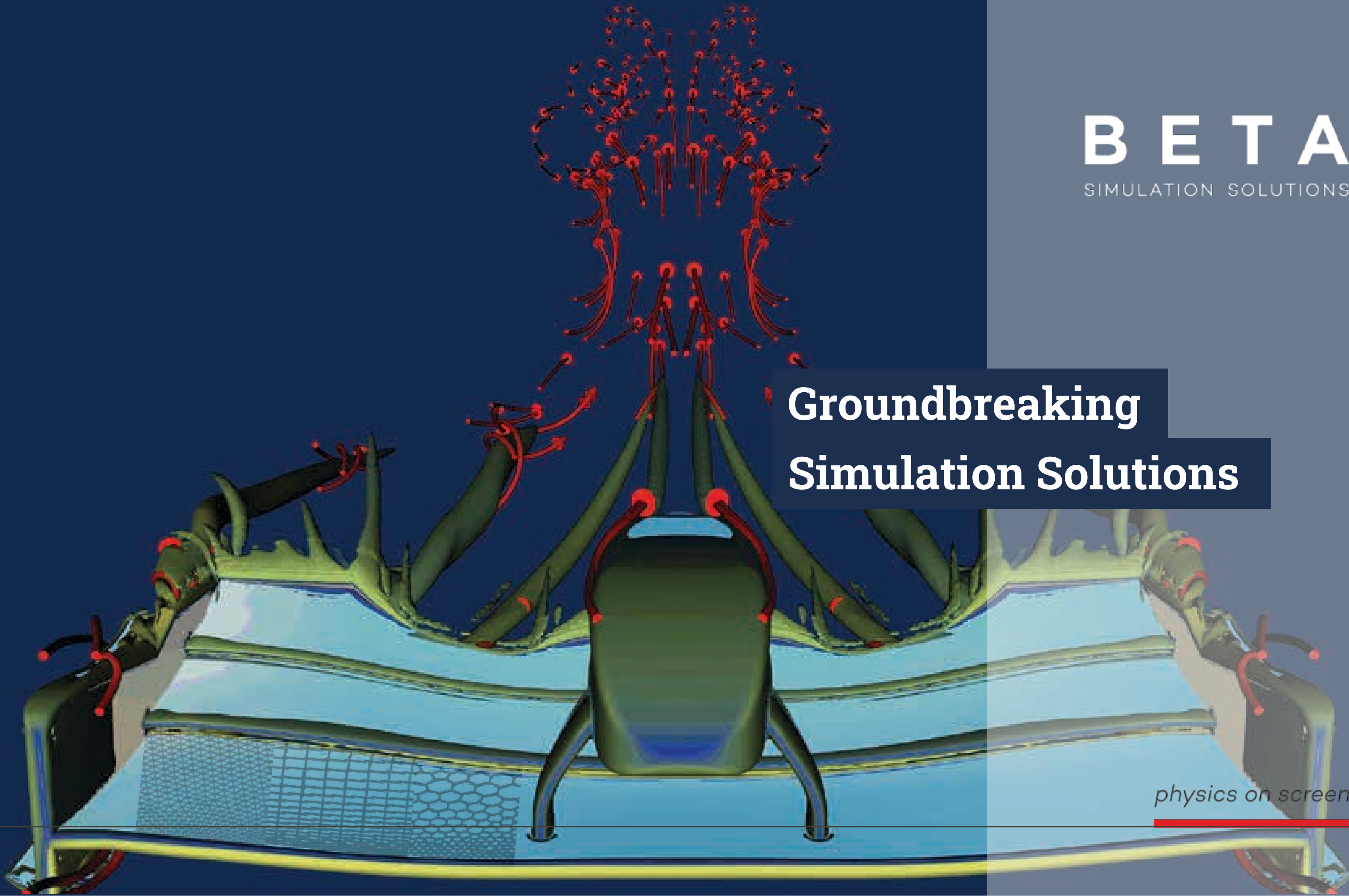


BETA
SIMULATION SOLUTIONS

Groundbreaking Simulation Solutions

physics on screen

Suitability of meshing strategies for CFD

N Mitroglou – BETA CAE Systems UK

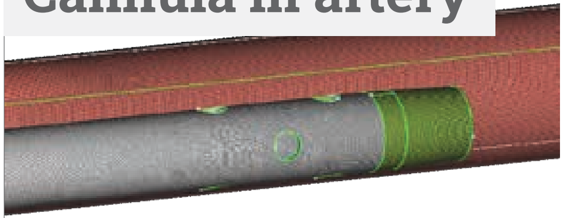
physics on screen

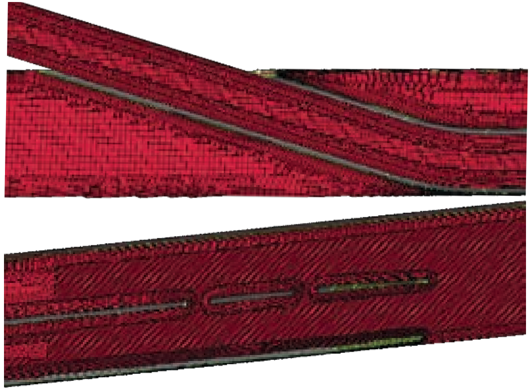
Background

- Traditional surface and volume meshing is still the preferred choice for high-fidelity CFD results
- Hexahedral elements are still considered ideal for CFD solvers
- Polyhedral elements are considered the “next-big-thing”
- Numerous combinations of surface, layers and volume mesh types
- Do we know the “best” choice for any one case?
  - Motorsports community prefers triangular surface mesh
  - The aerospace industry has no other option, but vote for quadrilaterals

Motivation

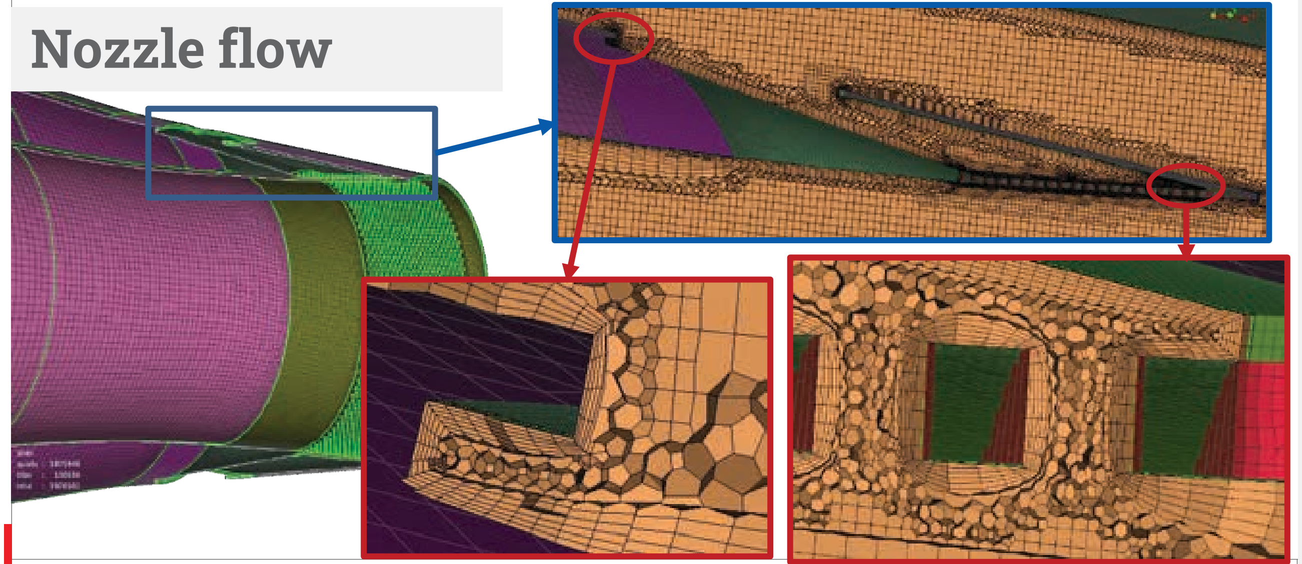
Cannula in artery





Dr Zhong-Nan Wang
University of Birmingham

Nozzle flow



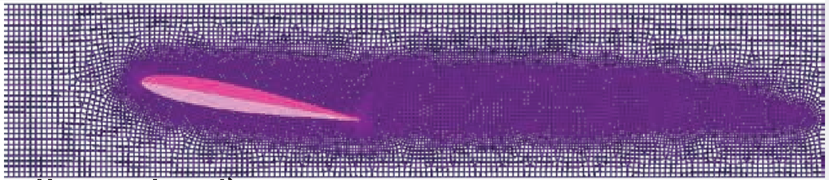
Internal & external flows

Highly complex models

Mesh sizes from 15 – 125M

Hexahedrals ~85%
Polyhedrals ~14%

NACA 0012 Wingtip vortex

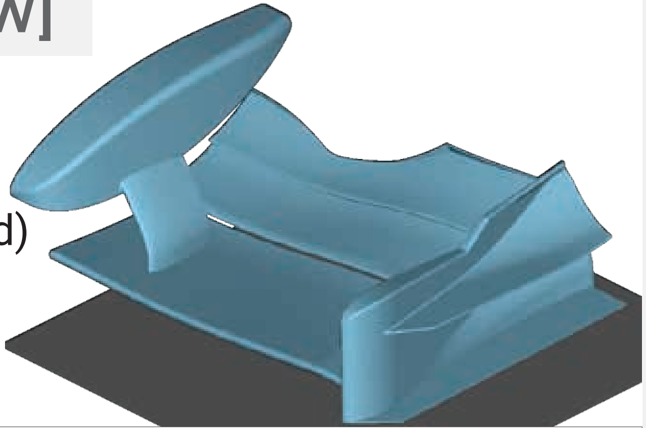


Solver: Flow360

Steady-state (RANS – wall-resolved)

4 mesh types

Imperial Front Wing [IFW]



Solver: Fluent 2022

Transient (URANS – wall-resolved)

12 mesh-type combinations

https://data.hpc.imperial.ac.uk/resolve/?doi=6049

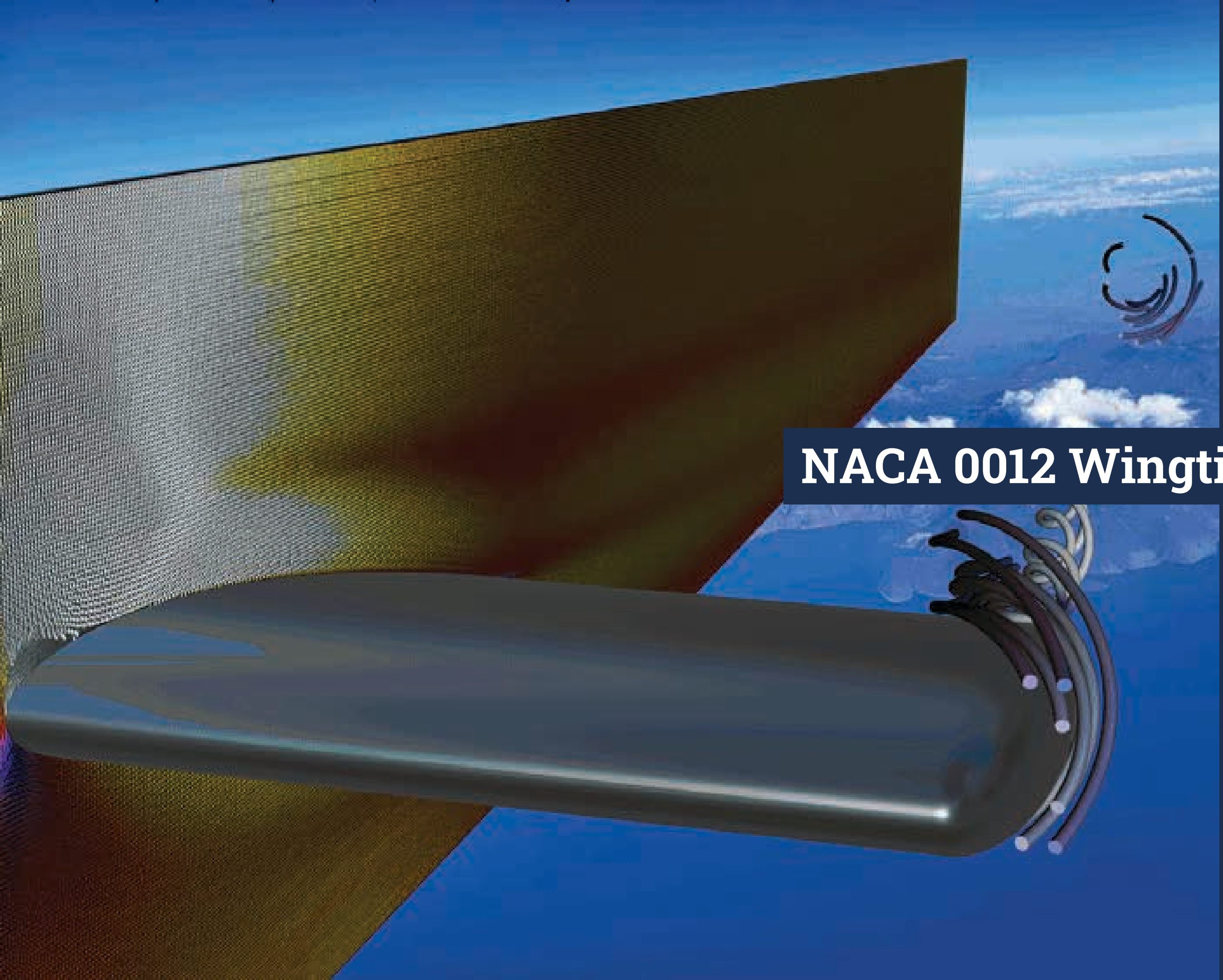
Introduction

Experimentally validated cases

An aerospace model

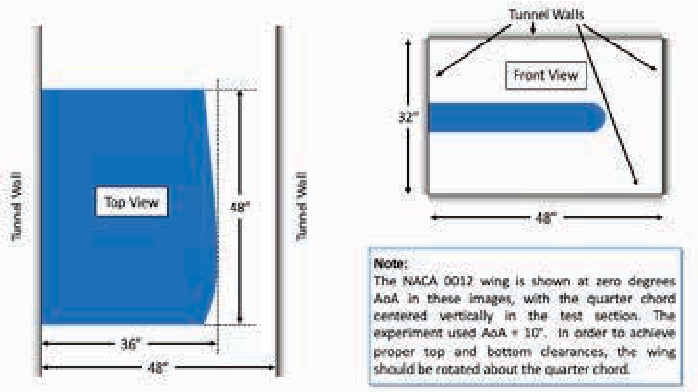
A motorsports model

Numerous mesh types

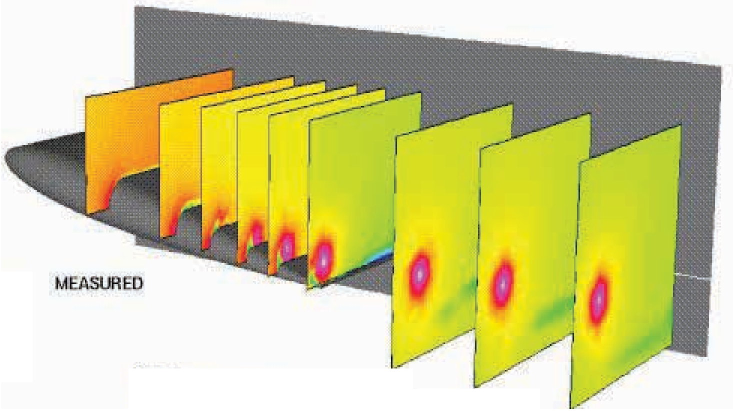


NACA 0012 Wingtip Vortex

Model setup



Exp. Results include planar velocity contours



https://turbmodels.larc.nasa.gov/Other_exp_Data/wingtip0012_exp.html

NACA 0012 Wingtip vortex

Data from NASA Ames - Turbulence Modelling Resource

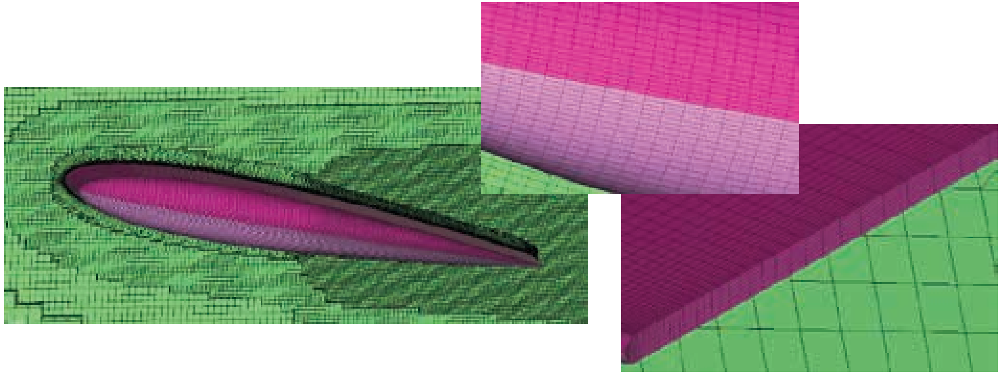
Light geometry

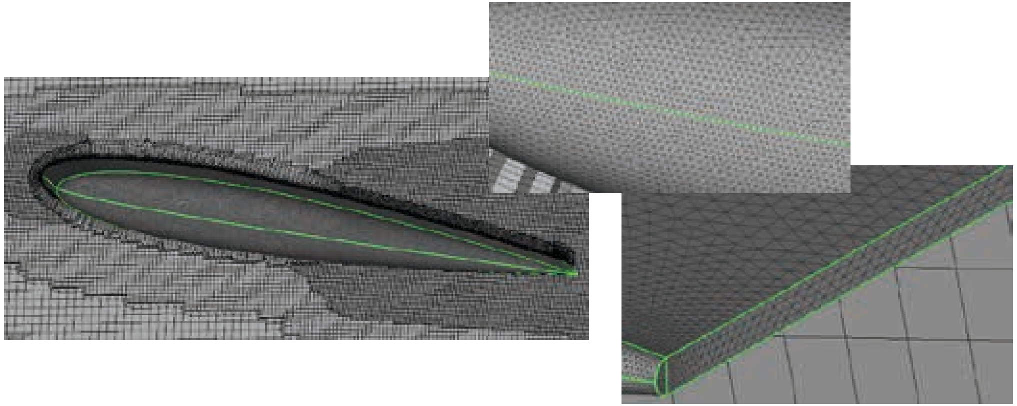
10° AoA

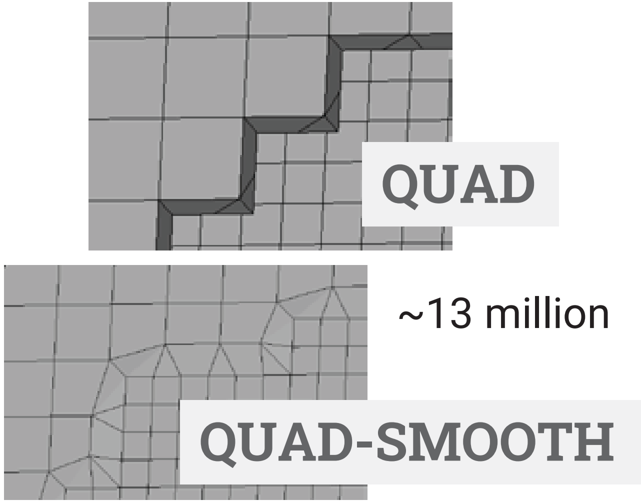
U_∞ = 0.152M (51.816m/s)

Tunnel length is 8.5m

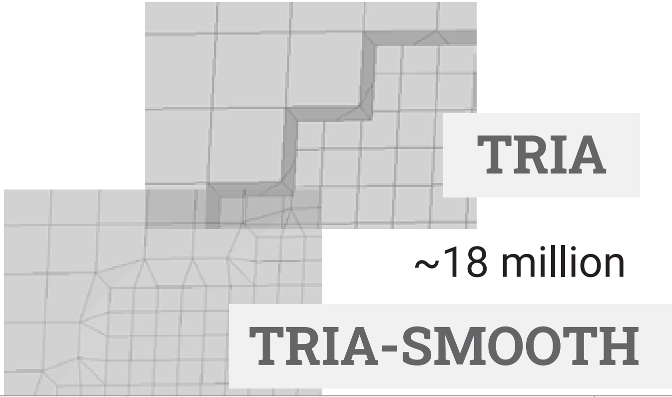
NACA 0012 Models







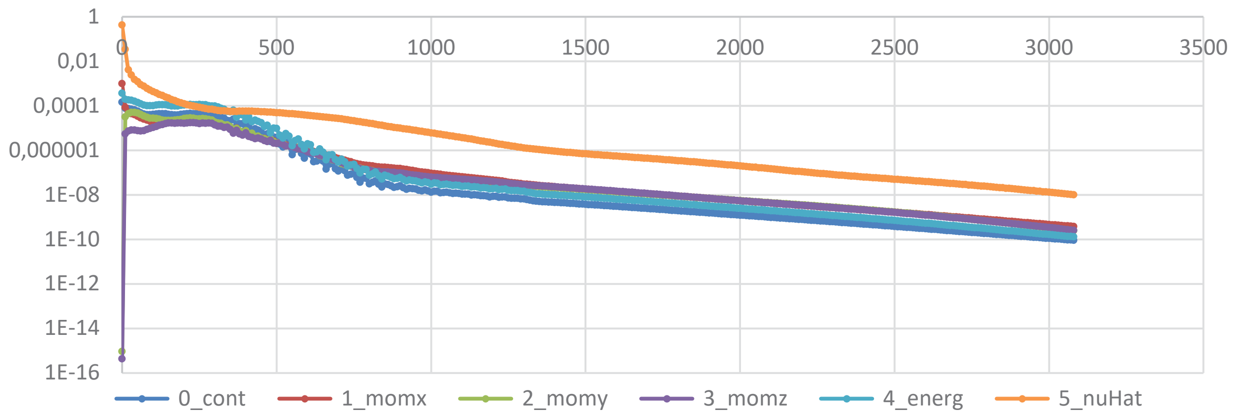
~13 million



~18 million

NACA 0012 Convergence

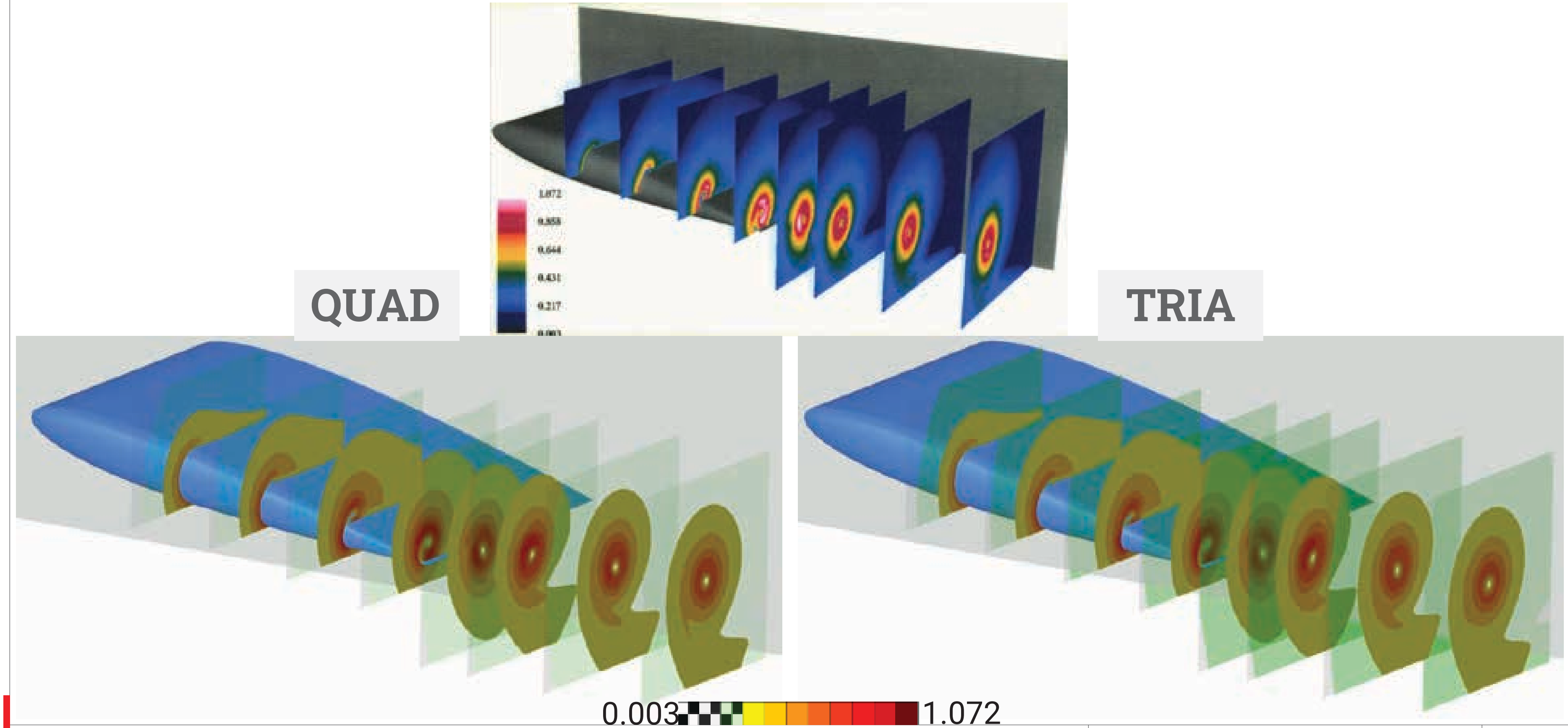
Limits:
NS solver: 1e-9
Turb.Solver: 1e-8



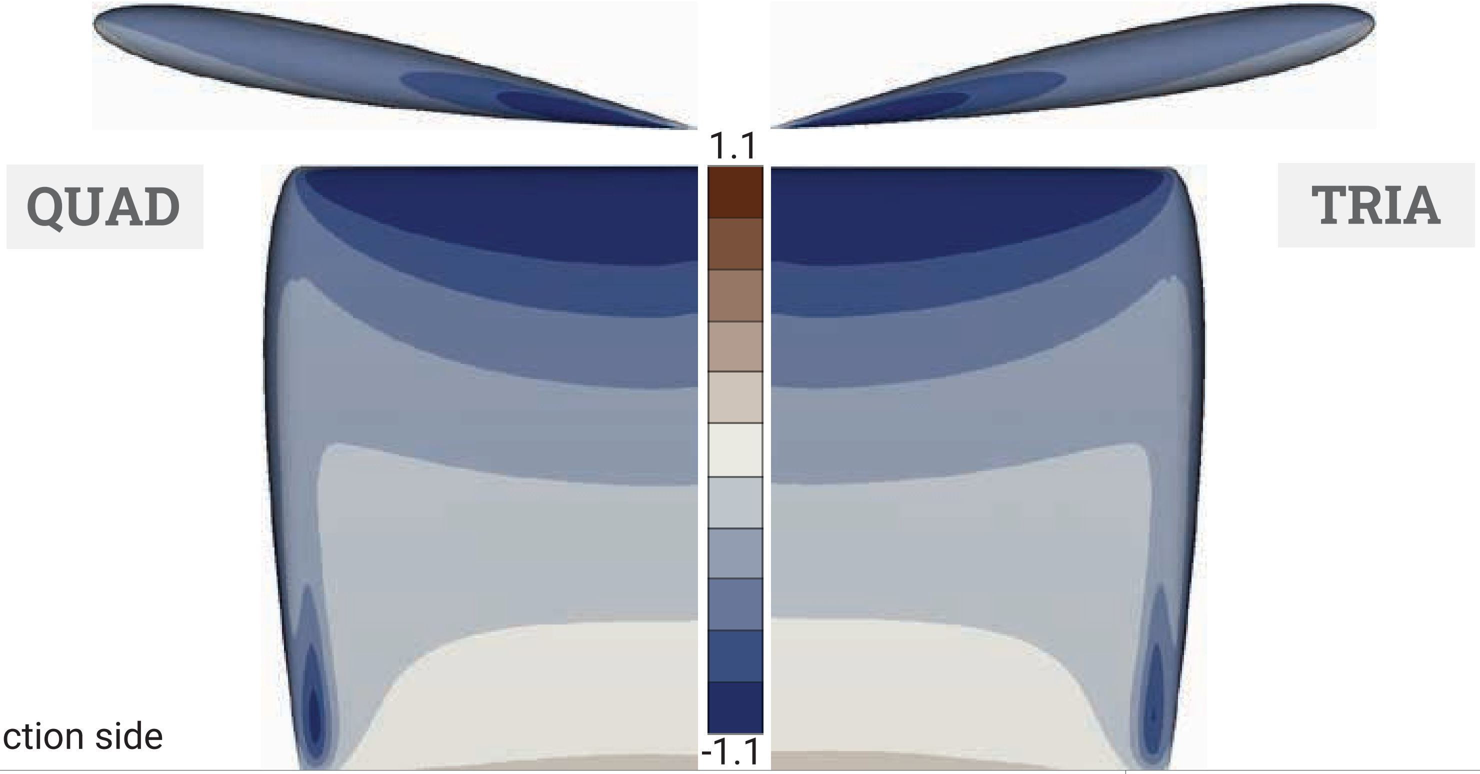
Type	Iters	Cl	Cd
QUAD	3084	0.505	0.056
QUAD-SMOOTH	3080	0.505	0.056
TRIA	2970	0.499	0.055
TRIA-SMOOTH	2980	0.499	0.055

- Is it pointless to look for the “perfect” mesh type?
- Or are there other dependencies?

NACA 0012 – Normalised U_{planar}

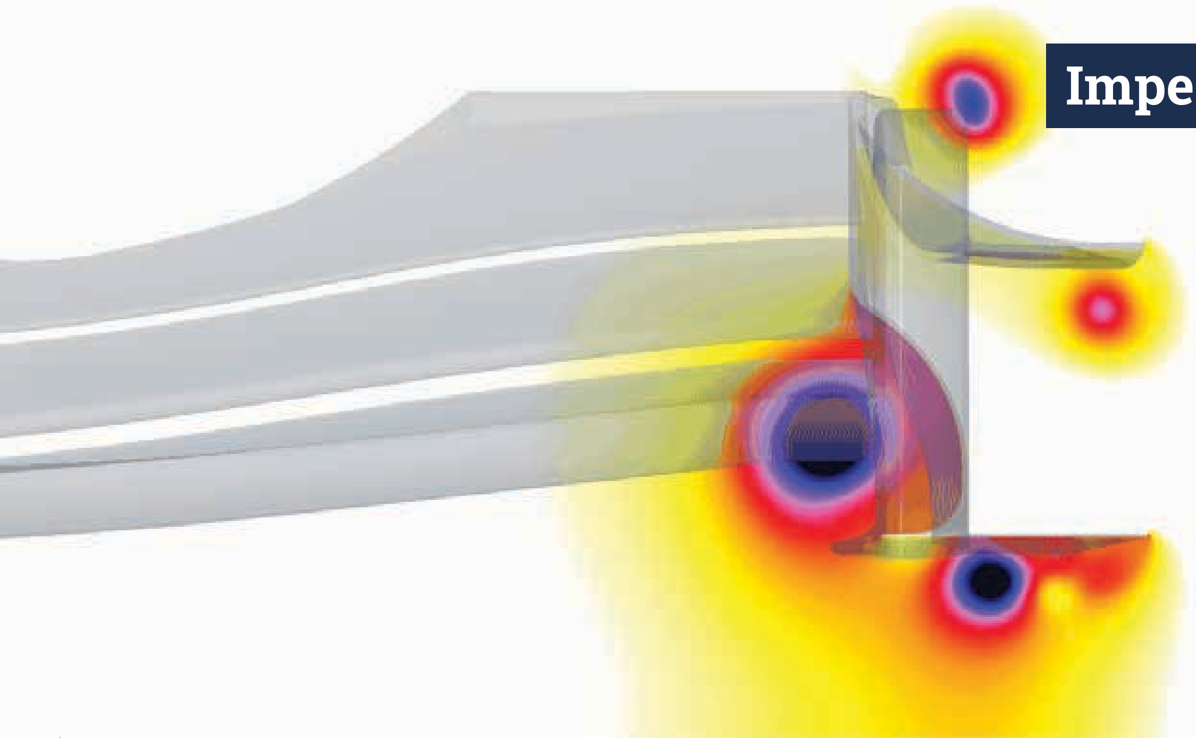


NACA 0012 – C_P



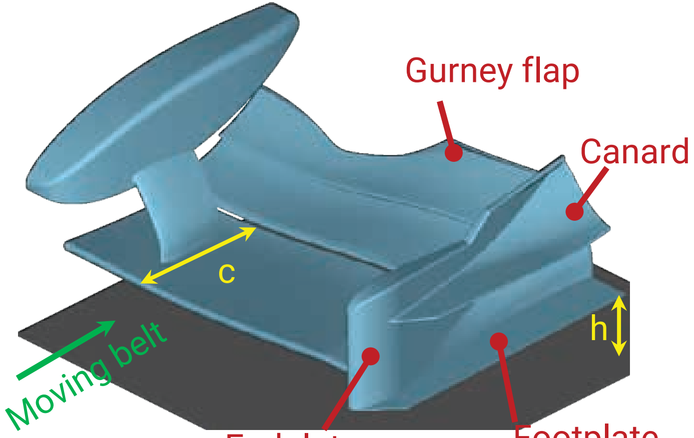
Suction side

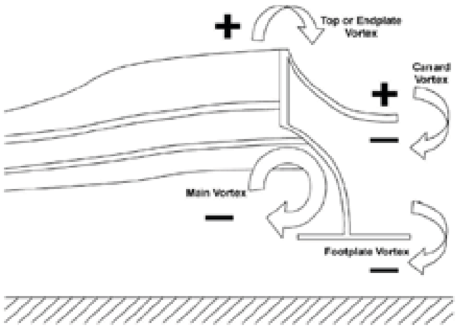
Imperial Front Wing



Model setup

Geometry as found in Imperial College London repository https://data.hpc.imperial.ac.uk/resolve/?doi=6049





IFW

Real motorsports model

Experiments in public domain

Freestream $U_{\infty} = 13\text{m/s}$

Moving ground

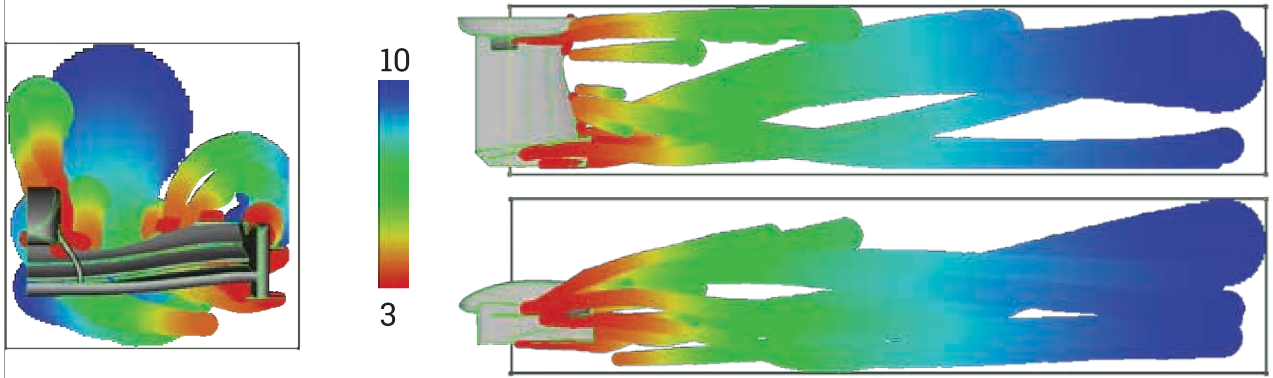
Chord length: $c = 250\text{mm}$

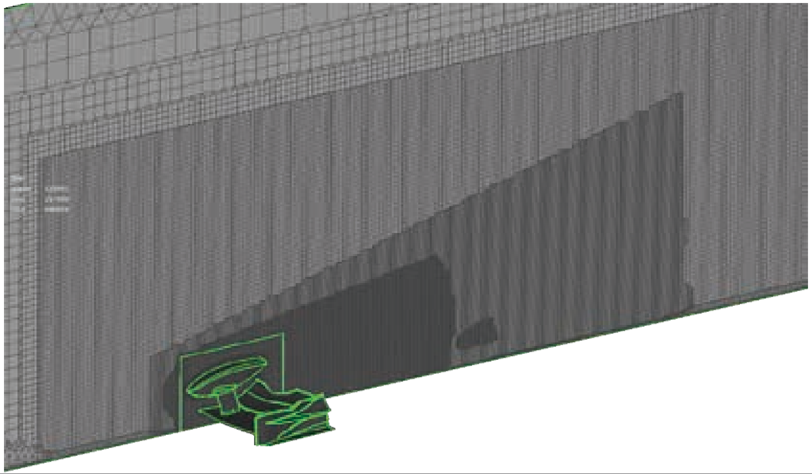
Ride height: $h/c = 0.36$

Buscariolo, F.F.; Hoessler, J.; Moxey, D.; Jassim, A.; Gouder, K.; Basley, J.; Murai, Y.; Assi, G.R.; Sherwin, S.J. *Spectral/hp element simulation of flow past a Formula One front wing: Validation against experiments*. J. Wind Eng. Ind. Aerodyn. 2022, 221, 104832.

Pegrum JM. Experimental study of the vortex system generated by a Formula 1 front wing. PhD thesis. Imperial College, London, 2007

Mesh





IFW

Mesh independence:

-ULOW/LOW/MED/FINE/XFINE
(x3) /(x2) /(x1.5)/(x1) /(x0.75)

-Adapted layers: y^{+}~<1

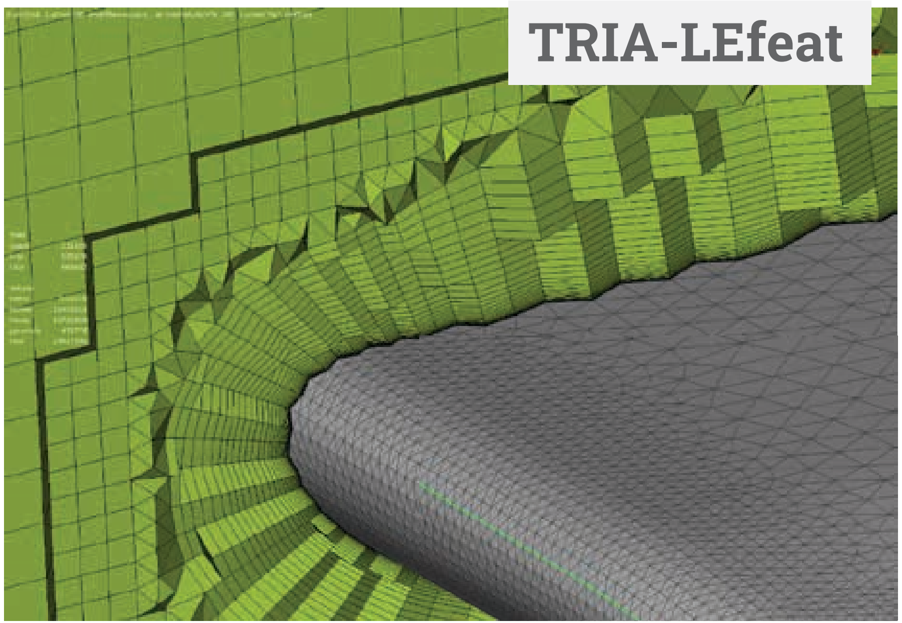
-30-35 layers

-Vortex cores refinement

-3 levels of bulk refinement

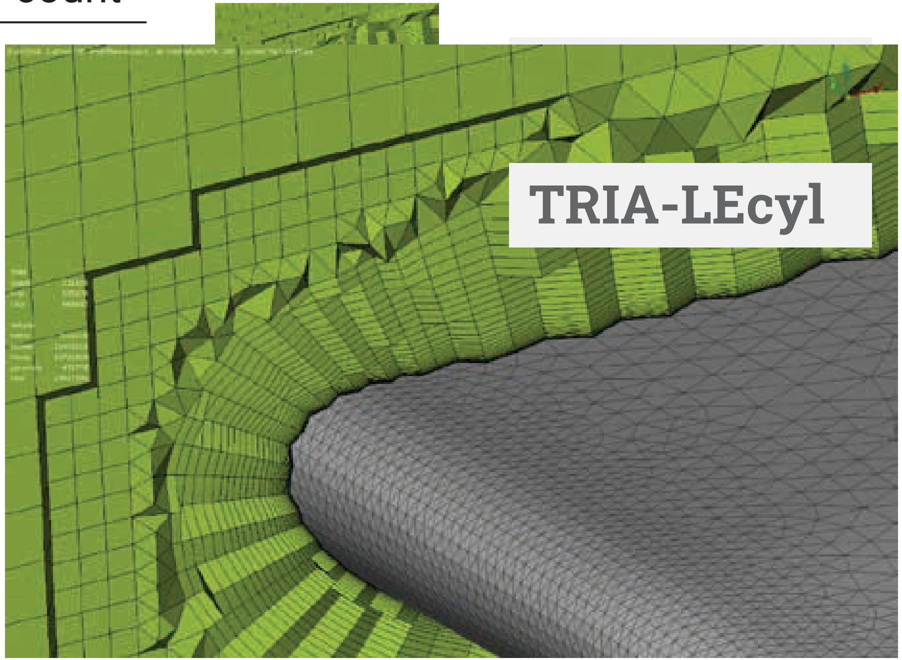
IFW mesh types [1]

Surface		Volume			
Main	Features	Layers	Transition	Bulk	count
Tria	Tria-Feat	Prisms	Tetra	HxInt	



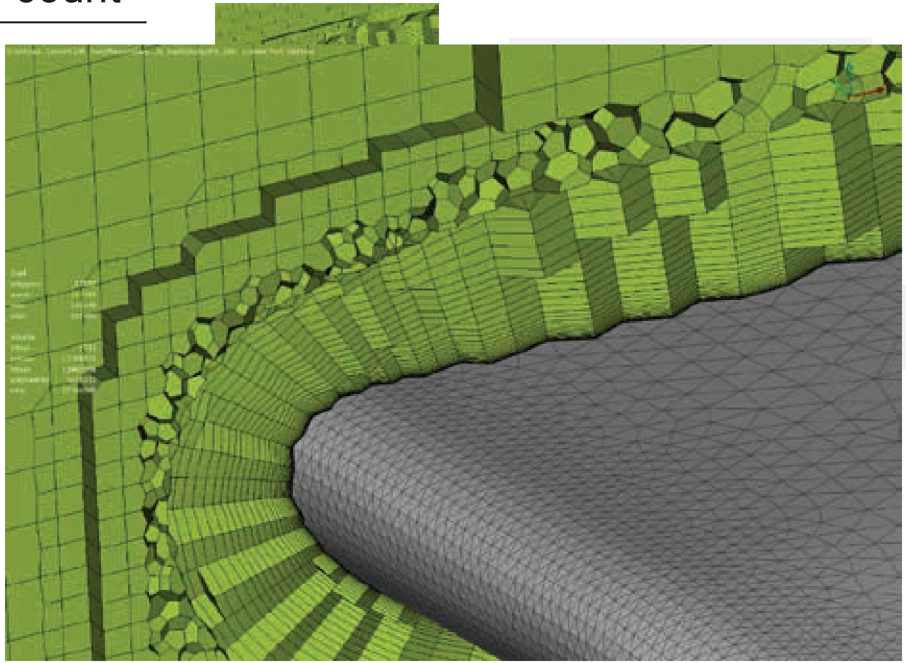
IFW mesh types [1]

Surface		Volume			
Main	Features	Layers	Transition	Bulk	count
Tria	Tria-Feat	Prisms	Tetra	HxInt	
Tria	Tria-SF	Prisms	Tetra	HxInt	



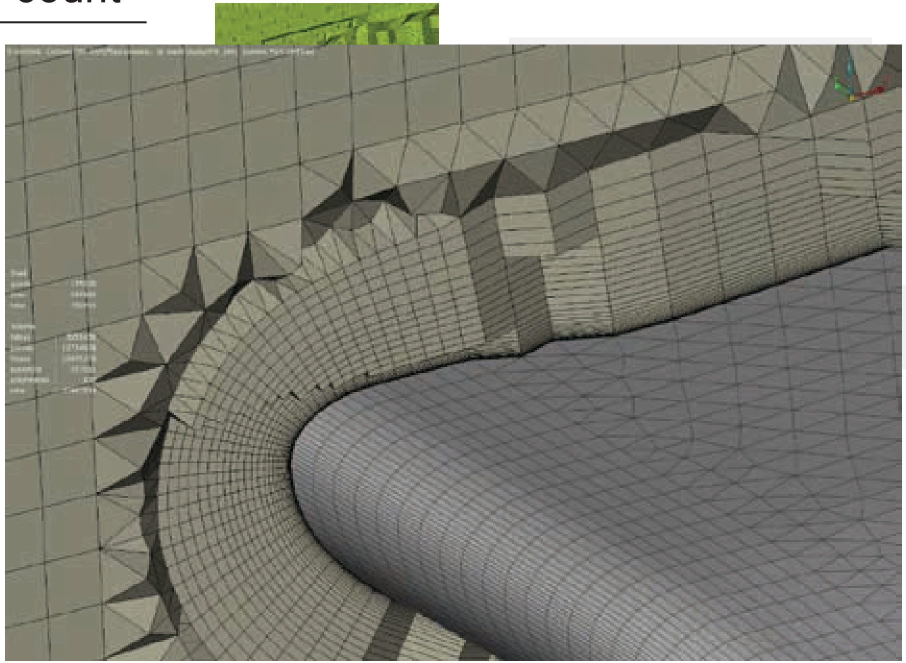
IFW mesh types [1]

Surface		Volume			
Main	Features	Layers	Transition	Bulk	count
Tria	Tria-Feat	Prisms	Tetra	HxInt	
Tria	Tria-SF	Prisms	Tetra	HxInt	
Tria	Tria-SF	Prisms	Poly	HxInt	



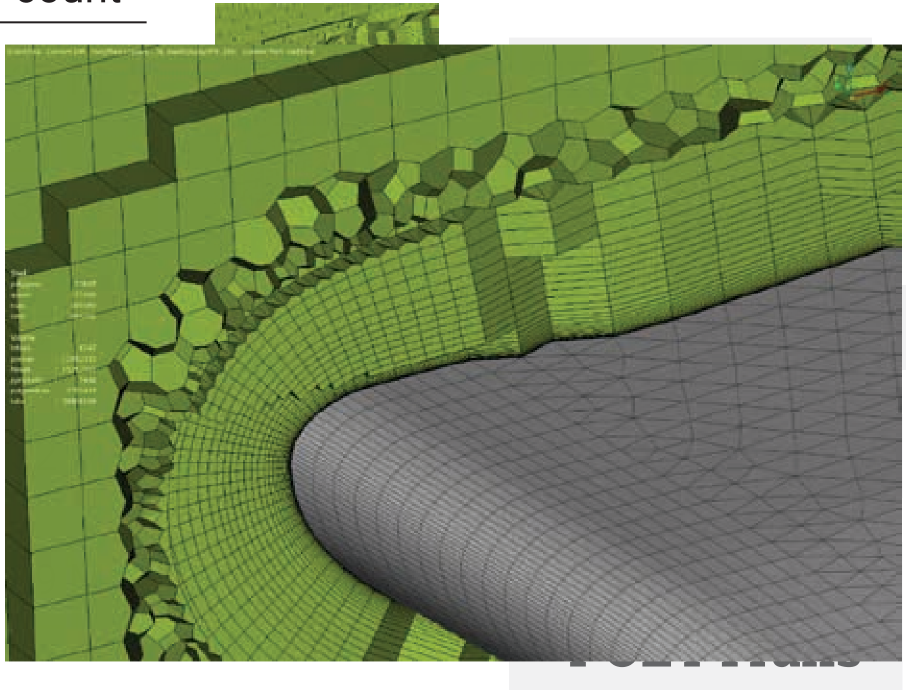
IFW mesh types [1]

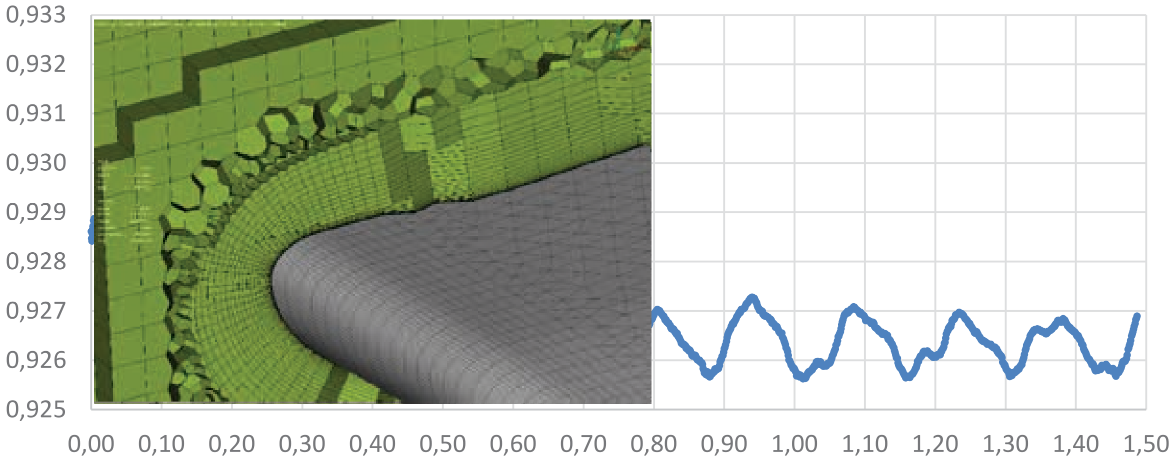
Surface		Volume			
Main	Features	Layers	Transition	Bulk	count
Tria	Tria-Feat	Prisms	Tetra	HxInt	
Tria	Tria-SF	Prisms	Tetra	HxInt	
Tria	Tria-SF	Prisms	Poly	HxInt	
Tria	Quad	Prisms	Tetra	HxInt	



IFW mesh types [1]

Surface		Volume			
Main	Features	Layers	Transition	Bulk	count
Tria	Tria-Feat	Prisms	Tetra	HxInt	
Tria	Tria-SF	Prisms	Tetra	HxInt	
Tria	Tria-SF	Prisms	Poly	HxInt	
Tria	Quad	Prisms	Tetra	HxInt	
Tria	Quad	Prisms	Poly	HxInt	





Convergence

Simulations run for 1+ flow-through time

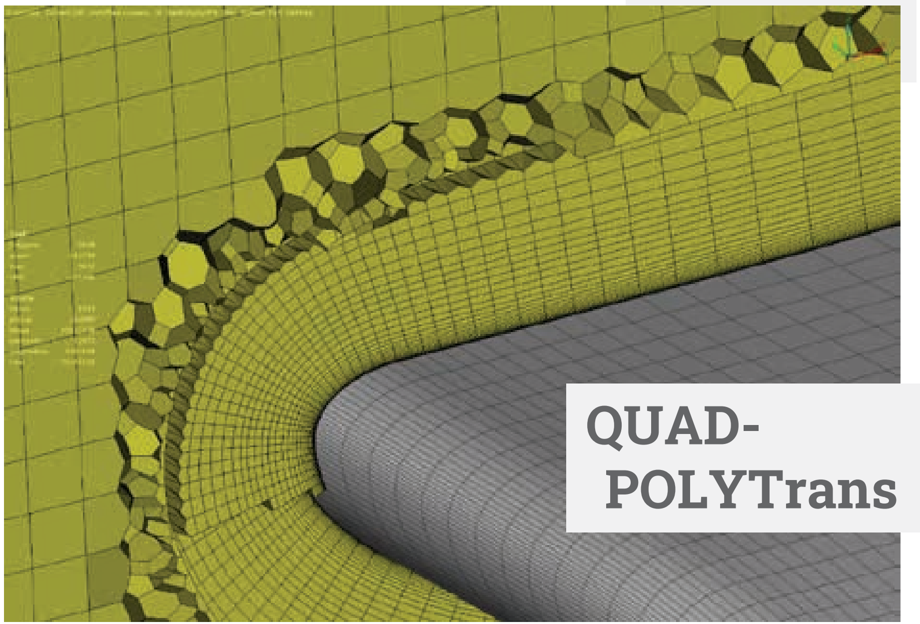
Last 500-700 time-steps

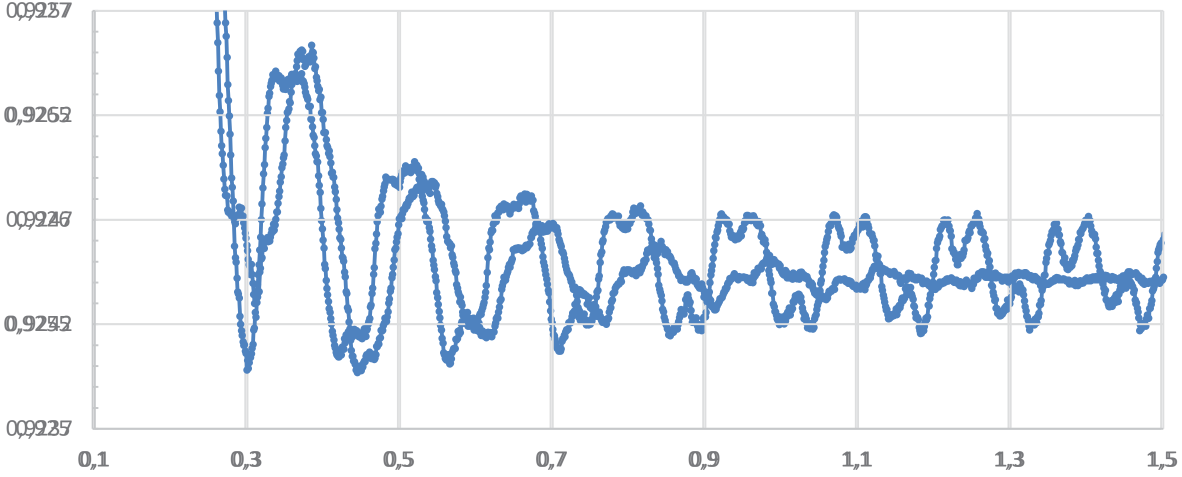
$\Delta t = 0.001s$

1 cnt = $\Delta C_d = 0.001$

IFW mesh types [2]

Surface		Volume			
Main	Features	Layers	Transition	Bulk	count
Quad	Quad	Hx	Tetra	HxInt	
Quad	Quad	Hx	Poly	HxInt	





Convergence

Simulations run for 1+ flow-through time

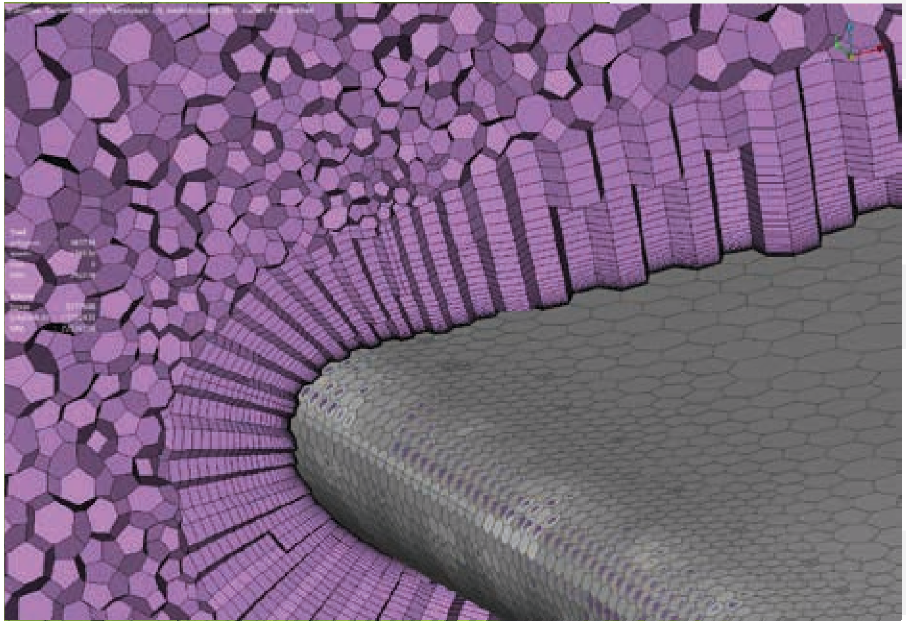
Last 500-700 time-steps

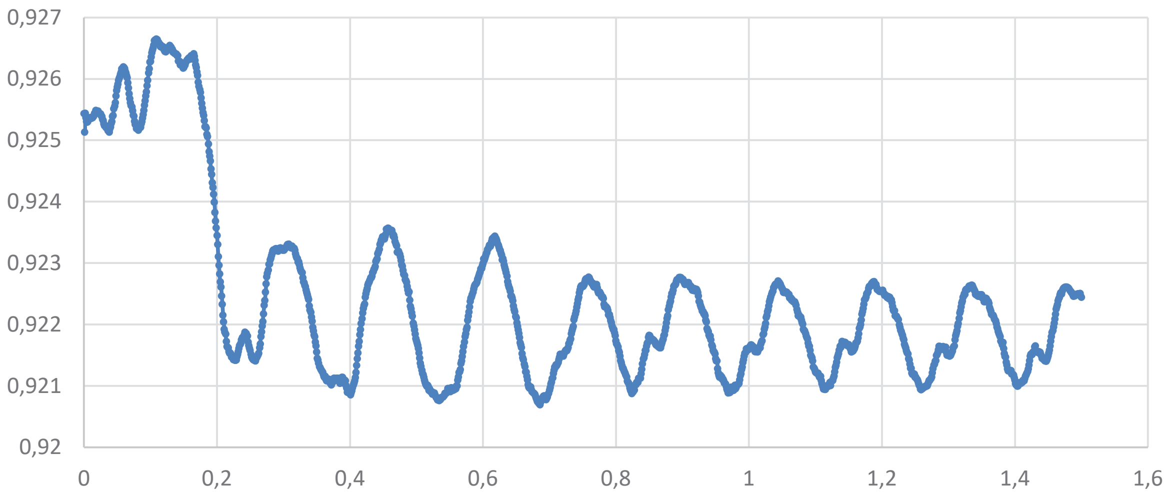
$\Delta t = 0.001s$

1 cnt = $\Delta C_d = 0.001$

IFW mesh types [3]

Surface		Volume			
Main	Features	Layers	Transition	Bulk	count
Poly	Quad	Poly-Hx	Poly	HxInt	
Poly	Poly	Poly	Poly	HxInt	
Poly	Poly	Poly	Poly	Poly	





Convergence

Simulations run for 1+ flow-through time

Last 500-700 time-steps

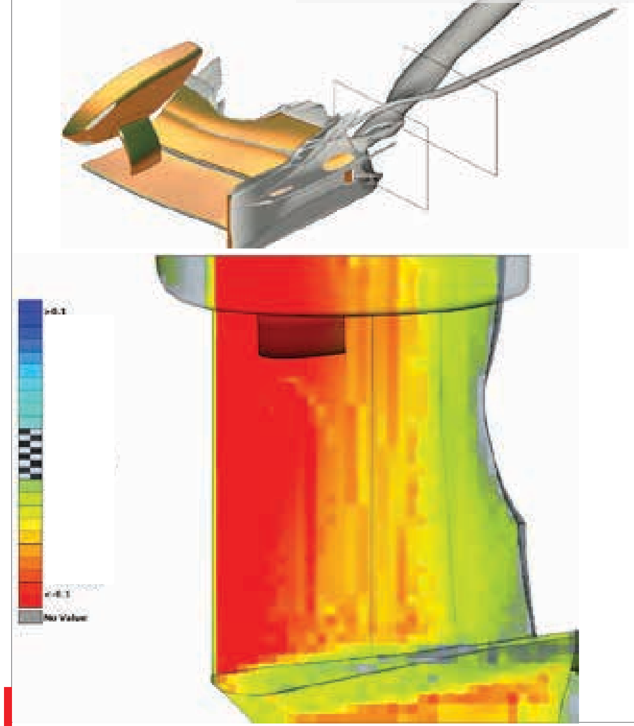
$\Delta t = 0.001s$

1 cnt = $\Delta C_d = 0.001$

IFW – Results

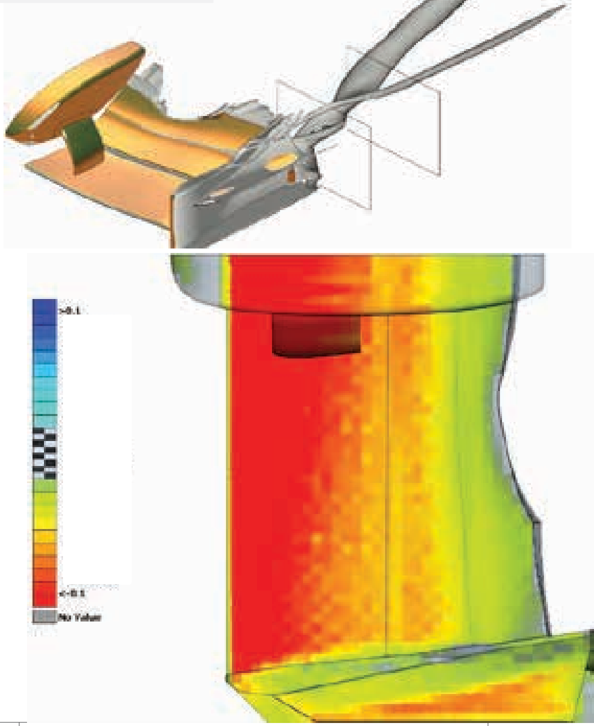
QUAD-POLYTrans

TRIA-POLYTrans



$0.924 :: C_d :: 0.916$

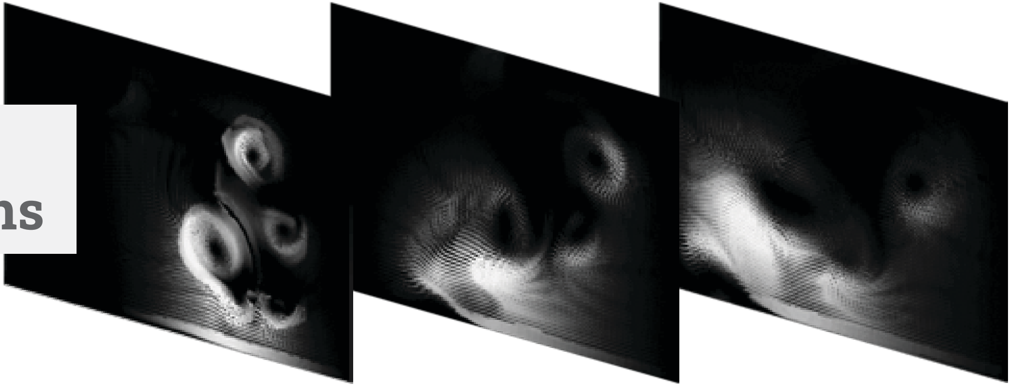
$-8.531 :: C_l :: -8.514$



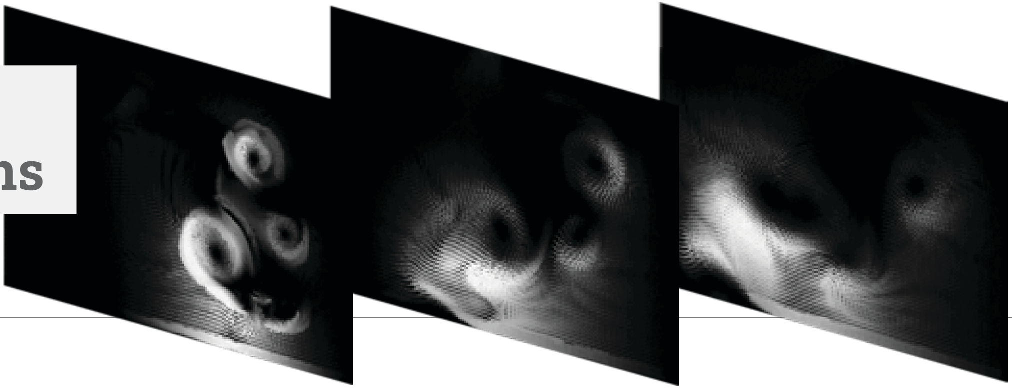
Downforce x-ray plot

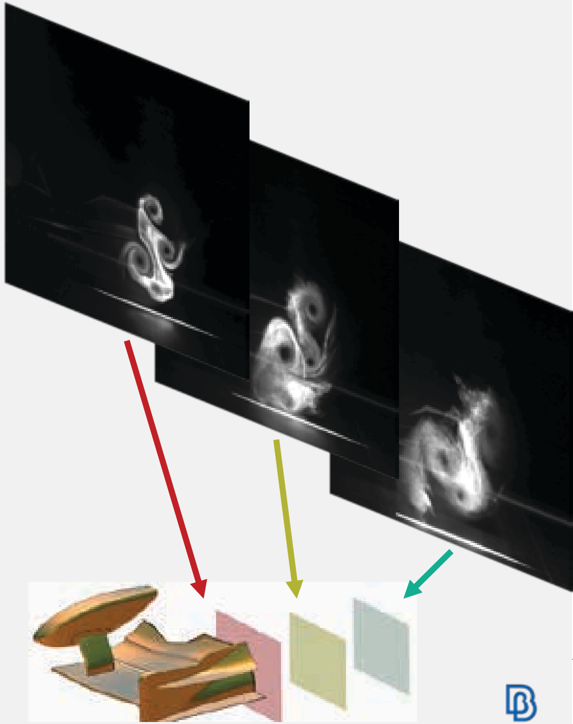
Flow visualisation

TRIA-POLYTrans

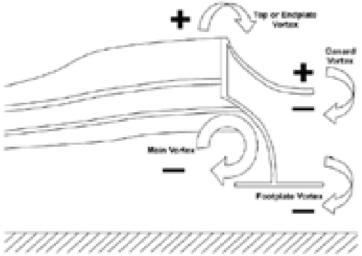


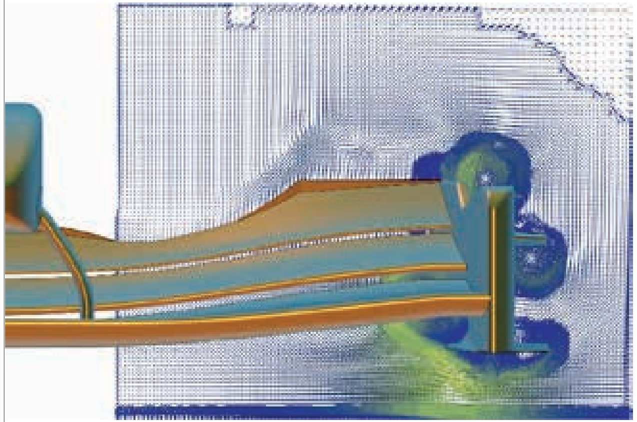
QUAD-POLYTrans

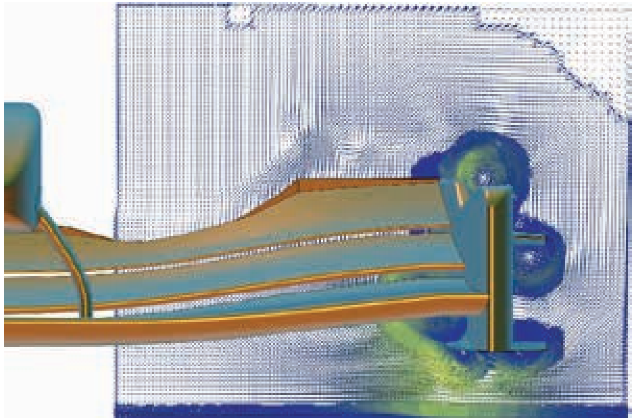




Flow visualisation

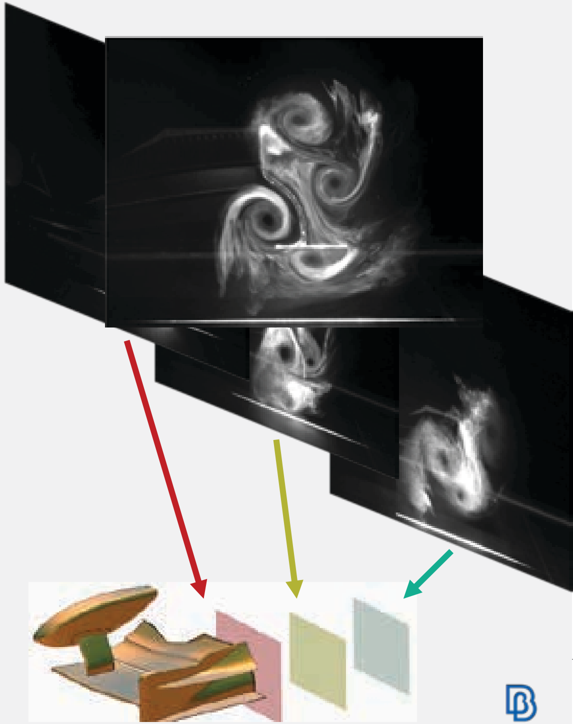




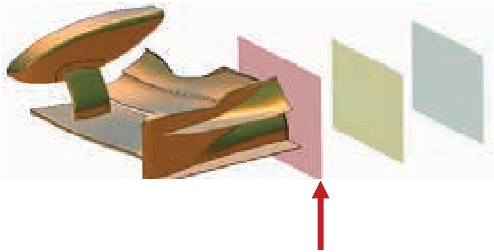


QUAD-POLYTrans

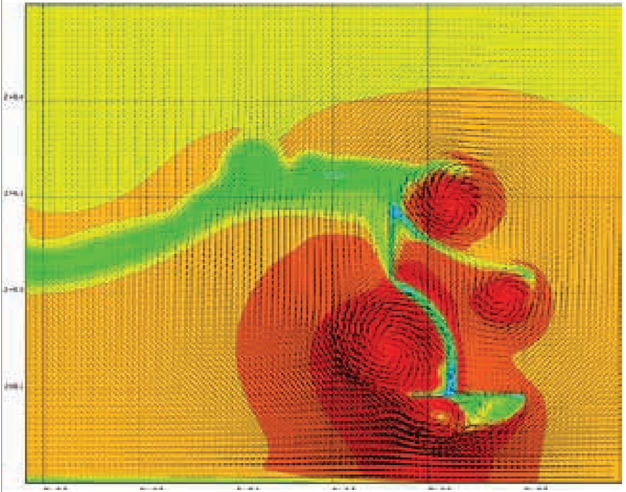
TRIA-POLYTrans

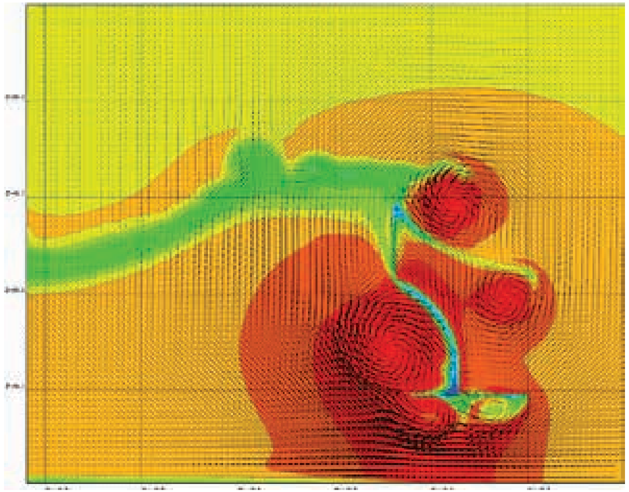


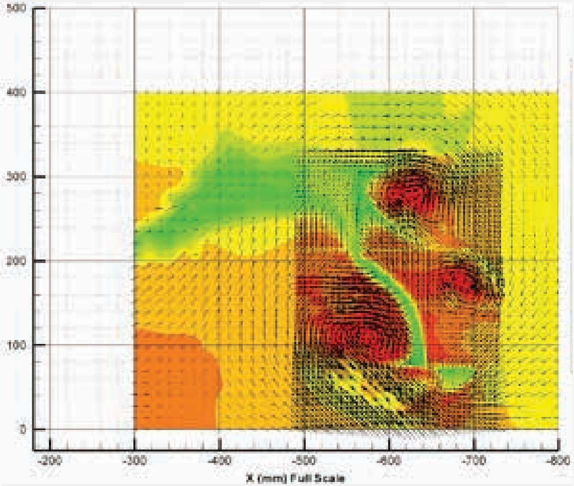
IFW



Velocity







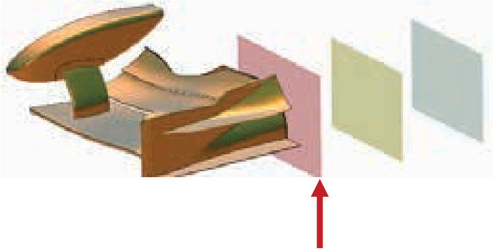
QUAD-POLYTrans

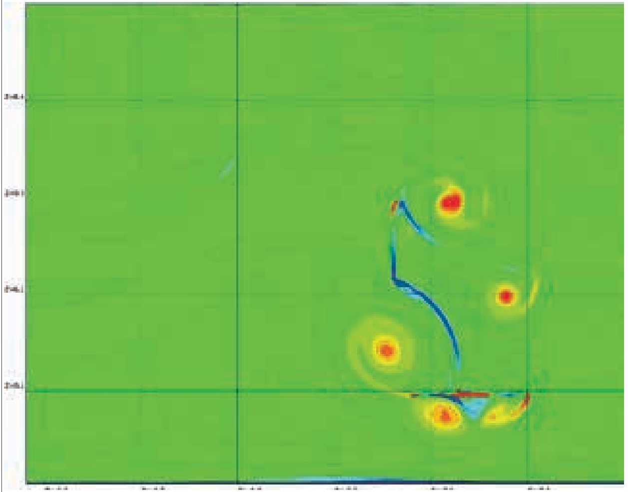
TRIA-POLYTrans

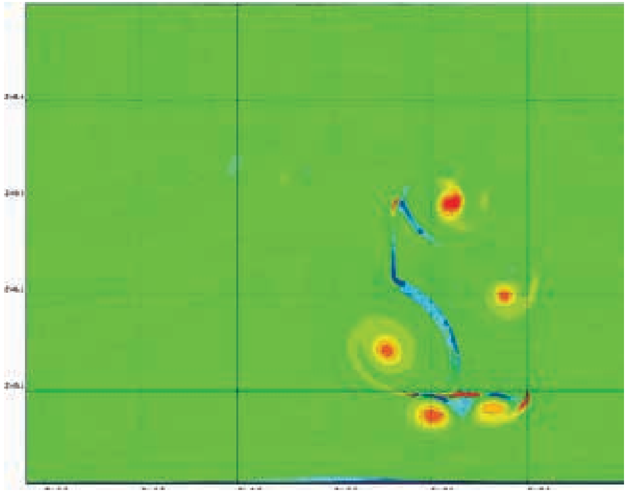
U

0 30

IFW



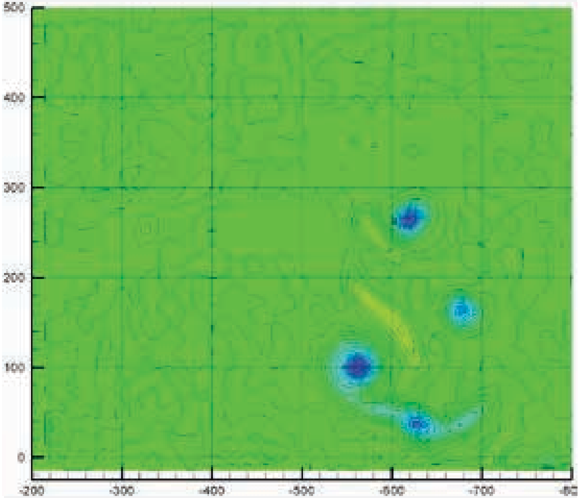




QUAD-POLYTrans

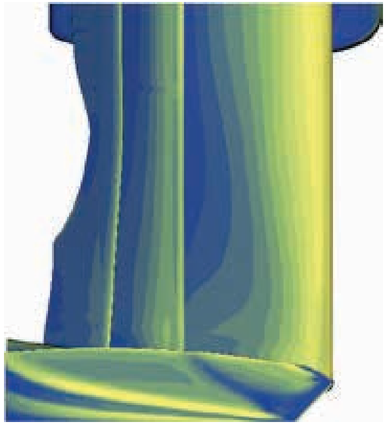
TRIA-POLYTrans

Normalised Vorticity(x)

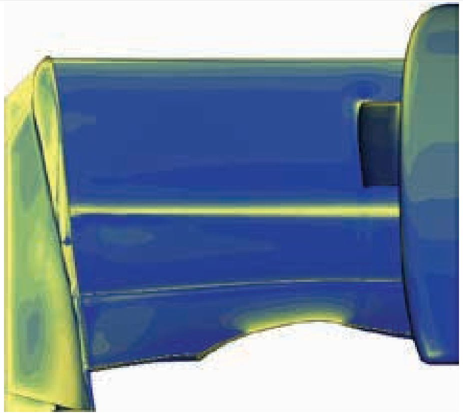


ω_x D/U

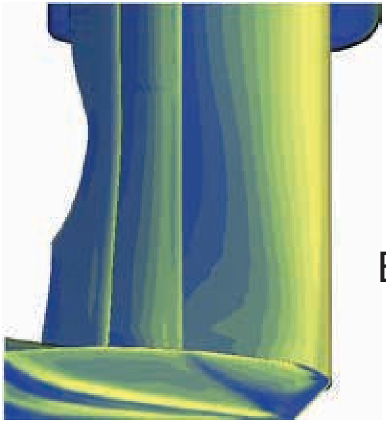
Wall shear stress



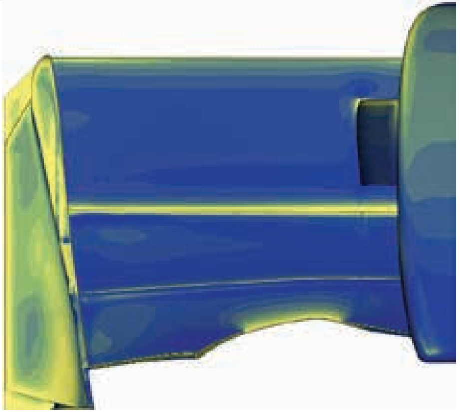
QUAD-POLYTrans



WSS

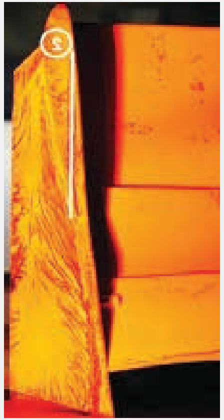


TRIA-POLYTrans

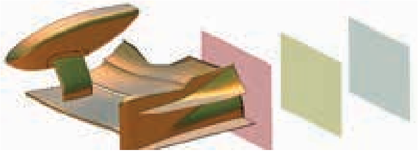


Bottom view

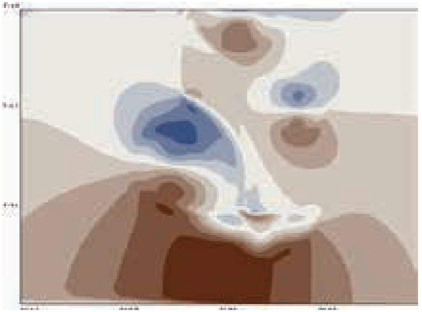
Top view

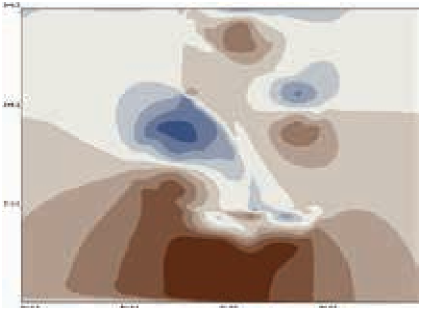


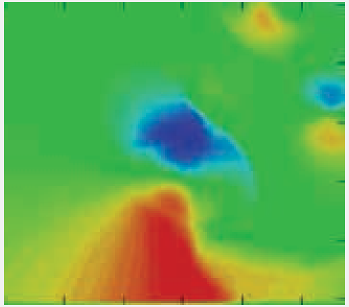
Normalised velocity (V&W)



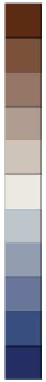
X=-294





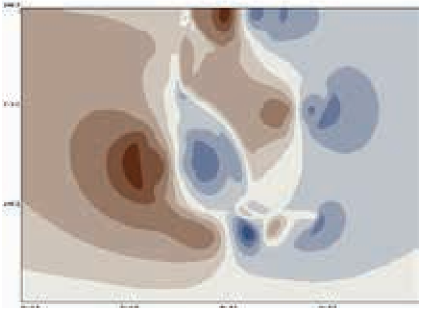


1



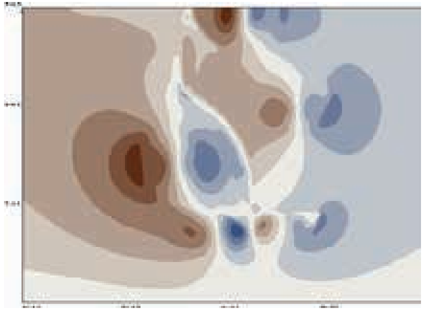
-1

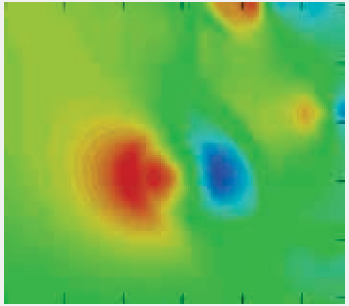
V=U_y



QUAD-POLYTrans

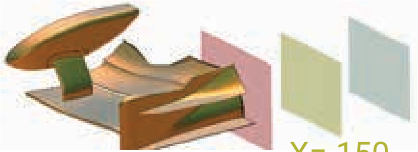
TRIA-POLYTrans



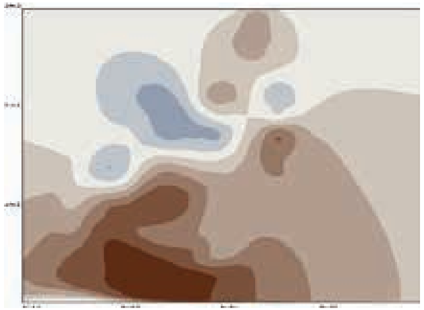


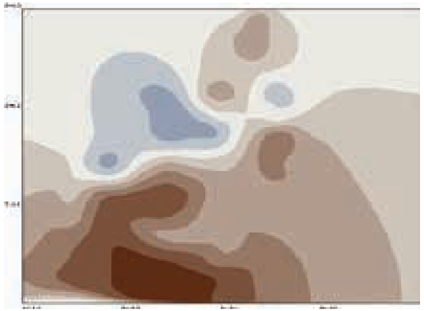
W=U_z

Normalised velocity (V&W)

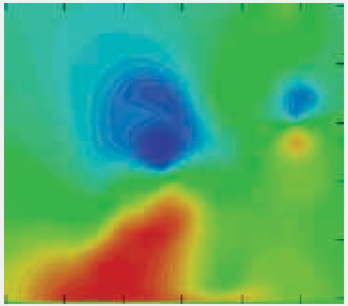


X=-150

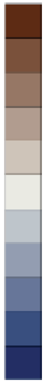




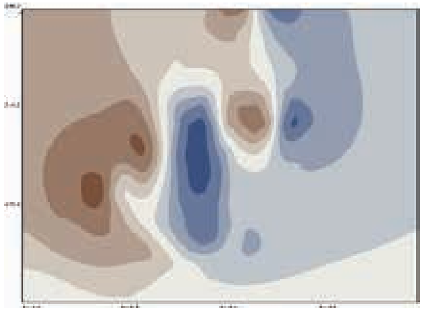
$V=U_y$

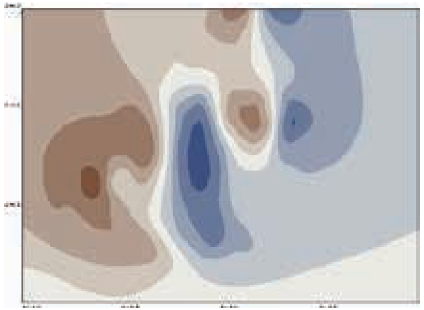


QUAD-POLYTrans

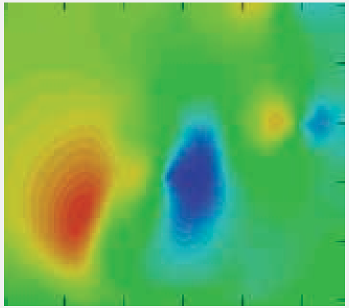


TRIA-POLYTrans

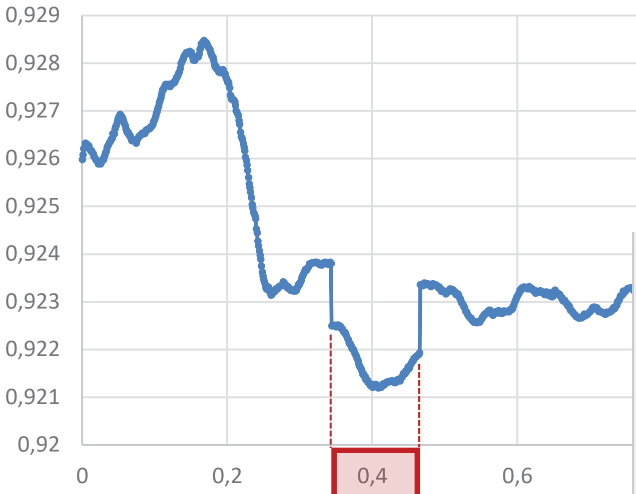




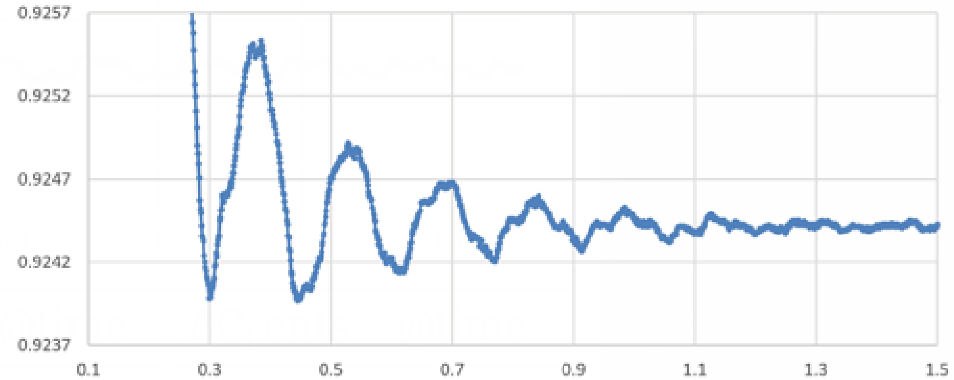
$W=U_z$

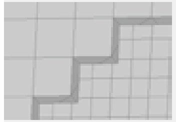


Smoothed Hexa Transition



Variant	ΔC_d cnts





Variant	ΔC_d cnts	@time	ΔC_l cnts	@time
QUAD	0.9	~0.6s	0.9	~1.0s
QUAD-POLYTrans	0.9	~0.6s	0.8	~0.75s

Single Intel(R) Xeon(R) W-2255 CPU @ 3.70GHz

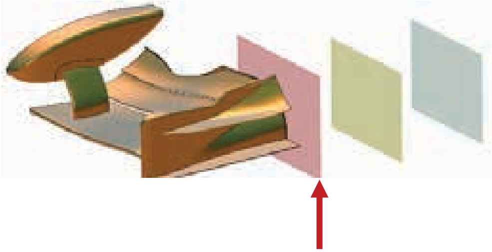
6248R CPU @ 3.00GHz

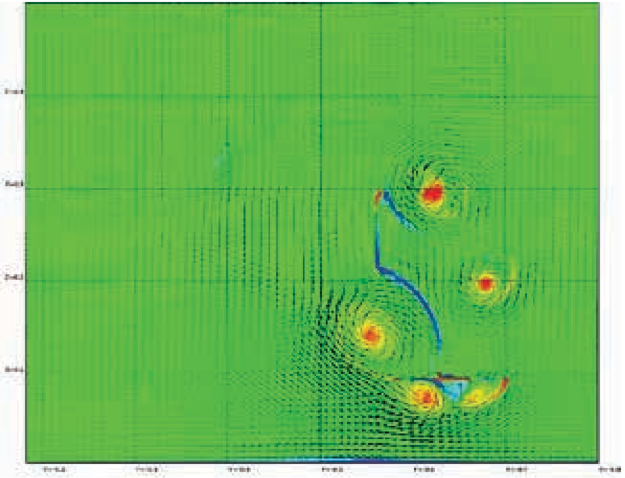
Conclusions

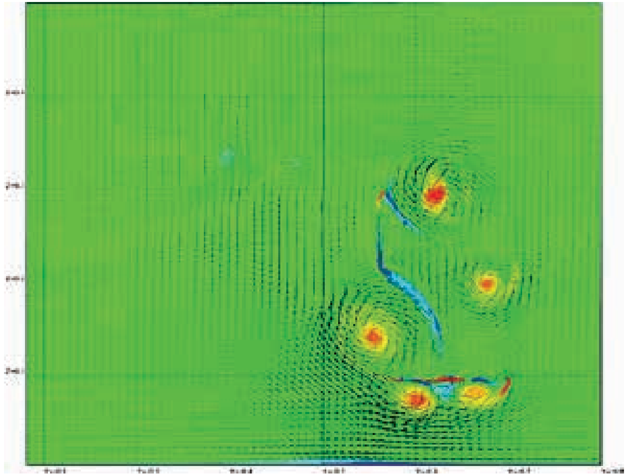
- Mesh type should “match with” the solver (dependency on solver technology)
- Polyhedrals on surface do not look so promising
- The best convergence in the study achieved by “Quads-Poly’s-HexaInt”
- No obvious discrepancies were identified between the two main grids (Q vs. Tr)
- In a real, complex motorsports case geometry
  - Quads on surface produced a small element count, without compromising results and demonstrated best convergence (C_d/C_l) [down to 0.06cnts]
  - Trias on surface produced moderate convergence and no apparent issue in the flow-field results
  - Smoothed hexa-interior transition between levels proved advantageous

Stay connected

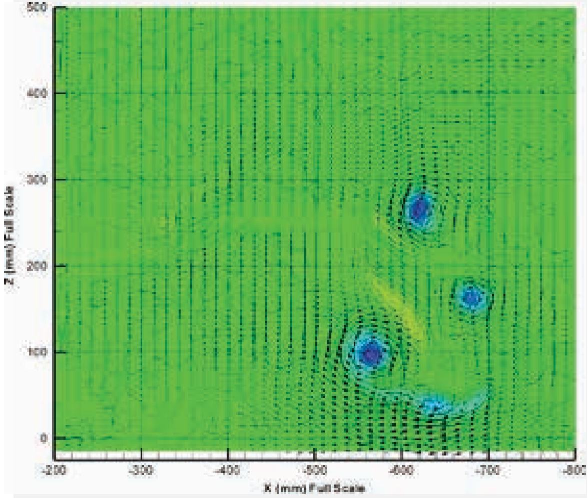
IFW







Velocity & normalized Vorticity

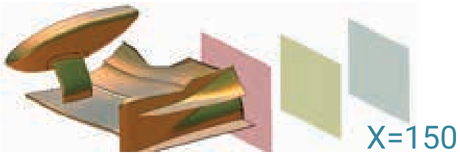


QUAD-POLYTrans

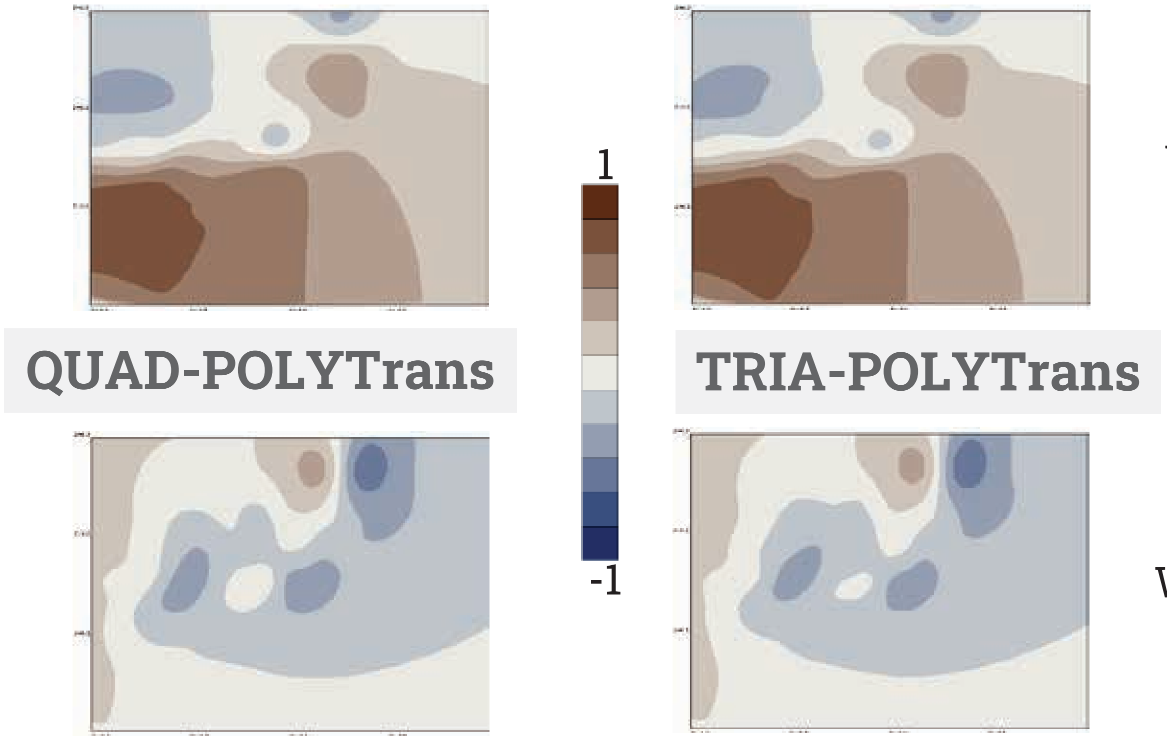
TRIA-POLYTrans

ω_x D/U

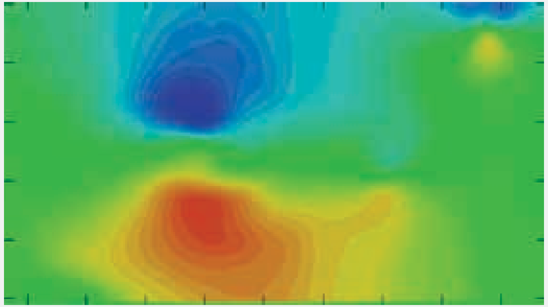
-50  50



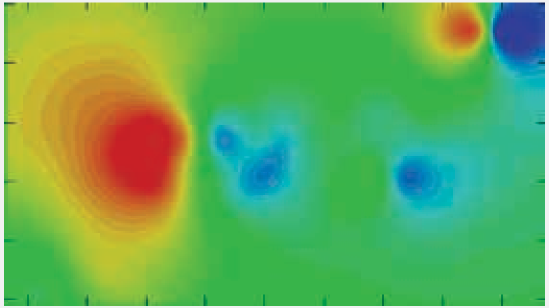
Normalised velocity (V&W)



$V=U_y$



$W=U_z$



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Title

Description

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Text Box

Title

Description

- Level
  - Level
    - Level