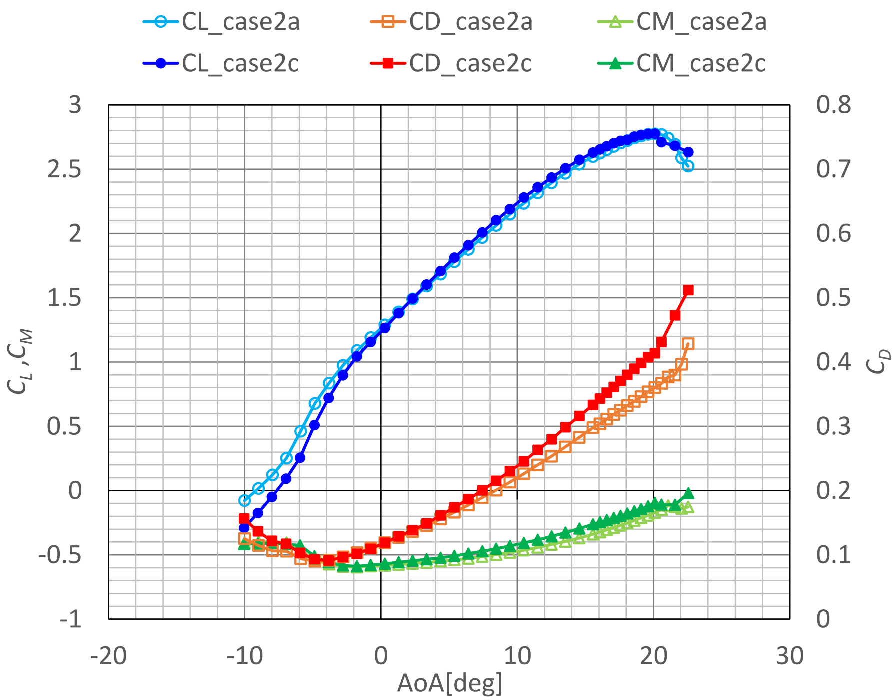
As-built CAD model



CFD CAD model

Force & Moment Data

- Balance data was measured in the "pitch & pause" mode
- Wind tunnel wall interferences correction
  - Model blockage and downwash were corrected by the method based lifting liner theory which is proposed by Alan Pope et all.
- Pressure measurement was done at the same time without the tube interference (tare)



Repeatability in three test campaigns

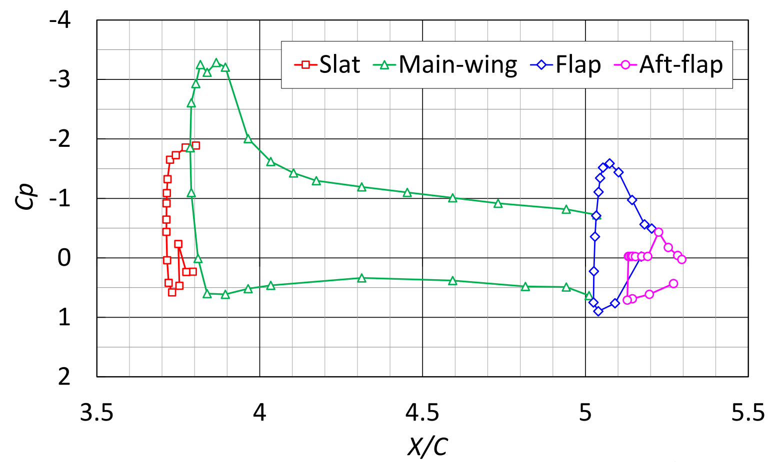
	AoA [deg]	Deviation from the mean value	Balance Accuracy	Recommended (*)
CL	4	-0.0112 ~ 0.0094	±0.0128	±0.0150
	10	-0.0173 ~ 0.0181		-
	18	-0.0172 ~ 0.0268		±0.0300
CD	4	-0.0021 ~ 0.0020	±0.0014	±0.0015
	10	-0.0024 ~ 0.0036		-
	18	-0.0049 ~ 0.0057		-
CM	4	-0.0102 ~ 0.0130	±0.0058	±0.0150
	10	-0.0108 ~ 0.0157		-
	18	-0.0133 ~ 0.0195		-

(*) F. M. Payne, AIAA Paper 99-0306, "Low Speed Wind Tunnel Testing Facility Requirements: A Customer's Perspective"

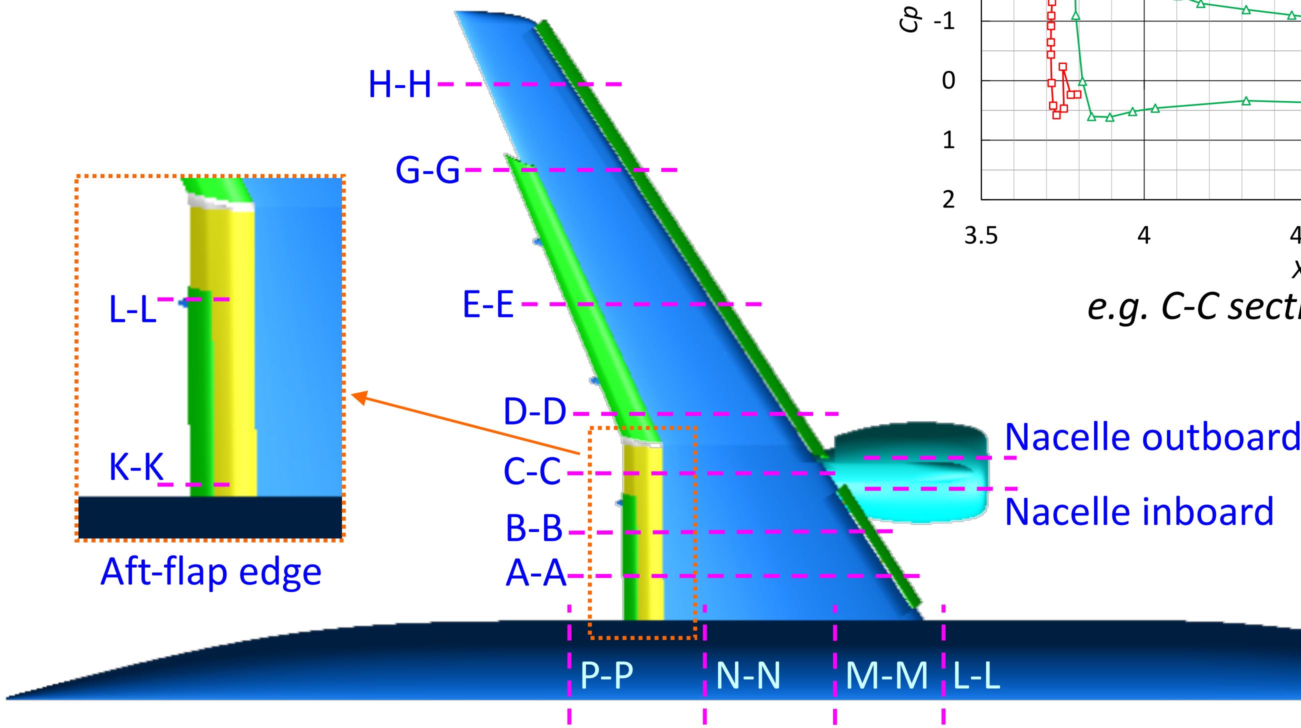
Pressure Coefficient Data

- Cp distribution from 436 taps
  - Main-wing, slat, flap, fuselage and nacelle upper surface
- 6 AoA conditions
- Pressure data is not corrected

  ➔difference is about 1%



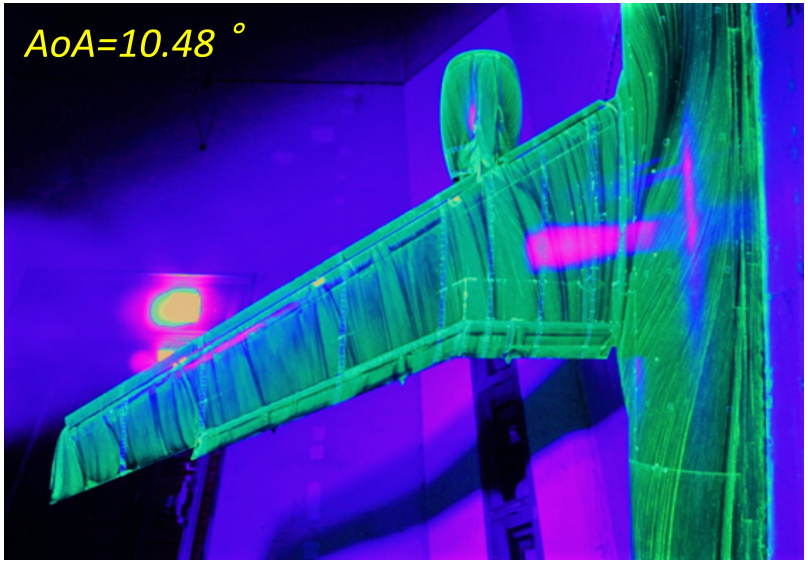
e.g. C-C section @ AoA=10°



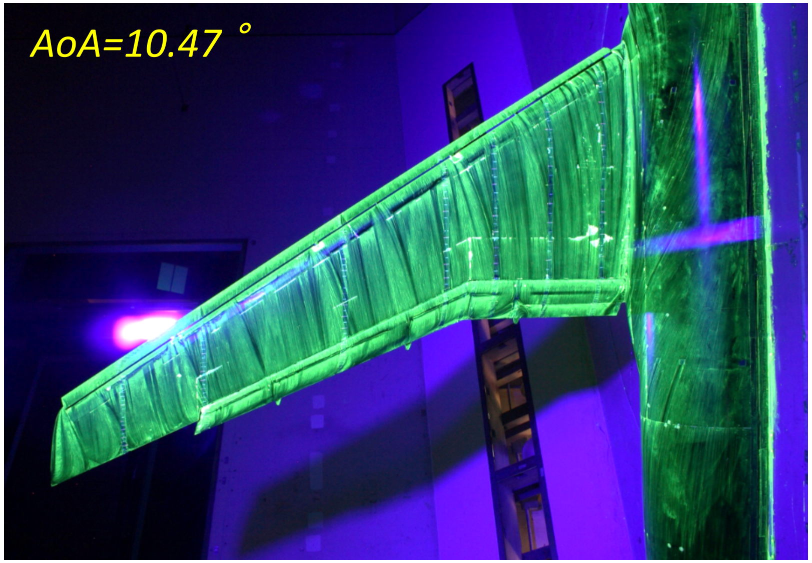
Oil Flow Images

- Surface flow visualization with fluorescence oil and UV-light
- 4 AoA conditions

(*) The nacelle-pylon OFF conditions were taken with standoff of 30 mm height while all other data for this workshop used 60 mm standoff height. However, the differences in aerodynamic forces between the 30 mm and 60 mm standoff was small.



Case 2c: Nacelle-on



Case 2a: Nacelle-off

Transition Information

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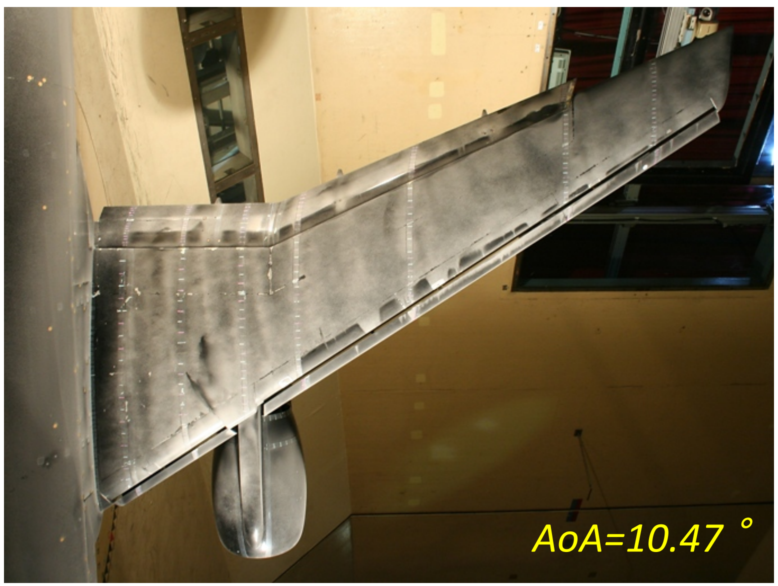
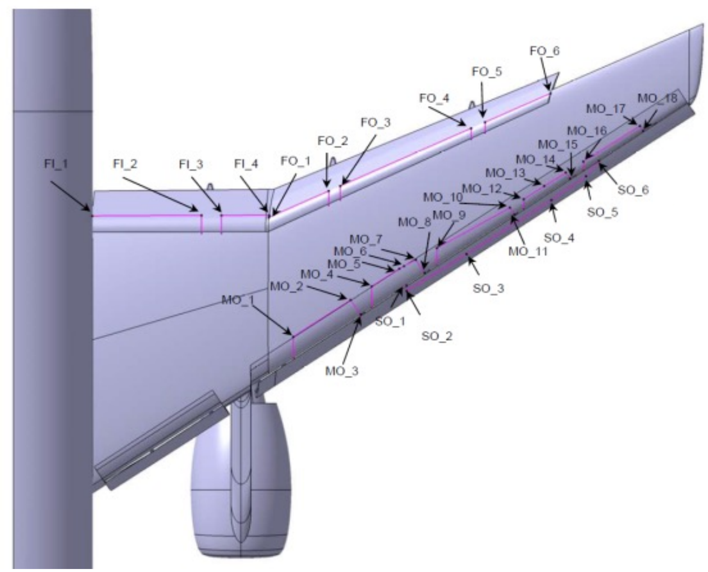
- Transition detection with china clay visualization
- 3 AoA conditions only for Case 2c (Nacelle-on)
- Transition location on the upper surface was digitized by the visual survey
  - The wing lower surface, nacelle, and pylon were also evaluated, but transition was extremely complex, so they have not been similarly digitalized. The boundary layer on the fuselage became fully turbulent well ahead of the wing.



China clay picture



Digitized in CAD

References

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- **Wind tunnel testing**
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- **Wind tunnel interferences (standoff effect)**
  - Murayama, M., Yokokawa, Y., Tanaka, K., Yamamoto, K. and Ito, T., “Numerical Simulation of Half-span Aircraft Model with High-Lift Devices in Wind Tunnel,” AIAA Paper 2008-0333, Jan. 2008.
  - Yokokawa, Y., Murayama, M., Uchida, H., Tanaka, K., Ito, T. and Yamamoto, K, “Aerodynamic Influence of a Half-Span Model Installation for High-Lift Configuration Experiment,” AIAA Paper 2010-684, Jan. 2010. DOI: 10.2514/6.2010-684
- **CFD**
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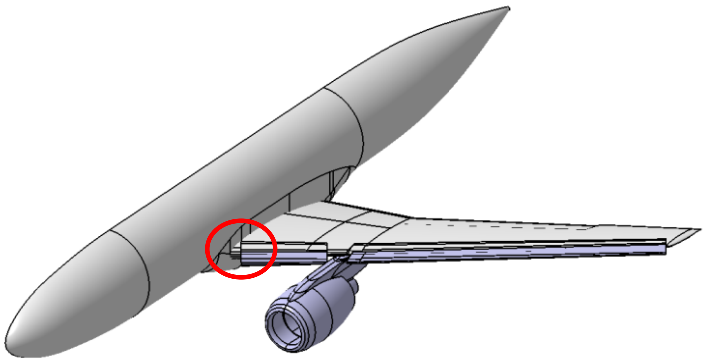
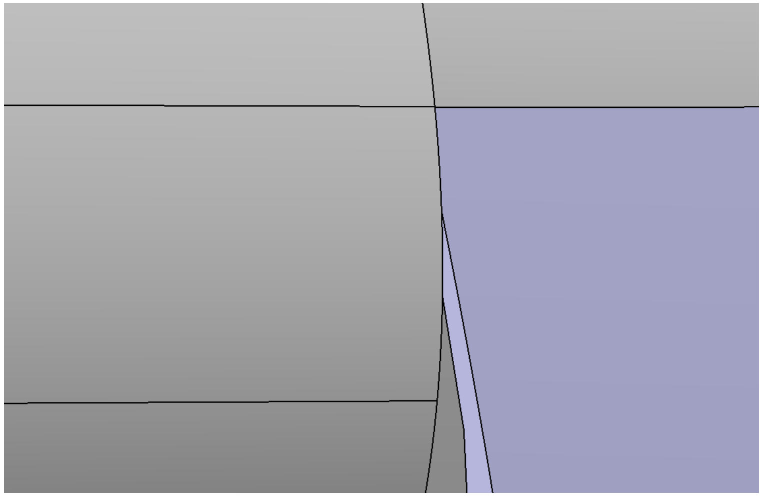
  - Murayama, M., Yokokawa, Y., Yamamoto, K., and Ueda, Y., “Evaluation of Computations and Transition Prediction Method for Aircraft High-Lift Configuration,” *Journal of Aircraft*, Vol. 46, No.5, September-October 2009, pp. 1487-1499. DOI: 10.2514/1.34948
- **Nacelle-chine effect**
  - Yokokawa, Y., Kanazaki, M., Murayama, M., Kato, H., Ito, T. and Yamamoto, K., “Investigation of the Flow over Nacelle/Pylon and Wing Controlled with a Vortex Generator in High-Lift Configuration,” ICAS2008, Sept. 2008.
  - Kato, H., Watanabe, S., Murayama, M., Yokokawa, Y. and Ito, T., “PIV Investigation of Nacelle Chine Effects on High-Lift System Performance,” AIAA Paper 2008-0240, Jan. 2008. DOI: 10.2514/6.2008-240
  - Kanazaki, M., Yokokawa, Y., Murayama, M., and Ito, T. “Efficient Design Exploration of Nacelle Chine Installation in Wind Tunnel Testing,” AIAA Paper 2008-0155, January 2008.
  - Ito, Y., Murayamat, M., Yamamoto, K., Shih, A. M. and Soni, B. K., “Efficient Computational Fluid Dynamics Evaluation of Small-Device Locations with Automatic Local Remeshing,” *AIAA Journal*, Vol. 47, No. 5, 2009, pp. 1270-1276, DOI: 10.2514/1.40875.

Appendix

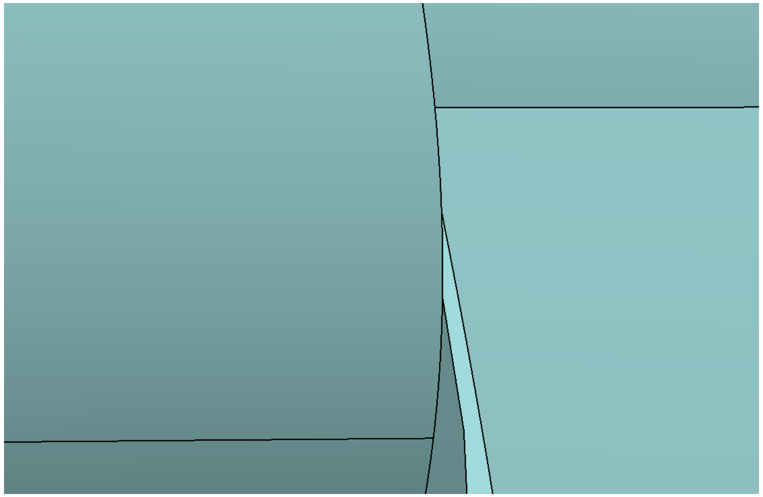
CAD model modification
by HiLiftPW-3 committee

Inboard Edge of Inboard Slat





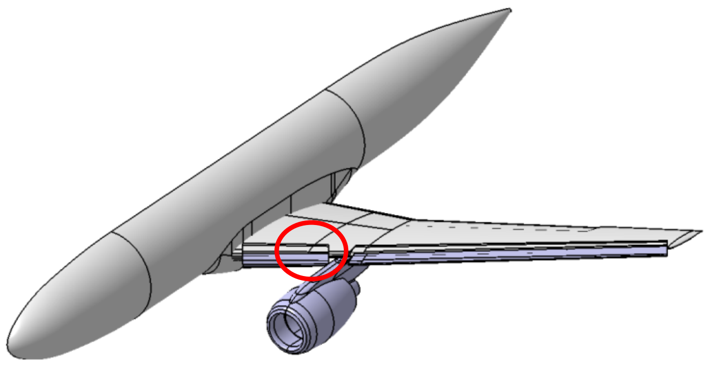
As-built CAD model

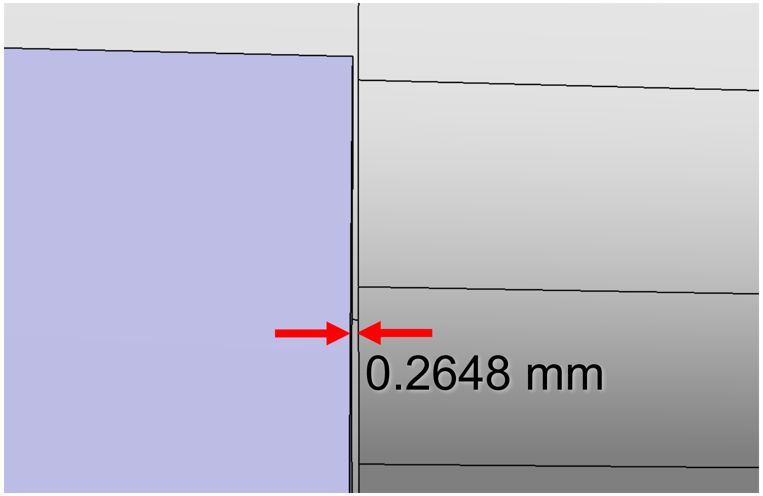


CFD CAD model

No changes

Outboard Edge of Inboard Slat





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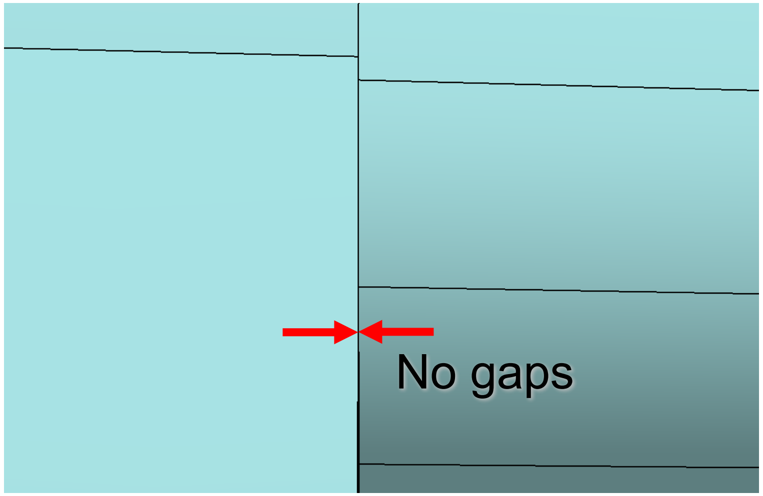
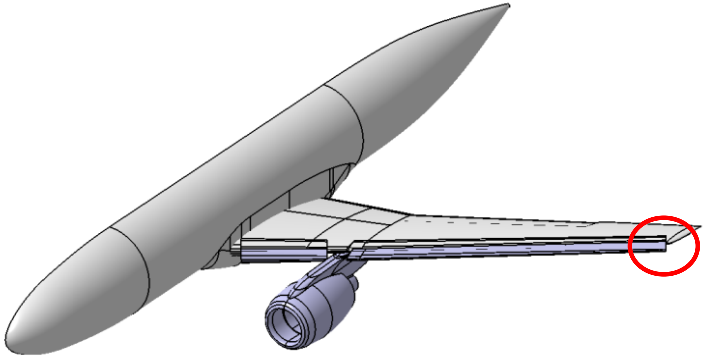
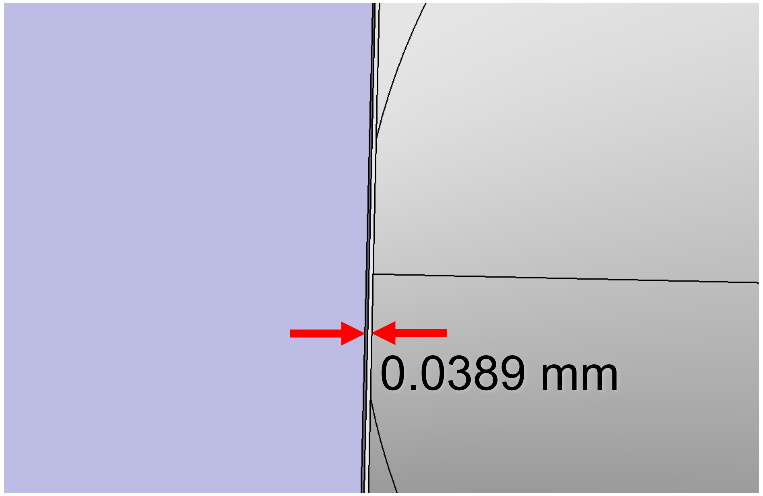


CFD CAD model

Outboard Edge of Outboard Slat





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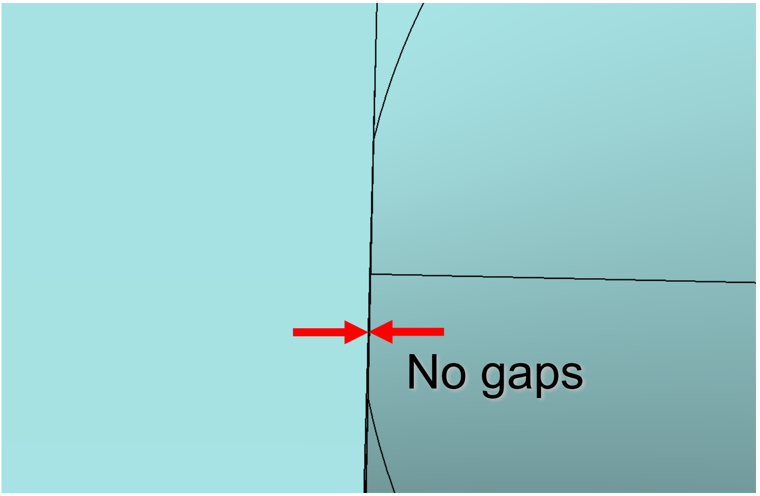

CFD CAD model

Inboard Edge of Aft Flap

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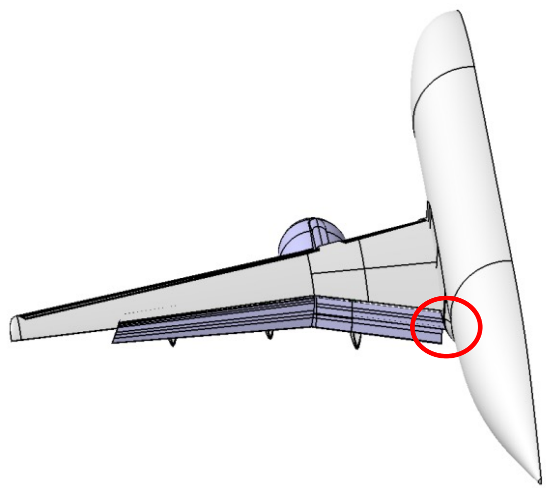

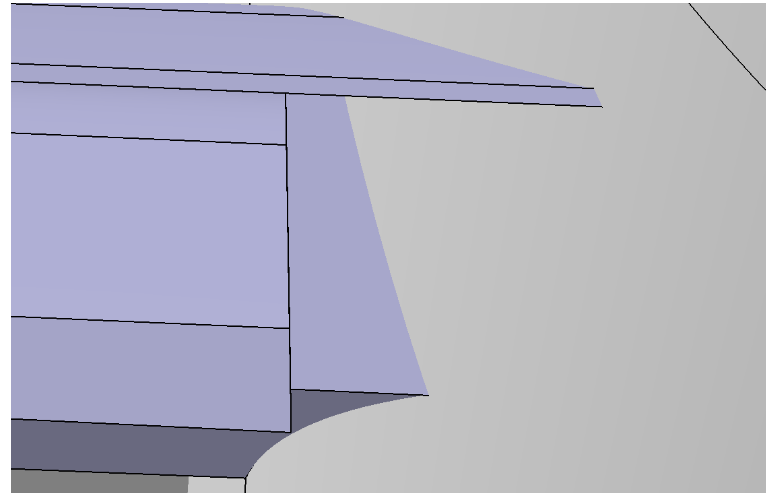

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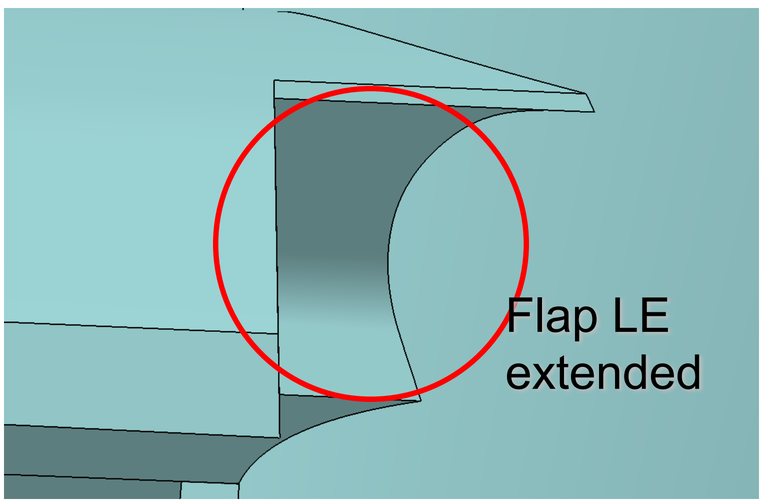

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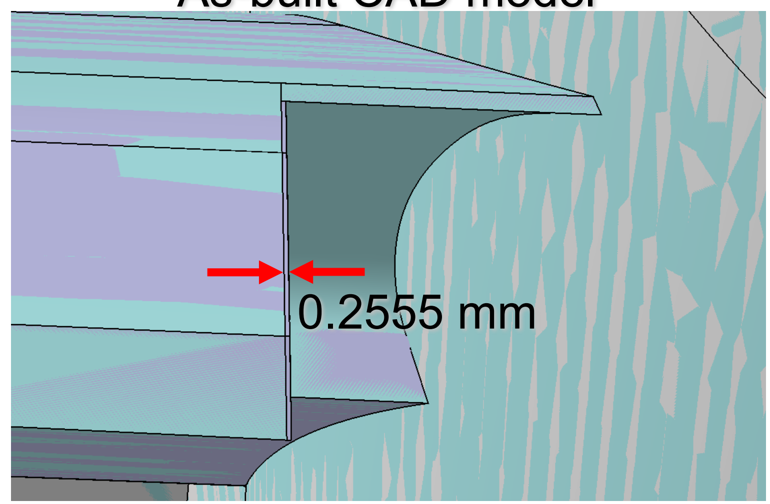

Model overlapped

Main & Aft Flaps (2)

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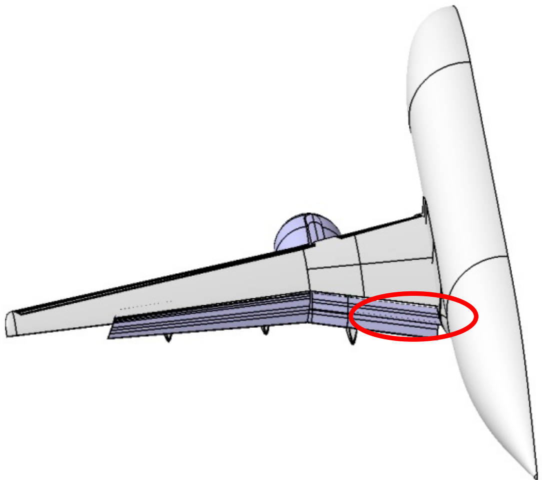

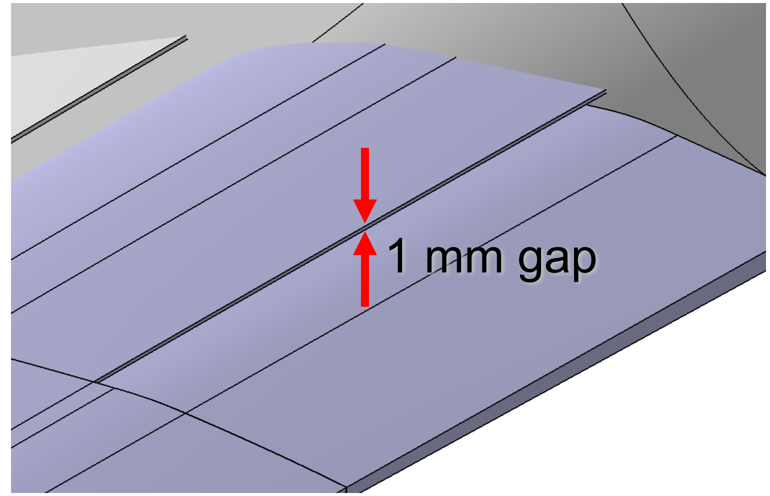

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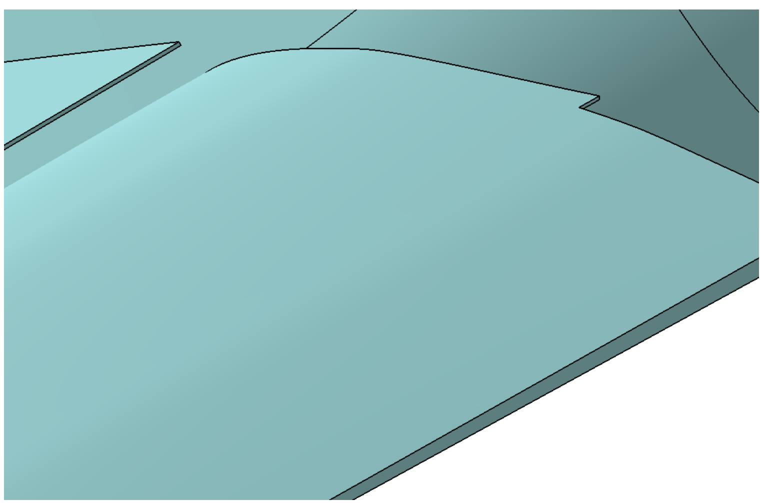
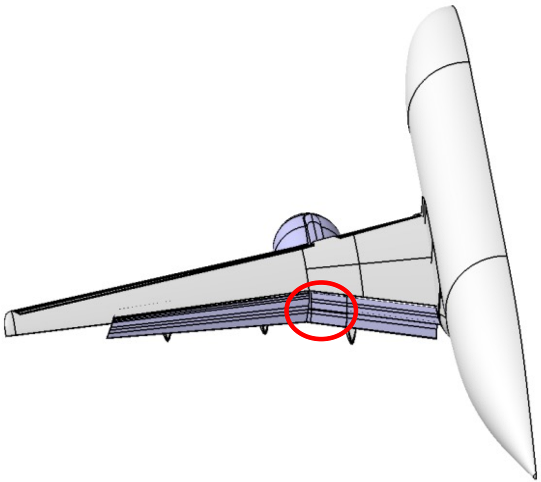
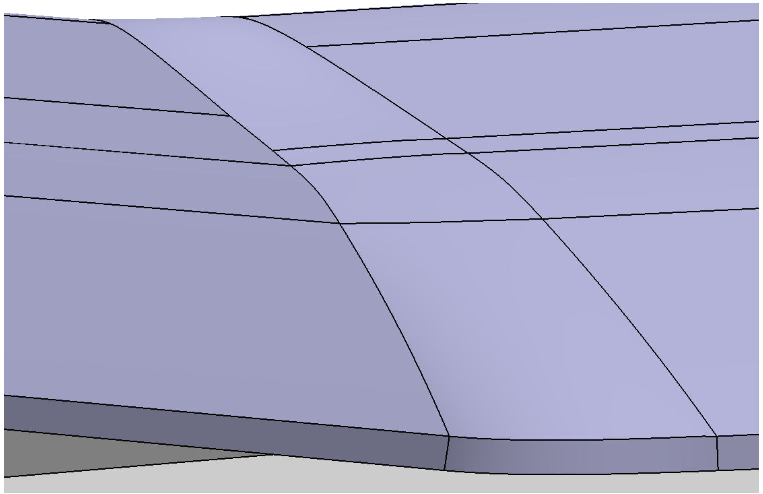


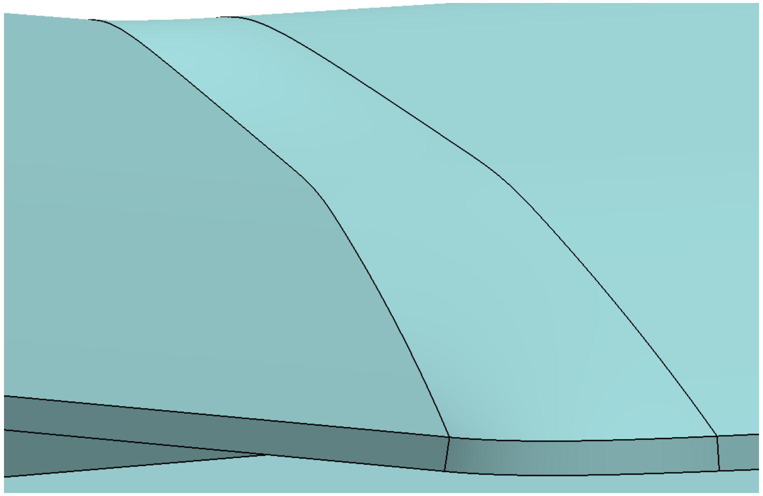
CFD CAD model

Flap Connector

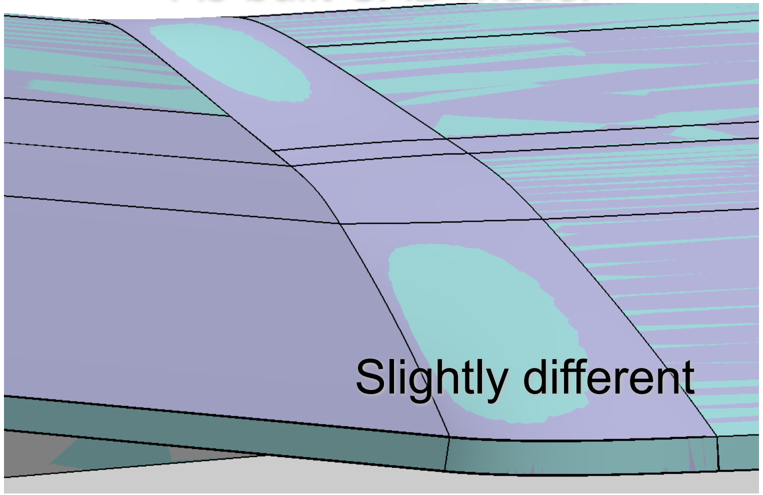




As-built CAD model

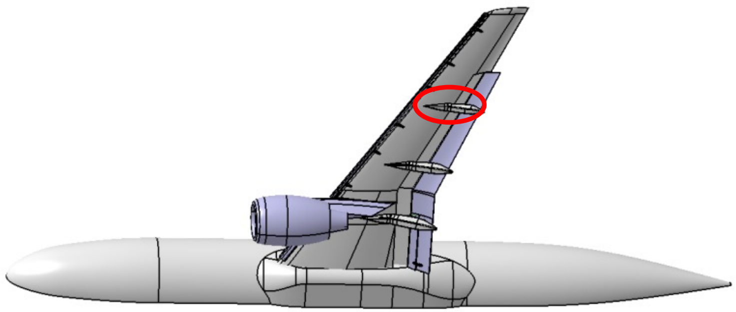


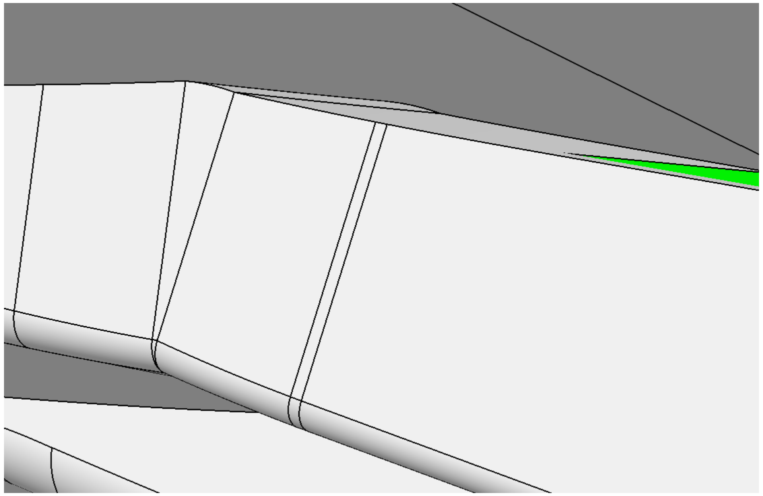
CFD CAD model



Model overlapped

Flap Track Fairings





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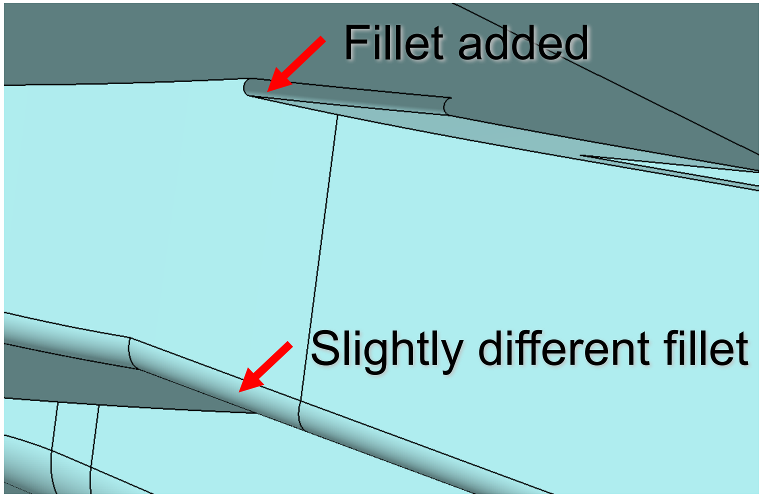
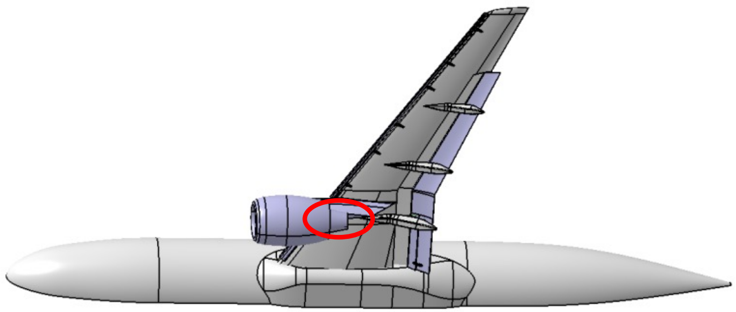
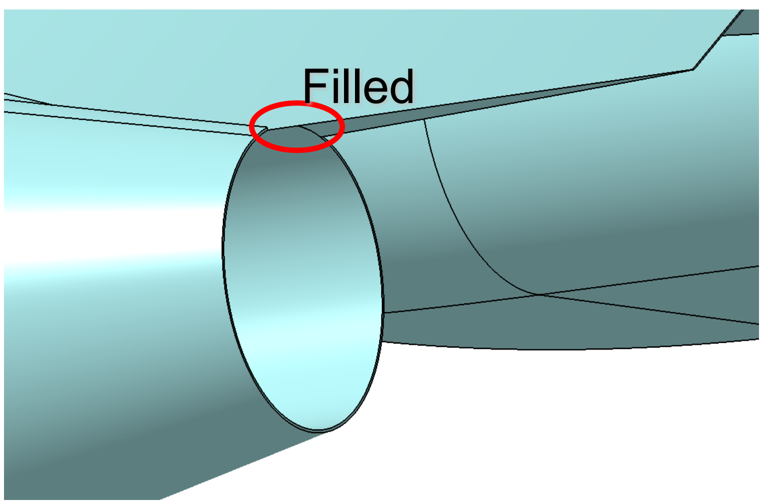


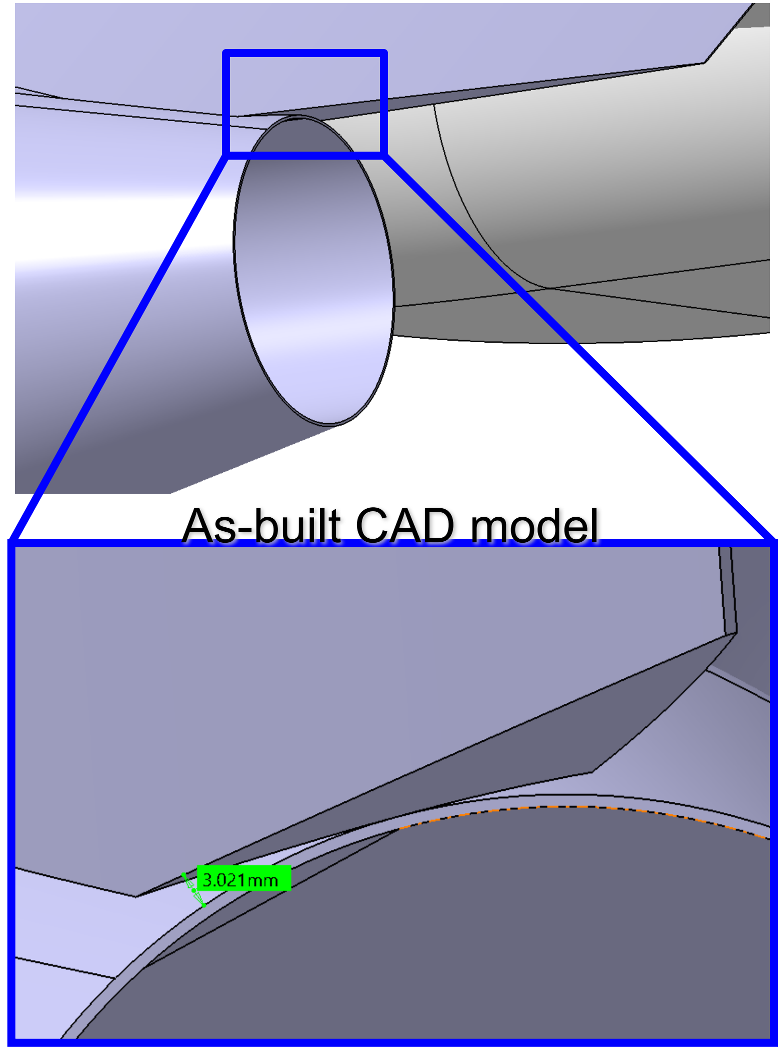
CFD CAD model

Gap between Nacelle & Pylon



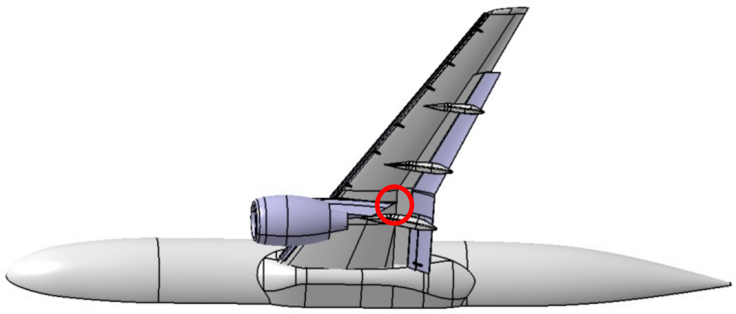


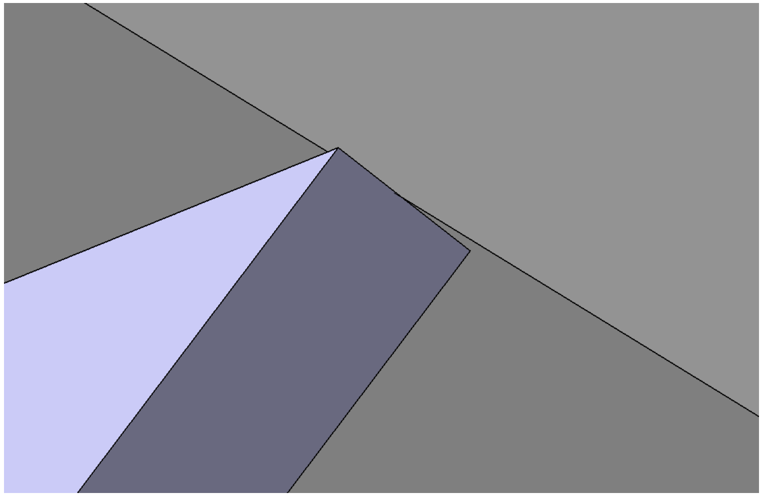
CFD CAD model



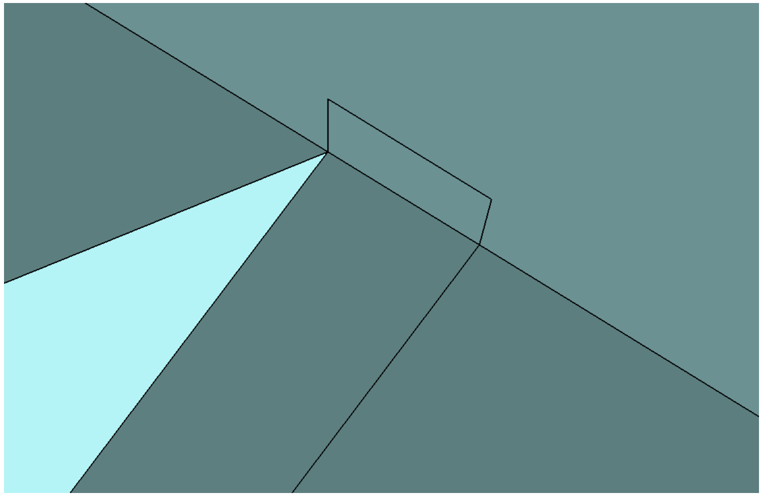
As-built CAD model

Wing Element Edge & Pylon



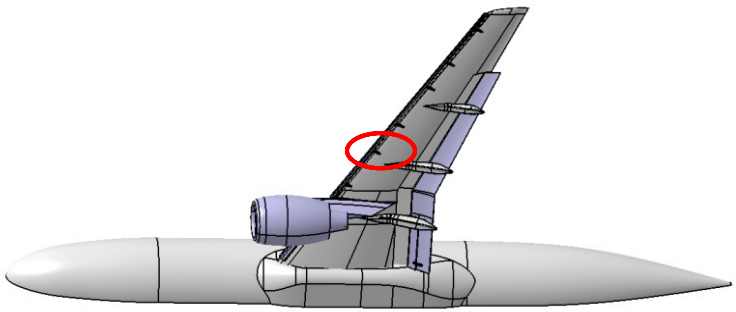


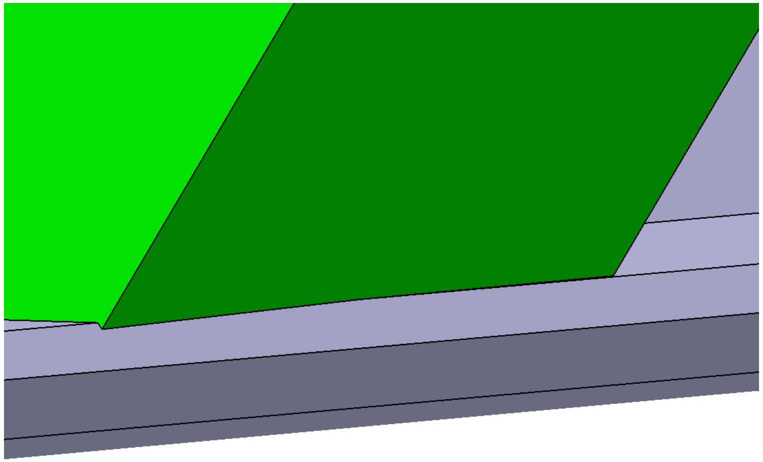
As-built CAD model



CFD CAD model

Slat Edge & Slat Supports





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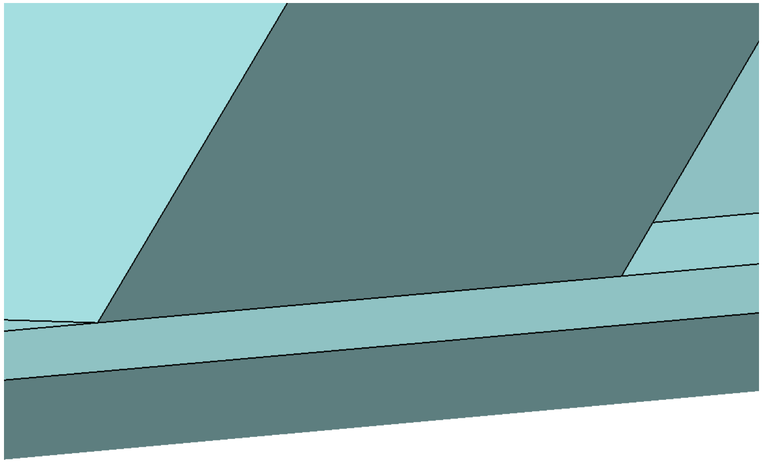
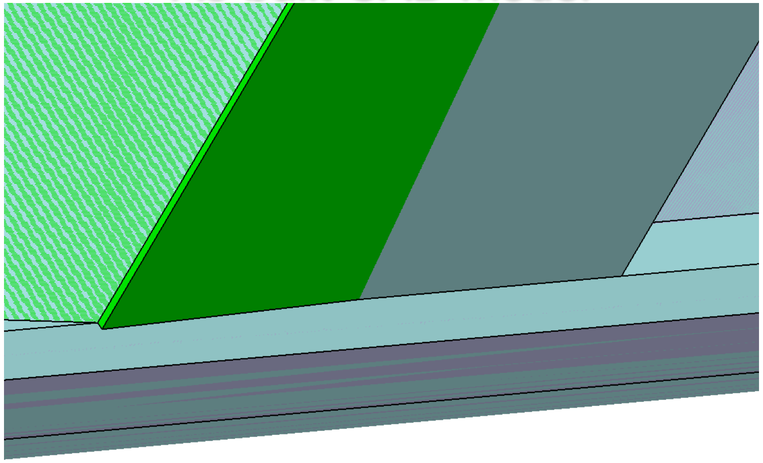


CFD CAD model



Model overlapped