# NUMERICAL SIMULATION OF FLOW IN A DIFFERENTIALLY HEATED ROTATING FLUID

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## 1 INTRODUCTION

The differentially heated rotating fluid annulus has contributed to the understanding of geophysical systems such as atmospheres and oceans.

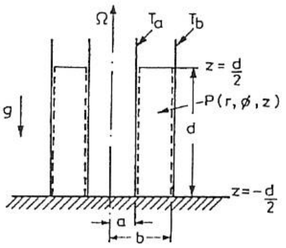
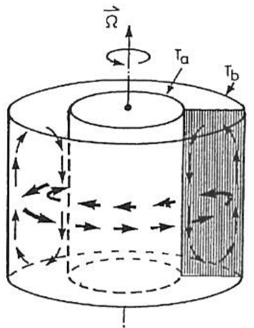
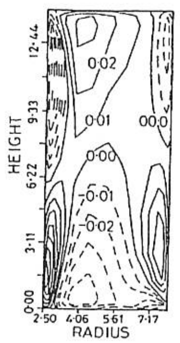



Diagram of fluid annulus $(r,\phi,z)$ are cylindrical polar coordinates of a point P, fixed in a frame which rotates uniformly with the annulus at $\Omega$ rad.sec$^{-1}$. $\Delta T = T_b - T_a = 4$ or 10°C. a=2.5cm, b=8.0cm, d=14.0cm, $0<\Omega<5$ rad.sec$^{-1}$.




The two main circulations seen in experiments when the annulus is fully blocked by a thin, thermally insulating, radial barrier.

The side-walls are held at constant temperatures $T_a$ and $T_b$, with $T_b > T_a$.



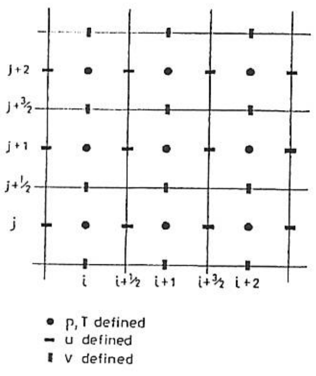

Previous finite-difference computer model results ($\Omega$=1.2 rad.sec$^{-1}$, $\Delta T$=4°C).

Cross-section in (r,z) plane showing mean azimuthal velocity, $v$ (cm.sec$^{-1}$). Solid contours denote $v \geq 0$, dashed contours $v<0$.

Note possible spurious eddy motion near r=2.5cm.

## 2 NEW COMPUTER MODEL

Based on control-volume approach. Discretization equation exactly conserves mass, momentum and energy over calculation domain. Grid stretched to resolve boundary layers.




**PROCEDURE**

*Time-level n+1*

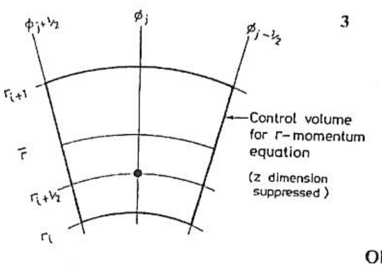
Fluxes at cell faces calculated by unwind approximation.

1. Calculate $u$, $v$, $w$ from Navier-Stokes momentum equations.
2. Find that $\nabla.\underline{u} \neq 0$, so solve for pressure correction

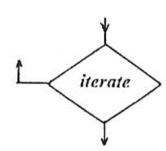
$$\nabla^2 p' = -\frac{1}{\Lambda}\nabla.\underline{u}$$

and velocity correction

$$\underline{u}' = \Lambda \nabla p'$$




3. Calculate updated fluxes from corrected velocities and pressure

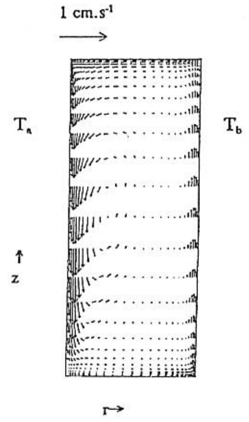


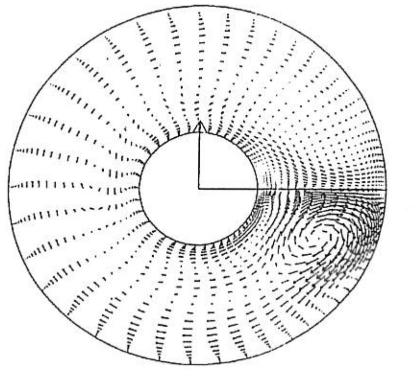

Obtain velocities satisfying both momentum and continuity equations.

*New time-step*

## 3 MODEL RESULTS

Flow patterns



Fluid Temperatures, $T(r_0, z_0; \phi)$

Azimuthal temperature gradient leads to barrier temperature drop, $\Delta T_B$. Sense of gradient correct, but magnitude of $\Delta T_B$ too large.

| Ω *rad.sec$^{-1}$* | $\Delta T_B$ °C | | |
|---|---|---|---|
| | Experiment | Models | |
| | | Finite-Difference | Control-Volume |
| 0.5 | 0.2 | - | 0.8 |
| 1.2 | 0.4 | 1.1 | - |

## 4 CONCLUSIONS

Model correctly calculates:

- Qualitative flow in (r,z) plane
- Azimuthal temperature gradient and correct sense of $\Delta T_B$

Model does not correctly reproduce:

- Qualitative flow in $(r,\phi)$ plane
- Magnitude of $\Delta T_B$

Comparison with Finite-Difference Model

- Flow patterns about as good
- Fractional error in $\Delta T_B$ about the same
- No sign of spurious eddies in control-volume model

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