

altitudes make the solution of these problems even more difficult and more urgent, especially as the sonic barrier is approached.

These are some of the problems. The Author hopes that his survey will have shown from what they arose and will provide a background against which to assess them.

The Paper is accompanied by five diagrams, from which the Figures in the text have been prepared.

Discussion.

The Author, in introducing the Paper, observed that he had thought it necessary to explain in it at some length the basic theory behind air navigation. That was not because air navigation was a particularly difficult subject or in any way mystical, only to be understood by highly-trained people who had studied at the shrine of learning for many years ; basically it was, in fact, very simple, but, owing to a number of circumstances, knowledge of the principles and of the details of air navigation was not widely spread outside those whose business it was to guide aircraft, nor, oddly enough, were its principles and practice very widely known even among aviators themselves. Experts would discuss at length the merits and demerits of some particular piece of equipment, but during such a discussion it was often evident that those taking part had no very clear idea of what it was that a navigator was trying to do. Therefore, he had attempted in the Paper to describe the air navigator's task and some of the methods by which he achieved it.

The aim of the navigator was quite simple, namely, to direct the aircraft to any required point on or over the earth's surface within the range of his aircraft, and probably it would be of benefit to all, including navigators, if that simple aim were kept in mind. To achieve that, the navigator should be able to tell whoever was actually guiding the aircraft what to do to get to that point and when he had arrived there.

He had not referred in the Paper to the disadvantages of astronomical methods, apart from the question of inaccuracy. The advantages arose to some extent from the entirely self-contained nature of the aids ; the aircraft could fly around without assistance from ground stations and, provided that the navigator could see the sky, he could determine his position with an accuracy which did not depend upon his distance from his base. One disadvantage of astronomical methods, however, was that a considerable time was needed to reduce astronomical data to any useful form. The old marine methods, which required 20 minutes or more to obtain a position line out of a sight, had been speeded up considerably by means of the tables referred to in the Paper, but about 20 minutes was

still required for a skilled observer to take three sights of stars and plot them. In an aircraft flying even at as low a ground-speed as 180 knots that time represented 60 miles, so that by the time the navigator had obtained his position he had travelled 60 miles and had to start all over again. Therefore he was even farther "behind the clock" than usual.

Moreover, astronomical methods were difficult to work out and involved a good deal of addition and subtraction, which in the air could lead to considerable errors. The noise, the high altitude, and the cumulative fatigue of sitting in an aircraft for 8 or 10 hours, all led even a skilled air crew to make stupid mistakes, and any method which depended upon the navigator's arithmetic suffered from a grave disadvantage. Considerable manual skill was required in the actual taking of the observations; and finally they were, in any case, inaccurate by modern standards when compared, for instance, with radar methods.

The method known as "H2S" was heavy and complex, and was not likely to be used by civil aircraft. The Author doubted whether any civil operator would be happy to sacrifice up to 1,000 lb. of pay-load, which was the weight of the equipment.

Navigation was not a mere collection of instruments. It was not a goal of itself, but was a science, and to some extent an art—skill being required from the navigator—which needed instruments and equipment to give certain answers to questions involved in the basic theory. Although navigation aids might come and go, the answers required were the same, and progress in the science of navigation was measured by the ease and speed with which those answers could be supplied to the navigator.

In the introduction to the Paper he had referred to the importance of accurate navigation, and had quoted one or two examples. Sir Arthur Harris, in his book "Bomber Offensive," had brought out very clearly that improved aids to navigation had an enormous influence on the success of the bomber offensive. Better aids led to better bombing, and better bombing had led to a more successful offensive and, together with many other factors, had helped to shorten the recent war. The ideal answers had not been reached during the war. Improved military and civil efficiency needed still better and more simple and more accurate aids to the navigation of aircraft. Navigation was really applied common-sense. It was not entirely a specialist concern, and any ideas which could be put forward for improving the means of guiding aircraft swiftly and efficiently from one point to another would be very welcome.

Group-Captain H. J. Saker observed that the Author had mentioned several times in the Paper the fact that the navigator was always behind time, and in his "Conclusions" he had referred to the problems which required practical solution. The Author had stated that the military problem was to fly from *A* to *B*, then, perhaps, on to *C*, and then back to *A*, whereas the civil problem was to fly from *A* to *B*. In Group-Captain Saker's opinion, the problem was rather more than that: it was, in

addition, to fly to intermediate points at times which were pre-arranged. That applied to both military and civil aircraft.

One method which had to be improved was what might be called close navigation, that was, navigation in the approach to a control zone or within it. For example, in order to avoid wasting time and being a danger to other aircraft, civil pilots flying to schedule had to arrive over an airport at a certain specified time. Similarly, military aircraft, particularly if large numbers of aircraft were operating in congested areas, would have to fly to a programme even more closely than was done in the war, or they would not be got down quickly and programmes could not be adhered to. Moreover, it was imperative to avoid danger from collisions.

During the war he had been detailed to carry out a series of tests to endeavour to reduce the time taken to get a heavy bomber squadron on the ground. Previously all aircraft, on returning, had had to make one or more circuits. The same thing applied now to civil flying; aircraft had to make one or more circuits, so wasting time and forming a danger to other aircraft in conditions of bad visibility. The aim in the experiments which he had made was to get aircraft down as quickly as the runway could be cleared. It was found possible to clear the runway at the rate of one per minute, and an attempt was therefore made to get aircraft into the approach at that rate. A point was detailed about 8 miles from the end of the runway, where pilots were instructed to report at particular times. In point of fact, very few pilots managed to do so, and some were as much as 5 minutes out in time and 5 miles out in space.

That problem was still unsolved. Despite the excellence of "Gee" and of the other devices mentioned in the Paper, it was necessary to take another step forward very quickly in order that civil pilots could arrive at the control zone and at the airport at the proper time, so as not to waste time or be a danger to other pilots, and also so that the military problem might be reduced, in view of the speeds and the density of traffic which might be expected in the future.

The pilot would probably have to have indications on his instrument panel, and might have to go so far as to operate the equipment himself. Developments might lie in the direction of linking the navigational aid with the automatic pilot. Even a device such as "Gee" could probably be linked up with the automatic pilot in some way, to ensure that pilots should be over the place where they wanted to be at the time that they were supposed to be there.

Another problem, closely allied to the first, was that the air traffic controller should know where all the aircraft were in his zone. Devices existed by means of which he could see up to about 30 miles, but beyond that he was blind. In ordinary radio communication at very high frequencies, it was possible to relay signals, and an effort should be made to relay the picture which the controller obtained in his control tower, so that his vision would extend as far as his zone extended—which

might be 100 miles or more. That was really all part of the navigator's problem, since if the pilot did not know where he was because his apparatus had broken down, the ground display would be able to tell him.

Mr. R. F. Lloyd-Jones observed that it was not always very evident how navigation was related to the design of an aerodrome. His own interest lay more in civil aviation, and in civil rather than military aerodromes, and he wished to discuss a problem which was affecting many municipalities at the moment, namely, whether or not some kind of provision should be made to cater for a growth of short-distance aerial travel. That was obviously a question to which nobody could expect an answer at the moment; it depended very much upon what navigational technique and air control would be in the future; but to people who had to make a decision now, any information which they could obtain on present navigational technique and air traffic control problems, and on likely developments, was of considerable assistance. He would welcome the Author's views as to the future of air travel over distances of perhaps only 100 miles or so, and the possible interference of aerodromes which were closely adjacent to one another.

Other and more immediate problems also affected the design of an airport. Usually it was difficult, in any case, to estimate the total future volume of traffic offering at an aerodrome, whether in the form of short-distance or long-distance services, but if some estimate were made, the next problem for the designer was to decide what the capacity of his aerodrome should be. At the present time a very considerable difference existed between the maximum movement rate in clear weather and that under instrument conditions. Group-Captain Saker had mentioned a rate of landing of one aircraft per minute. He had not stated whether that was in clear weather or under instrument conditions; but in the Advisory Panel on the lay-out of the London airport the maximum taken for clear-weather conditions was one landing every 90 seconds, and one take-off every 45 seconds, whilst the best that could be achieved under instrument conditions was taken as being two-thirds of the rates represented by those landing and take-off intervals. Would those estimates, which the Panel had put forward very tentatively, be considered by the Author to be reasonable?

No mention had been made in the Paper of blind approach and landing systems, which concerned anyone who was responsible for designing an aerodrome. Apart from that, there was the problem of getting the aircraft, at the beginning of the approach, accurately in position and in time. Had the Author any views on the methods by which the aircraft would be controlled to enable that object to be achieved? Should a form of stacking be adopted, or were the aircraft likely to have to make detours to fill in time so as to arrive accurately at the moment when they were wanted?

Another problem—and rather a big one—was that of multiple-runway

aerodromes. At Heathrow, for instance, a three-runway system in each direction had been adopted. Mr. Lloyd-Jones would welcome the Author's views as to the advantage of a parallel system of that kind, as comparison with the tangential system adopted by the Americans at, for example, the La Guardia airport near New York, particularly from the navigational point of view.

Mr. E. W. Pike observed that navigators seemed to be in almost universal agreement on fundamental problems, and he could echo the Author's statements about the basic methods of navigation, the use of instruments, their value, and the conclusions to be drawn. The whole subject had been covered so thoroughly in the Paper that he would touch only upon possible future developments. P.I.C.A.O. had held a special Radio Technical Convention in 1946 to discuss long-range navigation, short-range navigation, air traffic control, and other problems, at which a number of devices were shown and discussed; but very little in the way of agreement had been achieved, because so many views were held on the different technical problems involved.

Some of the questions had already been answered in practice. For instance, a device of which he had had actual experience gave an accurate measure of the distance from a particular station on which the device was sighted. That was not in the usual form of a radar tube which had to be interpreted, but was shown on the panel, so that the pilot could read accurately his distance from a particular station. Other developments enabled very accurate tracking to be obtained.

The problem of air traffic control, however, was so difficult to solve that nobody had yet produced a clear solution. Among the difficulties was the language problem which arose when pilots of various nationalities came to an international airport. It was necessary to have some device in the aircraft for visual signalling—a development of impulse signalling or facsimile or some way of giving an instruction which would be understood and obeyed in any language immediately. There was also the fundamental difficulty of accurate timing, of getting the watches of navigators and pilots so synchronized that they could arrive at a particular point with an accuracy of 1 minute. That problem was very hard to overcome. The best method which he had seen so far of dealing with it was employed in America, where investigations were being made into the ground control of a number of aircraft on a radar tube, which was very good, and a height device which was not so good. A fair measure of success had been achieved in giving instructions to pilots and spacing them on the approach to a runway and bringing them in on the ground control approach system (G.C.A.), whereby the controller indicated the height and speed at which they were to fly until they were in contact with the earth.

That method of solving the close approach problem seemed promising. All the other methods, which relied on the pilots doing exactly the right

thing in bad weather, were very difficult of operation, and considerable disagreement existed as to how that desirable aim should be achieved. Other interesting developments included the Teleran system, sponsored by the Radio Corporation of America, which gave a televised picture to the pilot. The pilot had an observation screen, stations were set up along the route, and instructions showing the airway and other aircraft were televised to the pilot. That system was very ingenious, but it was also very expensive and complicated. The General Signal Company of America had a block system whereby aircraft were controlled like trains, with a three-line system of "Stop," "Go," and "Hold." The pilot could see whether he was allowed to proceed through a certain block of air. That was worked on the radar responder beacon principle, and was also complicated. A tremendous amount of development work was being done, however, by the radio industry to solve the traffic control problem, and it was to be hoped that some solution would be achieved. It was the most vexatious problem in civil aviation, and would have to be overcome.

An interesting development in long-range navigation, in connexion with the use of meteorology rather more completely than in the past, was in carrying out what was described as "pressure pattern" flying, applying certain meteorological principles. That showed promise of being extremely successful for long routes, where it was desired to find the most favourable route to fly to take advantage of tail winds or to minimize the disadvantage of head winds.

The Author, in reply, observed that Mr. Pike had dealt mainly with pure navigation, as distinct from problems of aircraft control. The two were not distinct, but Mr. Pike had asserted that some of the answers had already been provided by equipment which had recently been introduced. That was true, but only to a limited extent. Equipment was in existence which would give the pilot his distance from a given point, but that point would not be very far away; normally it was the airfield which he was circling or which he had just left. He could obtain that information over distances of up to 20 miles or so. It had to be combined with the indication of bearings, and so on. Such apparatus, however, did not overcome the fundamental difficulty that, in order to obtain useful information for a long-range flight, the indications provided had to be plotted by somebody or other on a piece of paper or a chart and used as a basis for some form of computation. Means existed by which an aircraft could fly a given track accurately without more ado, but the answer there was a qualified answer, because in their present forms those means applied to aircraft flying between two points in friendly territory, and for military operations there were obviously certain difficulties.

All the speakers had led the Author into the very fascinating field of air traffic control. The Paper had not dealt with instrument landing systems, or in any specific way with air traffic control, and he wished to

acknowledge the reminders given of the importance of time, which he agreed he had not emphasized sufficiently, either in the Paper or in his introductory remarks. He had stated that the aim of the navigator was to guide the aircraft to a certain point on or over the earth's surface within the range of the aircraft: that was true, but he should add that navigation was the science of getting an aircraft to a given point along a given route at a given time. Time was of first-class importance in all operations, whether military or civil.

Group-Captain Saker had referred to "close navigation," and had also mentioned the provision of information to the controller which would enable him to keep an accurate check on the movements of aircraft. The Author agreed that highly accurate navigation was of the utmost importance within short distances of the airfield. It was also of first-class importance elsewhere; but in order to ensure the safety of aircraft, to avoid collisions, and to assist the aircraft to run to schedule on flights of any length, it was very important that navigation in the vicinity of airfields, both of departure and destination, should be as accurate as possible. If he were concerned only with military and civil operations in time of peace, he would agree that any system which achieved that, even though it might be expensive in men, money, and material, would be worthy of adoption at the earliest possible moment. Even in time of war accurate timing and adherence to schedules was important. At the moment, however, he was rather suspicious of embarking on such elaborate systems as Mr. Pike had described—the Teleran system, or the Block system with "Stop," "Go," "Hold," and so on—without more experience of their operation and more thought as to what the consequences might be.

Perhaps he was not being very logical or consistent, but what he had in mind was that it was essential that an Air Force should be mobile and able to move at the shortest possible notice, going from Great Britain to the Middle East, for instance, at short notice, and getting everybody there at the right time to prepare for operations. So far as an Air Force was concerned, it was necessary to ensure that whatever system were adopted for close navigation should be as flexible as possible. An air line from the La Guardia airport to Washington could well be run on a system similar to that used for a railway line, with signal-boxes and red and green lights, because it would be used many times a day; but an Air Force did not run on railway lines, and therefore any system which was adopted had to be flexible in operation and easy to set up anywhere.

The Author could discuss for a long time the different air traffic control questions, but he realized the possibility of navigation becoming more and more automatic. Many of the developments in equipment for civil use, and also to some extent for military use, were tending in that direction. The automatic pilot was being linked up to an instrument approach system, and it would not be long before the automatic pilot would also be linked up with any desired form of navigational aid. He believed, for example,

that it was simple to link it up to "Gee"—simple in the sense that it was theoretically possible; it merely remained to make the equipment.

The present tendency was that the aircraft should determine its position by the most accurate and simple means possible and should pass that information to the traffic controller, and that the traffic controller should be provided with equipment which would enable him to monitor the movement of the aircraft. He would not necessarily have to act on it, unless it was evident that one of the aircraft which he was controlling was not in possession of its full faculties and was not making use or able to make use of its navigation aids, and then he could tell it what to do.

Mr. Lloyd-Jones had asked a number of questions, some of which the Author felt rather diffident about answering. His statements on the general question of close navigation and air traffic control applied to distances of up to 100 miles—short-range flying. He considered that for such short distances timing should be highly accurate; aircraft should run to schedule and high accuracy should be maintained throughout the whole run. He felt confident that that would very soon be possible. Numerous systems existed which could, for such short distances, take control of an aircraft, take it off the ground, fly it through the air, and put it down a certain time later without deviating by more than a short time, by present standards, from the schedule.

With regard to the time of taking-off and landing, he would not quarrel with the figures put forward by the Panel, which appeared perfectly reasonable. The rate of landing and take-off of aircraft, whether in clear weather or under instrument conditions, was not primarily governed by the instrument approach system or by the accuracy of aircraft navigation in the approach during the last 100 miles. The Author believed that the main limiting factor was the rate at which aircraft could be cleared off the runway. For that purpose no high-class equipment comparable with the navigation and approach aids had been devised, and the problem had arisen, and been considered on a large scale, only since the end of the war. As Group-Captain Saker had stated, experiments had been made during the war, and had been continued since; but the aim of the later experiments had been confined more or less to a rate of landing under instrument conditions of one every 2 minutes, which was the shortest time under present conditions in which it was possible to clear the runway safely.

In reply to Mr. Lloyd Jones, many competing methods of control existed for achieving accurate and rapid instrument landing, and the argument as to which should be adopted had been continuing in Great Britain and in America and among civil aviators and military aviators at the meetings of P.I.C.A.O. almost ever since the Author had been concerned with navigation, and particularly for the past two years.

His personal view was that stacking, as it had been employed by the Americans, namely, the system by which an aircraft was told to circle

round a given point, and other aircraft were told to circulate at higher levels, one above the other, one at 1,000 feet, another at 2,000 feet, another at 3,000 feet, and so on—was very inconvenient, troublesome, and uncomfortable. It was far better to disperse aircraft over the countryside, although that led to certain difficulties, than to stack them one above the other. It might take the man at the top a long time to get down.

At the present time discussion of the best methods of control to achieve safe and rapid instrument landing was very interesting and necessary, but there was still a long way to go. The Americans had a system which they had used for years, and everybody knew how it worked; but he would be surprised to hear that they could exceed four landings per hour in instrument conditions.

With regard to parallel runways, in comparison with the tangential system in relation to navigation, he considered that the main factor was the instrument landing aid in use. In using present instrument landing systems, which consisted either of a radio beam in some form, or of the ground controller watching the aircraft by radar and telling the pilot where to go, the tangential system was possibly a little better, in that the aircraft on their approach to tangential runways were separated at the beginning of the approach by more than was the case with parallel runway systems; but he had not devoted a great deal of thought to the problem.

Finally, he wished to thank those who had taken part in the discussion for the points they had raised, which were of considerable interest and value.

The Chairman announced that the constitution of the Divisional Board for Session 1947-48 would be as follows:—

Appointed by the Council in accordance with Rules 1 (a) and 1 (b) of the "Objects, Constitution, and Rules." :—

Sir Arthur Whitaker (<i>Chairman</i>).	Mr. R. F. Lloyd-Jones.
Sir Stanley Angwin.	Mr. A. Shaw Maclaren.
Mr. M. G. J. McHaffie.	Mr. T. W. Moran.

Elected by the members present at the Meeting, in accordance with Rules 10 to 14 :—

Mr. G. T. Bennett.	Mr. E. C. Hodgson.
Mr. H. Q. Golder.	Mr. P. G. Hudson.
Mr. Henry Grace.	
