Impact of Plasma Flows on Tokamak Instabilities - An Investigation

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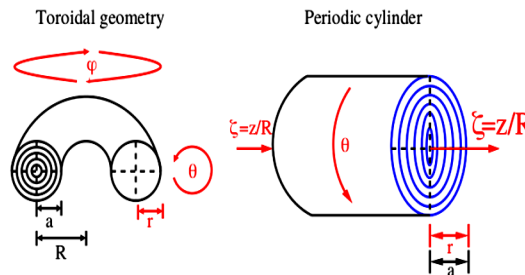*Email: jervis.mendonca@ipr.res.in*

Figure 1: A schematic representation of the geometry of a tokamak [6]. Here, R = Major Radius, a = Minor Radius and r = radial position.
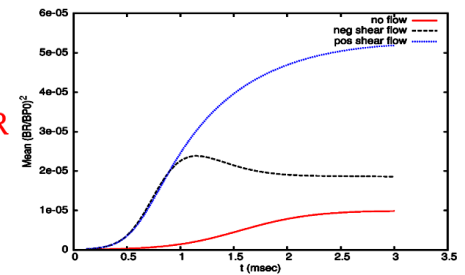

Figure 2: Comparison of nonlinear evolution in absence of flow and different directions of flow.
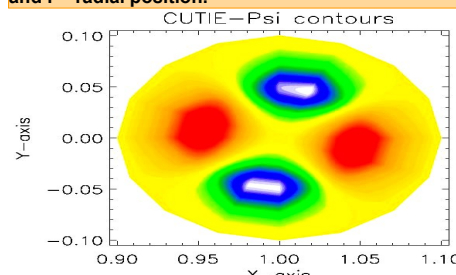

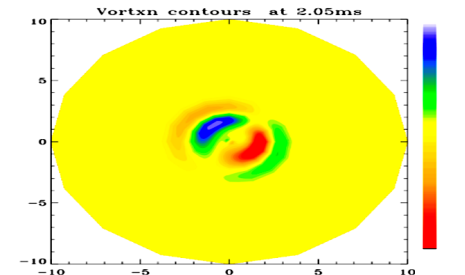Figure 3: Contour plot of the (2,1) tearing mode as obtained from the CUTIE code.

Figure 4: Vorticity contours of the (1,1) kink mode as obtained from the CUTIE code.

The word tokamak is a Russian acronym, "**to**roidalnaya **ka**meras **ma**gnitnymi **ka**tushkami", meaning toroidal chamber with magnetic coils, and is a literal description of the device. The strongest magnetic field in a tokamak is in the toroidal direction around the full length of the torus. This alone is however insufficient to contain the plasma, whose positively and negatively charged particles, although following magnetic field lines, would drift vertically in opposite directions due to the non-uniform toroidal magnetic field. Hence, a poloidal magnetic field is required to prevent particle motion resulting in this effect. The combination of these two magnetic fields produces helical nested (pseudo) magnetic flux surfaces around the full domain of the torus. Tokamak is affected by various instabilities, particularly Macro-instabilities (like classical tearing mode, kink etc.) which affect plasma stability, and Micro-instabilities (like micro-tearing mode) that affect plasma transport [1]. An approach to better understand tokamak plasma involves global simulations [2] using two-fluid plasma model and Maxwell's equations. Global simulations account for length scales up to the device size, and a two-fluid theory accounts for the different physics of the ion and electron species by treating them as separate interacting fluids. CUTIE [3] (CUlham Transporter of Ions and Electrons) is a nonlinear, global, electromagnetic, quasi neutral, two fluid simulation code, which allows interaction between plasma property profiles and electromagnetic turbulence that does such simulations.

Here, we have studied a particular class of Macro-instabilities, which are current driven resistive instabilities, such as the tearing and kink instabilities, which play a key role in tokamak plasma stability and disruptions [1,4]. Both tearing and kink instabilities have been numerically studied here. It is well known that flows are a common occurrence in a tokamak, which can be generated intrinsically [5] or induced externally, e.g., by unbalanced NBI injection. We have investigated the effect of equilibrium flows, which known to have a beneficial effect on these instabilities, hence are of great importance experimentally. We began with a simple fluid description of the plasma in a cylindrical

> *"In tokamak operations, flow is an unavoidable aspect of operations. By understanding the nature of flows, we can use it to our advantage and improve performance, confinement and control impurities."*

geometry and present a series of numerical computation results carried out with the code CUTIE. We have used grids from 101x9x5 to 1801x5x5 for the time evolution and resolvent versions of the CUTIE code. The methods used for defining the input parameters have been modified to run the code for a large number of parameters simultaneously on ANTYA with each parameter run on a single CPU core having a walltime of ~ 1 week. ANTYA allowed us to submit several parametric runs in parallel which was not possible on a workstation. The CUTIE model is based on a cylindrical tokamak with periodic boundary conditions [6] as shown in Figure 1.

The nonlinear evolution of the tearing mode with and without imposed axial flow is shown in Figure 2. The destabilizing trend of the axial sheared flow is seen to extend to nonlinear regimes. However, unlike the linear case, the saturated final state depends on the sign of flow shear. The saturation level of the (2,1) tearing mode magnetic island is higher for a positive sheared axial flow than that of a negative sheared axial flow and both are higher than the no flow reference case. Such dependence of nonlinear saturation level with the sign of sheared flow may be related to the fact that the nonlinear generation of poloidal flow component makes the flow helical. It can be shown that tearing mode stability depends on flow helicity sign, relative to the field helicity. In Figure 3, we show the contour plot of the (2,1) tearing mode having two lobes of the magnetic island. A contour plot is presented in Figure 4, showing a cross section of the device and the magnetic island which will subsequently evolve, and the growth of this island is the instability for (1,1) kink mode. To summarize, we have carried out extensive numerical studies to examine the influence of equilibrium sheared flows on the stability of a (2,1) tearing mode on ANTYA. Our cylindrical geometry investigations, using CUTIE show that in the linear regime pure axial sheared flows have a destabilizing influence while pure sheared poloidal flows tend to stabilize the mode. These effects are independent of the sign of the flows. This is the summary of the work published in [4,7].

References:

1. *John Wesson, D. J. Campbell, Tokamaks , Oxford University Press 2004, 749pp doi:10.1017/ S0022377804003058 .*
2. *Thyagaraja A., et al., Global twofluid turbulence simulations of l-h transitions and edge localized mode dynamics in the compass-d tokamak Phys. Plasmas 17 042507 (2010).*
3. *Thyagaraja A., Numerical simulations of tokamak plasma turbulence and internal transport barriers Plasma Phys. Control. Control. Fusion 42 255–69 (2000).*
4. *J. Mendonca et al "Visco-resistive MHD study of internal kink (m = 1) modes", Physics of Plasmas 25, 022504 (2018).*
5. *J. Rice, et al., " Inter-machine comparison of intrinsic toroidal rotation in tokamaks," Nucl. Fusion 47(11), 1618 (2007).*
6. *J. G. I. Douglas, Linear stability analysis of non ideal tokamak plasma fluid models. PhD thesis, University of Sheffield, 2012.*
7. *J. Mendonca et al "Simulation of the internal kink mode in visco-resistive regimes" Nuclear Fusion 60 046004 (2020).*

Running MATLAB Programs on ANTYA
Part-2: Running MATLAB in Batch Mode (Non-interactive)

There are times when you need to submit single or multiple non-interactive MATLAB jobs using the MATLAB scripts having MATLAB commands and saving the output/image file after the job is complete without starting the MATLAB GUI. This part-2 of the MATLAB series demonstrates how MATLAB batch jobs can be submitted using the PBS Scheduler for two examples, one for matrix multiplication and other for plotting.

What is a MATLAB Batch Job?

You can run your MATLAB codes/scripts on ANTYA compute nodes using the PBS scheduler job scripts but you can't use GUI (Graphical User Interface) on compute nodes.

When to use Batch Job for MATLAB Runs?

For the long production jobs using MATLAB in a non-attended fashion, it is recommended that MATLAB should be run on the compute nodes of ANTYA using the PBS job scripts. This will allow you to submit several runs in parallel if required. This will help to minimize the MATLAB frontend license requirements.

How to Implement in ANTYA?

Example-1: Let us suppose you need to do a matrix multiplication and for that, you have been using GUI mode. Now if you need to submit the same as a batch job, a MATLAB script is needed (.m file) having MATLAB commands which were used in matrix multiplication line by line. This script will be used to launch the batch job as demonstrated here:

```
# Check the matrix multiplication MATLAB script (.m file)
[user@login1 ~]$ cat matrix_multiplication.m

n = 5000;        % matrix size
A = rand(n);     % random matrix A
B = rand(n);     % random matrix B
tic              % Elapsed time using tic
C = A * B;       % matrix multiplication
time=toc;        % calculate the elapsed time using tic and toc
fprintf(['Processing time: ' num2str(time)]);
save('C.mat', 'C')


# Here is the PBS job script used for matrix multiplication in MATLAB. For us-
ers not familiar with PBS job script, please refer issue13 of GANANAM.
[user@login1 ~]$ cat job_matlab.sh

#!/bin/bash
#PBS -q serialq
#PBS -N test_M
##change the ncpus number to run the job in implicit parallel
#PBS -l select=1:ncpus=4
#PBS -l walltime=00:30:00
#PBS -j oe

## Load the matlab module
module load MATLAB/2016a

cd $PBS_O_WORKDIR

## Run MATLAB to execute the matrix multiplication file.

matlab -nodisplay -nosplash -r  "matrix_multiplication, exit"
exit 0


# Submit the batch job
[user@login1 ~]$ qsub job_matlab.sh
```

ANTYA UPDATES AND NEWS

1. New Packages/Applications Installed

⇒ **OpenMPI new version**
This package has been installed to resolve the multi nodes run issues faced in Nek5000 code with other available MPI modules.
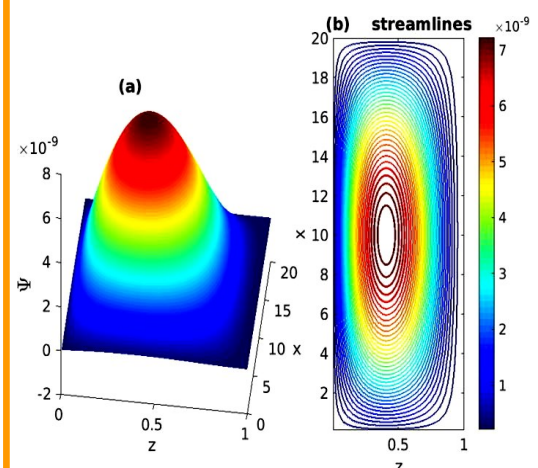**openmpi/4.0.1-new**

⇒ **Nek5000 Code**
A fast and scalable high-order solver for CFD problems has been successfully tested on ANTYA. Further scaling testing being carried out.

HPC PICTURE OF THE MONTH

2D Surface Plot Showing Vortex Structure and Streamlines in the Dust Flow Dynamics

Pic Credit: **Prince Kumar**

The figure shows the 2-dimensional equilibrium dust vortex flow (a) dust stream function (b) dust streamlines in the normalized units, which is driven in the absence any non-conservative fields or dust charge variation. The emergence of macroscopic dust vortex flow happens when there is a gradient in magnetic field. Ψ has units (UL), where U= 10^5 cm/sec (velocity) and L=10 cm (length).
[Ref: P. Kumar and D. Sharma, Phys. Plasmas 27, 063703 (2020). https://doi.org/10.1063/5.0010850]

The figures are generated in MATLAB with data obtained from in-house developed FORTRAN code on ANTYA.

TIP OF THE MONTH

Did you know that you can check the CPU percent usage of your running jobs and check if your code is running on as many cores you have requested in the job script?

```
[user@login1 ~]$ qstat –f jobID
        | grep cpupercent
```

(HPC Article Continues…) Part-2: Running MATLAB in Batch Mode (Non-interactive)

Example-2: For the MATLAB jobs in which you need to plot something, you may wonder how that can be achieved in batch mode. The process is more or less the same as followed in example-1. We just have to add the command in the .m file for saving the plot in some image format.

```
# Example MATLAB script (.m file) for plotting
[user@login1 ~]$ cat testplot.m
x = [0 1];
y = [0 1];
plot(x,y);
print -dpng testplot.png          % As an output, testplot.png will be saved.

# Here is the PBS job script used for matrix multiplication in MATLAB. For users non familiar with PBS job script, please re-
fer issue13 of GANANAM.
[user@login1 ~]$ cat job_matlab.sh
#!/bin/bash
#PBS -q serialq
#PBS -N test_M_plot
#PBS -l select=1:ncpus=1
#PBS -l walltime=00:30:00
#PBS -j oe

## Load the matlab module
module load MATLAB/2016a

cd $PBS_O_WORKDIR
## Run MATLAB to execute the matrix multiplication file.
matlab -nodisplay -nosplash -r "testplot, exit"
exit 0

# Submit the batch job

[user@login1 ~]$ qsub job_matlab.sh
```

Other Recent Work on HPC (Available in IPR Library)

Title	Author
Gyrokinetic simulation of electrostatic microturbulence transport in ADITYA-U tokamak	**SARVESHWAR SHARMA**
2D evolution of shear flow driven magnetic reconnection in the island coalescence instability	**JAGANNATH MAHAPATRA**
Dynamics of a novel quasi-recurrent flow in 3D MHD plasmas	**SHISHIR BISWAS**
Amalgamation of exergy analysis and experimental methods in optimization of regenerator packing pattern in a pulse tube cryocooler for no-load at 140 K temperature	**ROHAN DUTTA**
Development of HTS tape double pancake winding machine	**PIYUSH RAJ**
Edge Biasing and its Impact on the Edge and SOL Turbulence	**VIJAY SHANKAR**
Radiation Analysis and Design Study of Cooling and Baking Scheme for SMARTEX-C	**RITESH KUMAR SRIVASTAVA**

ANTYA HPC USERS' STATISTICS— JANUARY

♦ **Total Successful Jobs — 3295**

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

⇒   **CPU Cores — Jagannath Mahapatra**

⇒   **GPU Cards — Swapnali Khamaru**

⇒   **Walltime — Anjan Paul**

⇒   **Jobs — Swapnali Khamaru**

Acknowledgement

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