Henry Selby Hele-Shaw LLD, DSc, EngD, FRS, WhSch (1854–1941): Engineer, inventor and educationist

Author:
Jane Carruthers[1]

Affiliation:
[1]Department of History, University of South Africa, South Africa

Correspondence to:
Jane Carruthers

email:
carruej@unisa.ac.za

Postal address:
Department of History, University of South Africa, PO Box 392, Unisa 0003, South Africa

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ABSTRACT

H.S. Hele-Shaw (1854–1941) was one of the most outstanding engineering scientists of his generation and an eminent figure in engineering education during the late-19th and early-20th centuries. His work in hydrodynamics (the Hele-Shaw cell and Hele-Shaw pump) and his important contribution to the successful development of high-speed aircraft (his variable pitch airscrew), continues to be relevant today. In 1922, as President of the Institution of Mechanical Engineers, he introduced the National Certificate scheme in Britain. It is not well known that Hele-Shaw spent two years in South Africa (1904–1905) attached to the Transvaal Technical Institute, a forerunner of the University of the Witwatersrand. One of only three Fellows of the Royal Society of London in southern Africa in 1905, he was a founder Council member of the Royal Society of South Africa and one of the hosts of the 1905 visit to southern Africa by the British Association for the Advancement of Science. The purpose of this paper is to highlight the time he spent in South Africa and to contextualise it within the larger perspective of his engineering career.

INTRODUCTION

In 1977, on the occasion of the centenary of the foundation of the Philosophical Society of South Africa (forerunner of the Royal Society of South Africa), the Royal Society published an edited commemorative volume, entitled *A History of Scientific Endeavour in South Africa*.[1] The final chapter, by botanist and ecologist Anthony Hall, was a history of the Royal Society of South Africa. After explaining the beginnings of the Philosophical Society and its reconstitution as the Royal Society, Hall wrote, 'A provisional Council was formed in 1905 by Sir David Gill FRS, Mr S.S. Hough FRS, Professor Hele-Shaw FRS, and nine other persons'.[2] These three men were the only Fellows of the Royal Society of London living in South Africa in the early years of the 20th century. Gill and Hough were both well-known astronomers (Hough succeeded Gill as the Astronomer Royal in Cape Town), but I became intrigued by Hele-Shaw whose initials are not even provided and whose name does not appear elsewhere in the commemorative volume. Having discovered that he was an engineer and, unlike Capetonians Gill and Hough, was resident in Johannesburg at the time his name appeared as an initial Royal Society Councillor, I sought him, unsuccessfully, in G.R. Bozzoli's book *Forging Ahead: South Africa's Pioneering Engineers*.[3] Given that there is a dearth of engineering historiography in South Africa, I was obliged to turn to other sources. I discovered that South Africa had briefly been home to one of the great engineers of the late-19th and early-20th centuries, a man who was a research scientist and inventor and who also had an important and long-lasting impact on the structure of technical education in Britain. The purpose of this paper is to provide a brief biography of Hele-Shaw, paying particular attention to his two politically fraught years in South Africa (1904–1905), and to explain his significant contribution to engineering. Vasil'ev described Hele-Shaw as 'sadly, an example of one of the many undeservedly forgotten great names in Science and Engineering'[4], a comment that applies even more to his South African career than it does to his work in general.

EARLY LIFE 1854–1884

Henry Selby Hele Shaw (he later hyphenated his last two names) was born in Billericay, an old Roman town in Essex, about 15 km south-west of Chelmsford, on 29 July 1854. He was one of 13 children born to Henry Shaw, a solicitor and a local public figure, and his wife Marion, daughter of Henry Selby Hele, vicar of Grays, a larger town nearby on the Thames. The Shaws were part of the middle-class, professional society that emerged in Britain during the later phases of the Industrial Revolution. Hele-Shaw's curriculum vitae in the National Archives in Pretoria states that he was educated at various private schools, finishing at Chippenham School;[5] other biographies, including his Royal Society *Obituary Notice*[6,7] and his entry in the *Dictionary of National Biography*[8], suggest that he was privately educated until his late teens. The young Henry must have had an interest in science and shown an aptitude for engineering because, in 1871, he began his apprenticeship under Edwin Roach (sometimes spelt Rouch) at the Mardyke Engineering Works of Roach and Leaker in Bristol. The apprenticeship lasted for four years and on its completion Hele-Shaw remained in Bristol to work for Messrs G.K. Stothert and Co., Marine Engineers and General Engineers. Hele-Shaw continued with his studies during this time and his brother recorded that he worked for ten hours at the engineering firm every day and then attended night classes. He was, by all accounts, a dedicated and clever student, even winning the Senior Whitworth Scholarship in 1877, which enabled him to resume his studies at the 'red brick' University College Bristol, established just a few years previously. He won a Whitworth Senior General Scholarship twice more (1878 and 1879), obtaining the highest marks in his class despite a serious illness. These competitive examination prizes (and other awards, including the Miller Scholarship and one from the Institution of Civil Engineers in 1880) allowed Hele-Shaw to accumulate sufficient funds to continue his studies.[6]

The Whitworth Scholarships were financed by Sir Joseph Whitworth, one of the giants of Victorian mechanical engineering. Whitworth's contribution lay not in large projects like railways and bridges, but rather in the manufacture and perfection of accurate, standardised tools and precision instruments

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that made these possible. Later in his life, as President of the Institution of Mechanical Engineers in 1922, Hele-Shaw remained grateful for the help that these scholarships had given him and he founded the Whitworth Society (which is still active) to enable scholarship awardees to maintain professional and collegial contact with one another.[6]

Hele-Shaw completed his studies at the University College Bristol in 1879. It was one of the liberal science colleges that sprang up at the time and, apart from engineering, it offered mostly evening courses in plumbing, hosiery, brewing and bread-making.[9] Britain lagged behind Germany in technical education; therefore, a new generation of institutions of higher learning was established during this period to improve the situation. As a rigorous science, engineering was a new discipline in academia. The first Chair of Engineering was established at the University of Glasgow in 1840, but there was no degree in science or engineering, per se, until 1872 when, as a result of student pressure, a BSc was introduced.[10] In his survey of engineering education, Emmerson explained how engineering came to be considered a reputable profession during the 19th century, one to which even 'gentlemen' might aspire.[9] In the 18th century, all engineers had been military engineers and were regarded as manual workers with a low status. 'Civil engineering' (engineering for civilians and civilian life) came into its own in tandem with a growing academic trend in engineering education, which saw the foundation of the Institution of Civil Engineers in 1818, the Institution of Mechanical Engineers in 1847, and the Institution of Electrical Engineers in 1871. A number of prominent engineers were also knighted towards the end of the 19th century, which bears testimony to the rising status of the profession.[9]

After Hele-Shaw completed his studies in 1879, he was appointed Lecturer in Mathematics and Engineering at University College Bristol and, two years later (aged 27), he was promoted to the new Chair of Engineering. The young Professor had already made a name for himself as a research engineer, winning the Miller Scholarship for his paper 'Small motive power' that was published in the *Proceedings of the Institution of Civil Engineers* in 1880 (Vol. LXII:290). In 1881, he published two papers: 'A new integrating anemometer' (jointly with J.M. Wilson) in the *Report of the British Association for the Advancement of Science* (p. 543), and 'Some remarks on wind measurement' in the *Proceedings of the Bristol Naturalists' Society*. These were followed in 1882, by 'Measurement of velocity for engineering purposes' in the *Proceedings of the Institution of Civil Engineers* (Vol. LXIX: 394).[5] At the time, many engineers in Britain were focussed on the study of wind velocity and loading, after the bridge over the river Tay in Scotland collapsed in a violent storm in December 1879, killing 75 people. Hele-Shaw's work centred on the invention of a new integrating anemometer that provided a continuous graph of velocity, as well as a second type which recorded both velocity and direction. This was built and installed at Bidston Observatory near Liverpool.[6]

UNIVERSITY COLLEGE LIVERPOOL 1885–1903

In 1885, Hele-Shaw was offered the first Chair of Engineering at the University College in Liverpool, founded in 1881 as another of the new 'red brick' institutions of higher learning. Hele-Shaw's move from Bristol brought him in touch with eminent academics and politicians in Liverpool, then a major industrial centre. On 12 April 1890, he became associated with one of Liverpool's most prominent Unitarian and Quaker families when he married Ella Rathbone (1862–1946), a daughter of Samuel Greg Rathbone, Liverpool Councillor for the Liberal Party, with a special interest in furthering elementary education. The Rathbones were international merchants, philanthropists and supporters of schools and universities, as well as the nursing profession and social reform in general. Hele-Shaw's new family connection afforded him strong social, political and educational backing. His professorial chair had been only temporarily endowed, but due to the Rathbone interest and influence, Sir Andrew Barclay Walker, a wealthy Ayrshire brewer who had settled in Liverpool, donated the enormous sum of £23 000 to the University College in 1887, for the erection and equipment of suitably large engineering laboratories. Thomas Harrison also donated £10 000 for the endowment of a permanent Harrison Chair of Engineering.

Hele-Shaw thus came to be in charge of the best engineering laboratory in Britain at that time and found himself in an excellent educational institution. Under his direction it grew rapidly, rising from three students in 1887 to 130 in 1903, half of them reading for university degrees. The foundation laid by Hele-Shaw ensured the successful conversion of the Department into a Faculty in 1910 (the University College became a full University in 1903, with the right to confer its own degrees). Moreover, Hele-Shaw's students did exceptionally well, winning scholarships and prizes for their work. The entry for Hele-Shaw in the *Dictionary of National Biography 1941-1950* gives the following on his teaching ability:

> *As a teacher he had no difficulty in holding the attention and interest of his students. On his own subject of kinematics he was a fine lecturer, making use of frequent demonstrations which his inventiveness suggested to him. His geniality and his undoubted pre-eminence as a practical engineer never failed to earn him the affection and response of his students.*[8]

His obituary, though, is less flattering.

> *As a teacher, his success was partial rather than general. His talent for devising apparatus to illustrate principles in an attractive way, and his expertness in free-hand drawing made his lectures in the subject which commanded his special interest both interesting and successful. His students, however, sometimes felt that he devoted too much time to the study of kinematics, and was less interested in groundwork; but it was this very absorption with mechanism which inspired and made possible his later work as an inventor.*[6]

While placing his department on a firm scientific, educational and administrative foundation, Dr Hele-Shaw continued with his research. In his first year at Liverpool he published a paper on 'The theory of continuous calculating machines and of a mechanism of this class on a new principle' in the prestigious *Philosophical Transactions of the Royal Society*.[11] This work investigated how to advance the design of integrator mechanisms and fit them for tasks more complex than mere numerical calculating machines, and was extremely important in the development of analogue computing.[12] His paper on a similar topic, also in 1885, 'Mechanical integrators' published in the *Proceedings of the Institution of Civil Engineers* (Vol. LXXX11: 75) won him the Watt Gold Medal and Telford Premium.[6] Hele-Shaw was a prolific author, publishing no fewer than 38 papers between 1885 and 1900. His output was imaginative, eclectic and wide-ranging, encompassing mechanical integrators, testing of steam engines, friction and lubrication, molecular theory, engineering education, graphic methods in mechanical science, aerial navigation, the pneumatic tyre and trials of the then novel motor vehicles. While he was at Liverpool, Hele-Shaw became 'intensively and actively interested in both the scientific and practical development of the motor car'[6]. He owned an early Benz vehicle and he experimented with traction and road resistance. He was also a Foundation Member of the Royal Automobile Club and, later, President of the Institution of Automobile Engineers. In 1903, he invented (and patented) the Hele-Shaw Friction Clutch that fitted between the engine and gearbox of a car; it was generally standard issue, until it was displaced by the monoblock engine and linked gear box.[6]

Hele-Shaw's major theoretical work of the 1890s, however, lay in the direction of fluid mechanics. As explained by Bloor,

> *techniques for rendering hidden processes visible (Sichtbarmachung) have a long history in the physical sciences. Towards the end of the nineteenth century, and in the early years of the twentieth, there was a concerted effort to develop such techniques in the area of fluid dynamics.*[13]

In 1877, Osborne Reynolds (1842–1912), then Professor of Engineering at Owen College, Manchester, conducted his first experiment that showed the train of vortices that form in the path of a solid body through water. His work in the 1880s on the transition between streamline and turbulent motion became renowned as the dimensionless 'Reynolds number'.[14] The 'Reynolds number' can be used, for instance, for testing aircraft wing turbulence or river systems and is important in discovering how marine creatures are able to swim at speed. The equations governing viscous fluids are called Navier-Stokes equations. They determine velocity and pressure for any position of the flow at any given time, but are, unfortunately, mathematically intractable.[13] Hele-Shaw's contribution was to demonstrate visually how these flows operated in the real world by inventing the 'Hele-Shaw cell', to demonstrate to his students the two-dimensional flow of a viscous fluid in a narrow gap between two parallel plates. As Vasil'ev explains,

> *this cell is the simplest system in which multi-dimensional convection is present. Probably the most important characteristic of flows in such a cell is that when the Reynolds number based on gap width is sufficiently small, the Navier-Stokes equations averaged over the gap reduce to a linear relation for the velocity similar to Darcy's law and then to a Laplace equation for the fluid pressure.*[4]

Indeed, his work 'did much to bring hydrodynamics within the range of the experimental sciences'[6]. He was to refine and augment this work over the course of his life and, not only does it remain topical and useful (for the oil industry for example), the mathematics behind the Hele-Shaw cell has spawned a branch of study that was particularly strong in the mid-20th century Soviet Union, which has contributed to the new field of 'Integrable Systems and Mathematical Physics'.[4] It is remarkable that Hele-Shaw's work has enjoyed this long and complex life, even to the extent of a highly philosophical article on the question of what scientific 'reality' comprises, published in 2008.[13] This work raised Hele-Shaw's profile as a research engineer and he and Reynolds (rather controversially) exchanged ideas over three issues of *Nature* in 1898 and 1899.

In 1897, Hele-Shaw was awarded an honorary doctorate from St Andrews and, in 1899, he was elected a Fellow of the Royal Society of London. He was, however, no 'backroom scientist', for at that stage in his career, he was also the Chief Examiner of the Civil Service Commission as well as the Royal Naval College and other institutions, while serving on the Boards and Committees of numerous scholarly societies. He also supported amateur scientists who had interesting ideas, including promoting Frank Hornby's 'Meccano' sets, an endorsement that enabled Hornby to expand his business commercially and make his fortune.[15]

Hele-Shaw was the father of two children (a son and a daughter) and a keen sportsman who enjoyed athletics, mountaineering, golf, football and yachting.[5]

SOUTH AFRICA 1904–1905

Hele-Shaw, aged 50 and at the peak of his career, arrived in South Africa in January 1904. An engineering scientist of his calibre was attracted to the Transvaal after the end of the Anglo-Boer War (1899–1902) to put technical education in South Africa (then consisting of four colonies: the Transvaal, Orange River Colony, the Cape and Natal) on a firm foundation. For reasons that will be explained below, political factors thwarted Hele-Shaw's efforts and his legacy to South African engineering was not as substantial as it might have been.

Hele-Shaw arrived in South Africa at a 'trying period' in its history.[16,17,18,19] In May 1902, the subcontinent had emerged from a painful and destructive war and emotions between recent enemies still ran high. There was no state named 'South Africa' until 1910, when the Union of South Africa was created. Educational standards, requirements and administration differed among the four colonies and, although it was clear that some kind of closer union was perhaps inevitable, it was equally evident in the period shortly after the war, that this would not come about very soon.

In order to understand Hele-Shaw's South African career, it is necessary to provide some background to the state of education in the region. In 1900, the only 'university' was the University of the Cape of Good Hope, in Cape Town, founded in 1873 as an examining body (not a teaching university) for the University of London.[20] This University had the monopoly of examining and awarding degrees in the Cape Colony, a monopoly which was extended throughout southern Africa after 1875. Various 'colleges' of unequal quality were teaching institutions, the oldest of these being the South African College in Cape Town (founded in 1832). Other teaching institutions included Huguenot College, Victoria College, Graaff-Reinet College and Grey College.[20] The Transvaal, however, had no institutions of higher learning when war broke out in 1899. In 1891, a Hollander, Dr N. Mansvelt, was appointed the first head of education in the South African Republic. The requirements of the 1892 law introduced for schools by the Kruger government, included the provision that all teachers had to be Protestant, all lesson books had to be in Dutch, and only a few hours each week were to be devoted to a foreign language, including English. By the 1890s, however, the mining industry in the Transvaal was burgeoning and Johannesburg was becoming a wealthy city. English-speaking residents ('uitlanders') had soon become dissatisfied with these educational restrictions and began to make arrangements to educate those excluded by the Mansvelt system. In 1895, the Witwatersrand Council of Education was founded and attempted to establish classes for the Cape University Matriculation, which included science subjects that intended to serve employees on the mines. Additionally, in 1898, the Republican government passed a law enabling the establishment of technical schools in the Transvaal but nothing had come of this by the time war broke out the following year.[21] Prior to the Anglo-Boer War there had also been a School of Mines. This was a complicated institution, requiring two years of theoretical study in Cape Town (where the School of Mines was based), a third practical year in Kimberley at the School of Mines there (opened in 1896), and a final fourth year (afterwards reduced to six months) to be spent in a gold mine in Johannesburg. When completed, such a programme resulted in the award of a Mining Engineering Diploma, issued by the University of the Cape of Good Hope.[22]

Sir Alfred Milner (Governor of the Transvaal and Orange River Colonies after 1902), emphasised efficient administration and Anglicisation and thus turned his attention to education early.[16] He appointed Edmund Sargant, a university-trained and well-travelled man who had organised education in the concentration camps during the war, to be Director of Education for the Transvaal and Orange River Colonies. In September 1901, an Assistant Director was appointed, a graduate of the University of Paris and experienced teacher named Fabian Ware (later Sir Fabian and, in 1917, founder of the Imperial War Graves Commission, as well as Director-General at the British War Office during World War II). Shortly after the war ended in 1902, Sargant appointed a Committee under Ware to investigate how best to promote technical education in the Transvaal. Ware's report, issued in 1903, recommended the establishment of a technical institution that would later form part of a future teaching university in Johannesburg. As a result, the Transvaal Technical Institute (TTI) was founded in August 1903, with Ware himself as chairman of the Council. This was the initiative of Sir Arthur Lawley, Lt-Governor of the Transvaal, and not Sir Alfred Milner. A four-year course of study was proposed and premises were secured in Plein Square. The overall objective was to provide a practical education along the lines of the Birmingham 'red brick' model.[22] Ware and Sargant did not, however, get on well with each other. Sargant, an original thinker and imperial enthusiast, was apparently a 'wretched administrator' who was autocratic and erratic. Ware replaced him as Director of Education in the Transvaal in October 1903. Milner created a largely decorative

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post as 'Educational Advisor' for Sargant, while Ware courted the Transvaal Executive Council, thus creating divisions between Milner and the Transvaal government.[16]

Hele-Shaw arrived in the Transvaal as yet unaware of these developments and of the animosity and rivalry between Sargant and Ware. Also, Hele-Shaw did not then know that Fabian Ware, supported by TTI Council Member and eminent geologist George Corstophine, had tried to block his (Hele-Shaw's) appointment, on the rather surprising grounds that 'his ideas and methods were outdated'.[22] As Denoon summarised:

> *as in many pedagogic disputes, an innocent bystander was injured. Milner and Sargant proposed and appointed Professor Hele Shaw [sic] as head of the new Johannesburg Technical Institute (the lineal ancestor of Witwatersrand University). The unsuspecting Professor was startled to discover that Ware and the Transvaal Executive were consistently obstructive, and he could not understand why. Milner himself was appalled by the turn of events. He confided to Lionel Curtis (in itself an indiscretion) that he no longer took part in discussions involving the Institute because they were 'so mixed up with odious personal differences and intrigues'.*[16]

Hele-Shaw thus became enmeshed in this political and personal tussle for power. It seems that prior to the establishment of the TTI, Milner, with support from others, believed that education should be conceptualised on the basis that a new country, comprising all four colonies, would be established in due course. Thus he had envisaged Hele-Shaw's role as one that would create a sound technical education for the whole of the Transvaal, which might later, possibly, have been applied to the rest of the country. However, because the TTI had been established between the time of Sargant's approach to Hele-Shaw and his acceptance of the post, Hele-Shaw found that he was unexpectedly attached to the TTI and did not have a free hand, being subject to the decisions of the already existing Council. It had already been decided that, due to the unsatisfactory post-war conditions in the mining industry,[23] technical education should be confined to the third and fourth years of the mining course at the University of the Cape of Good Hope. Sargant had been annoyed by this and had wanted it to be made clear to Hele-Shaw that he (Sargant) had not known about the situation in which the newcomer would find himself. In addition, Sargant had thought that what Hele-Shaw was being offered was probably not 'sufficiently important to satisfy a man of the Professor's standing'.[24] By the time Hele-Shaw was brought fully into the picture at the end of November 1903, he had already resigned from his position in Liverpool and so could not refuse this post. He arrived in South Africa as Senior Professor of the TTI[24] and in January 1904 the TTI opened its doors to students.

Not only had Hele-Shaw been catapulted into the vortex of personal agendas and local Transvaal interests and rivalries, while being perceived as a 'Milner and Sargant man' in the Ware camp, seething beneath this had been the larger issue of the establishment of a teaching university for South Africa, a matter which was not resolved until many years later.[22] Milner had supported the idea of a technical university on the Witwatersrand, but the Cape Colony, on the other hand, had considered itself the cultural and educational hub and had thus argued that its long-standing teaching institutions might more easily facilitate its own conversion into a full university. Moreover, within the Transvaal itself, Pretoria – the seat of government – saw itself as the natural home for a university, rather than the more commercial centre of Johannesburg. After Hele-Shaw had left South Africa, the TTI, in 1906, was converted into the Transvaal University College, which split the following year when the College relocated to Pretoria (later, in 1930, to become the University of Pretoria), leaving the School of Mines in Johannesburg (later, in 1922, to become the University of the Witwatersrand).[20,22,25]

It had been intended that the TTI offer courses that had been provided in Kimberley and examined by the University of the Cape of Good Hope. Hele-Shaw, however, wanted to introduce courses of his own: a three-year general course in engineering, followed by a specialist fourth year. Examinations and awards of certificates and diplomas would be done by the TTI, but if students wanted a degree they could write the examinations of the University of the Cape of Good Hope.[22] The month after he arrived, Hele-Shaw addressed the graduation ceremony of the University of the Cape of Good Hope, stressing his belief that an independent teaching university should be established on the Witwatersrand (Alfred Beit donated his farm Frankenwald on the outskirts of Johannesburg for such a purpose in 1904). His speech was impressive, but probably did not endear him to many in the Cape Colony.[26] Hele-Shaw began teaching in March 1904 when there were 45 students of mining engineering at the Institute, by the following year there were 52. He also initiated the evening classes that had been so successful in England. There were 349 enrolled students in 1904 and 460 in 1905, in various centres on the Witwatersrand.[21] Hele-Shaw also took on a public role, lecturing to groups and promoting technical education. On 6 May 1904, for example, he addressed the Chemical, Metallurgical and Mining Society of South Africa, expressing his pleasure regarding the research that the Society conducted and congratulating it on its large membership.[27] He was also able to secure some excellent teachers and professors for the Institute, among them metallurgist George Stanley, mechanical engineer John Orr, mining engineer John Yates,[22] biologist H. Lyster Jameson and professor of law G.T. Morice.[28] Orr, a practical organiser rather than a theoretical engineer,[22] had originally trained at the Royal Technical College in Glasgow and had been on the staff of the School of Mines in Kimberley from 1898. (In 1961, a wing of the engineering faculty at the University of the Witwatersrand was named after Orr, who was the University's first Professor of Mechanical and Electrical Engineering from 1922 to 1926 and who bequeathed a considerable sum to the University.)

Hele-Shaw sailed for England in August 1904, but returned to the Transvaal early in 1905, this time as Principal of the TTI, a promotion that he perhaps owed to Milner's personal intervention.[29,30] He left South Africa permanently in December 1905, on the expiry of his contract.[26] A newspaper reported at the time that Hele-Shaw offered 'to give his services gratuitously in a consultative capacity after the expiry of his engagement'[31] but he was never called upon to do so.

During his time in South Africa and particularly in the speeches that he gave shortly before returning to England at the end of 1905, Hele-Shaw expressed strong opinions about the role of a South African university. In one lecture, for example, he expressed himself as being generally pleased with progress in the TTI , which he hoped that one day would become a 'modern university', the real core of which was intellectual development. He argued for the pursuit of learning, for research and for the avoidance of teaching from books.[31] His farewell function in mid-December 1905, as reported in *The Star*, was a 'charming affair' with attractive decorations and good food.[32] Speeches were apparently eulogistic and Hele-Shaw's work was highly praised. In reply, Hele-Shaw reiterated that scientific investigation was the lifeblood of any university and that he was pleased to have come across so many students with a bright future before them. By the time he left, Hele-Shaw had come to understand the situation in South Africa and appreciated that establishing his 'modern' university would be a very difficult task. When asked by *The Star* if he had a solution, Hele-Shaw apparently laughed and said 'To my mind, you have only one thing really to fear, and that is apathy, and a want of public spirit on the great questions of technical and higher education'. He ended the interview by expressing the hope that young men and women 'will, at any rate, start their active work in life free from the narrow prejudice and bitterness which ill-advised, often actually unpatriotic, counselors, apparently still seek to promote'.[33] This was as far as he went in publicly criticising his colleagues, his employers and the colonial governments.

The British Association for the Advancement of Science visited South Africa while Hele-Shaw was Principal of the TTI and so he was involved in arrangements for the Johannesburg portion of their subcontinental tour, particularly as it related to education.[17,19] The highlight was Richard Jebb's address in Johannesburg on 'University Education and National Life'.[18,20] Hele-Shaw published this address because it accorded with his own views, particularly as related to the importance of engineering as a 'scientific habit of study' in securing an intellectual future.[34]

It is difficult to evaluate Hele-Shaw's South African career. It can be said, however, that his leadership of the TTI, under difficult circumstances, established engineering as a reputable discipline in northern South Africa. His legacy within this country is perhaps the strong Faculty of Engineering that now exists at the University of the Witwatersrand. Indeed, his biographical notice and his obituary record stated that he founded three university engineering departments: Bristol, Liverpool and the Witwatersrand.[6,7] In March 1905, as he began his term as Principal of the TTI, Hele-Shaw wrote a 'private letter' to Milner. Here, Hele-Shaw expressed his disappointment at the

> *interference of the officials of the Transvaal Government who were in England at the time the Home Committee were considering the election of the Principal and Organiser, and which interference I never expected … I cannot, however, forget that the above adverse action followed upon a train of circumstances which required considerable determination and self-control to face and which but for you might have ruined my career … I did not desire my present post, except in so far as I could help a stage further the education work here, as I knew it would necessitate my giving up a valuable chair and place me in the position of having to start life afresh at the end of another year. So far as my scientific future and engineering work in England is concerned the arduous nature of my task here makes this period one of lost time. The extremely strong resolution passed by the Council of the Liverpool University and other public bodies on my departure from Lancashire would have been of great value had I gone straight to London from there – as it is, I find that most people think I have now obtained a permanent post in South Africa and if I return at the end of a year without recognition will draw their own conclusion.*[27]

At his farewell speech in Johannesburg on 12 December 1905, Hele-Shaw jokingly referred to the fact that

> *it was very few [in South Africa] who had escaped the clutches of the grave-digger of professional reputations, and even those who had escaped that gentleman for them was reserved very liberal plots of ground ready in case they did not depart in time.*[32]

It was clear that he counted himself among those who had narrowly escaped. Although he left South Africa good-heartedly in December 1905, it is entirely probable that he remained disappointed that he had not been given a permanent appointment and had had no real power to make an educational difference or enhance his personal stature. Moreover, he had accomplished none of the research that he enjoyed so much.

LATER LIFE 1907–1941

Whether his experience in South Africa was the deciding factor or not, it is interesting to note that Hele-Shaw never again sought or held an academic position. He established himself in London as a consultant focussing on the commercial production of his inventions, later going into partnership with his son-in-law, Harry Hall.[6,7] (Hele-Shaw's son, Henry Rathbone Hele-Shaw, an R.F.C pilot, was shot down and killed over France in February 1917, aged 20.)[35] As well as a number of smaller contributions (including a flame-throwing device in World War I, patent inkpots, walking machine, and chimney cowls), Hele-Shaw made three very significant contributions to engineering in his post-South African career. Firstly, he worked on the hydraulic transmission gear, writing a paper about his pump, the 'Hele-Shaw pump', which presented his preliminary findings in 1912.[36] This was a subject that he continued to develop into the 1920s. Secondly, he amplified his hydrodynamic 'Hele-Shaw cell' theory to observe the behaviour of suspended matter in a fluid. Thus he conceived his 'Stream-line filter' and his paper was published in 1923 in the *Proceedings of the Royal Society of London Series A*.[37] As explored further by Vasil'ev[4], its main application was (and remains) the purification of lubricating oils, therefore extending the life of petrol and diesel engines. It also has relevance for reducing pollution in waters contaminated by oily ballast, thus conserving coastlines and seabird and other marine life.[6] Thirdly, he made a contribution to the aeroplane industry, a subject which had first excited his interest in the 1890s. In 1924, together with Thomas Beacham, he invented an automatic variable pitch hydraulically operated airscrew. This invention came into its own when fast-flying aircraft were developed and it has been said that this airscrew played a major part in Britain's success during the Battle of Britain during World War II.[6,38] In all, Hele-Shaw registered some 82 patents,[4] many owing their success to his persona as 'a colourful showman and efficient salesman'[6].

Hele-Shaw's unpleasant experience in the Transvaal had not entirely put him off engineering education. One of his lasting contributions has been the National Certificate Scheme in Britain, which he conceived and established in the early 1920s, when he was Chairman of the Institution of Mechanical Engineers Education Committee. Indeed, one might argue that his experience of the inaction, politics and pettiness around the local, and jealously guarded, domains of South African higher education, actually led to his advocation of 'National Certificates', issued jointly by the Board of Education and the Institution for Mechanical Engineers, rather than 'Local Certificates', to avoid regional dissension.[39] This became the pattern for similar certificates in other branches of technology and commerce. Hele-Shaw administered this scheme until 1937 and he marked his retirement by endowing a prize to the best mechanical engineering student of the year.[6]

CONCLUSION

Hele-Shaw died at Ross-on-Wye, on 30 January 1941 (aged 86), just a year after his retirement. He has since been described as 'a man of great mental and physical alertness of great energy and courage'[6] whose inventions and contributions to engineering science have had lasting merit. It is therefore appropriate that his South African career is made more widely known. During the short period that Hele-Shaw was in the Transvaal, he energised the study of engineering at a higher level in the country, emphasising its academic credentials and the importance of creative, innovative research. Additionally, he campaigned for an intellectual, rather than purely vocational approach to higher education, promoting engineering as a research discipline and employing competent teaching staff. Although he was never allowed free rein on his own research initiatives during his Transvaal period – which, in view of his interests in fluid mechanics and its application to mining, might well have revolutionised aspects of the mining industry – his legacy remains the sound foundation upon which the Faculty of Engineering at the University of the Witwatersrand was built.

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