Application to Graduate with Honors

Student ID: 810-05-7645

I plan to defend in: FALL / [✓ SPRING] of 20 09

Personal Information:

Name: Benjamin Tyler Brown

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I am an: IN-STATE / [✓ OUT-OF-STATE] student

Academic Information:

☒ **I plan to graduate with *Departmental Honors* in:** Physics

☐ **I plan to graduate with *General Honors***

Cumulative GPA: 3.821

Please attach a brief **PROSPECTUS, BIBLIOGRAPHY,** and **TIMELINE** of your thesis project to this application. When summarizing your work, consider the following:

- What is the problem you are investigating?
- What is the hypothesis you are testing?
- What is the focus of your study?
- What is your goal in this study?

Primary thesis advisor:	Name: Tobin Munsat	Dept: Physics
List the other members of your committee:	Name: Robert Culp	Dept: Aerospace Engineering
	Name: Scott Parker	Dept: Physics
	Name: John Cumalat	Dept: Physics
	Name:	Dept:

Departmental and General Honors Committee Checklist:

Applicant has a total of at least three committee members.
At least one Honors Council Representative is included on committee.
At least one committee member from an outside department.

APPLICATION CONTINUED ON BACK OF THIS SHEET

Please initial if you are pursuing Departmental Honors:

BTB I have consulted with my department and have completed (or am completing) the requirements they have established.

For Honors Council Representative:

I have met with applicant and approve him/her for departmental honors.

Printed Name: John Perry Cumalat Signature: John Perry Cumalat

Please initial if you are pursuing General Honors:

_____ I have completed (or am completing) the requirements for graduating with General Honors.

Please list the courses you have or are taking toward General Honors:

_______________ _______________

_______________ _______________

For General Honors Council Member:

I have met with applicant and approve him/her for general honors. I agree to be on his/her defense committee.

Printed Name: _______________ Signature: _______________

For the Thesis Advisor:

I have met with the applicant to discuss the proposed work and agree to provide the necessary help and direction for this thesis project.

Printed Name: TOBIN MUNSAT Signature: _______________

For the Student:

I have read the requirements for graduating with honors at the University of Colorado. I also understand that my designation will be sent to the CU email address that I have provided and will not be given out over the phone.

Signature: _______________ Date: 12/4/08

For additional graduation information including requirements, guidelines and deadlines, you can download them online at www.colorado.edu/honors

Velocity Field Analysis of Edge-Turbulence Structures in NSTX

Benjamin T. Brown[1]

Prospectus

Originally designed in the mid-20th century, the tokamak is still widely regarded as the most successful mechanism for confining thermonuclear fusion plasmas. Figure 1 shows a schematic of a tokamak with its toroidally confined plasma, followed by a depiction of the National Spherical Torus Experiment (NSTX) at Princeton University. The tokamak uses a combination of magnetic fields, both externally-applied and internally-created via an externally driven plasma current (white arrow in figure), to confine the hot plasma. The resulting twisted magnetic field lines (black arrows in figure) form closed magnetic flux surfaces that confine the plasma particles which tend to orbit local magnetic field lines. The major limitation of this device lies in the generation and propagation of short-scale instabilities in the confined plasma which lead to turbulence near the outermost closed flux surface (the separatrix). This turbulence generates and expels spatially localized structures of increased plasma density, commonly called "blobs", significantly reducing the overall energy confinement of the tokamak [2,4,8].

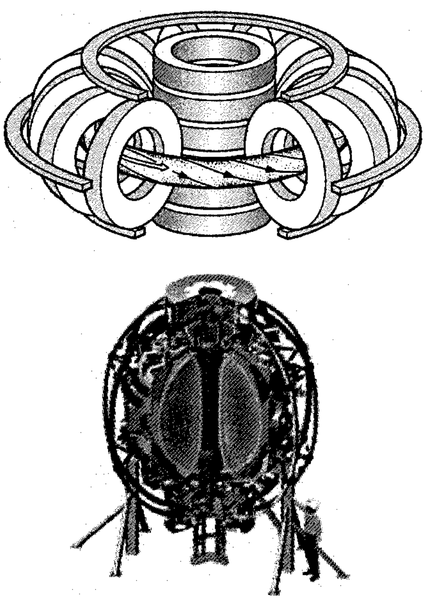

Figure 1: A general tokamak schematic (top) and depiction of NSTX (bottom).

In recent years, a collaborative effort to observe the appearance and motion of blobs at the plasma edge in tokamaks has led to the development of the Gas Puff Imaging (GPI) diagnostic [2,8]. In NSTX, the GPI diagnostic consists of injecting minute amounts of neutral Helium in a sheet perpendicular to the local magnetic field and observing the gas along a sightline parallel to the field lines (see Figure 2) with a fast framing camera. In quantities too low to significantly effect the confined plasma, the neutral gas emits characteristic spectral line radiation that is recorded by the camera (64×64 pixel images, ~1.5 cm spatial resolution, 250,000 frames per second, 300 frames per dataset) [3]. The plasma autocorrelation time in NSTX is ~16 μs, approximately four times longer than the time between GPI frames. Models of the intensity of the *He I* line emission using the DEGAS-2 simulation show that the intensity of the line (I) can be parameterized by the local plasma electron number density (n_e) and temperature (T_e) [8]:

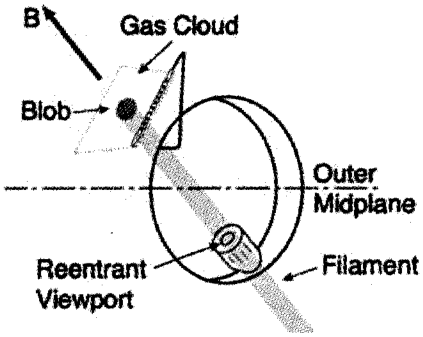

Figure 2: NSTX GPI Instrument Diagram.

$$I(\vec{x},t) \propto n_e(\vec{x},t)^{0.5}\, T_e(\vec{x},t)^{0.7}$$

Equation 1: He I *line emission intensity in NSTX.*

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A variety of techniques can be applied to the sequences of emission intensity images from the GPI diagnostic to derive spatially and temporally resolved velocity fields which approximate the bulk fluid flow of the plasma, orthogonal to local magnetic field lines. These velocimetry algorithms can be used to study the evolution of the plasma edge turbulence and its effect on the tokamak's energy confinement. Our research involves the development of several unique algorithms for the derivation of velocity profiles from a variety of NSTX GPI datasets. Currently, we employ the Hybrid Optical Flow Velocimetry (HOP-V) code which combines optical flow velocimetry and pattern matching algorithms to create smooth, spatially "dense" velocity fields that approximate the field which deforms each image frame to the next. Validated against a variety of artificial GPI datasets created with known deforming velocity fields, the HOP-V code has been shown to reliably extract plasma fluid velocities of up to 6 km/s, even in highly sheared cases [3]. The HOP-V code becomes less reliable for faster fluid flows due to the "aperture problem", an inherent limitation of finite differencing optical flow algorithms that prevents extraction of velocity perpendicular to the image gradient. HOP-V is also unable to reliably derive velocity fields for regions of low image intensity in the GPI datasets [3]. Furthermore, HOP-V is unable to preserve common fluid flow properties which we would like the derived fields to exhibit, one of which is vanishing divergence.

Recently, I have developed a new routine which derives dense velocity fields of any desired uniform divergence (including zero divergence) using optical flow techniques and an algorithm for nonlinear optimization. The new technique is based on a collection of papers on optical flow velocimetry by J. Yuan and C. Schnörr [6,7]. I first represent the image set and time-resolved velocity fields on a discrete spatial and temporal grid for scalar and vector functions. Next, I discretize a set of differential operators (including the gradient, divergence, and curl operators) that act on these scalar and vector functions. The differential operators are made to preserve similar identities (e.g. the Gaussian integral identity) as their continuous counterparts. I then represent the derived velocity field as a sum of a divergence-free field and curl-free field, each represented as a gradient of a separate scalar potential (Helmholtz decomposition) [6,7]:

$$\vec{v} = \vec{\nabla}\psi + \vec{\nabla}\phi\,,\ \ \vec{\nabla}\times\left(\vec{\nabla}\psi\right) = 0,\ \ \vec{\nabla}\cdot\left(\vec{\nabla}\phi\right) = 0$$

Equation 2: The Helmholtz decomposition.

By minimizing a set of objective functionals and an augmented Lagrangian that favor vanishing divergence as well as smoothness of the derived velocity field, I am able to find the "best" optical flow field solution for a given set of images. Because the derived velocity fields are smoothed by penalizing a linearized norm of the variation in the field, we call this new technique the "linear" algorithm. Figure 3 shows the results of a preliminary test of the linear algorithm on a set of images prepared with an imposed divergence-free velocity field with significant curl.

To investigate the link between plasma blob propagation and E×B drifts in the edge region of NSTX, we are using data from the BOUT 3-D plasma turbulence simulation code (developed at LLNL) to create artificial GPI datasets mimicking NSTX. The BOUT simulation data provides diagnostic information (local magnetic field, electron density, etc.) that is not available in the NSTX GPI datasets [1,4]. Our goal is to investigate the genesis and evolution of plasma edge turbulence in NSTX under a variety of operating modes, and to compare our results to those obtained from the BOUT artificial GPI datasets. We hope to be able to draw conclusions about the reliability of our velocity derivation routines in recovering the E×B drift velocities in the edge regions of tokamak fusion plasmas.

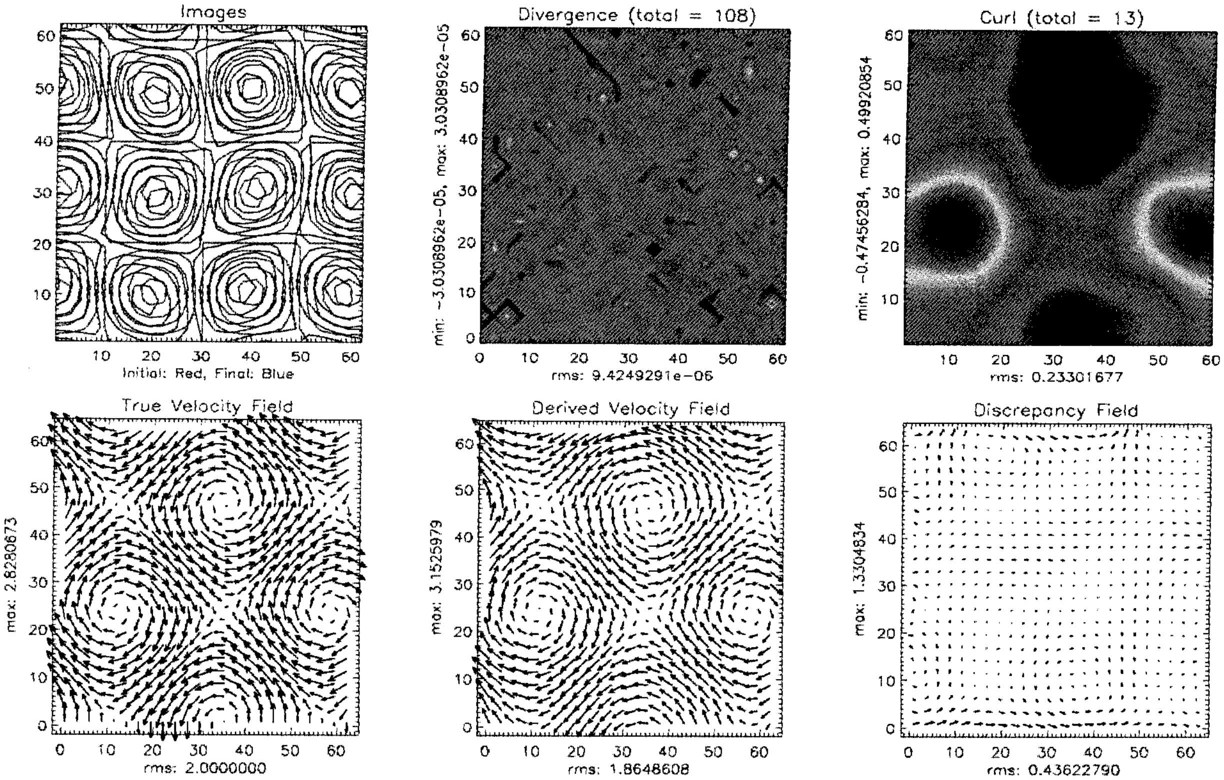

Figure 3: Preliminary results of a test of the linear algorithm. (Top-left) Contour plot of the artificial images with initial in red and final in blue. (Top-center and right) Contour plots of the divergence and curl of the derived velocity field. (Bottom-left) The imposed divergence-free velocity field. (Bottom-center) The derived velocity field. (Bottom-right) The discrepancy field found from subtracting the derived field from the true field. The derived velocity field was calculated using an IDL routine on a personal laptop computer in under 1.5 minutes.

Timeline

Spring 2008

- January-February: Develop initial BOUT conversion to artificial GPI scheme in IDL.
- March-April: Investigate “sweep” method for derivation of full optical flow field.
- April-May: Investigate “linear” algorithm as proposed by Yuan and Schnörr.
- May: Begin development of IDL routine for linear algorithm.

Fall 2008

- August-September: Finish development of IDL routine that implements linear algorithm, initial testing.
- September-October: Develop new BOUT conversion scheme using tricubic interpolator.
- October-December: Continue testing on linear algorithm fine tuning, investigation into “total variance” algorithm as proposed by Yuan and Schnörr.
- December: Thesis Proposal Submission, write full description of linear algorithm.

Spring 2009

- January: Begin development of IDL routine that implements total variance algorithm. Continue fine tuning and automation of linear algorithm.
- January-February: Create artificial GPI datasets from new BOUT simulation, detailed analysis of plasma drift velocities.
- February: Finish literature review, working draft of Thesis.
- February-March: Comprehensive comparison of partial optical flow, HOP-V, and linear algorithm on artificial GPI set. Assess fundamental reliability of GPI diagnostic and velocity derivation routines for extracting edge-plasma behavior under a variety of conditions.
- April: Honors Thesis Defense.
- April-July: Investigate variation in derived velocity fields for NSTX GPI datasets in Ohmic, L-mode, and H-mode operation.

Bibliography

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