as sound. That method was essentially one of "hit and miss" and begged the question of indeterminacy by making sufficient assumptions to reduce the problem to one of plain statics. Because the assumptions were really a confession of ignorance, it was necessary to make different assumptions on a "trial and error" basis in order to assess the consequences of an error in any one assumption. They agreed that with such a method it had to be admitted that there was some danger of a rather excessive overall factor of safety, and the only remedy against that was the experience and judgement of the designer.

CORRESPONDENCE
ON PAPERS PUBLISHED IN
JANUARY 1945 JOURNAL.

Paper No. 5446.

"The Design of Land Airports for Medium and Long-distance Civil Air Transport."†

By ARCHIBALD SHAW MACLAREN, M.A., Assoc. M. Inst. C.E.

Correspondence.

Mr. H. J. Coates observed that the problem of airport building lay-out was one of unusual complexity and those who had studied it would readily endorse the Author's comment about the difficulties involved, not least of which was that of acquiring information sufficiently reliable to enable the designer to anticipate and cater for future needs with reasonable accuracy.

It was necessary to start with a clear statement of the problem before attempting its solution, and in the case of airport buildings that meant that the requirements should be known in terms of volume of traffic to be handled, frequency of services, and the number and dimensions of aircraft to be berthed. The Author was to be congratulated on shedding some light on that formidable array of unknown quantities and in collecting from various sources estimates of future trends in civil air transport.

It should be remembered, however, that such estimates were of necessity based on assumptions, the correctness of which only the future could

† J. Instn Civ. Engrs, vol. 23 (1944–45), p. 100 (Jan. 1945).

show, and it would therefore be rash to expect that from such data buildings could be planned to fit exactly the shape of things to come. Furthermore, estimates of that kind tended to change very rapidly, so that it was a common experience to find that even before a design had left the drawing-board the information upon which it was based had been superseded. For example, Mr. Coates believed that the plans of the Idlewild airport, New York, had already undergone a number of radical changes.

For those reasons it was of vital importance not only to plan for stage-by-stage development, so that growing needs could be met as they arose, but also to eschew, as far as was humanly possible, any features or forms of construction which might be rendered obsolete by subsequent changes in aircraft design. The covered loading bay illustrated in Fig. 11, Plate 2, might fail to justify its very high cost on those grounds; for if it were designed to accommodate the largest aircraft envisaged within the life of the structure, it would be unnecessarily extravagant for present needs and might also prove inadequate for the future, should the dimensions of aircraft exceed the expert's forecasts.

Another difficulty inherent in the problem of airport building design was that of reconciling two sets of requirements not readily compatible, namely, the space requirements for the handling of passengers and cargo and the requirements in terms of building frontage for the manoeuvring and berthing of aircraft. Since he was not dealing in detail with the planning of buildings, the Author had, not unnaturally, emphasized the latter consideration at the expense of the former, and had even suggested that the building frontage—which, he said, for a main terminal might be of the order of 1 mile in length—should govern the design rather than internal layout. That appeared to be a somewhat unilateral approach to the problem, as it tended to ignore the chief function of the building and the needs of its human occupants. Thus the system of self-contained and interconnected building units illustrated in *Fig. 8*, admirably suited as it might be for the turntable method of berthing, had little to recommend it from any other point of view. The peculiar shape of the units did not lend itself to simple, direct, and straightforward planning and the concave frontage was the least economical for loading-bay purposes since each aircraft occupied a length considerably greater than its own wing span. From that point of view a convex frontage would obviously be preferable.

It was, in fact, doubtful whether terminal buildings, even at the largest airports, could be so completely decentralized as the Author appeared to suggest, for each self-contained building unit would need to have its own Waiting-Rooms, Restaurants, Traffic Offices, Customs Halls, etc., etc., and would result in an enormous multiplication of staff, services, and accommodation. Mr. Coates considered that the solution which most nearly satisfied all the diverse requirements of a major airport terminal lay neither in complete decentralization nor in attempting to combine all the operations within a single structure, but in designing a group of

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buildings consisting of a central terminal or clearing house, as it were, forming the hub of the system, around which the loading bays would be located, either in the form of a continuous outer perimeter, or of a series of interconnected units, sufficiently extensive to provide the necessary frontage and manoeuvring space, and linked by covered corridors with the central building.

Mr. F. W. Dawkes observed that, in considering the possible variations from conventional types of aircraft, no reference had been made to the towed glider which had proved so valuable for military purposes. For freight transport the glider with auxiliary power to assist landing and taxying would appear to offer commercial possibilities, but such gliders should be excluded from busy airfields handling passenger traffic. The segregation of passenger from freight traffic would seem desirable with a view to restricting the density of aircraft at any one airport.

The handling of passenger aircraft should always be governed by consideration for the safety of the passengers. Whilst very high rates of landing and take-off had been achieved by military aircraft during the war, it was not thought that a rate as high as fifty aircraft per runway per hour could be attained in safety with civil aircraft. The average time taken by one aircraft to traverse a 2,000-yard runway and taxi clear before a following aircraft touched down, allowing a small margin of safety, indicated that an average of from thirty-five to forty movements per hour was more probable. Twenty movements per hour under instrument landing conditions in low visibility was too optimistic and a more reasonable estimate would be ten to twelve aircraft per hour.

The figure of 150 given by Dr. E. P. Warner presumably did not refer to the maximum number of aircraft per hour, but to the maximum number within radio communication at any one time. Those aircraft might be spread over a flying time of 2 or more hours.

It was doubtful whether airport capacity could be doubled by twin parallel runways, in view of taxying delays and congestion in the air during approach circuits. Triple runways further aggravated that problem. A peak of fifty aircraft per hour with twin runways—normally one being used for landing and the other for take-off—was considered reasonable.

The suggestion that aircraft might taxi across the line of flight of aircraft on a parallel runway was strongly deprecated. The psychological effect on the airborne pilot and the possibility of engine failure on take-off or brake-failure on landing should not be overlooked.

Re-fuelling in hangars at the airport building was undesirable owing to risk of fire, and re-fuelling points should be away from all buildings.

No design of a land airport could be undertaken without definite knowledge of the functions and layout of the airport building, and the design of the latter should be considered by the engineer as part of the airport.

Customs and excise, with security and immigration facilities, were essential to all international airports, and in the loading and unloading of aircraft full control should be maintained by those officials over the movements of passengers and freight.

The system of loading bays suggested by the Author had several disadvantages :—

(*a*) the building frontage was extremely long and, apart from building costs, entailed long taxying and walking distances ;
(*b*) the method of handling each aircraft was laborious and increased aircraft-time at the building ;
(*c*) to service aircraft entailed the occupation of valuable space and re-fuelling was dangerous ;
(*d*) customs control, etc., was rendered difficult by dispersion of aircraft on a long frontage ;
(*e*) each operating line would probably require its own bay or bays, as central reception offices would be too remote from aircraft arrival and departure points. Full use could not always be made of the building frontage owing to reserved bays ;
(*f*) smaller aircraft would take up as much accommodation as larger aircraft unless various sizes of bays were provided ;
(*g*) the size of the bays might limit wing span and tend to restrict aircraft development.

The theoretical lay-outs illustrated in Plate 1 were all very complex and, apart from confusion for pilots generally, involved long taxying distances. The central airport building was inconvenient for access, whilst hangars and maintenance facilities should be situated either in or far from the airport building if they were not to form obstructions to flying.

The layout shown in Fig. 10 (*f*), Plate 1 was a more practical and economical solution. It could be improved still further by re-arrangement of the runways so that the approach and over-run of each was unrestricted, giving the following advantages :—

(*a*) separate landing and take-off runways ;
(*b*) all aircraft landed into airport building and took off away from the building irrespective of wind direction ;
(*c*) taxying was reduced to the minimum ;
(*d*) direct road and rail access could be provided to the airport building, unrestricted by flying ;
(*e*) convenient extensive hangars and parking areas might be provided where re-fuelling could take place away from buildings ;
(*f*) on calm days three runways could be used for simultaneous take-offs ;
(*g*) taxi-tracks joining the ends of the runways would be required for emergency use only.

Lieutenant-Colonel W. R. Greathead observed that whilst a maximum gradient of 1 per cent. was probably a safe minimum requirement for local aerodromes, it seemed steep for the type of airport visualized by the

Author. In a blind approach by an aircraft to a 1-per cent. runway, assuming a 2 per cent. angle of glide close to the ground down-grade the equivalent angle of approach would be 1 per cent., and up-grade 3 per cent. Down-grade, the tendency was for the pilot to land too far into the aerodrome, whilst up-grade there was the danger of a rough landing.

He considered that, in view of the cost of paving, expenditure on earthworks to obtain the flattest possible gradient was justified before making the major investment. He also considered that the Author's opinion, that the operator should have the final say in runway length, was wrong. In most countries, airports were municipally owned and it was unfair to expect such long runways to be built with no hope of an adequate financial return. It was also unfair to expect aircraft designers to put into production aircraft which could use only a very limited number of aerodromes. Such a state of affairs would not help the sale of British aircraft overseas.

In mountainous country a good rate of climb was essential for safety. Such areas existed on all Empire routes. Good climb meant good take-off performance and, therefore, the provision of runways of 5,000 yards seemed extravagant.

Dr. E. P. Warner, who had delivered to the Royal Aeronautical Society the Lecture cited by the Author,[1] had also presented a Paper to the Boston Society of Civil Engineers in March 1944,[2] which contained an excellent exposition of how runway-length should be determined and demonstrated that the economy in operation obtainable by increasing the length of runway obeyed the law of diminishing returns. Dr. Warner had pointed out that, for the extreme case of a trans-Atlantic flight, an increase in length from 4,000 feet to 6,000 feet would increase the pay-load by 30 per cent., but an increase from 10,000 feet to 12,000 feet would give only a $2\frac{1}{2}$-per cent. increase in the pay-load. For the next increase of 2,000 feet the beneficial increase in pay-load would be only approximately $1\frac{1}{4}$ per cent., and so on, each 2,000 feet increment in length resulting in an improvement in pay-load of half the previous increment.

Colonel Greathead considered that the Author's recommendations for altitude correction for runway length were unnecessarily complicated. He had seen a chart showing aircraft take-off performance expressed as runway-lengths to clear a 50-foot obstacle.

Owing to varying aerodynamic and engine characteristics none of the curves was a straight line, nor were they similar. The United States Civil Aeronautics Administration's standard, by which 10 per cent. of the altitude was added to the length at sea-level, gave the closest approximation and was easy to use. An elaborate calculation to give what could only be a rough approximation seemed out of place.

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[1] "Post-War Transport Aircraft", J. Roy. Aero. Soc., vol. 47 (1943), p. 186 (July 1943).

[2] "The Development and Forecasting of Airport Requirements", J. Boston Soc. Civ. Engrs, vol. 31 (1944), p. 88 (April 1944).

South African engineers were interested in soil mechanics as a science and had followed developments in the United States since 1936, when, with the introduction of a National Road scheme, soil testing became a feature of road construction in South Africa; they would read with interest any Papers published on soil testing or pavement construction.

Major J. K. Thorpe, R.E., observed that in the present relatively early stage in the design of airports it would be well worth while to obtain accurate information, by full-scale experiment, of the magnitude of the forces imposed on the runway surface by alighting aircraft.

Would it not be both possible and advantageous to lay down special sections of metal runway at selected airfields, so that the deflexions of the track sections caused by different types of aircraft at the instant of landing might be recorded by deflexion-meters, and the corresponding loads calculated both by static calibration of the track sections and by calculation from their dimensions and elastic properties? Such experiments would neither be very costly nor very difficult to carry out, (possibly existing types of Service track might be adapted), and the technical difficulties of design and automatic observation should be by no means insuperable. The results would be of great value to airfield engineers, by enabling them to base their designs, not on intelligent supposition, but upon something approaching exact knowledge. Such experiments were bound to come sooner or later, and the sooner the better.

With regard to Mr. Lloyd Jones's desire to see the wheels go round, surely the provision of a self-spinning mechanism was simply a matter of money? If it could be shown that the use of self-accelerated landing wheels would enable substantial economies to be made either in the initial cost or in the subsequent maintenance of runway surfaces, then airport authorities had but to offer preferential airport charges to aircraft so equipped. Competition for airborne freight was likely to be keen, and with such an incentive aircraft operators would be quick to demand such equipment from designers and manufacturers, who in their turn would soon respond by offering aircraft so equipped to their customers.

Without such an incentive it was unlikely that aircraft operators would sacrifice valuable pay-load capacity, by the provision of such mechanisms, unless indeed it could be shown that the saving in tire maintenance would make it profitable for them to do so. It seemed unlikely that the price of rubber would rise after the re-conquest of Malaya, so that the provision of such mechanisms would depend upon whether or not it paid the airports to grant such concessions.

He hoped that neither members nor The Institution as a body would approve barbarisms of bastard latinity such as "adastra" for airfield. There were coalfields, goldfields, brickfields, and even battlefields, with no very agricultural signification. Why not airfields? The sad military history of *pro forma* should serve as an awful warning against the abuses of latinity; and some might think it in doubtful taste to borrow even part of the noble motto of a great Service and degrade it to a base and mercantile connotation.

Wing-Commander J. K. Wilkins agreed with the Author that the designer of aerodromes should know as much as possible about the design of aircraft. As Mr. Hudson had remarked, it was the development of aircraft that primarily had brought about the development of the aerodrome from the small grass field of a few years ago to the elaborate and expensive thing it had become.

The civil engineer would very much like to see aircraft standardized so that he could build his airport with an exact knowledge of the type of machine that would use it. All other forms of transport had had to accept limitations: railways had limited gauge and road vehicles were limited in width, but until some stability in the design of aircraft was reached the airport designer would have to allow the aircraft designer full liberty. Therefore, in order to anticipate what was going to happen, he should know all about the trends of design, and he should try to allow for the unexpected.

Several speakers had emphasized the cost of a major airport and had expressed the view that economies should be made in runway width and length; but Wing Commander Wilkins considered that, immense though the cost might be, economies were not justified.

The one thing that could hold back air transport was its high accident rate in comparison with other forms of transport, and he was certain that civilian air travellers after the war would not accept factors of safety which were commonly accepted during war time.

Air transport was, or should be, at least as important as road and rail in the future and the fact that the railway companies were taking such an interest in it showed that they at least were alive to the possibilities.

If the cost of even two or three major airports were compared with the cost of roads and railways in Great Britain it became obvious at once that it was not excessive. The presence in Great Britain of even one airport so well designed that any type of aircraft could land or take off in perfect safety under all conditions would have a tremendous influence upon both long-distance and medium-distance flying. Therefore, so far from the Author's designs being too ambitious, they were too small.

The British Air Line Pilots Association had stated that the ideal airport should contain one runway 7,000 yards long by 300 yards wide and a secondary runway 5,000 yards long. If those runways were going to reduce accidents then they should be provided.

An airport in the London area could be regarded as a single runway aerodrome. An analysis of wind frequencies showed that allowing a maximum cross wind factor of 15 miles per hour, one runway in a N.E.-S.W. direction could be used for 94 per cent. of the total time. Although runways in other directions would have to be provided, an aircraft would generally be able to land and take off from the same runway. Wing Commander Wilkins considered that the best design for a major airport in the London area would consist of a number of parallel runways, say 1,000 yards apart, with facilities for parking and servicing between them. The present universal practice of bringing all aircraft to a central point for embarking and disembarking passengers and freight was cumbersome and was surely not essential. Passengers could quite conveniently be taken to the aircraft by subway under the runways. That would avoid the otherwise unsurmountable difficulty of taxying aircraft across the ends of runways in use and would enable each runway to carry its full traffic capacity.

The design of aerodromes was so bound up with the methods of wireless control of aircraft that it was essential for civil engineers to know as much as possible about it, and he hoped that as soon as it was off the secret list, a Paper on the subject would be submitted to The Institution.

The Author, in reply, recalled that he had observed, when introducing the Paper, that the subject was a developing one, and indeed a lot of air had flowed under the wings of aircraft since it was written more than a year ago. Advances had been made in the technique of the design of airports and he would endeavour to indicate some of those as they arose.

Both Mr. Coates and Mr. Dawkes had dealt with the lay-out of airport buildings, and those contributions to a subject in connexion with which a great deal still remained to be done, were much to be welcomed. Unfortunately, aircraft were not like ships or trains, which were narrow in proportion to their length so that multiple berths for them could be arranged within a reasonable compass by placing them side by side so as to take advantage of the small lateral dimension: aircraft occupied an area more nearly approaching a diamond shape in plan, and frontage had to be provided somehow. The system illustrated in *Fig. 8* was only one attempted solution of the problem, and the Author believed that there were altogether four ways of obtaining frontage. One other had been mentioned by Mr. Coates, namely, a central building around which the loading bays were arranged in an extended form; a third method was to have wings extending like spokes from a hub formed by a central building, both sides of the spokes providing loading bays; whilst the fourth method was for the loading and unloading of aircraft to be undertaken at dispersed island platforms or shelters located away from the main building but connected to it by subways. The Author understood that the spoke-and-hub arrangement had been decided on for the Idlewild airport, New York.

Admittedly a concave building frontage did not lend itself very happily to internal planning, but surely it did save length as compared with an arrangement in which the wings of aircraft were extended in a straight line. Was it not the case, too, that the growth of traffic would in itself lead to the multiplication of staff, services, and accommodation which Mr. Coates had envisaged as a drawback to a system of self-contained building units, and that it would become difficult, if not impossible, under those conditions to arrange that the functions of customs, immigration, medical examination, and general traffic handling were performed efficiently in a single building without causing overcrowding and delays ? If that were so, the multiplication of staff and so forth was an argument for the unit system rather than against it. Further, the uncertainty of the correctness of estimates of future traffic made a unit system appear to be the logical way of meeting demands as they arose, and it was favoured by many people who had looked at the question from a practical point of view. It seemed doubtful whether each operating company would require to have its own loading bays, and the Author visualized the units used rather according to the routes or regions which they served. It would be like having Waterloo, Victoria, Paddington, Kings Cross, Euston, and the other London stations arranged side by side in one street, which would surely be a highly convenient arrangement for the passenger, whether arriving or departing, and for the consignors and consignees of freight.

Perhaps Mr. Coates's contention that covered loading bays of the type illustrated in Fig. 2, Plate 2, might become obsolete, had less import when considered in relation to development by units used according to the system which he had described, as the dimensions of the loading bays could then be increased as the number of units grew and as aircraft became larger. That seemed to fit in with current thinking, which was that the larger aircraft would be used only on the longer distance routes. Servicing in covered loading bays was not intended except for such minor running adjustments and maintenance as could be done during the time when the aircraft was normally in the loading bay, and perhaps Mr. Dawkes's other points (*f*) and (*g*) could be met were such a project to be translated into detailed design. Nevertheless the Author did not wish unduly to stress such advantages as might be claimed for the arrangement portrayed in *Fig. 8*. He considered that it was the conception of development by units which underlay it, that really mattered.

The suggestion which Mr. Dawkes had made that freight traffic, whether with glider towage or simply with freighter aircraft, should be separated from passenger traffic introduced a refreshing note. The question of provision for air freight was rather easily overlooked, and it might be that freight would provide a larger proportion of the total traffic than was sometimes anticipated : for example the speed, cleanliness, and freedom from disturbance of goods during transit for which air transport was noted would probably open up new fields for commerce and was, in fact, already doing so in some countries. It might be that separation on the airport, that was, separate buildings for freight and passenger traffic, should be considered when only freighter aircraft without gliders were used and when the total volume of traffic was not such as to justify the use of separate airports.

In the Lecture referred to in the Paper, Dr. E. P. Warner had forecast forty landings and sixty take-offs on an airport during the busiest hour of the day, and presumably that referred to dual runways. That was an average of fifty movements per hour per runway, which was the figure which the Author had given; whilst Dr. Warner's figure for landings approximated to that given by Mr. Dawkes. Therefore, was there really any discrepancy of view? These figures were for good visibility and, as regards instrument landing in low visibility, twenty landings per hour had been achieved recently in the United States by the use of a calculator (designed, the Author believed, by Captain Saint) which enabled aircraft to leave their stacking-point in the air where they were awaiting their turn to land, in such a manner as to arrive on the runway at exactly 3-minute intervals. It was unfortunate that there appeared to be some doubt about the interpretation of another figure given by Dr. Warner which had perhaps not been quoted very clearly in the Paper. Dr. Warner's actual words were: "I believe that with a sufficient number of parallel sets of runways the movements of aircraft in the airspace can be so co-ordinated as to allow 150 operations per hour in bad weather, even under instrument conditions." Mr. Dawkes's estimates of airport capacity were perhaps not low for present conditions, but it was the future which one had to consider in a master plan of airport development.

Was taxying across the line of flight of aircraft on a parallel runway any worse for the airborne pilot than having a loaded bus traversing a similar route, if both the taxying aircraft and the bus were below the flightway floor which formed the underside of the prescribed approach to the runway? The case of the bus might occur at any airport, and the Author thought that the case of the taxying aircraft was the better when one got used to the idea. The bus might well be carrying the larger number of passengers, and there would be a serious risk of fire in the event of a collision in either case.

With regard to fire risk, refuelling in hangars had been put forward seriously as a suggestion for time-saving. The proposal would, however, need careful investigation, which he did not think had yet been given to it, both as regards the engineering problems involved and as concerned the economic aspect; it might be, for instance, that increased insurance charges would outweigh any other saving effected. However, refuelling at pits in the apron adjacent to the airport buildings appeared to be accepted practice in the United States; for instance, it was done at the Washington National Airport—and an operator with experience of both countries had remarked that American airlines would regard as archaic the principle of refuelling from tankers with men climbing on the top of the wings of the aircraft in order to reach the fuel intake points.

Mr. Dawkes had also commented on the long taxying distances involved in the theoretical layouts illustrated in Plate 1 and in that respect had favoured Fig. 10 (*f*), Plate 2. The Author had at first received the same impression from the latter lay-out, but, on measuring the total distance which had to be taxied by an aircraft in transit, from the end of its landing run to the start of take-off via the passenger building, he had been surprised to find that the saving was more apparent than real in comparison with the more conventional forms of lay-out, especially when using the E-W or

NW-SE runways. The total distance was, in fact, about 7,000–8,000 feet, which compared very closely with the distance to be taxied between the ends of a primary runway of about that length in a conventional lay-out, it being remembered that the primary runway would be used for about 80–90 per cent. of the time. (He would say more about runway length later.) Certainly that kind of lay-out was attractive, but its practical disadvantages were :—

(*a*) the spread of ground occupied, so that few suitable sites would be available in developed areas ;

(*b*) the inflexibility as regards the alternative use for take-off and landing of the two runways of a pair ;

(*c*) Construction cost was saved when one runway of a pair was made shorter than the other, which was now accepted practice, but was not possible with that form of layout.

Lieutenant-Colonel Greathead had raised an interesting point with regard to the correlation of longitudinal runway gradient with the final approach angle of an aircraft in a blind landing, and the Author had taken operational advice about it. The reply which he had received was that up to a maximum gradient of 1 per cent. the only practical effect of gradient was the consumption of power during an up-hill take-off, and that a pilot would adjust his flight-path to the gradient during the final act of landing, so that a receding gradient need not be counted dangerous from the point of view of wasted runway-length.

It seemed that the Author's remark about the operator's responsibilities in his reply to Mr. West in the oral discussion might have been misunderstood. He had not intended to convey that operators should have the final say in runway-length : what he had meant was that operators should realize that they should not specify requirements for aircraft which, if built, would require exceptionally long ground runs, and he thought that that was in fact now, happily, being realized.

The need for a good rate of climb was well established, and was a factor which affected runway-length and the design of airports generally. With regard to runway-length and the correction for air-density, developments had occurred since the Paper was written. The statement on p. 102 that 650 might represent the upper limit of WXP for commercial operation had been out-dated by improvements in the performance of new types of aircraft, and the position was now that while the WXP was rising above that figure owing to the adoption of higher wing loadings not entirely offset by decreased power loadings, the greatest runway-length required was not tending to increase and, in fact, even showed signs of a slight decrease. Again, it had been decided that the principle of landing again on the runway should one engine fail at or before the critical moment of take-off, should not be made a criterion of runway-length. Thus, whilst 9,000–10,000 feet remained the maximum basic length necessary under standard I.C.A.N. conditions at sea-level when the flightways rose directly from each end of the paved runway, the paved length could be decreased to 6,000–7,000 feet if a sufficient length of clear and level flightway were provided beyond each end of the paving in order to give the aircraft room to attain its rate of climb. The lower figure in each case appeared to be all that was necessary to cover future developments, but there was still a certain amount of feeling that it might be wise to provide lengths according to the higher figures as an insurance against unforeseen developments in connexion with, say, jet-propelled aircraft. It was interesting that the figures agreed well with those given by Dr. Warner in the Boston Paper to which Lieutenant-Colonel Greathead had referred.

With regard to altitude and temperature correction to runway-length, the method given in the Paper had also been out-dated, and new figures had been calculated, based on pressure altitude and temperature separately, which were less exacting than the previous requirements. The United States principle by which a percentage of the physical altitude was added to the basic runway-length at sea-level was certainly a simplification—incidentally, the figure given in the Civil Aeronautics Administration 1944 publication "Airport Design" was 25 per cent.—but the Author was inclined to think that it was designed primarily for use on the North American continent, and it might perhaps be a rather unwise extrapolation to apply it elsewhere, at any rate in final calculations. It also seemed likely that it had been based on the numerous observations of aircraft performance in airline practice which had been made under the auspices of the United States Civil Aeronautics Administration and which formed the nucleus of the Paper by Mr. A. L. Morse to which he had referred. If that were so, the process by which the approximation had been reached was just as elaborate as calculation, and it was merely another method of approach to the problem. It was also interesting to note that, according to the method using calculation, temperature was seen to be a more important factor than altitude.

With regard to Major Thorpe's wish to see tests carried out of the loads imposed on runways, it appeared that work of that nature was in hand in the United States, and it certainly seemed to be desirable that similar tests should go forward in Great Britain. Pre-rotation of landing wheels was almost exclusively of interest to the operator, as in nearly every case it was the tyre which suffered, not the runway.

Wing-Commander Wilkins had given voice to one of the Author's secret wishes when he said he would like to see aircraft standardized! That seemed too much to hope for, but it did appear that, as already mentioned in a different context, the size and cost of airports, together with the need to maintain rate of climb, were making aircraft designers improve performances to the extent that longer runways would not become necessary. On that assumption, the Author preferred neither to run to the extreme of economy in construction at the expense of safety, nor to adopt the principle which Wing-Commander Wilkins had suggested, that economies were not justified, but instead to strike a middle course based on a careful investigation of aircraft performances and trends. That seemed to lead straight to the provision of the minimum which was necessary for safety without incurring expenditure and producing difficulties for which there was no valid reason.

The figure of 94 per cent. for the usability of one NE-SW runway direction in the London area with a maximum cross-wind factor of 15 miles per hour seemed a little high. Similar calculations which the Author had made gave only 88 per cent. which, with the 99 per cent. maximum total usability for a three-runway system which he had obtained, left $5\frac{1}{2}$ per cent. to be catered for by each of two secondary runways. Those figures of 6 per cent. (the time lost according to Wing-Commander Wilkins's calculation) and $5\frac{1}{2}$ per cent. for the use of each secondary runway in the Author's calculation, did not seem high expressed in that way, but they were equivalent to three weeks in every year, and he did not think that such a large aggregate time-loss would be viewed with equanimity by an airline which had to run commercial scheduled services. It seemed that the only way to avoid the use of ground and the expenditure of money involved in providing more than one runway direction, was to make aircraft less sensitive to the effect of cross-winds, whether by the universal adoption of the swivelling or "drift" undercarriage, or otherwise.

He welcomed Wing-Commander Wilkins's suggestion that a Paper on radio and radar as applied to airports should be submitted as soon as possible to The Institution, as those sciences undoubtedly had a considerable bearing on the subject of airport design. So had air traffic control methods, and he hoped that one day members would see a Paper on that subject.

In conclusion, he wished once more to express his appreciation of the kind reception given to the Paper, and of the very interesting discussion, which showed clearly the widespread interest taken in the subject.

Paper No. 5433.

"Traffic Capacity of Roundabouts at Road Intersections."†

By ARTHUR JOHN HAMBLIN CLAYTON, B.Sc. (Eng.), Assoc. M. Inst. C.E.

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Mr. H. W. S. Husbands observed that the Author's thesis was based on a number of assumptions of doubtful validity, but the general conclusion was that the maximum capacity of a roundabout could scarcely exceed

† J. Instn Civ. Engrs, vol. 23 (1944–45), p. 149 (Jan. 1945).