Horace Lamb & Osborne Reynolds: Remarkable Mancunians … and their Interactions

B. E. Launder
School of MACE, The University of Manchester, Manchester, UK.

brian.launder@manchester.ac.uk

Abstract The paper provides glimpses into the professional lives of arguably, the two outstanding fluid mechanists of their time who were simultaneously professors at Owens College, Manchester. Their interactions with each other were sometimes amicable but, equally, sometimes testy and their views on their common professional subject differed radically. Reynolds was appointed to the Chair of Engineering in 1868 at the age of 25 against strong competition while Horace Lamb, graduating a decade after Reynolds, was appointed as the inaugural Professor of Applied Mathematics at the University of Adelaide where he stayed for nine years before being appointed to a chair at Owens College in 1885. Among their various interactions the most significant arose from Reynolds’ famous “Reynolds averaging” paper. That was sent for review by Lamb who was critical of the paper but finally recommended that a revised version be published since Reynolds had essentially invented the subject. Reynolds, in his turn, criticised Lamb’s patronizing reference to engineers’ approach to fluid mechanics in a draft revision of his book *Hydrodynamics*. Nevertheless, on Reynolds’ death in 1912, it was Lamb who attended his funeral on behalf of the University and the Royal Society and who later wrote a moving, much cited obituary of him.

1. Introduction

In the mid-19th Century, Manchester was at the centre of Britain’s industrial revolution. However, while the city grew rapidly, creating employment for a wide range of people, its only further-education establishment was the Manchester Mechanics Institute founded in 1824 which at that time was concerned with pre-university technical instruction. There was talk among the city’s political and business community, however, that the city needed a broader, higher-level educational establishment; all that was missing was the necessary financial support. This vital input was provided in 1846 by a wealthy textile merchant, John Owens, a bachelor who, on his death, bequeathed almost £100,000 – roughly equivalent to 100M€ in today’s money – to trustees for the creation of a college for young men within “the parliamentary borough of Manchester or within two miles of any part of its limits”, Clapp [1].

Thus, in 1851, Owens College, Manchester was opened. The college was not at the time accorded full university status but was, rather, approved as a “provincial examination centre for degree candidates of the University of London”. Its premises, figure 1, were the former home of Richard

---

1 Over the next 140 years the Institute underwent several re-profiling and re-namings before emerging as UMIST (the University of Manchester Institute of Science & Technology) in 1966 and finally amalgamating with the Victoria University of Manchester to form the current University of Manchester in 2004.
Cobden, the MP for Stockport (a town about 10km south of Manchester) who having achieved considerable national fame and popularity by forcing the repeal of the unpopular Corn Laws, decided to move his family to London to be closer to the centre of the nation’s political power. The College embarked on the recruitment of professors across the usual range of degree-level subjects of the period. This did not include the discipline of Engineering, however. While Kings College, London had had the distinction of appointing the first full-time professor of engineering in Great Britain & Ireland in 1840, it was Irish and Scottish universities that, over the ensuing decade, had taken the initiative in adding chairs in engineering at universities in Dublin, Belfast, Cork, Galway and Glasgow (Allen [2]). There had been no further appointments in England when, in the mid-1860s a group of prominent Manchester industrialists began lobbying for the creation of a chair. Indeed, under the leadership of William Fairbairn, FRS, a senior industrialist, they raised the additional funds to support this aspiration, [2]. Thus, in early 1868 the College was able to advertise for a professor in engineering.

2. Professor Osborne Reynolds: the first decade in post
A detailed account of Osborne Reynolds’ early life and how he was appointed, less than two years after his graduation in Mathematics from Cambridge, to the Chair of Civil & Mechanical Engineering at Owens College has been provided by Launder & Jackson [3]. The following paragraph, however, perhaps provides the essential background.

Osborne Reynolds was the second of three children, born in Belfast when his father was headmaster of a local school there. Shortly after his birth, however, the family returned to England but his mother died following the birth of Osborne’s younger brother. Thus, Osborne’s educational and personal development was largely due to his father who never re-married. His father had an unusual background: after graduating in Mathematics from Queens’ College, Cambridge he had trained to become a priest (like his father and grandfather), a calling he followed intermittently through his life. But he also had a good deal of interest in things practical of a mechanical nature, taking out several patents relating to farming [2], since the family had extensive agricultural estates in Suffolk. Thus, Osborne, following the personal tuition provided by his father, moved on at the age of 19 to spend rather more than a year as a trainee with a firm of boat-builders and general mechanical engineers owned by a Mr Edward Hayes of Stoney Stratford. This provided him with a general grounding in engineering manufacture and management. He then went on to read Mathematics at his father’s
college in Cambridge and, despite having to put much time into the study of Greek (which had not formed part of his curriculum with his father), he graduated in 1867 with high honours and immediately took up appointment with civil engineering consultants, Lawson & Mansergh in London (Allen [2]). However, once the Chair position at Owens’ College came to his notice, he knew that he had to apply. On January 18th, 1868 he wrote in response to the advertisement:

“Gentlemen, I beg to offer myself as a candidate for the Professorship in Engineering at Owen’s [sic] College. I am in my twenty-sixth year. From my earliest recollection I have had an irresistible liking for mechanics; and the studies to which I have especially devoted my time are mechanics and the physical laws on which mechanics as a science are based.” (University of Manchester, Osborne Reynolds Archive).

Some details surrounding the choice of the successful candidate are given in [3]. Briefly, of the 27 applicants just two were interviewed and of those, Osborne Reynolds emerged as the winner. Figure 2 shows fragments from the official document of appointment giving (upper) the terms of Reynolds’ appointment and (lower) his signature and that of the chairman of the trustees of Owens College (together with those of witnesses) confirming acceptance of the terms.

Figure 2. Two fragments from Owens College’s official appointment document. Upper: Opening statement; Lower: Confirming signatures by Osborne Reynolds and Alfred Neild, Chairman of the Trustees. (© University of Manchester, Osborne Reynolds Archive)
A photograph of Reynolds around the time of his appointment to the Chair appears in figure 3. The year 1868 would have been a very special one for him for besides his election to the Chair at Owens College he married Charlotte, a daughter of a doctor from Leeds. However, that joy was short-lived for the following year Charlotte died from a peritoneal infection twelve days after the birth of the couple’s son. This clearly posed a challenging start for Reynolds but he may have been comforted by the fact that his father had had to cope with a similar misfortune, indeed with bringing up three young children alone rather than one.

Figure 3. Photograph of Osborne Reynolds from around the time of his appointment to the Chair of Civil & Mechanical Engineering at Owens College ©University of Manchester.

J. J. Thomson, winner of the Nobel Prize in Physics and subsequently President of the Royal Society, was one of the first students to enrol at the College, at the age of 14. His memoirs (Thomson, [4]) noted that, to accommodate the new Department of Engineering, the stables at the rear of the building were converted into a lecture room and the hayloft above into a drawing office. There were, however, no laboratories so Reynolds had to rely on using other science laboratories in the College or performing simple experiments at home. Thus his early papers were mainly concerned with explaining natural phenomena: for example, the tails of comets, the solar corona and the aurora; the electrical properties of clouds and the phenomenon of thunderstorms; the destruction of sound by fog; the calming of seas by raindrops and oil films; and the formation of hailstones and snowflakes. Horace Lamb in his obituary notice of Reynolds, [5], records that there were shades of disappointment noted at the academic nature of these studies by practising engineers who had worked so hard to have the Chair of Engineering created. Following the College’s move in 1873 to the new campus to the south of Manchester (the site of the present University of Manchester), however, Reynolds did begin to address problems of a more pressing engineering importance beginning with two experimental papers on heat transfer, one considering the effect of the presence of air on the condensation rate of steam on a cooled surface (Reynolds [6]) and the other on the extent and action of the heating surface of steam boilers (Reynolds [7]). At about the same time Reynolds also initiated work on the ‘racing’
of ships’ screw propellers and on the multi-staging of turbines and centrifugal pumps (the latter leading in 1875 to a detailed patent specification [2]).

In the second half of the 1870s Reynolds’ research in fluid mechanics shifted towards more general phenomena such as the dispersion of surface waves in deep water and the motion of vortices, the latter made visible by dye traces in water. A fuller account of these and other studies from the period can be found in Allen [2] and Jackson [8]. In recognition of the exceptional contributions that he had made within eight years of his appointment to the Chair of Engineering, in 1877 Reynolds was elected to the Fellowship of the Royal Society.

Throughout this busy and productive period of his career he remained a devoted and involved father. However, in the summer of 1879, his son went down with a severe sickness that led to Reynolds renting accommodation for them both in St. Leonards-on-Sea, at the time a quiet community on the south coast of England. Despite his love and attention, however, his son died on September 27th. That event may be said to mark the end of the first phase of Reynolds career at Owens College.

3. Professor Horace Lamb: his full-circle route to Owens’ College
Unlike Reynolds, Horace Lamb, was a ‘town boy’ growing up in Stockport, a community just far enough from Manchester to be considered an independent township. Born November 29th 1849, he was the son of a cotton mill foreman who had earned a reputation for devising improved operating practices. However, his father died while Horace was still a boy and when, sometime later, his mother decided to re-marry, Horace was thenceforth brought up by his mother’s sister. Under her strict but loving regime Horace thrived, attending Stockport Grammar School and becoming the school captain. His specialties were mathematics and the classics. Indeed, he took the Cambridge examinations in classics and was awarded an entrance scholarship at Queens’ College which, on reflection, he declined having concluded that mathematics and its application was his primary love. However, the level of mathematics he had achieved was adjudged inadequate for him to be admitted to Cambridge; thus, he attended Owens College for a year under the tutorship of Thomas Barker, the professor of pure mathematics. Horace evidently prospered under Barker’s guidance for he was awarded a minor scholarship to Trinity College whence he graduated in 1872, being placed second among the two hundred or more mathematics graduates from Cambridge that year.

His outstanding degree performance led to his being immediately elected a Fellow of Trinity and appointed as a tutor in the college. Moreover, he had developed a passionate interest in the analysis of fluid mechanics and this interest he conveyed by way of what may well have been the first integrated lecture course on the mechanics of fluids delivered to final year undergraduates in 1874. Of his lectures one of those students was later to write “His lectures were a revelation … Lamb, in his own inimitable manner, revealed the mysteries of [vortex rings] and made the properties of a liquid in rotational motion clear to us” (Glazebrook, [9]). One might thus have supposed that the enthusiasm with which his lectures were received would have marked the start of a long and distinguished career at Cambridge – but it didn’t! Horace had remained on cordial terms with the headmaster of Stockport Grammar School and through that link met and became romantically entwined with the head’s sister-in-law. The Cambridge colleges at that time required that junior staff should be unmarried; so Lamb had to find an alternative employer.

On learning of Lamb’s predicament, a friend and former teacher at Stockport Grammar School who had subsequently emigrated to South Australia alerted him to the fact that the newly established University of Adelaide was creating a Professorship of Pure & Applied Mathematics. Lamb thereupon sought out further details about the University and the position from the Agent General for South Australia (based in London) and, having thus satisfied himself, submitted an application. The twenty-
odd applications were progressively whittled down via postal communications by two distinguished British mathematicians and finally Lamb was selected for the position. Thus, Horace Lamb and his wife, Elizabeth (née Foot), set out for Australia in January 1876, arriving in Adelaide in March, just in time for the official opening of the University.

Lamb threw himself with enthusiasm into the work of the new university. Besides his teaching load in mathematics, he voluntarily taught a course on experimental physics while in the evenings, one day per week, he ran classes of a popular nature that the public at large were invited to attend: basic courses on such topics as electricity and sound, figure 4. Moreover, it was not simply in the lecture room that Lamb contributed to the new university’s development. As one of just four professors on the staff he was deeply involved in the academic, administrative and developmental activities of the University, serving as Dean from early 1878.

He also found time to pursue research. The first papers from his antipodean period were published in London-based journals in 1877 with a further one or two articles appearing in most years thereafter. Moreover, his lectures on fluid mechanics delivered orally in Cambridge in 1874 were now formally shaped and expanded (to include more recent contributions) into a 258-page textbook, Lamb [10]. The quality and number of his publications was such that Lamb was recommended in November 1883 by seven Fellows, including Lord Rayleigh and Professor Cayley, for election to The Royal Society, a proposal that was accepted the following June.

However, despite his achievements within the university, his numerous publications and the enthusiasm of the students for his teaching, all was not well for Lamb. Adelaide was so remote: he desperately missed the interaction with other academics on research matters that had been an every-
would simply use the period of leave to seek out a new position in Europe. The exchanges went on for several months and, while these were in mid-stream, Lamb wrote a letter to his former tutor at Cambridge, H. M. Taylor from which relevant portions appear below (University of Manchester Archive, Horace Lamb chair application):

My dear Taylor,

I am going to ask you a very embarrassing question and so will acknowledge at once that I do not hope for any very satisfactory answer. However, I shall be grateful for anything you can say on the subject.

I would like to know, if possible, what chances I should have of getting employment in England. My position here is not uncomfortable, I get £1000 a year (which is, however, far from equivalent to the same sum at home), I have not too much work, although my time is a good deal cut up. On the other hand, most of the work is very elementary; and the sense of isolation is at times most painful. … I have hardly a soul to speak to who has any understanding of or sympathy with my pursuits. I confess too to feeling that I am fit for something better than the work I have here; but this kind of sentiment … is probably no more than vanity and conceit. I have been on the whole very happy and comfortable here, but after all, I think, 10 years is a long enough time in Australia, if one has any chance of getting out.”

That letter was to have profound consequences! The aforementioned Thomas Barker, having become seriously wealthy from astute stock-market dealings, decided to resign his chair of pure mathematics to follow a passionate lifelong hobby on the collection and study of mosses. Owens College thus promptly advertised the vacancy, figure 5.
On reading this, Taylor cabled Lamb to ask whether he would be interested in the position and, on receiving an affirmative response, promptly set about making an application on Lamb’s behalf and soliciting letters of reference from the Cambridge mathematics community. The committee assigned to assess applications for the chair, among whose members was Osborne Reynolds, concluded that Lamb was indeed the best candidate. The College thus invited Lamb to provide letters of reference from senior figures at Adelaide University and attend for formal interview in Manchester. At that stage Adelaide must have realized they had probably lost him: he was granted sabbatical leave and provided warm letters of support by four senior members of Council. Thus Lamb and his family (by then comprising his wife and six children) came to Manchester where, following interview, his appointment was confirmed, Horace assuming the chair on September 29th, 1885. Even before taking up his chair responsibilities, Lamb presented himself to the Royal Society to be admitted as a Fellow. Figure 6 shows both the official photograph with the reverse of the photo containing Lamb’s signature. His style ‘Prof’r’, with the postnomial letters ‘FRS’, suggest his contentment with his new estate!

4. Reynolds and Lamb at Owens College

Thus, by 1885 Owens College had on its staff two of the leading Fluid Mechanicists in the country, both under 45 and at the height of their creativity. It is true that Reynolds, unlike Lamb, had moved only slowly to a position where Fluid Mechanics had become the dominant theme of his life. Like the trio of distinguished mathematical physicists, Sir George Stokes, Lord Kelvin and Lord Rayleigh who made substantial contributions to fluid mechanics among other major themes, Reynolds in his first decade at Owens College had been peripatetic in the subjects on which his fertile mind threw light. Following the death of his son, however, he evidently sought a new beginning.
In December 1881 Reynolds had re-married; his wife was Annie Charlotte Wilkinson, just 22 years old who, we may suppose, took over the tasks of household management as Reynolds plunged more deeply into detailed observations and measurement of fluid motion. In 1883 his famous paper determining the conditions under which turbulent flow in a pipe decayed to laminar was published, Reynolds [12]. A few years later, an equally famous paper on film-lubrication appeared, Reynolds [13]. About, the latter, 32 years after its publication, Lord Rayleigh felt able to remark “it includes most of which is now known on the subject” [2].

As noted above, Reynolds had served on the selection committee leading to Lamb’s appointment to the chair of pure mathematics. Soon after Lamb’s arrival they were asked to work together in a way that, unexpectedly (for Reynolds at least), was also to have a significant impact on Lamb’s role within the College. In 1888 the senior professor of physics, Balfour Stewart, FRS, had died in post at a time when the College was conscious of the need to constrain its budget. The Principal thus appointed a committee comprising Reynolds and Lamb plus the junior professor of physics (an astronomer) and Arthur Schuster, FRS (the professor of applied mathematics) to consider whether the College could manage to avoid making a replacement chair appointment for Balfour Stewart without damage to its reputation. Lamb, who had been Dean at the University of Adelaide and was evidently a shrewd strategist, quickly took charge of the committee’s directions of thought. Its recommendation, presented to and approved by Senate, was that Schuster should move to take over Balfour Stewart’s chair as the Langworthy Professor of Physics and that the departments of pure and applied mathematics should merge under Lamb’s headship as the Beyer Professor of Pure and Applied Mathematics. Thus, at a stroke, Lamb’s responsibilities within the College were enlarged to embrace fully his interests and expertise as well as to increase his salary (since a significant proportion of his emolument arose from the fees paid by students attending his classes).

As the above example perhaps illustrates, Lamb was well-organized and decisive in his thinking, composed in his demeanour and lucidly precise in his writings. Reynolds, while sharing with Lamb a capacity for intense hard work, was in other respects almost the opposite of his colleague. While he had an engaging charm he would, for the most trivial of reasons or even for none at all, divert from the subject of his discourse leaving his listeners floundering. And he was forgetful! Turning again to the memoirs of J. J. Thomson, [4], we find as an example:

![Figure 6. Horace Lamb on his admission to the Royal Society with his signature on the reverse. (© The Royal Society)](image)
“The Professor I had most to do with was Osborne Reynolds. He never did anything or expressed himself like anybody else. The result was that it was very difficult to take notes at his lectures so that we had to trust mainly to Rankine’s text books. Occasionally in the higher classes he would forget all about having to lecture and after ten minutes or so we sent the janitor to tell him that the class was waiting. He would come rushing into the room pulling on his gown as he came through the door, take a volume of Rankine from the table, open it apparently at random, see some formula or other and say that it was wrong. He then went up to the blackboard to prove this. He wrote on the board with his back to us talking to himself, and every now and then rubbed it all out and said that it was wrong. He would then start afresh on a new line and so on. Generally, towards the end of the lecture he would finish one which he did not rub out and say that this proved Rankine was right after all.”

Nevertheless, it is for his contributions to research rather than his communication foibles that Reynolds is remembered. His celebrated 1883 paper noted above, [12], in which he showed that (what we now know as) the Reynolds number determined the transition between laminar and turbulent flow in a smooth straight pipe, had received wide acclaim. Nevertheless, Lord Rayleigh (one of the referees of that manuscript), while recommending publication and singing its praises in his address as President of the British Association, had ended his referee’s report with the remark: “In several passages the Author refers to theoretical investigation whose nature is not sufficiently investigated”. Just how heavily that observation weighed on Reynolds’ mind is of course unknown. It is likely that he didn’t need any such reminder; but for him to start to explain the phenomenon of transition was such a major undertaking that his ideas needed time for successive refinement. Then finally, on May 24th, 1894, he presented an oral version of his protracted considerations at a meeting of The Royal Society and later that year had a number of copies of the manuscript type-set and printed, several of which he submitted to the Philosophical Transactions of the Royal Society to be considered for publication.

In fact, by then Lord Rayleigh had become editor of the journal and he immediately chose Sir George Stokes (who had reviewed the 1883 paper and had acquired a reputation for being a pioneer in the use of that new fangled device, the typewriter) to referee this latest manuscript. However, this time Stokes’ response was not in the least helpful; his typed letter, shown in figure 7, is a classic example of a sitting-on-the-fence assessment. Rayleigh pressed him to be more decisive but in the mean time went to the only other fluid mechanicist in Britain with both the insight into the topic in question and the incisiveness to make plain his conclusions: Horace Lamb! Curious as it may seem for him to be asked to assess his own colleague’s work, Lamb did not demur. On November 21st, 1894 he sent his longhand assessment which began with the brisk summarizing statement:

“I think the paper should be published in the Transactions as containing the views of its author on a subject which he has to a great extent created, although much of it is obscure and there are some fundamental points which are not clearly established.”

(Royal Society Archive)

However, there followed, three pages of detailed and rather severe criticisms.
Eventually, Stokes was coaxed (presumably by Rayleigh) into writing a report. Thereafter, Stokes and Lamb were persuaded (again presumably by Rayleigh) – to provide a joint report setting out their collective concerns about the paper. Stokes’ contribution appears to have been in typing the covering letter while the report itself is in Lamb’s handwriting. The first page of this joint report (which largely repeats Lamb’s original assessment) appears in figure 8; but in case Lamb’s longhand is not easily deciphered, a transcription follows.

![Stokes' initial review of Reynolds' 1895 paper](image-url)

**Figure 7.** Sir George Stokes’ initial review of Reynolds’ 1895 paper

© The Royal Society
“Professor Reynolds’s Paper

The referees have found great difficulty in following the arguments of this paper; partly in consequence of the fact that such terms as “mean-mean motion” and “relative mean motion” are used without any precise definition. There is a well known distinction between molecular and molar motion; but it is not clear in the case of molar motion how any distinction is to be drawn between what is “mean” and what is “relative”.

The Introduction might be greatly shortened as a good deal of it can only be understood after reading the rest of the paper. The purport of §5(a) is not evident. The author’s view does not appear to be different from that generally held but it is insisted upon as something new.”

The faint handwritten instruction “copy this” in Rayleigh’s handwriting is presumably directed at office staff to transcribe the review prior to forwarding it to Reynolds.

Figure 8 Joint report (in Lamb’s handwriting) on Reynolds’ 1895 paper by Professors Lamb and Stokes (Royal Society Archive)

On receiving the referees’ report from Lord Rayleigh, Reynolds evidently reflected on the criticisms and made what he judged to be appropriate adjustments to his text. Then, on February 19th,
1895, he wrote from his home a two-page reply and sent it along with a revised version of the manuscript to the editor. The opening of the letter began as follows:

“Dear Lord Rayleigh,

From the copy of the remarks on my paper on the criterion which you sent me, it is clear that the referees have found great difficulty in understanding the drift of the main argument, namely that which relates to the geometrical separation of the components $u, v, w$ into mean components $\overline{u}, \overline{v}, \overline{w}$ and relative components $u', v', w'$ and as to the conditions of distribution of $u, v, w$ under which such separation is possible.

I am very glad to know of these difficulties and of the opportunity it afforded me of improving the paper in this particular.”

The principal alteration to the manuscript appears to have been in the Introduction. While Lamb had proposed that that section should be greatly shortened, Reynolds added a passage of nearly four printed pages that appears within square parentheses ending with the date ‘Feb. 18, 1895’, i.e. the day before he wrote the above letter to Lord Rayleigh. In the absence of any archival material to the contrary, it appears that the manuscript thus revised was accepted for publication.

Readers having some familiarity with Reynolds’ paper will recognize that the referees’ report had been entirely concerned with preliminary aspects of the analysis and had not at all ventured into the startling physical implications that Reynolds’ mathematical examination had revealed. Today, however, researchers whose interests lie in high-Reynolds-number phenomena are likely see the 1895 Phil Trans paper as the pinnacle of Reynolds’ contributions to Fluid Mechanics. With the perspective of more than 100 years, it still seems an extraordinarily innovative paper. Not only did he introduce for the first time the concept of decomposing the motion into mean and fluctuating parts, he did so within the framework of mass-weighted averaging (70 years before the paper that is generally cited as the first advocacy of that strategy, Favre [15]). Only later in the paper did he limit attention to uniform-density flows (since his earlier experiments had employed water as the working fluid) and thus arrived at the variables we nowadays regard as ‘Reynolds averaging’. He then went on to obtain the turbulent kinetic energy equation, identifying the physical significance of each of the terms. The conceptual innovation entailed in this step can be appreciated from the fact that the corresponding (albeit simpler) equation for the mean-square temperature fluctuations was only published nearly 60 years after (Corrsin [16])! It should also be noted that, in Reynolds’ time, tensor subscript notation had not been devised so an analysis that today might take only a few lines would at that time stretch over pages. Finally, the rationale for all these ‘preliminaries’ was to determine why and when the transition from laminar to turbulent flow was at risk of occurring. He showed that for flow between parallel planes (a less taxing configuration than flow in a circular pipe), as the Reynolds number was progressively raised, the spatially averaged rate of turbulence energy generation by mean shear interacting with (what we now call) the Reynolds stresses increased more rapidly than the rate of viscous dissipation. He proposed that the critical Reynolds number was the value at which these two agencies became equal. Because of the assumptions made about the velocity distribution, this calculated critical value was far too low. But that ‘failure’ was immaterial to the importance of the paper; indeed, the paper served as the basis for computational research in engineering-oriented fluid mechanics for the subsequent century!

Horace Lamb was, at around the same time, also engaged in a work that was to be his principal and lasting legacy to students and teachers of fluid mechanics. His textbook A Treatise on the Mathematical Theory of the Motion of Fluids, originally published in 1879 while he was still in Adelaide, was in need of expansion to include the many advances in the mathematical analysis of fluid motion over the ensuing years (including many that he himself had made). During the course of
shaping the new material he contacted Reynolds on a matter concerning the latter’s earlier 1883 paper. This drew from Reynolds a somewhat tetchy response. In a letter to Lamb of April 5th, 1895 (Allen[2]) he wrote:

“You have not noticed that just above the critical velocity the resistance \( dp/dz \) varies nearly as the cube of the velocity until \( dp/dz \) is about double what it is at the critical velocity. Of course these dimensional facts … are the definite clues to the physics and mechanics of the problem and the gist of the later research”.

Reynolds then went on to make a further (though in his mind perhaps the principal) complaint:

“Nor is it polite or true to speak of the ‘empirical formula adopted by Engineers’ since it is engineers who have done the scientific investigations which alone have given us accurate data”.

Then, possibly recognizing that his remarks were at least ungracious, given that the purpose of Lamb’s enquiry was simply to present what Reynolds had found as accurately as possible in the new edition of his book, he added the final remark, Allen [2]:

“I am obliged for the trouble [you] have taken to bring my work in[to your new edition]. I fear my criticism will bother you … but you will take what notice of it you like.”

Lamb, ever the calmer of aggrieved sensibilities, duly replaced the above offending phrase by ‘practical formula adopted by writers on hydraulics’ [3]. When, later that year, the new edition was published, [17], its length had more than doubled (from 279 to 604 pages) while its title had been shrunk to just a single word, Hydrodynamics, which when coupled with the surname of its author, still has resonance for fluid mechanicists well over a century after its publication.

5. The Final Years

Publication of the second of Reynolds’ major works on turbulent flow did not mark the end of his scientific outpourings. In 1887 he gave the Bakerian Lecture to the Royal Society (Reynolds & Moorby [18]) reporting his measurements of the mechanical equivalent of heat. Of this huge experimental programme, in which he obtained the equivalence within 0.2% of modern determinations, Lamb [5] later wrote “This whole investigation is a model of scientific method and may claim to rank among the classical determinations of physical constants.”

Osborne Reynolds’ final years in Manchester were marked by his intense efforts to provide a mechanical theory of matter which culminated in his work The Sub-Mechanics of the Universe being published as Volume 3 of his collected works (Reynolds [19]). However, as his colleague was later to observe, in what must be seen as a kind understatement, “unfortunately illness had begun gravely to impair his powers of expression and the memoir as it stands is affected with omissions and discontinuities which make it unusually difficult to follow” (Lamb [5]). By 1905 Reynolds had begun to suffer so seriously from this degenerative neurological illness – possibly what today would be diagnosed as Alzheimer’s disease – that he retired from what had by then become the Victoria University of Manchester. Figure 9 shows a portion of the fine retirement portrait of him painted by the distinguished portraitist, John Collier. In 1908 he moved with his wife and daughter to occupy the vicarage at St Decuman’s, a village community on the hill just above Watchet, a small coastal port some 300km south of Manchester. There on the 21st day of February, 1912 he died from influenza. His funeral in St Decuman’s church was attended by Horace Lamb and Reynolds’ remains are buried in the churchyard beneath a beautifully engraved art nouveau cross.
By then the time was approaching for Lamb himself to retire from his professorial responsibilities. As what may have been seen as a prelude to a normal-age retirement, in 1913 Ernest Rutherford, FRS had presented the University with a portrait of Lamb painted by Lamb’s son Henry, a photograph of which appears in figure 10. However, the outbreak of World War I in 1914 caused Lamb to postpone any thought of retirement until the end of hostilities. He had by then, among numerous other publications, produced a further edition of *Hydrodynamics* in 1906 and a new textbook on sound, Lamb [20]. Moreover, yet another edition of *Hydrodynamics* would appear in 1916. When, in 1920, Lamb’s actual impending resignation was announced it was met with considerably more than the usual expressions of appreciation and regrets. A retirement banquet was organized in his honour to express the University’s thanks for his thirty-five years of outstanding service and the University conferred on him the honorary degree of doctor of science. Even then Lamb did not retire in the accustomed sense for he then removed to Cambridge where, as the honorary Rayleigh Lecturer, he relentlessly pursued his scholarly and public-service activities for more than a dozen years. During this time he completed two further editions of *Hydrodynamics* (the final one appearing in 1932, the year after he was knighted) and served on the national Aeronautical Research Committee from 1921-27. The latter role led, in turn, to his appointment as editor of a major project to provide, through the ARC, an up-to-date account all aspects of aerodynamics with a bearing on flight. Alas, he died some years before *Modern Developments in Fluid Mechanics* was finally published in 1938, his role being taken over by Sydney Goldstein who had succeeded him at Manchester as the Beyer Professor of Applied Mathematics. This two-volume publication [21] is, however, dedicated to Horace Lamb’s memory.
Acknowledgements
I am indebted to Nicholas Higham, Professor of Applied Mathematics, University of Manchester, for his photograph of figure 10 and to Jeff Hurst for skilfully optically removing from my photograph a plethora of librarians’ markings that had been applied over the years to the reverse of figure 6.

References
[1] Clapp B W 1965 *John Owens: Manchester Merchant* Manchester University Press.
[2] Allen J 1970 The life and work of Osborne Reynolds In *Osborne Reynolds and Engineering Science Today* (Ed. D M McDowell & J D Jackson) 1-82 Manchester University Press.
[3] Launder B E and Jackson J D 2011 Osborne Reynolds: a turbulent life. In *A Voyage Through Turbulence* (Ed. P A Davidson et al.) 1-39 Cambridge University Press.
[4] Thomson J J 1936 *Recollections and Reflections* G. Bell & Sons, London.
[5] Lamb H 1913 Osborne Reynolds, 1842-1912 *Obituary Notices Proc. Roy. Soc.,* 88, xv-xxi.
[6] Reynolds O 1873 On the condensation of a mixture of air and steam upon cold surfaces, *Proc. Roy. Soc.,* 21, 274-281.
[7] Reynolds O 1874 On the extent and action of heating surfaces of steam boilers, *Proc. Manchester Lit. & Phil.* 14, Session 1884-5.
[8] Jackson J D 1995 Osborne Reynolds: scientist, engineer and pioneer *Proc. Roy. Soc.* 451A, 41-86.
[9] Glazebrook R T 1935 Sir Horace Lamb, *Obituary Notices of Fellows of the Royal Society* 1 374-392 (with additional material by A. E. H. Love).
[10] Lamb H 1879 A Treatise on the Mathematical Theory of the Motion of Fluids, Cambridge University Press.

[11] Launder B E 2012 Horace Lamb and the circumstances of his appointment at Owens College Notes Rec. R. Soc. 67 139-158.

[12] Reynolds O 1883 An experimental investigation of the circumstances which determine whether the motion of water shall be direct or sinuous and the law of resistance in parallel channels Phil. Trans. Roy. Soc. 174 935-982.

[13] Reynolds O 1886 On the theory of lubrication and its application to Mr Beauchamp’s tower Phil. Trans. Roy. Soc. 187 157-234.

[14] Reynolds, O 1895 On the dynamical theory of incompressible viscous fluids and the determination of the criterion Phil. Trans. Roy. Soc. 186A 123-164.

[15] Favre A 1965 Équations des gaz turbulents compressibles J. de Mécanique 4 361-390.

[16] Corrsin S C 1952 Heat transfer in isotropic turbulence J. Appl. Phys. 23 113-118.

[17] Lamb H 1895 Hydrodynamics (2nd edition of Ref [10]) Cambridge University Press.

[18] Reynolds O and Moorby W H 1897 On the mechanical equivalent of heat Phil. Trans. Roy. Soc. 190A 301-422.

[19] Reynolds O 1903 Papers on Mechanical and Physical Subjects – the Sub-Mechanics of the Universe, Collected Works Volume III Cambridge University Press.

[20] Lamb H 1910 The Dynamical Theory of Sound Edward Arnold, London.

[21] Goldstein S (Editor) 1938 Modern Developments in Fluid Mechanics Vol. I and II Oxford University Press.