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SMR 1161/18

AUTUMN COLLEGE ON PLASMA PHYSICS

25 October - 19 November 1999

A Review of Dynamo Physics Questions and Experiments - II

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These are preliminary lecture notes, intended only for distribution to participants.

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A Review of Dynamo Physics Questions and Experiments (Part II)

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October 30, 1999

MANY DYNAMO QUESTIONS ARE RIPE FOR EXPERIMENTAL STUDY

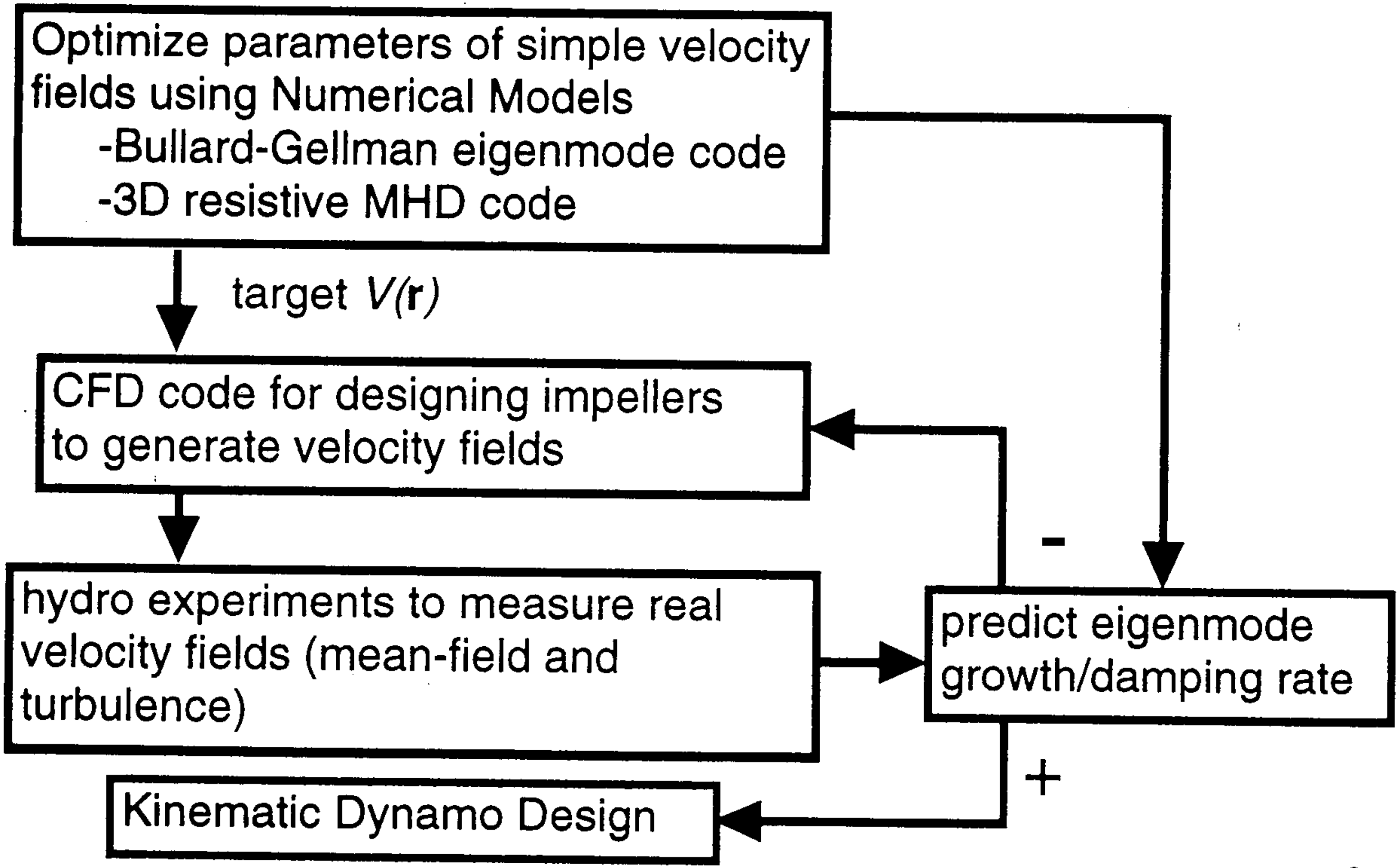
- 1. How to self-excited, homogeneous dynamos evolve?
- 2. Can helical fluid turbulence generate a mean-field EMF?
- 3. Can fluid turbulence transport magnetic flux and result in anomalous resistivity?

4. What is the backreaction of the self-generated magnetic field on these three questions?

DESIGN OF A DYNAMO EXPERIMENT

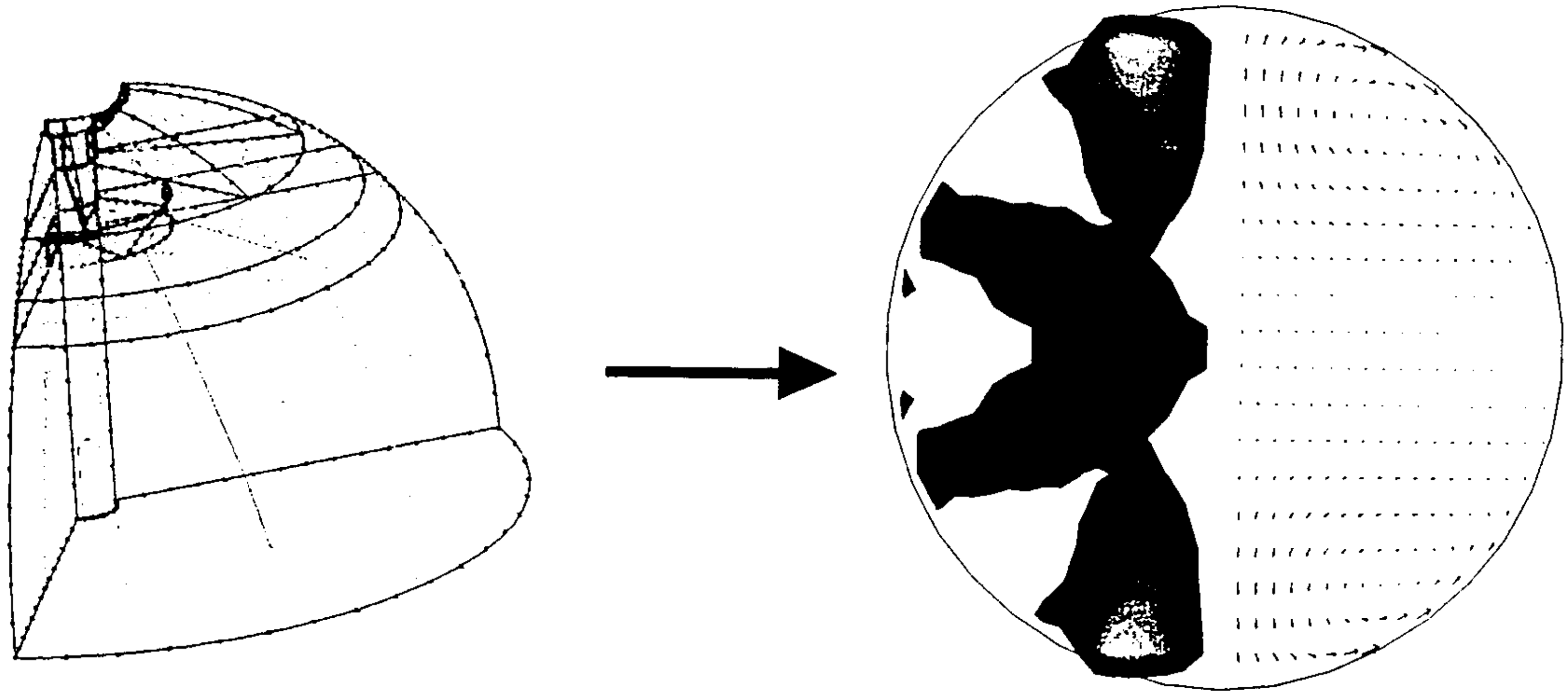
- **To observe a growing eigenmode will require Rm > 30**
  - sodium
  - a = 0.5 m
  - Vpeak = 10 m/sec
- **Build a dimensionally identical water experiment**
  - transparent
  - easier to work with than sodium
- **Characterize $\overline{\mathbf{V}}$ and $\langle \tilde{\mathbf{v}} \cdot \nabla \times \tilde{\mathbf{v}} \rangle$**
  - will be identical in water and sodium for B=0
- **Critical Rm is a sensitive function of the shape of the flow field**
  - Impeller design is critical

DESIGN STRATEGY LEADS TO A KINEMATIC DYNAMO



Computational fluid dyamics code (CFD) is used to design impellers to match theoretical flows

- finite element description of impellers

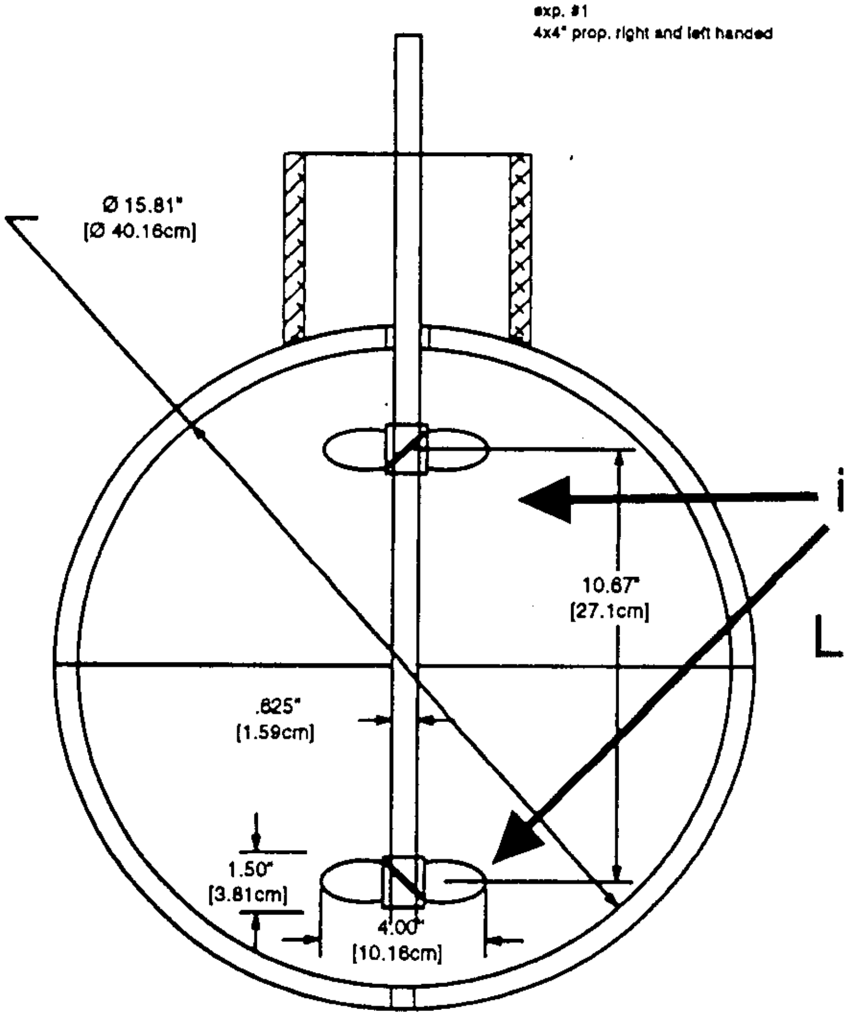


SODIUM AND WATER HAVE NEARLY IDENTICAL FLUID PROPERTIES

	Sodium	Water
Temperature	$110^\circ C$	$50^\circ C$
viscosity	$0.65\times10^{-6}\ \mathrm{m}^2\,\mathrm{sec}^{-1}$	$0.65\times10^{-6}\ \mathrm{m}^2\,\mathrm{sec}^{-1}$
mass density	$0.925\ \mathrm{gm\ cm}^{-3}$	$0.988\ \mathrm{gm\ cm}^{-3}$
resistivity	$10^{-7}\ \Omega\,\mathrm{m}$	

$$\longrightarrow \quad Rm = \frac{\mu_0 a V}{\eta} = 4\pi\, a(m)\, V(m/s)$$

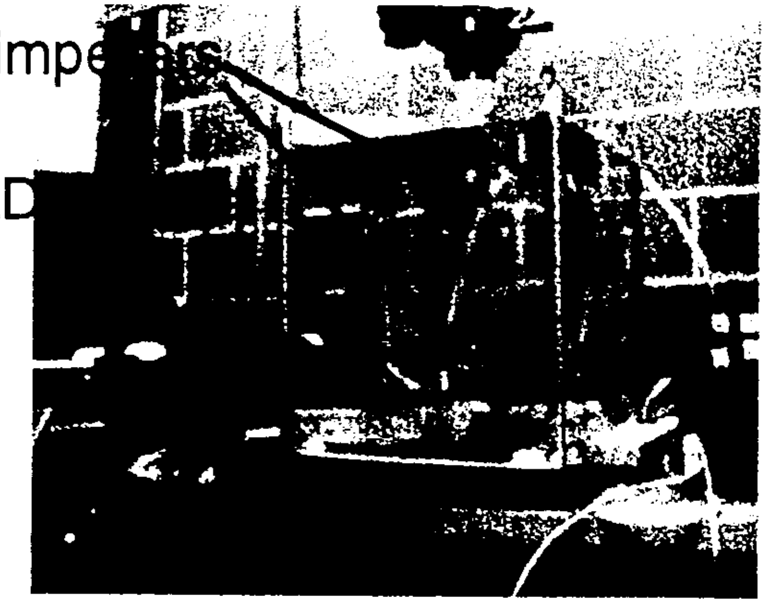
A SMALL WATER EXPERIMENT IS USED TO DESIGN PROPELLORS FOR THE SODIUM EXPERIMENT



$$a = 0.2\ m$$

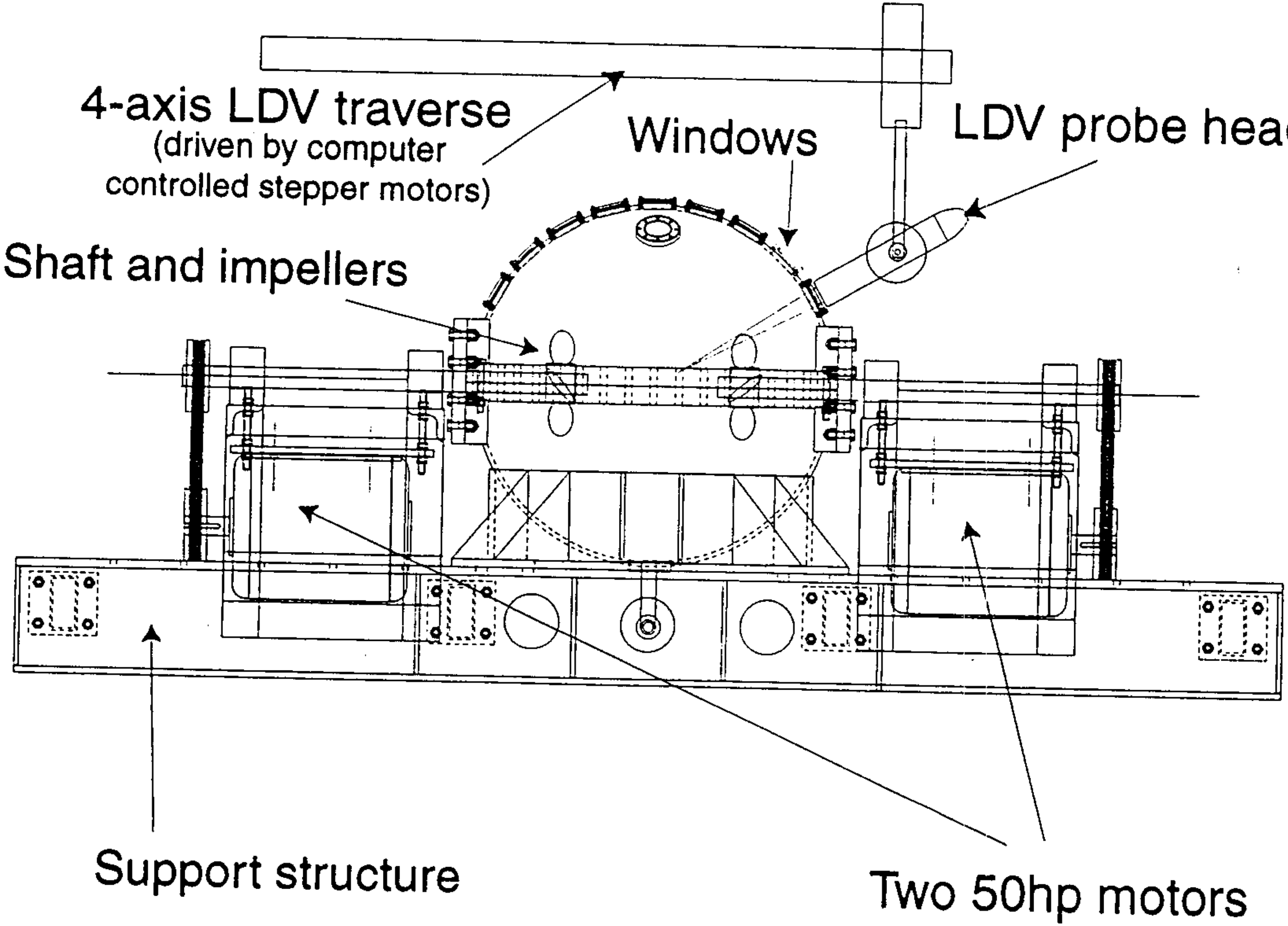
$$P = 2\ Hp$$

$$Re \leq 2 \times 10^5 (Rm \approx 2)$$



SWEAT - Small Water Experiment ATtempt

A DIMENSIONALLY IDENTICAL WATER EXPERIMENT IS ALSO UNDER CONSTRUCTION TO DOCUMENT HIGH Re FLOW PROPERTIES



LDV IS USED TO MEASURE FLOW VELOCITY PROFILES AND PROPERTIES OF TURBULENCE IN WATER EXPERIMENTS

- Laser Doppler Velocimetry (scattering off small test particles seeded in water)
- Provides highly resolved measurements of velocity (space and time).
- Have already measured mean flows
- Will be measuring turbulent helicity

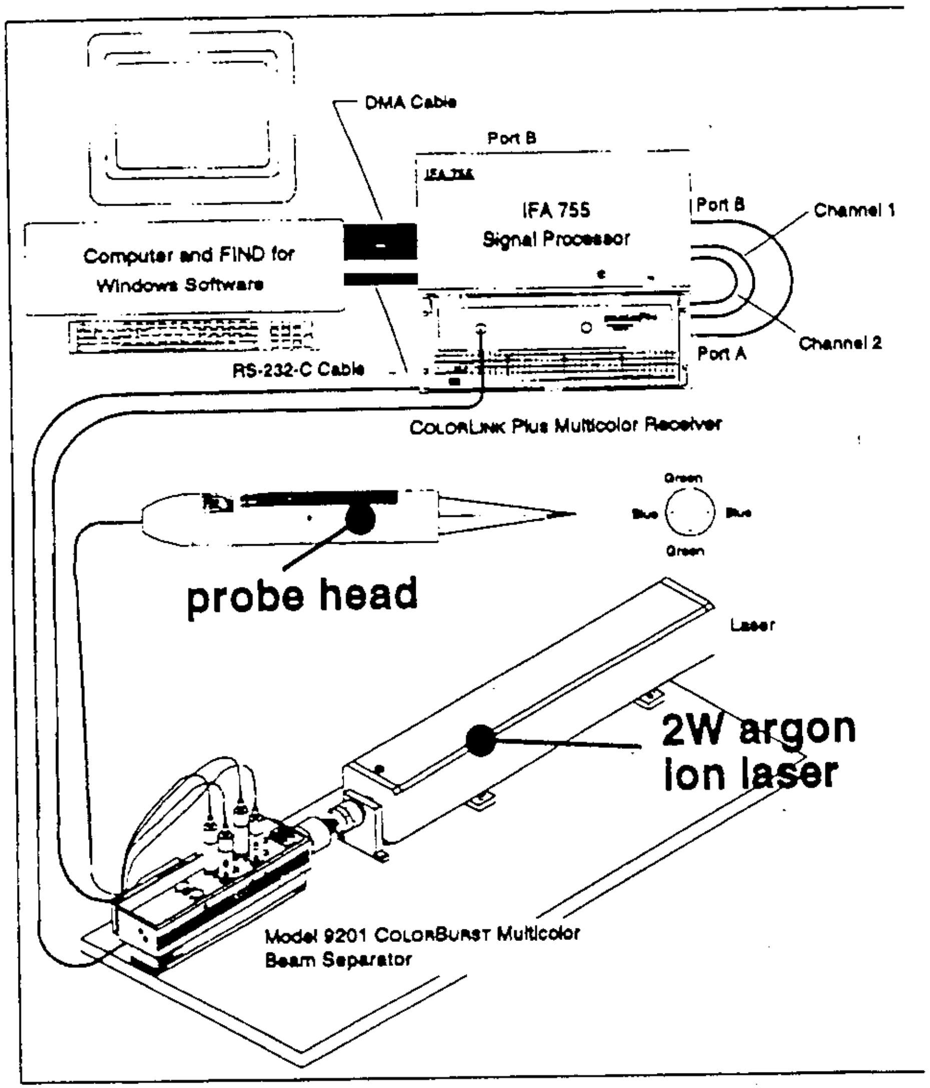
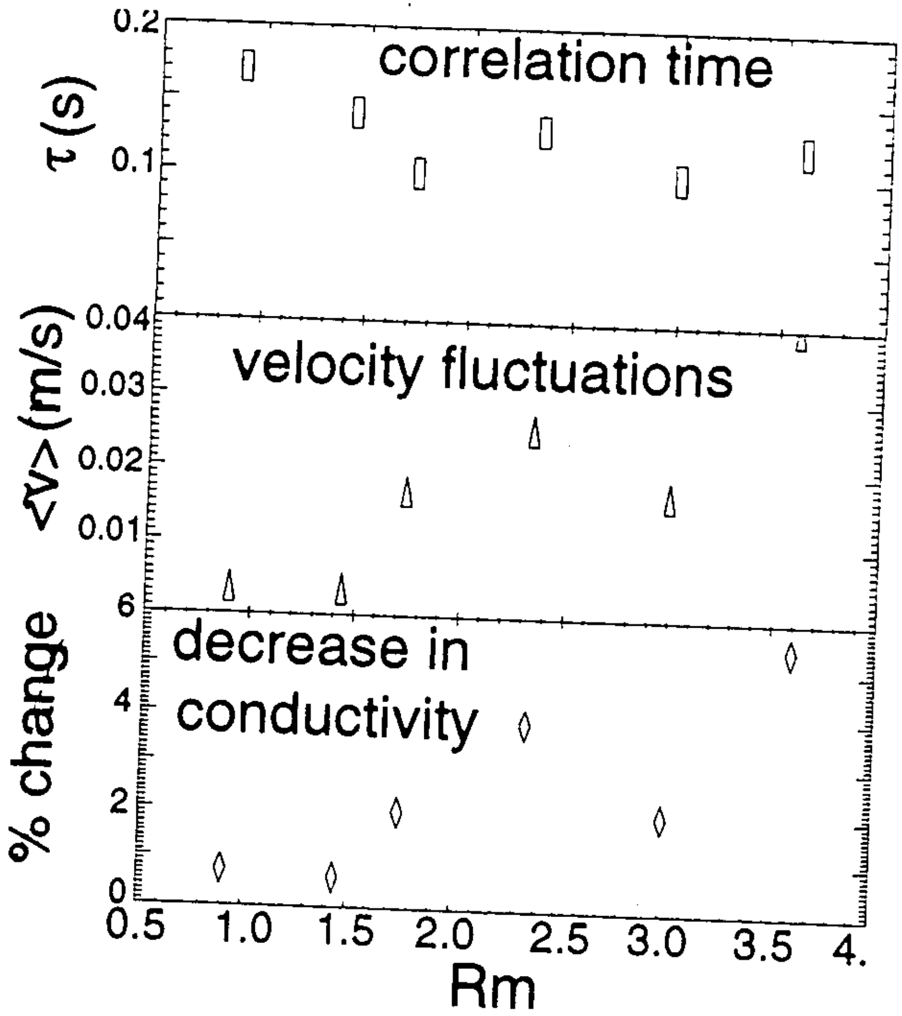


Figure 1-1
Relationship Between IFA 755 Digital Burst Correlator and Other LDV System

EXPERIMENTAL MEASUREMENTS INDICATE THAT β EFFECT SHOULD STRONGLY MODIFIY CONDUCTIVITY

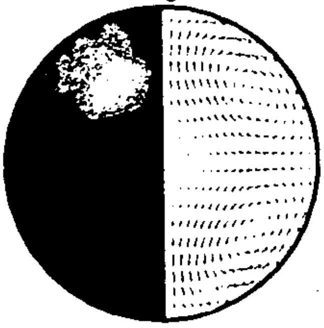


- **Turbulence measurements at low Rm already indicate a measureable β effect.**
  - extrapolated to sodium from water

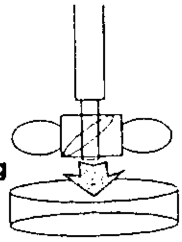
$$\beta = \frac{\tau}{3}\left\langle \tilde{\mathbf{v}}^2 \right\rangle$$

$$\sigma \rightarrow \frac{\sigma}{1+\mu_0\sigma\beta}$$

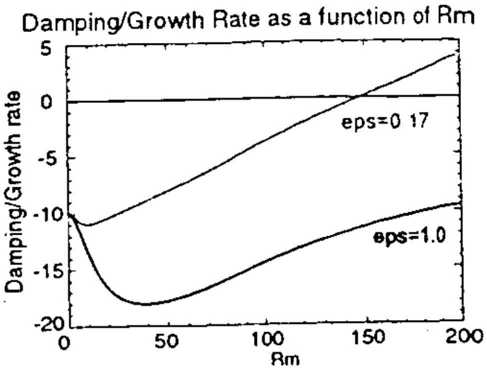
Counter-rotating Kort Nozzles



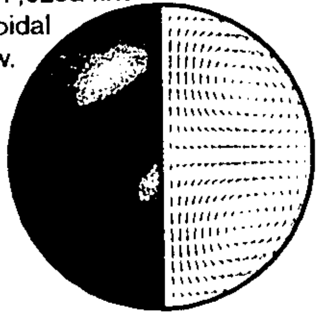
Standard counter rotating Kort Nozzles. If the poloidal flow is artificially enhanced, then the magnetic field grows.



Kort nozzle is made by fixing regular prop. to a band which reduced radial flow.

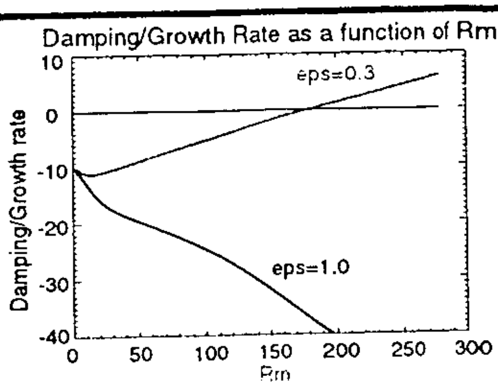


Counter-rotating Kort Nozzles with ,025a fins addedto increase toroidal flow.

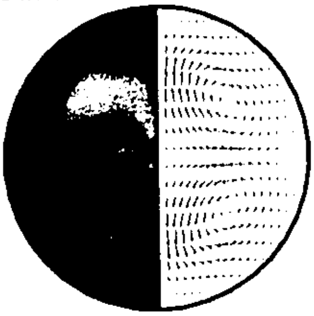


Based on this finding, we endhance the toroidal flow by adding fins. Flow is no better, so we scan the ratio of polidal to toroidal once more, the toroidal is still too weak - the toroidal flow must be made 3 times faster.

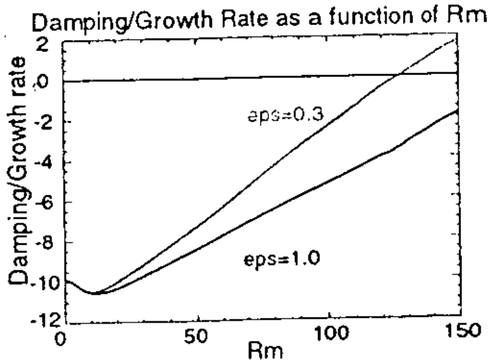
Fins added to Kort ring



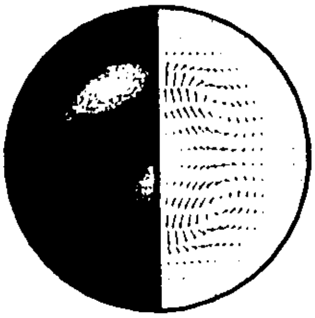
Fins increased to 0.05a.



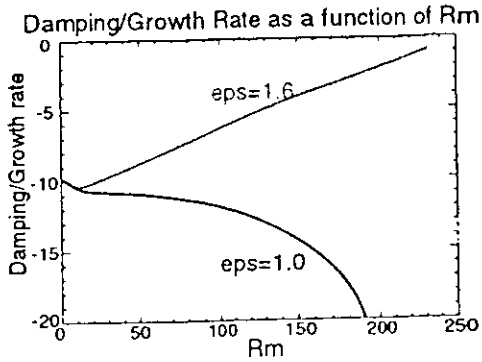
Bigger fins are added to the outside of the Kort nozzle. This time the flow is predicted to generate a growing field assuming this shape is preserved at higher speeds.



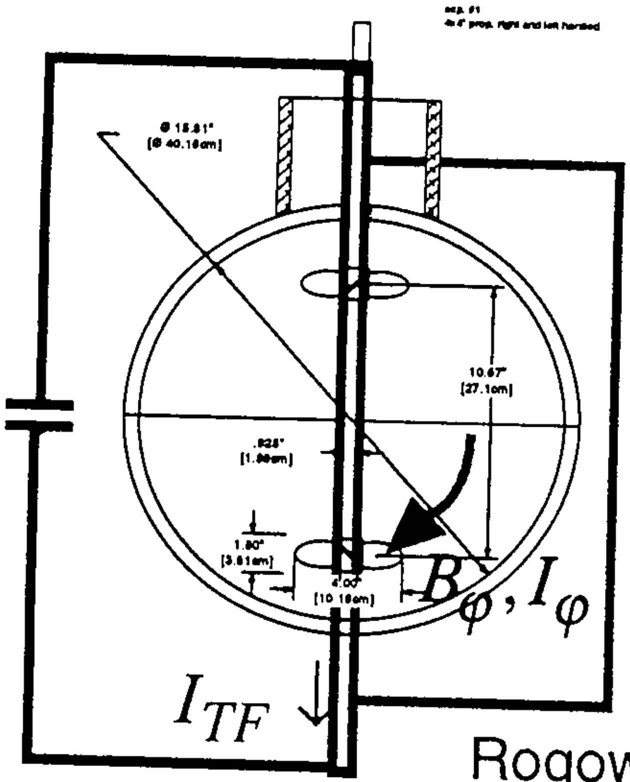
Fins increased to 0,1a.



The same flow which creates a growing magnetic field at Rm=180 is predicted to have a lower Rm_crit if the toroidal flow is increased slightly, so this is tried here, although the toroidal is too fast, adn there is little poloidal flow, epsilon needs to be increaed to 1.6 for this flow to generate a growing Magnetic field for any Rm.



POSSIBLE EXPERIMENT TO OBSERVE ALPHA EFFECT AND DOCUMENT TURBULENT BACKREACTION



- **Apply a toroidal field using a center conductor**
- **Measure** I_φ
- **Increase** B_φ

Hypothesis: $\alpha \approx \dfrac{\alpha_0}{1+\frac{\sigma\tau}{\rho}\overline{B}^2}$

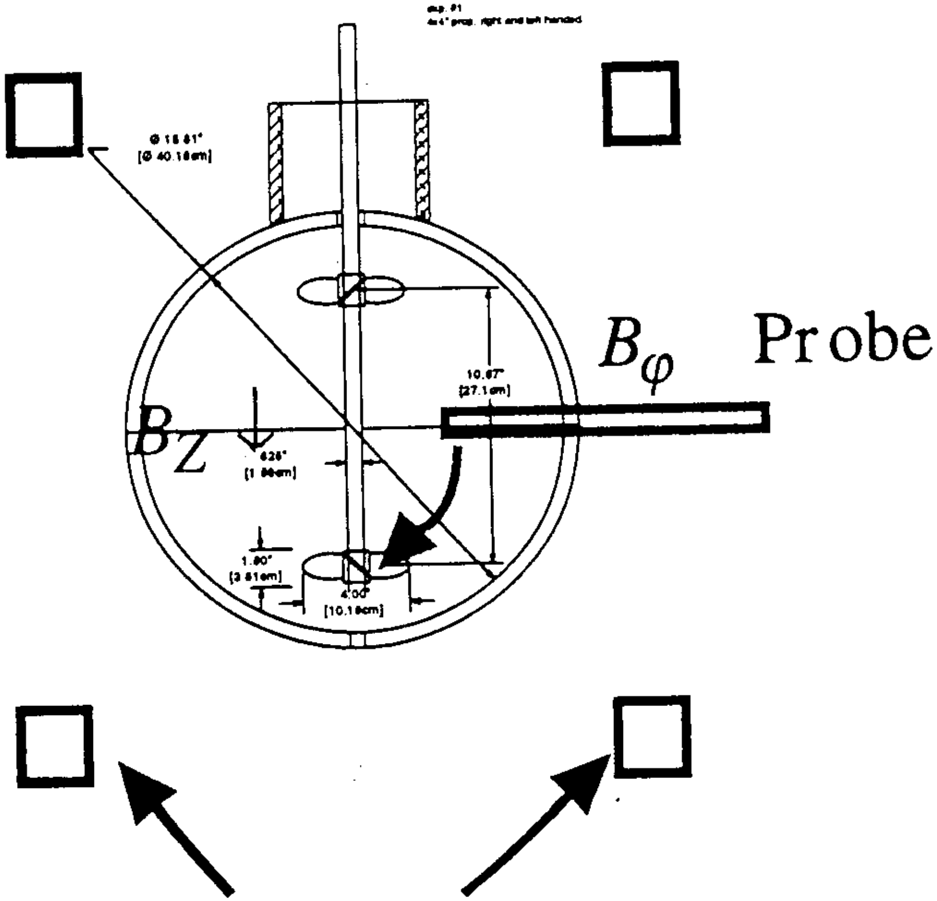
BOEC says $\overline{\mathbf{B}} \approx 100\ Gauss$ is necessary to observe a backreaction

Rogowski coil to measure enclosed current

$$I_\varphi = \int \sigma_T \alpha_\varphi B_\varphi dA$$

POSSIBLE EXPERIMENT TO DOCUMENT TURBULENT CONDUCTIVITY

- Apply B_Z
- Measure B_φ



Helmholtz coils

From induction equation:

$$\nabla^2 B_\varphi - \frac{1}{R^2} B_\varphi = \mu_0 \sigma_T R \frac{\partial \omega}{\partial Z} B_Z$$

$$B_\varphi \approx \mu_0 \sigma_T a^3 \frac{\partial \omega}{\partial Z} B_Z$$

SUMMARY

- **1. Numerical studies show the experiment is a feasible candidate for a *kinematic dynamo*:**
  - water experiments are underway to show feasibility
  - Growth rate and Rm-crit are sensitive functions of flow profile
- **2. Turbulence levels are significant and global helicity should convert into turbulent helicity and an EMF through the *α-effect*.**
- **3. Measured fluctuations on water experiment indicate a measurable *β-effect* for sodium experiment.**
- **4. Antennas and internal probes will allow us to examine the *backreaction and saturation*.**