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REVIEWS

The Aerodynamic Design of Aircraft. By D. KÜCHEMANN. Pergamon, 1978. 569 pp. £25.00 (hardback) or £10.00 (paperback).

The death of Dietrich Küchemann in February 1976 was a severe loss to the world of aerodynamics and to his many friends, but it is fortunate that he had by then assembled the material of this book and was engaged in its final editing. The book was completed and prepared for publication by some of his friends and colleagues.

After studying at the University of Göttingen, Küchemann became a research scientist at the A.V.A., Göttingen. He spent about ten years there, working mainly on the aerodynamics of aircraft propulsion. In 1946 he came to England to work at the R.A.E., Farnborough, and this was the start of an exceptionally productive period of nearly thirty years, during which he and his colleagues made great advances in understanding the aerodynamics of swept wings and developing design methods. They also established the slender wing with controlled leading-edge separations as the basis for a new class of supersonic aircraft.

During the last four years of his life, Küchemann gave a course of lectures to students at Imperial College, London. This gave him an opportunity to set out clearly his convictions about the way in which aerodynamics should advance to improve the design of aircraft. He linked this with an account of the great advances made during the previous thirty years and the emergence of three classes of aircraft – swept wing, slender wing and waverider – each suited to its own range of Mach number. The book follows the general theme of these lectures, but the material has been greatly expanded and the result is much more than a textbook for students.

Küchemann had a passionate belief in the value of air transport as a force for good in the world and for him aerodynamics had only one purpose – the design of better aeroplanes. He refused to allow his deep understanding of aerodynamics to be diverted towards any application outside the aeronautical field.

In a short preliminary chapter he argues that mankind needs a transport system that will keep the travelling time down to about two hours for any length of journey. This leads to a relationship between range and Mach number, extending up to about $M = 9$ at ranges approaching the maximum global value of 2×10^4 km. He points out that there is a range of possible propulsive systems (fan-jet, turbo-jet, ramjet and scramjet) giving propulsive efficiencies η_p that increase with Mach number. The three classes of aircraft to be considered (swept wing, slender wing and waverider) have maximum L/D ratios that decrease as Mach number increases, but the product $\eta_p(L/D)$ remains roughly constant at about 3. This means that to a first order, and for a fixed calorific value of fuel, the ratio of the weight of fuel required to the total weight of the aircraft at take-off is directly proportional to range and independent of speed. It is not possible at present to carry a useful payload over a range approaching the maximum global value, at any speed, but Küchemann forecasts that this will be achieved in the future by improved technology for high Mach numbers and by the use of hydrogen as a fuel. Then, by choosing the appropriate class of aircraft, in this case a waverider, the goal of a two-hour journey time can be achieved at the global range.

His enthusiasm for supersonic air transport has not been weakened by thoughts of

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limited energy supplies (which are not mentioned) or by problems of sonic bangs (which are dismissed in one paragraph). He also assumes without any comment that the problems of developing structural materials to withstand the high temperatures encountered in high-speed flight will be overcome without excessive weight of structure.

An important part of Küchemann's philosophy of aerodynamics was his belief that the aerodynamic design of an aircraft should start with consideration of what he calls a 'healthy' type of flow. Such a flow should be steady, stable and controllable. Any changes in forces and moments with flight conditions should be gradual and smooth and ideally the type of flow should be the same throughout the whole flight envelope of the aircraft. The word 'ideally' is inserted in the statement of the last requirement because the condition cannot be satisfied by the waverider aircraft which are favoured for Mach numbers above about 4. He emphasizes many times the importance of understanding the physical processes occurring in the flows and the weakness of calculation methods when these are developed without physical understanding.

Two early chapters are entitled 'The treatment of airflows' and 'Means for generating lift and propulsive forces'. The first of these is a brief general survey of the basic principles of aerodynamics, paying particular attention to boundary-layer separation in two and three dimensions and the formation and development of vortex sheets. The second begins with the use of the momentum equation to derive general integral relations for lift and drag. It continues with an account of 'classical' wings of high aspect ratio which are distinguished by the nearly planar form of the vortex wake, and goes on to an account of slender wings and their non-planar vortex wakes. The concept of the waverider is then explained and it is emphasized that, for each of these three classes of aircraft, classical (including swept wing), slender and waverider, one should start with a desired form of flow and design a shape to achieve it. The last part of the chapter gives an outline of the general principles underlying the generation of propulsive thrust. This is a useful generalized account, serving as an introduction to the short discussion of hypersonic propulsion that is given later.

In introducing the two chapters on 'classical and swept aircraft' Küchemann refers to Sir George Cayley as the originator of the classical type of aircraft. In aircraft of this type, separate 'organs' – the fuselage, wing and engines – are provided to fulfil the functions of providing volume for the payload, lift, and propulsive thrust. Interference effects between these organs are usually small, although they cannot be ignored. This class of aircraft, extended to include swept wings from the 1940s, has served aviation well and will continue to do so for subsonic speeds, but Küchemann emphasizes that there are other useful forms of aircraft in which the organs fulfilling the different functions are integrated and not provided separately. He is, of course, thinking mainly of the slender wing and waverider aircraft to be considered later.

The swept wing is introduced by considering the simple concept of a sheared wing of constant chord and infinite span. As an idealization this leads to the idea of a family of aircraft with the angle of sweepback increasing with the cruise Mach number, each having the same range for the same ratios of fuel weight and payload to total weight. Thus sweepback is seen as a means of reducing the flying time of the basic 'classical' aircraft without loss of economy.

Before starting his comprehensive account of the aerodynamics of swept wings, Küchemann gives a survey of the classical theory of wings of large aspect ratio and methods of calculating both the spanwise and chordwise load distribution. He then refers to the R. T. Jones theory of slender delta wings and an interpolation between this and the large aspect-ratio theory which he himself published in 1952.

Going on to the theory and design of swept wings, which form a major part of the book, he starts by drawing attention to the desired form of flow which is associated with the pattern of straight swept isobars as found on an infinite sheared wing. There are, of course, major problems at the centre and at the tips of a real swept wing of finite span and Küchemann describes in some detail the methods developed by himself and his colleagues for dealing with these. He also discusses fully the effects of the boundary layer, including separation and the formation of vortex sheets, and methods of calculating transonic flows.

A very wide range of other topics is also discussed in the chapters on swept wings. These include stalling, high-lift devices including 'flexible' variable-geometry systems, boundary-layer control, jet flaps, buffeting, supercritical aerofoils, wave drag in supersonic flight, blunt trailing edges and wing–body strakes.

He reiterates the need for design to be based on a 'well-ordered healthy type of flow under all flight conditions, which is calculable, measurable and predictable'. He acknowledges that this general aim has not yet been achieved and points out many problems that still remain to be solved.

There are useful sections dealing with the design of fuselages and wing–fuselage intersections. Various other forms of interference are discussed, including fin–tail-plane, wing–tailplane and ground effects. In a final section on the complete aircraft, he emphasizes the present lack of knowledge and the great advances that should be possible in the future.

The chapter on slender aircraft for supersonic flight starts with an interesting historical account of the evolution of the design concept in the 1950s, when Küchemann, E. C. Maskell and some others realized that the classical form of aircraft would not achieve economic supersonic flight and that a new set of aerodynamic design principles would have to be conceived. This led them to the idea of a slender wing with controlled flow separation from the leading edges. The first aircraft to be designed for this type of flow (apart from some small experimental ones) was the Concorde, but Küchemann makes clear his belief that the Concorde was only a first attempt and that greatly improved forms of slender supersonic aircraft will be designed and built in the future.

The discussion of slender aircraft starts with consideration of a family of aircraft and the main design limitations. It continues with a detailed account of vortex flows, conical flow fields as an approximation to the real flows, vortex breakdown and effects of varying Mach number. Theoretical methods for calculating the flows are described and the importance of the nonlinear component of lift is emphasized. In discussing design methods, the conditions to be satisfied at low speeds are considered first, before going on to a discussion of wave drag at supersonic speeds. The whole approach is based on the Küchemann philosophy of starting with a clear understanding of the type of flow that is required and then designing a shape to achieve that flow.

There is a short chapter on the possible use of large slender aircraft for short-range subsonic transport, based mainly on some papers by S. B. Gates which were

apparently never published. These aircraft would be of integrated design, with the passengers and crew enclosed within the slender wing.

Finally, there is a chapter on waverider aircraft and their design. For these aircraft the satisfaction of the conditions at the 'design point' is relatively straightforward and the more difficult aerodynamic problems arise in predicting the off-design characteristics. It is not possible to achieve the same type of flow throughout the flight envelope but Küchemann points out that nevertheless the changes in pressures, forces and moments occur gradually and smoothly. Theoretical results for waverider aircraft are reviewed and compared with experiments. It is explained that, where serious discrepancies are found, these can usually be attributed to effects of viscosity and these effects are discussed. Some possible forms of waverider incorporating integrated propulsive systems are described.

The book contains a list of more than 1900 references. These are predominantly British and German, with relatively few from the U.S.A. or other countries, and many of them are internal R.A.E. papers that have never been published. As a guide to the British work in the field from 1945 to 1975 the book and its references are excellent, but some American workers may feel that justice has not been done to them.

It is unfortunate that the index is not really adequate; many important topics that are discussed in the book cannot be found in the index. Perhaps if Küchemann had lived for another year or two he would have compiled a better index.

The book will be valued by Küchemann's many friends in Europe and the U.S.A., who will see it as a personal statement of his deep understanding and unique view of aerodynamics applied to aircraft design. Others will find it valuable as a guide to the great advances that have been made in aerodynamics during the last 35 years, many of them by Küchemann and his colleagues at the R.A.E.

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