APC-9の集計結果・サンシカ アンドレア（JAXA）

The 55th Fluid Dynamics Conference / The 41th Aerospace Numerical Simulation Symposium
12th July 2023

APC-9の集計結果
Summary of APC-9

サンシカ アンドレア (JAXA), APC有識者会議
Sansica Andrea (JAXA), APC committee

Statistics of Submitted Data

- Organization and number of submitted data (total 29 data)
  - National research institute — JAXA(11), RIKEN(1)
  - Aerospace industry — KHI(12)
  - University — University of Tokyo(1), TUAT(4)
- Grid
  - TMR grid (FAMILY1)*1 — 7
  - ANSA grid*2 — 11
  - Pointwise grid*3 — 2
  - JAXA grid*4 — 1
  - Cflow grid*5 — 1
  - Custom grid — 7

*1 https://turbmodels.larc.nasa.gov/multielementverif_grids.html
https://hiliftpw.larc.nasa.gov/Workshop4/grids_downloads.html
*2 103-ANSA-Unstructured-hiA-Yplus1
*2 105T-ANSA-Unstructured-Yplus1
*3 1-Pointwise-Unstructured
*4 240-JAXA-unstructured
*5 140-KHI-Unstructured

- Code
  - Unstructured solver — 27
  - Unstructured Cartesian solver — 1
  - Cartesian solver — 1
- Method
  - RANS (SA) — 21
  - RANS (AMM-QCRcorner) — 1
  - Hybrid RANS/LES (Delayed DES) — 5
  - LES (wall-resolved) — 2
- Initial condition
  - Cold start (Start from the uniform flow)
  - Warm start (Restart from the steady-state solution)

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Participants of Case 1

Method	Marker	ID	Name	Organization	Code	Grid	Description of the grid	Turbulence Model	Initial Condition
RANS		A1	Zehner Paul	JAXA	FaSTAR-GPU (Unstructured solver)	TMR grid (FAMILY1)		SA-nort2	Uniform Flow
		A2						SA-nort2-R	
		B1	内田 康介	TUAT	FaSTAR (Unstructured solver)	TMR grid (FAMILY1)		SA-noft2	Uniform Flow
		B2						SA-noft2-R	
		C1	田中 健太郎	JAXA	TAS (Unstructured solver)	TMR grid (FAMILY1)		SA	Uniform Flow
		C2						SA-noft2-R (Crot=1)	
		D1	澤木 悠太	KHI	Cflow (Unstructured solver)	TMR grid (FAMILY1)		SA-neg	Uniform Flow
WRLES		E1	キム サンウォン	RIKEN	CUBE (Cartesian solver)	Custom	Cartesian grid	Implicit LES	Initial perturbation using wall wedge geometry
		E2	Zauner Markus	JAXA	FaSTAR (Unstructured solver)	Custom	As close as possible to Moser et al., (1999)	WALE	Based on the synthetic generation method by Shur et al. (2014)

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Participants of Cases 2, 3, and 4

Case	Marker	ID	Name	Organization	Code	Grid / Level	Description of the grid		Turbulence Model	Initial Condition
2		A3	Zehner Paul	JAXA	FaSTAR-GPU (Unstructured solver)	ANSA grid (10ST-ANSA-Unstructured-Yplus1) / B			SA-noft2	Cold Start
		B3	内田 康介	TUAT	FaSTAR (Unstructured solver)	ANSA grid (10ST-ANSA-Unstructured-Yplus1) / B			SA-noft2	Cold Start
		B4							SA-noft2-R	
		C3	田中 健太郎	JAXA	TAS (Unstructured solver)	Custom	Equivalent to the grid provided by HLPW4 (240-JAXA-unstructured,C)		SA-noft2-R(Crot=1)	Grid of semi-span aircraft model + Grid of empty wind tunnel
		D2	澤木 悠太	KHI	Cflow (Unstructured solver)	ANSA grid (10ST-ANSA-Unstructured-Yplus1) / B			SA-neg	Cold Start
		D3							SA-neg-QCR2000-R(Crot=1)	
		D4				ANSA grid (10ST-ANSA-Unstructured-Yplus1) / C				
		F1	玉置 義治	University of Tokyo	UTCart (Unstructured Cartesian solver)	Custom	Hierarchical cartesian grid		SA-noft2	Cold Start
		J1	阿部 浩幸	JAXA	FaSTAR (Unstructured solver)	ANSA grid (10ST-ANSA-Unstructured-Yplus1) / B			AMM-QCRcorner	Cold Start
3		G1	Zauner Markus	JAXA	FaSTAR (Unstructured solver)	ANSA grid (103-ANSA-Unstructured-hiA-Yplus1) / C			SA-noft2-R Delayed DES	Cold Start
		G2								Warm Start
		H1	安田 英将	KHI	Cflow (Unstructured solver)	Custom	Cartesian grid + Layered grid	Coarse	SA-neg Delayed DES	Warm Start
		H2						Fine		
4		I1	Zauner Markus	JAXA	FaSTAR (Unstructured solver)	ANSA grid (10ST-ANSA-Unstructured-Yplus1) / C			SA-noft2-R Delayed DES	Cold Start (from INF)

Participant of APC-9 Case 5

Marker	ID	Name	Organization	Code	Grid	Number of grids	Turbulence Model	Initial Condition
	H3	安田 英将	KHI	Cflow (Unstructured solver)	Cflow-C1[1]	365745692	SA-neg	Cold Start
	H4				Cflow-C2[1]	367303332		
	H5				Cflow-C3[1]	371805988		
	H6				Cflow-C6[1]	409109709		
	H7				ANSA-C[2]	216724148		
	H8				PW-A[3]	21868681		
	H9				PW-C[3]	141518040		
	H10				JAXA-C[4]	208695005		

HLPW4 GRIDS DOWNLOAD PAGE
https://hiliftpw.larc.nasa.gov/Workshop4/grids_downloads.html
(1) 140-KHI-Unstructured: 140.C
(2) 101-ANSA-Unstructured-loA-Yplus1: 101.C
(3) 1.3-Pointwise-Unstr-HexPrismPyrTet-V2: 1.3A, 1.3C
(4) 240-JAXA-unstructured: 240.C

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Case 1: Verification

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Case 1 : Verification (1)

- RANS Conditions
  - 2D CRM-HL 3-element airfoil
  - M = 0.2
  - Re = 5.00 x 10^6 (C_{ref} = 1)
  - T_{ref} = 272.1K
  - AoA = 16 deg
  - Grid: NASA TMR website grid (family 1): https://turbmodels.larc.nasa.gov/multielementverif_grids.html

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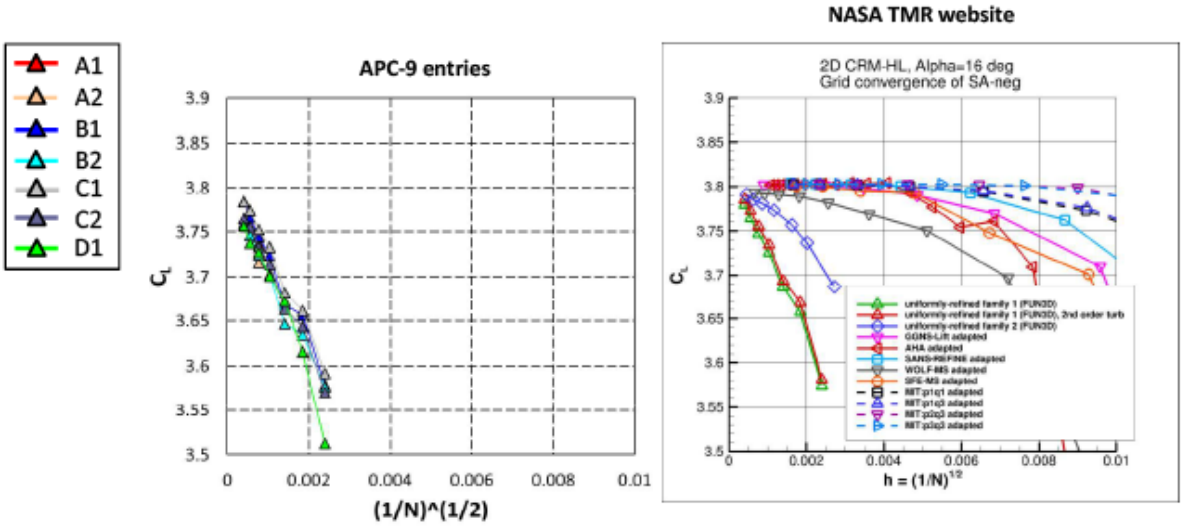
RANS Verification, Case 1

- Grid Convergence of CL



https://turbmodels.larc.nasa.gov/multielementverif_saneg.html

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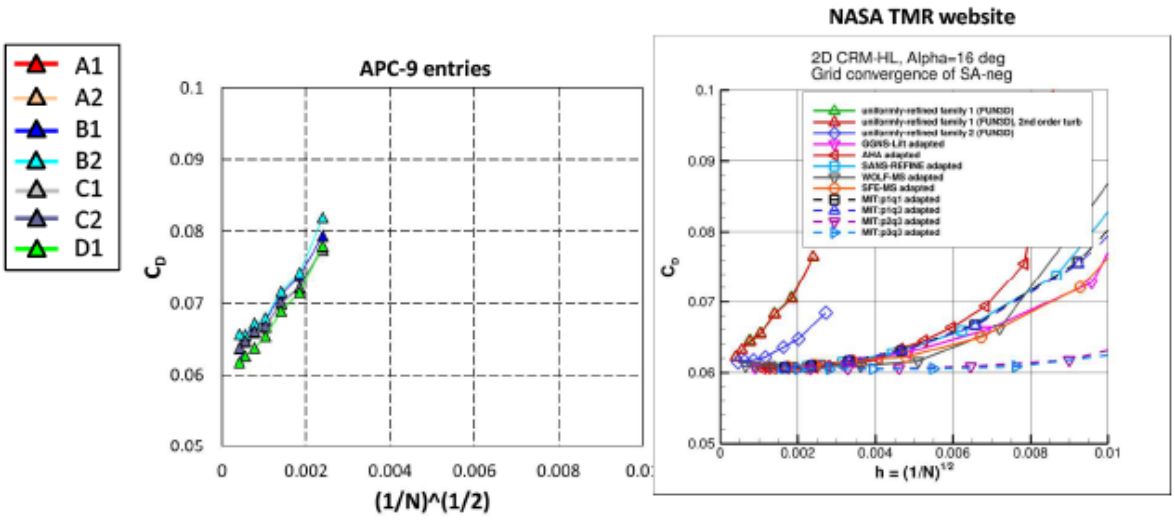
RANS Verification, Case 1

- Grid Convergence of CD



https://turbmodels.larc.nasa.gov/multielementverif_saneg.html

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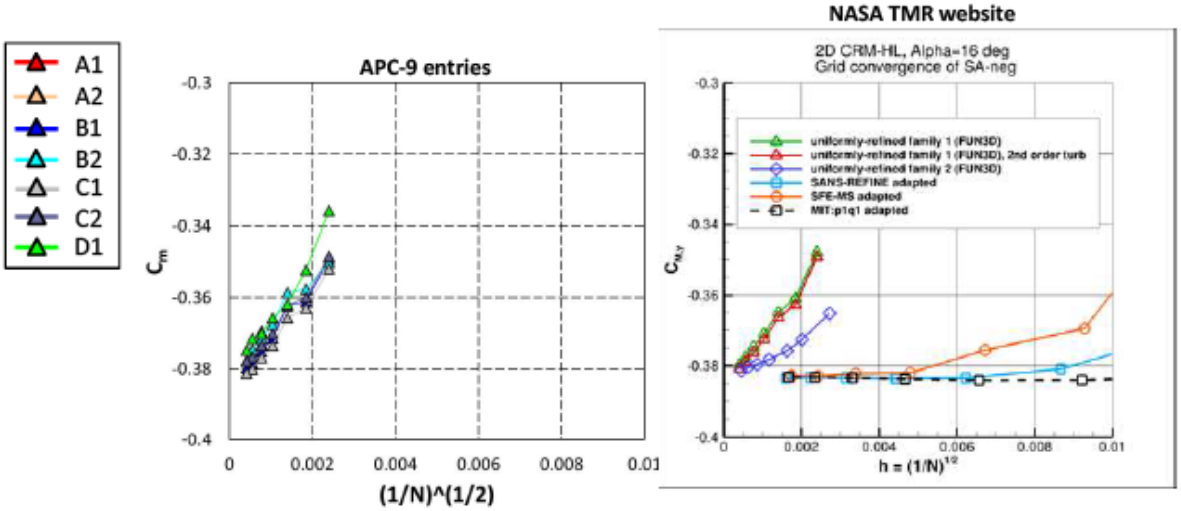
RANS Verification, Case 1

- Grid Convergence of Cm



https://turbmodels.larc.nasa.gov/multielementverif_saneg.html

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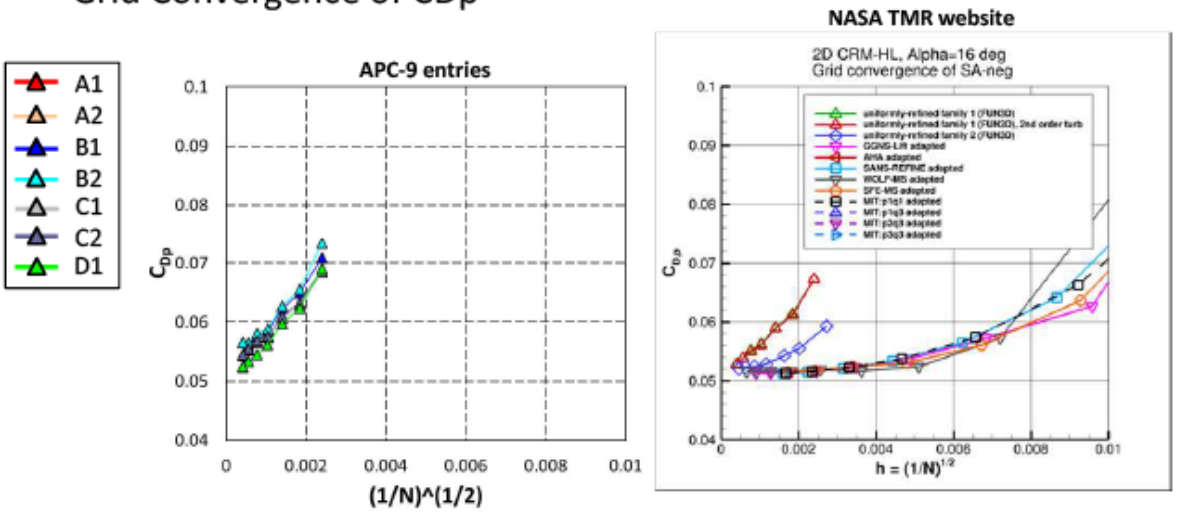
RANS Verification, Case 1

- Grid Convergence of CDp



https://turbmodels.larc.nasa.gov/multielementverif_saneg.html

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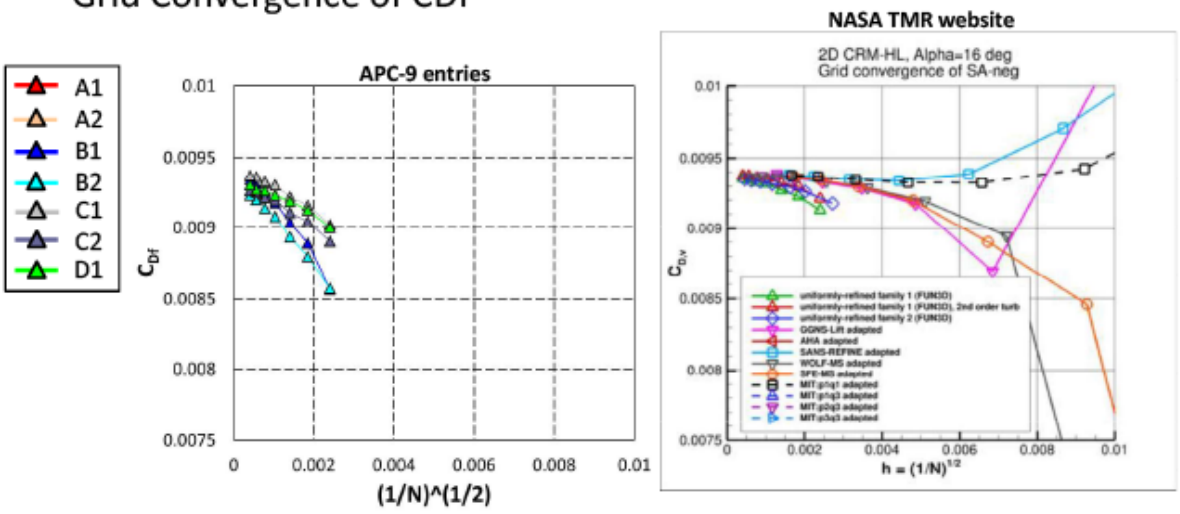
RANS Verification, Case 1

- Grid Convergence of CDf



https://turbmodels.larc.nasa.gov/multielementverif_saneg.html

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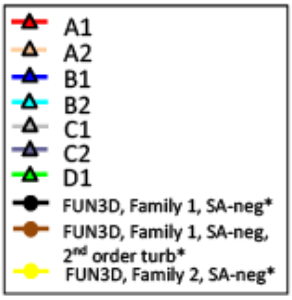
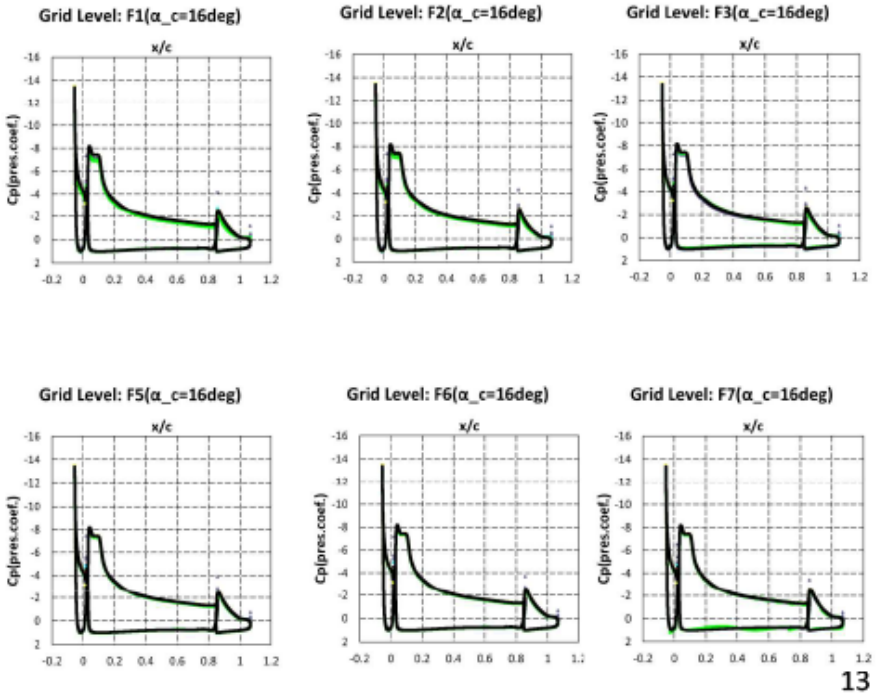
RANS Verification, Case 1

- Cp distribution



*https://turbmodels.larc.nasa.gov/multielementverif_saneg.html, cpcf_multielementairfoil_saneg_final.dat



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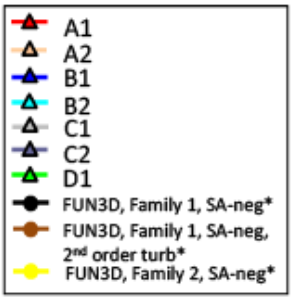
RANS Verification, Case 1

- Cfx distribution



*https://turbmodels.larc.nasa.gov/multielementverif_saneg.html, cfx_multielementairfoil_saneg_final.dat.

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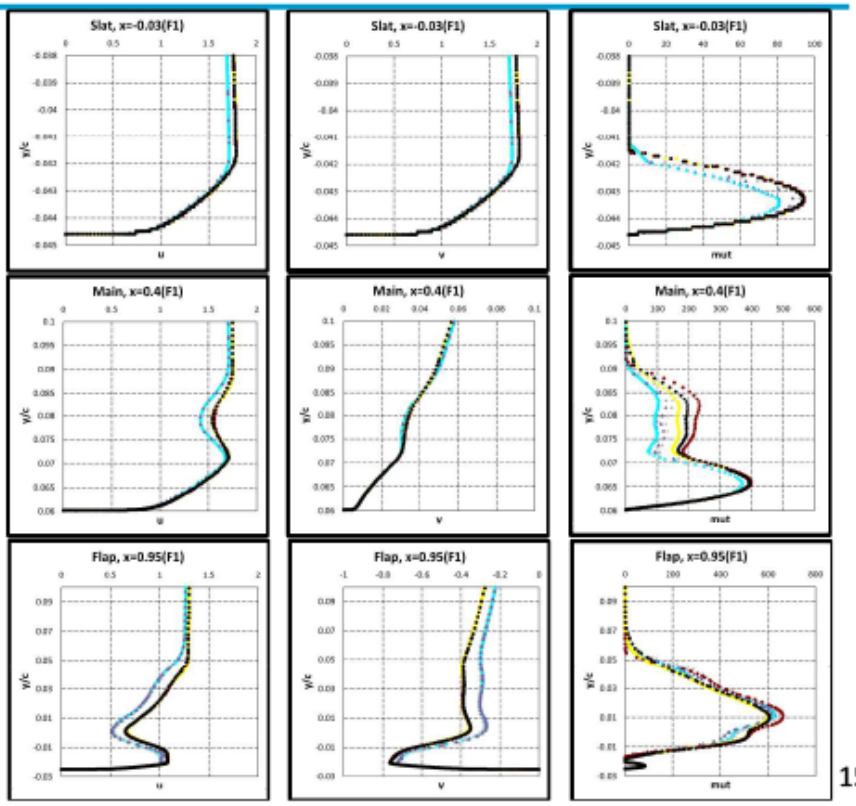
RANS Verification, Case 1

- u, v, μ_t (F1)

A1
A2
B1
B2
C1
C2
D1
FUN3D, Family 1, SA-neg*
FUN3D, Family 1, SA-neg, 2nd order turb*
FUN3D, Family 2, SA-neg*

*https://turbmodels.larc.nasa.gov/multielementverif_saneg.html, cfx_multielementairfoil_saneg_final.dat.



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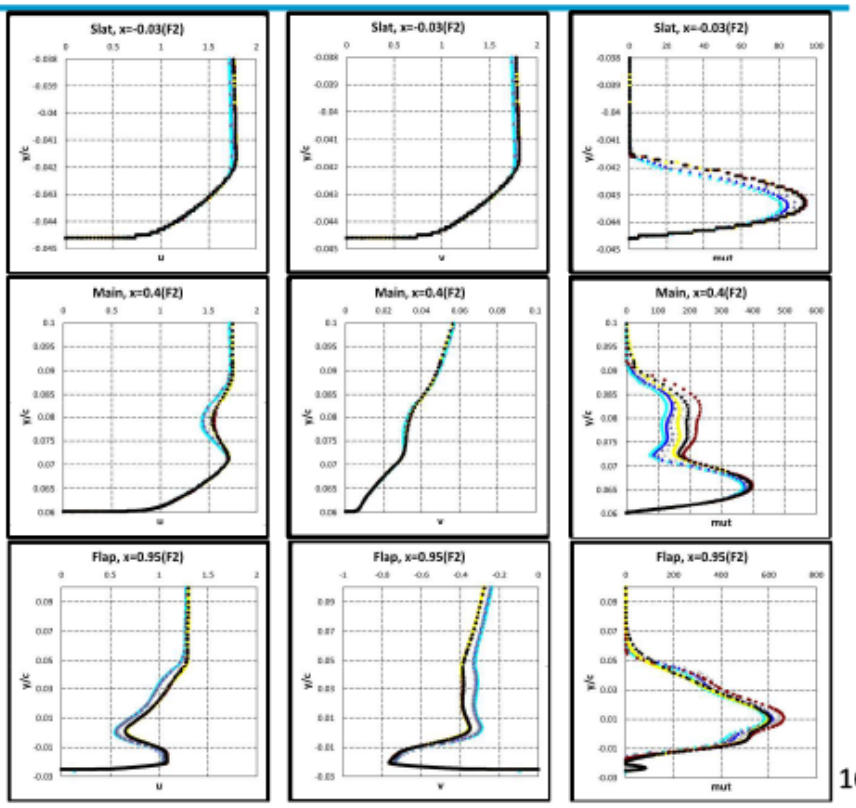
RANS Verification, Case 1

- u, v, μ_t (F2)

A1
A2
B1
B2
C1
C2
D1
FUN3D, Family 1, SA-neg*
FUN3D, Family 1, SA-neg, 2nd order turb*
FUN3D, Family 2, SA-neg*

*https://turbmodels.larc.nasa.gov/multielementverif_saneg.html, cfx_multielementairfoil_saneg_final.dat.



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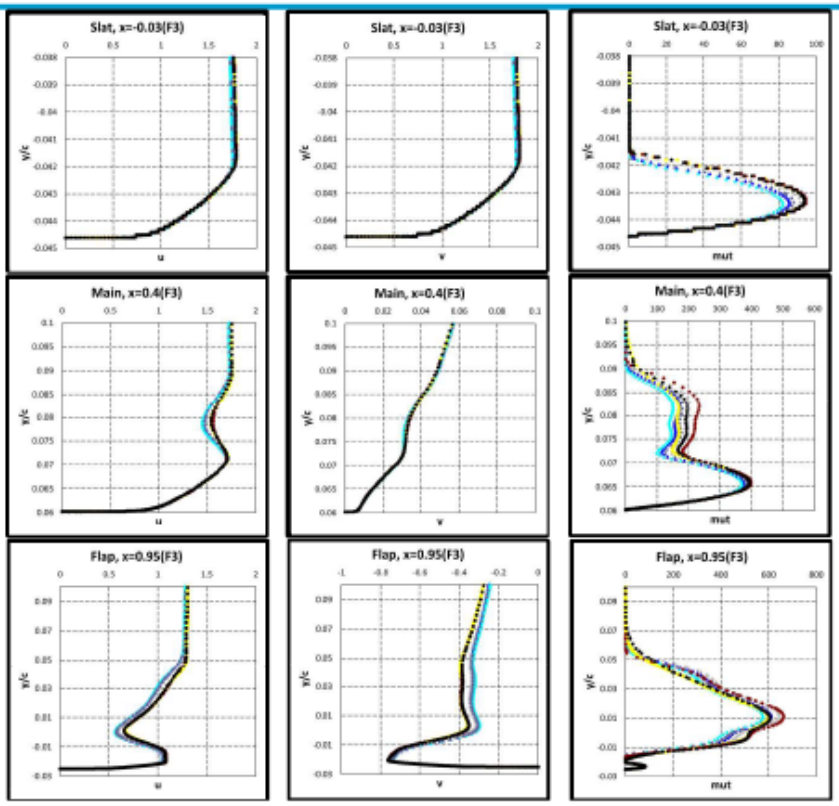
RANS Verification, Case 1

- u, v, μ_t (F3)

A1
A2
B1
B2
C1
C2
D1
FUN3D, Family 1, SA-neg*
FUN3D, Family 1, SA-neg, 2nd order turb*
FUN3D, Family 2, SA-neg*

*https://turbmodels.larc.nasa.gov/multielementverif_saneg.html, cfx_multielementairfoil_saneg_final.dat.



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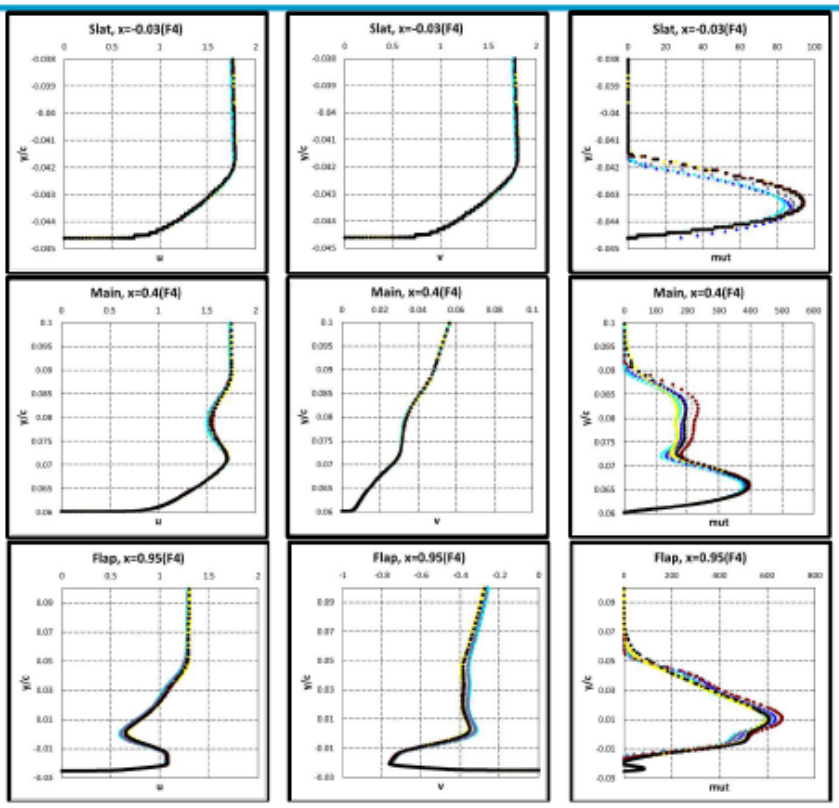
RANS Verification, Case 1

- u, v, μ_t (F4)

A1
A2
B1
B2
C1
C2
D1
FUN3D, Family 1, SA-neg*
FUN3D, Family 1, SA-neg, 2nd order turb*
FUN3D, Family 2, SA-neg*

*https://turbmodels.larc.nasa.gov/multielementverif_saneg.html, cfx_multielementairfoil_saneg_final.dat.



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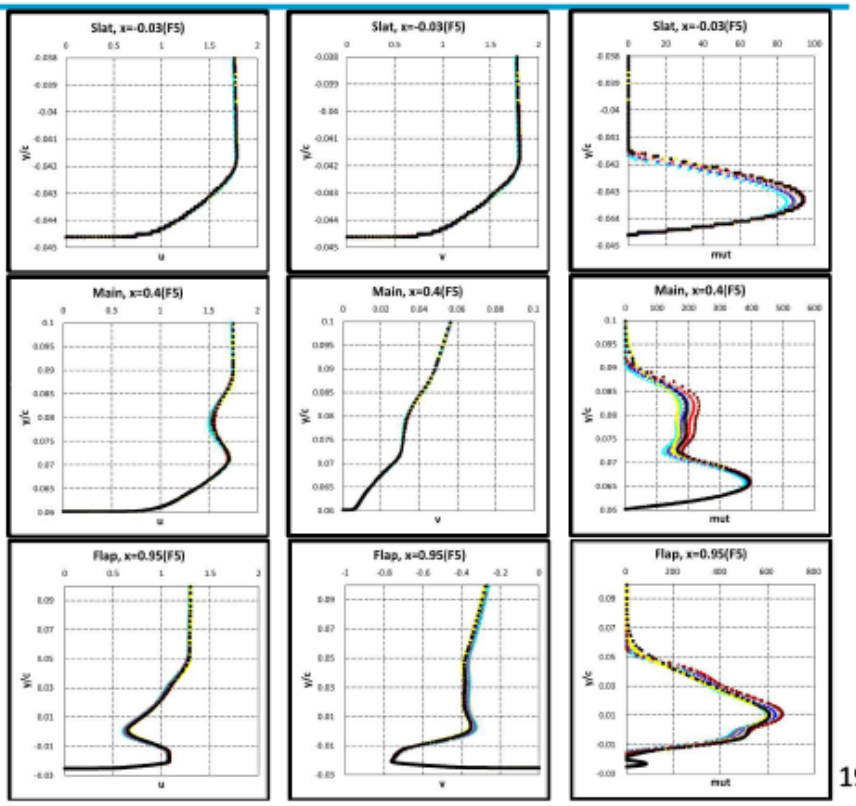
RANS Verification, Case 1

- u, v, μ_t (F5)

A1
A2
B1
B2
C1
C2
D1
FUN3D, Family 1, SA-neg*
FUN3D, Family 1, SA-neg, 2nd order turb*
FUN3D, Family 2, SA-neg*

*https://turbmodels.larc.nasa.gov/multielementverif_saneg.html, cfx_multielementairfoil_saneg_final.dat.



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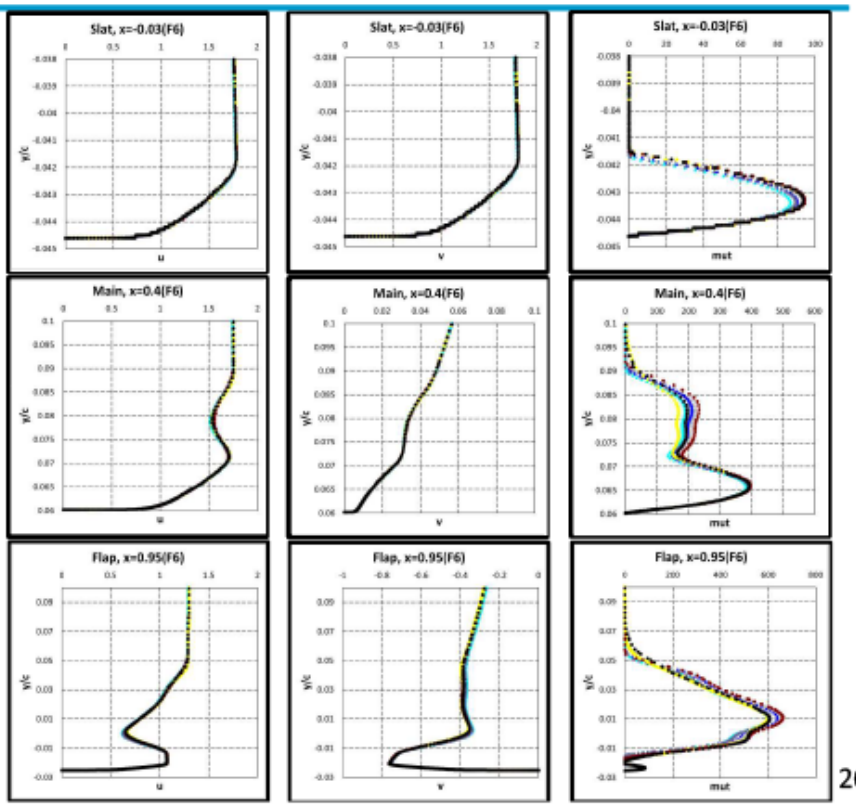
RANS Verification, Case 1

- u, v, μ_t (F6)

A1
A2
B1
B2
C1
C2
D1
FUN3D, Family 1, SA-neg*
FUN3D, Family 1, SA-neg, 2nd order turb*
FUN3D, Family 2, SA-neg*

*https://turbmodels.larc.nasa.gov/multielementverif_saneg.html, cfx_multielementairfoil_saneg_final.dat.



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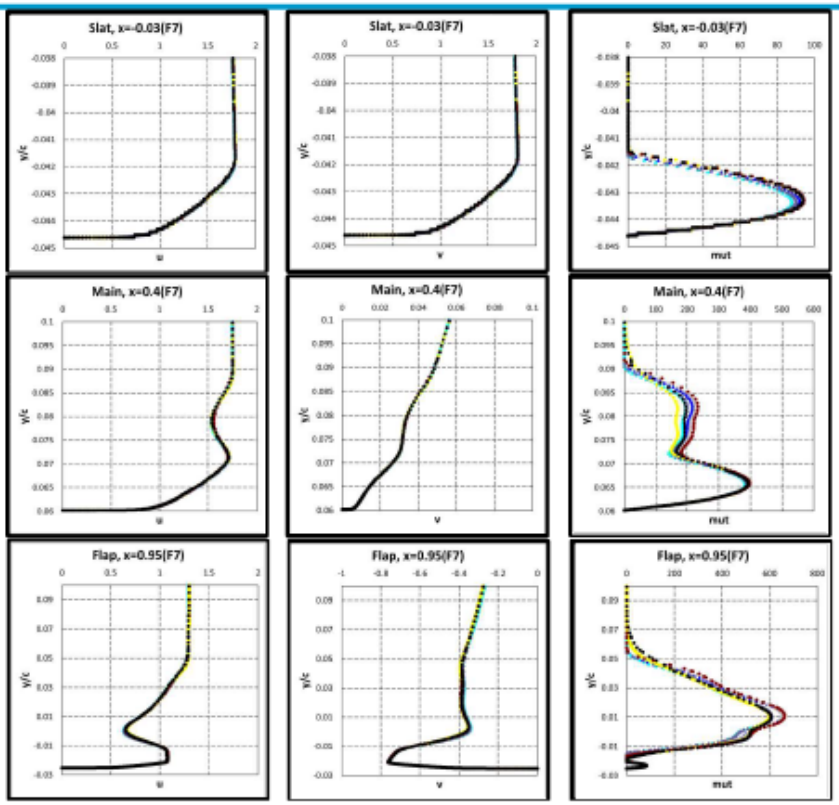
RANS Verification, Case 1

- u, v, μ_t (F7)

A1
A2
B1
B2
C1
C2
D1
FUN3D, Family 1, SA-neg*
FUN3D, Family 1, SA-neg, 2nd order turb*
FUN3D, Family 2, SA-neg*

*https://turbmodels.larc.nasa.gov/multielementverif_saneg.html, cfx_multielementairfoil_saneg_final.dat.



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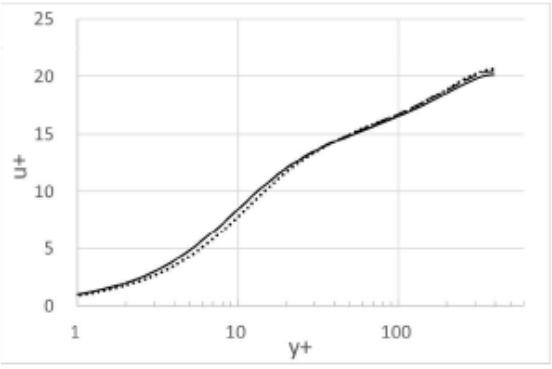
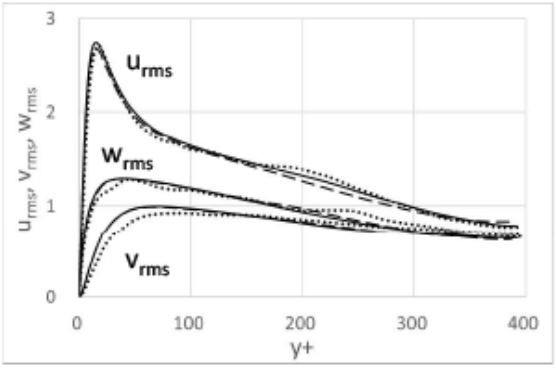
Case 1 : Verification (2)

- WRLES Condition
  - Channel flow
  - Re_τ=395
- u^+ vs. y^+
- u_{rms}, v_{rms}, w_{rms} vs. y^+

*https://turbulence.oden.utexas.edu/MKM_1999.html

DNS*
E1
E2





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Cases 2 and 4:
In-tunnel RANS and HRLES

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Cases 2 and 4 : In-tunnel Steady and Unsteady Computation

- Method
  - Case 2: RANS (steady) computation
  - Case 4: Hybrid RANS/LES (unsteady) computation
- Geometry and Flow Conditions
  - In-tunnel
  - 3D CRM-HL flap angle : 40°/37°(inboard/outboard)
  - M = 0.2
  - Re = 5.49 x 10^6 (C_{ref} = 275.8inches)
  - T_{ref} = 521°R
  - AoA = 5.98, 15.48, 17.98, 19.98 deg (RANS)
    15.48, 17.98 deg (Hybrid RANS/LES)

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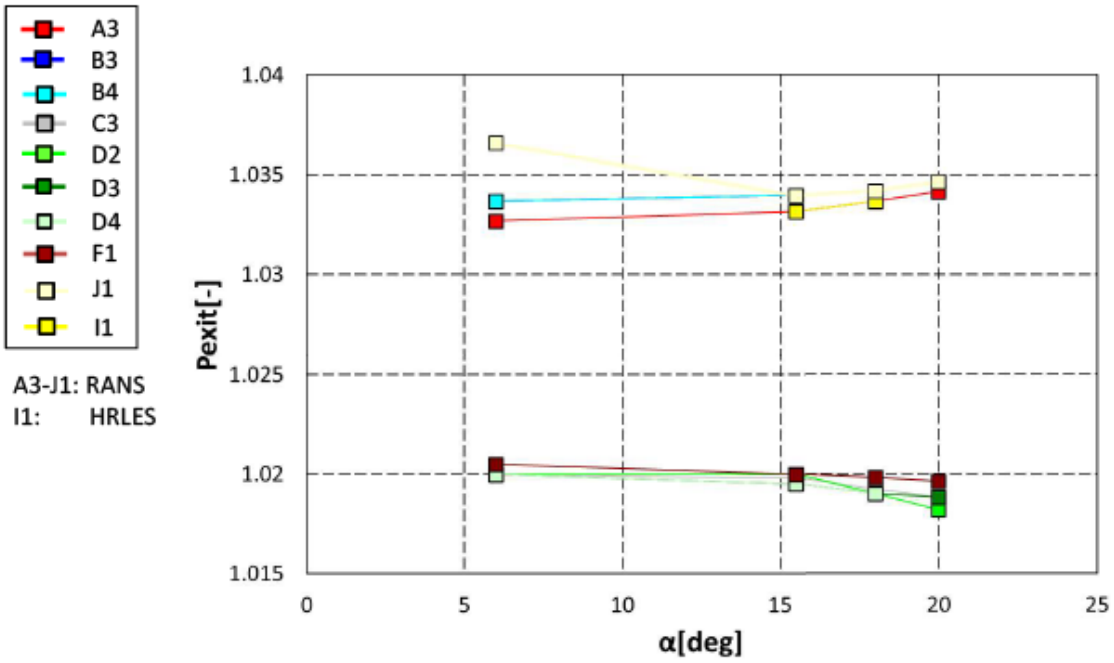
Static pressure at the outflow boundary, Cases 2 and 4



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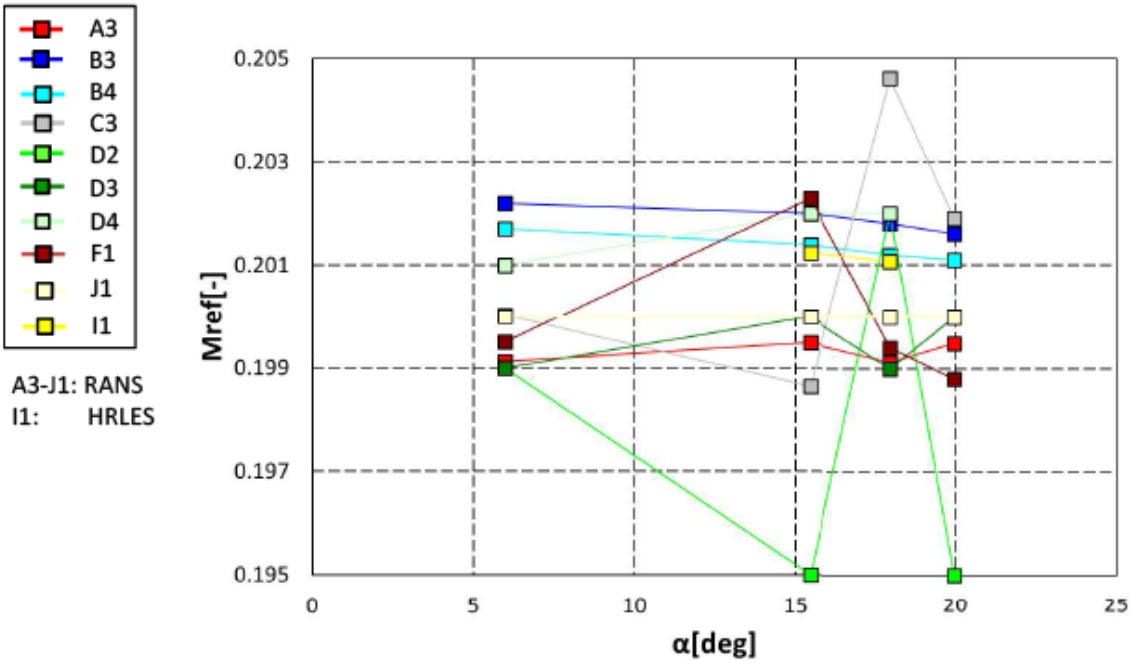
Mach number in the test section, Cases 2 and 4



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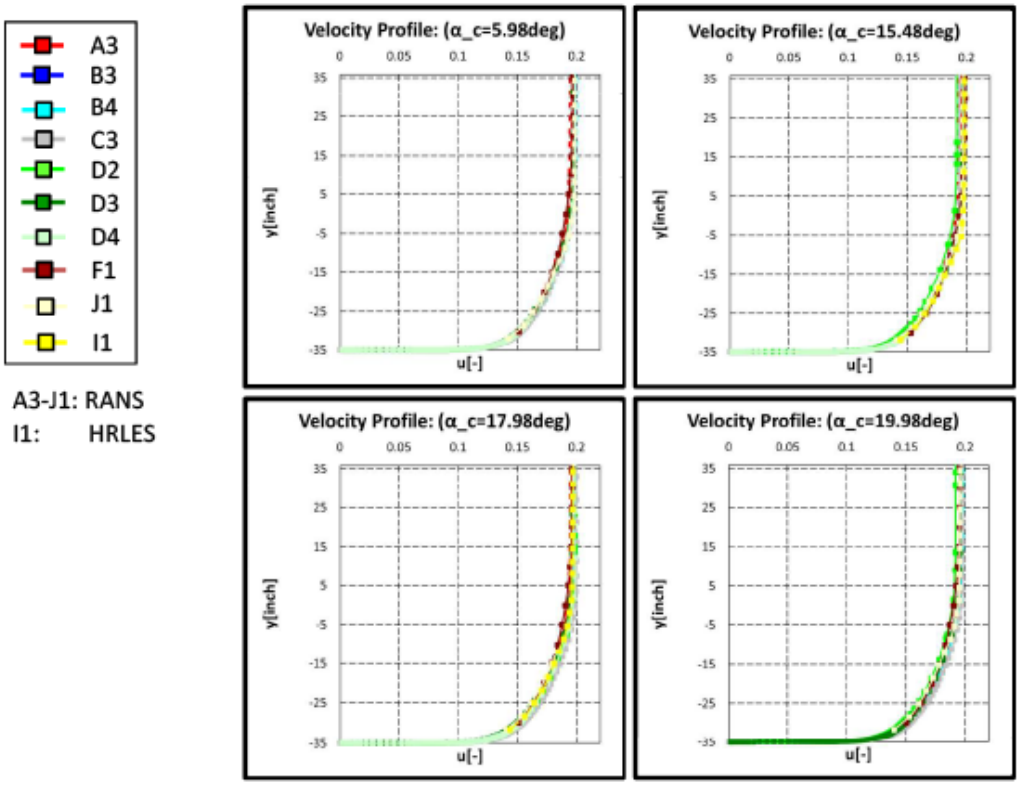
U-Velocity Profile, Cases 2 and 4



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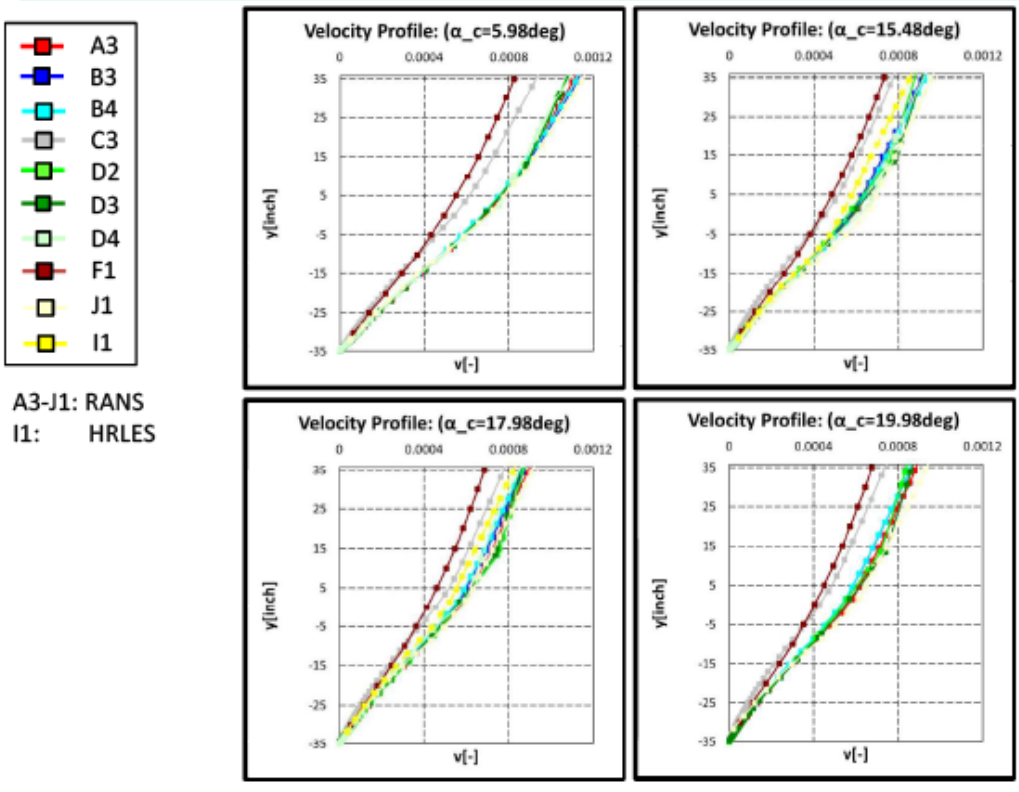
V-Velocity Profile, Cases 2 and 4



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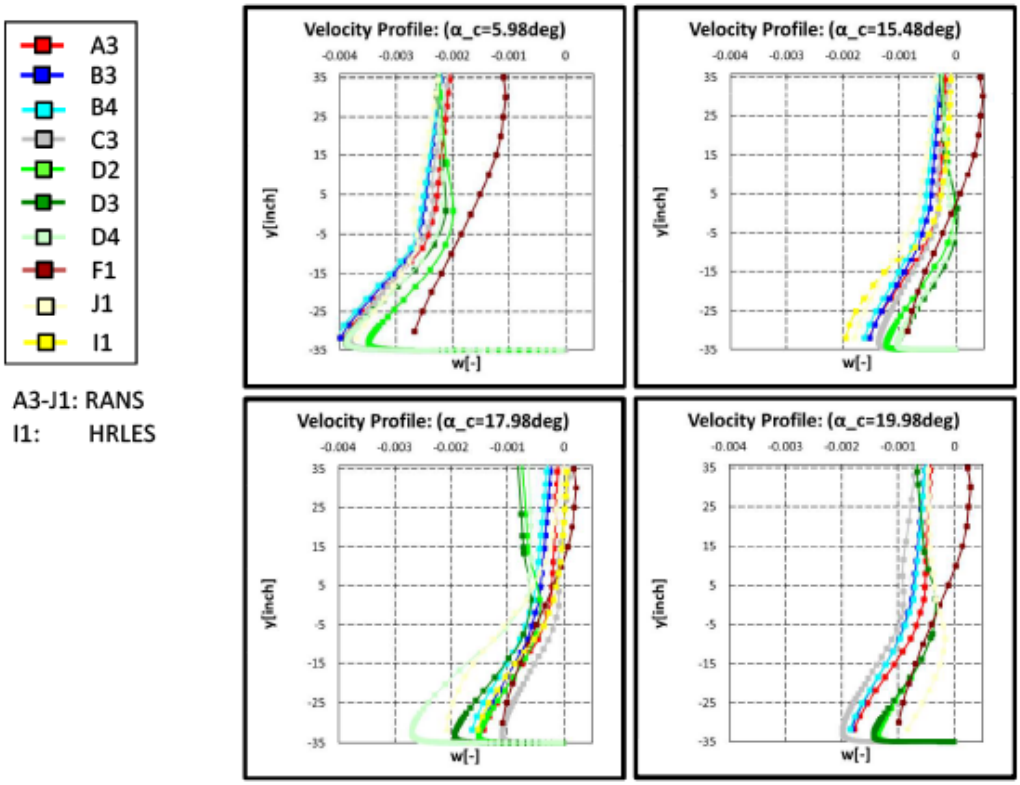
W-Velocity Profile, Cases 2 and 4



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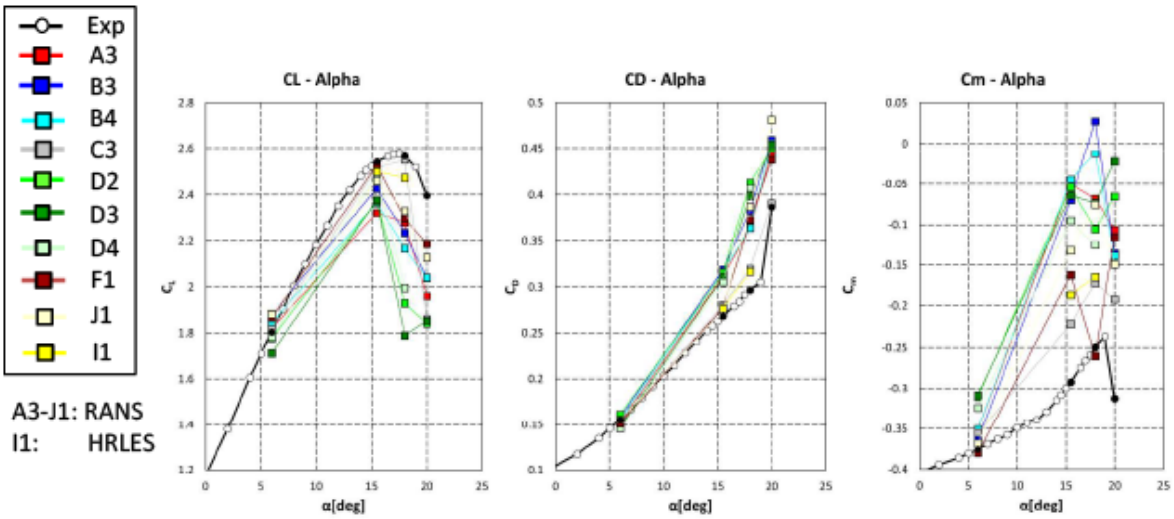
CL, CD, and Cm-Alpha, Cases 2 and 4



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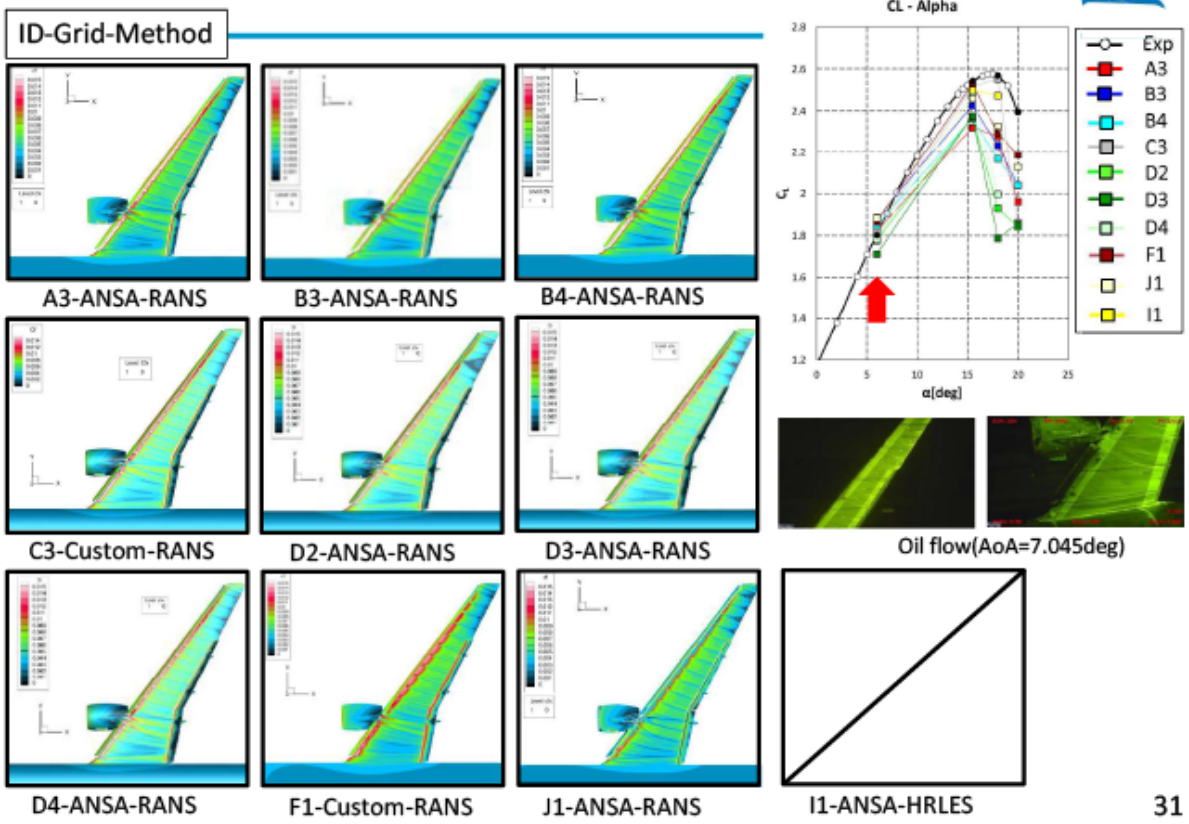
Surface Cf Contours（Cases 2 and 4, 5.98deg, Viewpoint 1）



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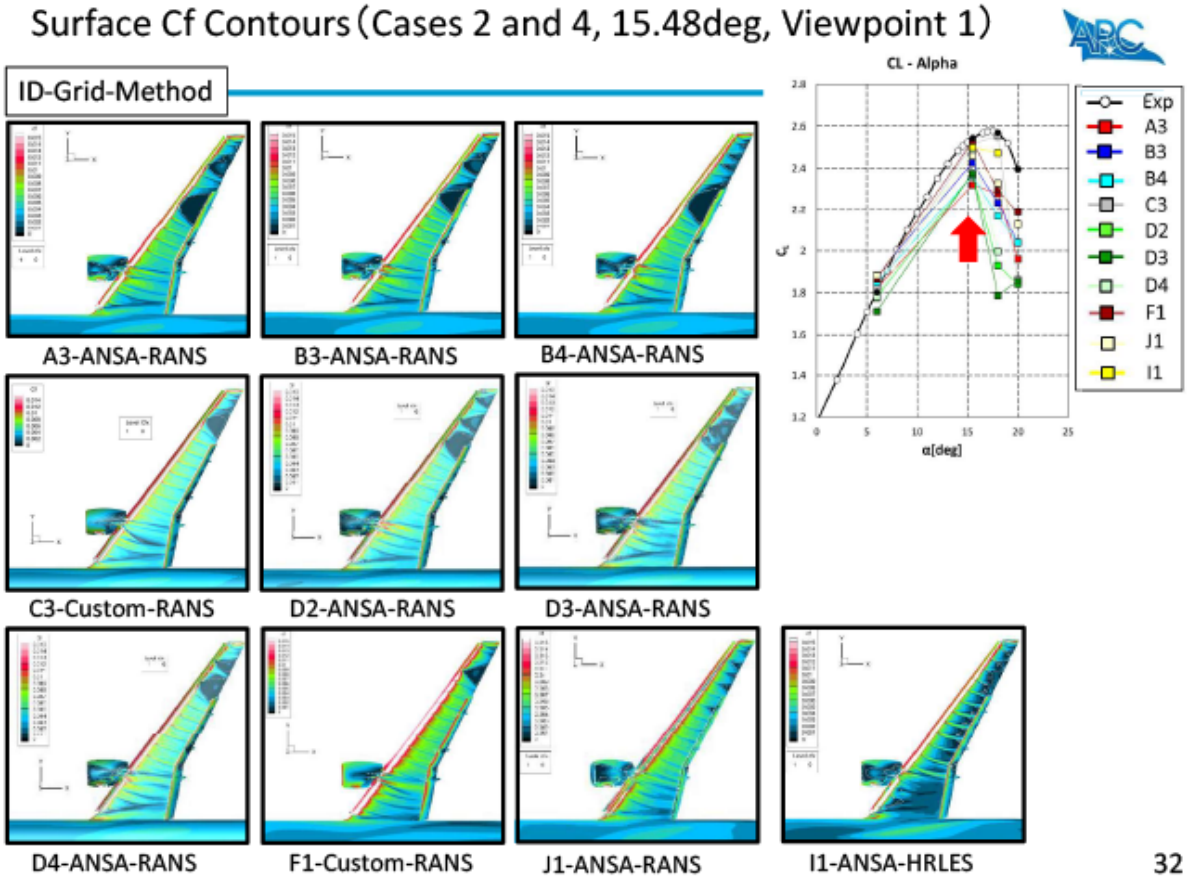
Surface Cf Contours（Cases 2 and 4, 15.48deg, Viewpoint 1）



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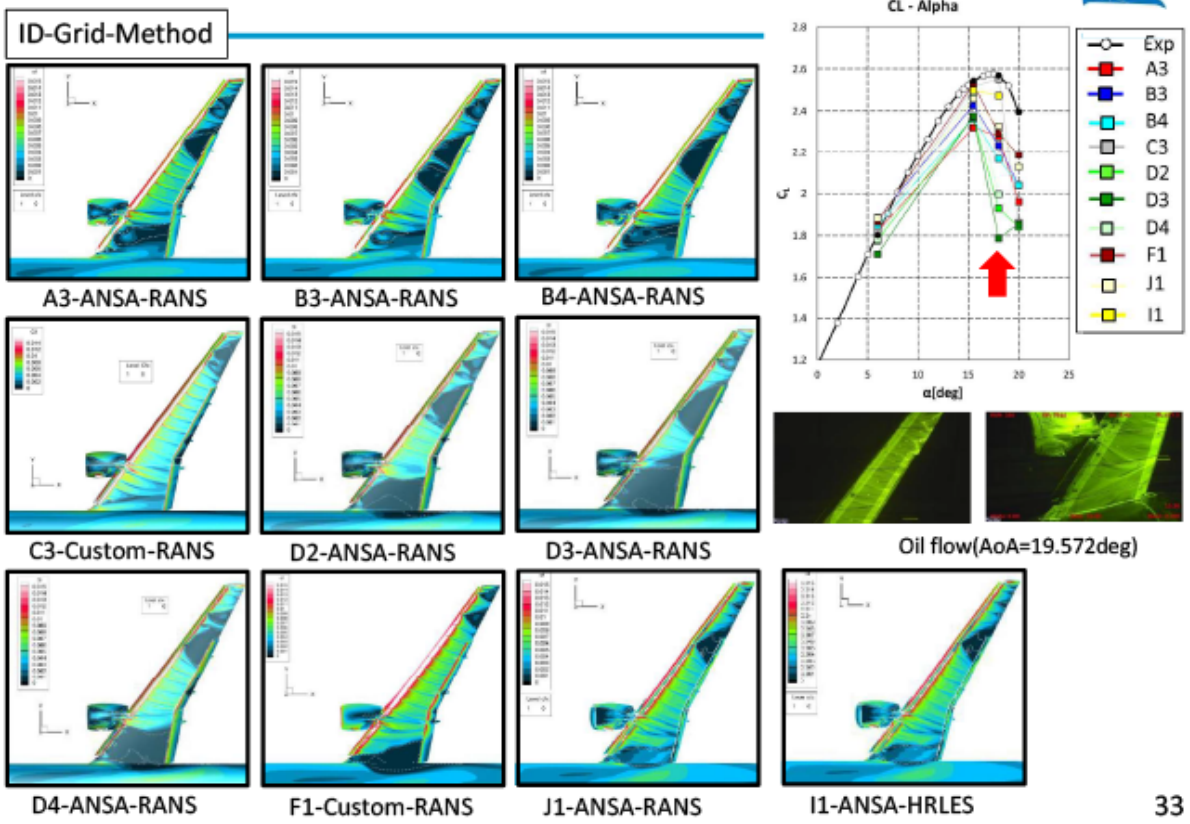
Surface Cf Contours (Cases 2 and 4, 17.98deg, Viewpoint 1)



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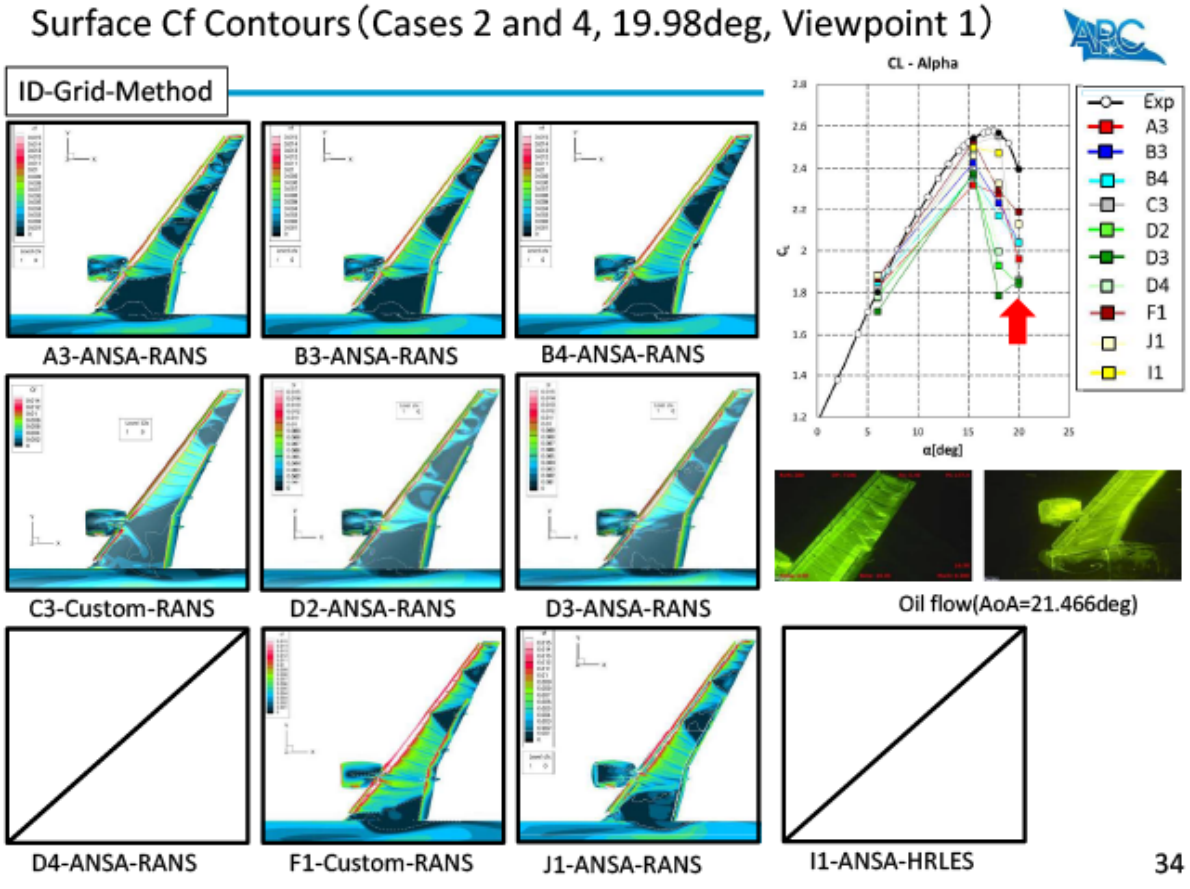
Surface Cf Contours (Cases 2 and 4, 19.98deg, Viewpoint 1)



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Case 3:
Free-air HRLES

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Case 3 : Free-air HRLES

- Method
  - Hybrid RANS/LES (unsteady) computation
- Geometry and Flow Conditions
  - Free-air
  - 3D CRM-HL flap angle : 40°/37°(inboard/outboard)
  - M = 0.2
  - Re = 5.49 x 10^6 (C_{ref} = 275.8inches)
  - T_{ref} = 521°R
  - AoA = 17.05, 19.57deg

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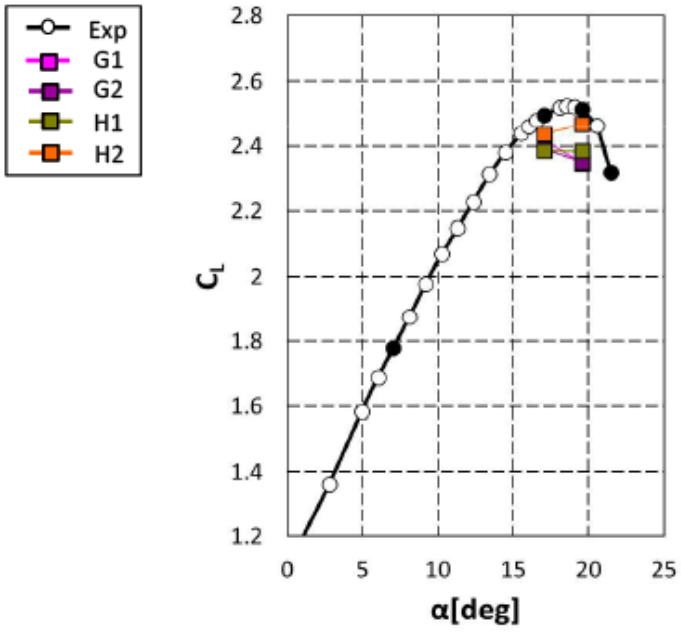
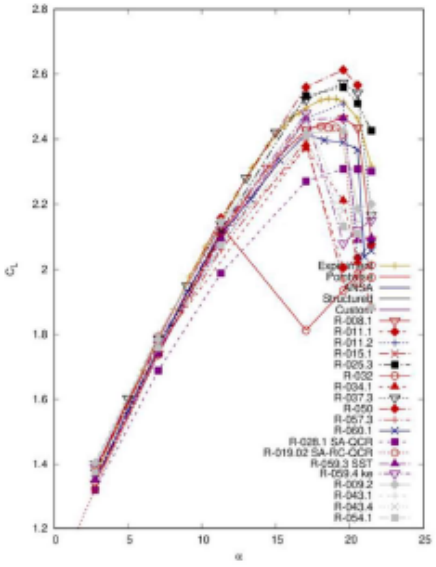
CL-Alpha, Case 3

Average Value





HLPW4
All Best-Practice Results
(03_GMGW3_HLPW4_RANS.pdf, p.17)

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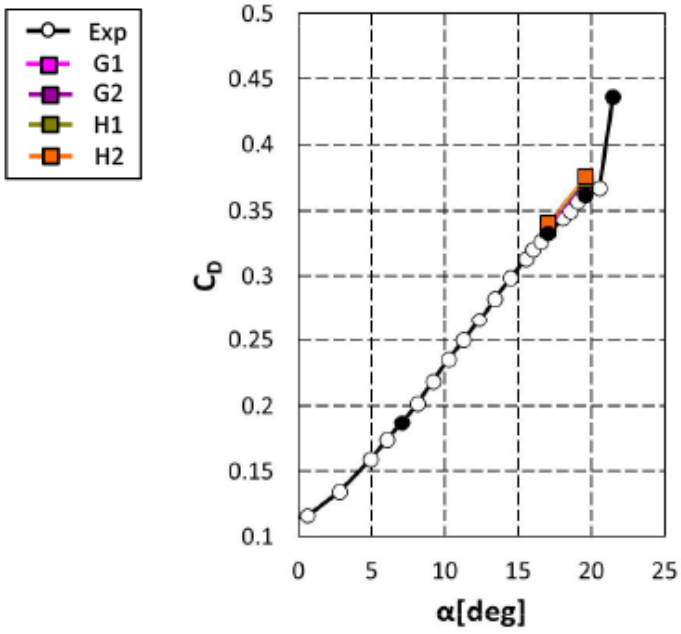
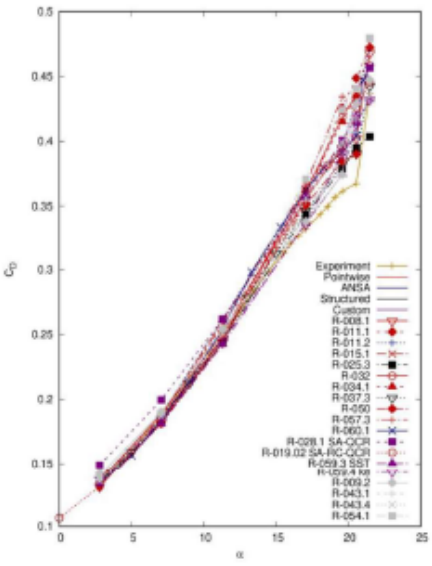
CD-Alpha, Case 3

Average Value





HLPW4
All Best-Practice Results
(03_GMGW3_HLPW4_RANS.pdf, p.17)

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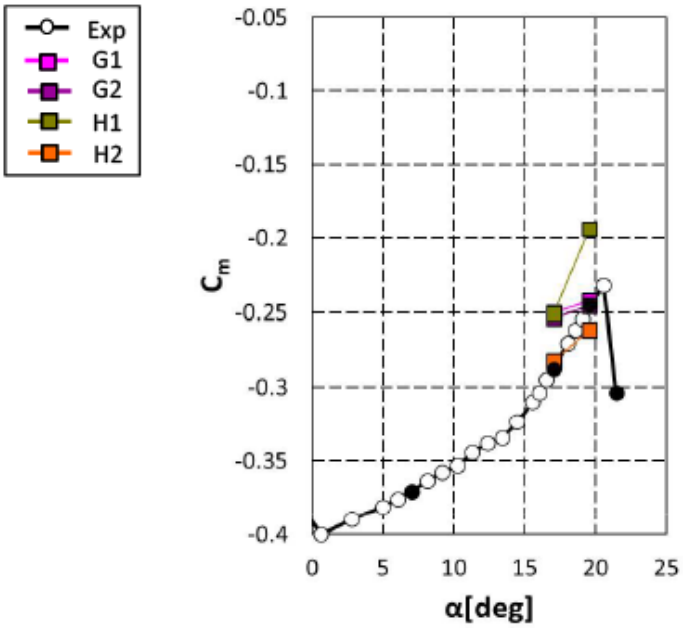
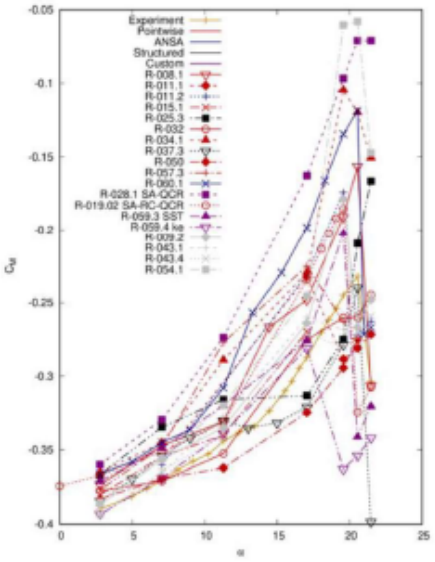
Cm-Alpha, Case 3

Average Value



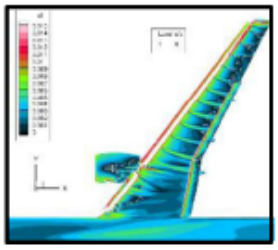


HLPW4
All Best-Practice Results
(03_GMGW3_HLPW4_RANS.pdf, p.17)

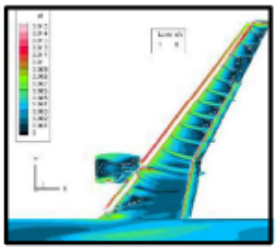
39

Surface Cf Contours (Case 3, 17.05deg, Viewpoint 1)

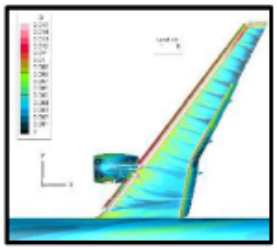
ID-Grid



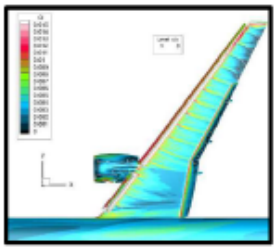
G1-ANSA



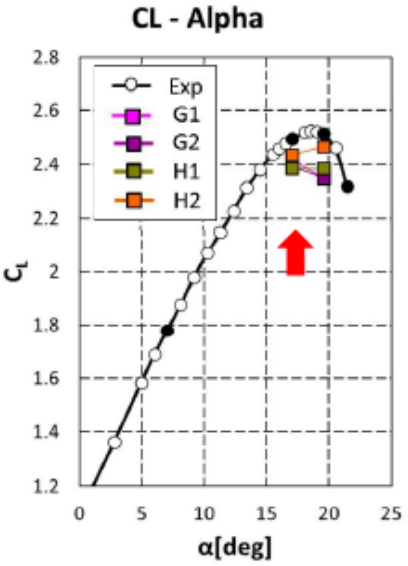
G2-ANSA



H1-Custom



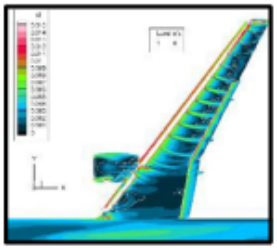
H2-Custom



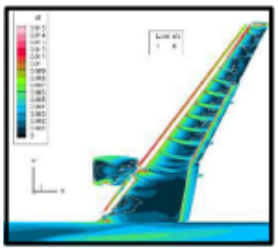
40

Surface Cf Contours (Case 3, 19.57deg, Viewpoint 1)

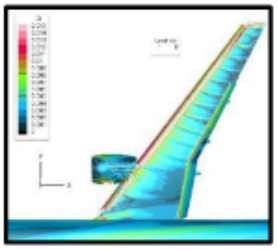
ID-Grid



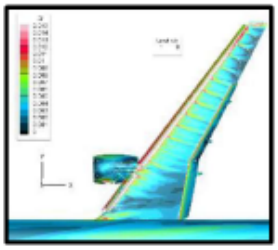
G1-ANSA



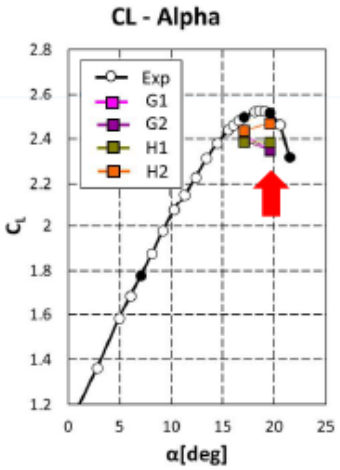
G2-ANSA



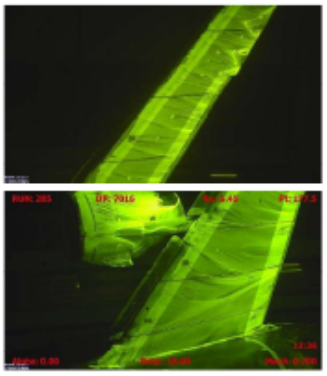
H1-Custom



H2-Custom

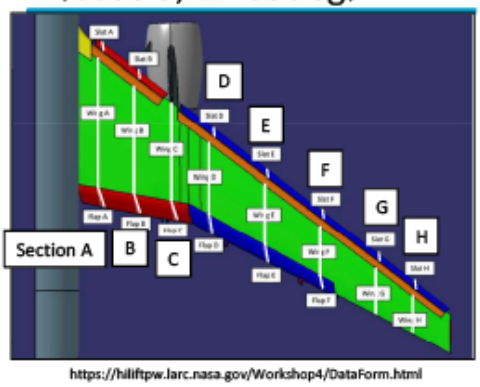


AoA=19.572deg

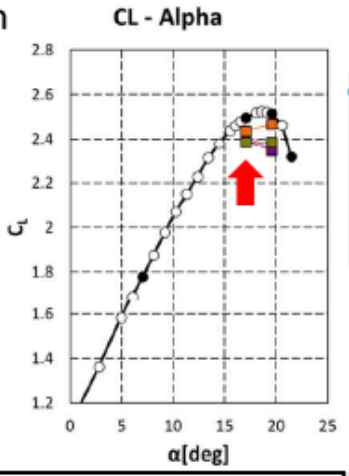


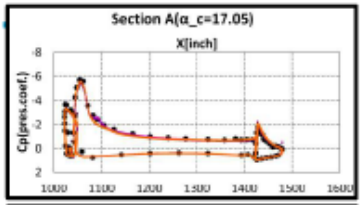
41

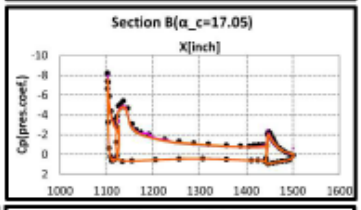
Surface Cp_ave distribution (Case 3, 17.05deg)

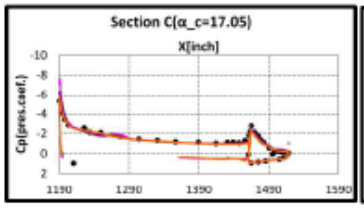


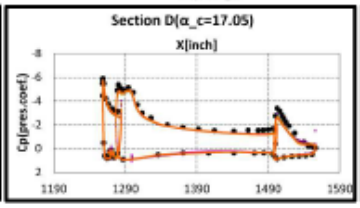
https://hiliftpw.larc.nasa.gov/Workshop4/DataForm.html

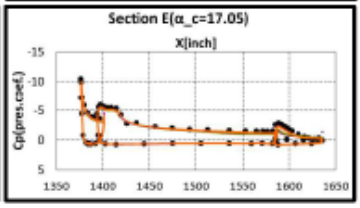


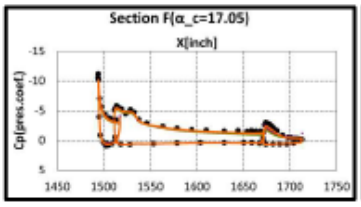


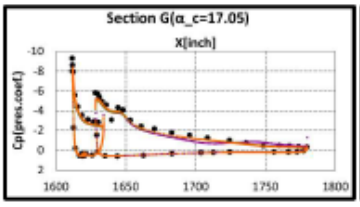


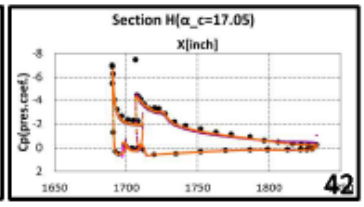




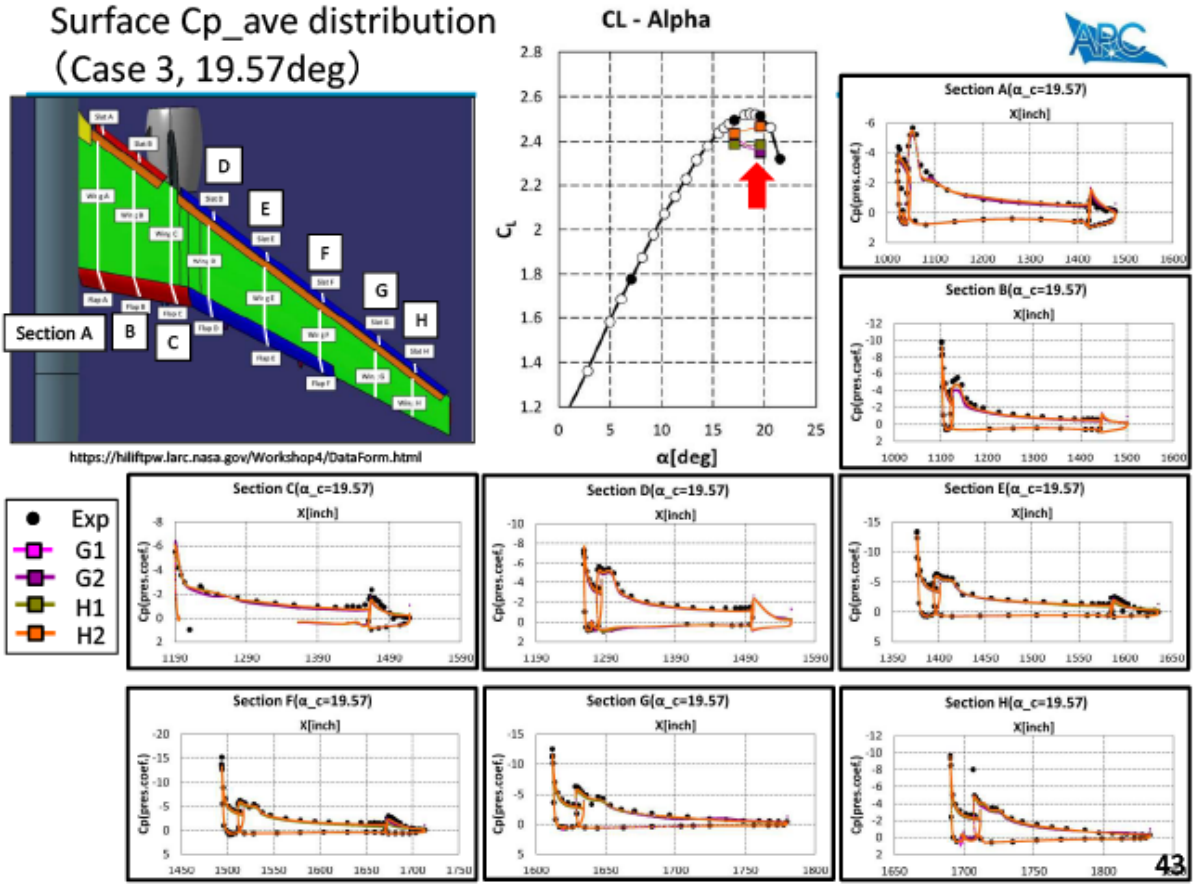


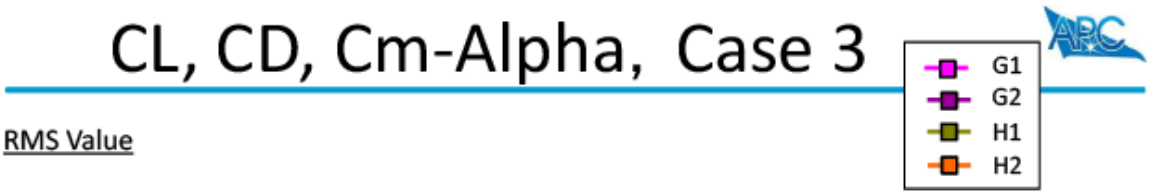


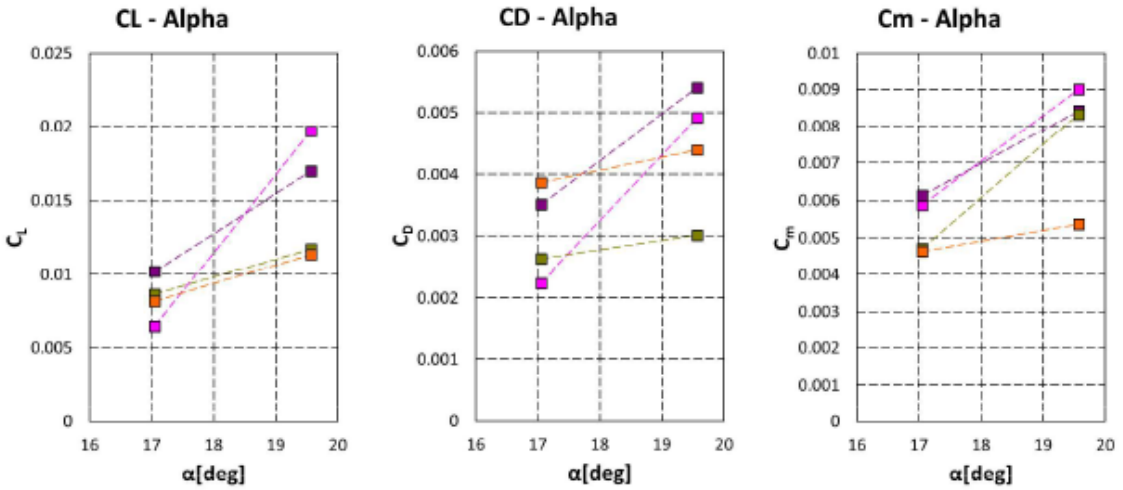


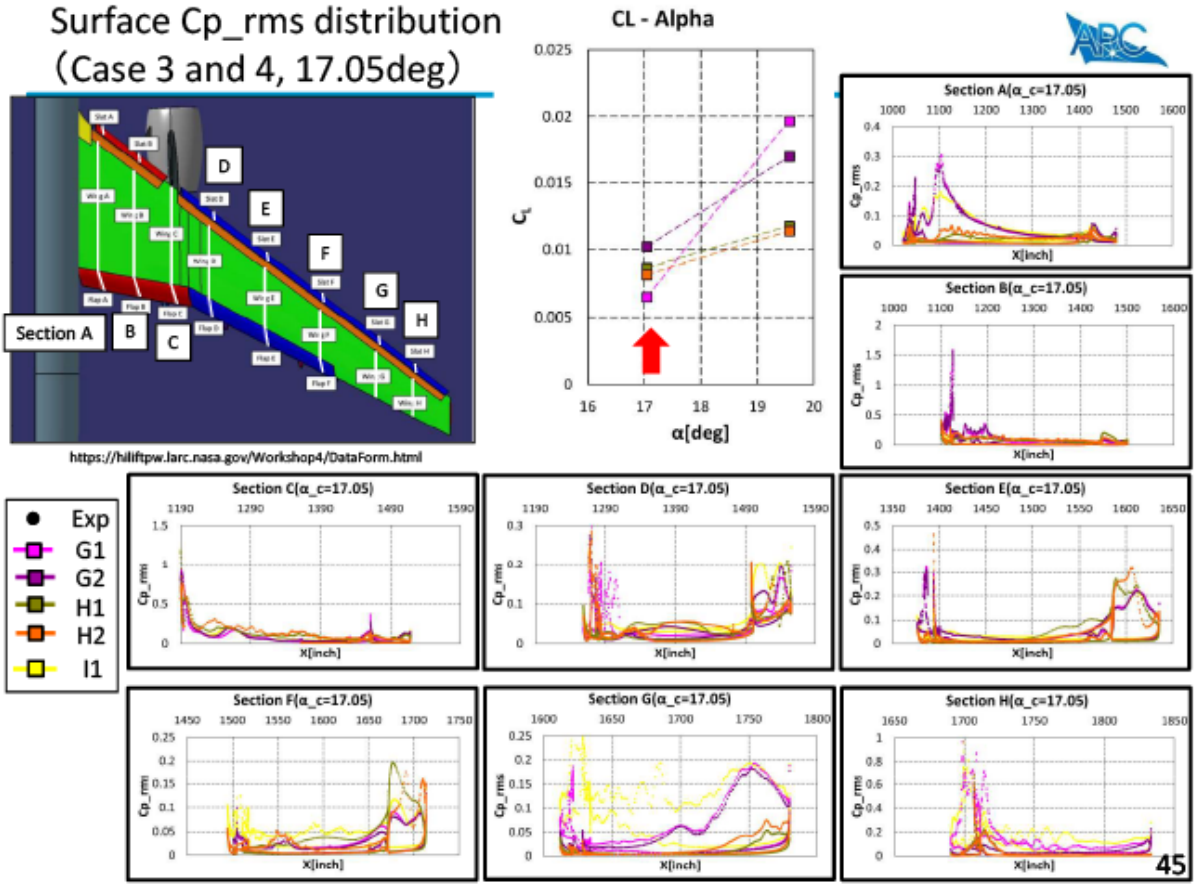


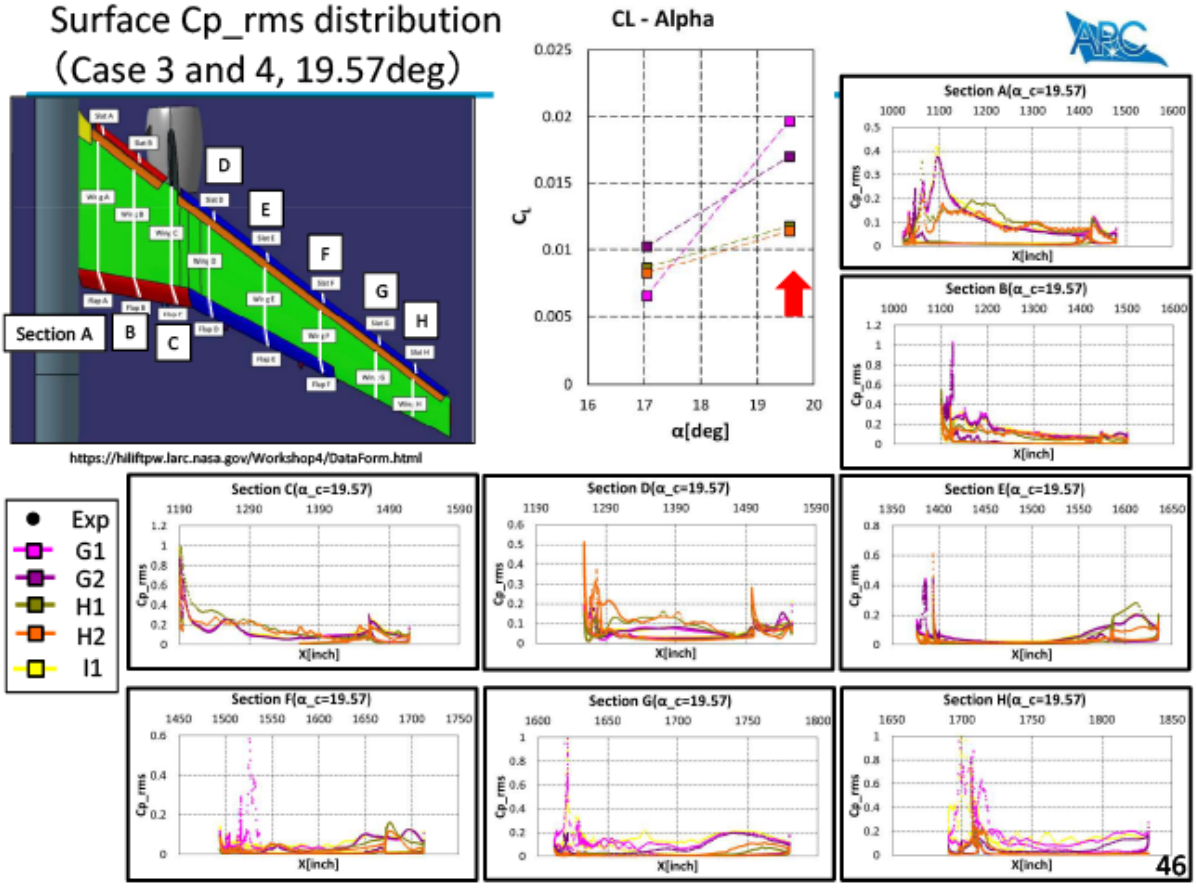
42











Comparison of In-tunnel (RANS, HRLES) and Free-air (RANS*, HRLES)

[*APC-8 results]

Note: For all in-tunnel vs free-air comparisons, the in-tunnel coordinates have been rotated to match the free-air reference system

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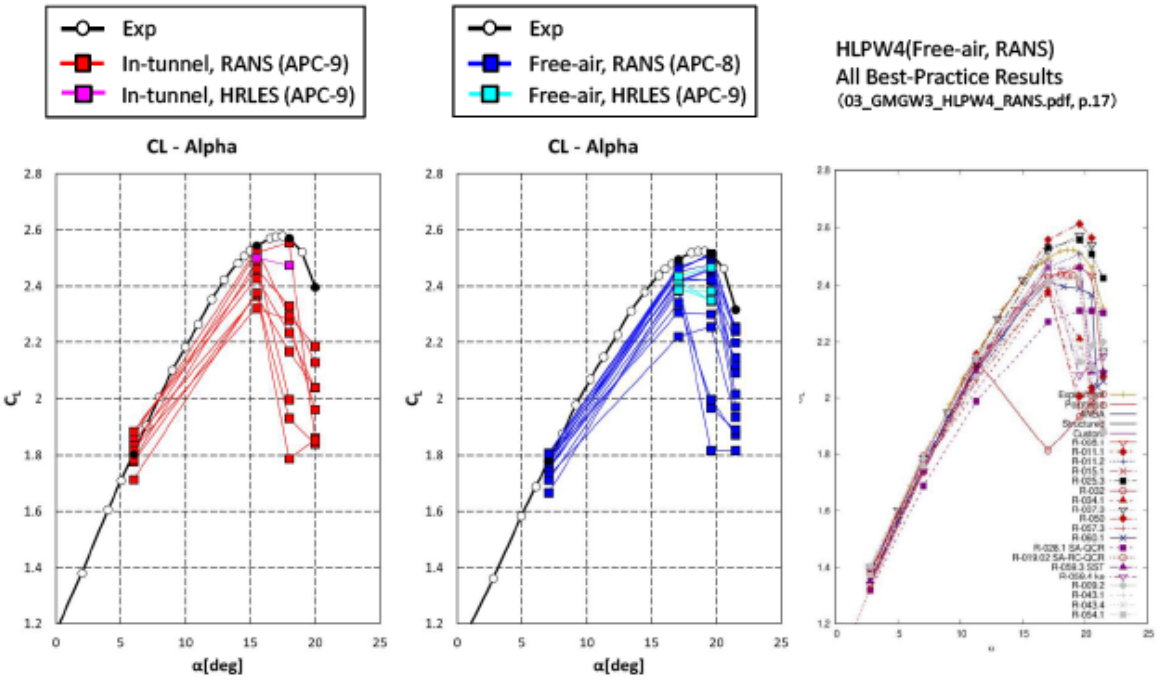
In-tunnel vs. Free-air vs. Oil flow

	In-tunnel	Free-air	Oil flow
AoA[deg]	5.98	7.05	7.045
	15.48	17.05	
	17.98	19.57	19.572
	19.98	21.47	21.466

48

CL-Alpha



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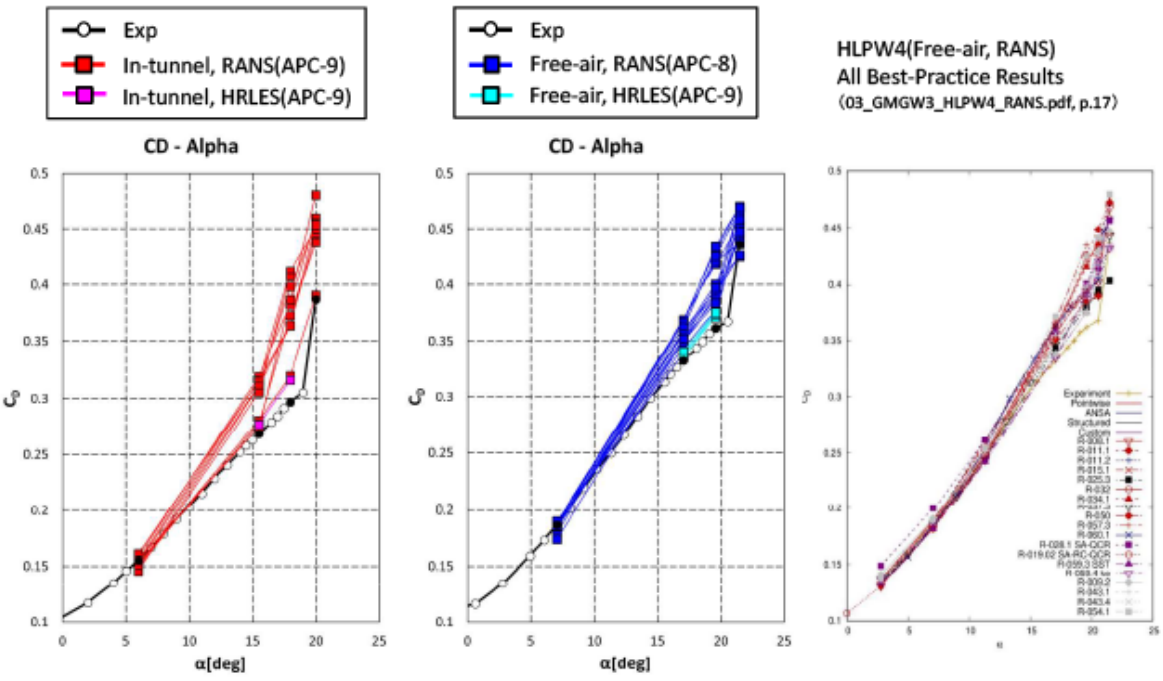
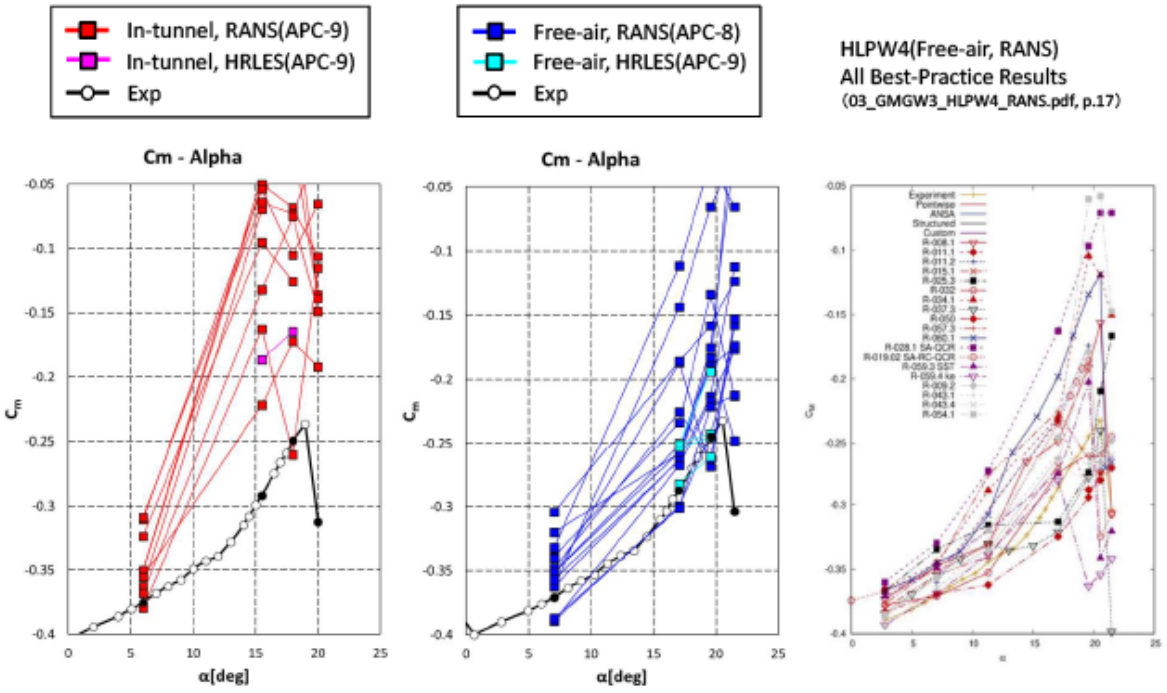
CD-Alpha



50

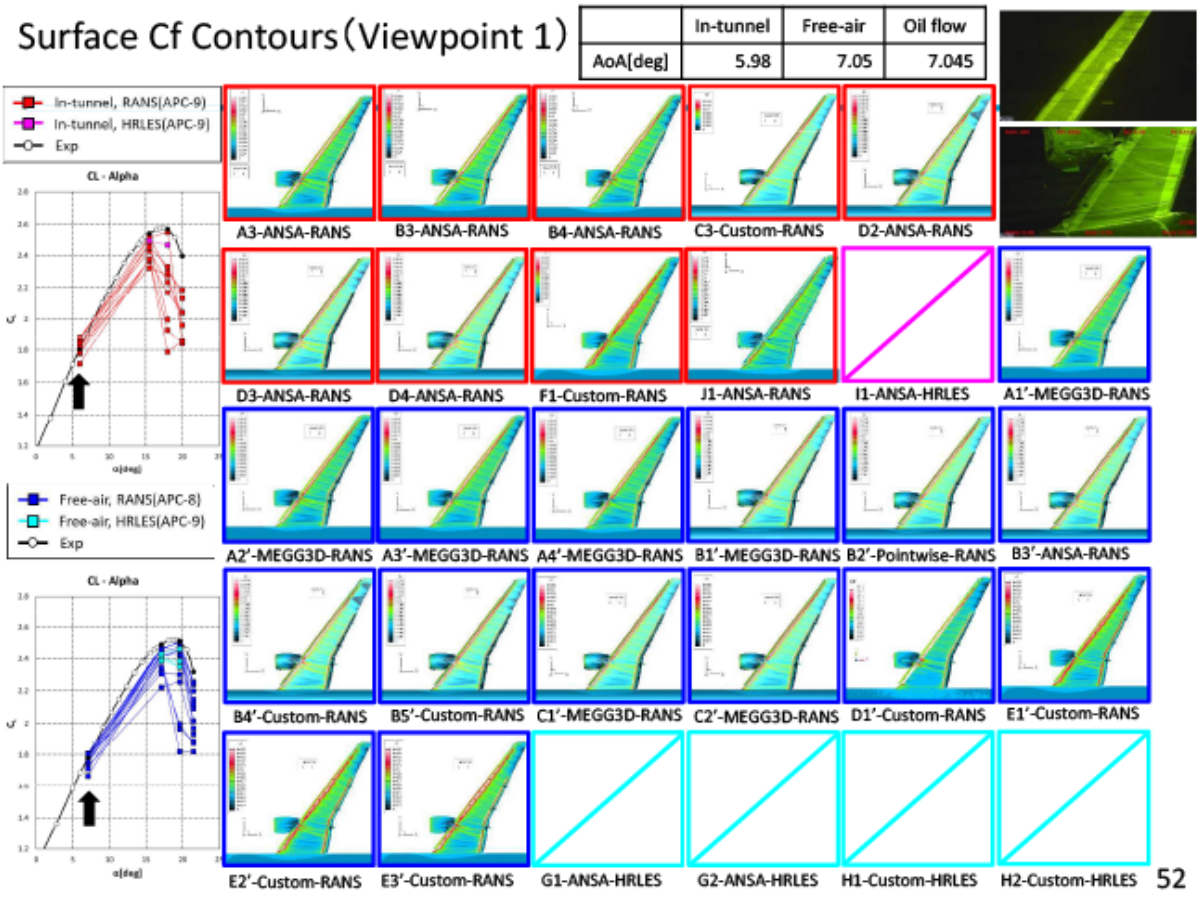
Cm-Alpha



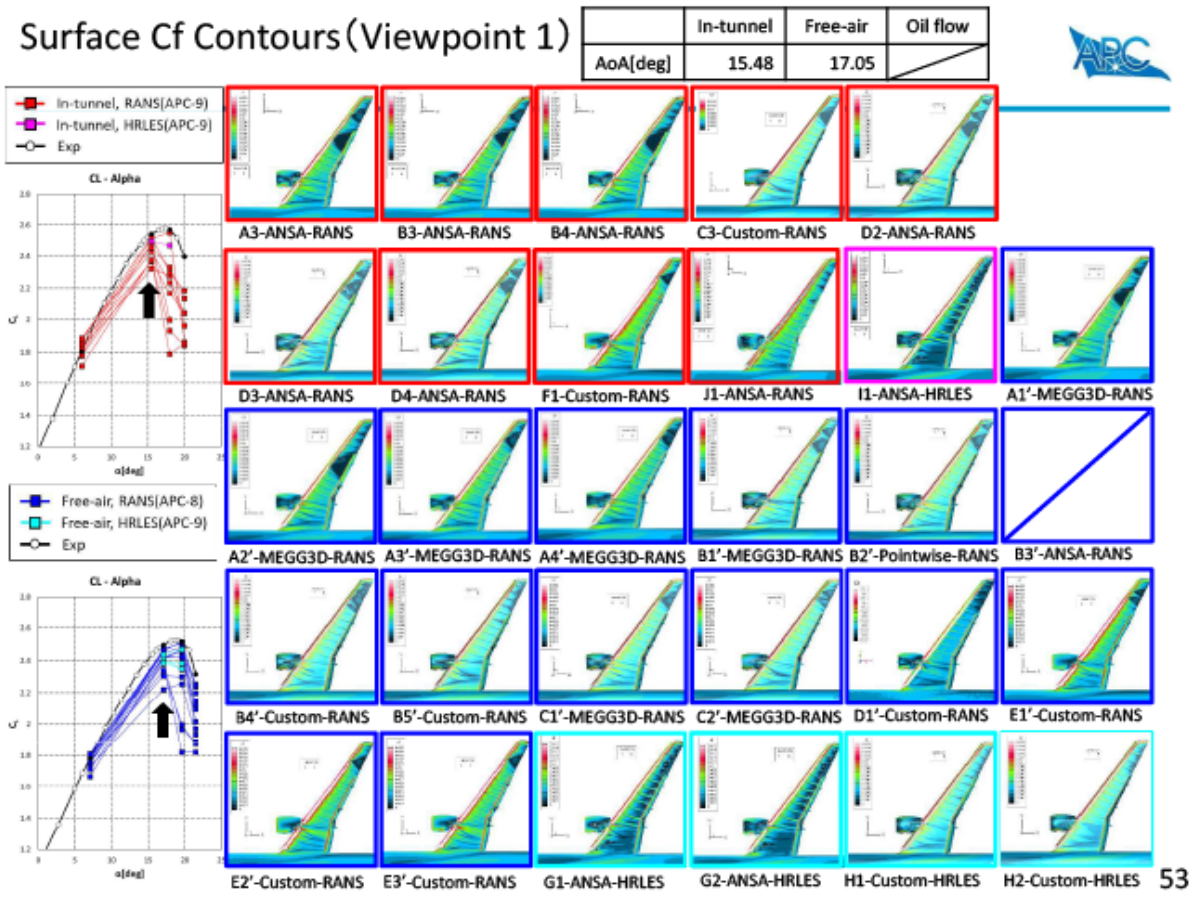
51

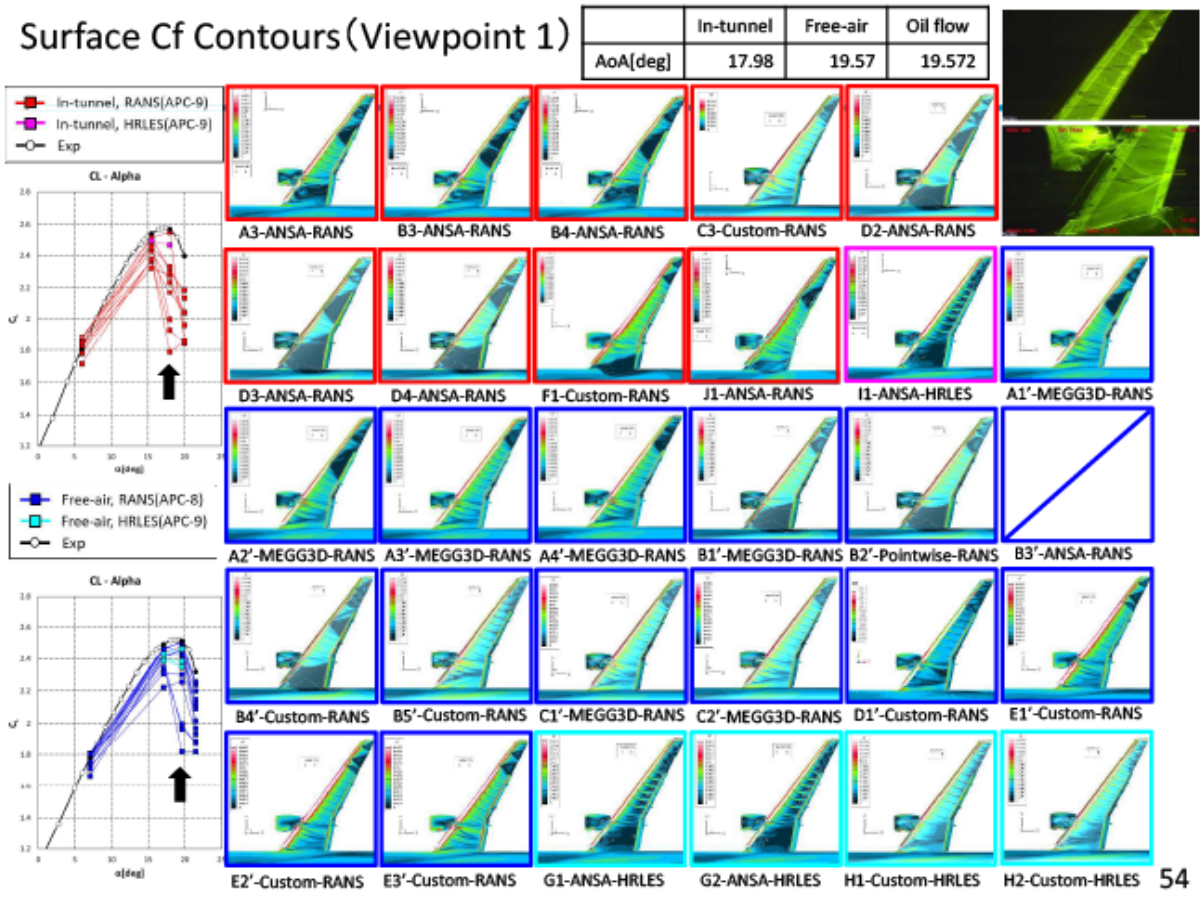
Surface Cf Contours (Viewpoint 1)

	In-tunnel	Free-air	Oil flow
AoA[deg]	5.98	7.05	7.045



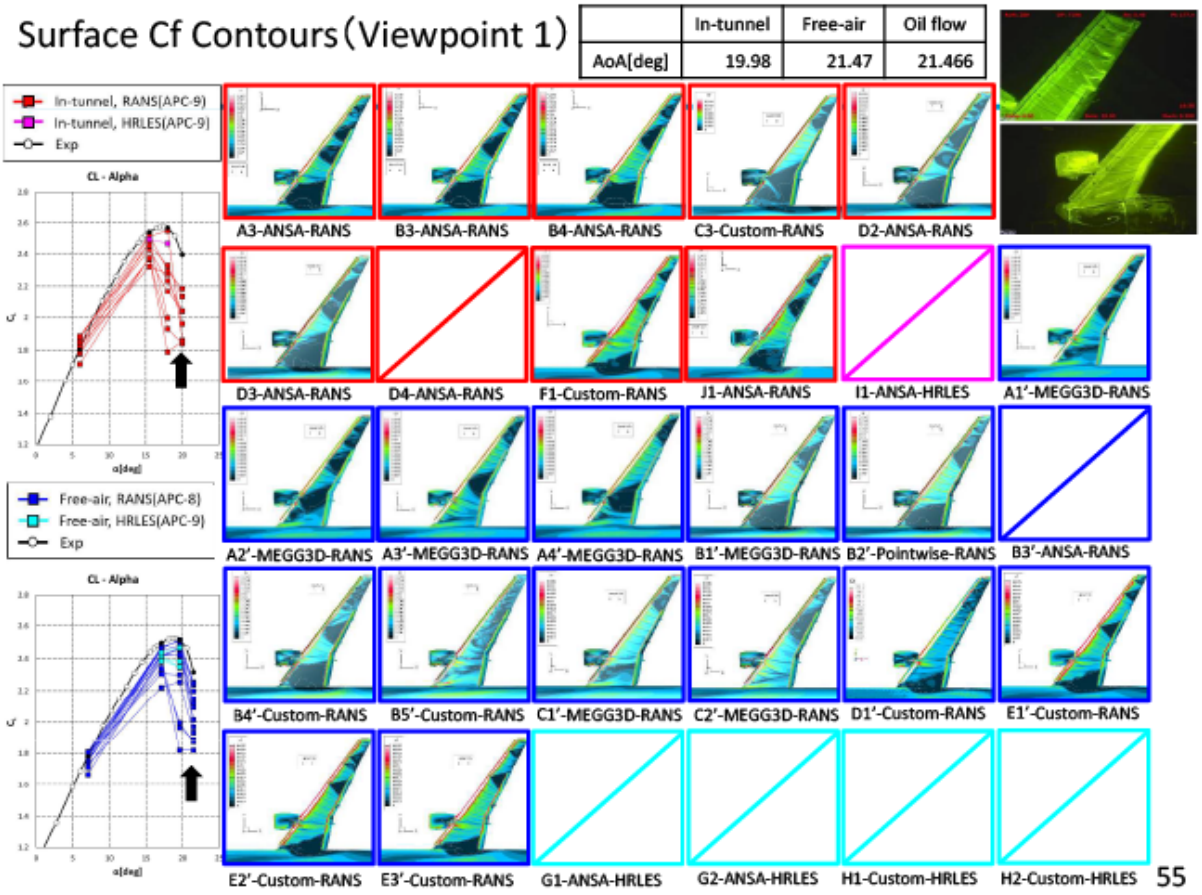
52





Surface Cf Contours（Viewpoint 1）

	In-tunnel	Free-air	Oil flow
AoA[deg]	19.98	21.47	21.466



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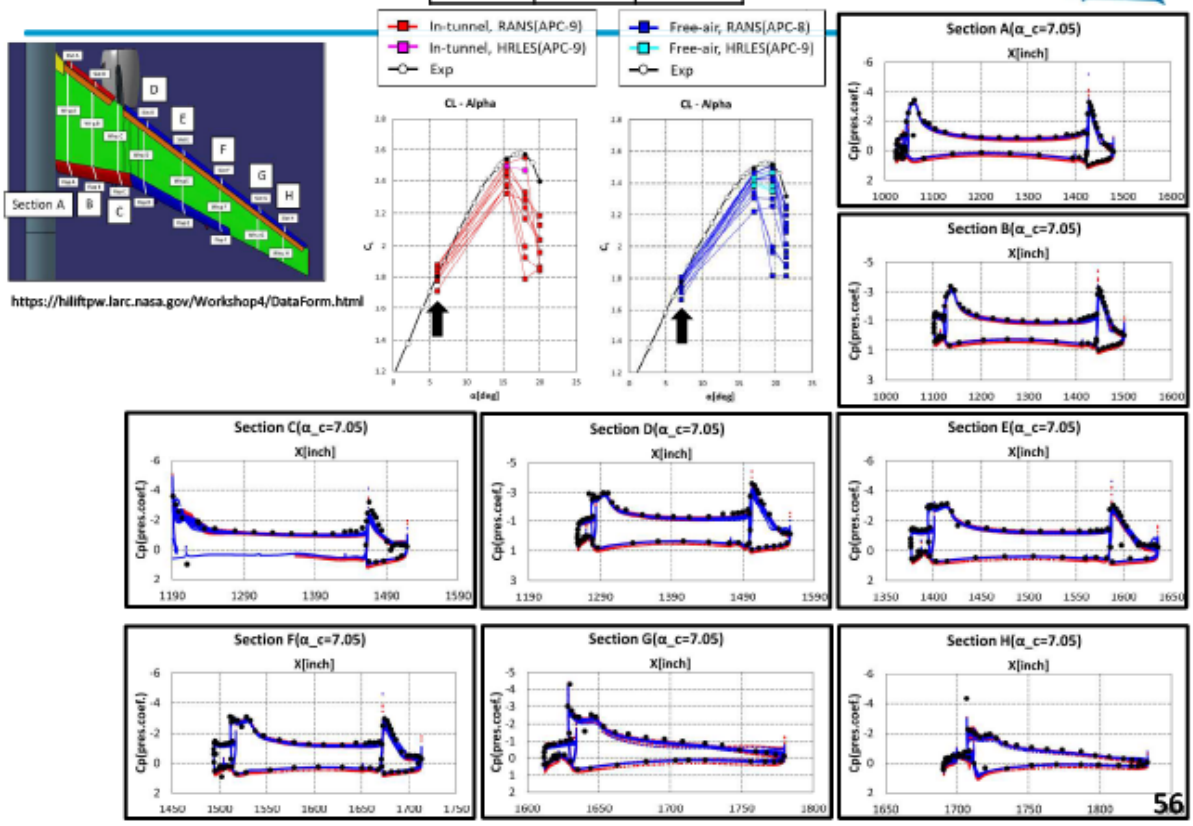
Surface Cp distribution

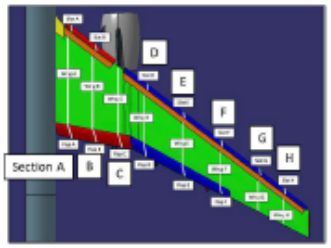
	In-tunnel	Free-air
AoA[deg]	5.98	7.05



56

Surface Cp distribution

	In-tunnel	Free-air
AoA[deg]	5.98	7.05



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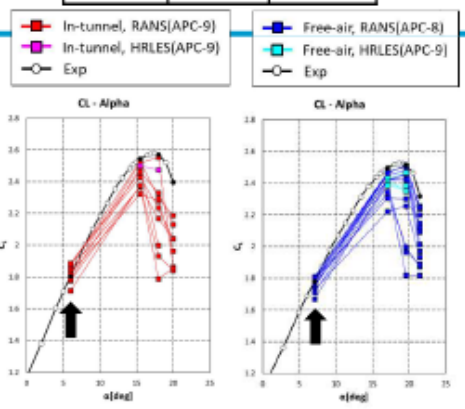

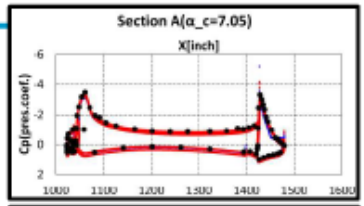

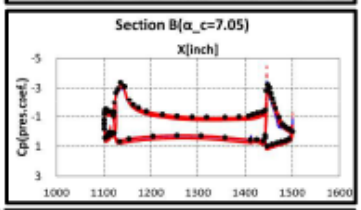

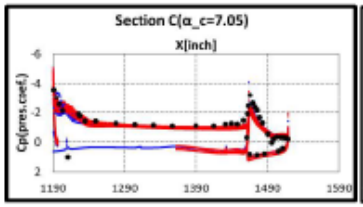

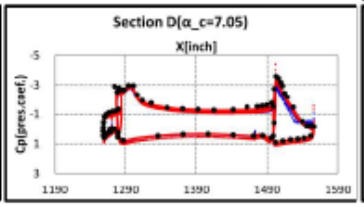

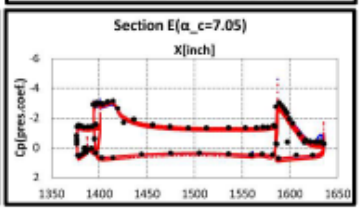

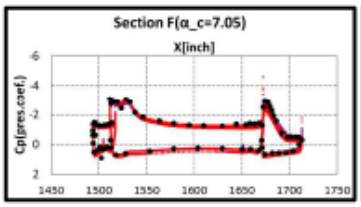

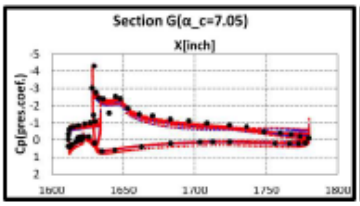

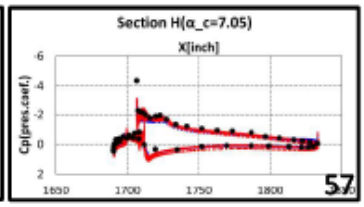

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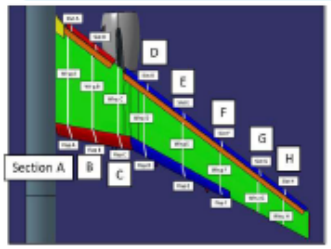
Surface Cp distribution

	In-tunnel	Free-air
AoA[deg]	15.48	17.05



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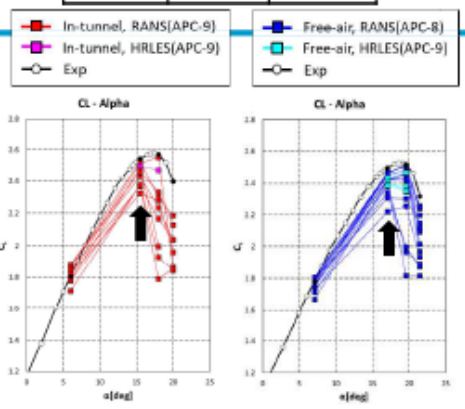

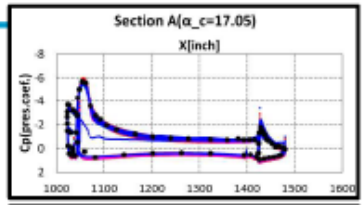

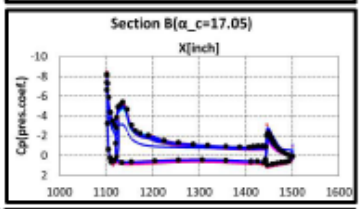

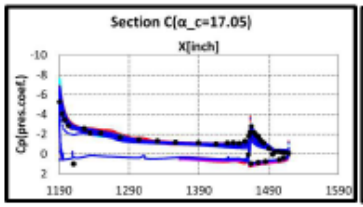

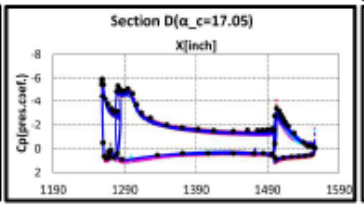

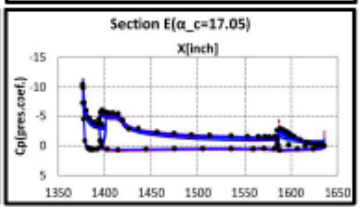

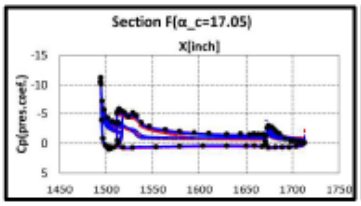

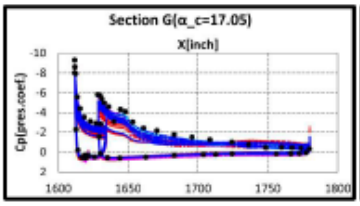

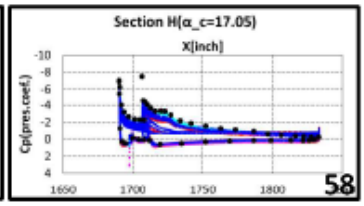

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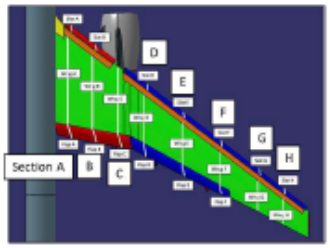
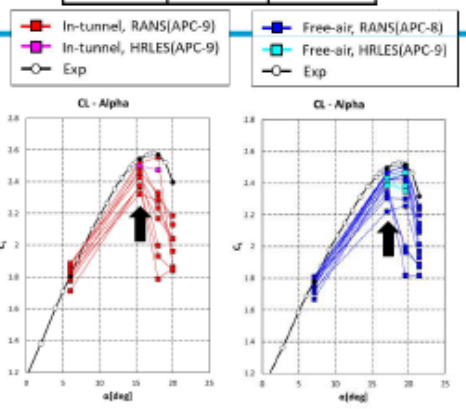
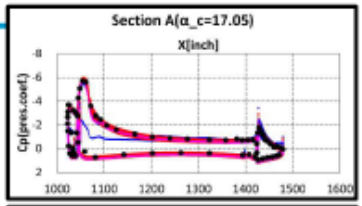
Surface Cp distribution

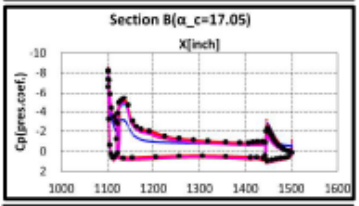
	In-tunnel	Free-air
AoA[deg]	15.48	17.05

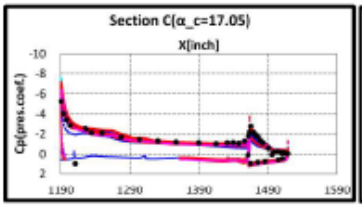


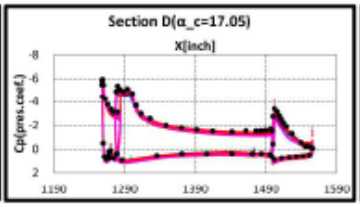
https://hiliftpw.larc.nasa.gov/Workshop4/DataForm.html

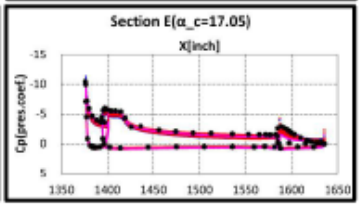


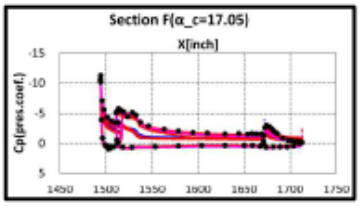


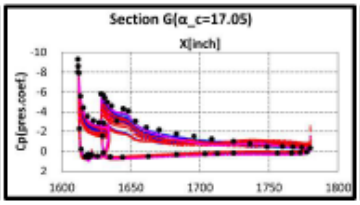


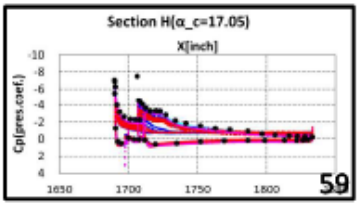












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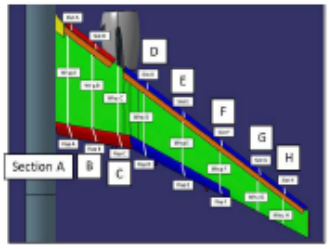
Surface Cp distribution

	In-tunnel	Free-air
AoA[deg]	17.98	19.57



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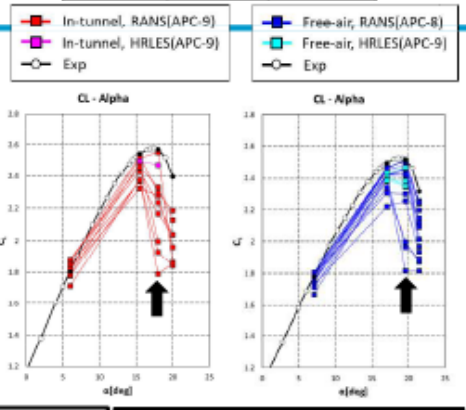
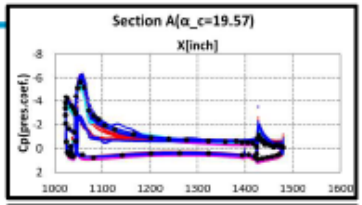
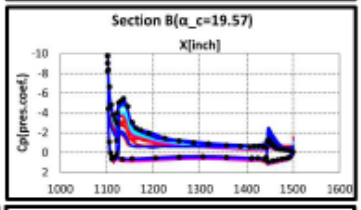
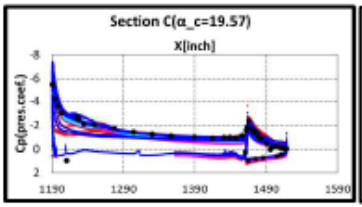
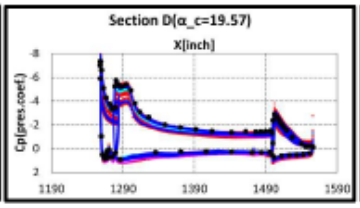
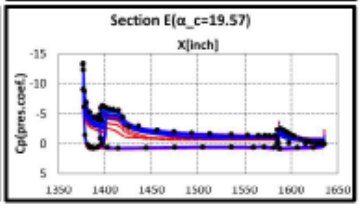


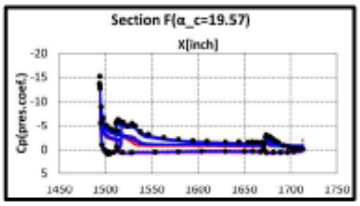


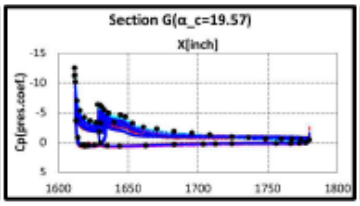


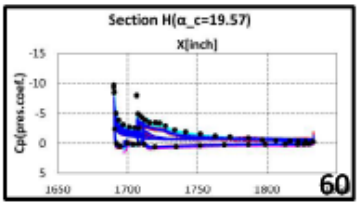








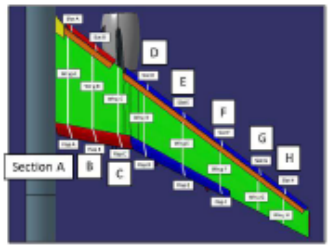




60

Surface Cp distribution

	In-tunnel	Free-air
AoA[deg]	17.98	19.57



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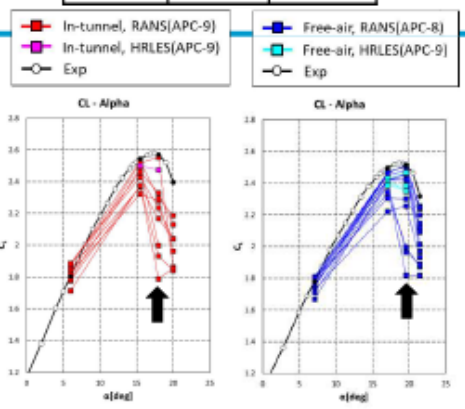

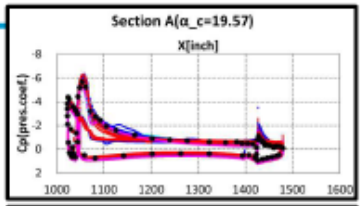

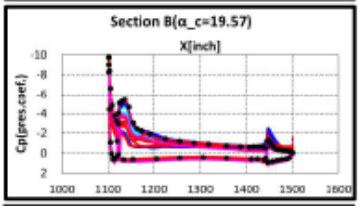

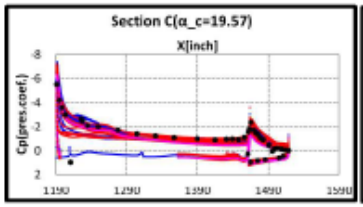

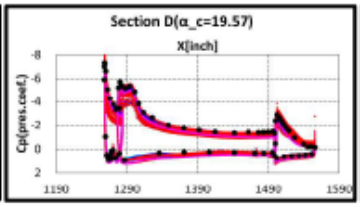

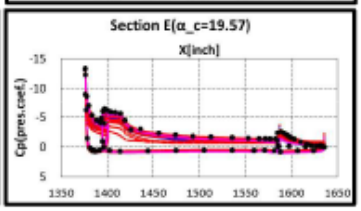

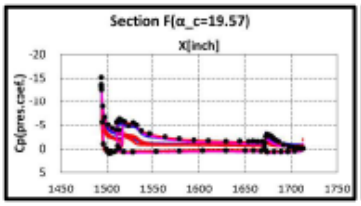

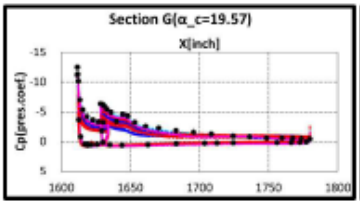

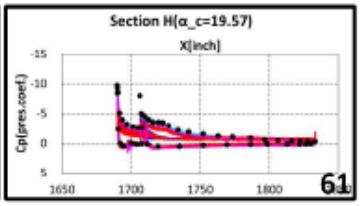

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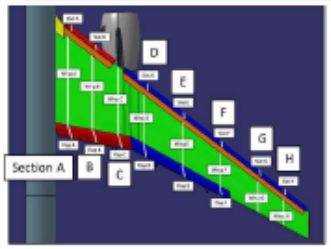
Surface Cp distribution

	In-tunnel	Free-air
AoA[deg]	19.98	21.47



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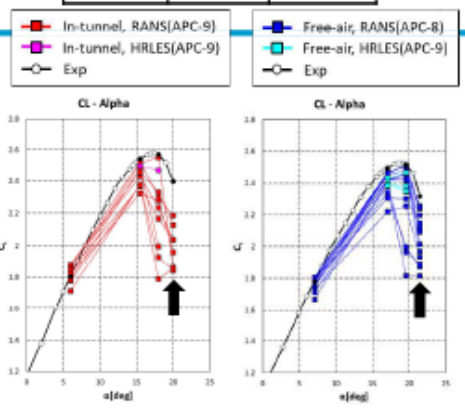
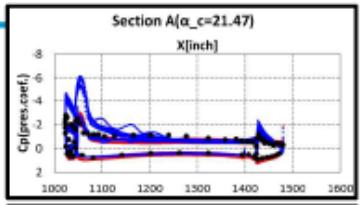
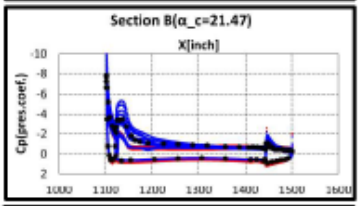
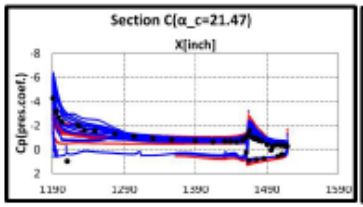
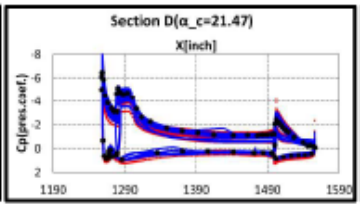
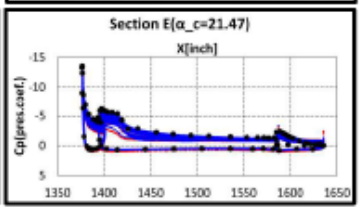


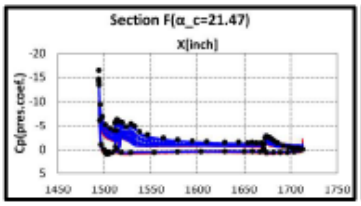


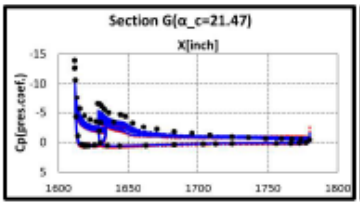


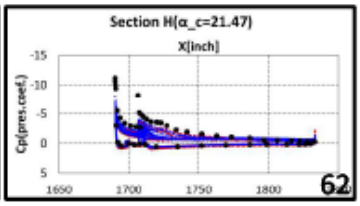








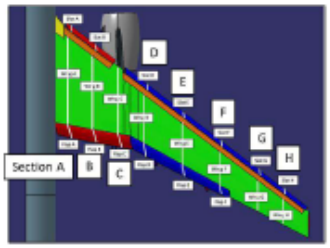




62

Surface Cp distribution

	In-tunnel	Free-air
AoA[deg]	19.98	21.47



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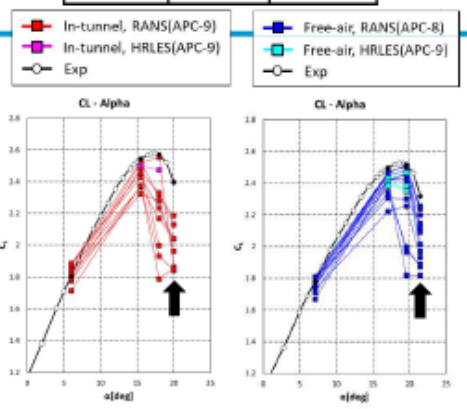

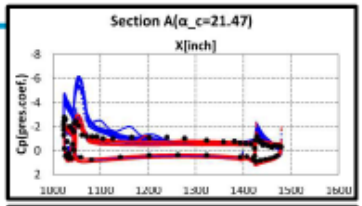

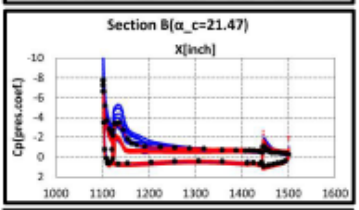

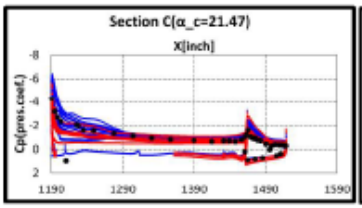

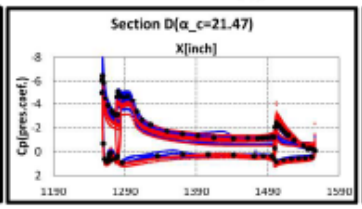

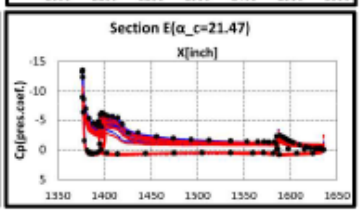

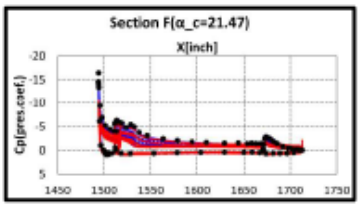

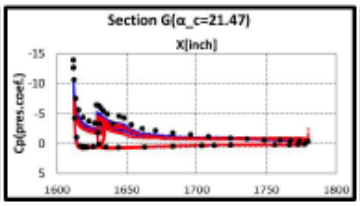

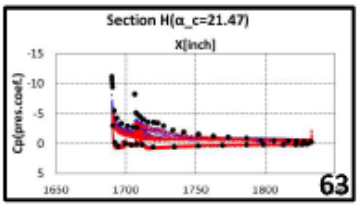

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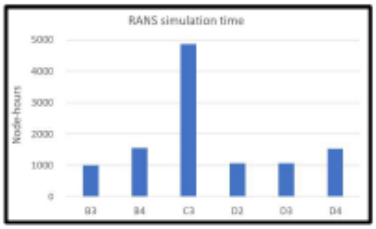
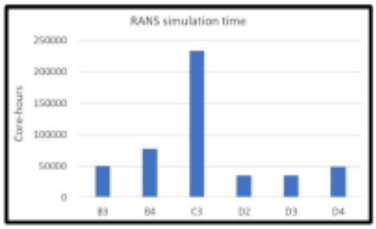
Simulation time (1)

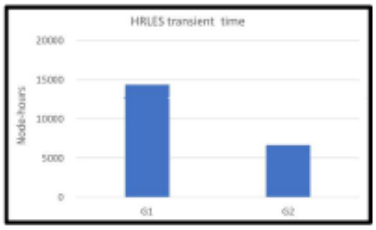
RANS: AoA＝5.98deg
HRLES: AoA=7.05deg

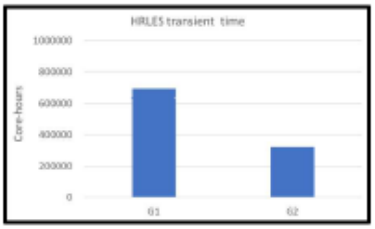
A3 and F1 are shown on later slide

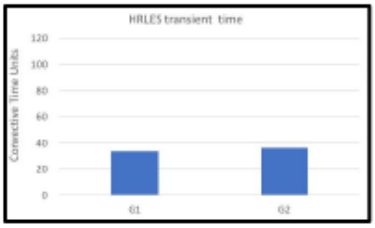
NOTE: no specific convergence criteria was requested, so these plots are for qualitative illustration

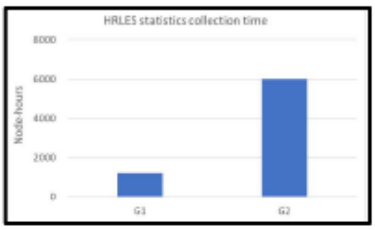


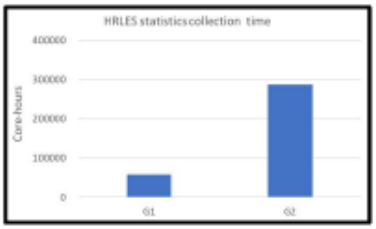


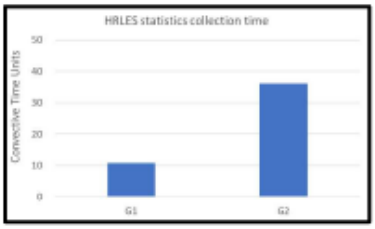












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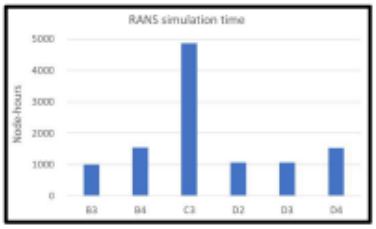
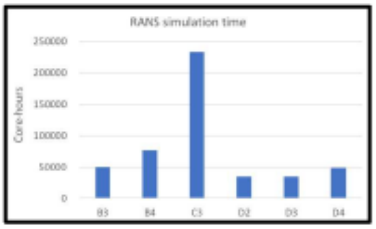
Simulation time(2)

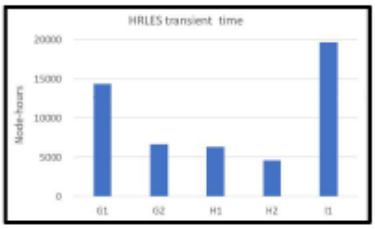
RANS: AoA＝15.48deg
HRLES: AoA=17.05deg

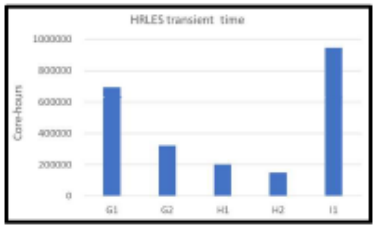
A3 and F1 are shown on later slide

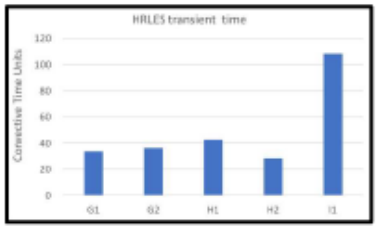
NOTE: no specific convergence criteria was requested, so these plots are for qualitative illustration

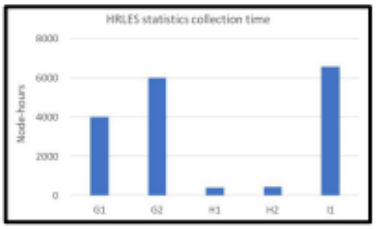


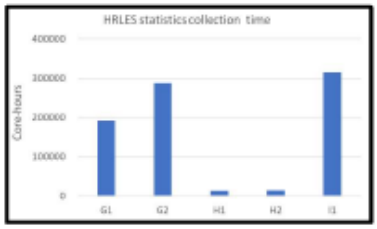












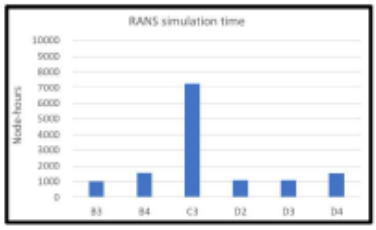
65

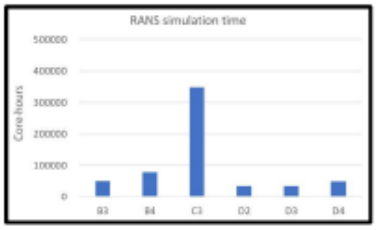
Simulation time(3)

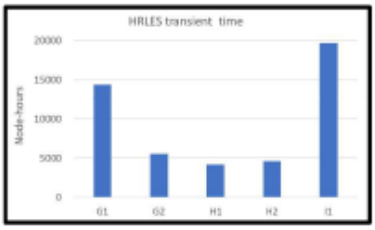
RANS: AoA＝17.98deg
HRLES: AoA=19.57deg

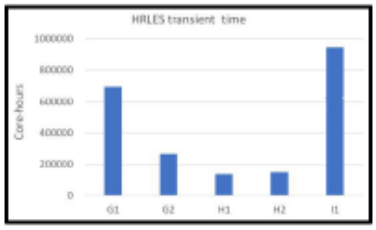
A3 and F1 are shown on later slide

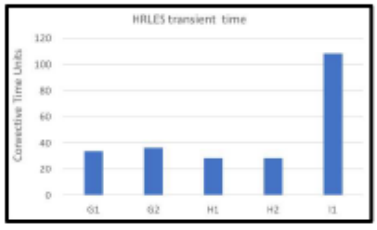
NOTE: no specific convergence criteria was requested, so these plots are for qualitative illustration

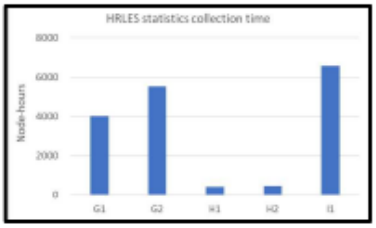


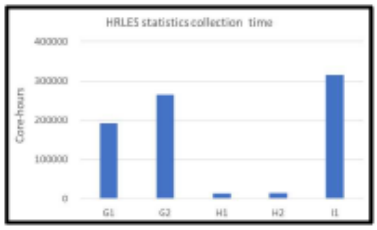


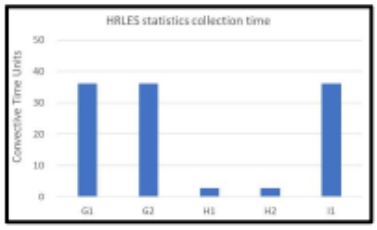












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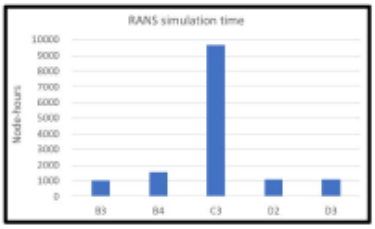
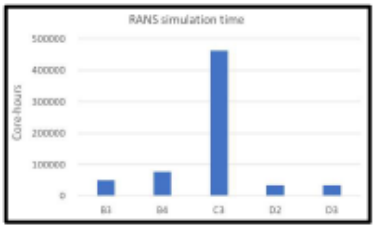
Simulation time (4)

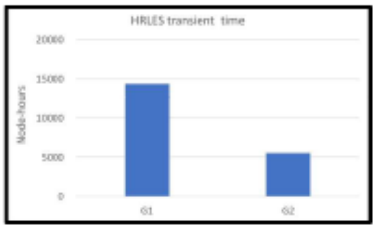
RANS: AoA＝19.98deg
HRLES: AoA=21.47deg

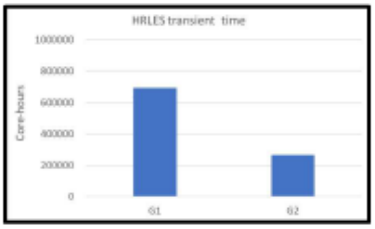
A3 and F1 are shown on later slide

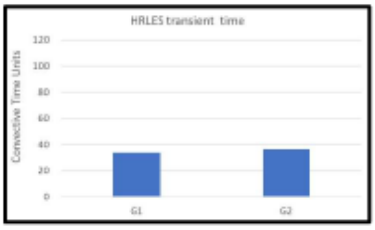
NOTE: no specific convergence criteria was requested, so these plots are for qualitative illustration

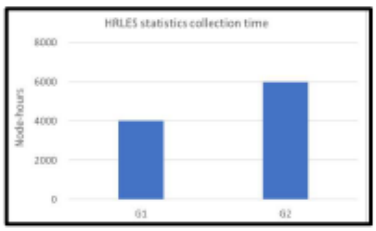


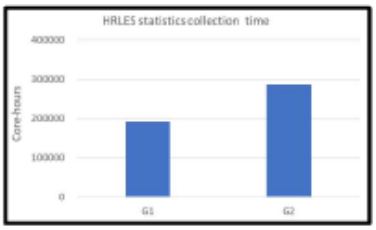


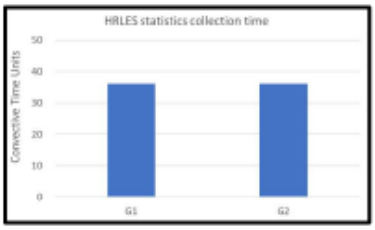












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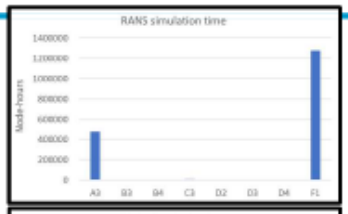
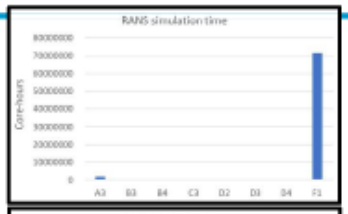
Simulation time (5, including A3 and F1)

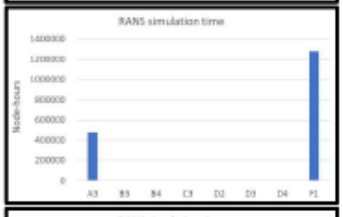
The simulation time from B3 to D4 cannot be seen because they are shorter than A3 and F1.

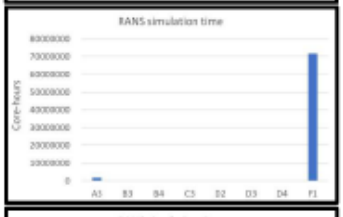
AoA =5.98deg



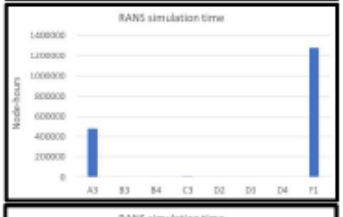


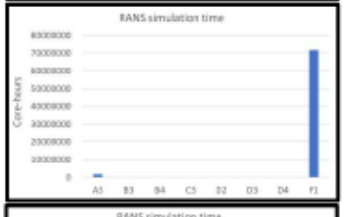
AoA =15.48deg



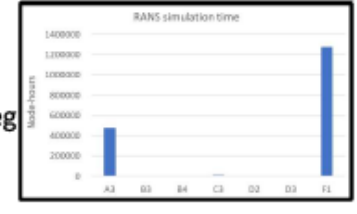


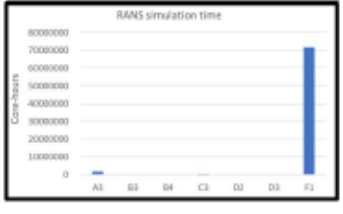
AoA =17.98deg





AoA =19.98deg





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Case 5:
Grid dependence of Free-air RANS

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Participant of APC-9 Case 5

Marker	ID	Name	Organization	Code	Grid	Number of grids	Turbulence Model	Initial Condition
	H3	安田 英将	KHI	Cflow (Unstructured solver)	Cflow-C1[1]	365745692	SA-neg	Cold Start
	H4				Cflow-C2[1]	367303332		
	H5				Cflow-C3[1]	371805988		
	H6				Cflow-C6[1]	409109709		
	H7				ANSA-C[2]	216724148		
	H8				PW-A[3]	21868681		
	H9				PW-C[3]	141518040		
	H10				JAXA-C[4]	208695005		

HLPW4 GRIDS DOWNLOAD PAGE
https://hiliftpw.larc.nasa.gov/Workshop4/grids_downloads.html
(1) 140-KHI-Unstructured: 140.C
(2) 101-ANSA-Unstructured-loA-Yplus1: 101.C
(3) 1.3-Pointwise-Unstr-HexPrismPyrTet-V2: 1.3A, 1.3C
(4) 240-JAXA-unstructured: 240.C

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Case 5 : Free-air RANS

- Method
  - RANS (steady) computation
- Geometry and Flow Conditions
  - 3D CRM-HL flap angle : 43°/40°(inboard/outboard)
  - Free-air
  - M = 0.2
  - Re = 5.49 x 10^6 (C_{ref} = 275.8inches)
  - T_{ref} = 521°R
  - AoA = 7.05 deg

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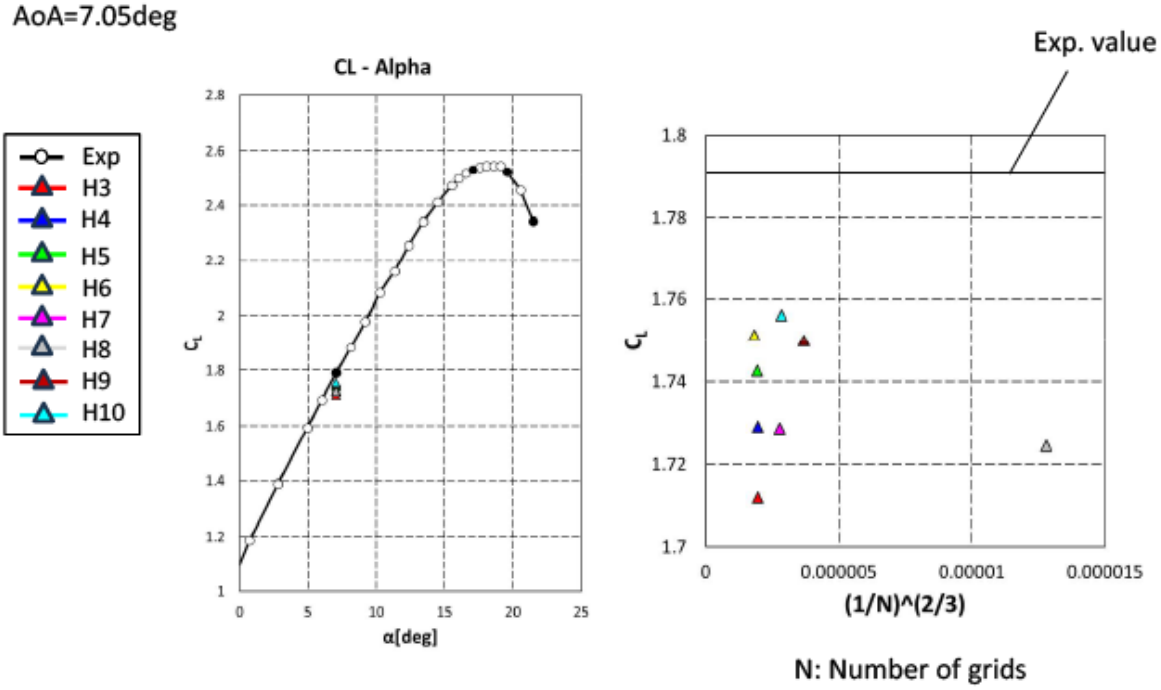
CL-Alpha, Case 5

AoA=7.05deg

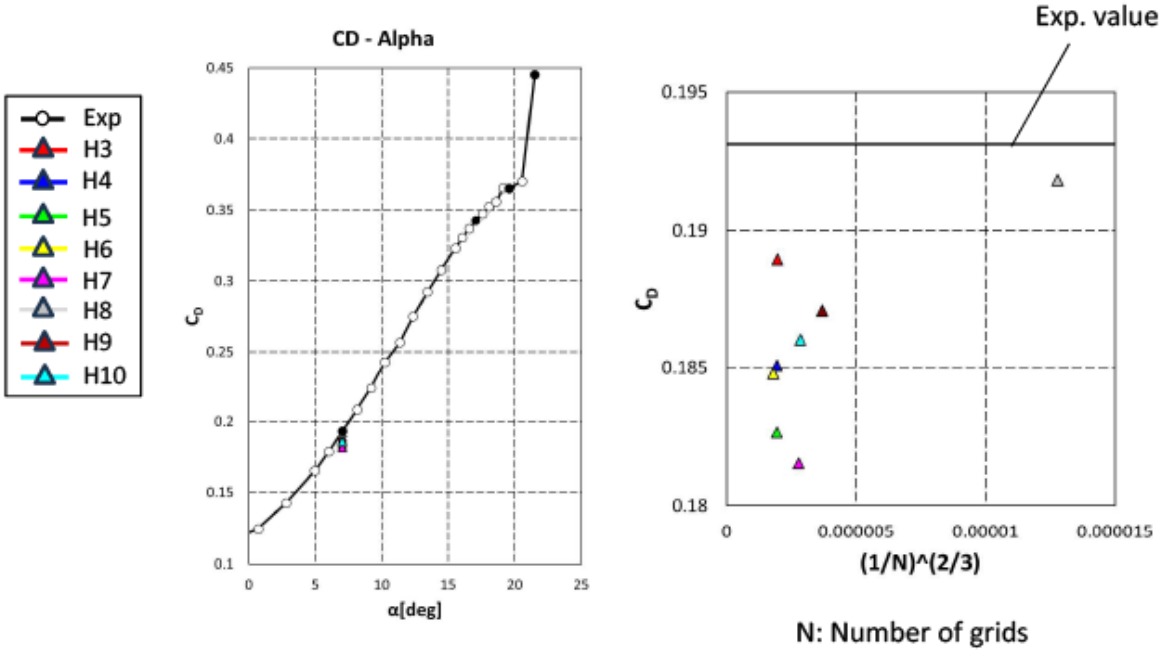


N: Number of grids

72

CD-Alpha, Case 5

AoA=7.05deg

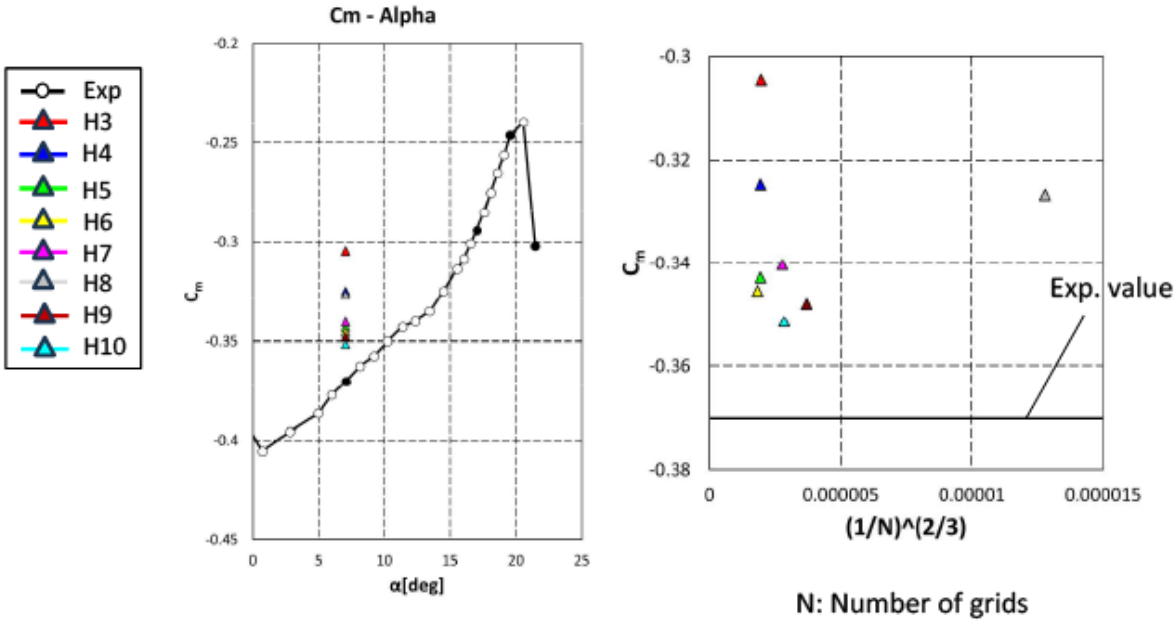


N: Number of grids

73

Cm-Alpha, Case 5

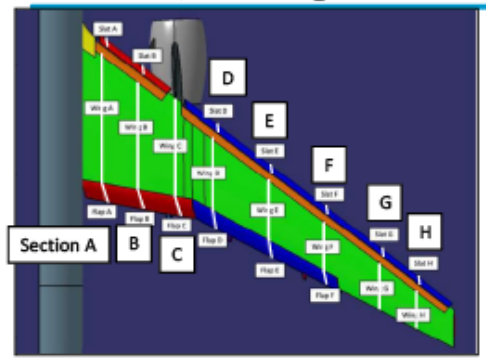
AoA=7.05deg



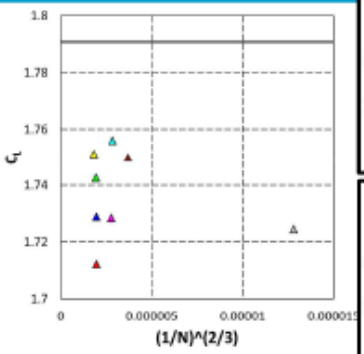
N: Number of grids

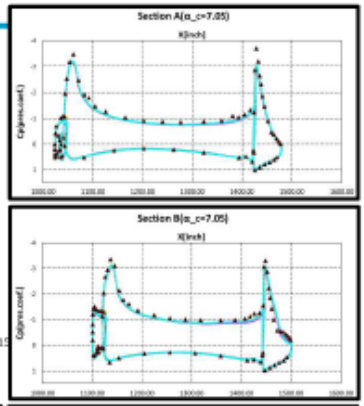
74

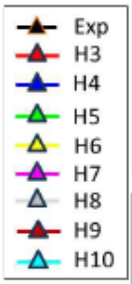
Surface Cp distribution (Case 5, 7.05deg)

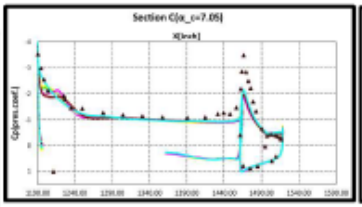


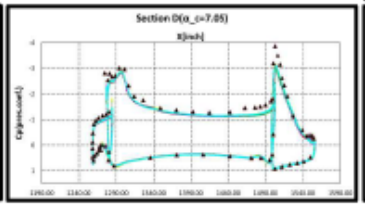
https://hiliftpw.larc.nasa.gov/Workshop4/DataForm.html

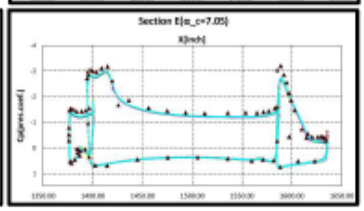


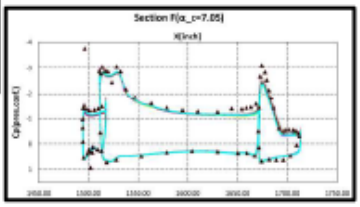


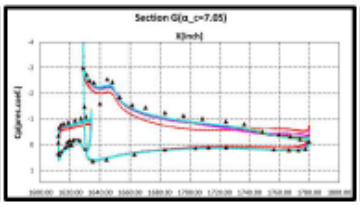


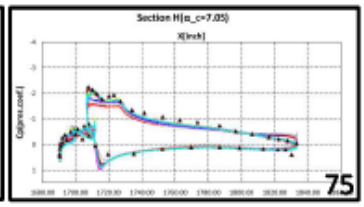












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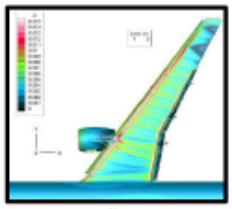
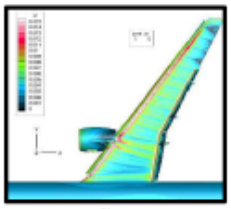
Surface Cf Contours (Case 5, 7.05deg, Viewpoint 1)

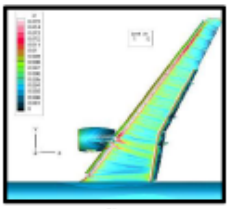
ID-Grid



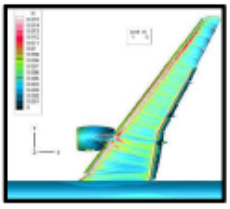
H3-Cflow-C1



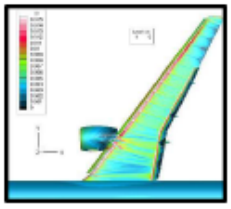
H4-Cflow-C2



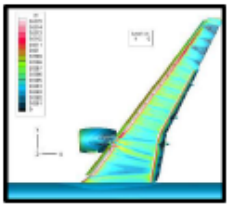
H5-Cflow-C3



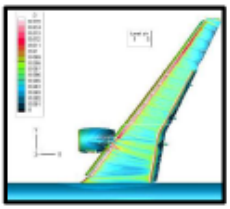
H6-Cflow-C6



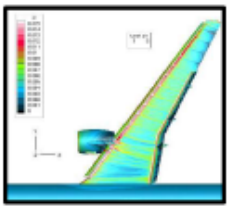
H7-ANSA-C



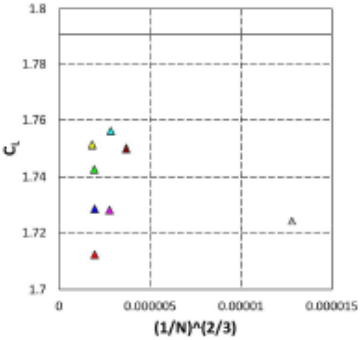
H8-PW-A

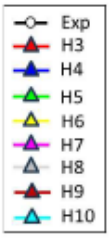


H9-PW-C



H10-JAXA-C





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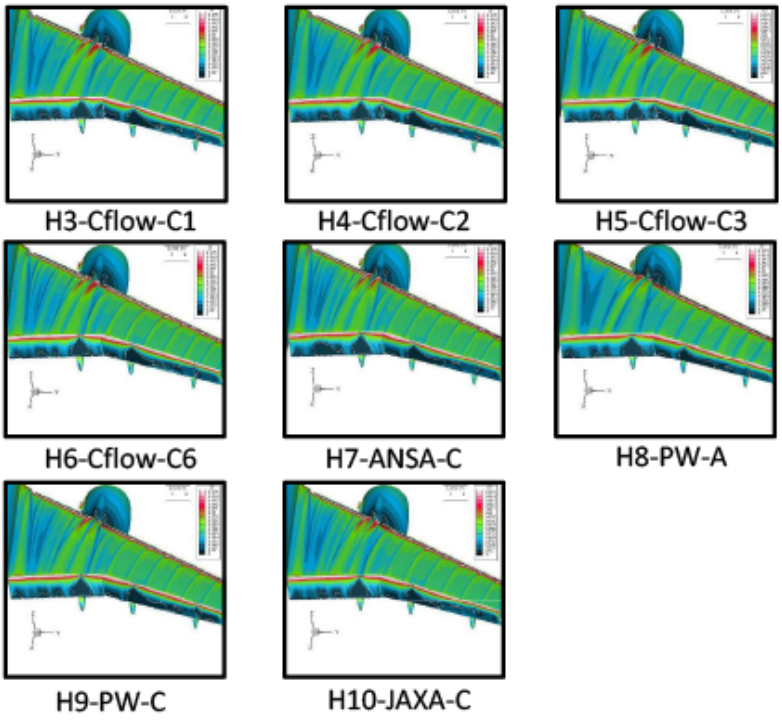
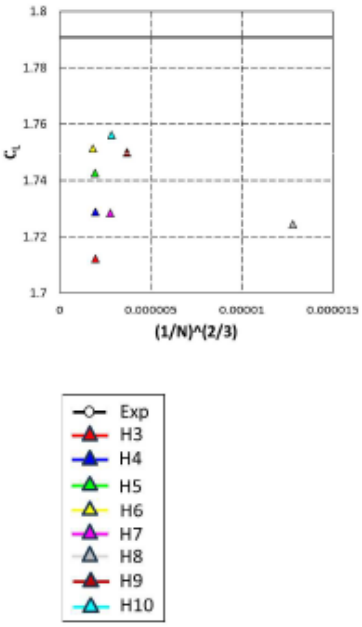
Surface Cf Contours (Case 5, 7.05deg, Viewpoint 2)

ID-Grid

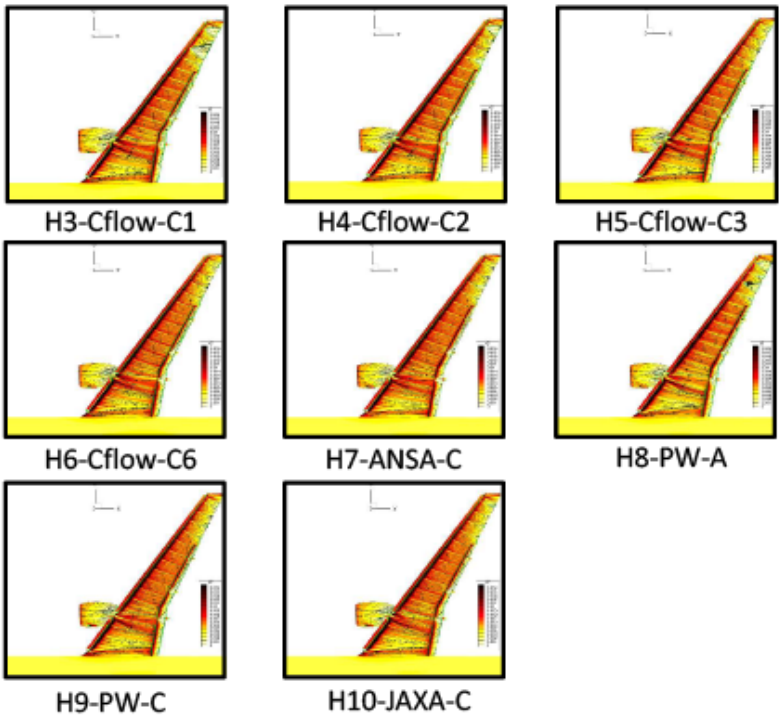


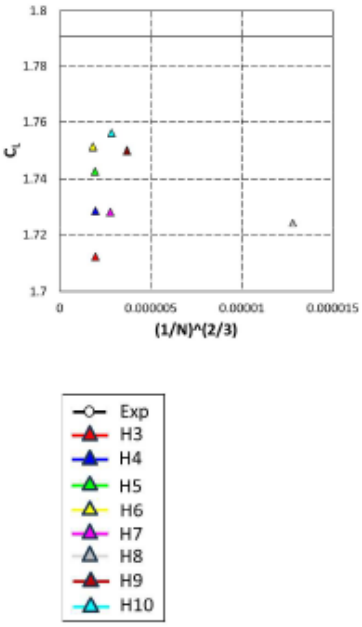


77

Wall-streamtraces (Case 5, 7.05deg, Viewpoint 1)

ID-Grid

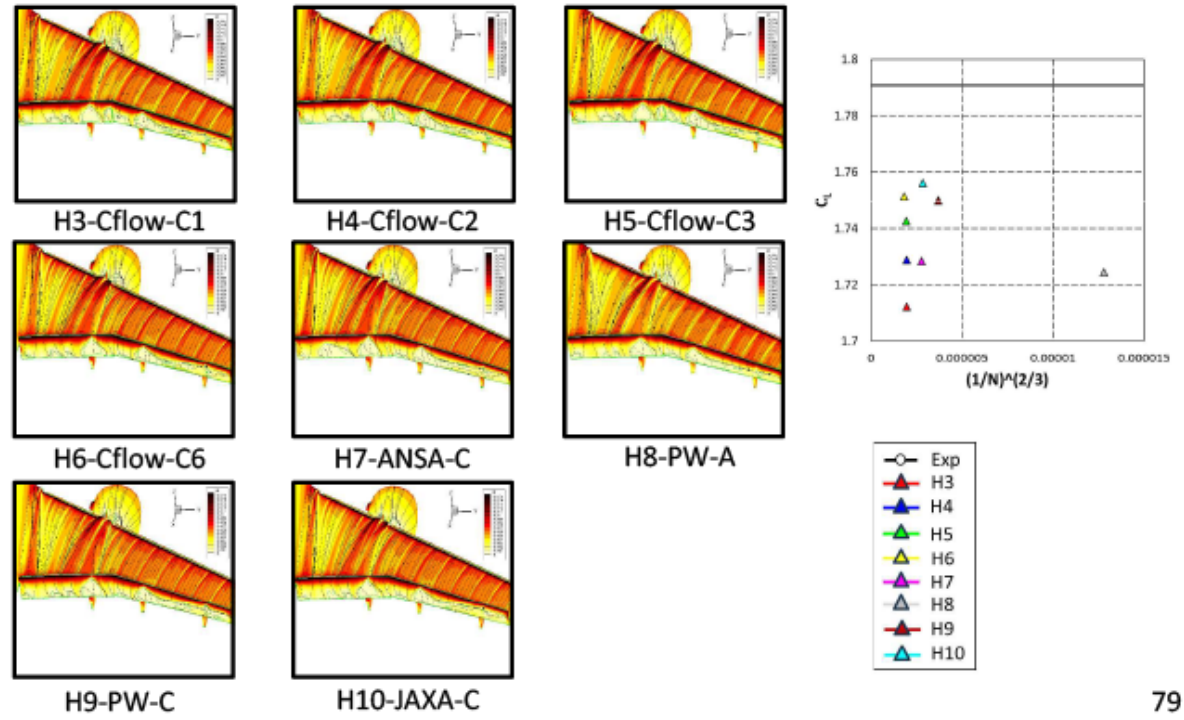




78

Wall-streamtraces（Case 5, 7.05deg, Viewpoint 2）

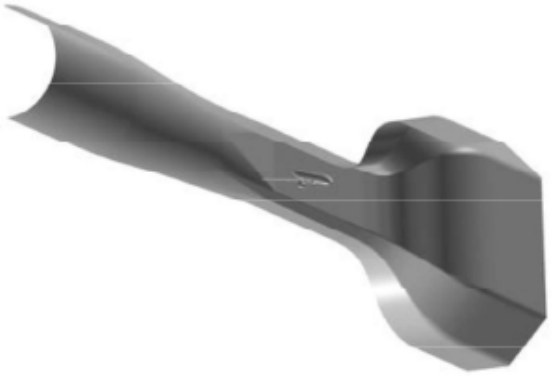
ID-Grid



79

APC-9のフォローアップの集計結果
Summary of APC-9 follow up

サンシカ アンドレア (JAXA), APC有識者会議
Sansica Andrea (JAXA), APC committee



Participants of APC-9

Case	Marker	ID	Name	Organization	Code	Grid / Level	Description of the grid	Turbulence Model	Initial Condition
2		A3	Zehner Paul	JAXA	FaSTAR-GPU (Unstructured solver)	ANSA grid (10ST-ANSA-Unstructured-Yplus1) / B		SA-noft2	Cold Start
		B3	内田 康介	TUAT	FaSTAR (Unstructured solver)	ANSA grid (10ST-ANSA-Unstructured-Yplus1) / B		SA-noft2	Cold Start
		B4						SA-noft2-R	
		C3	田中 健太郎	JAXA	TAS (Unstructured solver)	Custom	Equivalent to the grid provided by HLPW4 (240-JAXA-unstructured,C)	SA-noft2-R(Crot=1)	Grid of semi-span aircraft model + Grid of empty wind tunnel
		D2	澤木 悠太	KHI	Cflow (Unstructured solver)	ANSA grid (10ST-ANSA-Unstructured-Yplus1) / B		SA-neg	Cold Start
		D3						SA-neg-QCR2000-R(Crot=1)	
		D4				ANSA grid (10ST-ANSA-Unstructured-Yplus1) / C			
		F1	玉置 義治	University of Tokyo	UTCart (Unstructured Cartesian solver)	Custom	Hierarchical cartesian grid	SA-noft2	Cold Start
		J1	阿部 浩幸	JAXA	FaSTAR (Unstructured solver)	ANSA grid (10ST-ANSA-Unstructured-Yplus1) / B		AMM-QCRcorner	Cold Start
3		G1	Zauner Markus	JAXA	FaSTAR (Unstructured solver)	ANSA grid (103-ANSA-Unstructured-hiA-Yplus1) / C		SA-noft2-R Delayed DES	Cold Start
		G2							Warm Start
		H1	安田 英将	KHI	Cflow (Unstructured solver)	Custom	Cartesian grid + Layered grid: Coarse	SA-noft2 Delayed DES	Warm Start
		H2					Fine		
4		I1	Zauner Markus	JAXA	FaSTAR (Unstructured solver)	ANSA grid (10ST-ANSA-Unstructured-Yplus1) / C		SA-noft2-R Delayed DES	Cold Start (from INF)

Participants of APC-8

ID	Name	Organization	Code	Grid (generated by)	Description of the grid	Turbulence Model	Initial Condition
A1′	Zauner Markus	JAXA	FaSTAR (Unstructured solver)	HLPW4(MEGG3D)		SA-noft2	Cold start
A2′						SA-noft2-R-QCR2000	
A3′						SA-noft2	Warm start
A4′						SA-noft2-R-QCR2000	
B1′	山内優果	KHI	Cflow (Unstructured solver)	HLPW4(MEGG3D)		SA-neg	Uniform flow
B2′				HLPW4(Pointwise)	Pointwise grid(1.3.C)		
B3′				HLPW4(ANSA)	ANSA(101.C)		
B4′				Custom	Orthogonal octree + Body-Fitted layer grid	SA-neg	
B5′						SA-R-QCR	
C1′	古谷龍太郎	JAXA	TAS (Unstructured solver)	HLPW4(MEGG3D)		SA-noft2-R(Crot=1)	Uniform flow
C2′							Low angle of attack
D1′	中島吉隆	Hexagon	scFLOW (Unstructured solver)	Custom	Polyhedral mesh generated by scFLOW	SA-neg	Uniform flow
E1′	船田雅也	Univ. of Tokyo	UTCart (Unstructured Cartesian solver)	Custom	Hierarchical orthogonal grid(100M)	SA-noft2 +Wall function	Uniform flow
E2′					Hierarchical orthogonal grid(200M)		
E3′					Hierarchical orthogonal grid(400M)		

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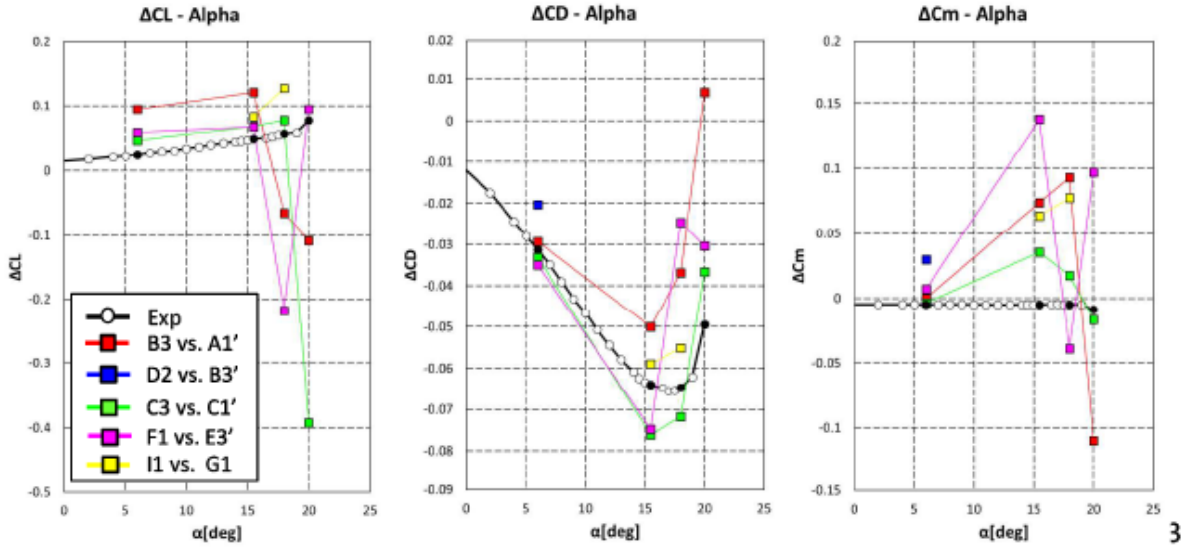
ΔCL, ΔCD, and ΔCm -Alpha

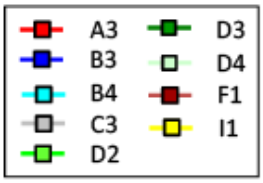
$\Delta CL \equiv CL_{In\text{-}tunnel} - CL_{Free\text{-}air}$
The same is true of ΔCD and ΔCm.

Marker	ID	Code	Grid	Turbulence Model	Initial Condition
	B3	FaSTAR	ANSA grid	SA-noft2	Cold Start
	A1'		MEGG3D grid		
	D2	Cflow	ANSA grid	SA-neg	Cold Start
	B3'		ANSA grid (101.C)		
	C3	TAS	Custom grid	SA-noft2-R(Crot=1)	Grid of semi-span aircraft model + Grid of empty wind tunnel
	C1'		MEGG3D grid		Cold Start
	F1	UTCart	Custom grid	SA-noft2	Cold Start
	E3'		Custom grid	SA-noft2 + Wall function	
	I1	FaSTAR	ANSA grid	SAnoft2-R Delayed DES	Cold Start
	G1		ANSA grid		

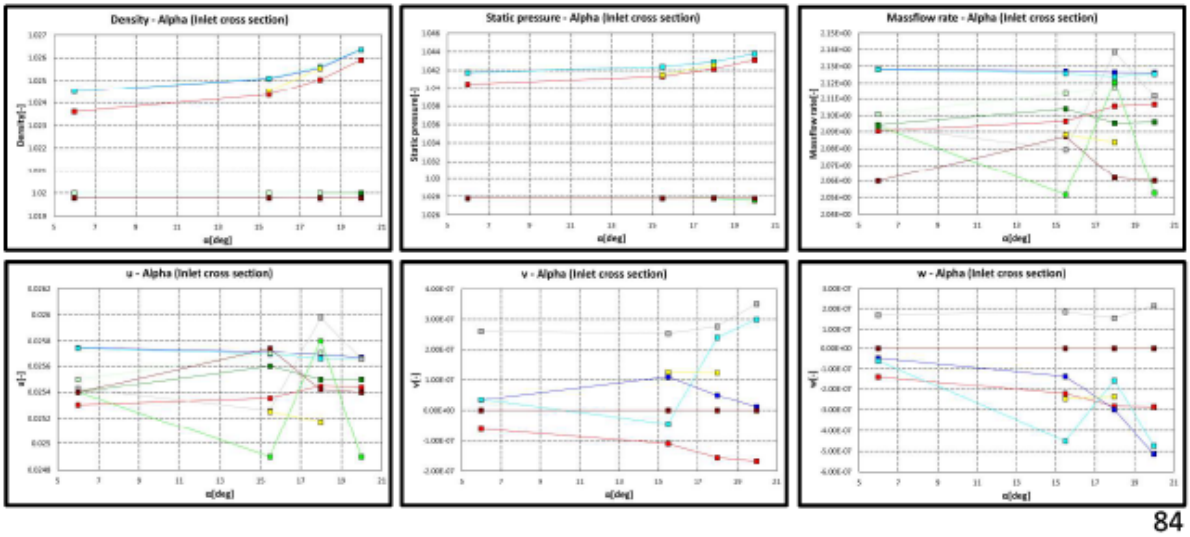


3

Inlet cross section

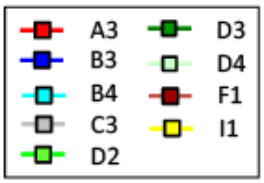


A3-F1: RANS
I1: HRLES

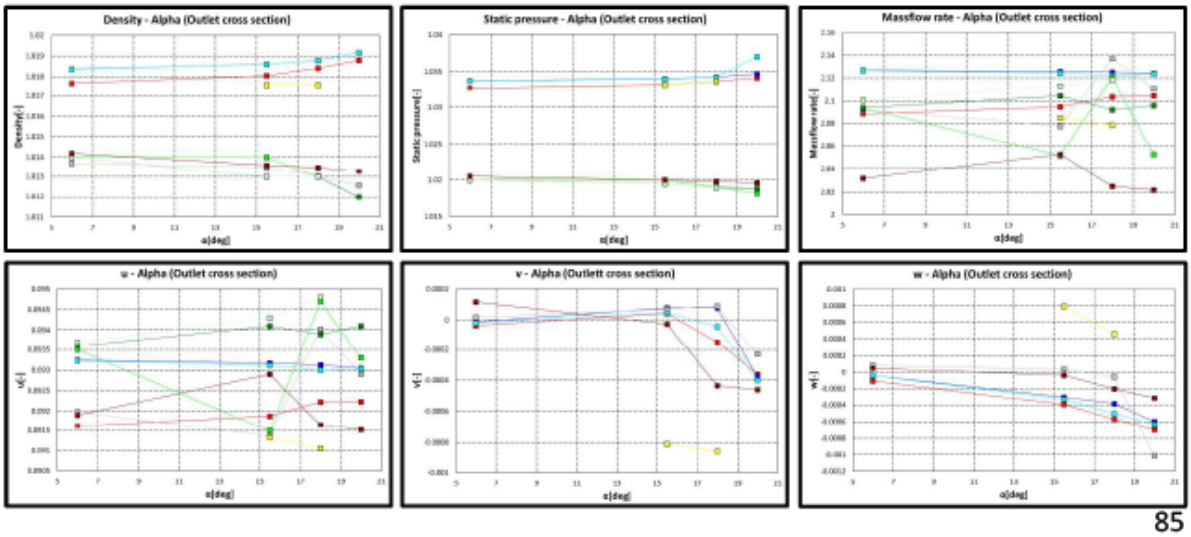


84

Outlet cross section



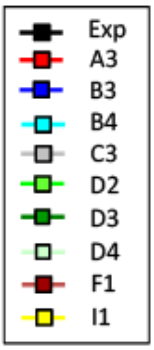
A3-F1: RANS
I1: HRLES



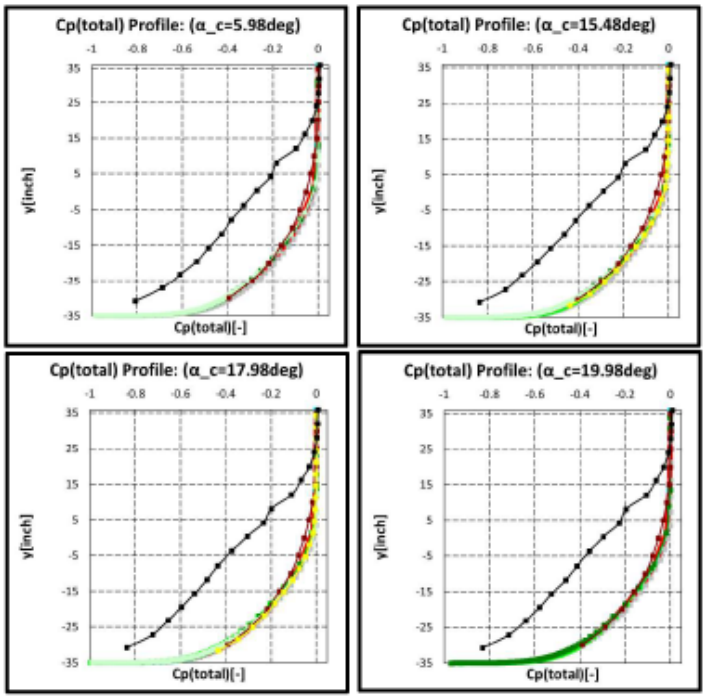
85

Cp(total)(1)

Cp(total) is the time average.



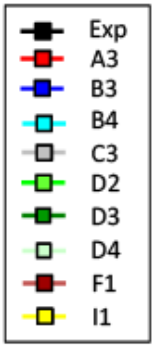
A3-F1: RANS
I1: HRLES



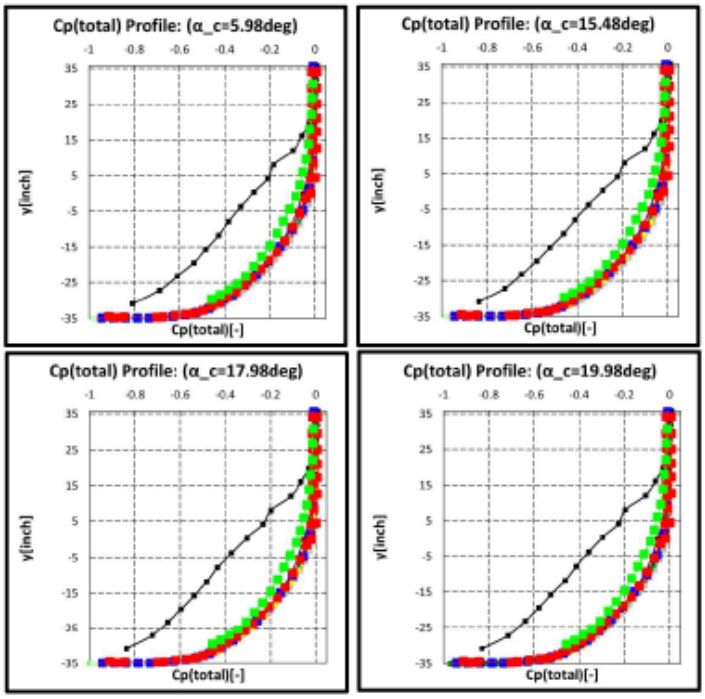
86

Cp(total)(2)

Cp(total) is the time average.



A3-F1: RANS
I1: HRLES

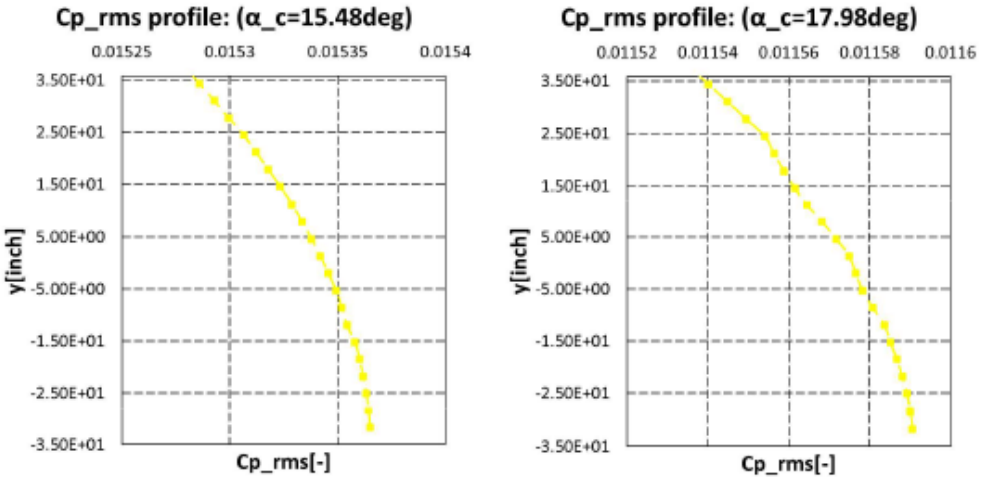


RANS, HRLES, and WMLES data are cited from the following paper.

Browne et.al, AIAA, 2022
https://arc.aiaa.org/doi/10.2514/6.2022-3523

87

Cp_rms



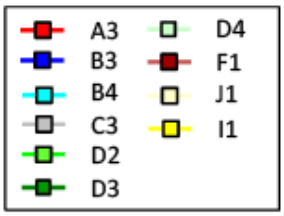
88

u deviation profile

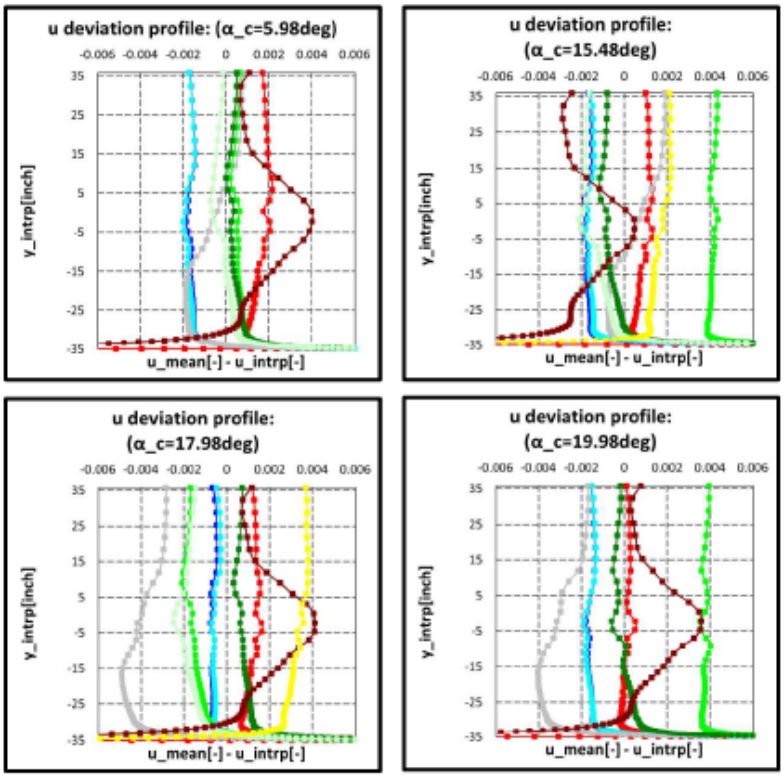
・y_intrp[inch]
-35.0≦y_intrp≦35.8662
Number of divisions: 100
Hyperbolic tangent distribution

・u_intrp[-]
Interpolated value of u for each participant mapped to y_intrp using cubic spline interpolation

・u_mean[-]
Average u_intrp for each participant



A3-J1: RANS
I1: HRLES



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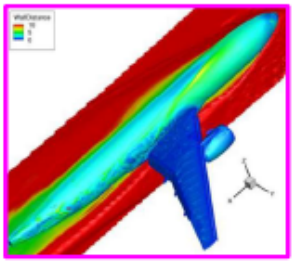
Shielding Function

(Description)
Iso-surface of fd=0.99 colored by wall distance (inch)

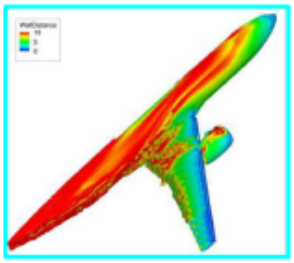
In-tunnel

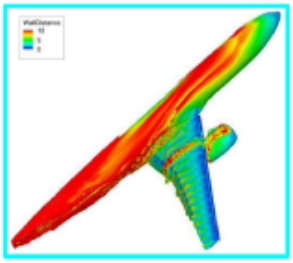
Free-air

AoA=15.48deg

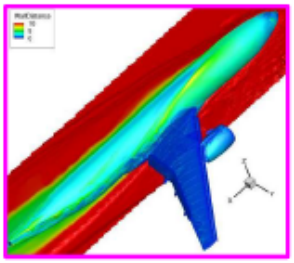


AoA=17.05deg



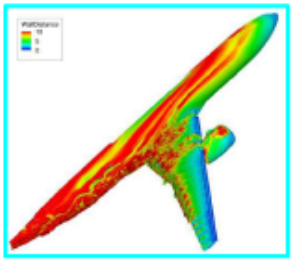


AoA=17.98deg

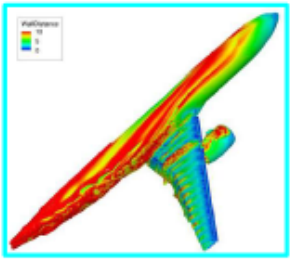


I1-ANSA-HRLES

AoA=19.57deg



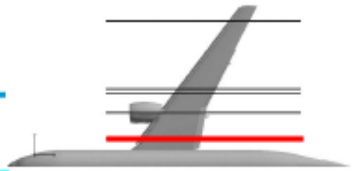
H1-Custom-HRLES



H2-Custom-HRLES

90

Shielding Function（Slice1）

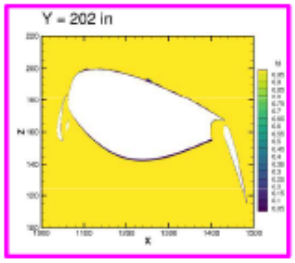


Description: Distribution of the shielding function.

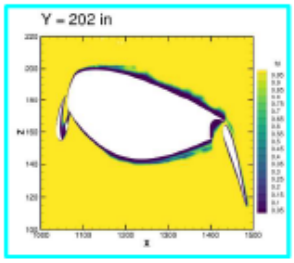
In-tunnel

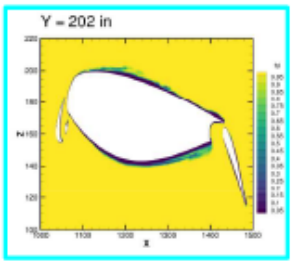
Free-air

AoA=15.48deg

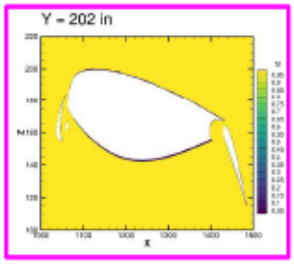


AoA=17.05deg

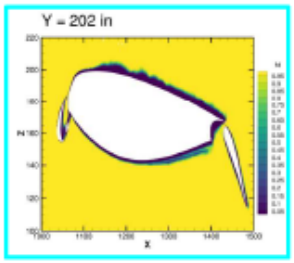


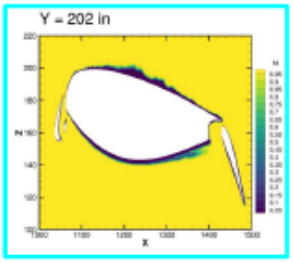


AoA=17.98deg



AoA=19.57deg

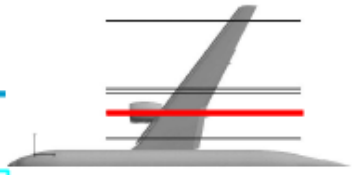




I1-ANSA-HRLES　H1-Custom-HRLES　H2-Custom-HRLES

91

Shielding Function（Slice2）

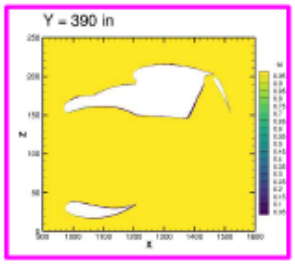


Description: Distribution of the shielding function.

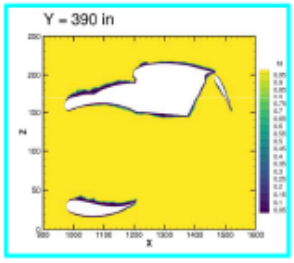
In-tunnel

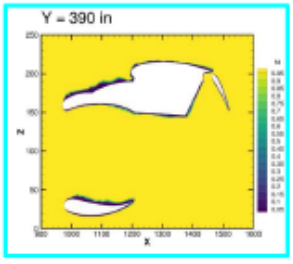
Free-air

AoA=15.48deg

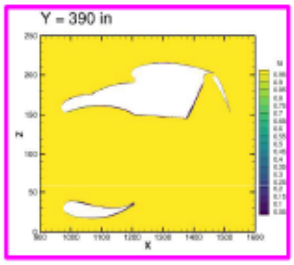


AoA=17.05deg

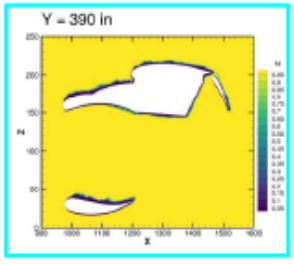


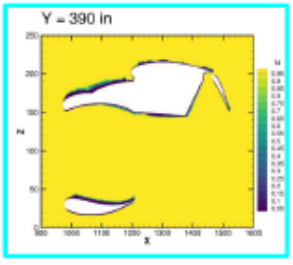


AoA=17.98deg



AoA=19.57deg





I1-ANSA-HRLES　H1-Custom-HRLES　H2-Custom-HRLES

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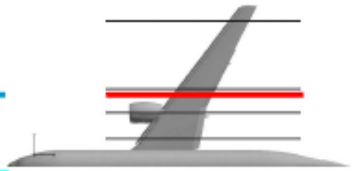
Shielding Function (Slice3)

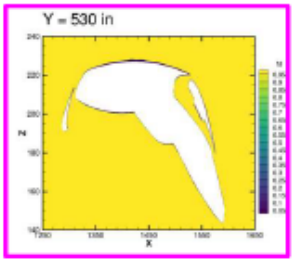


Description: Distribution of the shielding function.

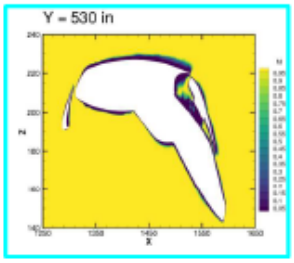
In-tunnel

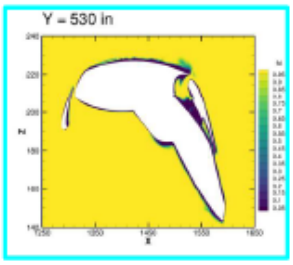
Free-air

AoA=15.48deg

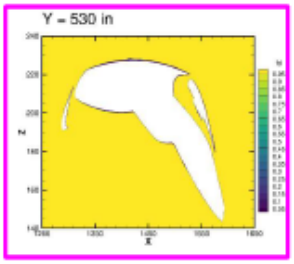


AoA=17.05deg

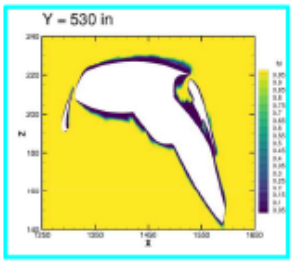


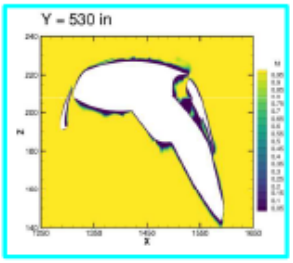


AoA=17.98deg



AoA=19.57deg





I1-ANSA-HRLES H1-Custom-HRLES H2-Custom-HRLES

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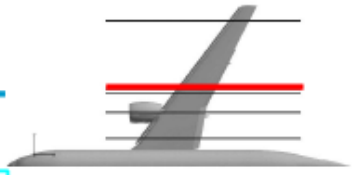
Shielding Function (Slice4)

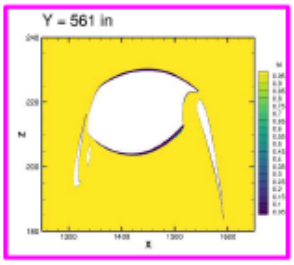


Description: Distribution of the shielding function.

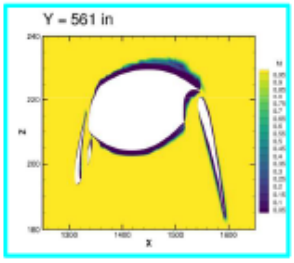
In-tunnel

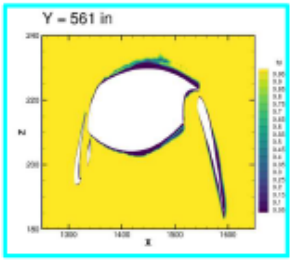
Free-air

AoA=15.48deg



AoA=17.05deg





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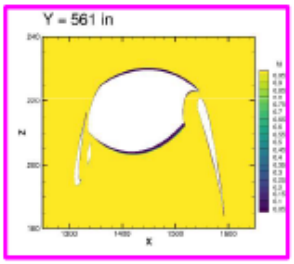
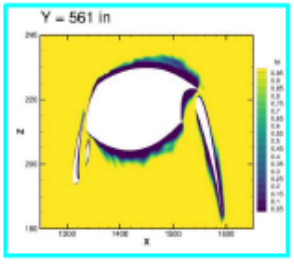
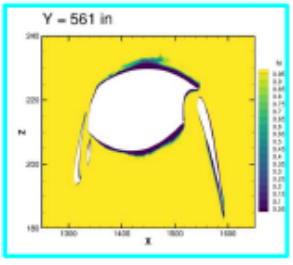


AoA=19.57deg





I1-ANSA-HRLES H1-Custom-HRLES H2-Custom-HRLES

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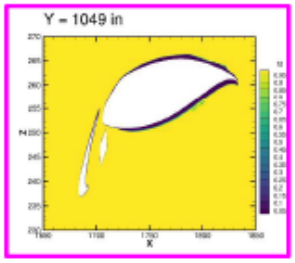
Shielding Function（Slice5）

Description: Distribution of the shielding function.

In-tunnel

Free-air

AoA=15.48deg



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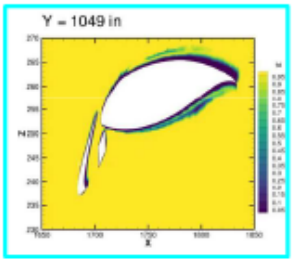

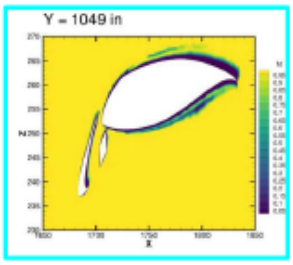

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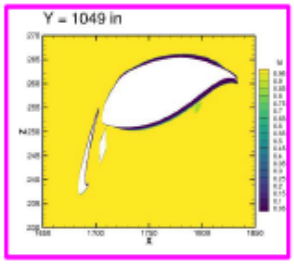

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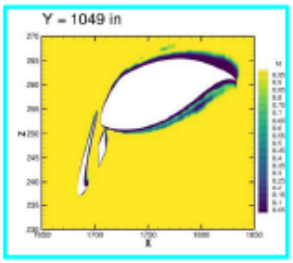

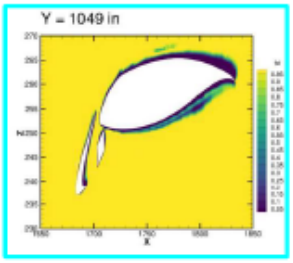

I1-ANSA-HRLES H1-Custom-HRLES H2-Custom-HRLES

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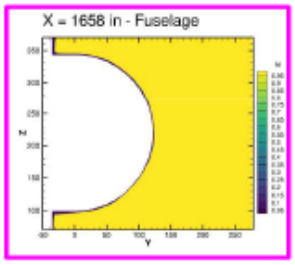
Shielding Function（Slice6a）

Description: Distribution of the shielding function.

In-tunnel

Free-air

AoA=15.48deg



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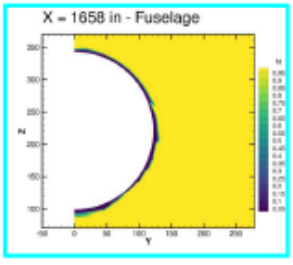

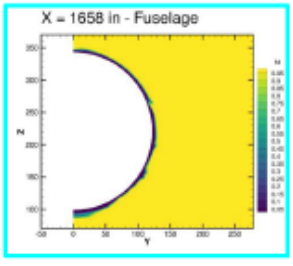

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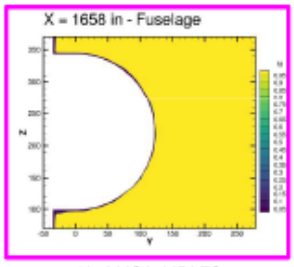

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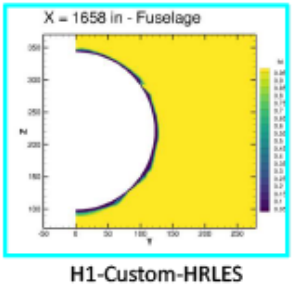

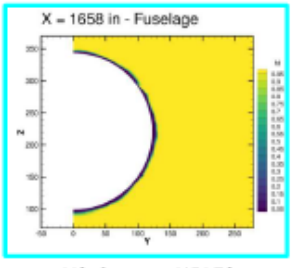

I1-ANSA-HRLES H1-Custom-HRLES H2-Custom-HRLES

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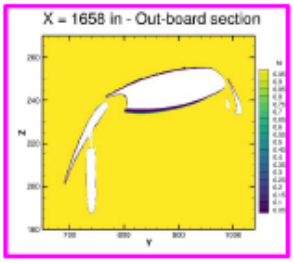
Shielding Function (Slice6b)

Description: Distribution of the shielding function.

In-tunnel

Free-air

AoA=15.48deg



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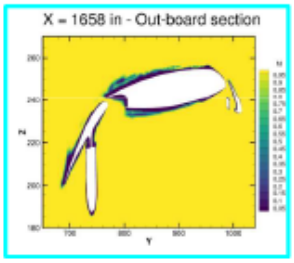
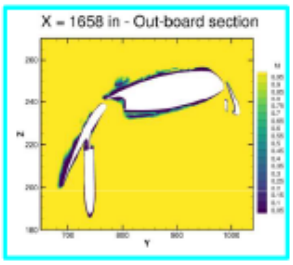
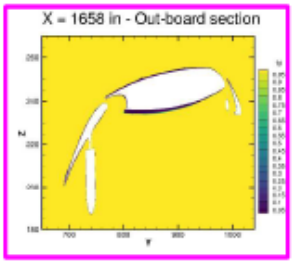




AoA=17.98deg



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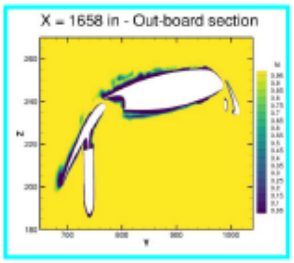

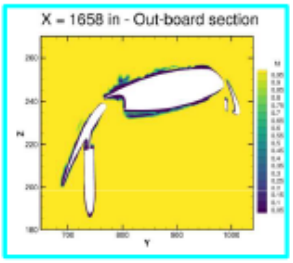

I1-ANSA-HRLES

H1-Custom-HRLES

H2-Custom-HRLES

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Summary

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Summary

- Case 1:
  - RANS verification: **good agreement** in general on aerodynamic forces and pressure and skin-friction distributions. However, **apparent differences on turbulent viscosity** (in agreement with NASA TMR data). Unclear what the "grid-converged" solution is in the wake regions for turbulent viscosity
  - WRLES: **good agreement**, although some statistical convergence might still need to be reached
  - WMLES: no participants

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Summary

- Case 2: In-tunnel RANS
  - Flow conditions:
    - Some differences on Pexit depending on the BCs used
    - Target test section Mach number obtained by all participants
    - Consistency in CFD incoming flow upstream of the aircraft, but differences with experimental BL thickness (floor rake data)
  - **Negligible improvement with respect to free-air RANS**
  - **In-tunnel RANS suffers of the same pathologies**, i.e. overpredicted inboard, nacelle and outboard separations. Cp distributions and skin-friction contours suggest the **over-prediction of the inboard separation is even exaggerated for in-tunnel RANS (earlier stall?)**
  - **Large scatter and convergence problems**
  - **Differences also at low AoA on flap separation**
  - **Some outliers, but overall consistency on CPU time cost**

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Summary

- Case 3: Free-air unsteady (HRLES, WMLES etc)
  - Only SA-based DDES contributions submitted
  - **CL prediction within 5% error with respect to the experiments** (always underpredicted)
  - **RANS pathologies "cured", but still some difficulties on the inboard separation and flaps**
  - **Some differences in RMS**
  - Evidence of **grid sensitivity**
  - **Cold vs warm restart virtually identical**
  - **Significant differences between participants in terms of RANS/LES regions**
  - Transient times are similar, **but statistics convergence time differs significantly. Some guidelines / best-practices are needed.**
  - **More data needed**

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Summary

- Case 4: In-tunnel unsteady (HRLES, WMLES etc)
  - Only SA-based DDES contributions submitted
  - **A slight improvement is obtained with respect to free-air HRLES**, but generally the same conclusions can be done
  - The **pitching moment coefficient accuracy decreases with respect to free-air HRLES**
  - **Very long transient times** (because of BCs?)
  - **The difference between in-tunnel and free-air aerodynamic forces indicate that increments are better predicted than absolute values**

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Summary

- Case 5: Free-air RANS grid sensitivity
  - **Significant sensitivity due to grid resolution**
  - **The resolution behind the brackets seems to significantly affect the prediction at low angles of attack**

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Acknowledgments

For the preparation of this document, I would like to thank:

All participants!

For the effort, time and patience when things did not go smoothly.

The APC Advisory Committee for the discussions and advices on how to gather and submit the results.

Tomoaki Matsuzaki (FMIC R&D) and Kenji Hayashi (Ryoyu Systems) for gathering, post-processing, summarizing the data and for the great input.

It would have been impossible without them!

For more information, please visit: https://cfdws.chofu.jaxa.jp/apc/

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Discussions

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HLPW-5

- Important dates:
  - **Data submission deadline: 2024 May 15**
  - Workshop date: early August 2024
- Geometry and flow conditions:
  - **CRM-HL at stall conditions**
- Reference data:
  - ONERA F1 wind-tunnel (**full-model**)
  - data to be released AFTER the workshop (**blind CFD simulations**)
- **Technology Focus Groups** (TFGs):
  1. fixed-grid RANS
  2. mesh adaptation RANS
  3. high-order discretization RANS
  4. hybrid RANS/LES
  5. wall-modeled LES

Intermediate virtual "Mini-Workshops" to check progress for each TFG

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HLPW-5 Test Cases

- **Case 1: CRM-HL Wing-Body Verification (both RANS and non-RANS solvers)**
  - Free-air RANS
  - M=0.2, Re=5.6 mil, AoA = 11 deg

  MAIN QUESTION:

  Are RANS and non-RANS solvers able to demonstrate verification on this problem?

- **Case 2: Configuration Build-Up (free-air)**
  - Wing-Body with horizontal and vertical stabilizers
  - Wing-Body with horizontal and vertical stabilizers + slats
  - Wing-Body with horizontal and vertical stabilizers + slats + flaps
  - Wing-Body with horizontal and vertical stabilizers + slats + flaps + nacelle
  - (Optional) Increased fidelity: use of static aeroelastic deformation, in-tunnel, tripping, mesh refinement

  MAIN QUESTION:

  Is there more consistency when modelling geometrically simpler configurations?

- **Case 3: Reynolds Number Study (free-air)**
  - Wing-Body with horizontal and vertical stabilizers + slats + flaps + nacelle
  - Re=1.05 mil, 5.49 mil, 16 mil, 30 mil
  - (Optional) Increased fidelity: use of static aeroelastic deformation, in-tunnel, tripping, mesh refinement

  MAIN QUESTION:

  Gridding requirements and CFD accuracy up to flight Reynolds number?

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Discussions (General)

- About the in-tunnel simulations
  - Was it worth complicating the simulations for small improvements (if any)?
  - Are they important only for half-model?
  - Should full-model experiments be prioritized?
  - Different BC strategies are possible, but difficult to conclude the correct one
  - KHI showed importance of resolution behind the brackets.
  - Even low angles of attack present scatter due to large flap deflection angles and it is not an easy problem. Further improvements are needed for CL prediction accuracy in aircraft design

- More detailed experimental measurements of the incoming flow are necessary
  - Can we minimize the differences upstream of the aircraft between CFD/EXP?
  - Modeling the wind tunnel with solid walls (no suction) is accurate enough?

- A half-span model wind tunnel experiment is important for high Re number flow simulation. However, we observed side effects, such as the tunnel wall effect, BL effect, AR effect, etc. Can we propose a good method for a half-span model experiment based on CFD simulations?

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Discussions (RANS)

- Is there any hope for RANS with current existing models?
  - The flow is unsteady and it is difficult to obtain solution convergence. Even if we obtained good solution convergence, do RANS calculations make sense? Do we have to insist with steady calculations?
  - Difficult to obtain grid-converged RANS solutions with quite fine grids (~200M). Should we go even higher?
  - Are methods like grid-adaptation going to help?
  - About warm/cold start and possible hysteresis around stall/post-stall. Are those numerical or physical?

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Discussions (Scale-resolving)

- Scale-resolving methods are promising but do we have enough evidence? At low angles of attack they seem to be less accurate than RANS*. How reliable and consistent are these methods?

*[see APC9 Zauner et al and HLPW4 HRLES summary]

- Sensitivity to grid, initialization strategy, turbulence model need more detailed investigation

- HRLES is ~10x more expensive than RANS. How can we reduce CPU time and keep good accuracy? Is WMLES the answer?

*[from HLPW4, HRLES 10-15x and WMLES 5-10x more expensive than RANS, respectively]

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Discussions (Scale-resolving)

- How important is it to correctly predict RMS? With CL-max prediction as objective, do we need to care about RMS?
- Pitching moment predictions are more difficult. How important is it to correctly predict Cm? Difference in magnitude compared to CL is significant?
- Verification methods for scale-resolving simulations are needed. What are good configurations to test scale-resolving methods? Full-aircraft configuration? Proving grid convergence is an absolute must?

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Discussions (APC-10)

- RANS results are unsatisfactory and HRLES inconclusive due to low number of participants:
  - Should we keep insisting on RANS?
  - Should we focus on unsteady calculations, both URANS and scale-resolving?
  - Simpler configuration?
  - Would that be just a repetition of APC-8 and APC-9?
- Is there any problem (i.e. complementary to HLPW5) that we want to focus on? What is the unique contribution we can give? Aeroelasticity?
- Considering the absence of new experiments (ONERA F1 experiments available after HLPW5) and the potential overlap of ACP-10 (mid-July 2024) and HLPW5 (end of July 2024), should we even consider skipping APC in FY24 and focus on HLPW5?

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