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GAṆANAM (गणनम्)

HIGH PERFORMANCE *COMPUTING* NEWSLETTER

INSTITUTE FOR PLASMA RESEARCH, INDIA

Magnetic Island Coalescence Driven Magnetic Reconnection and Role of Shear Flow

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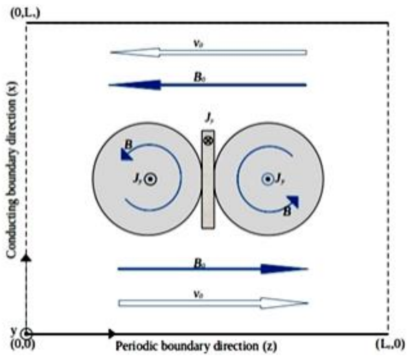


Figure 1: A schematic diagram of coalescing islands, reconnecting current sheet and initially applied shear flow.

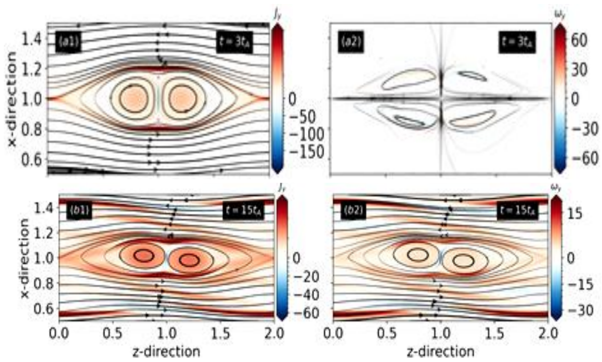


Figure 2: Colormap of J_y along with streamlines of magnetic field and colormap of vorticity (ω_y) along with streamlines of velocity profiles for v_0 = 0 (top) and v_0 = 1.4v_A (bottom).

In the early 1960s, the concept of "magnetic reconnection" (MR) was proposed to explain some of the most energetic phenomena within our solar system such as solar flares, coronal mass ejections, and geostorms. MR converts stored magnetic energy in plasma into various forms, like bulk plasma kinetic energy, generation of high energetic particles and plasma heating. To understand this [1], Peter Sweet and Eugene Parker introduced a theoretical model and proposed that the MR occurs at the thin current sheets in plasma. On both sides of these current sheets, two regions of magnetic field anti-parallel to each other are observed (see the current sheet at the center of Fig. 1). In the presence of finite plasma resistivity, the anti-parallel magnetic field diffuses into the current sheet and undergo MR. Based on a single-fluid magnetohydrodynamic (MHD) theory, the Sweet-Parker (SP) model calculates the rate of this energy conversion or the "reconnection rate" in terms of plasma collisionality or plasma resistivity. Subsequently, numerous analytical and numerical simulation studies (using different models like two-fluid, kinetic, Vlasov, gyrokinetic, etc.) have been carried out to understand the effect of different plasma parameters such as density, temperature, magnetic field intensity, guide field, parallel and perpendicular shear flows with respect to MR. Here, in this article, the effect of shear flow on MR has been discussed using an incompressible MHD model. Our study focuses on the magnetic island coalescence problem [2-3]. It employs an initial magnetic field profile with two magnetic islands and a shear flow profile parallel to the asymptotic magnetic field as shown in Fig. 1. Varying shear flow amplitudes (v_0) from sub-Alfvenic to super-Alfvenic values and length scales (a_v) are considered, along with intermediate plasma resistivity ($\eta=10^{-4}$), ensuring a valid single-fluid MHD model.

In this study, we utilize the ***BOUT++ framework*** [4] to investigate the viscoresistive Reduced-MHD equations [5-6] in a 2D Cartesian grid. This framework offers scalability and flexibility for solving numerous coupled partial differential equations in 3D. We employ fine grid structures to effectively resolve thin current sheets. We used Dirichlet boundaries at x = 0 and 2, employing periodic boundaries in the z-direction with FFTW. A fine, uniform grid (dx = 0.001, dz = 0.0005 corresponding to Nx = 2048 and Nz = 4096) accurately resolves the thin current sheet (Fig. 1) on 32 cores in 40 hours. In this scenario, the magnetic islands carry current in parallel, resulting in a Lorentz force attraction between the current filaments. This interaction forms a thin current sheet at the X-point. When finite dissipation is introduced, the frozen-in condition breaks down within the current sheet, permitting plasma to cross the X-point freely, thus initiating MR. This enables both islands to approach and merge into a larger, singular island. The reconnection rate is calculated as the time-varying reconnecting electric field ($E_y(t) = -\eta J_y(t)|_{X\text{-point}}$, where $J_y(t)$ signifies the y-directional current density). The maximum of E_y denotes the peak reconnection rate.

> ***"Using the ANTYA resources, we explored the impact of shear flows on magnetic island coalescence-driven MR, shedding light on phenomena in astrophysical and laboratory plasma physics."***

A large number of previous studies have reported the role of shear flow on MR during the tearing like instability in long Harris current sheet. These studies unveiled a reconnection rate scaling as $E_r = E_0 (1-v_0^2/v_A^2)$, associating Er with v_0 and E_0 as the reconnection rate at zero flow. When v_0 surpasses the Alfven velocity (v_A) [7], reconnection ceases (E_r = 0), and the system experiences the Kelvin-Helmholtz instability. However, in our magnetic island cases, even for super-Alfvenic flows, the reconnection rate remains nonzero, thanks to coalescence instability suppressing KHI (Fig. 3). Additionally, the presence of shear flow tilts the current sheet compared to the no-shear-flow case (Fig. 2). As shear flow amplitude increases, the peak reconnection rate (peak E_y) decreases, but the scaling diverges from previously reported findings.

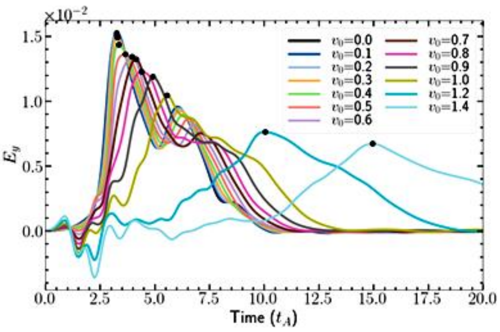


Figure 3: Time variation of Ey for different shear flow amplitude v_0.

For the present simulation study, ***ANTYA*** cluster is used. The parametric scan consisted of approximately 50 runs, with each job employing 32 cores for 40 hours. In summary, this work emphasizes the impact of shear flow on magnetic island coalescence-driven MR. Since magnetic islands are commonly observed in various astrophysical and laboratory settings, these results have broad applicability to diverse plasma scenarios. For detailed results, please refer to Ref. [5-6].

References:

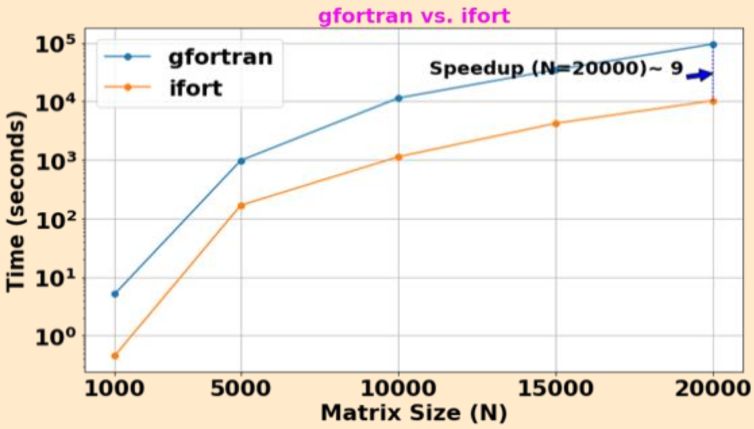
1. *E. Priest and T. Forbes, Magnetic Reconnection: MHD Theory and Applications (Cambridge University Press, Cambridge, England, 2000).*
2. *V. Fadeev, I. Kvabtskhava, and N. Komarov, Nucl. Fusion 5, 202 (1965).*
3. *J. M. Finn and P. Kaw, Phys. Fluids 20, 72 (1977).*
4. *B. D. Dudson et al., J. Plasma Phys. 81, 365810104 (2015).*
5. ***J. Mahapatra**, A. Bokshi, R. Ganesh, and A. Sen, Phys. Plasmas 28, 072103 (2021).*
6. ***J. Mahapatra**, R. Ganesh, and A. Sen Plasmas 29, 112107 (2022).*
7. *P. Cassak, Phys. Plasmas 18, 072106 (2011).*

Optimizing Code Performance through Compiler and Library Selection: A Matrix Multiplication Case Study

The choice of compiler and external libraries can significantly impact code execution speed. This article delves into this crucial aspect of code optimization by comparing two renowned compilers and two well-known external libraries. **The goal is to analyze their influence on matrix multiplication performance, a fundamental mathematical operation with widespread applications in computational sciences.** For this comparative study, we have selected a matrix multiplication code written in the Fortran language. All source and output files are accessible on GitHub (*https://github.com/deepakagg123/External_library_performance.git*).

Case-1: gfortran vs. ifort

The choice between GNU Compiler Collection's gfortran and Intel's ifort, the Intel Fortran Compiler, is critical for Fortran code performance. The following figure compares execution times of a Fortran matrix multiplication code with gfortran (gcc/11.2.0) and ifort (intel-2020), both available in ANTYA.



Achieving a 9-fold speedup is notable. To contextualize, a code taking 5 hours with ifort would extend to about 2 days when compiled with gfortran.

Case-2: BLAS vs. Intel MKL

Numeric libraries like Basic Linear Algebra Subprograms (BLAS) and Intel Math Kernel Library (MKL) are pivotal for boosting code performance. We empirically evaluate matrix multiplication's efficiency using both libraries. The following figure contrasts execution times: a Fortran matrix multiplication code with BLAS (blas/gcc/64/3.8.0) and gfortran, and another with Intel MKL (intel18/mkl) and ifort.

A significant ~150-fold speedup is impressive. Contextually, BLAS code taking 10 days executes in just ~1.6 hours with Intel MKL.

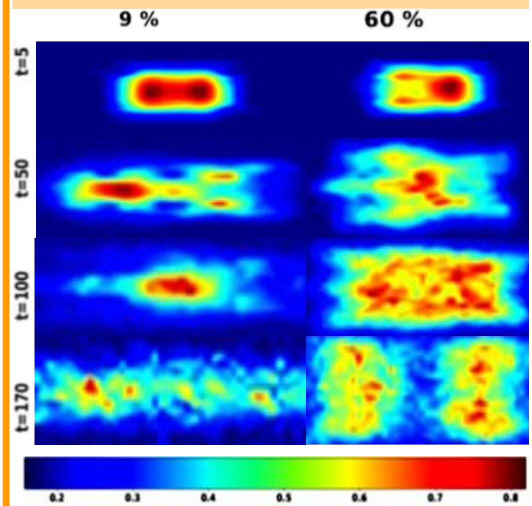
ANTYA UPDATES AND NEWS

1. New Packages/Applications Installed

Modules list remains the same for this month. To check the list of available modules:
$ module avail –l

HPC PICTURE OF THE MONTH

Subcritical Transition to Turbulence



Pic Credit: **Suruj Kalita**

This figure explains the subcritical transition to turbulence in a plane Couette flow taken in a 3D Yukwa liquid in the XZ plane. Subcritical transition to turbulence is abrupt and discontinuous; often takes place with the co-existence of laminar-turbulent regions. It occurs when a finite amplitude perturbation is added to the system. For 9% perturbation strength, the system relaxes to laminar state upto t = 170. However, at 60 % perturbation strength, turbulent patches are observed to invade the laminar region and the turbulence sustains for a longer period of time. As the turbulence fraction is higher for 60 % case, we consider the 60% case as an example of subcritical transition to turbulence. (S Kalita, R Ganesh, Phys. Fluids 33, 095118; https://doi.org/10.1063/5.0060089)

The simulation is performed with in-house multi-node, multi-gpu MPMD-3D code with mpi version taking 8 hour on 800 cores and multi-gpu taking 20 hours on 4 P100 GPU cards across 2 nodes.

TIP OF THE MONTH

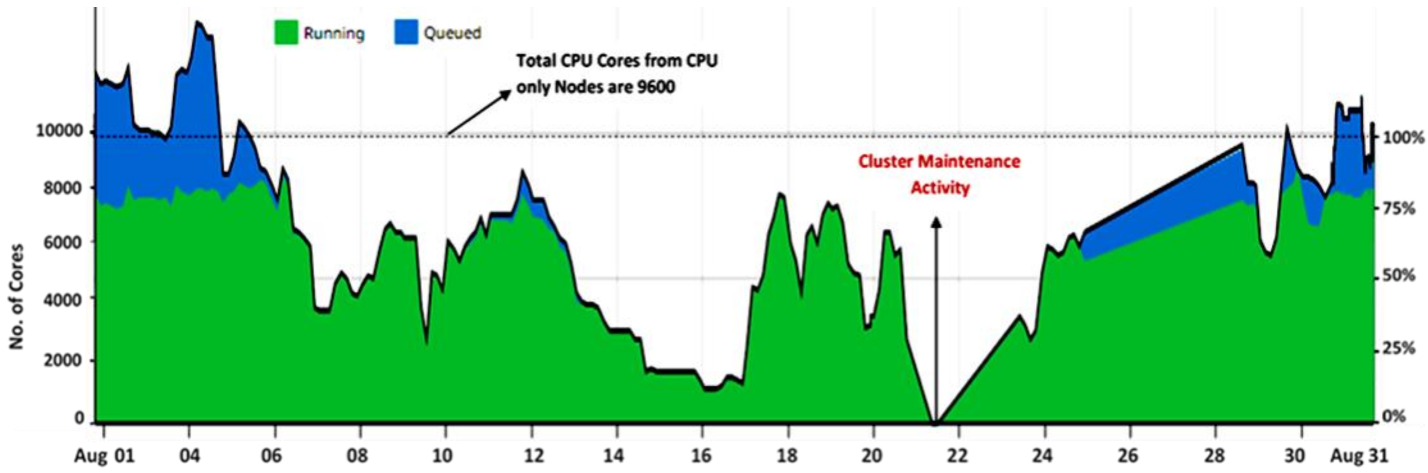
Checking Hyperthreading Jobs Leading to Compute Node Overloading

If the load average exceeds the number of available physical cores which are 40 on all compute nodes, it could be an indicator of thread overloading. The output of the following command represents the load averages for the last 1, 5, and 15 minutes, followed by the no. of currently running processes and the total no. of processes with PID of the most recently created process at the end.

```
[user@cn001 ~]$ cat /proc/loadavg
42.01 41.92 41.84 41/3313 204949
```

ANTYA Utilization: AUGUST 2023

ANTYA Daily Observed Workload



Other Recent Work on HPC (Available in IPR Library)

Electromagnetic analyses for Indian Tokamaks SST-1 and ADITYA	**Alli Amardas**
Role of system size on magnetic island coalescence driven magnetic reconnection in presence of shear flow	**Jagannath Mahapatra**
Force-free magnetic island coalescence instability and Shear flow effects	**Jagannath Mahapatra**
Development of a Monitoring Dashboard for High Performance Computing (HPC) Cluster to Enable Better Utilization of the Resources	**Deepak Aggarwal**
Excitation of cylindrical and spherical precursor solitons in a flowing dusty plasma: experimental and simulation studies	**Krishan Kumar**
Surface nano-structuring of tungsten with one dimensional WO3-x, by low-energy, very large flux/fluence He+ in the CPP-IPR CIMPLE-PSI	**Mayur Kakati**
Experimental validation of the analytic model for the temporal decay of the density auto-correlation function in a strongly coupled dusty plasma	**Ankit Dhaka**
Kinetic instability of whistlers in electron beam-plasma systems	**Anjan Kumar Paul**

ANTYA HPC USERS' STATISTICS— AUGUST 2023

♦**Total Successful Jobs ~ 2500**

♦**Top Users** (Cumulative Resources):

- **CPU Cores** — **Amit Singh**
- **GPU Cards** — **Shishir Biswas**
- **Walltime** — **Sapna Mishra**
- **Jobs** — **Shrish Raj**

Acknowledgement

The HPC Team, Computer Division IPR, would like to thank all Contributors for the current issue of *GAṆANAM*.

On Demand Online Tutorial Session on HPC Environment for New Users Available
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