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Five years ago carbon fibre first began to appear on the market. It was hailed, usually uncritically, as a wonder material which would sweep through the structural world, casting aside light alloys and steels as it went. Industry was more cautious in its approach, being well aware that considerable research would be needed to match the peculiar advantages of the new material to the large number of potential applications, and that carbon fibres could have their disadvantages. Carbon fibre has invaded a wide range of industry apart from aviation, a natural area in which to apply such a material, with its initially far-from-cheap production costs; work in other fields has now resulted in a large fund of knowledge about its behaviour, argues MARCUS LANGLEY, which is again reflected into aeronautical usage.

CARBON FIBRES—

THE FIRST FIVE YEARS

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UR CARBON-FIBRE DEVELOPMENT proceeds steadily, if
rather expensively. We have increased capacity,
and also our range of new products, which includes
some very high-performance material. We have reduced
prices. But the considerable technological breakthrough represented by carbon fibres is still in the use-development stage. With the fall-off in military spending in the USA, progress will be slower than the optimistic forecasts, so widely publicised, of two years ago." This statement, quoted from Lord Kearton's speech at the Courtaulds annual general meeting on July 14, seems to be a very fair summary of the general position today and would represent the activities not only of Courtaulds but those of the other firms and organisations working on the material.

It is almost exactly five years since carbon fibres were first introduced to the engineering industry by their co-inventors, W. Watt, L. N. Phillips and W. Johnson, scientists at the Royal Aircraft Establishment, Farn-borough1

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This trenchant statement aroused immediate interest, and the daily press, getting hold of it, spread banner head-lines on the subject. More slowly and soberly, the rest of the technical press followed, and in April 1967 the RAE produced a widely read initial evaluation2

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the earlier optimism about the properties of carbon fibre-reinforced plastics and outlined a possible future pro-gramme. In addition to the pilot production undertaken at the RAE and AERE, commercial manufacturers were found and a target of some 450 tons a year of the basic fibre material was set. Morganite came in with its know-ledge and experience of carbon technology, and Courtaulds with its familiarity with fibre manufacture and particularly with the percursor material, acrylonitrile. Rolls-Royce had been involved very early on, since the material seemed to have outstanding advantages for certain uses in aero-engines, notably in the compressor blades. ICI looked into the possibility of setting up a large plant for fibre manu-facture but thought that even a production of 2,000 tons a year could not reduce the price to an economic level. At that time the basic fibre was costing about £135 per lb to make but the RAE hoped that it would come down to about £5 per lb as the demand rose. Now, after five years, metre-length intermediate grade fibre can be bought for about £13 per lb, a target of £5 being forecast for the mid-1970s3

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Since carbon fibres are not used by themselves but must be carried in some kind of matrix, as with glass fibres, attention was then turned to the obvious polymers such as the epoxies and the polyesters. This brought in the chemical firms which make the resins (Shell Chemicals, CIBA, Union Carbide, Monsanto and others) and also Fothergill & Harvey with all its experience of composites.

Most synthetic resins appeared to be compatible with the carbon fibres, but there were certain difficulties in getting the correct degree of "wetting" of the fibres to give good surface adhesion with its consequent interlaminar shear strength. The fibres might tend to pull through the matrix unless this adhesion could be improved, but the problem was solved by further research work.
Pre-impregnated fibres ("prepreg") in sheet form ready for moulding, and containing 40-50 per cent of fibre by volume, became available at prices down to about £30 per lb. The aerospace industry began to experiment with these, Rolls-Royce being a leader in the field.
In order to put this matter of price into proper per-spective, it can be shown that in the ten-year life of a commercial aircraft a saving in weight of lib may be worth over £1,000 in revenue-earning capacity. Weight savings of the order of 10 per cent, 20 per cent, or more, derived from the replacement of metal by carbon fibre-reinforced plastics, have been forecast for aircraft primary structures. If these forecasts can be shown to be correct then the new material becomes viable.

It is interesting to consider that when aluminium was first exhibited 90 years ago it was thought of as a rare metal with a price of £2-50 per lb. Commercial aluminium is now sold at £0-16 per lb and the difference is much greater if one allows for the change in the value of money. In that same period Bessemer steel cost £0 • 008 per lb, an yet aluminium made progress and has since become a major commercial product.
One may ask whether a similar trend is likely to develop with carbon fibres. They require no expensive imported ores for their manufacture, the process can be made largely automatic and, once the capital cost of the plant has been written off, the main expense is for electricity to run the 2,000°C ovens. The price will then vary inversely as the demand.

In view of the short time since they began, the aircraft firms are as yet saying very little about their progress, although one has heard of experimental wing tips, control surfaces, spars, ribs and helicopter rotor blades. Some of these have been shown rather coyly at the SBAC Show and other exhibitions.
While the Americans have their own Thornel carbon fibre and have done a lot of work on boron/tungsten filaments as well as on "whiskers," they sprang in very quickly to take licences under the RAE carbon-fibre patents. It is difficult to assess their progress yet and their aircraft firms are being as reticent as the British ones are. The earlier carbon fibres shown five years ago were all in short lengths of one metre, but work had already begun on the manufacture of continuous filaments of great length. These made possible an entirely different approach to many structural problems. The first and most obvious application was for spiral winding, where the high tensile strength/weight ratio was a great advantage. But the experimental designers quickly went much further and

continued on page 407