NRELVI Debug

(Dated: 14 April 2023)

I. ON THE SPECIFIC DISSIPATION RATE (SDR) PRODUCTION TERM

The SDR production term in AMR-Wind is inconsistent with the Nalu-Wind implementation. In AMR-Wind, the SDR production term is unlimited and is implemented as:

$$P_\omega = \rho \alpha S^2 \tag{1}$$

where, $\alpha = \alpha_1 F_1 + \alpha_2 (1 - F_1)$ and $S = \sqrt{2 S_{ij} S_{ij}}$ is the strain-rate invariant. This formulation is from[1].

In Nalu-Wind, SDR production term is limited:

$$P_\omega = \frac{\rho \alpha \tilde{P}_k}{max\,(\mu_t, 1.0^{-16.0})} \tag{2}$$

where, $\tilde{P}_k = min\,(10\beta^* \rho\omega k, max(P_k, 0.0))$, and $P_k = \mu_t S_{ij} S_{ij}$

The limited production term is consistent with Menter's[2] standard k-ω SST model. The unlimited production term appears in Menter et al.[1] paper. However, as NASA Langley Turbulence Modeling resource page (*https://turbmodels.larc.nasa.gov/*) states, the unlimited version in the 2003 paper is a typographical error.

II. TEST MATRIX FOR SST RUNS WITH LIMITED VERSION OF PRODUCTION

A test matrix was generated to investigate two sets of turbulent intensities for four wind speeds with limited version of production for SDR equation in AMR-Wind. The details of the test matrix is presented below:

Inlet Boundary Conditions and Time Step Size:

- The turbulent kinetic energy (TKE) at the inlet boundary was selected such that it decays to 0.5% and 0.05% at the turbine location.
- Following TKE decay formula was utilized to estimate inlet TKE

$$k = k_{inlet} \left(1 + \omega_{inlet} \frac{\beta\ x}{u_\infty}\right)^{\frac{-\beta^*}{\beta}} \tag{3}$$

  where $\beta_2 = 0.0828$, $\beta = 0.09$, $\omega_{inlet} = 150$.

- For all runs, time step size corresponds to 0.25° rotation angle (i.e., $\Delta t = 0.0005795s$).

- All runs were conducted for 30 revolutions.

Wind Speeds:

Numerical experiments were performed for four wind Speeds: 7, 12, 15, 20 m/s.

Domain Size and Cell Count:

- The domain size is:

```
geometry.prob_lo       =    -100.0        -100.0       -100.0
geometry.prob_hi       =     150.0         100.0        100.0
geometry.is_periodic   =   0   0   0
```

- The mesh resolution at level 0 is:

```
amr.n_cell             = 320 256 256
amr.max_level          = 4
tagging.labels = static
tagging.static.static_refinement_def = static_box.txt
tagging.static.type = CartBoxRefinement
```

III. RESULTS

- With production limiter activated for SDR production term in AMR-Wind, the residuals for the equation diverge for all four wind speeds, and turbulent intensities of 0.5% and 0.05%.
- The results for both TI are summarized in the tables below:

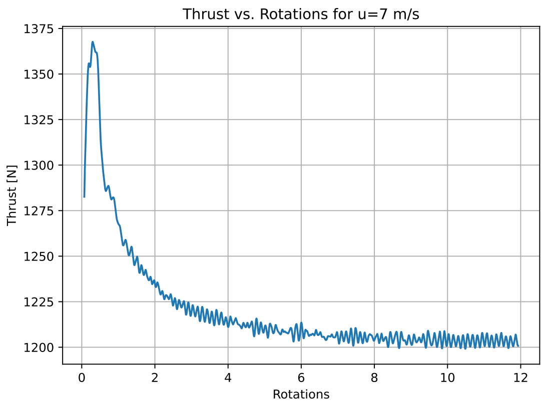
	TI (0.5%)					
Wind speed (m/s)	Inlet viscosity ratio	Iteration/Time (s)	# of rev.	CFL	Torque (N-m)	Restart file number with converged result
7	10.2	17168/9.947697	11.937	0.63	761.76	15840
12	29.4	8799/5.098441	6.18	0.92	1350.68	8640
15	44.9	6130/3.5517555	4.26	0.91	1042.88	5760
20	79.8	4314/2.4993835	2.999	0.92	1271.68	2880

FIG. 1: Summary of runs for turbulent intensity (TI) of 0.5%

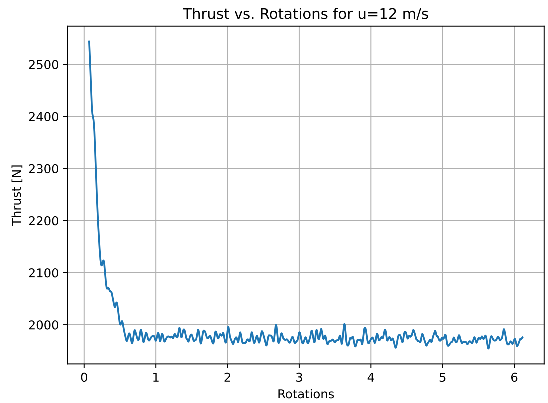
	TI (0.05%)						
Wind speed (m/s)	Inlet viscosity ratio	AMR-Wind			Nalu-Wind		
		It/time	# of rev.	CFL	It/time	# of rev.	Torque (N-m)
7	1.02E-3	243/0.1396595	0.16	0.69	11702/6.78073	8.13	763
12	4.07E-3	5841/3.38428	4.06	0.93	5847/3.38776	4.06	1358
15	4.07E-3	4422/2.5619695	3.07	0.95	4430/2.556661	3.07	1028
20	9.16E-3	3197/1.852082	2.22	0.95	3205/1.85672	2.22	1167

FIG. 2: Summary of runs for turbulent intensity (TI) of 0.05%

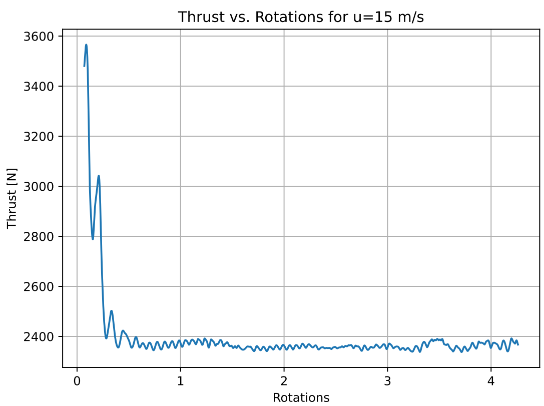
- For all cases, CFL is less than 1 .
- As the wind speed is increased, SDR diverges sooner.
- For $u = 7$m/s and TI$= 0.05\%$, the AMR-Wind SDR residuals diverge after only 243 iterations. However, the case continues to run for close to 7 revolutions as the error propagated to the Nalu-Wind solver is damped out due to lack of turbulent fluctuations in the flow.



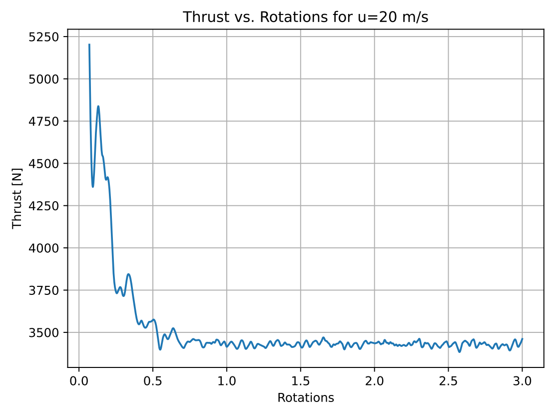
(a) u=7 m/s.



(b) u=12 m/s.



(c) u=15 m/s.



(d) u=20 m/s.

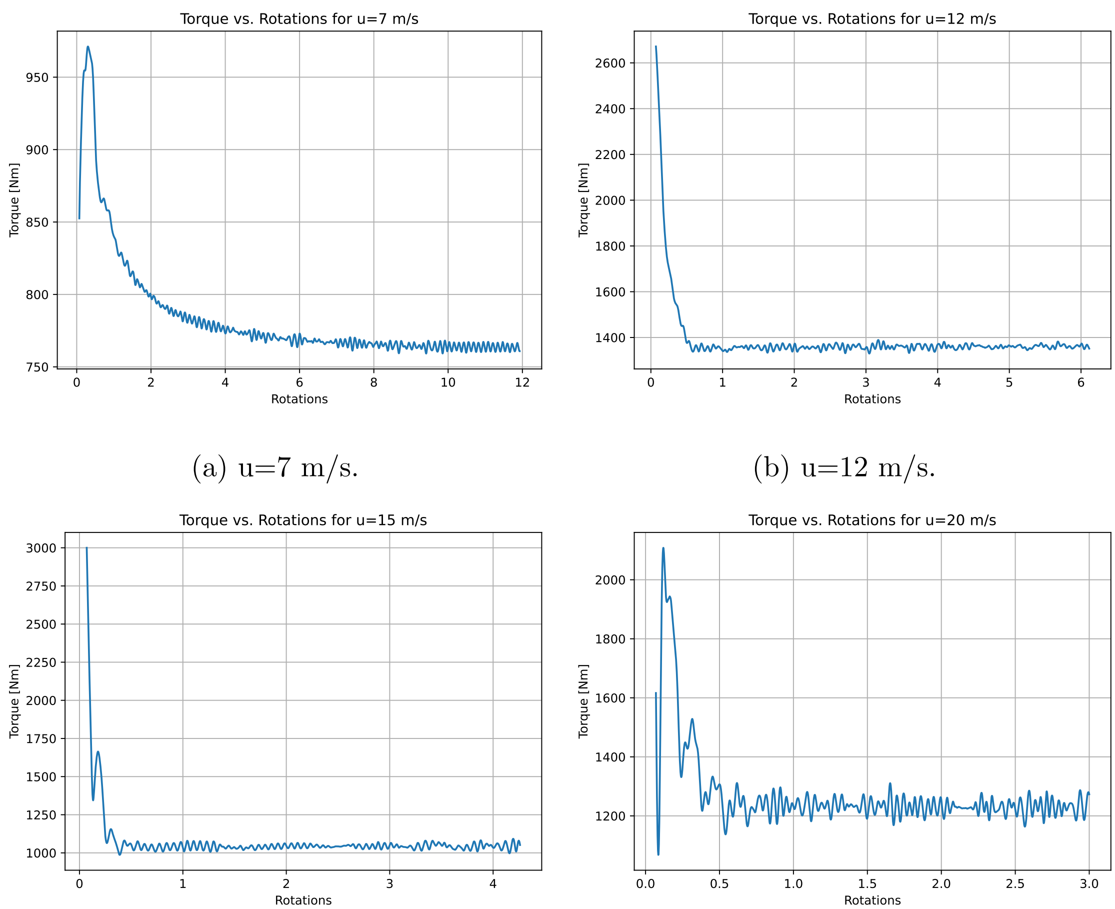
FIG. 3: Thrust vs. rotations.

Figures below show the temporal evolution of the following quantities for TI=0.5% and all four wind speeds:

- Thrust
- Torque
- Power
- CFL
- Initial SDR residual
- Final SDR residual

- Number of MAC projection iterations
- Initial MAC projection residual
- Final MAC projection residual
- Rank averaged wall time

Aerodynamic quantities converge to the correct result prior to the divergence of SDR residuals. Figure 10 - *Number of MAC projection iterations* shows the number of iterations needed to achieve convergence increasing several hundred to thousand iterations before SDR residuals begin to diverge.



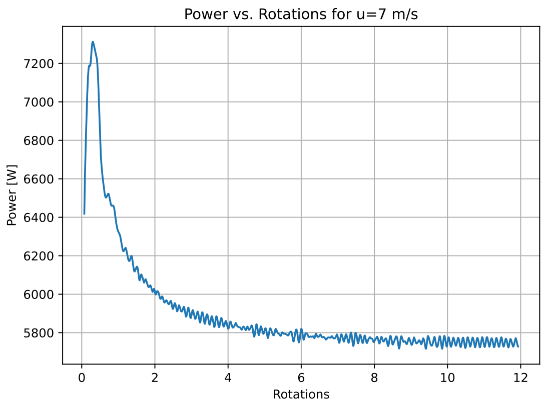
(a) u=7 m/s.

(b) u=12 m/s.

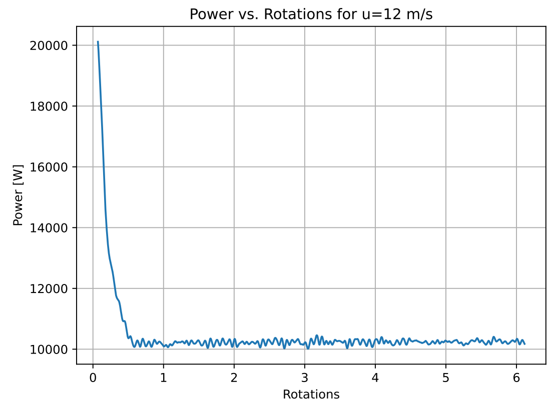
(c) u=15 m/s.

(d) u=20 m/s.

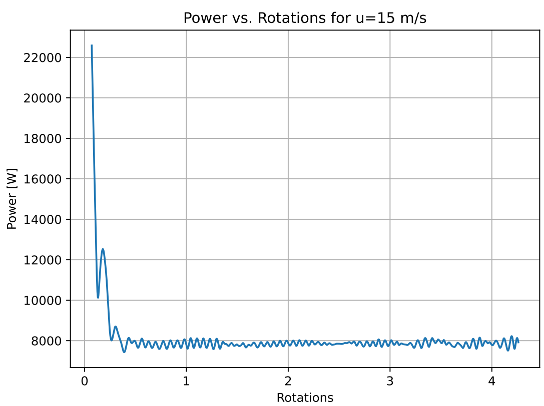
FIG. 4: Torque vs. rotations.



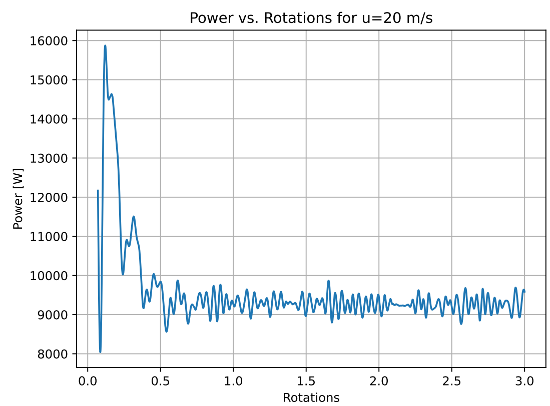
(a) u=7 m/s.



(b) u=12 m/s.

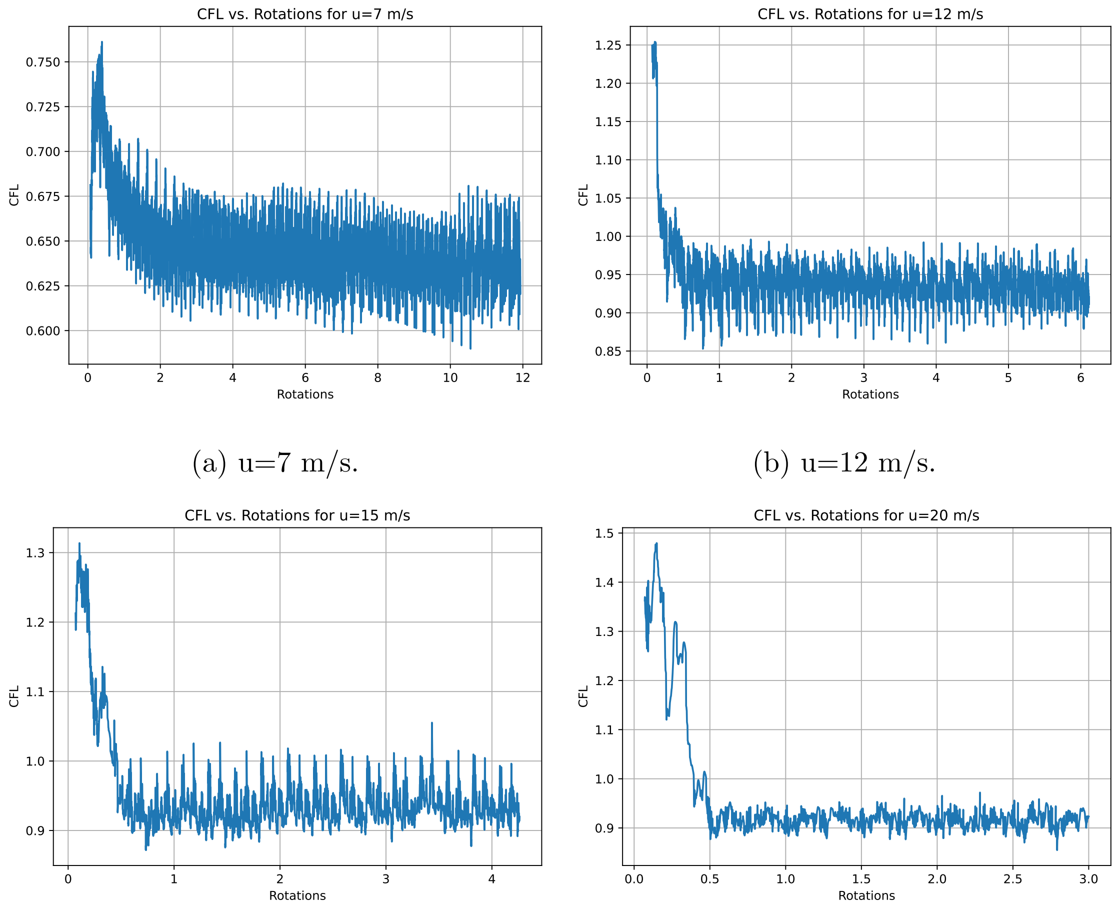


(c) u=15 m/s.



(d) u=20 m/s.

FIG. 5: Power vs. rotations.



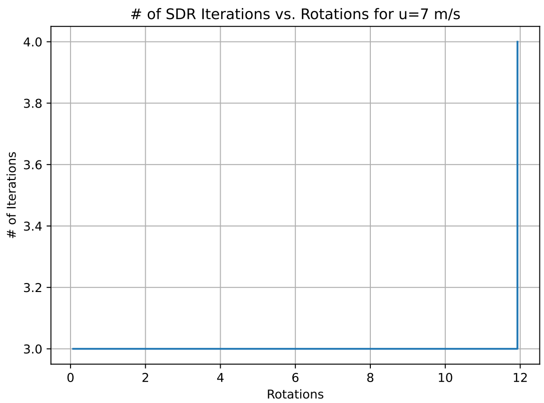
(a) u=7 m/s.

(b) u=12 m/s.

(c) u=15 m/s.

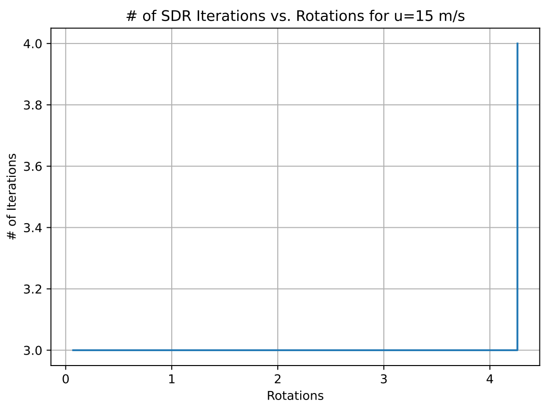
(d) u=20 m/s.

FIG. 6: CFL vs. rotations.

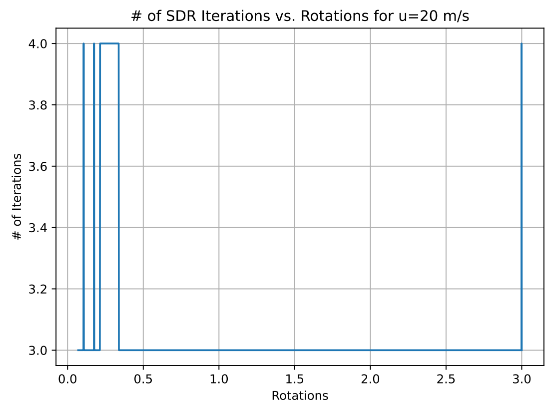


(a) u=7 m/s.

(b) u=12 m/s.

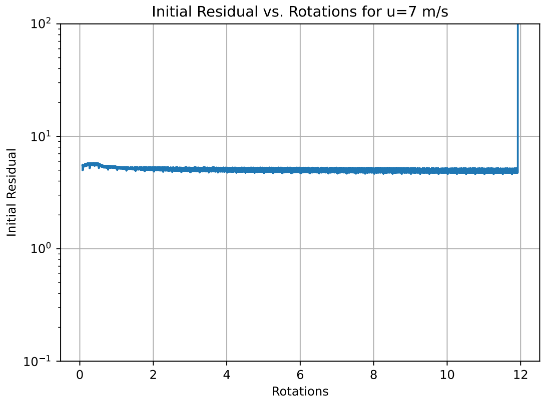


(c) u=15 m/s.

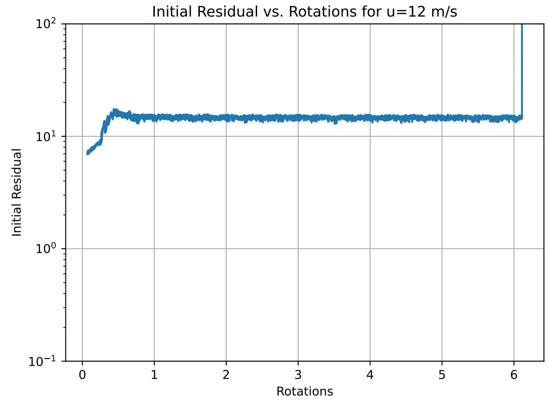


(d) u=20 m/s.

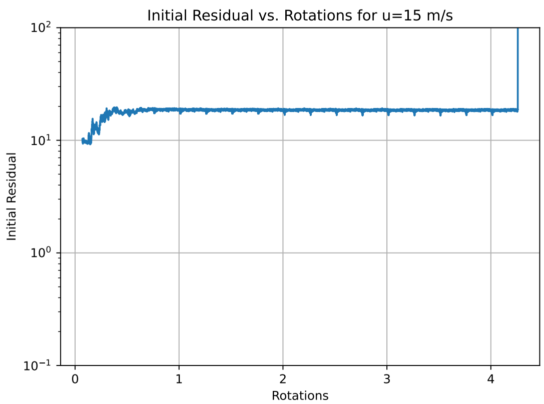
FIG. 7: Number of SDR iterations at each rotation



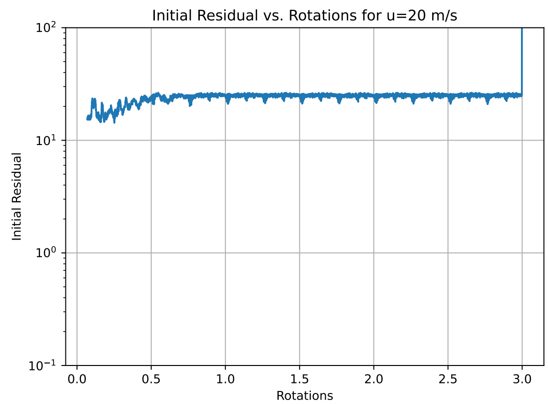
(a) u=7 m/s.



(b) u=12 m/s.

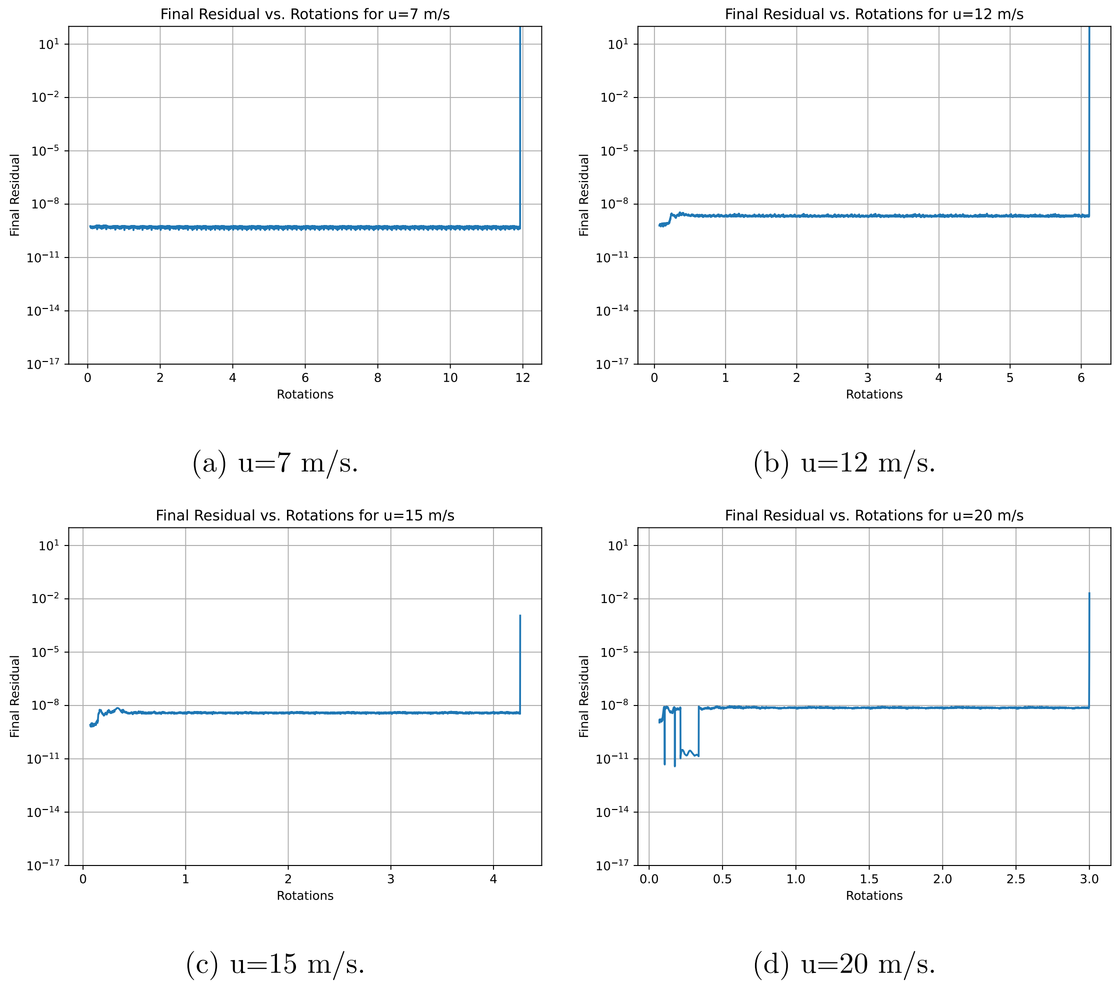


(c) u=15 m/s.



(d) u=20 m/s.

FIG. 8: Initial SDR residuals at each rotation



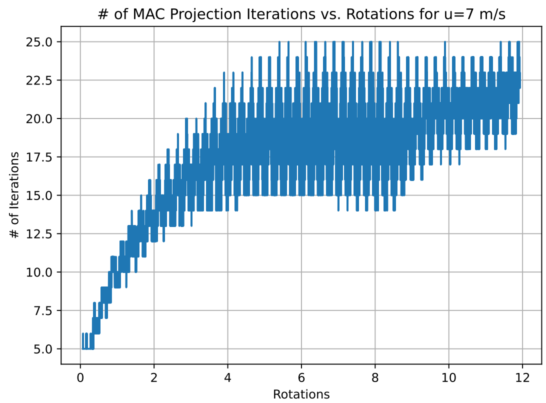
(a) u=7 m/s.

(b) u=12 m/s.

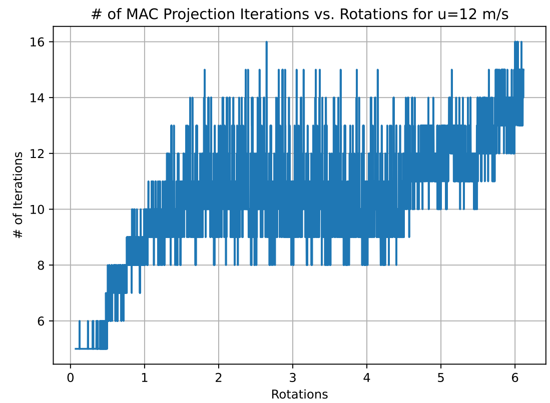
(c) u=15 m/s.

(d) u=20 m/s.

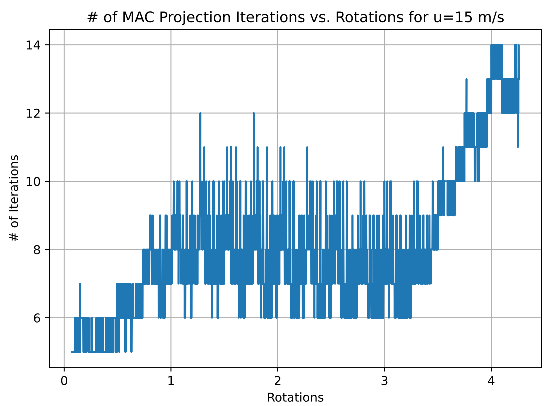
FIG. 9: Final SDR residuals at each rotation



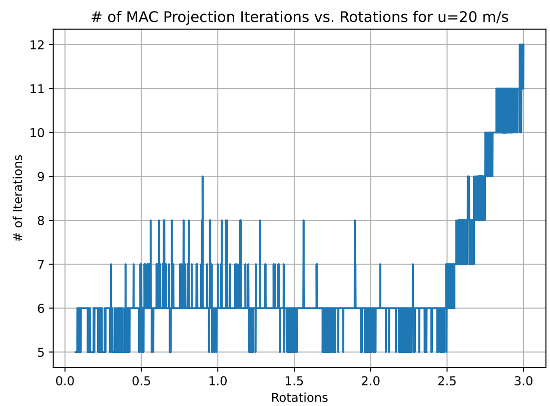
(a) u=7 m/s.



(b) u=12 m/s.

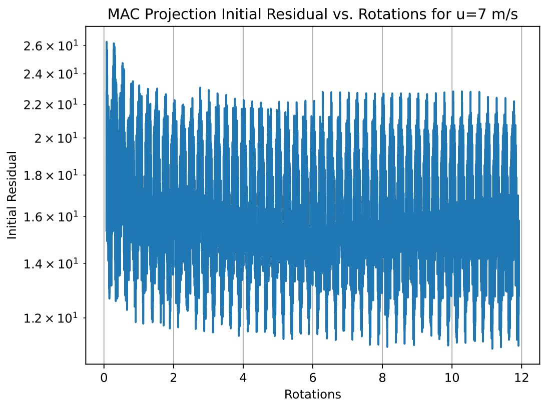


(c) u=15 m/s.

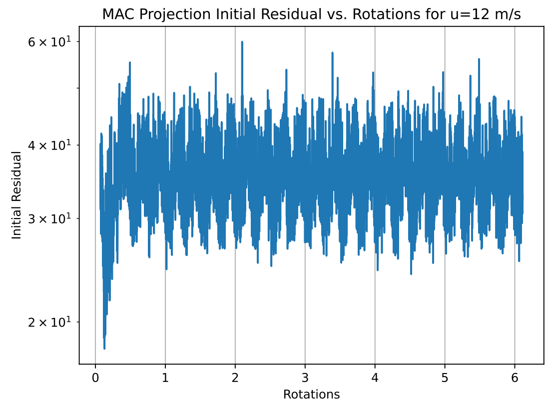


(d) u=20 m/s.

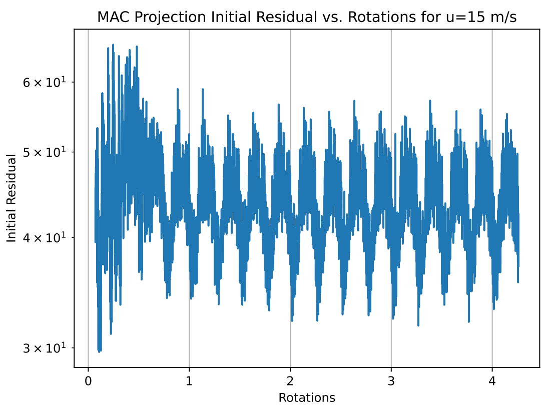
FIG. 10: Number of MAC projection iterations at each rotation



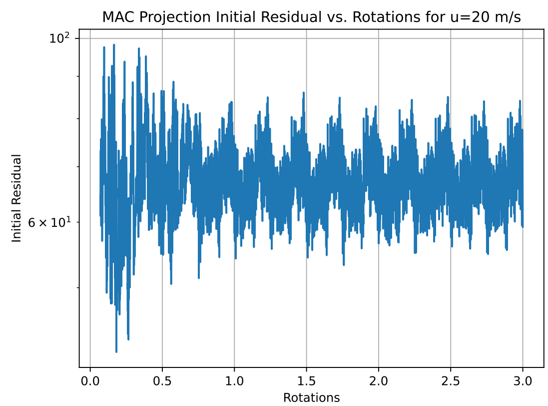
(a) u=7 m/s.



(b) u=12 m/s.

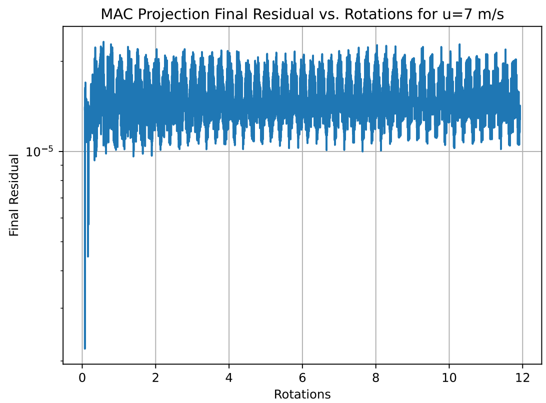


(c) u=15 m/s.

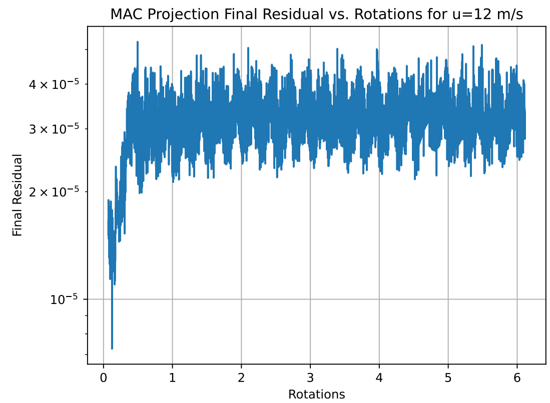


(d) u=20 m/s.

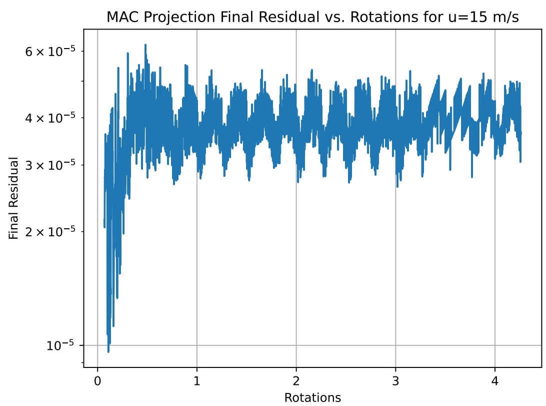
FIG. 11: Initial MAC projection residual at each rotation



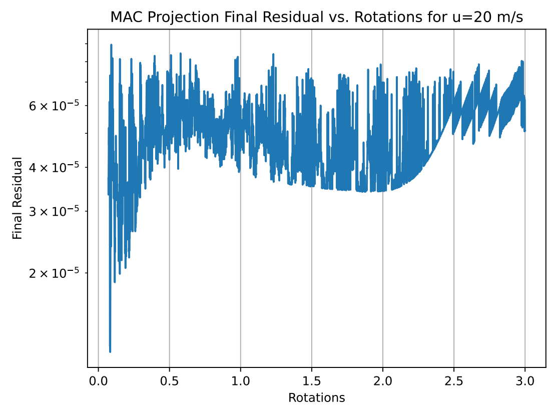
(a) u=7 m/s.



(b) u=12 m/s.

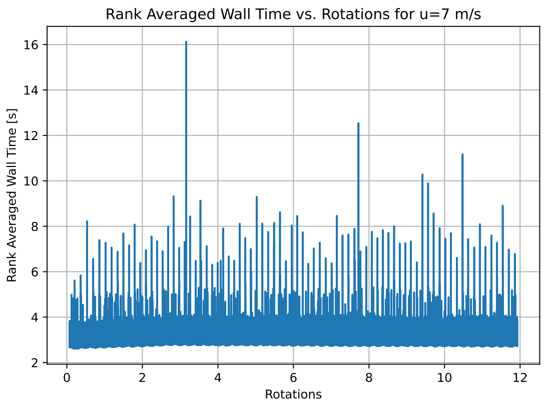


(c) u=15 m/s.

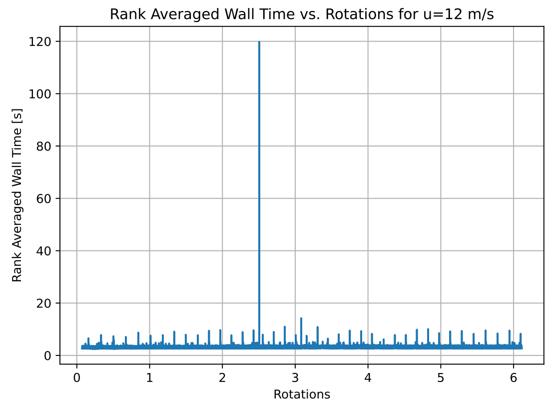


(d) u=20 m/s.

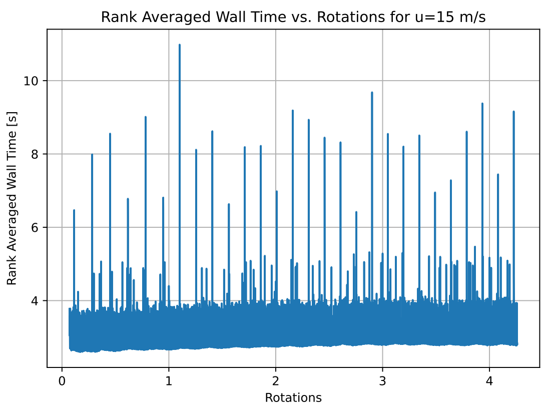
FIG. 12: Final MAC projection residual at each rotation



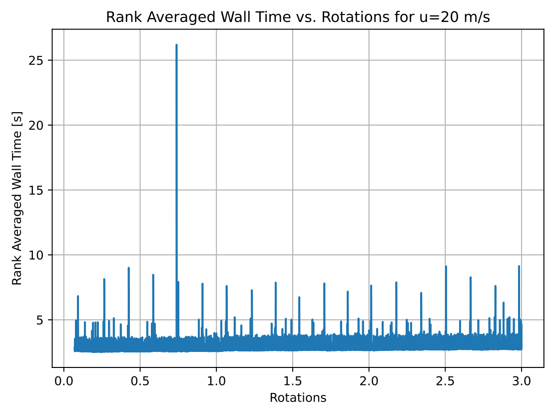
(a) u=7 m/s.



(b) u=12 m/s.



(c) u=15 m/s.



(d) u=20 m/s.

FIG. 13: Rank averaged wall time at each rotation

REFERENCES

[1]F. R. Menter, M. Kuntz, and R. Langtry, "Ten years of industrial experience with the sst turbulence model," Turbulence, Heat and Mass Transfer **4**, 625–632 (2003).

[2]F. R. Menter, "Two-equation eddy-viscosity turbulence models for engineering applications," AIAA Journal **32**, 1598–1605 (1994).