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# 2<sup>nd</sup> Ice Prediction Workshop

## Test Cases and Experimental Data

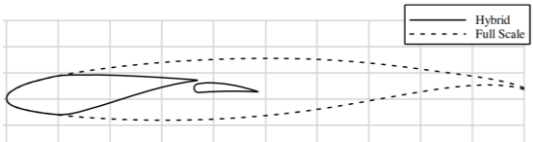
Sponsored by the AIAA Atmospheric and Space Environments  
Technical Committee (ASE TC)

AIAA IPW-2

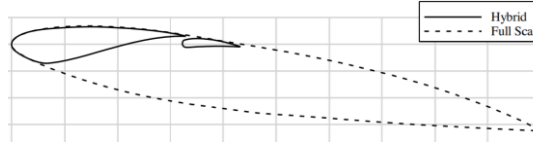
22-23 June 2023

# Test Case Summary

Case 1: CRM-65 Mid-span Hybrid (3D)



Case 2: CRM-65 Inboard Hybrid (3D)



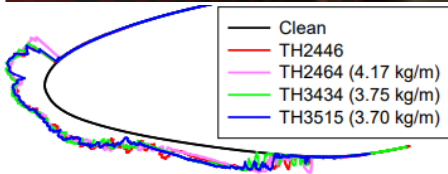
Case 3: RG-15 Low-Re Icing (2D)



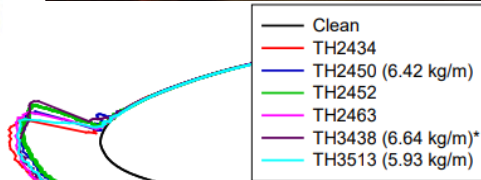
# Case 1: CRM-65 Mid-span Hybrid

IPW-2 Case no	AoA (deg.)	Flap angle (deg.)	Speed (knots)	Speed (m/s)	MVD ( $\mu\text{m}$ )	LWC ( $\text{g}/\text{m}^3$ )	Time (min.)	$T_{\text{static}}$ ( $^{\circ}\text{C}$ )	$T_{\text{total}}$ ( $^{\circ}\text{C}$ )	Freezing fraction	2015 ice mass ( $\text{kg}/\text{m}$ )	2021 ice mass ( $\text{kg}/\text{m}$ )	2022 ice mass ( $\text{kg}/\text{m}$ )
1.1	3.7	25.0	130	66.9	25	1.0	29.0	-3.6	-1.4	0.12	4.17	3.75	3.70
1.2								-8.5	-6.3	0.35	6.42	6.64	5.93
1.3								-26.0	-23.8	1.00	6.5	5.43	5.30

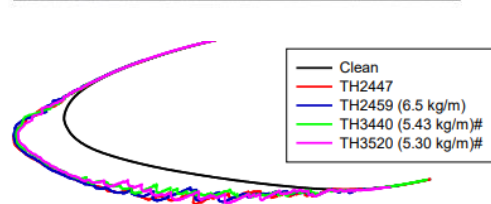
Case 1.1



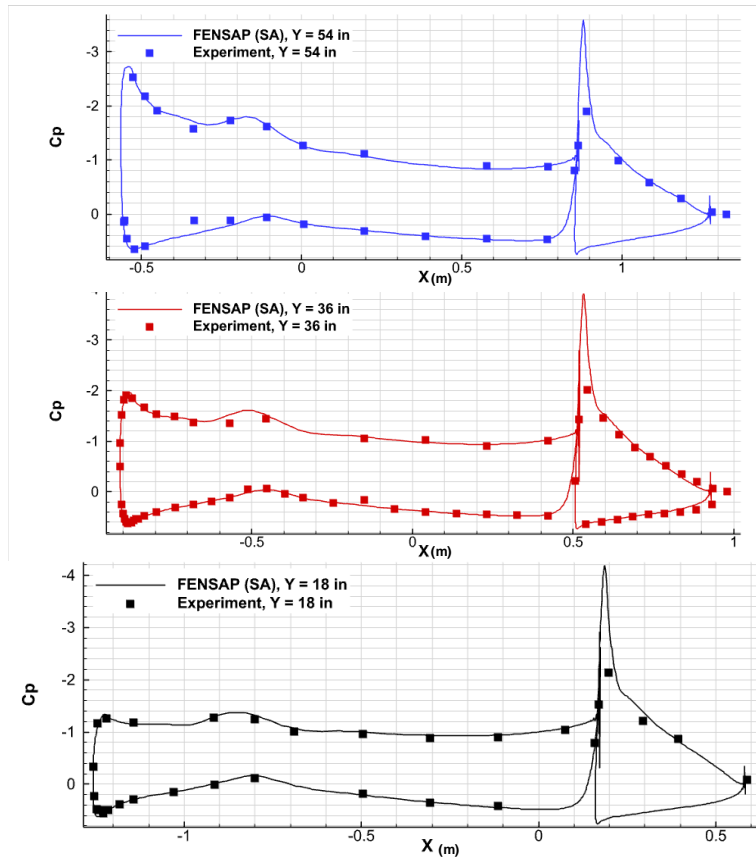
Case 1.2



Case 1.3

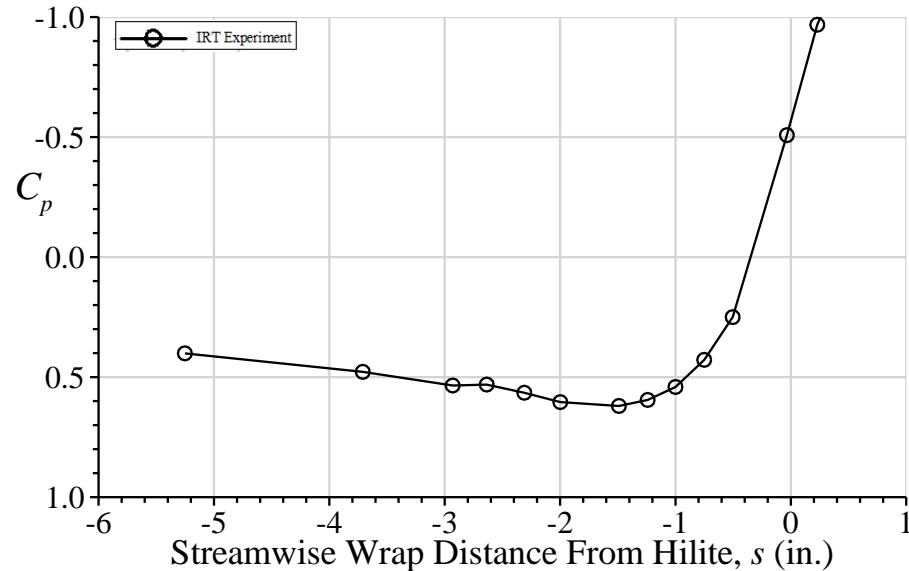


# Case 1: CRM-65 Mid-span Hybrid



## Attachment Line Location

$$s = -1.49 \text{ inches} \pm 0.25 \text{ in.}$$



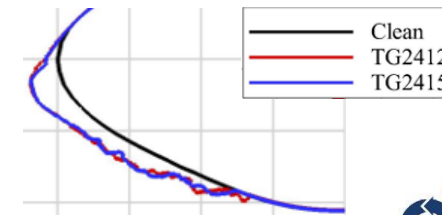
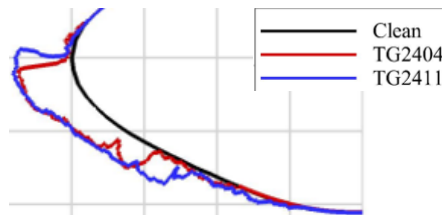
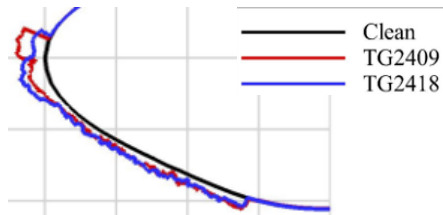
# Case 2: CRM-65 Inboard Hybrid

IPW-2 Case no	AoA (deg.)	Flap angle (deg.)	Speed (knots)	Speed (m/s)	MVD ( $\mu\text{m}$ )	LWC ( $\text{g}/\text{m}^3$ )	Time (min.)	$T_{\text{static}}$ ( $^{\circ}\text{C}$ )	$T_{\text{total}}$ ( $^{\circ}\text{C}$ )	Freezing fraction	2015 ice mass ( $\text{kg}/\text{m}$ )
2.1	3.7	13.8	130	66.9	25	1.0	29.0	-3.6	-1.4	0.12	4.92
2.2								-8.5	-6.3	0.35	8.22
2.3								-26.0	-23.8	1.00	7.9

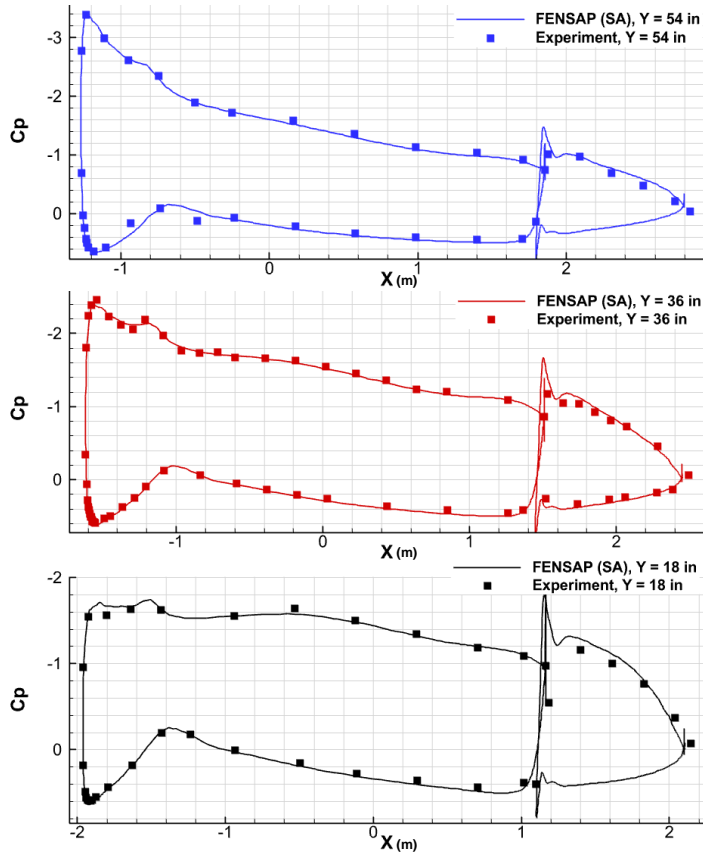
Case 2.1

Case 2.2

Case 2.3

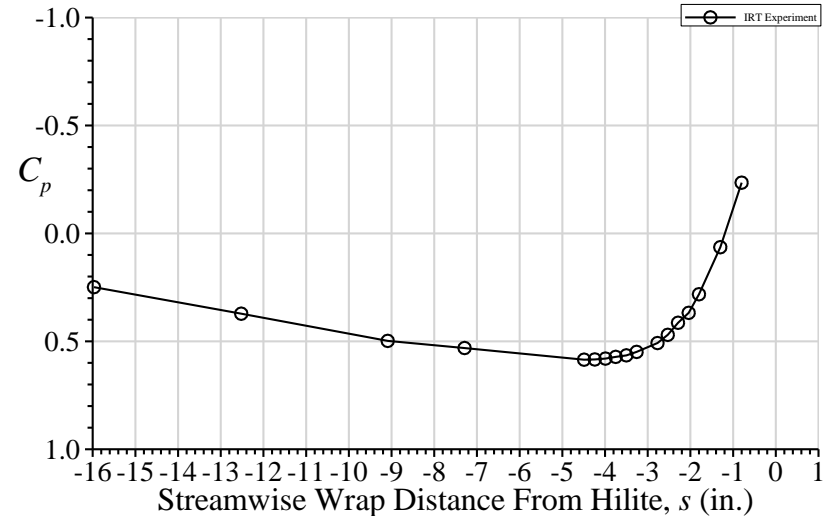


# Case 2: CRM-65 Inboard Hybrid - $C_p$



## Attachment Line Location

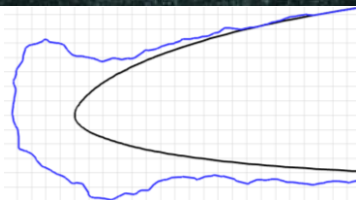
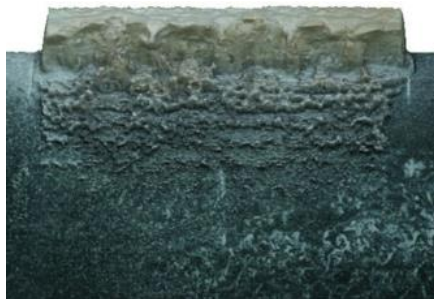
$$s = -4.49 \text{ inches} \pm 0.25 \text{ in.}$$



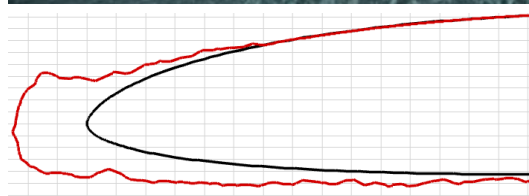
# Case 3: RG-15 Low-Re UAV wing

IPW-2 Case no.	Chord (m)	Re ( $10^6$ )	AoA (deg.)	Speed (m/s)	MVD ( $\mu\text{m}$ )	LWC ( $\text{g}/\text{m}^3$ )	Time (min.)	$T_{\text{static}}$ ( $^{\circ}\text{C}$ )	$T_{\text{total}}$ ( $^{\circ}\text{C}$ )
3.1	0.300	0.57	4	25	23	0.44	20	-2.0	-1.7
3.2		0.58						-4.0	-3.7
3.3		0.60						-10.0	-9.7

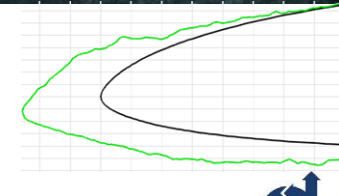
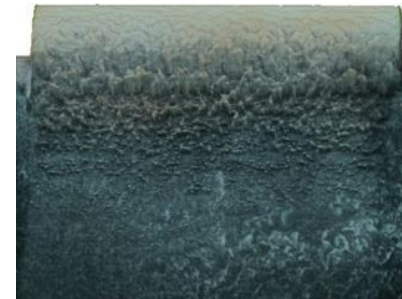
Case 3.1



Case 3.2

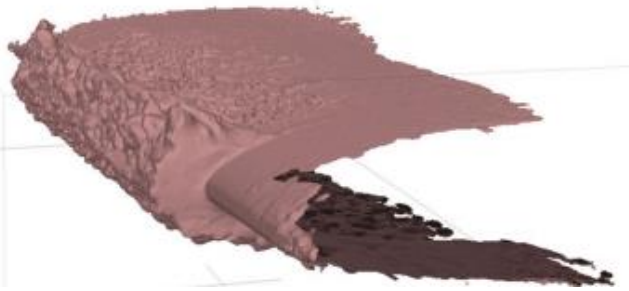
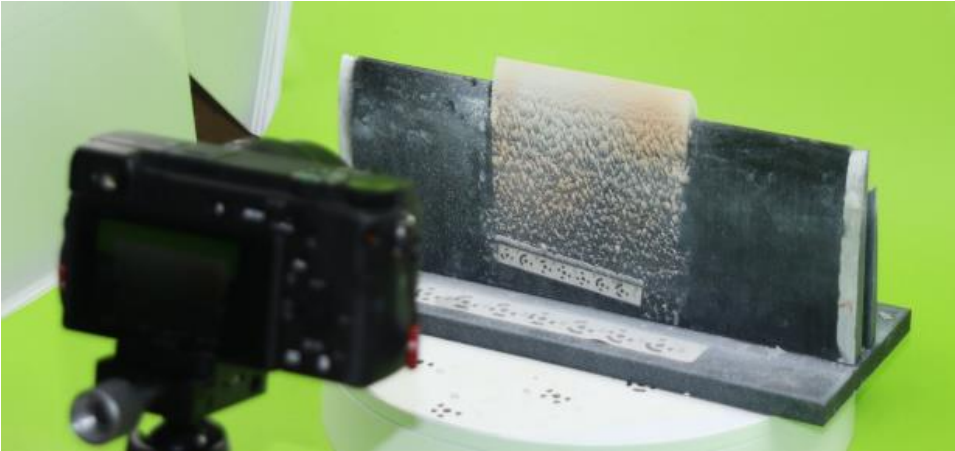
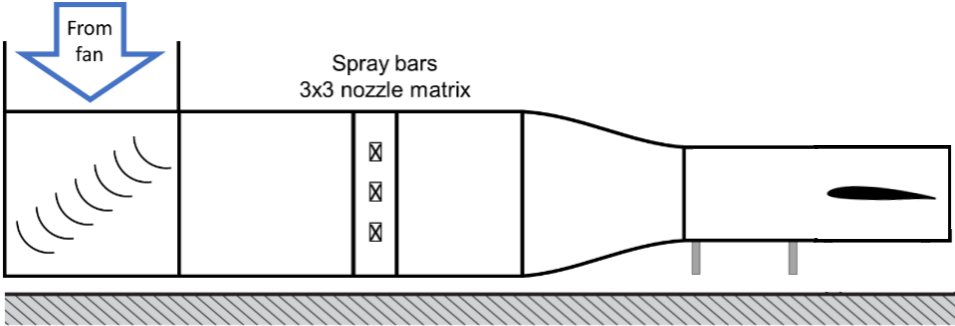


Case 3.3





# Case 3: RG-15 Low-Re UAV wing



# Workshop grids for CRM-65

## ***Unstructured grids***

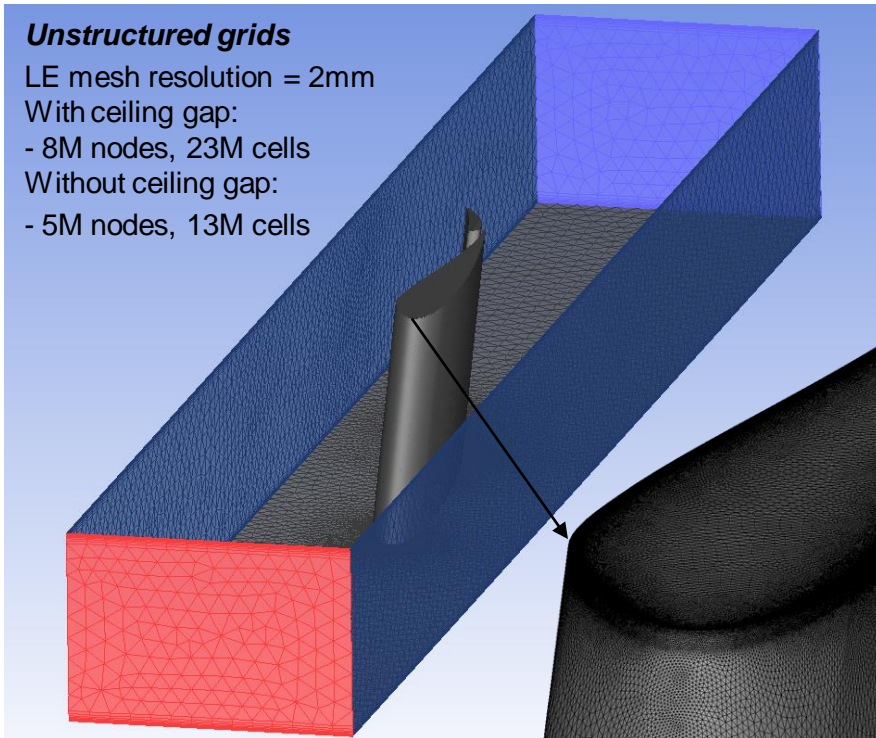
LE mesh resolution = 2mm

With ceiling gap:

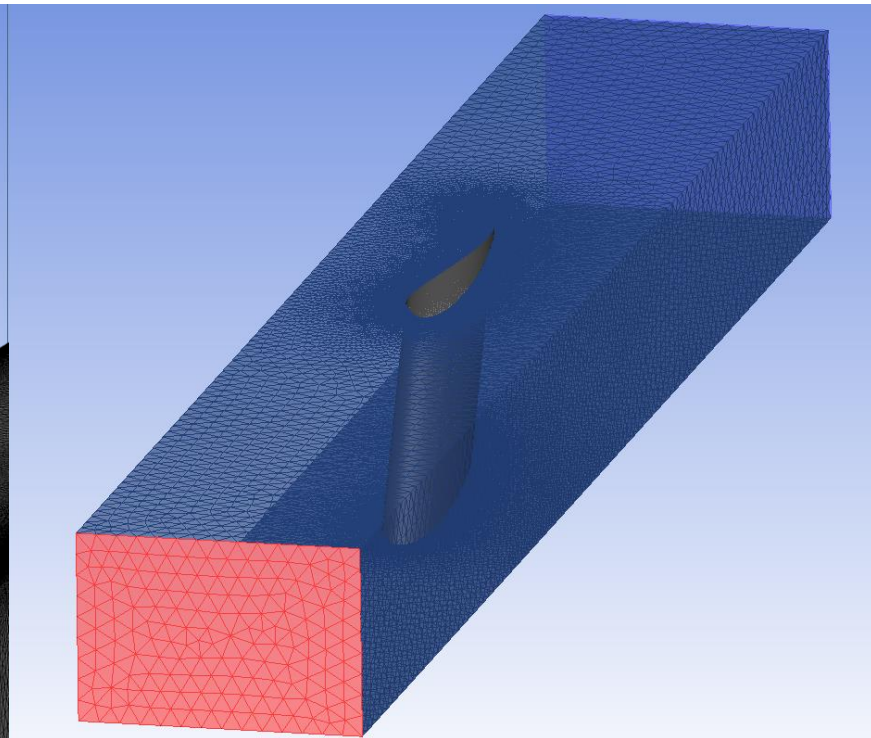
- 8M nodes, 23M cells

Without ceiling gap:

- 5M nodes, 13M cells



CRM-65 Inboard section with gap, viscous mesh on tunnel floor and ceiling



CRM-65 Inboard section without gap, symmetry bc on tunnel floor and ceiling

# Workshop grids for CRM-65

## **Structured grids**

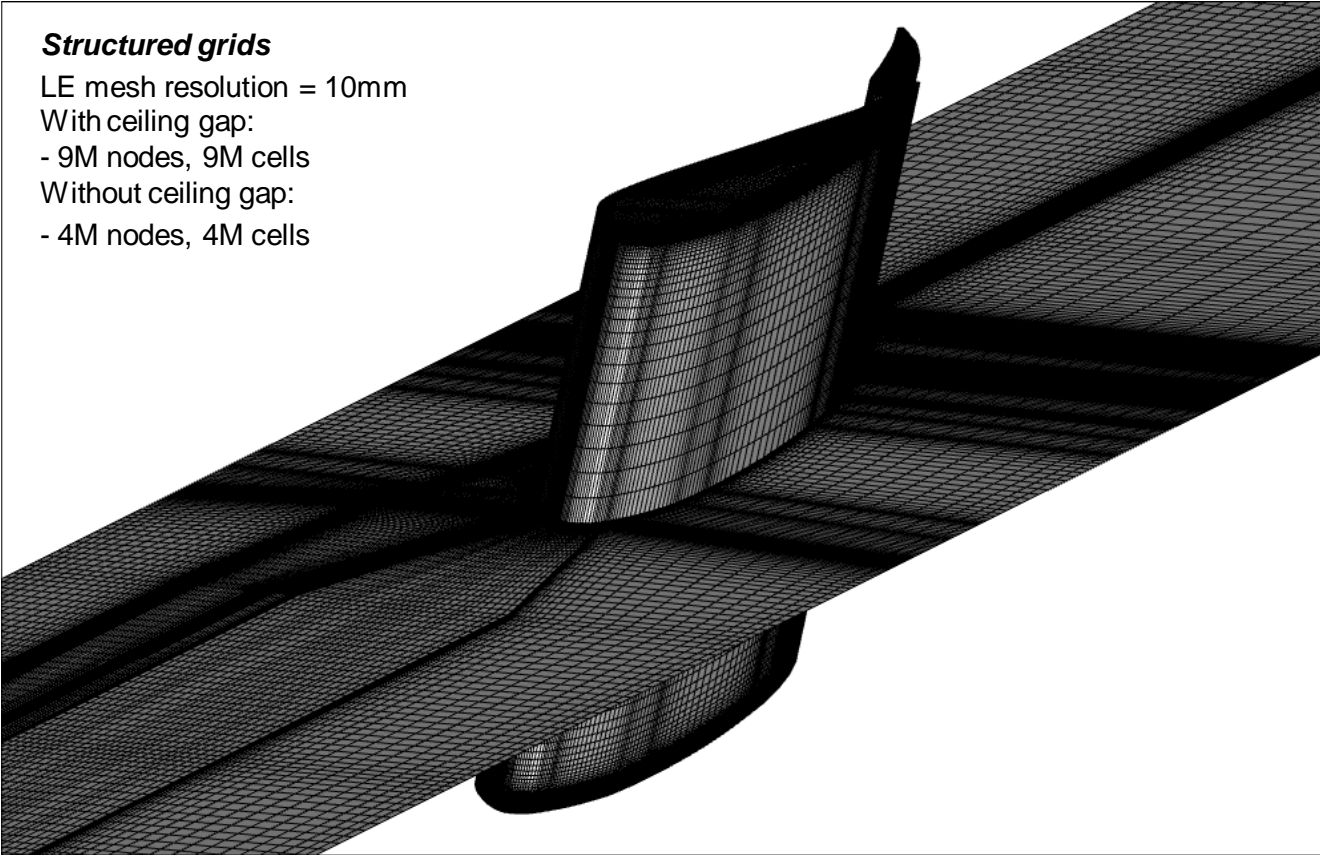
LE mesh resolution = 10mm

With ceiling gap:

- 9M nodes, 9M cells

Without ceiling gap:

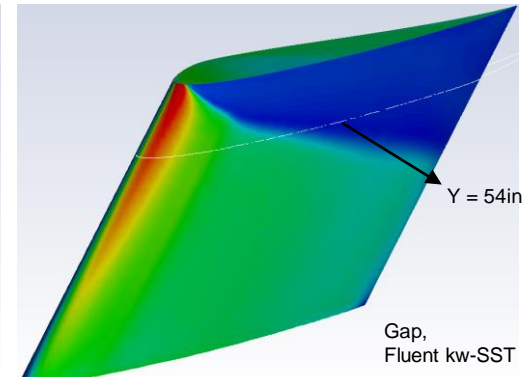
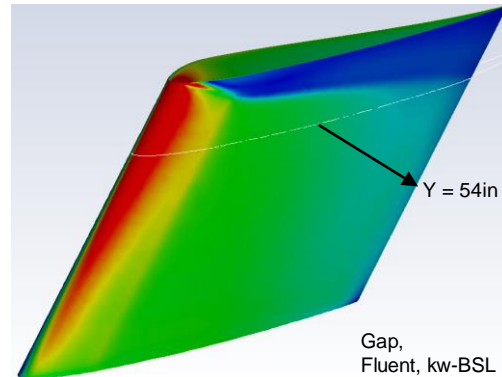
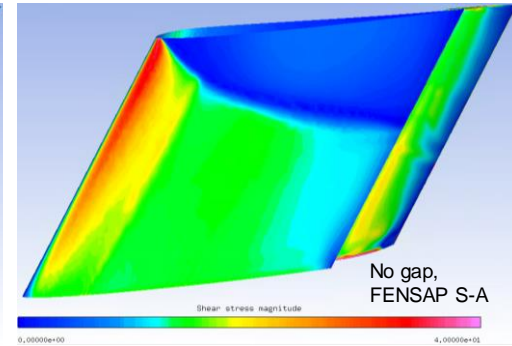
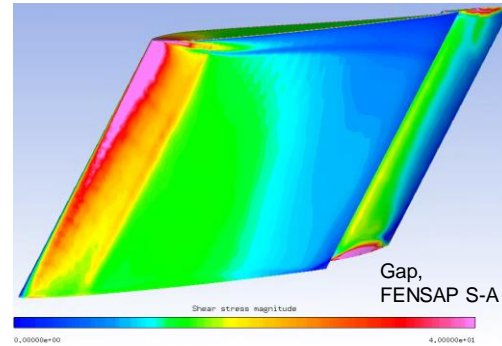
- 4M nodes, 4M cells



# Effect of the ceiling gap in the CRM65 cases

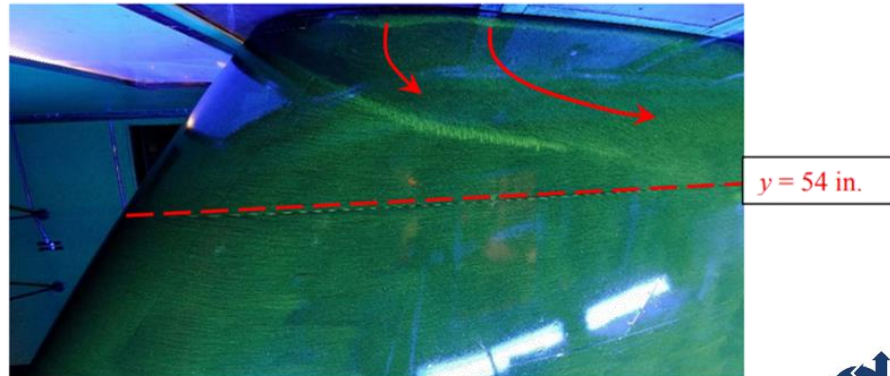
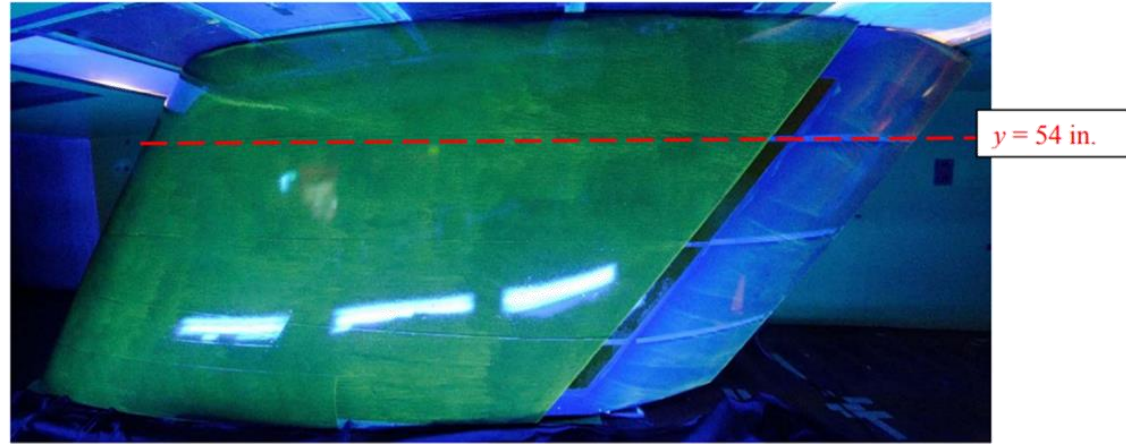
Shear stress distributions for the inboard case, using gap/no-gap grids

- Top row:
  - Large separation when gap is closed
  - S-A model
- Bottom row:
  - kw-SST on gap grid separates just as much as S-A on no-gap grid
  - kw-BSL is closer to S-A



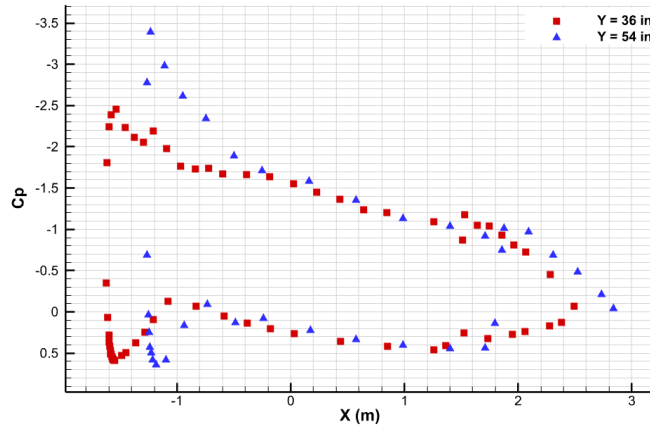
# Effect of the ceiling gap in the CRM65 cases

Experimental evidence to flow separation at wing/ceiling junction

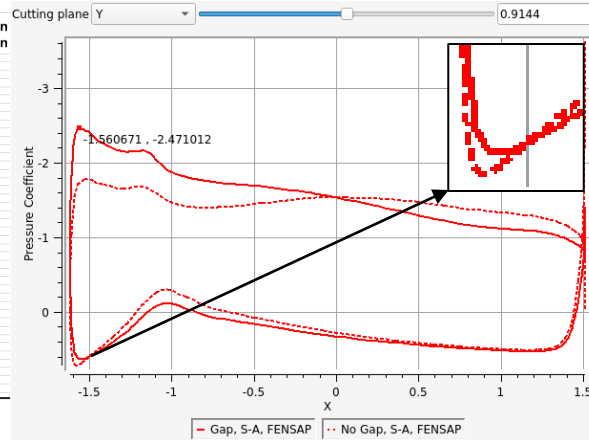


Surface oil flow visualization Inboard model

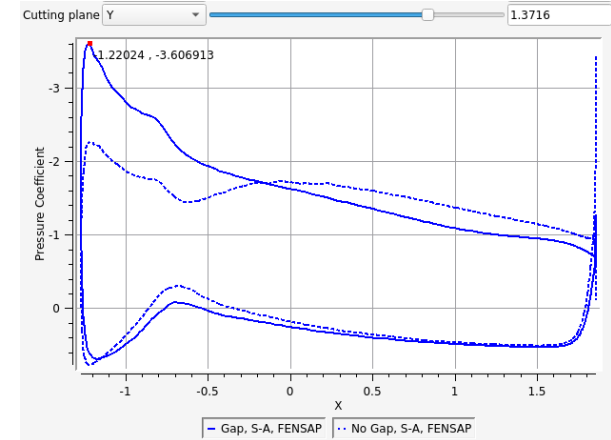
# Effect of the ceiling gap in the CRM65 cases



Experimental  $C_p$  on the inboard section



CFD: FENSAP S-A, gap vs no-gap at  $y = 36$  in, dimensions: tunnel coordinate system in meters

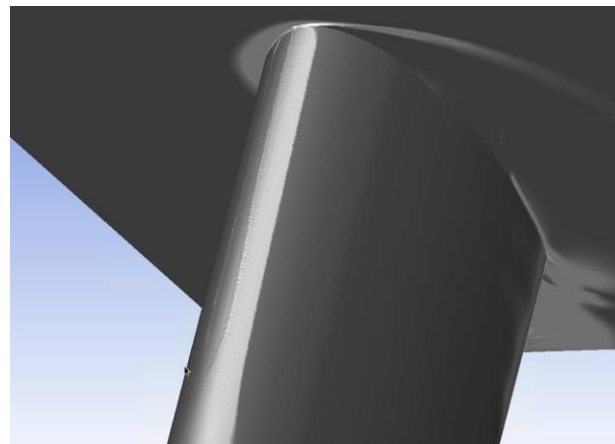
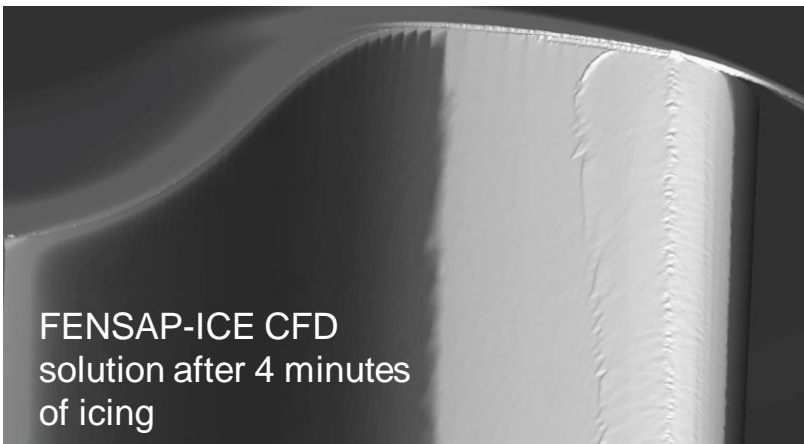


CFD: FENSAP S-A, gap vs no-gap at  $y = 54$  in, dimensions: tunnel coordinate system in meters

- Pressure coefficient distributions are strongly affected by the size of the separation
- Results with the gap flow resolved are more representative of the experimental measurements
- Attachment line position is also affected significantly when the gap is closed
  - Attachment line position could be adjusted with the flap angle
  - No-gap attachment line could be matched to gap version with a different flap angle

# Effect of the ceiling gap in the CRM65 cases

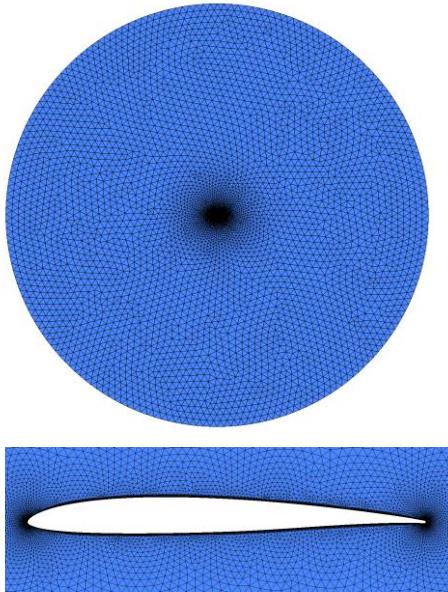
CRM65 inboard, Max Scallop icing



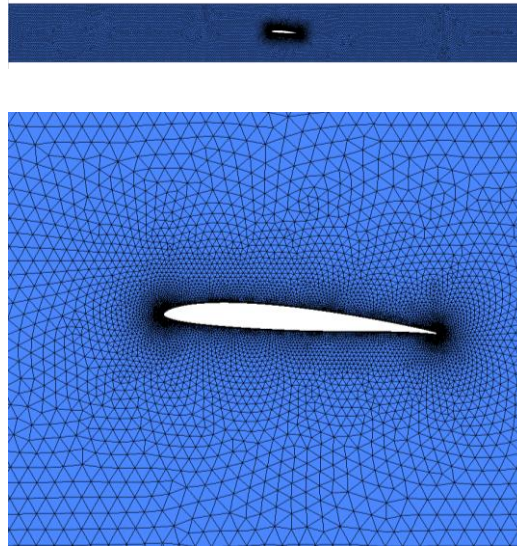
Top: Photograph showing ice blocking the gap in the experiment

Bottom: CFD icing solution showing gap closing within 4 minutes of icing

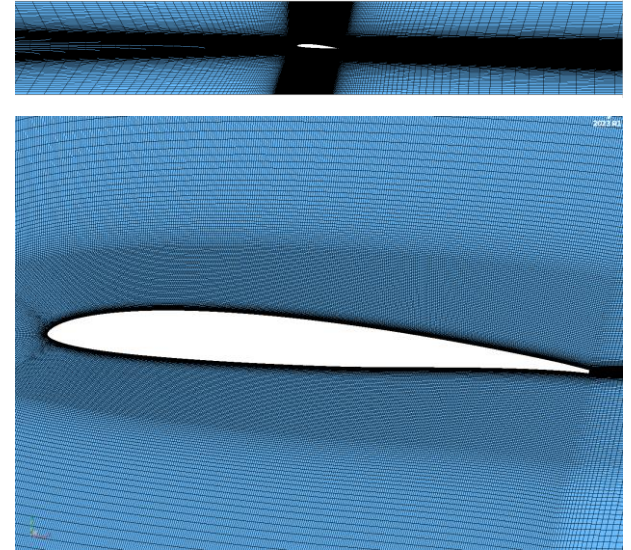
# Workshop grids for RG-15



Far field mesh with no AoA  
27K nodes

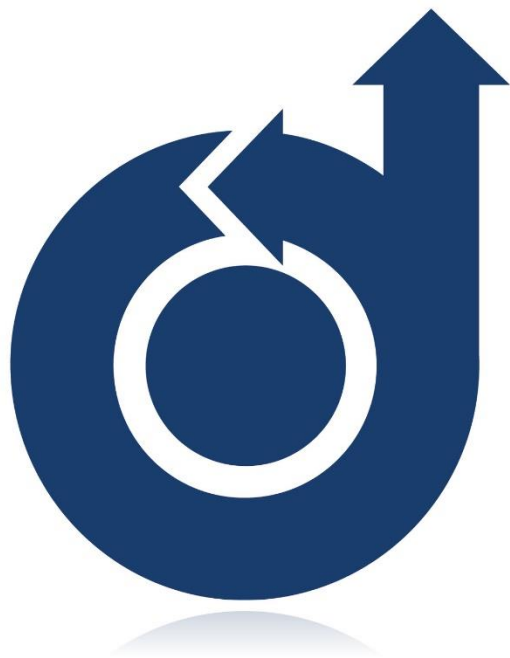


Tunnel mesh with AoA = 4°  
36K nodes



Tunnel mesh, structured  
100K nodes





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