the flow of work? Will not the volume of new finds always increase so as to overwhelm the resources available? On the face of things, this would seem a sensible extension of Parkinsonism, and, even as things are, Mr Musty reckons that he must pick and choose between potential candidates for detailed examination and conservation. Sometimes only 10 per cent of the objects recovered from an excavation will qualify for special treatment. This discrimination, inevitable though it may be, raises all kinds of questions about the wisdom of the procedure. Is it right, or even wise, that the laboratory, the ministry and individual investigators should decide among themselves how particular objects should be dealt with? There is a case for asking that the laboratory should work out a more manageable system of priorities than it has at present, and that it should do this more publicly.

But what about research? As things are, the laboratory tends to take the view that it would be only too happy to undertake the great burden of working out methods of examination and preservation more suited to the spate of objects now flowing in its direction if only it had the time and effort. But this, of course, raises the whole question of what the laboratory is for. To begin with, it may have been a prudent device for making sure that amateur diggers would not ignorantly destroy the treasures they uncovered. There is probably still a need for central services such as carbon-14 dating and X-ray analysis, but there is no earthly reason to believe that qualified excavators, working in conjunction with museums and universities, could not individually undertake the tasks of examination and preservation—indeed, these are as much a part of modern archaeology as is the analysis of data in the physical sciences. The laboratory itself could then be more free to undertake the kind of long-term work necessary to lay the foundations for the future—the use of polymer materials for preservation or new kinds of photography (why not holography?) for recording data. But even this, of course, is a job which could respectably be farmed out to a university or even perhaps to the larger museums. Dispersal along these lines would certainly be preferable to the present half-way house in which the laboratory exists. And if the ministry does not see fit to provide the laboratory with the money and the staff it needs to do its job respectably, it should at least give some serious thought to the Fulton-like possibility that the laboratory should be turned into a public corporation, paying its way with fees charged to investigators and owners for work done.

STATISTICS

Britain's Science Expenditure

ACADEMICS still fuming over Mr Aubrey Jones's claim that they do too much research should be discouraged from reading the latest *Statistics of Science and Technology 1968* (HMSO, £1 2*s* 6*d*). They show, among other things, that the universities have taken a growing share of the research and development expenditure in Britain over the past five years. The university share (see table) has gone up from 4·9 per cent of the total to 7·1 per cent, though there is evidence that it has now stabilized at around this figure. Although this has happened during a period of rapid expansion, when there has been a growing number of university mouths to feed, academics can scarcely feel deprived.

Although the total research and development budget has grown rapidly, a steadily decreasing proportion of it is supplied from central government sources. The decline of the defence research budget, in particular, has had the effect of reducing the central government share from 57·5 per cent in 1961–62 to just over 50 per cent in 1966–67. During the same period, the proportion provided by private industry has increased marginally, to 39·9 per cent, but the greatest increase has been shown by overseas sponsors of British research and development. The contribution under this head now amounts to £27·6 million, 3·1 per cent of the total budget. Although the defence research budget has only been holding its own, there does seem to have been a genuine switch of government resources into civil research. The amount spent in this way has more than doubled, from £135 million to £278 million in the five years between 1962 and 1967. Within the civil research expenditure, atomic energy has held its own at around £49 million a year, while all the other sectors have grown; the most dramatic growth is shown by transport research, which has increased from a miserable £293,000 to a more reasonable £4·7 million.

The statistics also say something about the exchange of information in the form of royalty transactions between UK companies and those abroad. The broad picture is that Britain has a small surplus in what is called the technological balance of payments, with the deficit on the export of royalties to overseas branches and subsidiaries, associates and parents being slightly exceeded by the surplus on transactions with other concerns overseas. Total receipts in 1965 were £47·8 million, while total expenditure was £45·9 million. Despite Britain's exclusion, the European Economic Community is a big buyer of British technology, spending £10·67 million on it in 1965, while Britain spent only £4·02 million in the EEC. West Germany spent the most, £4·34 million in 1965, and France

Table 1. DIVISION OF UK RESEARCH AND DEVELOPMENT BY PERFORMER

	1961–62		1964–65		1966–67	
	Amount (£ million)	Percentage	Amount (£ million)	Percentage	Amount (£ million)	Percentage
Government					194·6	22·0
Defence	93·2	14·2	91·5	11·9		
Civil	61·9	9·4	72·7	9·4		
Research councils	23·0	3·5	28·1	3·6		
Universities	32·4	4·9	55·9	7·2	62·2	7·1
Public corporations	21·4	3·3	24·5	3·2	30·6	3·5
Research associations	10·1	1·5	12·0	1·6	14·4	1·6
Private industry	389·4	59·2	467·0	60·5	560·5	63·5
Other	26·3	4·0	19·6	2·5	20·6	2·3
Total	657·7	100	771·4	100	882·9	100

spent £2·13 million. But the chances are that these statistics are not entirely reliable—most countries somehow contrive to show themselves in a good light where statistics of this sort are concerned.

Included in the tables are some further details of the choice of subject at school. In 1967, the numbers of pupils reading A-level studies in science fell by 1,000 to 35,000. This was the second successive year in which the total has fallen by 1,000. The numbers of arts students increased to 51,500, and those following a mixed course went up to 13,000, showing by far the most rapid rate of growth.

ENGINEERING

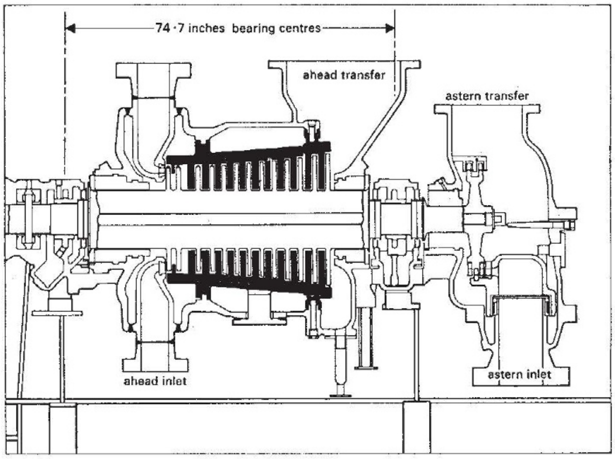
Cunard's Shake-down

If Cunard's publicity department had been told that the first cruise of the Queen Elizabeth 2 would win front page stories every day for a week, it would have laughed aloud. Unfortunately it has been the wrong sort of publicity. For one thing, the QE 2 (like many another passenger ship) was lamentably unfinished when the "shake-down" cruise began. This was bad enough, but worse was to come. As the cruise progressed, the two high pressure turbines began to run rough, and eventually the ship was forced to come home to Southampton at half speed. When the turbines were opened up, it was found that both had shed blades, although apparently without destroying the whole engine in the process. While workmen finish the interior of the ship at Southampton, the turbines are back at John Brown Engineering on Clydeside, being rebuilt and rebalanced.

John Brown is saying very little yet about the mode of failure of the blades. It is probable, however, that the blades failed in fatigue induced by vibration, and it is only fair to say that this kind of thing can happen to any new turbine design. The high pressure turbines in which the failures occurred have eleven stages of blading, increasing very gradually in size from about 2 ft overall diameter at the upstream end to about 2 ft 6 in. at the exhaust end. The first few blades are made from stainless iron containing molybdenum, niobium and vanadium, but further down the turbine, where temperatures are lower, the blades are simply molybdenum stainless iron. The rotor shaft and disks are made as a single forging in chromium niobium vanadium steel, and the high pressure turbine runs at speeds of up to 5,207 revolutions per minute.

Each set of blades, because of changes in dimensions and materials, has a slightly different natural frequency of vibration. The blades themselves can vibrate in various modes, and the whole bladed rotor assembly also has a characteristic resonance frequency. The first step is to calculate the single blade frequency, which is itself something of a task, as the blade is a continuously twisting beam which gets thinner towards the tip. But modern techniques make it possible to get within 5 per cent or so of the right answer. The calculation can be checked by making a mock blade in mild steel, and finding its vibration frequencies experimentally. The next stage is to produce a fully bladed disk and run it in a vacuum wheel chamber, where a number of magnets are used to simulate the impulses acting on the blades. Strain gauges are used to measure the frequencies of the vibrations of the complete assembly. (The process of testing turbines for vibration is admirably described by Mr F. R. Harris in the latest issue of the *GEC–AEI Journal of Science and Technology*.)

When the vibration frequencies are known, they can be compared with the frequencies of disturbances which are expected to occur in the operating turbine. To take a simple example, if a set of blades were out of balance, the turbine would be subject to a vibration equal in frequency to the rotational speed of the rotor; thus at a speed of 5,000 r.p.m., the vibration frequency would be 5,000 cycles per second. If this coincided with a natural frequency, there would be a danger of resonance in the system. In addition, there are many disturbances which occur as higher multiples of the rotation frequency which have to be taken into account. The technique is to plot all these as "order lines" on a Campbell diagram, in which frequency is plotted against rotational speed. The order lines are lines passing through the origin with a gradient which depends on the multiple of the rotational speed which they represent. Also plotted on the diagram are the characteristic vibration frequencies for different modes; where the vibration frequencies cross the order lines, there is a danger of resonance.



The QE 2 high pressure turbine (courtesy of *Engineering*).

The ideal, of course, is to prevent all resonance from occurring, but this is in practice impossible. Instead, the designer tries to make sure that the range of speeds over which the turbine is expected to operate is relatively clear of them. With a ship turbine, which has to operate over a wide range of speeds, this is difficult, and John Brown Engineering clearly failed to manage it. What seems to have happened is that steam conditions, apparently between the eighth and ninth sets of blades, set up a vibration which matched the resonant frequency of the blading. Once the resonant vibration began, it was only a matter of time before the blades failed.

What John Brown can now do is to replace the offending blades with new ones of slightly thicker section. This will prevent the repetition of the same resonance, but it does of course make it possible for other resonances to occur which might be just as serious. Turbine design is a very difficult business, as the QE 2 affair has illustrated. In its way, it provides a timely but rather backhanded compliment to the engineers of the CEGB and its suppliers, who