The Simple Science of Flight: From Insects to Jumbo Jets. By Henk Tennekes, The MIT Press, Cambridge Mass, USA & London, UK, 1992 English edition. 1996. $20.00

There are many books on the science of flight. Clark Millikan's book[1], written in the 1940s, probably introduced many an engineering student to the subject in the post World War II years. Kermode's *Mechanics of Flight* appeared some sixty years ago and became the gospel for airmen – pilots, and airline crews after World War I. The 10th revised and updated edition[2] appeared in 1996. Neither of these books mentions bird flight. Hankin's[3] was probably the first book on animal flight – but Lord Rayleigh – as in several other disciplines, was there first! His paper on the soaring flight of the Albatross appeared in *Nature*[4] in 1883. So one might ask: What's new? Tennekes' unusual book is fresh and different – it is lively, informative about flight in general and illuminates a number of topics – all amenable to simple calculation and linked with the main subject. Birds, bees, motor cars, trains, ships and airplanes are all strung together to reveal a point or two about how things that fly perform and why the Jumbo Jet should be considered a super-engineering marvel. In talking about birds the author is in good company as all the pioneers of flight used their observations of nature to good effect.

Tennekes' book is almost unique. For comparison two other books come to mind. *Flight of Fancy*[5] in which young Archibald Higgins is bored with walking on earth and envies the birds. He is introduced to flight by his pet bird Max and a young, presentable Parisenne, Sophie. Cartoons and – trials and tribulations, and fluid mechanics and the mysteries of flight get Archie into the air. This is fun and physics but does not have the range and engineering repertoire of Tennekes. The other book – on *Animal Flight*[6] by a noted biologist turned aerodynamicist, Pennycuick is a primer on the anatomy, physiology and performance of flying animals. While providing a good introduction to animal flight it does not cover airplanes.

In six chapters – each about 20 pages – profusely illustrated – Tennekes with his active background in aeronautical engineering, fluid dynamics, meteorology, as a pilot and not the least, naturalist of long standing, shows by physical argument, illustration and simple calculation, how one might understand the performance of flight systems – natural and man made – and also enjoy the subject.

Chapter 1 begins by looking out of the window of a passenger aircraft and musing how the airplane is kept in the air. Basic elements of Newtonian mechanics then rapidly lead to relations between wing loading, lift and air speed, culminating in the Great Flight Diagram with an astonishing collection of data from about a hundred fliers. It is eloquent testimony that science brings order into a seemingly disparate jumbles of entities. The SI systems of units is painlessly used and explained. So bird watchers, physiologists as well as engineers and physicists can all find their way. The author makes sure that the subject under discussion is comprehensible and comes alive to those who were brought up on 'horse power', 'pounds per square inch' or 'kilocalories'. Even today not all of us feel comfortable with Newtons and Pascals, Joules and Watts. Incidentally the similarity plot of the Great Flight Diagram was known to Helmholtz and is displayed by Von Karman in his historical book on aerodynamics[7].

Chapter 2 discusses the power required for and energy expended in, flight. An experiment conducted by a biologist who trained birds to fly in a wind tunnel, serves as introduction to a basic tool used by aeronautical designers. The author also shows how the power–speed relationship of flight systems is markedly different from other transport. Airplanes and birds achieve economy at relatively higher speeds because the resistance to motion is composed of compensating terms – one increasing and the other decreasing with speed. There is also an interesting diversion for weight watchers, displaying data and comments on the energy content of fuels and food stuff.

In Chapter 3 the effect of winds and weather on flight are examined. For reasons of safety, comfort and economy airlines have to keep track of winds, clouds and storms – so do birds foraging for food or migrating across continents. Gliding and soaring then naturally appear, preceding the Great Gliding Diagram of the next chapter. The calculation of the take-off runs of airplanes and the relationship with the required length of runways of airports is typical of the author's first hand grasp of the essentials and his ability to produce reasonable numbers. One hopes that those who finally build the much delayed, New Bangalore Airport will read Tennekes' book – or better still ask his advice!

Chapter 4 comes to grips with technicalities of aerodynamic efficiency and basic elements entering into the design and performance of flight systems. Being a keen skater, the author cannot help noting the similarities of the speed and force triangles in the two cases. The Great Gliding Diagram – (Glide Polar to Aero Engineers and sail plane fliers) – follows. Birds, sailplanes and aircraft can sustain their flight without expenditure of energy if their aerodynamic 'clean-ness' is above a certain value by seeking updrafts of about one meter per sec. The core element of this chapter is the discussion of the power required diagram and the elements of 'induced' and 'friction' drag. It is rather curious that 'circulation' and 'vorticity' or 'Reynolds numbers' do not appear – Prandtl, the father of modern fluid dynamics and aeronautics, showed many decades ago how these concepts lead to simple physical explanation of forces on a wing. Practically everyone has seen the 'contrails' of high flying airliners. Another relatively minor, omission relates to the high lift required by airplanes as well as birds during take-off (and landing) when the forward speeds are low. Airplanes use flaps and other devices. The birds (and insects) use large amplitude wing motions. A new aerodynamic principle (the clap and fling) for high lift was discovered by Weiss-Fogh[8] in his studies of moths and small insects. A more recent observation[9] shows that in their flight, moths with triangular wings create unsteady leading edge vortices similar to swept back aircraft wings of low aspect ratio. Perhaps the omission stems from the fact that these nonlinear and unsteady motions are as yet not amenable to simple calculation.

Chapter 5 discusses toy airplanes, kites, amateur racing aircraft as well as hang gliders, ultralights and manpowered aircraft. The discussion of Paul Mac Cready's Gossamer Condor and the MIT team's Monarch which won the Kramer prizes is particularly interesting as they do not yet figure in the usual aeronautical literature.

The final chapter discusses the Boeing 747 and its competitors. The discerning reader, while being impressed by the arguments marshalled to show that the 747 design is a superior, practical compromise solution for intercontinental air traffic, may wonder if the Concorde has received its due. Issues of cost, sonic booms and commercial viability are real but should they completely obscure the signal advances in the science of flight embodied in the Concorde, the Ogee wing, for example? It is also surprising not to find even a passing reference to the indomitable DC-3 (the Dakota) – of which more than 10,000 were built and which ushered in the Age of Civil Air Transport. Some 500 of these are still flying around all over the world. These are small omissions.

Tennekes' book is informative, simply written and full of entertaining asides. People from many disciplines – especially young people – can learn and enjoy the science of flight. The book is well produced and beautifully illustrated. The $ 20 price may put it out of reach for some – but libraries must acquire a copy.

1. Millikan, C. B., *Aerodynamics of the Airplane*, John Wiley, New York, 1941.
2. Kermode, A. J., *Mechanics of Flight* (eds Barnard, R. H., and Philpott, D. R.), Longmans, 10th edn, 1996.
3. Hankin, E. H., *Animal Flight*, Illife & Son, London, 1913.
4. Rayleigh, *Nature*, 1883, **27**, 534–535.
5. Jean-Pierre Petit, *Flight of Fancy* – (English trans. John Murray), 1982.
6. Pennycuick, C. J., *Animal Flight. Studies in Biology No. 33*, Edwin Arnold, London, 1972.
7. Von Karman, Th., *Aerodynamics*, Cornell Univ. Press, 1954.
8. Weiss-Fogh, T., *J. Exp. Biol.*, 1973, **59**, 189–230.
9. Ellington, C. P. *et al.*, *Nature*, 1996, **384**, (19/26), 609–610 and 626–630.

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Clifford (Geometric) Algebras. W. E. Baylis, ed., Birkhauser, Boston. 1996. 517 pp. DM 118.

This is a fairly large book (520 pages) on Clifford's geometric algebras written mostly from the point of view of applications in physics and to a much lesser extent, in engineering. For an introduction into the mathematical aspects of the subject, the reader may consult *Clifford Algebras and Dirac Operators in Harmonic Analysis* by J. E. Gilbert and M. A. M. Murray, Cambridge University Press, 1991.

Given a finite dimensional vector space V over real or complex field F, equipped with a quadratic form Q, one defines a Clifford algebra $\mathrm{Cl}(V, Q)$ over (V, Q) as the algebra generated by $\{\nu(v)|v \in V\}$ and $\{\lambda I | \lambda \in F\}$, satisfying $(\nu(v))^2 = -Q(v)I$. If we denote by $\mathbb{R}^{p,q}$ (p, q non-negative integers such that $p+q>0$) the real vector space $\mathbb{R}^{p+q}$ equipped with the quadratic form,

$$Q_{p,q}(u) = -\sum_{j=1}^{p} u_j^2 + \sum_{j=p+1}^{p+q} u_j^2 \quad (u \in \mathbb{R}^{p+q}),$$

then some simple examples of Clifford algebras emerge, e.g., $\mathrm{Cl}(\mathbb{R}^{0,0}) \simeq \mathbb{R}$, $\mathrm{Cl}(\mathbb{R}^{0,1}) \simeq \mathbb{C}$, $\mathrm{Cl}(\mathbb{R}^{0,2}) \simeq \mathbb{H}$, Hamilton's algebra of quaternions (which is isomorphic to the algebra generated by i times the Pauli matrices), etc. Then the basic results are that there exists a (universal) Clifford algebra over (V, Q) of full dimension $2^{\dim V}$ and this can be constructed canonically as a subalgebra of the algebra of maps on the exterior algebra on V, generated by the so-called creation and annihilation operators. Also the group $SO(V, Q)$ of orthogonal transformations on (V, Q) with determinant 1 has a covering group called spin (V, Q), whose Lie algebra is generated by the bi-vectors in $\mathrm{Cl}(V, Q)$. This feature enabled Dirac to construct the representations of the Lorentz Lie-algebra in his theory of electron.

Out of a total of 33 chapters in the book, 25 are devoted to various constructions involving Clifford algebras and their applications in physics. This reviewer found the chapter on the application of Clifford algebras in projective geometry and to computer vision the most interesting. Though it covers a wide range of materials, in some selected narrow areas, the book cannot be used either as a textbook or as a research monograph but only as a kind of a reference book.

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