A DIRECT NUMERICAL SIMULATION OF FLOW THROUGH A LOW PRESSURE TURBINE STAGE

Man Mohan Rai

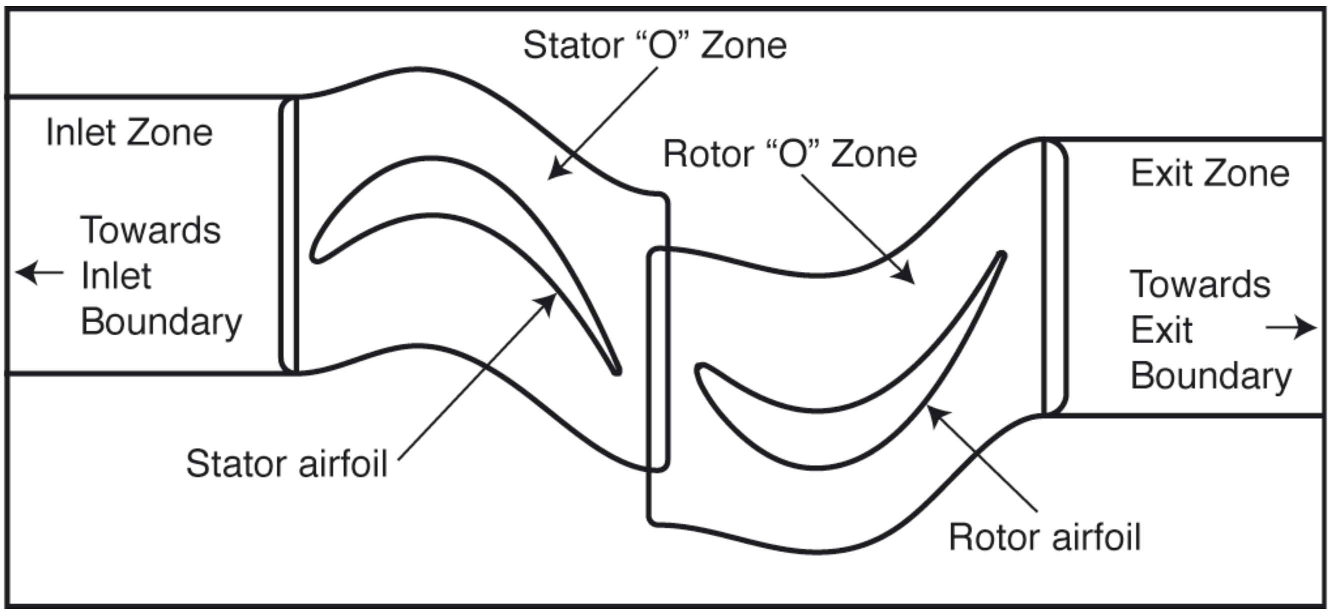
AIAA-2011-3092

-objective: understand interaction between the stator wake and the rotor blades (especially separation and transition)

-turbine/compressor flows are complex because of interaction between blade rows.
-Low-pressure turbines (LPT) high Re at take-off, low Re at cruise (50,000 – 500,000)
-At low Re, suction side tends to separate (leading to losses) and is influenced by transition
-recently DNS has been used to compute moderate Re turbine and compressor flows using supercomputers.

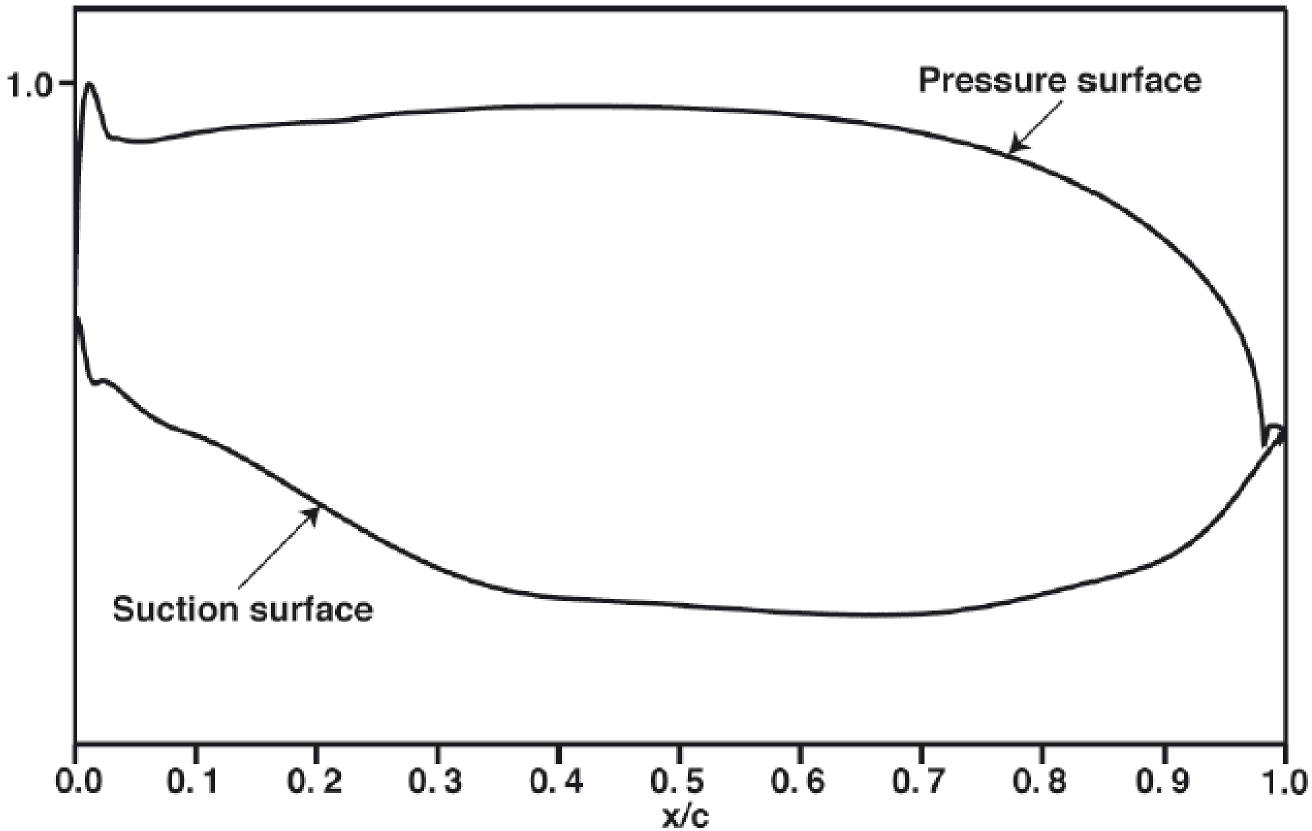
-All the boundary layers and wakes (stator and rotor) are computed via DNS.
-only one stator blade and one rotor blade used with periodic boundary conditions
-blades put in O-grids, inlet and outlet have rectangular grids

-rotor and outlet move relative to the stator and inlet
- rotor grid resolves transitional/turbulent boundary layers and the small scales of the stator wake as it interacts with the rotor blade
-rectangular grid in the inlet and outlet regions gradually expand in the x direction

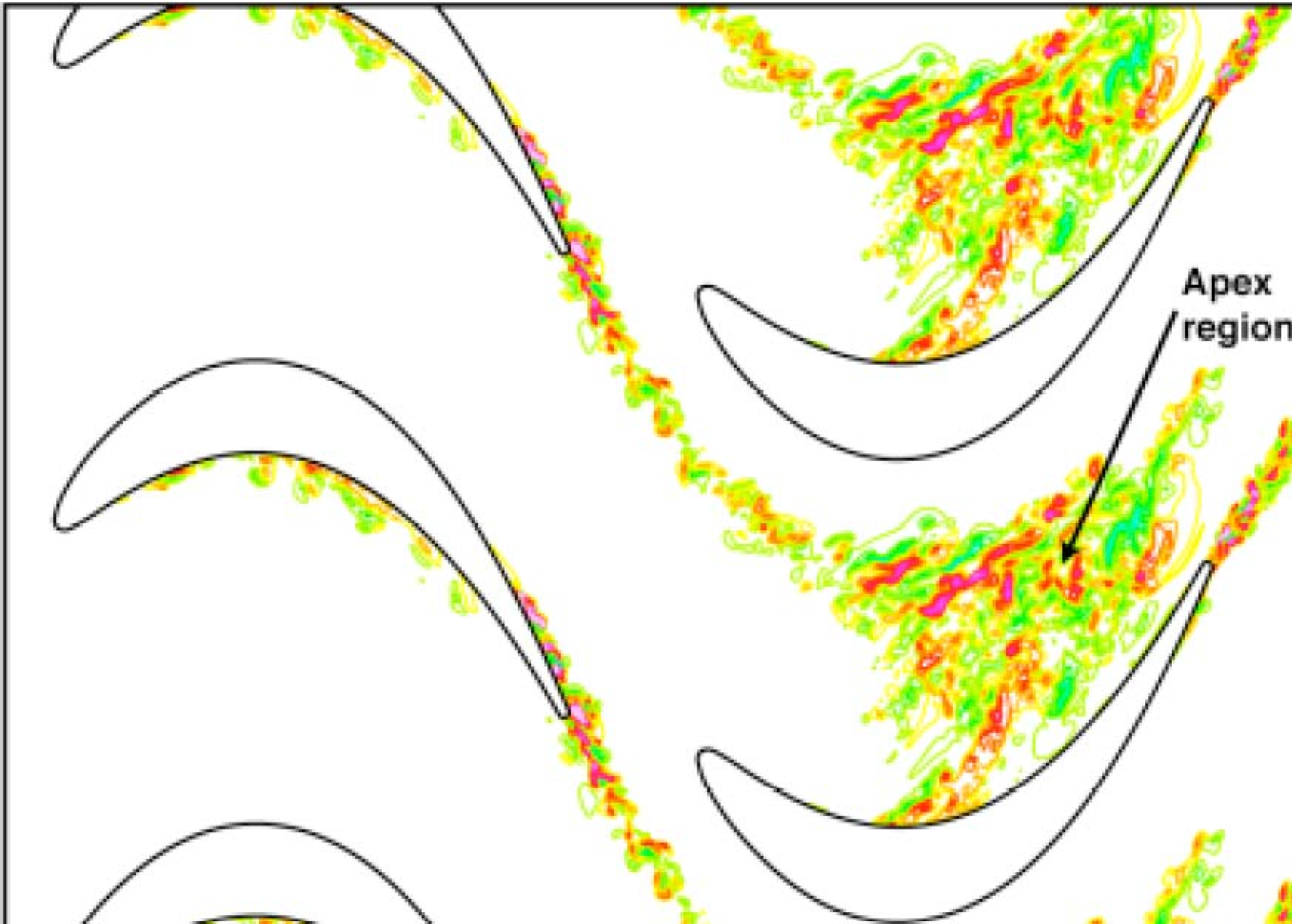


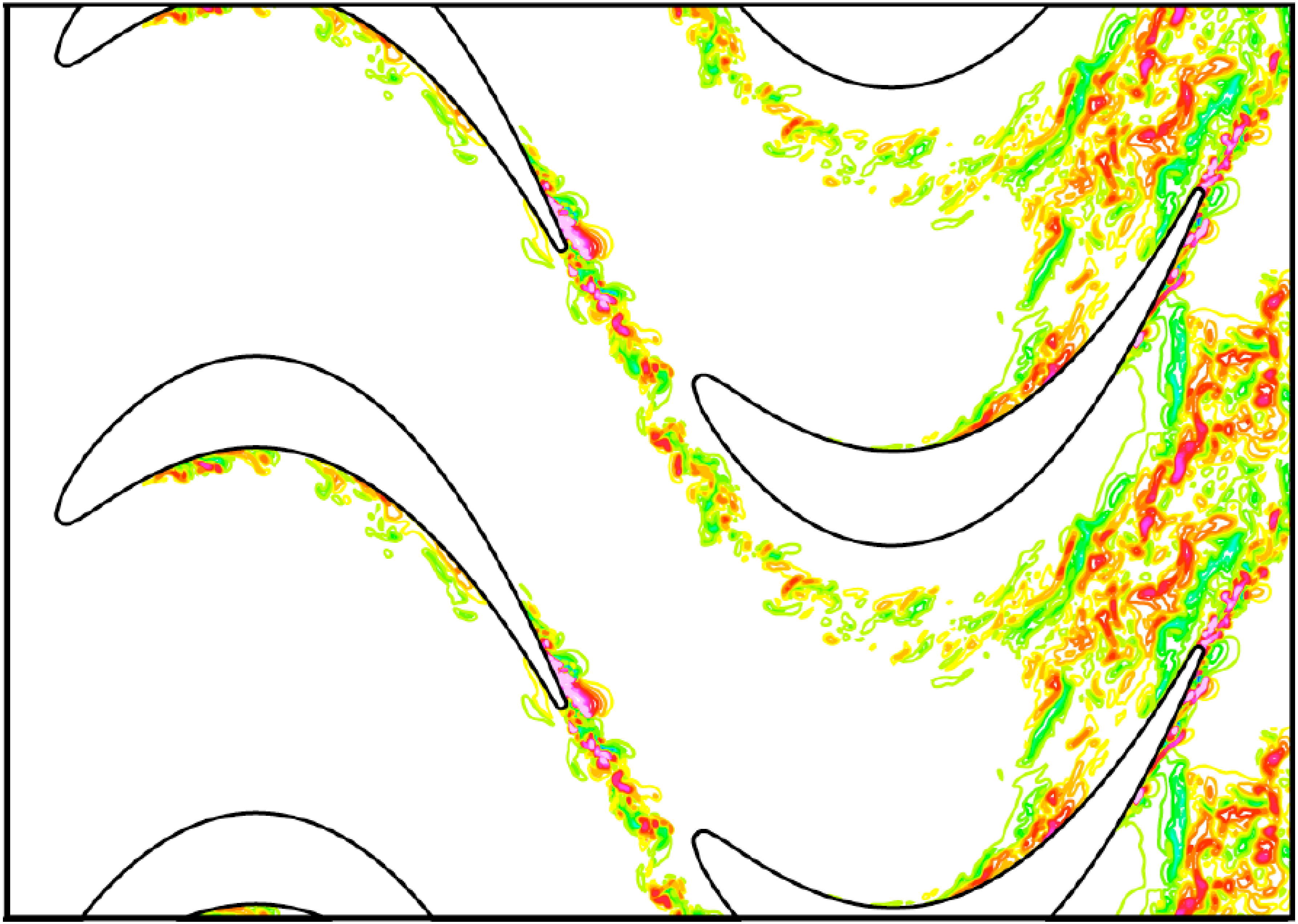
-high-order, upwind-biased, finite-difference method used
- results emphasize flow in the rotor passage, not the stator one

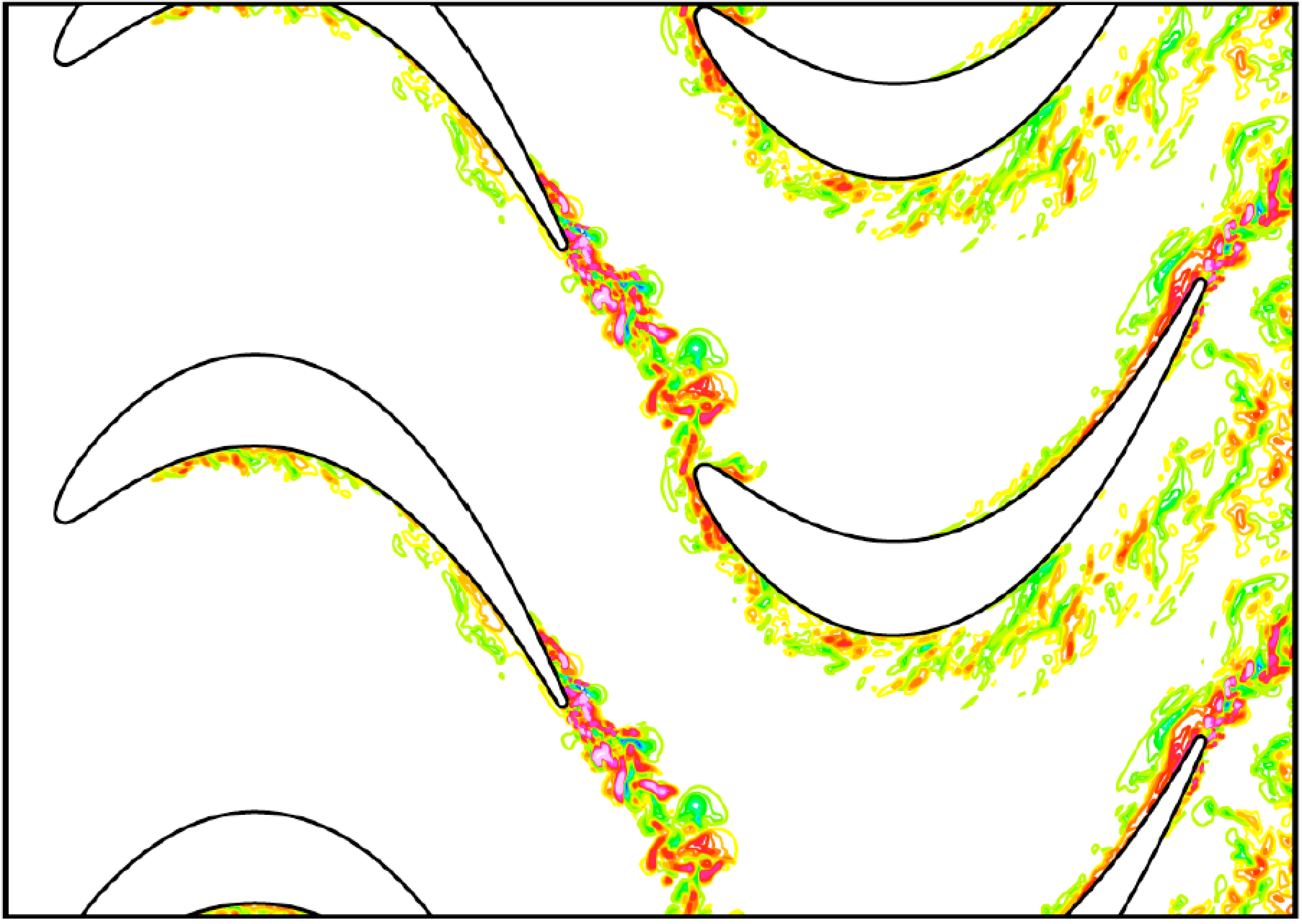
-on the suction surface, pressure gradient is favorable until 0.65c
- “disturbed” laminar flow on the first half of the suction side,
-then, downstream, flow separates periodically.

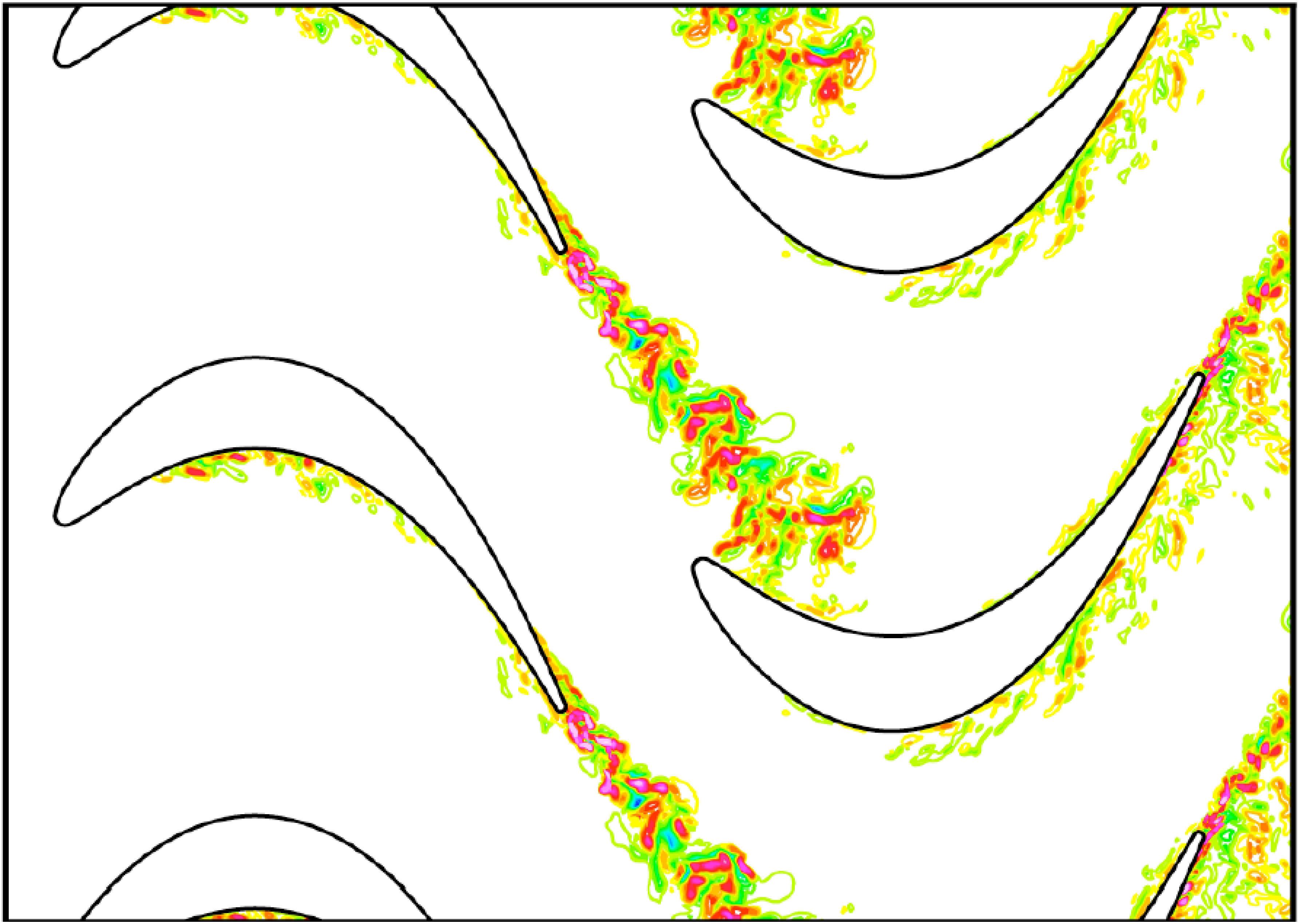


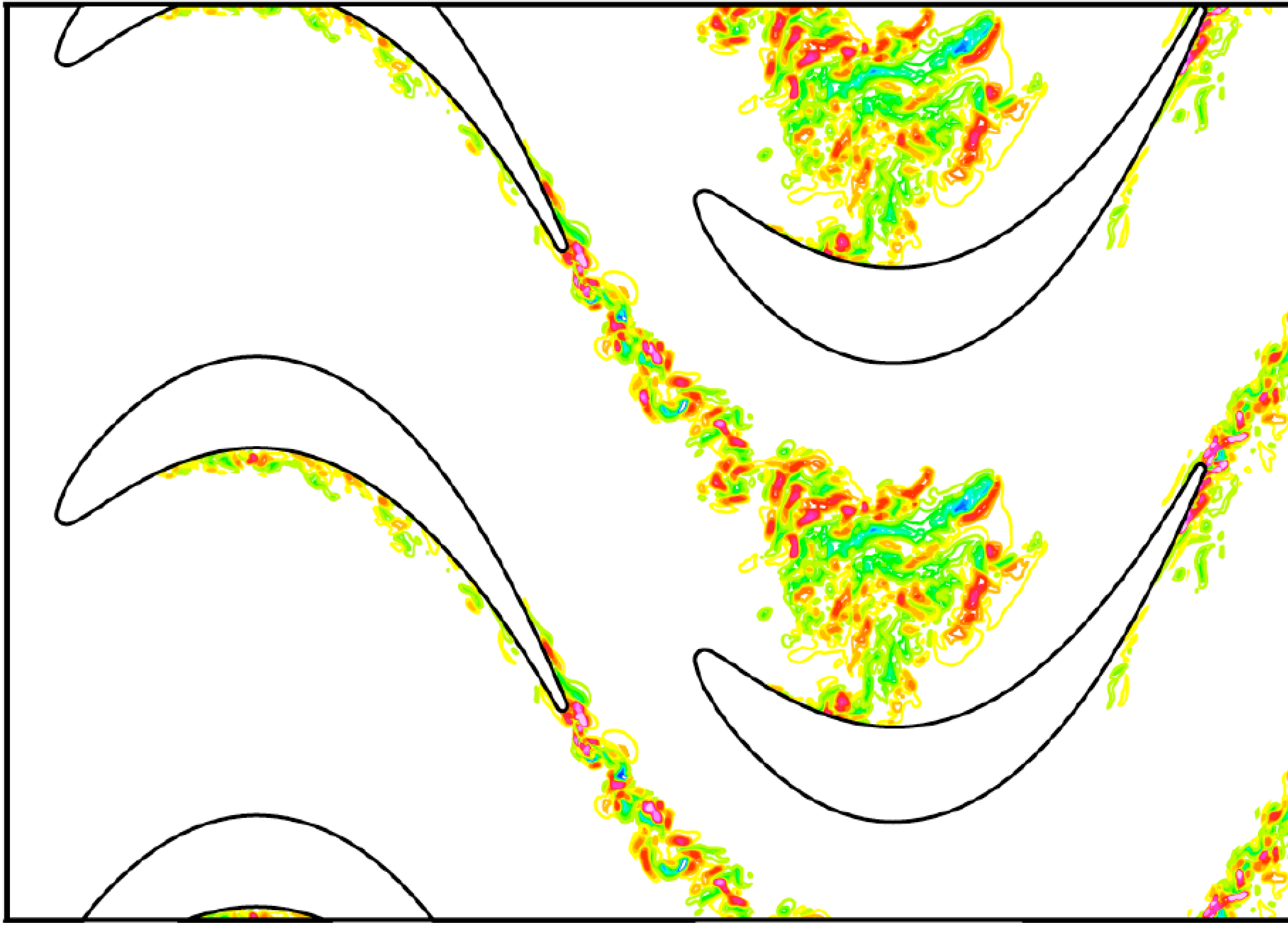
- instantaneous, spanwise velocity countours show generation and evolution of the stator wake:

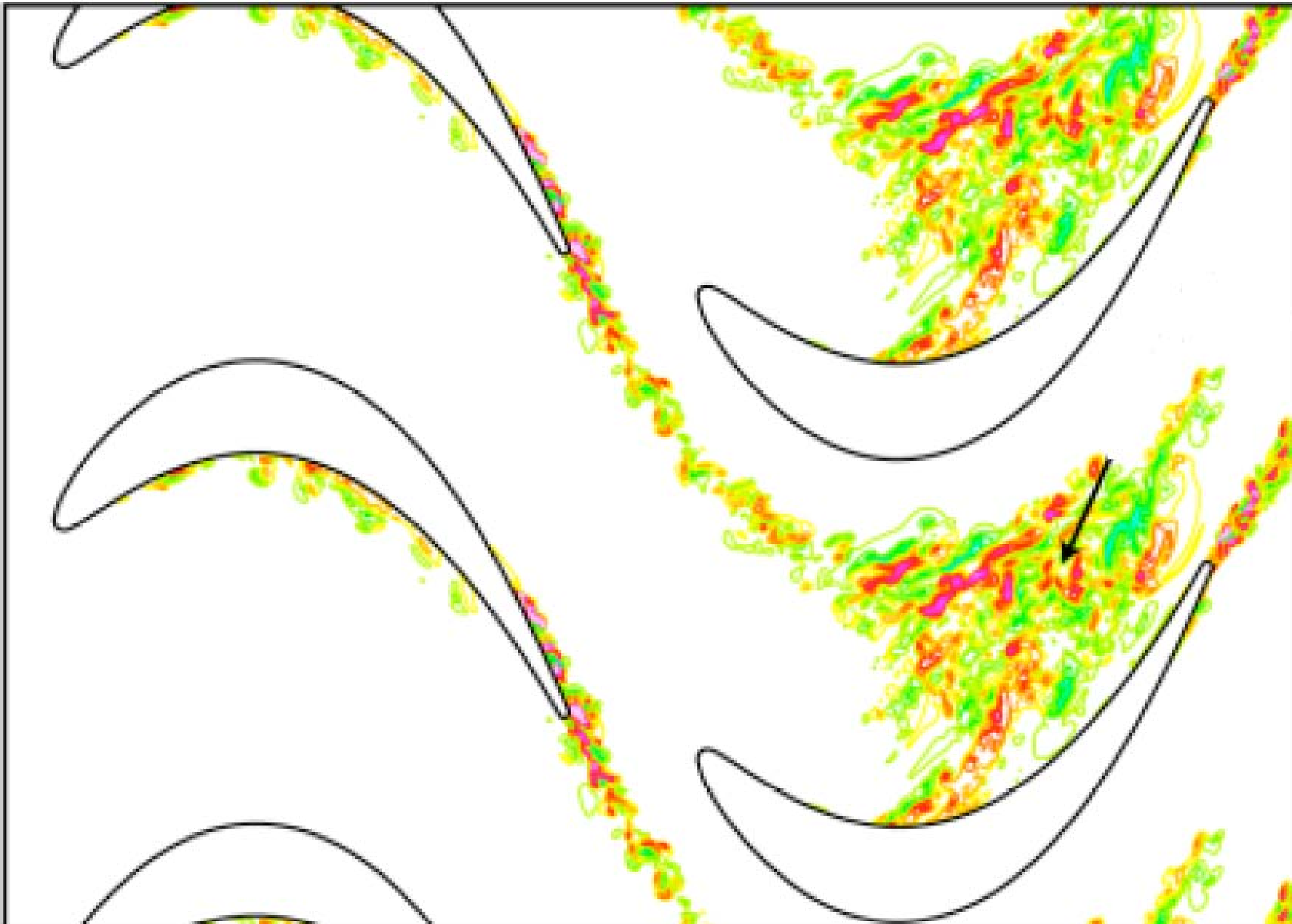

Apex
region

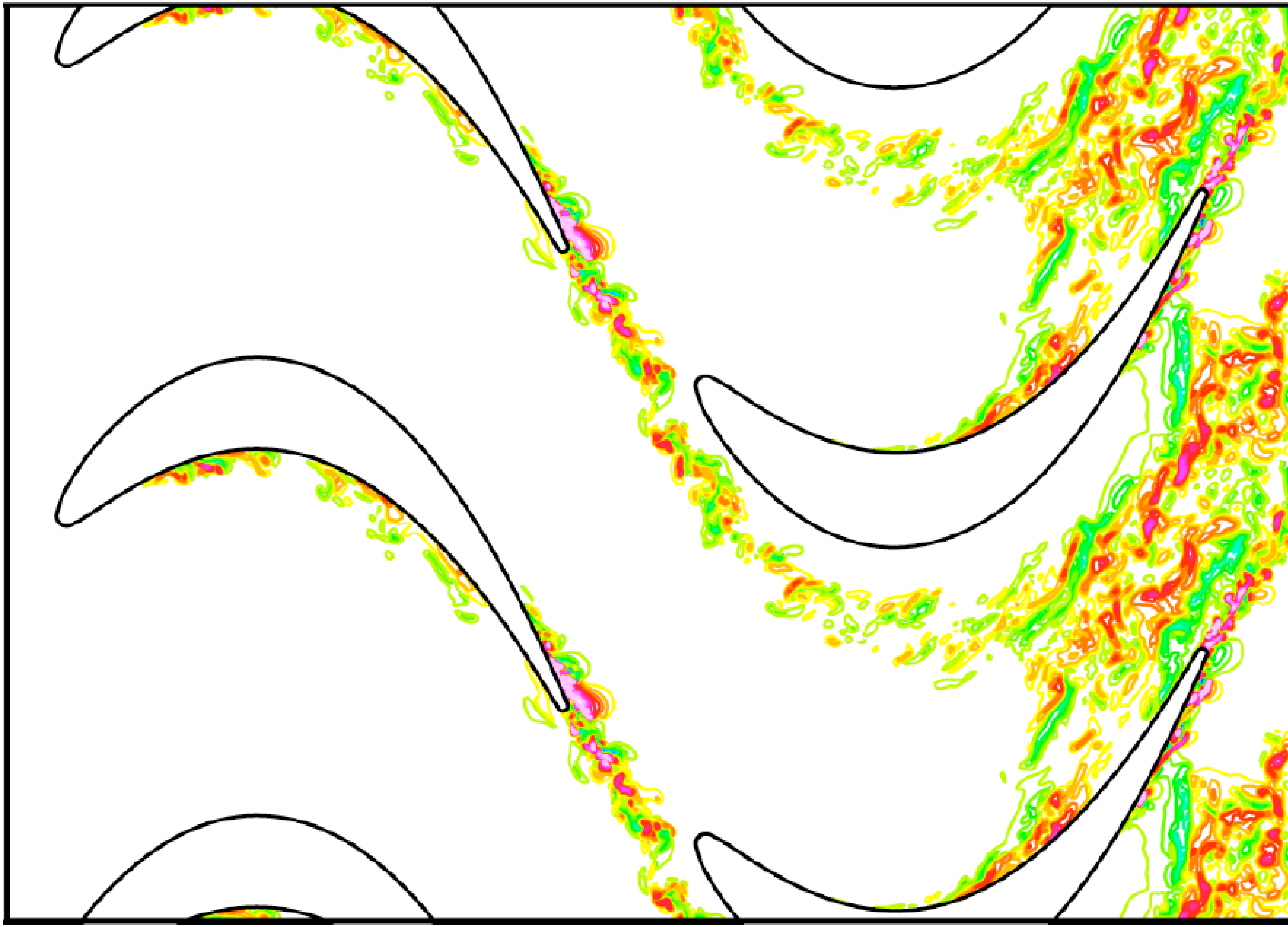


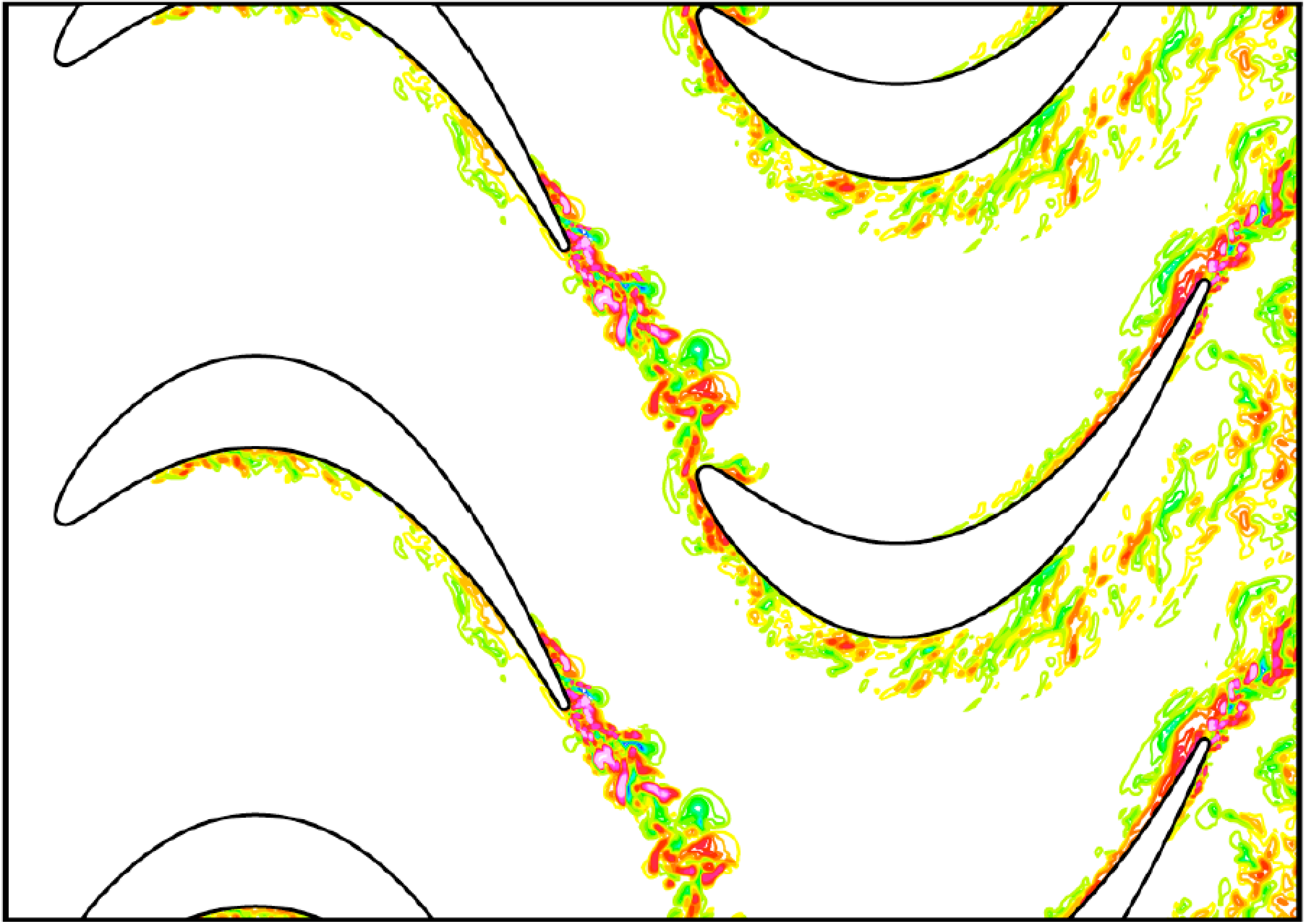


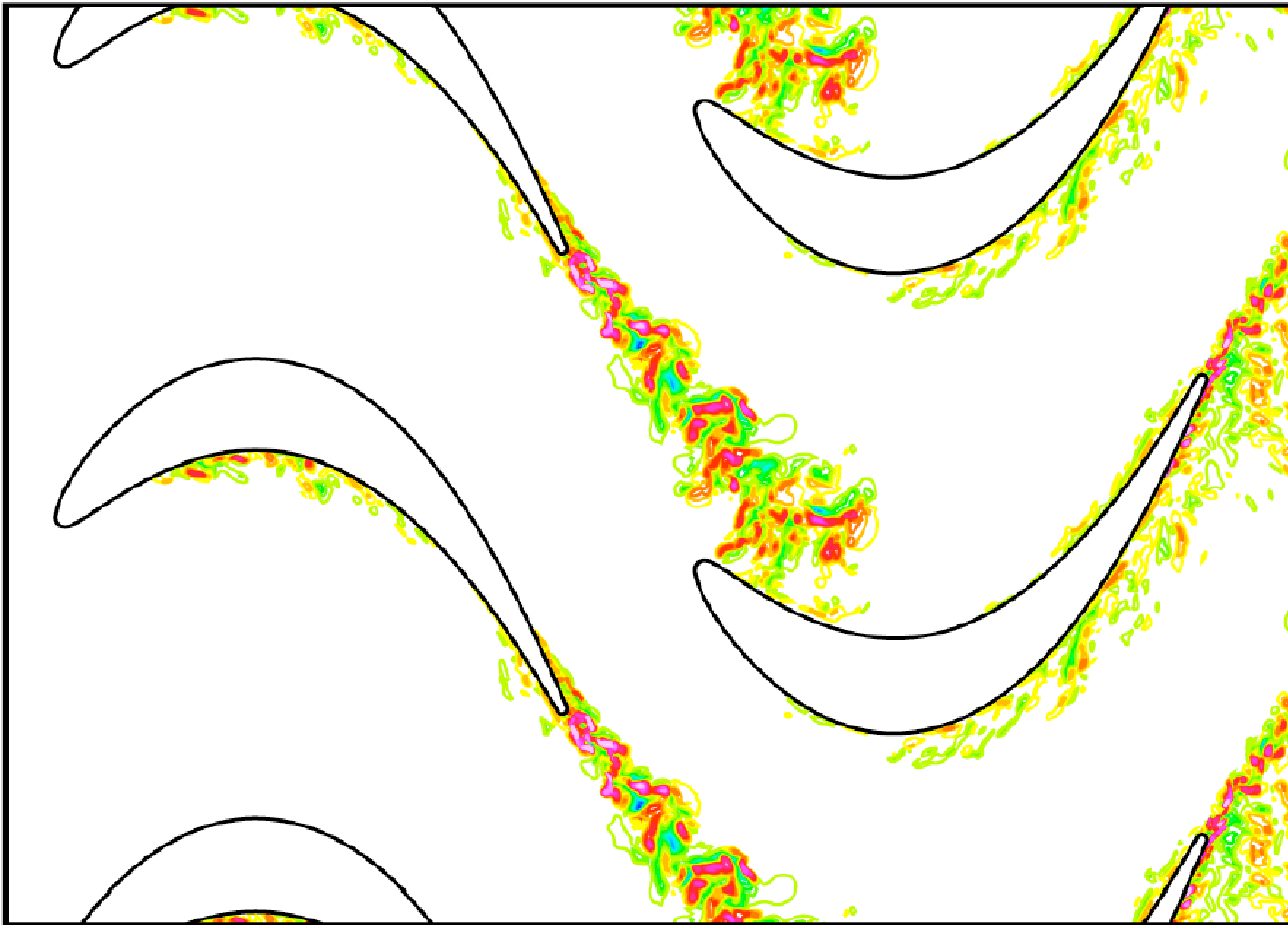


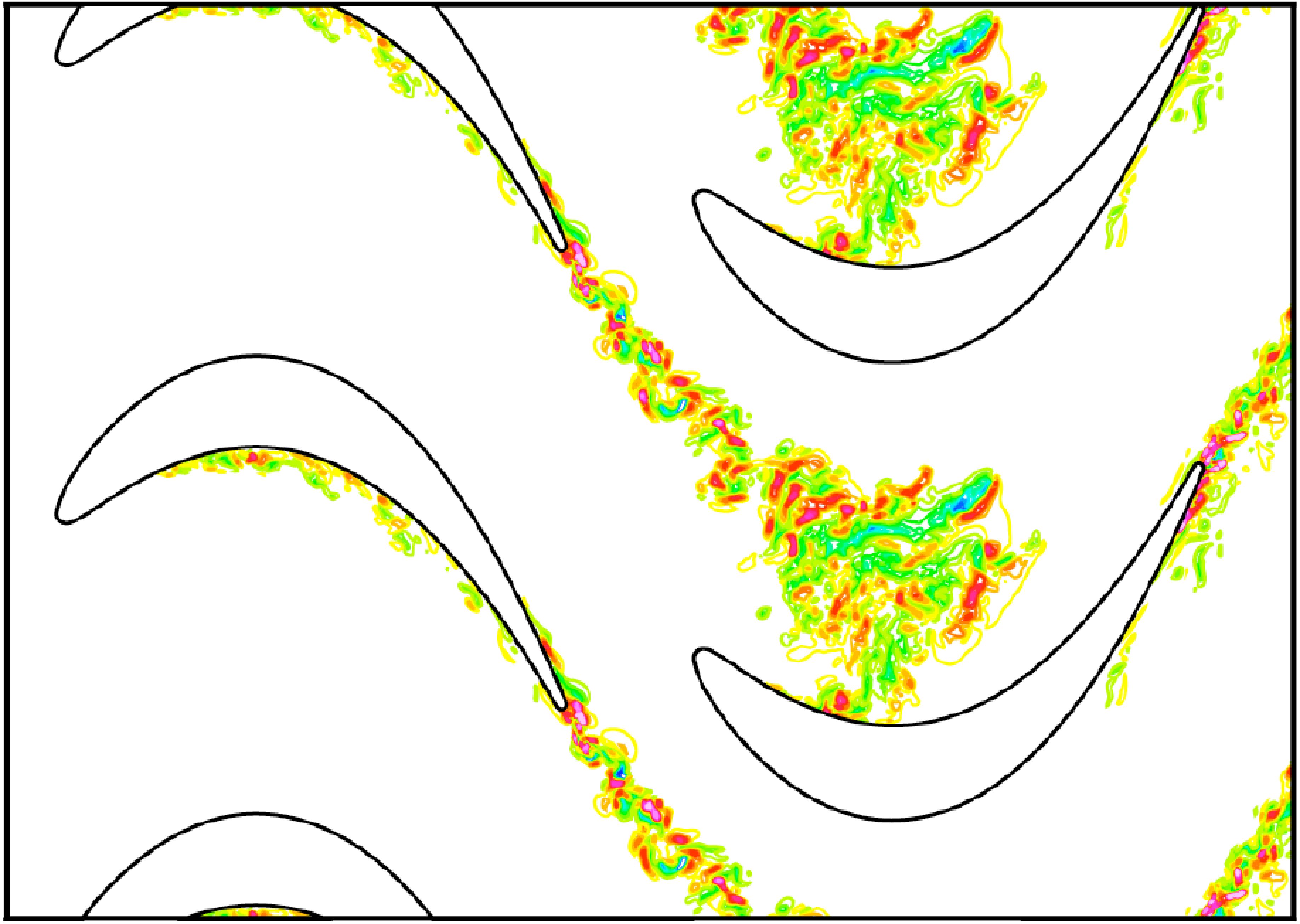


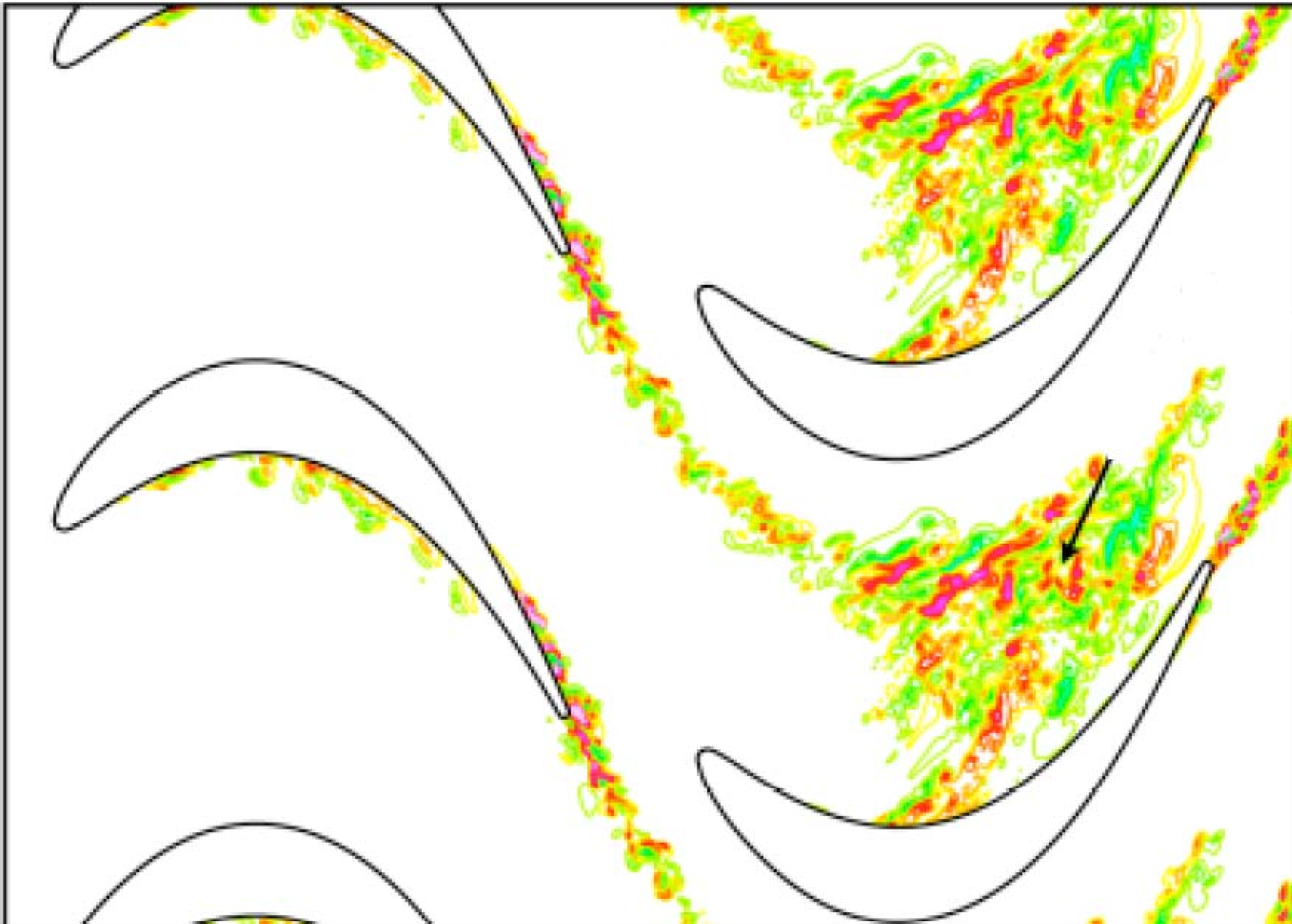


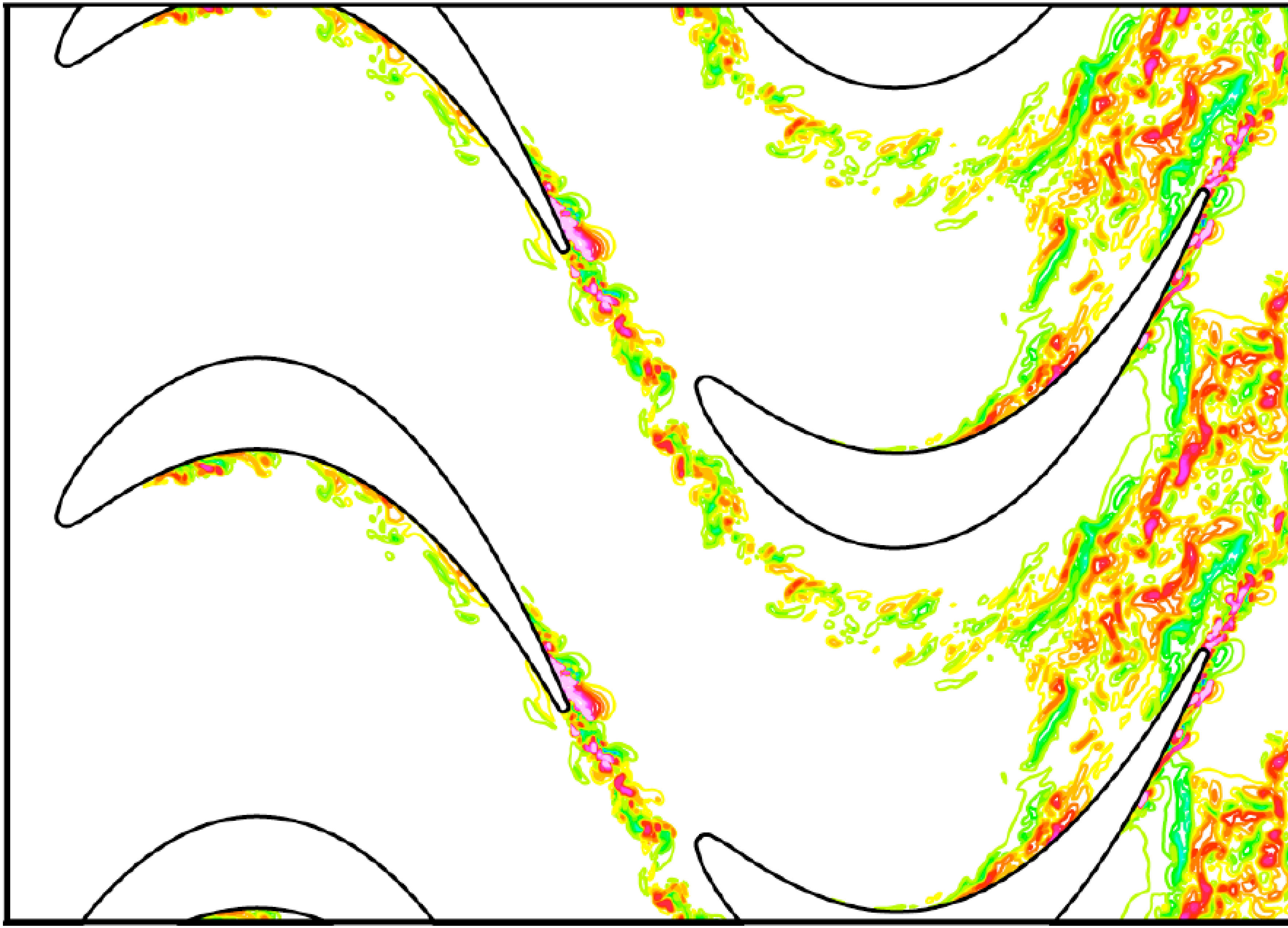


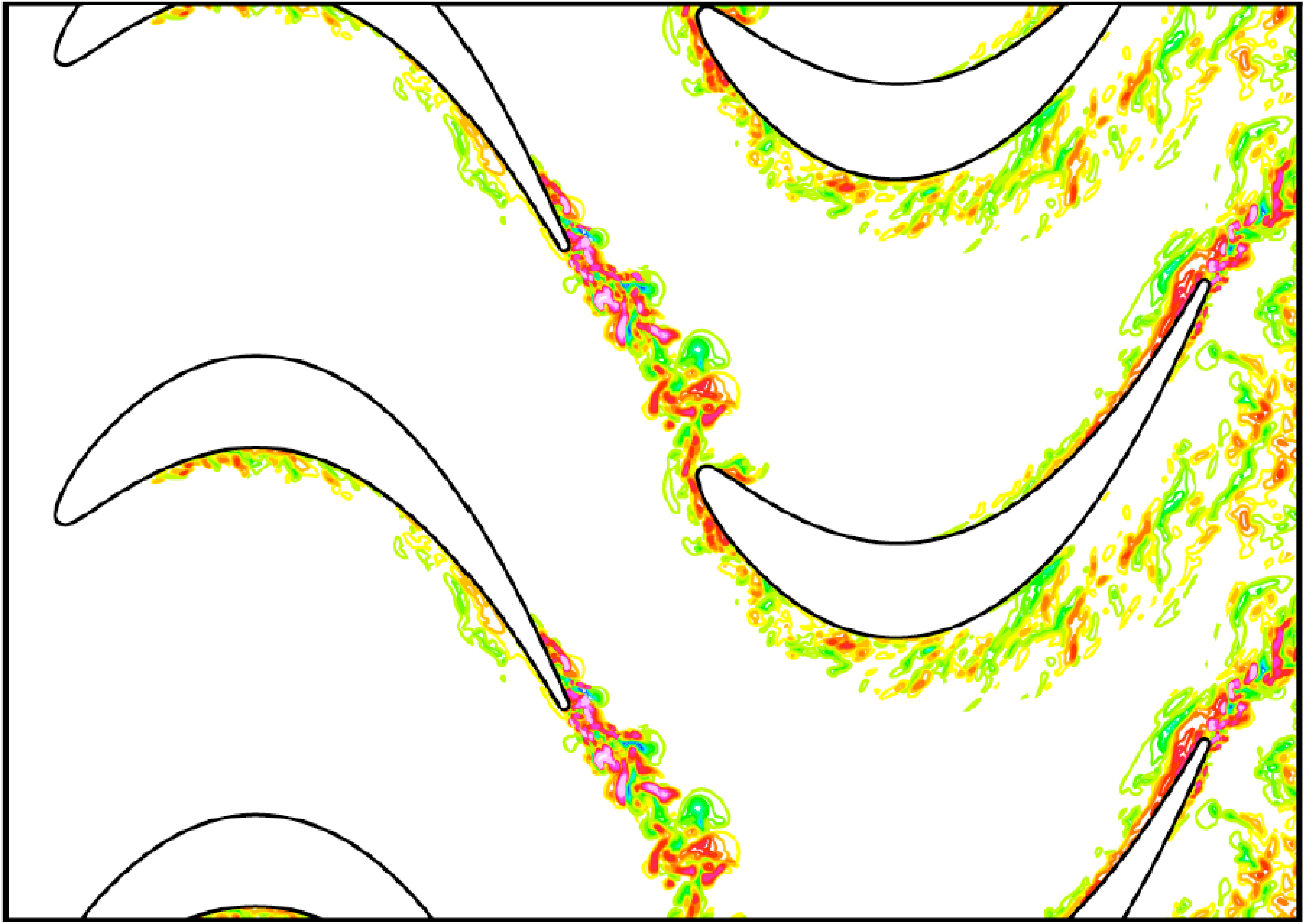


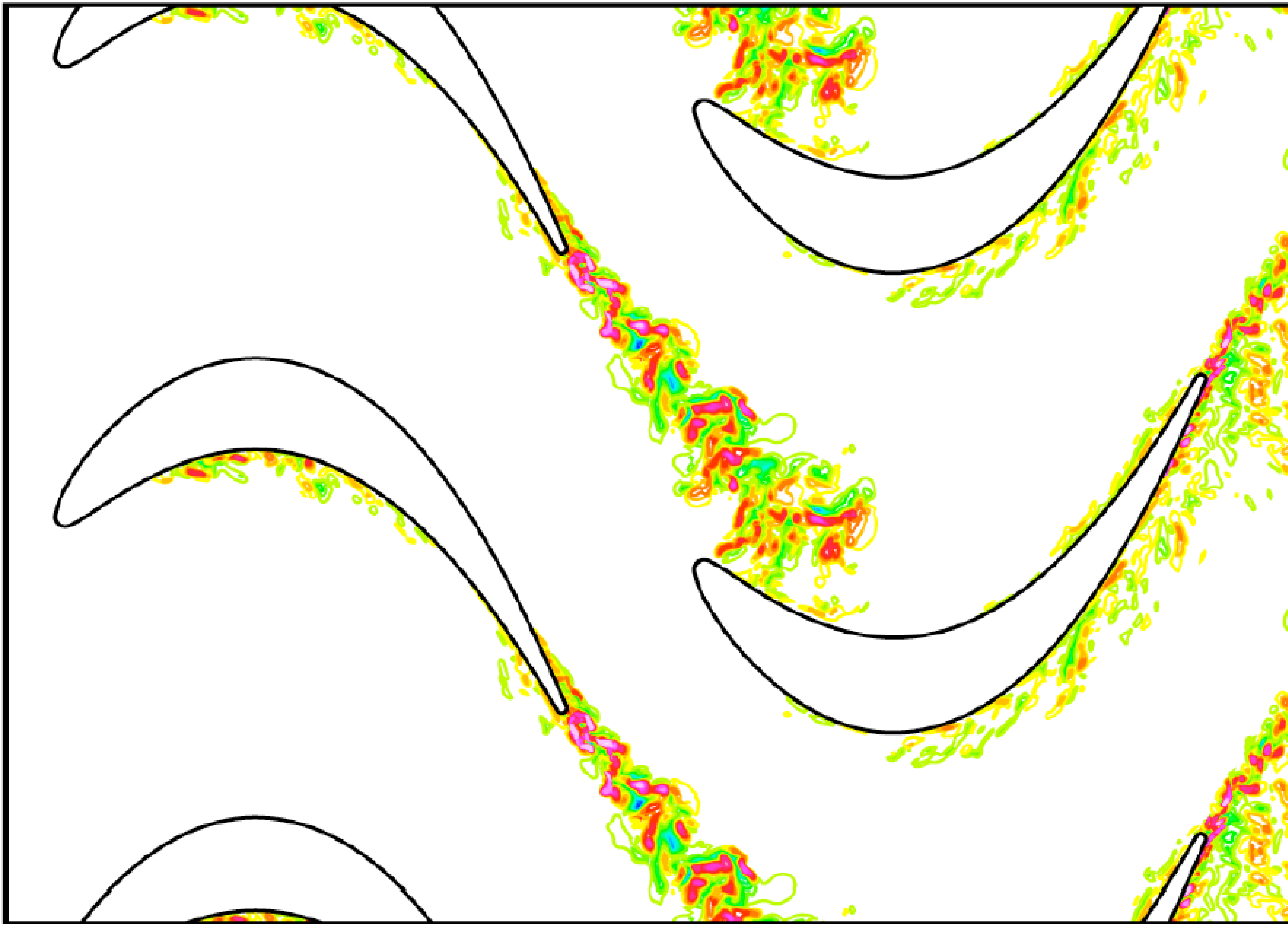


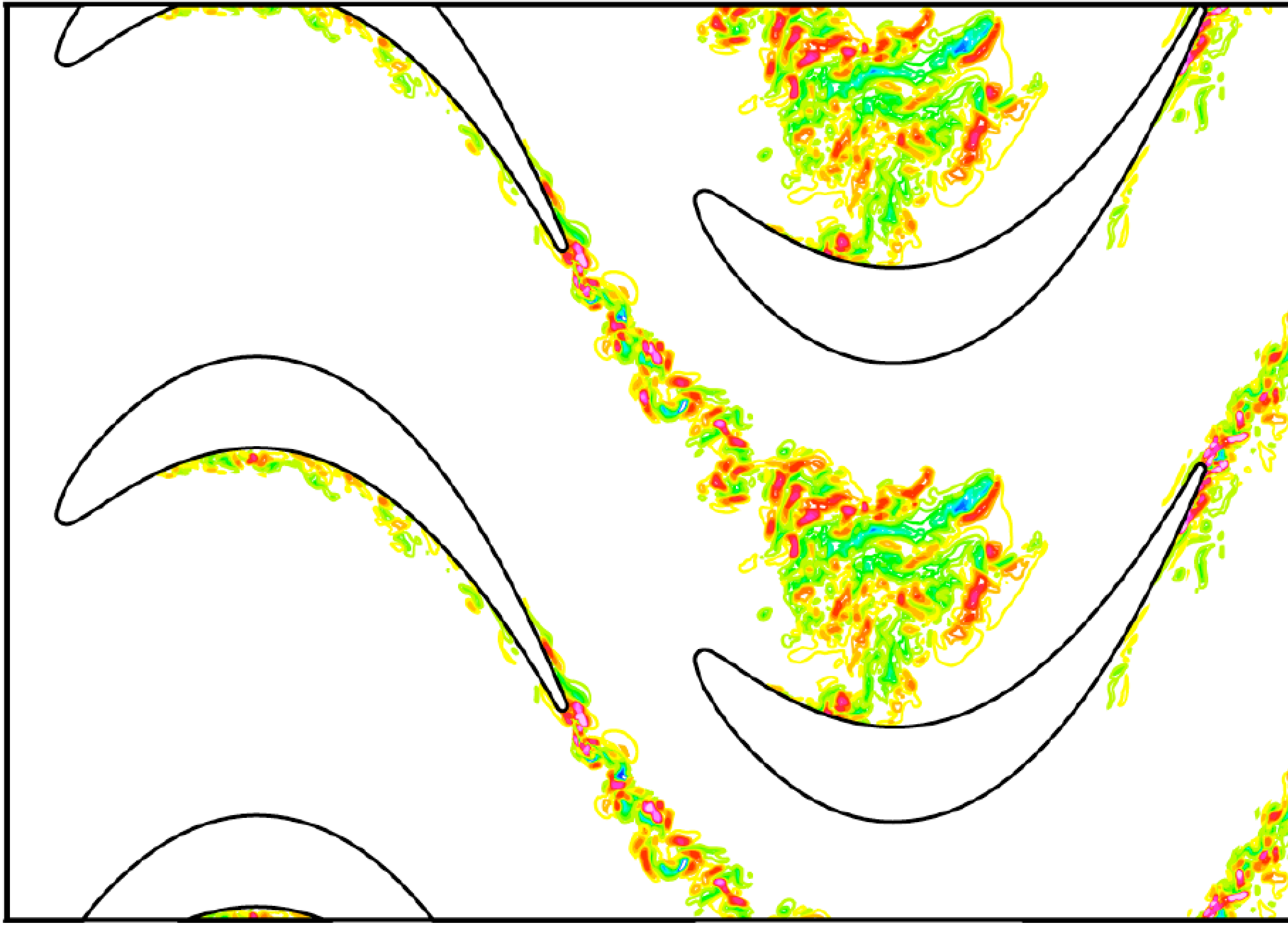








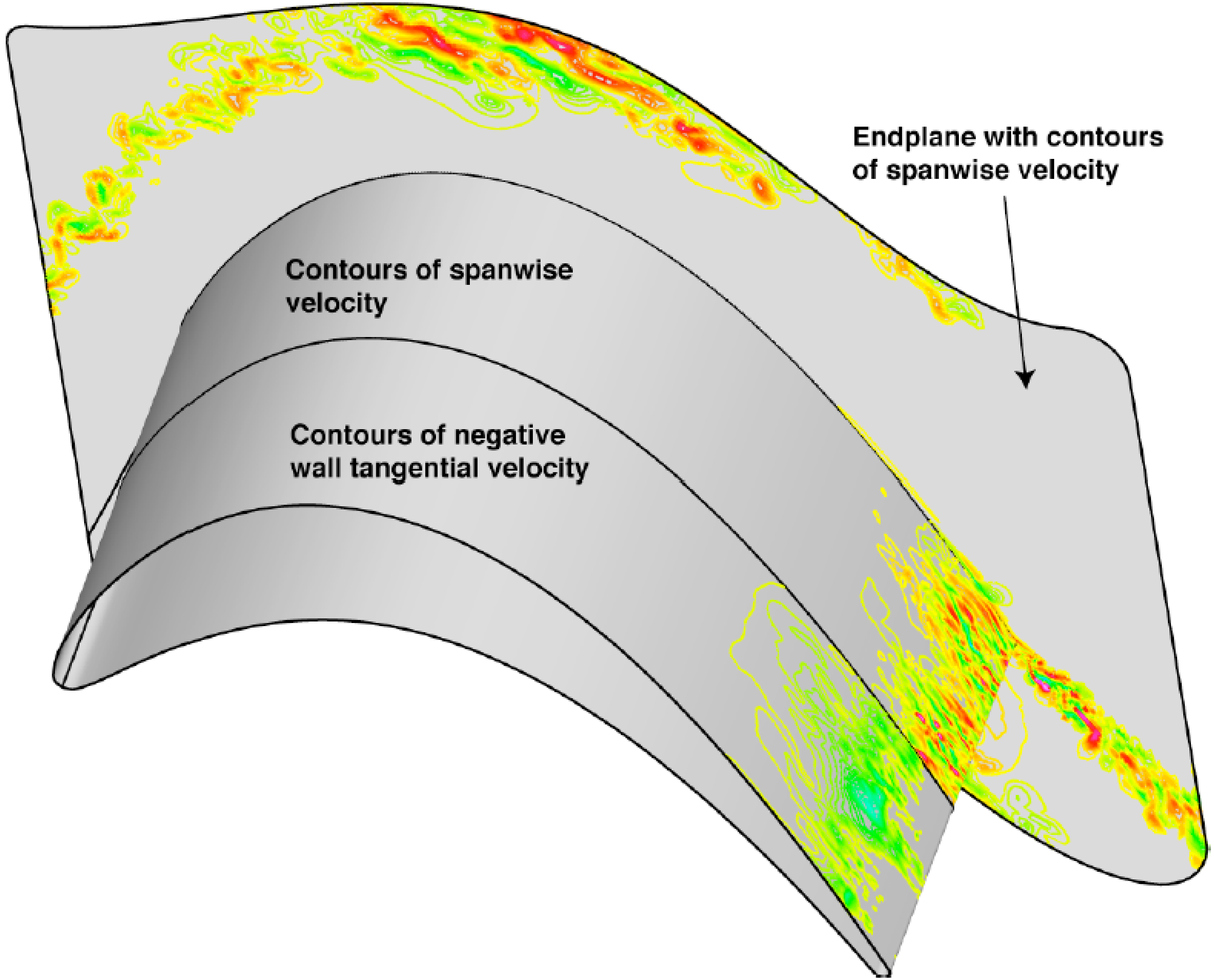


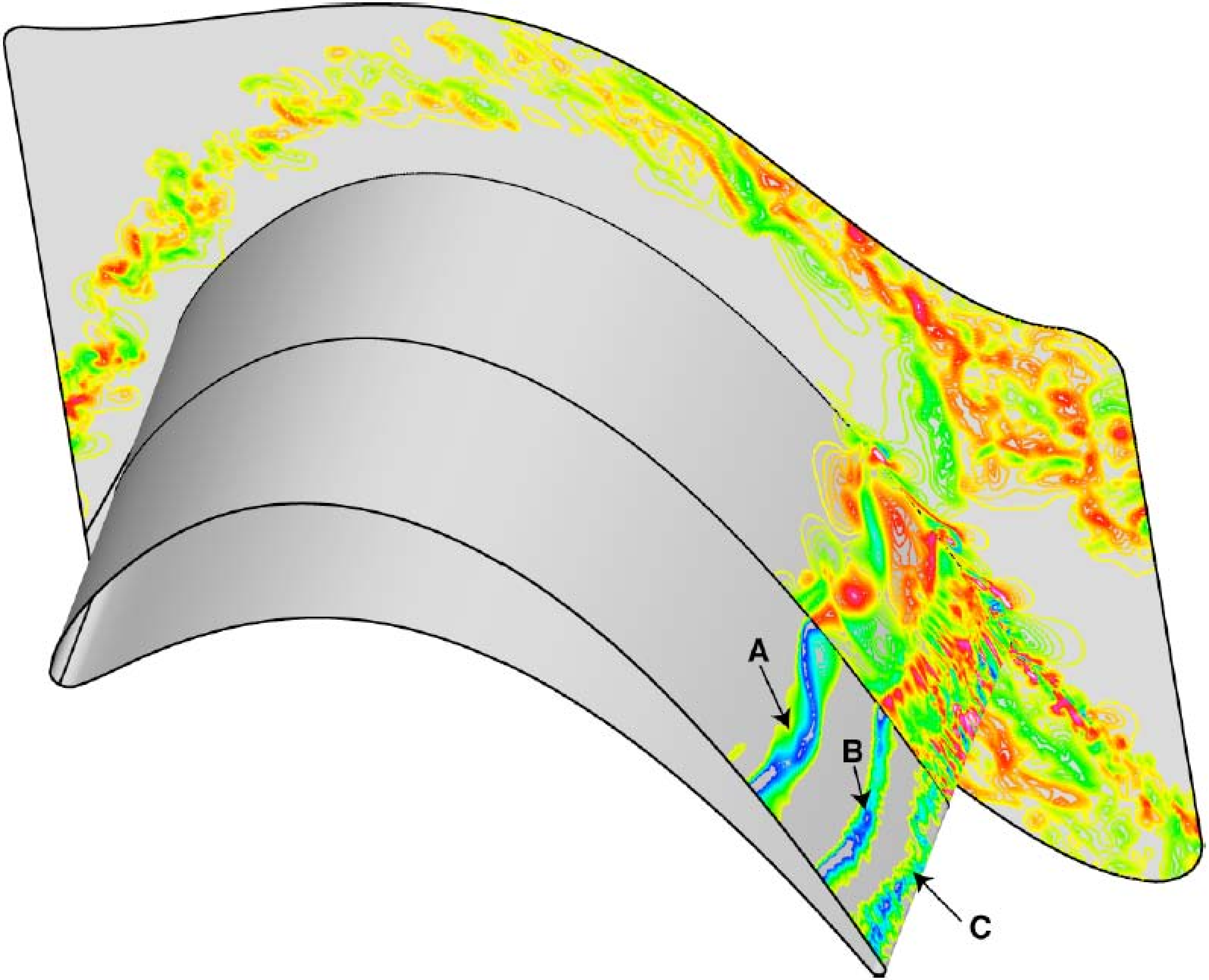


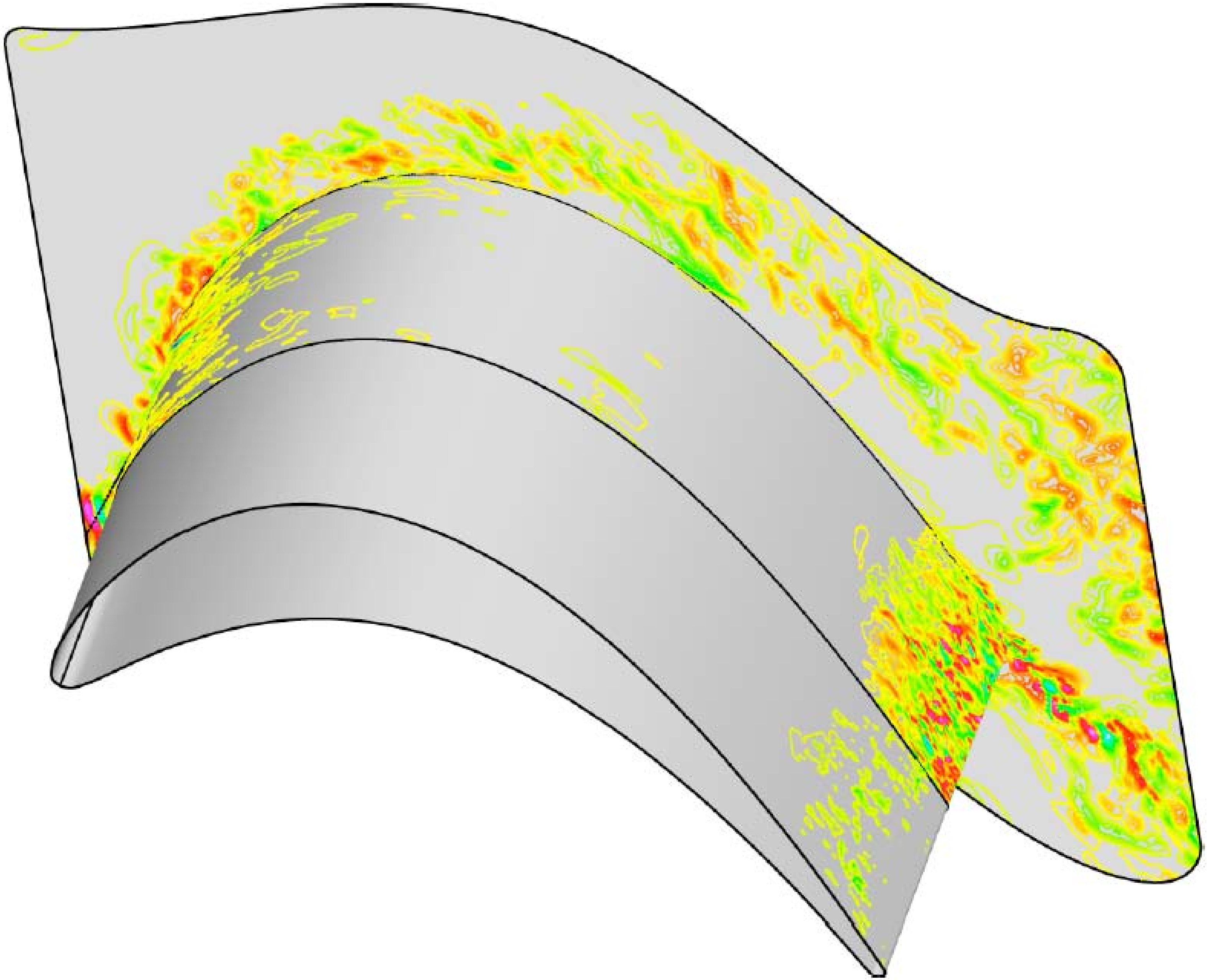
- results also looked at just the wake impinging on the suction surface, they show three things:

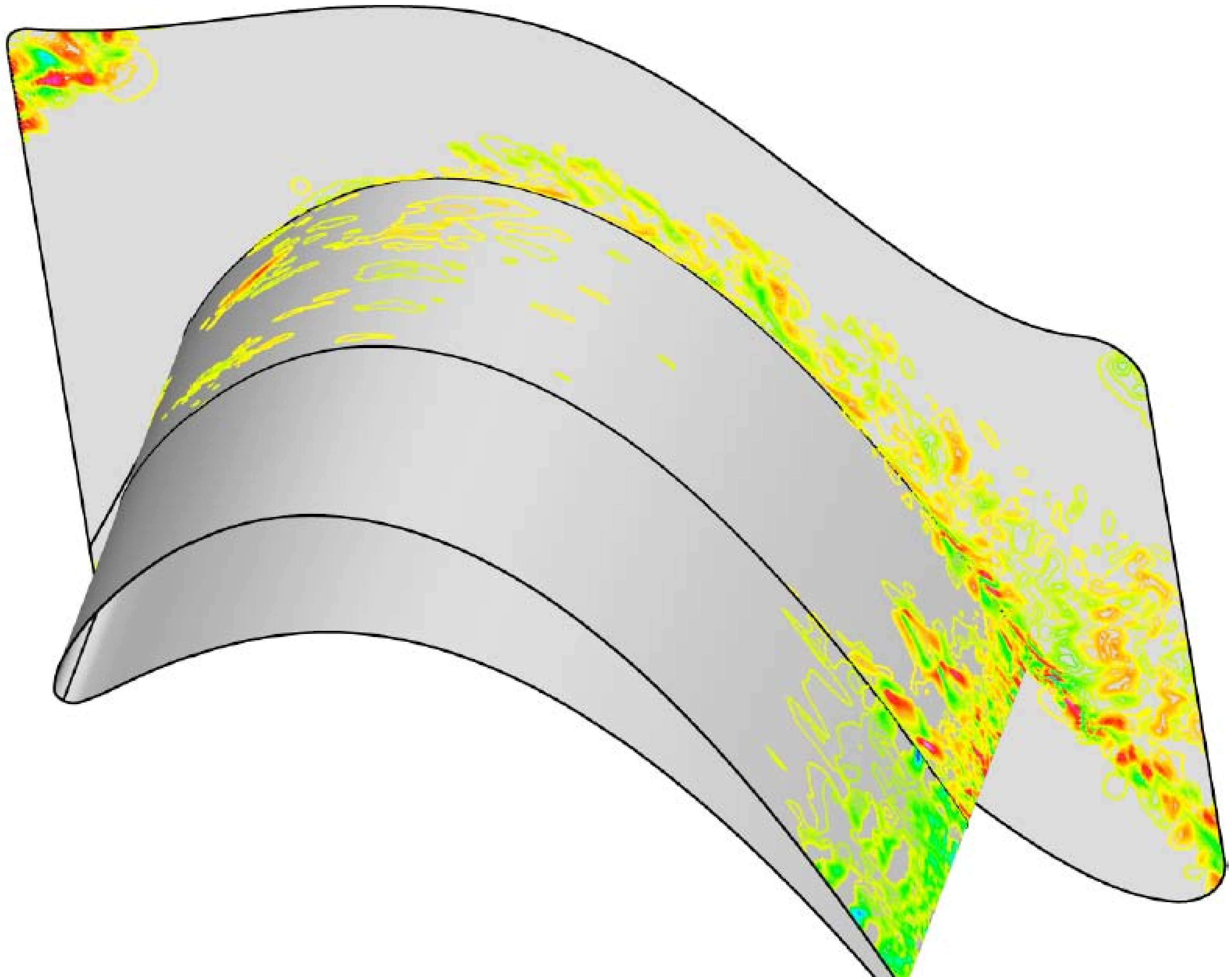
- 1) instantaneous spanwise velocity on the end plane
- 2) instantaneous, near surface, spanwise velocity
-3) near surface negative wall tangential velocity

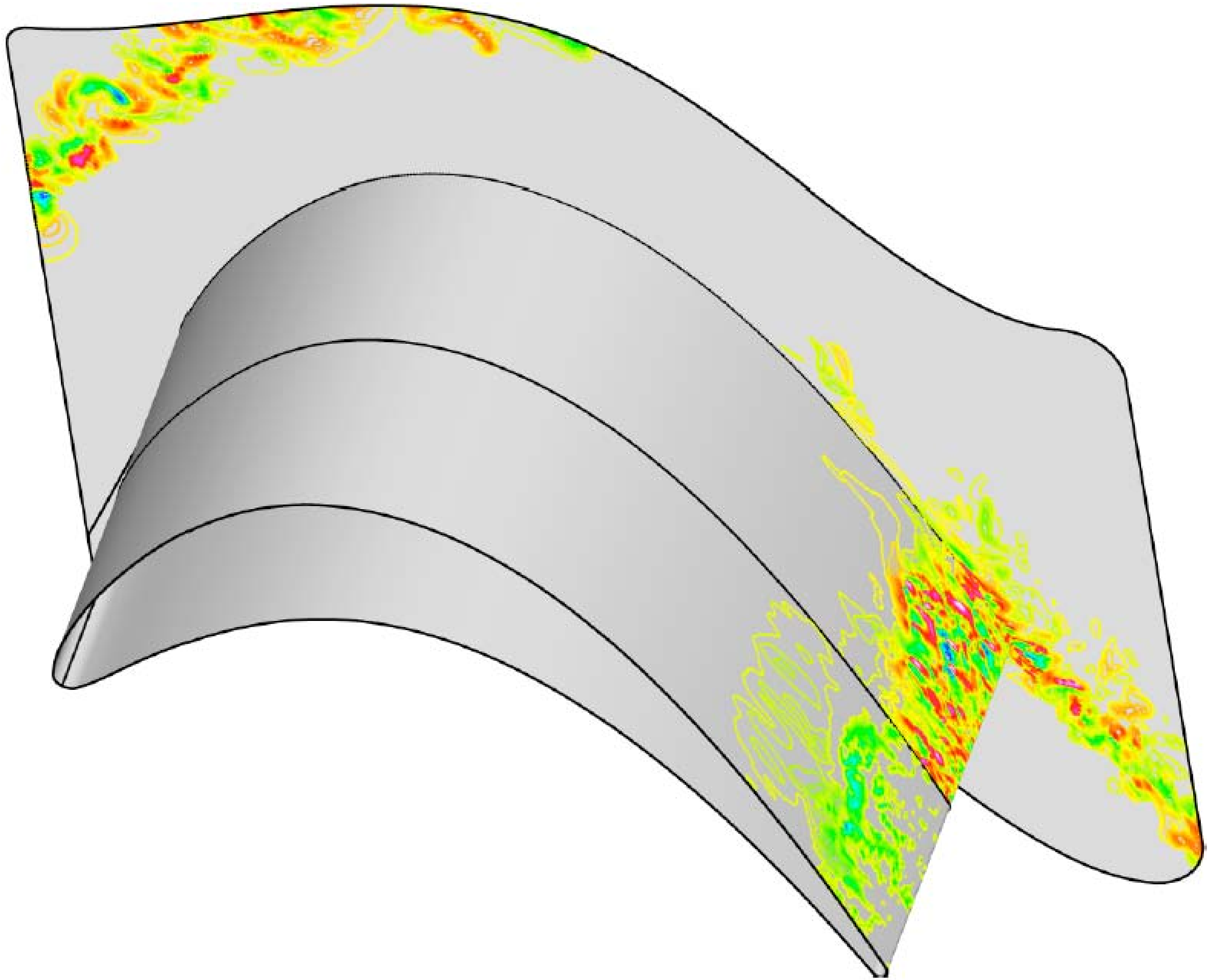
- The wall-tangential velocity contours show three distinct bands of separation (these bands actually exhibit some small-scale structure).

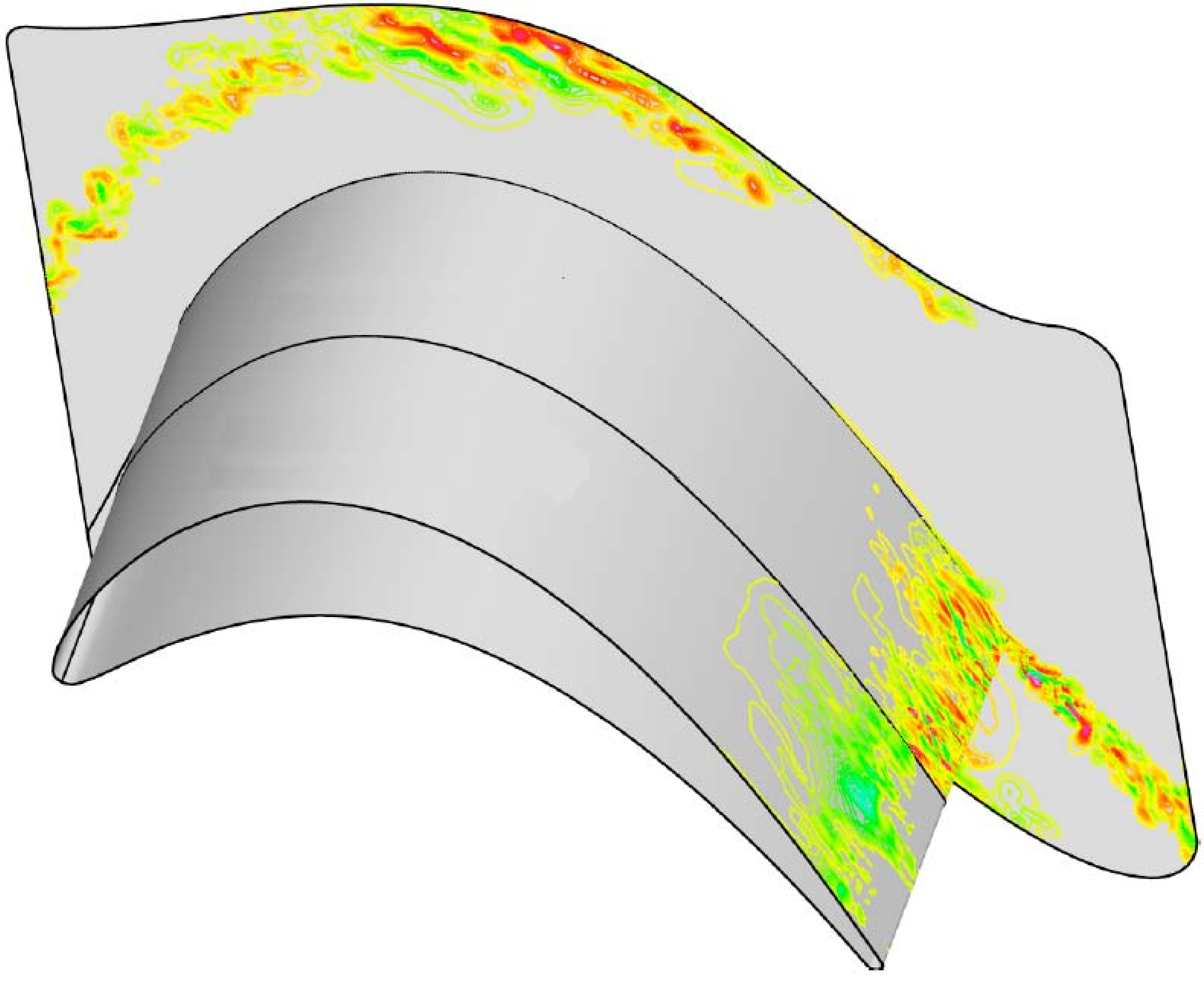

Endplane with contours of spanwise velocity
Contours of spanwise velocity
Contours of negative wall tangential velocity

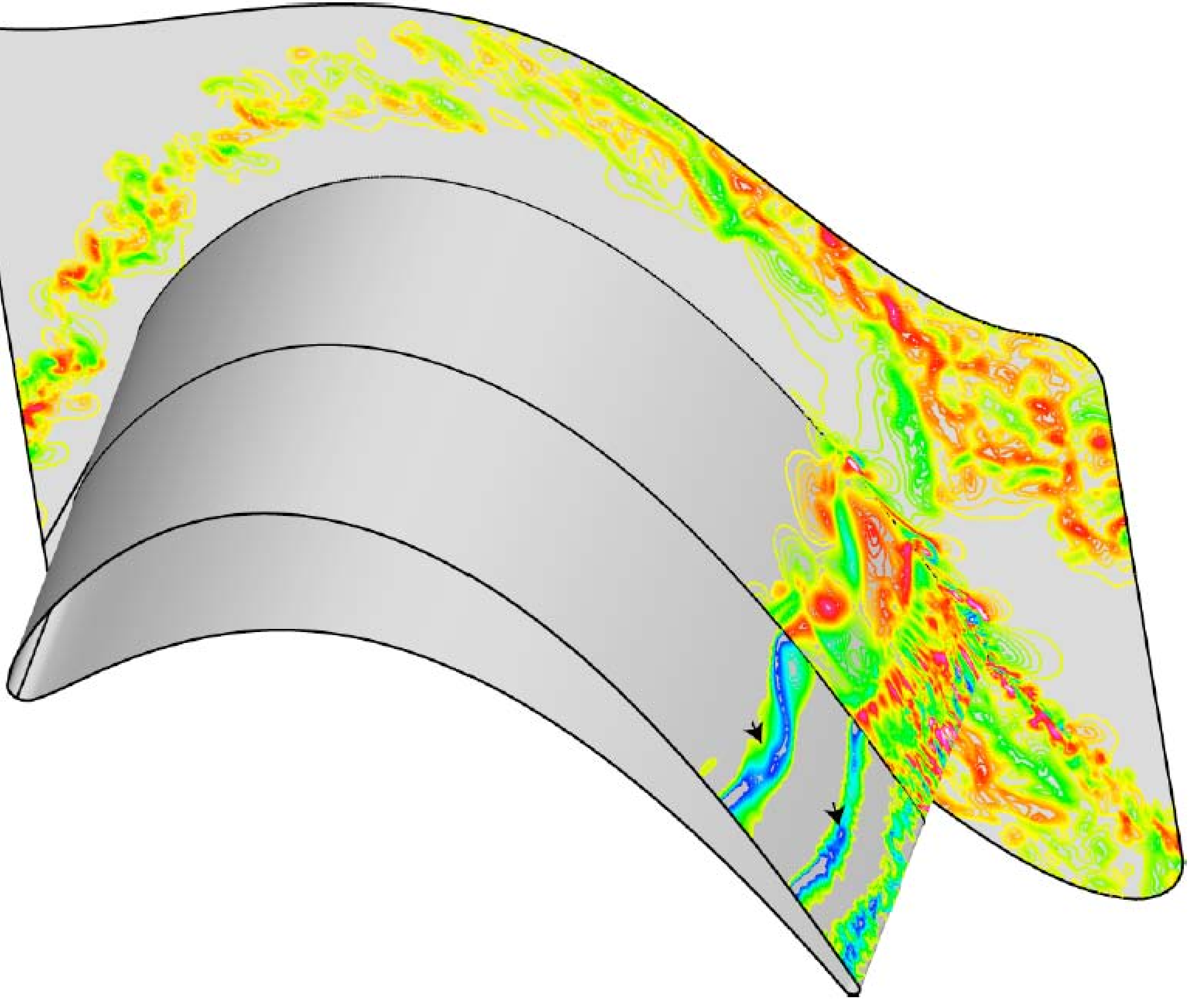

A
B
C

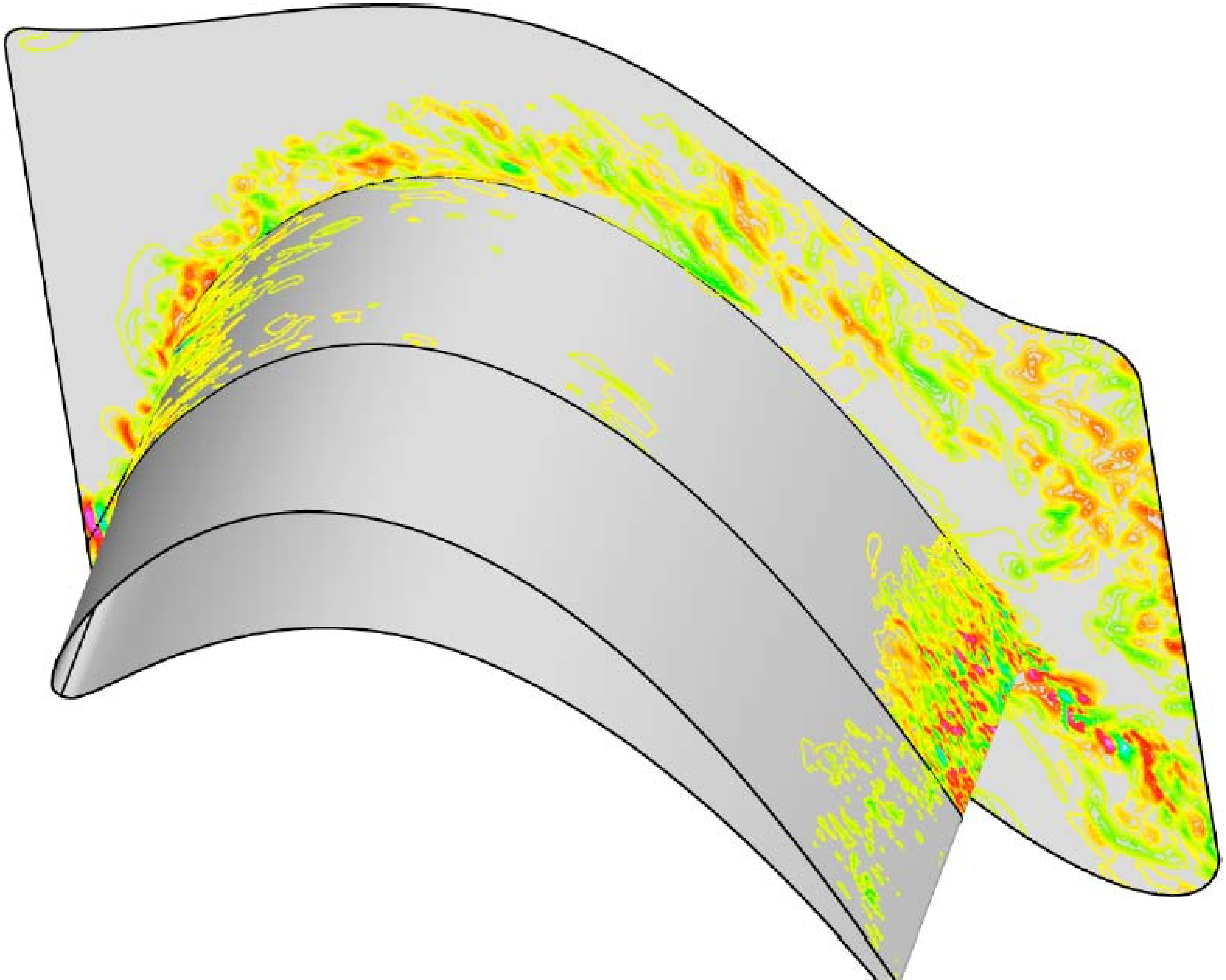


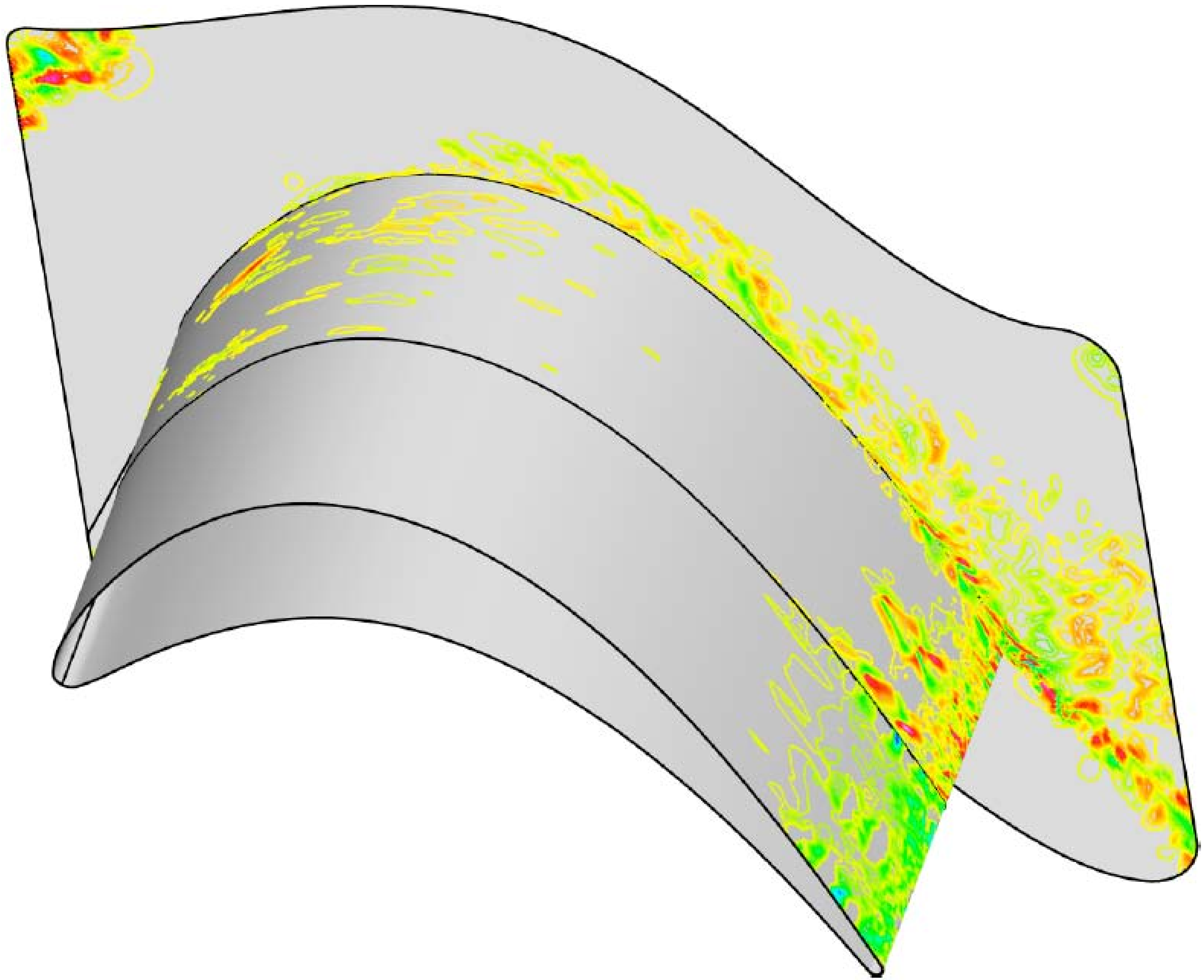


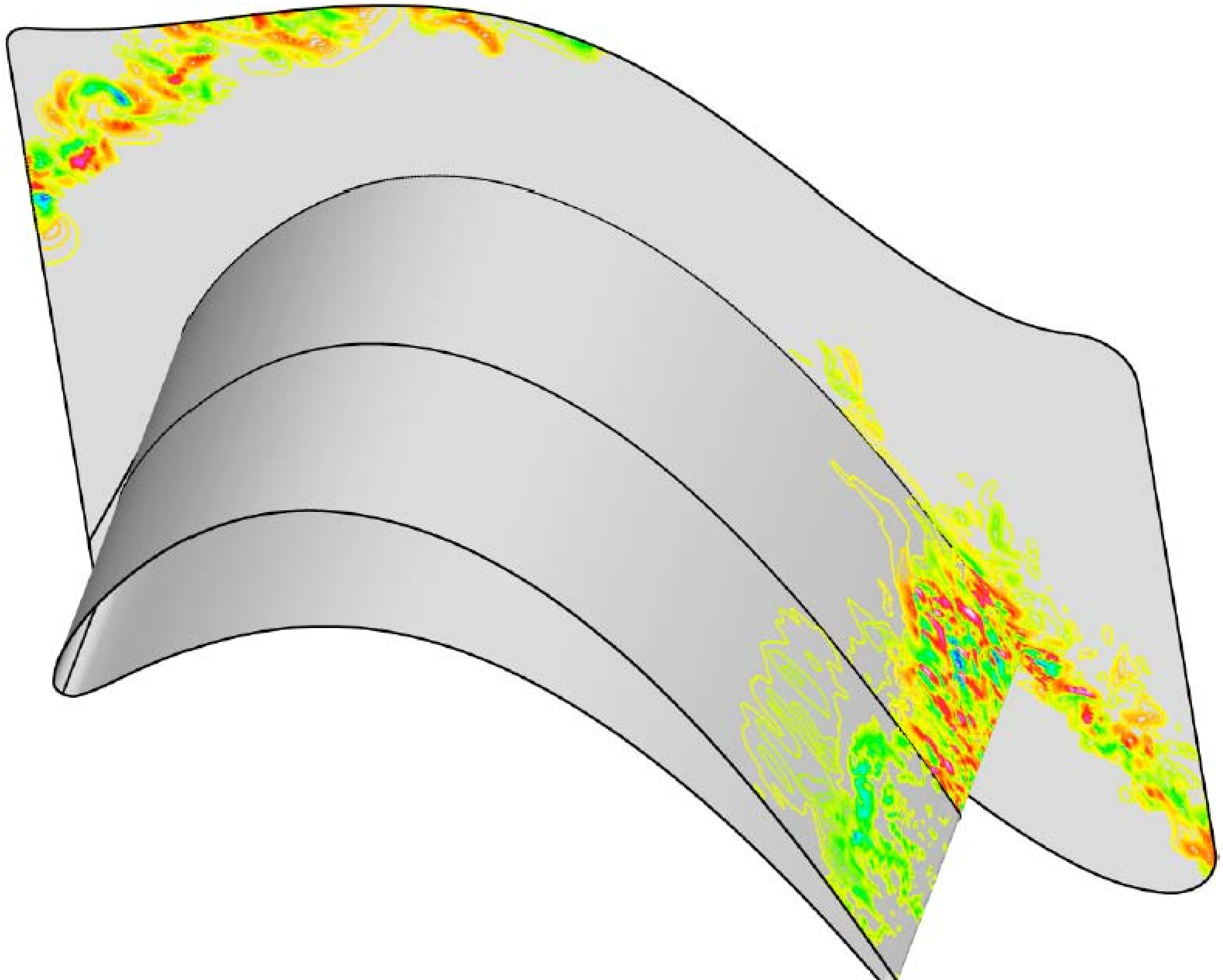


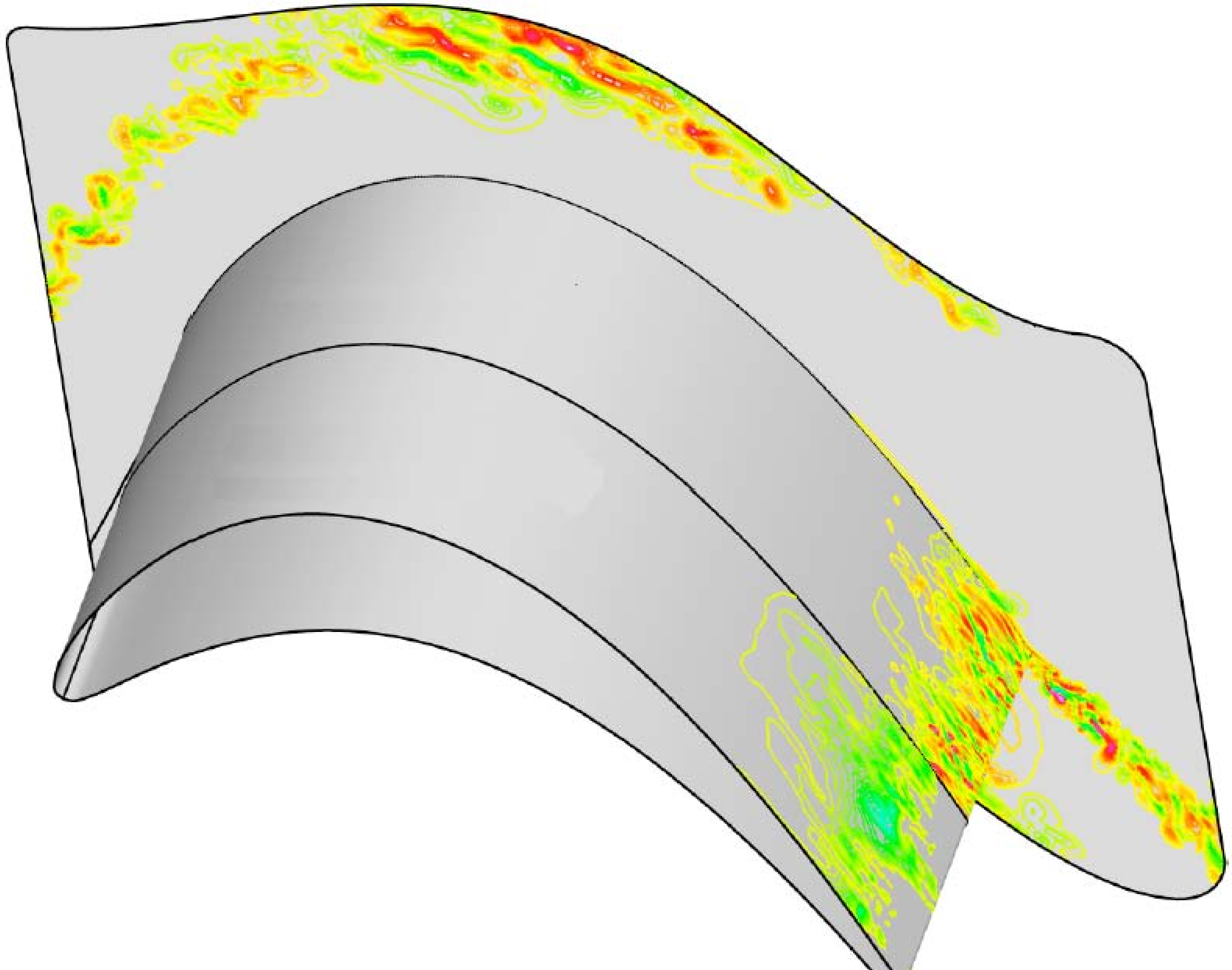


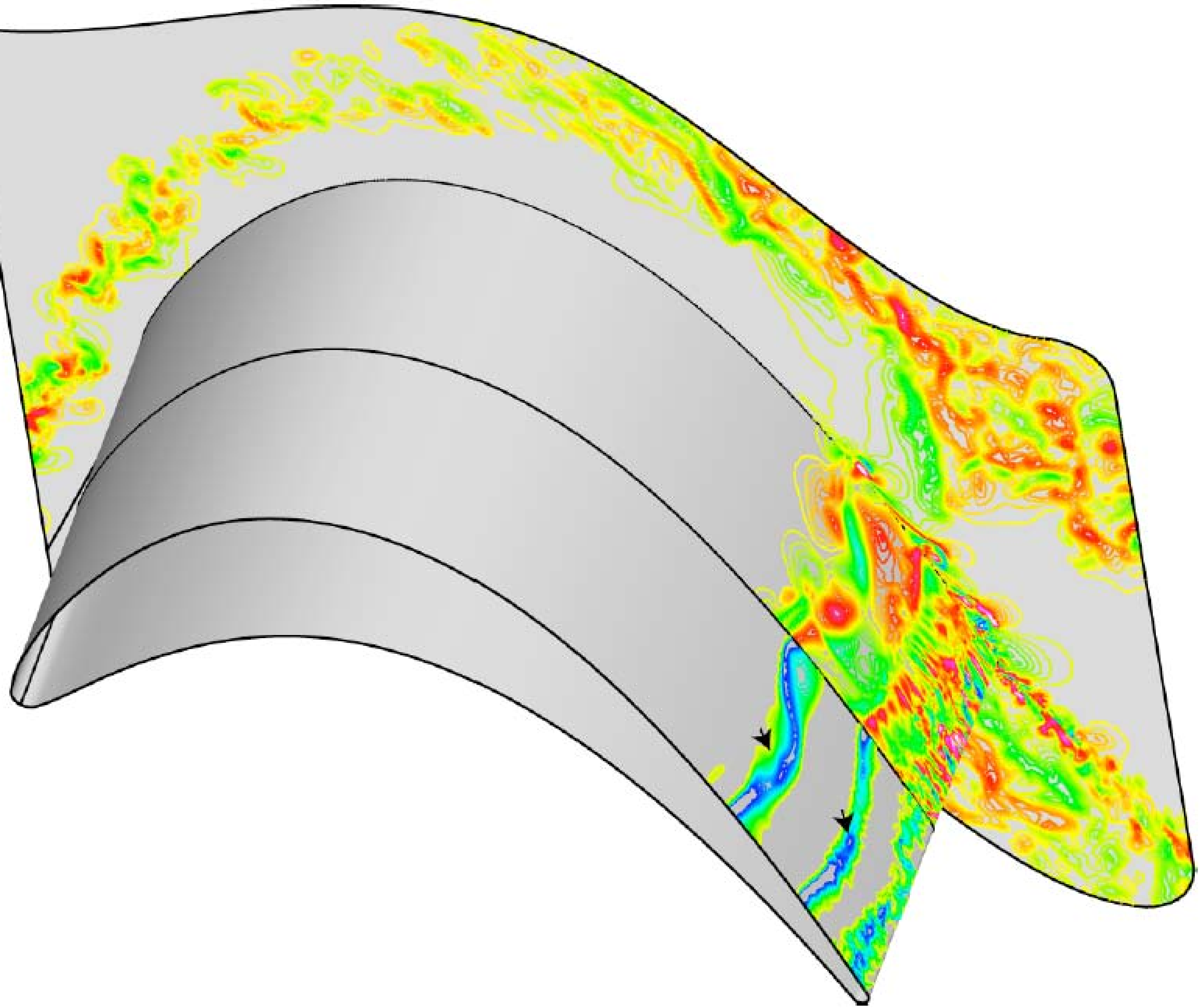


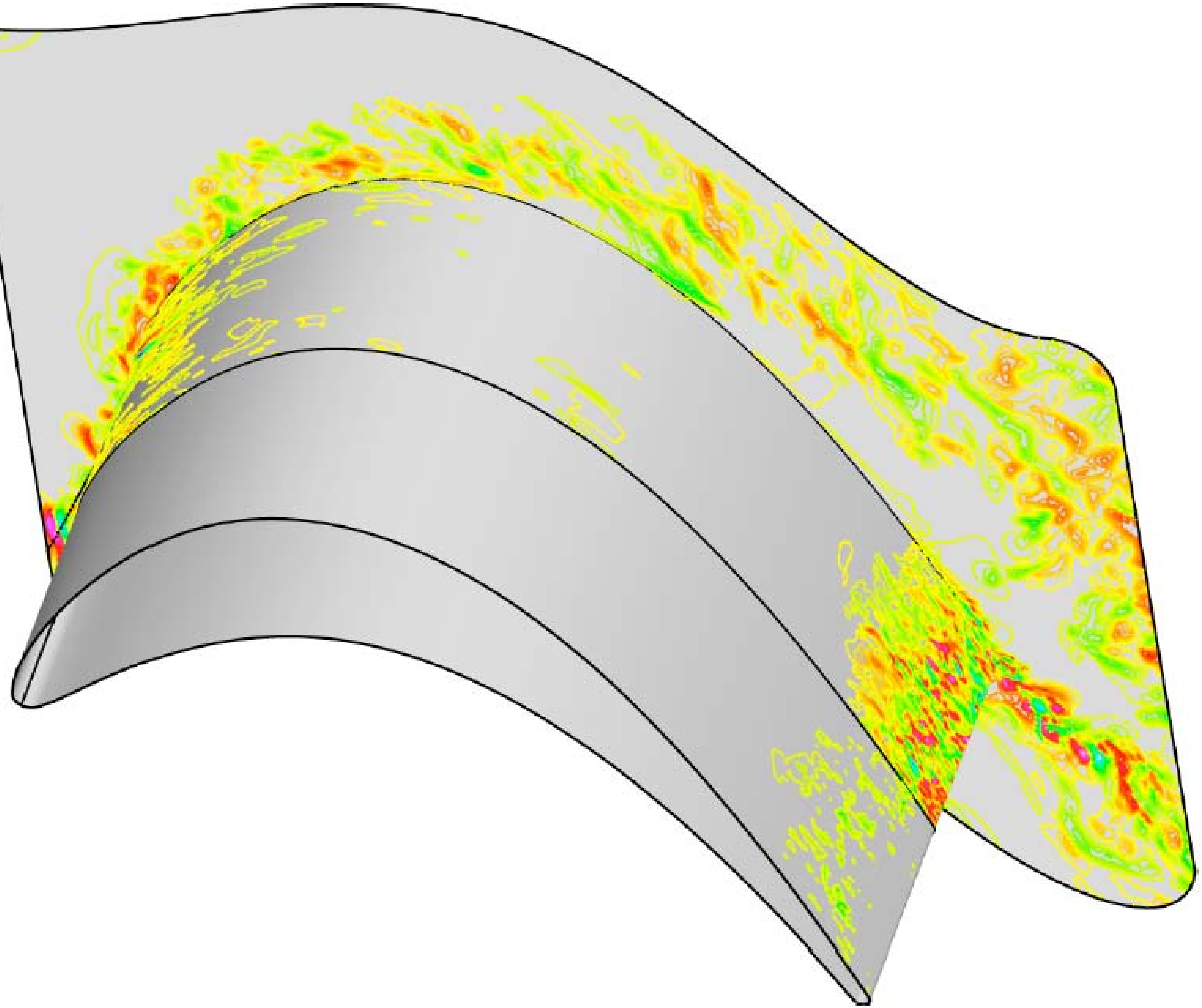


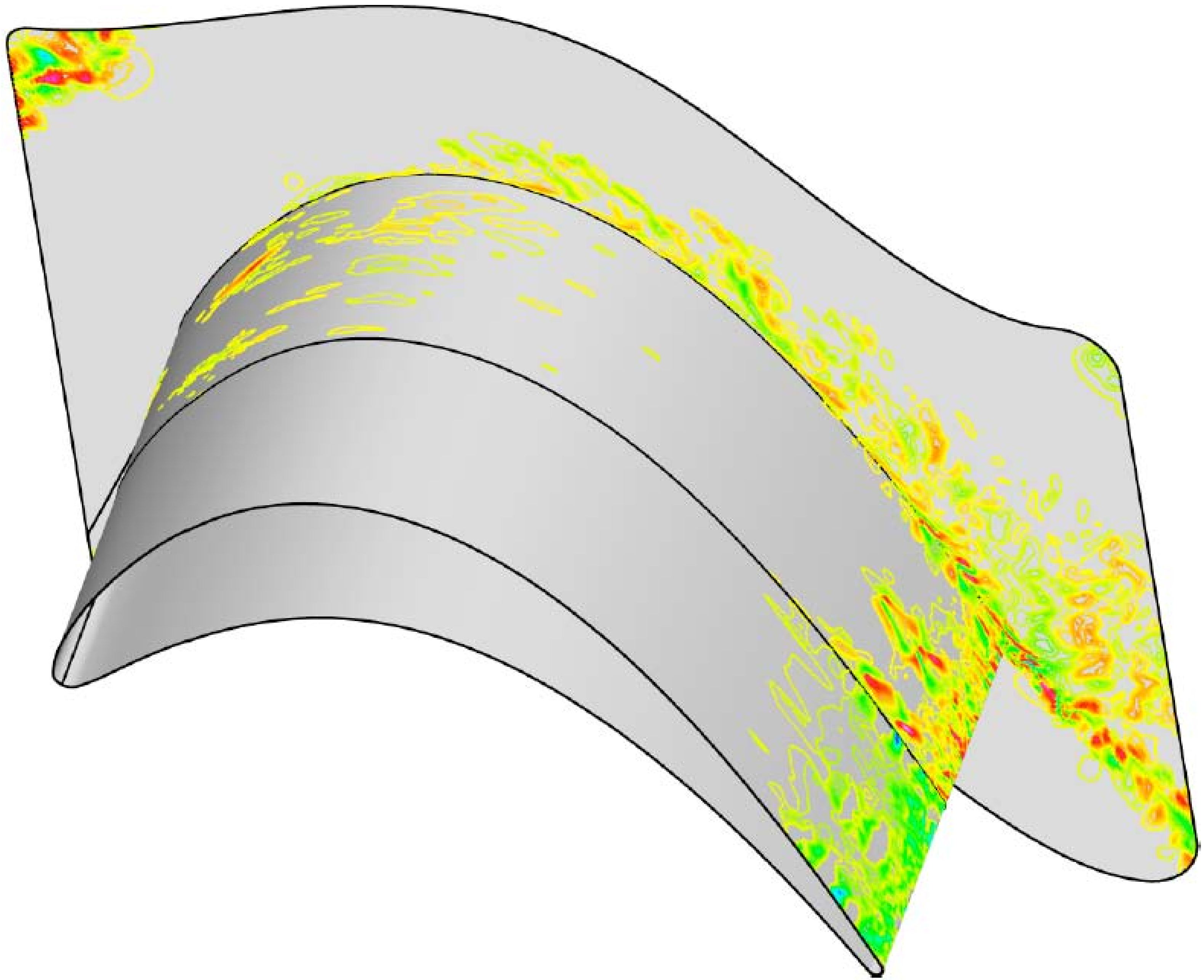


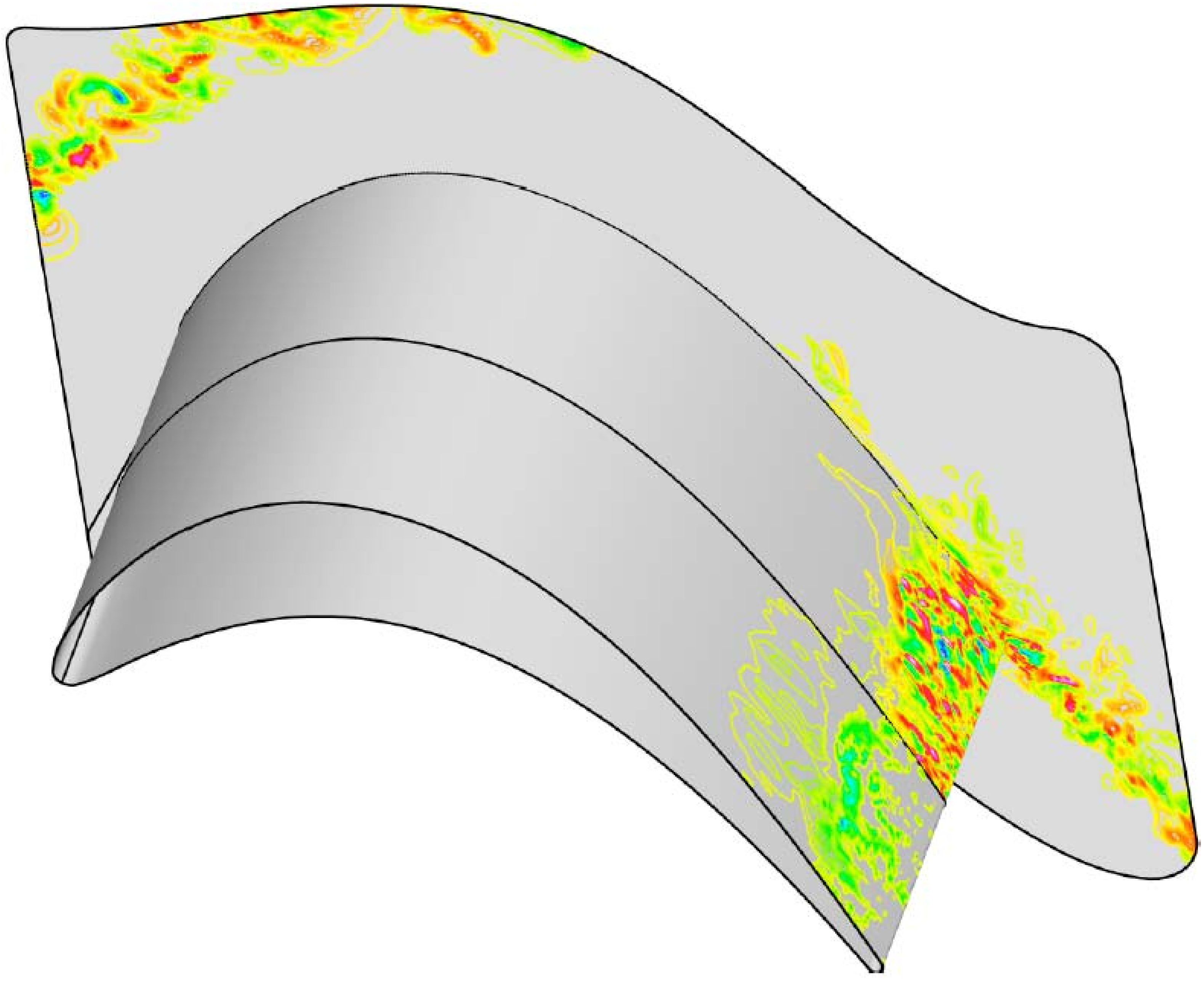




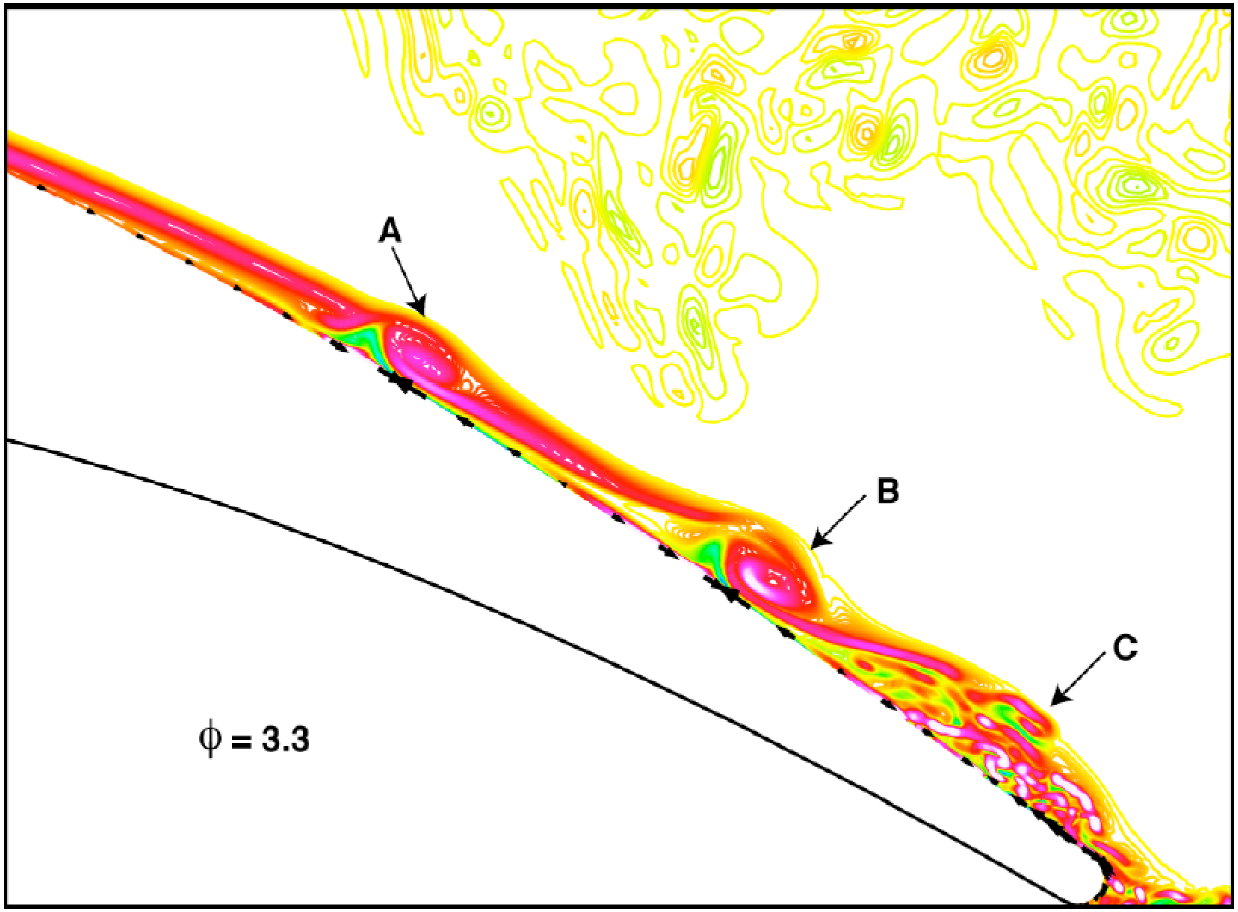








- instantaneous spanwise vorticity contours showing the bands of separation
- the shear layer rolls up
-the *rotor wake is turbulent and it’s a* source of three-dimensional disturbances that propagate upstream.



- roll-up and transition of each one explored in detail

- flow over the suction surface is laminar until ~0.6c

- flow near the trailing edge on the suction surface saw periodic separation of the boundary layer

- the separation occurred in bands

- vorticity contours show a roll-up of the shear layer just above the bands

- bands caused by periodically appearing, higher-than-average pressure gradient regions

- reattachment due to dissolution of the roll-ups
- dissolution due to transition and convection off the surface

- evolution of stator wake in the rotor passage matches that of previous studies

High-Order Accurate CFD/CSD Simulation of the UH-60 Rotor in Forward Flight

Jasim U. Ahmad and Neal M. Chaderjian

AIAA-2011-3185

- rotorcraft simulation is hard ‘cause you have to model the aeroelastic interactions of the blades

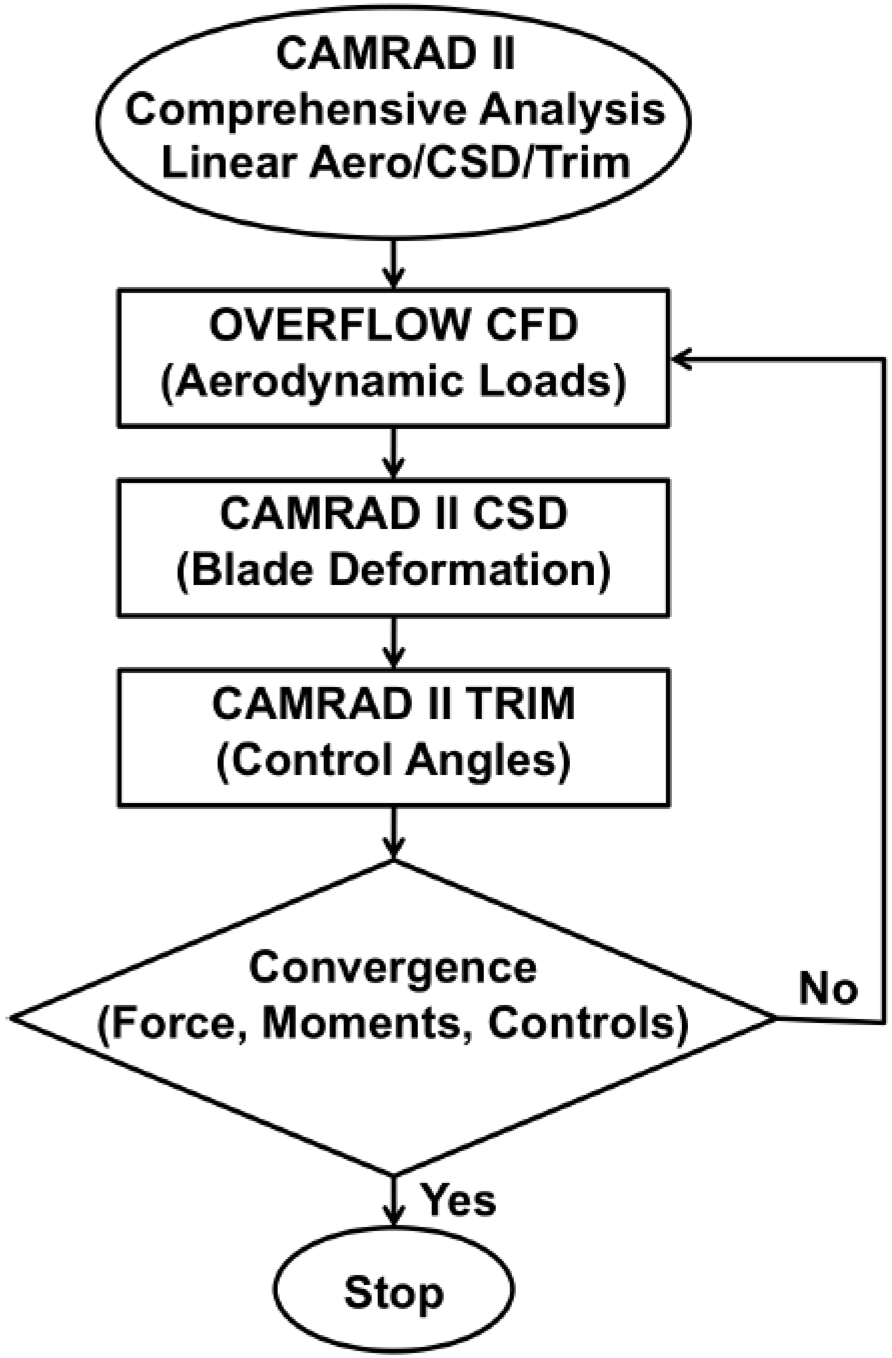
-not only do you have to model a lot of crazy stuff (e.g. 3D unsteadiness, transonic shocks, dynamic stall, boundary layer separation, vortical wakes, blade-wake interaction, wake-wake interaction, body motions, etc), but you have to be able to couple the CFD solver with the CSD code

-comprehensive codes like CAMRAD don’t have the high-fidelity aerodynamics needed to model rotorcraft flows

- to get around this, NASA couples OVERFLOW 2.2 with CAMRAD II

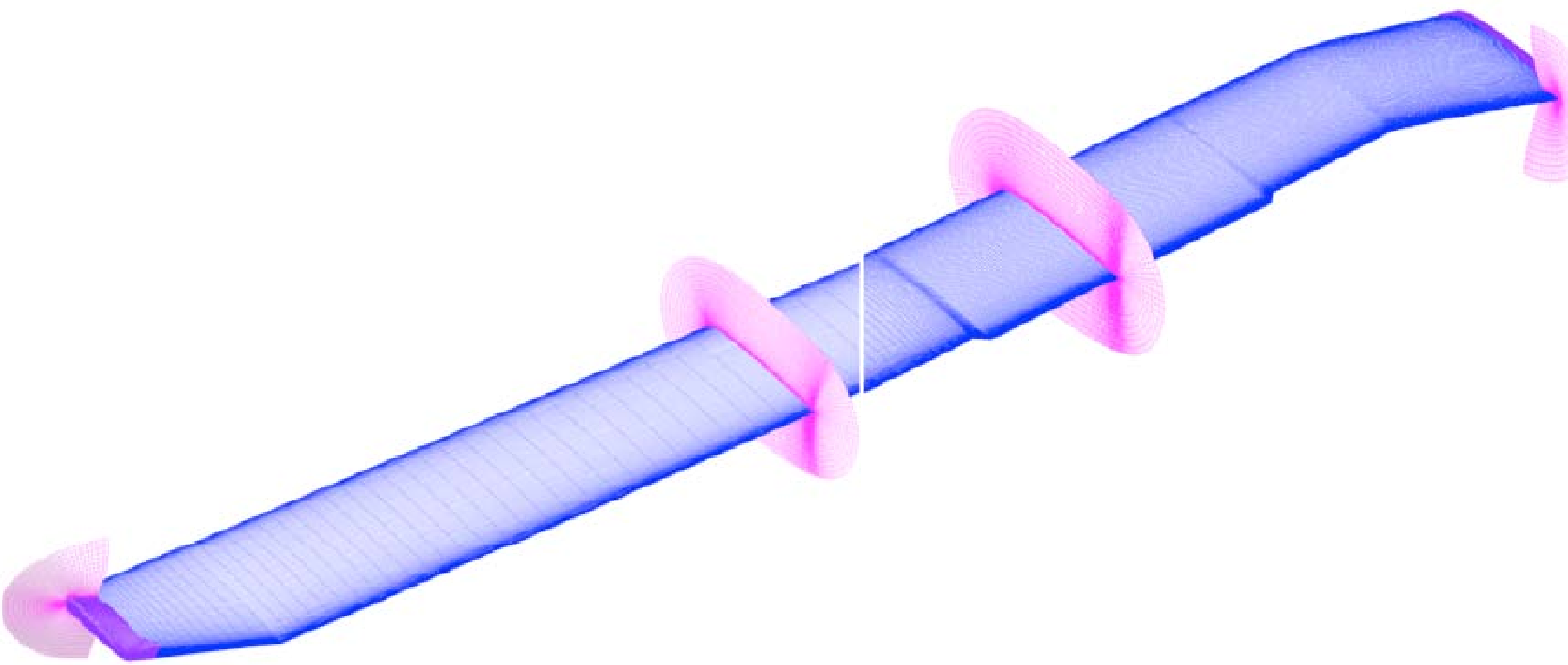
- OVERFLOW solves the time-dependent RANS using overset grids

- two cases considered: high-speed level flight and low-speed flight with BVI



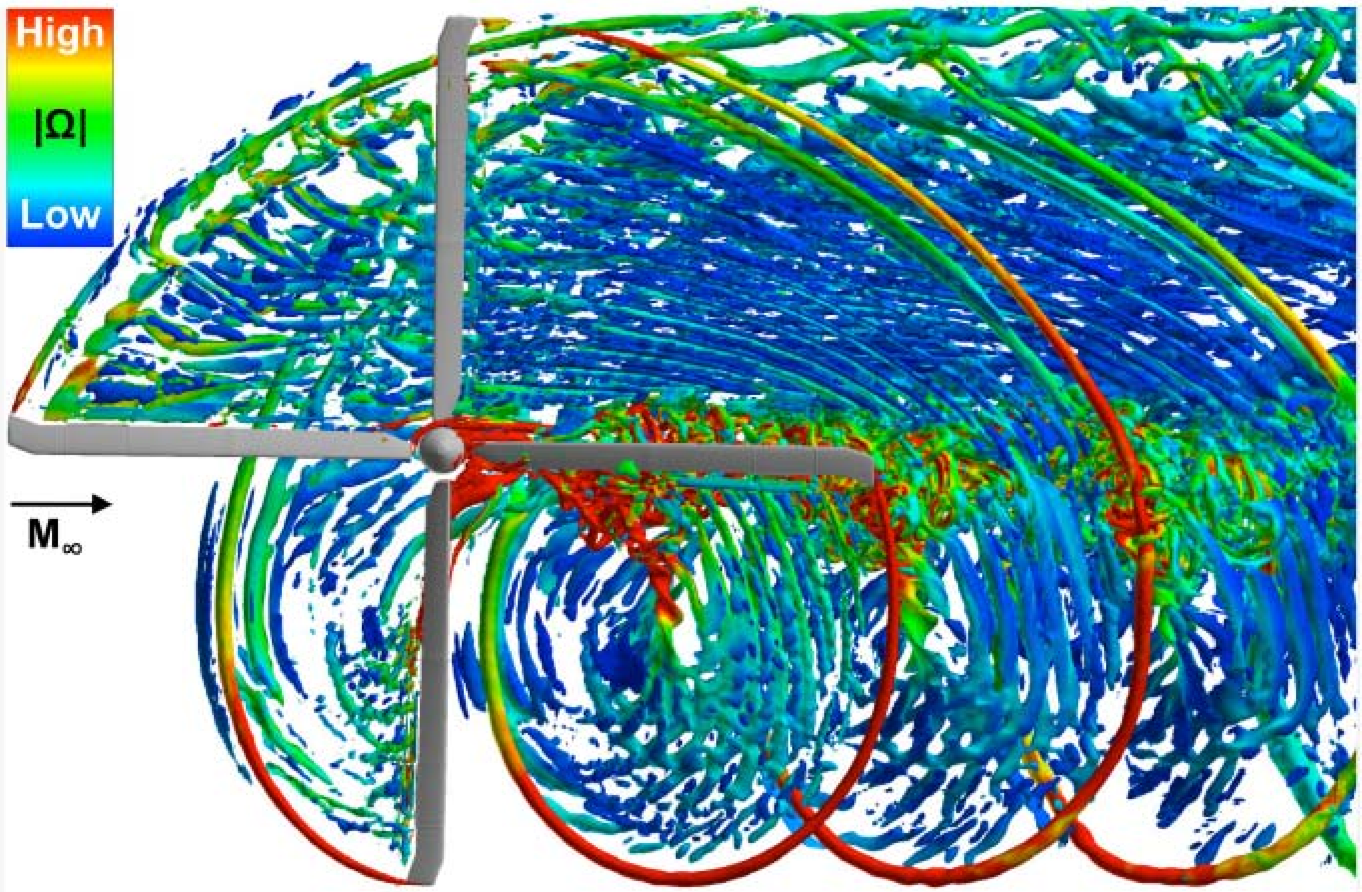
Loose coupling every ½ revolution

- total: 69,000,000 grid points
- an idealized hub is placed in the center
- fuselage not included
- near-body curvilinear grids with progressively coarsening Cartesian off-body grids
- finest Cartesian level as 0.1c_tip spacing

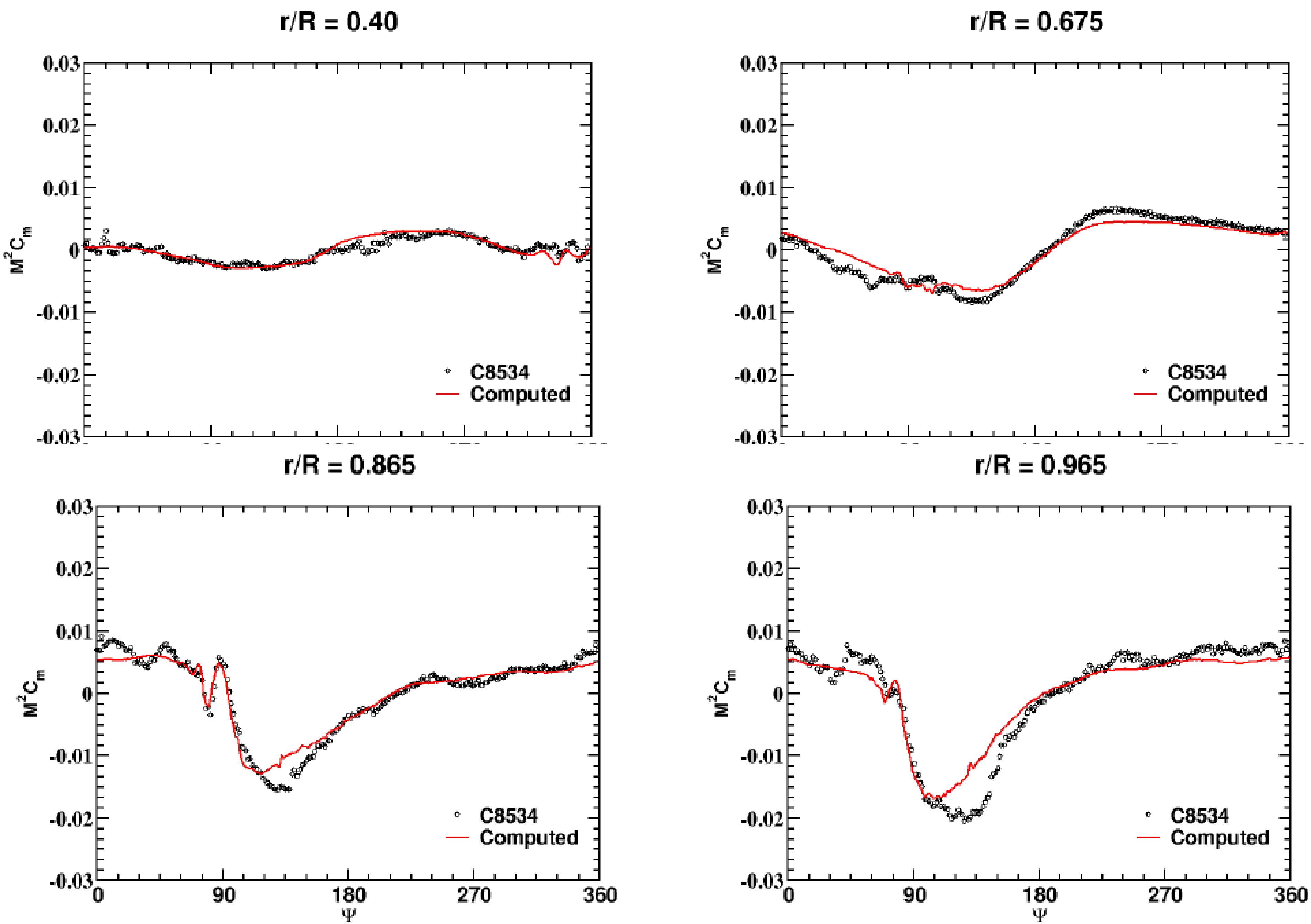


- intergrid-communication in OVERFLOW is done using “X-Rays” and the “very efficient Domain Connectivity Function”
- Spalart-Allmaras turbulence model

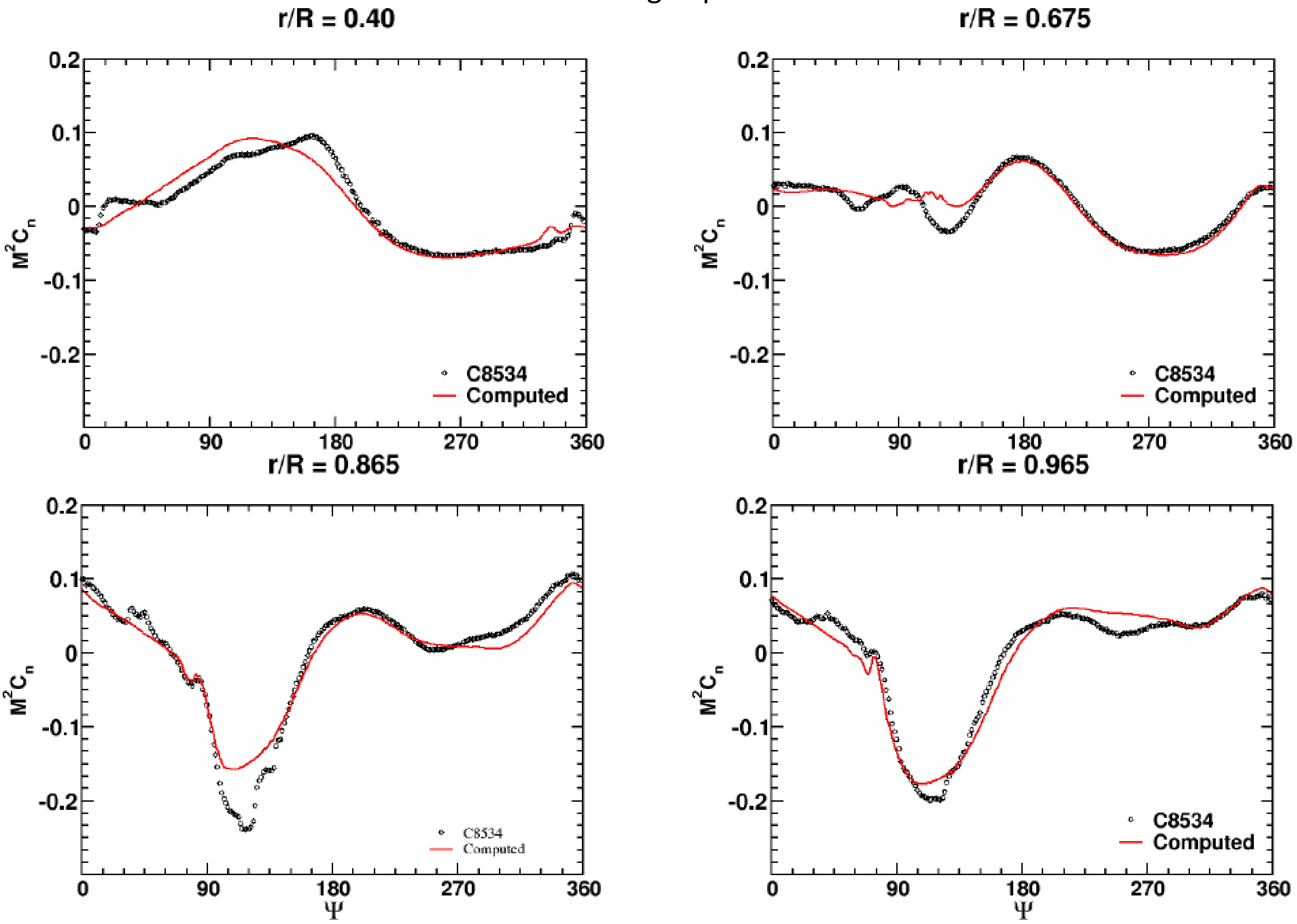
- high-speed level flight: M_inf = 0.236, M_tip = 0.64



- pitching moment coefficients for the high-speed case

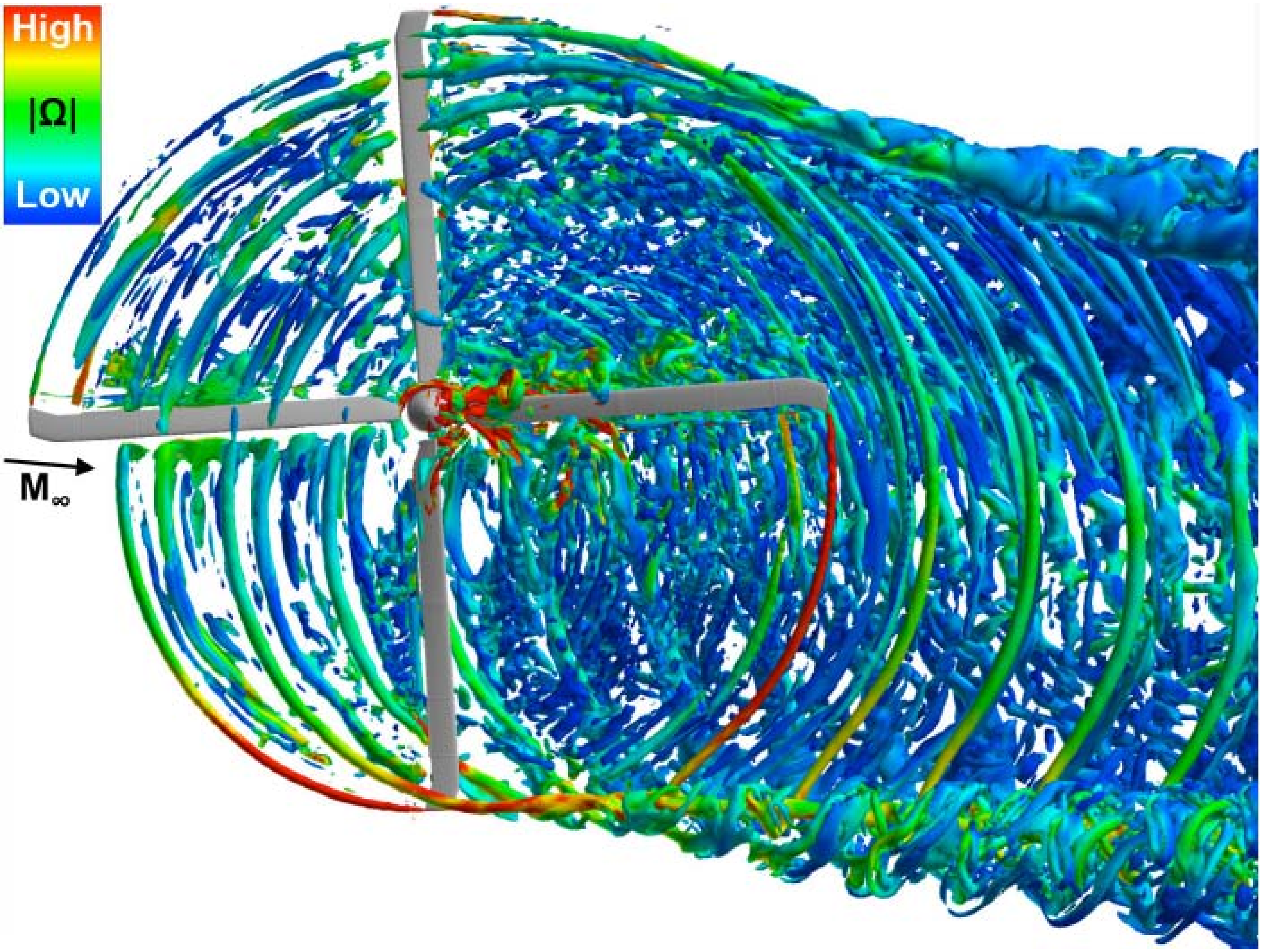


- sectional normal force for the high-speed case

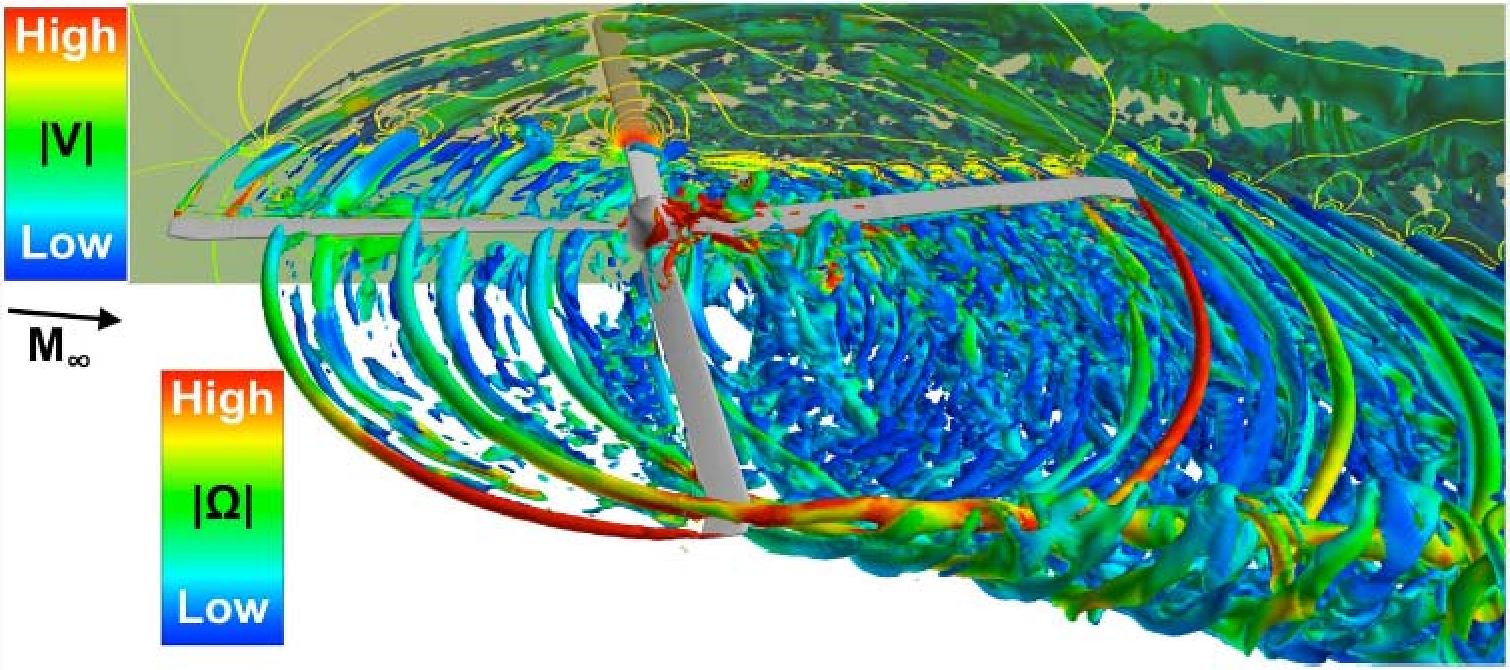


-low-speed level flight: M_inf = 0.096

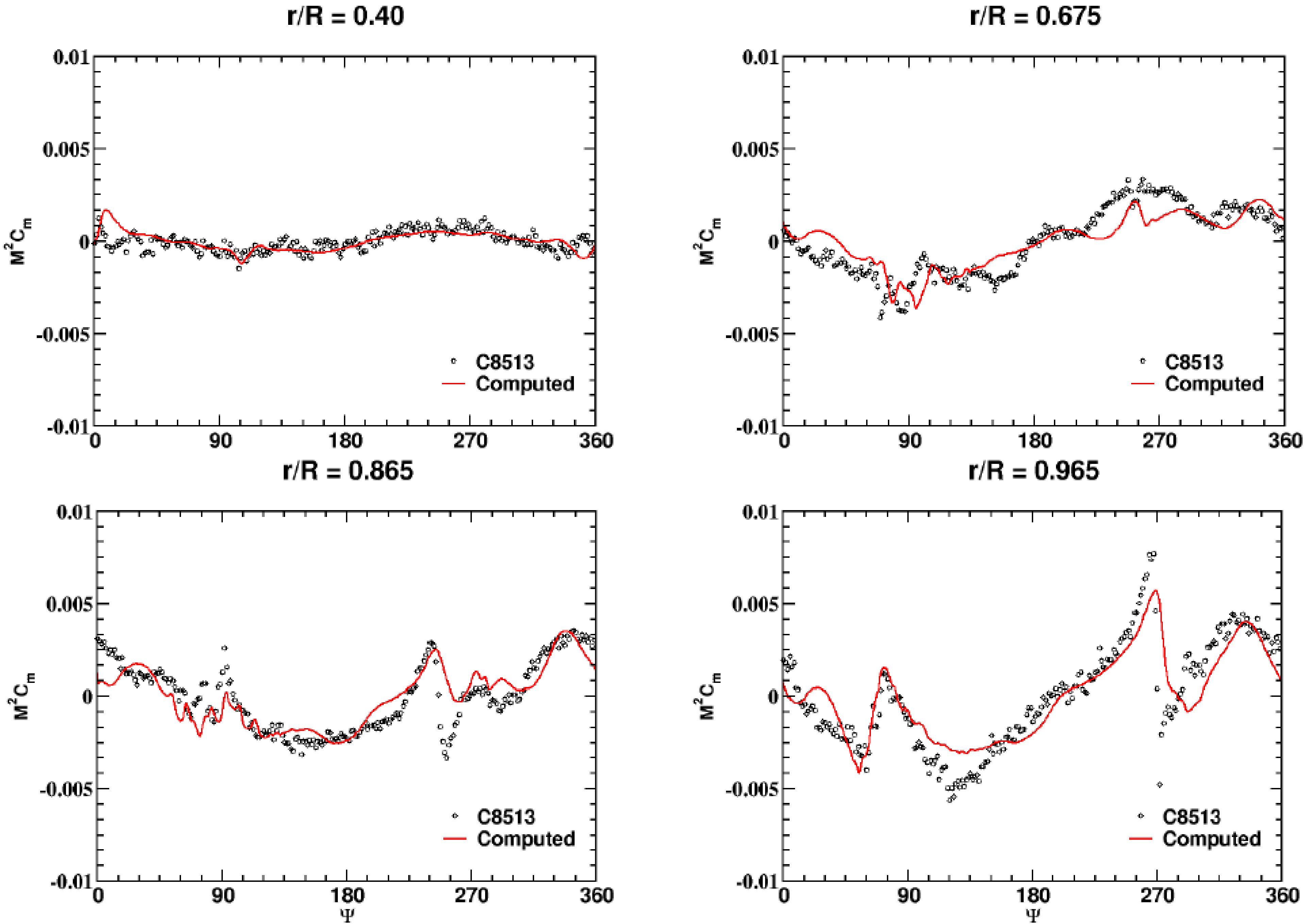
- lots of blade-vortex interaction



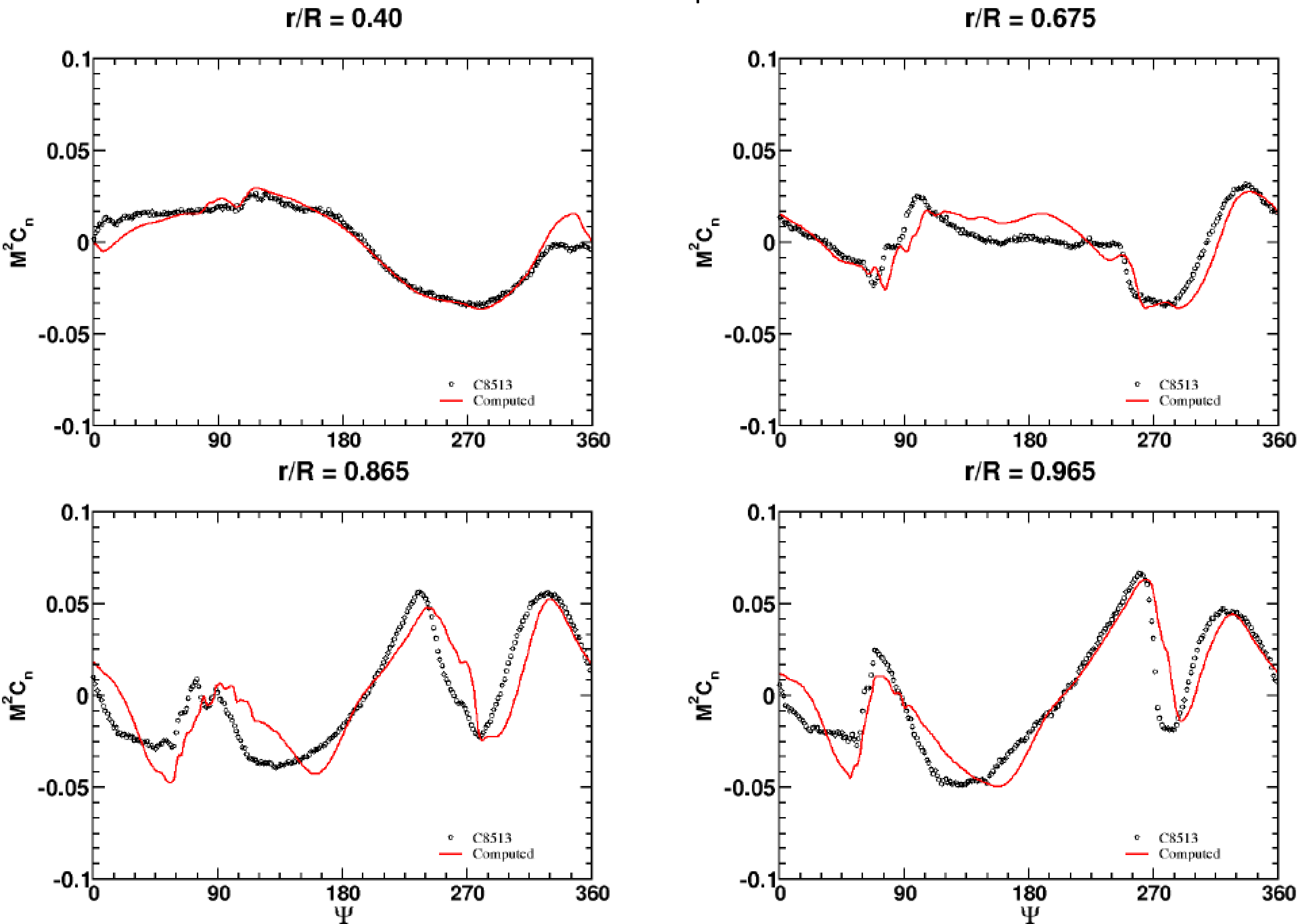
- oblique view with velocity magnitude shown on the transparent cutting plane



- pitching moment coefficients for the low-speed case



- sectional normal force for the low-speed case



-The computed normal force and pitching moment coefficients were found to be in good agreement with flight-test data

- achieved a factor-of-two improvement in the state-of-the-art prediction accuracy.

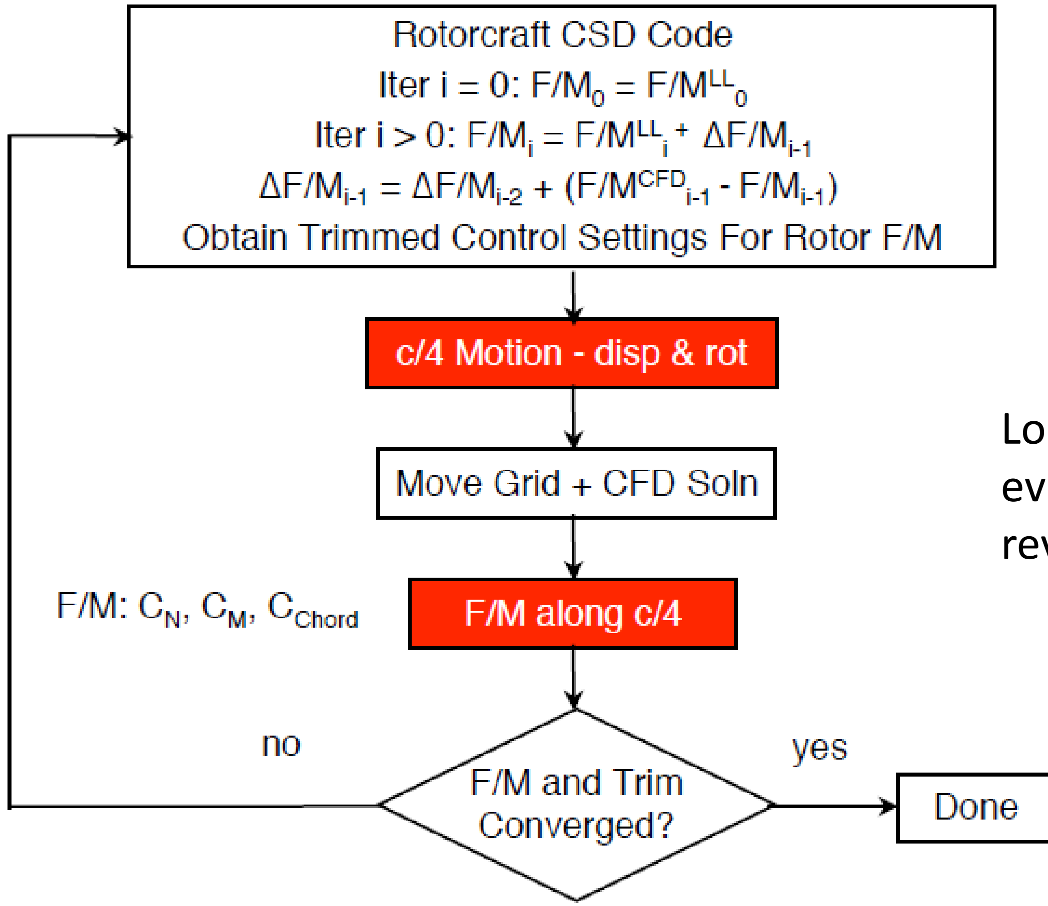
Code-to-Code Comparison of CFD/CSD Simulation for a Helicopter Rotor in Forward Flight

Jasim Ahmad Robert T. Biedron

AIAA-2011-3819

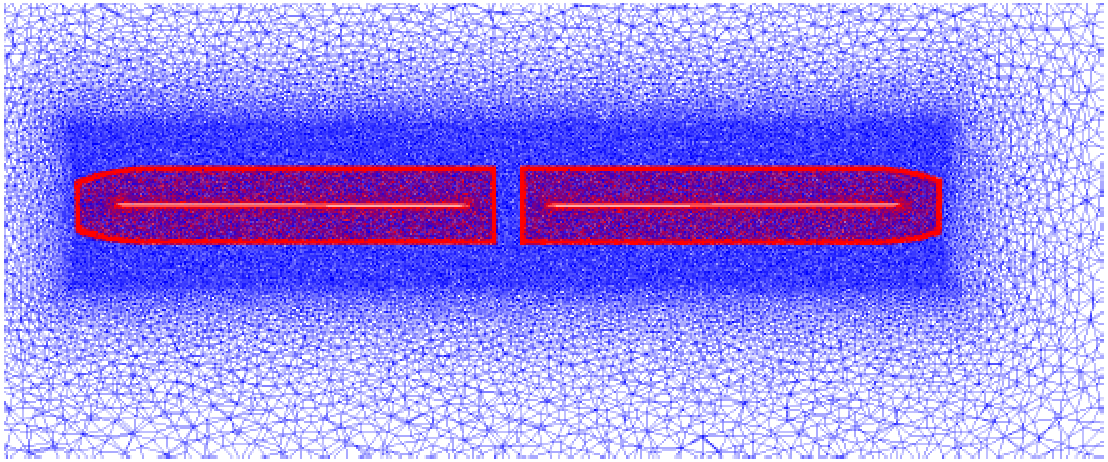
- comparison of two URANS codes in being able to replace the aero part of CAMRAD
- NASA's subsonic rotary-wing project is modifying OVERFLOW and FUN3D
- the point is to create validated, high-fidelity tools for analysis and design
- UH-60 cases were run and compared, since there's a lot of experimental data for them
- only the flow solver was changed, everything else was exactly the same
- any differences would be completely due to the CFD solver
- OVERFLOW is overset structured/Cartesian
- OVERFLOW is finite-difference
- OVERFLOW uses either PEGASUS or DCF for domain connectivity and X-Rays for hole-cutting
- FUN3D can have overset unstructured
- FUN3D is finite-volume
- FUN3D tends to use prisims near the surface, tetrahedra far away, and pyramids in the middle
- FUN3D uses DiRTlib and SUGGAR++ for communication within the mesh

- in CAMRAD, aero is done by lifting-line models, look-up tables, and wake models
- in CAMRAD, structural analysis is done with nonlinear beam elements
- CAMRAD also does trim (collective pitch angles, cyclic pitch angles, etc)

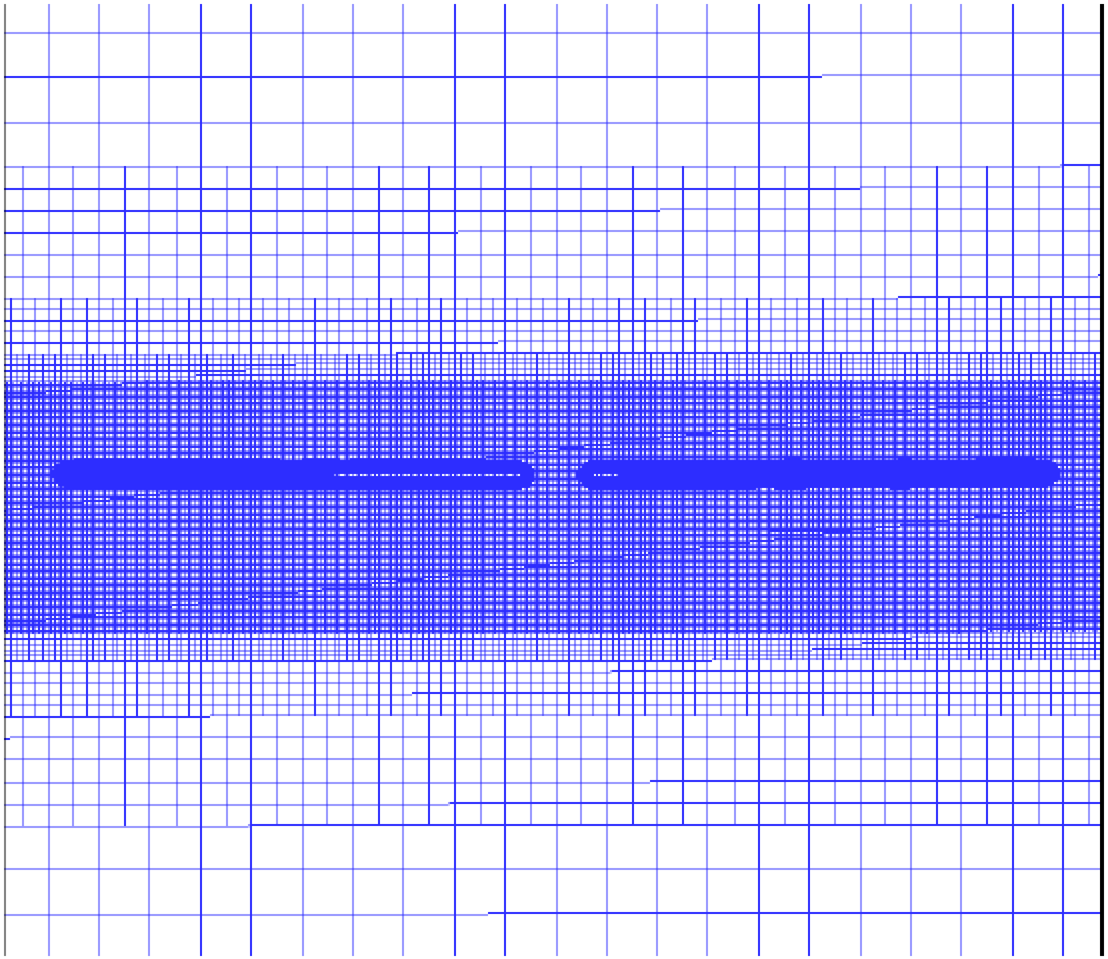


Loose coupling: every ½ revolution

- FUN3D grid had 15,000,000 nodes and 80,000,000 cells



- OVERFLOW grid had 71,000,000 nodes
- used so many because they're going to do DES with a fuselage later
- there are O-mesh grids surrounding each blade

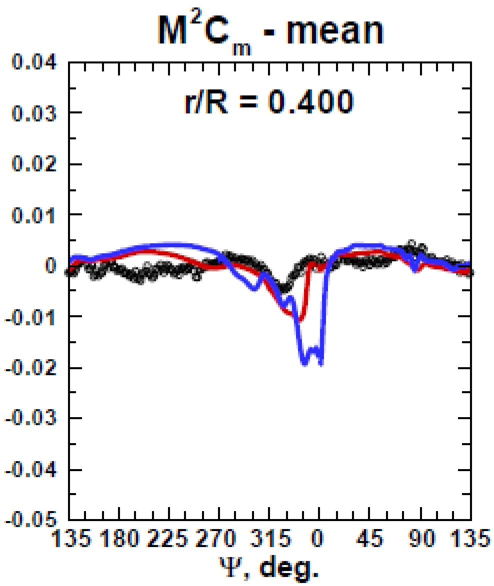


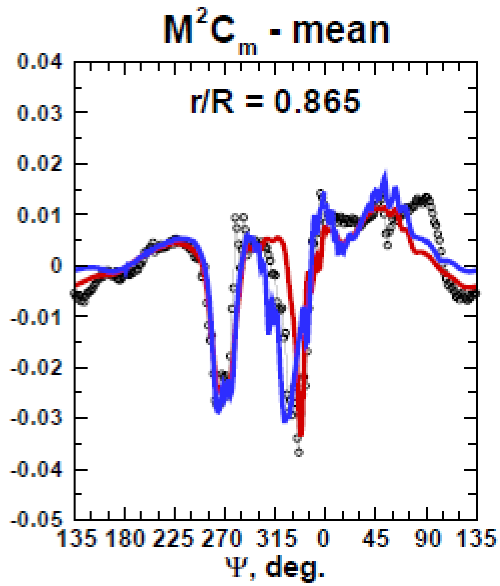
- two level-flight conditions considered:
  (1) high-thrust, moderate advance ratio
  (2) low-speed, level flight

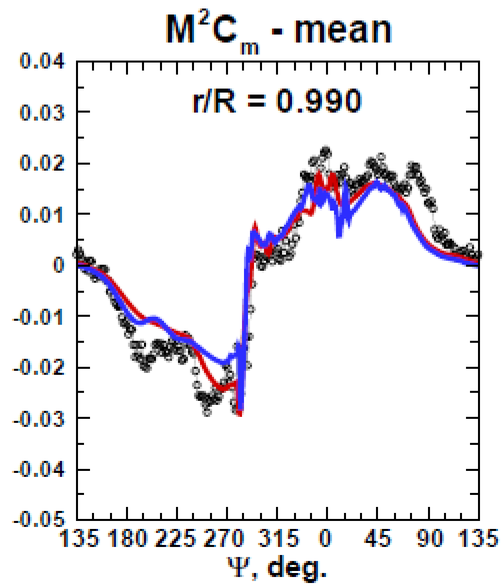
- FUN3D took 6.8 hours per half revolution on 289 cores on Pleiades

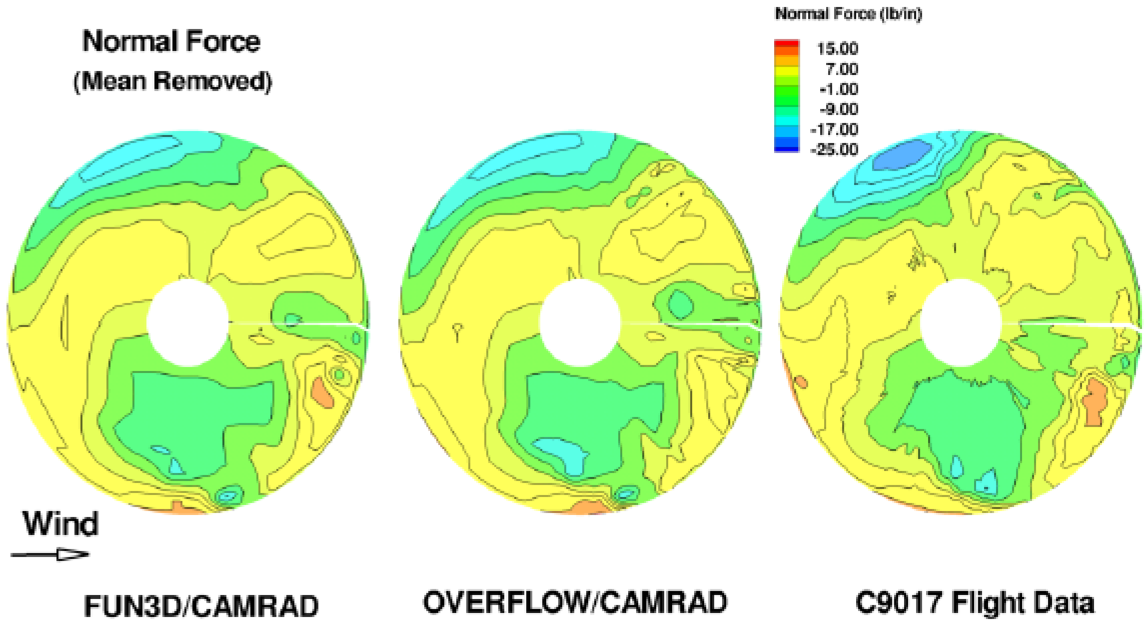
- OVERFLOW took 5.5 houts per half revolution on 984 cores on Pleiades

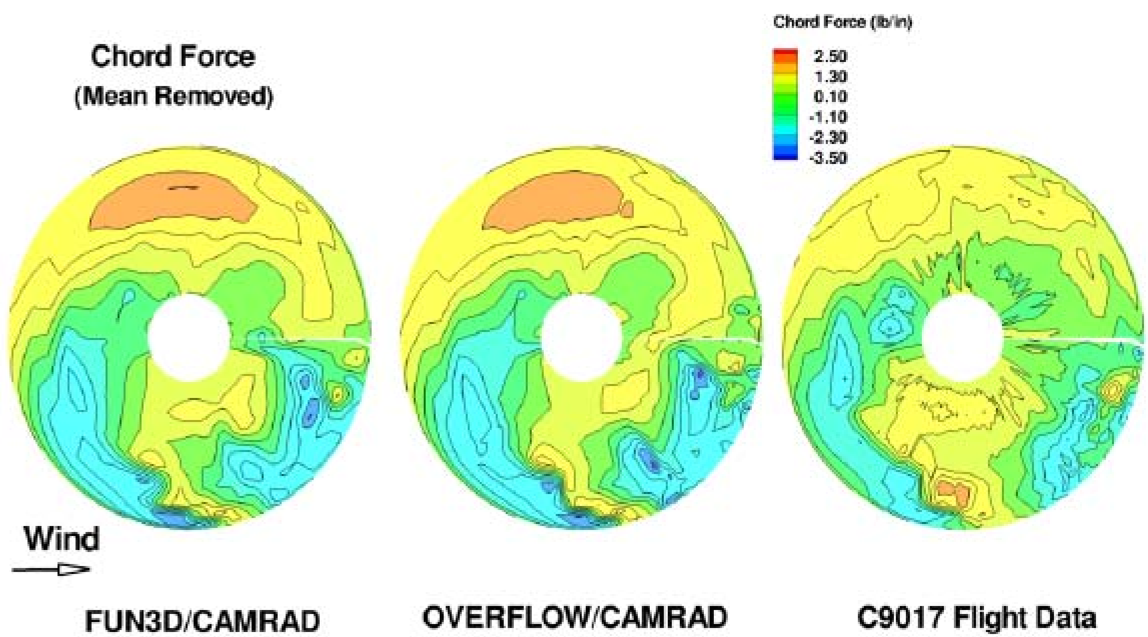
- high-thrust, moderate advance ratio (Counter 9017)
- leads to dynamic stall at several locations on the retreating side








Normal Force
(Mean Removed)
Normal Force (lb/in)
15.00
7.00
-1.00
-9.00
-17.00
-25.00
Wind
FUN3D/CAMRAD
OVERFLOW/CAMRAD
C9017 Flight Data

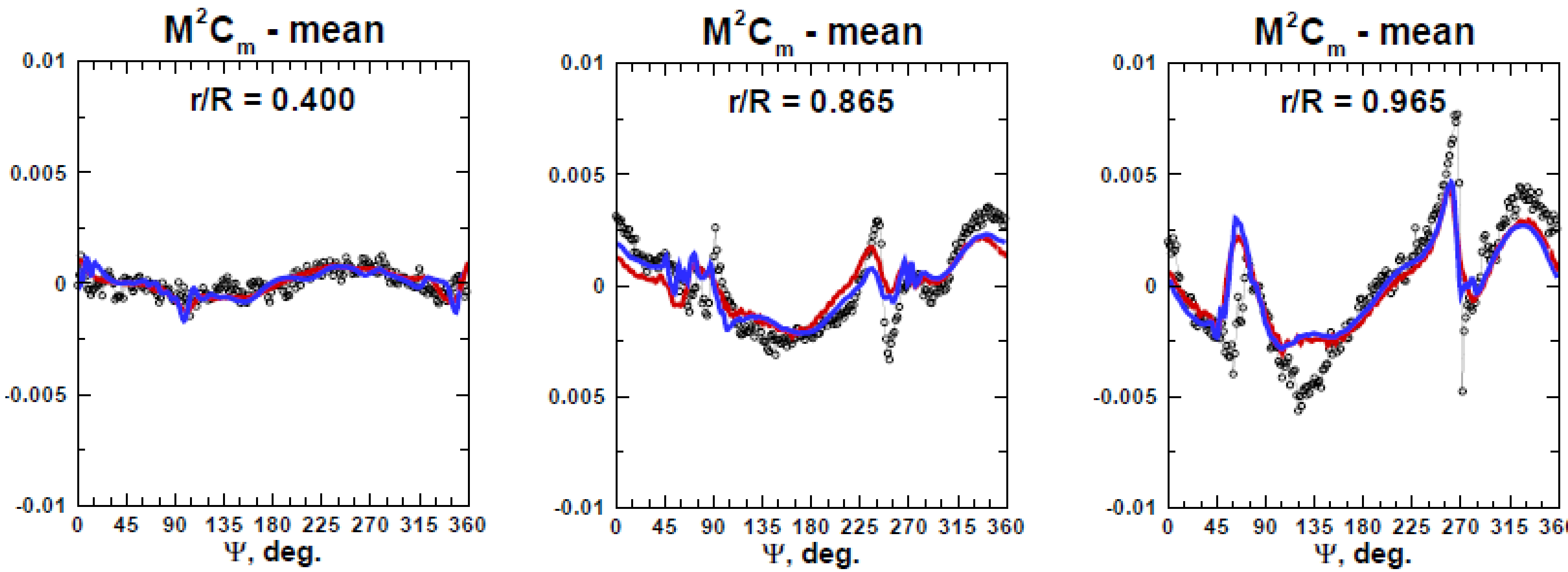

Chord Force
(Mean Removed)
Chord Force (lb/in)
2.50
1.30
0.10
-1.10
-2.30
-3.50
Wind
FUN3D/CAMRAD
OVERFLOW/CAMRAD
C9017 Flight Data

-The two CFD/CSD simulations agree well with each other, and generally agree well with the flight data.

- Both simulations miss the peak negative loading near the tip in the second quadrant of the rotor disc.

- Both codes predict too large a chord force in the second quadrant, two thirds of the way out the span.

- low-speed, level flight (Counter 8513)
- leads to BVI at 90^o and 270^o



-Both FUN3D and OVERFLOW results are almost identical.

- However, the agreement between computation and flight for the mean chord force, and the mean pitching moment is not satisfactory.