direction. In this model, galaxies are built up by repeated mergers of smaller fragments. In this case, there is no single epoch of galaxy formation, but rather a steady build-up of stars. This model is appealing because it is set in the context of a model for the formation of structure in the dark-matter component of the Universe. Models in which the mass of the Universe is dominated by weakly interacting particles known as cold dark matter, and which also have a significant cosmological constant or dark-energy component, are receiving impressive support from measurements of the cosmic microwave background radiation and the Hubble diagram of distant supernovae. However, this evidence is circumstantial: dark matter has not been detected in the laboratory, and there is no convincing theoretical explanation of dark energy.

Keel's own research has covered a wide range of topics, which is reflected in the richness and variety of subjects covered in this book. It is refreshing, in a market dominated by theorists, to come across a book on galaxy formation written from an observational perspective. After all, any model of galaxy formation, no matter how appealing from a theoretical point of view, is eventually judged by how well it describes what is actually out there.

In a book of this length it is impossible to cover in detail all of the most exciting advances of the past few years. Consequently, the discussion of Lyman break galaxies — the first significant population of galaxies to be identified at high redshift — is rather brief in view of the tremendous impact that these objects have had upon the subject. Also, galaxies that are detected by their emission at submillimetre wavelengths (which occurs when the dust that they contain is heated by starlight or by material falling into a central black hole) receive little attention until the final chapter. The book provides a flavour of the physics of galaxy formation, rather than a rigorous review of the theory. Readers who require a comprehensive theoretical briefing could turn instead to *Cosmological Physics* by John Peacock (Cambridge University Press, 1999) or *Cosmology*, 2nd edn by Peter Coles & Francesco Lucchin (Wiley, 2002).

Nevertheless, *The Road to Galaxy Formation* should prove to be a handy primer on observations of galaxies for graduate students, advanced undergraduates and theoreticians who feel too shy to visit a telescope. A particularly useful feature is the bibliography at the end of each chapter, which contains a brief résumé of selected research papers and will no doubt be invaluable to newcomers to the field who need guidance in selecting further reading from a burgeoning literature. ■

Carlton Baugh is in the Department of Physics, University of Durham, South Road, Durham DH1 3LE, UK.

Science in culture

Leonardo lifts off

A wing designed by Leonardo da Vinci proves to be aerodynamic.

Martin Kemp

Leonardo da Vinci is famous, among other things, for inventions that did not work, or rather that could not have worked in his own era. He was, as the cliché has it, a man ahead of his time. But like many clichés, this obscures rather than clarifies. Although he was undoubtedly productive as a 'jobbing' engineer, his grand, visionary projects, such as the flying machine and the tank, blended genuine aspirations with bouts of visual boasting directed at prospective patrons.

The brilliance and practical limitations of Leonardo's more extravagant visions have recently been vividly demonstrated in the project to build a flying machine undertaken by ITN Factual for Channel 4 Television in Britain. I was called in as their consultant, to work with Skysport Engineering of Bedfordshire in England, which specializes in the resurrection of early aircraft.

The brief was to construct something that would actually fly, but with the minimum of deviation from Leonardo's own designs, in detail and in spirit. We were determined to use nothing that he did not or could not have envisaged. The great *uccello* (bird) that he envisaged in the 1490s, with its flapping wings, had no chance of flying, so we favoured the gliding mechanisms to which he later resorted.

Our construction was based on a series of Leonardo's bat-like designs, which combined large spans with skeletal lightness (at least in terms of the materials available to him). Leonardo's concept was based on his conviction that nature's own inventions operated with no insufficiency and no redundancy in the context of natural law. Deciding to remake nature on its own terms, he worked on the principle that the aspiring aviator should not literally imitate a bird but should create a mechanical body that works analogously, in conformity with the causes behind natural effects. It is this approach that places the flying machine in much the same category as the *Mona Lisa*, that most synthetically contrived of portraits (*Nature* **389,** 799; 1997).

The problem that we faced, like everyone else who has attempted to fly Leonardo's machines, was that of achieving sufficient lift to raise into the air the relatively heavy materials available to him. Our breakthrough came with the observation of a detail on a sheet in the Biblioteca Ambrosiana in Milan that had appeared insignificant to my eyes. The Skysport engineers saw it differently. Near the lateral rib adjacent to the pole at the inner margin of the wing, they noticed a looped line that passes over the front edge (circled in red, below). The rear of the loop is labelled "*panno*" (cloth). What this detail said to the engineers was 'leading edge' and 'aerofoil' — the necessary features for lift-off.

However, Leonardo had no sense of the dynamic laws that underlie modern aerofoil design, which involve compression beneath the wing and rarefaction above. During his many hours watching birds wheeling on currents of air, fish swimming in streams, and boats tacking against the wind, he never doubted that water and air (both of which are fluids) behave in the same way. He did not pay attention to the fact that air, unlike water, is compressible, and had not considered such a possibility. But he had observed the robustness of the leading edge of a bird's wing and the relatively broad and blunt heads of some fish, which told him that air or water needed to pushed strongly out of the way.

The Milanese wing design achieved triumphant lift-off high on the Sussex Downs on a breezy autumn morning about 500 years after it was drawn. In the version that flew, Leonardo's wing design was doubled up, and we omitted the windlass, which was intended to adjust the angle of the wings but would have served no useful purpose. Also added was a leonardesque tail for stability and a somewhat less leonardesque A-frame for the intrepid pilot.

A new formula is needed to replace the cliché. Leonardo, with extraordinary visual inventiveness, envisaged more of the potentiality of his period's science and technology than any of his contemporaries. And, like many highly original inventors, he needed his slice of luck to come up with the right answer for the wrong reasons.

Martin Kemp is in the Department of the History of Art, University of Oxford, Oxford OX1 2BE, UK.

Winging it: a flying machine based on plans by Leonardo da Vinci has been flown. The red circle shows the loop that indicates the leading edge.

H. THOMPSON/CHANNEL 4

BIBLIOTECA AMBROSIANA

© 2003 Nature Publishing Group