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Teaching Aeronautics by Historical Example*

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The paper describes the experience of producing and using a video series aimed at assisting the early stages of the teaching of a degree course in aeronautical engineering. The video series surveys the history of the technical and scientific developments which culminated with the first powered flights of the Wright brothers. The experience of other users of the video suggests that the series may well have wider appeal, particularly in the teaching of fluid mechanics in more general engineering courses.

A PERENNIAL problem facing teachers of aeronautical engineering is to devise initial undergraduate courses in that subject which assist students in making the difficult transition from what has been taught in high school to the more elementary basic statements in aeronautics. Here, it is perhaps appropriate to remind readers that the fundamental problem of the interaction between air and a moving body is barely touched on in the high school syllabus. Thus, in contrast to other branches of engineering, the entrant to a course in aeronautical engineering embarks on what is, at least to him or to her, largely uncharted territory.

As teachers of aeronautical engineering, one problem which we have all, perhaps, faced in dealing with this difficult transition is that of persuading undergraduates to think in terms of non-dimensional coefficients such as C_L and C_D, and that, whatever else a pilot may do in flying an aeroplane, essentially he or she can fly only up and down the $C_L \sim \alpha$ graph. An attendant problem is that the initial curriculum of the student aeronautical engineer is often, perforce, crowded with other important basic topics: mathematics, structures, thermodynamics, electrical engineering, design (an increasingly pervasive topic in more recent years), and so on. During the first term of the first year, the student may well be inclined to feel that he or she is being exposed to a general engineering course, rather than one tailored specifically to aeronautical interests. This may suit some, but those who see themselves as 'aeroplane buffs'—often a significant proportion—may feel that their consuming enthusiasms are not being catered for, and a decline in motivation results. Of course, the student will be exposed to an introductory course in fluid mechanics but, because of the basic principles which it is necessary to establish, the student may not see too clearly how these can be related to aeronautics. In this respect, a parallel course in flight mechanics, at an elementary level, can help considerably, so that the student sees, for example, how school-based knowledge of motion in a circle can be related to the problem of an aeroplane executing a steady, horizontal turn. Nonetheless, certain of the more specifically aeronautical material may have to be presented merely as *de facto* results. There is then a crying need, I believe, for back-up material, presented at an elementary level, which is weighted heavily toward the specific interests of the budding aeronautical engineer.

Faced with such problems, I recalled my own experience as an aeronautical engineering student in the late 1950s. In those days, for fluid mechanics, we were directed to Prandtl's *Fluid Dynamics* [1]. Whilst in later years I came to appreciate that book's great strength and wealth of example, at that very early stage the book merely terrified. On the advice of more senior students, however, many of us turned to Sutton's excellent little book, *The Science of Flight* [2], a book sadly long since out of print. But it was from Sutton that I acquired a taste for aviation history, a subject otherwise treated more in terms of superlatives than science. In more recent years it began to dawn on me how valuable Sutton's approach could be. After all, in certain respects were not the early pioneers of flight in a rather similar learning situation to that of the modern student-and exposed, moreover, at its sharp end?

In the late 1970s I began to give short informal talks—less intensive, I hoped, and rather more relaxed than lectures—to first year students of aeronautics. My subject was, of course, the early history of aeronautics, but in this I tried to emphasize historical progression in the acquisition of scientific principles. It began to dawn on me as I did this that, for example, for all Leonardo's ingenuity, little progress in aeronautics could be expected until the lessons of the Newtonian age had been thoroughly absorbed. After all, before the era of Galileo, Descartes, Huygens and Newton himself, the pervasive principle of dynamics adopted since antiquity was that everything which moved must be

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pushed. Before that period embracing Galileo and Newton, then, the principle of inertia was far from discovery. In those circumstances, there was little chance of topics such as fluid resistance—lift as well as drag—being understood. Thus, early on in my presentation of aviation history, I felt that I knew where I must begin; after brief mention of people such as Aristotle, Leonardo and Galileo, I must begin with Newton's views on fluid resistance.

As the 1980s dawned, I was offered the opportunity of putting my talks on video. At that time, Manchester University Television Productions were looking for suitably visual material which might be considered as worthy of wider dissemination than the university environment. What they were able to offer were studio facilities of broadcast standard, generally recognized as being the best in the north-west of England outside those of the broadcasting companies, and a substantial graphics department for the preparation of visual material. All this seemed an opportunity too good to miss, and it is here appropriate, at least, to record my deep gratitude to all of the staff of MUTV for the vast amount of hard work and sheer professionalism they brought to the making of the videos [3].

As we began to make the video programmes, the major question facing me was: at what point in history do I stop? To a large extent, the answer was provided by monetary considerations. Whilst it was relatively cheap to obtain still photographs for video reproduction, use of film material became extremely expensive. As far as I could detect, filming of flight began with Wilbur Wright's demonstration in France in 1908. Thus, for me, a convenient point to finish seemed to be around 1905–1906, a stage in history at which the emotive step of achieving powered, fully controllable flight had certainly been taken. Moreover, such a stopping point would allow me to mention basic ideas in boundary layer theory and the early aerofoil analyses of Kutta and Zhukovskii, all of which had begun to emerge by that date. Rather arbitrarily, I decided to avoid going into turbulence and finite wing theory, all of which came a little bit later. Nevertheless, something of the advantages of high aspect ratio wings could be mentioned, I felt, since such advantages were recognized, as an experimental phenomenon, well before the emergence of the Lanchester–Prandtl theory. For example, as a result of their wind tunnel work, the Wrights built their No. 3 glider of 1902 with double the aspect ratio of that of their No. 2 glider of the preceding year.

A further question exercising my mind was: should I stick rigorously to actual historical progression in the presentation of my material? My answer was that I felt I could not do so, and for the following reasons, part historical and part educational. Readers are no doubt aware that the major advances in fluid mechanics which followed Newton's era sprang from the researches of the great eighteenth century hydrodynamicists, Daniel and Johann Bernoulli, d'Alembert and Euler. However, these researches were almost exclusively concerned with what we now recognize as inviscid flows, and they all led to such apparent stalemates as d'Alembert's Paradox. But, when set in the context of the attached flow field about a streamlined body, the importance of the eighteenth century work on hydrodynamics could be seen at once. Consequently, whilst the first video programme ends with a description of Newton's embryonic ideas on viscous resistance, the second programme begins with an elementary description of the division of attached flow fields into the inviscid region and the boundary layer. Thus the scene is set for the discussion which follows of the eighteenth century work on inviscid flow, the emergence of the Bernoulli equation and such. In this it should be mentioned, however, that no attempt is made to go into Euler's work on potential flow theory since, at this early point in the aeronautical curriculum, the viewer is unlikely to have met partial derivatives, the potential function and Laplace's equation, despite the fact that all of these mathematical tools were used with great virtuosity by Euler himself. One further departure from strict historical progression occurs in the video series, and this is found in substantial measure in the fifth and sixth programmes (synopses of all of the eleven programmes are included as an appendix to this paper). Before describing the practical measures taken by the aeronautical pioneers of the late nineteenth century, I felt strongly that it was necessary that the viewer see how small C_D might be for a well-streamlined body, why this is so, and also what C_L values might be expected from well-shaped aerofoil sections. Thus, whilst Programme 4 ends with Cayley's development of his practical aeroplanes up to the 1850s (Fig. 1), Programme 5 picks up the story in that era, but then concentrates on the advances made in the understanding of viscous flows, beginning with the work of Stokes. From there, the programme deals with the work of Reynolds, Prandtl, and his two early Göttingen students, Blasius and Hiemenz, so as to give an elementary description of flat plate flow and the separation of the boundary layer on a circular cylinder. Programme 6 moves through a similar time span, dealing with the development in the understanding of lift achieved by the work of Magnus, Lord Rayleigh, Kutta and Zhukovskii. The results for C_D and C_L given in Programmes 5 and 6 are thus intended as bench marks against which the achievements of the practical pioneers of the late nineteenth century can be compared. These achievements are described in the programmes following Programme 6. Moreover, the major point is emphasized that, rather by good fortune, the beginnings of a scientific explanation for lift and drag emerged in the same era as that in which powered flight was actually achieved.

As reviewers of the video series have noted (see [4–7]), the scientific heart of the series is contained in Programmes 2, 5, and 6. The remaining programmes deal largely with practical developments

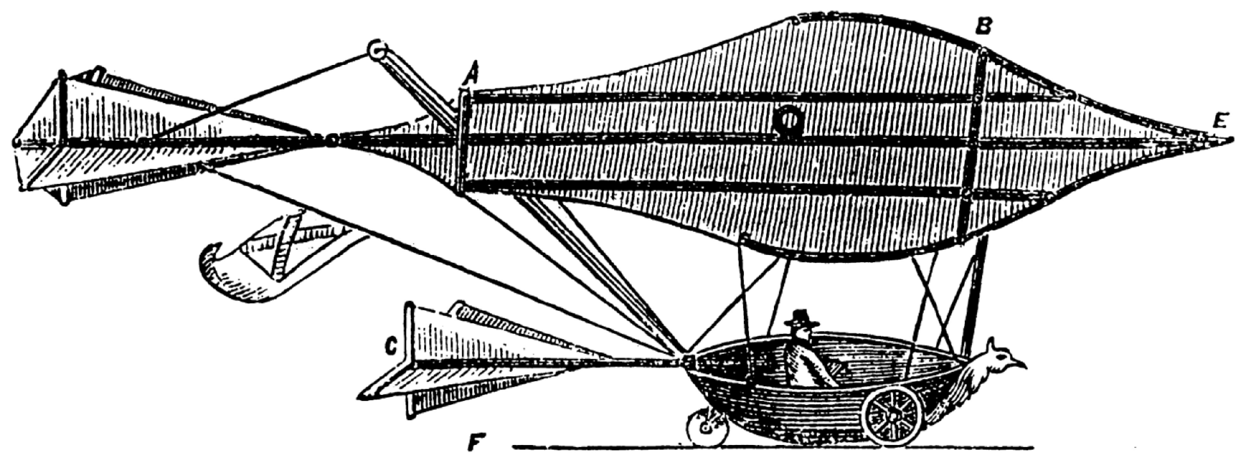

Fig. 1. Sir George Cayley's 'Governable Parachute' (1852). Note the duplicated tail unit. The lower, movable, unit provides the elevator and rudder, whilst the upper, fixed, unit provides the tailplane and fin. As Cayley remarks about this upper unit, 'it gives the most steady and secure course when slightly elevated, which also tends to secure the parachute from pitching, should it be exposed to an eddy of wind, and . . . immediately restores the horizontal position'. The remark reveals some appreciation of the tailplane's role in achieving trim and stability.

in experimental technique—the whirling arms of Robins, Smeaton, Cayley, Lilienthal and Langley, for example—and with the evolution of the aeroplane. With regard to the experimental programmes of, particularly, Cayley, Lilienthal and the Wrights, it should be remarked that these are passed over remarkably quickly in the more popular histories of aeronautics. In contrast, my view of these programmes of research is not only that they were crucial to the development of thinking of the pioneers concerned, but also, from the educational viewpoint, they provide graphic illustrations of wing behaviour. Thus some time is spent in Programme 8 describing the whirling arm (Fig. 2) and natural wind results of Lilienthal so as to illustrate the variation of C_L with both incidence and camber. Moreover, in the case of the Wrights' wind tunnel results described in Programme 10, these are used to illustrate the variation of both C_L and C_L/C_D with change of incidence and aspect ratio. Wherever possible, then, the theme is that suggested in this article's title: to teach aeronautics by historical example.

Because of the anticipated level of mathematical competence achieved by the viewer, the programmes, as I have indicated already, largely eschew complex mathematical expositions. For example, although elementary calculus is used in illustrating Newton's ideas on viscous resistance, thereafter calculus notation is used only in so far as it is more convenient to refer, both in the graphics and through the spoken word, to velocity gradients using the term $\mathrm{d}u/\mathrm{d}y$. Otherwise the mathematical notation employed centres largely on such items as the trigonometric functions. Generally, moreover, mathematical proofs are avoided. Thus the Bernoulli equation is merely stated, it being anticipated that the proof will be provided in a parallel course in fluid mechanics. As to the aerofoil work of Kutta and Zhukovskii, and the boundary layer studies of Prandtl and Blasius, again the results are stated without proof, but here it is anticipated that any of the required mathematical analyses would be far beyond the level then achieved by the viewer. Generally, the emphasis is on the understanding of physical principle, rather than mathematical method.

Having the opportunity to translate my ideas on aviation history to such a visual medium as video provided me with the spur to bring together a considerable quantity of old illustrations and photographs, some well known, others less so. In this I was aided immensely by various museums and individuals throughout the world. Thus, for example, the Smithsonian Institution was able to provide copies of a large number of the Wrights' own slides (Fig. 3). But here I must pay particular tribute to the unstinted help provided by John Bagley, then of the Science Museum, London, who dug out any number of the rare and valuable photographs collected by the late C. H. Gibbs-Smith. From all of this copious visual material, I hope that the viewer will be able to see, with an informed eye, what the early pioneers of aeronautics were about.

To date, the videos are in use in some 40 institutions throughout the world. And the uses to which they have been put have sometimes surprised me. Whereas some institutions appear to use the videos in the manner anticipated by myself—as a first introduction to aeronautics—others use the material towards the end of an undergraduate course, to remind students of the more essential elements of what has already been explained in more formal courses. However, I was surprised to learn that one university mathematics department uses the videos in order to encourage first year undergraduate engineers, and not merely aeronautical engineers, to take mathematical analysis more seriously—a use which I had certainly never anticipated. In contrast, a number of aircraft companies use the videos as part of their induction programmes for new graduates. Meanwhile, one

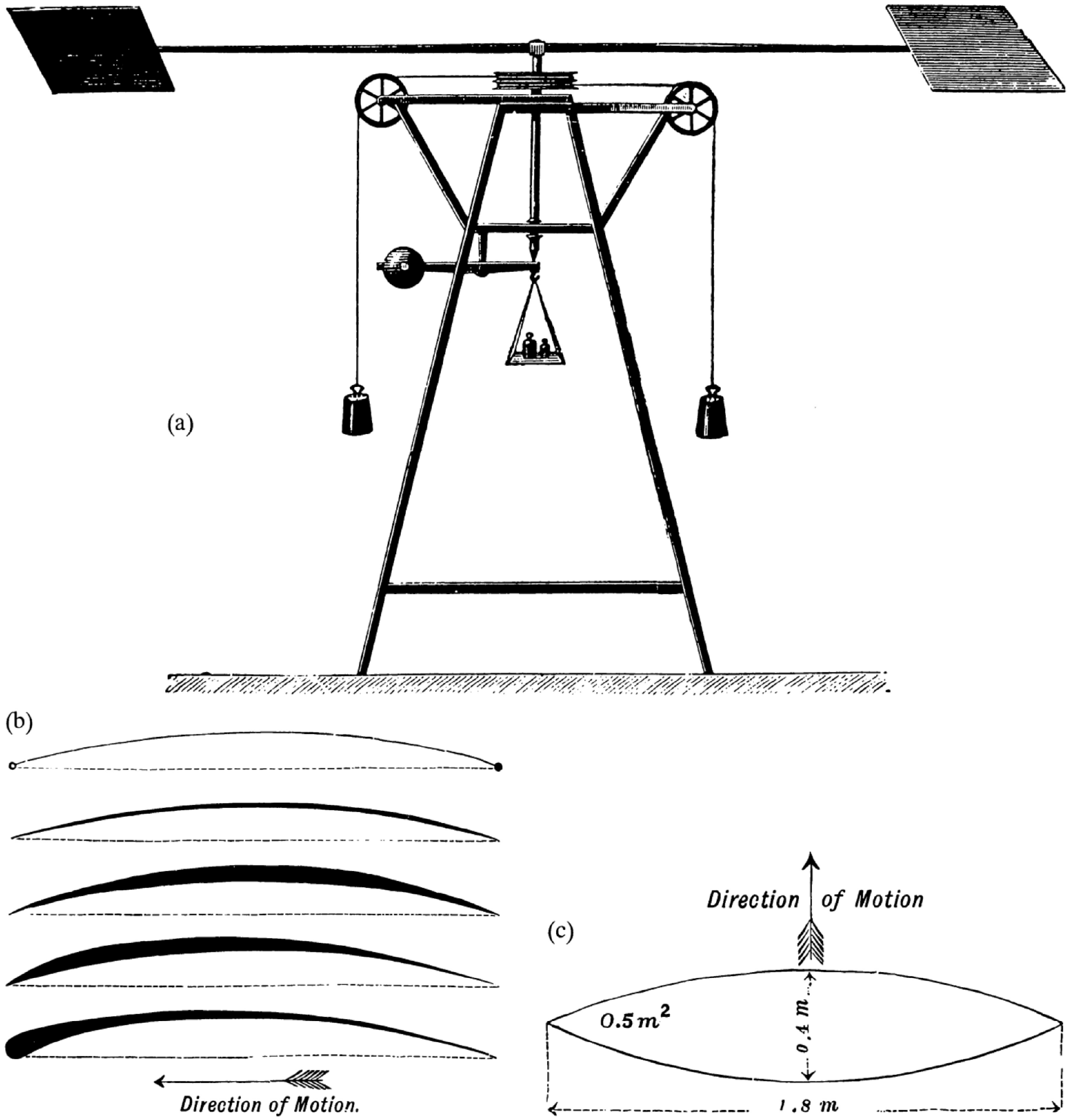

Fig. 2. (a) Lilienthal's whirling arm, on which various section shapes (b) were tested, the planforms all having that shown in (c).

of the reviewers of the videos (see [7]) has made the serious suggestion that my purpose behind the videos can, in a sense, be turned around, to the benefit of various other branches of engineering; that 'the history of aviation provides a dramatic setting for some of the elements of a course in fluid mechanics'. I am, of course, extremely pleased to see this diversification in the uses of the material, not least in that this might stimulate a more serious interest in the subject of aviation history, dragging it away from the somewhat over-romanticized aura it has acquired.

As to the video programmes themselves, each runs for between 25 and 30 minutes, allowing reasonable time thereafter for class discussion. The tapes are available in either Umatic, VHS or Betamax format, to PAL 625 and American (NTSC) standard. Enquiries should be directed to Manchester University Television Productions, University of Manchester, Manchester M13 9PL, U.K., and should state the format and television standard required. MUTV will then provide pro-forma invoices giving costs, including those for delivery to any address worldwide. Each complete set of tapes purchased includes a set of teaching notes and bibliography.

It was, I expect, inevitable that, having finished making the videos, I should turn to writing 'the book of the film'. Having had more opportunity to study the subject at greater length, it was also, I

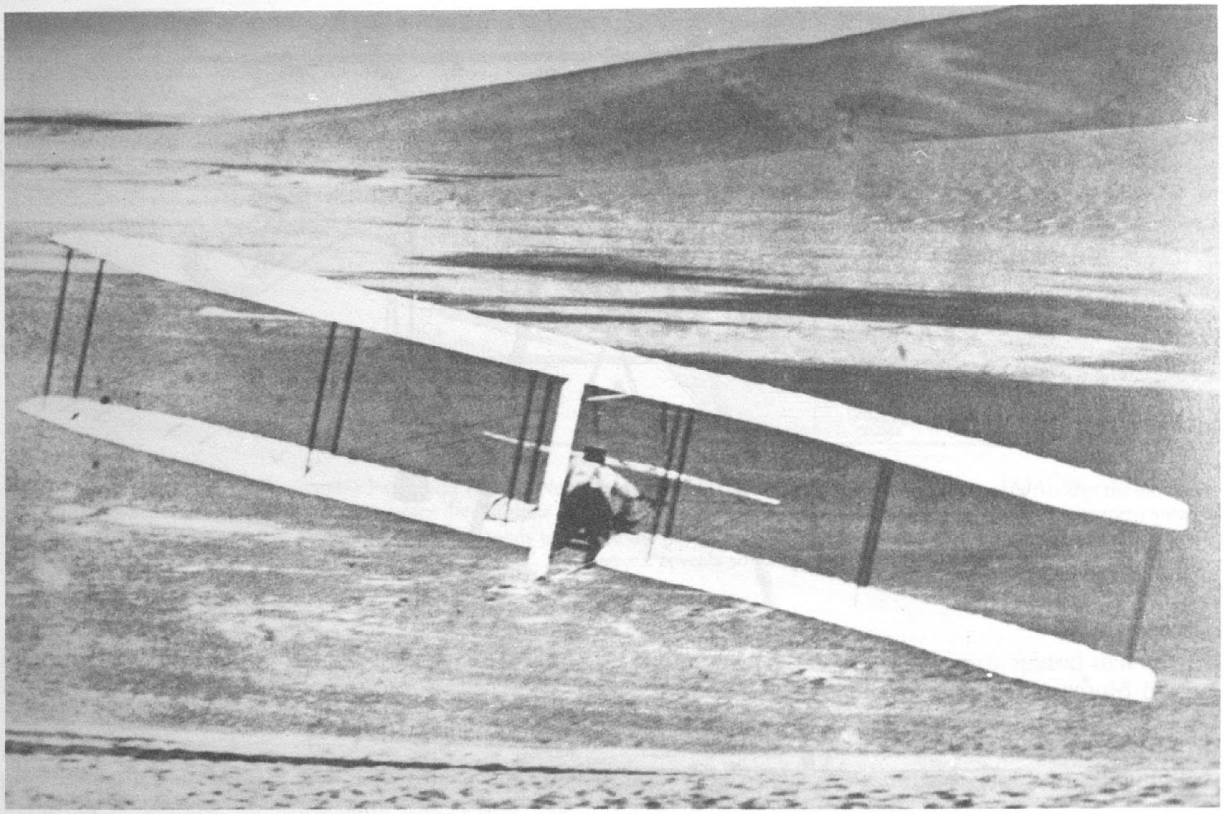

Fig. 3. Wilbur Wright executing a turn near Kitty Hawk in the modified No. 3 glider of 1902. Note, however, the sense of the wing warping and the set of the rudder, indicating that Wilbur is correcting the roll. Photograph courtesy of the Smithsonian Institution.

expect, inevitable that the video material would be subjected to considerable expansion. Indeed, the book emerges as a four-volume work in which topics are considered in much greater detail. Moreover, I have taken the opportunity to rectify various omissions in the videos, by including discussion of the historical background to such items as the Lanchester–Prandtl finite wing theory, aeroplane stability and control, and aircraft structures. The first volume, however, deals largely with a topic considered as being already understood in the videos, which is the kinematics and dynamics of moving bodies. In describing the evolution of these subjects from Aristotle up to Newton and Leibniz, I hope that the reader will gain a more definite impression of the reasoning behind my belief that serious attempts at flight had to await the scientific advances of the Newtonian era.

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APPENDIX
SYNOPSES FOR VIDEO PROGRAMME SERIES: THE SCIENCE OF AVIATION—A HISTORY'
Written and presented by JOHN ACKROYD

Programme 1: 'Newton's Pebble'

The programme begins with an introduction to the series, which makes the following points. Many people find aviation a fascinating subject but the programmes emphasize the physical and mathematical aspects: aeroplane design is not just an art. Also, and in contrast to many other branches of engineering, the scientific basis of aeroplane development (e.g. fluid mechanics/aerodynamics) is barely touched on in schools, so a scientific study of the historical development of the aeroplane can be particularly interesting. Furthermore, aeronautical engineering has many prominent features which are less striking in other branches of engineering. For example, the contrasts of the key personalities involved-the 'men of action' and the 'thinkers', the former being the perhaps better known practical pioneers, the latter, far less well-known, having had an equally profound influence, giving aeronautical engineering its strong mathematical flavour. The coming together of these two attributes of personality is stressed, in particular, in the case of the Wright brothers. Somewhat fortuitously, an explosion in scientific understanding of flight occurred around the time of the Wrights' first powered flights. Mathematical results quoted in the series are largely not derived but are discussed in terms of the uses in aeronautics to which they are put.

The history begins with Aristotle's (incorrect) arguments on the forces on bodies in motion through air and the persistence of these ideas until Leonardo da Vinci and Galileo. Leonardo's aeronautical interests are mentioned, as follows: ornithopters, parachutes, helicopters, but, equally importantly, his realization that air resists motion and that relative motion of the air over a body is of main importance. Galileo's observation that resistance is dependent on the velocity of a body is introduced. The programme then turns to Newton, his laws of motion and calculus. Newton's three concepts of fluid motion are described. The first concept leads to the result that the force on a body is proportional to fluid density × $(\text{velocity})^2$ × body area. The second concept produces the incorrect result that the lift force on a wing is proportional to the square of the sine of the angle of incidence. The third concept, of internal resistance in fluid flows, is extended to illustrate the modern view of viscous action in flows. It is stated that viscosity is not just the cause of aeroplane drag but is also the cause of aeroplane lift. The reasons for this emerge later in the series.

Programme 2: 'Early Ideas in Fluid Mechanics'

The programme begins by describing briefly, and out of historical context, how Newton's idea of internal resistance in flows gave rise to the modern concept of the thin viscous boundary layer flow around a streamlined body. It is explained why the flow outside the boundary layer can be considered to be inviscid. The consequences of this boundary layer/inviscid flow combination for the drag and lift forces on a wing are briefly mentioned. Since the eighteenth century mathematicians who followed Newton considered only the inviscid part of the flow, the history of the development of ideas in inviscid flows in this period is then related. The work of the Swiss mathematicians, Daniel and Johann Bernoulli is described, particularly Daniel's introduction of the relations between pressure and velocity and between velocity and flow area. Moving out of historical context again, it is shown how these relations begin to explain the process of lift generation on wings. Returning to historical context, the programme then describes the work of the French mathematician, Jean d'Alembert, particularly his proof that the drag is always zero in inviscid flow. Illustrations of this result are given and the apparent impasse that this gave rise to is described. Leonhard Euler's work in the eighteenth century, producing the first consistent theory for inviscid flows, is then discussed. Finally, it is pointed out how the 'age of reason' of eighteenth-century mathematics, out of necessity, led to the 'age of experimentation' in fluid mechanics.

Programme 3: 'The Invention of the Aeroplane'

The programme begins by taking up the history of the 'age of experimentation' in the eighteenth century. Early experiments in ballistics are described, particularly the work of Benjamin Robins. His inventions, the ballistic pendulum and the whirling arm for drag measurement, are described, together with his confirmation of Newton's result that the force on a body should be proportional to the square of the velocity. John Smeaton's use of the whirling arm to investigate the performance of windmills is then illustrated. Implications for the lift performance of wings follow from this. The remainder of the programme is concerned with Sir George Cayley's work at the beginning of the nineteenth century. His concept of the fixed-wing aeroplane, the first in history, is illustrated. The programme then describes how Cayley adapted Robins' whirling arm so as to measure wing lift. It is noted that Cayley is one of the earliest workers to suspect that Newton's square of the sine of the angle of incidence result for lift is incorrect.

Programme 4: 'Cayley's Aeroplanes'

The programme is devoted almost entirely to Cayley's development of the fixed-wing glider. It begins with Cayley's 1804 glider and the circumstances which prompted Cayley to publish his aeronautical studies in 1809 and 1810. The programme describes Cayley's early considerations of aeroplane stability and control and contrasts these with the modern understanding of the uses of the aeroplane tail, controls and wing dihedral angle. Cayley's ideas on streamlining, his 'body of least resistance', are also described. Cayley's temporary neglect of the fixed-wing aeroplane is then mentioned. The designs and model aeroplanes of William Henson and John Stringfellow in the 1840s then follow. It is shown how these renewed Cayley's interest in the fixed-wing aeroplane. The resulting gliders, the 'boy-carrier', the 'governable parachute' and the 'coachman carrier', are discussed, together with Cayley's partial realization of the functions of the aeroplane tail. The programme ends with Cayley's death in 1857.

Programme 5. 'The Drag Story'

The programme takes up the history of the development of ideas in fluid mechanics, beginning with the re-working in the early 1800s of Newton's ideas on internal resistance in flows. It is shown how the concept of the viscosity of a fluid became realized. The use of this by Sir George Stokes in 1851 to predict the drag on a sphere for very slow flows is then described. It is pointed out that Stokes' result apparently contradicts Newton's force results. Osborne Reynolds' original apparatus of 1883 is then used to illustrate the importance of viscosity in the understanding of flows and Reynolds number is introduced. The theoretical work of Lord Rayleigh on viscous flows around the turn of the century is described and the apparent contradiction between Stokes' and Newton's results is reconciled. It is shown how the drag can be expressed most conveniently as a drag coefficient and that this coefficient depends only on Reynolds number. The announcement by Ludwig Prandtl of the boundary layer concept in 1904 is then described. It is shown how the boundary layer concept, and boundary layer separation, lead to the very different values of drag coefficients for well and poorly streamlined bodies. The effects of sharp edges on the early poorly streamlined wings are then described.

Programme 6: 'The Lift Story'

The programme begins with a description of how a rotating body in a flow can generate lift (the Magnus effect described in the 1850s). Lord Rayleigh's explanation in the late 1800s of this effect is then given, the effects of the associated vortex around the body being described. The concept of vortex circulation is introduced. The relation between lift and circulation, due to Wilhelm Kutta and Nicolai Zhukovskii at the beginning of this century, is then described. The early theoretical studies by both Kutta and Zhukovskii on wing flows are discussed, particularly the influence of the sharp trailing edge on a wing. It is shown how the interaction between the boundary layer and the sharp trailing edge produces the wing vortex and hence lift. Thus viscosity, acting in the boundary layer, emerges as the root cause of lift. The lift coefficient is introduced and its dependence on incidence and camber is described. A simple experiment on a wing in a wind tunnel is used to illustrate some of the ideas introduced in the programme. Wing stall is observed and a description of the stall behaviour is given for early wings developed in the late nineteenth century.

Programme 7: 'Attempts at Powered Flight'

The programme continues the history of the practical development of the fixed-wing aeroplane following Cayley's death. It is explained that the history divides into two approaches at this stage; direct attempts at powered flight and the glider. This programme deals with the attempts at powered flight in the era preceding the Wrights. The founding of the Royal Aeronautical Society in 1866 and the influence of Francis Wenham on the Society is described. The early designs of Wenham and the results obtained from his wind tunnel, the first to be built, are discussed. The influence of Stringfellow's triplane of 1868 is mentioned. The influence of the French engineers, Félix du Temple, Alphonse Pénaud and Clément Ader is then described, together with their aeroplanes. The wind tunnel studies on practical wings by Horatio Phillips and his machines are described. There follows a description of the work at the turn of the century of Sir Hiram Maxim and Samuel Langley and their flying machines. The introduction of the petrol engine to aviation is mentioned.

Programme 8: 'The Gliding Pioneers'

This programme relates the history of the other approach to flight, through the development of the glider. The programme begins at the period following the death of Cayley and describes the two gliders built by the Frenchman Jean-Marie Le Bris in the 1860s. The hang-gliding pioneer, Otto Lilienthal, is then introduced. The programme describes in some detail the extensive wing testing done by Otto Lilienthal and his brother, Gustav, using whirling arms and balances exposed to natural winds. Their data are reduced to the modern forms of lift and drag coefficients. The discrepancies between the whirling arm and natural wind data are discussed. The remainder of the programme describes Otto Lilienthal's development of the hang-glider concept up to his death in 1896. It is pointed out that Lilienthal was not only reasonably successful in the development of his 17 hang-glider designs, but he was also seen to be successful. A number of original photographs of Lilienthal gliding are used to illustrate this point as well as to indicate the techniques of gliding developed by him.

Programme 9. 'An American Dream'

The programme continues the history of glider development and begins by describing the four hang-gliders developed by the Scotsman Percy Pilcher. The scene then changes to the United States, describing the influence of the railway engineer Octave Chanute. The importance of his book, *Progress in Flying Machines*, is stressed, together with the availability of information on flight which occurred in the United States in the 1890s. Chanute's early gliders and gliding experiments at Lake Michigan are described. The Wright brothers are then introduced. The point is made that the Wrights began to develop their gliders from the ideas introduced by Lilienthal and Chanute. The Wrights' vital contribution of the use of aerodynamic control, particularly roll control, is stressed. The first Wright kite experiments to test these ideas are described. The programme ends with the Wrights about to depart to Kitty Hawk to begin the testing of their first glider.

Programme 10. 'The Wright Brothers'

This programme continues the description of the work by the Wrights to develop their gliders. The testing of the first glider in 1900 at Kitty Hawk is described. This is followed by a description of the second glider of 1901, the test results being discussed also. Contemporary photographs, taken by the Wrights themselves, are used to illustrate features both of the gliders tested and the experience obtained. The gradual disillusionment of the Wrights with wing lift and drag data obtained by other experimenters is stressed. The remainder of the programme relates the story of how and why the Wrights at this stage, in 1901, began the most thorough experimental programme on wing behaviour yet attempted. A detailed discussion of the main features of their wind tunnel results concludes the programme.

Programme 11: 'Powered Flight'

This programme takes up the history of the development of the Wright aeroplanes at the point when they had completed their wind tunnel studies on wing performance. The third glider of 1902, designed around this wind tunnel data, is then described, together with a description of their gliding experience with it. It is shown how they came to realize that the correctly applied combination of wing-warping and rudder is necessary to make an aeroplane turn in flight. It is stressed that the Wrights at this stage had, in effect, developed the modern aeroplane control system. There follows a description of the development by the Wrights of their petrol engine and propeller system. The application of this, together with their unique knowledge of practical aerodynamics, to their first powered aeroplane, the Flyer I of 1903, is then described. Details of the testing of the Flyer I and the first powered flights at Kitty Hawk in December 1903 are given. The programme concludes with a description of the development and testing of the Flyers II and III at Dayton in 1904 and 1905. Extensive use is made of photographs obtained by the Wrights to illustrate points made in the programme.

Dr John Ackroyd. Born in Bradford, Yorkshire, in 1938, John Ackroyd graduated in 1960 in Aeronautical Engineering from Queen Mary College, University of London. He obtained his Ph.D. from the same institution for his work on shock tube and shock tunnel flows, supervised by Professor A. D. Young and Dr. L. Bernstein. Appointed Lecturer in the Department of the Mechanics of Fluids, University of Manchester, in 1965, he was Visiting Associate Professor of Mechanical Engineering, U.S. Naval Postgraduate School, Monterey, California, for one year during 1968/69. He has served as technical consultant to the Daresbury Nuclear Physics Laboratory and to ICI Fibres Division. A corporate member of the Royal Aeronautical Society, he became a Chartered Engineer in 1972 and was awarded the title of European Engineer in 1989. In that year he was appointed Senior Lecturer in Aeronautical Engineering in the University of Manchester. Apart from his research publications, which have largely been in the areas of shock tube flows and boundary layer theory, he was scriptwriter and presenter in the video series 'The Science of Aviation—A History'. These teaching videos, now used world-wide, review the scientific and technical development of aeronautics up to 1905.