Progress in Configuration Optimization

--- Optimizer Upgrade ---

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Capabilities Enhanced in "Fixed Boundary" Optimizer

- The "fixed boundary" optimizer used here at PPPL has been restructured to
  - take advantage of improved VMEC2000 (Courtesy of S. Hirshman),
  - improve the interfacing with other codes,
  - include more varieties of target functions.
- The expanded set of target functions for stability optimization now includes:
  - Mercier (due to S. Hirshman),
  - external kinks (Terpsichore, W. Cooper),
  - ballooning (Terpsichore, W. Cooper),

Capabilities Enhanced in "Fixed Boundary" Optimizer

- ballooning (COBRA, R. Sanchez and S. Hirshman),
- resistive interchange (JMC, J. Nuhrenberg).

- The expanded set of transport target functions now includes:

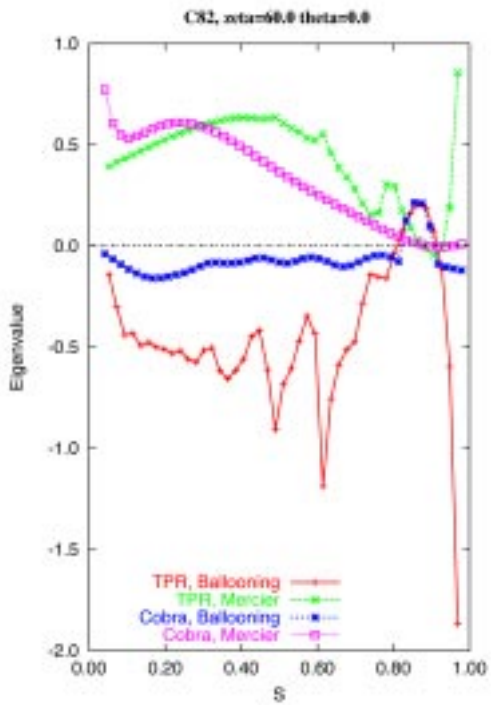
  - direct targeting Boozer spectrum,
  - "water" measure (due to M. Isaev),
  - diffusion coefficient for monoenergetic particles (DKES, D. Spong and S. Hirshman),
  - effective ripples in $1/\nu$ regime (NEO, Nemov and Kernbichler),
  - collisionless α particle loss (ORBIT, R. White, M. Zarnstorff and I. Zatz).

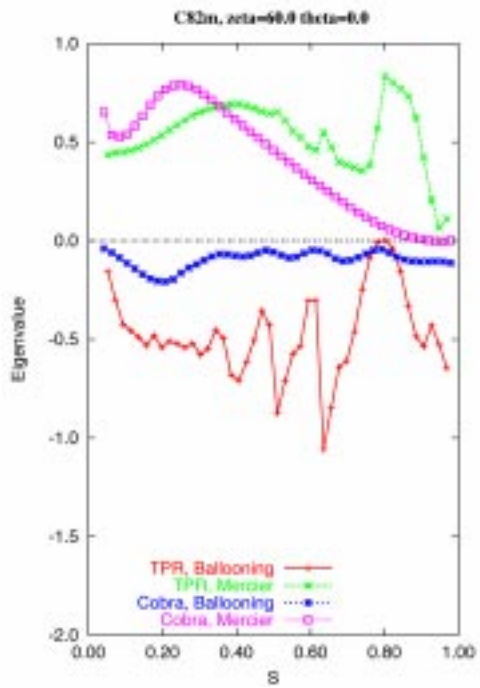
Testing New Capabilities

- Each of the newly implemented objective functions has been tested and benchmarked against stand-alone calculations.
  - streamline operations,
  - realize resource requirement and speed up calculations/reduce memory when necessary.
- Preliminary testing in the optimization cycle of these targets has been carried out using C82 as an initial state, each with kink stability as co-target.
  - ballooning benchmark and optimization with COBRA
  - transport optimization with DKES

COBRA-- Benchmark

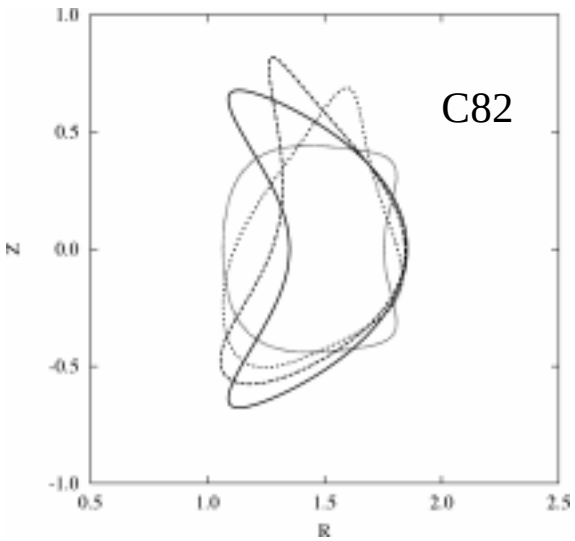
Cobra and Terpsichore give consistent results, as shown below for C82. Cobra, however, takes considerably less memory and time to run than Terpsichore; for the case here, Cobra uses 1 MW and 7 s on J90, Terpsichore uses 67 MW and 1250 s to prepare data and 1 MW and 308 s to complete integration.

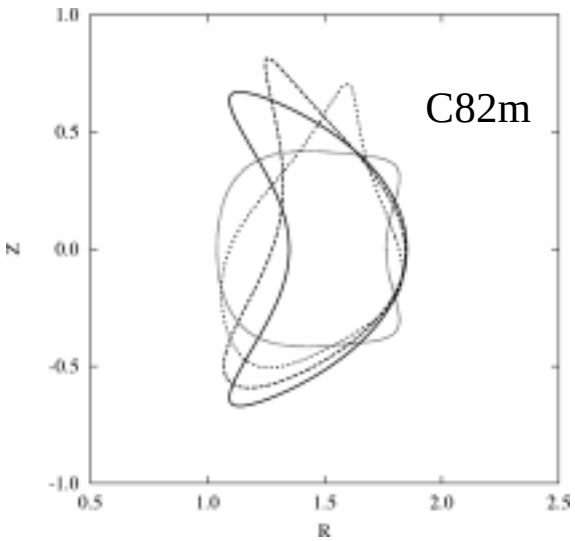




COBRA--Configuration Optimization

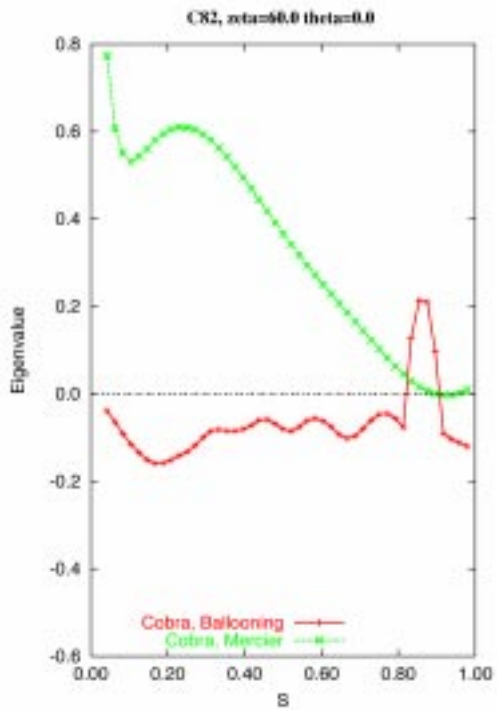
C82 may be stabilized with respect to ballooning and external kinks for the Aries reference pressure and current profiles by a small change in 3D shaping.

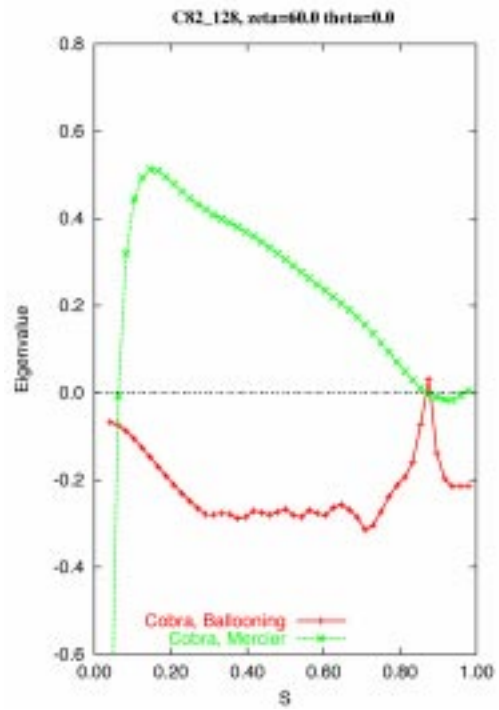




COBRA--Configuration Optimization, Cont.

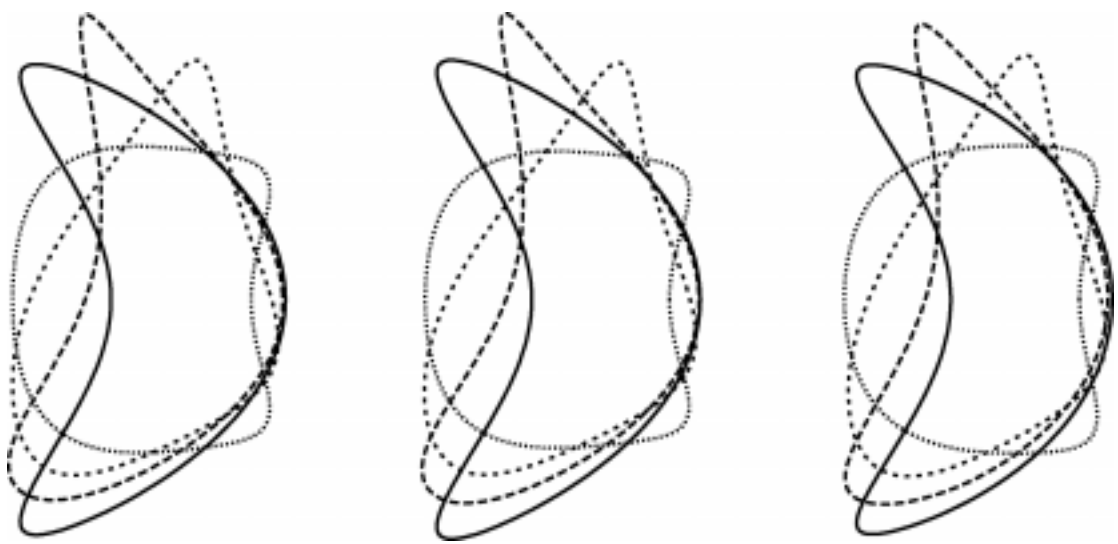
The following plots compare the ballooning eigenvalue and Mercier criterion. The Mercier of the new configuration is not stable near the edge and axis, but the stabilization may be included in the target function in future optimization.





Transport Optimization -- DKES

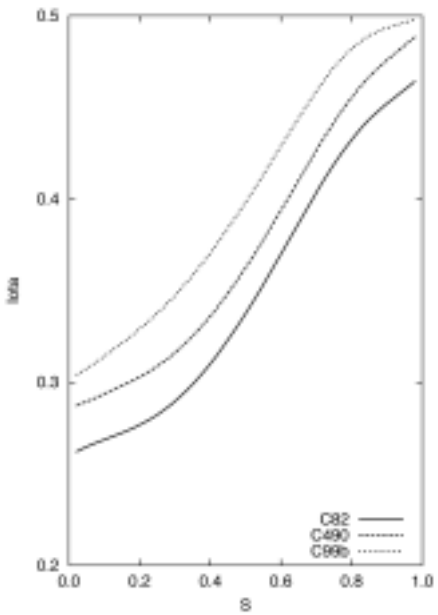
DKES, with modes optimally chosen, runs fast enough to allow multi-surface targeting in the optimization. Using 4 surfaces to target diffusion coefficient in low collisionality regime (mfp~1,000 m), a new configuration (C490) is obtained that has better confinement characteristics.

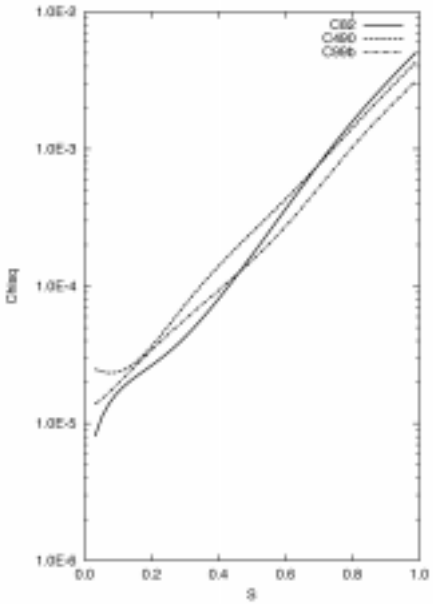


C82 C490 C99

Transport Optimization -- DKES, cont

Targeting diffusion coefficients leads to a configuration with higher iota and improved confinement. The ripple is higher in the inner region and lower in the outer region when compared to C82. Higher iota, however, does not automatically lead to better confinement, sometimes even with low ripples, as shown in the peculiar case of C99, which is optimized to be kink stable at 20% higher current.





τ^{nc} (ion):

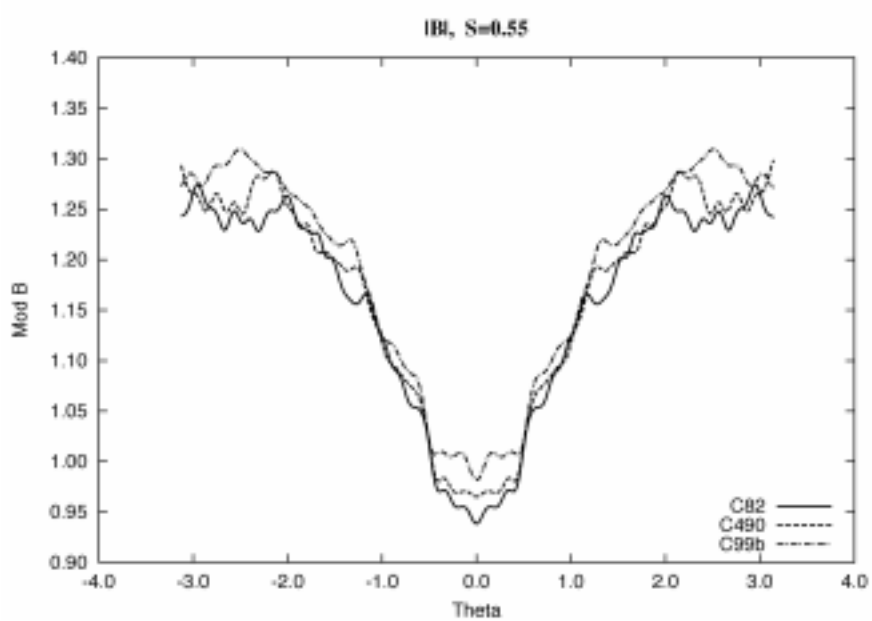
C82: 17.7 ms

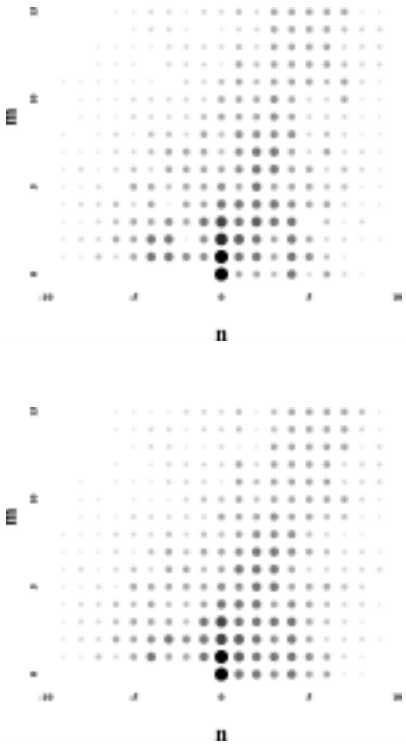
C490: 20.0 ms

C99: 19.4 ms

Transport Optimization -- DKES, cont

DKES optimized configuration has a larger $B_{1,1}$ but smaller $B_{4,1}$, $B_{3,1}$, leading to lower ripples in the outer region.





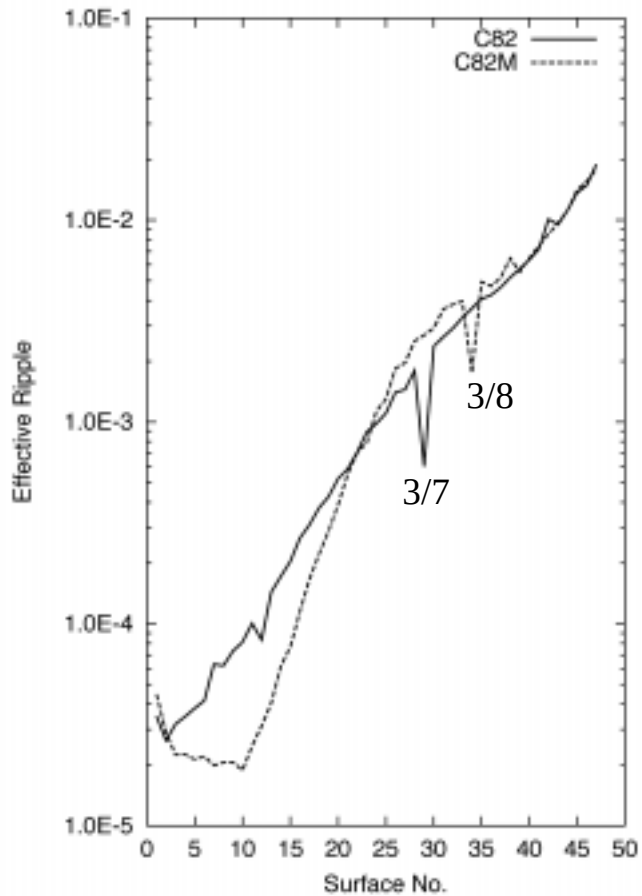
C82

C490

Work in Progress and Future Plans

- Many of the target functions need to be improved/modified so as to be able to obtain reliable results and to allow more robust operations.
  - NEO tends to have discontinuity when a surface is very close to a low order rational (figure on next page).
    - Multi-processing implementation,
    - Smoothing scheme development and implementation.
  - ORBIT tends to be sensitive to small changes in equilibrium.
    - Studies needed to understand if results are far too “noisy”.
    - Multi-processing to improve running statistics.

Neo results, with reduced resolution in the calculation, show distinctive irregularities near rational surfaces, as shown below for C82 and C82M, which is C82 further optimized with respect to the effective ripple on four surfaces. The irregularities move around depending on how close a surface is to a rational.



Work in Progress and Future Plans, Cont

- For the next phase of configuration development:
  - We shall include in the optimization a combined target of Mercier, kinks, ballooning and one of the transport measures using C82 (or C490) as an initial state.
  - We shall apply new capabilities to the optimization of other configurations developed in the past which were not considered seriously and to the development of new configurations. In particular, ES11--the higher elongation, 5% β configuration which is somewhat short in neoclassical confinement, will be the next to try.