systems would have an identical effect. No suitable optical means seem to exist for eliminating this interference. Even if great pains were taken to baffle the receiving optics against stray radiation reflected off the plane itself, one would not be able to discriminate against radiation reflected from nearby clouds; such clouds could easily lie directly in the detector's field of view and would therefore appear as genuine targets. Electronic discrimination against self illumination, therefore, is much to be preferred. It does raise one difficulty, however, if the duration of the Xenon discharge flash is about 1 msec and the repetition rate is one flash/sec, there exists approximately one chance in 500 that an aircraft on a collision course with the protected plane would have a coincident flash occurring while the protected plane's detectors were turned off; the aircraft would therefore remain undetected. A probability of one in 500 aircraft remaining undetected is far too high.

The main purpose of our Note is to show that this difficulty can be reduced to inconsequentially small proportions. This can be done quite simply by introducing a certain amount of random "jitter" into the timing of the Xenon flashes. If the Xenon light source is deliberately made to fire at a random time within an interval of, say, 20 msec around the one flash/sec repetition period, individual flashes that were exactly coincidental would still be ignored, but the chances of ignoring all the flashes from any given target plane are reduced by a factor of approximately $n^{(\Delta t_j/\Delta t_f)}$, where n is the number of flashes one would normally expect to detect during a collision course approach and where the exponent represents the ratio of the time uncertainty introduced by the jitter to the duration of the flash. Thus, if n were as low as 10 (in very unfavorable circumstances) and if $\Delta t_j/\Delta t_f$ were 10 also, there would be only about one chance in 10^{10} that no flash at all would be detected by either plane before colliding. In addition, there would be only one chance in 100 that the signals from the two planes would be that closely phased anyhow, and the over-all odds are therefore reduced to about one in 10^{12}; this represents satisfactorily high odds. In actual practice, the odds could be somewhat higher still, because one would expect n to be considerably higher than 10. On the other hand, the pilot would like to register more than just one flash from an approaching plane before a collision, if at all possible. These two factors more or less cancel, and representative system odds therefore appear to be about one chance in 10^{12} that two planes headed for a collision would not see each other because of coincidences in their own flashing rates. If even greater safety factors are considered desirable, a slight increase in $\Delta t_j/\Delta t_f$ can improve these odds substantially.

One can augment this action of the jitter by systematically making the flash repetition period different for different aircraft, so that the repetition period for two arbitrary approaching planes would differ by some 20 to 50 msec. This can be done either by using a relatively crude timing system design which would statistically assure that the repetition periods of individual lights were randomly distributed within, say, a 50-msec range around 1 cps, or by using a high-quality flasher design with repetition rates that are systematically distributed within the same 50-msec range. The first method, presumably, is much less expensive and should be equally effective.

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A Comparison of Access Systems to Present World Airports

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THIS Note deals with existing airport access systems and basically utilizes data compiled by the Port of New York Authority and published in July 1968. This report was based on a survey conducted by the Authority beginning in November of 1966 to which 23 of the world's major airports responded.

Since, in all cases, an access system by rail is competitive with highways, the distances, travel times, and frequency of service at both peak and off-peak periods are the basic data for comparison. Unfortunately, the questionnaire did not request highway journey times for private automobile and taxi.

There is every indication that in the choice of an airport access mode there is relatively little fare sensitivity or preference for vehicle type compared with such matters as exclusive right-of-way, transfers, baggage conveyance and handling, number of stops, or the actual distance the passenger must walk with or without luggage between the access vehicle and the aircraft.

It will be perhaps useful here to quote from the Port of New York Authority's summary:

> The questionnaires reveal that about one-half million daily airport travelers of all types enter the 23 airports surveyed in this study of ground access between central business districts and airports. Practically all of them use highway transport modes: automobile, taxis, coach-limo services, and to a considerably lesser extent, public bus, subway-bus combinations, and helicopter services.
>
> Rail passenger services link 11 of the 23 airports with the central business districts, but collectively serve few airport travelers. Several of the rail lines reach only the peripheries of the airports, and not all of these have bus connections to the airline passenger terminal buildings, drastically limiting their value. Only four of the 23 airports actually have direct rapid transit rail service to the airline passenger terminal buildings. One, Berlin-Tempelhof, is a station on one of the city's subway lines. Two of the airports, Brussels and London-Gatwick, have special railroad service connections. The fourth, Tokyo International (Haneda), has a monorail link.
>
> A rail rapid transit line extension into Cleveland Hopkins International Airport will be completed in late 1968. By early-to-mid 1970's, a railroad link and possibly the Underground are proposed to be extended into London-Heathrow. And by 1980, six other airport railroad or rail rapid transit links will be in operation—all in Europe—if present plans and proposals are consummated.
>
> Central business districts (CBD) now generate 17 to 50 per cent of total airport traffic at the ten airports reporting this information. Most airports are within 30 minutes of their central business districts during midday and evening hours, but 30-to-60 minute travel times are much more common during peak hours.† The London-Gatwick rail service is a real time saver, being 15 to 45 minutes faster than highway travel. Travel time on the rail ser-

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† It should be noted that travel times cited in this report generally reflect time spent between the downtown airline terminal and the airport, for both rail and bus modes and do not include travel time to reach the downtown terminal, baggage checking time or distribution time within the terminal. These times, however, are usually reflected in data for automobile and taxicab modes.

vice to Brussels Airport and the Tokyo monorail to Haneda Airport is only comparable to highway travel. The new installations to Cleveland Hopkins and London-Heathrow are expected to save considerable travel time compared to highway travel, according to advance estimates.

In this survey, airline passengers account for 27 per cent of all the airport trips, employees 36 per cent, and all others (including visitors) 37 per cent. In general, the planned new rail links will be of service to the airline passengers and "all others" if they are exclusively oriented to central business district-to-airport travel. If links are added to serve intermediate districts, more employee traffic would be accommodated, but en route stops would delay travel and thus inhibit the full development of airline passenger potential. Estimates vary widely with local circumstances and conditions, but as reported, rail service handles anywhere from 20 to 80 per cent of total traffic between central business districts and airports.

The results of this survey suggest that rail access can provide valuable service connections in some cases, but only the most careful analysis of an individual situation can determine its potential patronage and feasibility. However, it is clear that highway travel will continue to be important from the central business district because of personal preferences for automobiles and taxi services. In addition, highways will, of course, continue to be indispensable for access from all non-CBD areas served by the airport.

Perhaps the most exhaustive study of airport access of recent years has been carried out by the British Airports Authority with respect to London-Hearthrow and London-Gatwick airports. These reports, which tabulate very large samples of passengers, visitor/spectators and employees, provide a very comprehensive data base and are particularly significant in emphasizing the very heavy load imposed on the access systems by employees. Whereas, for Heathrow in 1965, daily trips by air passengers in each direction totalled 20,500 in summer and 9200 in winter and visitor/spectators varied from 7100 to 3200, the employees represented 35,000 trips all year round. It is anticipated by the BAA that airline passenger and visitor/spectator traffic will increase by two and a half times by 1975, while the employee population will increase to 47,000, again on a year-round basis. The important point for Heathrow, or for any other major airport, is that while an efficient rail link may attract substantial numbers of passengers and visitors/spectators away from automobiles and taxis, the employee population, in the main, does *not* commute from the CBD, and the likelihood of attracting the employees from private automobiles to any rail access system, even at the expense of downgrading the service by introducing intermediate stops, seems very poor. It may thus be that airport planners will continue to face mounting problems of access and parking created by employee vehicles without being able to siphon this traffic off to any other mode. It should be pointed out that, generally, employee traffic peaks substantially over-lap passenger and visitor/spectator peaks.

It should be noted that of the airports surveyed, 15 are outside the United States. Of the seven major American airports responding, only Cleveland has an existing direct rail link to the terminal complex. The other systems, like Boston's Logan Airport, involve a subway-bus routing or, like San Francisco, are in proposal or study stages. This simply means that the bulk of major airports in the United States will continue to be reached by highway systems and, in an overwhelming percentage, by automobile and taxi. The following comments by Mr. Peavey of Port of New York Authority with respect to the decline in airport bus passengers are significant.

1. Travel to JFKIA

In 1956, Carey handled 63% of the air passengers moving from Manhattan to JFK. By the time our in-flight survey was conducted in 1963, Carey's proportion had declined to 46%. We estimate Carey's percentage of the Manhattan market to have further declined to 28% in 1967. This, of course, excludes all transfer passengers. It is, therefore, a very significant decline in mass transportation usage.

2. Taxi use to LaGuardia

As we suspected, the use of taxis between Manhattan and LaGuardia Airport is somewhat higher than the 45% figure I indicated to JFK. In 1967, approximately 67% of air passengers going from Manhattan to LaGuardia arrived at the Airport via taxis. This was a small growth from the 65% in 1963 and a growth of 10 percentage points from the 57% in 1956.

This review of access systems for major world airports at present and in the immediate future has re-emphasized the overwhelming role of highway transport and the very minor role of existing alternatives. Such things as the decrease in the New York area of airport bus passengers, despite major highway congestion, may emphasize the absence of attractive alternatives other than the automobile and taxi, but the extent to which the most convenient high-speed, nonstop airport CBD service will attract the passengers away from "their own wheels" must certainly be evaluated with extreme caution. The economics of such alternatives also demand careful attention since there may be the need to justify very heavy subsidy for construction and operation on the basis of some sort of total system or total transportation concept. Finally, there is every indication that airport employees and their private vehicles will become an increasing and well-nigh irreducible portion of the airport traffic and parking problems of the future.

Criterion for Tolerable Roughness in a Laminar Boundary Layer

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Nomenclature

k = height of roughness element
R_{xk} $\equiv x_k U/\nu$
R_{xNT} $\equiv x_{NT}U/\nu$
R_k $\equiv kU/\nu$
u_k = velocity at the height k and at the roughness position in the absence of the roughness
U = stream velocity
x_k = distance from the starting point of the boundary layer to the roughness position
x_{NT} = distance from the starting point of the boundary layer to the position of natural transition
ν = kinematic coefficient of viscosity

1. Introduction

THERE has long been interest in the height of surface roughness that an incompressible laminar boundary layer can tolerate without transition being affected. A satisfactory measure has been sought and, as an example, Head[1] has advocated, as more generally useful, a criterion based upon a value of $u_k k/\nu$ in preference to one based upon a value of Uk/ν. It is important in this context first to define what is meant by "tolerable" roughness and second, to distinguish between the effects of two-dimensional and three-dimensional roughness shapes.

It has been pointed out[2,3] that the general problem of the effect of roughness upon transition is expressible in terms of three nondimensional groups. The case of the tolerable roughness is associated with a movement of transition forward from its naturally occuring position; that is, it is associated with a fixed value of one of the three nondimensional

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