THE CHANGING PATTERN OF AERONAUTICAL ENGINEERING EDUCATION

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ABSTRACT

After a brief, historical introduction some salient facts on higher education in general and engineering education in particular for some representative countries are presented and discussed. Then follows a more detailed discussion of aeronautical engineering education in which current trends in both undergraduate and postgraduate education as well as in research activities at teaching institutions are emphasised. A section is devoted to a consideration of the problems involved in meeting the growing pressures on courses imposed by modern developments and in particular by the development of the various national and international space programmes. The main conclusions are then summarised.

INTRODUCTION

The early history of aeronautical education throughout the world is not, so far as I am aware, adequately documented and much remains to be uncovered and put on record. What can be said is that during the first decade of this century, stimulated no doubt by the work of such great pioneers of aviation as the Wright brothers, Prandtl, Eiffel, Zhukovsky, Langley, Lanchester and many others, teaching and research in aeronautical topics were established in a number of universities and institutes in North America and in Europe. I need hardly remind an audience such as this of the important school that was by then well-established under Prandtl at Göttingen. I am proud of the fact that my own Department at Queen Mary College, London, was the first university department devoted to aeronautics to be founded in the U. K. It was started in 1908 by a great pioneer who died only a very few months ago, Dr. A. P. Thurston, a man whose important early research on leading-edge devices for increasing lift deserves more recognition than it has hitherto obtained [5,17]. Here in France the École Supérieure de l'Aéronautique et de Constructions Mecaniques, later to become l'École Nationale Supérieure de l'Aéronautique, was founded in 1909 [21].

The rapid development of aviation in the years between the two World Wars saw a parallel growth of academic teaching and research activity both in established institutes and universities and in new ones throughout North America and Europe as well as in Japan, but this activity almost fades into insignificance compared with the spectacular developments that have occurred since the end of the second World War. In the U. S. A. and Canada at present there are some 240 institutes offering degree courses in Engineering (almost double the number that there were in 1945) and of these about 60 offer courses of aeronautical and space content [10].* In the U.S.S.R. there are eleven major institutes devoted to aerospace technology, as well as two military aeronautical institutes and twelve aeronautical chairs in universities; in addition there are four aeronautical technical colleges training high grade technicians [16]. In France [20], in addition to l'École Nationale Supérieure de l'Aéronautique there is also l'École Nationale Supérieure de Mecanique et d'Aérotechnique at Poitiers (founded in 1945) and there are a number of other Grandes Écoles and Écoles d'Ingénieurs which teach specialised aspects of aeronautics or branches of engineering closely related to it. In the University of Paris there is a Chair of Aviation, and at a number of Universities there are Institutes of Fluid Mechanics (e.g., Paris, Marseilles, Lille, Toulouse, Bordeaux, Grenoble, Poitiers, Strasbourg, etc.) where courses of aeronautical content are given. Some of these Institutes have now been absorbed into Engineering Schools (E.N.S.I.), e.g., Grenoble, Poitiers, Toulouse, etc. In W. Germany [24,25,30(f)] there are Departments of Institutes devoted to aeronautical subjects at almost all the Technische Hochschule (e.g., Aachen, Berlin, Brunswick, Munich, Stuttgard, Darmstadt, Karlsruhe). In Italy [26], in addition to the Technical Institutes of Turin and Milan, there are eight Universities with Faculties of Engineering, and aeronautical engineers are trained at both the Technical Institutes and at three of the Universities. The aeronautical teaching and research at the Technological University in Zurich, Switzerland, in Delft, Holland, and in Stockholm, Sweden, are of outstanding quality and those Institutes are recognised as amongst the

* In what follows I have not attempted for lack of space to discuss the significant distinctions that exist between engineering education in the U. S. A. and Canada. I am indeed well aware of these distinctions as I am of the major achievements in aeronautical teaching and research of the Institute of Aerophysics, University of Toronto, and McGill University, Montreal. A valuable account of the Canadian scene will be found in Ref. 7.

best in the world. In Belgium aeronautical subjects are taught at the Universities of Brussels, Ghent, Liége and Louvain, and postgraduate courses and research in aerodynamics and gas dynamics are offered at the Von Kármán Institute for Fluid Dynamics at Rhode-Saint-Génese (formerly the Training Centre for Experimental Aerodynamics), which was founded in 1956. In my own country [17] there are now Chairs in Aeronautical Engineering at the Universities of Belfast, Bristol, Cambridge, Glasgow, London (two Departments—Imperial College, Queen Mary College), Southampton; and in addition the Departments of Fluid Mechanics at Liverpool and Manchester, as well as that of Engineering Science at Oxford have some considerable bias both in teaching and research towards aeronautical topics.* Most of these developments have occurred since the Second World War. Further [19], a number of Colleges of Advanced Technology (shortly to become universities), offer courses in Aeronautical Engineering (e.g., Northampton, Bristol, Loughborough, Salford) and there are similar courses offered in four Technical Colleges (Farnborough, Hatfield, Kingston, Lanchester). In addition the College of Aeronautics was founded in 1946.

I have by no means exhausted the list of centres of aeronautical education in Europe. Important schools have existed for many years in Poland, Czechoslovakia, and Rumania as well as in Spain and Norway. However, of particular interest are the developments in aeronautical education and research within the last two decades or so in countries in the Middle East, Asia, and in Australia. At the Haifa Technion, Israel, a department of Aeronautical Engineering was founded in 1950 and it has now established itself as an important centre of research, whilst in Japan, where interest in aeronautical matters lay dormant after the war until 1954, there are now two outstanding Departments at the Universities of Tokyo and Kyoto. In India, undergraduate teaching in aeronautics is given at the Madras Institute of Technology and postgraduate courses are offered in the Department of Aeronautics of the Indian Institute of Science, Bangalore [30*e*]. It is proposed to expand the teaching of Aeronautics in India by starting courses in a few other selected engineering institutions. In Australia [7] a Chair of Aeronautics was established in 1940 at Sydney University and since its foundation the Department has made many valuable research contributions both in aerodynamics and in aircraft structures. It is clear that the subject is far from dormant in China, but I regret that I have no information on current developments there.

This then is a very brief and certainly incomplete survey of the distribution throughout the world of institutions of higher education where

* For some further details on aeronautical teaching and research in the U.K. see Ref. 8.

aeronautical topics are taught. I believe that from this point my main task in this talk is to try to highlight the salient developments in the teaching of aeronautics in recent years and the problems that these developments present to universities. However, in attempting to deal with this task I find that I am faced with a number of major difficulties. In the first place it is almost impossible to consider the teaching of aeronautical engineering in isolation from that of engineering in general. Indeed, in many institutes and universities, whilst it is possible for undergraduate students to select some courses of aeronautical engineering topics from a number of options, the students themselves are not classified with the label of aeronautical engineer, the selected topics provide a bias towards rather than a specialised education in aeronautics. It has been said that aeronautical engineering is ordinary engineering but much more difficult and there is a great deal of truth in this. The whole of engineering and much of pure science is grist to the aeronautical mill, and the aeronautical engineer must have a sound foundation in topics basic to mechanical engineering, structural engineering, materials and electrical engineering.

The rapidity of change in the aeronautical scene, the ever-increasing ranges of operational speeds of aircraft and spacecraft and the consequent changes of design problems make early specialisation in the education of an aeronautical engineer undesirable. Also, aeronautical and space developments have spread into and strongly stimulated many of the other branches of engineering as well as of pure science so that it is in practice impossible to say where the dividing lines fall between the aeronautical engineer and the mechanical engineer, on the one hand, and the electrical engineer on the other. Indeed, one can say that such dividing lines do not exist, one sphere of activity shades into the other and the corresponding patterns of education must certainly overlap to a considerable extent.

For these reasons I felt that in what follows I should attempt first a survey of the essential features of higher education in a few selected countries and the consequent repercussions on the education of engineers. I will then examine some of the more important problems of aeronautical education in the light of industrial and social trends and needs and indicate how these problems are being tackled. In the process I will attempt to pick out, so far as is possible in this confused subject, salient features of importance to the future.

I must not end these introductory remarks without a few words of explanation, warning and of acknowledgement. Firstly, throughout I have interpreted the word "aeronautical" in the widest sense to include everything relevant to aircraft and to spacecraft. Secondly, in the limited time during the very few months that I have had available to prepare this talk I was unable to check as carefully as I would have liked the data and statistics that I needed for it and which I hurriedly collected from different sources, nor was I able to gather all the information that I would have wished. I believe the figures and data that I have presented and used are not grossly wrong or misleading, but I shall be glad to have any errors pointed out to me, and I shall be grateful for any further data to fill obvious gaps. Finally, I must acknowledge the great assistance I have had from colleagues all over the world, too numerous to mention individually, who responded magnificently to my appeals for help in the preparation of this talk.

SOME FACTS ABOUT HIGHER EDUCATION IN DIFFERENT COUNTRIES

By "higher education" (H.E.) is here meant education at a university or equivalent institute. It will be appreciated that it is not a very precise term and the educational standards implied by it in different countries can differ significantly.

In Table 1 some figures culled from Refs. 1, 2, 3, and 4 are presented for a number of countries showing for 1959 the number of the age group corresponding to the usual age of entry to higher education, the percentage of that group entering higher education, the percentage of that group of all the students starting courses in either Science or Engineering, the percentage starting courses in Engineering, and the approximate percentages of their age groups of the combined groups of Science and Engineering graduates and of the group that graduated in Engineering. In Table 2 similar data are presented based on estimates for 1970.* The two sets of data thus straddle those appropriate to the present year, although present figures are generally somewhat closer to those of 1959 than a simple linear interpolation between the two sets of data would indicate.

Certain salient points of interest are evident from these tables. First we note the very large fraction of the total age group that enters higher education in the U. S. A. at present as compared with the other countries listed. Whilst on the whole this is associated with lower standards of entrance requirements in the U. S. A. than in other countries and with a consequent high failure rate in the early university years (about 40–50 per cent), the figures impressively reflect the American doctrine of equality of educational opportunity [8]. In most other countries the number of available university places are generally well short of the number of young people with the requisite ability to cope with a university course [3,4].

* These data in Table 2 are also based largely on figures quoted in References 1, 2, 3, and 4 but some of the data cannot be claimed to be much more than guesses.

TABLE 1. HIGHER EDUCATION AND ENGINEERING EDUCATION IN DIFFERENT COUNTRIES (1959 approx.)

Country	Number in age group at entry to H.E. (Thousands)	Per cent entering H.E.	Per cent entering Science and Engineering	Per cent entering Engineering	Per cent graduating in Science and Engineering	Per cent graduating in Engineering
Belgium	93	6.2	1.9	0.8	0.9	0.4
France	526	9.1	3.6	0.9	1.4	0.6½
Germany (F.R.)	1,030	4.1	1.2	0.6	0.8	0.5
Holland	172	3.9	1.6	0.8	0.6	0.3
Italy	873	6.6	1.5	0.8	0.7	0.3
Sweden	97	7.6	2.4	0.8	0.6	0.6½
U. K.	601	4.4(+1.0)	2.0(+0.6)	0.7(+0.4)	1.4(+0.4)	0.5(+0.2½)
U. S. A.	2,500	34.4	6.1	2.8	3.7	1.7
U.S.S.R.	4,000	10.0	5	3	4	2.5

Notes: (a) The figures relate to full-time students, except in the case of the U.S.S.R., where about one third of the students are part time. In the case of the U. K. the inclusion of part-time students would increase the quoted figures by about 50 per cent. For the other countries it is believed that part-time students, if any, would represent a much smaller percentage.

(b) The figures quoted in brackets for the U. K. represent approximately the present contribution of the Institutions that have recently or will shortly attain university status following the Robbins Report (e.g., Colleges of Advanced Technology) and of Colleges other than Schools of the University offering full time courses leading to the Internal and External degrees of the University of London.

TABLE 2. HIGHER EDUCATION AND ENGINEERING EDUCATION IN DIFFERENT COUNTRIES (Estimates for 1970)

Country	Number in age group at entry to H.E. (Thousands)	Per cent entering H.E.	Per cent entering Science and Engineering	Per cent entering Engineering	Per cent graduating in Science and Engineering	Per cent graduating in Engineering
Belgium	139	9.5	3.7	1.5	1.7	0.8
France	805	13.9	7.3	2.0	4.7	1.6
Germany (F.R.)	771	7.8	1.9	0.9½	1.3	0.6½
Holland	218	4.4	2.0	1.2	1.0	0.6
Italy	776	12.5	2.9	1.4	1.4	0.6
Sweden	115	11.7	5.2	1.9	3.1	1.3
U. K.	724	8.9	4.3	1.8	3.1	1.3
U. S. A.	3,783	38.2	7.2	3.4	4.4	2.0
U.S.S.R.	5,000	30	18	10	14	8

Notes: (a) As for Table 1 except that in the U. K. part-time students are likely to increase the quoted figures substantially but not as much as 50 per cent.
(b) The figures quoted for U. K. are based on the Robbins Report recommendations.
(c) The figures for U.S.S.R. are largely guesses and can only be regarded as rough guides.
(d) See Refs. 1, 2, 3, and 4.

This situation has led to high standards of entry, sometimes associated with competitive entrance requirements, and a tendency for those from poorer households not to attempt the consequent struggle. However, the manifest injustice of this situation as well as its social and economic consequences are now widely understood in most countries and in many cases plans have been made and are under way for a major expansion of universities and institutes of technology. The estimated data for 1970 in Table 2 illustrate the changes that will by then be evident as a result of these plans. The U.S.S.R., Italy, France and Sweden in particular are already well advanced in putting major plans for expansion into effect; by 1970 the percentage fraction of the total age group entering higher education in the U.S.S.R. will be very comparable to that in the U.S.A.

A further point of interest is the fact that as much as half the total entry in the U.S.S.R. study either Science or Engineering whilst about a third study Engineering; in the other countries listed the corresponding fractions, particularly the fractions studying Engineering, are markedly smaller. For the U. S. A. less than one in ten students reads Engineering, nevertheless the total entry is so large that as a proportion of the age group the group of Engineering students in the U. S. A. in 1959 was about three to four times as great (2.8 per cent) as the corresponding proportions in the other countries (0.6 $\sim$ 0.9 per cent) with the exception of U.S.S.R. (3.5 per cent). By 1970 in the U.S.S.R. roughly ten per cent of the age group concerned will be Engineering students; both in relative as well as in absolute terms these students will be far greater in number than those of the other countries listed.

The question naturally arises as to what are the social factors that have contributed to this relative preponderance of students reading Engineering in the U.S.S.R. as compared with other countries. One factor of importance can immediately be noted, namely, the relative proportions of women students. The proportion of the total student entry that are women range from a little less than 30 per cent (e.g., in Germany, Holland and U. K.) to just over 40 per cent (in U.S.A. and U.S.S.R.). I have not got the corresponding figures for the proportion of Science and Engineering students that are women, but of the Engineering students the proportion is very small indeed in all the countries listed except in the U.S.S.R. where women account for about one third of the total. The next highest is France where about 5 per cent of the Engineering students are women. Clearly, if countries other than the U.S.S.R. wish to expand their output of trained engineers they must determine the reasons why half their populations tacitly accept that they are unsuited to engineering as a profession: in the face of the evidence from the U.S.S.R. the widely accepted belief that engineering is essentially a masculine activity is clearly fallacious and based on social attitudes and prejudices that have no relevance to the modern world.

Another factor of some importance is the status of the engineer relative to other professions and in particular relative to the pure scientist. I have the impression that, again with the exception of the U.S.S.R., the importance of the engineer is not fully appreciated by the public at large. Much of the glamour of his work is transferred in the public's mind to the realm of pure science (e.g., the achievement of space research), and at the same time there is often some confusion between the task of an engineer and that of a mechanic in the popular mind. That the top jobs in industry generally go to sales experts and accountants rather than to the engineers concerned with design and manufacture is yet another fact that helps to diminish the status of engineers. It may be noted that even in the U. S. A. where engineers on the whole enjoy high status and pay the numbers of entrants to engineering as well as of engineering graduates have tended to fall slowly in recent years even though the total number of graduates has been rising steadily. Thus in 1957–58 the engineering graduates were 10.2 per cent of those males of their age group that entered university whilst in 1961–62 they were only 7.8 per cent. The actual number of engineering graduates produced per year in the U. S. A. has decreased since 1958–59 when it was about 31,000 and it is not expected to reach this value again until about 1967 [10]. The proportion of students graduating in pure science has not shown a similar decline but has remained more nearly constant. An interesting and perhaps not insignificant fact is that the decline in popularity of engineering amongst students has been accompanied by an increase in popularity of the social sciences.

However, these data are related to the general question as to what is the maximum proportion of a given age group we can reasonably expect to train as engineers. In Ref. 14 it is argued that only 17 per cent of any group have an IQ of 120 or more and are therefore capable of completing a course of higher education. This is of course arguable but if we accept this the next question is how should this 17 per cent be apportioned to the humanities, social sciences, pure sciences and engineering? This must depend to a large extent on the state of development of the society concerned, but if Table 2 is any guide to the aspirations of highly developed countries a fifth (or 3–4 per cent of the age group) at least should be engineering students. If women are just as ready to become engineers as men, then this figure should be attainable, and in the U.S.S.R. the figure is already reached and will soon be exceeded, but without women engineers in substantial numbers it is doubtful if it can be reached.

SOME FACTS ON ENGINEERING EDUCATION IN DIFFERENT COUNTRIES

The pattern of engineering education varies a great deal from country to country and frequently within a country. In some cases engineering is taught in universities alongside the traditional disciplines of the humanities and the pure sciences as well as that of the social sciences; in other cases it is taught in special institutes devoted to technology. The latter is essentially the pattern in France (Écoles d'Ingénieurs and Grandes Écoles), Germany (Technische Hochschule), Holland, the Scandinavian countries, Switzerland and U.S.S.R. (V.T.U.Z.),* to name only some countries; the former

* V.T.U.Z. stands for *Vysshee Tekhicheskoye Uchebnoye Zavadenie*—Higher Technological Educational Establishments.

TABLE 3. SOME DATA ON ENGINEERING COURSES

Country	Normal age on entry	Is entry competitive after passing entrance exam.?	University or Inst. of Technology (I.T.)	Minimum duration of course, years
Belgium	18+	No	University + Polytechnique (Mons)	5
France	18+ 20+	Sometimes Yes	Écoles d'Ingénieurs Grandes Écoles and E.N.S.I. (former university institutes)	4 3
Germany	20	Yes	Technische Hochschule	4 (min.) 5–6 (usual)
Holland	18–20	No	I.T.	5
Italy	18–20	No	University and I.T.	5
Sweden	21	No	I.T.	4½
U. K.	18+	Yes	University C.A.T. (I.T.)	{3 E. and W.) {4 (Scotland) 4
U. S. A.	18	Sometimes	University and I.T.	4 (occasionally 5)
U.S.S.R.	18–19	Yes	I.T.	5–6

TABLE 3. Con't. SOME DATA ON ENGINEERING COURSES

Country	Industrial experience required	Failure rate (approx.) per cent	References
Belgium	—	30–50	2, 4
France	—	Total about 20–30 but very small for G.E.	2, 4, 6, 20, 23
Germany	6 months before entry 3–6 months in vacations	20–30	2, 4, 6, 24, 25, 30(*f*)
Holland	4–6 months in vacations (not all branches of engineering)	50	2, 4, 6, 22
Italy	—	50–60	2, 4, 6, 26
Sweden	3 months before 3rd year 6 months total	15	2, 4, 6
U. K.	1 year before and 1 year after for sandwich courses Usually every alternate 6 months in C.A.T.'s.	20–25 (40–50 for external and part time students) 30–40 in C.A.T.'s.	2, 3, 4, 6, 18, 19
U. S. A.	For cooperative scheme students at intervals totalling 1 year.	40–50	2, 4, 6, 8, 10
U.S.S.R.	½ year distributed over the course	15–20 (Much higher for part time than for full time students)	3, 15, 16, 30(*i*)

pattern is dominant but not necessarily to the exclusion of institutes of technology in Belgium, Italy, U. K. and U. S. A. as well as in Canada, Australia, India and the other countries of the British Commonwealth.

Table 3 lists certain basic data relating to the teaching of engineering in the selected countries already considered in Tables 1 and 2. It will be seen that the normal age of entry to an engineering school is usually about 18+; where it is higher either military service is required prior to entry or, as in the case of the Grandes Écoles in France, the conditions for being accepted for entry are so competitive and stiff as to be met only by two or more further years of study at high school after the baccalaureate or normal school leaving examination. In some countries all candidates who pass an entrance examination (frequently a State examination) are accepted; in other cases they are subjected to further tests in competition for the available places. Not unexpectedly, the more difficult the entrance requirements are to meet, the smaller are the numbers admitted and in general the smaller is the subsequent failure rate.

We see that with the exception of France, U. K. and U. S. A., the courses are generally about five years in duration. In the case of France the course at the Écoles d'Ingénieurs is four years but the entrance examination may require a year's postbaccalaureate study at high school, whilst we have already noted that the three years course at a Grande École will be preceded by at least two years of special study at high school beyond the baccalaureate examination. Thus, it may be argued that in France the student of engineering also requires five years of study beyond that required for the normal school leaving examination at eighteen, although the student of pure science or humanities would normally only require three years.

The normal university course for engineers in England and Wales is the shortest in the world (three years). However, certain points must be borne in mind. First, the schooling in U. K. starts at the age of five and not six or seven as in most other countries. This gives the U. K. child a year or so start which in most cases is maintained by relatively intensive schooling so that at the age of eighteen he has done much at school that is normally taught in other countries in the first and sometimes second year of the university. Further, he is expected to specialise fairly early, and after the age of fifteen or sixteen he can concentrate on a very few subjects. Thus, a would-be engineer would concentrate on Pure and Applied Mathematics, Physics and sometimes Chemistry and in those subjects would be expected to reach a fairly high standard by comparison with students of his age in other countries. This specialisation is undoubtedly at the cost of his general education which has stopped earlier than elsewhere, and many would maintain that it has stopped too early. Finally, it may be noted that whilst in many countries detail design and professional techniques figure prominently in the engineer's course, occupying usually much of the last year, they do not find a major place in the normal university course in the U. K. My Scottish friends would no doubt wish me to draw attention to the fact that in Scotland the school leaving examination takes place a year earlier than that in England and Wales and covers a broader range of subjects at a less advanced level. It is then normal in Scotland for a student to spend three years at a University to obtain a pass degree but he may subsequently be permitted to spend a fourth year studying a specialised field in some depth to obtain an honours degree. I think that this is an excellent arrangement and I am sorry to say that it now seems that the Scottish Universities will switch to the English system not because of any manifest advantages that it may have but for the administrative convenience of having common entry requirements. Further, since tuition fees are virtually nominal in the U. K. (about £60–80 per annum) and almost every student is largely or totally supported with State grants, the financial advantages of a three-year over a four-year course as far as the Treasury is concerned are all too obvious.

In general, the first year's course of the engineering studies at a university in the U. K. is the same for all the engineering students and consists essentially of basic engineering topics in addition to mathematics, e.g., engineering drawing, theory of machines, elementary structural analysis and properties of materials, thermodynamics, fluid mechanics and electrical engineering. A little elementary atomic and solid state physics is sometimes included. In the second year the course for the students in the various main branches of engineering (e.g., Aeronautical, Civil, Electrical, and Mechanical) begin to separate from each other; some specialisation then develops but many lecture topics are common to two or more branches. In the third year the specialisation is more marked. The patterns at Oxford and Cambridge differ from this in the sense that specialisation for different branches of engineering does not normally occur, although recently the specialised needs of the electrical engineers have been recognised at Cambridge. However, some optional subjects are available in the last year which permit a student to satisfy any bias he may have towards a particular branch of engineering.

The quality and organisation of the undergraduate engineering courses offered in the U. S. A. vary enormously and are continually subject to change and only the broadest generalisations can be made. The pressures to study a relatively narrow band of subjects in depth at high school (i.e., in the secondary stage of education) that are to varying extents present in most other countries are largely absent in the U. S. A. This coupled with the very high university intake implies that in general a high standard of knowledge in such basic subjects as mathematics, mechanics, physics and chemistry cannot be taken for granted on entry. Hence the first year or two of a typical American University course are largely devoted to such subjects at a level not uncommonly taught in Europe in high school. Further, liberal studies or humanities and some aspects of social science normally occupy a larger part of the course in the U. S. A. than elsewhere. The available time left over for what might be termed purely engineering subjects of the course is therefore relatively small; they are to be found largely in the last year or two of the course and in general the treatment of such subjects is at an elementary if broad level. An American first degree in a particular branch of engineering is unlikely to imply therefore the same specialised understanding and depth within that branch that might be associated with a similar first degree in another country, but at the same time it can imply a breadth of knowledge over a wide field extending outside engineering proper, the importance of which should not be underestimated. It is at the postgraduate level in American universities that specialisation and courses of strong professional content are to be found, and it is for this reason that it is not uncommon to equate an American Master's degree with a good (e.g., honours) first degree in some European countries.

Here it may be noted that American postgraduate education with its pattern of organised courses of instruction plus research is one of the most interesting and important developments in the last two decades and this pattern is one that I think will be widely adopted in its essentials elsewhere for a variety of reasons (not least, the relief it offers of the otherwise intolerable pressures that continually tend to swell the content of first degree courses).

The courses of about five years or more duration offered in various countries (e.g., Germany, Holland, Italy, Sweden, and the U.S.S.R.) display some broad resemblances in structure although in detail they may differ. In general the first two years of the course are largely devoted to pure science and mathematics although there may be a little basic engineering. An important examination that generally acts as a barrier to the weaker students occurs at the end of this stage and of those students who pass very few fail later. Subsequently the course becomes increasingly specialised, more specialised usually than in the U. K., and a large part of the final year is devoted to projects frequently of a detail design nature.

On the question of industrial training it will be noted from Table 3 that in the U.S.S.R., Germany, and Sweden such training is a general requirement for all engineers. This is in fact also true of the other Scandinavian countries. In Holland it is required for some but not all branches of engineering; for aeronautical engineers six months industrial training, generally taken during vacations, is obligatory. However, in most countries the students are strongly encouraged, if not required, to get some industrial training during the summer vacations. In the U. K. a sizeable proportion of the university students are student apprentices on a 1:3:1 sandwich scheme. By this is meant that they register as apprentices with a firm and spend a year with the firm prior to entry to the university. They spend a second year with the firm after the completion of their university course, and frequently they work at the firm for several weeks during the summer vacation. Their training then counts as a full apprenticeship and helps to meet an important requirement for industrial training and experience for membership of an Engineering Institution (e.g., Institution of Civil Engineers, Institution of Mechanical Engineers, Institution of Electrical Engineers, Royal Aeronautical Society, etc.*). The Colleges of Advanced Technology, established in 1956 in the U. K., have an interesting pattern of mixed industrial and academic training; these usually alternate for six-month periods over a total time of four years. The staffs of the College and firm concerned consult with each other on the details of the training offered. These Colleges are to become universities, as recommended by the Robbins' Committee, but they are expected to retain such a pattern of mixed training. A somewhat similar scheme operates in the U. S. A. at certain universities where it is called a co-operative plan, and there the normal four-year course is spread over five years, the extra year totalling the time devoted to industrial training.

In Tables 4 and 5 further data are presented on the hours per annum required for organised teaching of engineering courses in different countries and their distribution. What is meant by hours of organised teaching probably varies from country to country; tutorials, example classes and supervision periods may in some cases be included and in others not. Further, the time the student is expected to devote on his own, as distinct from organised periods, to the working out of examples, the writing of laboratory reports, the preparation of drawings, the study of his lecture notes and general reading varies from country to country. For these reasons it might be misleadnig to infer that these figures reflect inversely the laziness of the staffs and students in the various countries listed, with the U. K. at the extremely lazy end of the scale and the U.S.S.R. and Italy at the most diligent end. These figures are like the visible parts of icebergs: there is much hidden and I suspect that when the whole effort required of students in each case is examined it adds up to much the same and is about 50 hours per week. It is indeed a matter for discussion as to how closely a student's time should be organised for him; certainly a case can be made for keeping his organised work to a level at which he has adequate time to think and to study by himself.

There appears to be a small negative correlation between the hours devoted to laboratories and drawing offices and the percentage of the total university intake devoted to engineering in the various countries. Perhaps this reflects the considerable cost involved in providing the space, equipment and staff required for laboratory work. If this is true then we may expect that with the rapid increases in intake that are in progress or planned in most countries, financial pressures will tend towards a reduction of laboratory hours and possibly of standards.

* It is membership of such an Institution, and not a university degree, that is a necessary requirement for full professional recognition.

TABLE 4. FURTHER DATA ON ENGINEERING COURSES
(References as for Table 3)

	Belgium	France	Western Germany	Holland	Italy	Sweden	U. K.	U. S. A.	U.S.S.R.
Average hours per annum of organised teaching	700–750	650	650–800	700–800	970–990	840–980	530–560	800–890	970
Hours in laboratories and drawing offices as percentage of total	60	30	25–40	25–45	60	55	45 35 (C.A.T.)	35	13
Is there a final year project?	Yes	Yes. Takes about 20 per cent of final session	Yes. Takes half final session	Yes. Takes large part of final session	Yes	Yes	Generally. Takes about 20 per cent of final session	Occasionally	Yes. Takes almost whole of final session

TABLE 5. AVERAGE DISTRIBUTION OF HOURS IN ENGINEERING COURSES AS PERCENTAGES OF TOTAL HOURS

(References as for Table 3)

Country	Basic sciences	Engineering sciences	Engineering applications	Nontechnical
Western Europe (others than U. K.)	28	36	34	2
U. K.	32	45	21	2
U. S. A. and Canada	29	35	24	12
U.S.S.R.	25	22	40	13

In Table 5 are shown the results of a broad analysis (largely based on Refs. 6 and 16) of the total organised hours into percentages representing those devoted to basic sciences, to engineering sciences, to engineering applications and to non-technical subjects. Noteworthy points on which comment has already been made are (a) the relatively large proportion of time devoted in most west European countries and the U.S.S.R. as compared with the U. K. and U. S. A. to subjects concerned with engineering applications, (b) the relatively high proportion of time devoted in the U. K. to engineering sciences, and (c) the markedly higher proportion of time devoted in the U. S. A. and Canada as well as in the U.S.S.R. to non-technical subjects.

SOME FACTS ON THE EDUCATION OF AERONAUTICAL ENGINEERS

UNDERGRADUATE EDUCATION

The number of graduates from university departments and colleges who specialise in aeronautical engineering by no means includes all the science and engineering graduates who eventually take up employment in the aeronautical industry. As we have already noted an aeronautical or space project calls for a very wide range of knowledge and skills; electrical and mechanical engineers as well as metallurgists, physicists, chemists and mathematicians may very readily find employment in the industry. This must be borne in mind when considering the figures given in Table 6 which presents assessments of the number of aeronautical engineering graduates

TABLE 6
(1962, Approx.)

Country	Number of aeronautical engineering graduates (approx.)	As percentage of engineering graduates	Number of people employed in the aeronautical industry	References
France	150	2½	84,000	20, 28, 30 (*c*)
Germany	100	2	23,000	28, 30 (*f*)
U. K.*	220	5	268,700	19, 28, 30 (*b,h*)
U. S. A.	1,000	3	1,204,000	28, 30 (*a*)

*These figures include diploma technical graduates of 1962–63.

at present being produced in certain countries. For example, the figures for France do not include the university graduates from Institutes of Fluid Mechanics whose knowledge of aerodynamics and gas dynamics would readily fit them for positions in the aeronautical industry. It should also be noted that the figures refer to graduates with first degrees only; in the U. K. there are in addition about 150 students per year with post-graduate qualifications in aeronautics (diplomas, masters and doctors degrees), whilst in the U. S. A. there are some 450 masters and 50 doctors in aeronautical (including space) engineering per year. Finally, it may be noted that whilst the figures for first degrees in aeronautical engineering have been static or have fallen slightly in recent years in both the U. K. and the U. S. A., in France and in Germany they are rising. For example, in Germany the output of such graduates is expected to reach 200 per annum in a very few years.

In Table 7 are summarised the essentials of some representative under-graduate aeronautical engineering courses in France, Germany, U. K., U. S. A., and U.S.S.R. They reflect the points already noted about the pattern of engineering courses in general in these various countries. Thus, the French course reflects the high standards of mathematical ability expected, the German course displays a strong emphasis in the later years on design and professional practice, the British course places most empha-sis on engineering science and less on engineering applications and design, whilst the Russian course shows the greatest emphasis on specialised applications and design. The American course is a broad one with a much stronger content of nontechnical subjects than in the other courses.

TABLE 7. SOME SPECIMEN COURSES IN AERONAUTICAL ENGINEERING

FRANCE (E.N.S.M.A., Poitiers) (Ref. 21)

1st year:	Mathematical methods of physics, physical properties of materials, fundamentals of electricity, principles of manufacturing processes, economics, law, foreign languages, visits.
2nd year:	Mathematical analysis, numerical methods, electronics, nuclear physics, mechanics of fluids, manufacturing techniques, industrial experience, economics, law, foreign languages, visits.
3rd year:	Applied aerodynamics, mechanics of flight, applied heat, manufacturing processes, nuclear engineering, machine construction, industrial relations, foreign languages, industrial experience, visits, project.

GERMANY (West Berlin) [Ref. 30 (*f*)]

1st and 2nd years:	Mathematics, mechanics, descriptive geometry, physics, chemistry, manufacturing techniques, thermodynamics, machines, elements of electrical engineering, elementary principles of flight.
3rd, 4th, and 5th years:	Fluid dynamics, aerodynamic design calculations, properties of light alloys, structures, aircraft materials, aircraft construction and design, aircraft operation, navigation, aircraft propulsion, gas dynamics, 2 elective aeronautical subjects, project.

U. K. (Q.M.C., London)

1st year:	Mathematics, theory of machines, engineering drawing, strength of materials, science of engineering materials, fluid mechanics, thermodynamics, electrical engineering.
2nd year:	Mathematics, aerodynamics, elementary flight dynamics, performance, aircraft structures and materials, applied thermodynamics, theory of machines and control systems, electrical engineering (including electronics.)
3rd year:	Mathematics, gas dynamics, boundary layer theory, wing theory, stability and control, aeroelasticity, aircraft and spacecraft performance, applied thermodynamics, aircraft structures, project or nuclear engineering or economic analysis.

U.S.S.R. (typical) [Ref. 30 (*i*)]

1st and 2nd years:	Mathematics, theoretical mechanics, physics, physical chemistry, hydrodynamics, thermodynamics, technical drawing, strength of materials, electrical engineering, machine details, metallurgy, production techniques, Marxism-Leninism, political economy, military strategy, foreign languages.

TABLE 7. (Con't). SOME SPECIMEN COURSES IN AERONAUTICAL ENGINEERING

U.S.S.R. (typical) [Ref. 30 (*i*)] (Con't)

3rd year:	Radar engineering, aircraft propulsion theory, hydrodynamics, theoretical aerodynamics, mechanics of flight, experimental aerodynamics, aircraft armaments, theory of machines and metallurgy, design project, history.
4th and 5th years:	Aviation industrial economics, applied aerodynamics, aircraft design, aircraft structures, maintenance engineering, aircraft engine design, aircraft instruments, aircraft hydraulics, philosophy, design project.*
6th year:	Major design project and reviews of modern developments in chosen fields.

U. S. A. (Brooklyn Polytechnic Institute, N.Y.) (Ref. 29)

1st year:	Calculus, physics, chemistry, Western civilization, 1 elective subject, military training.
2nd year:	Calculus, differential equations, dynamics, physics, elementary structures, aircraft detail design, elementary aeronautical engineering, military training.
3rd year:	Dynamics of rigid bodies, linear oscillating systems, heat engines, electrical engineering and electronics, aerodynamics and its applications to aircraft, aircraft structures, humanities plus 1 elective subject.
4th year:	Aircraft propulsion, principles of automatic control, design of an aircraft, laboratory work, humanities, project, 1 elective subject of specialised aeronautical nature or 1 humanity.

*Note, students deal with some subjects in much more detail than others according to their final field of specialisation.

POSTGRADUATE EDUCATION

If the American undergraduate course may not go quite so deeply in some respects in the time available as some of the other courses the point that has already been made must be borne in mind that postgraduate courses of considerable depth are an important and virile feature of American education. The development of such courses since the War has been most marked and they are increasingly being adopted in many other countries following the lead set in the U. S. A. In Fig. 1 are shown plots of the total numbers of first degrees, masters and doctors granted in the U. S. A. in aeronautical, civil, chemical, electrical and mechanical engineering over the years from 1956 to 1962, whilst plots of the corresponding numbers for aeronautical engineering alone are shown in Fig. 2 (Refs. 9, 10, 30*d*). In both figures there is evident a marked decline in the number of

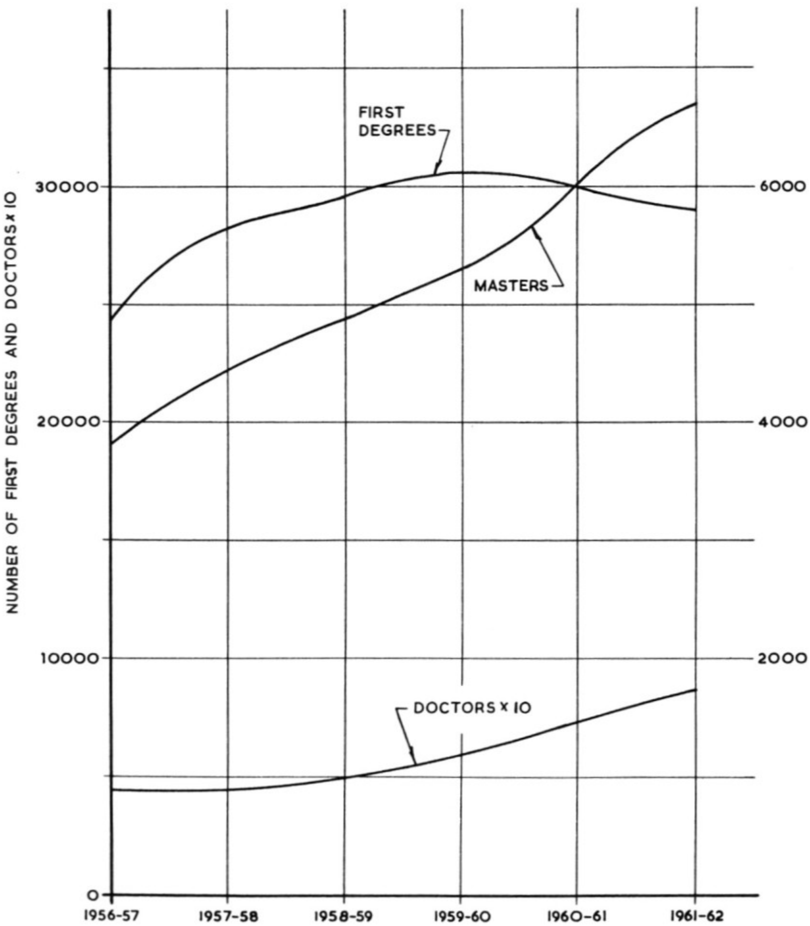

Figure 1. Numbers of first and higher degrees in engineering—aeronautical, civil, chemical electrical, mechanical—in the United States.

first degrees in recent years, whilst in constrast the numbers of ma
and doctors degrees have shown a significant increase. A number of sc
have in fact ceased to offer first degrees in aeronautical engineering
they now confine their work in this subject to graduate studies.

It is, as one might expect, in these higher degree courses that the in
of the space programme in the U. S. A. is most evident. It is here tha

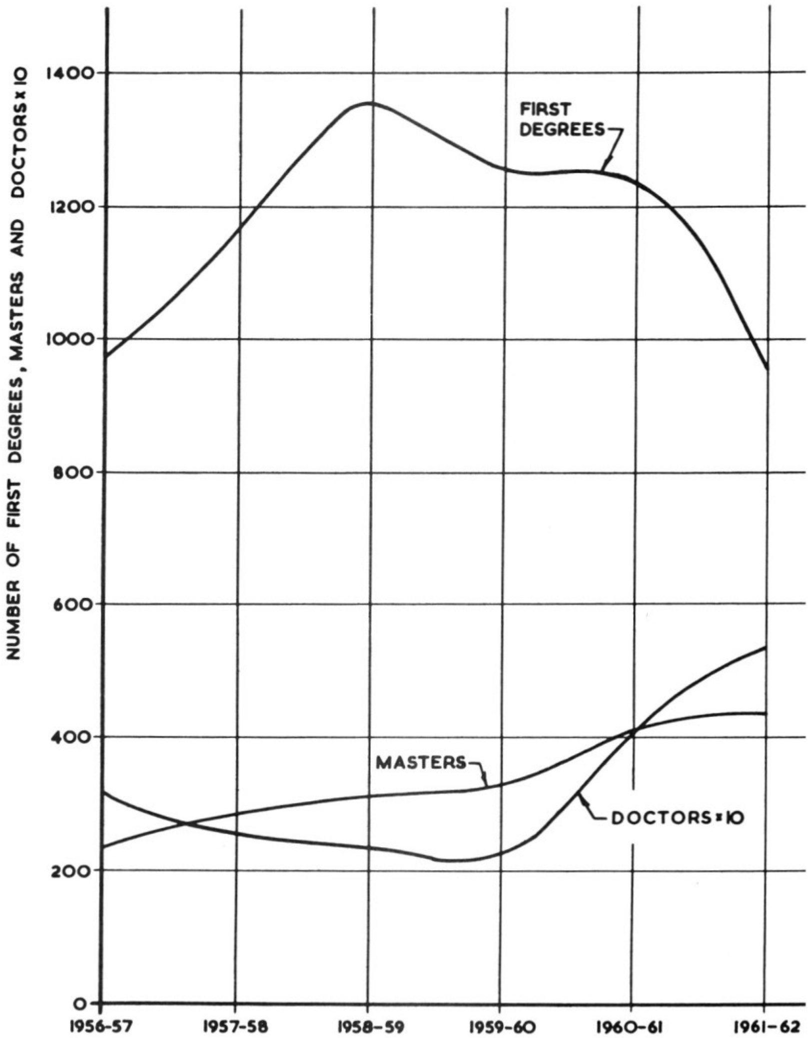

Figure 2. Numbers of first and higher degrees in aeronautical engineering in the United States.

finds courses on such subjects as magnetohydrodynamics, physics of the upper atmosphere, space mechanics, trajectories and orbits, electromagnetic propulsion, real gas effects, hypersonic flow, astrophysics, plasma physics, space guidance and control systems. Typically, a master's degree requires the attendance of the student at lectures occupying about 30 semester hours, the successful passing of examinations on those lectures, and the presentation and successful defence of a dissertation or thesis. The courses are usually strongly biassed in the direction of pure science, and have sometimes been the subject of criticism on this account. The work can be completed in one calendar year but it can readily take longer. A candidate for a doctor's degree must similarly attend a course of organised lectures, usually more extensive than the course required of a candidate for a master's degree, and he must complete a substantial piece of research and present and successfully defend a thesis on it. His work can be completed in three years but not infrequently it takes longer.

In the U. K. traditionally master and doctor degrees have been awarded on the basis of research, a master's degree requiring about two years of research work and a doctor's degree about three years, and whilst the students concerned may have been expected to attend some lecture courses it was usually on a voluntary basis and there were no examinations. However, in recent years there have been an increasing number of graduate lecture courses offered on the American pattern leading when combined with a project and successful completion of an examination to a master's degree. Such courses plus the project work usually require one calendar year but sometimes takes longer. Examples of such courses are being offered at Southampton University and some of the Colleges of Advanced Technology, and many of the courses offered at the College of Aeronautics can be regarded as in this category. The College of Aeronautics represents indeed a remarkable development in postwar graduate education in the U. K.; its equipment is without parallel in a teaching establishment and its contributions to research are of a very high standard. Latterly, it has diversified its activities into fields outside that of aeronautics proper, e.g., automobile engineering, production engineering, and materials.

The increasing pressure of new technological developments on undergraduate courses is well known; as new topics are introduced it is not always possible to discard old topics whose importance is still only too evident. The increasing demand on the student's time and capacity to absorb new ideas threatens to exceed what can reasonably be expected of him. The postgraduate courses of the American type is clearly the right answer to this problem. New developments of a specialised kind should surely be taught in the first instance in such graduate courses; at a later stage some of this material may find its way into undergraduate courses but only when room has been made available and the relevant ideas have clearly established their fundamental character. The importance of such graduate courses is now widely recognised in the U. K. and their number is rapidly increasing, but one has to admit that the response of students to register for them or industry to support them has not as yet been impressive. In contrast the response to short courses of a few weeks duration both by students and industry has been very strong and there is no doubt that such courses meet a major industrial need. I believe that this has also been the experience in many other countries.

In most European countries the sole postgraduate degree is that of doctor and it is awarded on the basis of research work extending over two or more years and a successfully defended thesis. However, in some countries (e.g., France and Belgium) there are in addition organised courses in special topics similar to the American type of master's course extending over a year or more and leading to a diploma. Thus at the E.N.S.M.A. (Poitiers) special diploma courses are available in advanced aerodynamics and thermodynamics, or the mechanics of space engines, applied electronics and servomechanisms [21]. There is also in Paris l'École Speciale des Travaux Aéronautiques where one-year diploma courses are offered in specialist aeronautical industrial and research topics. An interesting development is the establishment of courses leading to a Master's degree (the first I believe in France) at l'École Nationale Supérieure de l'Aéronautique [21]. These follow the usual pattern of sets of lectures on advanced topics on which examinations are held, and a thesis is required on a project covering about two months' work. In all about a year's work is required for this degree. Amongst the subjects offered are modern mathematical methods and numerical mathematics, automation as applied to aeronautics, aerothermodynamics, materials, electronics and radar, ballistic missiles and space vehicles and nuclear energy.

In Belgium at Rhode St. Génese the Von Kármán Institute for Fluid Dynamics (formerly the Training Centre for Experimental Aerodynamics) offers a postgraduate one-year diploma course in a wide range of subjects of experimental content. These subjects include viscous flows, unsteady aerodynamics, advanced electronics, the physics of gases including low density flows, hypersonics and turbomachinery. The course includes a research project and thesis. By continuing with his research work for at least one more year it is possible for a student to obtain a doctor's degree. This Institute is one of the many successful brain-children of that great man, Von Kármán, and he was Chairman of its Board of Direction from its foundation until his death last year. The Board has done me the signal honour of electing me his successor in that post. I believe that the Institute was his favourite brain-child; he particularly valued its unique international character for it was set up to provide teaching and research facilities in fluid dynamics for the various countries forming NATO. Both the staff and students are drawn widely from these countries and the contact between them is itself an educational experience of great importance.

In the U.S.S.R. the postgraduate degrees are those of candidates and doctors. The work of a candidate covers some three years and includes organised study and examinations as well as a thesis which he must successfully defend. The doctor's degree is higher than that of a candidate—it does not require further examinations, but is assessed on the basis of a thesis.

In most countries (e.g., France, Germany, Holland, U.S.S.R.) higher degrees can be obtained not only on the basis of work done in university departments and laboratories but they may also be awarded for research work done in industry or in national research institutes often under the supervision of a member of the staff of a university. In the U. S. A. this is not common and where it is permitted some period of residence and organised instruction is generally required and there are usually strong links between the place of research and the university concerned. In the U. K. only a few universities will award Master degrees for research that is not mainly done in residence and then only to their own graduates, and only the University of London will similarly award Ph.D. degrees. However, many universities in the U. K. award higher doctorates (e.g., D.Sc.) to graduates who over a number of years have made outstanding research contributions and have in consequence achieved positions of considerable eminence and for this purpose the research work can have been done anywhere.

RESEARCH AT EDUCATIONAL INSTITUTES

Research and teaching in institutes of higher education are not, as is sometimes suggested, antipathetic—they are essential and complementary parts of the total activity of the institute. Without an active research programme the teaching must eventually lack vitality and a sense of direction. Most universities and colleges of technology obtain the money that they use for research from various sources, some from funds of the institution itself earmarked for research, some from government agencies set up with the sole purpose of sponsoring research in general at universities, or acting for Ministries or Departments to sponsor research in certain specified fields, some from semipublic research institutes or associations, usually nonprofit making but supported by industry, and some from industrial organisations. In general, where funds are provided by outside bodies, whether public or private, the projects must be approved. The more private the source of the money the more closely defined is the field of work likely to be. In recent years there has been a very marked growth

TABLE 8. EXPENDITURE ON RESEARCH AND DEVELOPMENT IN U.S.A. (10^6 $)

Year	NASA	Defence
1953	78.6	2,832
1954	89.5	2,868
1955	78.8	2,979
1956	71.1	3,104
1957	76.0	4,027
1958	89.2	4,463
1959	145.5	5,048
1960	401.0	6,639
1961	744.3	7,719
1962	1,257.1	8,092
1963	2,400.0	8,515
1964	4,200.0	9,168

of such sponsored research in most countries, usually through the medium of government agencies; the growth in the U. S. A., particularly in the field of aeronautical and space engineering, has been exceptionally rapid and has had a most profound effect on the organisation and interests of American graduate schools. Table 8 shows some figures for research and development expenditure in the U. S. A. over a number of years by the NASA, which largely covers civil expenditure in aeronautics and space, and research and development expenditure that can be loosely classified under the heading of military expenditure or defence [28]. About half of the latter can be regarded as aeronautical and space work. The marked effect of the space race between the U. S. A. and the U.S.S.R. and the resulting programme in the U. S. A. which effectively began in 1947 is very evident. Since that time the expenditure of the NASA on research and development has increased more than fifty times whilst the corresponding defence expenditure has more than doubled. Only a relatively small part of these sums is directed towards sponsored research in universities and colleges of technology, but nevertheless in absolute terms this sum is large and is of vital importance to the research activities and potential of these institutes. Thus in 1957–58 the funds spent by universities on research totalled 71 million dollars of which about 50 million came from Federal government departments or agencies and 10 million from industrial sources, i.e., over 80 per cent of the research was sponsored. By 1961 this total figure had increased to 180 million [13] and it must certainly have increased substantially since then and almost all these increases must derive from sponsored research.* It should be noted that a large part of this sum goes

* These figures do not include the very considerable research contracts awarded to research institutes which are linked administratively to universities but which are wholly devoted to research (e.g., Cornell Aero Laboratory, JPL, etc.).

to a few of the engineering schools, so that for such schools a very substantial proportion of their total income must be derived from sponsored research.

In the U. K. there has similarly if on a much smaller scale been a growth in the availability of funds for research work, both through the agency of the D.S.I.R. and through various Government Ministries. Departments of aeronautical engineering have generally sought research contracts with the Ministry of Aviation and I understand that the funds devoted in recent years by that Ministry to contracts with universities have been in the region of £500,000 per annum and are now a little greater than that figure. The D.S.I.R. now awards studentships and research grants totalling about £8 $\times$ 10^6 per year and about 2 per cent of this sum goes to aeronautical engineering departments.

The rapid growth in the last decade or so of Government sponsored research, which in varying measure has occurred in most countries, has correspondingly important effects on the organisation of institutions of engineering education. It has stimulated the vigorous growth of old departments and the establishment of new ones. The degree of complexity of the tasks that are thought suitable for such institutions has increased by an order of magnitude or more and in some cases sponsored research has led to the formation of separate if associated institutions devoted solely to research.

It is however not entirely an unmixed blessing and characteristically it has attracted much critical analysis in the U. S. A. where its impact has been most marked. These criticisms may be summarised as follows. Even with the best will on the part of the government agencies concerned, there is always a strong tendency for the topics of research to be orientated along the lines currently regarded by the Government as important. As we all know, many of the most brilliant research discoveries have been made by lone individualists doggedly pursuing lines of thought that no one else has regarded as fruitful. Such individualists are unlikely to attract official support and in a world in which such support is dominant and generally regarded as essential they are more likely to be squeezed out of a position in which they can pursue their interests than when official support was in any case small. Certainly they will attract few students. Sponsored research calls for a high level of administration and team work, for periodic reports, the skilled services of accountants and even of public relations officers and advertising experts, and all this must make the task of the head of a department who is also a dedicated research worker more difficult and less palatable. University staff may find that their status and pay are related to the contracts they are able to attract and, contracts, equipment, staff and students may add up to little more than a rapidly growing

Another problem is how far should the courses include training in th process of design. Undoubtedly, an engineer must learn what is meant by a specification and the iterative and imaginative process involving th synthesis of knowledge, experience and intuition, in other words the proces that we call design, that is required to meet that specification. For thi process economic factors as well as questions of ease of manufacture maintenance and reliability are usually of paramount importance, and thei consideration must somewhere fit into the training of an engineer. It i perhaps fair to note that the needs for design teaching must differ somewha between the various branches of engineering. A branch for which the prob lems are such that almost exact mathematical models can be set up an readily solved obviously calls for less teaching of design than one for whicl the mathematical models capable of solution can at best be only crud approximations to the truth. It is in bridging the gap between the crud mathematical model and the final engineering reality that the art, skill, an judgement of the designer becomes most evident. From this point of vie there is perhaps less need for design teaching for some aspects of electrica engineering than for much of mechanical or aeronautical engineering With all these problems go inflexible boundary conditions imposed by th knowledge of science and mathematics of the students on entry to th course, their average level of ability and the duration of the course.

These problems have aroused heated controversy in most countries, par ticularly in the States. Indeed an interesting feature of engineering educa tion in the States is the intense self-criticism with which teachers continuall assess their policies and efforts. One influential school of thought at on time favoured a considerable injection of science and mathematics, botl modern and classical, into engineering courses largely at the expense o their technological and design content. This school won considerable sup port for a period, but the pendulum has swung back somewhat afte resulting deficiencies of many students in design led to serious complaint from employers.

I have long since formed the opinion that it is highly dangerous to giv educational theorists their head. We have such little scientific understand ing of the process of human learning that it is best for educational policie to evolve on the basis of empirical knowledge and experience rather than o the kind of unsupported dogma which so often go by the name of educa tional theory. I hesitate therefore to proffer my own thoughts on thes problems of course content, but they are pressing problems and we must al seek a solution. I base my ideas on the following points. Firstly, the stu dents emerging today from our universities will have some forty years o working life ahead of them and no one can predict the nature of the task that they will have to deal with during their working life or the details o the knowledge they will have to acquire to deal with those tasks. Secondly, in any average year only about ten per cent of the engineering students will have the aptitude and inclination to become research engineers or engineering scientists, the sort of people who seek posts in major national and industrial research institutes and departments or in academic life. The remaining ninety per cent will largely go into industry to tackle tasks which will not extend their scientific knowledge very much but which will certainly extend their technological knowledge and their design ability and they will work in an urgent atmosphere in which economic considerations will intrude at every stage. University teachers are themselves generally of the first kind, that is they are engineering scientists with strong research interests, and they have a marked tendency to create students in their own image. Consequently they tend to stress the scientific content of their courses, to mark out the paths to the frontiers of knowledge and to show the students the areas of research interest that lie beyond. A little of this is undoubtedly a good thing but there is a tendency, at least in some countries, for the teaching to cater too much for the needs of the academically gifted ten per cent and not enough for the needs of the remaining ninety per cent. My third point is best presented in the form of questions. How important really are the details of a course? How many of us recall more than a small fraction of what we learned as students and how often have we had occasion to use even that small fraction? And yet do we not agree that much of what we learned and have apparently forgotten nevertheless served a valuable purpose at the time in training our minds, in extending our capacity for ordered and purposeful thought and in demonstrating fundamental techniques of approach to problems, techniques which have in fact remained with us when the problems themselves have been forgotten? If one ponders on these questions one is forced to the conclusion that the precise details of the courses students follow are relatively unimportant. What is important is that the courses should mentally extend and exercise the student to the limit of his capacity and that they should exercise him in the processes of analysis and synthesis so that he can tackle problems of a kind he has not met before. He must also learn how and where to seek out information that he may need and his mind must remain flexible enough for him to be able to absorb such new information and ideas and subsequently use them.

It might be inferred from what I have just said that we should not attempt to educate aeronautical engineers as such, but that all engineers could well be subjected to the same course since the details are not very important and no one knows what the students will be concerned with in twenty or thirty years' time. This argument has indeed some force, but I feel that there are at least two strong points in favour of training aeronautical engineers as such. Firstly, as I remarked earlier, aeronautical engineering covers almost the whole of the engineering spectrum, and a course in aeronautical engineering must indeed be very general in its scope. Secondly, I think that one can best train a student through the medium of the subjects in which he is interested at the time, because those are the subjects which presumably fire his enthusiasm. Without this enthusiasm (or motivation as it is sometimes called) students tend to be dull and unresponsive and get little of value from their studies. This seems to me to be the main justification for offering differing courses to the different kinds of engineers; the alternative of a "cafeteria" system of optional subjects meets the same need if there are enough of such subjects.

What then should the guiding principles be on which an aeronautical engineering course can be framed, bearing in mind the vast panorama of aeronautical activity and the limitations imposed by the average length of a course? I can only offer you my own views for what they are worth. Certainly the basic scientific foundations of classical physics, mathematics and mechanics must remain; to this I would add the elements of the kinetic theory of gases, of atomic physics and perhaps of quantum mechanics to give the student a feel for the relations between the macroscopic and microscopic characteristics of the solids and fluids with which he will deal. The mathematics should include a basic course on computers as well as on numerical methods. The engineering sciences that are now taught, solid mechanics, aerodynamics, gas dynamics, structures, thermodynamics, materials, electronics, the elements of servomechanism theory are all subjects basic to the whole of aeronautical engineering whatever the directions in which it may develop. There remain the more technological subjects, propulsion, performance, stability and control, aeroelasticity, specialised structural and vibrational topics, and the host of old and new scientific subjects associated particularly with space, e.g., magnetohydrodynamics, plasma physics, physics of rarefied gases, power units suitable for propulsion and control of satellites, celestial mechanics, trajectories and their optimisation, etc., etc. Here one's choice is very limited because of time but I would suggest that the remainder of the undergraduate course should be devoted largely to the major technological subjects because they have great educational value in the widest sense. They most easily arouse the student's response and enthusiasm and it is through them that the student can most readily exercise his talent for design. I hesitate to suggest that design as such should be taught as a separate subject in the undergraduate courses, but much can be done throughout the course by frequent reference to problems of a kind that would arise in the course of the design of an aircraft or missile, by discussing the processes of design, by introducing design type of exercises in the laboratories, and by encouraging would-be designers to choose projects of a design nature. It is also very desirable that the undergraduate should at some stage be introduced to the subjects of industrial economics and management.

As for the many subjects that remain, most of which are of particular concern to Space activities, I feel that these are in general best provided in postgraduate courses. Those subjects are usually too mathematical in content for the average engineering student to make much of them, they are essentially subjects for the research engineer. In addition there are a host of other advanced topics and specialised topics of a technological kind which can only be presented in postgraduate courses, and amongst these could be included courses devoted to special design problems.

THE SPACE PROGRAMME AND ITS IMPACT ON EDUCATION

It may be argued that I have done less than justice to the needs of the space age that is now with us in my foregoing suggestions. To this my reply would be that in essentials the needs of engineers of space vehicles are not so different from those of aircraft and missile engineers that they call for a vastly different undergraduate curriculum. As that great man Von Kármán pointed out [12], "The problems which we had in airplane design we also have in missiles and spacecraft design. It would be a miracle if we could produce vehicles for space or vehicles for the upper atmosphere and not have the same problems—buckling, flutter, and so on—that we had in airplane design." Certainly, it is possible to introduce an occasional shift of emphasis in the direction of space problems and examples chosen from them in the undergraduate course, but if we accept the principle that it is the educational value of a course that is really important, little more than that should be necessary.

As far as the postgraduate courses are concerned it is a matter of judgement as to how far those courses should cater for the space engineer as distinct from the aircraft or missile engineer. Postgraduate courses are generally more closely tailored to current needs than are undergraduate courses and the answers here must depend on the importance individual countries attach to space research and development.

It would seem that space means all things to all men. To some the space age has opened up a new era of tremendous promise, an era of exploration and expansion for mankind at least as exciting and rewarding as that which the discovery of America opened up for the Old World. To others the effort and money devoted to space is a fantastic waste, a gigantic folly when viewed against the paramount needs of man on earth such as his struggle against disease and hunger. Lord Bowden [31] has described the attempt to put a man on the Moon as "the most highly organised system of outdoor relief ever devised by a civilized society in peace time."

TABLE 9. SPACE BUDGETS (£10^6) (Ref. 27)

		1962	1963	1964
France	National	3.6	7.8	11.5
	International	2.7½	4.3	5.0
	Total	6.3½	12.1	16.5
West Germany	National	0.9	3.8	4.5
	International	2.3	3.9	9.3
	Total	3.2	7.7	13.8

1963 (£10^6)

	National	International	Total	Defence
France	7.8	4.3	12.1	1,430
West Germany	3.8	3.9	7.7	1,650
U. K.	2.0	6.8	8.8	1,970
Italy	1.2½	1.8	3.0½	540
Belgium	0.2	0.6	0.8	132
Holland	0.1	0.5	0.6	228
Totals	15.1½	17.9	33.0½	5,950
U. S. A.	2,620	—	2,620	19,200

It is not difficult to take up a position somewhere between these extremes. From a scientific point of view there is no doubt a very strong case for space exploration just as there is for the increasingly costly investigation of the elementary particles of physics at the other end of the scale. The question remains as to how much money should we devote to space exploration and to this I doubt whether an answer can be provided based solely on rational grounds. Certainly, "payoffs" of considerable value are already apparent in the development of communications by satellites, weather observation satellites and the use of satellites for navigation. One American enthusiast has even gone so far as to suggest that American advertisers will be able to beam their advertisements over the whole world and thus provide a tremendous stimulus for American trade! I find it difficult to share his enthusiasm for this particular promised by-product of the space age.

However, an important argument in favour of a large expenditure on space is that every highly developed country needs a major technological activity operating near and at the limits of what is known to be possible.

TABLE 10. ECONOMIC DATA OF AERONAUTICAL INDUSTRIES (1962) (Ref. 28)

	National income ($\simeq$ 0.8 G.N.P.)	Number employed	Gross sales	Exports
France	£19.8 $\times 10^9$	84,000	£250 $\times 10^6$	£105 $\times 10^6$
U. K.	£22.4 $\times 10^9$	268,700	£589 $\times 10^6$	£115 $\times 10^6$
U. S. A.	£161 $\times 10^9$	1,204,000	£5,700 $\times 10^6$	£500 $\times 10^6$

They need such an activity not for any immediate economic return but because of the stimulus that it has on the rest of their industries and on the enthusiasm and morale of their young scientists and engineers. Further, such an activity can in due course be expected to throw up new industries. I am no economist and it is probably brash of me to say this but I believe that a modern industrial state also needs an activity supported by the Government on a large scale to act as a fly wheel for the economy of the country as a whole. One can indeed speculate as to how far the pyramids of Egypt and the cathedrals of mediaeval Europe served just such a purpose. In the States space activity largely took over these roles of technological pacemaker and economic fly wheel from the aircraft industry about 1957 as is evident from Table 8. Table 9 presents some figures showing the expenditure on space activities in a number of West European countries and in the U. S. A. [27]. The figures for the U.S.S.R. are not available but they are presumably of the same order as those for the U. S. A. It will be seen that the European countries are spending the equivalent of about ½ per cent of their total Defence budgets on space (in the case of France this figure is approaching 1 per cent) whilst the U. S. A. is spending the equivalent of about 15 per cent of its Defence budget. The total West European effort on space activities costs just over 1 per cent of the U. S. A. effort. The disparity here in the scales of effort is quite remarkable. It is possible that the future will see some scaling down of the American effort and some increase of the West European effort as the ELDO and ESRO programmes gather momentum, but I doubt whether there will be an order of magnitude change in the latter. Thus, the expenditure and effort devoted in the major West European countries to aircraft and missiles is and will remain vastly greater than that devoted to spacecraft (see Table 10). There would therefore seem to be little case for postgraduate courses in W. Europe to show the same predominance of space topics over aircraft and missile topics as is evident in many U. S. A. postgraduate courses. However, the space topics are novel and exciting and the demand for them as well as the desire to teach them is much greater than a cold appraisal of the relative national expenditure on space would indicate.

NUMBERS OF STUDENTS

A question that cannot be ignored even if like so many of the others raised it cannot be answered completely is how far does the current production of students of aeronautical engineering match up to the demand, and what changes if any should be made in the future output of such students?

Relevant to this question is the economic status of the aeronautical industry. In Table 10 are collected some data for the only countries for which such data are readily available, namely U. S. A., U. K., and France. The data refer to 1962 [28]. We see listed the total national income, number employed in the aeronautical industries, the gross sales of products of the industry in each case, and the value of the aeronautical exports. The value of the exports from the U. S. A. represent about 6½ per cent of the value of the total exports of all goods from the U. S. A. They fell after 1957 for two years and then recovered to roughly their present level in 1960. The U. K. figure of exports of aeronautical products is about 2½ per cent of the total. They have declined nearly 40 per cent since 1957 but they appear to have remained steady in 1963 and have recently risen. The French figures of exports from the aeronautical industry rose rapidly up to 1961 but have fallen a little (about 10 per cent since then).

One can infer from these figures that aeronautical activity in these countries plays a significant part in their economy but that a major expansion of aeronautical activity is not expected in the future. On the other hand a major contraction of activity is also not likely. The number of people employed in the U. S. A. industry has risen sharply in the last few years (it was 674,000 in 1960) and much of this increase is in the part of the industry concerned with spacecraft and missiles which now account for about half the labour force. The number of people employed in the U. K. industry has fluctuated but by relatively small amounts over the past five years. In France the number of people employed has risen steadily if slowly in recent years.

If we accept the general inference that in those countries major changes are not to be expected over, say, the next decade then the output of aeronautical engineers must match the wastage rate due to retirements, deaths, etc. In the U. S. A. about 16 per cent of the labour force in the aeronautical industry are graduate engineers and scientists. This figure when compared with the overall average for the U. S. A. industry of 2.8 per cent shows immediately the relatively great demand that aeronautical products make for high quality graduate manpower. The corresponding figure for engineers and scientists in the French industry is about 7 per cent. On the other hand the technicians in the U. S. industry are quoted as about 6 per cent of the total labour force whilst in the French industry they account for about 20 per cent. It is possible therefore that the differences in these figures reflect national differences in modes of distinguishing between engineers and technicians.

The industry in the future will certainly not call for a lower percentage of graduate engineers and scientists. Let us suppose therefore that in Western Europe this percentage will be about 8 and in U. S. A. it will be about 18. We will further suppose that the replacement rate is about 3 per cent. It follows that for every 100,000 people employed in Europe about 240 graduate engineers and scientists will need to be recruited whilst in U. S. A. the corresponding figure is 540. However, a sizeable proportion of this number, say about half, will be recruited from graduates of branches of engineering other than aeronautical and also from graduates in science or mathematics so that the above figures become 120 and 270 respectively. A glance at Table 6 shows that the output in the U. K. and U. S. A. is short of what is required, but to the output figures an extra 50 per cent must be added to allow for the extra output of students with postgraduate diplomas and degrees. Additional factors that have not been taken into account in this crude analysis are the needs of the air transport industry and the research establishments. These are by no means insignificant. In the U. S. A. the air transport industry in 1961 employed 167,000 people, that of France employed about 30,000 people and the figure for the U. K. is probably similar to that of France. We can conclude therefore that only a modest and limited expansion in the output of aeronautical engineers in the U. K. and France is likely to be required to meet the needs of their industries, but in U. S. A. there is a need for a more considerable expansion.

CONCLUDING REMARKS

Positive conclusions that have emerged from this somewhat untidy study are:

(a) To meet the expansion of output of graduates in engineering that is required in this fast-moving age of applied science we must in countries, other than the U.S.S.R., find ways and means to persuade women to make their careers in engineering.

(b) Undergraduate courses in aeronautical engineering need not be strongly modified as a result of the developments of space activity, and the educational rather than the vocational function of those courses should be given most stress.

(c) An essential feature of an undergraduate course in engineering should be a conscious effort to help the student develop his powers of synthesis and creativity as a designer.

(d) Post graduate courses of organised study on the American pattern are being and should be widely developed. It is by means of these courses that the special needs of industry as well as new developments such as space can most effectively be dealt with and disrupting pressures on the undergraduate courses can thereby be relieved.

(e) These courses should be supplemented by short courses.

(f) Government financial support for university research should be administered in such a way that the more harmful features of sponsored research can be avoided. To this end a substantial part of the sums allotted should be given unearmarked to institutions or if given for a particular project it should be awarded because of the quality of the work expected rather than because the project is of short term interest to a particular Government Department.

(g) There is no reason to suppose that the present or planned output of aeronautical engineers in Europe is likely to exceed the demand, but in the U. S. A. it is likely to fall well short of the demand.

In my discussion I have avoided drawing up an order of merit of the various systems of aeronautical engineering education in the different countries although I have pointed out the major differences. I have done this not out of a politic wish to avoid arousing national susceptibilities, but because I believe that an order of merit is meaningless. The educational system of each country is an organic growth rooted in the social and political traditions of that country and reflecting its needs, and it undoubtedly evolves so that it does its job on the whole efficiently for the country at the time. However, there may well be aspects of detail in the systems of other countries from which it could borrow to advantage.

Certainly, as far as my own country is concerned I would welcome an extension of the period of our university undergraduate courses to at least four years as in most other countries with a consequent reduction of the pressure on students at school to specialise too early. I hope this survey will help some of my listeners to see similarly their own systems in relation to others with sufficient objectivity to decide where improvements are both desirable and possible.

Finally, I would like to quote again something said by Von Kármán. He said with regard to the impact of space on education, "I believe that on the one side the continuity of the engineering profession and engineering can be preserved. On the other side, however, an honest and competent effort is necessary to adapt engineering education to the new age" [12]. I am sure that we would all agree with this and I hope that this talk will be of some small assistance to those of us who have to make this effort.

REFERENCES

1. Resources of Scientific Mechanical Personnel in the OECD Area (3rd International Survey, 1960).
2. Report on Education and Training of Professional Engineers (EUSEC and OEEC countries), vols. I, II, and III (1960).
3. Robbins, Lord (Chairman), Report of the Committee on Higher Education, H.M.S.O. (1963).
4. Bowles, F., *Access to Higher Education*, vol. I, UNESCO (1963).
5. Thurston, A. P., "Fifty Years Theoretical and Experimental Research in Aeronautics," Extract des Memoires sur la Mecanique des Fluides offerts à M.D. Riabouchinsky à l'Occasion de son Jubilé Scientifique, Publications Scientifiques et Techniques du Ministère de L'Air. See also *Flight* (Nov. 20, 1914), pp. 1134–1136.
6. Wood, J. F. D., Survey of First Degree Courses in Mechanical Engineering, *J. Eng. Educ.*, vol. 51, no. 3 (December 1960), pp. 218 ff.
7. Woodward-Nutt, A. E., Aeronautical Research and Development in the Commonwealth, *J. Roy. Aero. Soc.*, vol. 28, no. 638 (February 1964).
8. Rogers, F. M., "Higher Education in the United States" (Cambridge: Harvard U. P., 1960).
9. Allison, D., "Educating the Engineer," *Int. Sci. Technol.* (June 1963).
10. Various Articles on American Engineering Education, Undergraduate and Graduate, *J. Eng. Educ.*, vol. 51, no. 4 (June 1961).
11. Thornton, J. A., and A. B. Cambel, "Educational Programme in Astronautics," *Astronautics* (October 1961).
12. von Kármán, T., "Space-Age Education," *Astronautics* (October 1961).
13. Bisplinghoff, R. L., "Graduate Engineering Education and University Research," *J. Eng. Educ.*, vol. 53, no. 5 (January 1963).
14. Ingram, S. B., *Elect. Eng.*, (1961), p. 341.
15. Karol, A. G., *Soviet Education for Science and Technology* (New York: Wiley, 1957).
16. Tokaty, G. A., *Aeronautical Engineering and Research in the U.S.S.R.* (Univ. of Kansas, 1960).
17. Young, A. D., "British Universities and Aeronautical Research" (4th Lanchester Memorial Lecture), *J. Roy. Aero. Soc.* (March 1961).
18. Logan, D. W., Report by the Principal, Univ. of London (1963–64).
19. Report of the National Council for Technological Awards (1962–63).
20. Various, "Les Carrières de L'Aviation et de l'Industrie Aerospatiale," *Avenirs 142* (May 1963).
21. Brochures of l'École Nationale Supérieure de l'Aéronautique, and l'École Nationale Supérieure de Mecanique et l'Aérotechnique.
22. Brochure, "Studying at the Technological University of Delft, the Netherlands" (September 1959).

23. Various Articles on Engineering Education in France, *The Engineer* (June 1962).
24. Welbourn, D. B., D. B. Spalding, and G. L. Ashdown, "Engineering Education at the Technical Universities in West Germany," *Proc. Inst. Elect. Eng.*, vol. 106A (1959).
25. Hermann, R., "Aeronautical Research, Development and Engineering Education in West Europe, Particularly in W. Germany," Univ. of Minnesota Eng. Memo. No. 80 (December 1958).
26. Sesini, O., "Situazrone attuale delle Scuole di Ingegneria. XIII Convegno Nazionale Degli Ingegner Italiane," *Milano Politechnico* (June 1962).
27. Stephens, W. H., "European Co-operation in Space Vehicle Developments," *J. Roy. Aero. Soc.*, vol. 68, no. 641 (May 1964).
28. McAllister, J. (ed.), *Aerospace Facts and Figures 1963* (Los Angles: Aero. Publishers, Inc.)
29. *Bulletin of the Polytechnic Institute of Brooklyn* (March 1961).
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31. Bowden, Lord, "The Migrant Scientist," *The New Scientist* (March 1964).
32. Brebner, L. V., "Space Flight and Science," *Astronautics* (October 1961).