

## The UK Daily Mail:

The UK Daily mail is an absolutely awful newspaper. Awful with a capital A. My work is not for cheap thrills. The [hatchet job](#) they did on my article "[An Analysis of Lockheed-Martins' Fusion Effort](#)" was appalling. They mis represented all of the key facts.

Nuclear fusion research is a nuanced, exacting science. Explaining it – both accurately and clearly – is tough. I try very hard to get the facts correct. To use peer reviewed sources. To break the concepts down. My reputation with fusion researchers to do a fair and accurate job of explaining their work, attests to this.

For the record, no one at the Daily Mail contacted me about this article. If they had, I would have turned them down. My content is not cheap. Below is everything they got wrong.

- Nowhere in my article does it say that this machine would be 2,000 tons.
- Nowhere in my article does it say that this machine is 100 times larger than originally planned.
- Nowhere in my article does it say that Lockheed projected the weight to be 20 tons.
- The line: "When the plasma tries to expand, the magnetic field fights back to contain it. In effect, this means the plasma works to contain itself" is terribly misleading.
- The picture they give is completely inaccurate.



If you really want to know what is really going on with the Lockheed-Martin machine, I recommend you read my original article. I based it – very closely – on the poster the company presented at the 2016 American Physics Society Conference in San Diego, California.



# Lockheed Martin Compact Fusion Reactor Concept, Confinement Model and T4B Experiment



Thomas J. McGuire, Gabriel Font, Artan Qerushi and the Lockheed Martin Compact Fusion Reactor (CFR) Team  
Lockheed Martin Aeronautics

The Lockheed Martin Compact Fusion Reactor (CFR) concept relies on diamagnetic plasma behavior to produce sharp magnetic field boundaries and confine fusion plasma in a magnetically encapsulated, linear ring cup geometry. Simulations show stable inflation to the high beta, sharp boundary state with constant thickness sheaths. Zero dimensional confinement models predict effectiveness of neutral beam heating to produce high electron temperatures in the T4B experiment. These same models are used to determine feasibility of an operational reactor and determine required magnetic shielding performance for design closure. The T4B experiment will characterize and test plasma sources in the CFR geometry and conduct initial neutral beam heating experiments. The T4B experiment design and diagnostic suite are presented.

## Lockheed Martin Compact Fusion Reactor Concept

The Lockheed Martin CFR concept is a magnetically encapsulated linear ring cup that relies on high beta cup confinement.

- Plasma confinement achieved in magnetic wells with self-generated sharp magnetic field boundaries.
- Design chosen for 200 MW  $P_{\text{net}}$  reactor, 12 m long by 7 m diameter device assuming solid gain with sheath and cup widths and good coil support magnetic shielding.
- Neutral beam heating plasma to ignited state.
- The diamagnetic forces are ion losses through the ring cup into sheath and away through the wire confined sheath.
- Good shielded current gives interchange stability over entire volume.
- Real pressure is confined to the bridge region, with significantly reduced density and non-Maxwellian streaming plasma.
- Compact size permits quick development iterations.

## Preliminary Grad-Shafranov Equilibrium

GRADSHAFRANOV equation without  $\beta$  is adequate to obtain target plasma

$$\nabla^2 \psi = -\frac{1}{c^2} \frac{dI^2}{dr^2} \quad \psi = 0 \quad \psi = \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

$$\psi = \psi_0 - \frac{1}{2} \frac{r^2}{R^2} \psi_0$$

## Zero Dimensional Performance Model

Goal: Model the performance of CFR plasmas for experiments and effects of reactor plasmas in limited conditions.

- Model all major power inputs and losses, search forward in time.
- Fast ions heat electrons, electrons heat ions, and ions carry majority of losses through sheath and cup.
- Simulation terminates when trap  $\beta$  at beta = 1, not necessarily steady state.

## Assumptions

Constant density, variable volume based on beta = 1.

Plasma is strongly positive due to anisotropic effects, parallel  $\beta = 1$ , which holds for typical values of  $T_e/T_i$  and minor radius (Zemlin, 2002).

Due to potential, ions carry all of the power losses.

Ion sheath loss is calculated using integrals over distribution function with factor of minor radius and ion ion collision with half of bulk density.

Coupling losses are calculated using integrals over distribution function with assumed local sheath thickness for area and local minor radius and plasma potential.

The magnetic field is modeled as linear with radius.

Start with a small initial ion population created by neutral beam and then self-consistently solve for total volume.

Classical Spitzer rate is used to find energy transfer between bulk ions and electrons (Spitzer, 1962).

Fast ions and alpha particles are treated separately from bulk ions, energy transfer rate calculated with electron temperature (Spitzer, 2002).

Losses to ring cup are reduced due to geometric inhomogeneity and magnetic shielding.

Ignore charge exchange losses, so heating power are effectively reduced power after charge exchange.

Losses to ring cup are reduced due to geometric inhomogeneity and magnetic shielding.

Ignore charge exchange losses, so heating power are effectively reduced power after charge exchange.

Losses to ring cup are reduced due to geometric inhomogeneity and magnetic shielding.

Ignore charge exchange losses, so heating power are effectively reduced power after charge exchange.

Losses to ring cup are reduced due to geometric inhomogeneity and magnetic shielding.

Ignore charge exchange losses, so heating power are effectively reduced power after charge exchange.

Losses to ring cup are reduced due to geometric inhomogeneity and magnetic shielding.

Ignore charge exchange losses, so heating power are effectively reduced power after charge exchange.

Losses to ring cup are reduced due to geometric inhomogeneity and magnetic shielding.

Ignore charge exchange losses, so heating power are effectively reduced power after charge exchange.

Losses to ring cup are reduced due to geometric inhomogeneity and magnetic shielding.

Ignore charge exchange losses, so heating power are effectively reduced power after charge exchange.

Losses to ring cup are reduced due to geometric inhomogeneity and magnetic shielding.

Ignore charge exchange losses, so heating power are effectively reduced power after charge exchange.

Losses to ring cup are reduced due to geometric inhomogeneity and magnetic shielding.

Ignore charge exchange losses, so heating power are effectively reduced power after charge exchange.

Losses to ring cup are reduced due to geometric inhomogeneity and magnetic shielding.

Ignore charge exchange losses, so heating power are effectively reduced power after charge exchange.

Losses to ring cup are reduced due to geometric inhomogeneity and magnetic shielding.

Ignore charge exchange losses, so heating power are effectively reduced power after charge exchange.

Losses to ring cup are reduced due to geometric inhomogeneity and magnetic shielding.

Ignore charge exchange losses, so heating power are effectively reduced power after charge exchange.

Losses to ring cup are reduced due to geometric inhomogeneity and magnetic shielding.

Ignore charge exchange losses, so heating power are effectively reduced power after charge exchange.

Losses to ring cup are reduced due to geometric inhomogeneity and magnetic shielding.

Ignore charge exchange losses, so heating power are effectively reduced power after charge exchange.

Losses to ring cup are reduced due to geometric inhomogeneity and magnetic shielding.

Ignore charge exchange losses, so heating power are effectively reduced power after charge exchange.

Losses to ring cup are reduced due to geometric inhomogeneity and magnetic shielding.

Ignore charge exchange losses, so heating power are effectively reduced power after charge exchange.

Losses to ring cup are reduced due to geometric inhomogeneity and magnetic shielding.

Ignore charge exchange losses, so heating power are effectively reduced power after charge exchange.

Losses to ring cup are reduced due to geometric inhomogeneity and magnetic shielding.

Ignore charge exchange losses, so heating power are effectively reduced power after charge exchange.

Losses to ring cup are reduced due to geometric inhomogeneity and magnetic shielding.

Ignore charge exchange losses, so heating power are effectively reduced power after charge exchange.

Losses to ring cup are reduced due to geometric inhomogeneity and magnetic shielding.

Ignore charge exchange losses, so heating power are effectively reduced power after charge exchange.

Losses to ring cup are reduced due to geometric inhomogeneity and magnetic shielding.

Ignore charge exchange losses, so heating power are effectively reduced power after charge exchange.

Losses to ring cup are reduced due to geometric inhomogeneity and magnetic shielding.

Ignore charge exchange losses, so heating power are effectively reduced power after charge exchange.

Losses to ring cup are reduced due to geometric inhomogeneity and magnetic shielding.

Ignore charge exchange losses, so heating power are effectively reduced power after charge exchange.

Losses to ring cup are reduced due to geometric inhomogeneity and magnetic shielding.

Ignore charge exchange losses, so heating power are effectively reduced power after charge exchange.

Losses to ring cup are reduced due to geometric inhomogeneity and magnetic shielding.

Ignore charge exchange losses, so heating power are effectively reduced power after charge exchange.

Losses to ring cup are reduced due to geometric inhomogeneity and magnetic shielding.

Ignore charge exchange losses, so heating power are effectively reduced power after charge exchange.

Losses to ring cup are reduced due to geometric inhomogeneity and magnetic shielding.

Ignore charge exchange losses, so heating power are effectively reduced power after charge exchange.

Losses to ring cup are reduced due to geometric inhomogeneity and magnetic shielding.

Ignore charge exchange losses, so heating power are effectively reduced power after charge exchange.

Losses to ring cup are reduced due to geometric inhomogeneity and magnetic shielding.

Ignore charge exchange losses, so heating power are effectively reduced power after charge exchange.

Losses to ring cup are reduced due to geometric inhomogeneity and magnetic shielding.

Ignore charge exchange losses, so heating power are effectively reduced power after charge exchange.

Losses to ring cup are reduced due to geometric inhomogeneity and magnetic shielding.

Ignore charge exchange losses, so heating power are effectively reduced power after charge exchange.

Losses to ring cup are reduced due to geometric inhomogeneity and magnetic shielding.

Ignore charge exchange losses, so heating power are effectively reduced power after charge exchange.

Losses to ring cup are reduced due to geometric inhomogeneity and magnetic shielding.

Ignore charge exchange losses, so heating power are effectively reduced power after charge exchange.

Losses to ring cup are reduced due to geometric inhomogeneity and magnetic shielding.

Ignore charge exchange losses, so heating power are effectively reduced power after charge exchange.

Losses to ring cup are reduced due to geometric inhomogeneity and magnetic shielding.

Ignore charge exchange losses, so heating power are effectively reduced power after charge exchange.

Losses to ring cup are reduced due to geometric inhomogeneity and magnetic shielding.

Ignore charge exchange losses, so heating power are effectively reduced power after charge exchange.

Losses to ring cup are reduced due to geometric inhomogeneity and magnetic shielding.

Ignore charge exchange losses, so heating power are effectively reduced power after charge exchange.

Losses to ring cup are reduced due to geometric inhomogeneity and magnetic shielding.

Ignore charge exchange losses, so heating power are effectively reduced power after charge exchange.

Losses to ring cup are reduced due to geometric inhomogeneity and magnetic shielding.

Ignore charge exchange losses, so heating power are effectively reduced power after charge exchange.

Losses to ring cup are reduced due to geometric inhomogeneity and magnetic shielding.

Ignore charge exchange losses, so heating power are effectively reduced power after charge exchange.

Losses to ring cup are reduced due to geometric inhomogeneity and magnetic shielding.

Ignore charge exchange losses, so heating power are effectively reduced power after charge exchange.

Losses to ring cup are reduced due to geometric inhomogeneity and magnetic shielding.

Ignore charge exchange losses, so heating power are effectively reduced power after charge exchange.

## Zero-D Results for Ignited 200 MW TX Reactor

Required reactor performance:

- Cup width, ring "hybrid" gain radius to close.
- Shielding, 2 makes density reduction reqd.
- General behavior
- Neutral beam can be terminated after alpha production is able to heat electrons.
- Density plays key role in electron ion transfer and steady state electron ion temperature ratio.
- Electron beam density potential and then space up the ion loss cone.
- Reference and optimize main losses, for constant  $\beta$ .
- Ionization power  $\propto n^2 \propto n_e n_i$ .
- Sheath loss  $\propto n^2 \propto n_e n_i$ .
- Cup loss  $\propto n^2 \propto n_e n_i$ .
- Recombination losses  $\propto n^2 \propto n_e n_i$ .

## TX Parameters

7 m diameter  $\times$  20 m long, 1 m thick blanket

500 MW Gross

40 MW heating power, 2.5 m