From: M.J. Schaffer 2008 June 03
To: FESAC Toroidal Alternatives Panel

# Oblate Compact Tori: FRCs and Spheromaks

1. Concept description

The oblate FRC, like the spheromak, is stabilized against global tilt ($n$=1) and low-$n$ external kink instabilities by a nearby conducting wall (and active low-$n$ feedback coils for long pulse). Thus, the tilt stability does not rely on the smallness of $s/E$ like the highly elongated prolate FRC ($s$ = number of ion gyroradii across the outboard minor radius, $E$ = separatrix elongation), and the oblate FRC is free to access the high-$s$ MHD fusion reactor regime. The oblate FRC concept shares the generic fusion reactor advantages of prolate FRCs, including: $\langle\beta\rangle \approx 1$, toroidal magnetic flux surfaces inside a simply connected boundary with no coils linking the plasma, unrestricted plasma exhaust along open magnetic lines, and the possibility (albeit remote) of advanced fuel fusion. The quasi-spherical nuclear core is compact. The spheromak has lower $\beta$ and is not considered an advanced fuel candidate. FRCs have predominantly diamagnetic current and spheromaks predominantly parallel current. The reactor vision comprises: high-flux FRC formation by merging a counter-helicity pair of high-flux spheromaks; further buildup and steady state sustainment by rotating magnetic field (RMF) current drive plus tangential neutral beam heating and seed current drive (FRCs and spheromaks); and possibly direct conversion of exhaust power. For pure spheromaks, one or more high-flux, co-helicity spheromaks would be injected to initiate.

Formation of $E \sim 1$ FRCs by merging spheromaks is robust and is frequently used in TS-3 [1], MRX [2], and SSX [3], including merging spheromaks in a short, $E$ = 0.6 oblate flux conserver in SSX [4]. It is anticipated that the magnitude of spheromak poloidal fluxes can be increased greatly by developing high-flux RFP loop sources [5] similar to but much larger than the half-torus sources of HIT-SI [6]. A proposed experiment, "HIFLUX", meant to test this concept is shown in the figure. Most of the HIFLUX features have been used separately and are quite well understood.

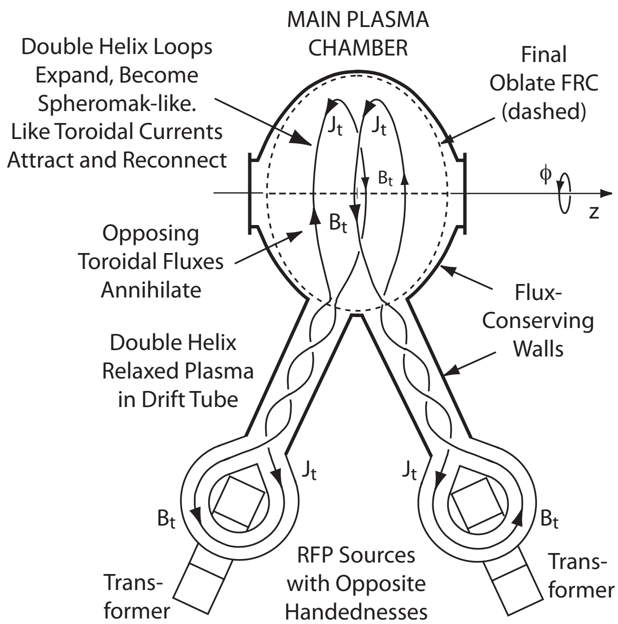
2. Goals for ITER era

The main goal for the ITER era is to determine whether plasma confinement of an oblate FRC or spheromak in the reactor-relevant high-$s$ MHD regime can be good enough for fusion energy applications. In practice this probably means showing that unstable medium and high-$n$ internal modes, including cointerchange, interchange, and lower hybrid modes, do not excessively reduce confinement. Velocity shear might be a useful stabilizer, as shown in the ZaP Z-pinch [7] and tokamaks.

Oblate FRC plasmas can explore the science of plasmas in closed magnetic line configurations with high cross-$B$ diamagnetic current, eventually up to high $s \sim 100$.

3. Scientific and technical issues needed to reach goals

Several obstacles must be overcome to reach the stated goal. It will be necessary to burn through the C and O impurity radiation barriers at high flux. Sustainment is essential. This is because at $\beta \sim 1$, disparities among the loss rates of flux, particles and energy can severely distort plasma profiles in freely decaying FRCs that are constrained to nearly constant volume, as in oblate FRCs kept close to a stabilizing shell. These matters could be addressed in a quasi-spherical HIGHFLUX-like device 1.5~2 m in diameter. RMF can enter through toroidal cuts (1 cut for even RMF, 2 cuts for odd). Cuts are not shown in the figure. RMF-sustained high-flux spheromaks with RMF current drive could be studied, too, perhaps solving the spheromak current drive problem.




4. Facilities and gaps

SSX is the only facility studying oblate FRC physics at present without any large solid object penetrating the CT plasma. SSX attains $s$ up to ~10 but only in cold, dense plasmas at ~5 mWb poloidal flux. SSX is small, 0.5 m in diameter, and there is no space to make an appreciably larger facility. Simultaneous large $s$ and $T$ in oblate FRCs requires larger size, and confinement studies require quasi steady sustainment for at least a few confinement times.

[1] Y Ono et al., 14th IAEA Conf., Würzburg, Germany 1992, (Proceedings, v. **2**, IAEA, Vienna, 1993, 619).
[2] M Yamada et al., 16th IAEA Conf., Montreal, Canada 1996, paper CN-64/CP-19.
[3] C Cothran et al., Phys. Plasmas **10** (2003) 1748.
[4] T Gray, M Brown, M Schaffer, C Cothran, to be presented at Innovative Confinement Concepts Workshop (Reno, NV, 2008 June 24-27).
[5] M Schaffer, J Boedo, "HIFLUX: Oblate FRCs, double helices, spheromaks and RFPs in one system," General Atomics Report GA-A24391 (2003), presented at Innovative Confinement Concepts Workshop (Seattle, WA, 2003 May 28-31); http://web.gat.com/pubs-ext/MISCONF03/A24391.pdf
[6] T Jarboe Fusion Technology **41** (2001) 1423.
[7] J Loverich, U Shumlak, Phys. Plasmas **13** (2006) 082310.