A brief note on the likely influence of current developments in numerical fluid dynamics* on (i) the cost of performing research into Gas Centrifuge technology and (ii) the proliferation of the capability for performing such research.

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1. Purpose of note

Dr. Derek Bradley has explained what a Gas Centrifuge (GC) is, what it is meant to do, and the principle upon which it works.

The purpose of this brief note is to point out that:

1. current developments in the field of numerical fluid dynamics can reduce by several orders of magnitude the costs of evaluating the economics of alternative designs of the GC;

2. the computer programs necessary for conducting this evaluation can be developed at low cost (order of tens of thousands of pounds sterling);

3. some of the 'frontier' research in this field is being done by workers from Third-World countries.

In view of 1 to 3 above, I would judge that:-

1. Any country with a good university department in applied mathematics or fluid dynamics and having access to a medium-sized computer (order of 100 K CPU store) can conduct evaluation research into alternative designs for a GC: and

2. The ability to fabricate, rather than to design, will be the main constraint on the proliferation of GC technology.

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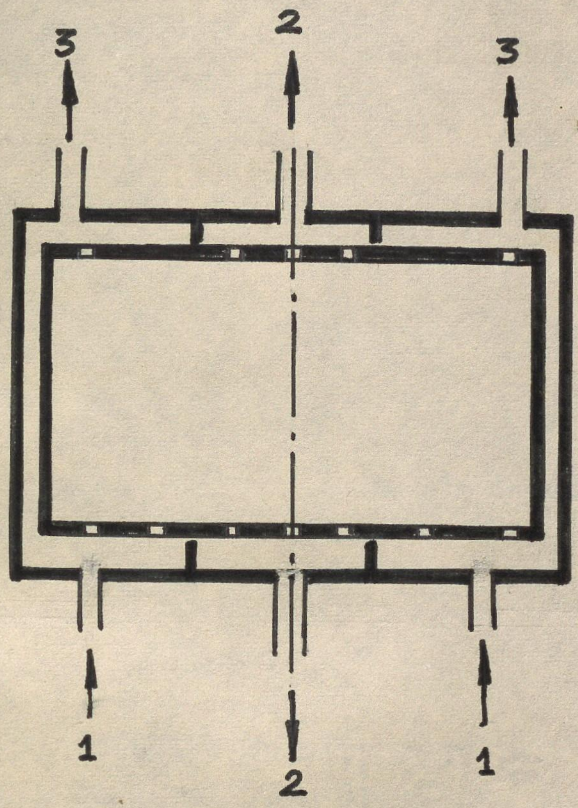
* Fluid Dynamics is a field of applied science concerned with the study of the motion of (mainly) liquids and gases. Numerical fluid dynamics is a relatively new sub-branch of the field concerned with the computer-based solution of the equations governing the flow of fluids.

2. The relevance of fluid dynamics to the evaluation of the economics of alternative designs for GC's.

I have never seen a GC but were I to think of designing one, my first rough idea would look like the schematic diagram below.



1. Raw Uranium Hexaflouride
2. Enriched Uranium Hexaflouride
3. Depleted Uranium Hexaflouride

Figure 2.1. A plausible design for a Gas Centrifuge

The device would consist of a drum constrained in some sort of cage which doubled as a gas bearing. The drum could be rotated magnetically rather like the rotor of an induction motor. The scheme depicted in Fig. 2.1 may be wild but it is a plausible one and, assuming I could fabricate (or learn to fabricate) such a device, I would wish to evaluate this design in respect of its economics before committing resources to its development.

In particular, I would need to have the answers to the following two main questions.

1. What is the relationship between the enrichment efficiency* of the device, the shape of the drum (i.e. tall and thin or short and squat), and its rotational speed?

2. What is the relationship between overall power consumption, the shape of the drum and its rotational speed?

The answer to the first question depends upon the dynamics of the gas flow within the drum; while the answer to the second depends (mainly) upon the dynamics of flow outside the drum — in the gap between the drum and the cage.

3. Alternative methods of answering the questions in 2.

Technique and hardware are often ahead of the theoretical understanding of the working of many engineering devices. Much engineering analysis is a mass of empirical information codified by broad scientific principles.

Until as late as 10 years ago, the only way of answering the questions posed in 2. above would have been to build and experiment with a number of model centrifuges of different shapes and sizes. At the end of the experimentation one could not be sure that the "scale-up" law could be extrapolated to the full-size unit. Guesswork and gamble would have been almost unavoidable.

A great deal of time and much expense could be saved if the questions could be answered without recourse to extensive experimentation and testing. This would only be possible if one could predict the flow patterns inside and outside the drum of the GC depicted in Fig. 2.1.

Such prediction is now possible as a consequence of current research in numerical fluid dyamics. The technical points are dealt with in the Annex.

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* How this quantity is defined is not relevant to our purposes here.

4. The costs of 'evaluation' research

The basic techniques and computer programs are available more or less off-the-shelf for a few tens of pounds. These need to be adapted to the GC problem.

On the basis of expenditures incurred at Imperial College* for the development of the basic techniques and computer programs, I would estimate that a determined research team would need to put in no more than 3-5 man-years of effort and between £30,000 - £50,000** to adapt and develop the relevant computer programs for the GC application.

5. Implications for the proliferation of GC technology

As research costs go, the above estimates (even if they be under-estimates by a factor of 3 - which they are not) are peanuts; they are the sort of expenditures usually set against the petty-cash allocation of large research programmes.

Insofar as experimentation and testing account for the major part of the R&D expenditure on an engineering device, the development of techniques which obviate the need for such empiricism will have a major influence in reducing R&D costs. In turn, this will bear on the number of countries able to afford such research.

Research may not cost very much but the techniques can be classified and thereby prevented from being extensively used. The techniques referred to in this note are not in this category. Indeed, there is much publication activity by, and international rivalry amongst, the leading schools where research into numerical fluid dynamics is done.

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* At this time, the Heat Transfer group in the department of Mechanical Engineering at Imperial College is the world's leading group in this field.

** 5 man-years at £2,000 per man-year plus 20 to 40 hours of CDC 6400 time and overheads at £1,000 per hour. I suspect the Imperial College group would think this a substantial over-estimate!

My judgements on the implications for proliferation have been set-out in Section 1 above.

Annex

1. Progress in the numerical solution of the equations of Navier-Stokes

The literature on the subject of the numerical solution of the steady, two-dimensional Navier-Stokes equations is now extensive.[1] The problem of the flow between rotating disks bounded by a close-fitting shroud has recently been solved.[2] This problem is very closely related to the flow inside a rotating drum.

Research currently under way at Imperial College has solved the problem of the confined three-dimensional boundary layer; this research has greatly enlarged the capabilities of the earlier work into two-dimensional elliptic flows. The relevant computer program has been applied to the problem of developing laminar flow in rectangular cross-section ducts. The extensions of this work to the flow in gas bearings is obvious.

2. The non-problem of turbulence

It is desirable in a GC to avoid turbulence both within and outside the drum as turbulent mixing would greatly reduce the enrichment efficiency and increase the friction drag on the drum.

The GC problem is one of the few occasions when what is a desirable flow is also one that which presents few difficulties in respect of its prediction.

The prediction of the onset of turbulence remains something of a problem; but here too there has been much progress in the study of the stability of rotating flows.

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1. See for examples: Gosman, A.D. et. al. (1969), "Heat and Mass Transfer in Recirculating Flows", Academic Press, London and New York.

2. Gosman, A.D. and Spalding, D.B. (1970), "Computation of laminar flow between shrouded rotating discs", EF/TN/A30, Dept. of Mech. Eng., Imperial College, London, S.W.7.