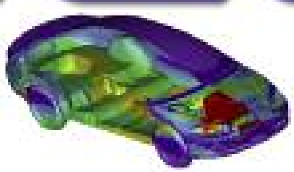
icons of CFD



Lewis Fry Richardson

"The Father of Weather Forecasting"

It seems almost inconceivable that Lewis Fry Richardson (1881 – 1953) could have computed the first numerical solution of the partial differential equations governing the weather[1], by hand, and whilst serving as an ambulance driver at the French front in the 1914-1918 war. Yet that is the truth of the matter, for he was an extraordinary man.

Born in Newcastle upon Tyne in the north-east of England, he was the youngest of seven children from Quaker parents. Following early education at Bootham's Quaker school, York, and two years at Durham College of Science (eventually becoming the University of Newcastle upon Tyne), he studied physics at King's College, Cambridge, graduating with a first, in 1903. He remained at Cambridge for ten years, holding a number of research posts and positions in industry. It was while working as a chemist with the National Peat Industry Limited, 1906 -1907, that he was faced with the task of calculating the percolation of water through peat. This is a diffusion problem and so is governed by the Laplace equation, but the difficulty he found was that the boundary of the region had a complex topography, meaning that exact solutions could not be found. In anticipation of his later work in the numerical modelling of weather, he based his solution on a finite difference methodology. Following publication of his methodology[2] he submitted it as a dissertation in a competition for a Fellowship at King's College, but apparently mathematicians from Trinity College were of the opinion that this was "approximate mathematics and were not impressed"[3]. Richardson never returned to Cambridge.

Instead, in 1913, he joined the Meteorological Office, as Superintendent of the Eskdalemuir Observatory, Scotland. It was here that he worked on numerical methods for forecasting the weather, writing a first draft of the book[1] which was eventually to be published in 1922. He resigned in May 1916 and joined the Friends Ambulance Unit in France, working alongside French military ambulances, transporting wounded soldiers, often under shell fire. Over the next two years he refined his numerical methods and carried out the forecast described in his 1922 book, essentially providing the first 'CFD' solution of the Navier-Stokes equations which govern fluid flow. Let us read what Richardson has to say about his computations and in particular his imaginings of a "forecast-factory":

The Speed and Organization of Computing[1]

"It took me the best part of six weeks to draw up the computing forms and to work out the new distribution in two vertical columns for the first time. My office was a heap of hay in a cold rest billet. With practice the work of an average computer might go perhaps ten times faster. If the time-step were 3 hours, then 32 individuals could just compute two points so as to keep pace with the weather, if we allow nothing for the very great gain in speed which is invariably noticed when a complicated operation is divided up into simpler parts, upon which individuals specialize.

If the co-ordinate chequer were 200 km square in plan, there would be 3200 columns on the complete map of the globe. In the tropics the weather is often foreknown, so that we may say 2000 active columns. So that 32 x 2000 = 64,000 computers would be needed to race the weather for the whole globe. That is a staggering figure.

Perhaps in some years' time it may be possible to report a simplification of the process. But in any case, the organization indicated is a central forecast-factory for the whole globe, or for portions extending to boundaries where the weather is steady, with individual computers specializing on the separate equations. Let us hope for their sakes that they are moved on from time to time to new operations.

After so much hard reasoning, may one play with a fantasy ? Imagine a large hall like a theatre, except that the circles and galleries go right round through the space usually occupied by the stage. The *walls of this chamber are painted to form a map of the globe. The ceiling represents the north polar regions, England is in the gallery, the tropics in the upper circle, Australia on the dress circle and the antarctic in the pit.*

A myriad computers are at work upon the weather of the part of the map where each sits, but each computer attends only to one equation or part of an equation. The work of each region is coordinated by an official of higher rank. Numerous little "night signs" display the instantaneous values so that neighbouring computers can read them. Each number is thus displayed in three adjacent zones so as to maintain communication to the North and South on the map. From the floor of the pit a tall pillar rises to half the height of the hall. It carries a large pulpit on its top. In this sits the man in charge of the whole theatre; he is surrounded by several assistants and messengers. One of his duties is to maintain a uniform speed of progress in all parts of the globe. In this respect he is like the conductor of an orchestra in which the instruments are slide-rules and calculating machines. But instead of waving a baton he turns a beam of rosy light upon any region that is running ahead of the rest, and a beam of blue light upon those who are behindhand.

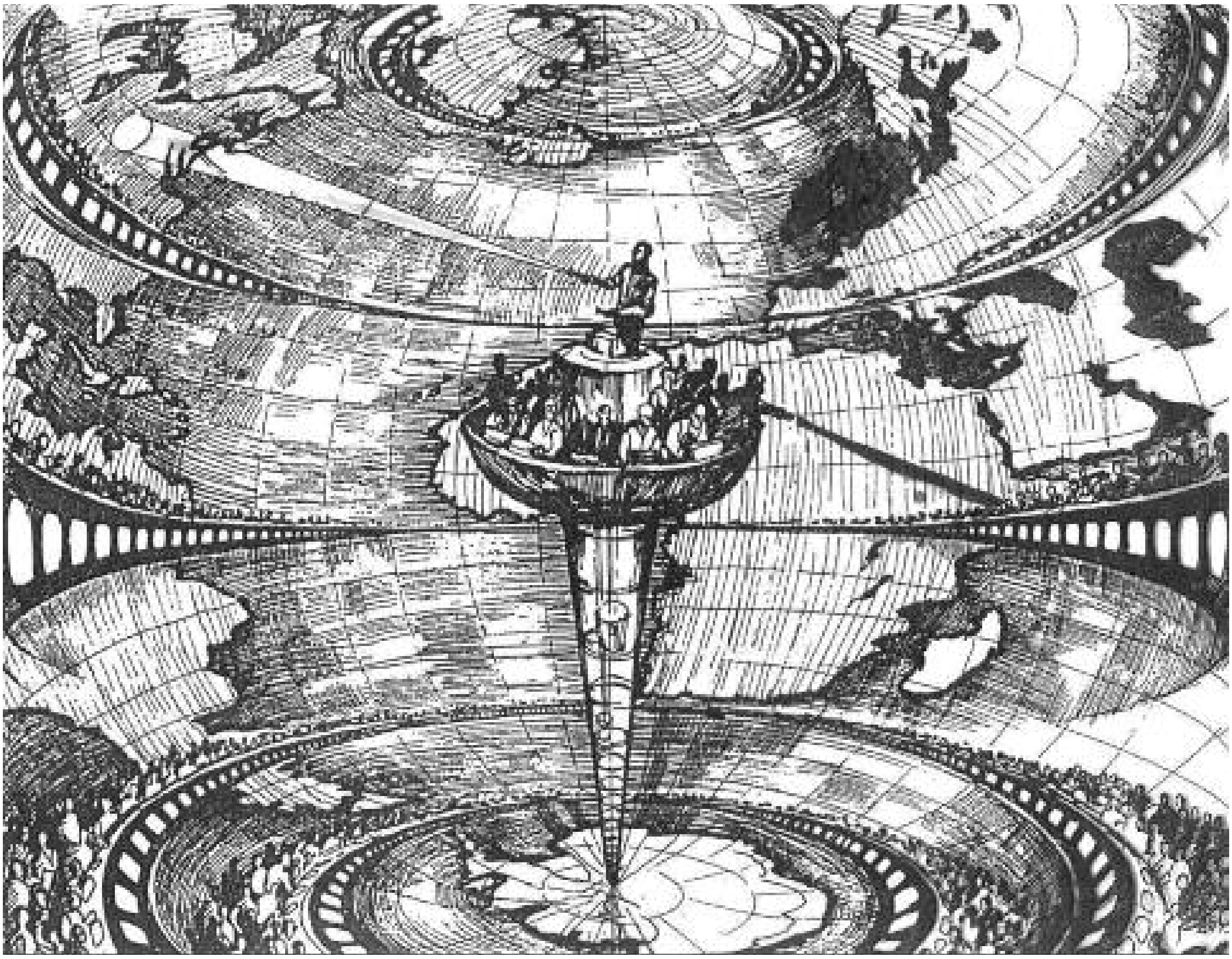
Four senior clerks in the central pulpit are collecting the future weather as fast as it is being computed, and despatching it by pneumatic carrier to a quiet room. There it will be coded and telephoned to the radio transmitting station.

Messengers carry piles of used computing forms down to a storehouse in the cellar.
In a neighbouring building there is a research department, where they invent improvements. But there is much experimenting on a small scale before any change is made in the complex routine of the computing theatre.

In a basement an enthusiast is observing eddies in the liquid lining of a huge spinning bowl, but so far the arithmetic proves the better way. In another building are all the usual financial, correspondence and administrative offices. Outside are playing fields, houses, mountains and lakes, for it was thought that those who compute the weather should breathe of it freely."

This is a remarkable vision, in which 'computer' means only one thing: a human calculator.

During his time in France, Richardson had calculated the weather for a six hour period over Germany, applying a precise and detailed implementation of an algorithm outlined by the Norwegian scientist Vilhelm Bjerknes. It was a spectacular failure, greatly over-predicting the rate of pressure rise. The mathematical techniques were



correct, but we now know that the initial conditions which Richardson used were 'noisy' and needed to be 'smoothed'. In addition, Richardson's computational time-step was too large. Peter Lynch[4] provides an interesting analysis of Richardson's prediction.

Nevertheless, through his audacious calculations Richardson had shown that numerical techniques could be applied to solve what appeared to be intractable physical problems.

Richardson rejoined the Met. Office upon his return from France in 1919. However, when the Met. Office was brought into the Air Ministry at the insistence of Winston Churchill – and the Air Ministry controlled the RAF - Richardson's pacifist convictions meant that he had no option but to resign. He continued his research whilst lecturing at Westminster Training College, where he taught physics and mathematics to prospective school teachers, publishing numerous papers and making outstanding contributions in the meteorological field. He gives his name to the Richardson number; a key non-dimensional parameter for turbulent flows affected by stratification caused by buoyancy. In a meteorological context, the Richardson number represents a ratio of the stabilizing/destabilizing effects of vertical density gradients on turbulent mixing, compared to shear-generated turbulent mixing.

The Richardson number is a crucial parameter in the field of atmospheric dispersion. For his contributions to the field of meteorology, he was elected as a Fellow of the Royal Society of London, in 1926.

It was in 1926 that Richardson completely changed his field of research, to psychology, again making important contributions – in particular in experimental and mathematical modelling methods in the field of sensory perception. In 1929 he moved to the Technical College in Paisley, but from 1935 his research shifted to yet another field; mathematical theories of human conflict and the causes of war. He pursued these studies until his retirement, in 1943, and in the process was first to characterise the irregularity of borders between countries by an index which we now recognise to be a fractal dimension. However, his research efforts did not end upon retirement, as in 1948 he published a key paper[5] on the diffusion of particles in turbulent flow, apparently based on experiments in which he and Henry Stommel threw parsnips into Loch Long – close to his last home.
Richardson was a bold visionary whose work has had a lasting impact. For instance, he devised a method[2,6] for the extrapolation of numerical solutions which is widely used today. However, we finish with a rhyme which he wrote to illustrate the cascade of energy from the large to small scales in turbulent flows, to be found on page 66 of his 1922 book, which incidentally is still in print - as a 2007 second edition with foreword by Peter Lynch.

"Big whirls have little whirls that feed on their velocity, and little whirls have lesser whirls and so on to viscosity"

Lewis Fry Richardson is most certainly an 'Icon of CFD', from the days of 'human computers'.

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