

MAGNETIZED TARGET FUSION DRIVEN BY PLASMA LINERS

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Magnetized target fusion (MTF) attempts to combine the favorable attributes of magnetic confinement fusion (MCF) for energy confinement with the attributes of inertial confinement fusion (ICF) for efficient compression heating and wall-free containment of the fusing plasma. It uses a material liner to compress and contain a magnetized plasma. For practical applications, standoff drivers to deliver the imploding momentum flux to the target plasma remotely are required. Spherically converging plasma jets have been proposed as standoff drivers for this purpose [1]. The concept involves the dynamic formation of a spherical plasma liner by the merging of plasma jets, and the use of the liner so formed to compress a spheromak or a field reversed configuration (FRC).

For the successful implementation of the scheme, plasma jets of the requisite momentum flux density need to be produced. Their transport over sufficiently large distances (a few meters) needs to be assured. When they collide and merge into a liner, relative differences in velocity, density and temperature of the jets could give rise to instabilities in the development of the liner. Variation in the jet properties must be controlled to ensure that the growth rate of the instabilities are not significant over the time scale of the liner formation before engaging with the target plasma. On impact with the target plasma, some plasma interpenetration might occur between the liner and the target. The operating parameter space needs to be identified to ensure that a reasonably robust and conducting contact surface is formed between the liner and the target. A mismatch in the "impedance" between the liner and the target plasma could give rise to undesirable shock heating of the liner leading to increased entropy (thermal losses) in the liner. Any irregularities in the liner will accentuate the Rayleigh-Taylor instabilities during the compression of the target plasma by the liner.

Progress in the theoretical understanding, modeling, and experimental research of these issues are reviewed. Using a linearized stability theory based upon the Orr-Sommerfeld equation governing the growth of a flow perturbation in a shear-flow layer, it is shown that the growth rate of a flow perturbation at the interface of the jets is relatively small for velocity differential between neighboring jets for as much as 20% or more [2]. It is shown that, with the appropriate choice of the flow parameters in the

liner and the target, the impact between the liner and the target plasma can be made to be shockless in the liner or to generate at most a very weak shock in the liner. At the same time, an extremely strong shock propagates through the target, producing the required preliminary heating of the target, thus setting the target at an initially high temperature (of a few 100's eV) on an efficient adiabat for subsequent compression. The first converging and reflected shocks are analyzed using Richtmyer-Lazarus theory for spherically converging shocks. With the target temperature significantly raised by these first two shocks, subsequent shocks are relatively weak, and the compression is nearly acoustic. The acoustic phase of the compression is modeled using Braginskii's transport coefficients for a magnetized plasma, allowance being made for losses due to bremsstrahlung and synchrotron radiation, and assuming ideal flux freezing in the target plasma. With the appropriate choice of operating parameters, the thermal losses are found to be relatively small. To check the overall flow dynamics, 3-D simulations of the merging of the jets and the compression of a target plasma are performed with the Los Alamos SPHINX code which uses a numerical scheme based upon the smoothed particle hydrodynamics (SPH) method [3]. The detailed analysis and modeling of the implosion of a spheromak or an FRC by the plasma liner and of the Rayleigh-Taylor instabilities associated with this implosion remains to be done. Pilot experiments to study the interaction of the jets to form a 2-D cylindrical liner by the merging of 12 plasma jets launched by a circular ring of plasma guns are underway.

- [1] Y. C. F. Thio, E. Panarella, R. C. Kirkpatrick, C. E. Knapp, F. Wysocki, "Magnetized Target Fusion in a Spheroidal Geometry with Standoff Drivers," *Current Trends in International Fusion Research II*, ed. E. Panarella, National Research Council Canada, Ottawa, Canada, 1999.
- [2] J. T. Cassibry, S. T. Wu, Y. C. F. Thio, R. Eskridge, J. W. Smith, M. Lee, C. Dobson, D. Davenport, G. R. Schmidt, "An estimation of tolerances on relative velocities of spherically converging plasma jets," AIAA Paper 2000-2267, 31st AIAA Plasmadynamics and Lasers Conference, Denver, Colorado, June 2000
- [3] C. E. Knapp, Y C Francis Thio, "Computational Modeling of the Dynamic Formation of Plasma Liner by the Merging of Plasma Jets" *Current Trends in International Fusion Research III*, ed. E. Panarella, National Research Council Canada, Ottawa, Canada, 2001.

Speaker: Dr. Y. C. Francis Thio

Ph.D. (Mathematical Physics) 1977, Monash University, Melbourne, Australia. An experimental and computational physicist, Dr. Francis Thio has extensive experience in a number of areas in high energy density physics including fusion energy, pulsed power, electromagnetic launch, and geophysics. He has authored over 60 technical publications in these areas combined and holds four patents. He was among the first researchers to set the record of launching a gram-size projectile reproducibly in the laboratory to orbital velocity (8.2 km/s) using a high-density plasma driven by submegagauss magnetic field in 1986. He has also made fundamental contributions to the analytical and numerical solution of equations of mathematical physics in the area of electromagnetic fields, geophysics and plasma physics. He has undertaken detailed CFD and MHD modeling in the design of high-power pulsed plasma accelerators and

plasma compression. He has performed critical mechanical design of high power electromagnetic equipment using finite-element stress analysis. In instrumentation, he has designed, developed and/or applied magnetic probes, pulsed current probes, electrical (plasma) probes, voltage probes, x-ray probes, and emission spectroscopy, including extensive experience in optoisolation, optoelectronics, digital data acquisition, computer control of experiments, high-speed pulsed electronics, computer data manipulation and analysis.

He has been a Principal Investigator and Program Manager of research programs and grants totaling more than \$40 M. He has undertaken scientific advisory assignments to Los Alamos National Laboratory, Strategic Defense Initiative Office (Pentagon), Defense Nuclear Agency, Naval Air Engineering Center (Lakehurst, NJ), David Taylor Research Center (Annapolis, MD), and SPARTA, Inc. He is an Associate Editor of *Physics Essays*.

Employment:

- 1999 - Present: Leader, Plasma Propulsion, NASA Marshall Space Flight Center.
- 1996 - 1999: Section Head, Mathematics, Massey University, Auckland, New Zealand.
- 1991 - 1996: Associate Professor of Physics, University of Miami, Coral Gables, FL.
- 1988 - 1990: Scientific Associate, Physics Division, Los Alamos National Laboratory.
- 1986 - 1988: Senior Research Physicist, GT-Devices (subsidiary of General Dynamics), VA.
- 1982 - 1986: Senior Research Scientist, Westinghouse R&D Center, Pittsburgh, PA.
- 1978 - 1982: Research Scientist, Aeronautical and Maritime Research Laboratory, a National Laboratory of the Defense Science and Technology Organization, Australia.
- 1977 - 1978: Postdoctoral Fellow, Computer Science, Monash University, Melbourne, Australia.

Visiting Appointments:

- 1997 - 1998: Consultant, Los Alamos National Laboratory.
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- 1994 - 1995: Summer Faculty Fellow, High Energy Plasmas Division, Phillips Laboratory, Kirtland AFB, NM.
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