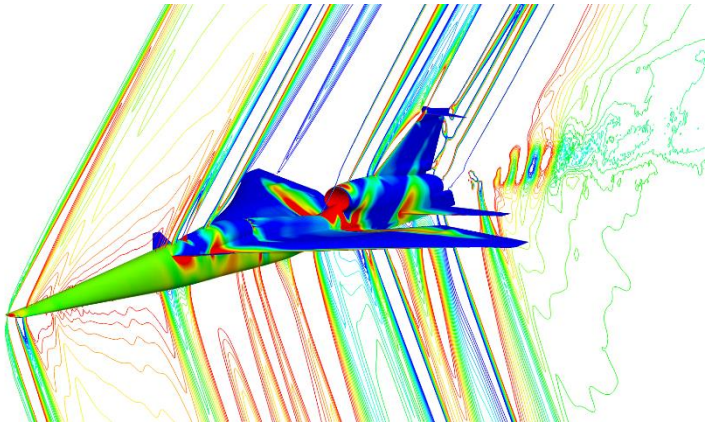
Near-field Pressure Signature Prediction by JAXA

3rd AIAA Sonic Boom Prediction Workshop



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Outline

I. Summary of cases analyzed

II. Flow solver / Computing platform

- ✓ Flow solver (TAS,FaSTAR,UPACS)
- ✓ Computing platform : JSS2

III. Biconvex

- ✓ Provided grids cases
- ✓ Flow solver convergence
- ✓ Results (Limiter)

IV. C608

- ✓ Grids (Provided, Own)
- ✓ Flow solver convergence
- ✓ Near field signature
- ✓ Propagation results

VII. Conclusion

Highlight topics

I. Limiter function

- ✓ Venkatakrishnan limiter
- ✓ Barth-Jespersen limiter
- ✓ Hishida limiter based on van albada

II. Overset structured mesh (own grid)

- ✓ Provided unstructured mesh + Own structured mesh
- ✓ Near field comparison with the provided and own grid

III. Sonic boom on the ground

- ✓ Ground signature comparison
- ✓ Loudness comparison (PLdB)

Summary of cases analyzed

Coarse ⟷ Fine

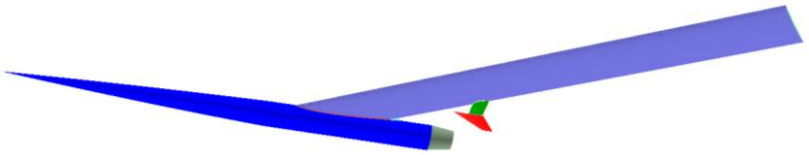
Model	Providor	mesh	Sover	Limiter	Grid Spacing(Resolution) 2	1.57	1.28	1	0.8	0.64	0.5
biconvex	SBPW	mixed	TAS	ven Kat.		✔	✔	✔			
			FaSTAR	ven Kat.		✔	✔	✔			
				B-J		✔	✔	✔			
				Hishida(VA)		✔	✔	✔			
		tetrahedra	TAS	ven Kat.		✔	✔	✔			
			FaSTAR	ven Kat.		✖	✖	✖			
				Hishida(VA)		✔	✔	✔			
		adapt.	TAS	ven Kat.	✔	✔	✔	✖	✖	✖	
C608	SBPW	mixed	FaSTAR	ven Kat.			✔	✔	✔	✔	✔
				B-J						✔	
				Hishida(VA)			✔	✔	✔	✔	✔
		tetrahedra		ven Kat.			✖	✖	✖	✖	✖
				Hishida(VA)			✔	✔	✔	✔	
	JAXA	structured	UPACS	van albada			✔	✔	✔		

→ submitted to SBPW

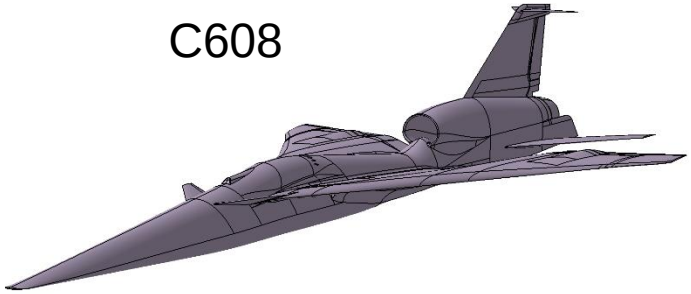
✔ → Simulation has been done.

✖ → Could not be calculated.

Biconvex 9×7 Shock-Plume Interaction Model



C608



Flow solver/Computing Platform

CFD solver

Solver	TAS	FaSTAR	UPACS
	Tohoku university Aerodynamic Simulation	FAST Airodynamic Routines	Unified Platform for Aerospace Computation Simulation
developer	Tohoku university & JAXA	JAXA	JAXA
Mesh	Unstructured mesh	Unstructured mesh	Structured mesh
Finite volume method	cell-vertex finite volume	cell-vertex / cell-centered finite volume	cell-centered finite volume
discretization scheme	HLLEW	HLLEW	AUSMDV
spatial accuracy	2nd order	2nd order	2nd order
limiter function	Venkatakrishnan	Venkatakrishnan	van Albada
		Barth-Jespersen	
		Hihida (van Albada like)	
time integration	LU-SGS implicit method	LU-SGS implicit method	MFGS implicit method
Equation	RANS	RANS	NS
Turbulence model	Spalart-Allmaras [SA-noft2-R(C_{rot}=1)]	Spalart-Allmaras [SA-noft2-R(C_{rot}=1)]	N/A

Propagation(Additional)

Xnoise : Burgers equation ← Details will be presented by Knamori (tommrrow).

BoomMetre : Loudness estimation

Computing Platform

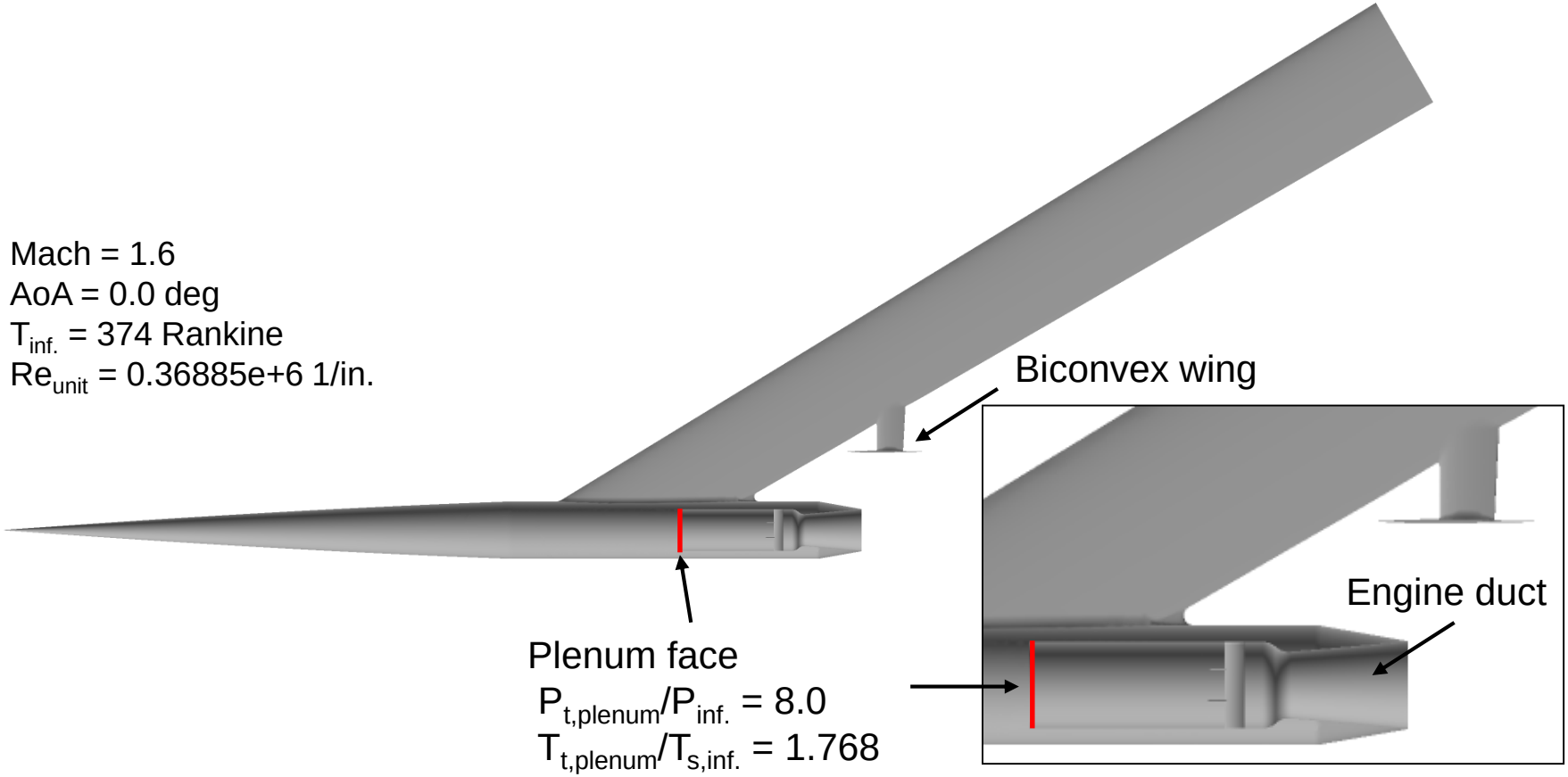
JSS2 SORA-MA

- JAXA Supercomputer System generation 2
- Fujitsu Supercomputer PRIMEHPC FX100
- Architecture: Scalar machine
- Processor Type = SPARC64 Xlfx (32 cores/node)
- Nodes/System = 3,240 nodes
- Memory/Node = 32GiB
- Memory/System = 101.25TiB ← 3-400 processors x 2-3.5h for SBPW3
- Peak Performance = 3.495 PFLOPS

Biconvex

9×7 Shock-Plume Interaction Model

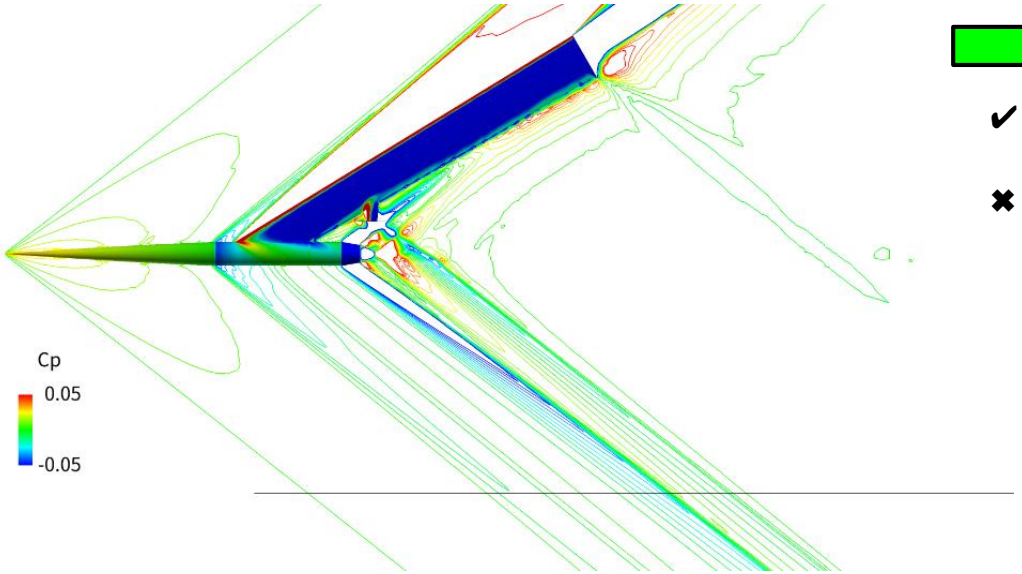
Mach = 1.6
AoA = 0.0 deg
$T_{inf.}$ = 374 Rankine
Re_{unit} = 0.36885e+6 1/in.



Biconvex

9×7 Shock-Plume Interaction Model

mesh	Sover	Limiter	Limiter Factor (ven Kat.)	Grid Spacing(Resolution) 2	1.57	1.28	1
mixed	TAS	venkat.	10		✔	✔	✔
			1				✔
			0.1				✔
			0.01				✔
	FaSTAR		1		✔	✔	
			0.1				✔
		Barth-Jespersen	----		✔	✔	✔
		Hishida(VA)	----		✔	✔	✔
tetrahedra	TAS	venkat.	10		✔	✔	✔
	FaSTAR				✖	✖	✖
		Hishida(VA)	----		✔	✔	✔
adapt.	TAS	venkat.	10	✔	✔	✔	✖



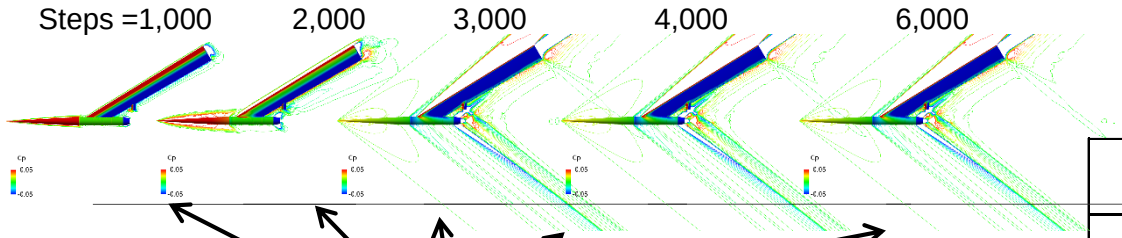
→ submitted to SBPW

✔ → Simulation has been done.

✖ → Could not be calculated.

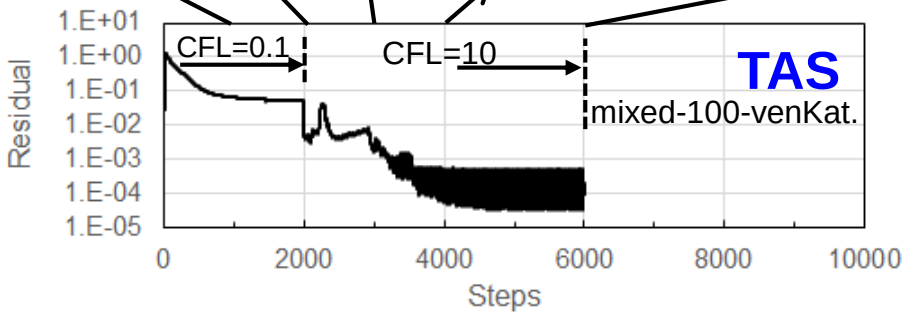
The all simulations are conducted by the provided grid from the SBPW.

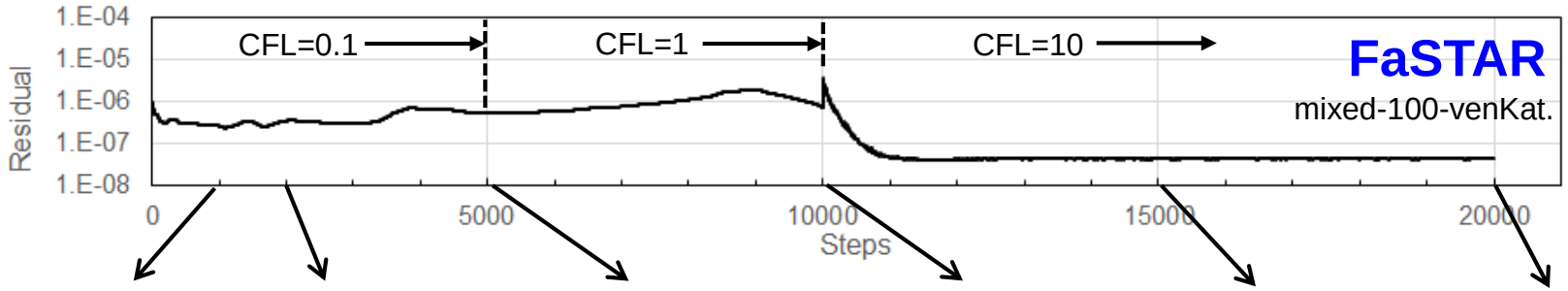
Flow solver convergence

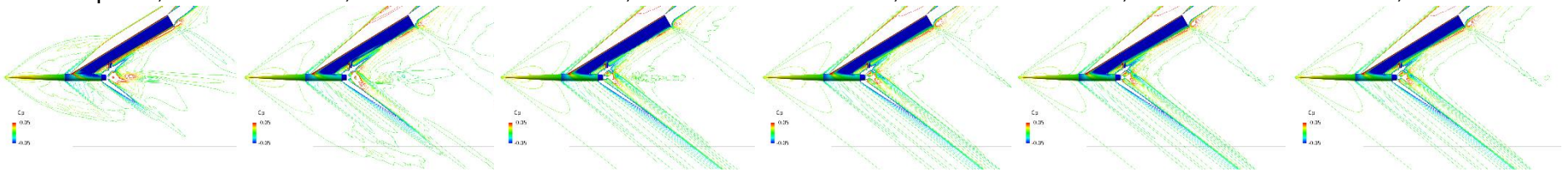


CFL number list

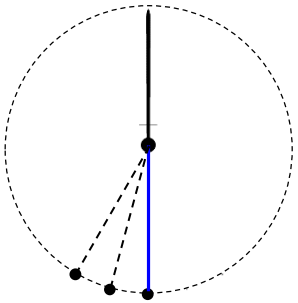
mesh	Sover	Limiter	Grid Spacing(Resolution)			
			2	1.57	1.28	1
mixed	TAS	venkat.		100	100	(100)
	FaSTAR			10	1->10	0.1->1->10
		Hishida(VA)		50	50	50
tetrahedra	TAS	venkat.		10	10	10
	FaSTAR	Hishida(VA)		50	50	50
adapt.	TAS	venkat.	100	100	0.1	



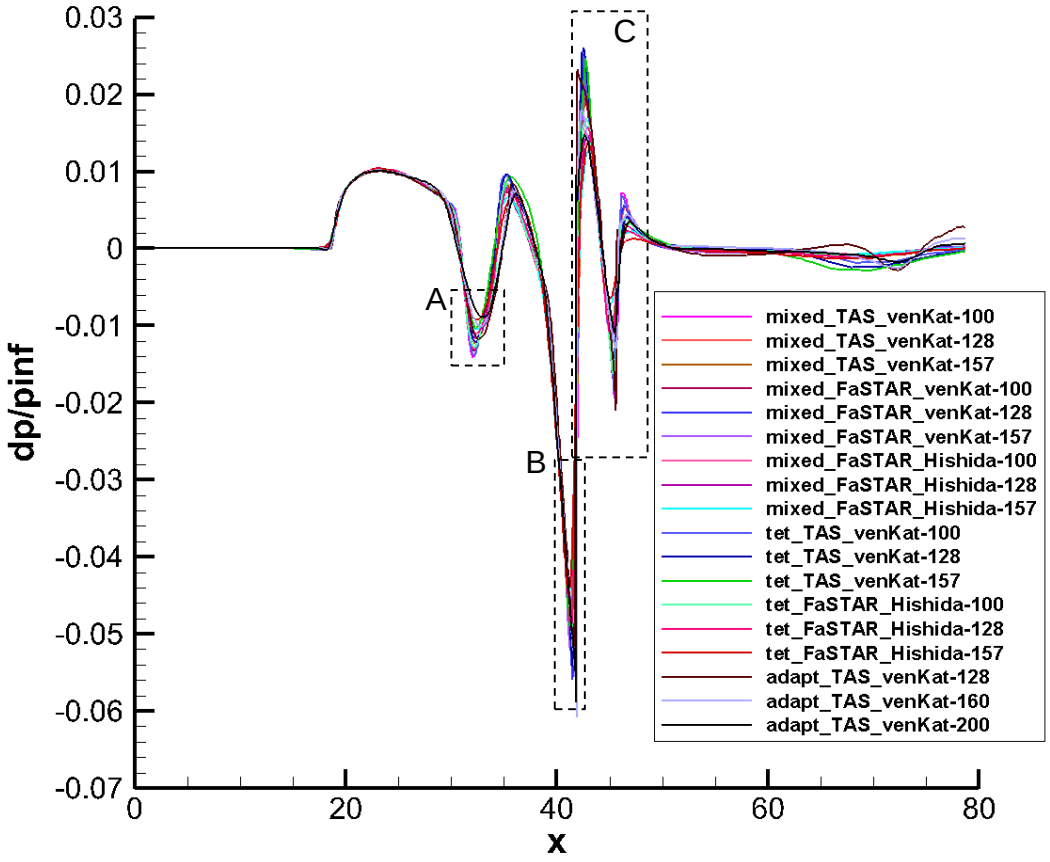


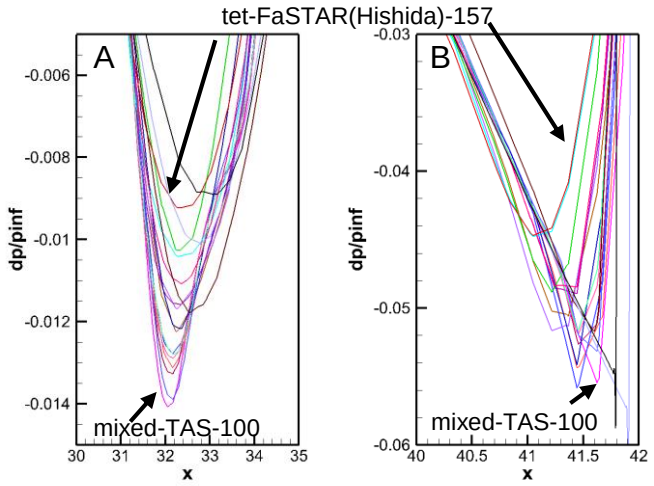


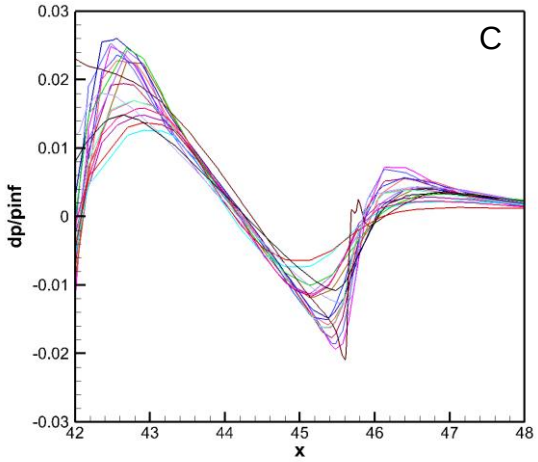
All signatures (under-track, 0deg)



mesh	Sover	Limiter	Grid Spacing			
			2	1.57	1.28	1
mixed	TAS	venkat.		✔	✔	✔
	FaSTAR	venkat.		✔	✔	✔
		Hishida(VA)		✔	✔	✔
tet.	TAS	venkat.		✔	✔	✔
	FaSTAR	Hishida(VA)		✔	✔	✔
adapt.	TAS	venkat.	✔	✔	✔	







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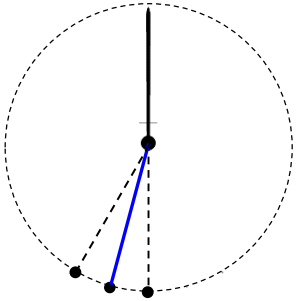
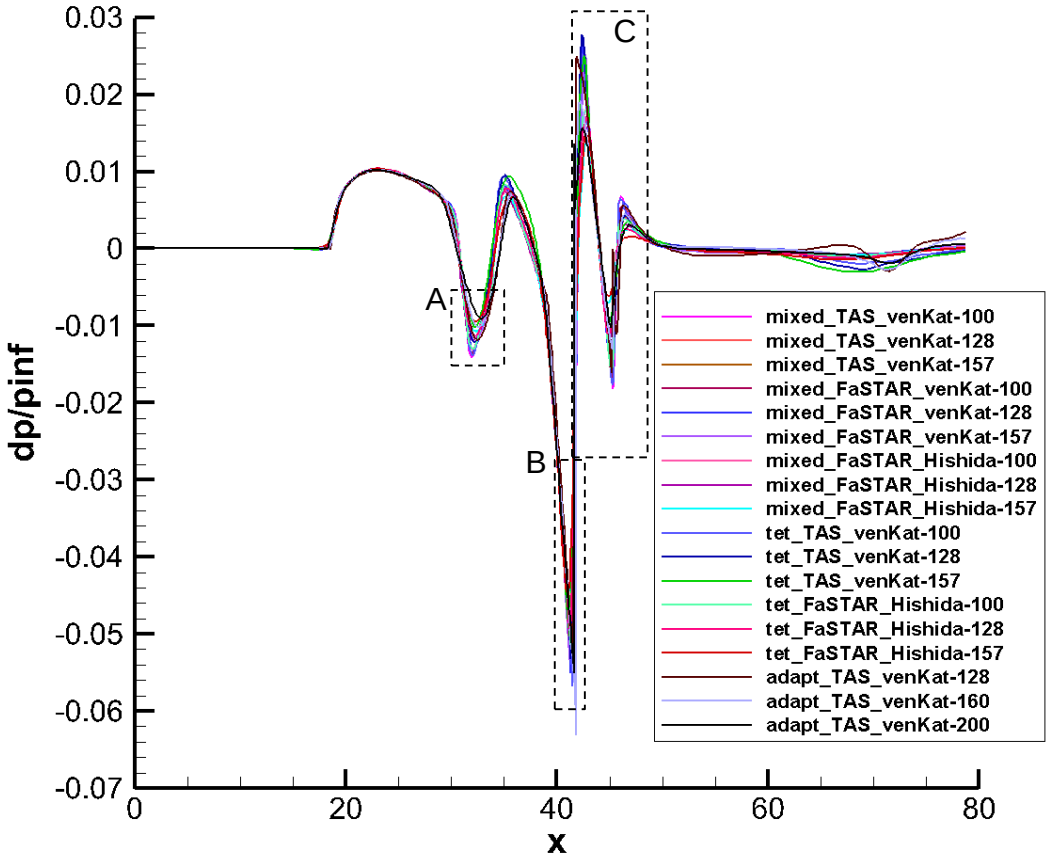
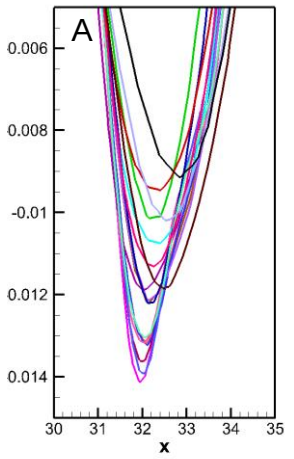
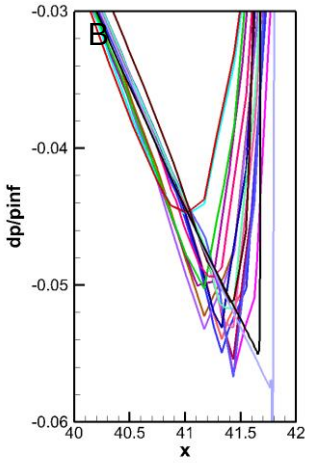
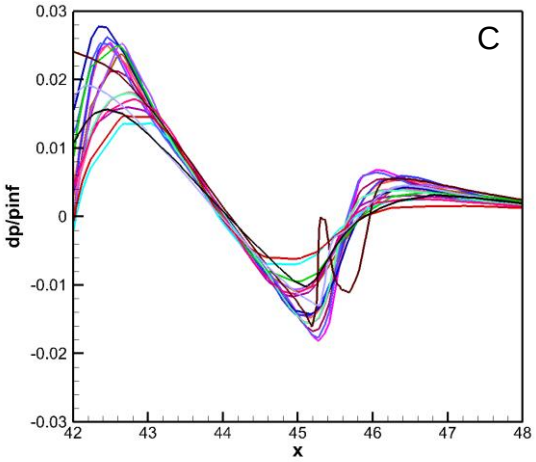


mesh	Sover	Limiter	Grid Spacing			
			2	1.57	1.28	1
mixed	TAS	venkat.		✔	✔	✔
	FaSTAR	venkat.		✔	✔	✔
		Hishida(VA)		✔	✔	✔
tet.	TAS	venkat.		✔	✔	✔
	FaSTAR	Hishida(VA)		✔	✔	✔
adapt.	TAS	venkat.	✔	✔	✔	

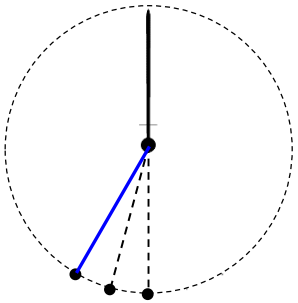




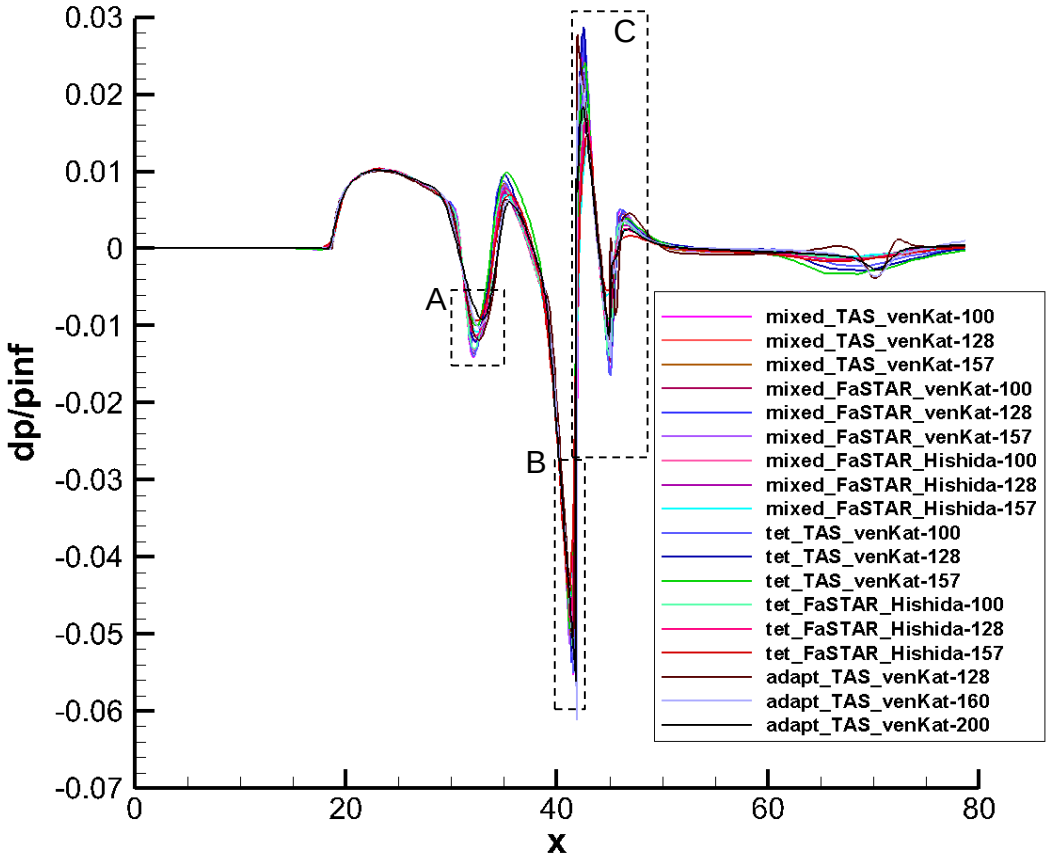


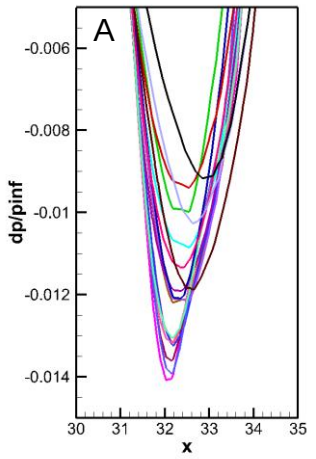


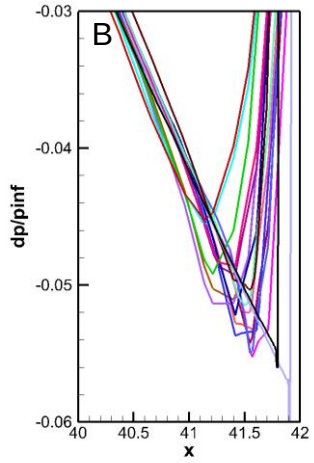
All signatures (off-track, 30deg)

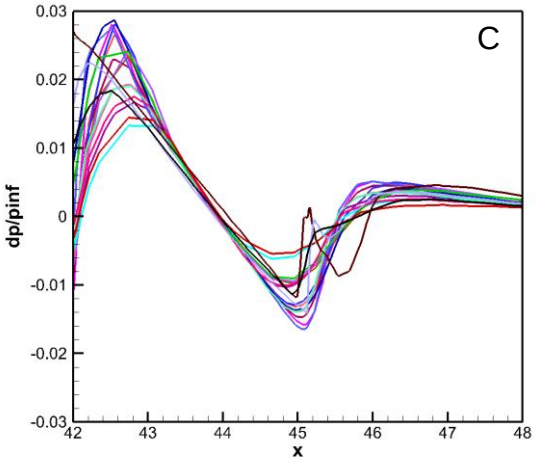


mesh	Sover	Limiter	Grid Spacing			
			2	1.57	1.28	1
mixed	TAS	venkat.		✔	✔	✔
	FaSTAR	venkat.		✔	✔	✔
		Hishida(VA)		✔	✔	✔
tet.	TAS	venkat.		✔	✔	✔
	FaSTAR	Hishida(VA)		✔	✔	✔
adapt.	TAS	venkat.	✔	✔	✔	





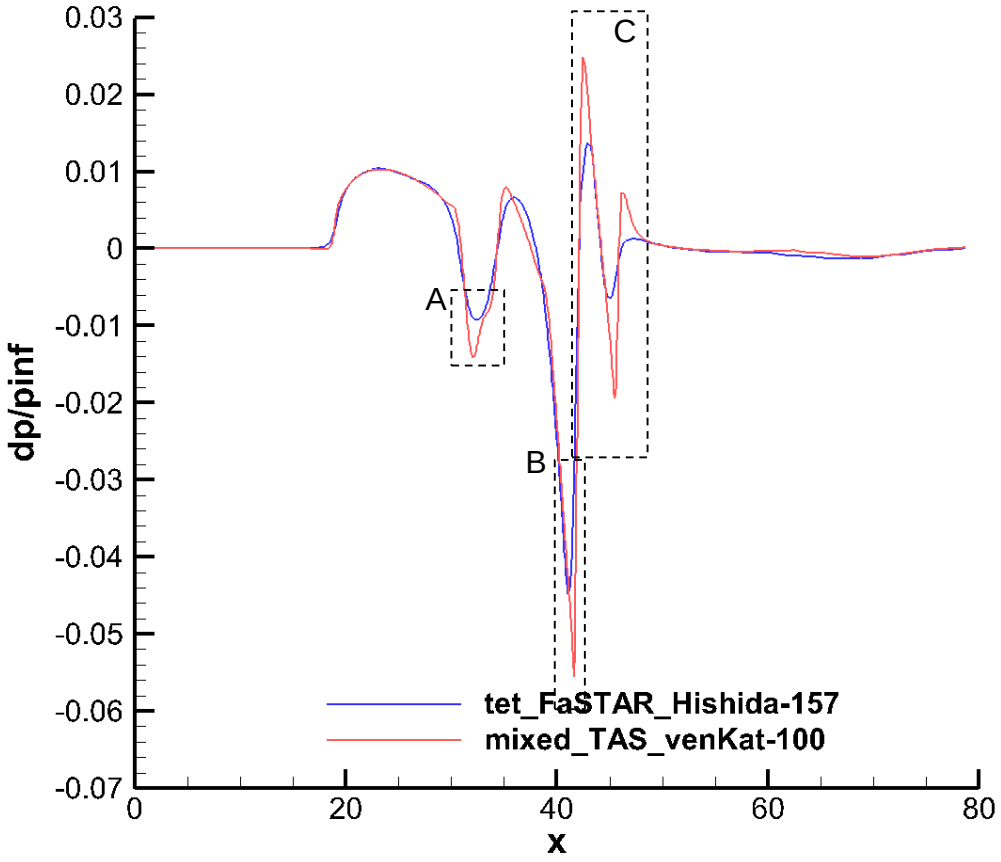


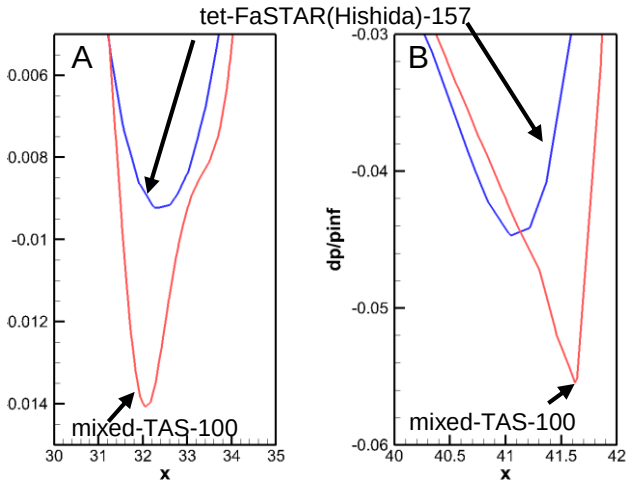


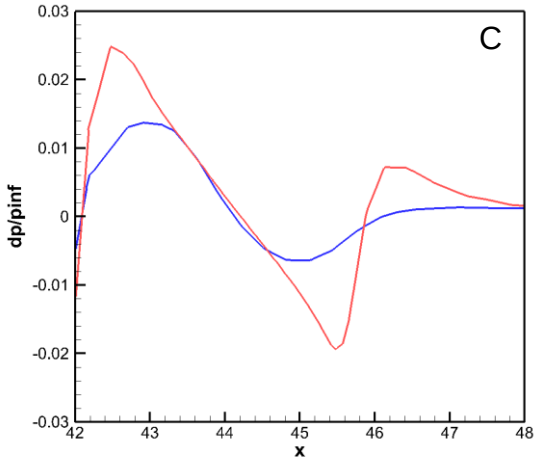
Reference signatures

	mesh	Sover	Limiter	Spacing
-----	mixed	TAS	venkat.	1
-----	tet.	FaSTAR	hishida	1.57

mesh	Sover	Limiter	Grid Spacing			
			2	1.57	1.28	1
mixed	TAS	venkat.		✔	✔	✔
	FaSTAR			✔	✔	✔
		Hishida(VA)		✔	✔	✔
tet.	TAS	venkat.		✔	✔	✔
	FaSTAR	Hishida(VA)		✔	✔	✔
adapt.	TAS	venkat.	✔	✔	✔	

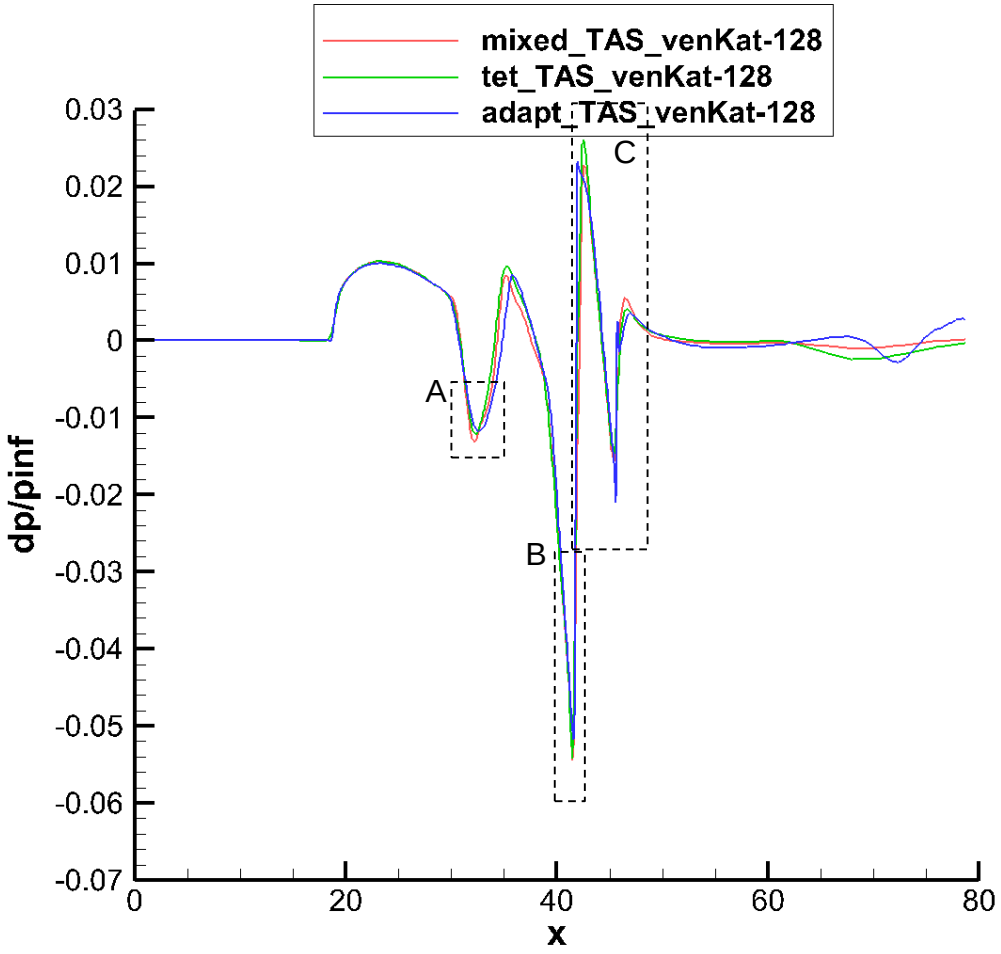


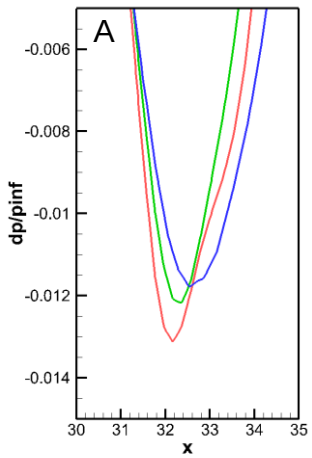


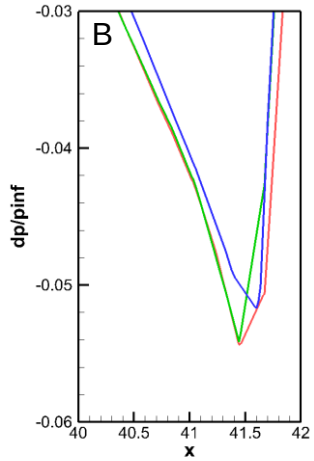


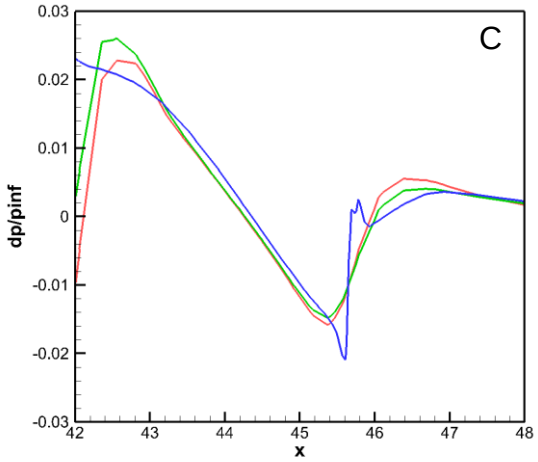
Mixed – Tet – Adapt.

mesh	Sover	Limiter	Grid Spacing			
			2	1.57	1.28	1
mixed	TAS	venkat.		✔	✔	✔
	FaSTAR			✔	✔	✔
		Hishida(VA)		✔	✔	✔
tet.	TAS	venkat.		✔	✔	✔
	FaSTAR	Hishida(VA)		✔	✔	✔
adapt.	TAS	venkat.	✔	✔	✔	



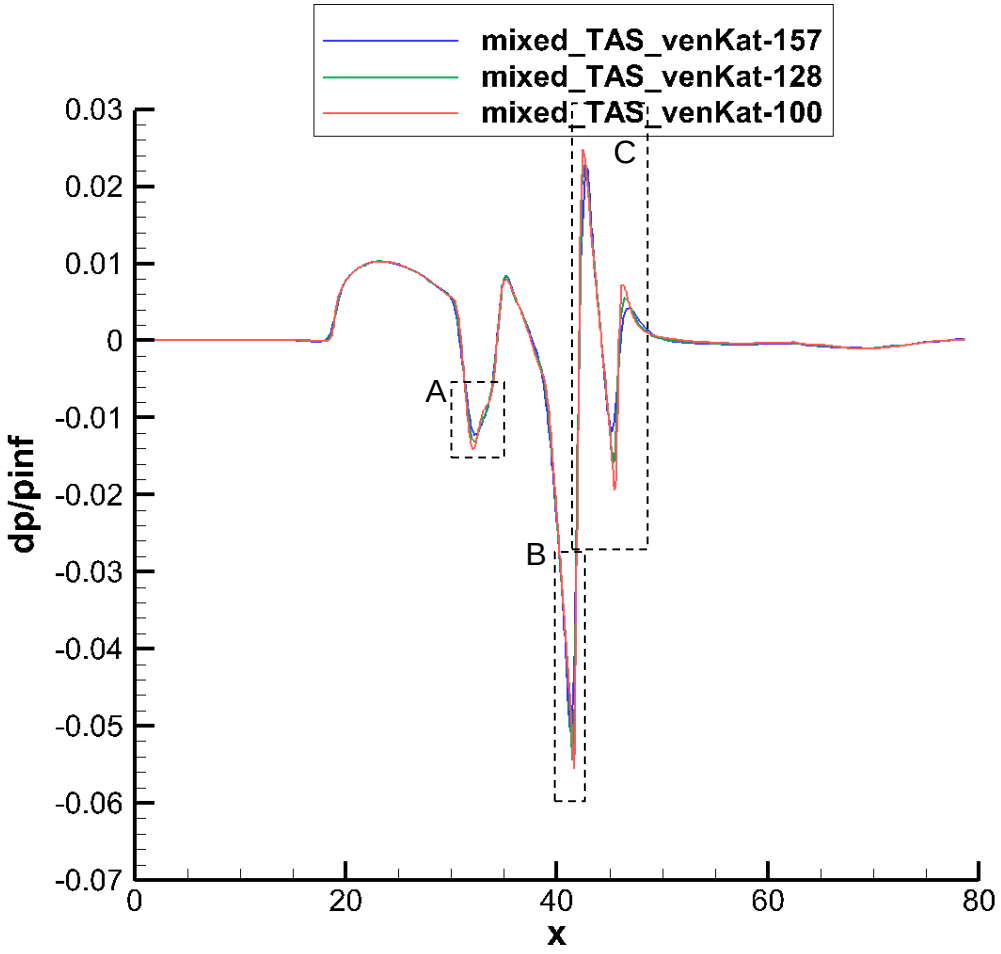


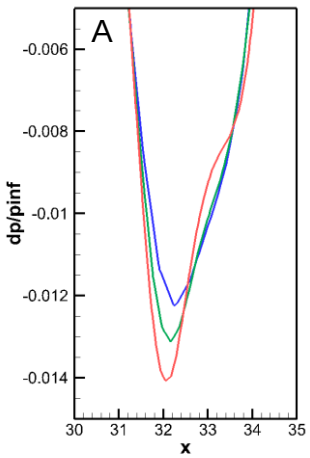


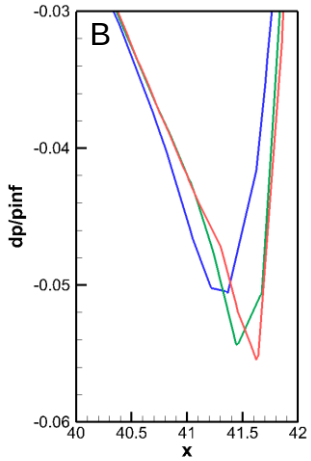


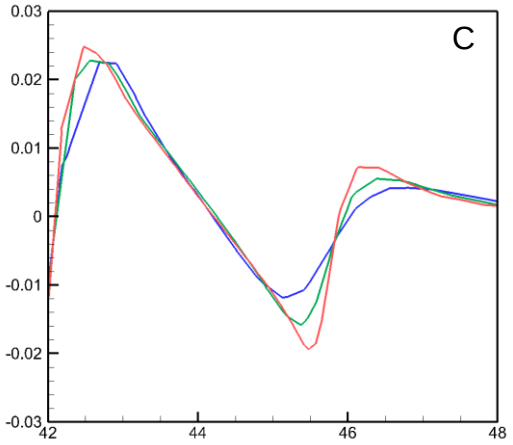
1.57 – 1.28 – 1.00

mesh	Sover	Limiter	Grid Spacing			
			2	1.57	1.28	1
mixed	TAS	venkat.		✔	✔	✔
	FaSTAR	venkat.		✔	✔	✔
		Hishida(VA)		✔	✔	✔
tet.	TAS	venkat.		✔	✔	✔
	FaSTAR	Hishida(VA)		✔	✔	✔
adapt.	TAS	venkat.	✔	✔	✔	









Venkatakrishnan Limiter

Venkatakrishnan limiter (AIAA 93-080)

$$\Phi_{i+1/2} = \frac{1}{\Delta_-}\left[\frac{\left(\Delta_+^2 + \varepsilon^2\right)\Delta_- + 2\Delta_-^2\Delta_+}{\Delta_+^2 + 2\Delta_-^2 + \Delta_-\Delta_+ + \varepsilon^2}\right]$$

$$\varepsilon^2 = \left(K\overline{\Delta}\right)^3$$

where $\overline{\Delta}$ is an average grid size and K is a constant (limiter factor).

Limiter factor, K

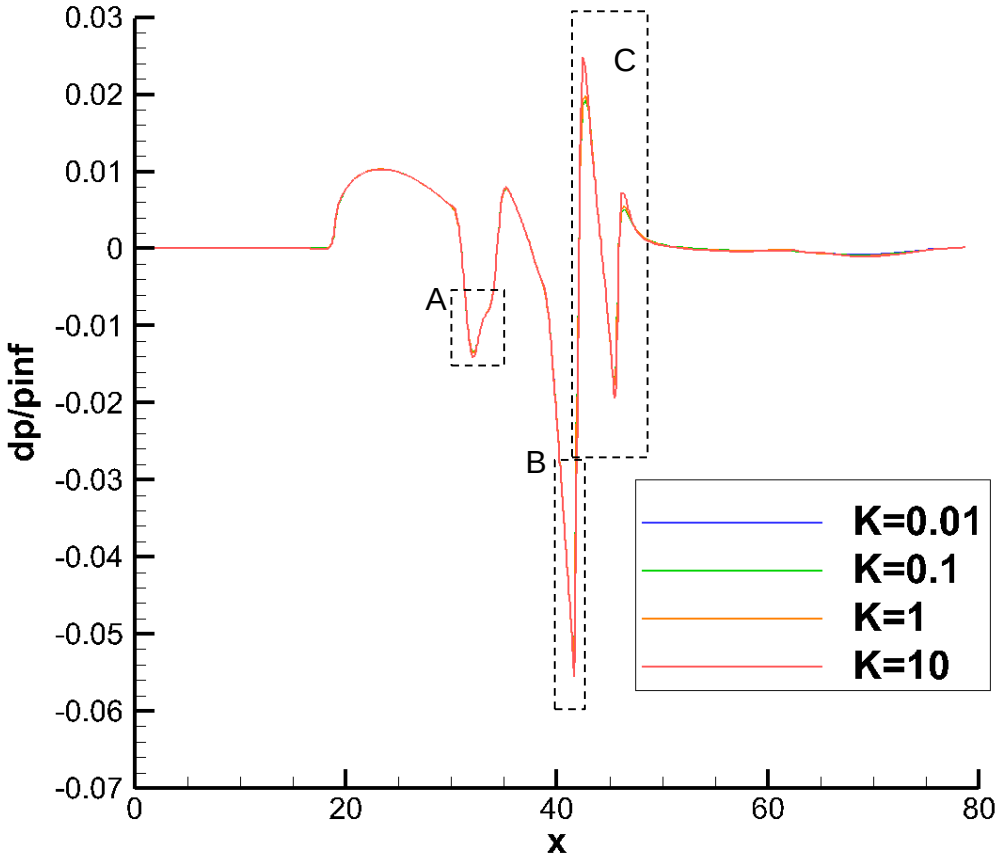
K	Stability	Accuracy
10	Low ⇕ High	High ⇕ Low
1		
0.1		
0.01		

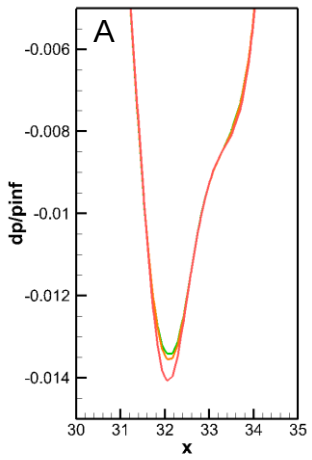
mesh	Sover	Limiter Factor	Grid Spacing(Resolution) 2	1.57	1.28	1
mixed	TAS	10		✔	✔	✔
		1				✔
		0.1				✔
		0.01				✔
	FaSTAR	1		✔	✔	
		0.1				✔
tetrahedra	TAS	10		✔	✔	✔
adapt.	TAS	10	✔	✔	✔	✖

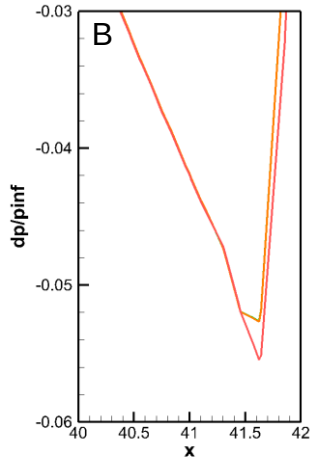
Limiter factor (K) of venKat.

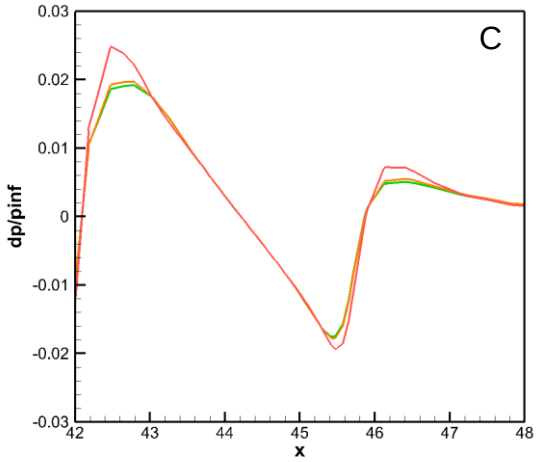
TAS mixed-100

mesh	Sover	Limiter	Grid Spacing			
			2	1.57	1.28	1
mixed	TAS	venkat.		✔	✔	✔
	FaSTAR			✔	✔	✔
		Hishida(VA)		✔	✔	✔
tet.	TAS	venkat.		✔	✔	✔
	FaSTAR	Hishida(VA)		✔	✔	✔
adapt.	TAS	venkat.	✔	✔	✔	





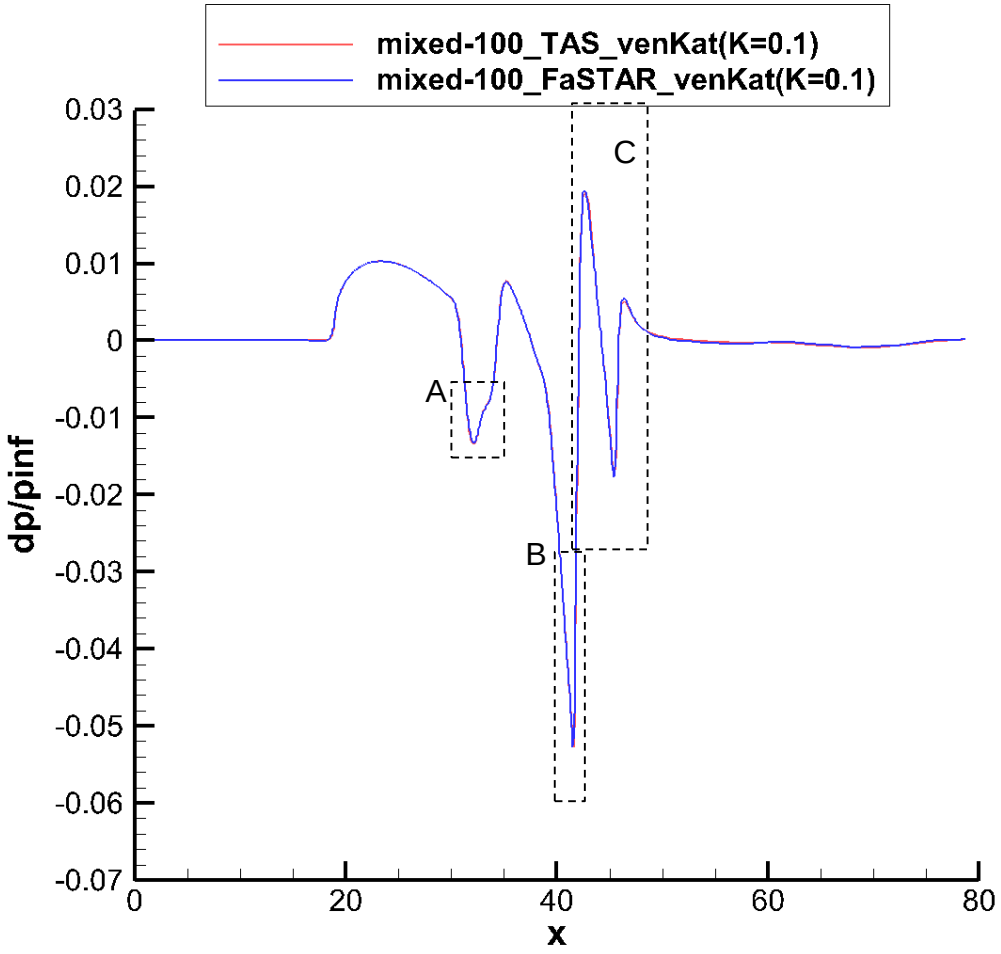


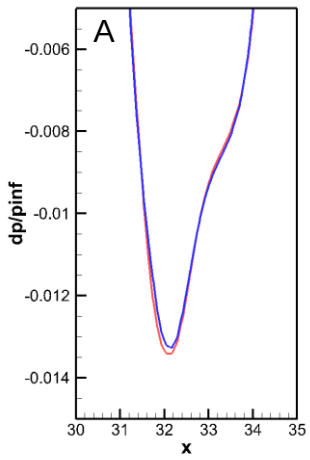


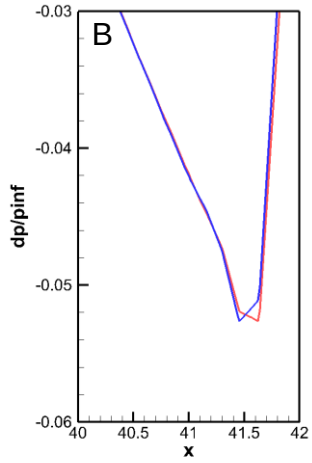
TAS – FaSTAR

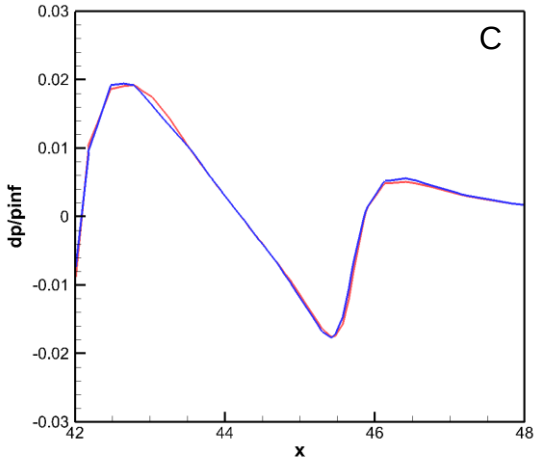
mixed-100, Venkat;K=0.1

mesh	Sover	Limiter	Grid Spacing			
			2	1.57	1.28	1
mixed	TAS	venkat.		✔	✔	✔
	FaSTAR	venkat.		✔	✔	✔
		Hishida(VA)		✔	✔	✔
tet.	TAS	venkat.		✔	✔	✔
	FaSTAR	Hishida(VA)		✔	✔	✔
adapt.	TAS	venkat.	✔	✔	✔	





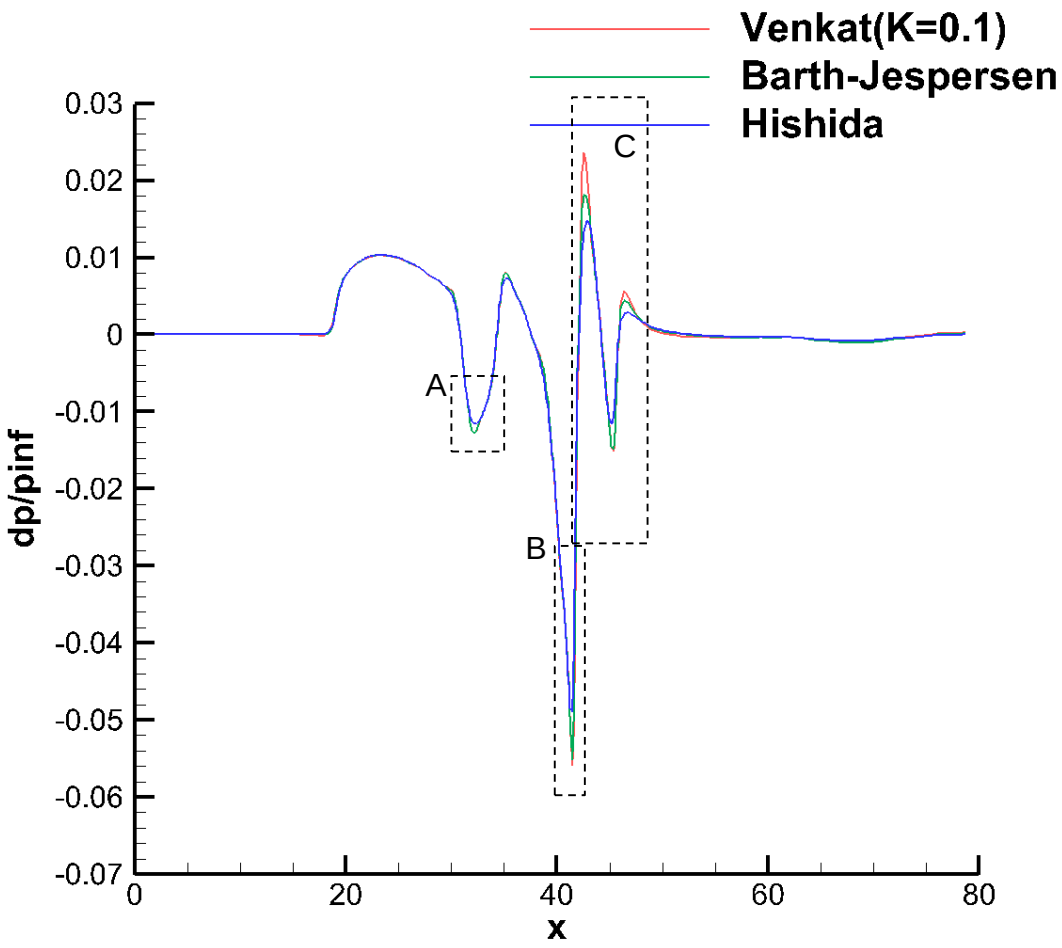


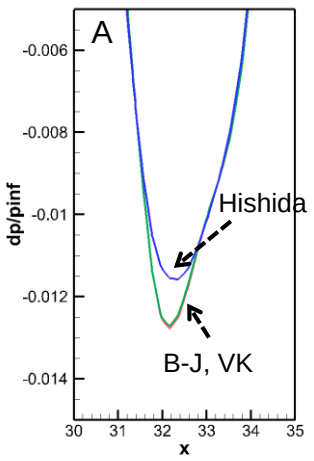


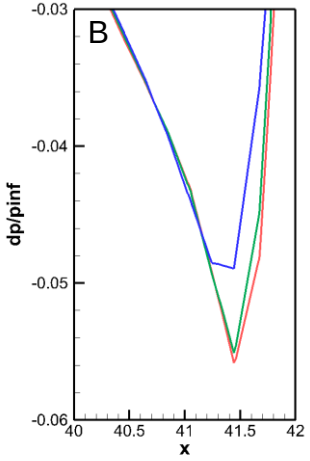
Limiter Function

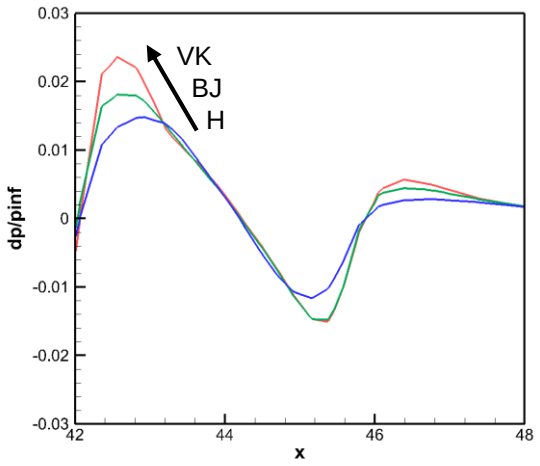
FaSTAR, mixed-128

mesh	Sover	Limiter	Grid Spacing			
			2	1.57	1.28	1
mixed	TAS	venkat.		✔	✔	✔
	FaSTAR	venkat.		✔	✔	✔
		B-J		✔	✔	✔
		Hishida(VA)		✔	✔	✔
tet.	TAS	venkat.		✔	✔	✔
	FaSTAR	Hishida(VA)		✔	✔	✔





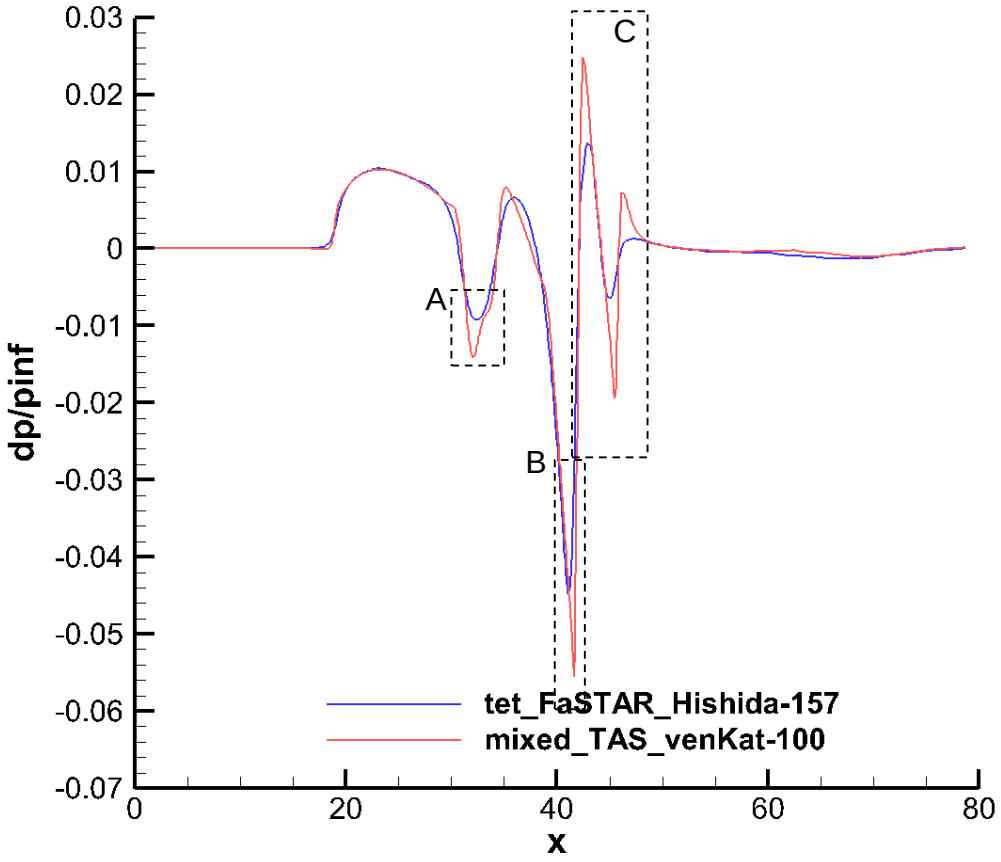


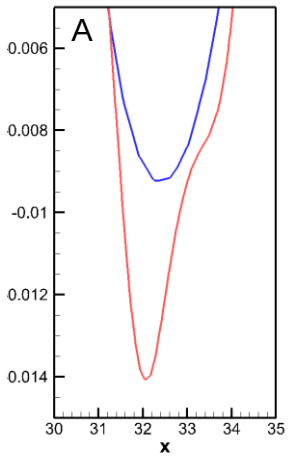


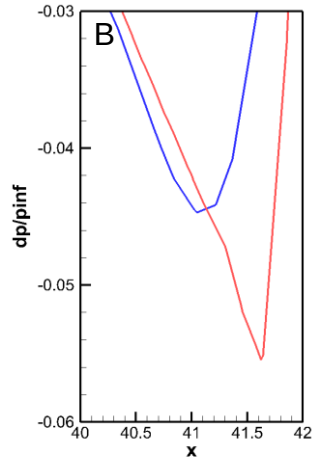
Reference signatures

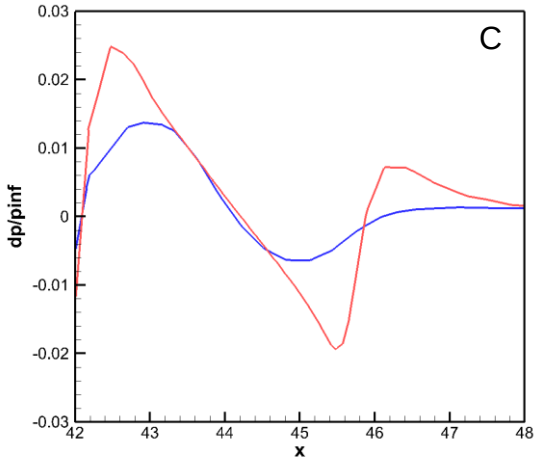
	Blunt		Sharp
Grid resolution	157	→	100
Grid type	tet	→	mixed
Limiter	Hishida	→ B-J →	Venkat.
Limiter factor(VK)	0.01	→	10

mesh	Sover	Limiter	Grid Spacing			
			2	1.57	1.28	1
mixed	TAS	venkat.		✔	✔	✔
	FaSTAR			✔	✔	✔
		Hishida(VA)		✔	✔	✔
tet.	TAS	venkat.		✔	✔	✔
	FaSTAR	Hishida(VA)		✔	✔	✔
adapt.	TAS	venkat.	✔	✔	✔	



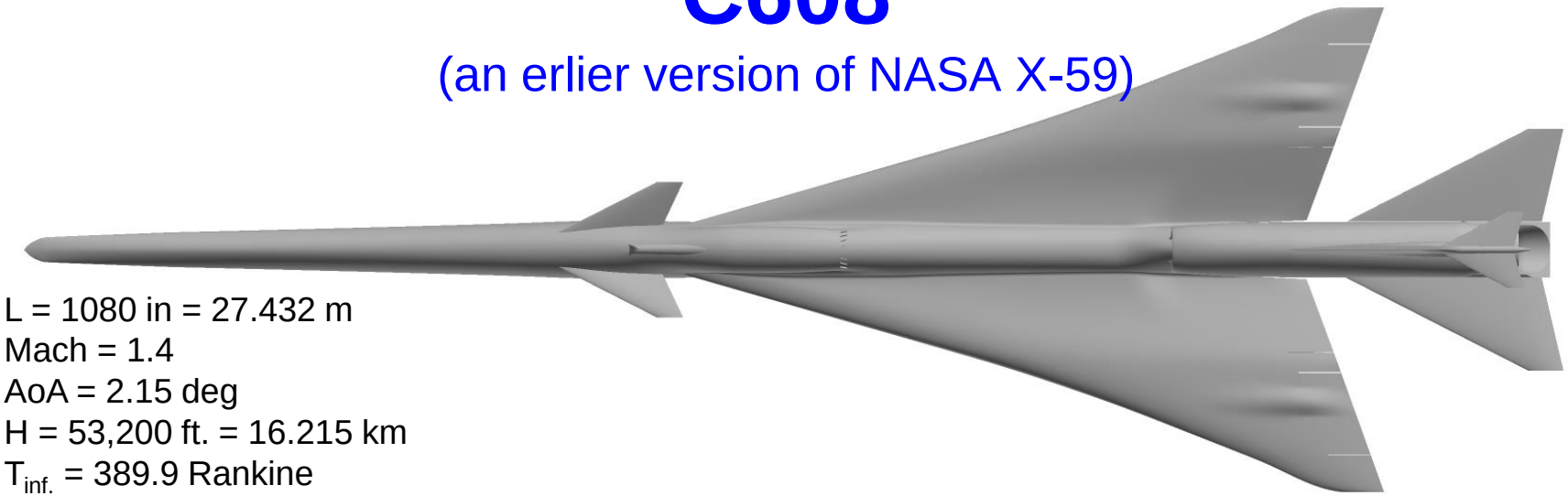




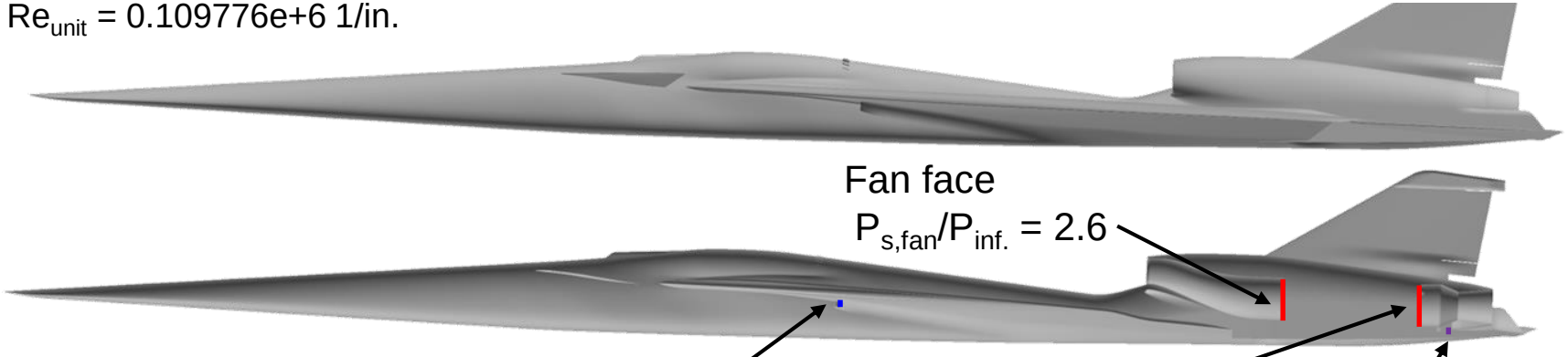


C608

(an erlier version of NASA X-59)



L = 1080 in = 27.432 m
Mach = 1.4
AoA = 2.15 deg
H = 53,200 ft. = 16.215 km
$T_{inf.}$ = 389.9 Rankine
Re_{unit} = 0.109776e+6 1/in.



Fan face
$P_{s,fan}/P_{inf.}$ = 2.6

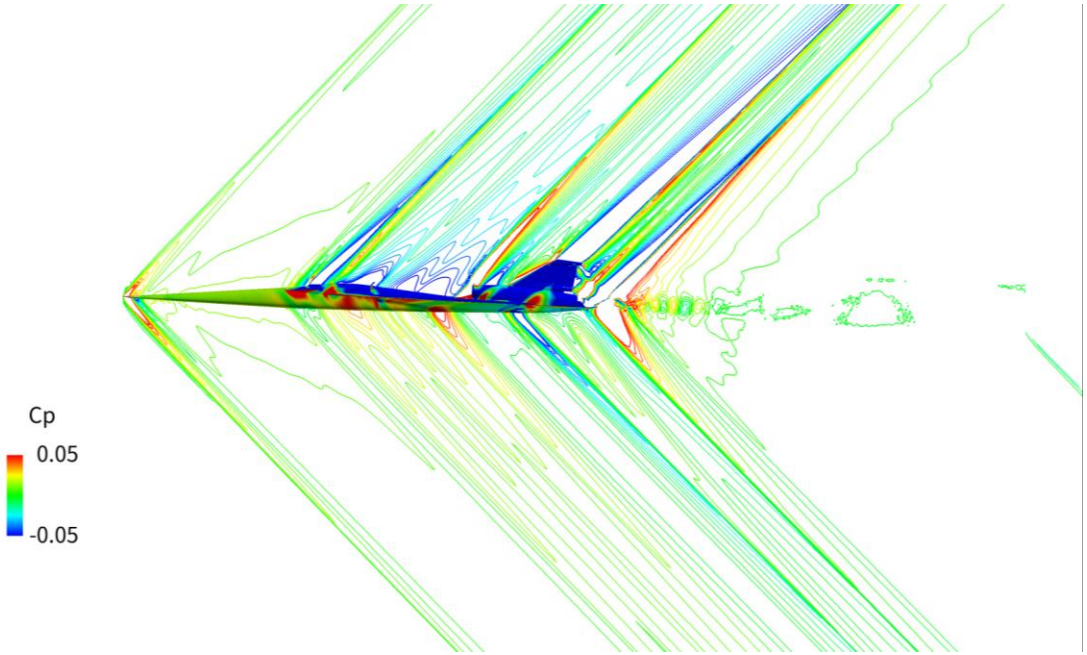
Inlet face of ECS
(Environemental Control System)
$P_{s,ECS}/P_{inf.}$ = 1.4

Plenum face
$P_{t,plenum}/P_{inf.}$ = 10.0
$T_{t,plenum}/T_{s,inf.}$ = 7.0

Bypass
$P_{t,bypass}/P_{inf.}$ = 2.4
$T_{t,bypass}/T_{s,inf.}$ = 2.0

C608 list

Providor	mesh	Sover	Limiter	Grid Spacing(Resolution)				
				1.28	1	0.8	0.64	0.5
SBPW	mixed	FaSTAR	venkat.(K=0.1)	✔	✔	✔	✔(Hishida->vK)	✔(Hishida->vK)
			B-J				✔	
			Hishida(VA)	✔	✔	✔	✔	✔
	tetrahedra		venkat.	✖	✖	✖	✖	
			Hishida(VA)	✔	✔	✔	✔	
JAXA	overset Hexa from mixed	UPACS	van albada	✔	✔	✔	✔	
	overset Hexa from tet			✔	✔	✔	✔	



→ submitted to SBPW

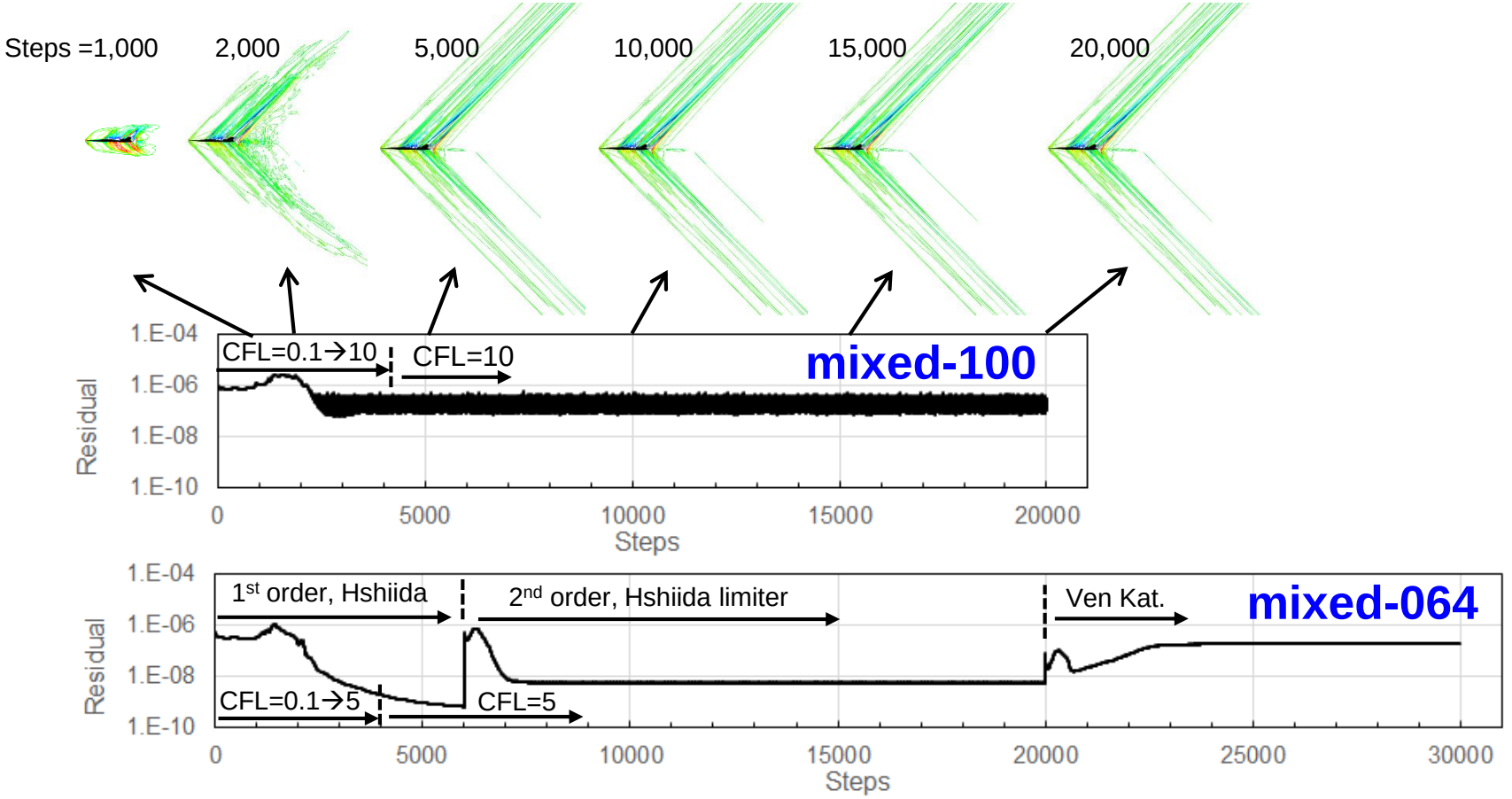
✔ → Simulation has been done.

✖ → Could not be calculated.

Flow solver convergence

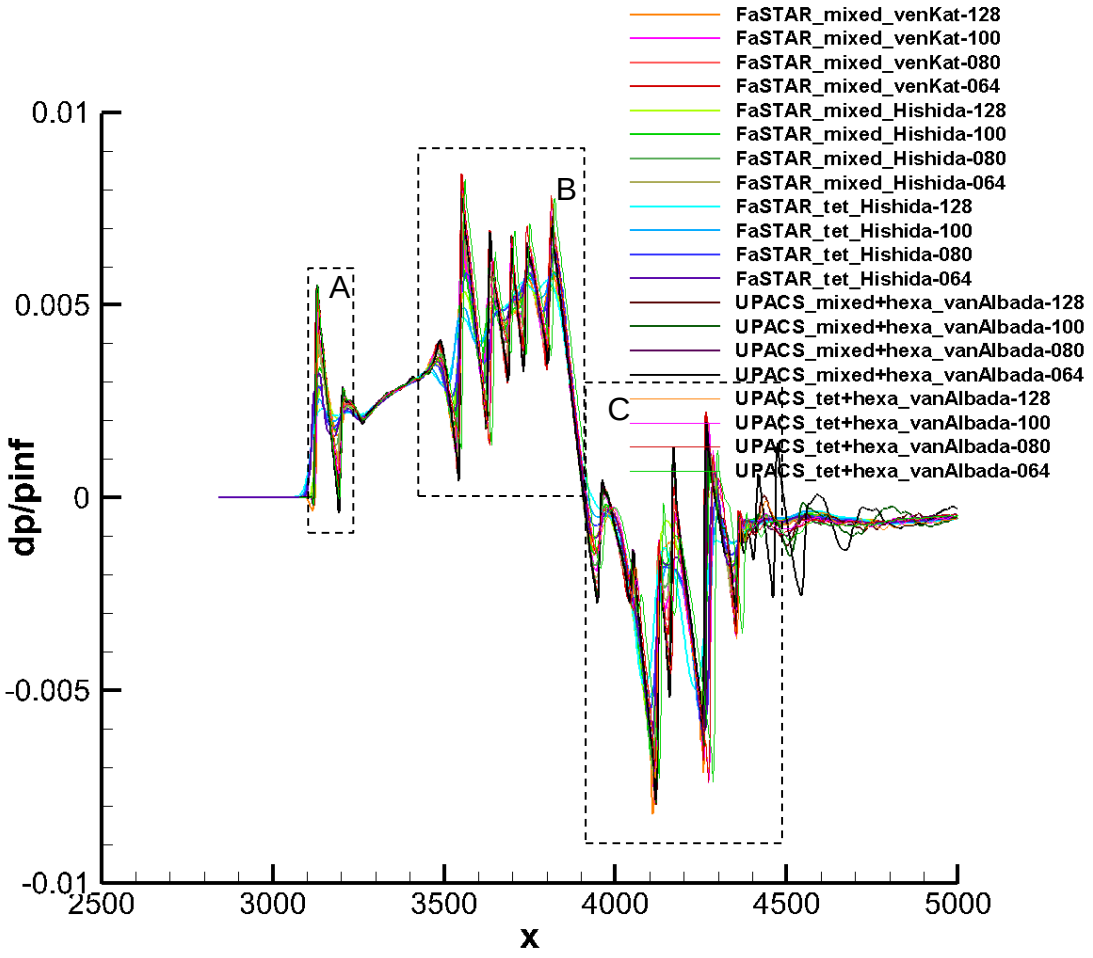
CFL number list

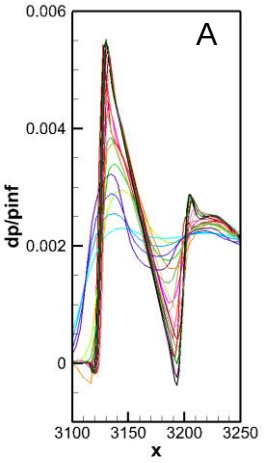
Providor	mesh	Sover	Limiter	Grid Spacing(Resolution)			
				1.28	1	0.8	0.64
SBPW	mixed	FaSTAR	venkat.	10	10	0.1->1->10	5
			Hishida(VA)	50	50	10	5
	tetrahedra		Hishida(VA)	10	10	10	10
JAXA	Hexa by mixed	UPACS	van albada	100	100	100	100
	Hexa by tet			100	100	100	100

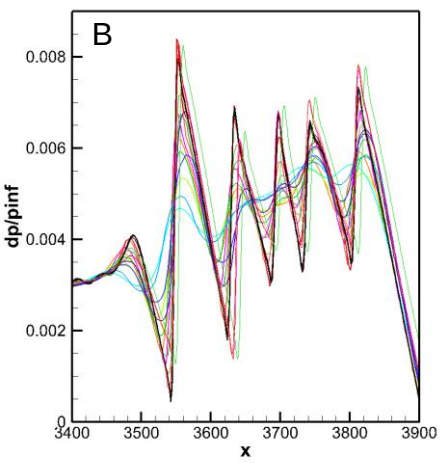


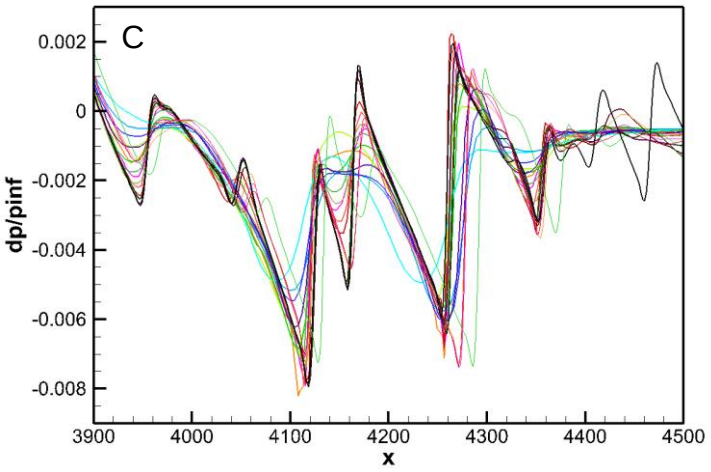
All signatures

Providor	mesh	Sover	Limiter	Grid Spacing			
				1.28	1	0.8	0.64
SBPW	mixed	FaSTAR	venkat.	✔	✔	✔	✔
			Hishida(VA)	✔	✔	✔	✔
	tet		Hishida(VA)	✔	✔	✔	✔
JAXA	mixed+Hexa	UPACS	van albada	✔	✔	✔	✔
	tet+Hexa			✔	✔	✔	✔



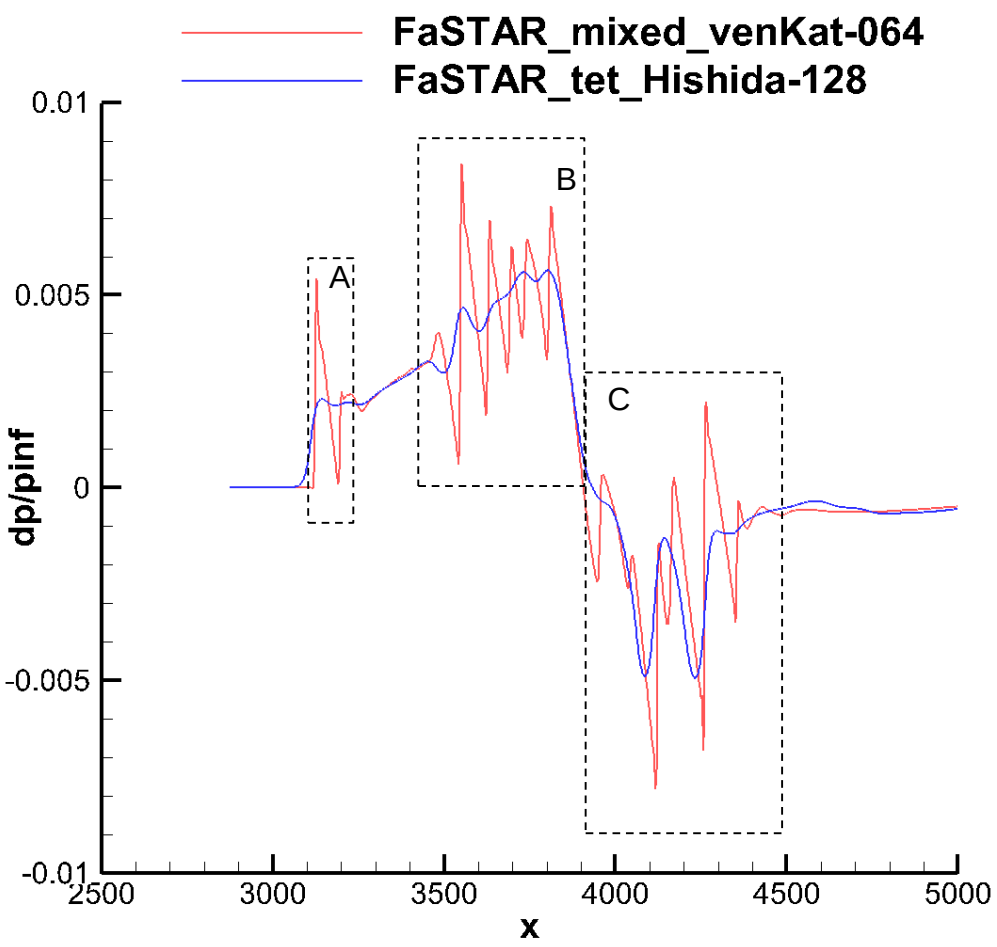


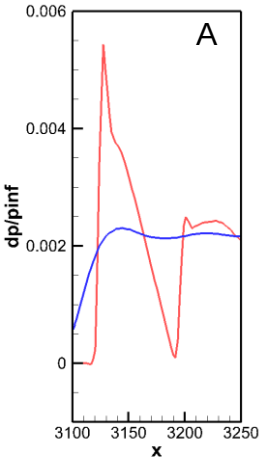


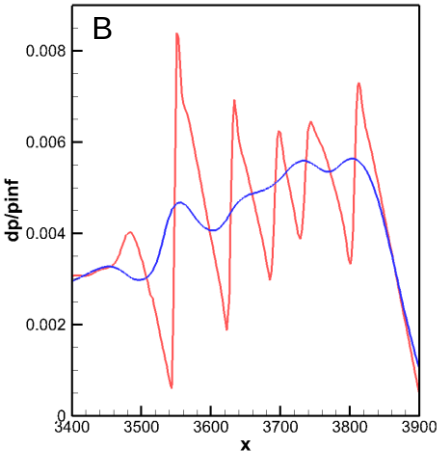


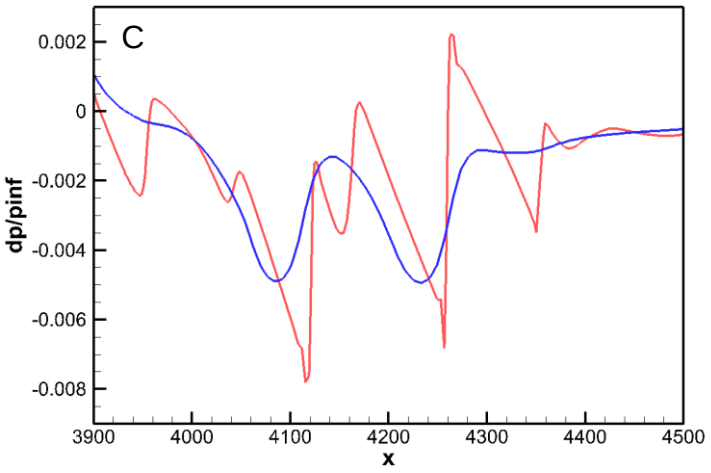
Reference Signatures

Providor	mesh	Sover	Limiter	Grid Spacing			
				1.28	1	0.8	0.64
SBPW	mixed	FaSTAR	venkat.	✔	✔	✔	✔
			Hishida(VA)	✔	✔	✔	✔
	tet		Hishida(VA)	✔	✔	✔	✔
JAXA	mixed+Hexa	UPACS	van albada	✔	✔	✔	✔
	tet+Hexa			✔	✔	✔	✔





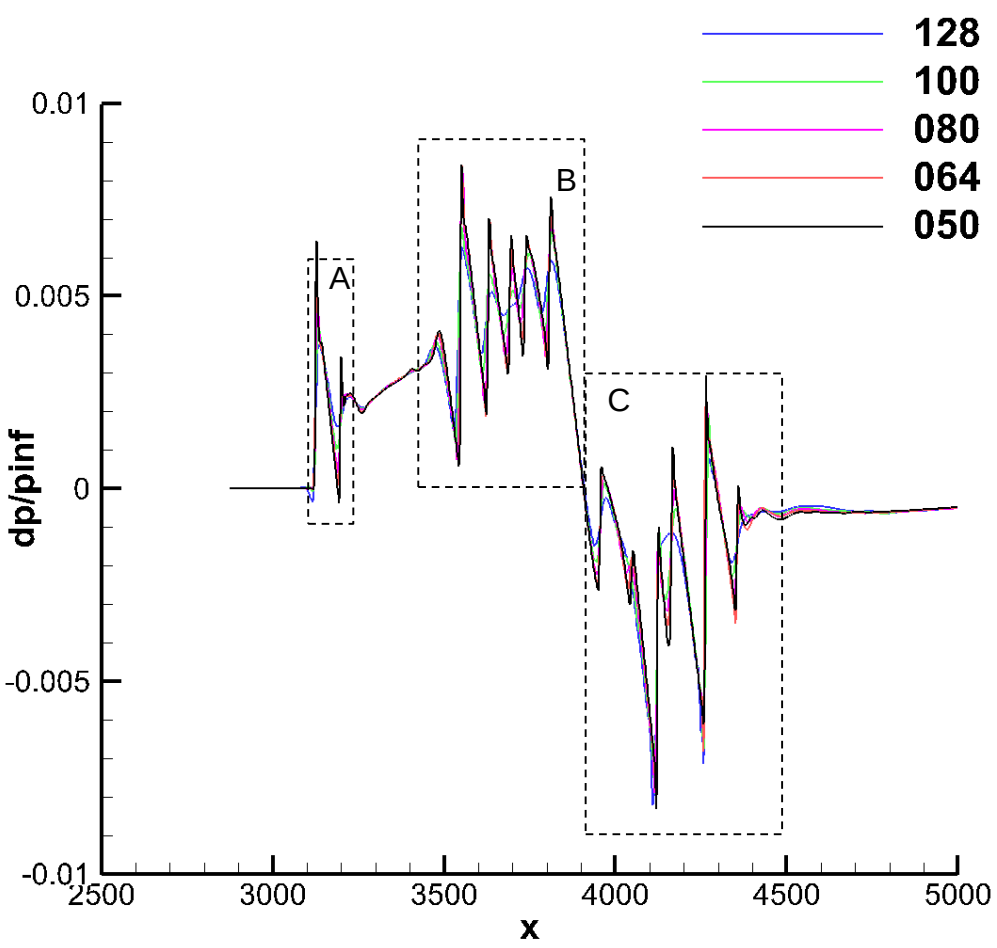


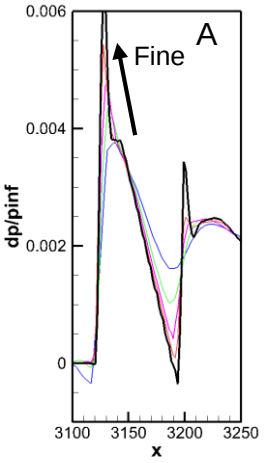


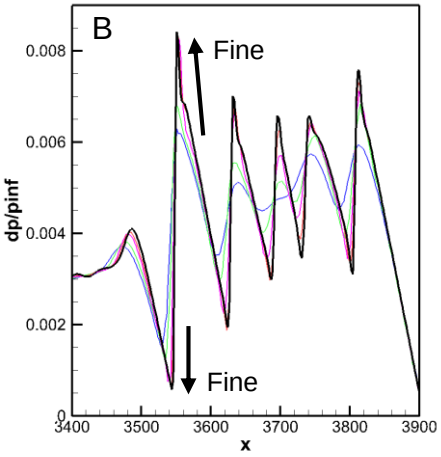
Grid resolution (128,100,80,64,50)

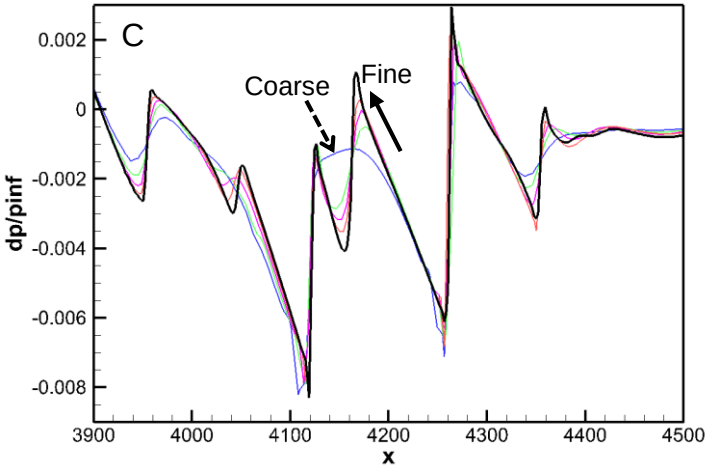
FaSTAR, mixed, venkat. limiter

Providor	mesh	Sover	Limiter	Grid Spacing				
				1.28	1	0.8	0.64	0.5
SBPW	mixed	FaSTAR	venkat.	✔	✔	✔	✔	✔
			Hishida(VA)	✔	✔	✔	✔	✔
	tet		Hishida(VA)	✔	✔	✔	✔	
JAXA	mixed+Hexa	UPACS	van albada	✔	✔	✔	✔	
	tet+Hexa			✔	✔	✔	✔	





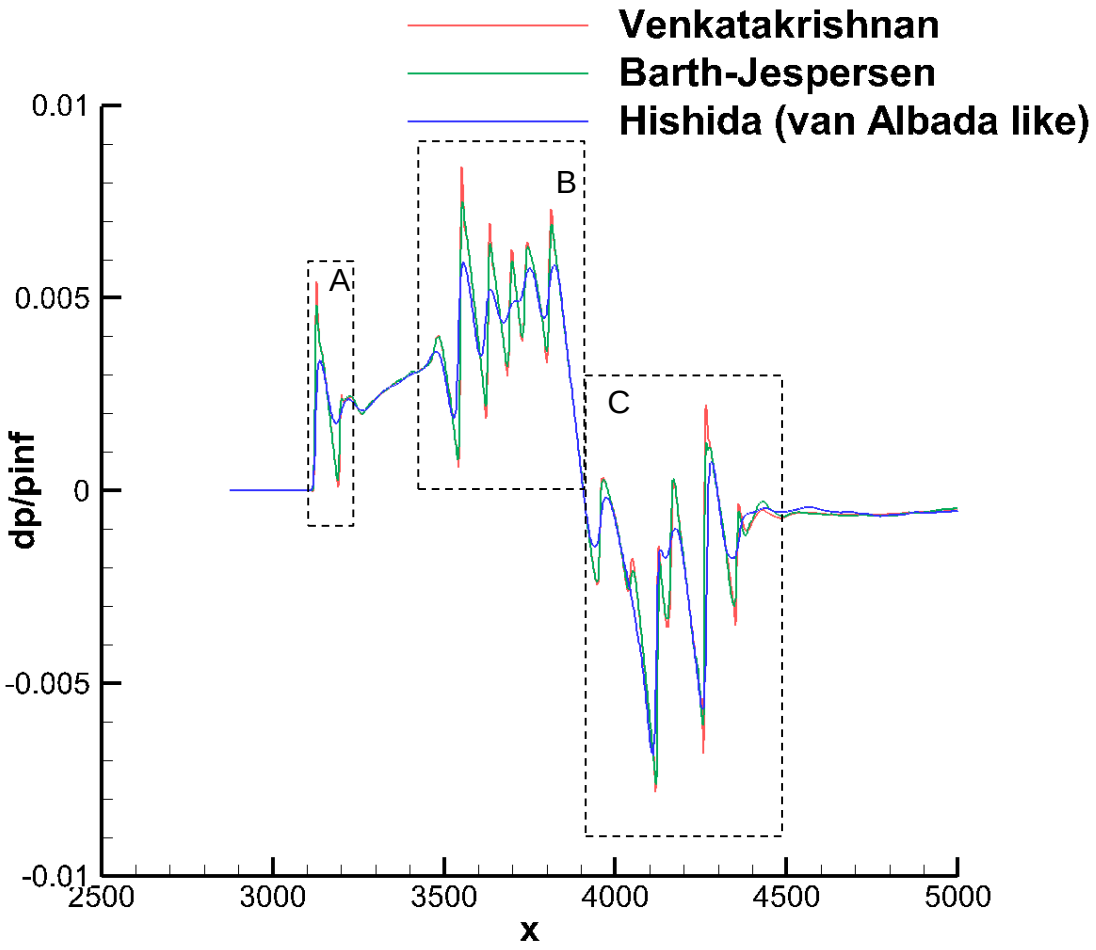


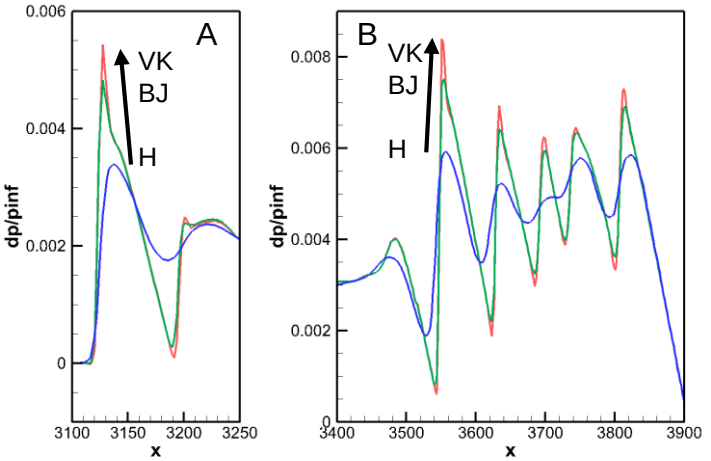


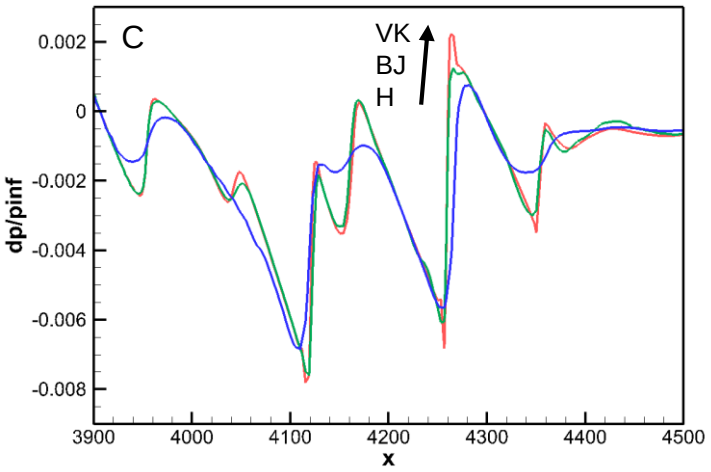
Limiter function

FaSTAR, mixed-064

Providor	mesh	Sover	Limiter	Grid Spacing			
				1.28	1	0.8	0.64
SBPW	mixed	FaSTAR	venkat.	✔	✔	✔	✔
			B-J				✔
			Hishida(VA)	✔	✔	✔	✔
	tet		Hishida(VA)	✔	✔	✔	✔
JAXA	mixed+Hexa	UPACS	van albada	✔	✔	✔	✔
	tet+Hexa			✔	✔	✔	✔



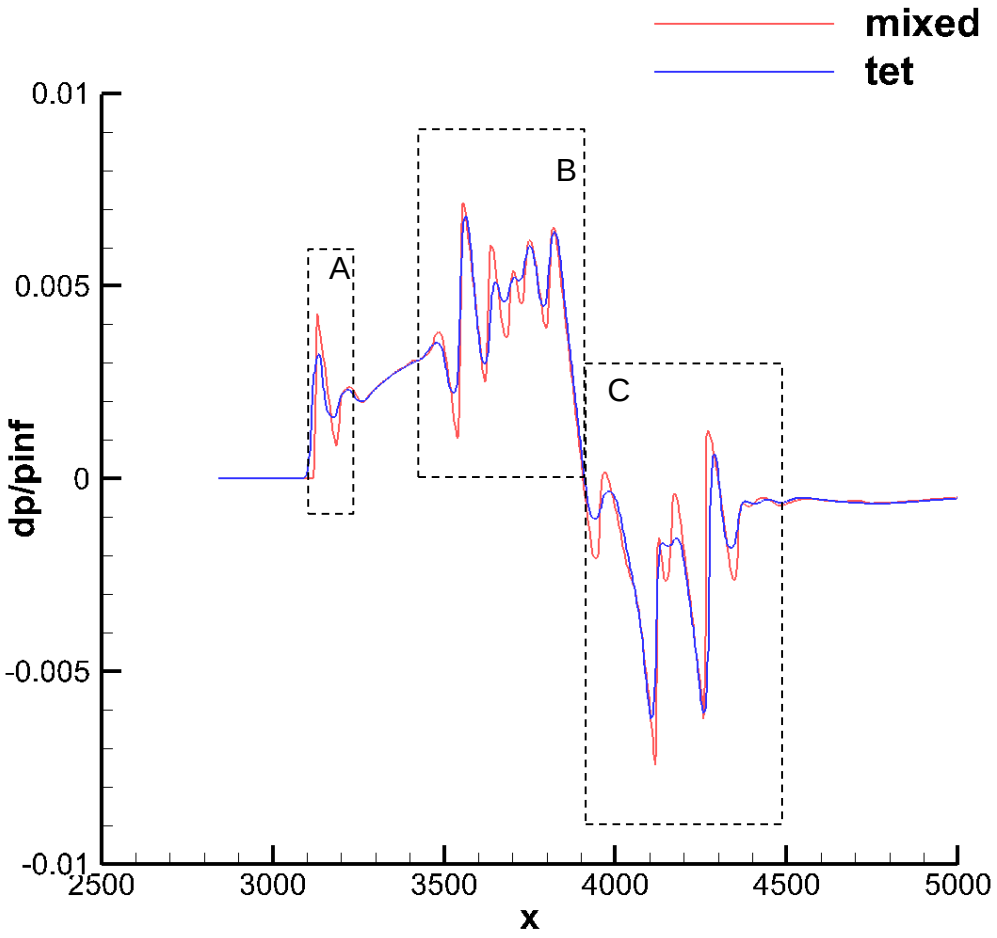


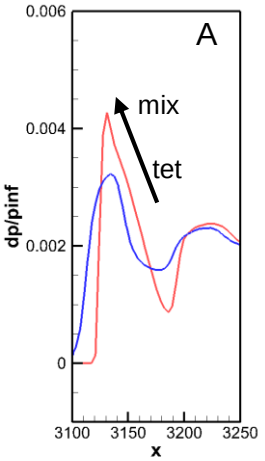


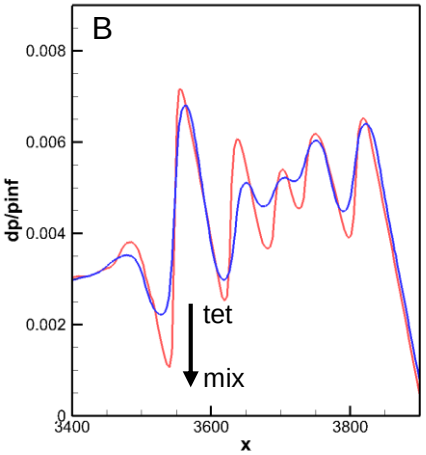
mixed - tet

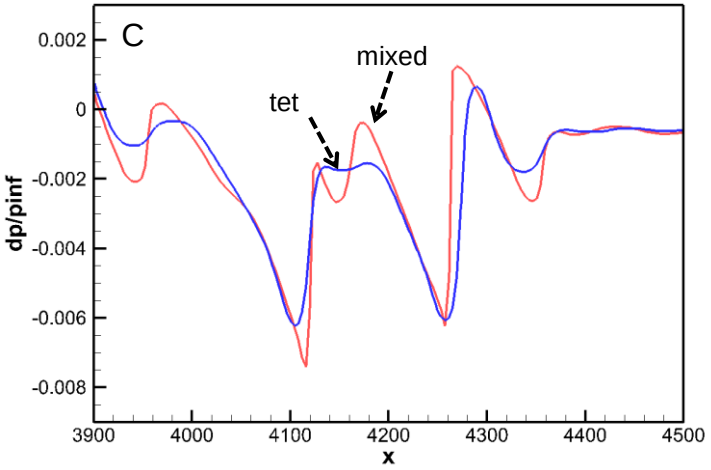
FaSTAR, Hishida limiter, 064

Providor	mesh	Sover	Limiter	Grid Spacing			
				1.28	1	0.8	0.64
SBPW	mixed	FaSTAR	venkat.	✔	✔	✔	✔
			Hishida(VA)	✔	✔	✔	✔
	tet		Hishida(VA)	✔	✔	✔	✔
JAXA	mixed+Hexa	UPACS	van albada	✔	✔	✔	✔
	tet+Hexa			✔	✔	✔	✔





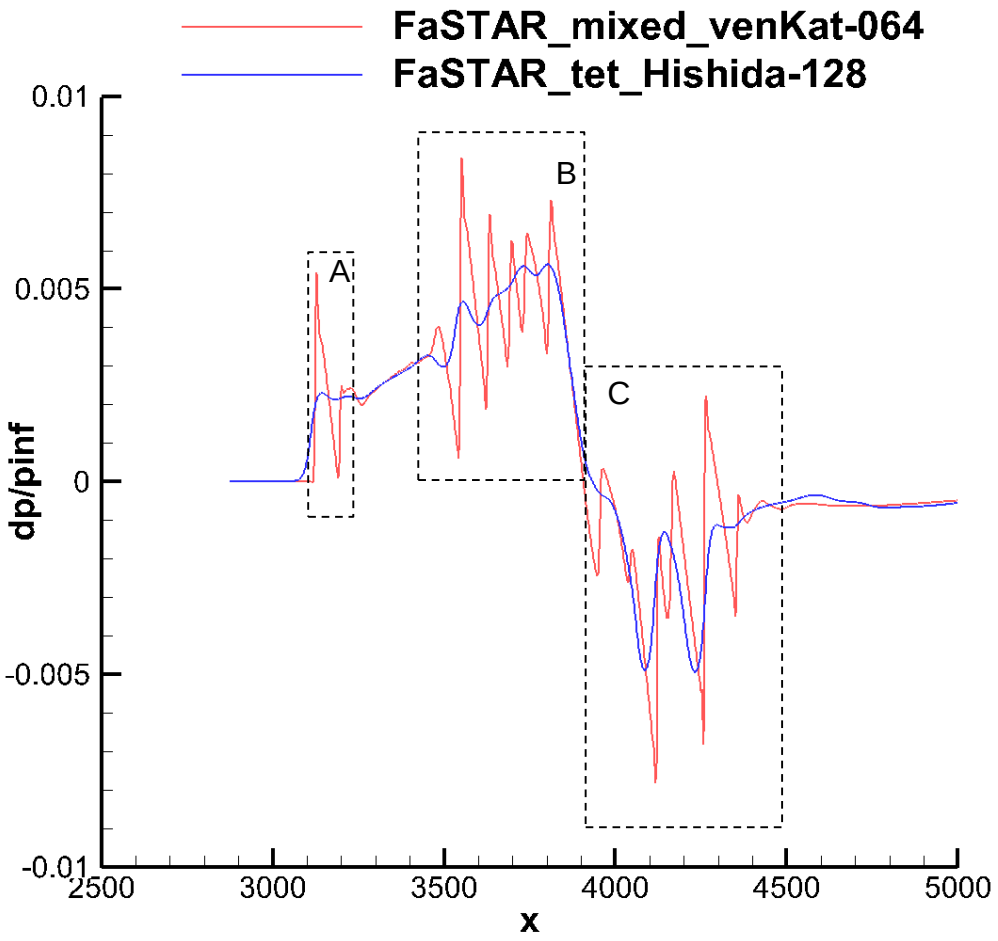


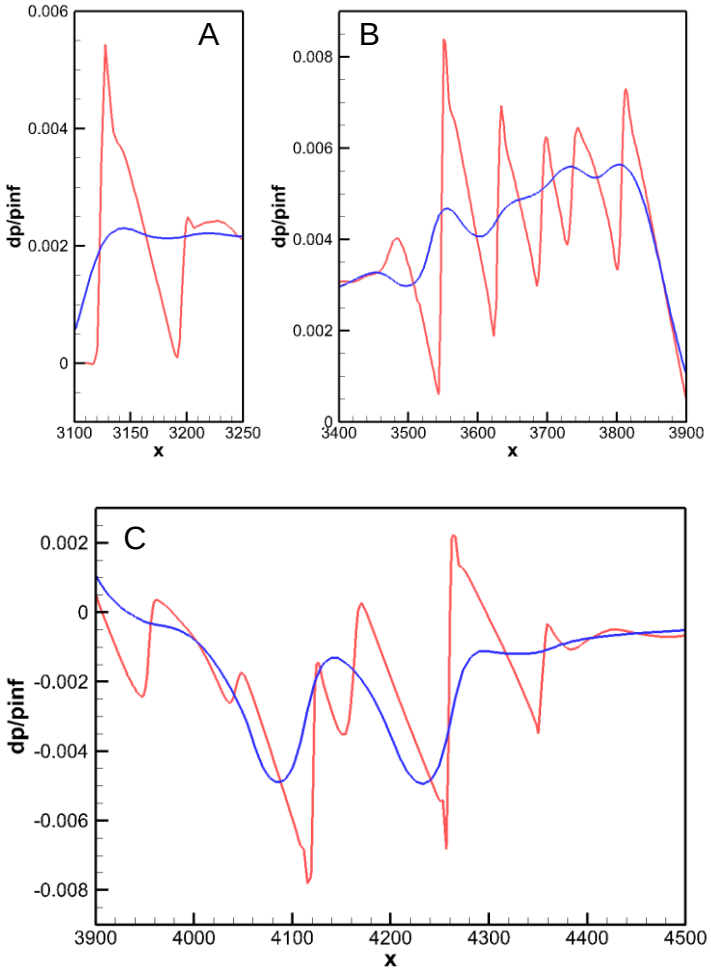


Reference Signatures

	Blunt	Sharp
Grid resolution	128 →	050
Grid type	tet →	mixed
Limiter	Hishida → B-J →	Venkat.

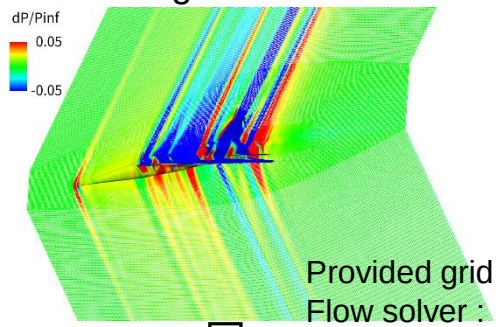
dor	mesh	Sover	Limiter	Grid Spacing			
				1.28	1	0.8	0.64
W	mixed	FaSTAR	venkat.	✔	✔	✔	✔
			Hishida(VA)	✔	✔	✔	✔
	tet		Hishida(VA)	✔	✔	✔	✔
A	mixed+Hexa	UPACS	van albada	✔	✔	✔	✔
	tet+Hexa			✔	✔	✔	✔





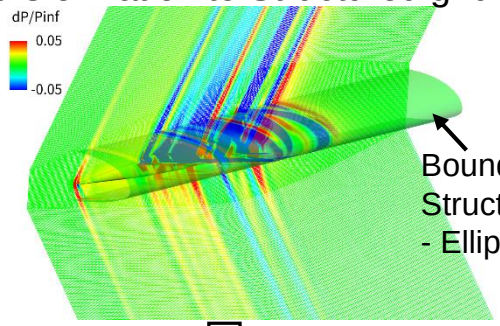
Unstructured/Structured overset method

1. Unstructured grid simulation



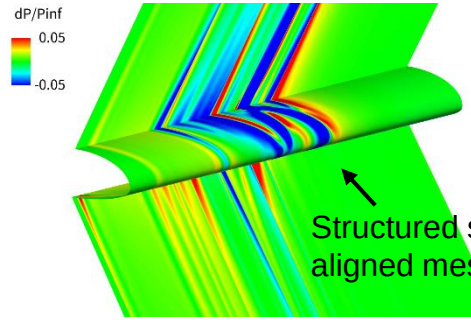
Provided grid by SBPW
Flow solver : FaSTAR

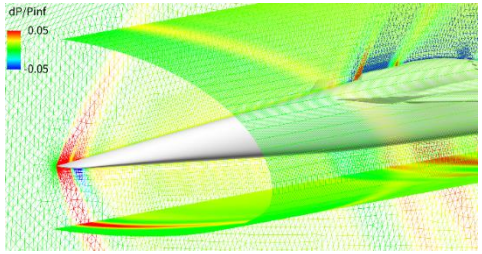
2. Transformation to Structured grid



Boundary surface of
Structured mesh
- Elliptic cylinder

3. Structured grid simulation





Structured shock
aligned mesh

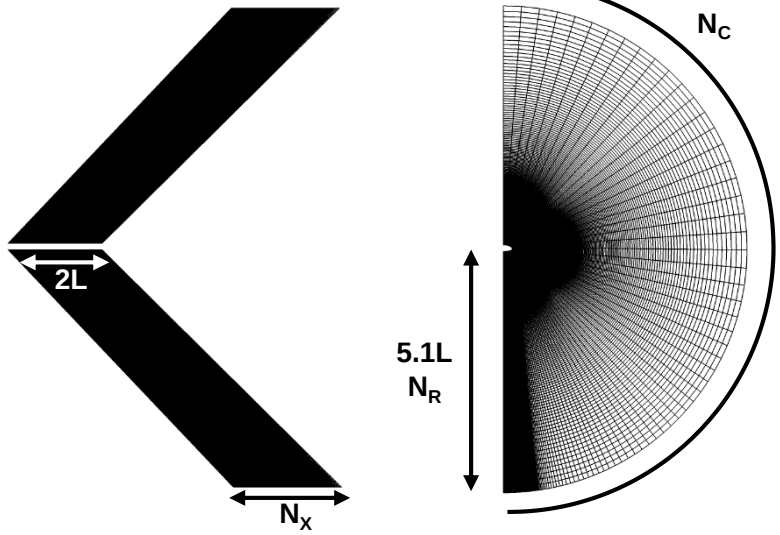
Grid generation : MBG(Make Boom Grid)
Flow solver : UPACS

◆ Specification of Structured grid

N_X	N_R	N_C
1200	400	111

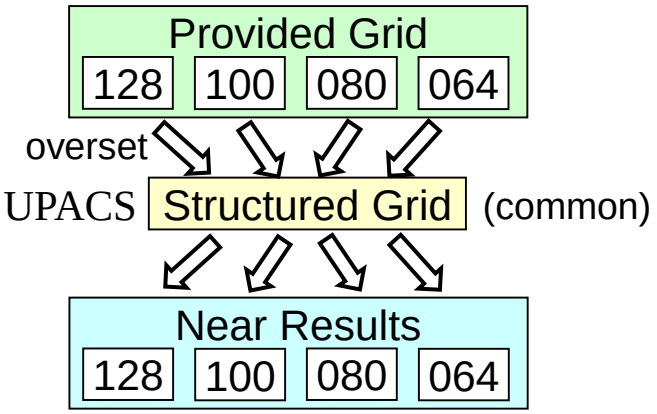
◆ Total Grid (million)

Nodes	Cells
55	53



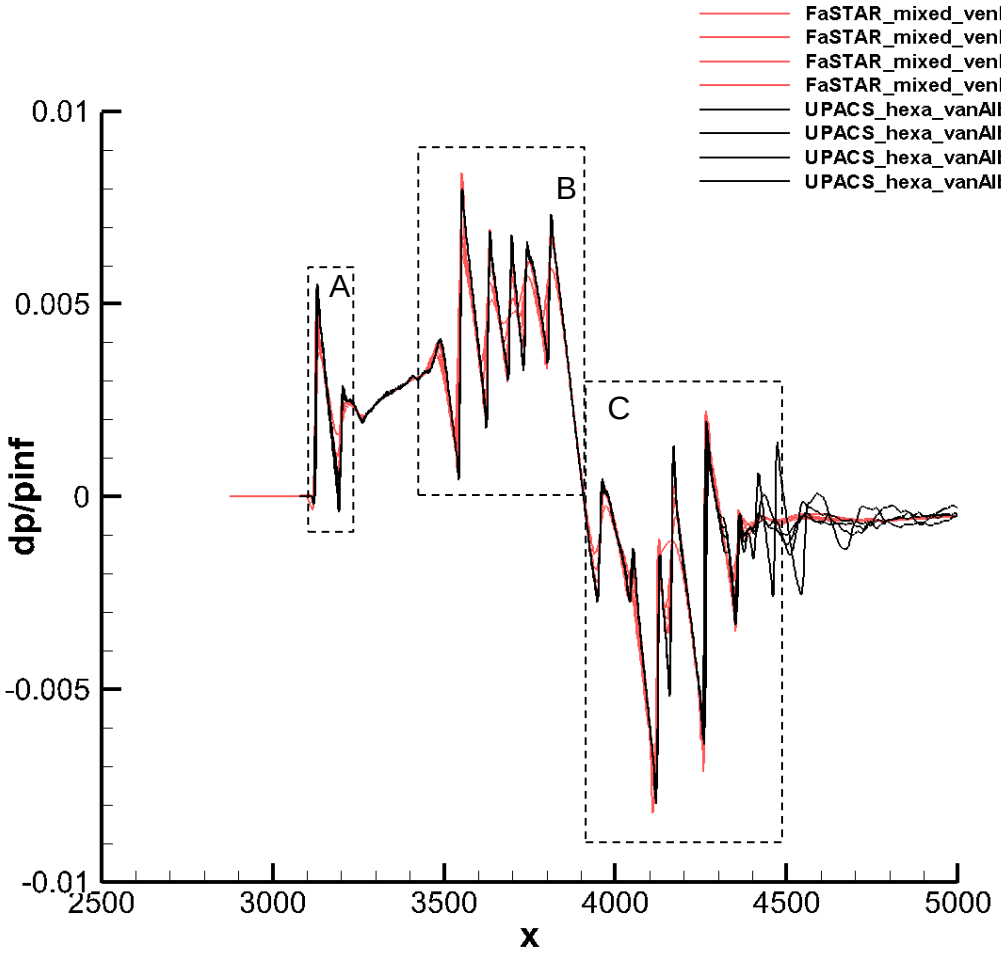
◆ Simulation image

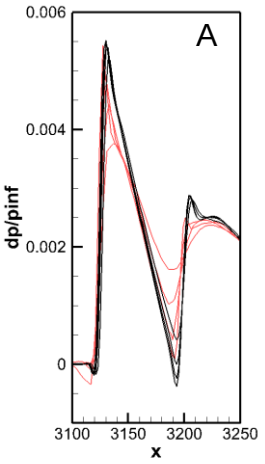
FaSTAR

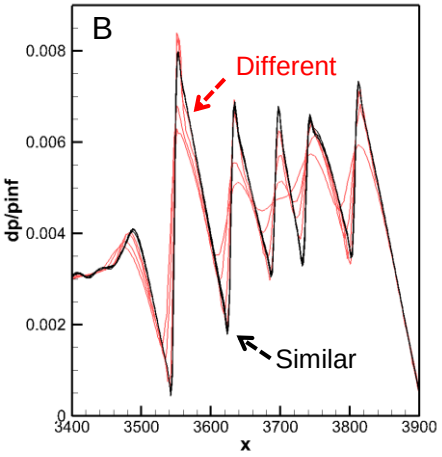


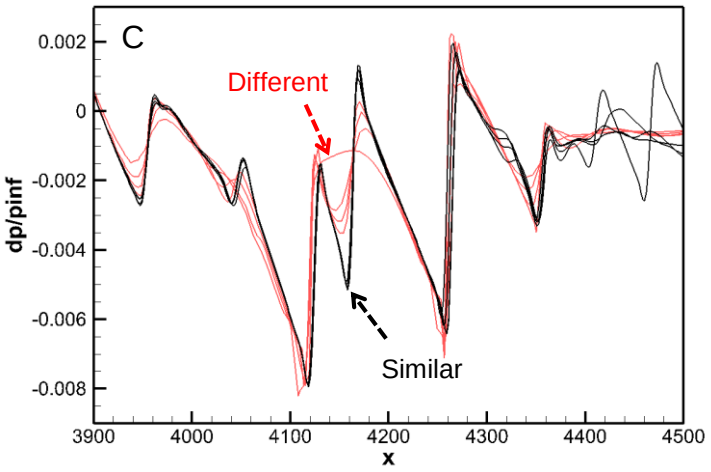
Mixed FaSTAR – overset UPACS

Providor	mesh	Sover	Limiter	Grid Spacing			
				1.28	1	0.8	0.64
SBPW	mixed	FaSTAR	venkat.	✔	✔	✔	✔
			Hishida(VA)	✔	✔	✔	✔
	tet		Hishida(VA)	✔	✔	✔	✔
JAXA	mixed+Hexa	UPACS	van albada	✔	✔	✔	✔
	tet+Hexa			✔	✔	✔	✔





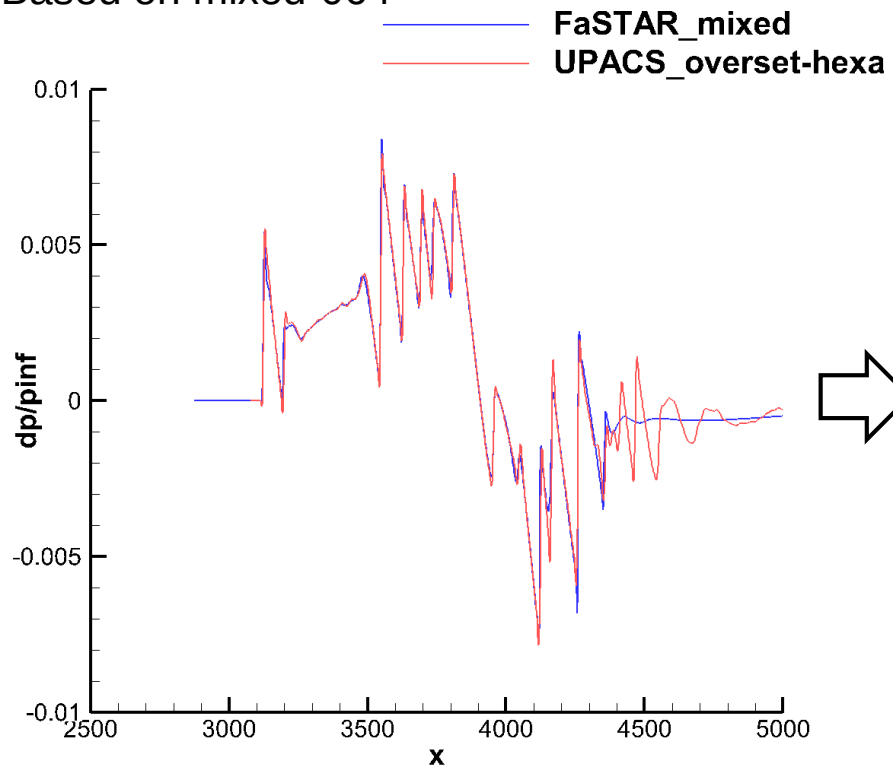




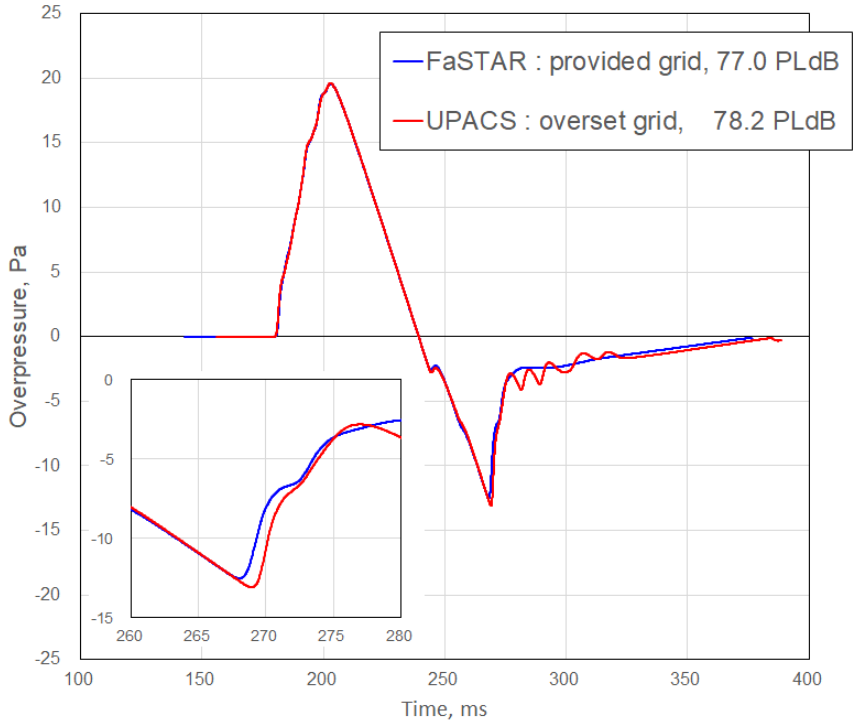
Fine grid (mixed-064)

Providor	mesh	Sover	Limiter	Grid Spacing			
				1.28	1	0.8	0.64
SBPW	mixed	FaSTAR	venkat.	✔	✔	✔	✔
			Hishida(VA)	✔	✔	✔	✔
	tet		Hishida(VA)	✔	✔	✔	✔
JAXA	mixed+Hexa	UPACS	van albada	✔	✔	✔	✔
	tet+Hexa			✔	✔	✔	✔

Based on mixed-064



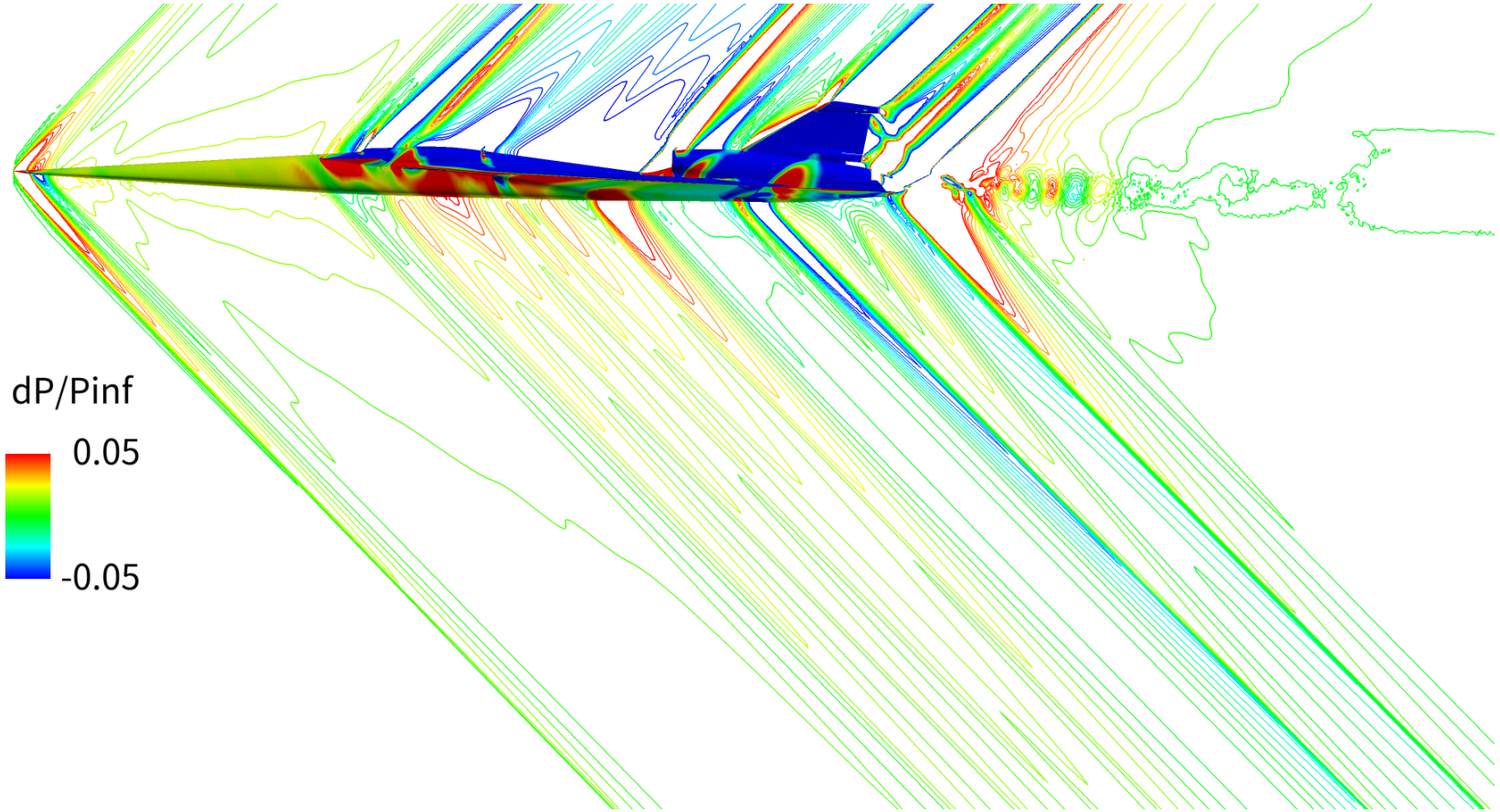
Near-field signature



Ground signature

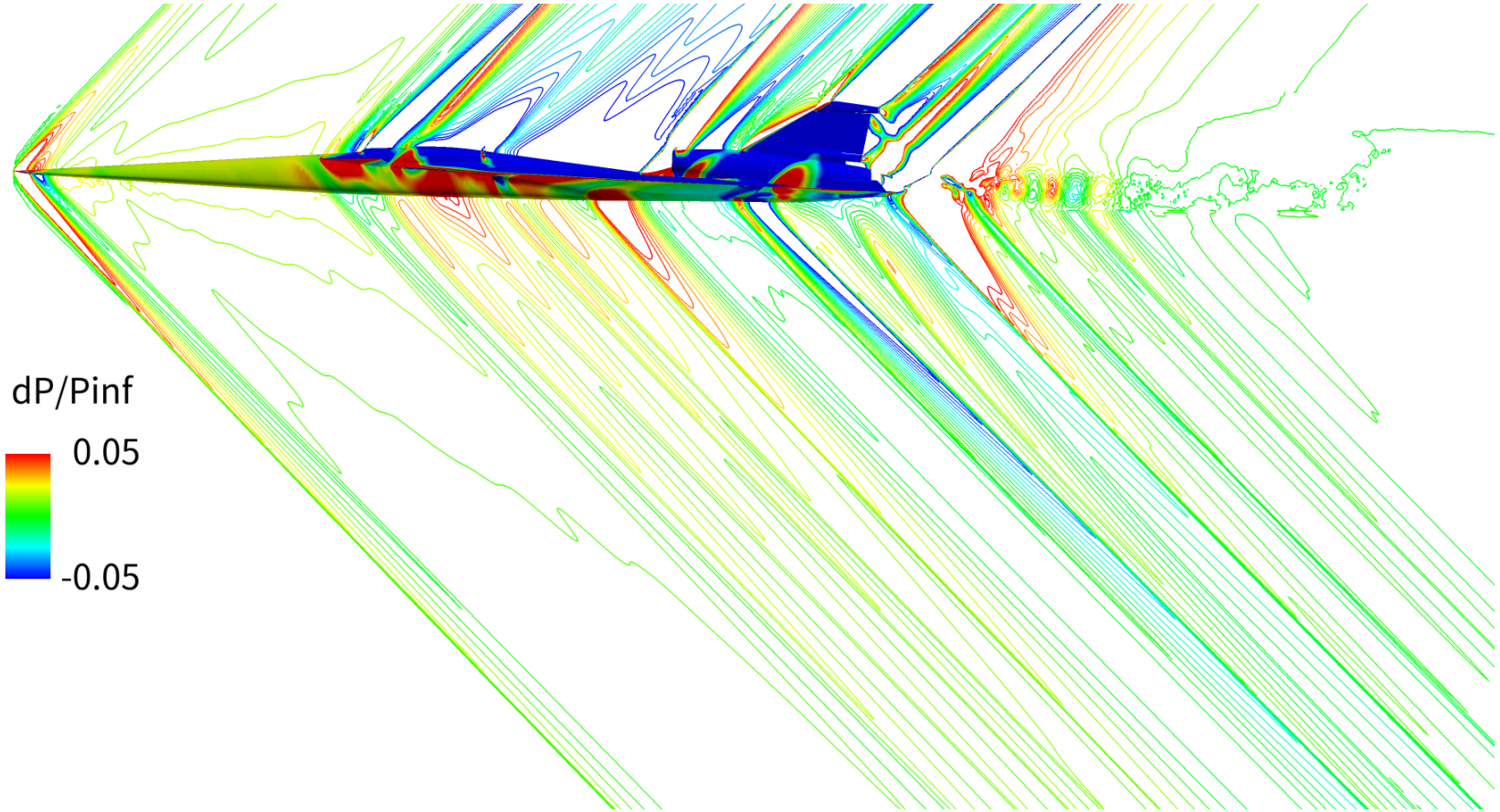
dP distribution (mixed-064)

Providor	mesh	Sover	Limiter	Grid Spacing			
				1.28	1	0.8	0.64
SBPW	mixed	FaSTAR	ven Kat.	✔	✔	✔	✔
			Hishida(VA)	✔	✔	✔	✔
	tet		Hishida(VA)	✔	✔	✔	✔
JAXA	mixed+Hexa	UPACS	van albada	✔	✔	✔	✔
	tet+Hexa			✔	✔	✔	✔



dP distribution (overset-064)

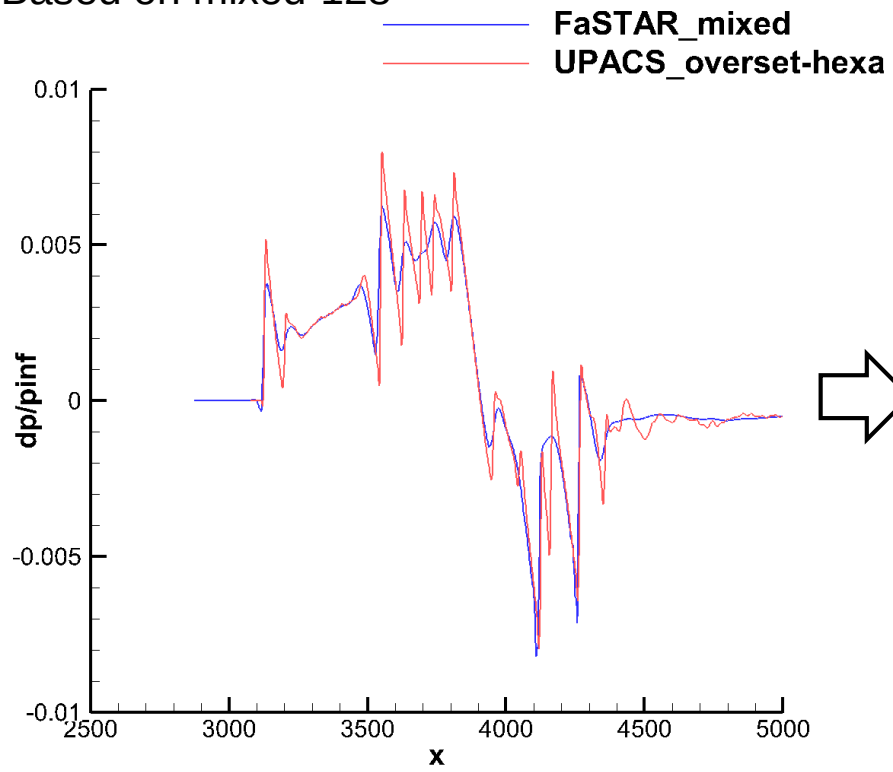
Providor	mesh	Sover	Limiter	Grid Spacing			
				1.28	1	0.8	0.64
SBPW	mixed	FaSTAR	ven Kat.	✔	✔	✔	✔
			Hishida(VA)	✔	✔	✔	✔
	tet		Hishida(VA)	✔	✔	✔	✔
JAXA	mixed+Hexa	UPACS	van albada	✔	✔	✔	✔
	tet+Hexa			✔	✔	✔	✔



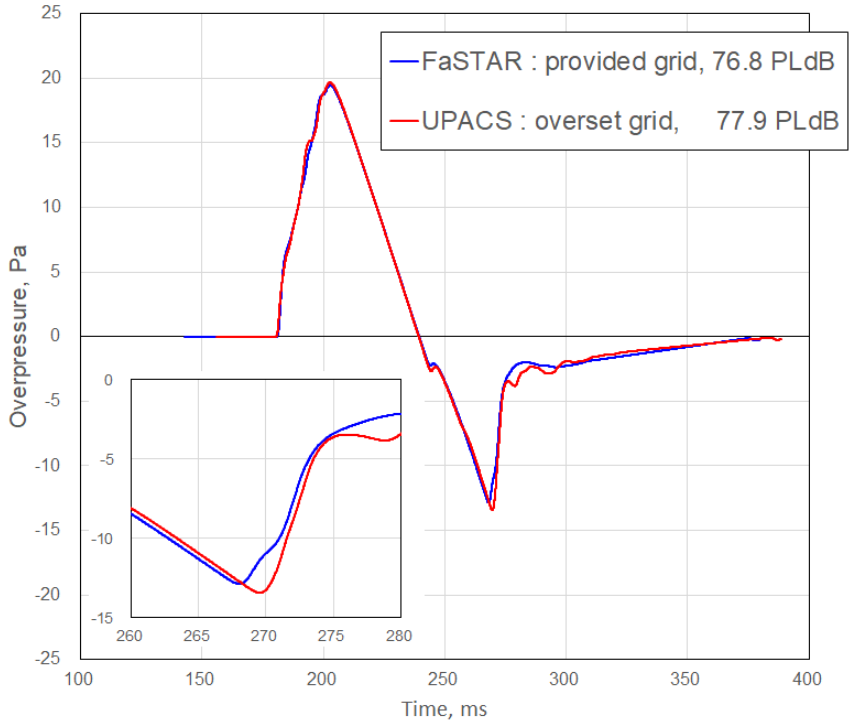
Coarse grid (mixed-128)

Providor	mesh	Sover	Limiter	Grid Spacing			
				1.28	1	0.8	0.64
SBPW	mixed	FaSTAR	venkat.	✔	✔	✔	✔
			Hishida(VA)	✔	✔	✔	✔
	tet		Hishida(VA)	✔	✔	✔	✔
JAXA	mixed+Hexa	UPACS	van albada	✔	✔	✔	✔
	tet+Hexa			✔	✔	✔	✔

Based on mixed-128



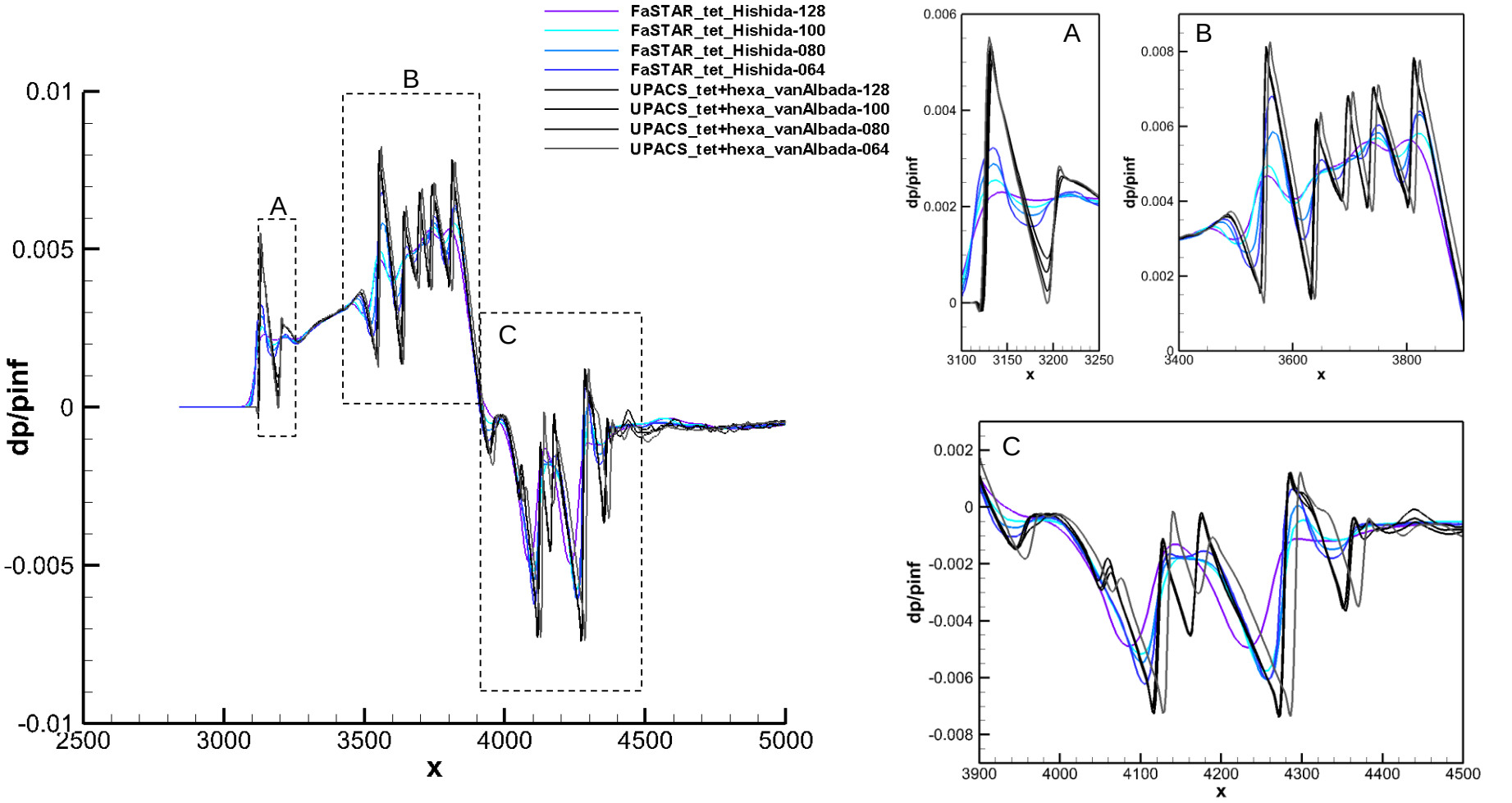
Near-field signature



Ground signature

Tet FaSTAR – overset UPACS

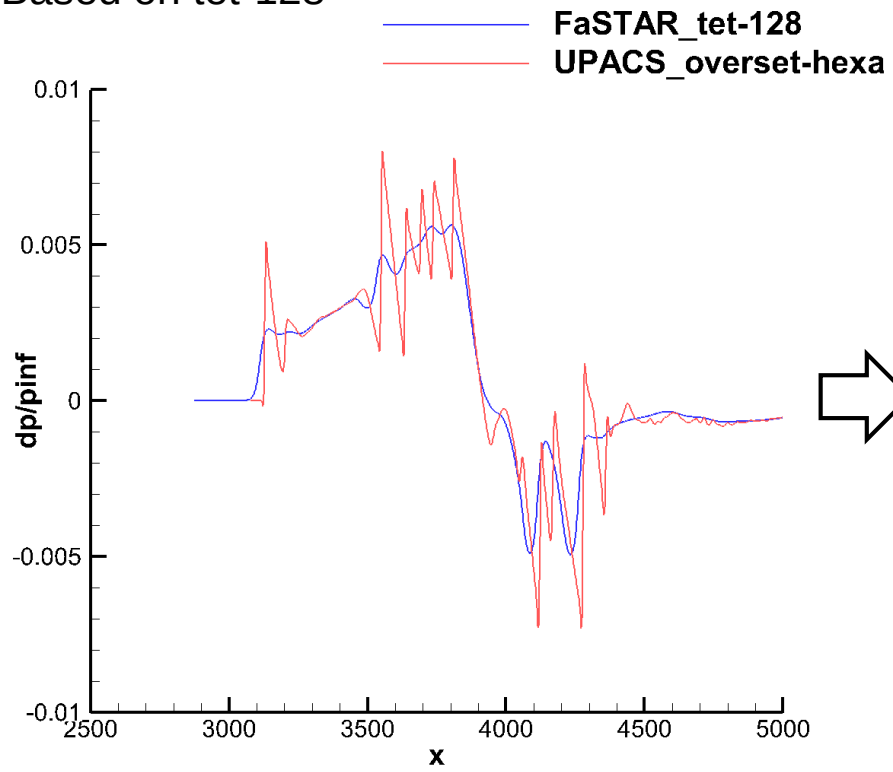
Providor	mesh	Sover	Limiter	Grid Spacing			
				1.28	1	0.8	0.64
SBPW	mixed	FaSTAR	venkat.	✔	✔	✔	✔
			Hishida(VA)	✔	✔	✔	✔
	tet		Hishida(VA)	✔	✔	✔	✔
JAXA	mixed+Hexa	UPACS	van albada	✔	✔	✔	✔
	tet+Hexa			✔	✔	✔	✔



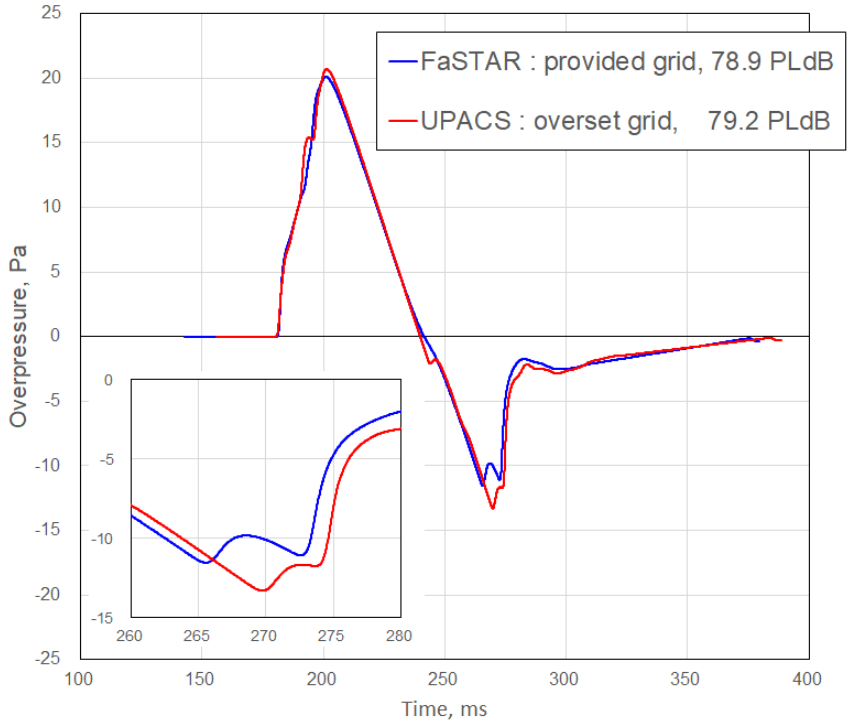
Coarse grid (tet-128)

Providor	mesh	Sover	Limiter	Grid Spacing			
				1.28	1	0.8	0.64
SBPW	mixed	FaSTAR	venkat.	✔	✔	✔	✔
			Hishida(VA)	✔	✔	✔	✔
	tet		Hishida(VA)	✔	✔	✔	✔
JAXA	mixed+Hexa	UPACS	van albada	✔	✔	✔	✔
	tet+Hexa			✔	✔	✔	✔

Based on tet-128



Near-field signature



Ground signature

Conclusion

- **Analyzed cases**

  The biconvex and The C608 + JAXA's own overset structured grid

- **Provided mesh analysis**

	Blunt		Sharp
Grid resolution	157	→	100
Grid type	tet	→	mixed
Limiter	Hishida	→ B-J →	venkat.
Limiter factor(VK)	0.01	→	10

  TAS & FaSTAR results are almost same.

- **Unstructured/Structured overset method**

  Variations due to the CFD analysis were suppressed by the unstructured/structured overset grid method.

  The calculation accuracy in the region away from the model is essential.

- **Ground signature / loudness**

  A clear difference like the near-field signature is small in the ground signature, however, ground level loudness difference of 2 dB was show.