Analysis and interpretation of the CFD results including a self-propulsion optimization

Michal Orych, 2019

SHIPFLOW®
a flowtech product

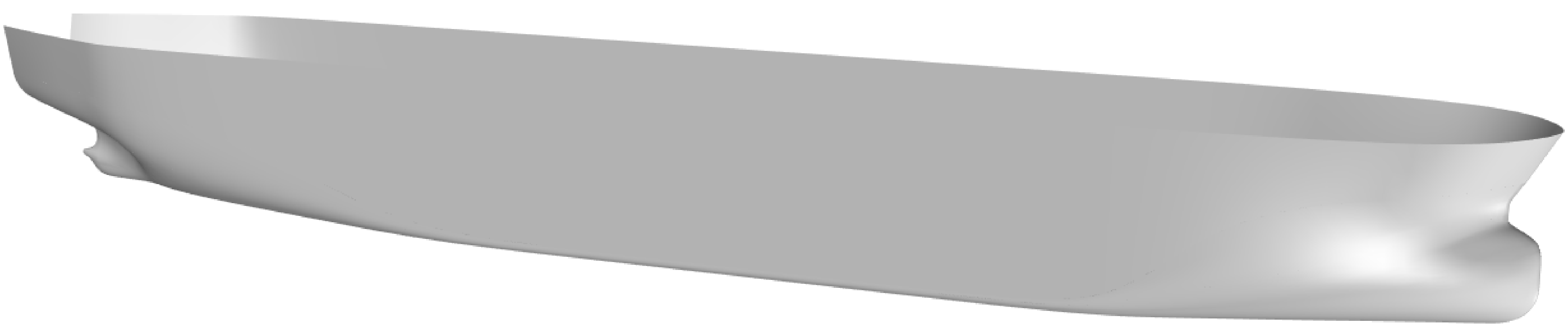
Project Case

船体主尺度：

Lpp(m)	314.6
B(m)	52.5
T(m)	18.1
排水体积（m^3）	253000

螺旋桨参数 Propeller：

Diameter (m)	9. 6
P/D（0.7R）	0. 74
Ratio	0. 498



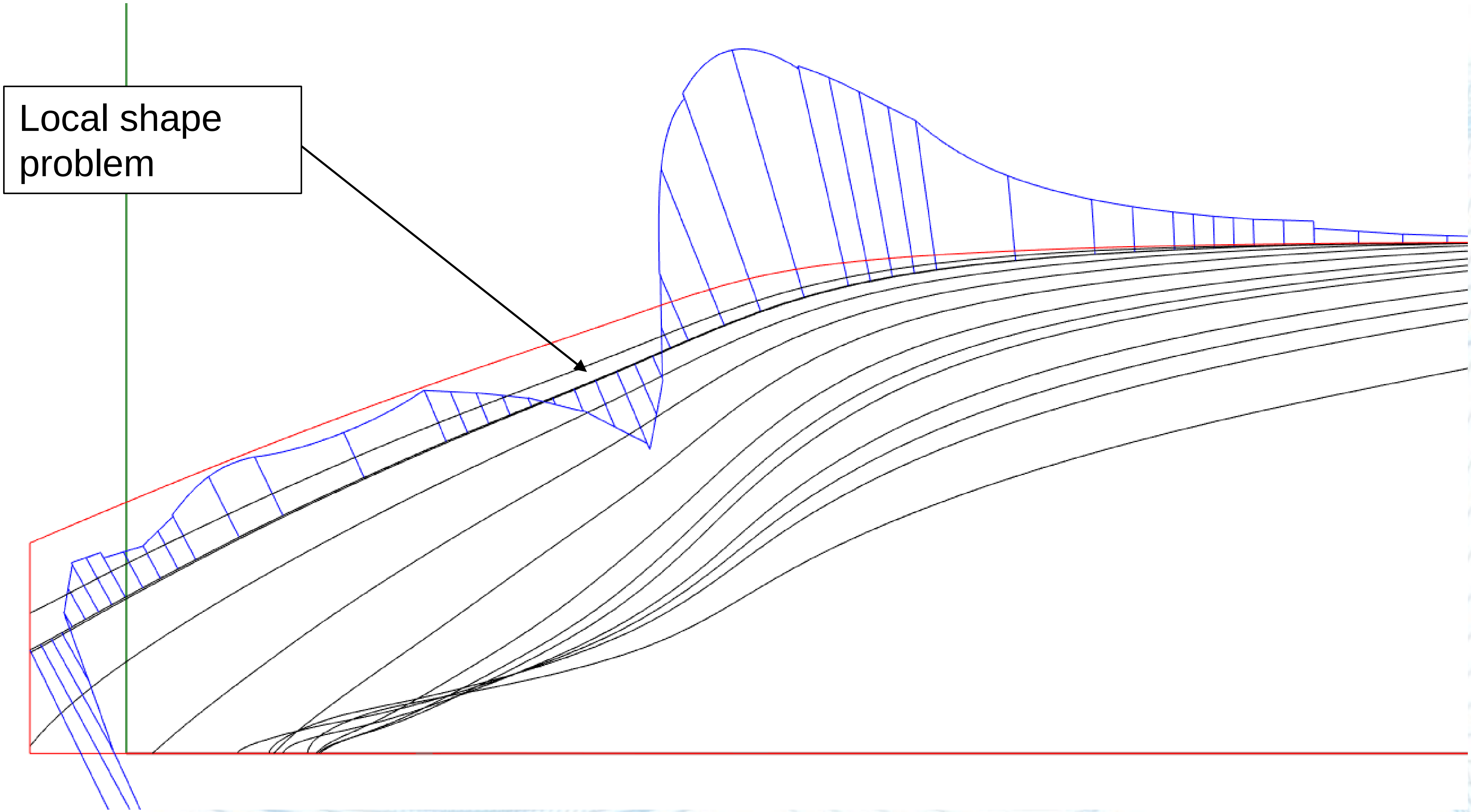
Tools

- Rhinoceros3d
  - hull inspection
  - initial corrections
- CAESES
  - hull transformations
  - optimization methods
  - postprocessing
- SHIPFLOW 6.5
  - CFD simulations (resistance, self-propulsion)

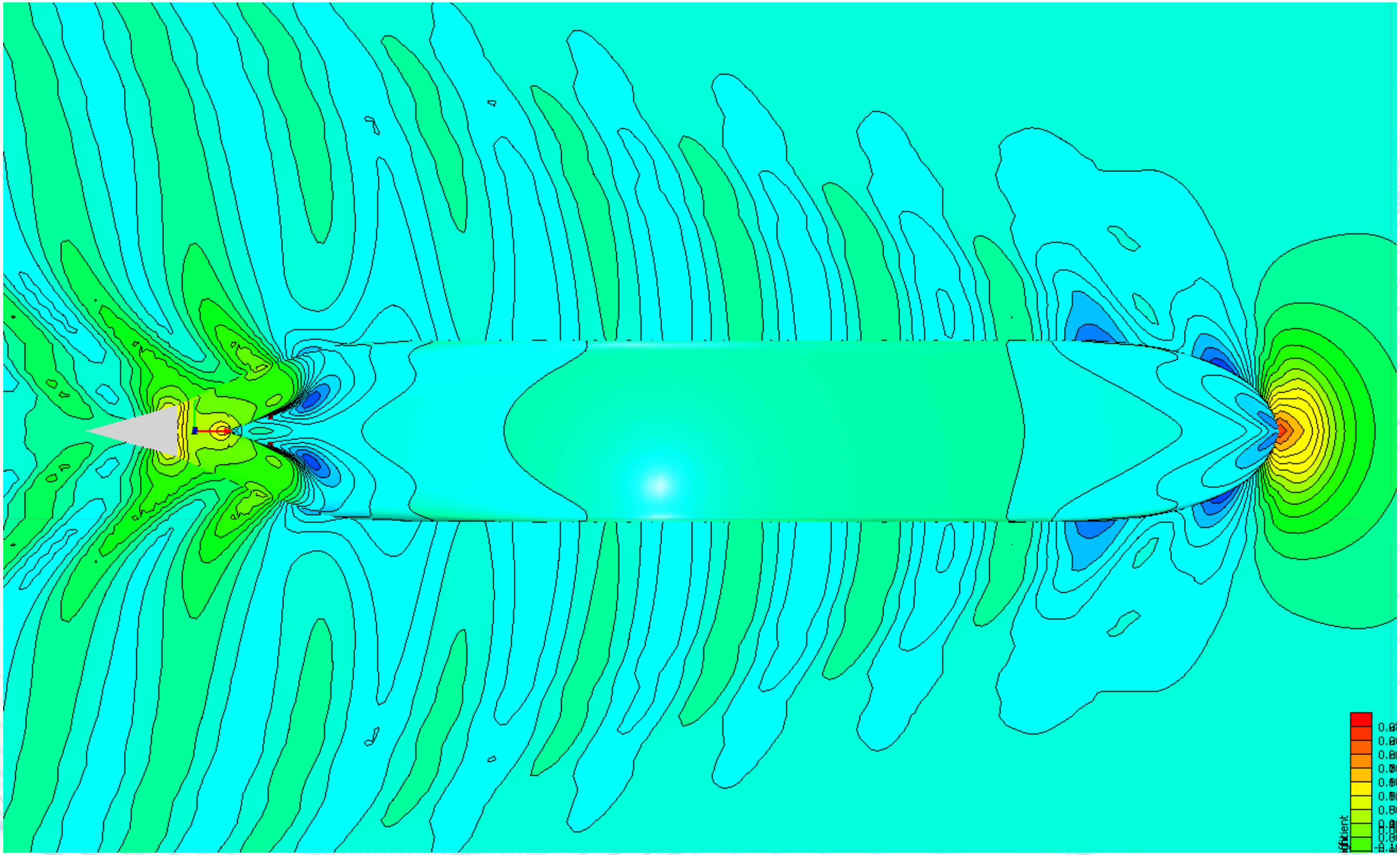
Initial hull evaluation

SHIPFLOW®
a flowtech product

Hull Shape Inspection

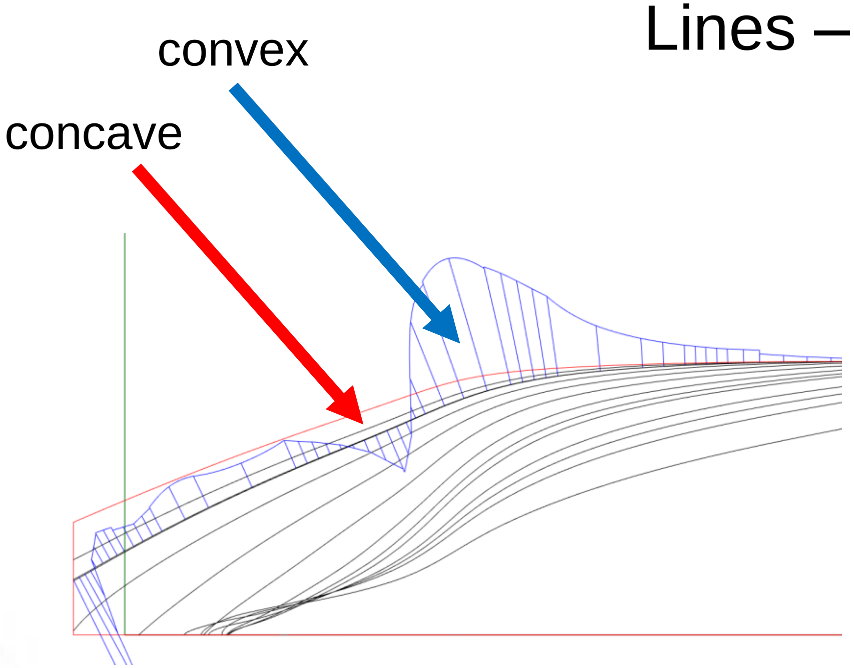


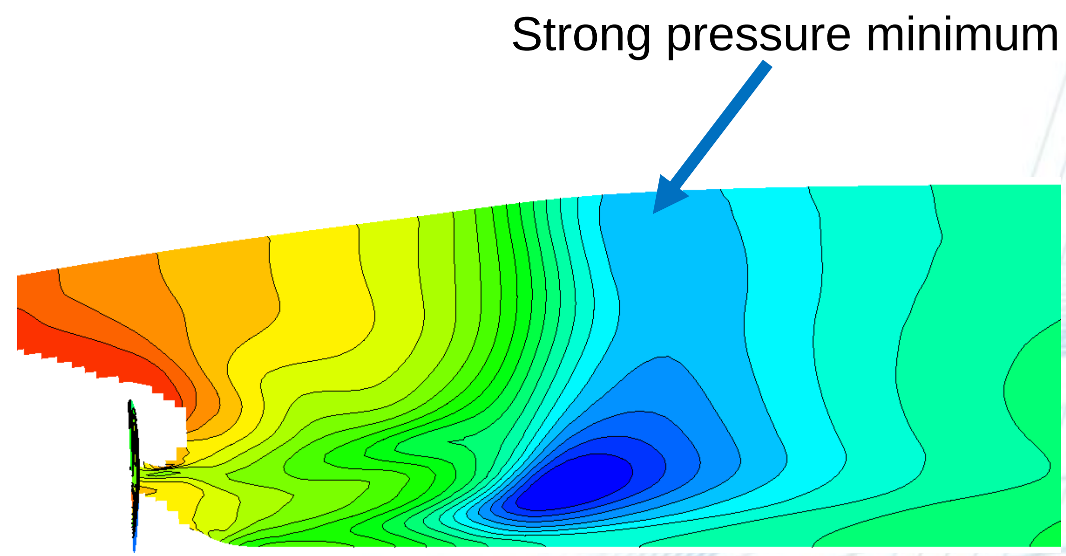
Wave pattern and hull Cp distribution

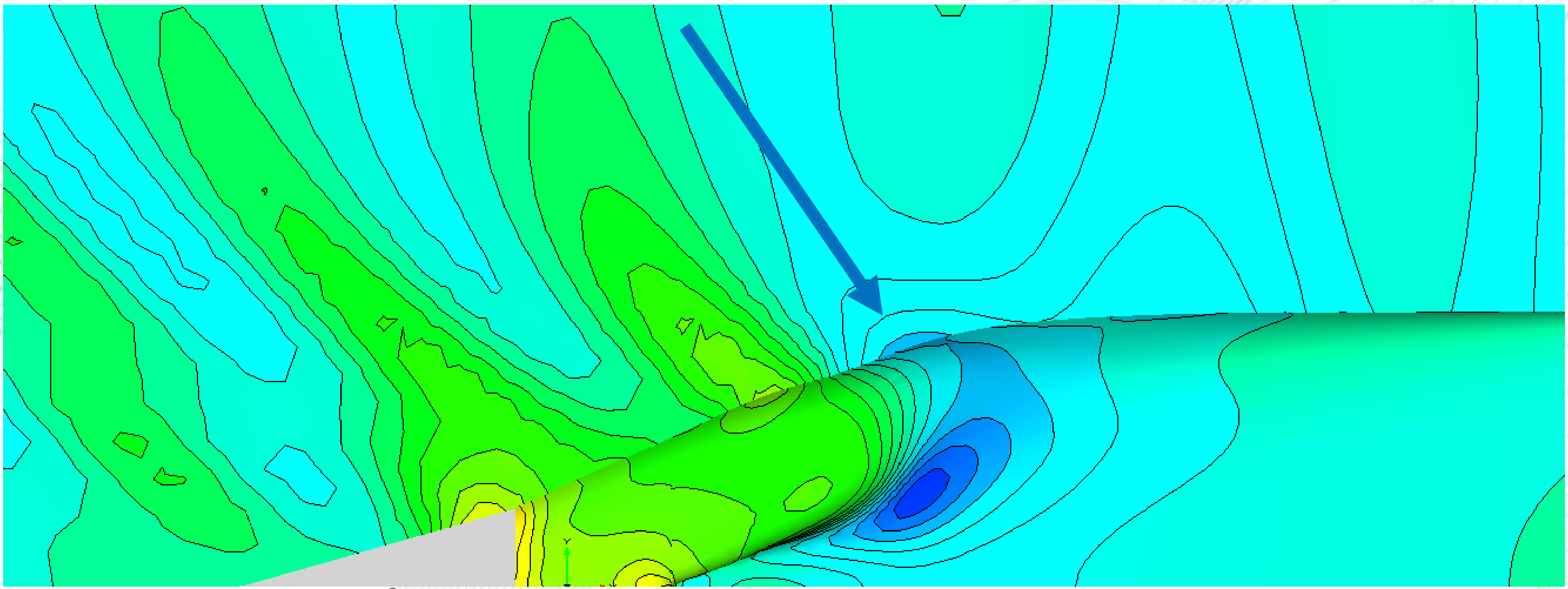


SHIPFLOW®
a flowtech product

Lines – pressure correlation





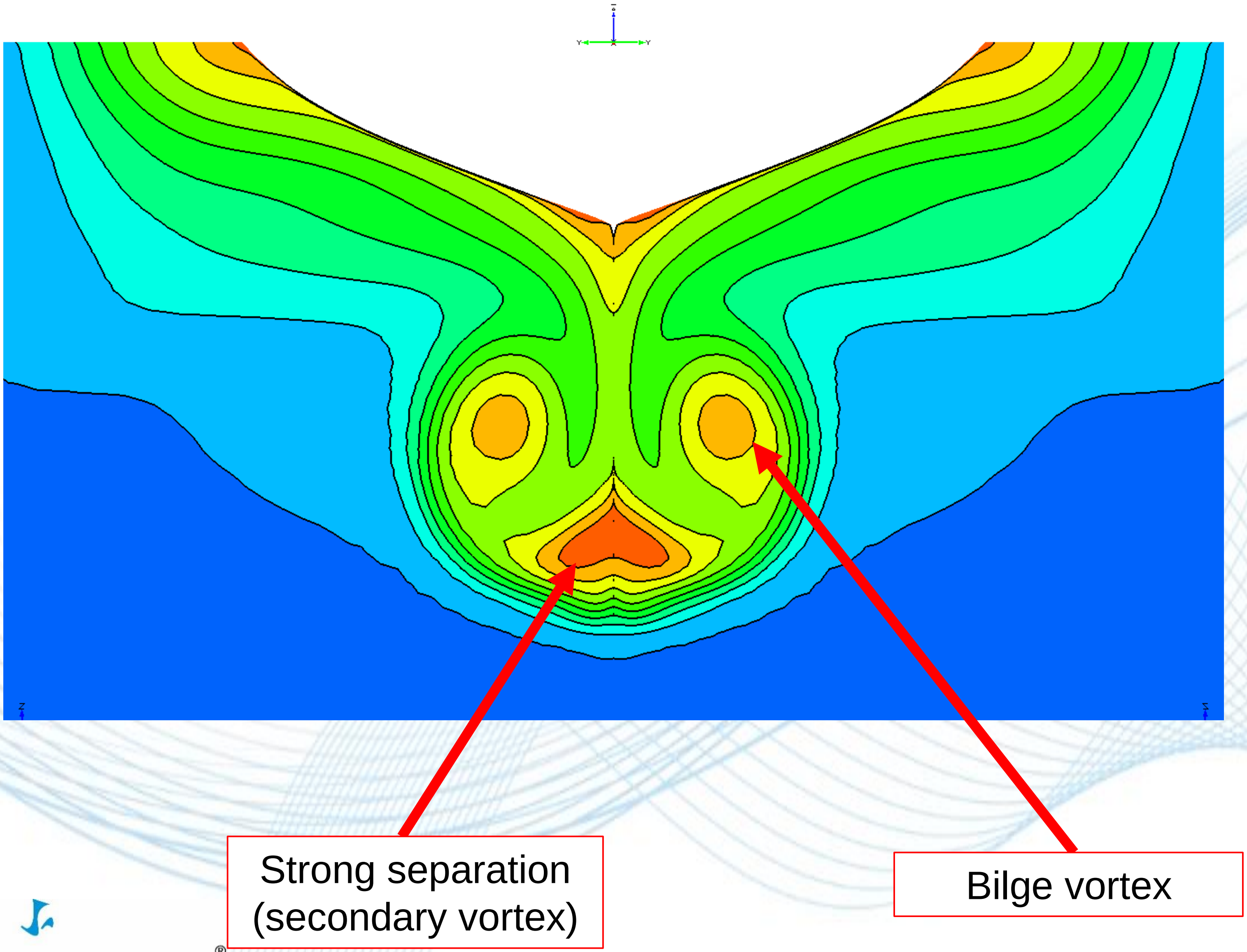


WAVE RESISTANCE presentation: 2_

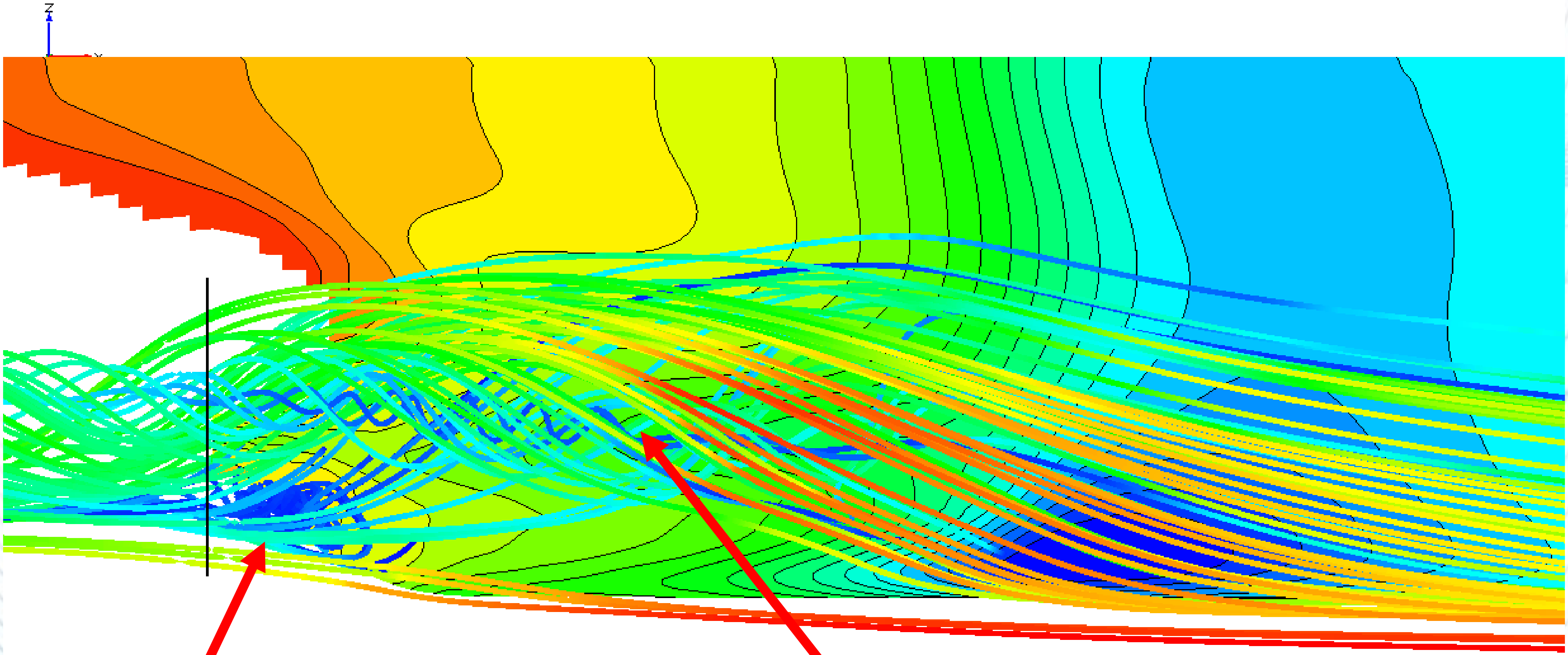
Viscous Flow

SHIPFLOW®
a flowtech product

Wake at the propeller plane



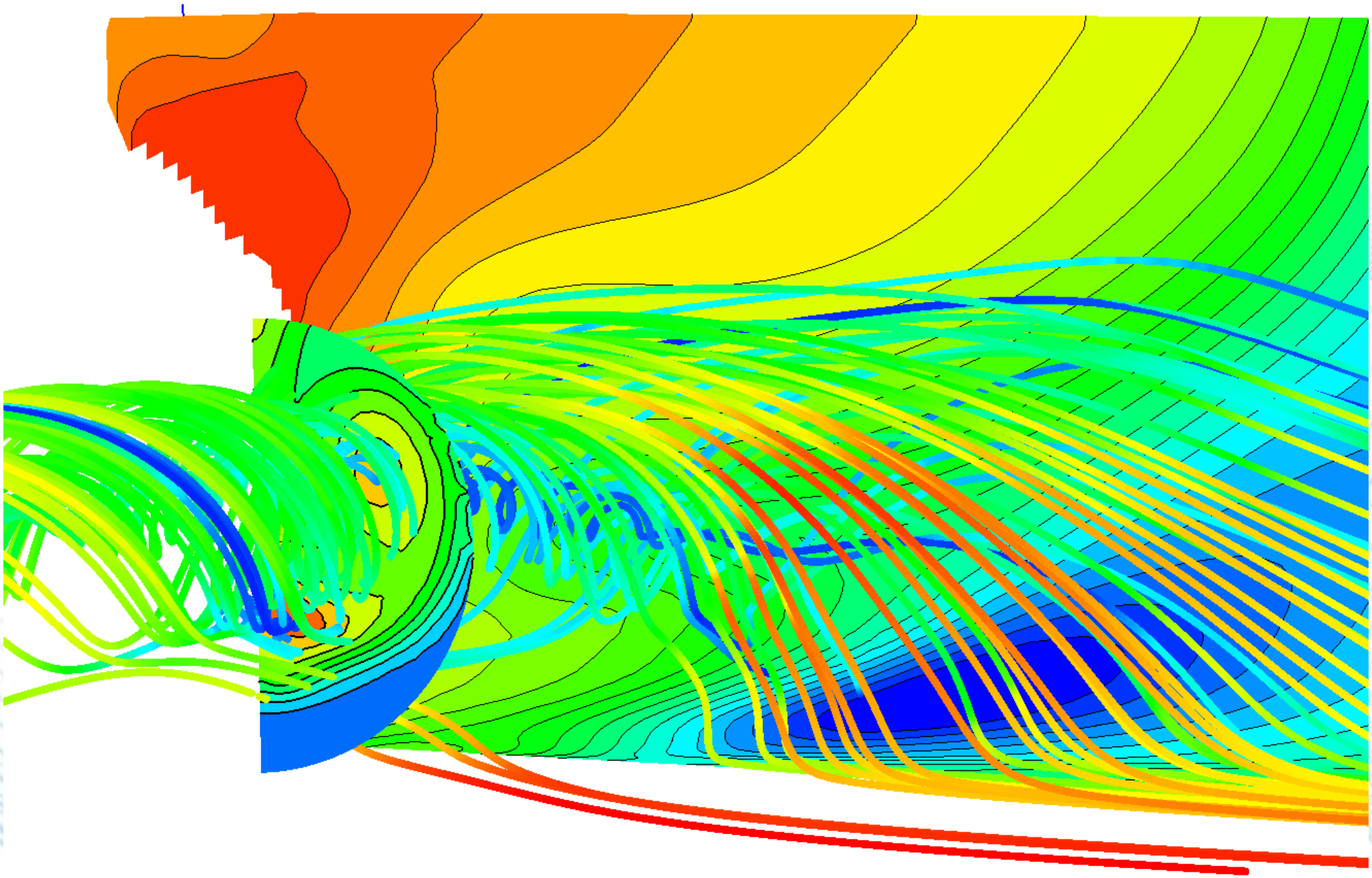
Streamlines



Strong separation

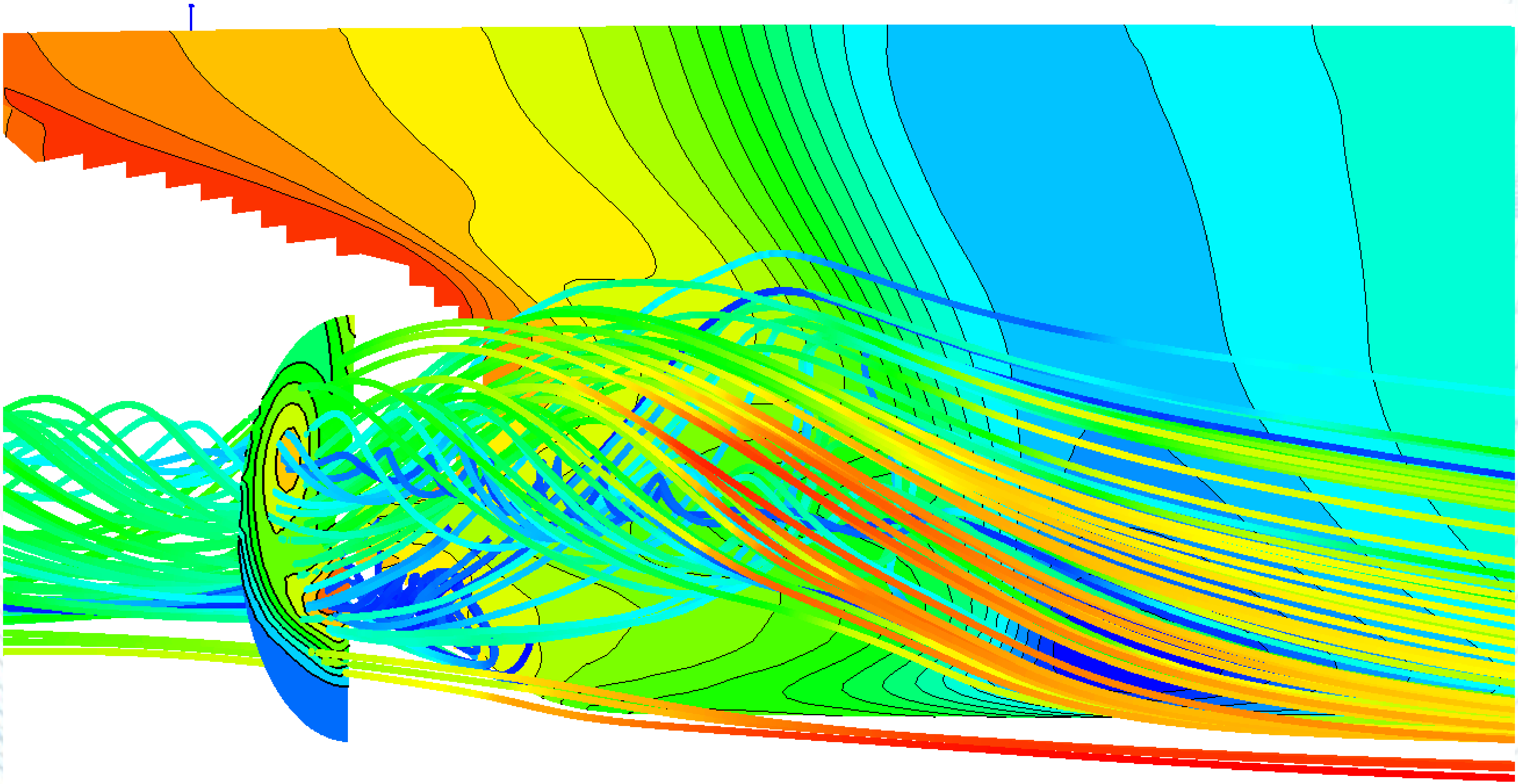
Bilge vortex

Streamlines



SHIPFLOW®
a flowtech product

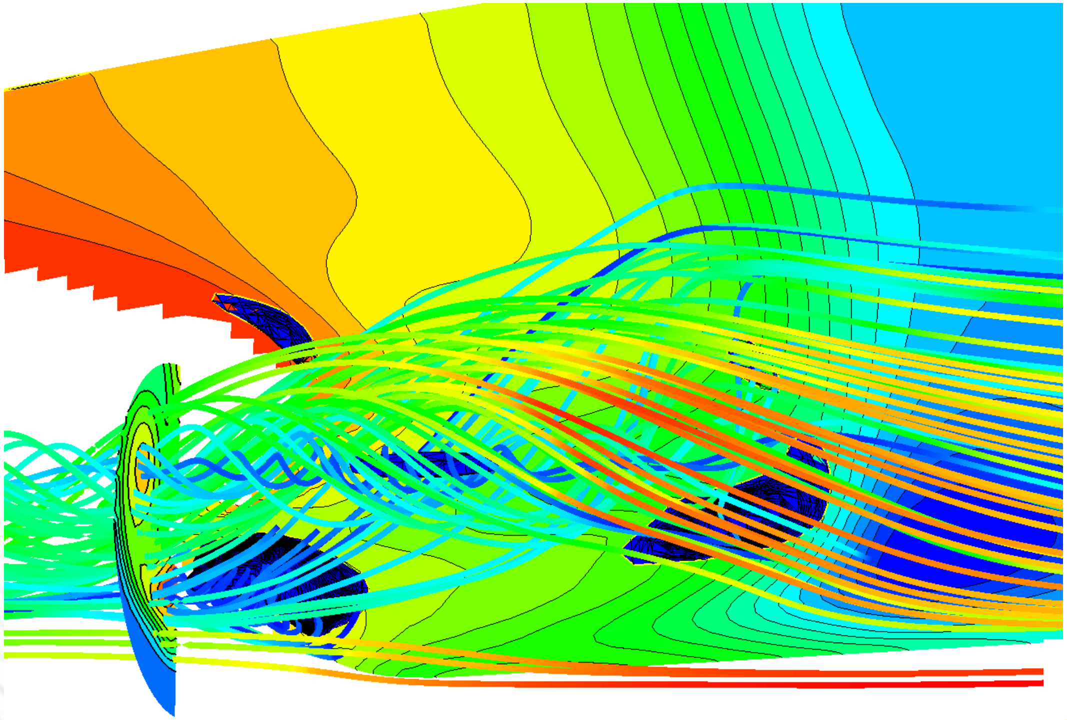
Streamlines

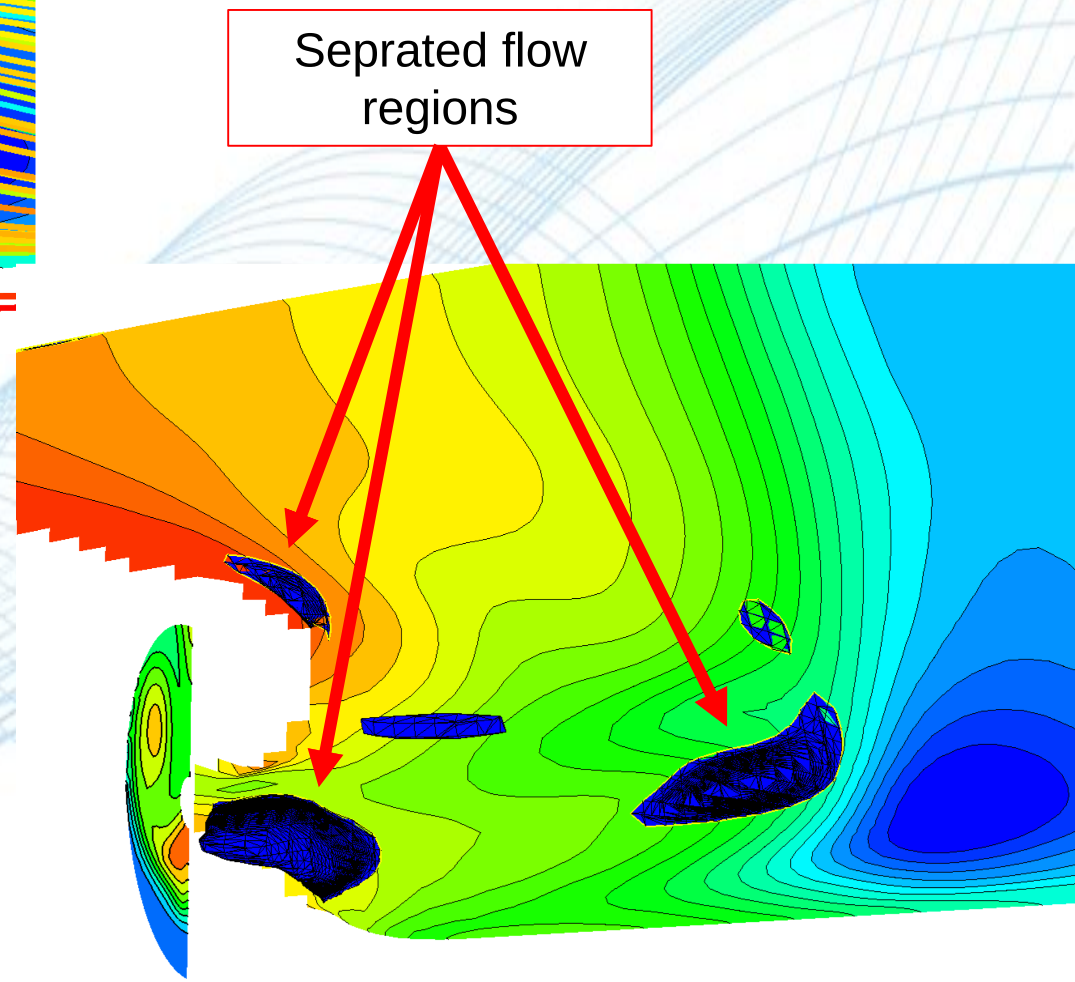


Vortex generation require energy = increase resistnce

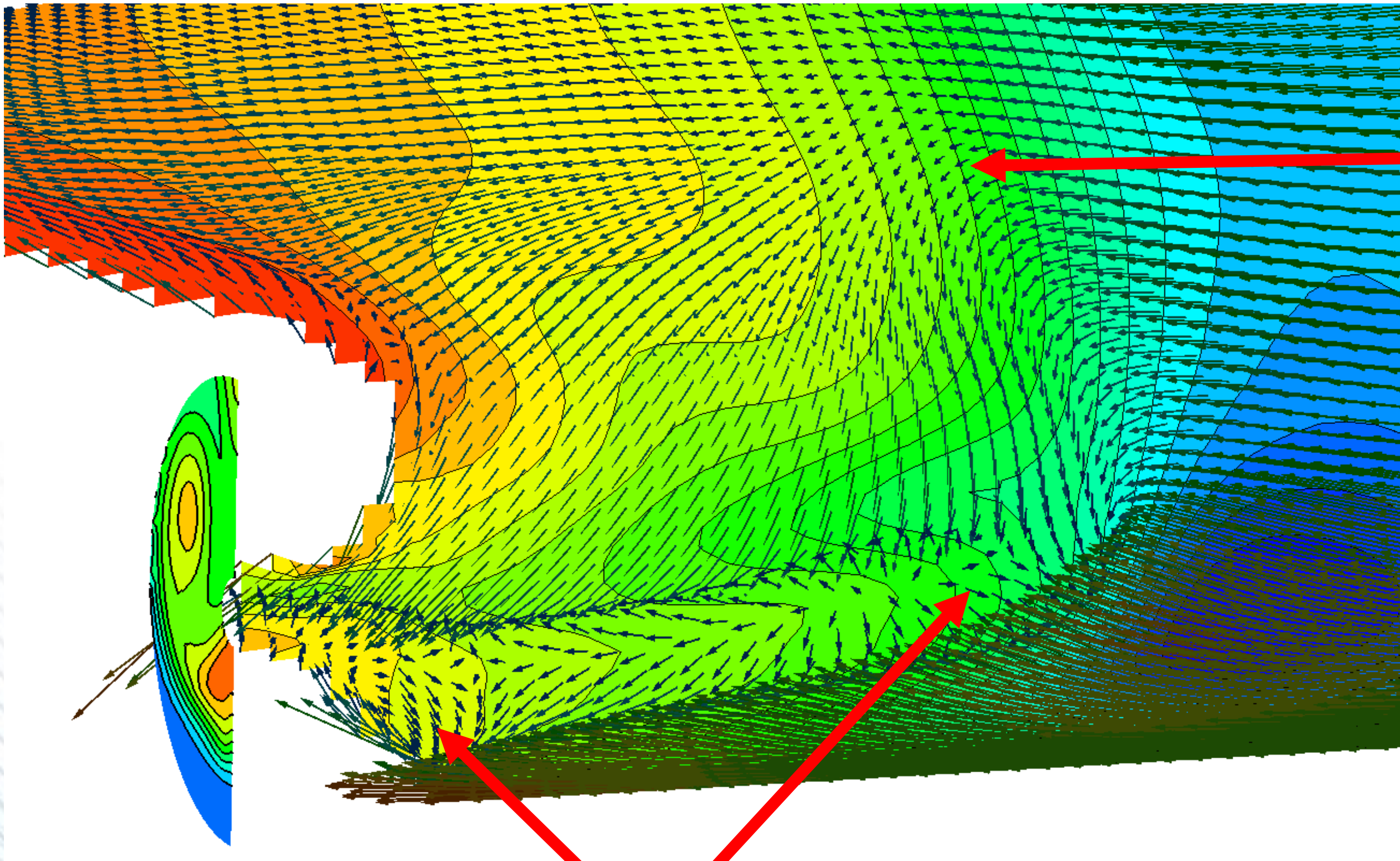
SHIPFLOW®
a flowtech product

“zero” velocity iso-surface



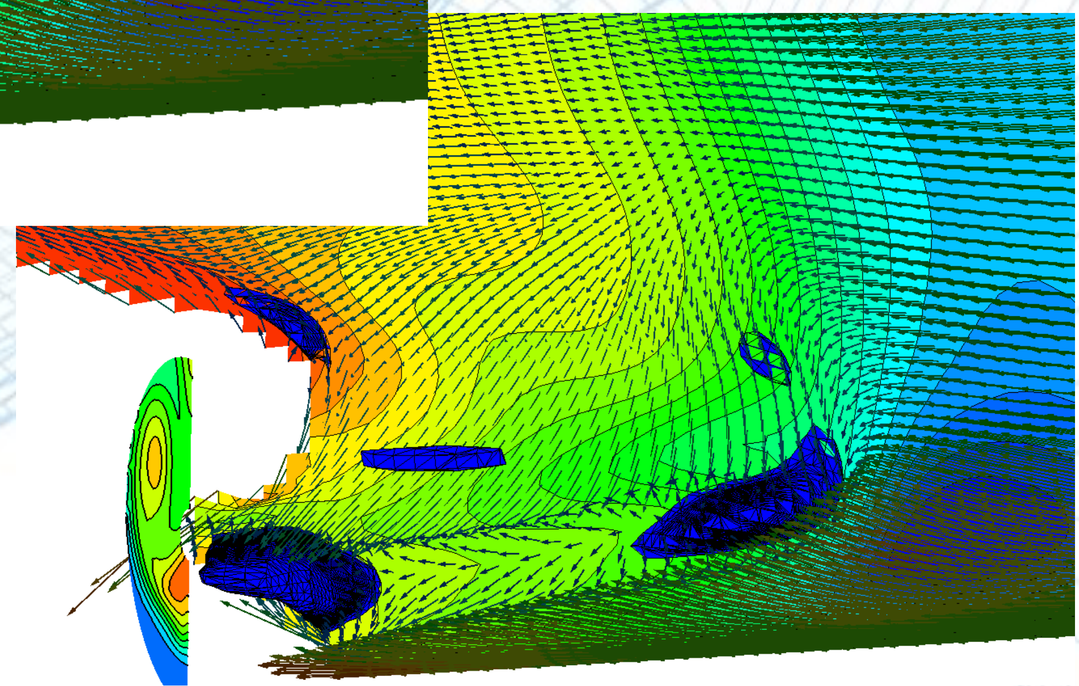


Limiting streamlines



Limiting streamlines represented by surface vectors

Reversed flow of streamlines



SHIPFLOW®
a flowtech product

Demo – postprocessing: 3_

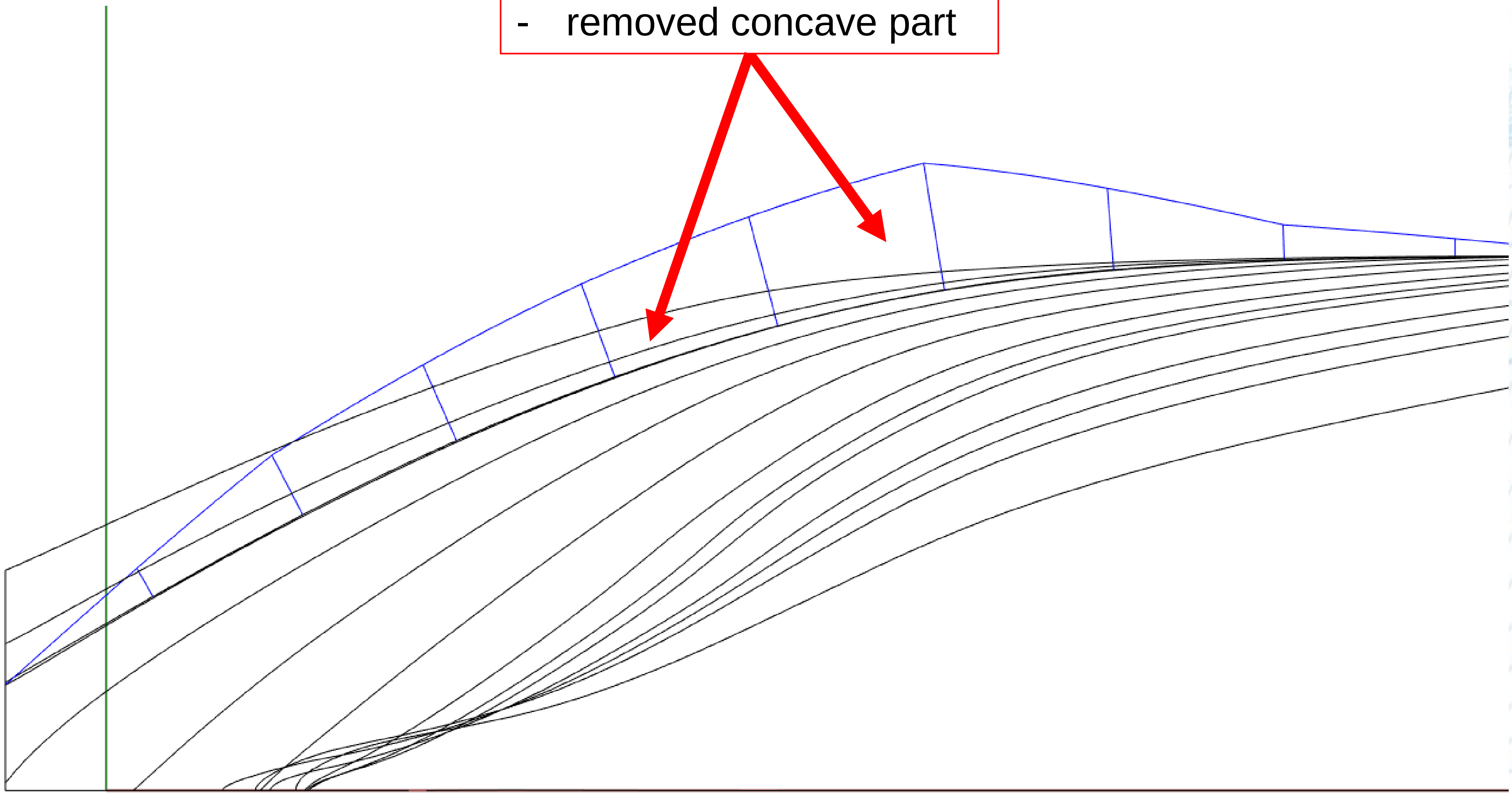
Hull modification

a flowtech product

Demo – fairing/fixing: 4_

Removing the imperfections of the initial hull

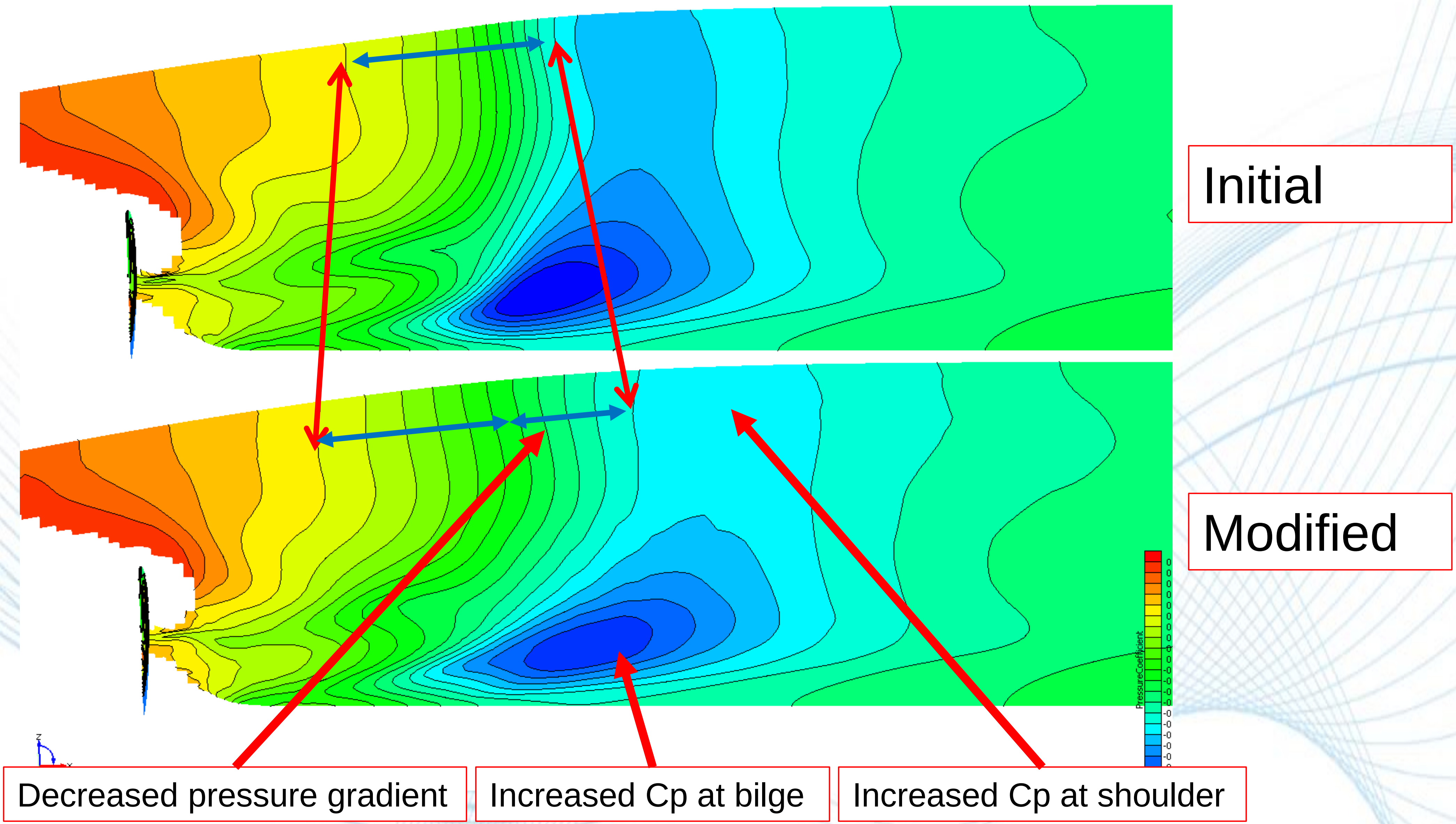
Smoothened lines:
- reduced max. curvature
- removed concave part



This has been done with Rhino 3D but can be done with any other CAD system

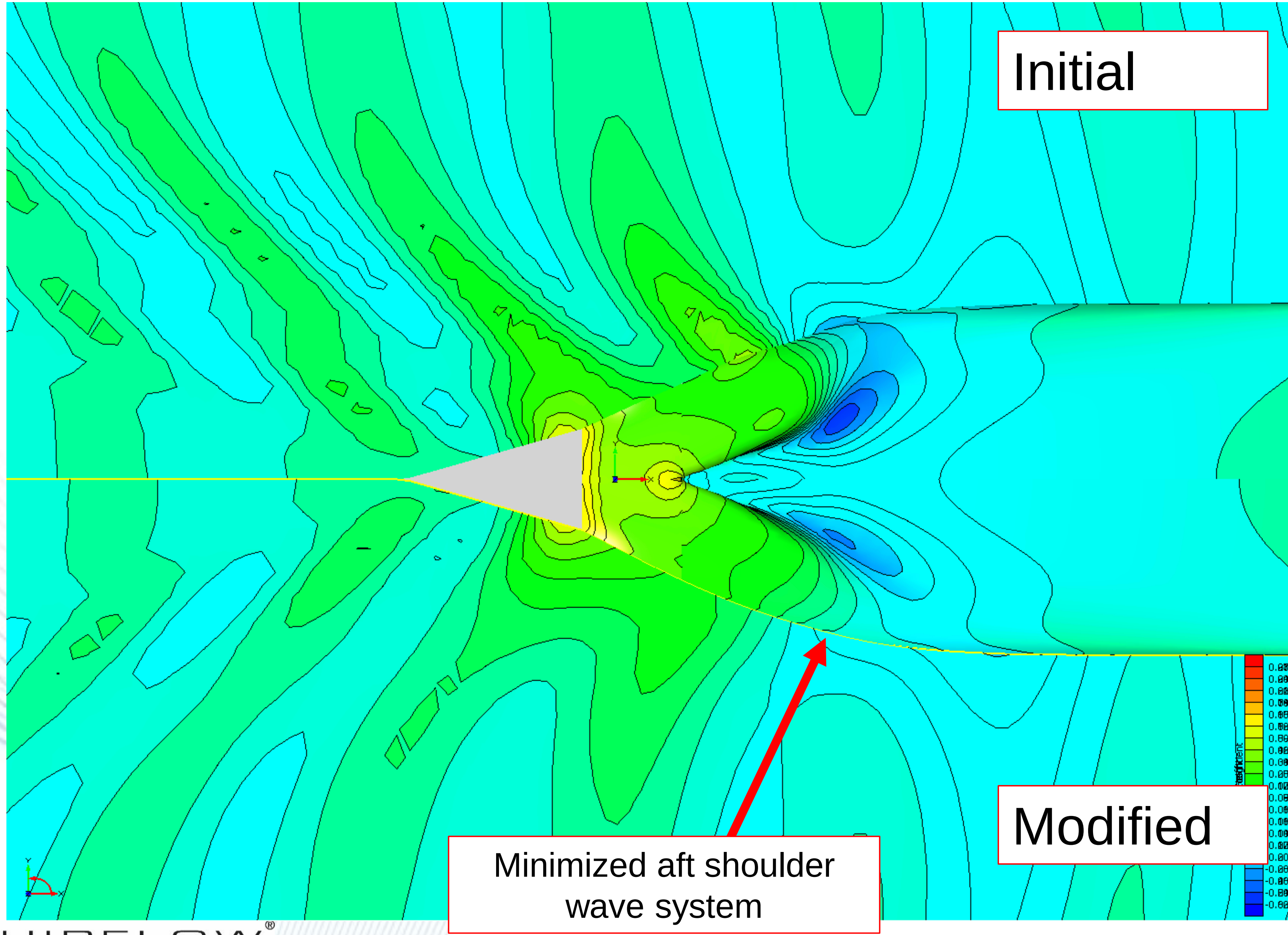
SHIPFLOW®
a flowtech product

Cp distribution comparison



SHIPFLOW®
a flowtech product

Effect on the wave pattern



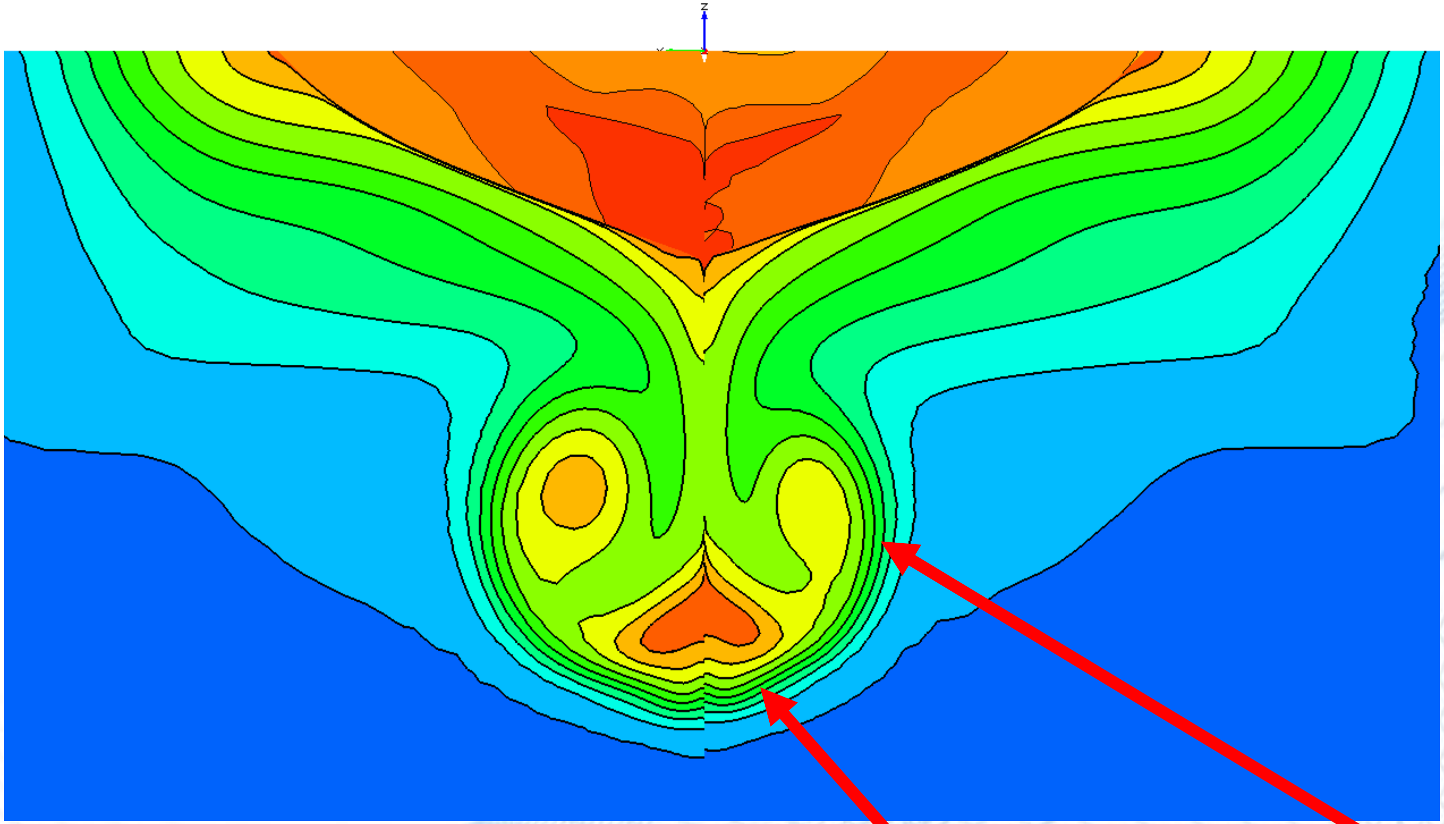
SHIPFLOW®
a flowtech product

Further modifications and flow changes

-

More slender stern

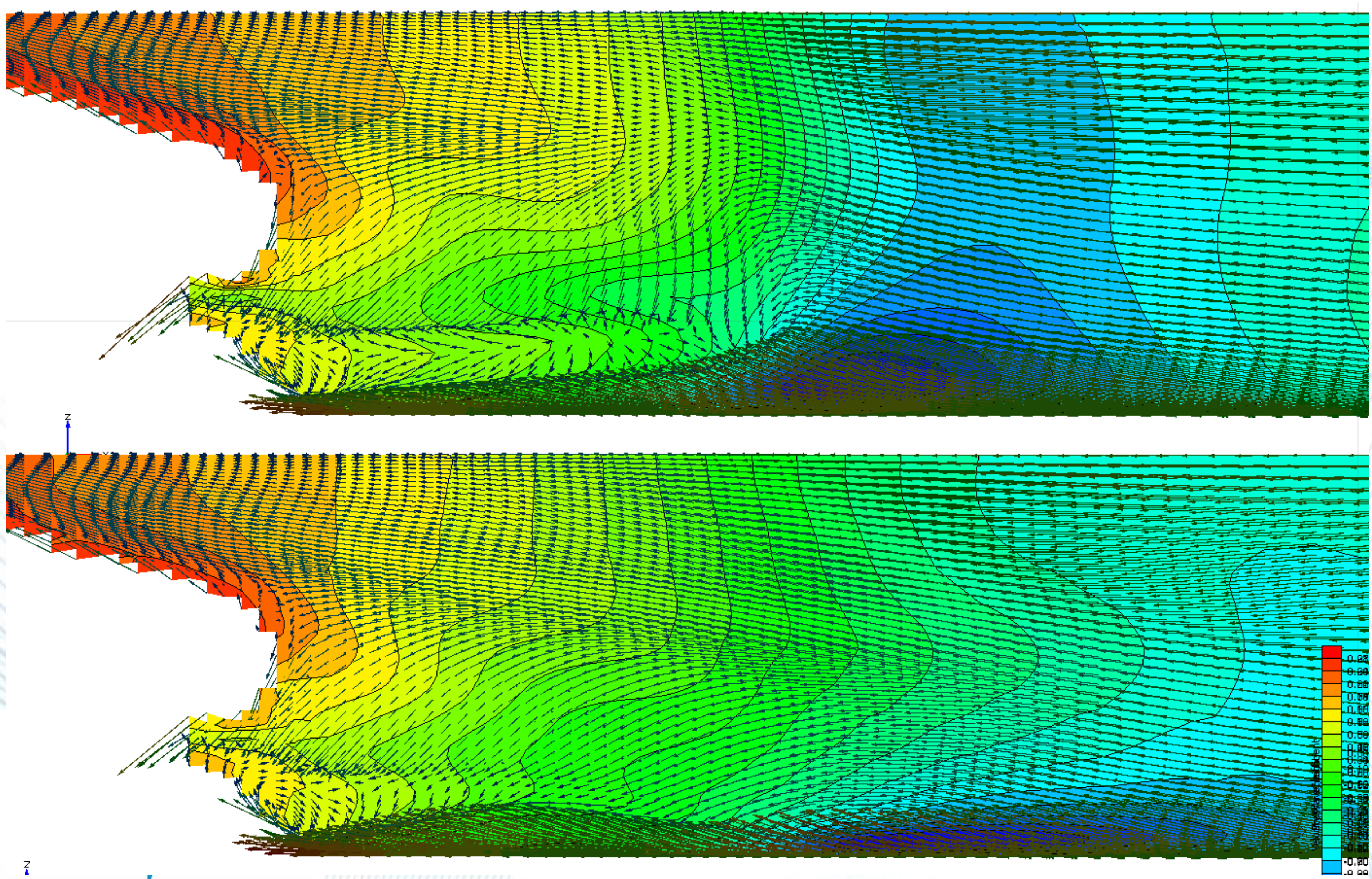
Wake comparison



Smaller bilge vortex

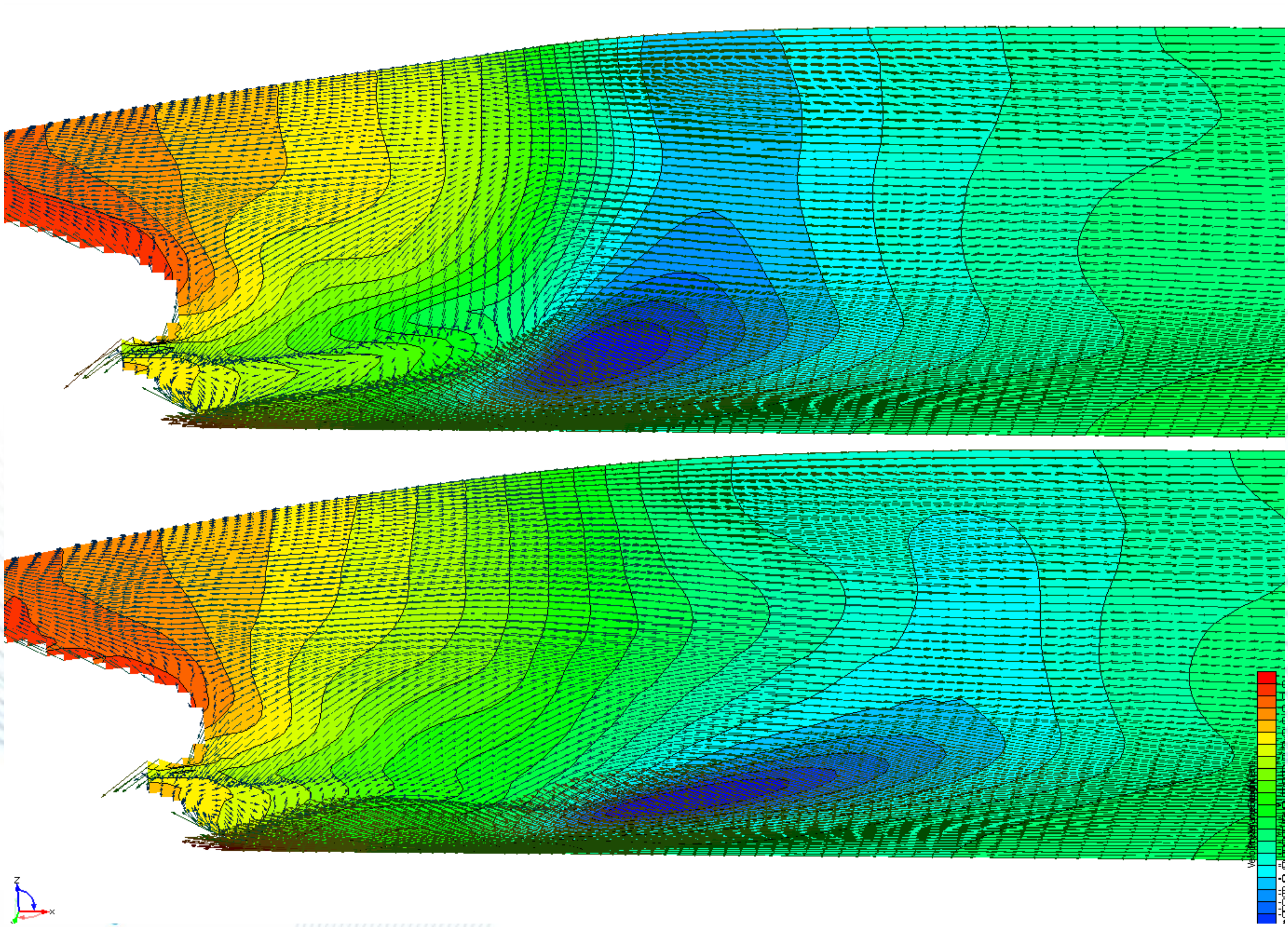
Weaker secondary vortex

Limiting streamlines comparison



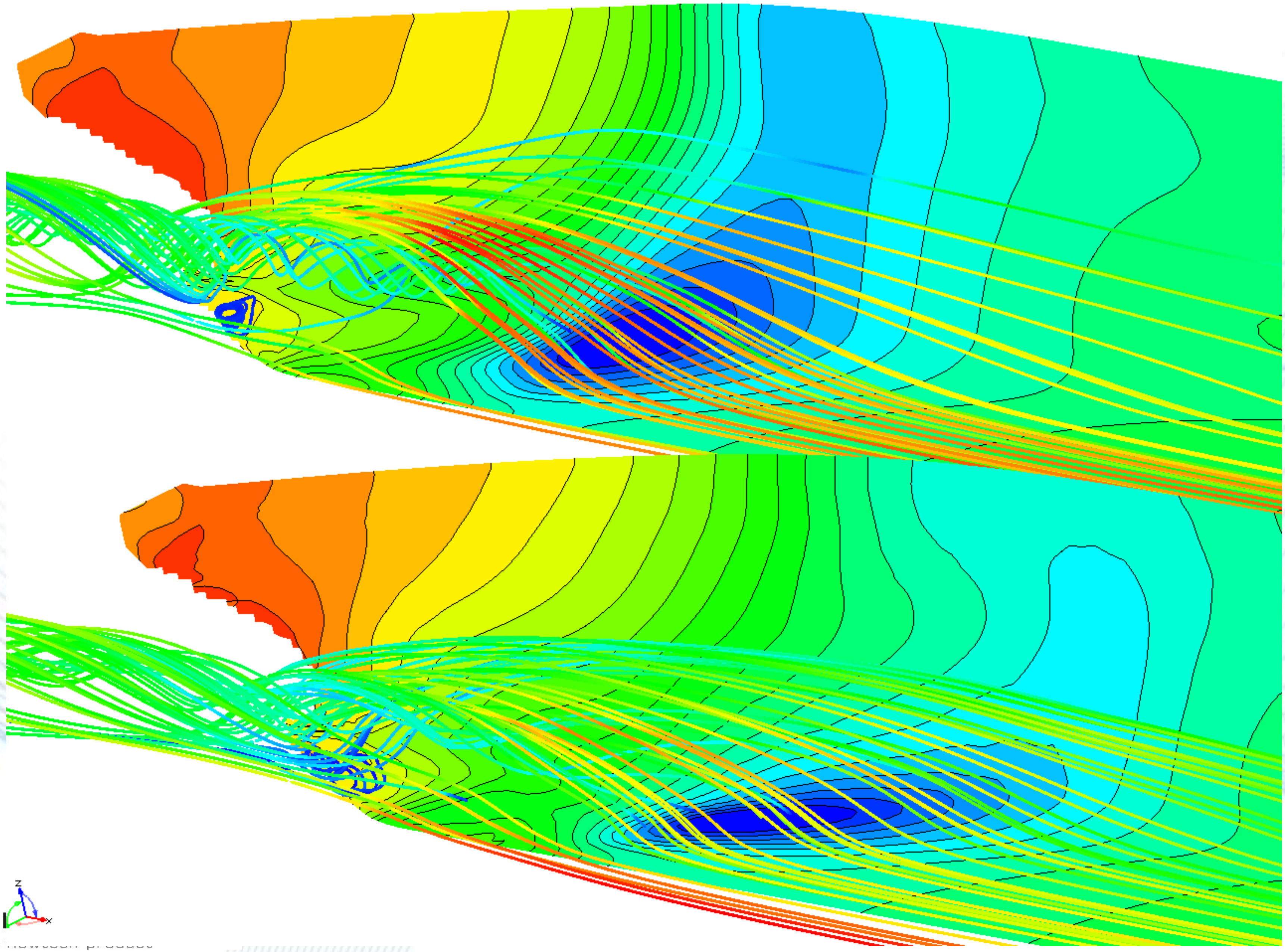
SHIPFLOW®
a flowtech product

Limiting streamlines comparison



SHIPFLOW®
a flowtech product

Streamlines comparison



Integrated data

- Wave resistance:
  - smaller aft shoulder wave system
- Viscous pressure resistance:
  - No separation
  - thinner boundary layer (pressure recovery)
  - smaller bilge and secondary vortices
- Lower Wn

Results from SHIPFLOW
(where to find the information)

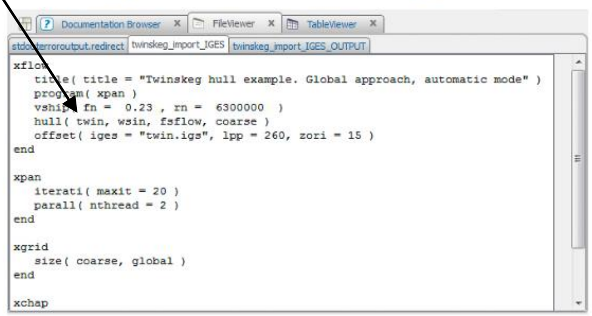
SHIPFLOW®
a flowtech product

In Design GUI or CAESES

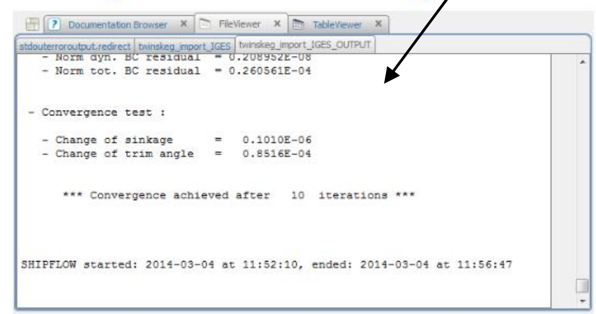
”config” file

config_OUTPUT file

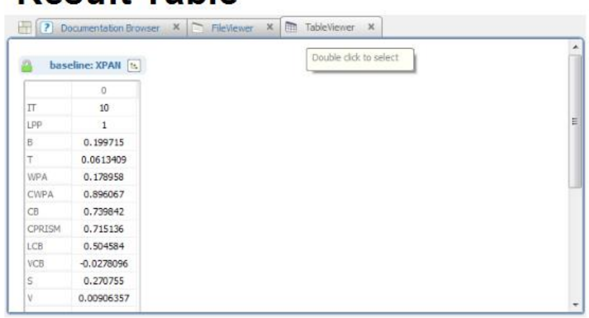
Configuration Summary



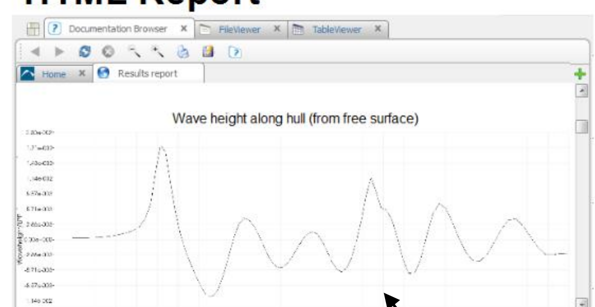
Computation Summary



Result Table



HTML Report



config_REPORT/config_report.html

SHIPFLOW®
a flowtech product

File structure: 6_

SHIPFLOW®
a flowtech product

Resistance case

GUI:

baseline: XCHAP

	0
WVAR	0.598286
WRAD	1
Wn	0.457932
Wn_a	0.473302
stdCPV	0.19
stdCF	0
Forcelog	111
CF	0.002849
CPV	0.0008863
CV	0.003735
CW	0.000269
CT	0.004004
K	0.258
S	0.2302
_LPP	6.403
_S	9.438
_Displ	1.999
_Vm_s	1.89
_Lref	6.403
_Fn	0.2385
_Rn	1.063e+07
_rho	999.1
_nu	1.139e-06
_g	9.807
_RF	47.99
_RV	62.92
_RW	4.531
_RT	67.45

baseline: XPAN

	0
IT	8
LPP	1
B	0.178944
T	0.067567
WPA	0.149734
CWPA	0.836762
CB	0.6298
CPRISM	0.656806
LCB	0.510252
VCB	-0.029856
S	0.23671
V	0.00761473
CW	0.000268987
CWTWC	0.000182142
Sref	0.230186
CZSINK	-0.04713
CMTRIM	-0.000754818
XCOF	0.549259
BML	1.31355
TRIMAN	-0.125917
ZSINK	-0.00216941
ZSINKF	-0.00206116
ZSINKB	-0.00326825
ZSINKS	-0.00107058

config_OUTPUT

Requires propeller position and diameter definition

```
-
- MAXIMUM TOTAL WAKE VARIATION, PROPELLER: ID1
  WVAR ( maximum total wake variation )        :  0.598286
  WRAD ( maximum found at radius )             :  1

- MEAN WAKE FRACTION, PROPELLER: ID1
  Wn   ( Mean wake fraction for ID1 ) : 0.457932

- MEAN AXIAL WAKE FRACTION, PROPELLER: ID1
  Wn_a  ( Mean axial wake fraction for ID1 ) : 0.473302

- Resistance Coefficients:

  CF      ( Frictional resist. coeff. )          : 2.849E-03
  CPV     ( Viscous pres. resist. coeff. )       : 8.863E-04
  CV      ( Viscous resist. coeff. )             : 3.735E-03
  CW      ( Wave resist. coeff. )                : 2.690E-04
  CT      ( Total resist. coeff. )               : 4.004E-03

  K       ( Form factor )                        : 0.258
  S       ( Wetted surface / L**2 )              : 0.2302

=======================================================================
=                          SIMULATION SUMMARY                         =
=======================================================================

- HULL DATA:

  _LPP     ( Model Lpp             [m] )         : 6.403E+00
  _S       ( Wetted area         [m^2] )         : 9.438E+00
  _Displ   ( Displacement        [m^3] )         : 1.999E+00

- CONDITIONS:

  _Vm_s    ( Model speed         [m/s] )         : 1.890E+00
  _Lref    ( Reference length      [m] )         : 6.403E+00
  _Fn      ( Froude number         [-] )         : 2.385E-01
  _Rn      ( Reynolds number       [-] )         : 1.063E+07
  _rho     ( Fluid density    [kg/m^3] )         : 9.991E+02
  _nu      ( Fluid viscos.      [m^2/s] )        : 1.139E-06
  _g       ( Gravity            [m/s^2] )        : 9.807E+00

- RESISTANCE:

  _RF      ( Frictional resistance [N] )         : 4.799E+01
  _RV      ( Viscous resistance    [N] )         : 6.292E+01
  _RW      ( Wave resistance       [N] )         : 4.531E+00
  _RT      ( Total resistance      [N] )         : 6.745E+01
```

Self-propulsion case (1)

```
- EXTRAPOLATION TO FULL SCALE ACCORDING TO ITTC78

  CFM   ( Model friction coefficient) :   0.0029684
  CFS   ( Ship friction coefficient ) :   0.00149689
  DCF   ( Ship roughness coefficient) :   0.000401551
  CTS   ( Ship drag coefficient     ) :   0.0025718
  RS    ( Ship drag [kN]            ) :   614.421
  PE    ( Ship effective power [MW] ) : 5.68954
```

Requires ITTC command

```
- PROPULSIVE FACTORS, PROPELLER: ID1
  KT    ( Thrust coefficient              ) : 0.208026
  KQ    ( Torque coefficient              ) : 0.0288515
  JV    ( Advance ratio                   ) : 0.887445
  CT    ( Prop thrust coeff               ) : 3.61204

  From resistance test
  CTMR ( CT model from resistance test )    : 0.00403928
  From self-propulsion simulation
  CTOW ( Non-dimensional towing force  )    : 0.00106996
  CTMS ( CT model from self prop. test )    : 0.00471575
  t    ( Thrust deduction fraction     )    : 0.18555
```

Requires Cttot to be included in selfpropulsion command

```
  From open water test
  JTM   ( JTM ) : 0.541175
  KQO   ( KQ0 ) : 0.0295465
  ETAO ( Propeller efficiency ) : 0.606415
  WTM   ( Effective mean wake   ) : 0.390188
  ETAR ( Relative rotative efficiency ) : 1.02409

  ETAH ( Hull efficiency ) : 1.33558
  ETAD ( Propulsive efficiency ) : 0.829423
```

Requires POW data to be included in selfpropulsion command

Self-propulsion case (2)

```
Re_min ( Min blade Re                        ) : 731118
Re_max ( Max blade Re                        ) : 755292
WTS    ( Effective mean wake ship            ) : 0.326107
Kt/J^2 ( Propeller load                      ) : 1.01589
JTS    ( Advance ratio ship scale            ) : 0.466383
KTS    ( Thrust coefficient ship             ) : 0.220969
KQS    ( Torque coefficient ship             ) : 0.0354645
NS     ( Propeller speed ship scale [rpm])   : 131.607
TS     ( Thrust ship scale [kN]              ) : 1508.8
QS     ( Torque ship scale [kNm]             ) : 1442.4
PD     ( Delivered power ship scale [MW] )   : 19.8791
etaDS  ( Total efficiency ship scale         ) : 0.286208
eta0S  ( Propeller efficiency ship scale )   : 0.462487
etaHS  ( Hull efficiency ship scale          ) : 1.20858
```

Requires ITTC command

SHIPFLOW®
a flowtech product

Self-propulsion case (3)

```
 - Resistance Coefficients:

   CF      ( Frictional resist. coeff. )          : 2.873E-03
   CPV     ( Viscous pres. resist. coeff. )       : 1.591E-03
   CV      ( Viscous resist. coeff. )             : 4.465E-03
   CW      ( Wave resist. coeff. )                : 2.690E-04
   CT      ( Total resist. coeff. )               : 4.734E-03

   K       ( Form factor )                        : 0.504
   S       ( Wetted surface / L**2 )              : 0.2302
=======================================================================
=                          SIMULATION SUMMARY                         =
=======================================================================

 - HULL DATA:

   _LPP     ( Model Lpp              [m] )         : 6.403E+00
   _Dprop   ( Propeller diameter     [m] )         : 2.542E-01
   _S       ( Wetted area          [m^2] )         : 9.438E+00
   _Displ   ( Displacement         [m^3] )         : 0.000E+00


 - CONDITIONS:

   _Vm_s    ( Model speed          [m/s] )         : 1.890E+00
   _Lref    ( Reference length       [m] )         : 6.403E+00
   _Fn      ( Froude number          [-] )         : 2.385E-01
   _Rn      ( Reynolds number        [-] )         : 1.063E+07
   _rho     ( Fluid density     [kg/m^3] )         : 9.991E+02
   _nu      ( Fluid viscos.      [m^2/s] )         : 1.139E-06
   _g       ( Gravity            [m/s^2] )         : 9.807E+00


 - PROPULSION:

   _PD      ( Delivered power        [W] )         : 1.131E+02
   _n       ( Propeller rev.       [rps] )         : 8.380E+00
```

Model scale or Full scale depending on the scale factor

Other important files

id_REPORT:

- img
- TEST_hamb_selfpropulsion_full__64GB_report
- Wake_report

Images and *.dat files

Summary of wake data

id_RUN_DIR:

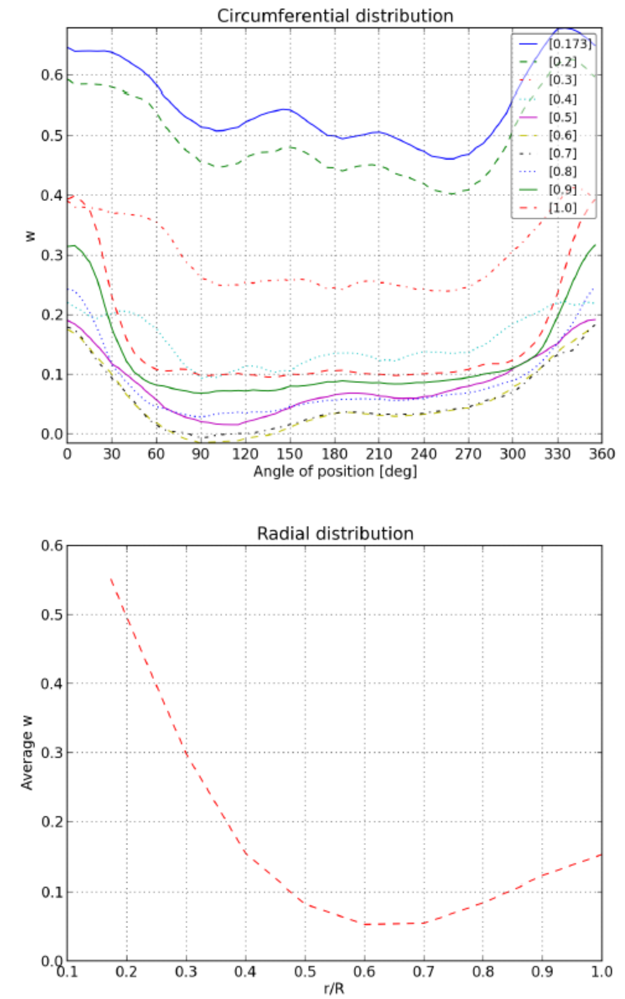
- history_DIR
- ID1_DIR
- TEST_hamb_selfpropulsion_full__64GB
- TEST_hamb_selfpropulsion_full__64GB_AREA
- TEST_hamb_selfpropulsion_full__64GB_chp
- TEST_hamb_selfpropulsion_full__64GB_CONV
- TEST_hamb_selfpropulsion_full__64GB_FORCEAVERAGE
- TEST_hamb_selfpropulsion_full__64GB_FORCELOG
- TEST_hamb_selfpropulsion_full__64GB_ID1_effective_field
- TEST_hamb_selfpropulsion_full__64GB_ID1_effective_field
- TEST_hamb_selfpropulsion_full__64GB_ID1_flow_angle
- TEST_hamb_selfpropulsion_full__64GB_ID1_flow_angle
- TEST_hamb_selfpropulsion_full__64GB_ID1_flow_field
- TEST_hamb_selfpropulsion_full__64GB_ID1_flow_field
- TEST_hamb_selfpropulsion_full__64GB_OUTPUT
- TEST_hamb_selfpropulsion_full__64GB_SUMMARY
- TEST_hamb_selfpropulsion_full__64GB_XBDB
- TEST_hamb_selfpropulsion_full__64GB_XVPROF
- TEST_hamb_selfpropulsion_full__64GB_XYZFOR

Flow field data at the propeller plane in html and csv file formats

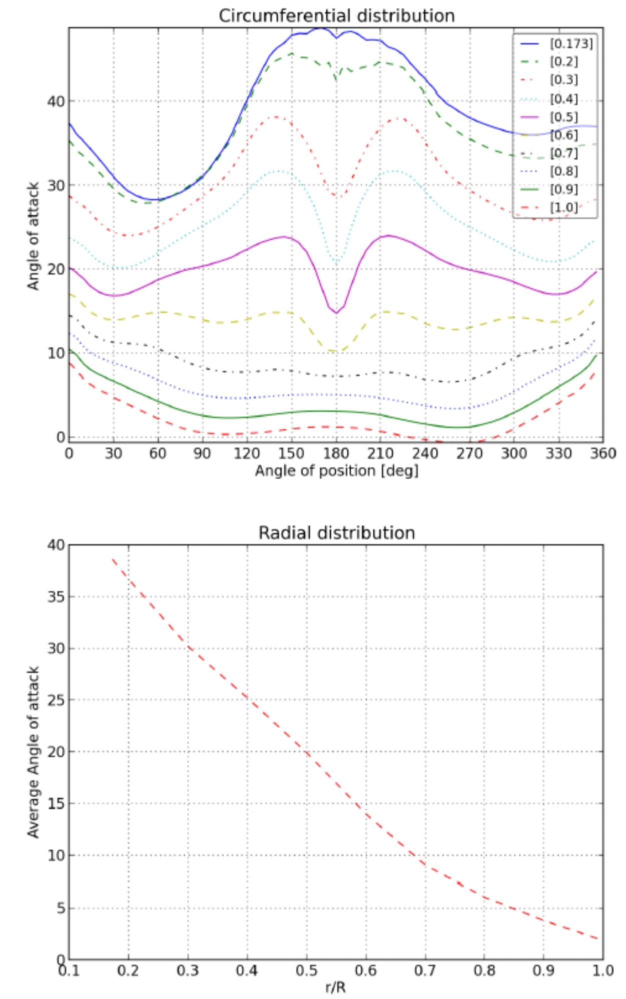
SHIPFLOW®
a flowtech product

Summary of wake data – selected examples from resistance

Nominal Wake

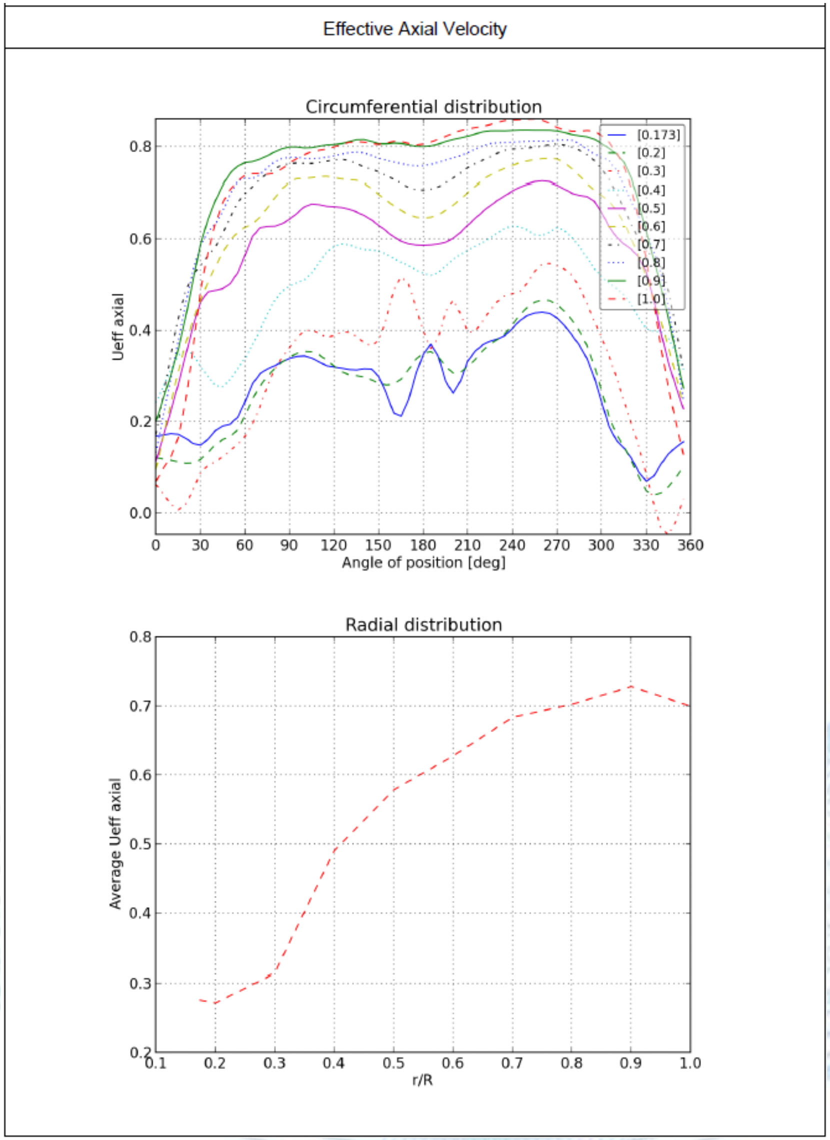


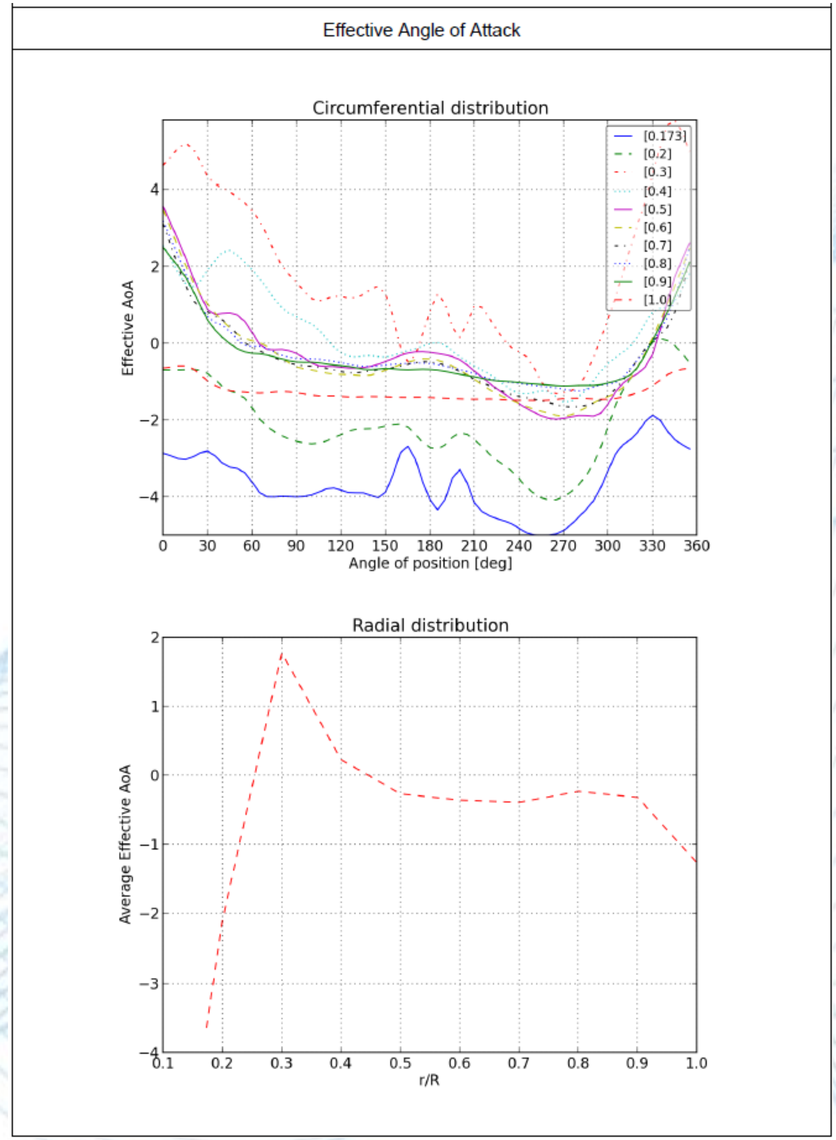
Nominal Angle of Attack



SHIPFLOW®
a flowtech product

Summary of wake data – selected examples from selfpropulsion





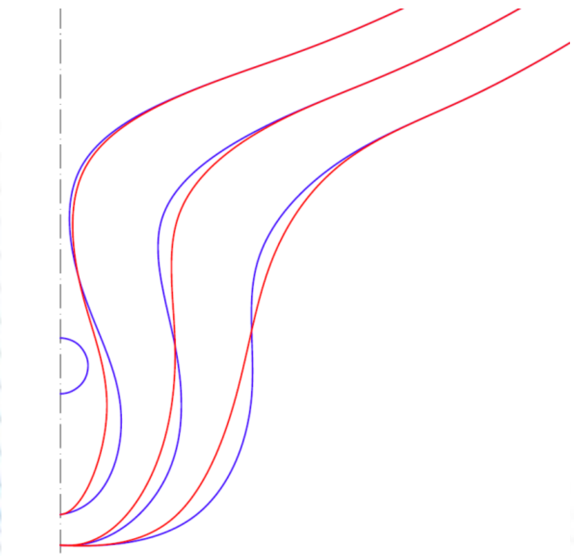
SHIPFLOW®
a flowtech product

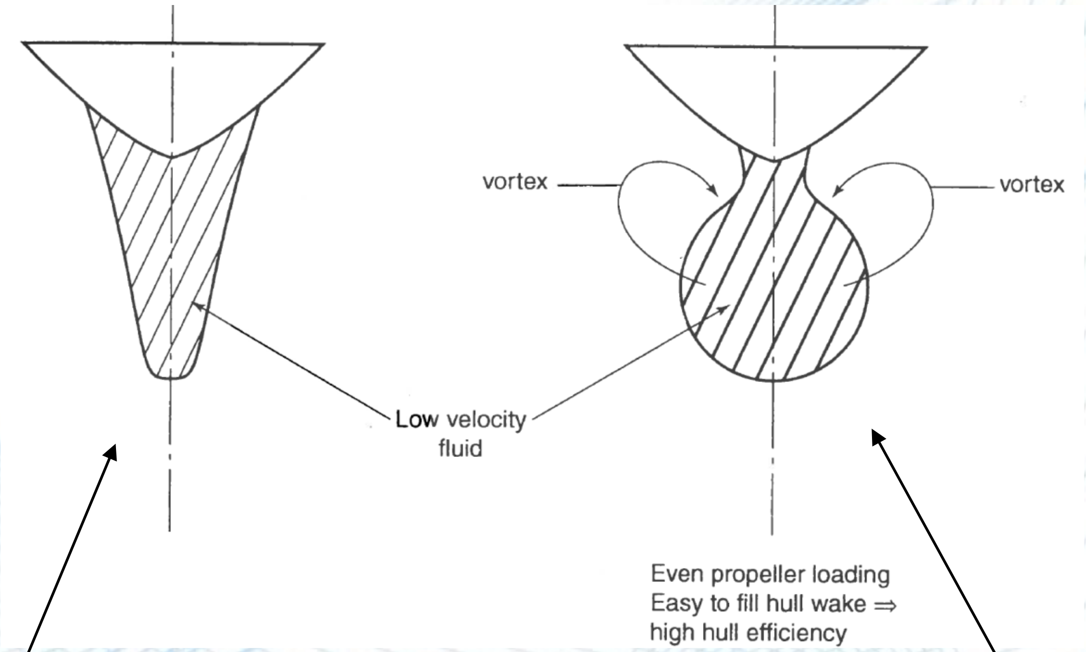
PYTHON interface: 7_

Example
large aft-body modification

Shape variations vs. Wake

To increase hull efficiency and avoid sudden changes of propeller loading the wake should be more circular and concentrated in propeller disc – however, this often leads to resistance increase





U- or V-shaped sections

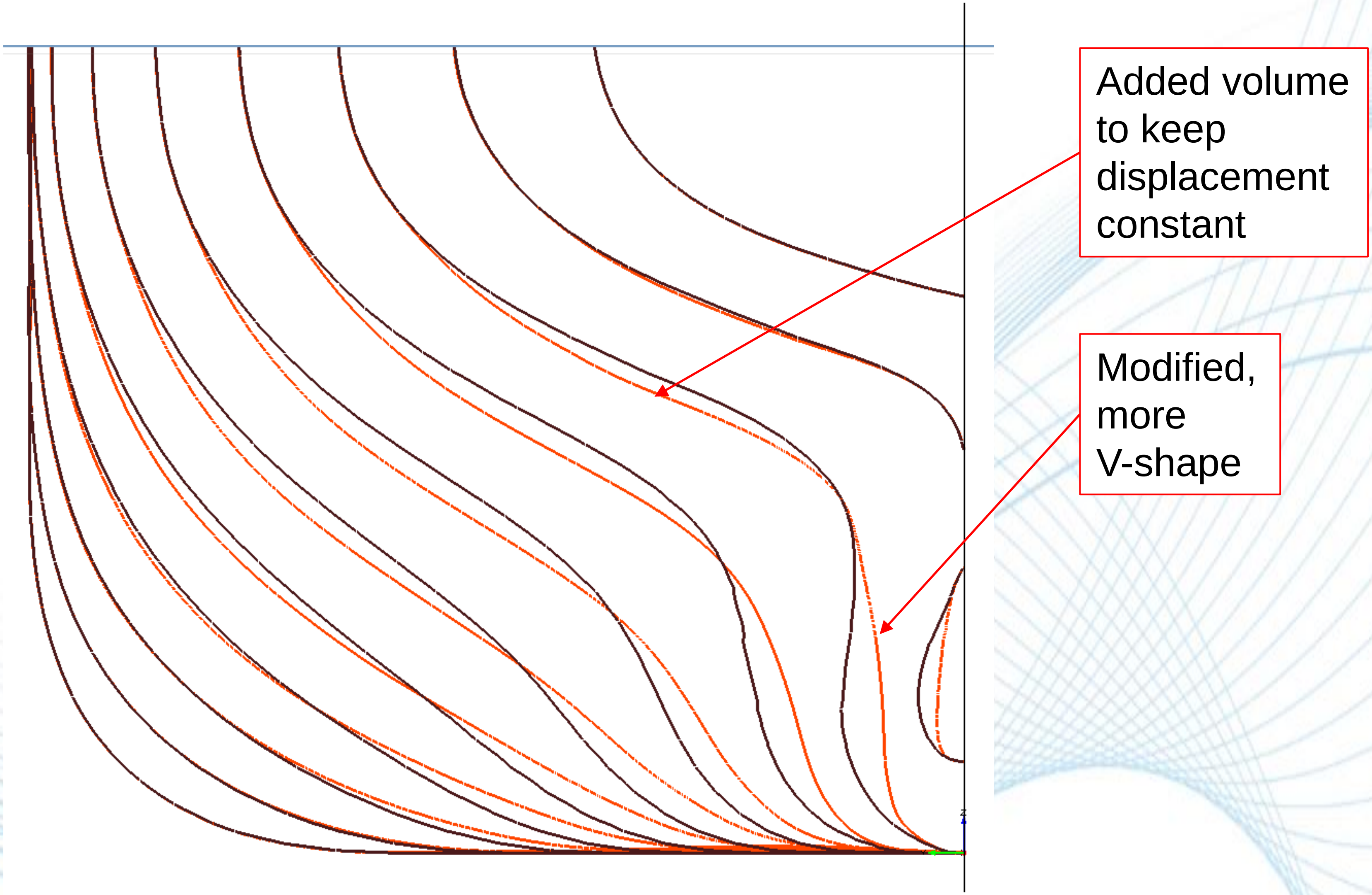
Utilize the bilge vortices

Most likely less resistance

Most likely higher resistance but better efficiency

SHIPFLOW®
a flowtech product

KVLCC2

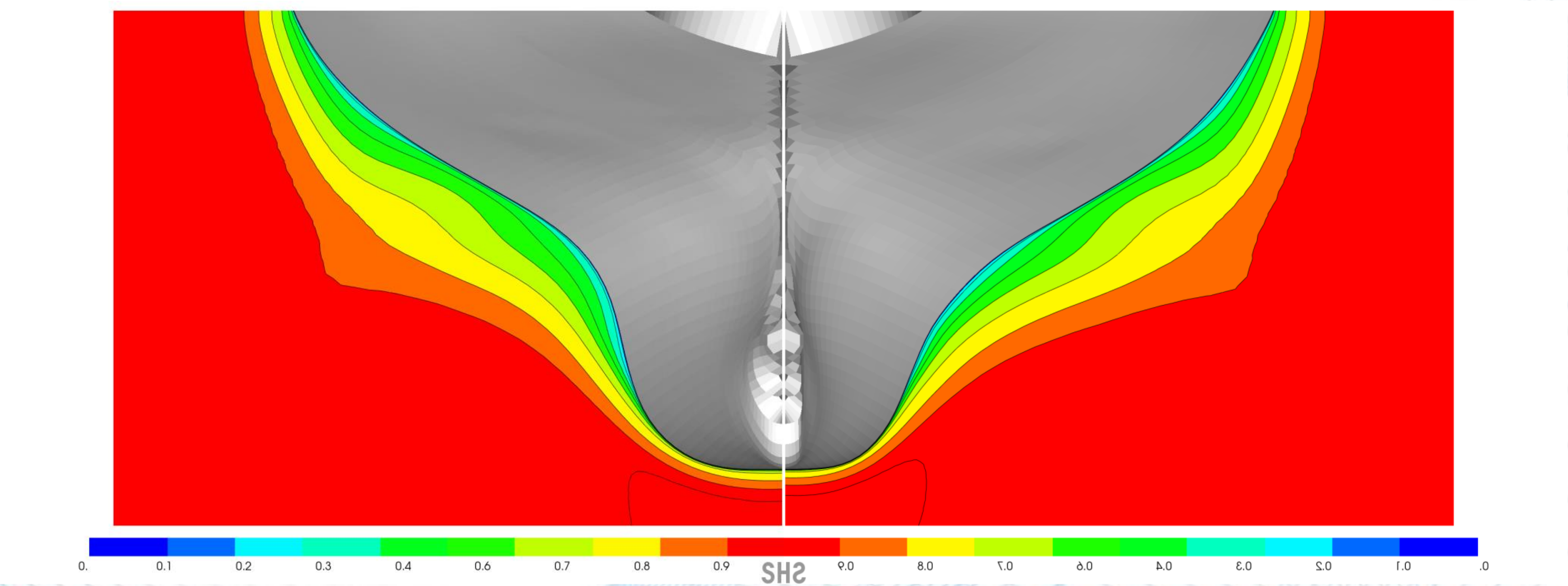


SHIPFLOW®
a flowtech product

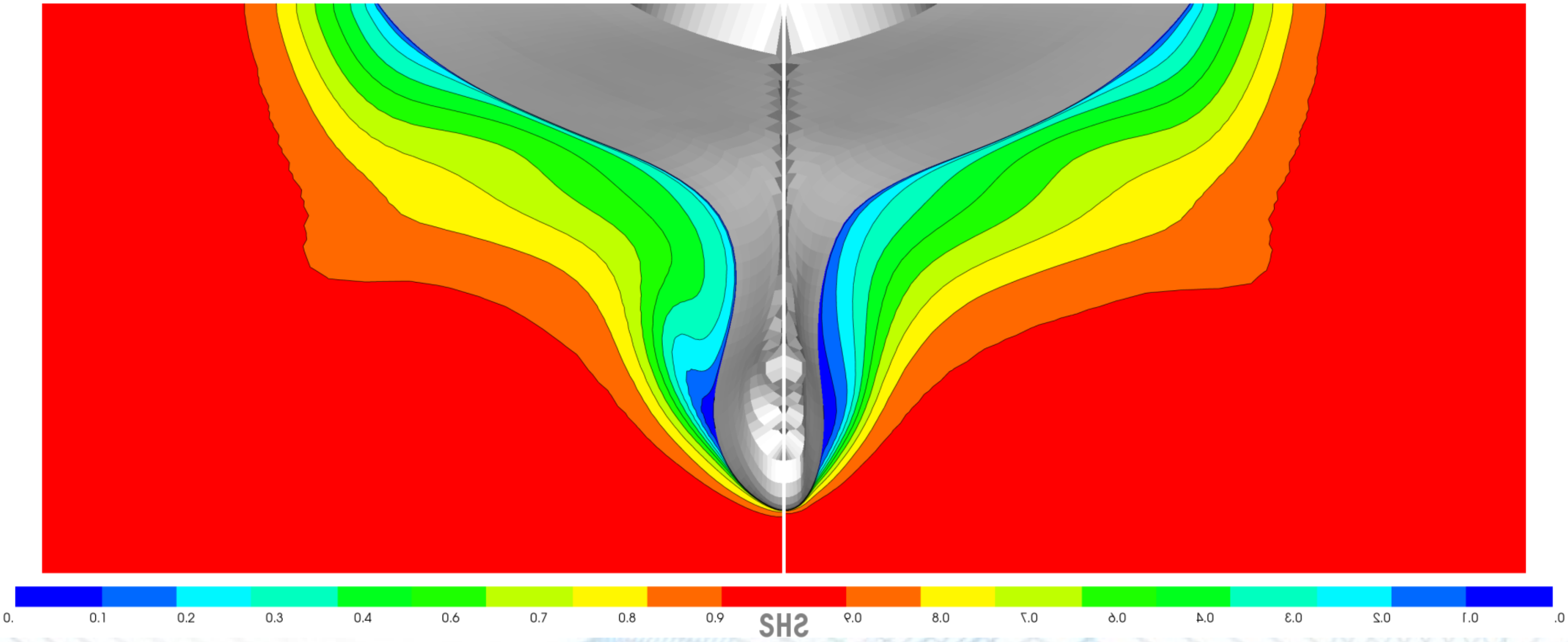
Patches - kvlcc2-aft-V.fdb

SHIPFLOW®
a flowtech product

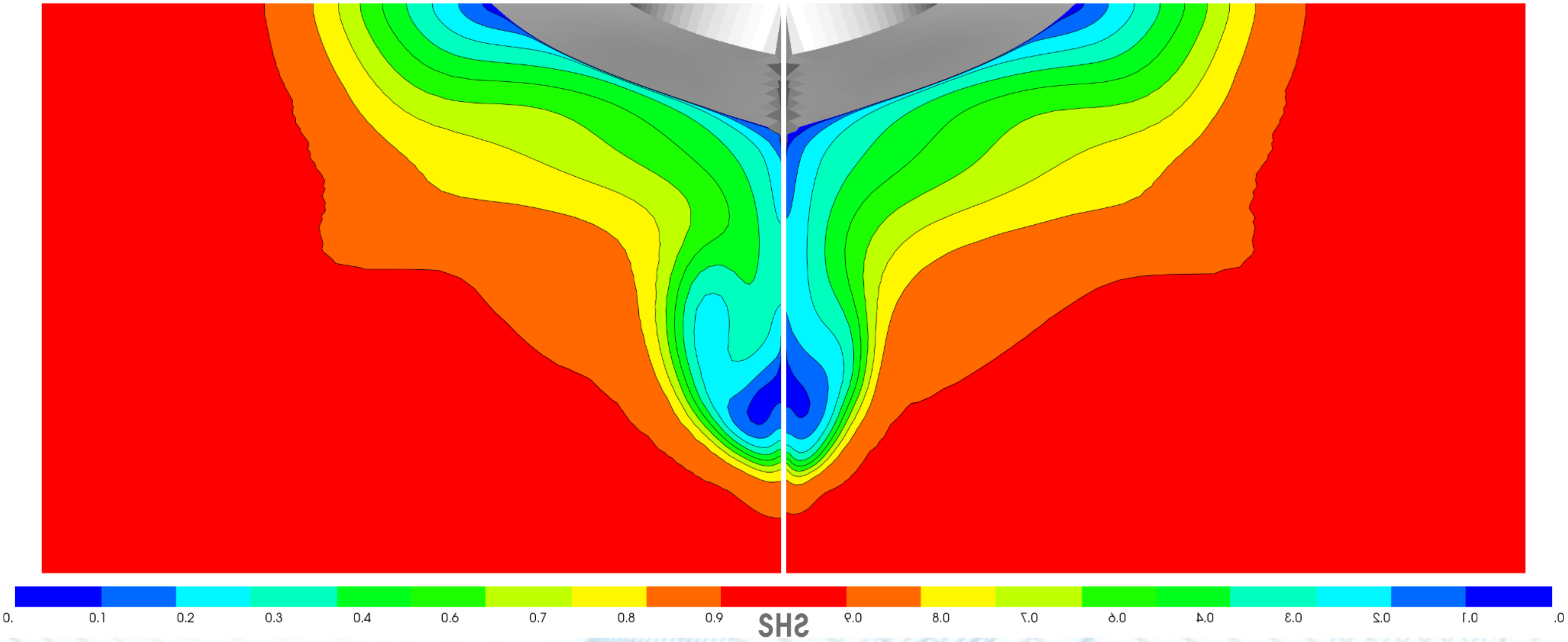
Wake development, x/Lpp=0.9



Wake development, x/Lpp=0.95

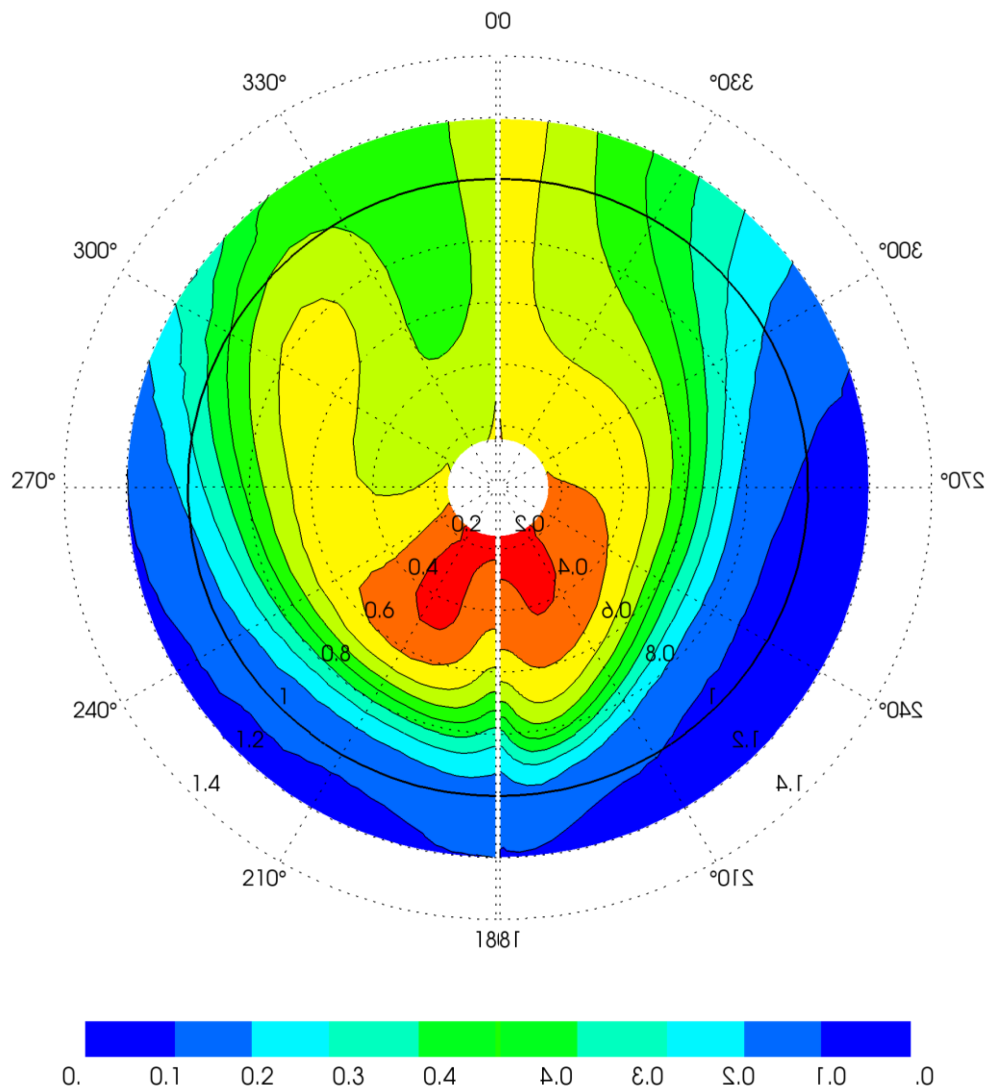


Wake development, x/Lpp=0.9825

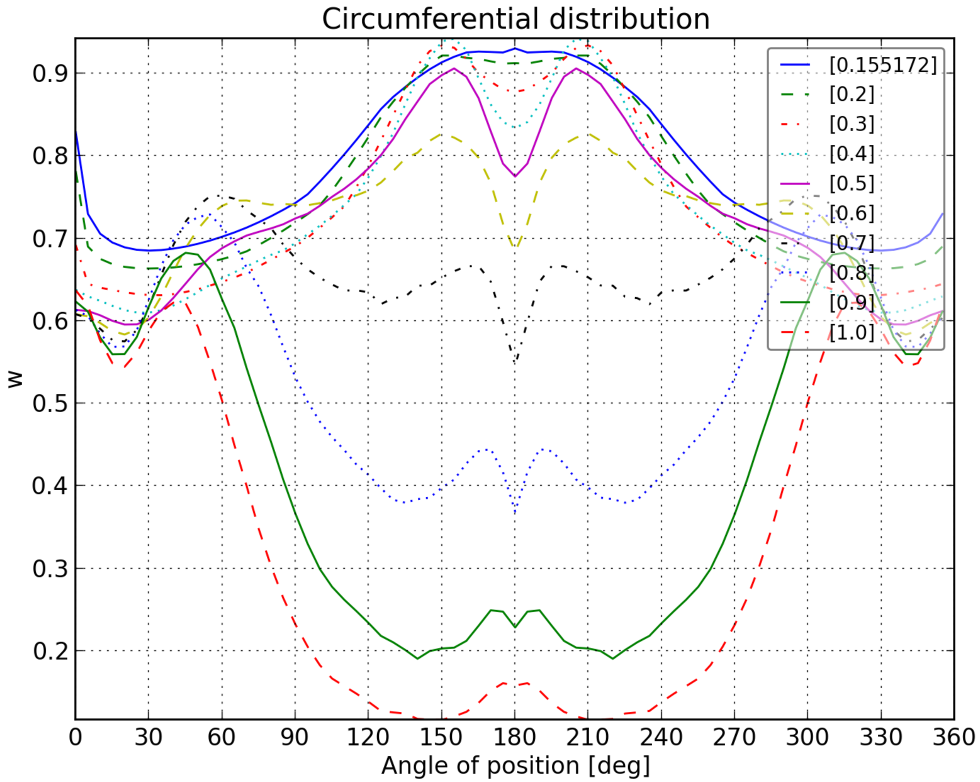


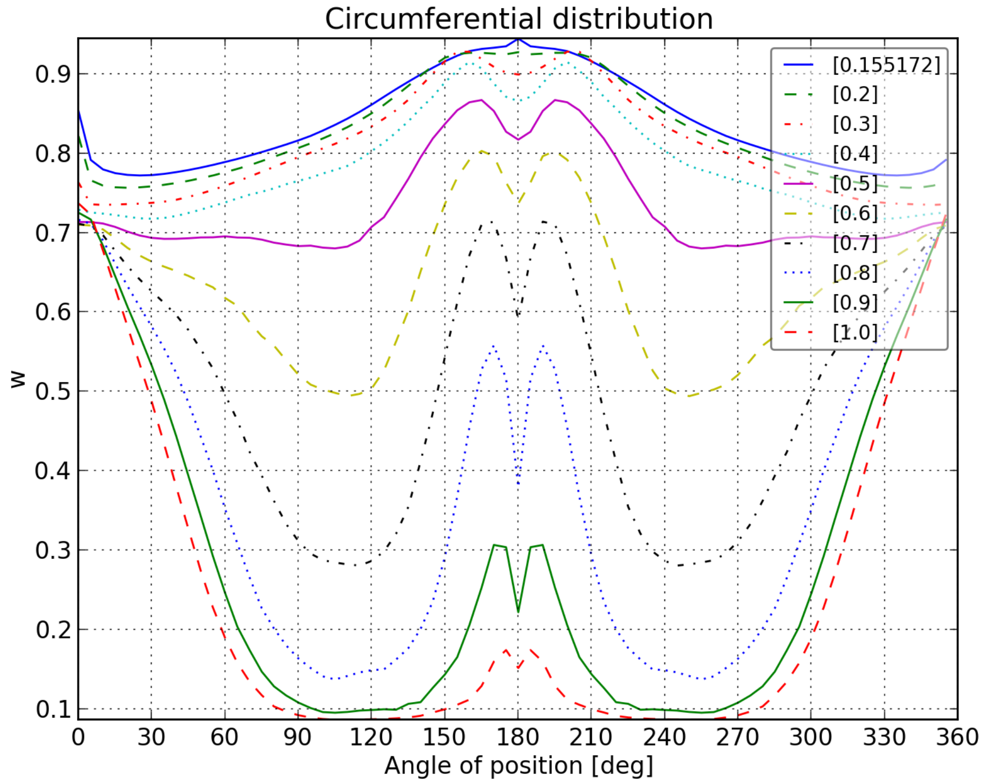
SHIPFLOW®
a flowtech product

Wake in the propeller disc



Circumferential wake distribution





SHIPFLOW®
a flowtech product

Numbers

	U	V	Comments
Ct	-	-2%	Good! Lower resistance.
Wn	-	-15%	Not so good. Lower nominal wake may result in lower propulsive efficiency.
WVAR	-	+25%	Not so good. Circumferential wake variation much higher. Larger vibrations, increased risk of cavitation in the wake peak.
PD	-	+/-0%	No improvement!

SHIPFLOW®
a flowtech product

Things to consider for propulsion efficiency

- Bilge vortex strenght
- Bilge vortex position
- Shape of the wake
- Circumferential flow velocity variation

REPORT on GDS from JDP: 8_

Thank You

SHIPFLOW®
a flowtech product