BRITAIN ENTERS THE SPACE AGE

A Report of the Conference sponsored by the Air League

More than 2,000 people, young men and women drawn from universities, public schools, technical colleges and the Services, attended the conference "Britain Enters the Space Age", which was organised by the Air League of the British Empire and held at the Royal Festival Hall, London, on Monday, 14th April.

The Duke of Edinburgh, who opened the conference, was introduced by the chairman, Marshal of the Royal Air Force Sir Dermot Boyle, Chief of the Air Staff, who said that he knew he was speaking for everyone at the conference when he said how delighted and privileged we are that you should do us the honour of opening this conference.

The Duke of Edinburgh began by saying that, generally speaking, there are two schools of thought on the subject of space travel. He continued: "There are the addicts of science fiction, and those who say that space travel is a lot of nonsense, and I suspect that the truth lies somewhere in between. Science fiction is splendid stuff, but not unnaturally tends to avoid the rather awkward practical detail. Interplanetary rockets are treated more like motor-cars. People get in and blast off, or whatever the expression is, to wherever they want to go, but the details of motors, control systems, navigation equipment and so on, are conveniently ignored. On the other hand, the nonsense school only see the problems and difficulties and conclude that they cannot possibly be overcome. Now the object of this meeting is to establish just what are the facts of space flight, and to hear expert opinion on if and how space travel might develop in the future. If this conference had been held as little as three years ago I think we might all have risked being called "cranks". As it is, several artificial satellites have been launched, and I think until this morning there were something like four buzzing around outside the earth's atmosphere. All of them were put there by man-made rockets, and this has given the nonsense school their first major set-back. But on the other hand, it does not mean that any of us here will be able to buy a return ticket, or even a one-way ticket to the moon next year. Now some people are bound to ask what is the point of trying to get to the moon or to any of the planets. And I think that the only reasonable answer is the one which the mountaineer gave when asked why he climbed mountains. He said quite simply: "Because they are there." To inquire, to find out, to have a look round the next corner has always been a characteristic of the human race, and this characteristic is most unlikely to wither just at this moment of history when the first steps into another unknown have just been taken. Some of you may be wondering why it is that this country has no immediate plans for space travel, when one hears that Russia and America are apparently hard at work. And you can be quite certain that it is not from a lack of willingness or scientific brain-power, but is simply that research and development for space travel is almighty expensive, and we could only possibly go in for this if we were prepared to make very considerable sacrifices in other directions. You may think we ought to, and you may think we ought not to take part in the development of space travel, that's a matter of opinion, but the tremendous cost is a matter of fact. Although I personally cannot believe that the British people, or the peoples of the Commonwealth will be content to sit by and watch others explore the Universe around us. One final word, this discussion is not concerned with military matters, but I don't have to remind you that there is no branch of science that cannot be used for military purposes. Space flight, like air flight, is no exception. I am here today as Patron of the Air League of the British Empire and I'd like to welcome you all here on its behalf. And now let's get on with the business."

The first lecturer was Professor W. H. McCrea, Professor of Mathematics at the University of London (Royal Holloway College). He began by saying that: "Man is becoming master of unlimited slave labour in the form of machines that will be powered by atomic energy and controlled by electronic brains. This makes it the Atomic Age. Man is also gathering knowledge of the universe about him, and particularly to Earth and Sun which support his life. He's doing this by means of exploration that he'd never expected to possess. This makes it the Space Age. Maybe man will be no longer tied to this planet, the only home he's ever known, but we must say something about that later."

He went on: "The rockets and space vehicles we're considering employ old familiar physical principles. In fact, they're the best ever examples of the sort of mechanics we tried to learn at school. That they're a near miracle in the way of combined operations and technology, then the way in which they make a dream come true is tremendously exciting in itself. But it's important obviously because of the great crowd of discoveries to which it will surely lead. While we're getting things in perspective, I may say a word about outer space. If we think of the earth as a cricket ball, then the orbits of the first satellites at the centre wouldn't be very much above the seam and the farthest that any satellite has reached would be less than an inch from the ball. On this scale the distance to the nearest planet would be about from here to the other side of the Thames, the distance to the furthest planet in our solar system would be from about here to Windsor and the nearest fixed star would be about 100,000 miles away.

"You all know the three basic principles of space travel. They are first, away from all other matter, you'll keep the same velocity for ever if you do nothing about it. That's fairly well illustrated by a motor car on an icy, level road. If you're matched nearer to one astronomical body than to any other, the gravitation of that body will for the time being control your motion unless you do something about it. You can't shield yourself from gravity and you can't alter extent on your motion by making your vehicle lighter or heavier. Some illustration of that is given by the behaviour of a motor car on an icy slope. Finally, you cannot change your motion in speed or direction without pushing upon something that's not attached to yourself. That's the principle of all locomotion. In ordinary life we are liberally supplied with push-upons. We walk or drive by pushing on the ground, but in empty space there's nothing really there to push upon. You must take something with you and put it there. You let go of it and that gives you something to push on. That is to say, you push material away from you and you've got to keep on pushing material away from you until you've given yourself the velocity you want. That's the rocket principle.

"In considering the implications of the rocket principle, since you've got to carry all your push-upon with you, you must use it as economically as possible, so you've got to push as hard as you can on every bit you use. That means sending it away from you with the greatest speed you can give it. In an actual rocket the push-upon is whatever comes out in the jet. We say that we want a rocket to produce the greatest jet velocity possible. Now to get something moving, in this case the jet of gas, you have to give it energy. And energy is something you can't create. If you want energy to use in empty space you've got to take it with you. That's something else you've got to carry with you. The best way we have at present of carrying energy around is in the form of chemical energy.

"In a rocket, therefore, the burning of a propellent mixture converts chemical energy into heat energy which in turn is converted into the energy of the motion of the jet. A high jet velocity requires a high burning temperature. In the future it may be possible to use other forms of energy instead of chemical, but that wouldn't be a change of principle. Any departure from those principles is fiction without science. The principles are just as inescapable in a game of cricket. When you bowl you give the ball a velocity it didn't have before. That's where your effort comes in, and it takes only a second or two. Then you release the ball and gravity takes charge. You can do nothing more about it. The cricket ball in flight is a genuine satellite and the ground just happens to get in the way before it gets very far in its orbit. Conversely a satellite is just a cricket ball that's been bowled faster than even Trueman can bowl. All the rocketry effort goes into lifting the satellite's orbit. That's the runner. And then giving it the right speed in the right direction. That's the delivery. Even for an artificial satellite it takes only a few minutes. Thereafter, once again gravity takes charge. That's what's already been achieved has been to throw a satellite into a natural orbit.

"To come back to the rocketry. The main exercise is to give a particular body—say, this cricket ball—a particular speed. In principle we attach a stove-pipe, say, and pack in the mixture and strike a match and away it goes. As we have seen, we shall choose a mixture with a high burning temperature. Then by using enough of it we could get any rocket speed we like were it not for the inconvenient fact that the stove-pipe itself has weight. That can't be reduced below 10 or 20 per cent of the whole weight, that works out to mean that there's a limit to the speed a rocket can attain using any specified fuel. That's much less than the speed you want in practice so the obvious thing is to make the stove-pipe in sections that can be thrown away as they become empty, or what comes to the same thing, by using several rockets that operate in turn and drop off when burnt out.

"You have, therefore, to start by sending skyward much more material than the space vehicle in which you're really interested. It's been about a thousand times as much for the American satellites and perhaps two hundred times for the Sputnik. But even if the Russians got it down to that, they must have started by sending out something weighing not so very much less than the good ship *Mayflower*. In order to launch a satellite or other space vehicle, what's needed is therefore the vehicle itself, which is really a flying observatory plus broadcasting station; the stove-pipe, which has now developed into several rocket cases, fuel tanks, rocket motor or more, and an electronic brain and, of course, the fuel. We saw a moment ago one lot of inescapable principles that you know must be obeyed before ever you start designing your rocket. But now we see that there's a second set of inescapables depending on the simple fact that you've got to make things out of materials that actually exist. Just to take one example, suppose someone has a brilliant idea for producing a temperature of, say, 10,000 degrees inside a rocket. What would be the use when most metals melt below about 2,000 degrees and the most refractory substances now melt at 4,000 degrees approximately. Amongst other things that shows one of the obstacles to the use of nuclear energy in rockets.

"Also we now see more fully why the launching of a satellite is such a wonderful technological achievement. The miniature observatory would have to be about as big as a normal-sized table if you are to make it out to the components in an ordinary laboratory. The Americans are using solar batteries for the telemetering system, and that increases the useful life a hundredfold or a thousandfold and at the same time enormously reduces the weight needed. In the rocket itself the electronic brain, as we can call it for want of a better term, reckons the height and controls the speed of the final stage to within a per cent or so and controls the direction to within a degree or less. It may have rather a one-track mind but all the brute force that hurls the vehicle into space would be literally aimless without the electronic brain.

"From what I have tried to say I hope it's clear that upon the one hand we've witnessed only the bare beginning of anything that can be called space travel; on the other hand, what's been done has been the outcome of gigantic effort and expenditure. The United States has already indicated some awe-inspiring but perfectly soberly stated programmes for future developments. We must suppose that Russia has similar plans. What's already been done has come more quickly than most people expected, and that is cause for optimism about the future. However, I must point out that the next steps are very, very long ones compared with those already taken. Something like the present satellites may be expected to go as far as the moon in perhaps the next two or three years, but we'll all be a lot older before anyone arranges another conference like this to view developments beyond that.

"The first object of space travel, oddly enough, is not to get closer views of other astronomical bodies but to get the first really good look at the earth itself. There are things about the shape of the earth, the mass distribution, its magnetic field, the amount of heat it's losing into space and even about its weather distribution, that can be found out best or only by sending vehicles into the surrounding space. We shall learn what we want from the behaviour of the vehicle itself or from readings of instruments that are carried in it and telemetered back. Were we imprisoned from birth in a room with windows made of glass of one particular colour, we should have a restricted knowledge of the universe and the world outside. Well, as regards the rest of the universe, we're all in much that fix. Our atmosphere lets through the visible light and some radio waves but it stops other radio frequencies and some infra-red radiation and, fortunately for our health, it stops X-rays and cosmic rays. But the sun does emit these radiations, and in order to understand the sun and its effects on the earth we need to know about them. The most direct way of learning is to let a satellite go and catch these radiations before they're stopped. And that's what's been done.

"What if our instruments are more feasible for useful passengers in space vehicles than ourselves? The Atomic Age has got going quite well although no man has ever seen an atom or ever will; the Space Age may go a long way before any human gets far into space and is able to see things themselves. And what if the distances reached by satellites so far are tiny compared with astronomical distances, that's not a measure of the vast new knowledge they'll bring us. And finally, what if the knowledge is about our own earth? Provided we keep the outfit well intact, it's the place where we've got to live and where our successors have got to live, and it must mean a lot to us and to them to know more about it. Well, assuredly as regards our own earth, and we hope as regards much else in the universe, the space age is to be an age of more spacious knowledge."

The next speaker was Mr. J. E. Pateman, Chief Engineer of the Aviation Division of Elliott Brothers (London), Ltd., and he spoke of the complexities of navigating satellites in outer space. He said that the problem of navigating in space is one of those subjects that tend to get overlooked whenever space travel is discussed.

"People", he said, "are interested in rocket motors because they can see lots of flame and smoke coming out of them, and they also tend to forget that there are severe problems associated with finding where we are and where we're going to. Can I make one thing quite clear first of all, and that is you can't do it by looking over the side. It's much too difficult. The only space ships, if we can call them that, going outside the atmosphere at the moment are the intercontinental missiles which we're not allowed to know very much about, and the satellites that the Russians and Americans have sent up. These devices are only controllable until you cut off the rocket motor, that is once you have cut off the rocket, then the thing is controlled entirely by gravitational forces and its own inertial forces, and these are quite fundamental matters. But the whole thing is rather similar to that of a gun in many respects, in which you've made the barrel extremely long corresponding to where the rocket motor cuts off, and while you've got it in the barrel you can control the space vehicle. Once you've got it outside the barrel, you can't.

"The paths that the projectiles follow are all orbits in one sense or another. In the case of the ballistic missile, the orbit hits the earth again as does the cricket ball, and we're not really interested in it. But the orbit of a true satellite is organised so that it doesn't intersect the surface again, and it's usually arranged to be slightly elliptic, the outer centre mass being at one focus of the ellipse. Because the present satellites are so close to the earth's surface the ellipticity has got to be kept quite small, otherwise the satellite re-enters the earth's atmosphere and comes to a grinding halt. But if we're going to develop long-range satellites, say to circumnavigate the moon, we must have an orbit which is wholly elliptical, and with a greater penetration into space beyond the moon it's got to be even more elliptical. And this raises certain difficulties. This distance that a space ship will travel from the earth in one of these orbits becomes extremely sensitive to the velocity which it acquires at the instant of rocket motor cut-off. The physical explanation for this is not too difficult to follow. If you drop a body from a very great distance outside the earth, it will acquire a finite velocity before it strikes the earth's atmosphere, and even if you go an infinite distance away it still gets to a finite velocity of about 25,000 miles per hour. This velocity is known as the escape velocity, because if we play things the other way round and shoot the object away from the earth at that velocity, it will travel an infinite distance away before coming to rest.

"But we don't want to travel this infinite distance, we only want to go to, say, the moon, about a quarter of a million miles away; and in order to do so we shall have to acquire a speed which is very close indeed to the escape velocity—somewhere between 23,000 and 24,000 miles per hour. So if we make an error of about 1,000 miles per hour in our speed, which is 1 in 25, say about 4 per cent, it makes all the difference between travelling a quarter of a million miles and then returning to earth, or going on for ever. If we wish to travel to the moon with an accuracy of navigation of, say, 2,000 miles, then we must control our velocity at the instant we cut off the rocket motors to within about 2 miles per hour, which is quite close order of accuracy, and things can get worse later on. In these sums I have made some simplifications of forgetting about gravitational fields other than that of the earth and various other simplifications.

"We've got, therefore, two problems in front of us. We must calculate the desired path of the satellite and allow for all these disturbing forces, and secondly we must provide instruments and control means necessary to establish the satellite in the calculated orbit. The calculations themselves are not particularly simple, but the instrumentation for a journey around the moon itself appears to be pretty formidable. One method which we might employ is reputed to have been employed by the Russians in sending their Sputniks into orbit is to use a combination of radar and dopler effect. The dopler effect is well known as that which causes the change in pitch of, say, a railway engine whistle as it passes close by the observer. Now similar effects can also be observed when a source of radio waves is moving relative to the observer. The change in frequency obeys nice, precise mathematical laws, and if we measure the change we can calculate quite accurately the component of velocity along the line joining the satellite to the observer or the source to the observer.

"In order to make matters a little bit easier, we can transmit a known frequency from the ground and then receive its echo from the satellite. So the two different frequencies may be compared together and we then have them both in one spot on the ground, which makes life all the easier. It's unlikely that the satellite will be moving directly away from the receiver. We must assume that it's moving across it to some extent, and in order to compute its total velocity in three dimensions we have to instal three or more dopler stations some distance apart so as to obtain velocities in several different directions, which we can then add together by vector addition and get the result of these velocities.

"But the method as a whole has got another significant virtue, that the physical measurements that we have to make are a frequency, and it so happens that we can measure frequency to a rather high order of accuracy without very much trouble. And this is an extremely convenient factor in all this. This doesn't necessarily mean, though, that we can achieve the same high order of accuracy for the total velocity, because at very long ranges the vectors are adding together with rather a small angle between them. So that at long ranges we have some little difficulty in maintaining the high accuracy, and we can only improve on this and get a really good accuracy if we can control the spacing of the dopler stations to a very high order, and we are now talking in terms of order of accuracy of spacing on, say, the fraction of an inch for every mile of separation, which is quite high.

"There is a completely different approach to the same problem of measuring your speed, which has been described by writers in the United States. This is the technique known as inertial navigation, and in principle it's extremely simple. In fact, it's one of those things where it's extremely true to say that it's so simple it isn't really possible. I assure you this is the case. It presents very difficult problems indeed to the engineers and designers. The principle of it is extremely simple. All we do is that we take three accelerometers, which are devices which make acceleration, and we mount them at right angles to one another, pointing in accurately known fixed directions in space. In order to do this we put them in a gimbal system which is stabilised either by means of rather expensive gyroscopes, or by hanging telescopes on to the gimbal system and making them look at the stars, and follow them automatically, either method which will stabilise your accelerometers in space. Then when the rocket motors fire and the whole gimbal system accelerates, the accelerometers continuously measure this, and if we carry out the mathematical operation of integration on these outputs this will give us a continuous measure of velocity. We don't require any ground equipment at all in principle in this method, although I suspect that a good deal will be required to service it, and all the working bits are carried in the space ship. But because of the complexity of equipment it's likely to be fairly heavy, and there are difficulties, of course, in the use of telescopes in a space ship or satellite because of difficulty of providing satisfactory windows—all sorts of things like that. But these are more or less incidental difficulties, but there are other difficulties with this method which are even worse. In order to achieve our velocity to the accuracy which we require, which you remember is about 2 miles per hour, the accelerometer must be accurate to better than 1/3000th of a gravitational unit. Now for many years geophysicists have been measuring accelerations due to gravity to a much higher order of accuracy than this and they wouldn't regard this, I think, as a particularly severe problem. Unfortunately, though, the equipment which they use calls for the use of nice temperature-controlled radiums entirely isolated from vibration and suchlike things, and these conditions will be unlikely to obtain in a space ship and it's a major problem to engineer these accelerometers to measure sufficiently accurately in the rather unsatisfactory environment which they have to operate in. To take a typical example, we may well have vibrational accelerations which are 30,000 times larger than the steady accelerations we wish to measure.

"Another difficulty arises in a rather more obscure manner. Let us suppose we have organised our accelerometers so that one is vertical and the other two are horizontal, one pointing north-south and the other pointing east-west. The vertical accelerometer will also be sensitive to the gravitational pull of the earth, and since this acceleration does not produce a corresponding motion of the satellite at least while we have rocket power on, then we must arrange to cancel this, and we do this electrically. The other two are horizontal and therefore at right angles to the earth's gravitational field, and these accelerometers therefore don't detect this field at all. This is quite satisfactory.

"But now let's suppose that owing to an error of some sort these accelerometers are not quite horizontal. They are therefore no longer at right angles to the earth's field and we start to pick up a component of gravity on the accelerometer. If our accelerometer has tilted by only one degree, then we pick up a component of gravity corresponding to 1/60th of a gravitational unit approximately. And this is fifty times as big as we are prepared to allow so that we must therefore maintain the accelerometer's level to within about 1/50th of a degree, and even if we do this then this one error alone will buy up alone the whole of our permissible error, and we can't really allow this to happen.

"Prior to launching, it isn't too difficult to get the accelerometer's level because we can use the accelerometers themselves to tell us that they're level by giving zero output, and one can do this automatically without any great difficulty. Then after launching we must rely entirely on performance of the telescopes and their automatic tracking mechanism or the gyroscopes or what have we. Furthermore, as the ship travels around the earth gaining speed, the direction of gravity alters proportionately to the distance that we travelled round the earth, and this must be accurately allowed for, again to better than 1/50th of a degree, and this is quite difficult.

"So much then for the picture as it is at present. We appear to have two navigational methods of sufficient accuracy to reach the moon, or near enough anyhow. But what about if we want to go any farther? The next step looks extremely difficult indeed. In order to reach Mars, which is approximately 50 million miles away, with the present types of satellites, assuming we could put a bit more power into them, we require an absolutely impossibly accurate velocity at the instant that we cut off our rocket motors. We are now talking of accuracies of something in the order of 3 inches per hour as a speed when we happen to be travelling at roughly 25,000 miles an hour, and this is pretty close. This is again in order to get within 2,000 miles of Mars and such an accuracy is quite clearly out of the question. We just haven't got a hope at the moment. There are various things that one could do to improve the navigational devices. We might, for example, put a dopler station on the moon in addition to the ones on earth. This would give us a nice long base line of about a quarter of a million miles, and we should be able to extend the range of our measurements quite considerably. We should, of course, have to know the exact length of the base line rather accurately and here we might get away with the conventional radar systems which could measure the range of the base line to an accuracy of perhaps a tenth of a mile or even better if we're lucky. We would still be in a very severe difficulty, though, because the analysis of all the measurements would present quite a problem. We have the moon rotating around the earth with a velocity of about 3,500 miles an hour, the earth itself with a surface velocity at the equator of about 1,000 miles per hour due to its own rotation, and the whole lot is rotating about the sun at another 60,000 miles an hour, and these velocities are all going to come into our measurements. Fortunately, we can determine these velocities to a fair sort of accuracy, but it's quite clear we're going to be involved in a mass of digital computing in order to sort out all the answers, and it's likely to be impossible to compute the answers as we go along, that is as the rocket is being fired. And what we shall have to do is to organise our conditions very closely indeed, have precomputed set of calculations and control the time of take-off and things like that to a matter of thousandths of a second, and this is clearly going to land us in severe trouble from the point of view of organising things. It's very difficult indeed to get things to happen to the nearest thousandth of a second when you perhaps went a few weeks getting them organised.

"There's also another little difficulty in that we must have at least three dopler stations, and we therefore want another one about a quarter of a million miles from both the earth and the moon.

"The only remaining hope is that we shall be able to carry relatively large amounts of fire with us on the journey so that we can correct our course at any time. This still leaves the question of how do we know when and how much to change course, and as we have already seen, earth and moon via navigational aids are not very likely to help us greatly. We must, therefore, rely on being able to fix our position with respect to our destination by means of radar or optics or something like that. And this would appear feasible provided we've got adequate power at our disposal and can carry sufficiently powerful radar. It is already known that such a radar is at least theoretically possible and I understand that the Jodrell Bank radio telescope is going to be used as a radar set in order to try and obtain echoes from Mars and Venus. So if we can do it from the earth then we should be able to do it from our space ship.

"Even when we have determined where we are, we have still got a tremendous amount of calculation necessary to determine how best to change our course and reach the target, and it seems quite certain that we shall have to relay all the information back to earth for analysis and then send out the necessary instructions by radio so that we can control our power supplies. Once we've got the necessary instructions it shouldn't be too difficult to use the inertia navigator to establish that we've made the correct changes to course and to velocity.

"Summing up the more distant future then, it seems unlikely that we can ever navigate to even near planets unless we can carry enough power on board to change our course when relatively near to our destination."

Mr. Pateman was followed by Mr. D. G. King-Hele, of the Royal Aircraft Establishment, Farnborough. Mr. King-Hele devoted his lecture to work the R.A.E. was doing on the Russian and American satellites.

He said that the first Sputnik was launched on 4th October last year and it was split into three parts on entering its orbit. He went on: "The satellite proper was a sphere 23 inches in diameter weighing 180 lb. and carrying quite a powerful radio transmitter. This sphere was very difficult to see and as far as I know was not observed at all from this country, though there were a number of sightings from countries that enjoy better weather than we do. No one appears to have known where the satellite was in the later phases of its career, and there is some disagreement about the date when it came down, but probably between the 4th and 8th of January this year. The orbit of Sputnik I was at an angle of about 65 degrees to the equator, it took 96 minutes to go round the earth to begin with and its height varied between 140 and 560 miles.

"The second satellite launching was on the 3rd November last year when the Sputnik II, with the dog Laika aboard, was put into its orbit. This time the last stage of propulsion and the compartment housing the instruments did not separate and went round together. The total weight of the assembly was 1,120 lb. and it seemed to be much the same size as the three pieces of Sputnik I put together. Sputnik II transmitted radio signals for one week only, but it was easily visible. Sometimes it was difficult to see because when it is between us and the sun it has faded for quite long periods, about a minute at a time though we think this was due to the fact that it was rotating and the sun was being reflected off it in different ways and this did make it difficult on those occasions as between us and the sun.

"The Sputnik II went round the earth in 140 minutes to start with and its height varied between 140 and 1,040 miles. The inclination to the equator, like Sputnik I, was about 65 degrees. The reports from Barbados suggest that Sputnik II made its final descent through the atmosphere at about 2 o'clock* this morning after 2,366 revolutions.

"The first American satellite, Explorer I, was launched on the 1st February this year. It's very much smaller, a cylinder 80 inches long and 6 inches in diameter weighing 31 lb. Explorer doesn't pass over this country. Its angle to the equator is only 34 degrees, but even in the countries it does pass over it's very difficult to see because it's so small and only the professional astronomers can expect to observe it. It has a minimum height of about 220 miles and a maximum height of about 1,600 miles to start with, and it went round the earth in 115 minutes and is expected to remain up, I think, about two years.

"The second American satellite, Vanguard I, began life on the 17th March this year, and it's in two parts, the satellite proper, the sphere 6½ inches in diameter weighing 3¼ lb. and probably you can hardly see it up there. The rocket from the last stage of propulsion is also going round with it. It is about 4 ft. long and over 1 ft. in diameter. The angle to the equator is almost the same as Explorer I, about 34 degrees, and the height varied between the minimum of 400 miles and a maximum of 2,400, and the satellite is expected to remain up for several years and is much higher than the others.

"The third American satellite, called Explorer III, launched on the 26th of March, was similar to Explorer I, but its minimum height was much lower and I believe it's only expected to stay up for a few months.

"I shall next go on to describe some of the work which has been done on the Sputniks at the Royal Aircraft Establishment, and we haven't taken much notice of the American satellites because they don't come near this country. First, the methods of observation. Visual observations are the most satisfactory in many ways and there are two main types of visual observation which are made. These might be called the accurate and the not-so-accurate. The accurate observations are made by kine-theodolytes.

"The kine-theodolyte takes a series of snapshot photographs of the Sputnik, four or five every second and the elevation and bearing of the instrument and the time are accurately recorded and it is possible to obtain an accuracy of about a hundredth degree in direction and a hundredth of a second in time with this instrument.

"The not so accurate observations are those which are made by people standing in their back gardens. We get a lot of observations of this type from people all over the country and what they do is to wait until the Sputnik goes between two stars they know and then start up a stop-watch, and this type of observation might come in as part 3/10th of the way between Castor and Pollox, at 20 hours 23 minutes 14 seconds. These visual methods of observation have some disadvantages. First, of course, the satellite can't be seen in daylight and second, of course in England it's very rarely visible at all because of the weather. And so we want to have other methods of observation. Well, if the satellite is emitting radio signals there are two useful techniques. The first is the interbarometer. There are two aerials set up and the difference in the distance travelled by the waves reaching one and the waves reaching the other is measured and it determines the direction of the satellite. If the two aerials are four wavelengths apart and the difference in the distance between the paths is two wavelengths, the satellite is at 60 degrees elevation and if it's one wavelength difference it's 75 degrees elevation. A radio interbarometer of this type is to be set up at Lasham Aerodrome in Hampshire and it was used on the first Sputnik and we hope to use it again to determine the initial orbit of the next Sputnik. The great advantage of this radio method as opposed to visual method is that you can obtain two heights of a satellite on one day, one when it's going north and one when it's going south and this enables the orbit to be determined very quickly.

"A second technique which can be used when the satellite is sending out radio signals is the dopler method already mentioned by Mr. Pateman.

"Both these methods are no good if the satellite is not broadcasting radio waves and in that case there's one last resort, radar. Radar is an excellent method but difficult to make it work. The trouble is that the radar beam is very narrow and the prediction of the satellite track and its height have to be very accurate before the radar can hit it off. This method has been used in the last few days by the Jodrell Bank radio telescope but they haven't been able to locate it on very many occasions, because of this trouble.

"Now how are these observations used? The kine-theodolyte records or the radio interbarometer records will all provide you with a large number of positions of the satellite in the sky, and from this the orbit can be determined essentially by a method of trial and error. You see what the orbit is, see how much it differs from the observe point and then make a better guess at the orbit and so on, and this process can be done quite quickly on the digital computer which it's been programmed for. Or not-so-accurate observations are used to provide the prediction service and the procedure here is rather simpler. It just plots the position of the satellite on a map and places over it a

** Sputnik II did in fact disintegrate at about the time mentioned by Mr. King-Hele.*

track diagram of the satellite so that it goes as near it as possible through all the points which have been plotted from the observations. And this enables us to find the time to within one or two seconds and the position of the track to within about half a degree of longitude and this provides a starting point for further predictions.

"The last general topic of discussion is the scientific results being obtained, and there are three main subjects. First the ionosphere, the electrically charged layers in the upper atmosphere and their behaviour isn't very clearly understood and the satellites have provided a new method of research by allowing radio waves to measure which will pass right through the ionosphere.

"The second subject on which we have obtained some useful results has been the shape of the earth and the density of matter inside it. You may think we know all about that already, but we don't because the accepted value for the earth's diameter may be about a quarter of a mile in error and we are told that the earth is flattened at the poles like an orange but no one can tell you whether it's flattened more at the south pole or the north or whether it's exactly the same at both. And the satellites should be able to tell us more about this because the effect of the flattening at the Pole is to rotate the plane of the orbit about the axis of the earth, and quite slowly and for a typical Sputnik this rate of rotation is about three degrees a day. And this three degrees per day can be measured very accurately with the accurate visual observation and we hope that these measurements will give us a better idea of the real shape of the earth and of the distribution of matter inside it.

"The last subject to discuss is the effect of the atmosphere on the satellite's orbit. Every time the satellite comes nearest to the earth it's slowed down a little by the drag of the atmosphere. And this slight slowing down means that it doesn't go up quite so far on the other side of the earth and so the orbit gradually becomes more circular. As the satellite comes nearer to the earth it has to go round faster to balance the earth's gravity which is stronger nearer the earth and so the time taken to go round decreases.

"Sputnik II has behaved rather irregularly from the very beginning and the air drag on it has fluctuated quite a lot. It's quite possible that its behaviour was caused by changes in the density of the atmosphere because even at sea-level you get changes from day to day of 2 or 3 per cent, and at high altitudes where there is no great mass of air pressing down you expect these changes to be very much greater, and an analysis of these oscillations may well tell us a lot more about the changes in density that have been caused by the satellite—by the change in density.

"Well, some of the oscillations may have been caused by the satellite changing its attitude. We believe that it started off going nose first and that the last few months it's been rotating or tumbling head over heels. And this is, of course, another difficulty in trying to predict a thing which is behaving in such an irregular manner. And I'm afraid it's kept up this fickle behaviour right to the end, and it seems to have done another of these oscillations on Saturday, which means that our prediction that it will come down early on Sunday turned out to be wrong and it stayed up for about half a day longer than we expected."

The last speaker was Mr. A. C. Clarke, the well-known writer and lecturer on inter-planetary and space subjects. Mr. Clarke dealt with the colonisation of the planets by man and began by saying that "The first impact of space travel upon human life is going to be very direct and rather unexpected. It's going to affect I'd say every home on earth. It concerns T.V. As you know," he said, "the present range of a television transmitter is very limited because the short waves used travel in more or less straight lines and you can't therefore receive a transmitter much beyond the horizon. You need, therefore, a good many stations even in a country as small as this. But if you could take your transmitter and put it in a satellite a few hundred or a few thousand miles up, then obviously its service area would be enormously increased and, in fact, if you had just three satellites equally spaced round the earth they could provide a T.V. or radio service over the whole planet without much more power than is needed today for a single large metropolitan area. And this would mean the end of all communication barriers. It would be theoretically possible, in fact, for such a satellite communication network to provide channel space for a million simultaneous T.V. transmissions.

"When such a network is established it will be possible for us here in this country to tune in to Russian or American programmes just as easily as we can tune in to our local B.B.C. ones, with complete freedom from interference. And of course the Russians would just as easily be able to tune in to ours. Any form of censorship would be impossible. You can't stop people receiving from a station which is sitting in the sky over their heads. Such a global T.V. network could be built in perhaps fifteen years. If any one nation were to establish it, providing entertainment, news, business and private communications facilities and other services not dreamed of today, that nation would dominate the earth culturally, politically, economically. And its language would become the main language of mankind.

"There are many other uses of satellites I'd like to mention briefly. Some of the scientific ones have been discussed. And later when we can build manned space stations to laboratories in space then all sorts of other possibilities will open up. In particular we'll have out there access to a vacuum of unlimited extent and would also be under conditions of weightlessness. Nothing will have any weight. This may allow types of industrial operation manufacturing process which are quite impossible here on earth. The handling of highly corrosive, very hot materials, for example. There are also medical possibilities. The effect of low or absent gravity on life may have some very interesting consequences. It's been seriously suggested that the span of life many be greatly extended when the wear and tear due to gravity is eliminated. If this is so, it will start a rush of octogenarians to the moon.

"My guess is that the first landing on the moon by a manned vehicle will be in about twenty years' time, and much more interesting places such as Mars and Venus will be reached before the end of this century. But getting to the other planets is the easiest part of the job. The real challenge arises when we reach them for there are no planets in the solar system upon which men can exist without artificial aids. Colonising the moon, which will be the first step in extra-terrestrial expansion, will be similar in many respects to colonising the antarctic, another project for future engineers. In some ways it will be simpler. There's no weather on the moon and that's a great advantage, but there is also no air or water which is a considerable disadvantage. We'll have to take these things with us in our first expeditions and later extract them from the lunar rocks when we establish permanent self-contained bases there. For there's no doubt that if it proves worth while, we can eventually establish such self-supporting colonies on at least the moon, Mars and Venus, despite the fact that conditions there are completely alien. To do this will require the development of a technology which has been christened 'planetary engineering'. It will involve air conditioning, mining, food production by soilless farming and a synthesis of all the necessities of life from some pretty unpromising raw materials. But even there we know, in principle, ways of doing these things, so you can be sure therefore that when the time comes to do them thirty or fifty years from now, our descendants will know even better ways.

"I have left until the end one of the questions which you must all be asking. What can this country do about space travel? The Americans are spending not millions but literally thousands of millions of dollars on the development of large rockets, and the Russians can't be far behind. Even now, a very useful astronautics programme which could keep this country in the forefront of space exploration, would cost about a shilling a week per head, and I refuse to believe that we can't afford that. So I'd like to emphasise once again that the huge chemically-fuelled rocket that wil take the first men to space is not the long-term answer to the problem of space travel. That answer, as I said, will depend on atomic energy, and here this country leads the world. It looks at the moment as if the first really practical space ships will be powered, once they leave the atmosphere, with what are known as plasma jets—that is, streams of electrified gases at enormous temperatures, far higher than can be attained in any flames. They'll be controlled by magnetic fields and will in fact be produced and handled by exactly the same techniques that are used in ZETA, the machine which our scientists at Harwell have built: one of the first milestones on the road to thermo-nuclear power. It's quite possible that in this kind of research, which is well within our financial means, may come the engine which will take men to the planets.

"I feel pretty sure about making this final prediction which perhaps brings home better than anything else I can say the imminence of the things I've been talking about. I think it's virtually certain that many of you here in this hall today will have grandchildren who will not be born on earth."