Tokyo 2015 - JBC Local Flow Analysis

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JBC Local Flow Analysis
Tokyo, December 2, 2015

JBC local flow analysis 1/3

- This analysis is very preliminary and has been written in the urgency under high pressure,
- For the JBC, the proceedings composed of more than 1000 pages and 6000 figures were sent only 5 days ago...
- The objectives of this discussion are to assess the current CFD simulations, identify limitations and to some extent provide guidelines for future research directions.
- This workshop gives an opportunity of exchanges in order to progress towards even better simulation practices in marine hydrodynamics.

JBC local flow analysis 2/3

More specifically, we will see if:

- The main characteristics of the flow around the naked JBC hull are captured and by which combination of grids and turbulence models,
- The influence of the duct on the flow without propeller is correctly predicted,
- The influence of propeller on the flow around the naked hull is also correctly predicted,
- The influence of the duct on the flow around the hull with propeller is reliaby simulated and leads to a reduction of the energy consumption.

JBC local flow analysis 3/3

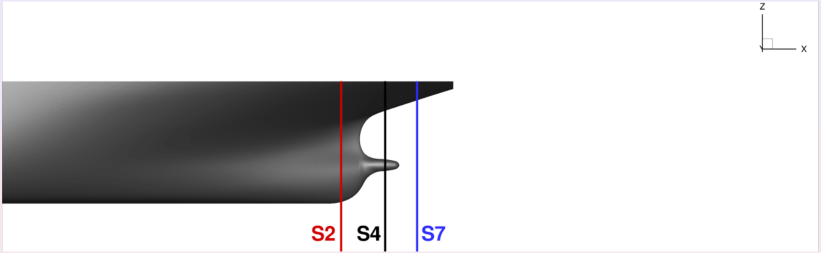
Five configurations should be analyzed from a local flow standpoint

- Case 1-3a (Re=7.46 10^6, Fr=0.142, without duct, without propeller, (Experiments from NMRI)
- Case 1-3b (Re=2.74 10^6, Fr=0.0, without duct, without propeller, (Wind tunnel experiments from TUHH)
- Case 1-4 (Re=7.46 10^6, Fr=0.142, with duct, without propeller, (Experiments from NMRI)
- Case 1-7 (Re=7.46 10^6, Fr=0.142, without duct, with propeller, (Experiments from NMRI)
- Case 1-8 (Re=7.46 10^6, Fr=0.142, with duct, with propeller, (Experiments from NMRI)

In all the test cases, the rudder is omitted.

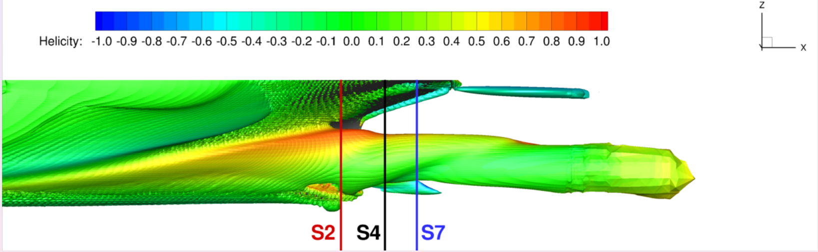
The analysis will be performed on the basis of the proceedings for all the cases and an additional local vortex flow analysis will be presented for case 1-3a.

JBC - Case 1-3a



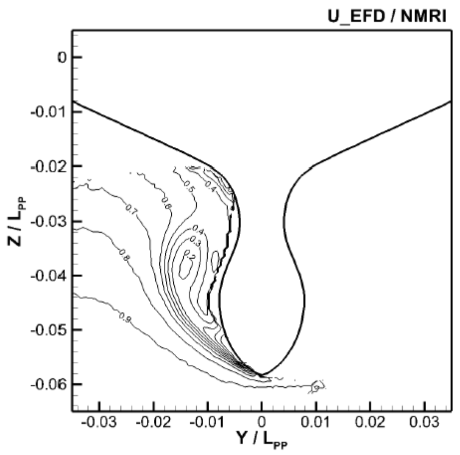
$Re=7.46\ 10^6$, $Fr=0.142$

JBC - Case 1-3a



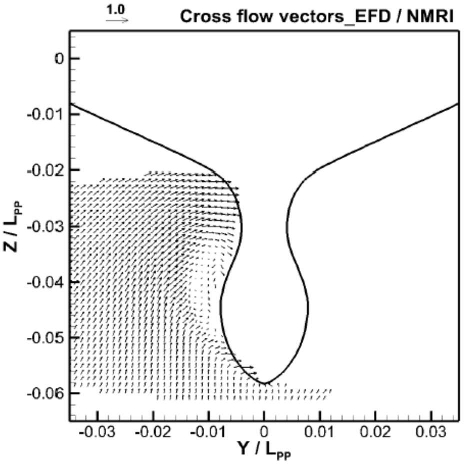
Re=7.46 10^6, Fr=0.142

Iso-U contours - Station S2



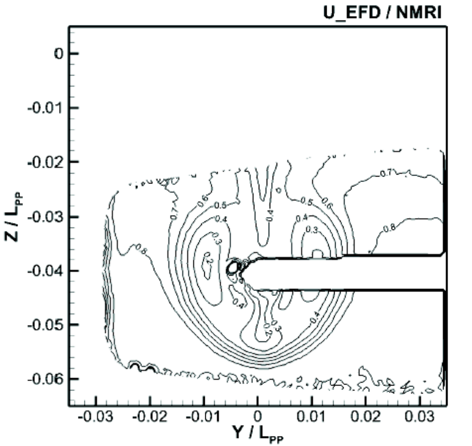
EFD(NMRI)

Cross-flow velocity components - Station S2



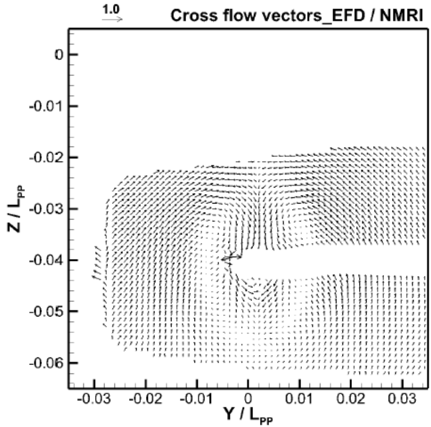
EFD(NMRI)

Iso-U contours - Station S4



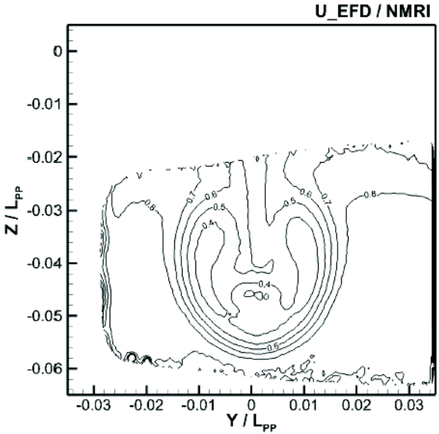
EFD(NMRI)

Cross-flow velocity components - Station S4



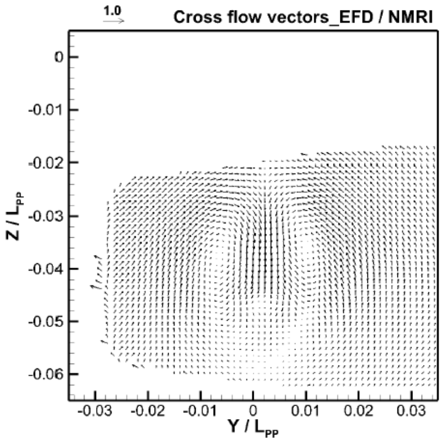
EFD(NMRI)

Iso-U contours - Station S7



EFD(NMRI)

Cross-flow velocity components - Station S7



EFD(NMRI)

Grid sensitivity

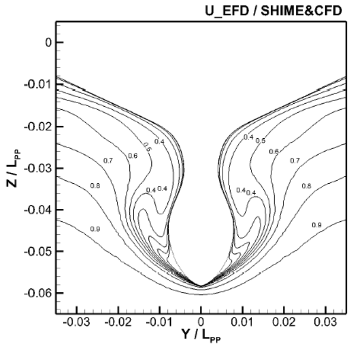
Main characteristics of the computations - Case1-3a

Grids can be organized into three groups for 18 participants:

- Not So Fine: Ncell < 2 M cells (MARIC, HHI)
- Fine: 2 M cells < Ncell < 10 M cells (ABS, CHALMERS, INSEAN, ECN, HSVA, KRISO, SHIME, NMRI, PNU, YNU, CSSR)
- Very Fine: 10 M cells < Ncell < 50 M cells (SOTON, MHI, MARIN, URO)
- Tremendously Fine: Ncell > 50 M cells (None)

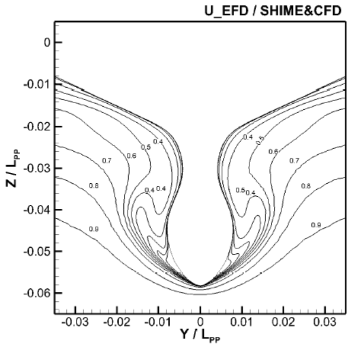
Comparison with Gothenburg 2010 (average size was 4M cells)
Just a global picture: one does not have access to the local grid density !

Grid influence - Station S2 - Grid comparison from SHIME



SHIME-OpenFOAM-Fine

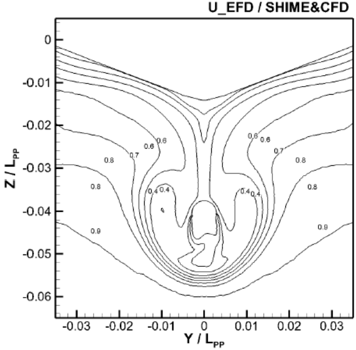
10M



SHIME-OpenFOAM-VeryFine

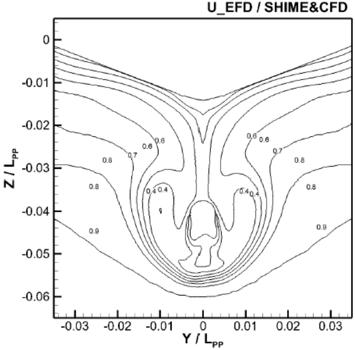
25M

Grid influence - Station S4 - Grid comparison from SHIME



SHIME-OpenFOAM-Fine

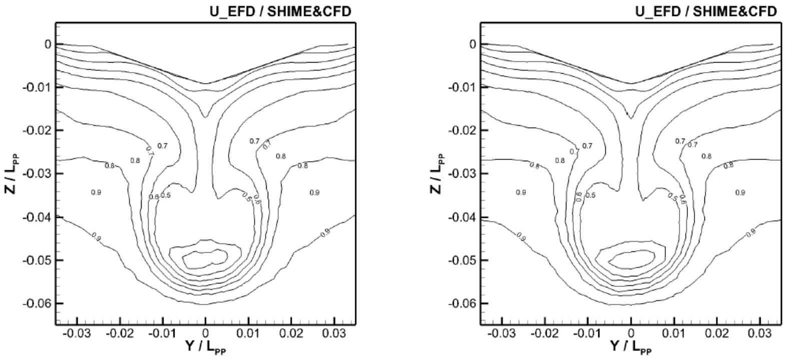
10M



SHIME-OpenFOAM-VeryFine

25M

Grid influence - Station S7 - Grid comparison from SHIME



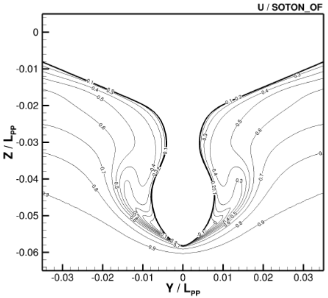
SHIME-OpenFOAM-Fine

SHIME-OpenFOAM-VeryFine

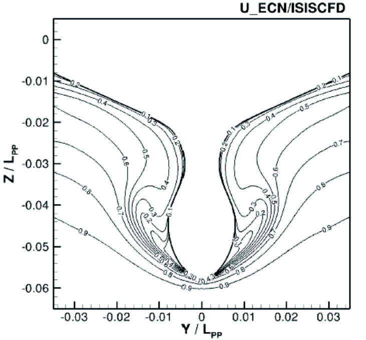
10M

25M

Grid influence - Station S2



SOTON-OF



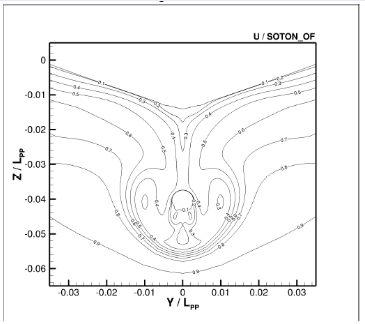
ECN_CNRS-ISISCFD-LRN_SST

Very Fine
25M

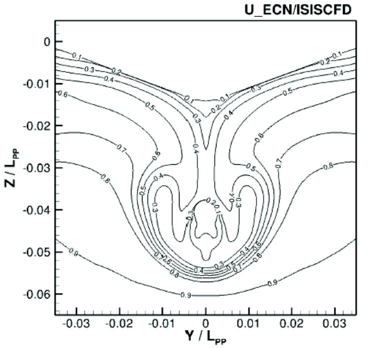
Fine
5.7M

Similar turbulence model (k-ω sst) but different grid category

Grid influence - Station S4



SOTON-OF



ECN_CNRS-ISISCFD-LRN_SST

Very Fine

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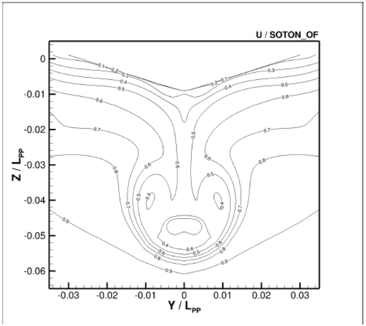
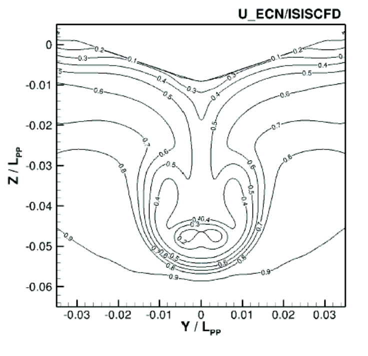
Similar turbulence model (k-ω sst) but different grid category

Grid influence - Station S7



SOTON-OF



ECN_CNRS-ISISCFD-LRN_SST

Very Fine	Fine
25M	5.7M

Similar turbulence model (k-ω sst) but different grid category

Influence of the Turbulence Closures

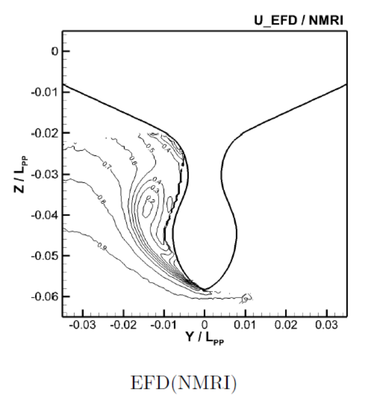
Main characteristics of the computations

Turbulence models can be organized into three groups:

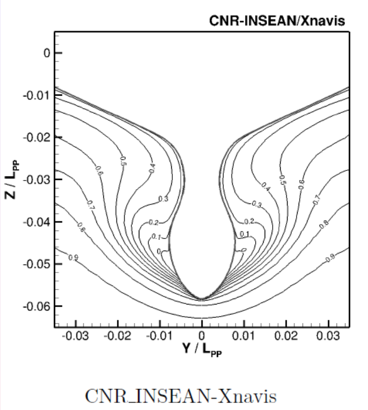
- The isotropic linear closures: INSEAN (Spalart-Allmaras), HSVA (Linear EASM), MARIN (k-w SST + DM), MARIC (k-w SST), URO (k-w SST), PNU (k-e), SHIME (k-w SST), CSSRC (k-e), ABS (k-w SST), SOTON (k-w SST), ECN-CNRS ((k-w SST),MHI (k-w SST),
- The anisotropic non-linear models: MHI (RSM), ECN-CNRS (EASM), NMRI (EASM), CHALMERS (EASM), YNU (EASM), KRISO (EASM)
- The hybrid LES models: URO (Hybrid).

Linear Isotropic Turbulence Closures

Linear Isotropic Turbulence Closures - Station S2

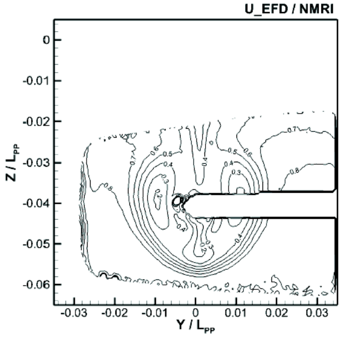


Experiments

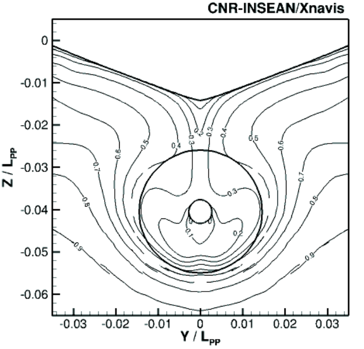


Spalart-Allmaras

Linear Isotropic Turbulence Closures - Station S4



EFD(NMRI)

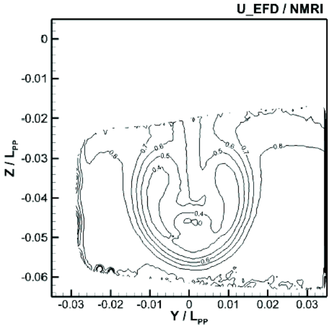


CNR_INSEAN-Xnavis

Experiments

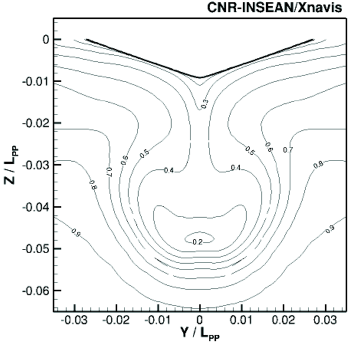
Spalart-Allmaras

Linear Isotropic Turbulence Closures - Station S7



EFD(NMRI)

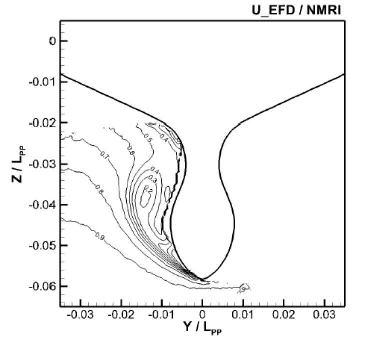
Experiments



CNR_INSEAN-Xnavis

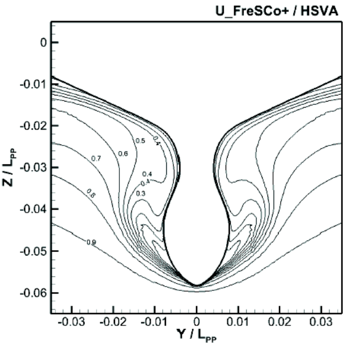
Spalart-Allmaras

Linear EASM Turbulence Closures - Station S2



EFD(NMRI)

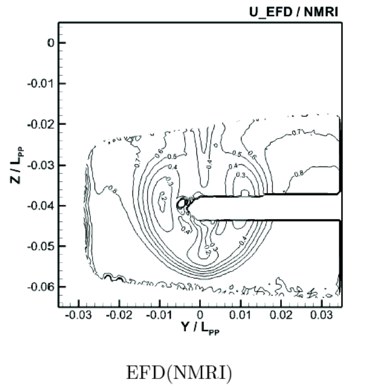
Experiments



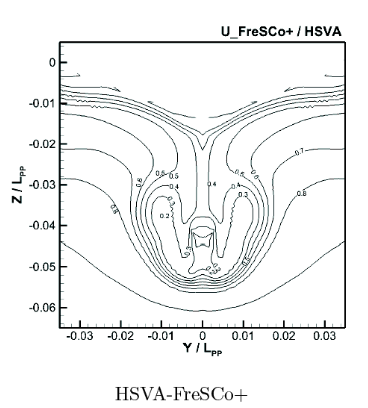
HSVA-FreSCo+

Linear EASM

Linear EASM Turbulence Closures - Station S4

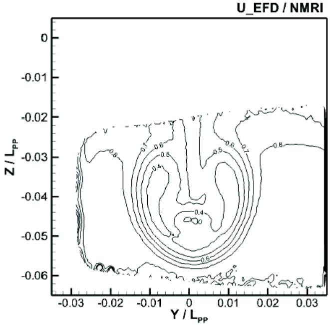


Experiments



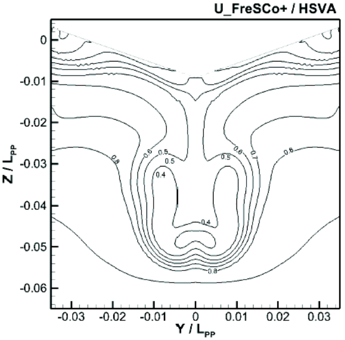
Linear EASM

Linear EASM Turbulence Closures - Station S7



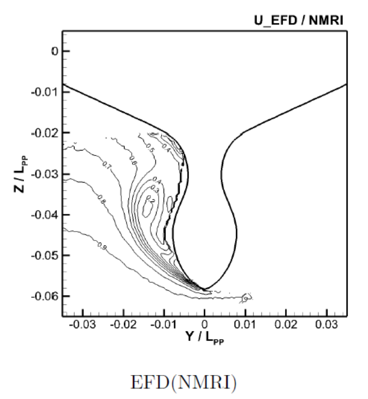
EFD(NMRI)

Experiments

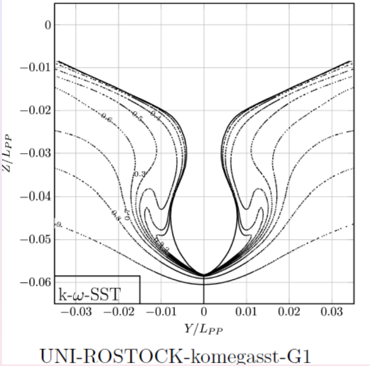


HSVA-FreSCo+

Linear EASM



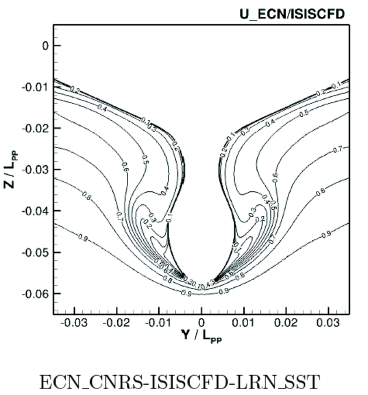
Experiments

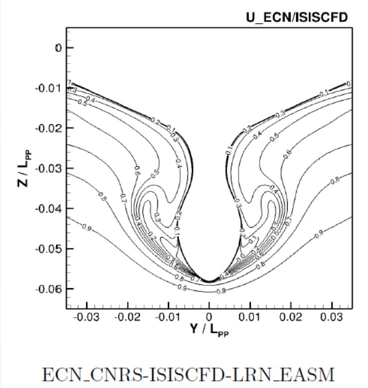


k-ω SST

Non-Linear Anisotropic Turbulence Closures

Isotropic vs Anisotropic turbulence closures - Station S2



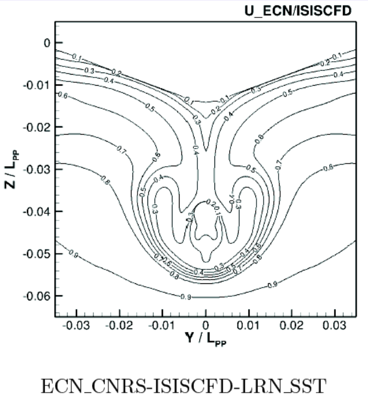


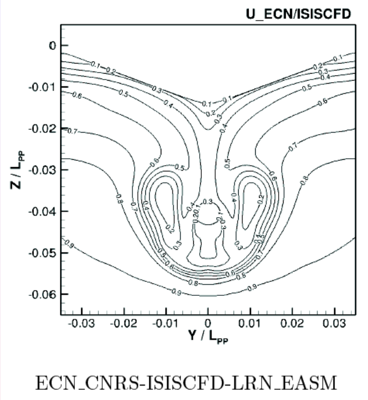
k-ω SST

EASM

Same grid, same code

Isotropic vs Anisotropic turbulence closures - Station S4



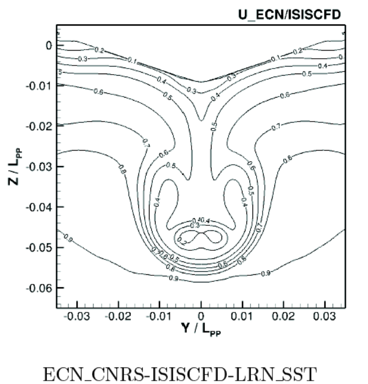


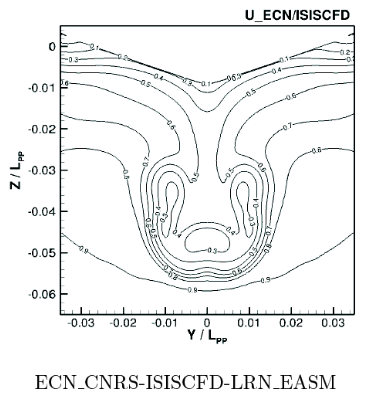
k-ω SST

EASM

Same grid, same code

Isotropic vs Anisotropic turbulence closures - Station S7



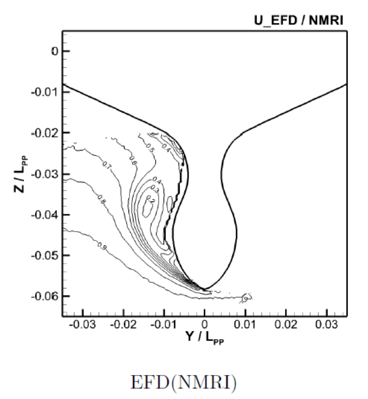


k-ω SST

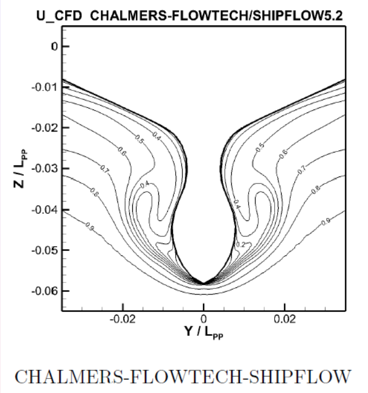
EASM

Same grid, same code

EASM Turbulence Closures - Station S2

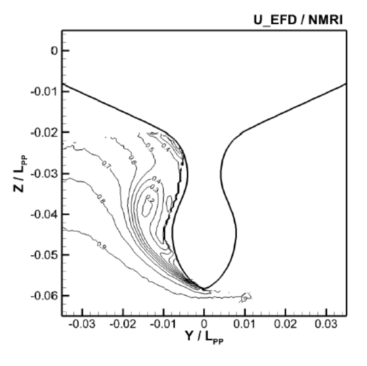


Experiments



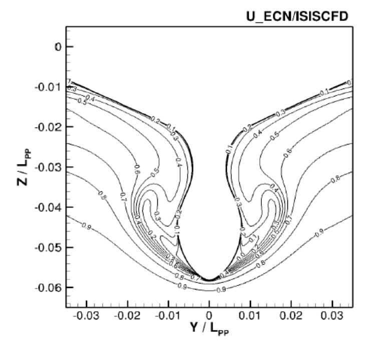
EASM CHALMERS

EASM Turbulence Closures - Station S2



EFD(NMRI)

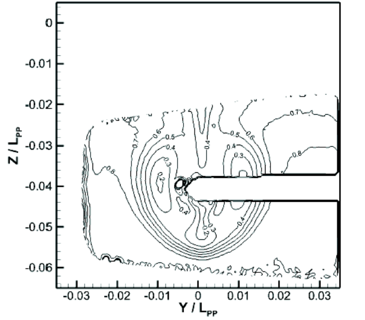
Experiments



ECN_CNRS-ISISCFD-LRN_EASM

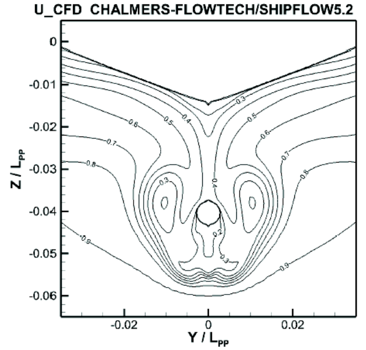
EASM ECN

EASM Turbulence Closures - Station S4



EFD(NMRI)

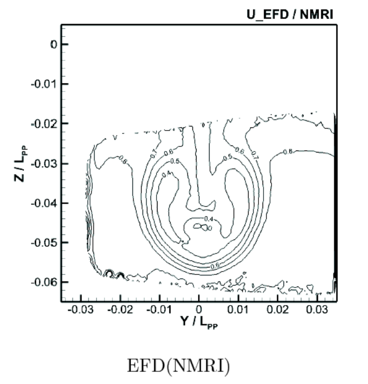
Experiments



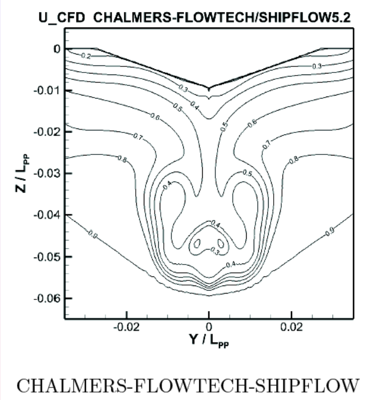
CHALMERS-FLOWTECH-SHIPFLOW

EASM CHALMERS

EASM Turbulence Closures - Station S7



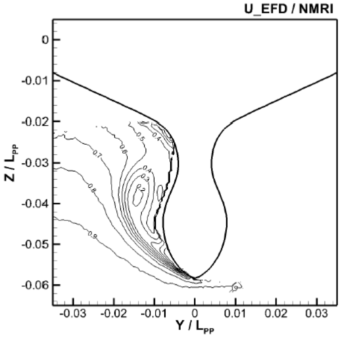
Experiments



EASM CHALMERS

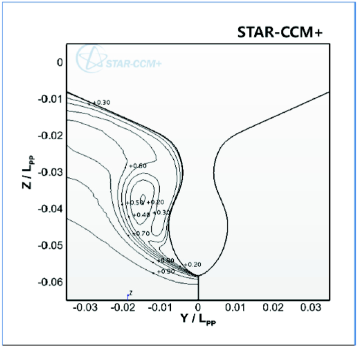
Full RSM Transport Turbulence Closures

Full RSM Transport Turbulence Closures - Station S2



EFD(NMRI)

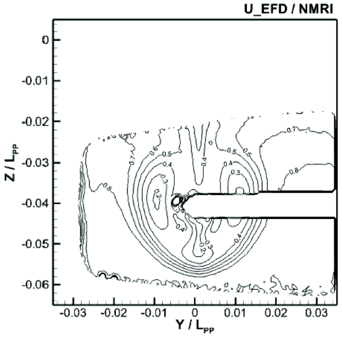
Experiments



HHI-STARCCM

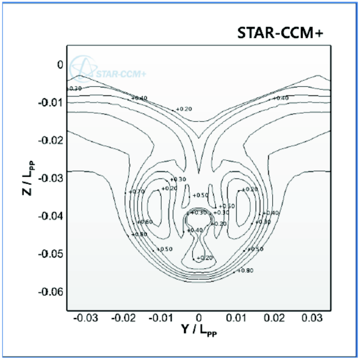
Full RSM

Full RSM Transport Turbulence Closures - Station S4



EFD(NMRI)

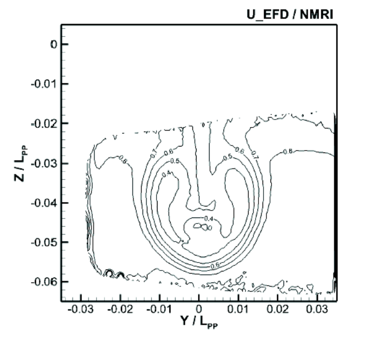
Experiments



HHI-STARCCM

Full RSM

Full RSM Transport Turbulence Closures - Station S7



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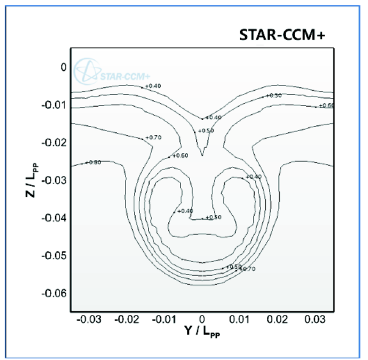


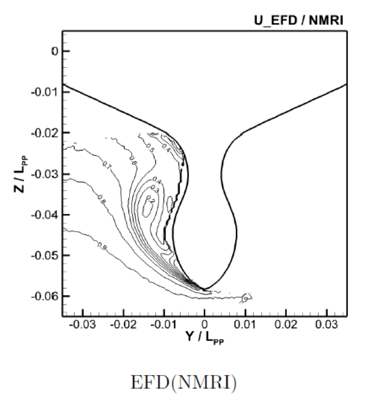
HHI-STARCCM

Experiments

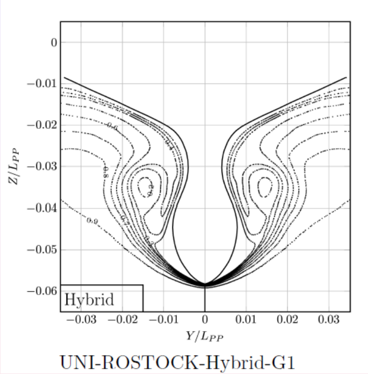
Full RSM

Hybrid LES Turbulence Closures

Hybrid LES Turbulence Closures - Station S2

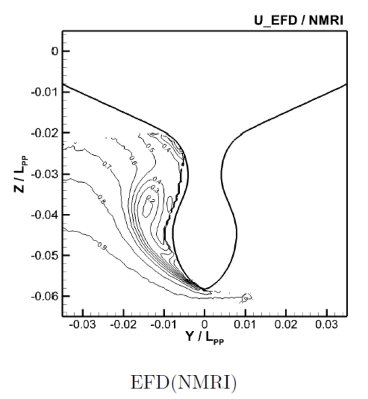


Experiments

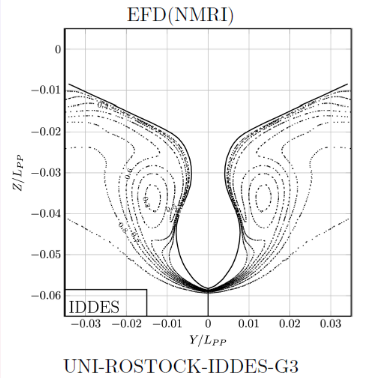


Hybrid LES

Hybrid LES Turbulence Closures - Station S2

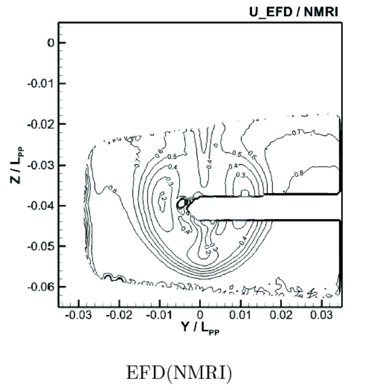


Experiments

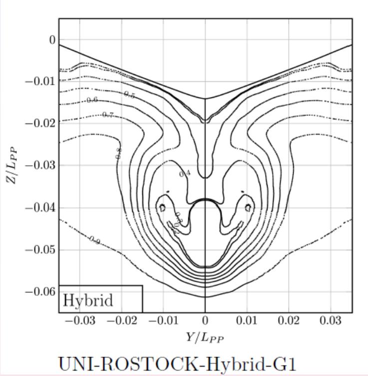


IDDES

Hybrid LES Turbulence Closures - Station S4

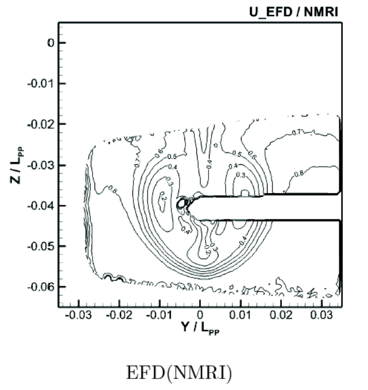


Experiments

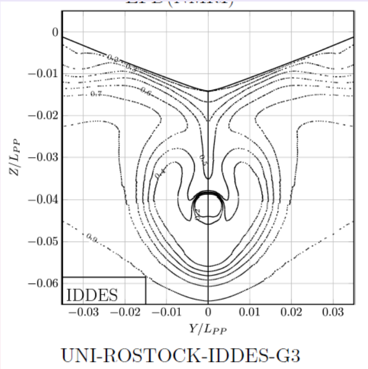


Hybrid LES

Hybrid LES Turbulence Closures - Station S4

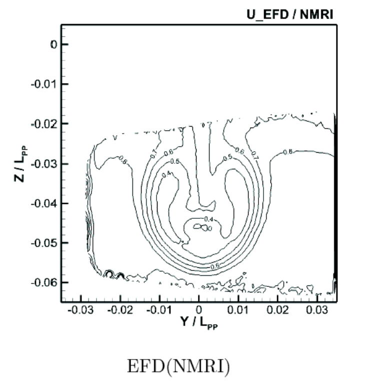


Experiments

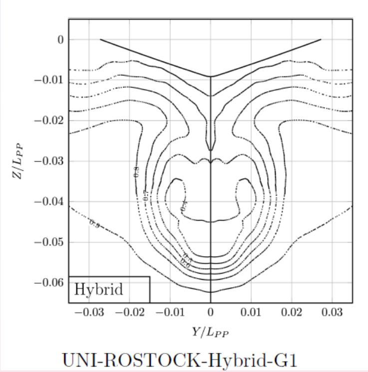


IDDES

Hybrid LES Turbulence Closures - Station S7

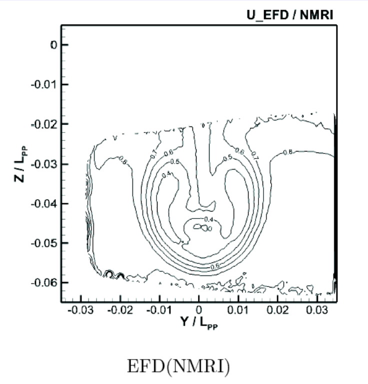


Experiments

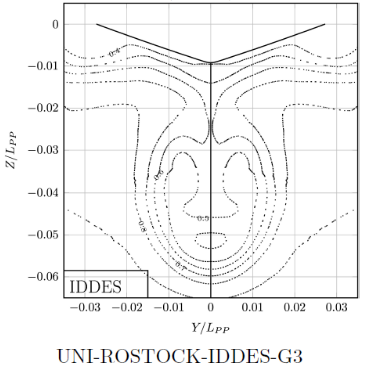


Hybrid LES

Hybrid LES Turbulence Closures - Station S7



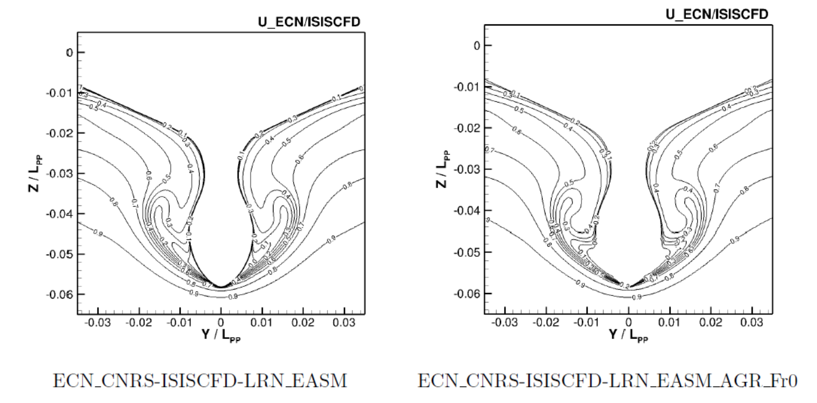
Experiments



IDDES

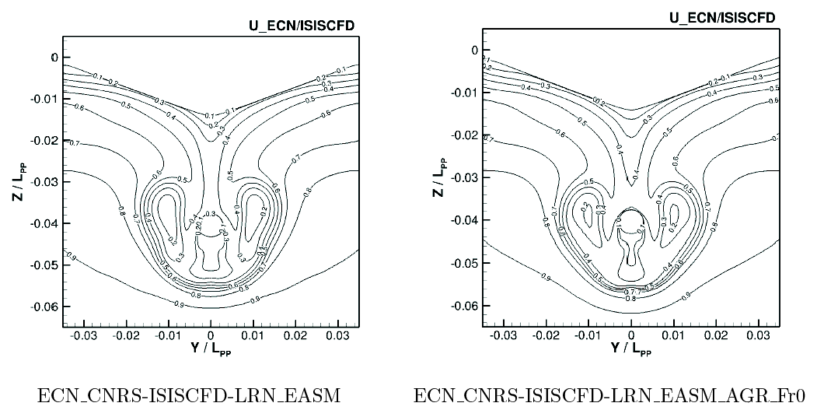
Influence of the free-surface

Influence of the free-surface - Station S2

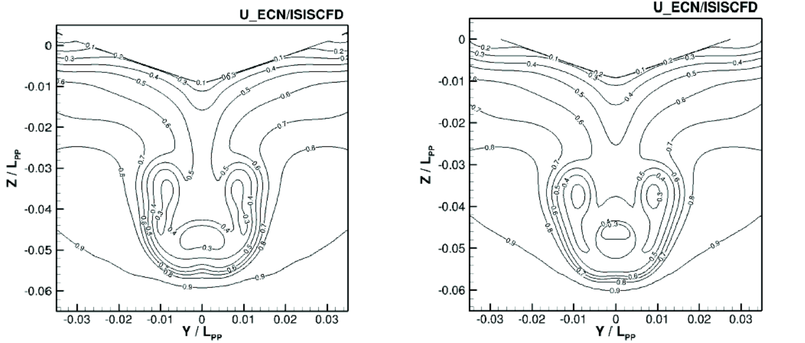


Fr=0.142 Fr=0.0

Influence of the free-surface - Station S4



Fr=0.142 Fr=0.0

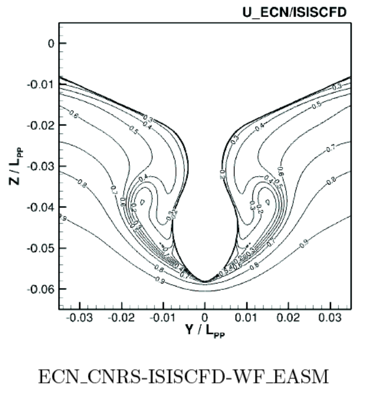


ECN_CNRS-ISISCFD-LRN_EASM   ECN_CNRS-ISISCFD-LRN_EASM_AGR_Fr0

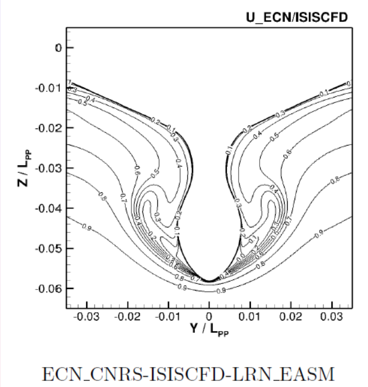
Fr=0.142   Fr=0.0

Influence of the wall boundary condition

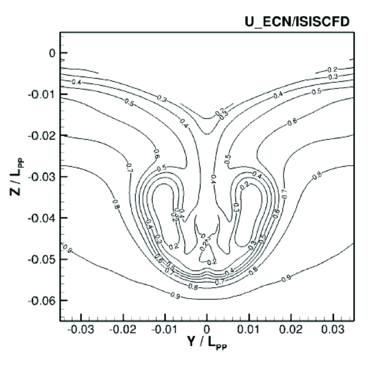
Influence of the wall boundary condition - Station S2



Wall modeled

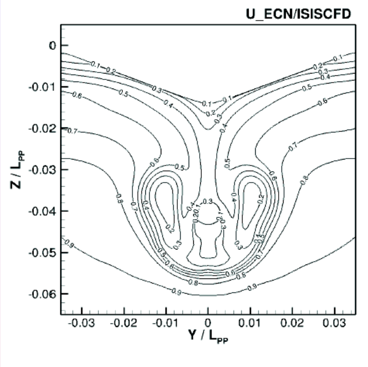


Wall resolved



ECN_CNRS-ISISCFD-WF_EASM

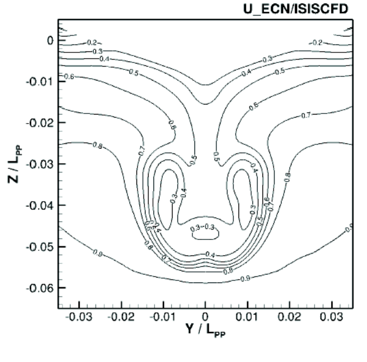
Wall modeled



ECN_CNRS-ISISCFD-LRN_EASM

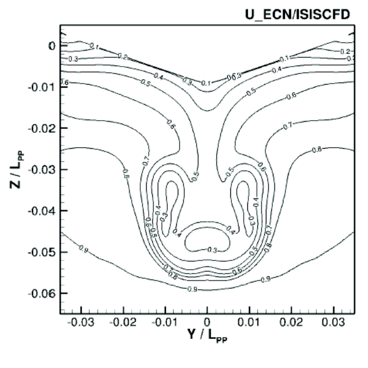
Wall resolved

Influence of the wall boundary condition - Station S7



ECN_CNRS-ISISCFD-WF_EASM

Wall modeled

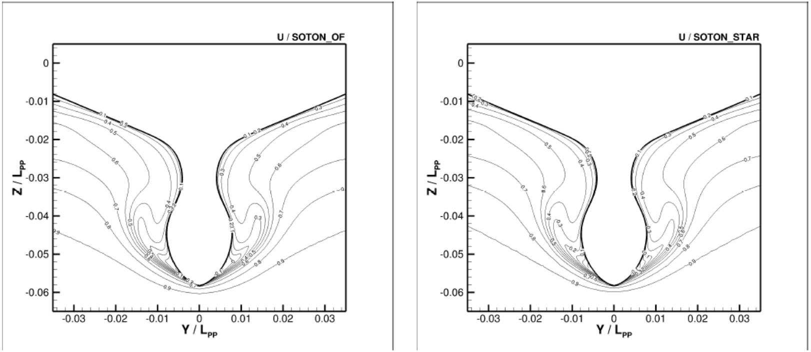


ECN_CNRS-ISISCFD-LRN_EASM

Wall resolved

Codes comparison

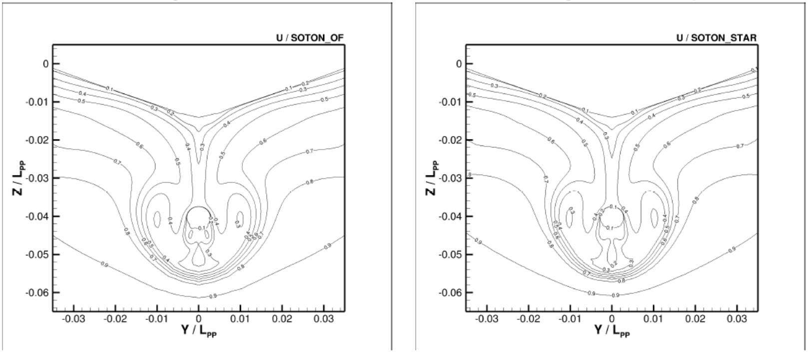
Code comparison - Station S2



SOTON-OF SOTON-STAR

Same grid, same turbulence model

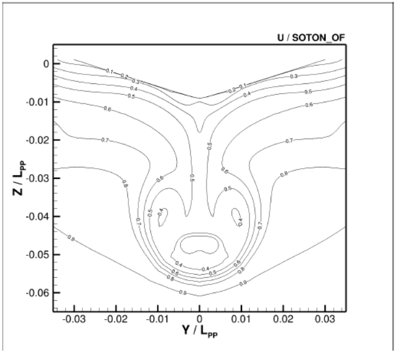
Code comparison - Station S4



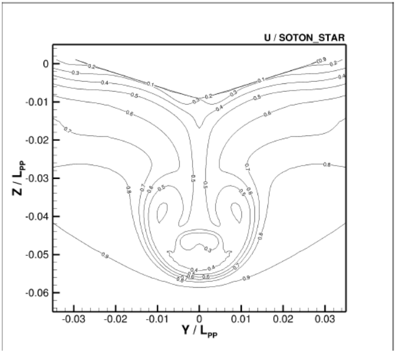
SOTON-OF SOTON-STAR

Same grid, same turbulence model

Code comparison - Station S7



SOTON-OF



SOTON-STAR

Same grid, same turbulence model

Case 1-3a - Temporary conclusions 1/2

- With the typical grids used (5-10 M points), the influence from the grid discretisation is moderate for RANSE,
- The major influence comes from the turbulence closure. Linear isotropic closures under-predict the longitudinal vorticity at S2 while full RSM closures slightly over-predict it at the same station.
- Non-linear anisotropic closures offer a good compromise from the standpoint of the local flow although they slightly underpredict the vorticity at S2.
- New results from hybrid LES are promising but IDDES seems to over-predict the vorticity again (need to check TKE in the bilge vortex).

Case 1-3a - Temporary conclusions 2/2

- Codes seem to be mature since we do not observe large discrepancies when same turbulence closures on similar grids are used.
- The infuence of the free-surface on the local flow is not negligible.
- The infuence of the wall boundary condition on the local flow is weak.

JBC - Case 1-3a
Local vortex flow analysis

Objectives of this local analysis

- Previously, the local flow analysis was uniquely based on the inspection of the flow characteristics at specific cross-sections where experiments were available.
- This typical assessment provides a global picture of the flow for each experimental cross-section. This interpretation can be misleading since it is based on visual inspection.
- Here, we would like to enrich this cross-section based evaluation by a more detailed and local vortex flow analysis in order to draw more elaborate conclusions about the generation and evolution of the longitudinal vortices.

Procedure and instructions

- Longitudinal evolution of characteristic flow data in the core of the main vortex (by drawing a streamline through the center of the vortex at station S4),
- Y and Z transversal evolutions of characteristic flow data across the vortex center at stations S2, S4 and S7.

Difficulties and perils of the exercise

The longitudinal and transversal evolutions in the vortex core

- It was first decided to use the same information in computations and experiments to locate the vortex center,
- Since we have no volumic information from the measurements (no tomographic PIV), we were forced to use the local max(ω_x) to locate the vortex center in each section instead of max(Q),
- The procedure is more or less OK for stations S4 an S7 where the main vortex is roughly aligned with X but it is less justified for station S2 where (for some computations), the vortex is not aligned with X.
- Therefore, additional figures were produced based on max(Q) instead of max(ω_x) to locate the center of the vortex at station S2.

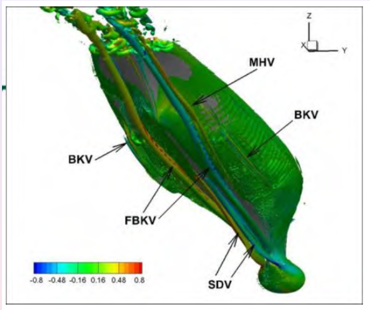
JBC - Case 1-3a

Local vortex flow analysis

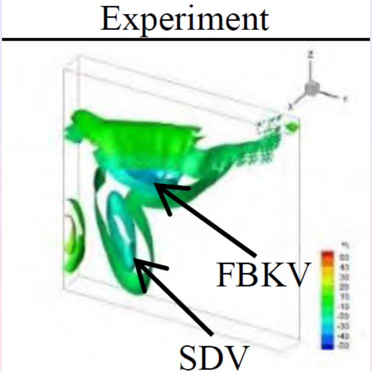
Genesis from NATO-AVT183

DTMB5415 at straight ahead condition

NATO AVT183 - DTMB5415 at straight ahead condition

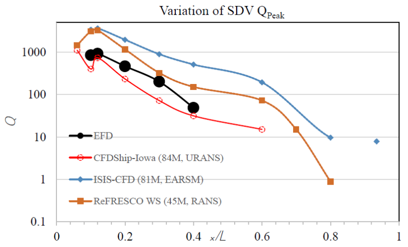


3D view
(SDV and FBKV vortices)

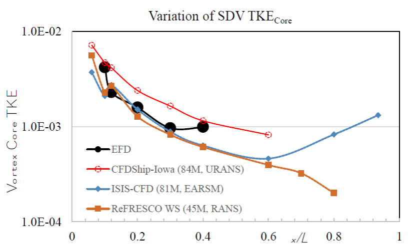


IIHR 3D experiments (ω_x)
behind the sonar dome

DTMB 5415 - SDV core longitudinal evolution

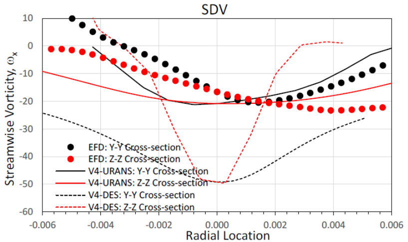


Invariant Q

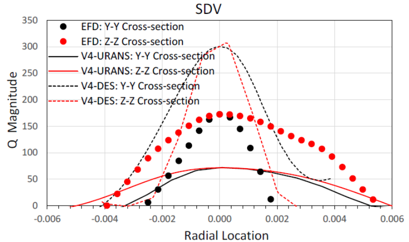


TKE

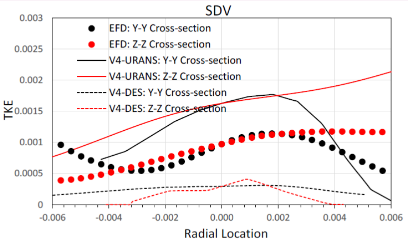
DTMB 5415 - SDV radial evolution



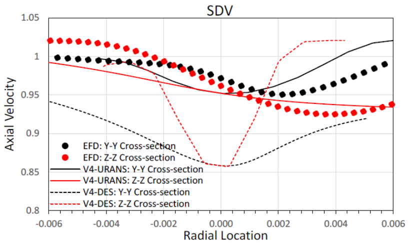
ω_x



Invariant Q



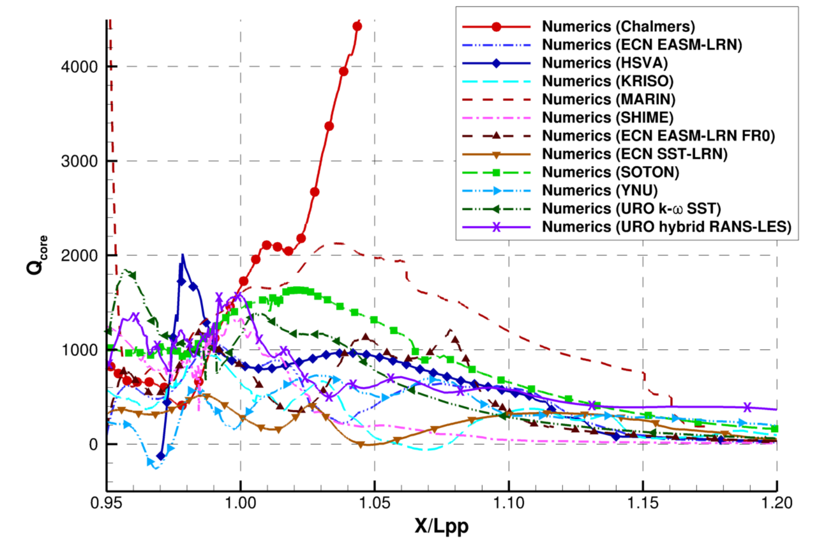
TKE



U

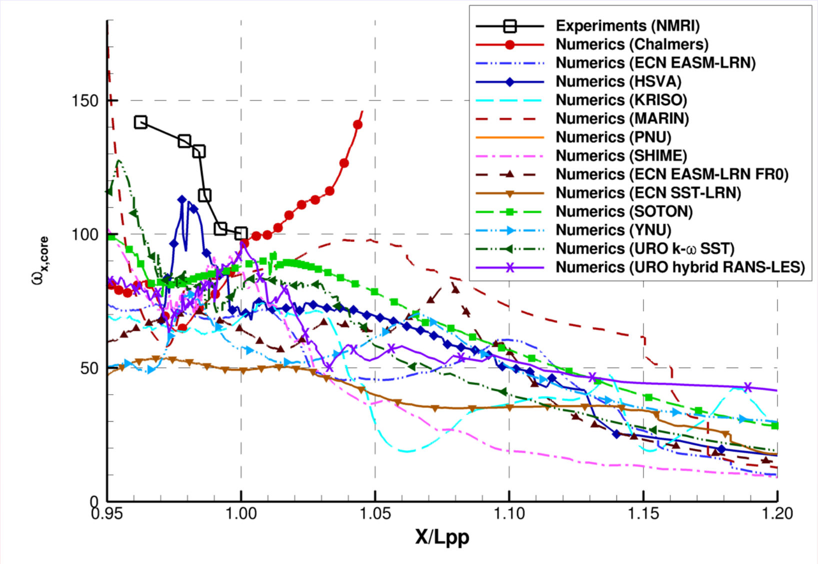
JBC - Case 1-3a
Local vortex flow analysis
Longitudinal evolution

Longitudinal evolution in the core of the main vortex



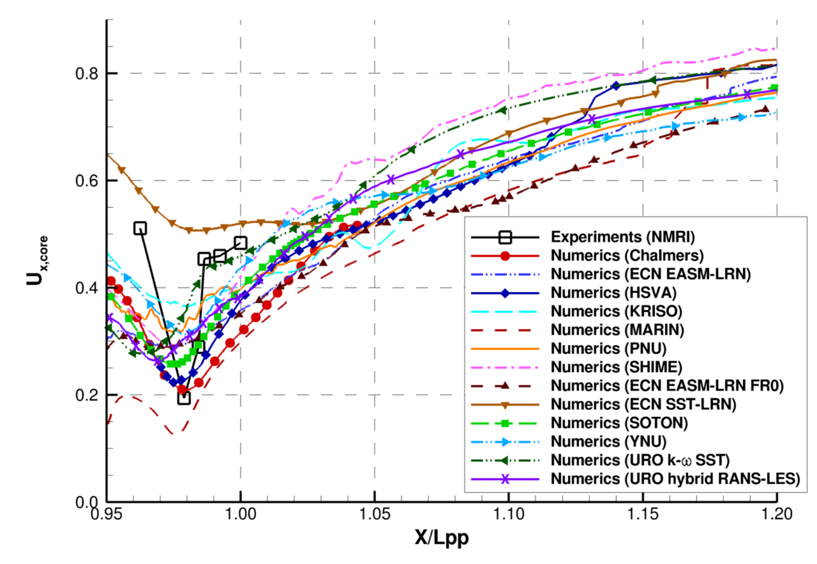
Invariant Q

Longitudinal evolution in the core of the main vortex



ω_x

Longitudinal evolution in the core of the main vortex



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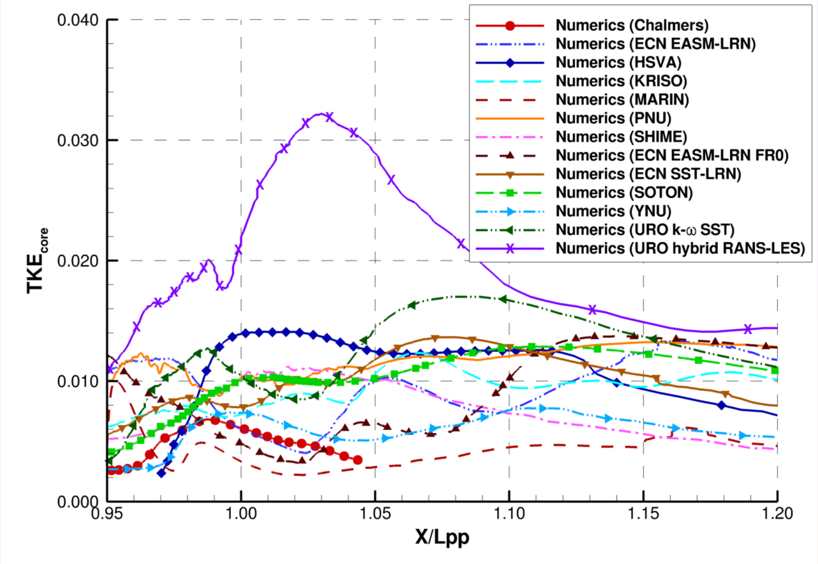
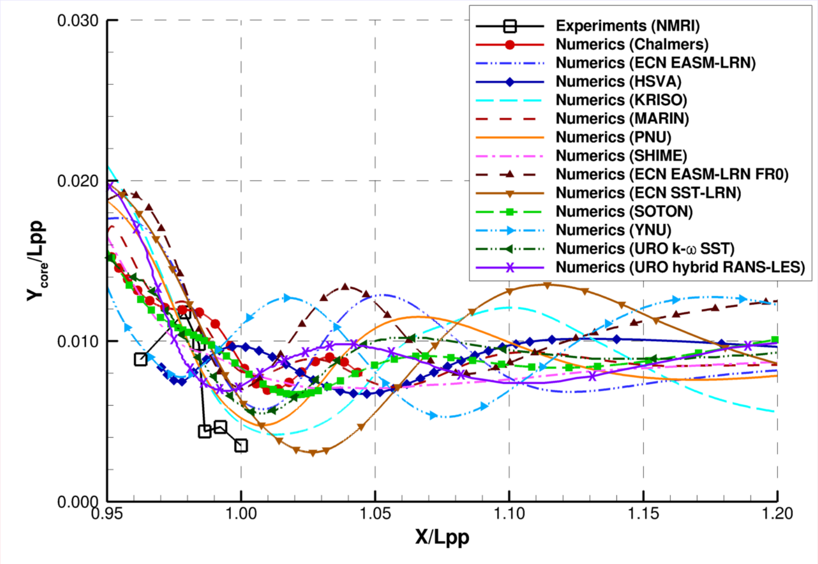
Longitudinal evolution in the core of the main vortex



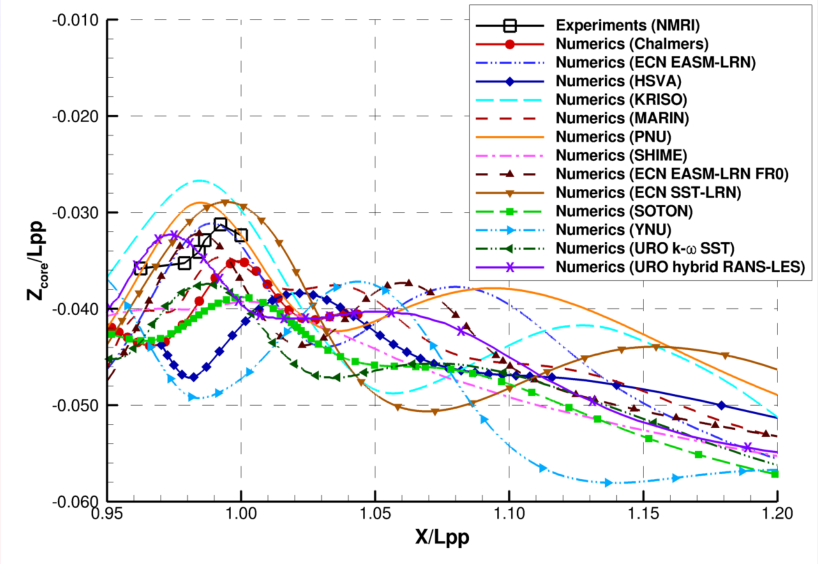
TKE

Longitudinal evolution in the core of the main vortex



Coordinate Y

Longitudinal evolution in the core of the main vortex



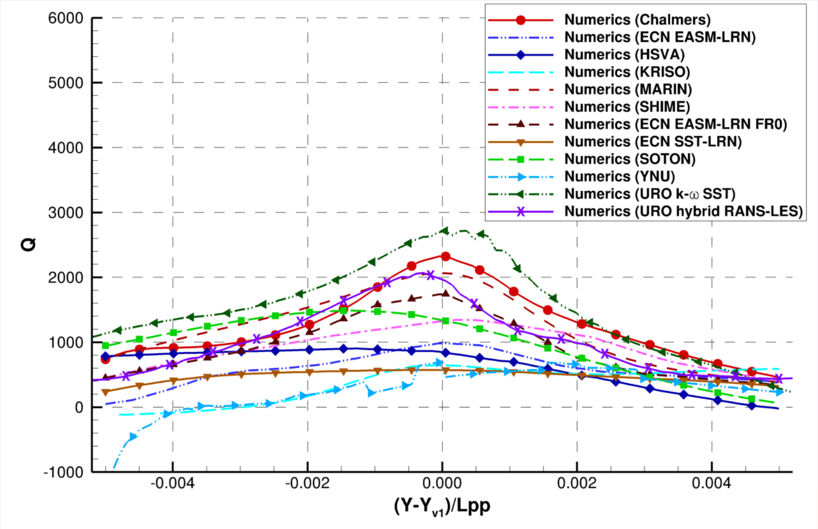
Coordinate Z

JBC - Case 1-3a

Local vortex flow analysis

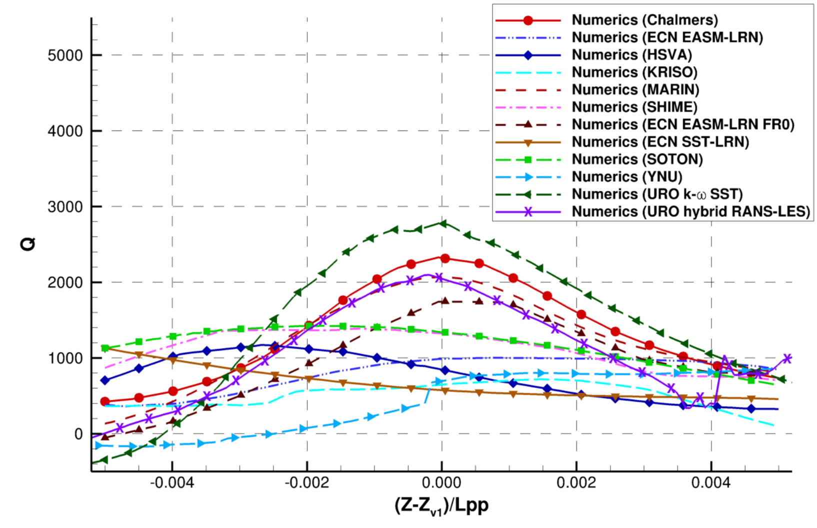
Transversal evolution

Transversal evolution along y at station S7



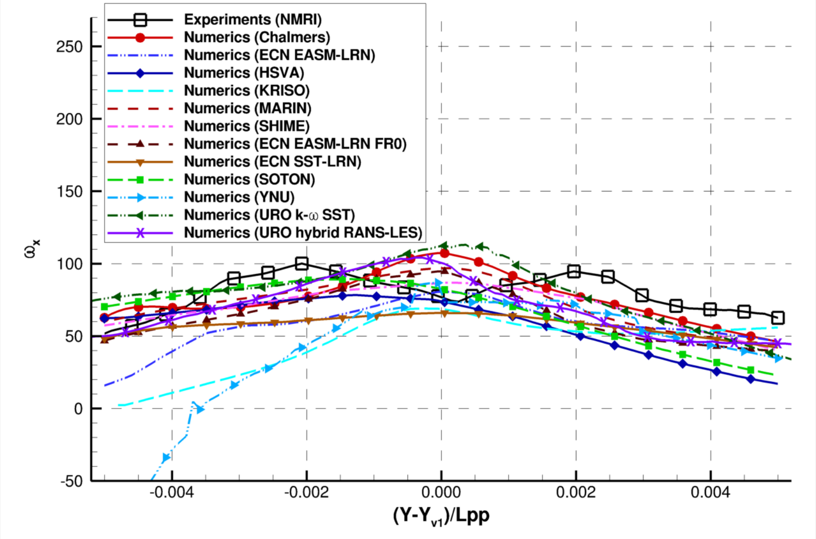
Invariant Q

Transversal evolution along z at station S7



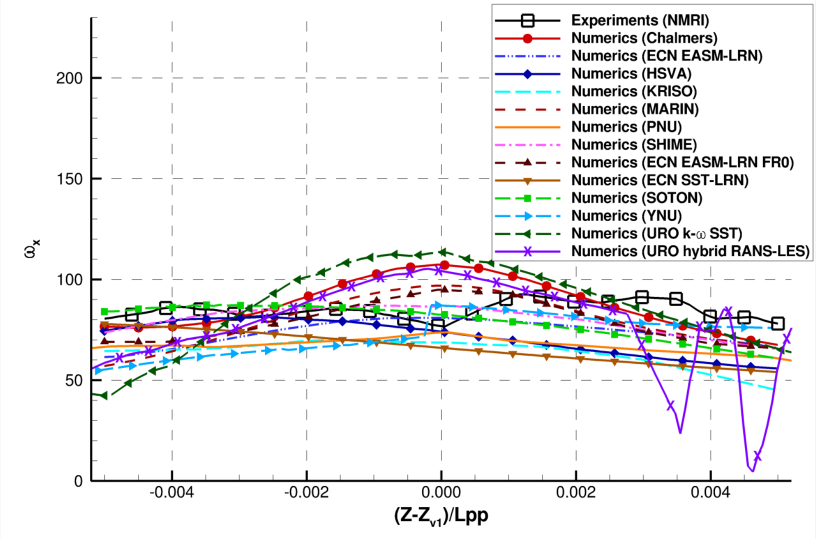
Invariant Q

Transversal evolution along y at station S7



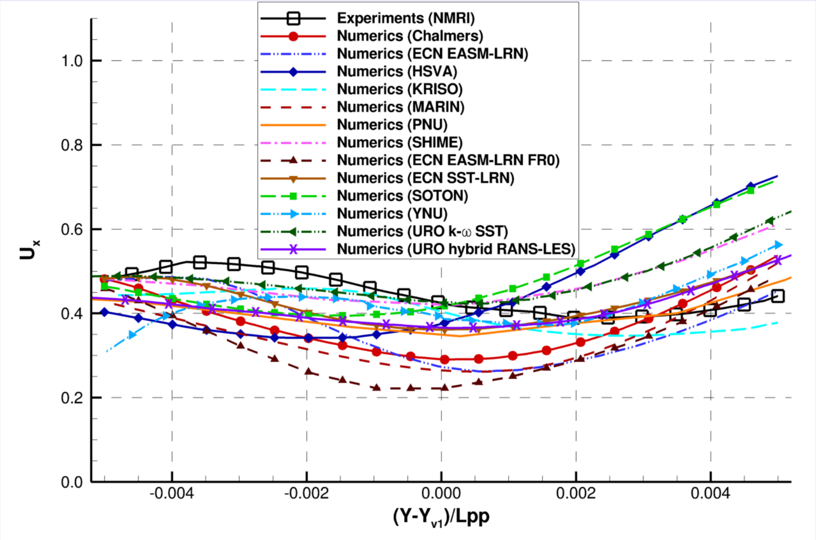
ω_x

Transversal evolution along z at station S7



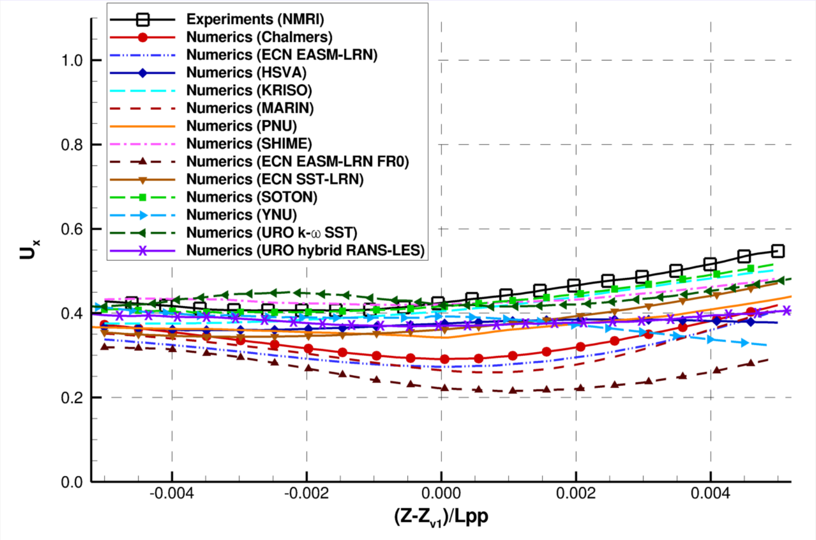
ω_x

Transversal evolution along y at station S7



U

Transversal evolution along z at station S7



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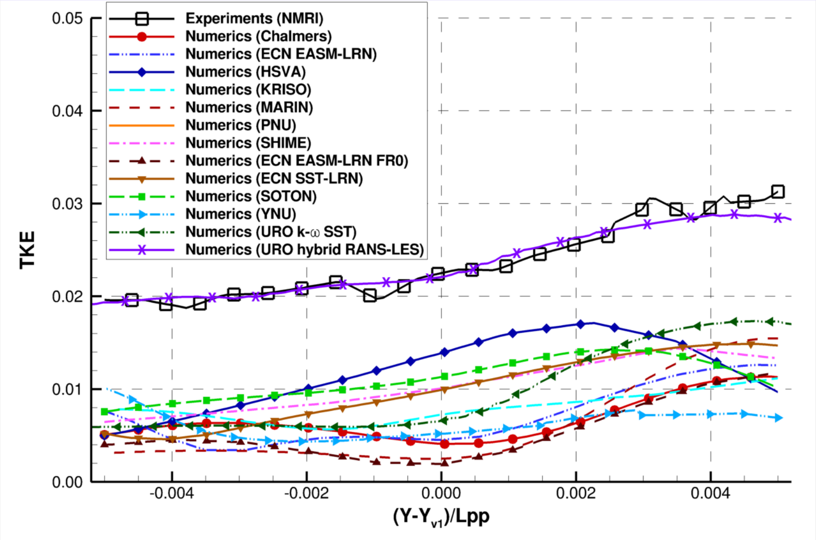
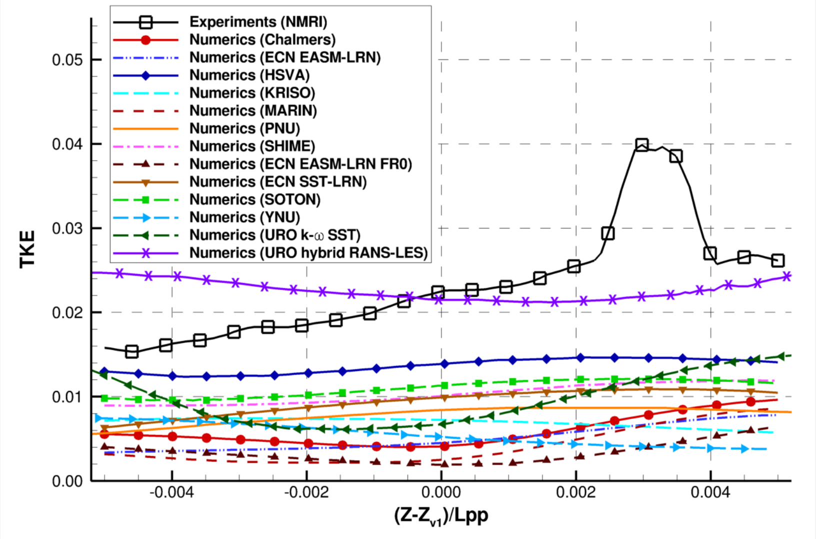
Transversal evolution along y at station S7



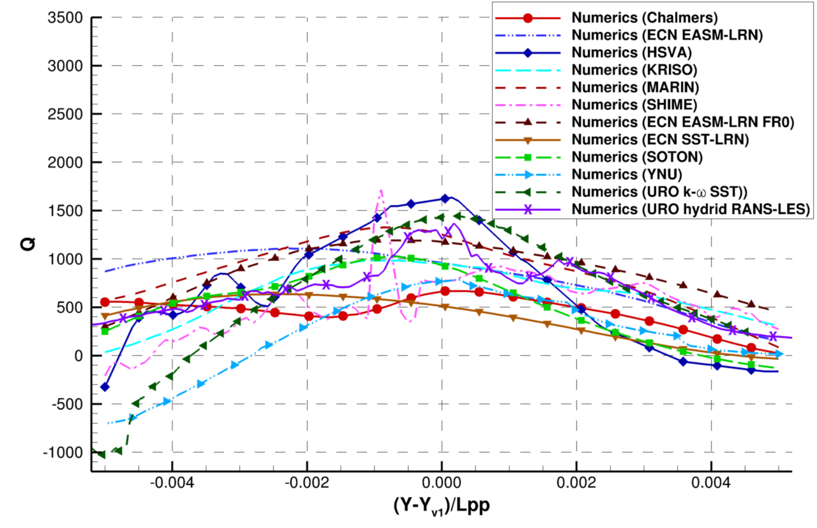
TKE

Transversal evolution along z at station S7



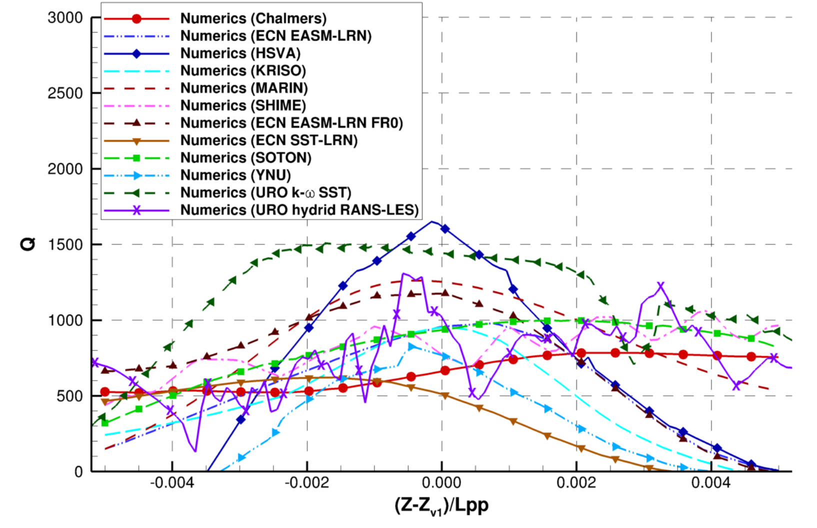
TKE

Transversal evolution along y at station S4



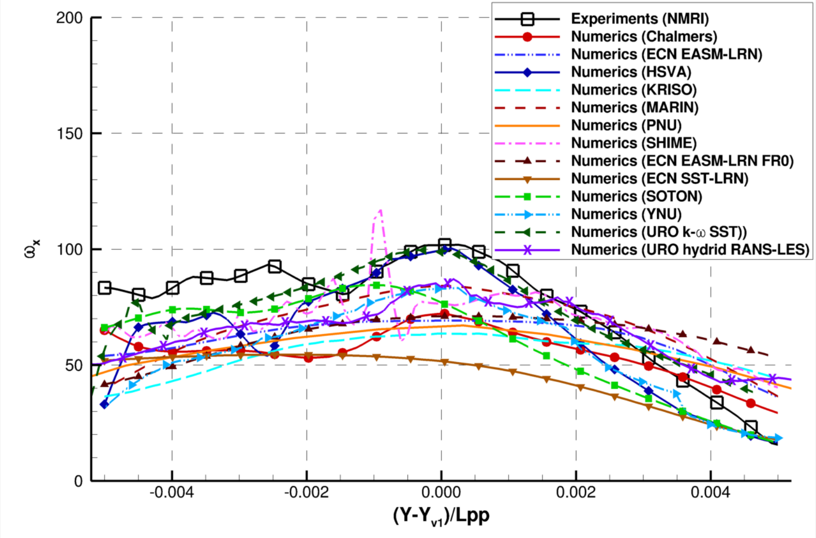
Invariant Q

Transversal evolution along z at station S4



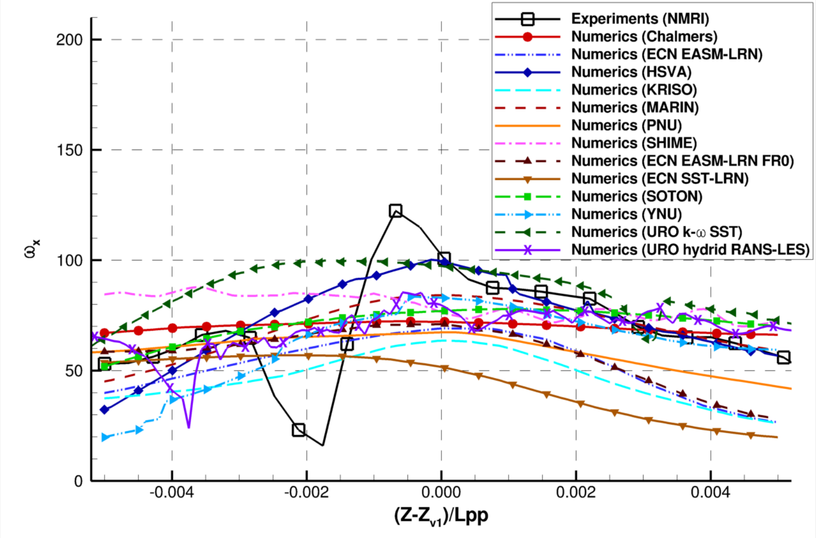
Invariant Q

Transversal evolution along y at station S4



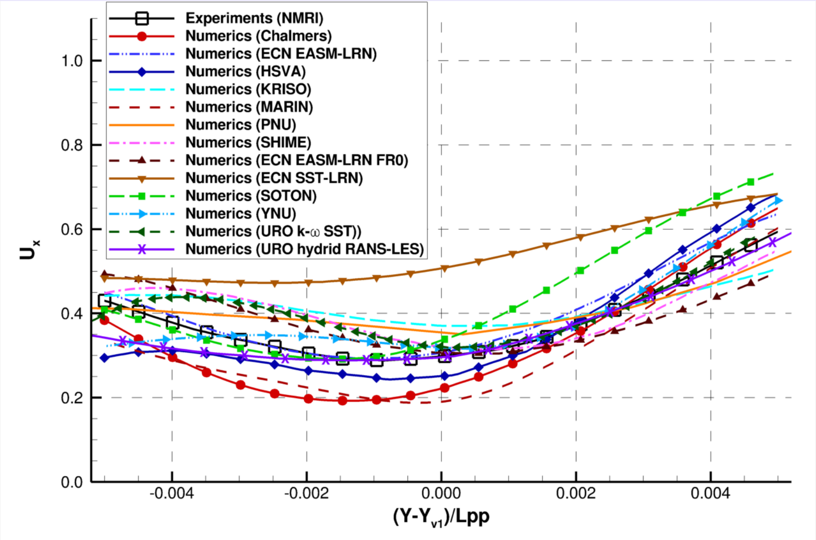
ω_x

Transversal evolution along z at station S4



ω_x

Transversal evolution along y at station S4



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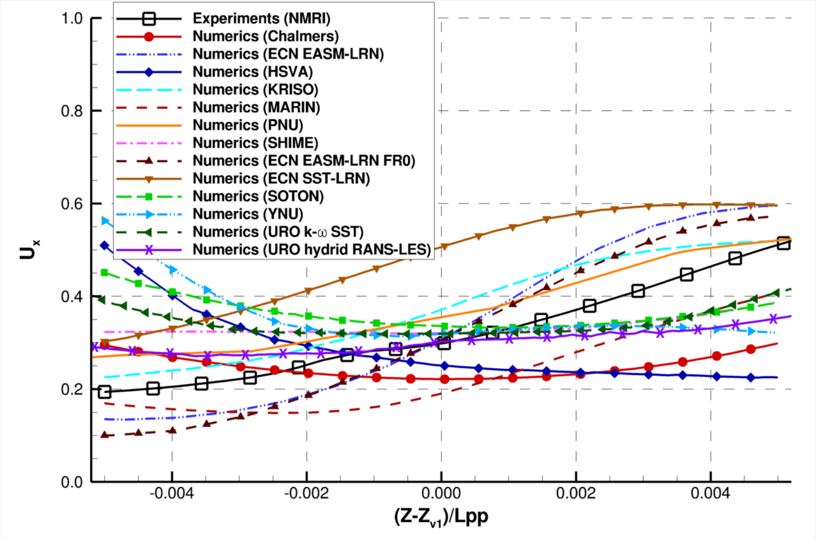
Transversal evolution along z at station S4



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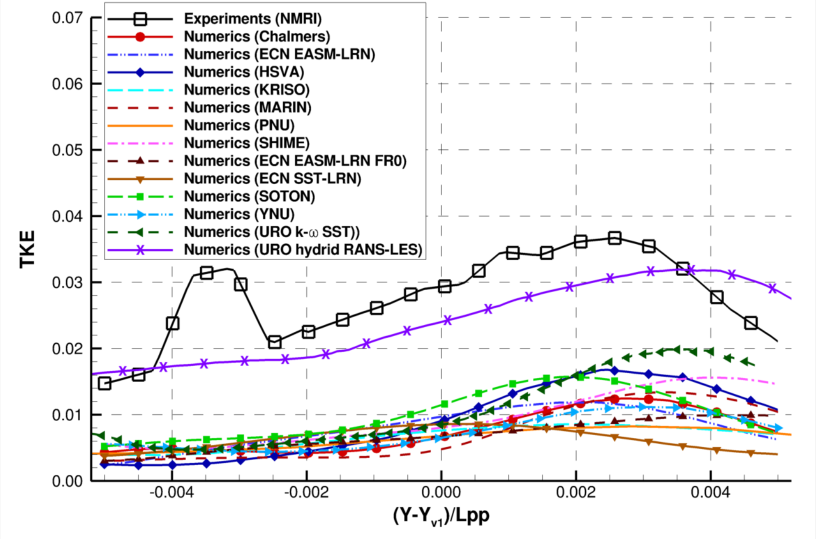
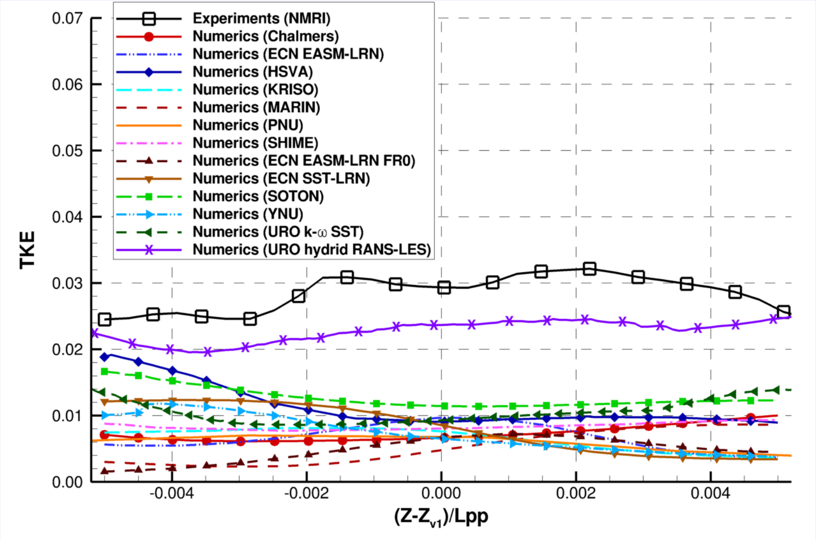
Transversal evolution along y at station S4



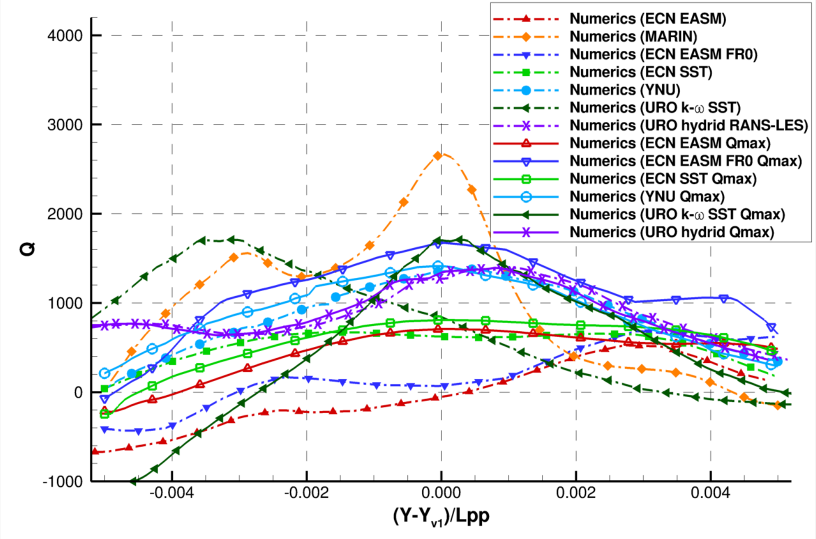
TKE

Transversal evolution along z at station S4



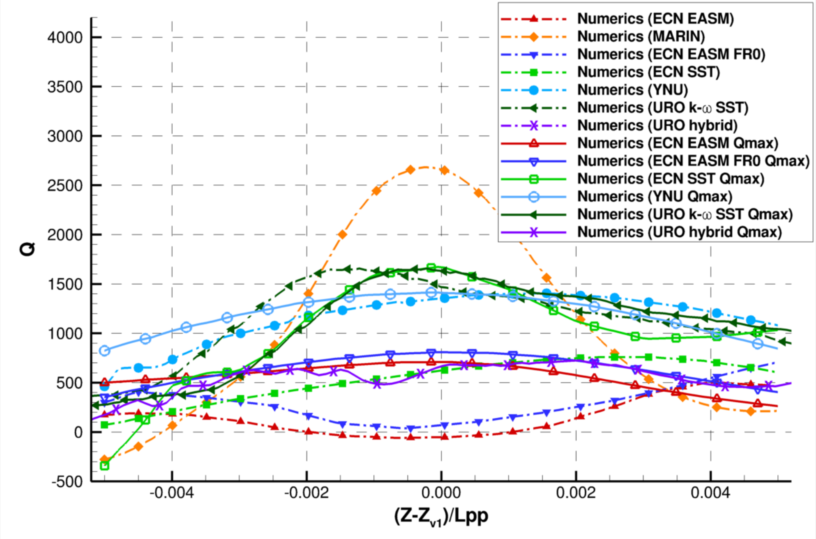
TKE

Transversal evolution along y at station S2



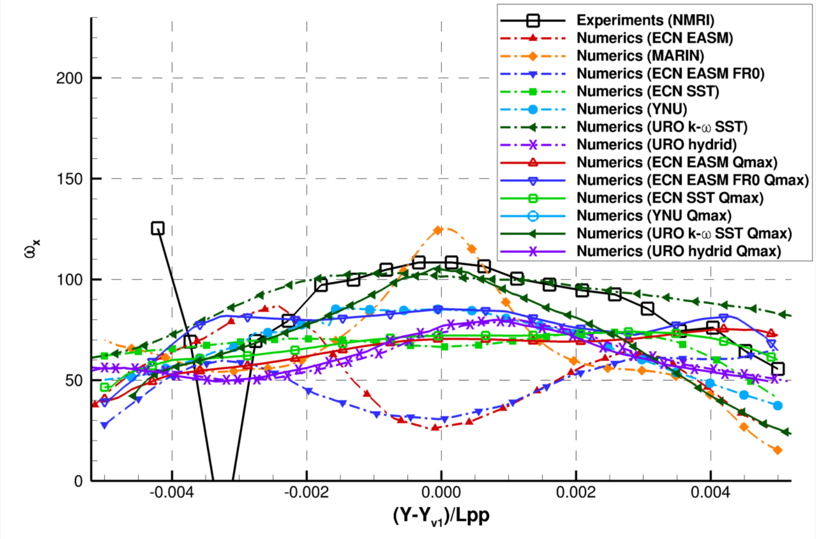
Invariant Q

Transversal evolution along z at station S2



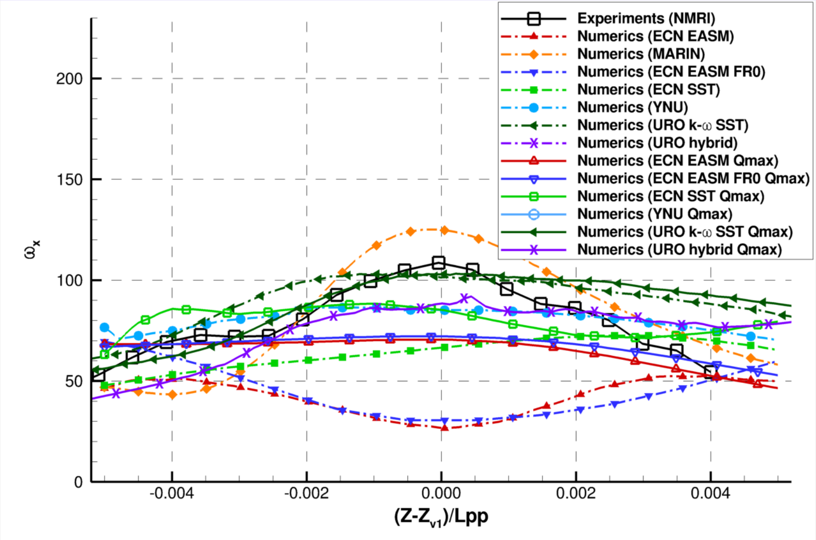
Invariant Q

Transversal evolution along y at station S2



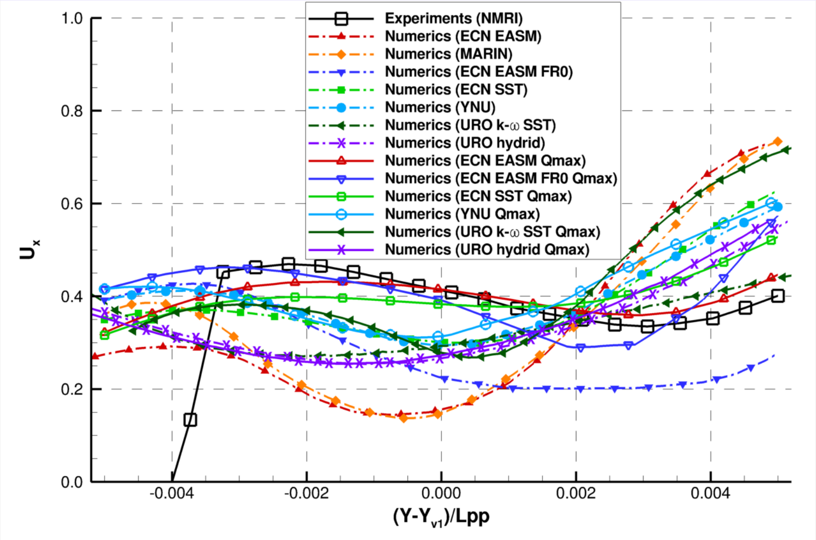
ω_x

Transversal evolution along z at station S2



ω_x

Transversal evolution along y at station S2



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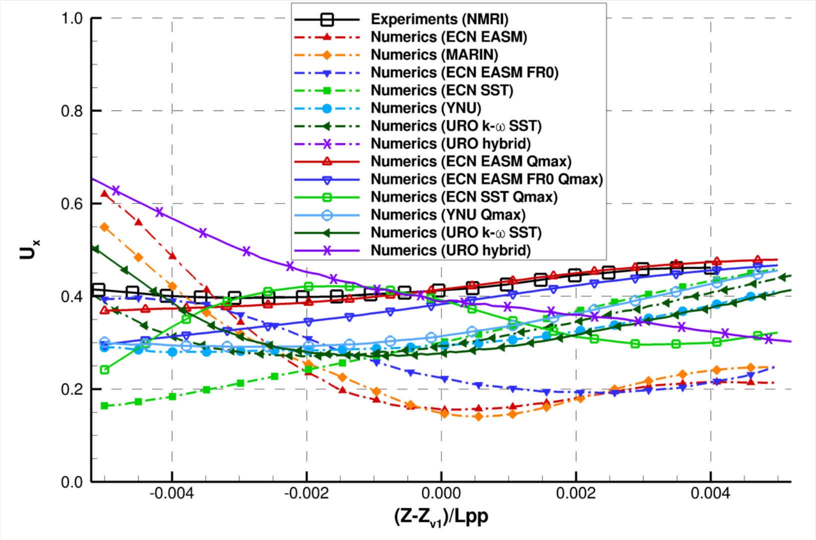
Transversal evolution along z at station S2



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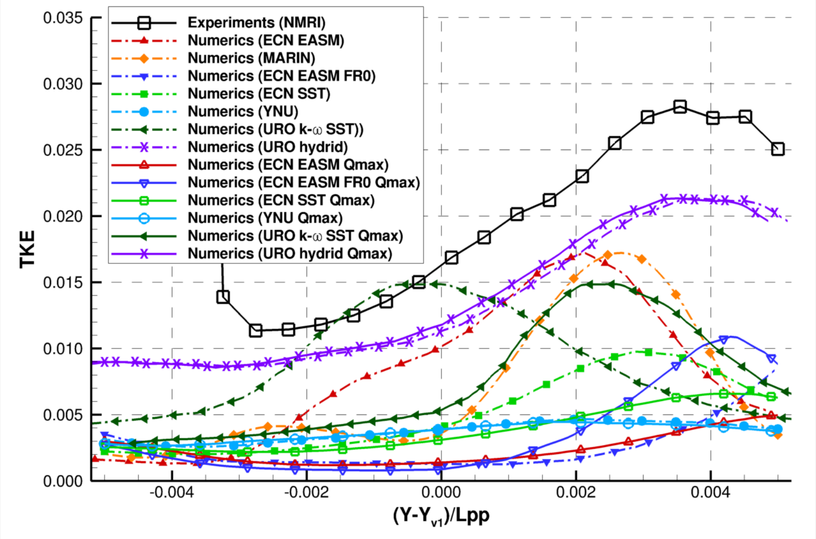
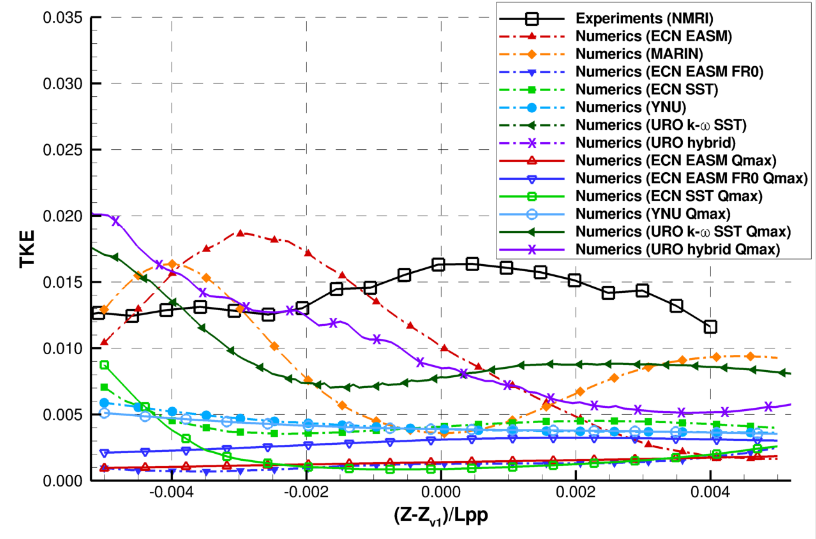
Transversal evolution along y at station S2



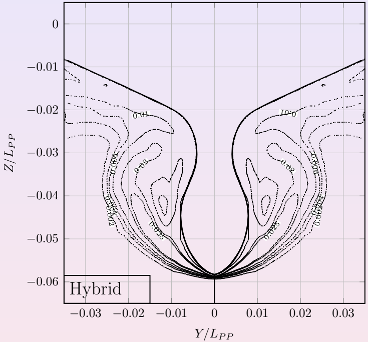
TKE

Transversal evolution along z at station S2

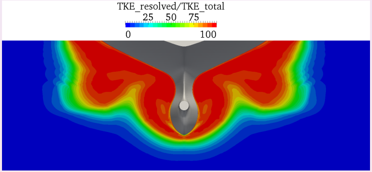


TKE

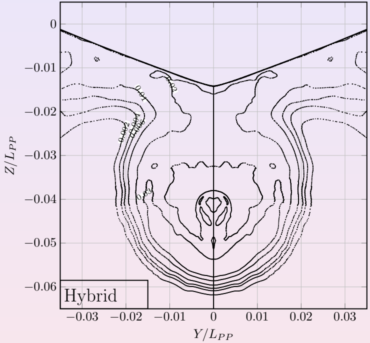
TKE distribution at station S2 (Hybrid LES from URO)



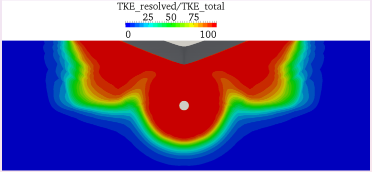
Total TKE



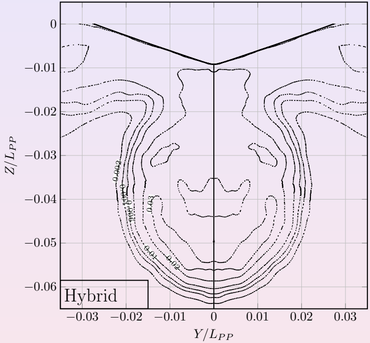
Resolved TKE



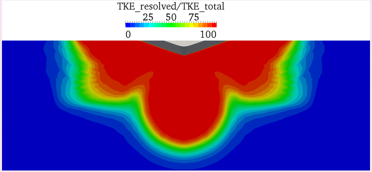
Total TKE



Resolved TKE



Total TKE



Resolved TKE

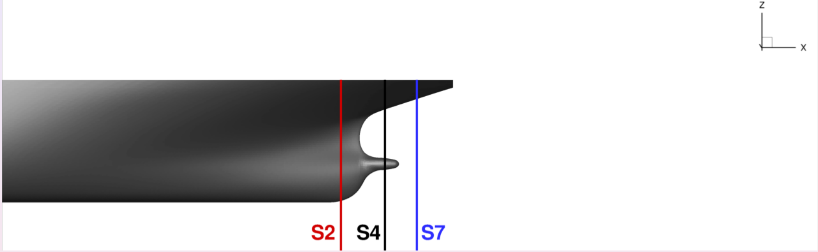
Temporary conclusions 1/2

- Relative dispersion of the computations,
- Lack of grid points to assess the flow characterisitics in the core,
- Lack of experimental points to trust the measurements,
- Few expected transverse evolutions of quantities like Q or ω_x,
- Influence of the turbulence closures reinforced by this local analysis,
- To be continued with locally refined experimental and computational grids,
- Important to use 3D tomographic PIV to trust this analysis, whatever the vortex evolution.

Temporary conclusions 2/2

- Non-linear anisotropic closures increase the maximum vorticity (and Q) in the core,
- Hybrid LES closure from URO is the only one able to predict the right level of TKE,
- In this case, the major part of TKE comes from the computed contribution.

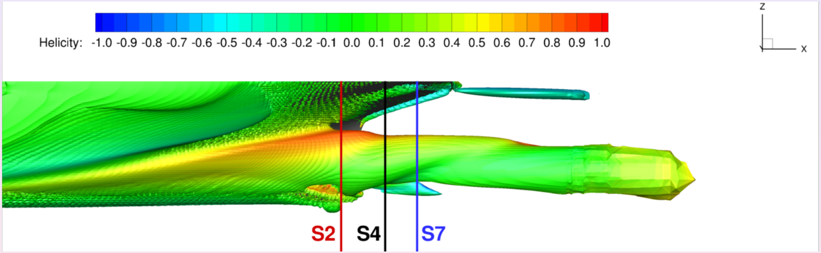
JBC - Case 1-3b



Re=2.74 10^6, Fr=0.

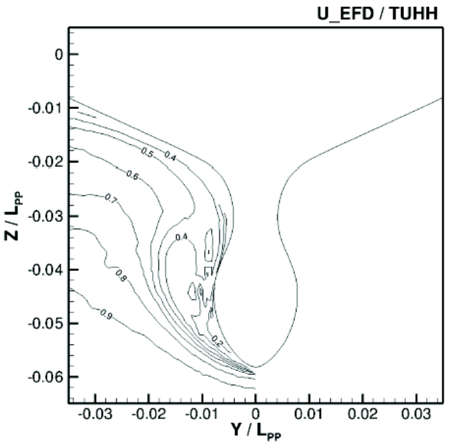
Experiments from TUHH

JBC - Case 1-3b



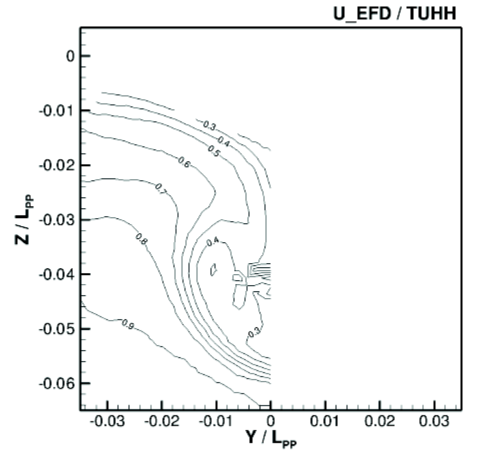
Re=2.74 10^6, Fr=0.

Iso-U contours - Station S2



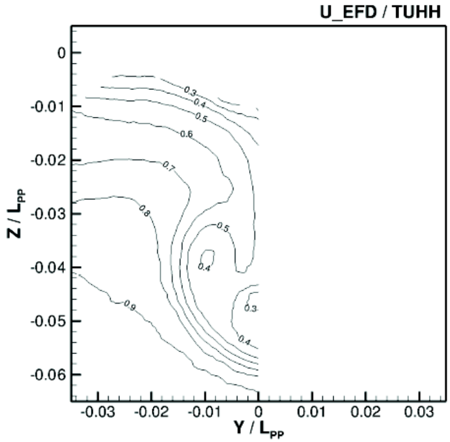
EFD(TUHH)

Iso-U contours - Station S4



EFD(TUHH)

Iso-U contours - Station S7



EFD(TUHH)

Main characteristics of the computations - Case1-3b

Grids can be classified into 3 groups for 3 participants:

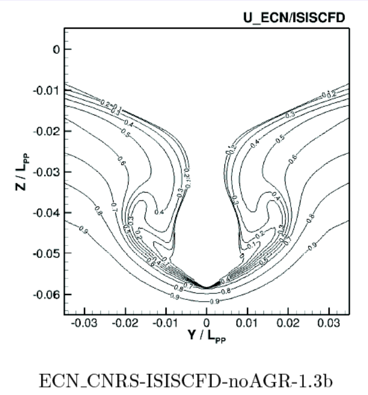
- Not So Fine: Ncell < 2 M cells (None)
- Fine: 2 M cells < Ncell < 10 M cells (ECN without AGR)
- Very Fine: 10 M cells < Ncell < 50 M cells (ECN with AGR)
- Tremendously Fine: Ncell > 50 M cells (FOI (150M cells), SRC (4.9G cells !!!))

Comparison with Gothenburg 2010 (average size was 4M cells)

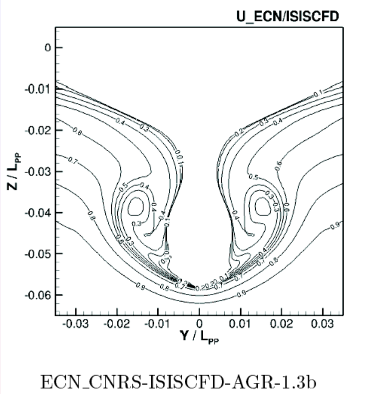
Just a global picture: one does not have access to the local grid density !

Grid influence

Grid influence - Station S2



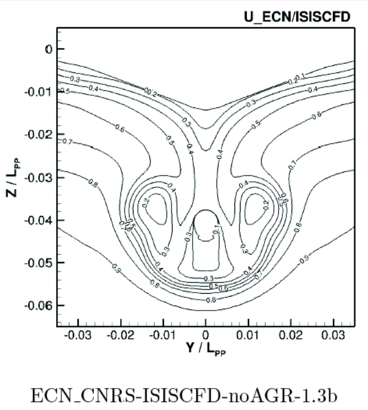
Without AGR



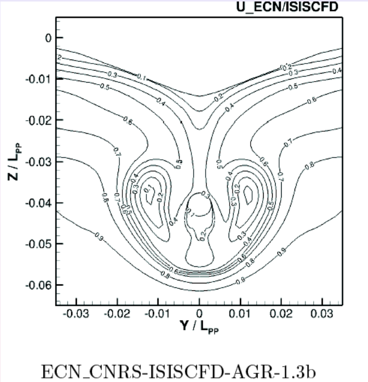
With AGR

Automatic Grid Refinement (AGR) is controled by the Hessian of the velocity flux

Grid influence - Station S4



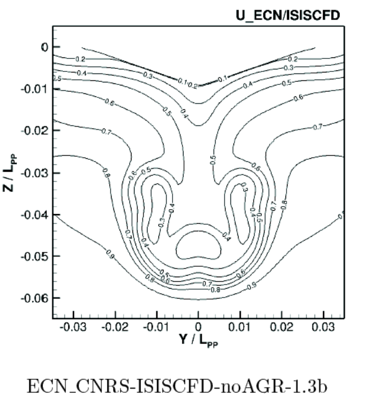
Without AGR



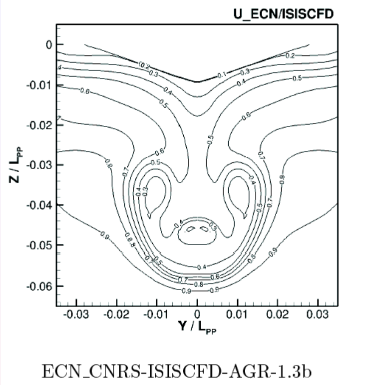
With AGR

Automatic Grid Refinement (AGR) is controled by the Hessian of the velocity flux

Grid influence - Station S7



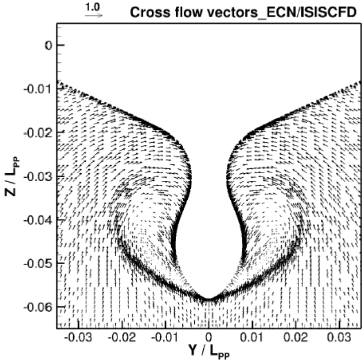
Without AGR



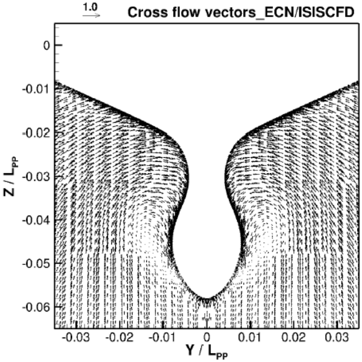
With AGR

Automatic Grid Refinement (AGR) is controled by the Hessian of the velocity flux

Grid influence - Station S2



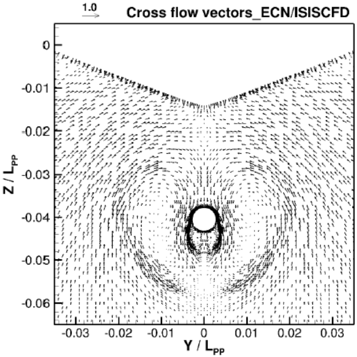
ECN_CNRS-ISISCFD-AGR-1.3b



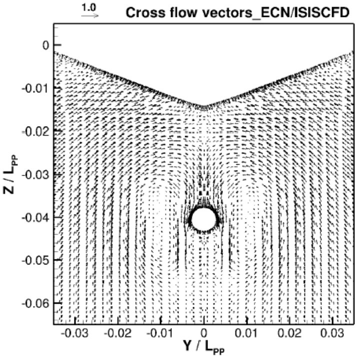
ECN_CNRS-ISISCFD-noAGR-1.3b

Points are added in the regions of high shear stress

Grid influence - Station S4



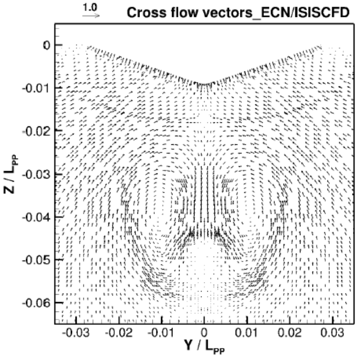
ECN_CNRS-ISISCFD-AGR-1.3b



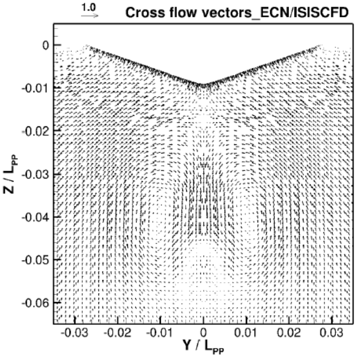
ECN_CNRS-ISISCFD-noAGR-1.3b

Points are added in the regions of high shear stress

Grid influence - Station S7



ECN_CNRS-ISISCFD-AGR-1.3b



ECN_CNRS-ISISCFD-noAGR-1.3b

Points are added in the regions of high shear stress

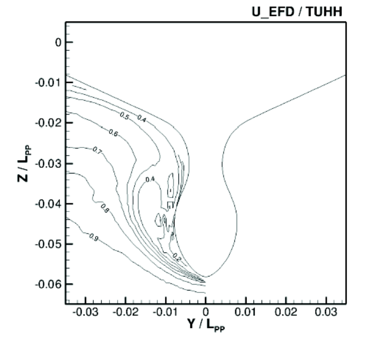
Main characteristics of the computations

Turbulence models can be organized into three groups:

- The isotropic linear closures: FOI (k-ω SST),
- The anisotropic non-linear models: ECN-CNRS (EASM),
- The LES models: FOI (NWM-LES), SRC (LES).

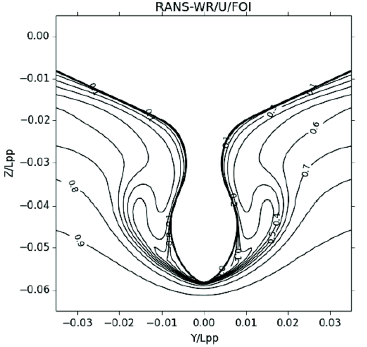
Linear Isotropic Turbulence Closures

Linear Isotropic Turbulence Closures - Station S2



EFD(TUHH)

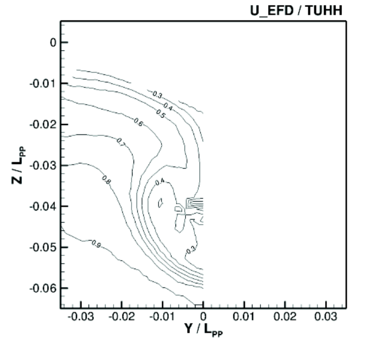
Experiments



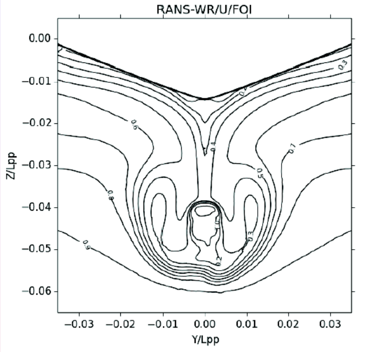
FOI-RANSWR-1.3b

k-ω SST

Linear Isotropic Turbulence Closures - Station S4



EFD(TUHH)

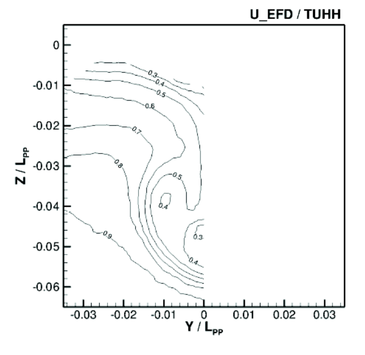


FOI-RANSWR-1.3b

Experiments

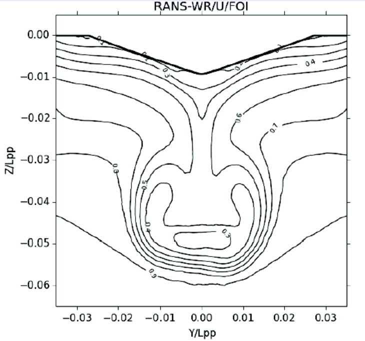
k-ω SST

Linear Isotropic Turbulence Closures - Station S7



EFD(TUHH)

Experiments

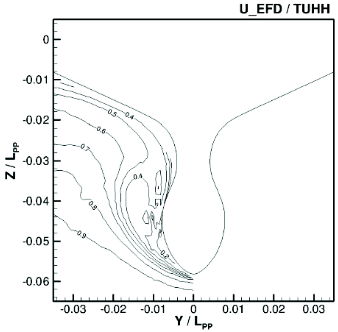


FOI-RANSWR-1.3b

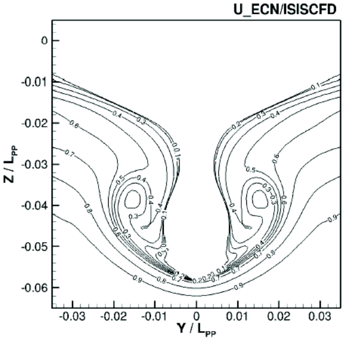
k-ω SST

Non-Linear Anisotropic Turbulence Closures

Non-Linear Anisotropic Turbulence Closures - Station S2



EFD(TUHH)

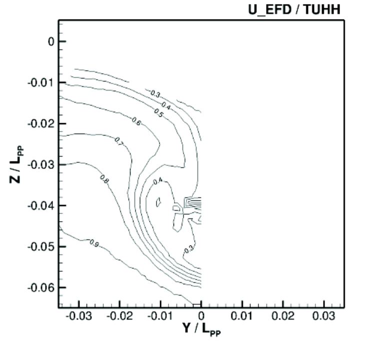


ECN_CNRS-ISISCFD-AGR-1.3b

Experiments

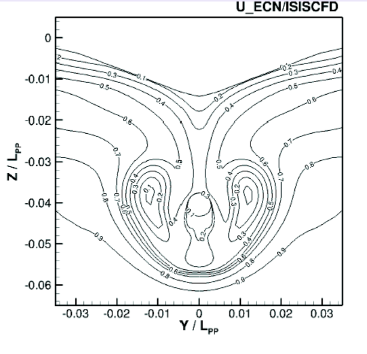
EASM

Non-Linear Anisotropic Turbulence Closures - Station S4



EFD(TUHH)

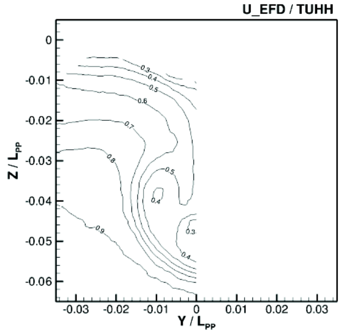
Experiments



ECN_CNRS-ISISCFD-AGR-1.3b

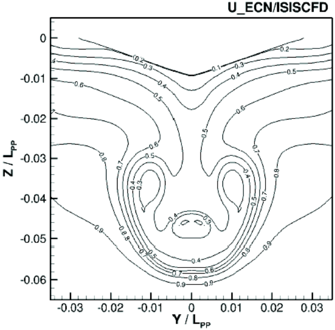
EASM

Non-Linear Anisotropic Turbulence Closures - Station S7



EFD(TUHH)

Experiments

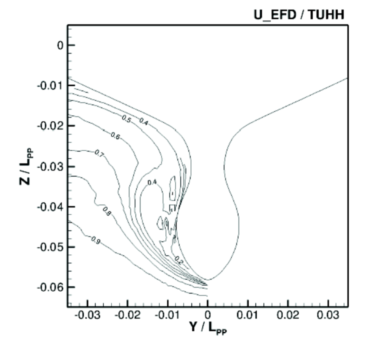


ECN_CNRS-ISISCFD-AGR-1.3b

EASM

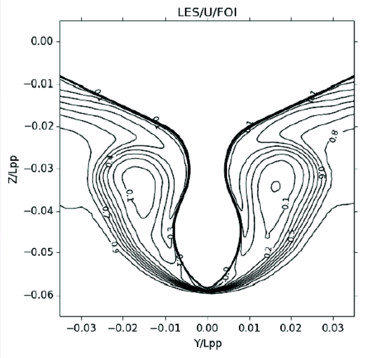
LES Turbulence Closures

LES Turbulence Closures - Station S2



EFD(TUHH)

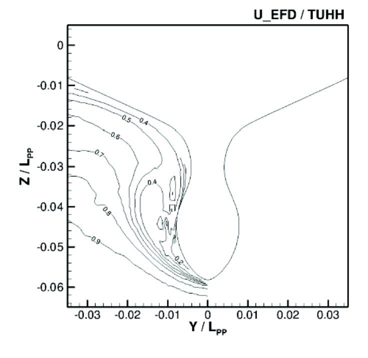
Experiments



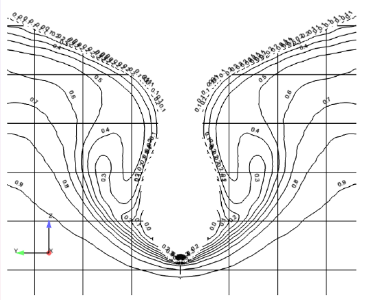
FOI-LESWM-1.3b

FOI/NWM-LES (143M points)

LES Turbulence Closures - Station S2



EFD(TUHH)

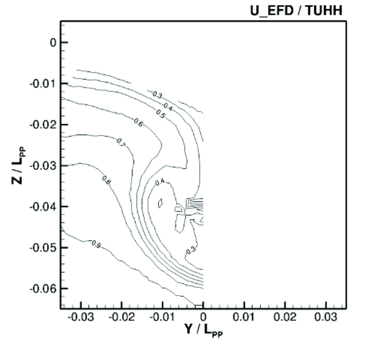


SRC-LES-1.3b

Experiments

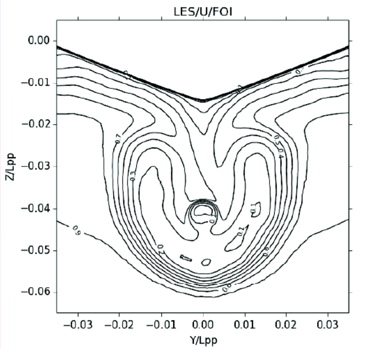
SRC/LES (4.9G points)

LES Turbulence Closures - Station S4



EFD(TUHH)

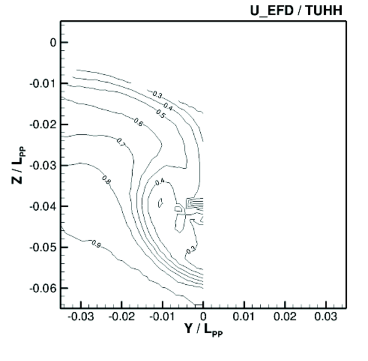
Experiments



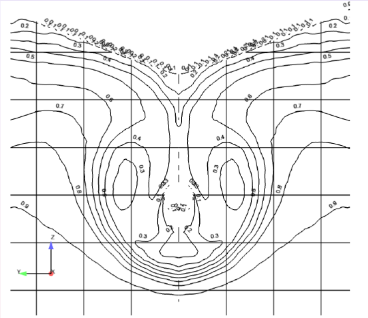
FOI-LESWM-1.3b

FOI/NWM-LES (143M points)

LES Turbulence Closures - Station S4



EFD(TUHH)

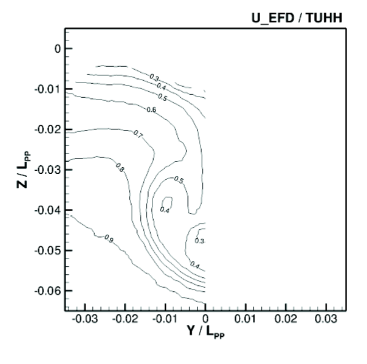


SRC-LES-1.3b

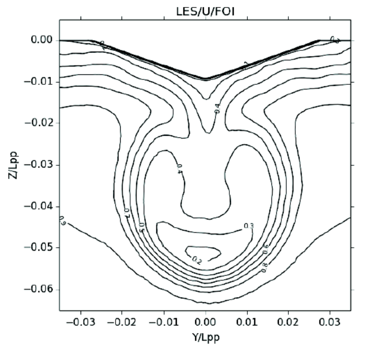
Experiments

SRC/LES (4.9G points)

LES Turbulence Closures - Station S7



EFD(TUHH)

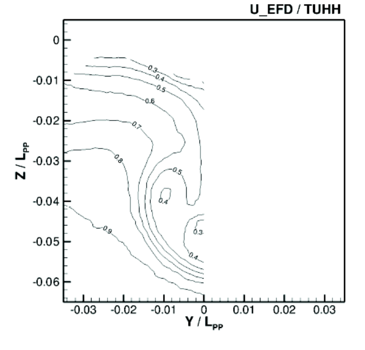


FOI-LESWM-1.3b

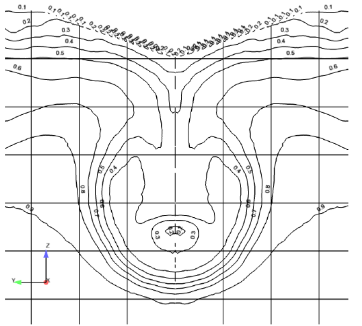
Experiments

FOI/NWM-LES (143M points)

LES Turbulence Closures - Station S7



EFD(TUHH)

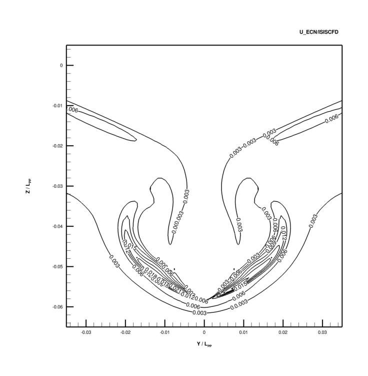


SRC-LES-1.3b

Experiments

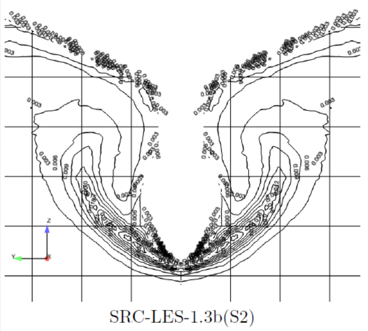
SRC/LES (4.9G points)

TKE contours - Station S2



ECN-CNRS/EASM

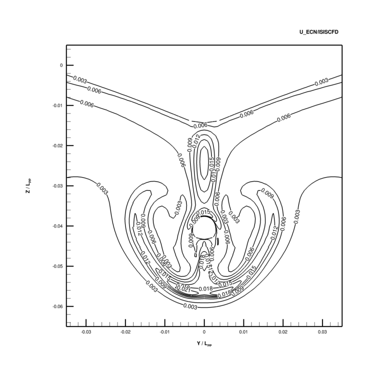
Max TKE 0.018

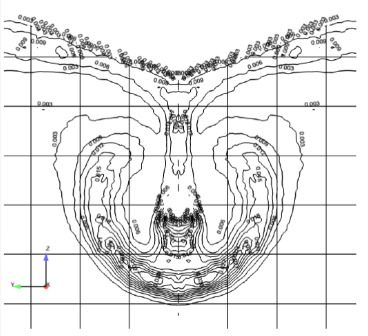


SRC/LES

Max TKE 0.022

TKE contours - Station S4

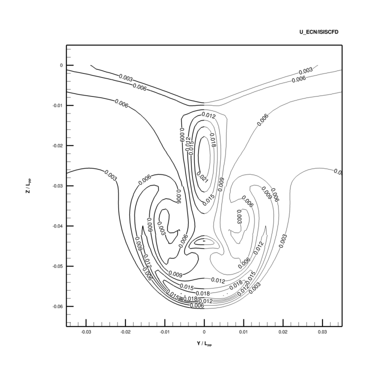




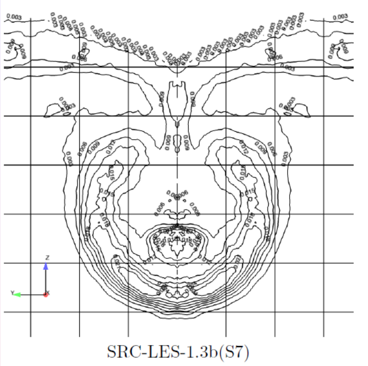
ECN-CNRS/EASM
Max TKE 0.021

SRC/LES
Max TKE 0.030

TKE contours - Station S7



ECN-CNRS/EASM
Max TKE 0.018

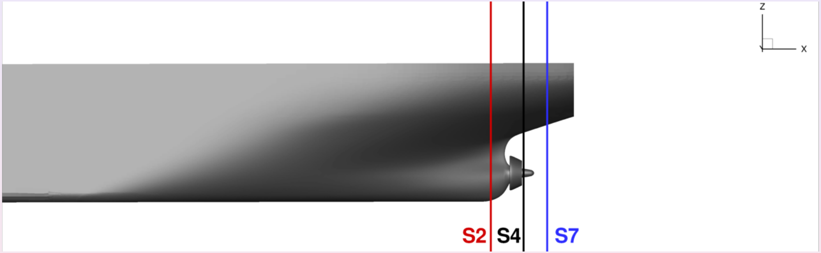


SRC/LES
Max TKE 0.024

Case 1-3b - Temporary conclusions

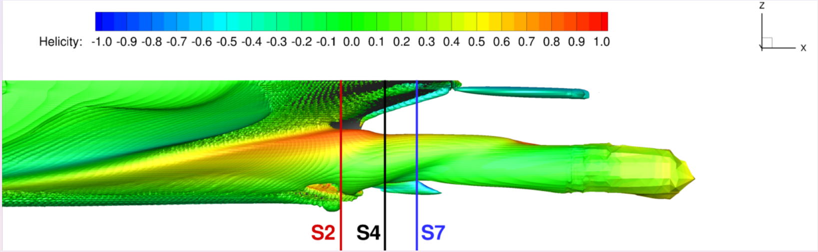
- A sensitivity to the local grid density is observed, which contradicts somewhat the conclusions drawn for the previous case,
- The major influence comes from the turbulence closure. Linear isotropic closures under-predict the longitudinal vorticity at S2 while full RSM closures tend to over-predict it at the same station.
- For the first time, two LES computations are presented.
- LES results from SRC predict the right level of TKE in the core of the bilge vortex (higher than what is modeled by EASM)
- Results from NWM-LES are promising but this model seems to over-predict the vorticity (need to check TKE in the bilge vortex)

JBC - Case 1-4



Experiments from NMRI

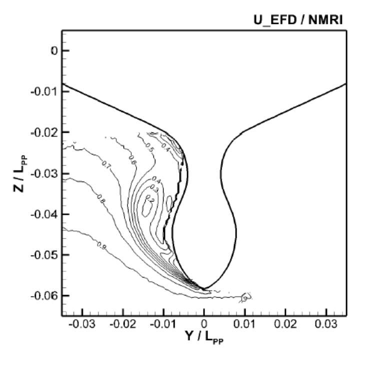
JBC - Case 1-4



Experiments from NMRI

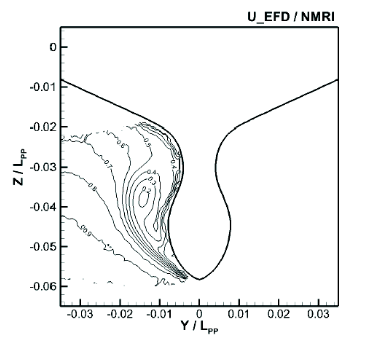
Influence of the duct - Experiments

Duct influence - Station S2



EFD(NMRI)

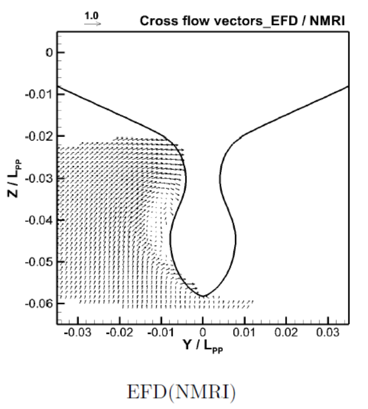
Without duct



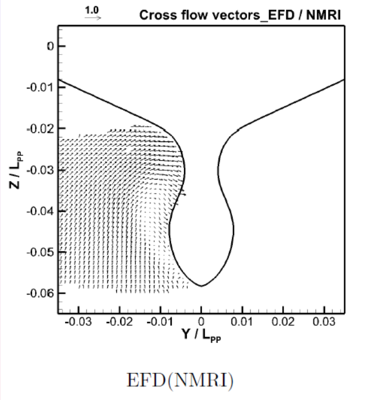
EFD(NMRI)

With duct

Duct influence - Station S2

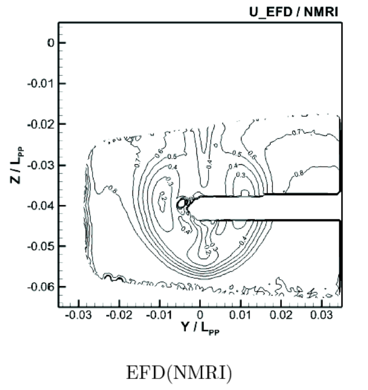


Without duct

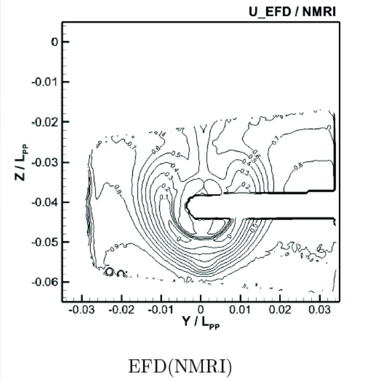


With duct

Duct influence - Station S4

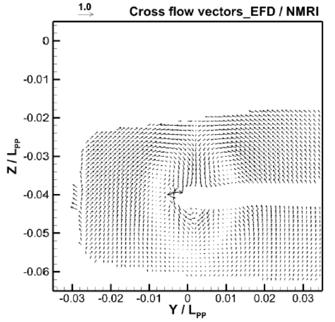


Without duct



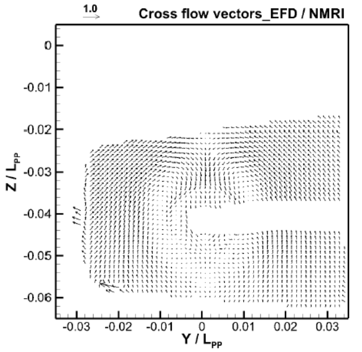
With duct

Duct influence - Station S4



EFD(NMRI)

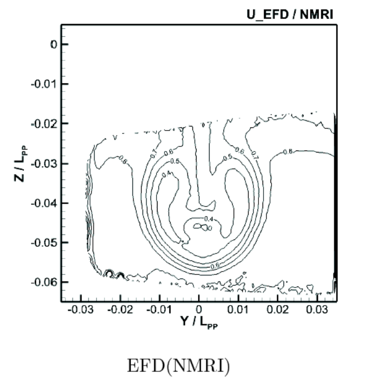
Without duct



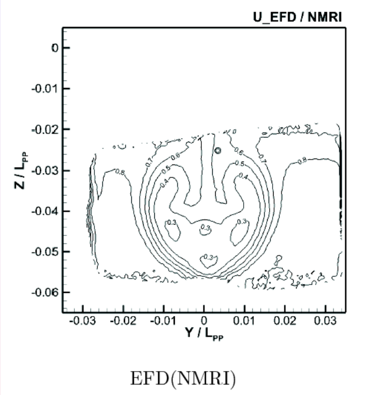
EFD(NMRI)

With duct

Duct influence - Station S7

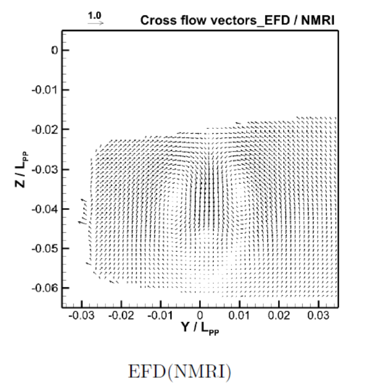


Without duct

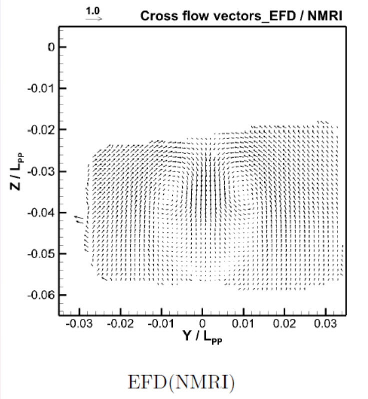


With duct

Duct influence - Station S7



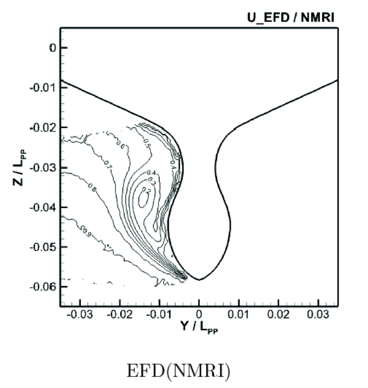
Without duct



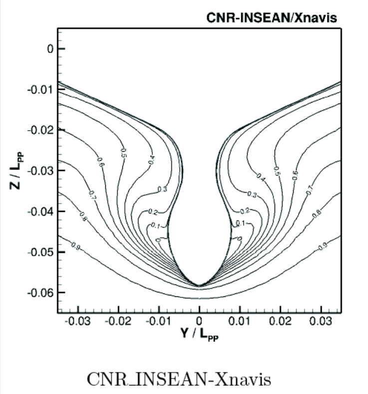
With duct

Linear Isotropic Turbulence Closures

Linear Isotropic Turbulence Closures - Station S2

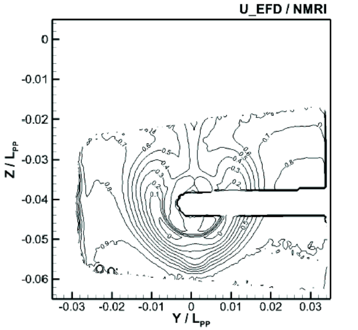


Experiments

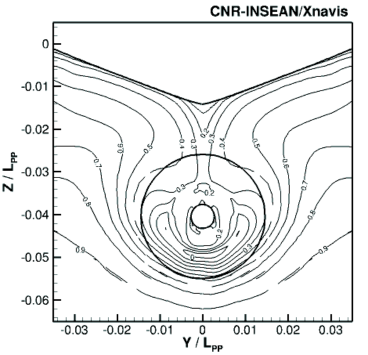


Spalart-Allmaras

Linear Isotropic Turbulence Closures - Station S4



EFD(NMRI)

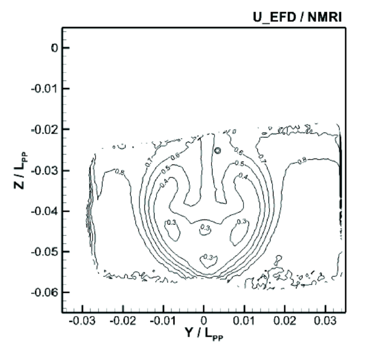


CNR_INSEAN-Xnavis

Experiments

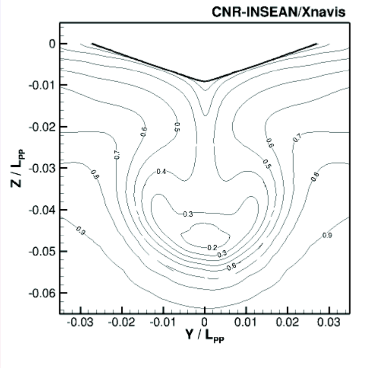
Spalart-Allmaras

Linear Isotropic Turbulence Closures - Station S7



EFD(NMRI)

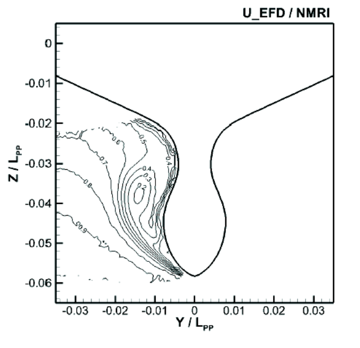
Experiments



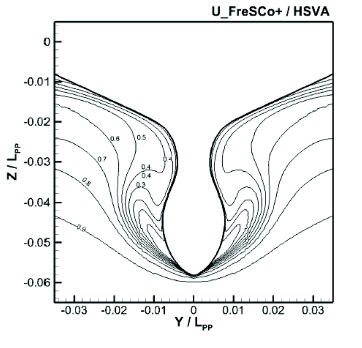
CNR_INSEAN-Xnavis

Spalart-Allmaras

Linear EASM Turbulence Closures - Station S2



EFD(NMRI)

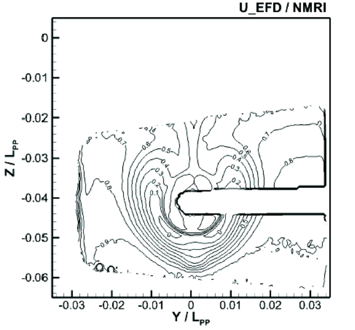


HSVA-FreSCo+

Experiments

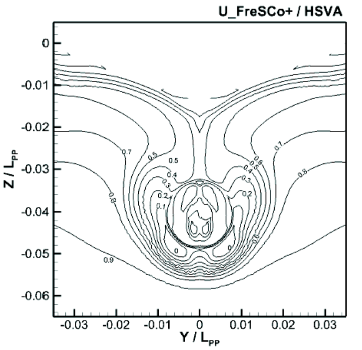
Linear EASM

Linear EASM Turbulence Closures - Station S4



EFD(NMRI)

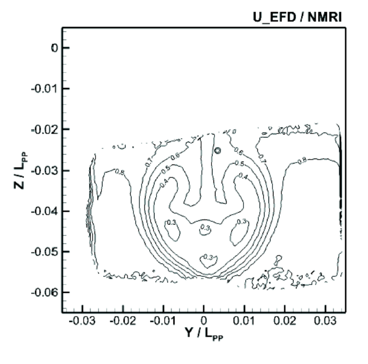
Experiments



HSVA-FreSCo+

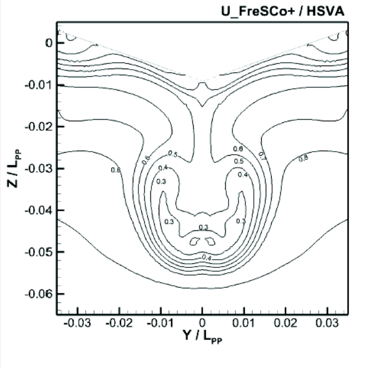
Linear EASM

Linear EASM Turbulence Closures - Station S7



EFD(NMRI)

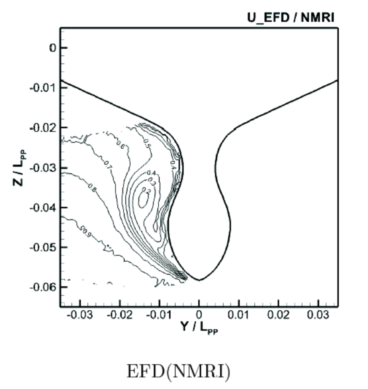
Experiments



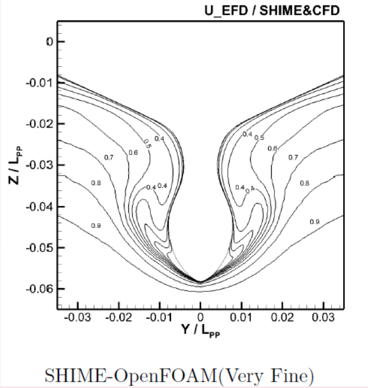
HSVA-FreSCo+

Linear EASM

Linear Isotropic Turbulence Closures - Station S2

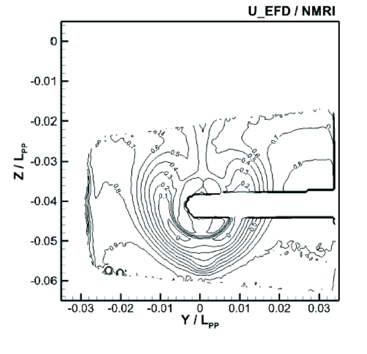


Experiments



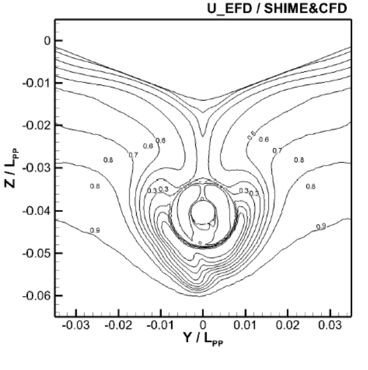
K-ω SST

Linear Isotropic Turbulence Closures - Station S4



EFD(NMRI)

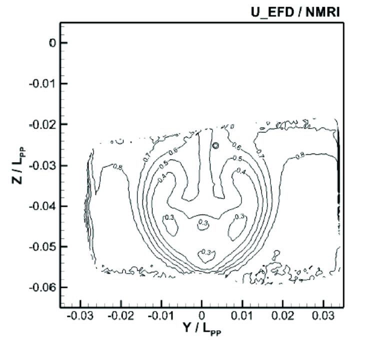
Experiments



SHIME-OpenFOAM(Very Fine)

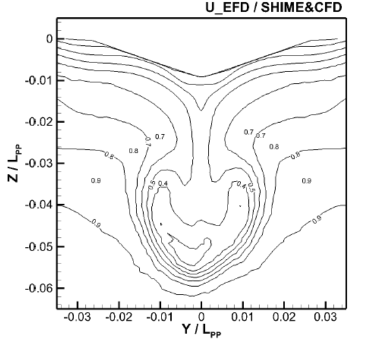
K-ω SST

Linear Isotropic Turbulence Closures - Station S7



EFD(NMRI)

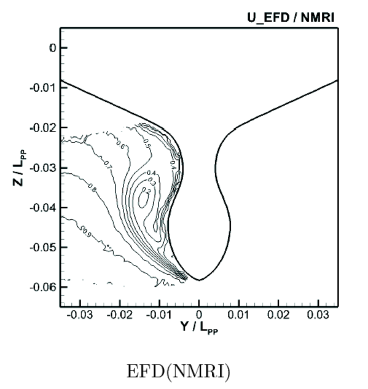
Experiments

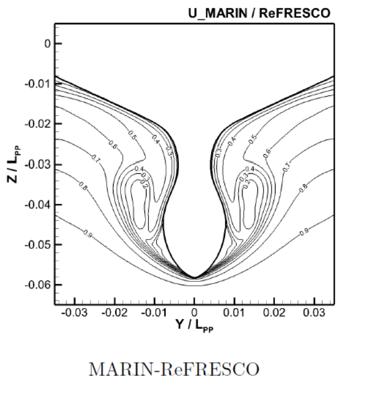


SHIME-OpenFOAM(Very Fine)

K-ω SST

Linear Isotropic Turbulence Closures - Station S2

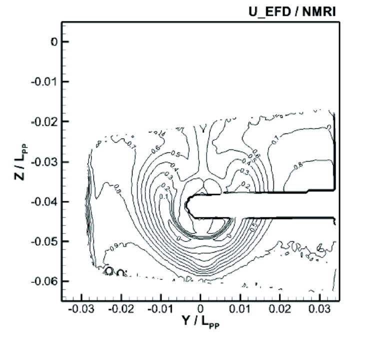




Experiments

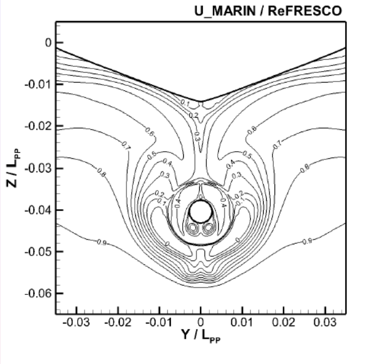
K-ω SST + Dacles-Mariani correction

Linear Isotropic Turbulence Closures - Station S4



EFD(NMRI)

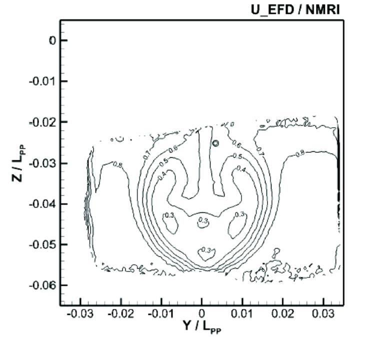
Experiments



MARIN-ReFRESCO

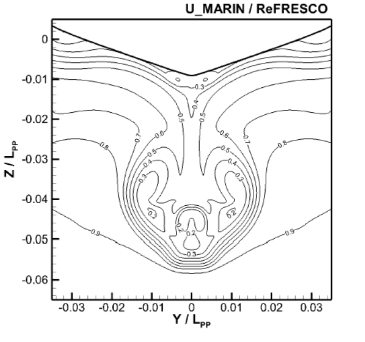
K-ω SST + DM

Linear Isotropic Turbulence Closures - Station S7



EFD(NMRI)

Experiments

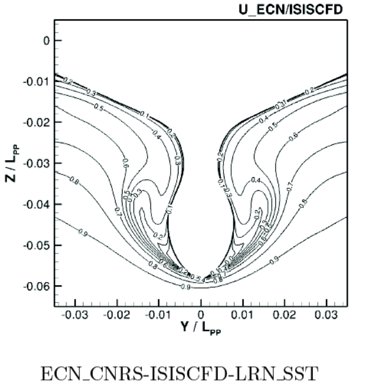


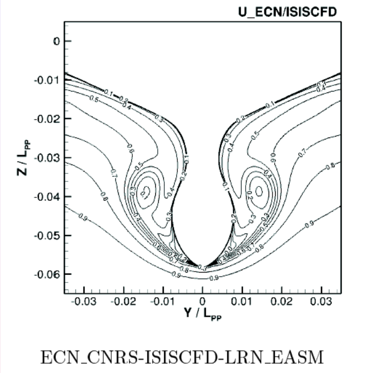
MARIN-ReFRESCO

K-ω SST + DM

Non-Linear Anisotropic Turbulence Closures

Isotropic vs Anisotropic turbulence closures - Station S2



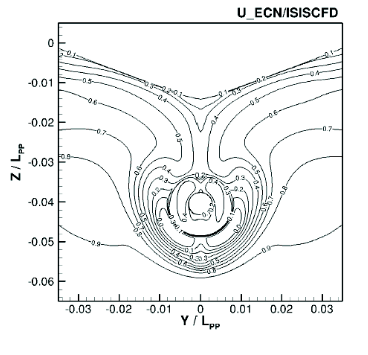


k-ω SST

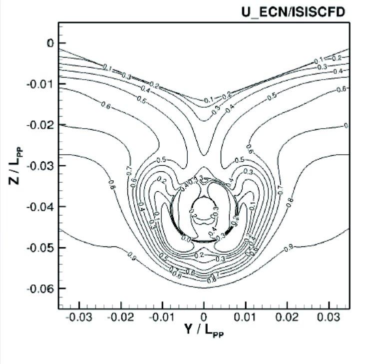
EASM

Same grid, same code

Isotropic vs Anisotropic turbulence closures - Station S4



ECN_CNRS-ISISCFD-LRN_SST



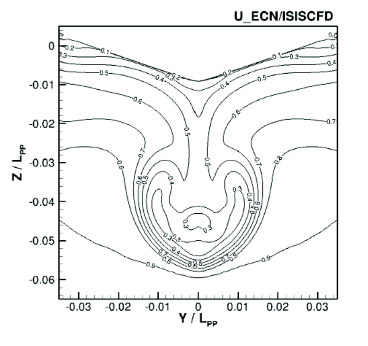
ECN_CNRS-ISISCFD-LRN_EASM

k-ω SST

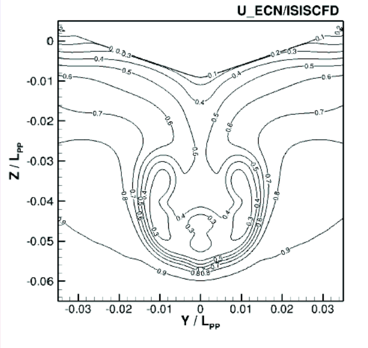
EASM

Same grid, same code

Isotropic vs Anisotropic turbulence closures - Station S7



ECN_CNRS-ISISCFD-LRN_SST



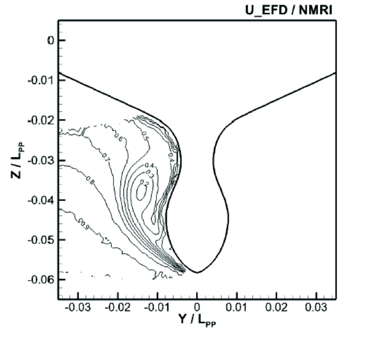
ECN_CNRS-ISISCFD-LRN_EASM

k-ω SST

EASM

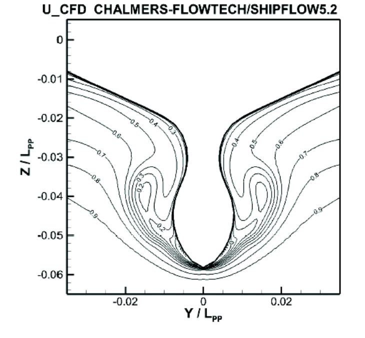
Same grid, same code

EASM Turbulence Closures - Station S2



EFD(NMRI)

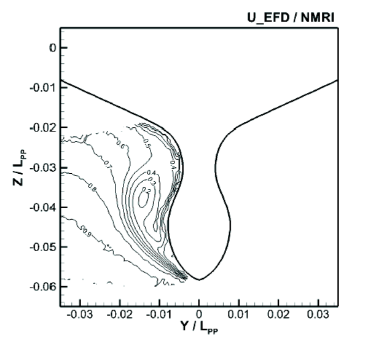
Experiments



CHALMERS-FLOWTECH-SHIPFLOW

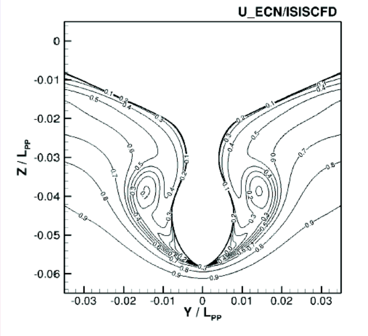
EASM CHALMERS

EASM Turbulence Closures - Station S2



EFD(NMRI)

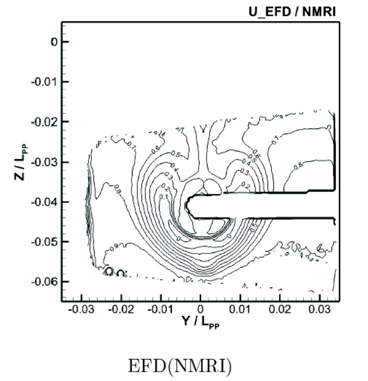
Experiments



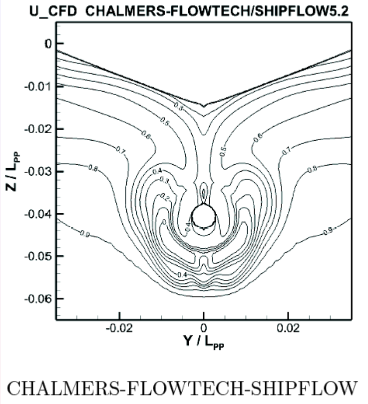
ECN_CNRS-ISISCFD-LRN_EASM

EASM ECN

EASM Turbulence Closures - Station S4

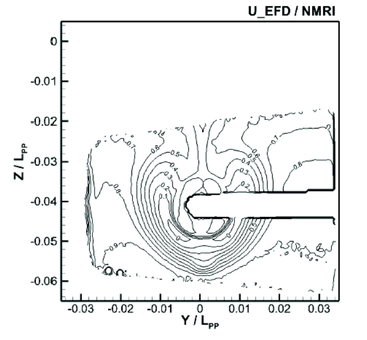


Experiments



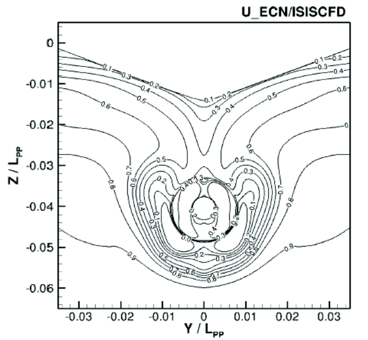
EASM CHALMERS

EASM Turbulence Closures - Station S4



EFD(NMRI)

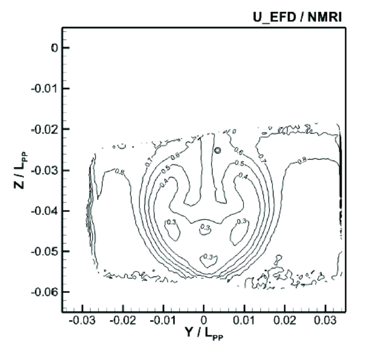
Experiments



ECN_CNRS-ISISCFD-LRN_EASM

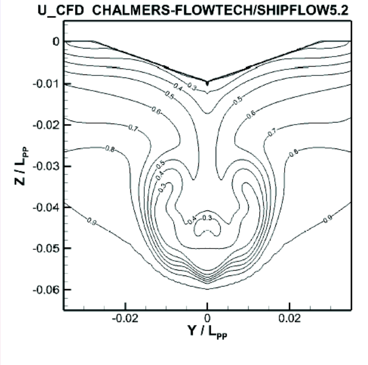
EASM ECN

EASM Turbulence Closures - Station S7



EFD(NMRI)

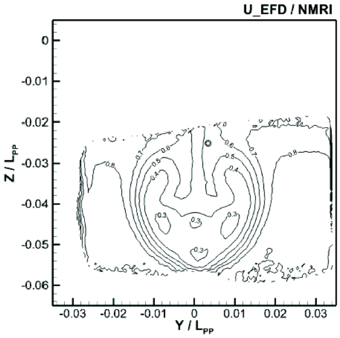
Experiments



CHALMERS-FLOWTECH-SHIPFLOW

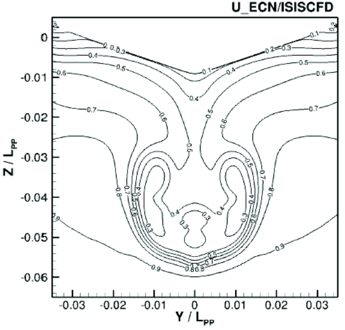
EASM CHALMERS

EASM Turbulence Closures - Station S7



EFD(NMRI)

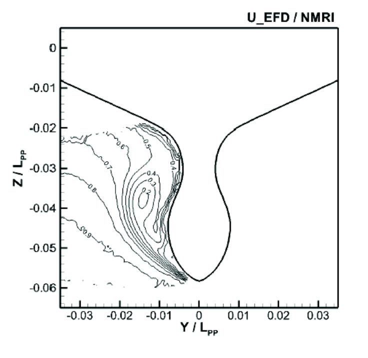
Experiments



ECN_CNRS-ISISCFD-LRN_EASM

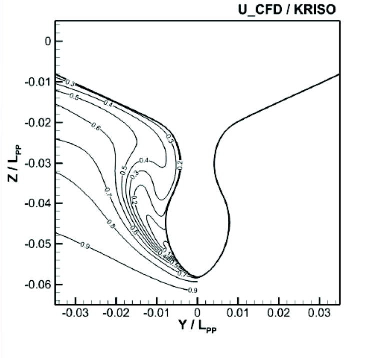
EASM ECN

EASM Turbulence Closures - Station S2



EFD(NMRI)

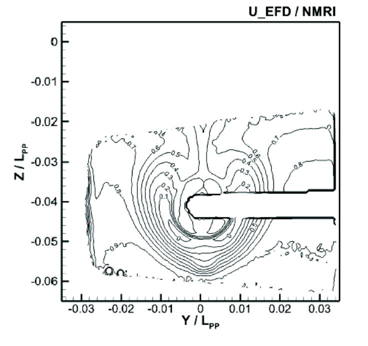
Experiments



KRISO-WAVIS

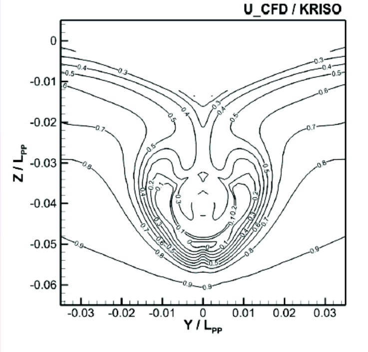
EASM KRISO

EASM Turbulence Closures - Station S4



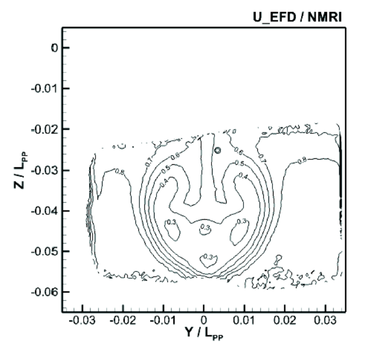
EFD(NMRI)

Experiments



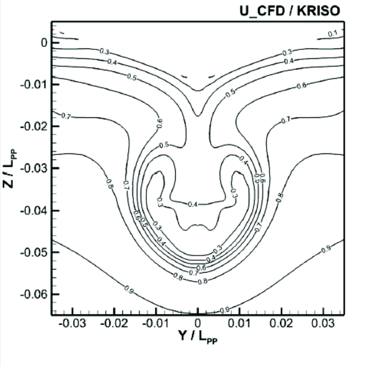
KRISO-WAVIS

EASM KRISO



EFD(NMRI)

Experiments

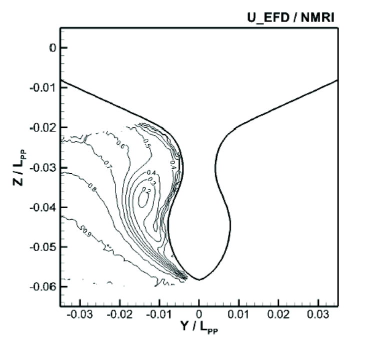


KRISO-WAVIS

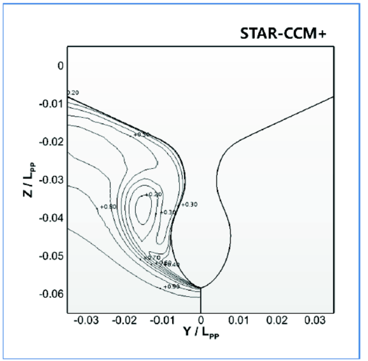
EASM KRISO

Full RSM Transport Turbulence Closures

Full RSM Transport Turbulence Closures - Station S2



EFD(NMRI)

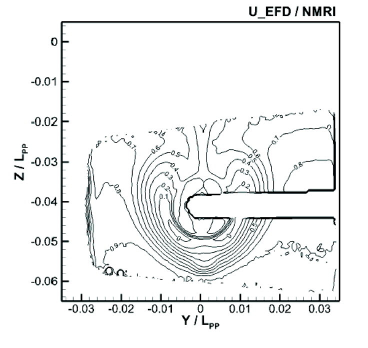


HHI-STAR-CCM+

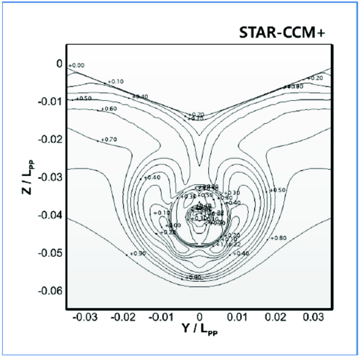
Experiments

Full RSM

Full RSM Transport Turbulence Closures - Station S4



EFD(NMRI)

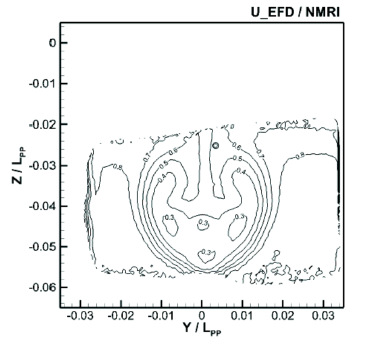


HHI-STAR-CCM+

Experiments

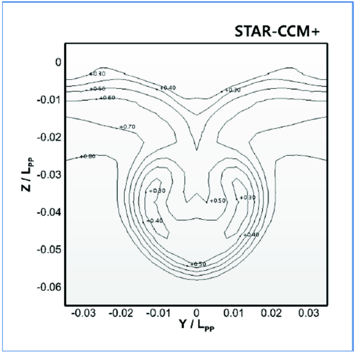
Full RSM

Full RSM Transport Turbulence Closures - Station S7



EFD(NMRI)

Experiments



HHI-STAR-CCM+

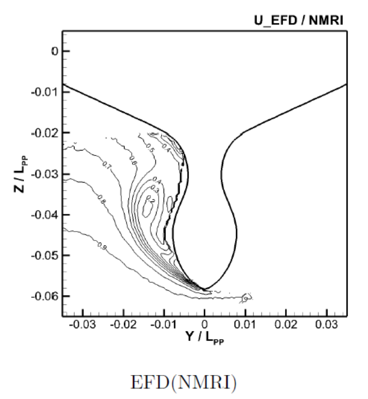
Full RSM

JBC - Case 1-7

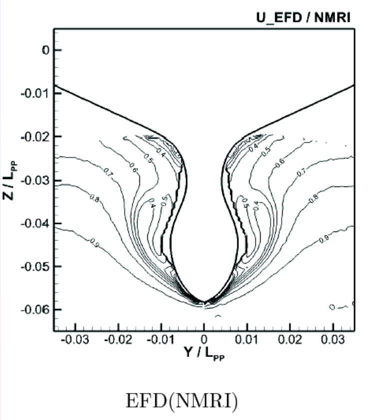
Without duct, with propeller

Influence of the propeller - Experiments

Propeller influence - Station S2

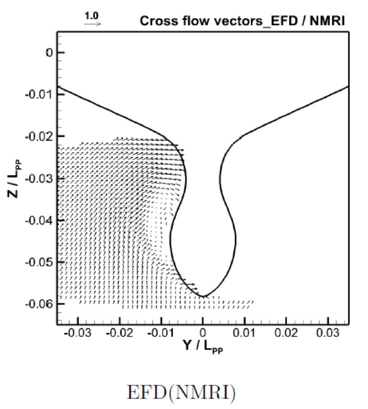


Without propeller

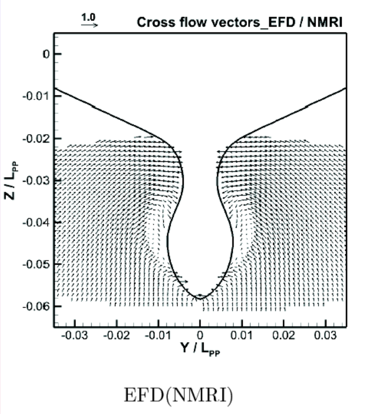


With propeller

Propeller influence - Station S2

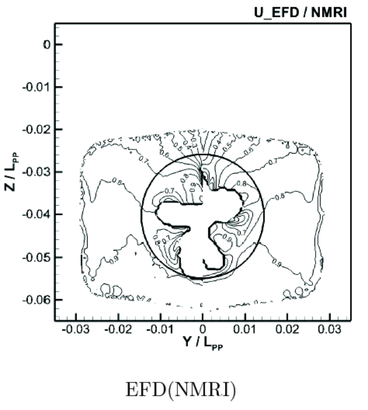


Without propeller



With propeller

Station S4 - 0 deg.



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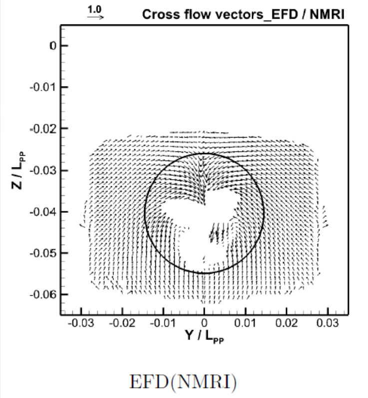
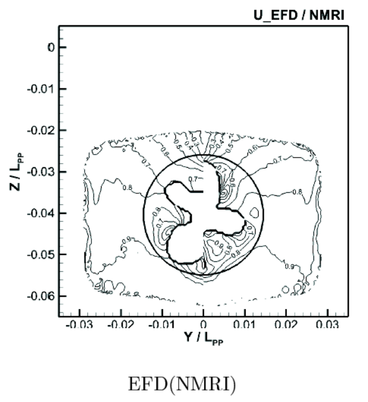
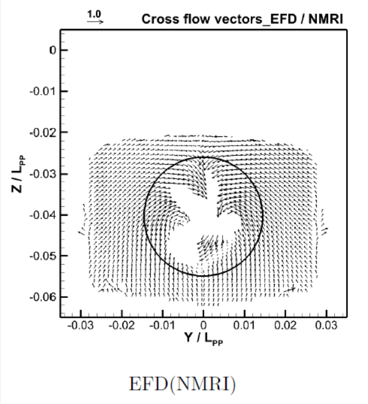


Cross-flow components

Station S4 - 24 deg.

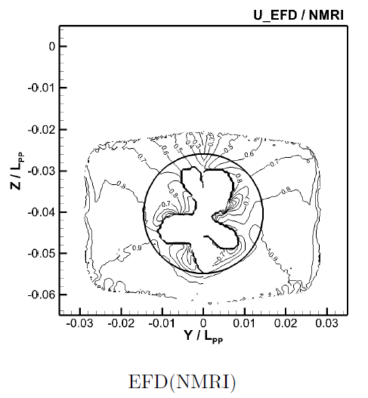




U

Cross-flow components

Station S4 - 48 deg.



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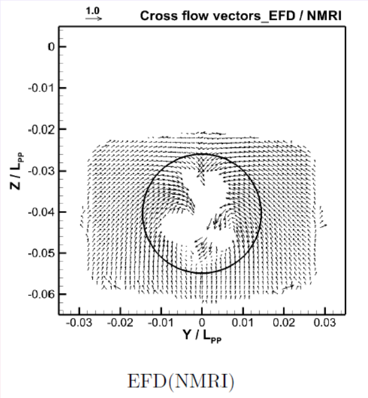
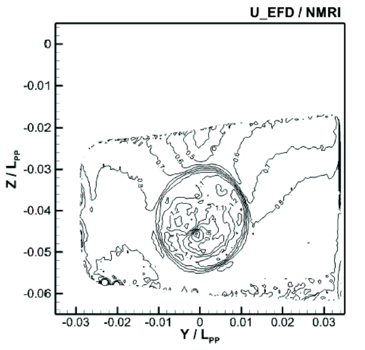


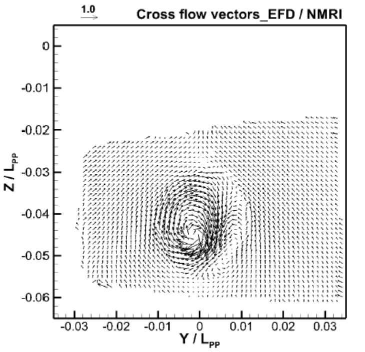
Cross-flow components

Station S7 - 0 deg.



EFD(NMRI)

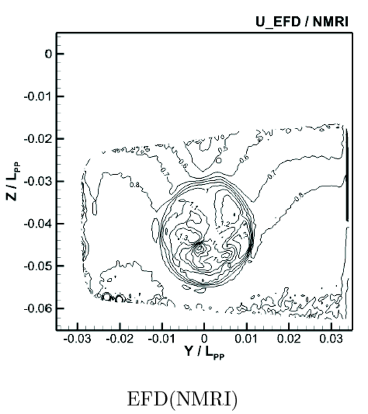
U



EFD(NMRI)

Cross-flow components

Station S7 - 24 deg.



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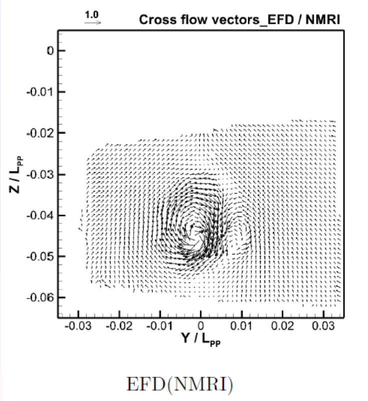
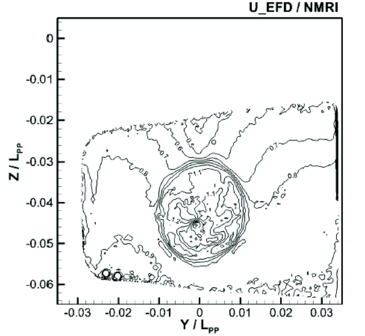


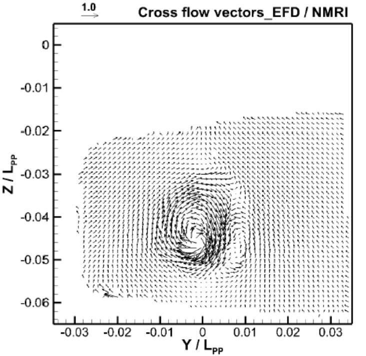
Cross-flow components

Station S7 - 48 deg.



EFD(NMRI)

U

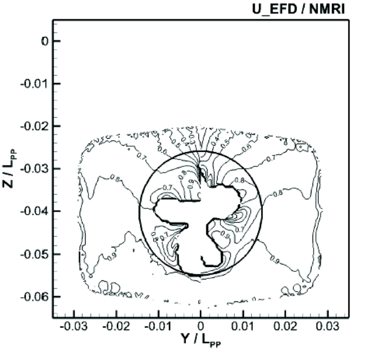


EFD(NMRI)

Cross-flow components

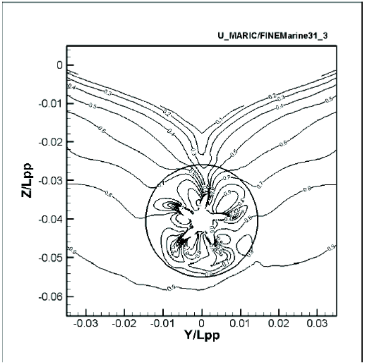
Comparison of results

Linear Isotropic Turbulence Closures - Station S4 - 0 deg.



EFD(NMRI)

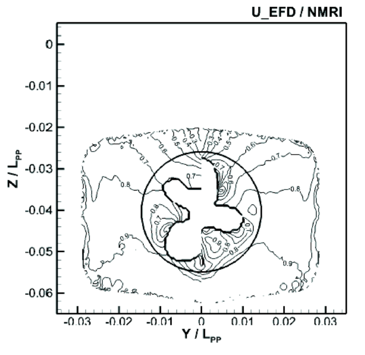
Experiments



MARIC-FINEMarine

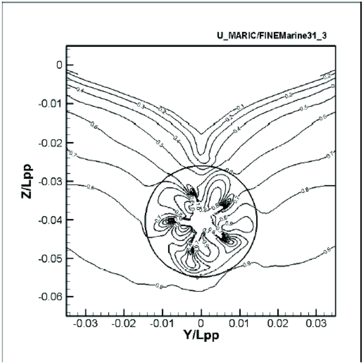
SST MARIC

Linear Isotropic Turbulence Closures - Station S4 - 24 deg.



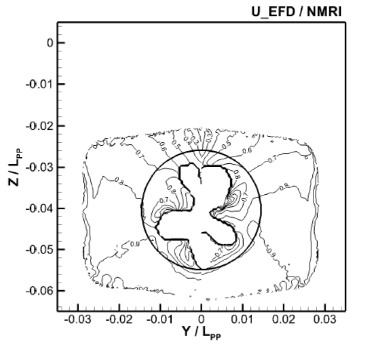
EFD(NMRI)

Experiments



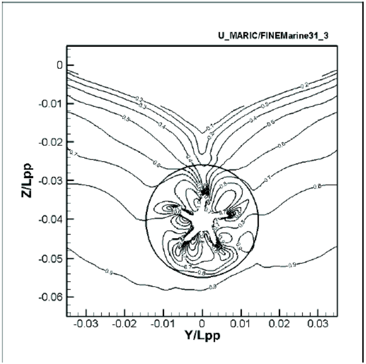
MARIC-FINEMarine

SST MARIC



EFD(NMRI)

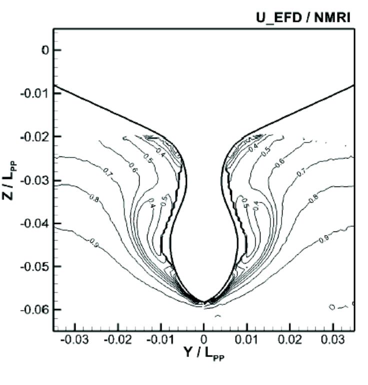
Experiments



MARIC-FINEMarine

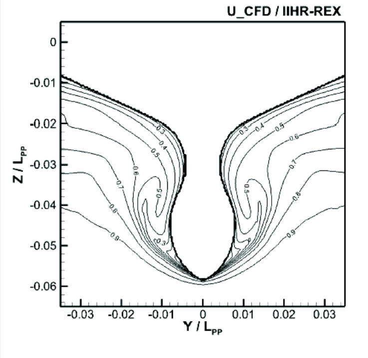
SST MARIC

Linear Isotropic Turbulence Closures - Station S2



EFD(NMRI)

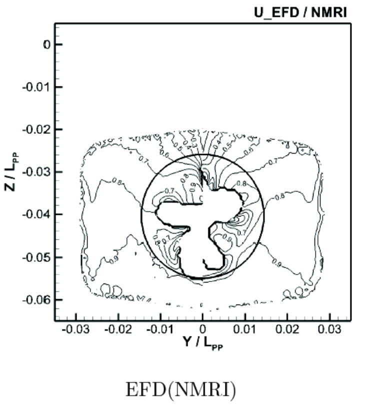
Experiments



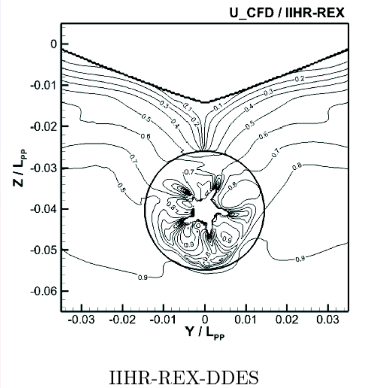
IIHR-REX-DDES

DDES IIHR

Linear Isotropic Turbulence Closures - Station S4 - 0 deg.

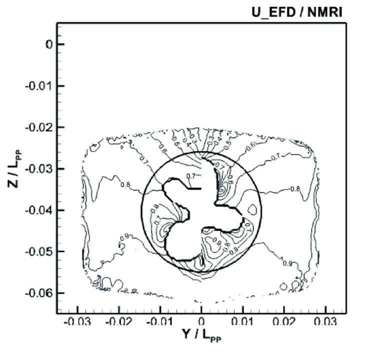


Experiments



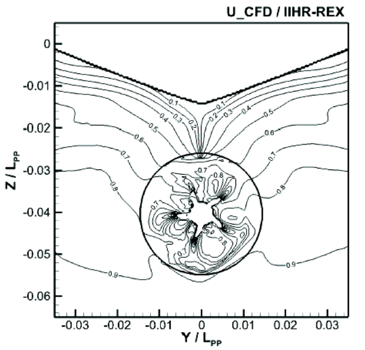
DDES IIHR

Linear Isotropic Turbulence Closures - Station S4 - 24 deg.



EFD(NMRI)

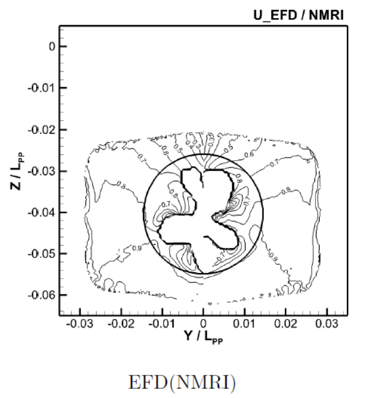
Experiments



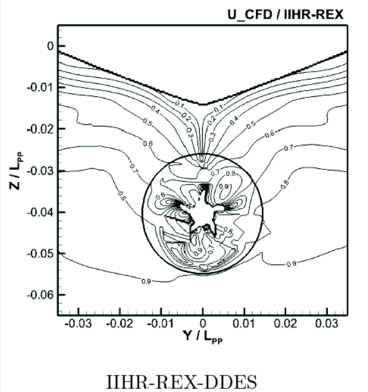
IIHR-REX-DDES

DDES IIHR

Linear Isotropic Turbulence Closures - Station S4 - 48 deg.



Experiments



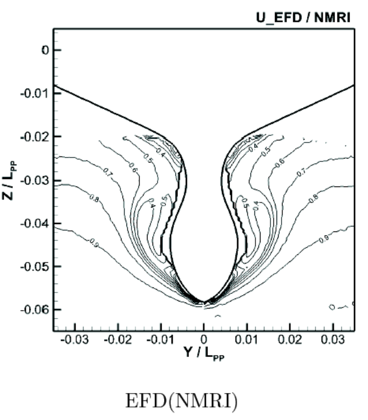
DDES IIHR

JBC - Case 1-8

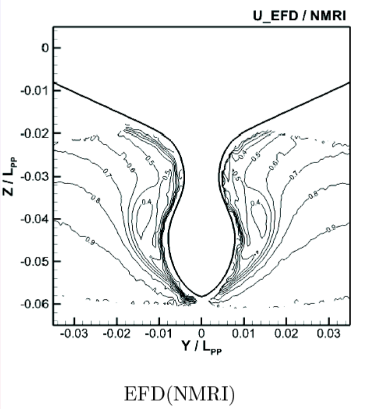
With duct, with propeller

Influence of the duct - Experiments

Duct influence - Station S2

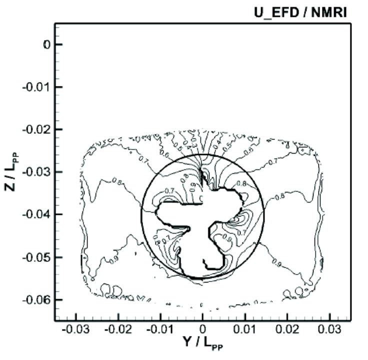


Without duct



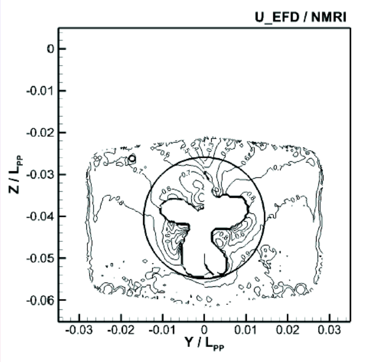
With duct

Duct influence - Station S4 - 0 deg.



EFD(NMRI)

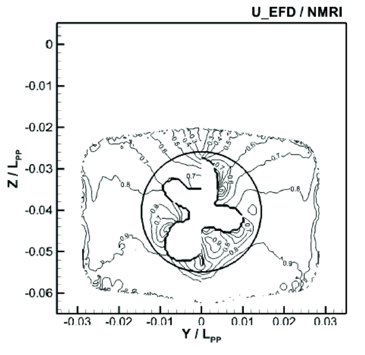
Without duct



EFD(NMRI)

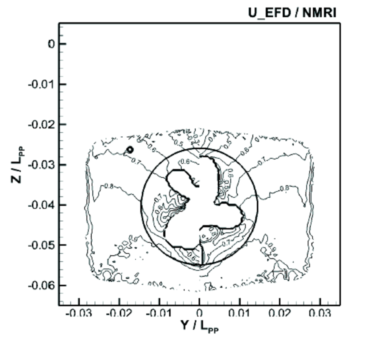
With duct

Duct influence - Station S4 - 24 deg.



EFD(NMRI)

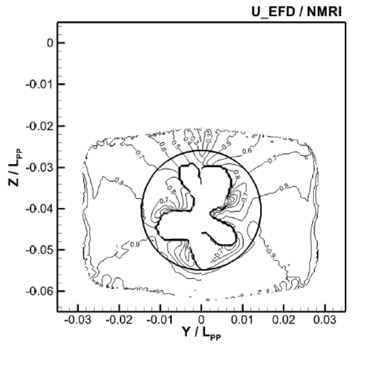
Without duct



EFD(NMRI)

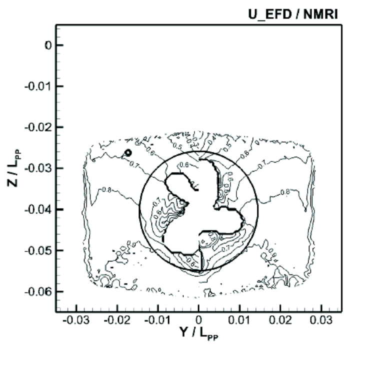
With duct

Duct influence - Station S4 - 48 deg.



EFD(NMRI)

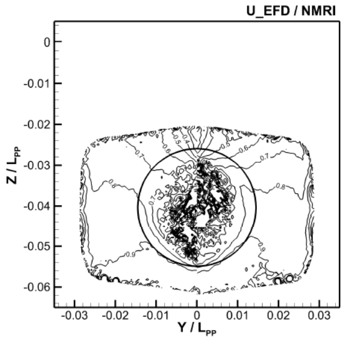
Without duct



EFD(NMRI)

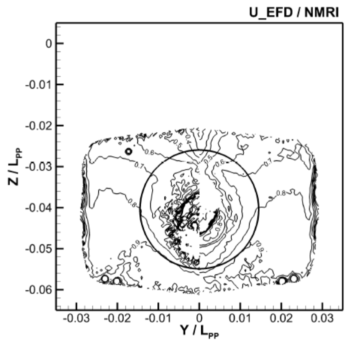
With duct

Duct influence - Station S4 - Temporal mean



EFD(NMRI)

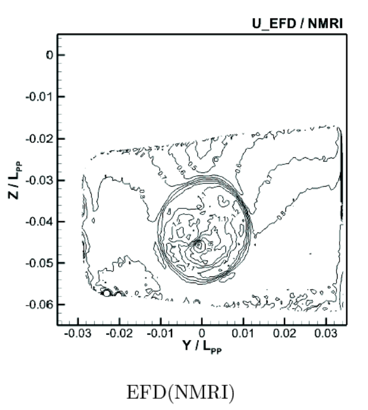
Without duct



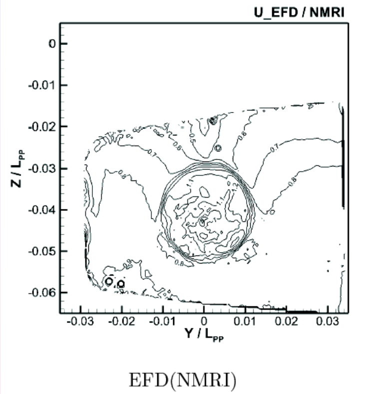
EFD(NMRI)

With duct

Duct influence - Station S7 - 0 deg.

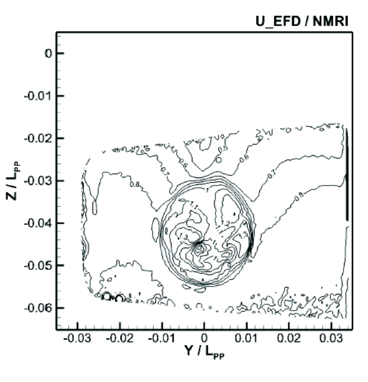


Without duct



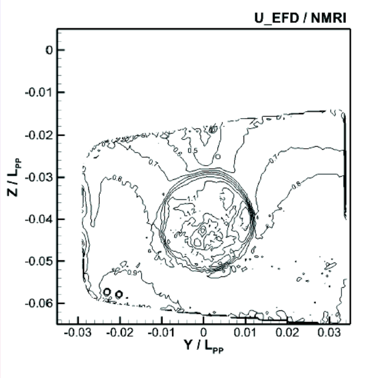
With duct

Duct influence - Station S7 - 24 deg.



EFD(NMRI)

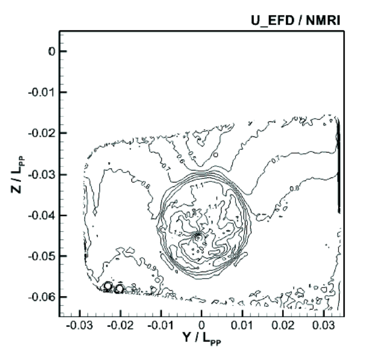
Without duct



EFD(NMRI)

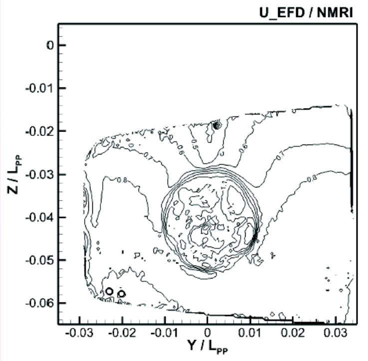
With duct

Duct influence - Station S7 - 48 deg.



EFD(NMRI)

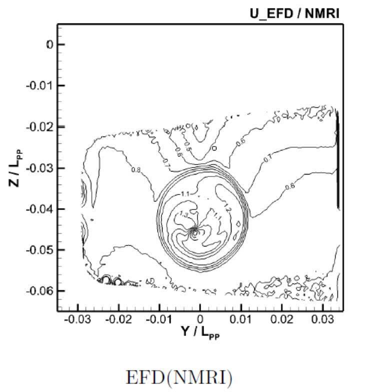
Without duct



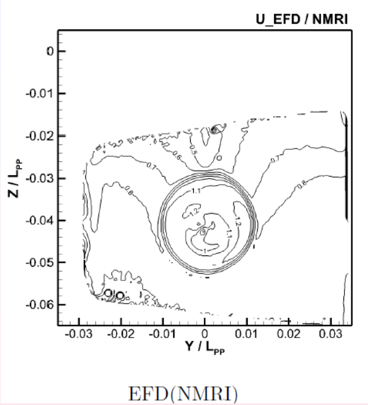
EFD(NMRI)

With duct

Duct influence - Station S7 - Temporal mean



Without duct



With duct

It is 2:00 am today and this is the end of this presentation...
Thank you for your understanding !