news and views

Wider implications of catastrophe theory

from Henry Chilver

THE interesting article you publish today by Thompson on 'experiments in catastrophe' (page 392) prompts me to make a plea for wider study, by both physical and social scientists, of a very important area of 'systems analysis' in which the concepts of catastrophe theory may well have an important part to play. It will be evident to anyone who has attempted to 'design' a system—and particularly a complex system—whether this is in the field of engineering, organisation, planning, or in other fields, that modern design has encouraged designers to converge, in their ideas, on optimal systems.

The forces at work to encourage designers to converge on optimal solutions are very strong. All systems are based on ideas of increasing efficiency in one form or another: for example, in his article Thompson demonstrates how the search for the lightest (and therefore most efficient) structural forms leads to potentially catastrophic engineering structures. There are other examples in the fields of solids and fluids: the breaking of bonds between solid particles leading to the catastrophic failure of materials; the breakdown of smooth flow around bodies, leading to turbulent flow.

But there are many other types of systems—of widely different sorts—where catastrophe becomes more critical as design becomes more 'optimal'. Many transport systems are highly sophisticated and optimised—and therefore highly sensitive to small perturbations which may lead to collapse or catastrophe. One of the most sophisticated transport vehicles—the aeroplane—is itself a highly optimised system: its structure is highly efficient and its power in flight is highly sensitive to the reliability of its engines; more optimisation comes into the picture during the operations of the aircraft, and the history of the aeroplane is very sensitive to any perturbations which lead to loss of control and thus to catastrophe; again, this particular mode of transport is highly sensitive to weather conditions, and fog at the airport may mean diversion to other airports, and, thus, to disruption of the system.

But social systems themselves are 'planned' and 'designed' for equally critical states: one of our present social

problems is that we are optimising so strongly the complex interlocking and interdependence of institutions of many sorts that small perturbations of these systems can be catastrophic and lead to complete disruption. States of employment (and unemployment) of vital minority groups are clearly very sensitive to small changes of economic parameters, and this suggests we have built highly critical systems of social institutions.

Again, in manufacturing industry, the economy of production processes is highly sensitive to the volume of production, to the supply of crucial materials and components, and to the attitudes of small groups of staff. For this reason, the present world decline in trade is giving some industrial manufacturing companies serious problems, because their continuing good health is so sensitive to the scale of production. In such situations, sensitivity to small changes of the important parameters is wholly undesirable, but how can this be avoided if we are constantly forcing production processes to the extremes of low-cost and efficiency?

As pointed out by Thompson, Zeeman has shown some interesting catastrophe phenomena in natural systems. Alternative animal states may be compared with the bifurcating paths of classical stability theory, although in such cases it may be very difficult to give numerate values to the many 'axes' or 'vectors' involved. The state of good health of an individual is obviously an optimised condition—the 'design' in this case being reached through evolution and natural selection. In the course of evolution, many inadequate optimal states have been weeded out; a possible reason for their being weeded out is that they showed high sensitivity to small perturbations of their systems. In spite of this evolutionary process, the state of good health, in some respects, is still highly sensitive to a limited number of parameters, as, for example, to blood temperature and the working of a limited number of vital organs.

Some aspects of ecology may well present problems of potential catastrophe. The ecological balance in some systems is a delicate one: perhaps between tropical forest and desert, or between alternative forms of animal life.

In extending the concepts of Thompson, Zeeman and Thompson to a wider range of systems one is tempted to look for a common thread between all these problems. Following classical stability theory, we may search for 'potential functions' for all such problems, but this is not possible, since many of the common problems do not possess a simple potential function, nor, indeed, can be expected to possess them. Another approach would be to construct simple models of these systems and apply general concepts of perturbation in studying their behaviour; this would bring catastrophe theory very close to general control theory.

But one feature common to all these problems, and very correctly Thompson emphasises this, is that they are generally optimal systems. Many are indeed highly optimal. If we try to formulate a general problem it is something on the following lines: as we pursue increasing optimisation in the design and planning of systems, how can we determine in simple terms those parameters to which the stability of the whole system is most sensitive? We might then follow this question with another: is the degree of instability, or sensitivity to the critical parameters, an acceptable one?

Answers to these questions would be invaluable to designers of systems in many areas. The teaching of such concepts as part of the philosophy of design would add a new dimension to our design methodology. The ultimate goal in such studies is to determine common patterns between the many different systems we design and build, and in which catastrophe can occur. What can be envisaged long-term is not only concepts of how to build optimal systems—indeed our knowledge of this is already very extensive—but how to study their sensitivity to disturbances and perturbations, and thus be able—as designers—to distinguish between highly critical and less critical systems.

At the end of the day, of course, catastrophe cannot be avoided, but at least we should have a feel for the sensitivity of any optimal system to catastrophe. Thompson's paper is a helpful pointer in this direction: how can we encourage others in the same general direction?